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# Magnetic Anomalies in Archaeological Survey: Results from the Nasinu Ring-ditch Site, Viti Levu, Fiji

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**ABSTRACT**

The magnetic anomalies encountered on a typical lowland ring-ditch fortification located on the east side of the Suva peninsula, Viti Levu, are documented. Relatively large (± 200 gammas), extensive anomalies indicate considerable anthropogenic disturbance of the soil within the habitation area. The major cause of the anomalies is considered to be the presence of fired clay and stones originating in the hearths of individual houses but now widely dispersed. A secondary factor contributing to higher gamma levels throughout the site may be the enhanced magnetic susceptibility of the soils resulting from haphazard burning and repeated oxidation-reduction cycles caused by wetting and drying in the presence of organic waste material.

*Keywords:* ARCHAEOMAGNETISM, ARCHAEOLOGICAL PROSPECTING, ANTHROSOL, RING-DITCH FORTIFICATION, FIJI ISLANDS.

Only a small fraction of the archaeological detail of a site is visible at the surface; by far the greater part has been obscured by the gradual accumulation of soil in the period since the area was abandoned. Aerial survey is a powerful technique for the discovery of such sites, and aerial photography is particularly effective in capturing the evidence of partly obscured patterns. Features with a significant geometry are revealed in a variety of ways and the appropriate techniques for examining prehistoric settlement patterns in Fiji have already been documented (Parry 1977, 1982, 1984). Often, however, there are features of such sites that lack any kind of topographic expression or visible effect in the vegetation. Such features, which are not detectable on the air photo, can be examined using geophysical techniques because they give rise to abnormalities in the physical properties of the soil and subsoil.

The efficacy of these techniques should not be overestimated. There are few occasions when a geophysical survey produces such complete details that an archaeological interpretation is possible without the need for excavation. In fact, aerial survey, geophysical ground survey, and excavation are complementary. The geophysical survey provides details that are lacking on the air photograph, and points to particular locations on the site where excavation will be most rewarding. To the detriment of Pacific archaeology, very few large areal excavations are carried out. In the circumstances, geophysical techniques are an attractive substitute in revealing the spatial patterning of archaeological detail.

The geophysical procedures available to the archaeologist include both magnetic and electrical resistivity techniques; only the former will be examined here. Although magnetic surveys for mineral deposits have been undertaken since the turn of the century, it was only with the development of the proton free-precession magnetometer by Packard and Varian in 1954 that an accurate instrument suitable for archaeological survey became available. The idea of using the proton magnetometer at the local level for the survey of archaeological sites was suggested by Belshé in 1956. However, it was not until a transistorised version of the instrument became available in 1958 that the first trials were carried out. The Research Laboratory for Archaeology and the History of Art at Oxford pioneered the use of the instrument in an attempt to locate Romano-British pottery kilns that were threatened by the construction of a new highway. The unqualified success of these trials stimulated great interest in the technique, and in the next four years, some fifty sites were surveyed in Britain alone (Aitken and Tite 1962). Two European journals, *Archaeometry* and *Prospezioni Archeologiche*, played an important role in stimulating an interest in this technique by devoting sections of particular issues to magnetic prospecting in archaeology. Equally important was the assessment of the limitations imposed by soil properties, a topic that was given special treatment in the journal *Archaeo-Physika* (Mullins 1974; Graham and Scollar 1976). Magnetic survey of archaeological sites has been widely used in Europe, West Africa and North America and to a lesser extent in other areas, including New Zealand, but so far there are no reports of its use in Oceania.

In this article the results obtained in the survey of a typical Fijian ring-ditch fortification are described. The Nasinu site, located to the southeast of the Teachers College, approximately 8 km from Suva, was selected for the study because there is an excellent air photo coverage, and some preliminary excavation has already been undertaken (Palmer 1965, 1968). This combination of basic information provides a useful background against which the contribution of the survey can be viewed. The instrument used for the survey was a G826 portable proton magnetometer manufactured by Geometrics Inc. of Sunnyvale, California (Breiner 1973). This instrument measures total field strength and the results are presented in the form of absolute survey values.

## THE NASINU RING-DITCH FORTIFICATION

The Nasinu ring-ditch site is shown in the air photo (Fig. 1) enlarged to a scale of 1:750. The low sun angle at the time of photography (1700 hours local time) provides excellent shadow enhancement of surface details—house mounds, ditch and causeways. The four quadrants of trial excavation in the largest house mound, undertaken by J. B. Palmer in 1965, are clearly visible at E in Figure 1.

More than 5,000 pottery sherds, a stone adze, and a stone artefact resembling an *ulu* were obtained from the excavation. In addition, post holes were located in two of the quadrants in the southwest corner of the house mound, which shows signs of lateral extension (Palmer 1968).

The basic form of the Nasinu fortification can be appreciated from the air photograph (Fig. 1) and the site photographs (Figs 2 and 3). The main element in the morphology is a more or less circular defensive ditch or fosse (*i keli-ni-valu*), which follows the contour around a small knoll (Fig. 2A). Material excavated from the ditch was thrown uphill to fill and level the habitation area and downhill to form an earthen bank surrounding the perimeter of the fortification. This had the effect of steepening the approach slope or glacis, thereby slowing an uphill rush attack, and providing the defenders with a longer time to decimate the attacking forces with arrows, throwing clubs and spears. The inner face of the habitation area leading from the ditch was packed hard with a batter of approximately 30 degrees, as shown in Figure 3. In former times, this slope would have been generously studded with foot spikes—small sharpened sections of bamboo or tree fern called *soki*, which were fire-hardened, and sometimes poisoned. A palisade or fighting fence (*bai-ni-valu*) would have circled the inner margin of the scarp leading up from the ditch forming


*Figure 1:* Air photograph of the Nasinu ring-ditch site. The low sun angle at 1700 hrs local time provides excellent shadow enhancement of surface irregularities. A. house mound. B. causeway. C. erosion scar and cattle track. D. former cultivation ridges. E. trial excavation quadrants. → location and view direction of ground photography. Fiji landsphoto 67/51–16, July 1967, enlarged to approximate scale 1:750.

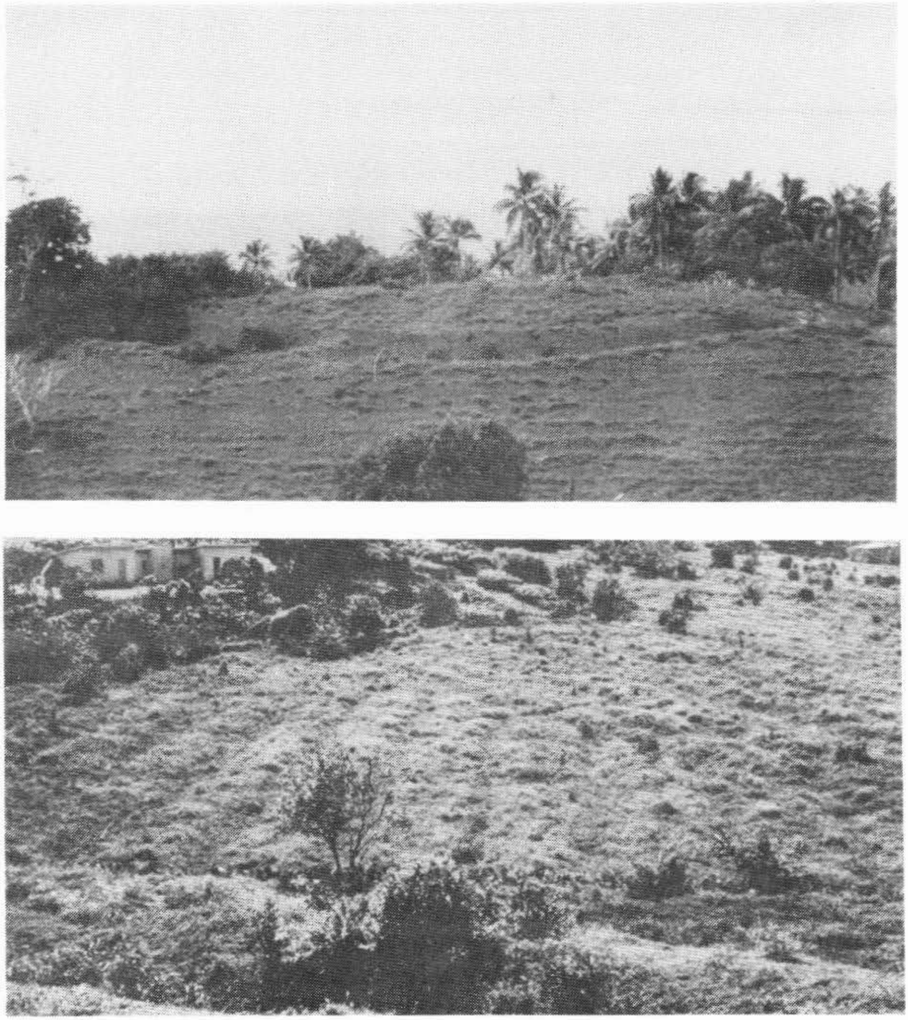

*Figure 2:* A. General view of the Nasinu ring-ditch site. B. Cultivation ridges to the north of the site.

the final element in the defence system. A typical fence would have been 4 m in height, and could have been equipped with fighting stages or platforms at various points around the interior. This allowed the defenders a considerable advantage compared with the attacking forces in that they had a breastwork protection, and the elevation of the fighting stage significantly increased the range and impact velocity of their weapons, which were hurled downslope compared with those of the attacking forces which were launched up slope. The maximum effective combat range of the Fijian throwing club (*i ula*) and the spear (*motu*) was approximately 20 m; however, the *cori vuka* (a type of spear hurled with a throwing cord) was effective up to a range limit of 70 to 80 m (Clunie 1977).

*Figure 3:* A. The bank, ditch and batter on the southwest side. B. The bank, ditch and batter on the northwest side.

Access to the habitation area was provided by causeways (B in Fig. 1) in the form of narrow earthen banks leading across the ditch to gateways in the palisade. There are four causeways at the Nasinu site, more or less equally spaced. The palisade at these entry points would have been reinforced with gateway passages which could have been quickly barred with sliding logs in the event of an attack.

In the area of lower ground to the north of the ring-ditch, there are obvious signs of cultivation ridges (Figs 1 and 2B). In all probability, the food gardens of the settlement were located in this local bottom land; however, the pattern of ridges that appears on the air photo is too regular to be an early Fijian taro garden(*vuci*) and probably represents later European attempts to cultivate the area.

## THE PROTON FREE-PRECESSION MAGNETOMETER

The advantages of the proton magnetometer include light weight, an unambiguous digital display or count, relatively high resolution (typically 1 gamma), and the rapidity with which the measurements can be made. It should be emphasised from the outset that the technique is basically that of identifying anomalies, plotting the pattern and intensity of the anomalies and using this as a guide for probing and excavation. Magnetometer survey cannot identify the feature causing the anomaly, it can only indicate the location and probable depth of the feature, thereby focussing the excavation effort on potentially rewarding sites. The technical details of the construction and function of the proton magnetometer are well known and need not be elaborated here. The interested reader can consult Aitken (1974).

In modern instruments the display is digital, and the circuitry is usually designed so that the last digit of the count corresponds to 1 gamma (1 gamma = $10^{-5}$ gauss, $10^{-9}$ webers/m$^2$, $10^{-9}$ tesla). For most archaeological purposes there is no point in improving the sensitivity beyond 1 gamma because the random variations in field intensity arising from "soil noise" can range as high as $\pm$ 5 gammas (Aitken 1974).

The total magnetic field intensity as measured by a proton magnetometer is a scalar quantity; it is an indication of the earth's field vector independent of its direction. This varies from region to region, and it is important before carrying out archaeological survey in an area to establish a typical total intensity value which can be considered as the norm. In Fiji, the total intensity of the magnetic field is typically 43,500 gammas. A local anomaly, which might result from a buried artefact such as a fired pot, introduces a vector of arbitrary direction, which adds to or subtracts from the field intensity in the usual manner of vector resultants. In most situations, the proton magnetometer is measuring the component of the disturbance vector in the direction of the original total field.

## HAZARDS AND MAGNETIC DISTURBANCES

In order to derive the maximum benefit from a magnetometer survey it is essential to guard against various hazards which could seriously jeopardise the readings. The most obvious hazards, such as metal objects on the person of the operator, iron litter on the site, wire fences, a.c. or d.c. power lines or motors, and radio transmittors in the vicinity, are easily recognised and avoided. However, there are other less obvious causes of disturbance which must also be recognised. These include regular temporal variations in the earth's magnetic field, sudden magnetic storms resulting from solar flares, and distortions caused by the high iron content or remanent magnetisation of local rock types.

Regular temporal variations in the earth's magnetic field are the direct or indirect effect of ionisation in the upper atmosphere by the solar flux. Diurnal variations in the tropics show a fairly regular mid-day increase in the intensity of the magnetic field of the order of 50 to 100 gammas. This effect can be avoided by ensuring that the survey is carried out before or after this oscillation in the periods of steady field strength which occur betwen 0600–0930 and 1430–1800 hours.

Superimposed upon these diurnal variations are short-period phenomena or micropulsations which are random in behaviour, much smaller in amplitude, and unpredictable in the time of their occurrence. Micropulsations exhibit a broad range of periods between $10^{-2}$

seconds and $2 \times 10^2$ minutes. For a periodicity of a few seconds the amplitudes are less than 0.1 gammas. Micropulsations are seldom a serious problem because their amplitude is within the range that one normally expects to encounter as a result of "soil noise". Only in a situation where the researcher is attempting to detect very weak anomalies in a site with low "soil noise" is it necessary to use a second magnetometer at a fixed reference base for recording the micropulsations so that corrections can be made to the readings obtained with the "roving" instrument used in the actual survey.

Of greater concern as a possible source of erroneous data are the magnetic storms which can occur with a frequency of several per month, and a duration of one or more days. Variations in the earth's magnetic field of several hundred gammas are observed during magnetic storms with rapidly changing values occurring in a period of a few minutes. It is best to avoid such days for magnetic surveys. A simple check procedure is to set up the instrument at a fixed position and record the readings at regular time intervals over a period of 10–15 minutes. A steady record with deviations of only a few gammas indicates quiet ionospheric conditions—a safe period for magnetic surveying. Even so, it is always a wise precaution to close a magnetometer survey at the start position. If the initial and the final readings correspond (as they did in this survey), it is safe to assume that no major disturbances occurred during the period of the traverse.

Disturbances in the earth's magnetic field caused by local concentrations of magnetic material, such as magnetite or its related minerals, or thermoremanent magnetisation in igneous and volcanic rocks, create problems for the archaeologist. On these rock types, particularly recent lavas, the magnetic disturbance is far too strong to permit the detection of archaeological features. Therefore, it is essential for the archaeologist to make a careful check of the local geology before embarking on a site survey with the proton magnetometer.

At Nasinu, the local rock type is a calcareous clay, the Suva marl, known locally as soapstone. Its main mineral constituents are alumino-silicates with organic carbonates forming up to 10 percent of the total. Chemical analysis of eight samples from the Suva-Nausori area indicates that the iron oxide content (mainly haematite—$Fe_2 0_3$) is in the range 3–8 percent (Ibbotson 1960). Such a relatively low value is unlikely to create a problem for magnetic survey. However, in order to check the variability or noise level created by the local geology, a test was conducted by running a short traverse on an area of undisturbed ground 50 m to the north of the Nasinu site. The random variation due to "local noise" was found to be only $\pm$ 15 gammas, which is quite acceptable as a background level for archaeological work (Aitken 1963, 1970).

## LAYOUT OF THE MAGNETOMETER SURVEY AND DATA PRESENTATION

In an area that is clear of bushes and undergrowth, the actual layout of a magnetometer survey is relatively easy. Closely-spaced measuring points are necessary because archaeological anomalies are generally limited in size, and even if the survey is undertaken in order to detect relatively large features, close measurements are useful because they allow the identification of irregularities caused by modern surface litter.

The most effective survey layout is a grid. This allows contouring of the data and interpretation of the pattern in relation to topographic irregularities still present on the site. At the Nasinu ring-ditch site, a base line was laid out with a tape at a slight angle to the magnetic meridian (6–186 degrees magnetic) across the eastern sector of the habitation area (Fig. 5, line 1). This was staked out with wooden pegs at two metre intervals. A series of ten parallel lines were surveyed in at four metre intervals to the west of the base line and pegged at two metre intervals within and adjacent to the site and at four metre intervals beyond the outer banks. The survey area is a rectangular grid which covers the greater part of the Nasinu site and continues beyond the outer bank in each direction as shown in Figure 5. Grid positions are referred to by line number and peg distance, thus the southeast corner of the plot is grid point 1:0 and the northwest corner is grid point 11:92.

The survey was carried out by two people, one locating the instrument and making the reading, the other acting as a recorder. An initial test to establish that the instrument was providing valid readings was carried out by taking ten readings in succession at the first survey point in each line. The test is made without moving the instrument, and if successive readings are within ± one gamma at the appropriate strength for the region (43,500 gammas in the case of Fiji) then it is clear that the instrument is functioning correctly. In carrying out the survey, two readings were made at each grid point and the average recorded for plotting. After the completion of each line, a reference check was made on the start point (grid position 1:0) to establish that no instability of the earth's magnetic field was occurring as a result of pulsations in the ionosphere. The detector was operated at the standard 0.3 m height. An increase in the anomaly strength can be obtained at lower operating heights; however, the anomaly levels recorded were quite substantial, and so a lower sensor height was not considered necessary.

The results of the survey are presented in two forms—simple profiles (Fig. 4) and a magnetic contour map (Fig. 5). No attempt has been made to smooth the profiles since their purpose is to show the amplitude of the anomalies encountered across the site, and the differences between profiles that traverse areas of human disturbance, such as house mounds (Fig. 4, upper and middle set), and those that cross a relatively undisturbed section of the habitation area (Fig. 4, lower set).

The gamma contour plot (Fig. 5) is an iso-intensity map analogous to a topographic contour map. The contoured values are extrapolations and interpolations based on the assumption that the magnetic field is varying smoothly. The contour interval selected for plotting the Nasinu data was 25 gammas; however, for convenience this is recorded as 2.5 on the map. Thus the true field strength of contour 52.5, for example, is actually 43,525 gammas, and that for contour 60 is 43,600 gammas. After posting the relevant values to each grid point, the contours were constructed and smoothed, with minima closed contours differentiated from maxima by hachure marks.

## ARCHAEOLOGICAL ANOMALIES

A distinction is made between magnetic disturbances and archaeological anomalies for the sake of clarity in this discussion. Disturbances are considered to be the result of responses to magnetic events, such as solar flares and diurnal changes in the ionosphere, or geological circumstances, such as intrusion or volcanism, with their attendant thermoremanent magnetic effects. These events constitute a problem for the archaeologist because they introduce local changes in magnetisation which are quite unrelated to any archaeological features. In contrast, archaeological anomalies representing local distortions in the normal values of the magnetic field are directly related to subsurface features resulting from human occupation of the site. A local increase in the magnetic field strength above the average level is termed a normal anomaly in contrast to a reverse anomaly, which represents a local decrease in the average field strength.

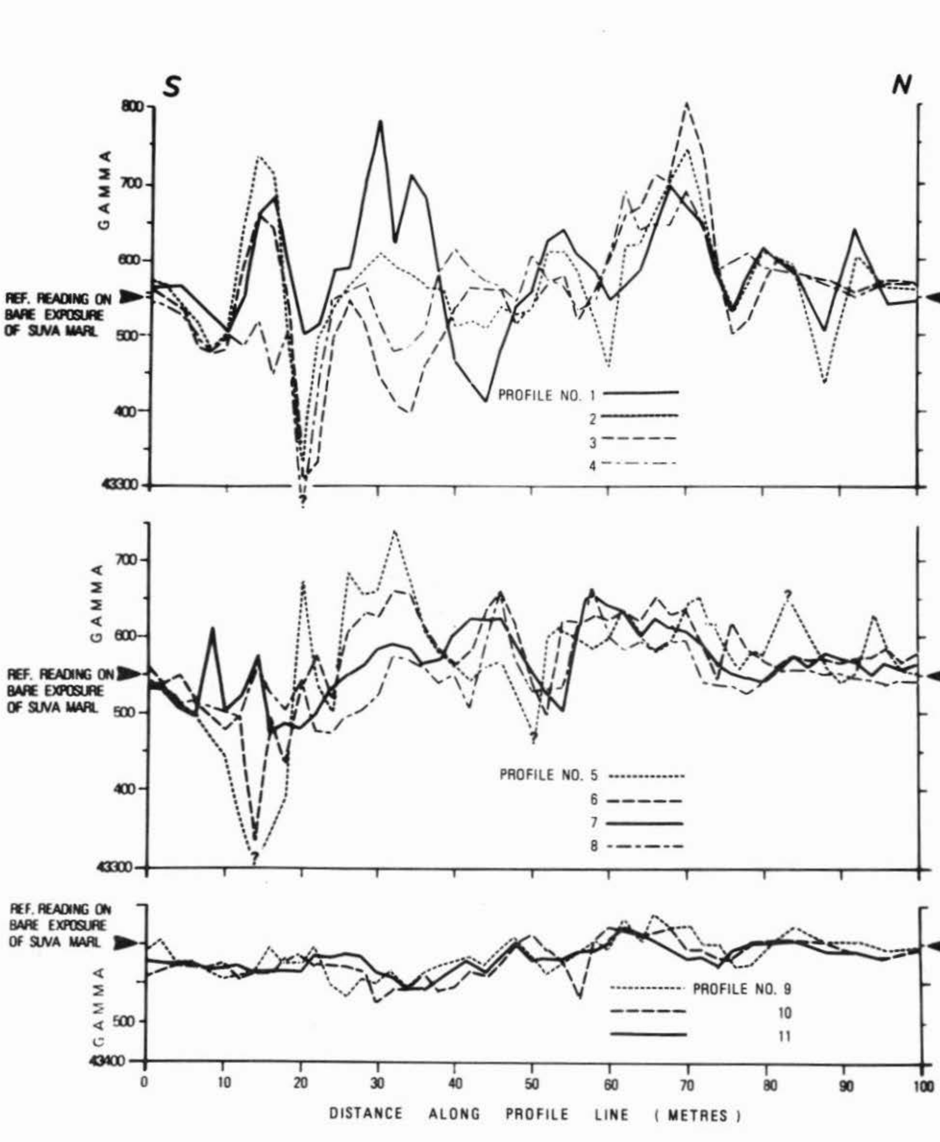


*Figure 4:* Magnetic profiles of the Nasinu ring-ditch site obtained with the G826 proton magnetometer.

Archaeologically induced anomalies can occur for various reasons, and in many cases there are specific details of the anomaly which provide important clues in attempting an interpretation of the subsurface feature responsible. Before attempting an analysis of the magnetic data from the Nasinu ring-ditch site it will be useful to review the general characteristics of archaeomagnetic anomalies and the form they take in the local area. Most of the research on archaeomagnetic prospecting has been carried out in western Europe, and the rules established for the interpretation of the results require appreciable modification before they can be applied in Fiji, where the geomagnetic inclination is very different

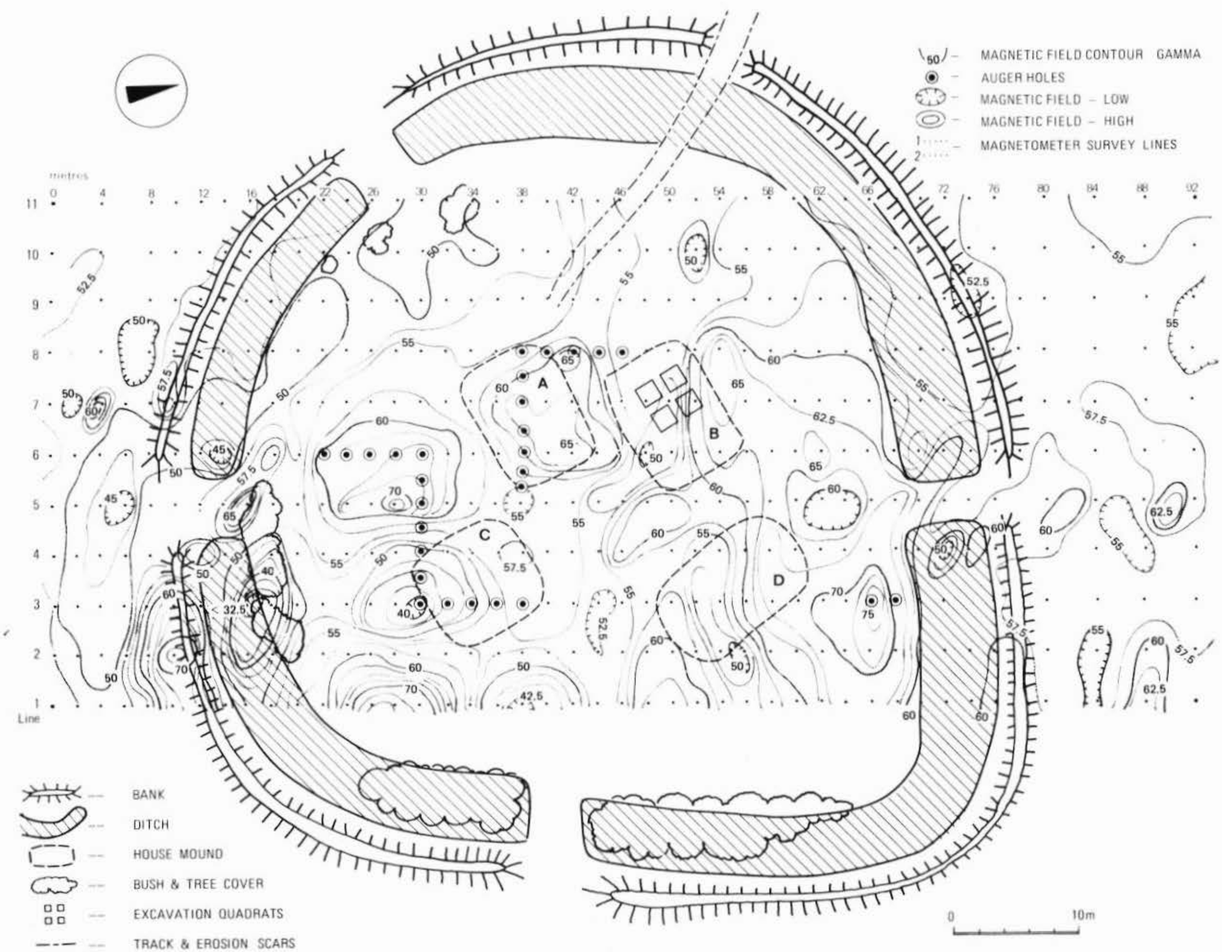


*Figure 5:* **Magnetic contour map of the Nasinu ring-ditch site plotted from data obtained with the G826 proton magnetometer.**

from that of western Europe; 42 degrees south in Fiji compared to 60–70 degrees north in Europe.

The quantity measured by the proton magnetometer is the vector sum of the earth's strength in the area and the additional vector introduced by the archaeological feature. If we assume that the latter is a simple dipole, then the theoretical anomalies that will be sensed along a north-south line passing over the feature can be readily calculated for different geomagnetic inclinations. The form of the magnetic signature generated by the dipole in the latitude of Fiji (a geomagnetic inclination of 42 degrees south) is shown in Figure 6A. The anomaly strength represents the deviation from the normal field strength, and it will be noted that the buried feature gives rise to both normal and reverse components. The ordinate scale represents the deviations from the normal strength in the area; however, for convenience, only the positive and the negative anomaly values are shown. The horizontal scale is calibrated in distance units equal to the depth of the source below the detector. Reference to this magnetic signature provides the following general rules for archaeomagnetic survey in the Fiji island group:

1) The total field anomaly is asymmetric in shape as a consequence of the interaction of the field lines created by the source and the inclination of the earth's magnetic field in this latitude.
2) The source of the anomaly lies between the normal and reverse components of the signature.
3) The displacement distance of the peak of the normal component of the signature from the plumb line through the source is approximately half the depth (d) to the source.
4) The depth of the feature (d) is approximately equal to the separation width of the half intensity value of the normal component of the anomaly (w).
5) The reverse component has a maximum strength of approximately one third of the normal component, and its peak intensity will be found to occur to the south of the source at a distance of slightly more than half a depth width.
6) The spatial extent of the anomaly is limited, and the effects are generally not felt at distances greater than two depth units from the plumb line through the source.

The general rules apply to sources which are relatively small and compact. The effect of a more extended source is to widen the spatial extent of the anomaly with the result that the separation width of the half intensity value of the normal component of the anomaly (w) is more likely to reflect the width of the feature.

The maximum amplitude of the normal component of the anomaly is largely a function of the depth of the source. The shallower the source, the more accentuated the signature. It is this feature of the anomaly which enables the researcher to assess the approximate depth of the source independent of other characteristics of the signature. For more precise depth calculation, the ratio of burial depth to anomaly width provides the most convenient procedure. This ratio, d/w, is controlled by the geomagnetic inclination and, as shown in Figure 6B, it is approximately 0.93 in the Fiji islands. This indicates that the source of an anomaly will be found at a depth of slightly less than the separation distance of the half intensity value of the normal component of the anomaly.

## ARCHAEOMAGNETIC ANOMALIES AT THE NASINU RING-DITCH SITE

Different types of archaeological feature give rise to different magnetic anomalies. They can be grouped into five main categories on the basis of their anomaly signatures.

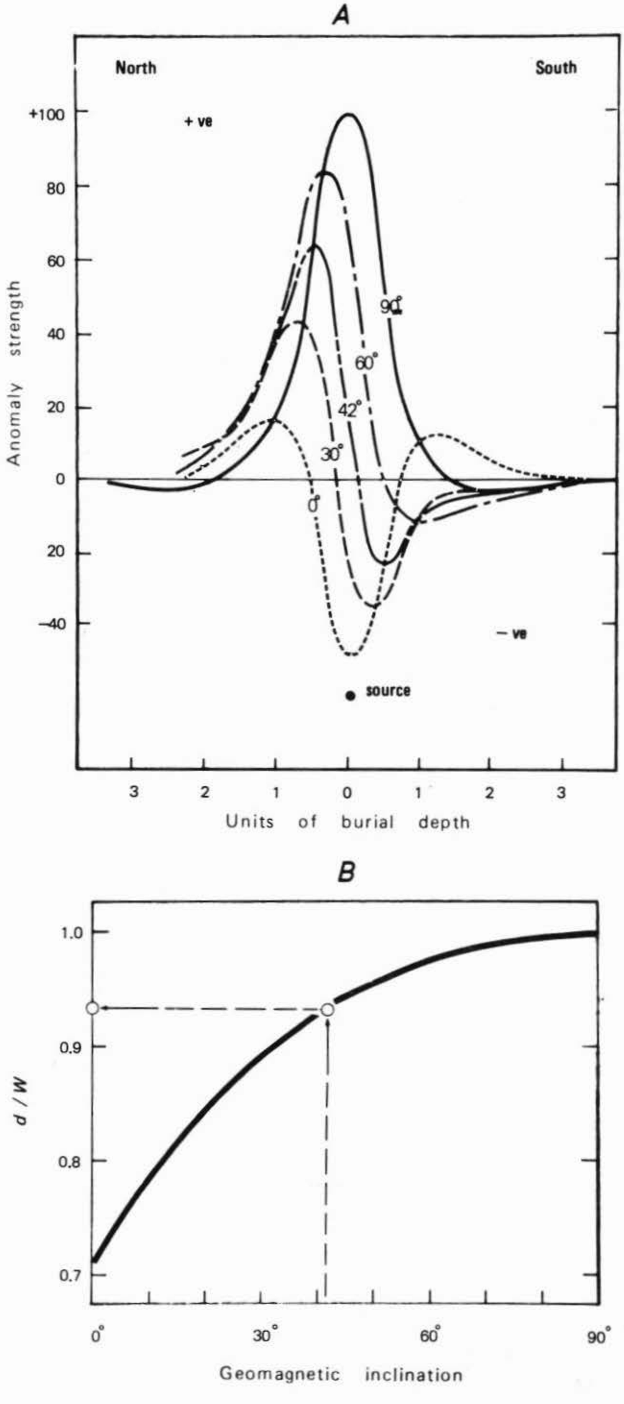


*Figure 6:* A. Generalised magnetic anomaly signature produced by a simple dipole in the latitude of Fiji (geomagnetic inclination 42 degrees S). B. Relationship between the anomaly depth/width ratio and the geomagnetic inclination.

1. IRON OBJECTS

Iron in metallic form produces a very strong anomaly and is often inconvenient because the interference from contemporary iron litter is characteristically sharp and irregular, and consists of both normal and reverse components. The very limited width of the anomaly provides the best clue as to its origin. According to rule 4 above, a short separation distance between the half intensity value of the normal component of the anomaly indicates a source very close to the surface. The instrument is operated at a height of 0.3 m above the ground surface, and so a w value of 0.5 m for an intense, isolated anomaly strongly suggests the presence of an iron object just below the surface.

An alternative method of identifying near-surface iron is to monitor the rate of decay of the signal generated by the precession of the protons in the detector. In situations where there is a strong magnetic gradient the signal is reduced to zero within a second, and for very strong magnetic gradients the signal may be completely neutralised. In either case, the effect is readily observed when the magnetometer survey is in progress and such points should be noted.

The gamma contour map of the Nasinu ring-ditch site (Fig. 5) provides three excellent examples of near-surface iron signatures. There are two anomalies showing typical small dimension, closely-spaced normal and reverse components (grid positions 4:72–74 and 7:2–4), and one example of a "killed" signal (3:16). The cause of this last anomaly was found to be an iron fence post just below the root mat.

2. WALLS AND FOUNDATIONS

Except when formed of kiln-fired bricks or volcanic rocks, walls and foundations are not magnetic. In effect, a reverse anomaly is created because non-magnetic wall material has replaced soil; and, as will be shown in a later section, anthrosols are often strongly magnetic. Walls are generally difficult to detect because the remains are fragmentary, the stones having been scavenged for other purposes. No reverse linear anomalies of the type generated by wall foundations or broad negative anomalies resulting from stone-covered mounds were found at the Nasinu ring-ditch site. This is not surprising because although house mounds (*yavu*) were frequently faced with stone (Parke 1961: 24), such forms are not known from sites on Suva marl, which is a very poor working stone.

3. OVENS AND HEARTHS

In former times, all Fijian dwellings would have their own *miqa* or cooking hearth in which a fire was constantly burning. Contemporary eye-witness descriptions of house interiors provide good detail of hearth size and position:

> Fire places are sunk a foot below the floor, nearly in the centre of the building, and are surrounded by a curb of hard wood. In a large house, the hearth is twelve feet square, and over it is a frame supporting one or two floors, whereon pots and fuel are placed. (Williams 1858: 81)

The house mounds at the Nasinu ring-ditch site are relatively small, and so large central hearths are not likely to occur. In smaller houses, the hearth would often be placed off on one side near the wall in order to provide more space in the central area. The size would vary depending on the rank of the householder and the needs of his family; probably 2 m in length by 1 m in width would be typical. The cooking temperatures on such hearths were not high and would seldom attain more than 700 degrees C, even with hot burning woods.

The anomalies from burnt features result from the thermoremanent magnetism that is induced as a result of heating the ferromagnetic minerals above the Curie temperature. The strongest anomalies are associated with kilns because of the relatively high temperatures involved and the substantial size of the feature. There is considerably less baked material in a hearth, the temperatures are generally lower, and so the anomaly is smaller. A strength of 20 to 50 gammas is cited for many hearths in European investigations (Aitken 1963; Cook 1963).

In an unbaked clay or soil, the magnetic domains of each grain of magnetic oxide (magnetite or haematite) are organised more or less at random and because of mutual counteraction the net magnetic effect is slight. As the material is heated, the intrinsic magnetisation of each particle is weakened and the material exhibits paramagnetic behaviour: the magnetic moments of each atom and molecule seek an alignment with the prevailing magnetic field of the earth. The essential effect of heating to a temperature of several hundred degrees Celsius is to create magnetic domains that are mutually reinforcing, thereby imparting an appreciable total effect. The duration of heating is unimportant; however, the maximum temperature reached does affect the degree of magnetisation because the Curie points of oxidised magnetites vary according to the composition (Mullins 1977: 226). The effect would be 10 percent of maximum for a temperature of 200 degrees C, 30 percent for 400 degrees C, 50 percent for 500 degrees C, and 90 percent after reaching 600 degrees C (Aitken 1963: 557). On cooling, this magnetisation remains "imprinted" in the material.

Most fired clays have a very stable remanent magnetism, and so hearths are likely to be detectable by magnetometer survey as long as they have remained undisturbed. Disarrangement by raking or washing will seriously attenuate the effect because magnetism by its very nature is directional, and so the random re-orientation of hearth materials can result in a relatively weak anomaly. For this reason, the magnetic return from a hearth may be poorly defined in some circumstances.

Examination of the magnetic contour map of the Nasinu ring-ditch site reveals several broad anomalies which show some relationship to the position of the house mounds. House mound A is associated with a broad normal anomaly of approximately 50 to 100 gammas with peaks at the northern corners of the mound. House mound B has been very much disturbed by the trial excavation, which may account for the steep north-south magnetic gradient from one side to the other and the marked reverse anomaly running through the centre. Both house mounds C and D exhibit broad anomalies with normal and reverse components. The strength of these anomalies can be assessed from an examination of Figure 4. The lower set of profiles (8–10) exhibit relatively low amplitude, and indicate the weak magnetic susceptibility of the soil where no house mounds were encountered. The upper profiles (1–4 and 5–8) which traverse the house mounds, exhibit strong anomalies that are 200–250 gammas above the reference level of 43,550. Part of the reason for these strong anomalies is undoubtedly the presence of material from hearths now widely spread in the topsoil of the mounds. A post-hole auger was used to obtain soil samples along several traverse lines as indicated in Figure 5. Pottery fragments and charcoal were found to be widespread in the upper 30 cm of the profile, and there was a marked reduction in the Munsell colour value in the upper 60 cm of the profile within and adjacent to house mounds. The normal colours recorded for the clay loams developed on the Suva marl in the 0–30 cm section of the profile were found to be reddish browns (5 YR 4/3 to 4/4) and yellowish reds (5 YR 4/6 to 4/8). On the house mounds, the soil colours were generally dark reddish browns with Munsell values in the range 5 YR 3/2 to 3/4. Exceptionally dark soils (5 YR 3/2 and 2/2) were encountered in the profiles across house mounds A and C (grid positions 5:38–8:38, and 3:30–38). A similar darkening of the surface soil was found along the line 6:22–30. This feature, in association with the shape of the gamma contours in the immediate vicinity, strongly suggests the presence of another house mound which was not detected on the air photographs and is not apparent in the field. The form of this *yavu* is approximated by the 43,600 gamma contour.

4. CULTURALLY MODIFIED SOILS

In addition to the strong magnetic effects resulting from combustion in open hearths, there is another mechanism which has probably contributed to the generally enhanced gamma values across the habitation area of the Nasinu site. The European literature on archaeological prospecting with the proton magnetometer contains frequent reference to the relationship between the intensiveness and duration of occupation of a site and the increase in strength of the magnetic anomaly. This effect has been termed the enhanced magnetic susceptibility. The magnetic susceptibility of soil is defined as the magnetisation induced by a magnetic field per unit mass, the soil remaining at its ordinary temperature. The enhancement effect is explained in terms of magnetic domains as a slight growth of those domains which have a component in the same direction as the magnetic field at the expense of those which do not. The degree of enhanced magnetic susceptibility in soils from occupation sites is indicated in Figure 7. The details are derived from an extensive study of soils from archaeological sites in Europe (Tite and Mullins 1971; Tite 1972). In all cases, the soils from archaeological sites were found to have higher values of susceptibility than either the subsoil at the site or the non-anthropogenic soils of the surrounding area.

The reason for the enhanced magnetic susceptibility of anthrosols has been investigated by Le Borgne (1955, 1960, and 1965) and Mullins (1974). They demonstrated that diamagnetic and paramagnetic substances have either negative or minimal susceptibility; antiferromagnetic substances, such as haematite ($\alpha Fe_2O_3$) have variable susceptibility. The only minerals with strong susceptibility are magnetite ($Fe_3O_4$) and maghaemite ($\gamma Fe_2O_3$). Soils which do not contain magnetite, such as the Suva marls, but have a high magnetic susceptibility, owe this property to their maghaemite content. Mullins (1977) has provided a useful review of the formation and occurrence of maghaemite. Only two of the four processes which he described are relevant here—burning of surface materials and repeated oxidation-reduction cycles. Both of these processes can result in the conversion of iron oxide from its antiferromagnetic form, haematite ($\alpha Fe_2O_3$) to its strongly ferrimagnetic form, maghaemite ($\gamma Fe_2O_3$).

Formation of maghaemite as a result of burning was first proposed by Le Borgne (1955). The haphazard burning of vegetation and refuse which occurs repeatedly in a village involves relatively low temperatures. However, when there is sufficient material for combustion, gases, such as carbon monoxide, will cause the reduction of finely divided oxides and hydroxides of iron. When the fire dies out, air re-enters the soil and the iron is oxidised to maghaemite. The net effect is that a thin layer of top-soil acquires an enhanced magnetic susceptibility. Dispersal of this soil, followed by repeated burning in other parts of the habitation area, results in a generally enhanced susceptibility throughout the top soil of the whole site.

The second process by which maghaemite is formed has been termed fermentation. This is probably the more important; however, it is less well understood. Repeated oxidation-reduction cycles are induced by alternating periods of wetting and drying giving rise to

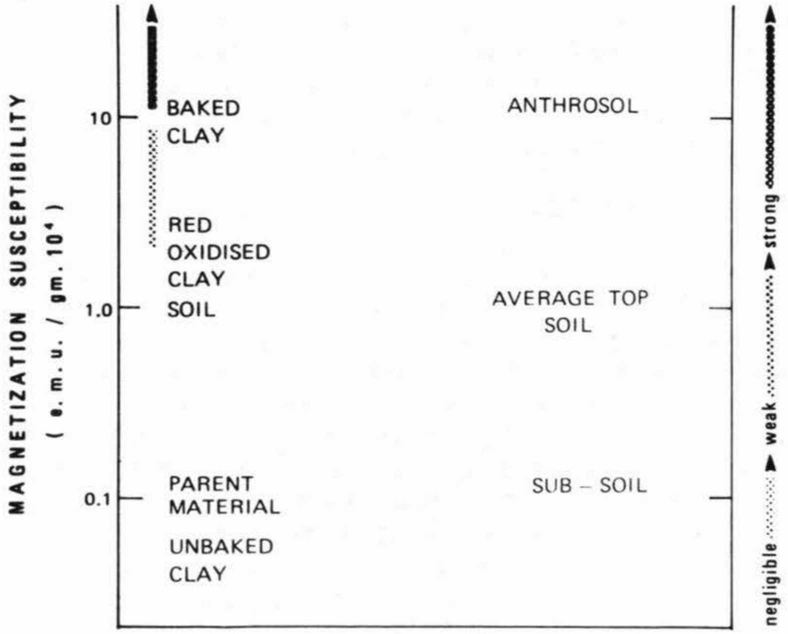


*Figure 7:* Magnetic susceptibility of soil and subsoil from occupied and unoccupied sites.

oscillating anaerobic and aerobic conditions, which promote the conversion of haematite to maghaemite. Higher concentrations of organic material appear to favour the process (Aitken 1963; Oades and Townsend 1963; Mullins 1974; Neumeister and Peschel 1968; Scollar 1965).

Conditions favourable to fermentation in the top soil of a Fijian village site were all too common judging from the description of the habitation area at the ring-ditch fortification at Sawayeke on Gau Island which was recorded by a contemporary witness.

> The town is very dirty and in wet weather one has literally to wade through mud and filth. The offal of every kind seems to be left to be cleared off by the pigs, numbers of which roam about at large. (MacGillivray 1853: entry for September 12)

In order to test whether there are demonstrable differences in the soil chemistry of the Nasinu site which can be related to the two processes described above, soil samples were obtained for chemical analysis. Two sets of samples were obtained, one from the habitation area, the other from a position 30 m outside the ring-ditch on the slope of the knoll. The data presented in Table 1 are mean percent values for the two sets of samples. Insufficient samples were collected to allow any kind of statistical analysis.

Among the trace elements, both copper and nickel show somewhat higher concentrations in the samples from the habitation area. The reason for this is not known. No differences appear between the two sets of samples in the amounts of exchangeable bases (Ca, Mg, K). However, the ferrous oxide content of the soils of the habitation area is some

**TABLE 1**

**COMPARATIVE RESULTS OF SOIL SAMPLE ANALYSIS FROM THE KNOLL SLOPE (UNDISTURBED) AND FROM WITHIN THE HABITATION AREA (DISTURBED)**

| | Habitation area | Knoll slope |
|---|---|---|
| Cu | 110 ppm | 66 ppm |
| Ni | 21 | 10 |
| Pb | <1 | <1 |
| Zn | 78 | 78 |
| $Al_2O_3$ | 24.56 % | 25.19 % |
| CaO | 0.28 | 0.21 |
| *$Fe_2O_3$ | 14.19 | 9.24 |
| $K_2O$ | 0.09 | 0.11 |
| MgO | 0.50 | 0.78 |
| MnO | 0.17 | 0.15 |
| $Na_2O$ | 0.09 | 0.05 |
| Total N | 0.33 | 0.19 |
| #Organic | 2.24 | 1.73 |

#=loss on ignition
*$Fe_2O_3$ is dimorphous and can occur as haematite and/or maghaemite

5 percent higher than that of the knoll slope. Because of the difficulties of distinguishing maghaemite from haematite it is not known in which form the ferrous oxide occurs. Total nitrogen, although at low levels in absolute terms, is more abundant in soils within the habitation area, and the organic content of these soils is appreciably higher than those outside the ring-ditch. Although far from conclusive, the soil analyses lend support to the view that human occupation has affected the composition of soils within the habitation area, producing higher concentrations of organic matter and iron oxide. In such a situation, one could expect maghaemite formation with increased magnetic susceptibility of the top-soil.

## 5. PITS AND DITCHES

From the previous discussion it is clear that pits, particularly if they have a "ripe fill" of fermenting food, bodies or excreta, can give rise to strong magnetic anomalies. Normal anomalies of 30 to 200 gammas from pits of various sizes are reported in the literature (Aitken 1974). However, it should be emphasised that pits with a rich organic content are the exception. The great majority of pits were refilled with the original material soon after their excavation or have been filled by soil wash over the years, with the result that the magnetic anomaly is negligible and lies within the amplitude of the soil "noise".

In the same way, ditches may yield only weak anomalies because the fill usually consists of wash from the sides. However, in some circumstances there can be a substantial fill of organic material of vegetable or human origin.

The ring-ditches around Fijian settlement sites probably received a variety of organic waste material, and soils with poor internal drainage would provide anaerobic conditions throughout the year. The ditch at the Nasinu site has been deliberately drained by breaching the bank on the west side, and so it is now dried out. The material in the ditch floor is somewhat finer grained than that occurring on the bank or batter of the habitation area, but otherwise indistinguishable in a hand sample.

The magnetic contour map of the site shows no specific magnetic anomalies associated with the ring-ditch. There is a general conformity of the gamma contours with the topographic contours on the inner batter of the northern section of the site, but the values are close to the reference levels for the Suva marl. On the south side there is again a generally parallel alignment of topography and magnetic contours and signs of a weak anomaly in the southwestern sector. The strong disturbance in the southeastern sector is the product of the iron fence as noted earlier.

## CONCLUSION

In this study, the magnetic anomalies encountered on a typical small ring-ditch fortification sited on a knoll of Suva marl have been documented. Relatively large, broad anomalies indicate considerable anthropogenic disturbance of the soil within the habitation area. The major cause of the anomalies is considered to be the presence of fired clay and stones originally concentrated in the hearths of individual houses, but now widely dispersed over the house mounds. A secondary factor contributing to the anomalies may be the greater magnetic susceptibility of the soils within the habitation area. Of the two mechanisms responsible for magnetic susceptibility enhancement, it is probable that fermentation has been the more important in view of the impeded internal drainage of the site.

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