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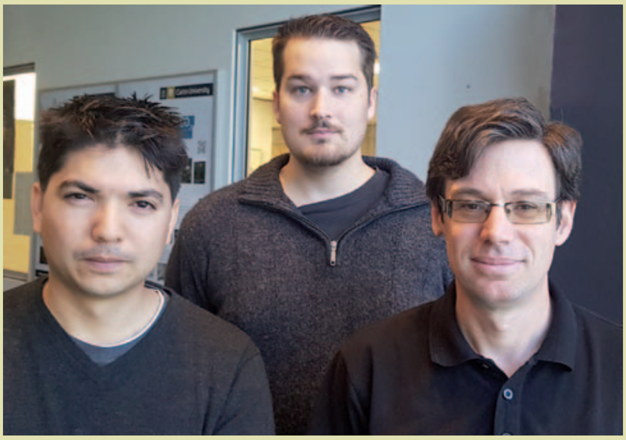
Perth's lost guns: a geophysical case study



Andrew Pethick, Alex Costall and Tim Dean
Tim.Dean@curtin.edu.au

T. Dean[1], A. Costall[1], A. Pethick[1] and J. Blylevens[2]

[1]*Department of Exploration Geophysics, Curtin University*
[2]*Royal Australian Artillery Historical Society of Western Australia*

Introduction

The fear of a Japanese invasion of Australia grew significantly during the first months of 1942. The recent capture of Singapore (15 February) and the bombing of Darwin (19 February), resulting in over 234 deaths, and other air raids across northern Australia, suggested that an attack could be imminent. The port of Fremantle, just south of Perth in Western Australia, was an important naval base throughout this period; housing one of the largest submarine fleets in the southern hemisphere.

Figure 1. *Location of the Leighton Battery relative to Fremantle, Perth, and the Swan River inlet.*

A series of coastal defences, including large-calibre naval gun emplacements, were therefore constructed to defend the port. Buckland Hill, approximately 3 km northeast of the harbour (Figure 1) is one of the highest topographic sites near the port and was chosen as the site for the Leighton Battery of 6-inch guns in 1942. It is currently the only coastal defence installation in Perth that remains accessible to the public.

Construction began at the end of 1942 (Figure 2) with the battery becoming operational in February 1943. It consisted of two 6-inch guns (Figure 3 left panel) along with several 3.7-inch anti-aircraft guns (Figure 3 right panel). As well as the guns, over 300 m of tunnels were constructed. These tunnels are up to 10 m below the surface, and provided storage, communications, rest areas, and observation posts.

Before the end of World War 2, three additional 5.25-inch guns were installed at the site. These guns could be used in both coastal defence and anti-aircraft roles (Figure 4). Three specially constructed emplacements hosted the guns. These were located adjacent to, but disconnected from, the existing tunnel complex (Figure 5). 1947 saw the completion of this work, and the site was manned until 1963 when coastal artillery was declared obsolete. The site then became a base for a transport unit, until the army finally vacated it in the mid-1980s.

Following the abandonment of the site, the state government sold the land for housing. The area immediately surrounding the battery, however, was retained as a park. The guns themselves were sold for scrap, and two of the three 5.25 inch gun emplacements were backfilled and revegetated (sites 2 and 3

Figure 2. *Photograph of Buckland Hill during construction of the Leighton Battery. The North Mole of Fremantle harbour can be seen in the background.*

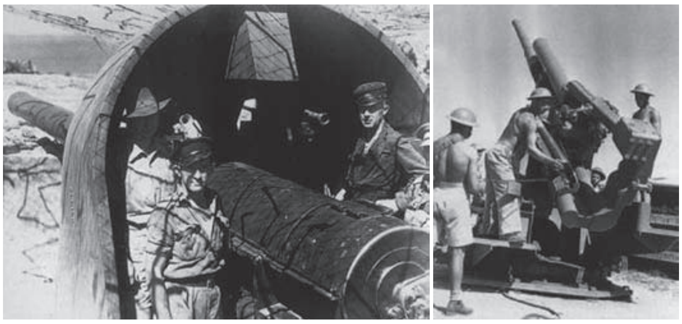


Figure 3. *Left: 6-inch gun. Right: 3.7 inch anti-aircraft gun.*

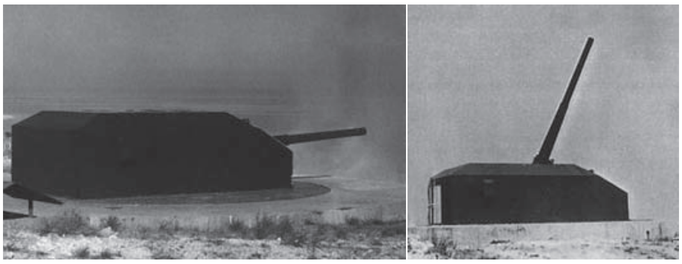


Figure 4. *The 5.25-inch guns fired in (left) coastal defence and (right) anti-aircraft roles.*

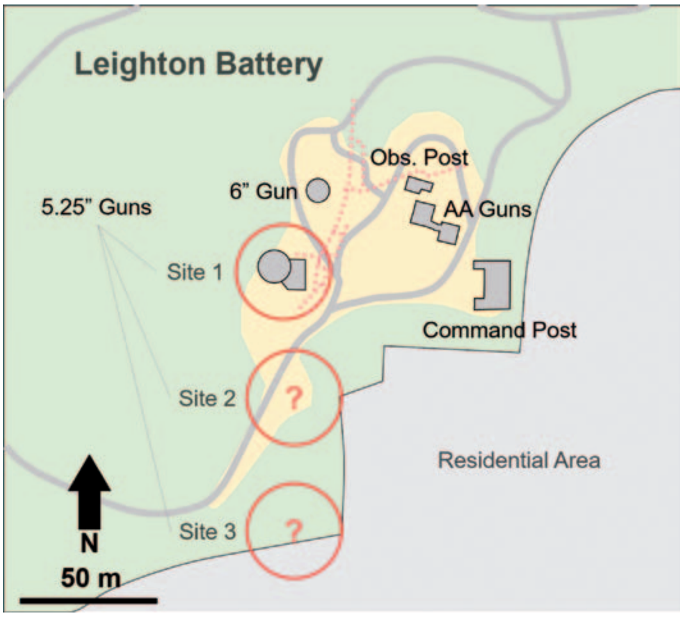


Figure 5. *Location map of the 5.25-inch gun emplacements (site 1, 2, and 3) relative to what is now a residential area. The location of the tunnels are shown by the dashed red lines. The blue line is the 2D seismic line.*

in Figure 5). In 1990, the Royal Australian Artillery Historical Society of Western Australia (RAAHSWA) were given permissive occupancy to develop the site as a military museum, which opened to the public in late 1997.

As part of their continuing restoration, the RAAHSWA is in the process of obtaining funding to restore the exposed 5.25-inch gun emplacement (site 1 in Figure 5). They then aim to excavate the two remaining (buried) gun positions. The exact position of these emplacements is unknown, and in one case, even its existence is uncertain (Figure 6). To this end, the Department of Exploration Geophysics at Curtin University conducted a series of near surface geophysical surveys at the site. The paper begins with a short description of the methods we employed in the area. We then give an overview of the current results and identify areas for future work.

Method

The gun emplacement consists of a ring of reinforced concrete within which the gun was mounted along with three adjacent rooms (Figure 7). By comparing the current topography of the site to historical maps, we expect the second emplacement to be buried at a depth of about 1 m. On this basis, we acquired the following data around its suspected position:

- Ground penetrating radar (GPR).
- 3D electrical resistivity imaging (ERI).

Figure 6. *Current photo of the suspected site of the second gun emplacement. Compare this with Figure 2.*

- 2D seismic.
- EM31 – frequency domain electromagnetics (EM).

Results

Ground penetrating radar (GPR)

GPR is a high-frequency electromagnetic method commonly used for near-surface investigations. It is employed to image contrasts in dielectric permittivity, which is the degree of electrical polarization that occurs under the influence of an electric field. Water, for example, is extremely polarizable resulting in strong reflections where the transition from dry to saturated layers exist. In addition, subsurface conductivity can strongly affect the propagation of GPR signal. Highly conductive media, such as saline water, can rapidly and completely attenuate any GPR signals.

In a first-pass survey, GPR is useful to discriminate changes in both the presence of reflectors (e.g. ground disturbances) as well as their relative strength. Targets can be further analysed with tightly spaced grids to identify their shape and extent.

Figure 8 shows a radargram from the 670 MHz antenna, which intersects a potential gun emplacement site. This particular image also covers part of the ERI grid. The chaotic reflection signature of the porous and dry local Tamala Limestone is present at both edges; however, a distinct change in the

Figure 7. *Photograph of the currently exposed gun position.*

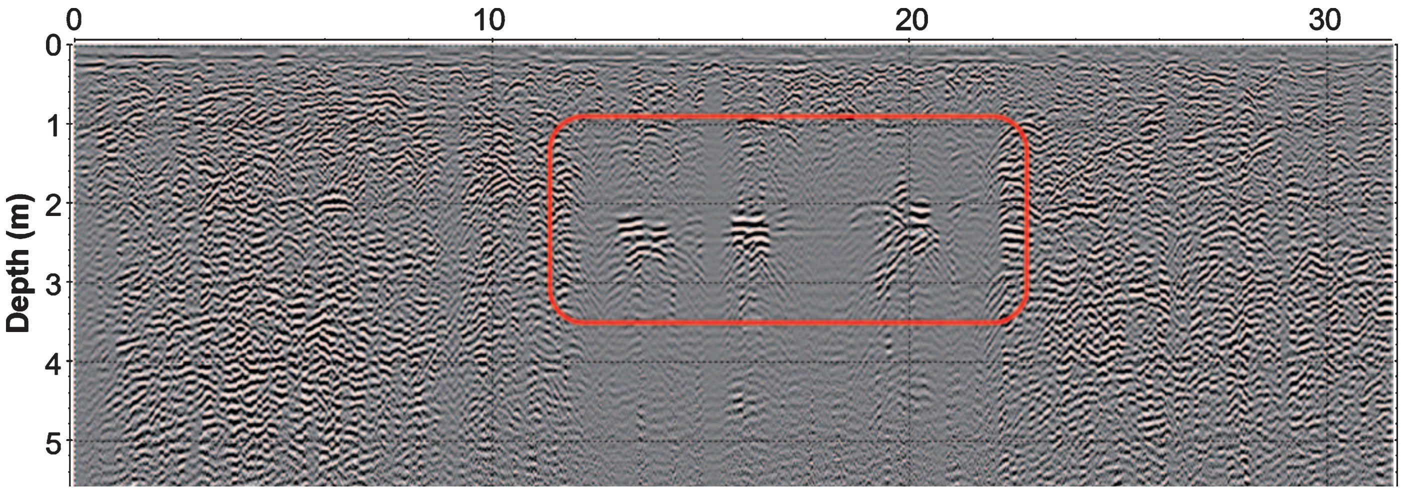


Figure 8. *GPR profile showing the likely location of the gun emplacement. The red box highlights strong horizontal reflectors at a depth of approximately 2 m.*

reflection characteristics exists at the centre of the profile. Here, a set of strong horizontal reflectors can be seen approximately 2 m below ground level. Given the abrupt change in reflection characteristics and abnormal reflectors within otherwise-plain earth, we believe the highlighted area is likely to be the position of the gun emplacement.

3D electrical resistivity imaging (ERI)

ERI is a geophysical method that images the conductivity distribution of the near subsurface. An electric field is created by injecting a current across two electrodes, which is measured as a voltage by one or more pairs of electrodes in a different location. The conductivity distribution of the ground is then recovered through numerical inversion.

The 3D ERI survey was located over the approximate location of the buried gun emplacement (site 2 on Figure 5), identified from the GPR survey. The grid consisted of 2 m spaced stainless-steel electrodes in a 12 × 6 rectangular grid. Resistivity-imaging data was collected using a set of dipole-dipole electrode sequences, including cross-diagonal measurements. The data was inverted using the 3D finite-element inversion algorithm, BERT (Günther et al., 2006).

Figure 9 shows the inverted 3D dataset. An extremely conductive (<1 Ω m) body in the centre of the grid is interpreted as the gun pit. The conductive body is clearly not geological, the Tamala Limestone is approximately 1000–3000 Ω m when dry, and local elevation eliminates the possibility of seawater intrusion. We suggest it may be the reinforced concrete, or the material used to backfill the gun emplacement. An extremely resistive region exists on the north eastern end of the grid. Such high resistivity values are usually associated with dry concrete or air-filled cavities, consistent with the underground rooms located next to the gun pit.

2D seismic

The seismic data was acquired using a single line of 48 10 Hz geophones with 1 m spacing. A sledgehammer source was employed at 1 m intervals. The line was positioned so that one end was located over the suspected gun pit position (the blue line on Figure 5).

Figure 10 shows two records taken at the western and eastern ends of the 2D line. The likely position of the gun emplacement is outlined in red. The effect of the much higher velocity of the concrete can be seen by comparing the first arrivals of the near-

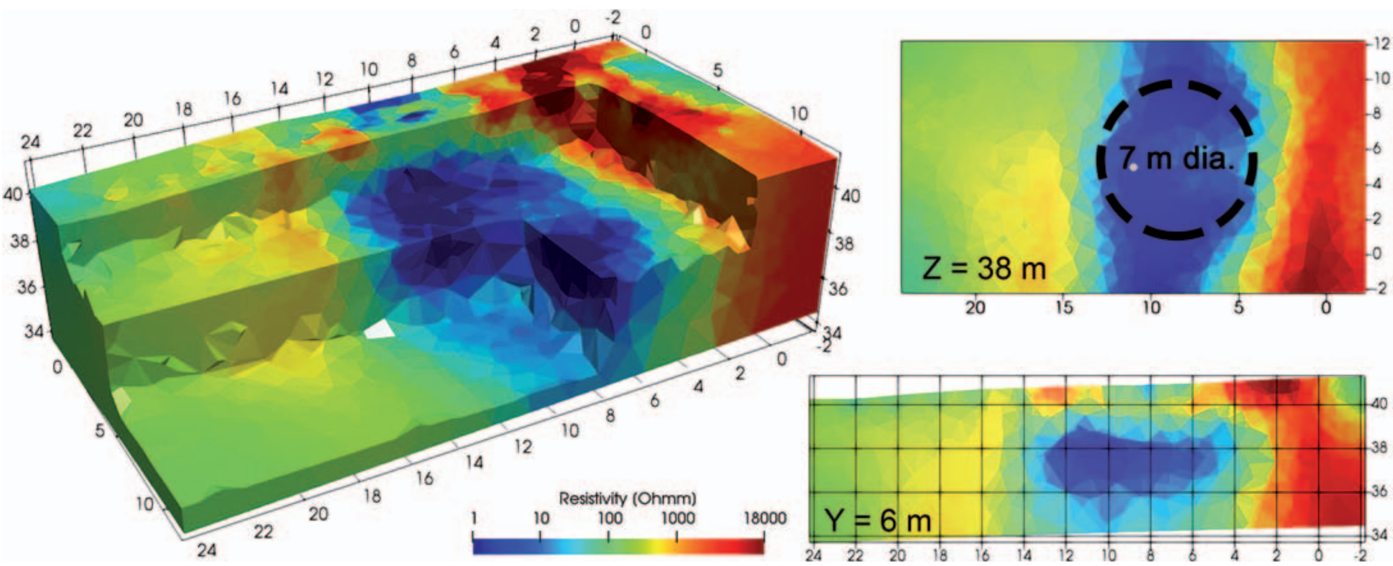


Figure 9. *3D image visualising the inverted ERI electrical resistivities over the approximate gun pit location. The cube is clipped to highlight the conductive body in the centre of the grid.*

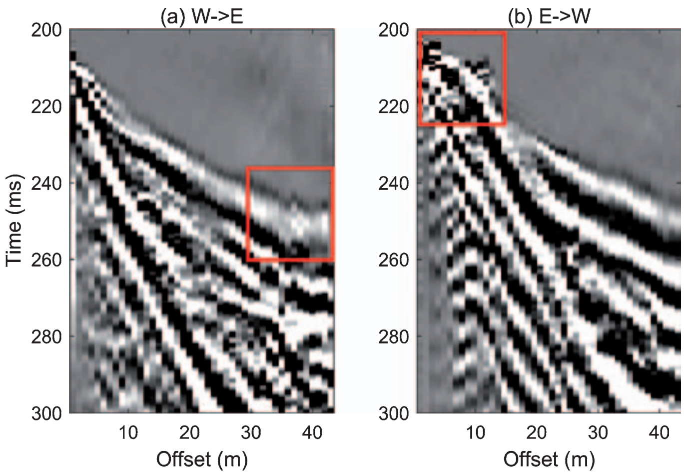


Figure 10. *Seismic data plots acquired with the source at (a) the western end of the line and (b) the eastern end of the line. The order of the traces has been reversed in (b) to enable a direct comparison. The position of the gun emplacement is outlined by the red boxes.*

offsets in Figure 10*b* with those in Figure 10*a*. Similarly the arrival times at the far offsets in Figure 10a differ from those in Figure 10*b*.

EM31

The Geonics EM31 frequency domain EM survey was co-located with the 3D ERI survey. The EM31 system detects subtle variations in magnetic susceptibility and bulk electrical conductivity. The survey involved collecting in-phase and out-of-phase data on a dense 1 m grid. The EM31 was operated with vertical magnetic Tx-Rx dipoles in a horizontal coplanar configuration.

A significant circular-shaped electrical conductor in the resistive host was detected (Figure 11). The anomaly has similar lateral dimensions to the known gun emplacement — both having an inner diameter of approximately 6 m (Figure 11 compares the EM31 response with the dimensions of the existing gun emplacement; a faint dotted circular line has been added to assist the comparison).

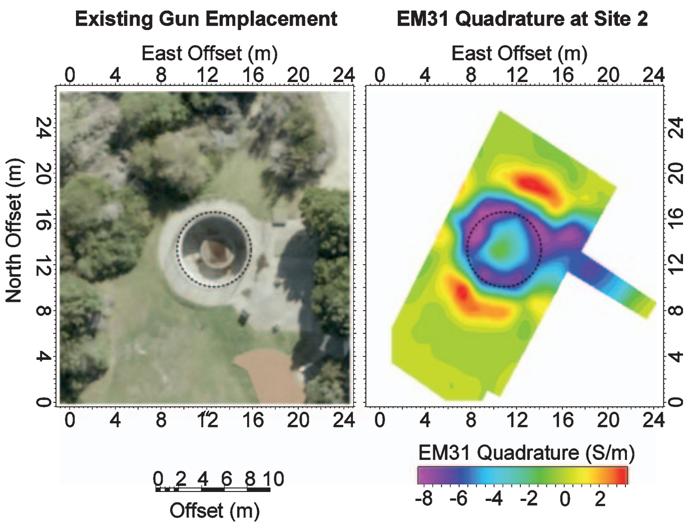


Figure 11. *Left: Aerial imagery of the existing gun-emplacement. Right: the recorded EM31 quadrature apparent conductivity response over the area with the suspected buried gun-emplacement.*

According to McNeil (2016) a time lag in the received secondary field is caused by 'soil magnetic viscosity'. This may occur in areas of high concentrations of ferromagnetic minerals. The highly negative (<–7000 mS/m) out-of-phase component is most likely a cultural artefact produced by the steel in the reinforced concrete of the original gun-emplacement. For reference, the typical background quadrature component value recorded over the shallow sands and Tamala limestone ranged between 15 and 30 mS/m (note that the scale in Figure 12 is in S/m so the anomalous values are several orders of magnitude higher than the surrounding electrically resistive earth).

Discussion and future work

Not only did this survey aid the historical society in helping pinpoint the location of the missing gun emplacement, it also gained considerable media coverage with stories on multiple radio stations and the local news (Figure 12).

Figure 12. *Screenshot of a story on the survey broadcast on Channel 10 news. The full story can be viewed at tinyurl.com/ybvg7rzt.*

In terms of the data already acquired, the co-located GPR and FDEM data offer further inversion opportunities; which would incorporate structural constraints and tailored seed-models to direct the inversion process.

Future work is also currently being undertaken to locate the third gun position (which is likely to intrude into a local backyard, 'site 3' on Figure 5) and a reputed tunnel that goes from the battery to an observation post on the other side of Stirling Highway.

Acknowledgements

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References

Günther, T., Rücker, C., Spitzer, K., 2006, Three-dimensional modelling and inversion of dc resistivity data incorporating topography - II. Inversion: *Geophysical Journal International* **166**, 506–517. doi:10.1111/j.1365-246X.2006.03011.x

McNeil, J. D., 2013, The magnetic susceptibility of soils is definitely complex: Technical Note TN-36, Geonics Limited.