The Application of Earth-Resistivity Surveys to Australian Archaeological Sites

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Location of buried archaeological features using earth-resistivity surveying is an established procedure. Its application to Australian sites is long overdue. In this paper, an outline of the physical principles governing the method is given, along with a description of the field technique commonly used. The associated computer-assisted analysis of results utilizing RESPLOT software is also outlined. The authors, Don Ranson of the Victoria Archaeological Survey and Brian Egloff of ANUTECH, Canberra, then discuss two cases where earth-resistivity surveying has been successfully used. These are, first, the location of an Aboriginal burial ground at Wybalenna on Flinders Island and, second, the location of landscape features at Port Arthur, Tasmania. They conclude that earth-resistivity surveying has widespread application in Australia.

INTRODUCTION

The measurement of earth resistivity was first described by Wenner.[1] Its application by geologists for the location of ore bodies and water and oil-bearing strata was quick to follow.[2] The earliest archaeological application of the method was the location of pits and ditches associated with Neolithic henge monuments in Britain in 1946.[3] The location of buried archaeological features by earth-resistivity surveys is now an established practice.[4]

THEORY

Electrical resistivity is a fundamental property of matter and has been defined as: 'the ratio of the voltage gradient across a small surface element within the medium to the current density (A/m^2) flowing across the element and at right angles to it.[5]' When an electrical current is passed through soil, the ease with which the current travels through that soil depends in the main on the amount of moisture held in the soil. The more moisture, the lower the resistivity; the less moisture, the greater the resistivity. The moisture content for any particular soil depends in turn on the compaction of the soil. The less compact the soil, the greater the spaces between the soil particles and the more moisture the soil holds between the particles. The more compact the soil, the less space between soil particles and the less moisture held between those soil particles.

It follows, therefore, that less compact soil such as that produced when soil is disturbed through human activity (be it the digging and filling of a ditch, a foundation trench, post-hole, beam-slot, well, or a grave) will have a lower resistivity. Highly compacted soils or even rocks and rubble features such as walls and roadways will have a high resistivity. Soil which has not been humanly modified, that is 'natural' soil, will have resistivity values lying somewhere between the two extremes.

A more detailed exposition of the theory of earth-resistivity is available.[6]

INSTRUMENTATION

Earth resistance instruments can be linked to a variety of probe configurations such as the Wenner, Schlumberger, Palmer and two-probe,[7] each of which has accompanying advantages and disadvantages. Lynam undertook experiments in a simulation tank that allowed a comparison of a number of these configurations.[8]

In the Wybalenna and Port Arthur studies the surveys were undertaken using a two-probe array,[9] linked to a Gossen Geohm 3 direct-reading resistivity meter (Fig. 1). The two-probe array has the advantage of allowing rapid surveys. It produces high resolution results by providing easily interpretable 'one peak to one anomaly' observations without 'ghost' effects and is insensitive to varying electrode alignments with respect to buried features. Thus it compares well with, for instance, the commonly used Wenner array which, in traversing a feature, may give up to three maxima. Large scale surveys over a complex of features using a Wenner or similar array would produce a confusion of maxima and minima and make the survey results impossible to interpret. This is avoided using the two-probe array. The disadvantage of the two-probe configuration is that it is slightly less sensitive than the other arrays, giving a smaller magnitude of response for any given feature. This diminished sensitivity, however, can be overcome by computer-assisted plotting.

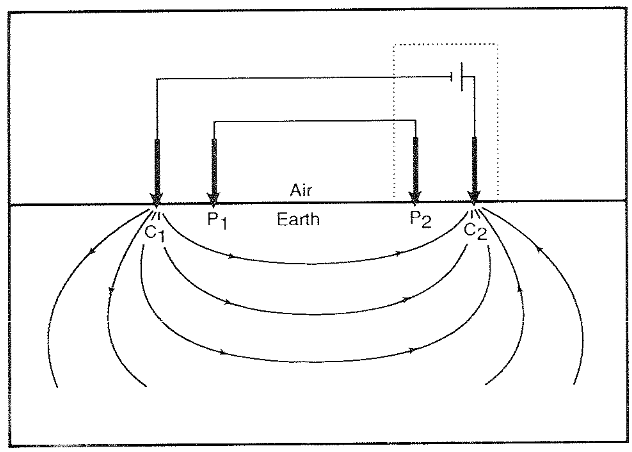

Fig. 1: Geometry of the twin-probe array showing pattern of current flow between two current electrodes C_1 and C_2. P_1 and P_2 are the potential electrodes. Dotted lines indicate mobile part of array which includes voltage sources and resistance instrument. C_1 and P_1 are fixed probes.

Choice of probe separation has to be considered carefully. In theory there is no limit to current penetration but, because the current falls off through increasing depth, there is an effective limit at which features can be located. This limit is approximately one to two times the probe separation depending on soil conditions. Maintaining a large probe separation will allow the recording of deeper features but a loss in resolution will result. Conversely, smaller probe separations will increase resolution but only detect shallow features. The most universally applicable probe separation used with the two-probe method is 0.5 m. Under Tasmanian conditions this probe separation was able to resolve small features such as old fence lines and in some cases single graves. Smaller probe spacings, say of 0.25 m, would probably be able to locate most graves and smaller features such as large post holes (see discussion later).

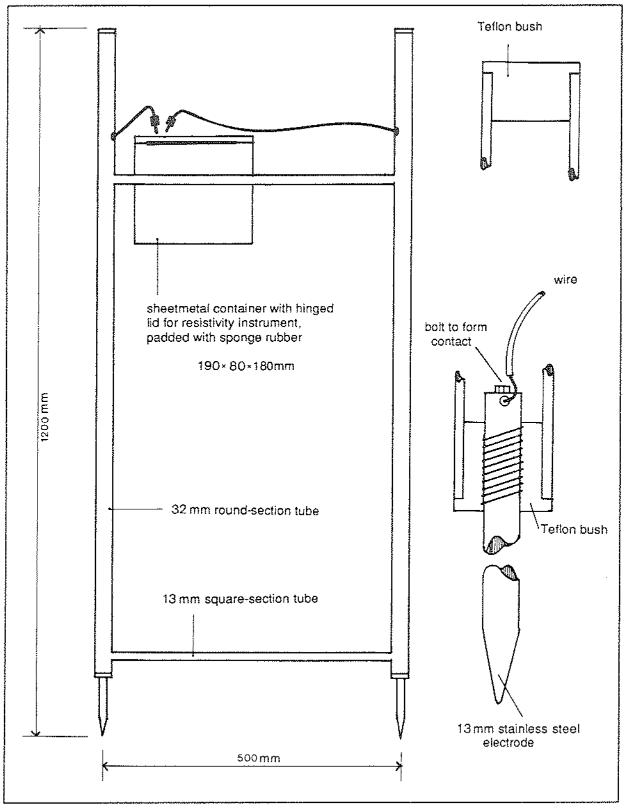

Fig. 2: Resistivity array. Not to scale.

The probe array (Fig. 2) is made of typically two 32 mm diameter lightweight steel pipes of convenient height, braced top and bottom by two 13 mm wide square-section steel tubes to form a strong rigid structure. The top brace supports a metal, lidded container which holds the resistivity meter, the bottom brace being positioned to afford a comfortable foot rest to assist in pushing the probes a sufficient distance into the ground to effect an adequate contact. Two 20 cm long, 12 mm diameter high-quality stainless steel bars, machined at one end to points, act as the array electrodes. These are fitted into the upright steel pipes with insulating Teflon bushes. Electrical contacts are affixed to the top of each electrode and wires are passed up the tubes and out to the appropriate ports on the resistivity meter.

Two other machined stainless-steel electrodes of 40 cm length and 12 mm diameter are needed as fixed controls. The control electrodes are linked to the other ports on the resistivity instrument, via 50–70 m of two-ply wire of cross-sectional diameter of 0.75–1.0 mm, arranged on a spool for convenience.

SURVEY CONDITIONS

The method is influenced by climate, geological effects and vegetation.[10] Because the moisture content of the soil determines its resistivity, recent rainfall may influence the results considerably. Heavy rainfall accumulating on the surface, or moisture collecting above a comparatively impermeable surface (a clay layer, compact wall or rubble), or waterlogging within low-lying reclaimed land, may give extreme results. As a corollary, diurnal variation in resistivity values through evapotranspiration and evaporation of near-surface moisture may also occur.[11] Variation in readings can also be brought about by variation in near-surface moisture caused by differential vegetation cover, such as found between grassed and ploughed paddocks. Almost invisible vehicle or pedestrian tracks can give changed resistivity values, due to the compaction of the subsoil and subsequent loss in moisture.

Geological effects, especially caused by soil inhomogeneities, such as juxtaposed clay, gravel and sand lenses commonly occurring in glacially originating soils, may also produce false anomalies. Soil containing numerous small rock fragments, such as found in karstic regions, may also be difficult to survey; probe contact with rocks will produce spuriously high readings. Archaeological sites with extensive spreads of rubble and bricks near the surface may provide similar problems.

However, in all cases, barring random soil inhomogeneities, judicious employment of controls during surveys, in order to measure and counteract climatic variation, together with the application of mathematical filtering techniques during analysis to eliminate either long wavelength 'noise' (e.g. variable topsoil thickness) or any short wavelength 'noise' (e.g. near-surface rocks or bricks), can greatly assist in producing plots which highlight only archaeological features.

SURVEY PROCEDURE

There are two procedures available to the surveyor: linear transects or area coverage. Resistivity surveying is not amenable to serendipitous spot surveys, as the method requires the regular collection of sufficient surrounding data to highlight a feature. Without preknowledge of the feature, adequate data collection is unlikely with a spot survey.

With respect to a linear survey, it is usual for a tape to be laid out on the ground across the presumed feature and extending beyond the feature at either end to provide for an adequate comparison. Resistivity readings are then taken along the tape at 0.5 m intervals and plotted on graph paper. Visual inspection of the plot can then be used to locate features.

Linear surveys are only useful for initial exploration purposes and then only when large, deep, contrasting features are expected. The method suffers through the inability of the operator to distinguish between genuine small scale features and 'noise' produced by occasional spurious readings. Its advantage lies in its relatively fast application, useful for defining prospective areas which would benefit from a closer examination through a larger scale, more time-consuming, area survey. It is especially useful in finding large features such as buried roads, banks and ditches, fortification earthworks and the like.

An area survey is undertaken by laying out a grid of 0.5 m squares, and taking resistivity readings at each point on the grid. The grid is most simply achieved by marking the corners of a suitably sized square or rectangle with wooden pegs. Fixed tapes are then laid down along two parallel sides of the survey plot. A mobile tape is then placed at right angles to the fixed tapes along the third side of the survey plot. Resistivity readings are then made at 0.5 m intervals along this third tape. On completion of that series of readings, the third tape is moved 0.5 m with respect to the fixed tapes and the procedure is repeated. The third tape is moved sequentially along the fixed tapes until all the readings are made.

Area survey is in effect a number of parallel linear surveys undertaken side by side. Its advantage is that spurious readings (short wavelength noise) can be more easily discernible; single readings being highlighted in contrast with the more normal readings occurring in the vicinity. The disadvantage of the procedure is that it is time-consuming; many more readings have to be taken compared to linear surveys.

In practice, the most convenient grid is 20 m x 20 m. Any survey smaller than 10 m x 10 m usually does not produce results that are useful; the eye finds if difficult to pick up contrasting features in the plot over such a small area.

Using the resistivity instrumentation, probe spacing and grid size mentioned in this paper, it takes about seven seconds to take one measurement. With a probe operator and a recorder, 400 readings can be taken in an hour, about 3000 readings in a day. Half a hectare takes about seven days of mind-numbing work! Methods can be attempted to lighten this work load and these are discussed later.

DATA PRESENTATION

The systematic plotting of resistivity values, usually on a grid, enables a picture to be built up of sub-surface features in the survey area. The simplest, though least efficient, method is the construction of contour plots either by visual inspection or by the use of a specific computer program designed to do the job. A contour plot, because it is basically an averaging technique or a smoothing process, loses information thereby lessening the resolution of features and feature edges; negating to a great extent the work that has been undertaken in collecting the data in the first place.

A much more efficient method of reproducing the data pictorially is by using either a dot-density or a differentially shaded grey-plot generated by a specific computer program. Dot-density plots are produced by assigning a fixed number of dots to each range of resistivity values and then causing them to be plotted around the equivalent position of each resistivity value in a random manner. The random positioning of dots prevents construction of artificial features that can be brought about when utilising a fixed pattern of dots. Such a program (DOTTY) is used in the School of Archaeological Sciences, at the University of Bradford, in Britain.[12]

The other method of pictorially representing the data is by differentially shaded grey-plots. This was the method used in the Wybalenna and Port Arthur studies which are discussed in this paper. Such grey-plots are formed by assigning to each grey level a range of resistivity values. In this study, thirty-two grey levels were used. These grey levels are then plotted out in square cells representative of each resistivity value. This method can in some instances produce artificial contours formed at the fixed boundaries of the cells. However, in practice, if a sufficiently large number of grey levels are used, these will not become apparent to the eye. The final effect is similar to the tone drop-outs of newspaper photographs. The lower the resistivity the lighter the shade of grey, the higher the resistivity the darker the shade of grey. In general, the areas of lighter shades of grey suggest human modification by digging and filling of features, the darker shades of grey suggest either 'natural' (unmodified) soil or, if very dark, the remains of rubble or rock fill such as would be found in buried walls or roadways. Such a representation is much more efficient than a contour plot, little data is lost, and with practice small features and quite complex sets of features can be discerned.

In this particular study the grey-plots were generated by RESPLOT, a computer program designed by Mr Michael Rochford to aid in the analysis and graphical presentation of the data.[13] RESPLOT was run on a 512K Macintosh personal computer, with an 800K disk drive linked to an Imagewriter printer. RESPLOT has an editing facility where stray or erroneous readings can be discarded. The program has the capability of outputting data in contour or grey-plot form. Either various contour intervals or from eight to sixty-four grey levels can be selected for. RESPLOT also has the capability of filtering the raw data to extract non-archaeological noise. These simple filters are based on the moving average method, and are useful for smoothing short wavelength noise. Most usually a central reading and its surrounding eight readings are averaged and the central point given the average value. This process is repeated for all points and on completion the smoothed data is plotted. Algorithms of one's own choosing can also be programmed in to provide other forms of filters. This is especially useful in filtering long wavelength noise.

RESPLOT has also a 'transform' function, whereby the raw data can be transformed into a new data set. This is especially useful when data is collected over a number of days or in different weather conditions and where the different data sets have to be reconciled with a control reading. A 'recode' function is also provided, allowing data of any specified range to be given one value: in effect a contrast control. In addition, RESPLOT has a statistics option which can produce frequency counts and some basic statistics. This option is useful for describing the modality of the data set, which in turn can assist in selecting recode values to filter for features of certain resistivity values.

RESPLOT is a powerful package for presenting two dimensional numerical data. It is possible to create false objects and patterns through the combination of filters, recodes and transformations. RESPLOT automatically logs the changes to the data, providing a useful check for reconsidering the validity of the finished plot. Using simple filters as described, the data can be efficiently displayed in various useful forms. The authors have yet to explore the full potential of RESPLOT.

CASE STUDY: WYBALENNA, FLINDERS ISLAND, BASS STRAIT

The Flinders Island Aboriginal Association had been concerned for some time about the lack of protection afforded the old burial ground at Wybalenna. This burial ground contains a large number of Aboriginal graves, dating from the time when Wybalenna acted as a place of incarceration for Aborigines after they had been removed from mainland Tasmania.[14] The exact location of the burial ground was unknown but it was thought to be in the general vicinity of the modern cemetery. If this was the case it was likely that all or part of the old burial ground was open to and affected by stock.

In 1985 the Flinders Island Aboriginal Association received a grant of $4500 from the Australian Institute of Aboriginal Studies, to locate and investigate the Aboriginal burial ground. The Flinders Island Aboriginal Association and the Tasmanian National Parks and Wildlife Service agreed that the most efficient method of arriving at a detailed understanding of the site was to undertake an earth-resistivity survey, in conjunction with both an inspection of any ground features evident and an examination of selected archival records.

An attempt was made at locating the burial ground from an early map. Examination of the supposed area revealed some linear features and depressions. A resistivity-survey covering this area was made and features were revealed that strongly point to the presence of a burial ground and associated structures.

Robinson's map

While Commandant of the Aboriginal settlement on Flinders Island, George Augustus Robinson undertook a survey of the area. The original map drawn up from this survey has not been located. However, a copy of the map was made by F. S. Edgar of the Survey Office, Hobart Town, in 1838, under the auspices of Edward Boyd, Surveyor General of Van Diemen's Land.[15]

The map is beautifully crafted, finely detailed and annotated and shows in plan-view roads, paths, streams, ponds, coastlines, buildings and even in some cases, rooms within structures. Axonometric representation is made of post-and-rail fences, hanging gates, trees and hedgerows. The map is polychromatic, at least ten shades of colour being used, three of which are used to delineate the major fabric types (mud, stone and brick) used in building construction.

Amongst the many features represented on the map which are of special relevance to this discussion are the burial ground, the chapel, the hospital and surgeon's residence, the Natives' square, the commandant's residence and the storekeeper's residence (see Figure 3 for a simplified copy of this map). It would appear that locating the old burial ground would be an easy matter of taking bearings and distances from Robinson's map.

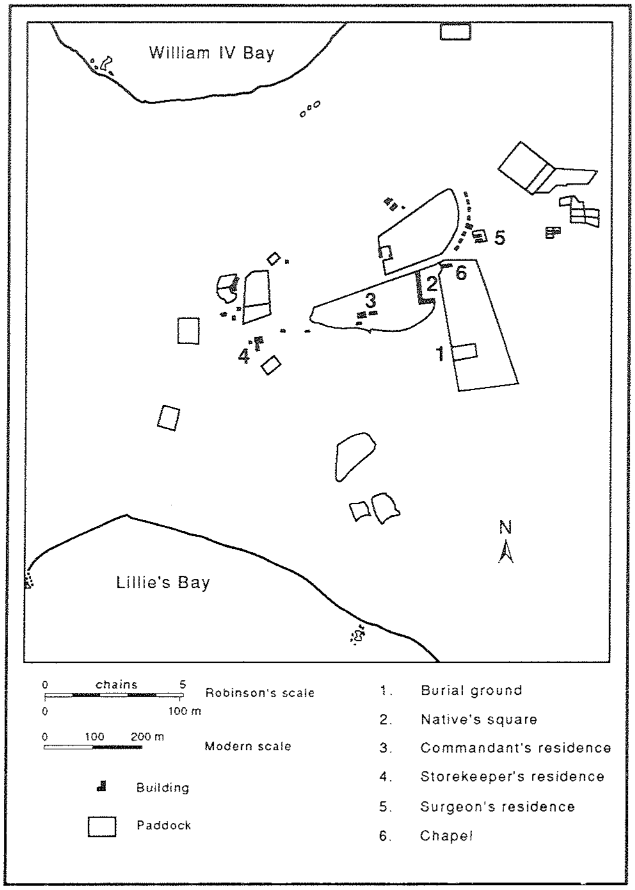

Fig. 3: Simplified copy of Robinson's 1838 map of Wybalenna.

On first inspection in the field, however, the map appears to be both distorted and inaccurate. The errors are of both orientation and distance. The relative bearings of structures represented on the left side of the map, from those represented on the right side, are not in accord with the physical evidence to be found on the site today. Similarly, while the *relative* distance between most structures represented on the map (especially the right-hand side) are accurate, the *absolute* distances are not. Indeed the inaccuracies inherent in the map do not reflect an ability that Robinson would most certainly have gained during his earlier apprenticeship and career as a builder. Experience from the trade would have enabled Robinson not only to read and draw plans but to actually lay out a building accurately. Conversely he would not have been troubled in accurately depicting on a plan an already extant group of buildings.

The errors in the plan probably arose during the tracing of Robinson's original field drawings by Edgar in the survey office. The first error mentioned, that of orientation, can be best illustrated by the relative bearings and distances of the storekeeper's residence, located on the left of the plan, from the commandant's house, Natives' square, chapel, hospital and surgeon's residence located on the right side of the plan. The representation of the structures in the latter group is internally consistent with the evidence on the ground. The maximum error in the bearings between structures is less than 1.5° and the maximum error in the relative distances in one case is 8 per cent but more usually lies between 0 and 3 per cent. However, the error in the bearings of the storekeeper's residence, on the western side of the settlement, from the eastern structures, for example the chapel, is greater than 4° and the error in relative distances is approximately 14 per cent.

As suggested above, these errors may have originated during the copying of Robinson's field sketches. If the original map was indeed rendered in more than one sketch, misalignment of sketches during tracing could have arisen, thereby producing the error in orientation. In fact the error can be reconciled simply by moving the left part of the map away from the right by the requisite amount; the two parts of the map being formed by a line bisecting north-south the space between the storekeeper's residence and the commandant's residence. Such an adjustment would enable the relative position of all the structures to be made internally consistent. The second error noted on the Edgar copy is the inaccuracy of the absolute distances between structures. Modern plotting of distances between extant structures and comparison with the 1838 plan, suggests that Robinson's units of scale are 2.3–2.7 times too large. This error could have come about simply through the miscopying of Robinson's original scale.

If these two errors are taken into account, then Robinson's rectified map is in fact a very accurate rendition and the burial ground can be located.

Modern interpretation

Superimposition of a tracing from aerial photographs[16] over a corrected copy of Robinson's map, shows just how accurate the early survey was (Fig. 4). Of particular interest is the position of the old burial ground, as shown on Robinson's map, compared with the modern one-acre cemetery reserve, as observed from the aerial photographs. It can be seen that:

1. Almost all of the old burial ground lies *within* the modern cemetery reserve.

2. Most of the old burial ground lies outside the present fenced portion of the modern cemetery reserve.

3. The old burial ground is an irregular quadrilateral, having sides with approximate dimensions of 49 m, 28 m, 45 m and 28 m.

4. There is a 12° difference in alignment between the old burial ground and the modern cemetery reserve.

5. The southern boundary of the old burial ground runs to the south of the square structure surrounding the 1844 grave of Eliza Milligan, the wife of a Superintendent of Wybalenna. Indeed Milligan's grave appears to be very close to the south-west corner of the old burial ground.

6. The north-eastern corner of the old burial ground appears to run under an old boxthorn.

7. The northern boundary of the old burial ground runs to the south of the line of pines which demarcate the boundary of the present cemetery.

8. The western boundary of the old burial ground probably cuts the modern fence line and lies, in part, outside the present reserve.

Realignment

Examination of Figure 4 suggests that at some stage a modern cemetery reserve was placed in close proximity to the old burial ground but with a different alignment, shape and area. This change came about in January 1889, when a survey was made of Robert

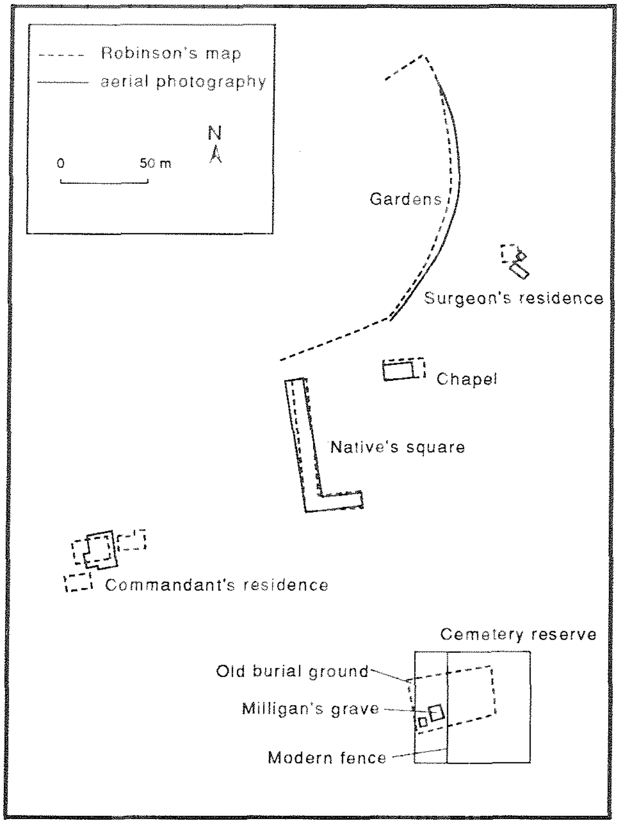

Fig. 4: Best-fit comparison of Robinson's 1838 map with modern aerial photographs.

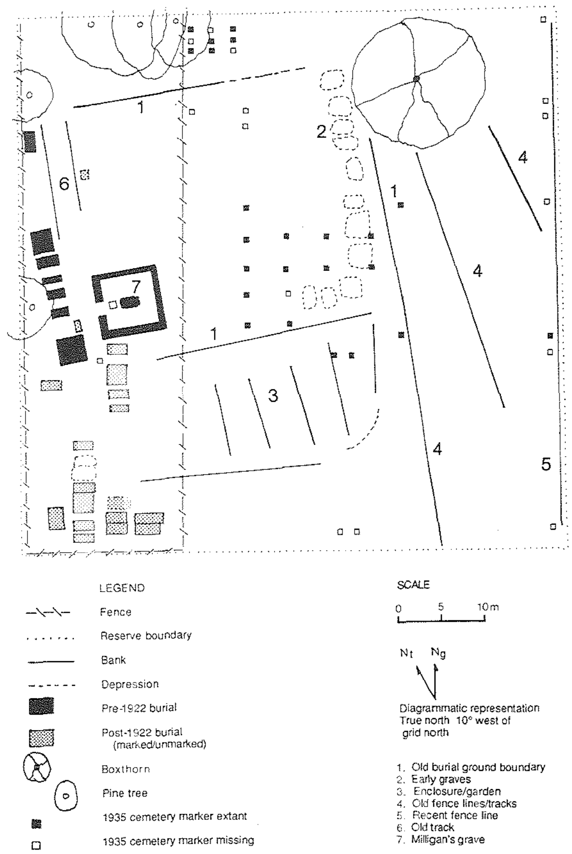

Fig. 5: Plan of Wybalenna cemetery.

Gardener's land which included the Wybalenna settlement.[17] Opportunity was probably taken at the time to lay out a cemetery reserve to remain as Crown Land. The cemetery was rigorously surveyed; being made square, exactly one acre in area, and aligned to magnetic north. Why this survey did not take note of the earlier burial ground is open to conjecture. Certainly by 1862 the boundary fence of the old burial ground was being destroyed and the boundary may have rapidly become indistinct.[18] Even so it is unlikely to have been totally obscured to the later surveyor.

What is of interest is that the new alignment was ignored during later interments. All burials up to the end of 1920 were aligned on the axis of the old burial ground. In 1922 the next and subsequent burials were aligned to the modern cemetery reserve. Why this new policy was adopted then is not known but by 1935 the layout of the cemetery was formally set down on a plan drawn up for the Flinders Island Council.[19] Evidence of these formal plots are present today as small concrete blocks, set into the surface of the paddock, which marked the boundaries of the proposed burial areas. What is of interest to note in this plan is that the layout of the burial plots does not take cognizance of any earlier Aboriginal burials.

Modern survey

As part of the procedure for laying out the base grid for the earth-resistivity survey of the modern cemetery reserve, a careful topographic survey was undertaken (Fig. 5). During this survey a number of surface features became apparent, especially just after dawn when the low incident angle of the sun's rays caused the features to throw deep and obvious shadows which contrasted sharply with the surrounding area. These features consist of a number of very low linear banks, shallow ditches and isolated shallow depressions. The linear features are consistent with the small banks and ditches which form as a by-product of fence lines. Eroded soil from hill-wash and/or tilling methods forms under fence lines and is consolidated due to the inability of the tilling methods to reach close to the fence. Additionally, depressions parallel to these banks arise through the habit of stock forming a 'run' by moving close alongside fences. These phenomena do not take long to arise; observations beneath fences erected probably around the 1930s show extensive banks and ditches in some places. The shallow depressions are consistent with slumped pit fill (graves?).

Examination of the distribution of these and other features in the survey area (Fig. 5) would suggest that they represent:

1. The position of a boundary fence delineating the quadrilateral enclosure of the original burial ground (1) inside of which are graves (2).
2. An early fenced enclosure probably post-dating the burial ground and, on the basis of the size and width of the parallel banks and ditches, probably a garden (3).
3. Field boundaries/tracks (4) pre-dating the setting out of the modern cemetery reserve (1889).
4. The field boundary of the modern cemetery reserve (5).
5. A track (6), probably the original entrance to the old burial ground.

Comparison of the position and extent of the original burial ground as marked on Robinson's map, with the position and extent of the incomplete quadrilateral feature that can be seen today, shows a startling agreement. The present features show that:

1. All of the quadrilateral feature lies inside the modern cemetery reserve.

2. Most of the quadrilateral feature lies outside the present fenced portion of the modern cemetery reserve.

3. The dimensions of the quadrilateral feature are greater than 41 m east-west and approximately 29 m north-south.

4. The major quadrilateral feature is offset by 9°–11° with respect to the modern cemetery reserve.

5. The southern boundary runs to the south of Milligan's grave which may, along with a tomb over a supposed mass grave of sailors from a nineteenth-century shipwreck, form the south-west corner of the quadrilateral.

6. The north-east corner, while not apparent because of the disturbance in the general locality, has been covered by the boxthorn.

7. The northern boundary of the quadrilateral passes south of the present line of pines.

8. The western boundary of the quadrilateral is not apparent but may be presumed to be west of a line formed by the early (pre-1922) European graves in the cemetery, which lay at a different orientation (12° difference)[20] to the modern graves. This alignment may parallel and therefore reflect the original western boundary. This alignment of early graves also lines up closely with the western edge of the chapel, which is consistent with Robinson's map.

9. In addition to the above factors, there is the evidence provided by eleven rectilinear depressed features along the eastern and south-eastern interior edge of the quadrilateral, which are postulated to be graves. Such features are not present outside the quadrilateral. Their different appearances probably arise from the grave robbing activities of the late nineteenth century. In addition to these more formal features, there are many less obvious features without distinct edges scattered within the quadrilateral which were not mapped but which are consistent with heavily worked and reworked ground.

All the evidence strongly supports the contention that the quadrilateral feature marks the boundary of the burial ground.

Resistivity survey: results

Some 15,000 readings were taken by two operators over a six day period in April, 1986. The data is presented as a grey-plot in Figure 6. Inspection of this plot reveals a number of interesting features.

Running north-to-south down the western side of the plot can be seen a very dark linear feature (A). This feature can be correlated with a linear feature that can be observed in the field as a slight raised area running from the present cemetery gate southward towards the entrance to the enclosure around Milligan's grave. It is suggested that this feature is a buried roadway and the dark plot (high resistivity) supports such a conclusion.

Adjoining this linear feature to the east can be seen a large quadrilateral showing as a light grey area (B). It is suggested that this area has received a great deal of modification. Low resistivity values suggest a large area that has been excavated and refilled. The contrast between the light grey of the quadrilateral and the darker grey surrounding it (most notably towards the east and south of the quadrilateral) would suggest that this excavation activity took place

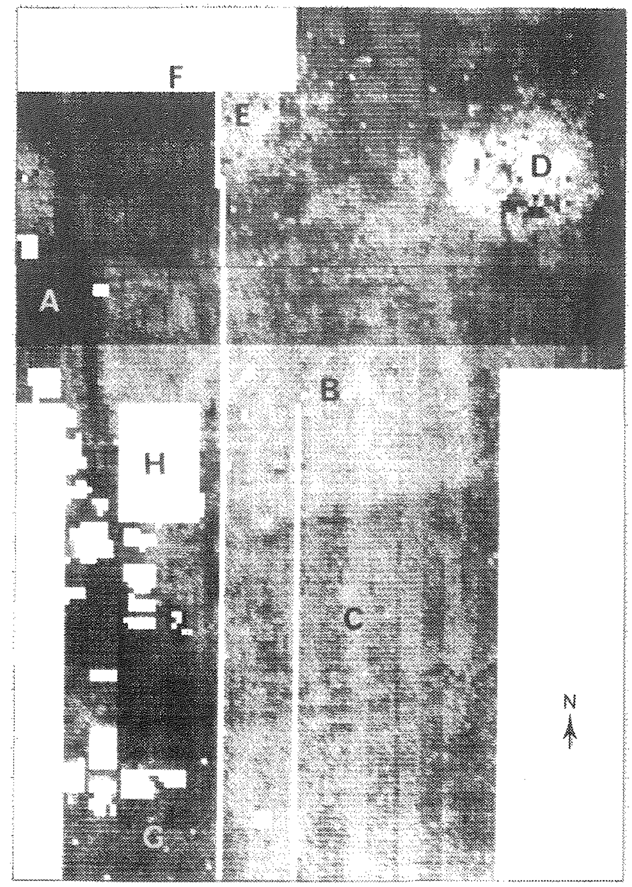

Fig. 6: Resistivity plot of Wybalenna cemetery. Border marked in 0.5 m divisions.

within a carefully designated and confined area. The size, shape and orientation of this quadrilateral make it strikingly similar to that delineated in Robinson's survey (Fig. 3) and to the feature noted during the topographic survey that preceded the resistivity survey (Fig. 5). It is suggested that this area of low resistivity is the enclosure containing the Aboriginal burial ground.

In Figure 6, abutting the southern border of this quadrilateral can be seen a striated area of dark and light bands encompassed by a faintly defined border (C). These striations represent banks and ditches and indeed can be observed today as features on the ground (Fig. 5). It has been suggested earlier that these features represent an enclosed garden plot post-dating the original formation of the burial ground.

Other features of note include: the large circular area of low resistivity to the north-east, representing the very moist soil underneath a large boxthorn, removed to allow access to its ground beneath (D); a low resistivity area representing moist soil pugged by stock turning the present fence corner (E); a high resistivity area of dry soil caused by the shelter provided by a row of pines (F); and a very lightly defined striation running west–east in the southern part of the survey, which can be correlated in part with the southern boundary of the present fenced area and its continuation, and which probably formed after the 1889 survey (G).

Some of the white areas on Figure 6 represent areas where it was not possible to take readings (e.g. modern concrete grave cappings, represented by small rectilinear features, Milligan's enclosure, shown by a large rectangle (H), and the eastern fence of the presently demarcated area which appears as a white column running north–south). Areas also occur where readings were not taken because of time constraints (the large white rectilinear blocks in the north-west, south-west and south-east of the survey). The white column stopping in the centre of the survey is a survey error; the readings were not taken for that row.

A slight caveat should be made at this juncture. It is being suggested here that the large quadrilateral area of low resistivity is the Aboriginal burial ground. The only way that this could be tested rigorously would be by archaeological excavation; a methodology that would not be acceptable to members of the Flinders Island Aboriginal Association or to the general public at large! While it is recognised that other features besides graves can produce low resistivity plots, the similarity in shape and dimensions of the quadrilateral to both the feature noted in the modern survey and the burial ground shown on Robinson's map would suggest that it is the cemetery.

Further resolution of the features in this area can be made. Because RESPLOT is designed to assign to each grey level an equal range of resistivity values, broadacre plots such as Figure 6, having as they do areas of very high resistivity (the roadway) and areas of very low resistivity (the soil beneath the boxthorn), tend not to discriminate amongst the many similar values lying in the mid range. In effect the mid-range values, the ones of particular interest to this study, are 'burnt-out' (to use a photographic term). This limitation can be partly overcome by dividing the area under examination into sub-plots. Each sub-plot is independently produced using the full range of grey levels available, thereby allowing a smaller number of resistivity values to be represented by each individual grey level. This in turn allows for greater resolution of features within a single sub-plot. These individual sub-plots can be combined in turn to form a mosaic of the whole area which has a much better resolution than

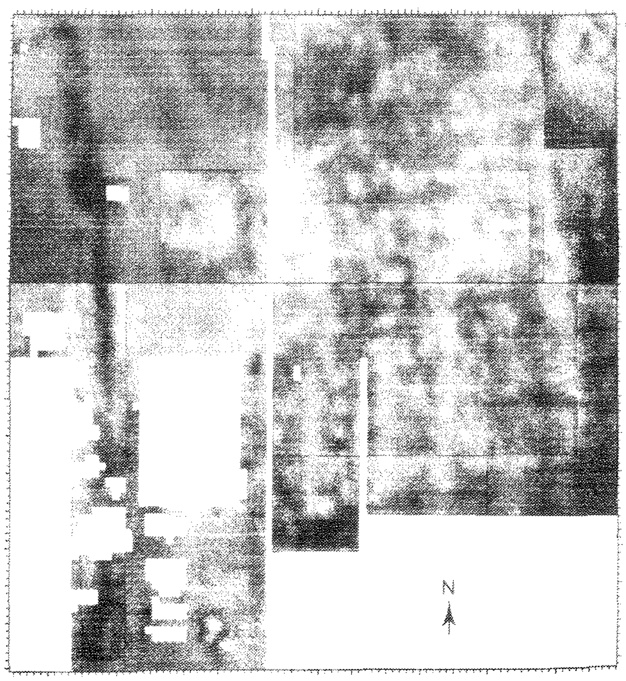

Fig. 7: High resolution mosaic of old burial ground. Border marked in 0.5 m divisions.

a single plot of the entire survey area. In Figure 7 a mosaic has been constructed of a number of sub-plots of the quadrilateral.

Two types of features within this structure can be distinguished, both illustrated as generally lighter areas of lower resistivity: striations running north to south and areas of diffuse mottling. Both features are bounded by a darker area representing undisturbed 'natural' soil. This is particularly apparent in the south and east. The other boundaries are not so obvious, being hidden by the boxthorn, pugged area, roadway and Milligan's enclosure in the north-east, north, west and south-west respectively.

With respect to the features within the quadrilateral, it is suggested that the light striations represent rows of graves, while the dark striations represent the unexcavated areas between these rows. Within these light striations the mottling that is apparent may represent individual graves. The fact that there seems to be a number of very distinctive rectilinear light patches may be a result of these graves being still extant, never having been disturbed during the later period of grave robbing. The light areas of the diffusely mottled area may represent those graves which have been robbed; the re-excavation and the subsequent disturbance of the surrounding ground, together perhaps with the remaining soil not being wholly replaced in the graves but left scattered around, may have given rise to such an effect.

In attempting to isolate individual graves, given a likely grave area of 2 m x 1 m, the limit of the method with a probe spacing of 0.5 m, is reached. The instrument response to various graves would differ depending how often the two probes impinged on a grave at the same time; different transect alignments over graves of similar areas could allow from one to four ideal readings to be taken. More often, however, one probe would be over a grave while its twin would be over the unexcavated area adjacent. This problem could be resolved by shortening the probe spacings to say 0.25 m and undertaking the survey on a grid of a similar cell size. However, while this would allow for an approximate four-fold increase in resolution, it would also require a four-fold increase in readings and therefore survey time. This may be acceptable, however, if each grave needs to be accurately located.

A final plot is offered illustrating extreme filtering (Fig. 8). In this plot the lower third of the range of resistivity readings (representing in the main infilled disturbances in the 'natural' soil) are shown as white areas. The remaining upper two-thirds of the readings (representing 'natural' soil and compacted features such as the roadway) are shown as black areas. In effect this plot is an exaggerated form of the preceding plot.

It can be seen, especially in the southern half of the quadrilateral, that there appear to be rows of low resistivity features. These rows are formed, in part, by small rectilinear features of a similar order of size to that expected of graves. That these phenomena are not so apparent in the northern half of the cemetery, may be due to the features being too close together to be resolved with the current probe spacing and/or may be due to features becoming confused through re-excavation and subsequent spreading of soil, as would occur during grave robbing. Of note also is a separate area of low resistivity in the north-west corner of the quadrilateral. If these are graves it is likely that they are either the graves of a special group of individuals buried apart or, as bodies were usually buried sequentially from a common origin, they may represent the first or last group of interments in the old burial ground.

The interpretation of the results illustrated in this particular plot is probably pushing the method to the limits and should therefore be viewed with some caution. However, the extent and distribution of

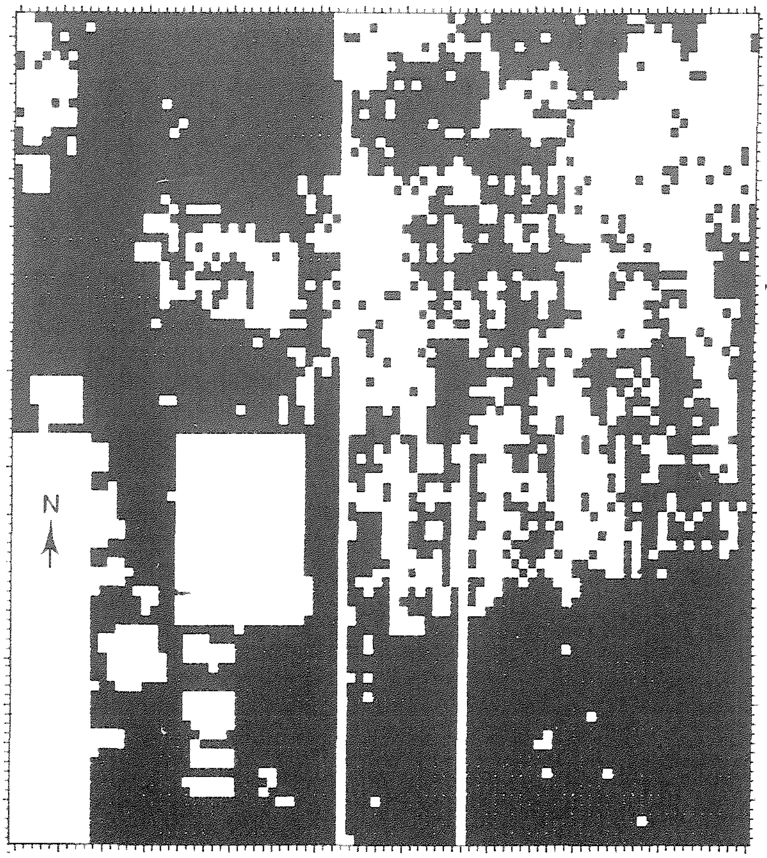

Fig. 8: Filtered plot of old burial ground. Border marked in 0.5 m divisions.

features are intriguing, especially in light of evidence that came to hand as this paper was being prepared.

Robinson's chart of the old burial ground

After the body of this paper had been written, a copy of a chart drawn by Robinson in 1838 of the old burial ground was brought to our notice.[21] Figure 9 is an adaptation of this chart. The similarity between the depiction of the burial ground by Robinson, the modern topographic survey (Fig. 5) and the results of the resistivity survey (Figs 6–8) is striking.[22]

1. Robinson depicts the burial ground as measuring 105 x 130 x 90 x 130 feet. The metric equivalents of these dimensions, that is 39.5 m east to west and between 27.5 and 32 m north to south, are very close to the measurements of the quadrilateral feature noted in the field: greater than 41 m east to west, and approximately 29 m north to south.

2. Of note also is that the graves were placed in rows and lie predominantly in the eastern half of the burial ground. This is a pattern which is reflected by the resistivity survey (Figs 6–8). The area of low resistivity in the north-west of the quadrilateral, which is not represented on Robinson's map, probably represents burials post-dating 1838.

Conclusion

From the observations made in this study, namely the examination of Robinson's map of Wybalenna, the modern topographic survey, the resistivity survey and latterly Robinson's chart of the burial ground, it is concluded that the old Wybalenna burial ground lies within the present cemetery reserve but that most of it lies outside the protected, fenced enclosure erected by the Flinders Island Council to keep stock off the European graves.

CASE STUDY: THE PORT ARTHUR HISTORIC SITE, TASMANIA

From 1979 to 1986 the Port Arthur Conservation and Development Project conducted archaeological studies at the historic site.[23] The majority of the investigations were directly related to conservation works. Staff archaeologists were regularly called upon to provide information which could be used in the restoration of historical structures and landscapes. As part of the conservation process, consultant architects and engineers drafted plans which required additional historical and archaeological research. This case study is a response to a plan which was prepared for the reconstruction of the foregrounds of the Medical Officer's cottage. Of particular concern was the form of the carriageway and garden paths. Extant historical plans differed with respect to the representation of these landscape features.

A program was conducted from December 1986 to February 1987 which combined remote sensing techniques with excavation. Landscape features were identified by the remote sensing operation and their form was confirmed by the archaeological excavations.

Port Arthur historic site

The convict establishment at Port Arthur was a remarkable institution that combined penal servitude with colonial development. Situated on the south-east coast of Tasmania, within a protective bowl of wooded hills, the settlement thrived from its founding in 1830 until transportation to Tasmania ceased in 1853. In 1877 the penal institution was closed, to be resettled in the 1880s as the township of

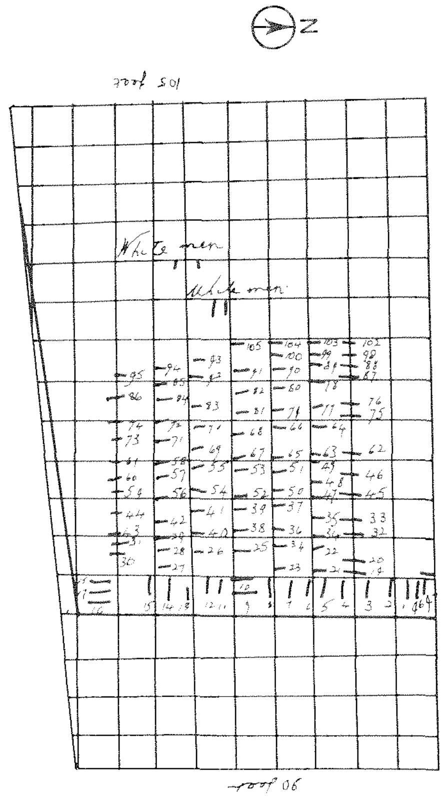

Fig. 9: Robinson's 1838 chart of the old burial ground (adapted, simplified, from Plomley 1987: plate 20). To compare with Figures 6–8 rotate 90° anticlockwise. Note that the southern and eastern boundaries are represented with a heavier line.

Carnarvon.[24] The remains of that prison establishment, with the more recent changes during the days of the township, as well as the facilities added within the last decade by the National Parks and Wildlife Service, give an inventory of more than seventy structures. Represented in this figure are only a small number of the many penal, industrial and residential structures which once belonged to the convict settlement. Most of the structures were removed as salvage or consumed in the bush fires which swept the peninsula at the end of the nineteenth century. The extant structures are regarded as being particularly significant, as collectively they represent a symbol of convictism, that institution which figured so prominently in the founding of Australia.

For the purposes of this study we are interested in only a small part of the convict establishment. On the far western slopes of the settlement, a row of residential units was constructed in the 1840s for prison officials (Figs 10–12). Each of the five residential units in the row of officials' quarters was a complex of buildings, which included a main house and an outbuilding containing a kitchen and scullery. Either separate or attached to this building were privies, a stable and sheds for livestock. The far southern unit in the row, the grandest, was constructed for the Visiting Magistrate. To the north of the Visiting Magistrate's was the Roman Catholic Chaplain's cottage and further north, the Medical Officer's house.[25] On the other side of Champ Street (Fig. 10) was the Accountant's (or Commissariat Officer's) residence and the Parsonage which housed the Church of England Chaplain.

During the days of the township of Carnarvon, the 1880s to the 1920s, the three southern units served at various times as residences, guest houses and as a hotel. The Carnarvon Post Office (Parsonage) and the Accountant's each have well defined front gardens with pathways and either brick or paling fences marking their boundaries. With respect to the three southern structures: the Visiting Magistrate's, the Chaplain's and the Medical Officer's residences, the front garden areas lack definition. In recent years, the digging of trenches for the installation of water, sewerage, drains and electrical services, as well as a 'clean-up-the-landscape' policy by site management has erased all but a few vestiges of the original landscape design. The extent of this assault on the landscape can be seen in a 1977 infra-red aerial photograph, which clearly shows the installation throughout the historical site of a reticulated water and sewerage system.[26] Also visible is an earth-grader on the front lawn of the Medical Officer's. Besides showing the massive earth-moving activities on the lawns of the residential units, east–to–west-tending lineal features are also visible. These features appear to be indications of former pathways and carriageways. It is reasonable to expect that evidence of the early pathways and fence alignments would have been partially, but not entirely, erased.

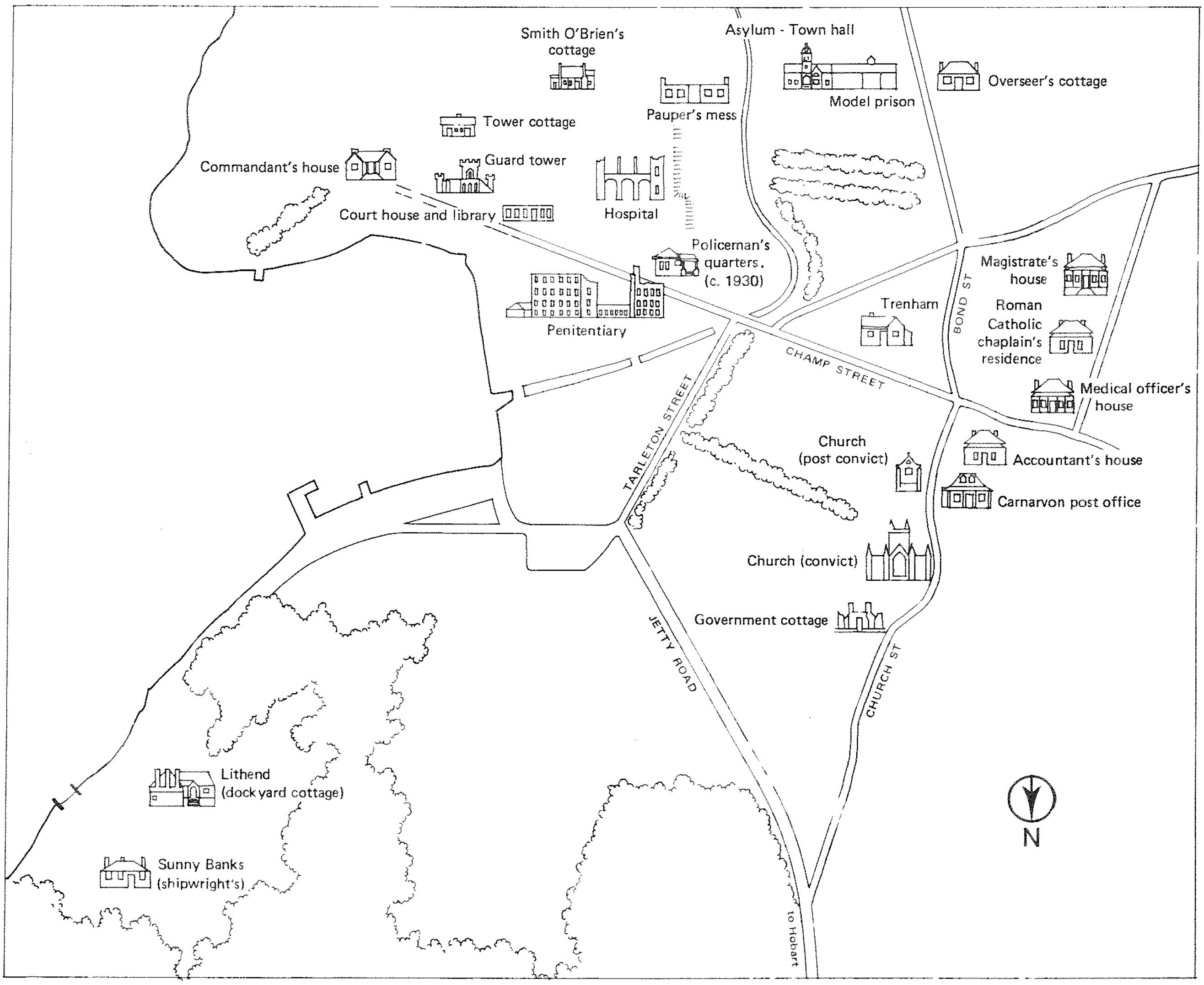

Fig. 10: Port Arthur Historic Site as presented to visitors in 1988.

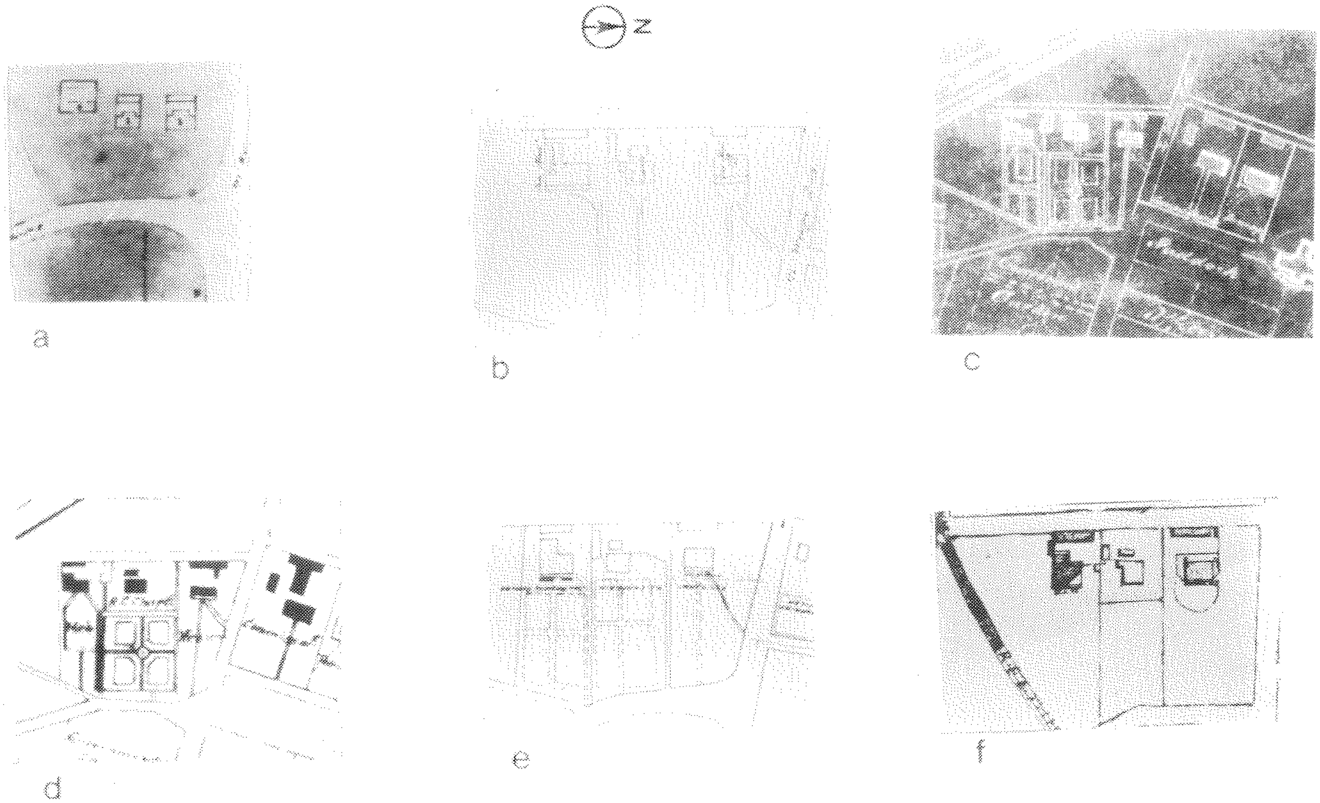

Fig. 11: Portions of historical plans which relate to the penal officials' residences at Port Arthur: (a) 'Boyd' plan of 1854. (b) 'Lander' plan of 1858. (c) 'Pembroke' plan of 1858–62. (d) 'Imperial' plan of 1858–62. (e) 'Block' plan of 1862. (f) 'Blackwood' plan of 1877.

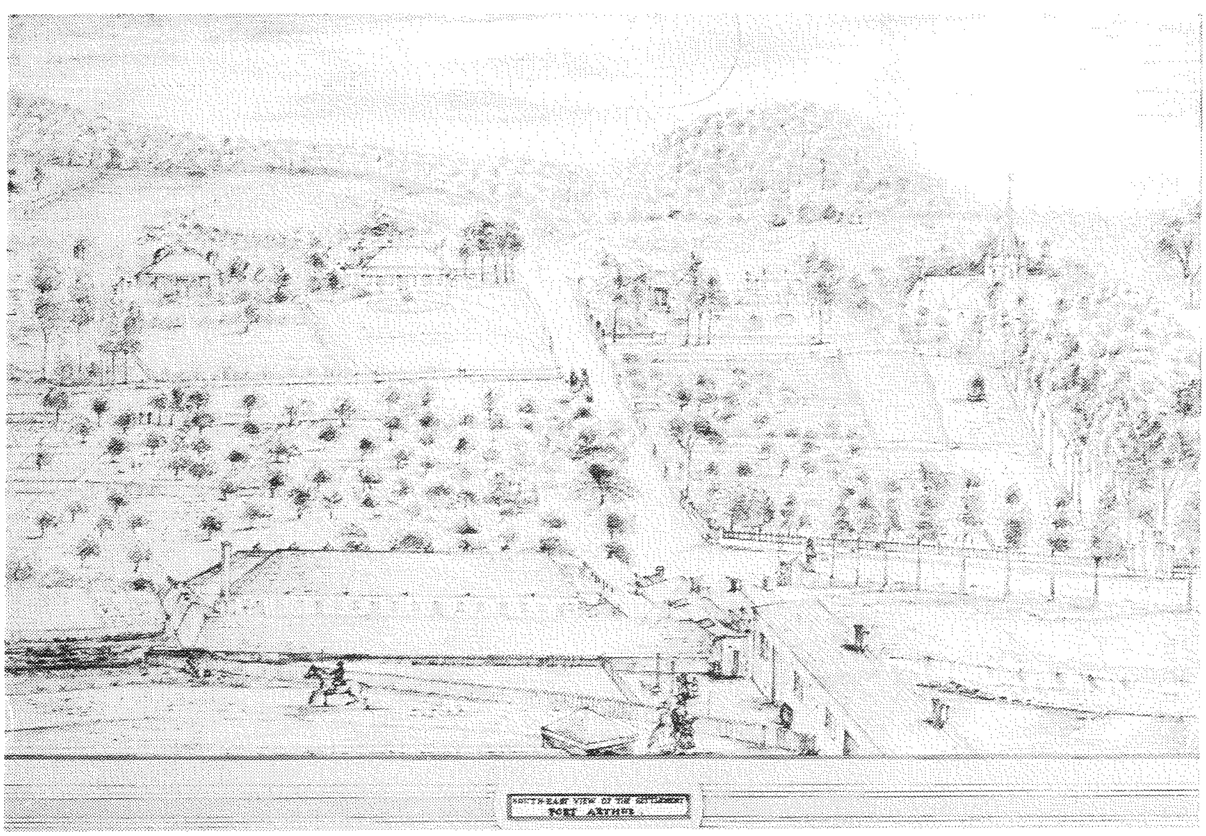

Fig. 12: A contemporary sketch of Port Arthur from the south-east. Dated to 1853–1854.

Restoration in 1983 of the Medical Officer's house by the Port Arthur Conservation and Development Project, received both state and national architectural and museum awards. This structure was the only residence to be restored using traditional materials and methods. As a house museum, the building is open to the public, furnished to represent that period in the 1850s when it was occupied by the settlement's Medical Officer. The cottage makes a perfect 'chocolate box' scene, except for the foreground which lacks the landscape ornamentation, carriageway and fences which are known to have once provided the all-important setting for the residential structure. To the architects, Clive Lucas and his associate Ian Stapleton, their excellent work which served to bring the building alive is diminished by the absence of suitably restored surroundings. This feeling is accentuated by the presence of a nicely restored cottage garden immediately in the front of the adjacent Roman Catholic Chaplain's residence. Hence it was felt that a resistivity survey and archaeological excavation, followed by reconstruction of the landscape to an appropriate convict period, would enhance the restored Medical Officer's cottage.

Another factor to be taken into account is that Port Arthur hosts about two hundred thousand visitors each year and those guests make their way around the site from one historical feature to another. Without defined pathways leading to the Medical Officer's residence, except for a short modern driveway, people approaching from the south after leaving the Visitor Centre and Model Prison often traverse the lawns in front of the historical residences. Restoration of the pathways would facilitate pedestrian access and add considerably to the historical ambience.

Although much of the historical pathway system has no doubt been destroyed, remnants of it are visible. Each morning, Henry and Simeon, the sons of the Project Manager, walked down the historical pathway from the Visiting Magistrate's to Bond Street, to catch the school bus. Recent trenching, associated with the rebuilding of drains, brought to light remains of a central pathway surfaced with crushed bricks which led from Bond Street to the Chaplain's. Accounts of elder residents established that the carriageway once entered the grounds of the Medical Officer's in the north-eastern corner of the block, directly opposite Church Street. A surface inspection of the area supported these accounts. Also, ridged lineal features running in an east–to–west direction are visible between the Chaplain's and the Medical Officer's foregrounds. These were believed to be the remains of the historically documented carriageway which ran from Bond Street to the Chaplain's Cottage.

The documentary evidence

Diaries and reports written by penal officials[27] while living in the Medical Officer's cottage do not describe the grounds. Those documents, as well as other sources, were reviewed by Margaret Glover in 1984 when she prepared a report on the lifestyles of officials at the penal settlement.[28] She found that very little was said about the use of the interiors of the cottages and less was said about the grounds. Compilations of historical data, commissioned by the Conservation and Development Project, brought together information relating to all structures, either planned or constructed at the Port Arthur penal settlement. This work by Ian Brand[29] and Margaret Glover[30] provides a ready reference to archival material. Although very little was written about the layout or use of the grounds, historical maps and plans were located and copies placed within a portfolio. The sequence of land use and development detailed by the portfolio of maps and plans is clear in general terms, but specific details are often contradictory. In some instances, there are major discrepancies between documents.

A plan of the settlement dating to the 1830s shows the area of the officials residences as a woodland which was cleared and assigned to the settlement officers for vegetable gardens.[31] The 'Boyd' plan of 1854 shows the three residences, and the roads to the north, south and east, but not the lane to the west. The design of the grounds is not detailed (Fig. 11a).[32]

Two sketches, most likely contemporary, dated to 1853–1854, show views of the settlement. One of the views illustrates the row of five residential units complete with detailed representations of the foregrounds (Fig. 12).[33] Fences, paths, gates and garden beds are sketched. At the Medical Officer's, a carriageway is depicted which sweeps around a central garden bed. A gate is positioned at the entry, on the north-east side of the block, opposite Church Street. This sketch is the only known historical document to depict a circular carriageway at the Medical Officer's residence. A smaller gate in the surrounding fence is central to the block on Bond Street. At the Chaplain's, a larger gate gives entry to a lane between the Chaplain's and the Medical Officer's. The lane appears to serve only the Chaplain's cottage. Pathways are shown from Bond Street leading to the front door of the Chaplain's and to the Medical Officer's cottage. At the Visiting Magistrate's, which is at the far left of the sketch, there is a slightly larger gate giving entry to a path or lane-way which runs the length of the far northern side of the block. Other details are not shown. Of interest is the two-tiered appearance of the Chaplain's garden, an upper tier extending in the front, to a position on the same north–to–south alignment as the central garden bed at the Medical Officer's.

The 'Lander' plan of the settlement provides more detail, depicting paths (or carriageways) from Bond Street to the Visiting Magistrate's, to the Chaplain's and to the Medical Officer's (Fig. 11b).[34] Also shown on the plan is the curving carriageway from Champ Street to the front of the Medical Officer's. The pathway to the Visiting Magistrate's appears to be divided, perhaps the narrowest path to the south was for foot traffic while the broader way to the north could have been for carriages.

Two other very similar plans exist. One of the plans 'TASMAN'S & FORESTIERS PENINSULAS TASMANIA PEMBROKE',[35] is believed to pre-date what appears to be another version of it labelled 'IMPERIAL CONVICT ESTABLISHMENT PORT ARTHUR V.D.L' (Figs 11c & 11d).[36] Both plans agree in general terms on the layout of the residential units. The carriageway at the Medical Officer's is shown without a central turning circle. The front path is present. Both the gardens of the Visiting Magistrate's and the Chaplain's are elaborate, more so than is depicted on other plans. Here the Chaplain's garden is divided into four portions with a central feature. The Visiting Magistrate's has a path leading from Bond Street, which divides midway into two approaches to the building. The path or carriageway on the northern boundary of the Visiting Magistrate's block is shown, but there is also a similar way on the southern side of the Chaplain's block which extends to the stables.[37] A path on the northern side goes from the front of the Chaplain's block to the rear. These plans offer a different garden layout from that depicted on plans dated only a few years earlier.

A 'Block' plan dated to 1862[38] shows the same basic arrangement in a simplified form but with changes in detail. There is no central circle at the Chaplain's and, instead of being divided into three parts, the Visiting Magistrate's garden now has a four-part division like the Chaplain's (Fig. 11e).

In 1877, prior to the settlement being sold, a survey of township blocks was prepared (Fig. 11f).[39] The plan does not detail the garden layouts but does show the fences between the Medical Officer's and the Chaplain's and between the Chaplain's and the Visiting Magistrate's. A semicircular feature is shown in front of the Medical Officer's cottage.

A photograph published in 1911[40] shows the foregrounds of the buildings overgrown with orchards and other plantings. A side entry directly from Champ Street to the Medical Officer's is shown, as is the front central path to the Chaplain's and double gates at the laneway between the Medical Officer's and the Chaplain's. Photographs in the files of the Port Arthur Conservation and Development Project show the southern residential units during the early portion of this century, but they add little to the interpretation of the penal period landscape.

Aerial photographic interpretation and visual inspection of the ground surface provides tangible evidence of east–to–west lineal features, most likely the traces of the pathways and carriageways. These can be seen at the northern boundary of the Visiting Magistrate's, central in the Chaplain's block, and between the Chaplain's and the Medical Officer's. There are very faint traces of a central path at the Medical Officer's, possible indications of a curved carriageway but no evidence of a circular garden bed.

In 1980–81, when plans were being drafted for the restoration of the row of residential units, two excavations were carried out at the front of the Medical Officer's.[41] One was at the presumed entry point of the carriageway. At this location remains of the entry road were found. This evidence consisted of a layer of crushed gravel ('blue metal') directly below the topsoil. The crushed gravel was reported as being on top of a layer of broken shells, which in turn overlapped a layer of broken bricks. In an attempt to locate the semicircular feature depicted by Blackwood in the survey of 1877 (Fig. 11f), Orme excavated at '66 links' in front of the Medical Officer's house (or verandah, the report does not specify). A layer of broken bricks was located but was considered to be too indistinct to define a pathway. As no plan was provided in the report, it is impossible to tell the exact location of the archaeological excavation.

In summary, for the Medical Officer's garden, the presence of a central garden feature as depicted in the 1853–1854 sketch is not verified by plans drafted at that period or later. In fact, the balance of documentary evidence suggests that the sketch is an artist's creation to fit a Georgian model of good taste. Archaeological investigations were inconclusive. The central landscape feature and the pathway from the avenue in front of the residence, Bond Street, depicted on a number of historical plans, was not located by the archaeologist.

For the Roman Catholic Chaplain's garden, the general location of the central pathway is known. However, the fourfold division of the garden with a central feature, as depicted on plans dating to 1858–1862 (Figs 11c and 11d) is not confirmed by other sources. Nor was it represented on the 1853–1854 sketch.

At the Visiting Magistrate's, the path at the northern boundary is well marked on the surface but the nature of the paving is unknown. The 1858–1862 threefold division (Fig. 11d) of the garden appears to contradict the fourfold division (Fig. 11e) represented on the 1862 'Block' plan.

Resistivity survey

Three days were set aside in December 1985 for the writers to undertake preliminary testing of the Gossen Geohm resistivity meter.

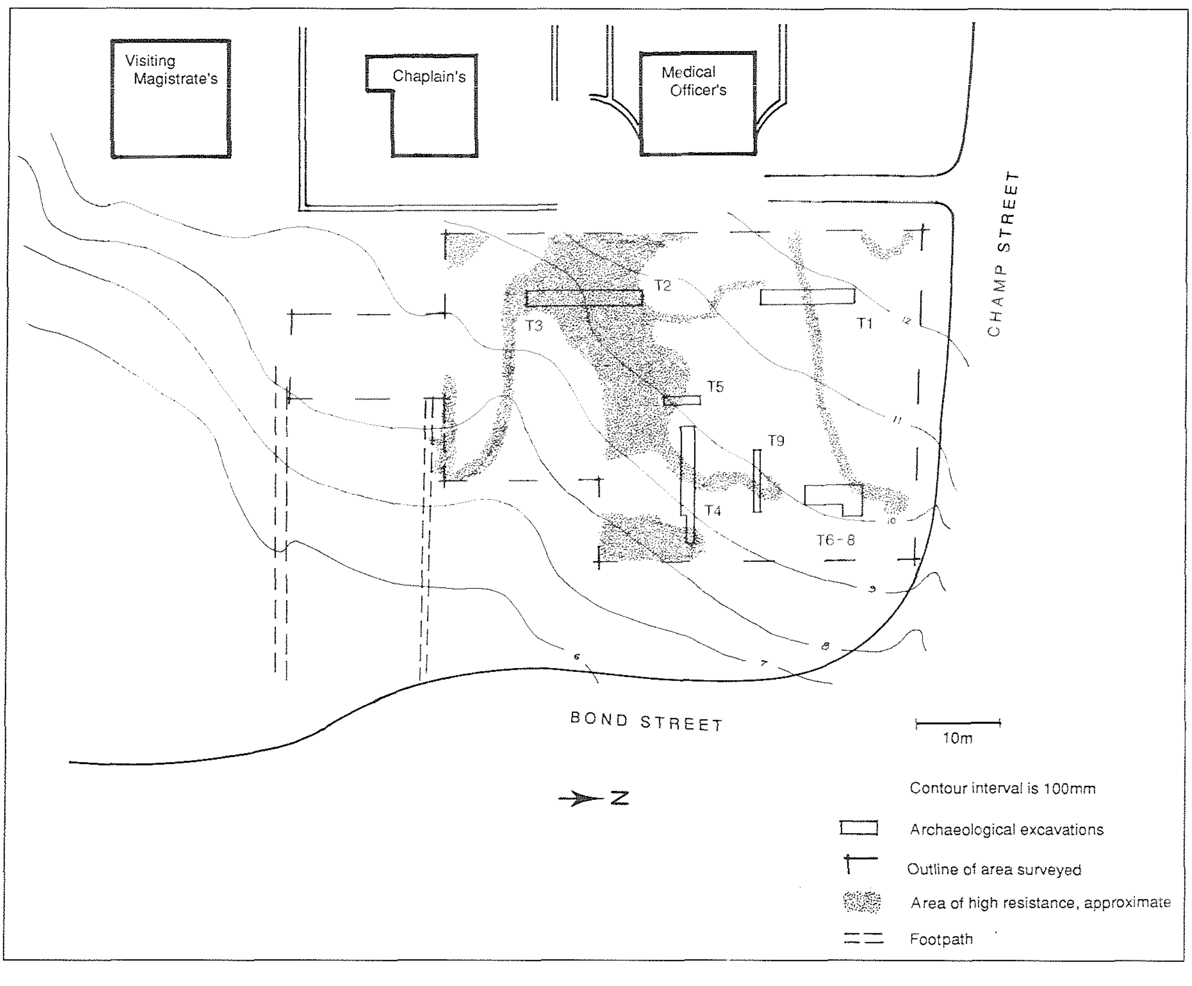

Fig. 13: Archaeological investigations of the Medical Officer's landscape, Port Arthur.

Unfortunately, the weather conditions were not ideal, with twenty-four days in the month registering rainfall, the total being the greatest ever recorded. With the ground sodden under foot there was some concern that the resistivity meter would not operate at its best. However, it was known that such conditions were frequent in Britain and it was apparent by the range of readings recorded that the system was responding adequately to the soil conditions.

In the fortnight preceding the preliminary resistivity survey, a 10 m x 10 m grid was laid out over the north-western portion of the lawns in front of the Medical Officer's and the Chaplain's cottages. The resistivity survey moved along briskly, with two 10 m x 10 m units requiring about 2.25 hours to survey.

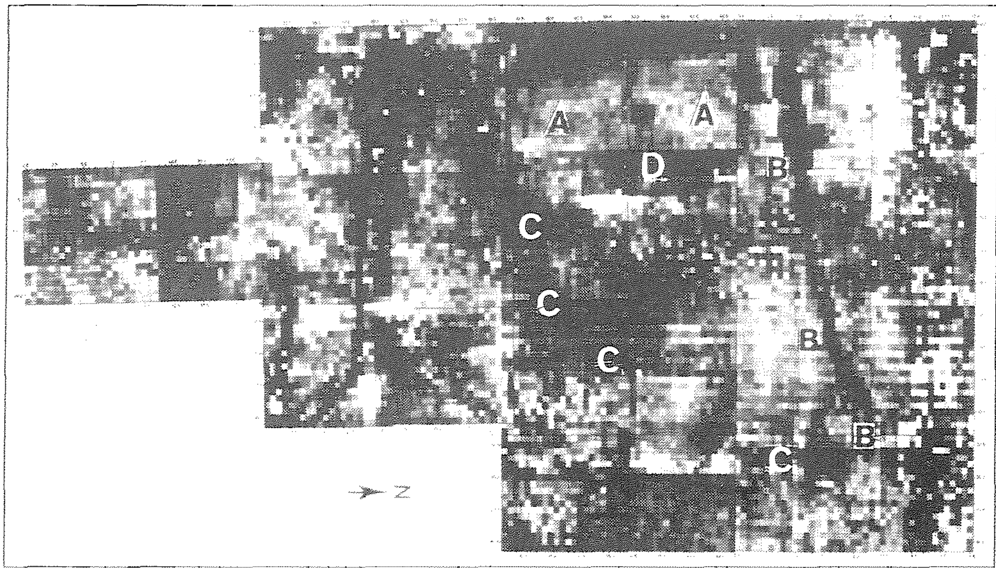

Fig. 14: Plot of the resistivity readings of the Medical Officer's landscape, Port Arthur. The A's in upper mid centre mark an area of low resistivity, which is believed to represent the central garden feature of the carriageway turning circle. D suggests the location of the earlier archaeological excavation. C's are the hard-packed crushed rock surface of the entry road. B's are the later entry road.

A plan was drafted based upon the resistivity readings of the twelve 10 m x 10 m units. As at that time the RESPLOT computer program had not been written, a grey-plot could not be generated. A contour plot was prepared by drawing lines connecting all points of equal resistivity. This was regarded as a preliminary effort but sufficient for programing the initial stages of the archaeological program. Before the survey commenced, it was realized that the area was badly disturbed and that recent features would tend to dominate. The plot defined modern features such as the hard-packed gravel at the base of an information sign in front of the Medical Officer's and the network of drains in front of the Chaplain's. East-to-west-tending interruptions to the north–south resistivity contour lines were present at the front of the Medical Officer's. These anomalies were positioned close to where the borders of the enigmatic turning circle would have been.

Archaeological excavation of the Medical Officer's landscape

In January 1986, excavations were carried out to locate and identify landscape features in the front garden of the Medical Officer's quarters. Six areas were excavated (Fig. 13).

Trench 1 (12.0 m x 1.5 m) in the north-west quadrant of the foregrounds was excavated to define the northern approach to the structure (Fig. 13). It was believed that this carriageway was in use at an early date and continued to be used until quite recently. In this area of the site the subsoil proved to be relatively close to the surface, at a depth of 200–300 mm.[42] The excavation revealed a series of superimposed road surfaces and ditches, lending support to the hypothesis that this route had been in use for a considerable period of time.

Trench 2 (10.0 m x 1.5 m) and Trench 3 (5.0 m x 1.5 m) were excavated in the south-west quadrant of the foregrounds at a location where there was a strong anomaly in the resistivity readings. Trench 3 was then extended to the south to intersect the presumed alignment of the Chaplain's carriageway. Clay subsoil in Trench 3 was encountered at a depth of 1500 mm. The additional spoil in this trench has been interpreted as the result of a cut-and-fill operation associated with the construction of the Medical Officer's cottage. At approximately the same level as the road surfaces in Trench 1, a scatter of crushed road metal was encountered. This material was in a location coincident with the enigmatic circular carriageway. At the southern extent of Trench 3, the surface of the Roman Catholic Chaplain's carriageway was encountered. Also, in the base of Trench 3, at the borderline between the Chaplain's and the Medical Officer's the remains of a fence post was excavated.

Trench 4 was an extensive but shallow excavation at the eastern side of the garden, directly in line with the front door of the cottage. It was anticipated that an excavation in this location would reveal both the central east–to–west pathway to the front of the residence as well as the remains of the circular carriageway. The diffuse layer of crushed road metal believed to be associated with the carriageway was found here. To the west of the carriageway the central path leading to the front of the residence was located.

Trench 5 (0.5 m x 3.0 m) was a small trench excavated directly to the west of Trench 4 to confirm the alignment of the central pathway. Trenches 6, 7 and 8 were excavated at the junction of the circular carriageway and the north-eastern entry to the Medical Officer's residence. Excavation indicated that the south-eastern segment of the carriageway lay stratigraphically beneath the northern section. Trench 9 was excavated midway between Trench 4 and Trenches 6, 7 and 8. At this location a well preserved segment of a carriageway was uncovered.

The excavations confirmed the existence of the circular carriageway shown in the 1853–1854 sketch. Time constraints did not permit the excavation of the central carriageway feature depicted as a small garden bed on the sketch. Further support was provided later by a grey-plot (Fig. 14) which shows a circular area of lower resistance to the front of the Medical Officer's cottage. Also shown on this map is an anomaly which is believed to represent the 1981 excavation by Z. Orme (Fig. 14, indicated as 'D').

By combining information from the archaeological excavations, documentary sources and the resistivity survey, a tentative sequence of landscape development for the Medical Officer's residence has been established (Fig. 15). The first building to be constructed in the row, the Roman Catholic Chaplain's cottage, was served by an entry to the north (Fig. 15a). A lane was constructed behind the residences when the Medical Officer's and the Visiting Magistrate's were built (Fig. 15b). The former Chaplain's drive was truncated, now going

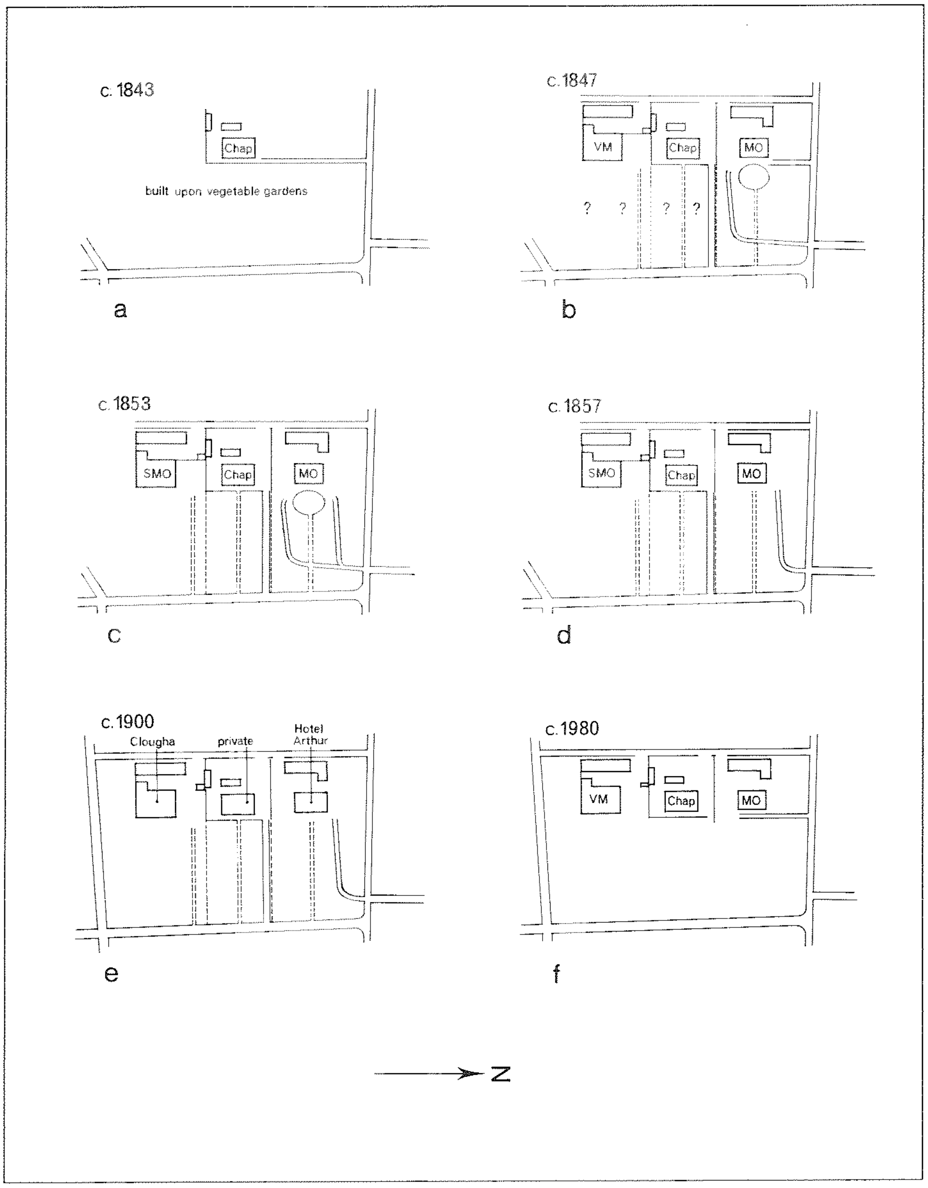

Fig. 15: Evolution of the landscape of the officials' residences, Port Arthur.

only as far as the Medical Officer's. The Chaplain's residence then had a drive from the front as well as the rear. The southern link of the Medical Officer's carriageway was constructed and then the northern link as the former Chaplain's entry fell out of use (Fig. 15c). At some unknown time the southern link ceased to be used (Fig. 15d). The northern link remained until quite recent times, to be supplanted when the northern entry, the earlier route to the Chaplain's, was reopened (Fig. 15e & f).

Conclusion

Archaeological excavation of the Medical Officer's landscape indicates that the 1853–1854 sketch is correct, in that at one time the residence did have a circular carriageway. Although not defined on a contour plot of the resistivity readings, the circular feature is defined on a grey-plot.

Two factors diminished the effectiveness of the resistivity survey. Firstly, there are the circumstances related to the initial construction of the residences, when a terrace was cut into the side of the hill to accommodate the structures. Spoil from the cutting was used as fill to level the southern sector of the Medical Officer's front grounds. The resistivity method works best when employed to differentiate between undisturbed soil and intrusive features. The presence of large quantities of fill would serve to mask historical features, which would have been readily sensed if they had been constructed on undisturbed soil. Secondly, just prior to and immediately after the site came into public ownership, orchards were planted and then at a later date grubbed out. The surface was then smoothed by a tractor-drawn rotary-hoe. The implement would have scattered the crushed rock or brick surfaces of the carriageways and paths.

That the resistivity survey, when combined with the RESPLOT computer program, did detect historical features under far less than ideal circumstances, indicates that the technique may have a wider range of application than previously believed.

DISCUSSION

Earth-resistivity prospection is an efficient means of locating buried archaeological features that are not apparent from surface inspection. This paper has shown that earth resistivity has widespread application in Australia. It is of especial relevance to cultural resource management, where it can be used to 'clear' sites prior to development without the need to undertake prior exploratory excavations and/or the continual monitoring of machinery during development. The method would also benefit research programs, enabling sophisticated questions to be asked of the site before excavation, besides assisting with more exact placement of trenches without the usual cost in time and effort of large systems of exploratory trenches. The cost of the instrumentation and probe array is approximately $2000. It requires about twenty-four person-days to survey a hectare. Operators of the instrument do not have to be highly skilled, though interpretation of the finished plot requires some expertise. The cost of examining a similar area by standard excavation methods, using skilled people and heavy machinery, would be so much greater as to be prohibitive.

Resistivity surveying is not the only form of geophysical prospection. Magnetometry using either a proton gradiometer,[43] a differential fluxgate magnetometer,[44] or a caesium vapour magnetometer,[45] is commonly employed. Use of ground-probing radar is becoming more widespread.[46] Other methods with more limited or specialised applications such as seismic reflection,[47] temperature probing,[48] the induced polarisation method,[49] the electromagnetic method,[50] and the self-potential method,[51] are occasionally used.

The resistivity system compares well with the magnetometry systems commonly available. The proton gradiometer, needing to be reset after every reading, is only marginally faster in operation than a

9. Aspinall & Lynam 1970: 67–75. Theory of the method is mentioned in passing but to the authors' knowledge the use of the method has never been fully described in the literature.
10. Hesse 1966; Clark 1969; Tite 1976: 31–32.
11. Hesse 1966.
12. D. Ranson, personal observation.
13. Rochford 1987.
14. Ryan 1981: 174–204, Appendix 3.
15. Edgar 1838.
16. Department of Lands, Parks and Wildlife (Tasmania): Aerial photographs.
17. Department of Lands, Parks and Wildlife (Tasmania): Survey diagram.
18. Reibey 1862.
19. Original cemetery plan held in Council Chambers, Whitemark, Flinders Island.
20. This figure is very close to the difference between magnetic north and true north. Perhaps the old burial ground was aligned on true north. The modern cemetery reserve was aligned on magnetic north (approximately 10° east of true north in 1889).
21. We would like to thank Mr N.J.B. Plomley for bringing this information to our notice. Plomley 1987: plate 20.
22. A reorientation of Robinson's chart by 90° anticlockwise should be made to reconcile it with the resistivity survey.
23. Egloff 1987.
24. Refer to Weidenhofer (1981) for a history of Port Arthur penal settlement and the later townships of Carnarvon and Port Arthur.
25. The Visiting Magistrate's residence was later lived in by the Senior Medical Officer and the Medical Officer's cottage housed the Junior Medical Officer.
26. Infra-red aerial photograph, Department of Lands, Tasmania, M7711–118, 1977.
27. Lempriere 1954.
28. Glover 1984, 1985.
29. Brand 1983.
30. Glover 1979.
31. Plan of settlement by H. Lang. Tasmanian State Archives, Con 87/1 & 2, dated to 1836.
32. Plan of settlement by J. Boyd. Tasmanian State Archives, CO/280/316, dated to 1854.
33. Sketch labelled 'SOUTH-EAST VIEW OF THE SETTLEMENT PORT ARTHUR', by an unknown artist. Allport Collection, State Library of Tasmania, dated to 1854 by I. Brand and to 1853 by R. Morrison.
34. Plan of settlement by J. Lander. Department of Lands, Tasmania, dated 1858.
35. Plan titled 'TASMAN'S & FORESTIERS PENINSULAS TASMANIA PEMBROKE', Department of Lands, Tasmania, believed to pre-date the c. 1858–1862 version.
36. Plan titled 'IMPERIAL CONVICT ESTABLISHMENT PORT ARTHUR V.D.L.', a plan of Tasman Peninsula including details of Port Arthur, State Archives, 537/1, dated 1858–62.
37. It is believed that the 1.5 m high terrace, which now blocks this approach, is an early landscape feature. If so, the lane could not have functioned, yet as the Chaplain's block is presently laid out there is no practical access to the stables. This is another discrepancy in the documentary records which needs to be investigated with archaeological techniques.
38. Plan of Port Arthur, Tasmanian State Archives, dated [*sic*] '1802' (1862).
39. Plan of Carnarvon by J. Blackwood. Department of Lands, Tasmania, dated 1877.
40. 'Some Prosperous Districts in Southern Tasmania'. 'A Part of Carnarvon, Tasman Peninsula', *Tasmanian Mail*, 20/7/1911. Tasmanian State Archives.
41. Orme 1981.
42. Egloff 1986a,1986b; Hall 1986.
43. Aitken & Tite 1962; Tite 1972: 2.
44. Alldred 1964; Tite 1972: 22.
45. Stanley 1982.
46. Vaughan 1986.
47. Stright 1986.
48. Benner & Brodkey 1984.
49. Aspinall & Lynam 1968, 1970.
50. Tite & Mullins 1970; Bevan 1983.
51. Wynn & Sherwood 1984.
52. Geophysical Technology Pty Ltd.
53. For instance see Linnington 1967.
54. Kelly et al. 1984.
55. Mr A. Aspinall, pers. comm.
56. Hesse et al. 1986.
57. For the most up-to-date review see Scollar et al. 1986; Scollar 1970.
58. Egloff et al. 1972; Packard 1972; Parrington 1979, 1979–80.

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twin-probe resistivity system. The differential fluxgate or caesium vapour magnetometer give continual readings and are therefore much faster; claims for survey rates for the latter system of two hectares per day on a 0.5 m grid have been made.[52] However, the costs of magnetometers are prohibitive for most archaeological organisations and probably outweigh the benefits gained from their speed of operation on most sites. Proton gradiometers cost approximately $10,000 and caesium vapour magnetometers up to $80,000 (cf. $2000 for a resistivity system). Magnetometers also suffer from extreme sensitivity, being easily affected by extraneous non-archaeological noise such as localised soil magnetism, metallic 'clutter' (bottle tops, nails, etc.), wire fences, water pipes, drains, nearby vehicles, and power cables. Magnetometers have severe limitations in suburban environments because of such noise and have to be used with caution in rural areas. On an ideal site, however, magnetometers are very sensitive and can locate and resolve much smaller features than the resistivity system: though again this very sensitivity can make interpretation of plots potentially more difficult.

It has been suggested that the resistivity system has limited application to arid Australia. However, these limits to the system have yet to be explored. Preliminary tests seem to indicate that there is likely to be enough moisture in even the driest soils to carry out efficient surveys. Surveys in other dry regions of the world have been carried out effectively.[53] Indeed, it is possible that dry soils allow for deeper effective current penetration, because of the absence of masking caused by the presence of immediate subsurface water.

The main disadvantage of the resistivity system is its speed of operation. In the older literature the Wenner and Schlumberger arrays are most commonly described. Besides the results being difficult to interpret from them, these arrays are very slow and cumbersome to operate. The twin-probe array described in this paper produces unambiguous results and is fast to operate. Even so, the system can be improved. The attachment of a data-logger to the instrument enables data to be automatically read and stored on tape or floppy disc to be dumped, at the end of each day, into the computer memory for processing.[54] The use of a data logger is an immense labour-saving device, avoiding the need to record each reading manually and later to input the readings into a computer file. Increasing the speed of operation by mechanising the probe array is another potential area of development. An unsuccessful attempt to mechanise the probe array by fixing probes on a rotating drum, towed behind a vehicle, may bear further perusal.[55] An interesting system comprising a square array with electrodes formed by high pressure liquid and towed behind a tractor, can make approximately 1200 continuous readings an hour;[56] not yet as fast as the top-of-the-range magnetometers but over three times faster than the resistivity system described in this paper.

Other improvements to the method can be made by introducing more sophisticated image enhancement and display. Image enhancement is a rapidly developing field, spurred on by the development of satellite imagery of the earth's surface and deep-space probe examinations of planets. This has brought about an increase in the sophistication of mathematical filtering techniques, which can often be applied to geophysical prospecting. The literature is large but the reader is directed to its archaeological applications[57] which, while used mainly for magnetometry surveys, are relevant to processing resistivity results.

This paper has discussed the application of resistivity surveying to historical sites. It is just as applicable to prehistoric sites. The method could be used to plot large features such as the field systems of Highland New Guinea where, using a larger (1 m) survey grid, a greater area could be explored each field season than by conventional techniques. Other site types amenable to resistivity surveying are middens and mounds. It is intended shortly to explore the application of vertical profiling on Australian sites. Successive lengthening of probe spacing will allow for a concomitant sensing of deeper features. It should be possible using this method to detect major matrix changes and hence major phases within sites such as middens and cave deposits, and also to discover successions of midden sites within areas of major soil accretion such as dunes, lunettes, alluvial fans and the like. It is also intended to experiment in the near future with narrower probe spacings to locate smaller though, by necessity, shallower features such as small pits, graves and post-holes.

In conclusion, resistivity surveying offers an efficient and cheap prospection technique for Australian archaeologists. Using this method, sites ranging in size from single buildings to extensive penal settlements or townships can be effectively surveyed, even when no above-surface structure remains. The application of such surveys to both research design and cultural resource management strategies is immense.

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NOTES

1. Wenner 1915.
2. Clark 1969: 695; Aspinall & Lynam 1970: 67.
3. Atkinson 1952; Tite 1972: 8; Clark 1969: 695.
4. Aitken 1974; Clark 1969, 1975; Tite 1972: 25–32; Weymouth 1986.
5. Parasnis 1975: 161.
6. Samson 1979: 13–20.
7. Aitken 1974; Tite 1976: 29–31.
8. Lynam 1970.

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