A New Approach to Investigating Shipwreck Sites in Littoral Environments: Multi-Technique Geophysical Investigations of Port Elliot, South Australia

Ian Moffat and Jason Raupp

ABSTRACT

A bipartite geophysical survey methodology has been developed in order to locate archaeological sites in littoral environments and to gain precise information on their location, size and physical properties. The initial reconnaissance phase establishes the presence of prospective anomalies with limited time and budget. The second phase provides comprehensive information on the anomaly as context for further investigation if necessary. This approach was tested at Port Elliot, South Australia to locate the remains of the cutter *Lapwing*. An anomaly discovered during reconnaissance phase investigations proved inconsequential in phase two, and follow-up work was not carried out. This outcome demonstrates the benefits of using this approach in terms of money and time saved.

Introduction

A bipartite methodology is proposed for geophysical survey on geographically extensive sites when a limited understanding of subsurface conditions exists. This approach employs two phases of investigation. The first consists of a reconnaissance survey to cover large areas and detect geophysical anomalies; the second refines the results of the preliminary survey through detailed investigation of the location and physical properties of the located anomalies.

The survey methodology employs inexpensive, widely available geophysical instruments and positioning systems enabling initial, rapid, subsurface assessment. If anomalies are identified, detailed geophysical survey is used to define their character and location. The employment of the bipartite methodology potentially saves time and money that otherwise can be spent elsewhere on a project.

Reconnaissance Investigation Phase

The reconnaissance survey facilitates a rapid acquisition of data for large areas to provide an initial data set for review. Geophysical methods most amenable to this phase are magnetometry and electromagnetic induction (Benech and Marmet 1999:31). The choice between instruments and configurations should be made with reference to site conditions (Milsom 1989:46), expected physical properties of the targets (ASTM 1999:2) and the probable depth of features of interest.

Magnetometry is the preferred method for reconnaissance in many littoral environments as the presence of saline groundwater hinders the effective employment of an electromagnetic induction survey (Paine 2003). The use of magnetometry has an established history within archaeology, predominantly for its ability to detect ferrous materials (Black and Johnston 1962), evidence of burnt materials (Abbot and Frederick 1990; Frederick and Abbot 1992), or disturbances in soil stratigraphy (Field et al. 2001; Nobes 2006). Magnetometry has also been used extensively in maritime archaeology for littoral sites (Cushnahan and Staniforth 1982), offshore sites (Postle 1980; Arnold 1976), or sites including both environments (Hudson et al. 1981).

A proton precession magnetometer was used in the reconnaissance phase investigation at Port Elliott because of its low daily cost. Other researchers have employed alternative sensor types or data acquisition configurations. For example, an alkali vapor sensor provides an increased rate of data acquisition (Reynolds 1997:146), a gradiometer sensor configuration increases sensitivity (Silliman et al. 2000), while deploying multiple horizontal sensors aids survey speed (Tabbagh 2003:75). Best practice suggests that a diurnal correction be applied to data, although Silliman et al. (2000) have shown that surveys of limited duration do not suffer from a significant reduction in data quality in its absence. This further reduces survey costs.

An alternative technology that has proven useful for archaeological investigations is electromagnetic induction surveying (Witten et al. 2003). This technique has the advantage of being able to detect non-ferrous material and to either survey multiple depths simultaneously or focus on a particular depth of interest (Huang 2005). This method has limited application in saline water due to limitations of conductivity. It is, however, a highly effective tool in areas with fresh ground water in the littoral zone or in freshwater environments.

Typically, positioning data in the reconnaissance phase is gained by a handheld navigational global positioning system (GPS). These instruments are less expensive than real time kinematic (RTK) or differential units, and they are widely available. Geophysical equipment needs to be set to acquire data points automatically at a time interval coincident with that of the GPS to allow data acquisition to proceed continuously. The accuracy of the positioning information is estimated at ±10 m without a beacon correction. This level of precision is suitable for identification of high probability areas for the detailed investigation phase (Bullock 1988:521). In the reconnaissance phase, survey lines are loosely established at approximate intervals smaller than the minimum expected size of the target (Reynolds 1997:17). Operators do not focus on establishing precisely parallel lines in this phase; instead they use the track log displayed on the GPS screen and flagging to define the start and finish of each line. Overall, the reconnaissance phase results in a rapid, low-cost acquisition of geophysical data over the largest area possible.

Detailed Investigation Phase

Anomalies discovered during the reconnaissance phase require a detailed geophysical investigation phase to locate their positions and define their physical properties accurately (Sarris et al. 2007:15). In comparison to reconnaissance surveys, these investigations are more time-consuming for the same area and sample density. They nevertheless allow for a more refined positioning of the identified features. The detailed investigation phase is augmented when multiple geophysical methods are used (Kvamme 2006:57), as this allows a more complete definition and understanding of subsurface features.

Multi-technique investigations may use commonly employed archaeological geophysical techniques such as ground penetrating radar, direct current resistivity, magnetic susceptibility, electromagnetic induction, or magnetometry. Instrument choice is conditioned by the expected physical properties of the target, and the nature of the survey area as discussed by Kvamme (2006:59) and the American Society of Testing and Materials (ASTM 1999:2).

Precise positioning information can be acquired through the use of standard surveying techniques and/or RTK differential GPS, although the latter substantially increases the cost of survey. Survey precision is greater and more time-consuming than with reconnaissance data collection, but it ensures correspondence between the mapped anomaly position and the below-surface feature. For magnetometer data it is essential that data points are collected while stationary, with the sensor in a consistent orientation to ensure a data set of the highest possible quality (Breiner 1999:12). With electromagnetic induction data it also is essential that the instrument is horizontal and in a constant orientation with respect to all survey points.

Case Study

The proposed bipartite survey methodology was tested at Port Elliot, South Australia. On the southeastern coast of the Fleurieu Peninsula, Port Elliot has a unique history as a short-lived outlet for the River Murray trade in the mid-19th century. Over a period of 11 years, seven ships were lost in the port's Horseshoe Bay and on its shores. The approximate location of the grounding and eventual breaking up of one of these vessels, the cutter *Lapwing*, is illustrated on the colonial harbor master's map of 1856 (Figure 1). Using that map as a guide, a prospective survey area was selected in the eastern part of the bay. Previous archaeological surveys have been unsuccessful in locating the remains of *Lapwing*, although geophysical techniques have not been employed. This site, therefore, provided an excellent case study location to test new methods for locating and delineating shipwreck remains buried in littoral environments.

Lapwing was built in Mevagessey, Cornwall, England in 1808 for use as a revenue cutter. The 63-ton, oak-built,

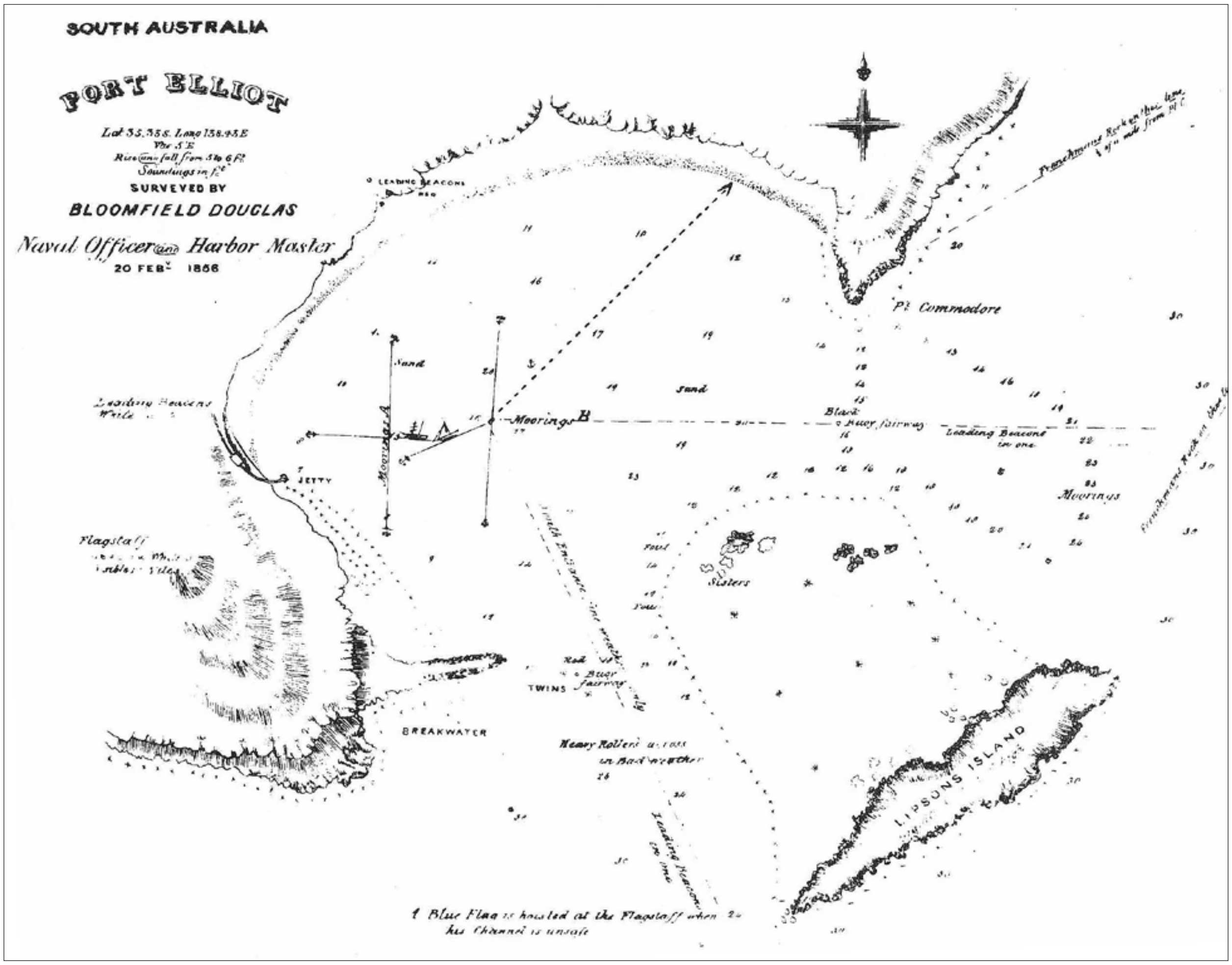

Figure 1. Map of 1856 illustrating the projected path along which Lapwing came ashore (SAAP 1856).

and copper-fastened cutter measured 60.8 ft. in length, 9.8 ft. in beam, and had a 9.9 ft. draught (*SAPP* 1856:6; Perkins 1988:19; Coroneos 1997:62). *Lapwing* was brought to Australia for use in the inter-colonial trade after a long career in the revenue service. At the time of loss, the cutter was loading timber at Port Elliot when gale force winds began to blow; the vessel then was moved to government moorings in deeper water. The harbor master subsequently tied the schooner *Swordfish* to the same mooring (*Adelaide Times* 1856a). The mooring anchors dragged, and *Lapwing* wrecked broadside on the beach (*SAPP* 1856:1). Due to the violence of the storm, *Lapwing* completely broke up, and in the words of her captain, "[t]he beach was strewed [*sic*] with various parts of the wreck for a long distance and presented a wretched appearance" (*Adelaide Times* 1856b). Though the local public demanded the removal of the harbor master, an official inquiry failed to find sufficient grounds on which to blame him for the loss of *Lapwing*, instead citing the "poor holding ground of the anchorage, the exposed position of the harbour and the confined space to moor vessels therein" (*SAPP* 1856:4). For Port Elliot, the loss of *Lapwing*, the third of four wrecks in 1856, reflected poorly on the harbor. Eventually it contributed to the closure of the port in favor of nearby Victor Harbor (Sibly 1972:69).

Reconnaissance Investigation Phase Results

Geophysical investigations for the Horseshoe Bay reconnaissance were conducted using a Geometrics G-856 proton precession magnetometer collecting data at five-second intervals. A Garmin 12XL navigational GPS was used for positioning information with an approximate accuracy of ±10 m or better. Survey data were collected at a line spacing of approximately 2 m with eight lines extending for approximately 500 m. This provided a total of 8 km of magnetometer data. The collected data were then plotted using MagPick software to produce a contour map of magnetic intensity (Figure 2). This was overlaid on an aerial photograph using MapInfo software.

The survey produced only one significant anomaly, corresponding with the location of *Lapwing* on the historic map (Figure 1). The anomaly appeared as a positive monopolar anomaly of approximately 4,000 nano-teslas (nT) above background with a maximum duration of 8 m. A magnetic anomaly of this size was surprising given the known construction details of the vessel and the assumption of scattered wreckage, as reported by the *Lapwing's* captain. It is known that the vessel underwent several refits over its long career, and it is almost certain that wooden and copper fittings had been replaced with iron ones. It seemed unlikely, however, that the remains of this principally wooden vessel could produce the magnetic anomaly being recorded. The second phase of investigation was to clarify this discrepancy and determine whether further research, including excavation, were necessary.

Detailed Investigation Phase Results

The detailed investigation was conducted approximately two months after the completion of Phase 1 reconnaissance. This work focused on a 20 x 20 m grid centered on the location of the recorded anomaly. The center of the survey grid was established using a Garmin 12XL uncorrected navigational GPS. Subsequently a surveyor's level and survey tapes were used to establish north-south and east-west grids surrounding the feature. Electromagnetic induction and magnetic intensity surveys were conducted using a GEM-2 electromagnetic induction (EM) instrument at frequencies of 4075, 9875, 18075, 24975 and 41375 Hz; a Geometrics G-856 proton precession magnetometer also was employed. Data were collected along parallel, 1 m interval survey lines running in an east to west direction, with survey stations established at 1 m intervals along these lines. Data points were manually collected at the appropriate survey position after checking for sensor stability and orientation. Data from both instruments were separately combined with positioning information, and contour maps were prepared using MagPick software (Figures 3 and 4).

Figure 2. Horseshoe Bay reconnaissance magnetometer map overlaid on an aerial photograph. Grid lines are easting and northing with a spacing interval of 50 m. (Map by authors).

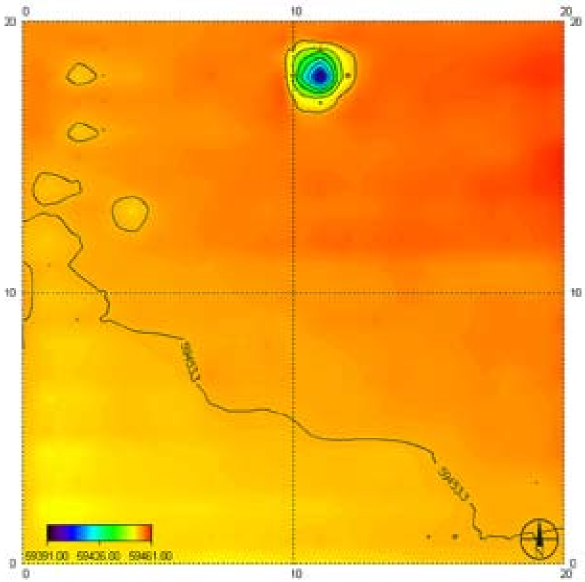

Figure 3. Port Elliot detailed magnetometer investigation map. Grid spacing is 10 m (Map by authors).

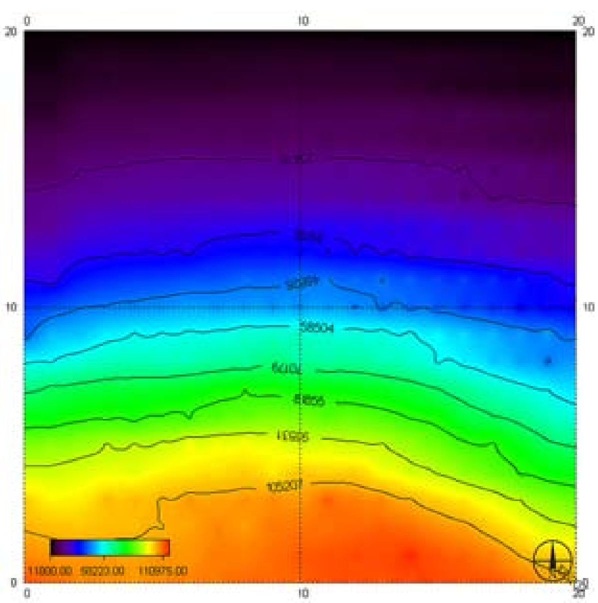

Figure 4. Detailed electromagnetic induction investigation map from data collected at the 18075 Hz frequency. The data are plotted as conductivity in Ec units showing no significant anomaly. Grid spacing is 10 m (Map by authors).

The detailed magnetometer survey confirmed the existence of an anomaly within the survey grid, but one much smaller in size. This appeared as a negative monopolar 60 nT anomaly with a maximum extent of 2 m. It also occurred in a location 9 m north of the originally recorded anomaly. The significant difference in anomaly size might be attributed to either of two possibilities. First, during the original survey the sensor may not have faced due north when that data point was collected. The coil axis of the instrument, therefore, would not have been parallel to the earth's magnetic field (Breiner 1999). Second, it is possible that the sensor experienced excessive motion during initial data acquisition (Geometrics 2002). The difference in anomaly location and variable strength of the magnetic reading illustrates the utility of using a detailed phase of investigation to better resolve target locations. It further indicates that the anomaly is not associated with large amounts of non-ferrous material such as wood. Indeed, the maximum weight of the object is estimated to be 1 kg, if the nomogram of Postle (1980:35) is applied to the magnetic intensity data and a burial depth of 1 m is assumed.

Conclusions

The proposed bipartite survey provides a new methodology for the geophysical investigation of littoral zone archaeological sites where the geographic extents are poorly understood. The use of a two-phase approach allows for the locations of targets to be established first through inexpensive reconnaissance investigations; it then seeks information about their exact location, size, and physical properties through detailed surveys in the second phase. As shown in the case study at Horseshoe Bay, Port Elliot, this methodology can help determine the appropriateness of applying direct investigation techniques on a site. In turn this can lead to potential savings in time and expense.

ACKNOWLEDGMENTS

The authors acknowledge the in-kind support of Ecophyte Technologies Pty. Ltd. in providing the GEM-2 instrument without charge for this survey. Jennifer McKinnon and Lynley Wallis are thanked for reading earlier drafts of this manuscript; McKinnon also assisted with the reconnaissance phase of this survey. Chris Brailsford from the Department of Environment and Heritage, South Australia, assisted with the provision of aerial photography. The earlier work of John Perkins and Cosmos Coroneos on the maritime history and archaeology of the region inspired the location of this case study in the Port Elliot region. The comments of David Burley and two anonymous reviewers contributed significantly to the clarity and accuracy of the manuscript, although the authors remain responsible for any errors.

REFERENCES

Abbot, James. T., and Charles D. Frederick
1990 Proton Magnetometer Investigations of Burned Rock Middens in West-Central Texas: Clues to Formation Processes. *Journal of Archaeological Science* 17(5):35–545.

Adelaide Times
1856a Disaster at Port Elliot. *Adelaide Times* 9 September 11 (1801), 3d.
1856b Miscellaneous. *Adelaide Times* 12 September 11 (1804), 2d.

ASTM
Standard D6429, 1999, *Standard guide for selecting surface geophysical methods,* ASTM International, West Conshohocken, PA. <http://www.astm.org>.

Arnold, James Barto III
1977 Site Test Excavations Underwater: The Sequel to the Magnetometer Survey. *The International Journal of Nautical Archaeology and Underwater Exploration* 6(1):21–36.

Benech, C., and E. Marmet
1999 Optimum Depth of Investigation and Conductivity Response Rejection of the Different Electromagnetic Devices Measuring Apparent Magnetic Susceptibility. *Archaeological Prospection* 6:31–45.

Black, G.A., and R.B. Johnston
1962 A Test of Magnetometry as an Aid to Archaeology. *American Antiquity* 28(2):199–205.

Breiner, Sheldon
1999 *Applications Manual for Portable Magnetometers*. Geometrics, San Jose, CA.

Bullock, S.J.
1988 Future and Present Trends of Navigation and Positioning Techniques in Exploration Geophysics. *Geophysical Journal* 92(3):521.

Coroneos, Cosmos
1997 *Shipwrecks of Encounter Bay and Backstairs Passage*. Australasian Institute for Maritime Archaeology Special Publication No. 8. Fremantle, Australia.

Cushnahan, Steve, and Mark Staniforth
1982 Magnetometers for Wreck Site Location: A Case Study. *The Bulletin of the Australian Institute for Maritime Archaeology* 5:62–80.

Field, G., G. Leonard, and D.C. Nobes
2001 Where is Percy Rutherford's Grave? In *Australasian Connections and New Directions: Proceedings of the 7th Australasian Archaeometry Conference*, M. Jones and P. Sheppard, editors, pp. 123–140. University of Auckland, New Zealand.

Frederick, Charles, D., and James T. Abbot
1992 Magnetic Prospection of Prehistoric Sites in an Alluvial Environment: Examples from North-West and West-Central Texas. *Journal of Field Archaeology* 191(2):139–153.

Geometrics
2002 *G-856 Memory Mag Proton Precession Magnetometer: Operators Manual*. Geometrics, San Jose, CA.

Hudson, Jack, Kay G. Hudson, and Harry W. Rhodes III
1981 Magnetic Search and Survey in Shallow Water and Beach Areas. In *In the Realms of Gold: The Proceedings of the Tenth Conference on Underwater Archaeology*, Wilburn A. Cockrell, editor, pp. 117–119. Fathom Eight, San Marino, CA.

Huang, Haoping
2005 Depth of Investigation for Small Broadband Electromagnetic Sensors. *Geophysics* 70(6):135–142.

Kvamme, K.L.
2006 Integrating Multidimensional Geophysical Data. *Archaeological Prospection* 13:57–72.

Milsom, John
1989 *Field Geophysics*. Milton Keynes, Open University Press, United Kingdom.

Nobes, David. C.
2006 Clay vs. Silt vs. Sand: Does Geophysical Surveying of Burials Work All the Time? Paper presented at the 2006 International Workshop on Criminal and Environmental Soil Forensics, Perth, Australia.

Paine, Jeffery, G.
2003 Determining Salinization Extent, Identifying Salinity Sources, and Estimating Chloride Mass Using Surface, Borehole, and Airborne Electromagnetic Induction Methods. *Water Resources Research* 39(3):3-1–3-10.

Perkins, John
1988 *Shipwrecks of Port Elliot 1853–1864*. Society for Underwater Historical Research, Adelaide, Australia.

Postle, M.P.
1980 The Proton Precession Magnetometer and Its Role in Marine Magnetic Searches. *The Hydrographic Journal* 17:31–46.

Reynolds, John M.
1997 *Introduction to Applied and Environmental Geophysics*. John Wiley and Sons, Chichester, United Kingdom.

Sarris, A., R.K. Dunn, J.L. Rife, N. Papadopoulis, E. Kokkinou, and C. Mundigler
2007 Geological and Geophysical Investigations in the Roman Cemetery at Kenchreai (Korinthia), Greece. *Archaeological Prospection* 14:1–23.

Sibly, Colin W.
1972 Port Elliot 1848–1864: The Rise and Fall of a Colonial Port. Honors thesis, Department of History, Flinders University, Adelaide, Australia.

Silliman, Stephen W., Paul Farnsworth, and Kent G. Lightfoot
2000 Magnetometer Prospecting in Historical Archaeology: Evaluating Survey Options at a 19th-Century Rancho Site in California. *Historical Archaeology* 34(2):89–109.

SAPP (South Australian Parliamentary Papers)
1856 Wrecks at Port Elliot. *South Australian Parliamentary Papers,* Second Session, 45:1–6.

Tabbagh, J.
2003 Total Field Magnetic Prospection: Are Vertical Gradiometer Measurements Preferable to Single Sensor Survey? *Archaeological Prospection* 10:75–81.

Witten, Allan, Greg Calvert, Benjamin Witten, and Thomas Levy
2003 Magnetic and Electromagnetic Induction Studies at Archaeological Sites in Southwestern *Journal of Environmental and Engineering Geophysics* 8(3):209–215.

Ian Moffat
Research School of Earth Sciences
The Australian National University
Building 61, Mills Rd, Canberra, Australia, 0200

and

Department of Archaeology, Flinders University
GPO Box 2100
Adelaide, SA, Australia, 5001

Jason Raupp
Department of Archaeology
Flinders University
GPO Box 2100
Adelaide, SA, Australia, 5001