The Magnetic Map of a Fireplace Base

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This geophysical survey detected no magnetized rim around the inner perimeter of this fireplace; there was also no hint that there is any magnetic material below the visible layer of bricks. These findings suggest that the present excavated surface could be beneath the original base of the fireplace: On this surface, the soils and brick were never heated to a high temperature by fires in the fireplace.

A magnetic map was measured on the excavation surface that crossed part of the H-shaped foundation of an early double fireplace. There were about a dozen bricks or brick fragments on this test surface; these were within the foundation of that fireplace. These bricks were found to differ widely in the strength and direction of their magnetization. One brick fragment was much more magnetic than normal, three bricks or fragments were about typical, but the remaining brick fragments were invisible to the magnetic survey. This is because of two facts: The soil itself is fairly magnetic; the soil is also quite variable in its magnetism. The variably magnetic soil hid the magnetic patterns of the bricks whose magnetism was weak.

This report is prepared as a Portable Document Format publication; blue-colored text marks links to figures or sections. While the final figure (Figure 15) is in color, the report is designed to be printed in black-and-white. The sections of this report are as follows:

The Site

This geophysical experiment was done on Jamestown Island, Virginia, within an area now being excavated by Jamestown Rediscovery (Association for the Preservation of Virginia Antiquities). This excavation is within the earthen Confederate fort that is west of the early church. Figure 1 is a sketch of part of the excavation.

The purpose of this geophysical test was simply a further exploration of the magnetic character of fired materials. It continues tests that were begun in a nearby excavation in 2001.

The sketch in Figure 1 does not have the accuracy of a normal archaeological map; its typical error may be about 0.1 ft (the maximum error may be 0.2 ft). Time was not taken to register this survey area with the site grid; the pattern in Figure 1 will allow the location of the work to be estimated from the archaeological site plan. The geophysical grid was oriented parallel with the excavation edge, and this edge is probably a cardinal east-west direction in the site grid. The drawing in the lower part of Figure 1 was prepared by laying a sheet of clear plastic over the excavation. This sheet had parallel and perpendicular lines on it at intervals of 0.5 ft, forming a grid. The locations of the bricks and stones were sketched relative to this grid. Since the flexible sheet was neither stretched nor flat on the surface, errors in location were created.

The excavation, likely done within the last few months, had revealed part of the base of a fireplace. As pointed out to me by Eric Deetz, this was probably a double fireplace, with fires on the east and west sides of a common back. It is likely that the I or H-shaped fireplace base extends into the unexcavated soil to the south.

The location of the fireplace is evident from the oriented bricks that are rather flat on the excavation surface. The excavators also noted a soil change (perhaps texture or color) whose location was scribed on the surface. This is approximated with a dashed line at the top of Figure 1; this is the edge of the fireplace base. Most of the bricks that were within the fireplace base are inside the 4-ft square where the magnetic map was measured. Even in this area, only part of the soil surface is covered by brick. The remaining surface is bare soil; this soil has a cementation that makes the surface quite firm. However, two stones are present at the edge of the geophysical test area; these are located at the upper left part of the lower drawing in Figure 1. I did not identity the stones, but they were found to be not magnetic.

Eric Deetz mentioned that it is fairly sure, but not certain, that the original (heated) base of the fireplace was above the excavated surface; this geophysical survey added further confirmation of that. Eric said that fireplaces were typically constructed beginning with an excavation of the topsoil at their base; this probably allowed the construction to begin on firm, compact, cemented soil. The archaeological surface may expose that early excavation and some of the bricks that were placed to start the foundation. While it is not known if there is a layer of bricks at a greater depth here, the geophysical evidence is that this is unlikely.

The excavators discovered an early cannonball near the base of the excavation a few feet to the east of this geophysical test. While that iron sphere has been removed, some fragments of rust were visible where the iron was, and these were readily detected with a simple audio-indicating magnetometer (a Schonstedt GA-52B magnetic locator).

Excavations were ongoing during this geophysical experiment, to the east of the geophysical grid and at a distance of 5 - 15 ft. One or two excavators deepened an excavation there. Visitors to the excavations were to the north, but at least 15 ft distant. A survey instrument (theodolite, transit, or EDM) remained fixed on a tripod near E0 S4 in the geophysical grid during the period of this survey; the instrument was not operated during this field work. Tall steel channel posts strung with plastic tape form a fence outside the excavation; these posts are over 5 ft distant, and they were not moved for this test. Spikes that were nearby and just outside the edge of the excavation were temporarily removed for this geophysical test; these spikes were linked by string and marked the excavation boundary on the unexcavated soil surface. Iron nails that held aluminum tags that labeled features on the excavated surface were also temporarily removed. The dome shelter that covers some excavations was quite distant from this test, and there were no other large steel objects in the vicinity. No vehicles were closer than 80 ft from this survey area.

My thanks go to Eric Deetz for coordinating my work on this experiment, and to him and William Kelso for allowing this test to be made in their excavations at Jamestown. It is valuable to have excavations available for tests like these, and these two individuals have always done everything they could to aid this work.

The Geophysical Survey

The magnetic measurements were made with an instrument that has a small magnetic sensor; this allows readings to be made very close to objects and with a very small distance between the measurements. These two factors enable magnetic maps to be made with very high spatial resolution. When most exploration surveys are done, the spacing between the readings is seldom less than 1 ft; for this work the measurement spacing was either 0.1 or 0.01 ft.

The magnetometer is sketched in Figure 2. The cross-section of the sensor housing is square and 1 inch on a side. This sensor was slid along lines that were defined by a thin board that was set on the excavated surface. The readings were transferred to a small computer for storage. An example of a line of measurements that passed over a brick is shown in Figure 7. A combination of similar lines yielded the map in Figure 15.

The remainder of this section is detailed and sometimes technical. The archaeological findings of this experiment are described in the following section, Results of the Survey.

The magnetometer was a model FGM-5DTAA triaxial fluxgate instrument, manufactured by Walker Scientific. Its sensor measures three perpendicular components of the earth's magnetic field. This fluxgate sensor has a pair of magnetic ring cores; the By and Bz components of the field are measured at one core, and the Bx component at the second. Each component is recorded with a moderately low precision in amplitude (1 nT); since magnetic anomalies are large, the low precision is acceptable.

The magnetometer was operated in two modes that differed in the speed of measurement. An initial survey was made with the fast mode of operation: A series of readings were taken at a speed of 17.4 per second as the sensor was slid along a thin wooden strip that was set on the excavation (the gridded plastic sheet located each traverse). I kneeled next to the strip and moved the sensor by hand along the strip. The wooden strip had lines ruled on it at 0.5 ft intervals. The speed of the sensor's traverse was adjusted so that about 50 readings were made in each of these half-foot intervals; the associated palmtop computer acted as a metronome, and sounded a beep when 0.5-ft intervals should be crossed.

The calibrated wooden strip (like a yard stick) was 0.02 ft thick; the height of the middle of the sensor was 0.063 ft (0.76 inch) above the bottom of the strip. This was the minimum height of the sensor above the archaeological surface; since that surface was not perfectly flat (but had a relief of generally less than 0.5 inch), the sensor height would have been greater where there were depressions.

The three components of the total magnetic field were recorded, but an adjustment was needed for the offset (2.18 cm) between the Bx and the By-Bz sensors. This was accomplished with an interpolation between the series of Bx readings at each location of the By-Bz sensor. The resultant total field was then calculated from the three components. The temporal change in the earth's magnetic field was not monitored, and the data were not corrected for the temporal change. On the day of this survey, the magnetic A-index at Fredericksburg, Virginia, was about 25; therefore, temporal change in the earth's field had no significant effect on this survey.

Magnetic profiles were measured on six lines across the 4-ft square; the lines were spaced by 0.5 ft. These measurements are plotted as solid lines in Figures 3 - 8; the measurement spacing was 0.01 ft for these fast mode profiles.

The six magnetic profiles were measured on 16 October 2003, between 12:33 and 12:57 pm (EDT). At the end of this initial test, the whole 4-ft square was resurveyed between 1:19 and 2:31 pm. For this resurvey, a slower mode for the operation of the magnetometer was chosen: Readings were made at time intervals of 1 s and the entire square (4 ft on a side) was mapped.

For this second survey, a 4-ft square sheet of fiberboard was placed on the excavation. Straight lines had been marked on this board to form a grid with a separation between lines of 0.5 ft. Since this fiberboard was 0.01 ft thick, the minimum sensor height for this resurvey was 0.053 ft (0.63 inch). Each line of traverse was defined with a thin strip of wood that guided one edge of the magnetic sensor. This strip was held along the correct line on the fiberboard with wooden clips at the ends of the board (these clips were like clothes pins).

For the creation of this magnetic map, the magnetic sensor was mounted on the bottom of a wooden rod that was 40 inch long. This allowed the sensor to be moved along the lines of traverse while I was standing beside the board; had I kneeled on the board, the board would have flexed and changed the sensor height, altering the magnetic map.

For the map on this fiberboard, the magnetometer was programmed to make its measurements at intervals of 1 s; a beep from the computer signaled each measurement. The sensor was moved along each line on the board so that the measurement spacing was about 0.1 ft. The electrical cable that connects the magnetic sensor to the readout was 7 ft long; this allowed the readout and the computer to be sufficiently distant to the north that they did not affect the survey.

The measurements were processed the same way as those with the initial, fast mode, survey; they are plotted in the map of Figure 9. The magnetic anomalies can be compared to the locations of the brick with the aid of Figure 15.

The major magnetic anomaly is the dipolar pattern centered at E1.5 N2.2 in the map. This anomaly was analyzed by assuming that it was caused by a compact magnetic object that could be approximated by a magnetic dipole. The analysis also assumed that the earth's field had the parameters: Magnitude = 52,000 nT, inclination = 65.7^{o} (from IGRF2000), declination = -10.5^{o} (grid angle, from a magnetic compass). The magnetic dipole that best fit the measurements had the following parameters: Moment = 6.4 mAm^2, inclination = 14.7^{o}, declination = -151.6^{o}, location = E1.55 N2.31, and depth = 0.21 ft. This location is marked with an asterisk in Figure 1; it is evidently brick fragment 1 that causes this anomaly. The interpreted moment and depth are more likely overestimates than underestimates (because of the dipole approximation). Brick fragment 1 is roughly a quarter of a brick, so the entire brick would have had a total magnetic moment of about 25 mAm^2. This brick is about twice as magnetic as the average of two samples of brick from structure

163 that were measured in 2001.

The remaining anomalies in the magnetic map of Figure 9 are not distinct enough to be worth a careful analysis. However, there are clearly three more magnetic anomalies that are so close to bricks that they must be caused by those bricks; this are numbered as 2 - 4 in Figure 1.

It is unlikely that there is an additional layer of bricks below the ones that are seen in the excavation. From the dipole parameters above, a brick fragment with the same magnetic parameters, but at a distance of 0.25 ft underground (to its top), would cause an anomaly of 206 nT (39% of the measured anomaly). No anomalies were found anywhere close to this amplitude at locations where a brick is not visible at the surface.

The soil over this excavation was about 2.6 ft deep. Had a magnetic survey been done with the sensor on that soil surface, the magnetic anomaly of brick fragment 1 would have been about 3 nT. It is unlikely that the brick would have been detectable during that survey.

The magnetic sensor measures the three perpendicular components of the earth's field; these components have been combined in the map of Figure 9. The separated components allow the direction of the magnetic field to be determined, in addition to its magnitude (shown in Figure 9). These directions are plotted as inclination in Figure 10 and grid declination in Figure 11. The original measurements are rather erratic and show a striated pattern when mapped; this is because the angle of the magnetic sensor cannot be held constant as it is moved down each line of traverse. For this reason, the readings in Figures 10 and 11 are smoothed; the value at each point is the average of the 100 readings that are found in a square that is 1 ft on a side and centered on the plotted point.

The magnetic maps (total field and direction) can be better understood with the aid of calculations of the magnetic field of an approximated brick. For these calculations, the brick is assumed to be square, with sides that are 0.8 ft long, and its thickness is 0.2 ft. The top of the brick is assumed to be 0.1 ft underground, and the sensor is at a height of 0.053 ft above the ground. The magnetic moment of the brick is assumed to be 10 mAm^2, and its direction of total magnetization is that of the earth's field. The earth's field is assumed to have the parameters listed above.

The calculated total field map is plotted in Figure 12. This anomaly is weaker (with a peak of 531 nT) than that of brick fragment 1 in Figure 5. The calculated anomaly has its magnetic low to the north, while the measured anomaly of brick 1 has its low to the south. This just reveals the fact that brick 1 has a strong remanent magnetization, and that it is not oriented as it was when it was fired in a kiln. Brick 1 could not have been remagnetized by the heat in the fireplace.

The calculated directions of the magnetic field over the brick are plotted in Figures 13 and 14. While these patterns were not observed in the measurements of Figures 10 and 11, the smoothing of those measurements would have mostly eliminated small-area patterns like these calculated anomalies.

Similar calculations were made along a surface below the brick. These revealed patterns that are similar to those in Figures 12 - 14, although the patterns are rotated: With the total field map, the low would be to the south, rather than the north; with the inclination map, the angle would still be high over the brick, but inclination angles would now be low to the north; with the declination map, the highs and lows on the east and west would be swapped. Since the inclination angle of the magnetic field should be low to the north of and below a magnetic feature, it is likely that the low inclination angles in Figure 10 are caused by the fact that the ledge of unexcavated soil to the south of this test area is rather magnetic.

Each of the magnetic profiles in Figures 3 - 8 shows duplicated lines of measurement. These repeated measurements differ by a good amount at some locations. Part of the difference is due to the differing resolutions of the repeated surveys: With measurements spaced by 0.01 ft, many more small features are detected than can be found with an 0.1-ft measurement spacing. However, there are also large differences that cannot be explained by the change in resolution. These large differences, which are almost entirely found on the eastern side of the survey area, are caused by the iron tools that were moving in the excavation to the east. These moving iron objects cause the fine-textured patterns that are seen on the right-hand side of the magnetic map in Figure 9.

Several potential causes of the noisiness on the eastern side of the magnetic map can be discounted. While interference from electrical wires can cause similar patterns, there are none overhead or underground in the vicinity. In principle, the palmtop computer could have caused electromagnetic interference to the magnetometer; however, this computer was often stationed to the north of the square, and the noise is not high on that side of the map. Iron that I may accidentally have been carrying can cause somewhat similar patterns, but usually more striated; however, I was careful with iron and too distant to have caused these anomalies. Perhaps the magnetometer simply creates more irregular readings after it has measured about 70 values; there is no known mechanism for this, and I have not seen it before. Finally, there could be bits of iron in the soil on the eastern side of the square; perhaps rust fragments from the cannonball were swept across this band. There are indeed patterns that look dipolar on the eastern side of the map, and the sources of these patterns could be small objects at a very shallow depth. However, this cannot be the cause, for the readings that were made with the fast mode show almost none of these irregularities.

It is the differences between the two repeated surveys that reveal the origin of the magnetic irregularities. The survey with the fast mode (solid lines in Figures 3 - 8) was done during the noon hour, when the excavators had left for lunch. The magnetic map that was measured with the slow mode was done when the excavators had returned after lunch, and it is this map that has the irregularities. The small-area irregularities diminish with increasing distance to the west, which is greater distance from the excavators. A final clue is the fact that there are typically more magnetic lows than highs in the irregular portion of the map; iron objects that are laterally offset from the area of measurement are more likely to cause lows than highs.

I measured the magnetic anomaly of a shovel that is similar to those of the excavators. It caused an anomaly of about 100 nT at a distance of 3 - 4 ft. There may have been two shovels in the excavation at some times. The soils were screened on the north side of the excavation, and there was little effect from the iron in the screen. However, a wheel barrow was brought there at some times to remove that soil to a disposal area, and this wheel barrow had a large amount of steel. The large double spike at E3.5 in Figure 3 must almost certainly be caused by the wheel barrow.

While the iron tools caused a larger irregularity to the magnetic map than I anticipated, the interference is in the eastern part of the map and this eastern edge does not appear to be as important as the central and western parts. However, I should have tested the effect of the tools while I was at the site.

This magnetic survey was done on 16 October 2003. The temperature was about normal for the season that day, and there was no rainfall. The excavations had been covered with a tarp, and the soil surface was dry, although there might have been rainfall in this area a day before this survey.

Results of the Survey

The magnetic map that was measured over the fireplace base is plotted in Figure 15. The most distinctive pattern is to the left of the center of the map; the adjacent pair of areas with high and low readings is caused by a fragment of a brick (perhaps a quarter of a whole brick).

Most of the bricks (outlined in red in Figure 15) were not detected by the magnetic survey. This is because the soil itself is rather magnetic; it is as magnetic as some of the brick. Weakly magnetic bricks are invisible in the soil here.

Four bricks were detected by this magnetic survey; these are marked with circled numbers in Figure 1. There are no magnetic anomalies where bricks are not visible at the surface. This means that it is unlikely that there is a layer of bricks deeper in the soil. If there was a layer of bricks at a depth of 0.25 ft underground, some of them should have caused magnetic anomalies that would have been seen in this map.

In Figure 1, the edge of the fireplace is marked with a line. There is no change in the magnetic readings near this line. This means that the soil along this line was not magnetized by the fires that would have been inside the fireplace. There was also no suggestion from the magnetic map than any of the visible bricks were remagnetized in the fireplace. It is possible, therefore, that the archaeological surface that is visible now was underground and cool during the operation of the fireplace. This finding is not certain, because it is possible that the base of a fireplace may have been insulated by ash, keeping it cooler than one would think. This result was suggested by magnetic measurements on fireplace bases in structure 165; no evidence of brick refiring was found within two fireplaces there.

The two stones that are found in the northwest corner of the survey square (Figure 1) were found to be not magnetic. The white stone probably does not contain iron minerals, and would not be magnetized in a fire. The red stone could contain iron; it probably is not igneous and was never in or next to a hot fire.

In Figure 15, there is a band of small magnetic anomalies on the eastern (right hand) side of the map. These patterns are caused by the moving iron tools of the excavators who were to the east. These irregularities do not affect the important central part of the magnetic map. Figure 15 shows a magnetic anomaly at E3 N0; this is at the excavation face on the south side of the survey area. There is clearly a magnetic object, such as a brick fragment, at that location; however, I did not locate a brick in my map there. An initial test was done in the square with a simple audio-indicating magnetic locator. This suggested that bricks whose color was dark orange were more magnetic than light-orange bricks. This difference in color and magnetism may be due to different clays or simply to a different location in the firing kiln. The colors of the bricks in Figure 1 were not recorded.

The soil was mottled with an orange color at the southern side of the survey area (Figure 1). The geophysical survey did not find any magnetic anomalies in this area. This suggests that the possible firing of these soil clumps was not enough to magnetize the soil to any detectable extent.

It is impossible that there could be another cannonball to the south, in the unexcavated soil, within a distance 2 ft or so; iron is so magnetic that any nearby cannonball would have been readily detected.

Conclusions

This test has shown that there are large differences in the magnetic properties of the bricks in this area. The soil itself is quite magnetic at this location; in fact, it is as magnetic as some bricks. There may partially be a cultural origin to the magnetic soil (biological decay of organic soil can make the soil more magnetic); however, much of the soil's magnetism is probably natural. Earlier tests at the eastern end of Jamestown Island found a large fraction of magnetite (lodestone) in the soil. This magnetite sand was deposited by the James River.

The main magnetic measurements of this survey had a spatial resolution that is over ten times higher than that applied to a normal archaeological survey. However, tests showed that a further ten-fold increase in the resolution would be practical. This extremely high resolution survey would allow magnetic objects smaller than 0.1 inch in size to be identified, and this may increase the understanding of small features in excavations.

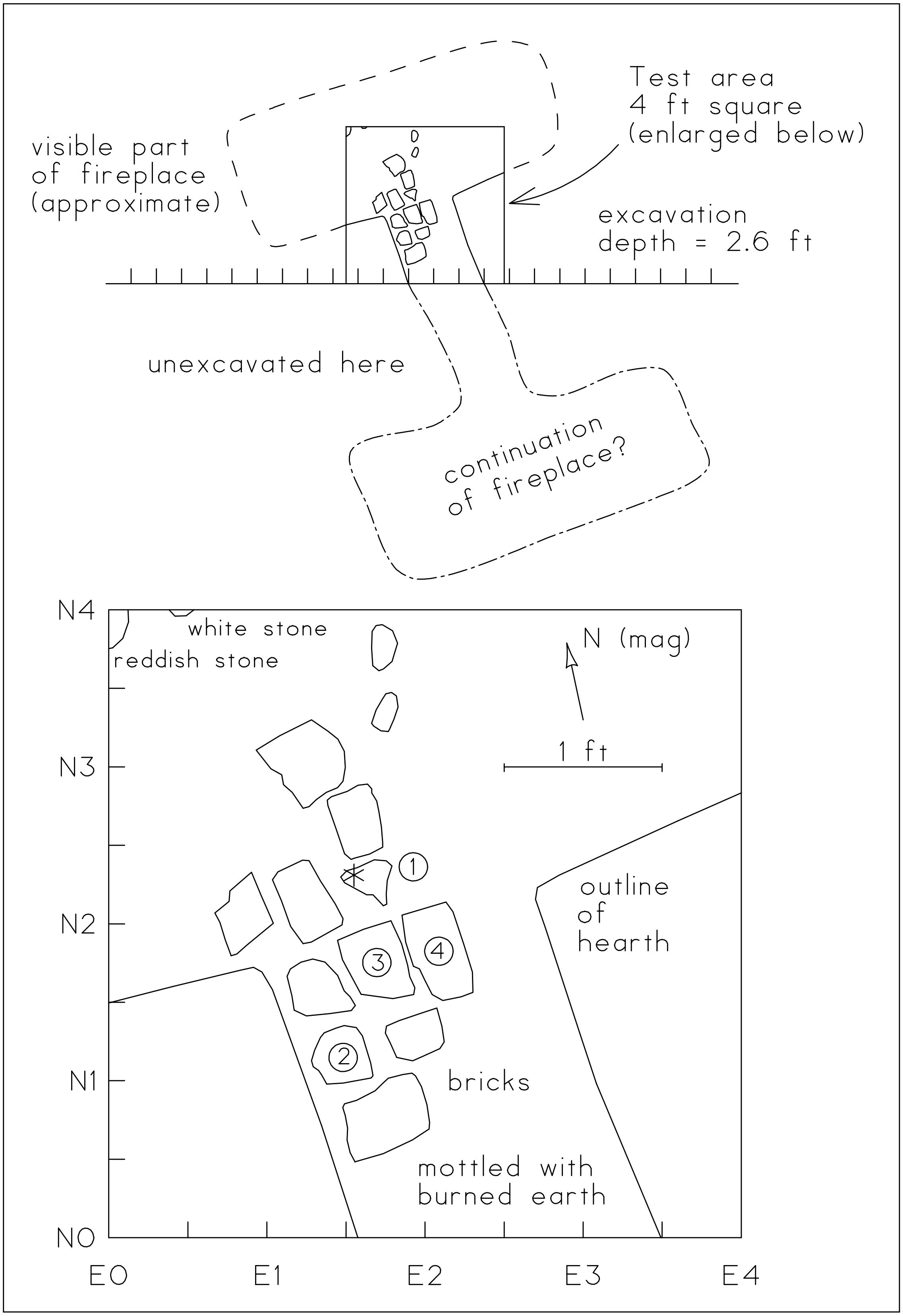

Figure 1: The area of the geophysical survey. This is feature JR1361, the base of an early fireplace. A magnetic map was measured in a square area that is 4 ft on a side. Brick fragment 1 (next to the circled number) was found to be very magnetic; while bricks 2 - 4 were moderately magnetic, the remaining bricks could not be detected with the magnetic survey.

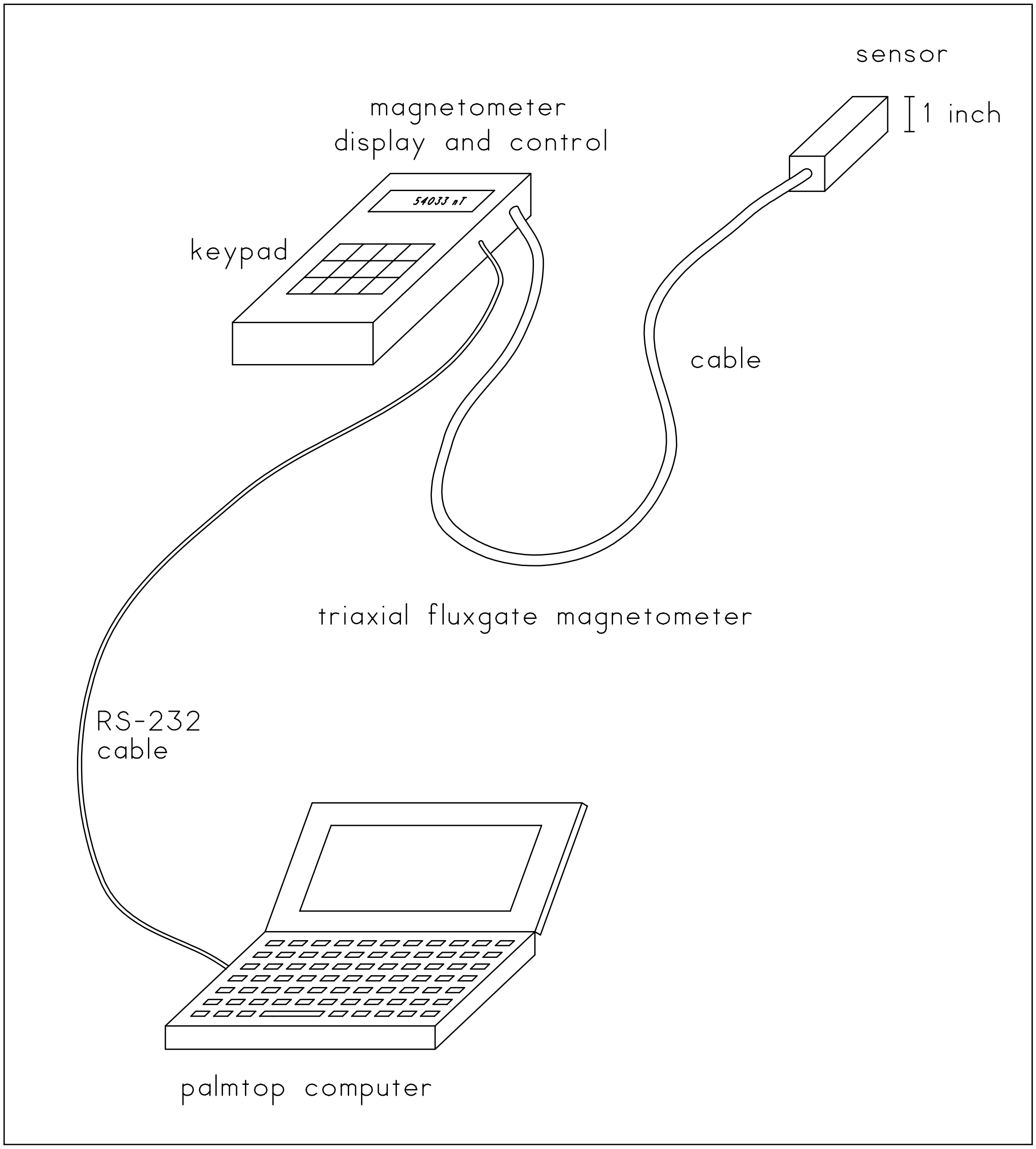

Figure 2: The magnetometer. A small sensor is connected to a control and display console with an electrical cable. While the measurements are shown on the LCD, they can also be sent to a computer with the aid of a serial (RS-232) cable. The magnetic sensor was moved over a square area, and the measurements created a magnetic map of that square.

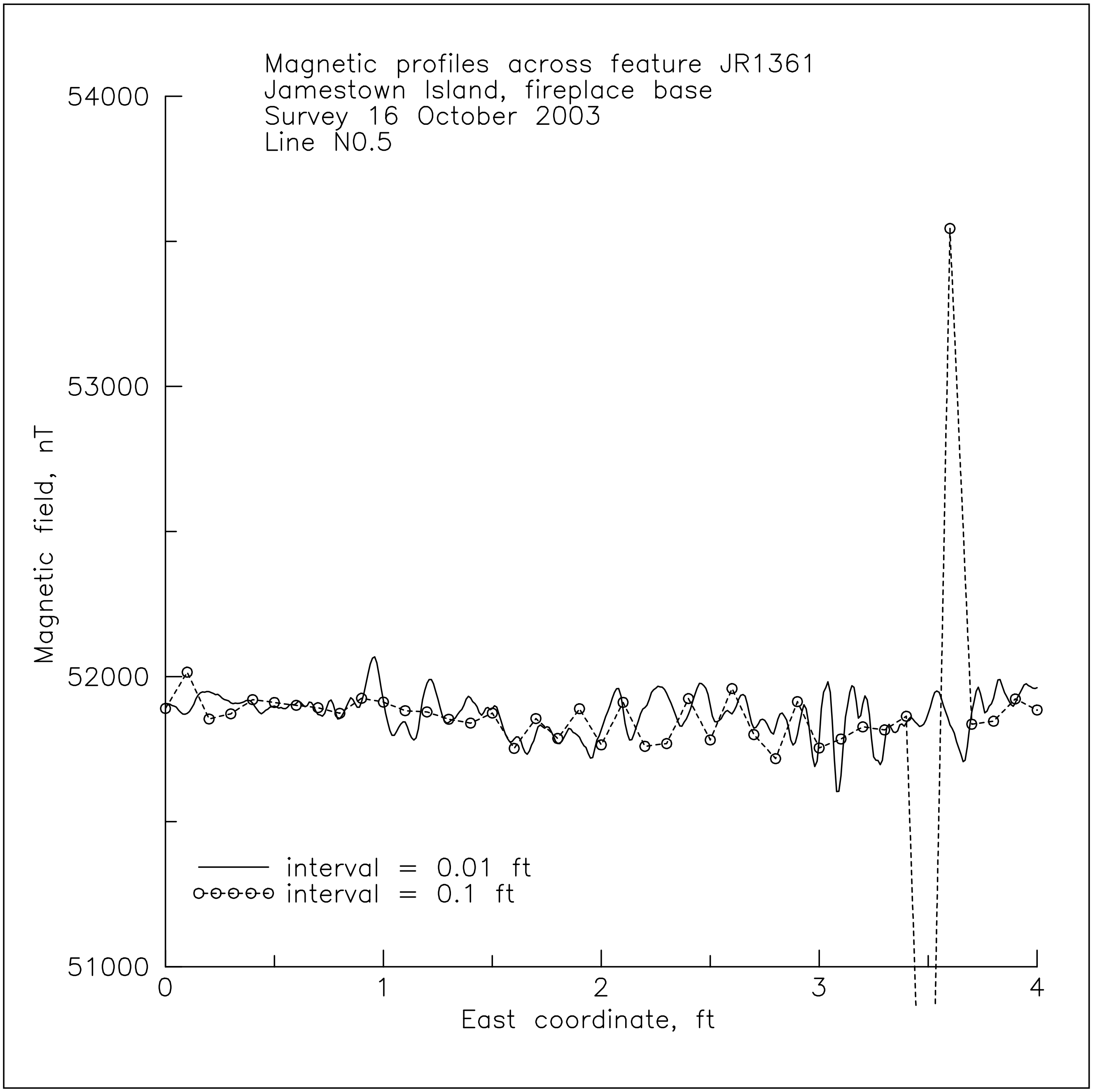

Figure 3: A duplicated magnetic profile across the fireplace base. The smooth solid line shows the initial measurements; the spacing between these readings was 0.01 ft. The line was later repeated with a measurement spacing of 0.1 ft; the circles on the broken line show these readings. The double spike on the repeated readings at E3.5 was caused by iron moving in the nearby excavation.

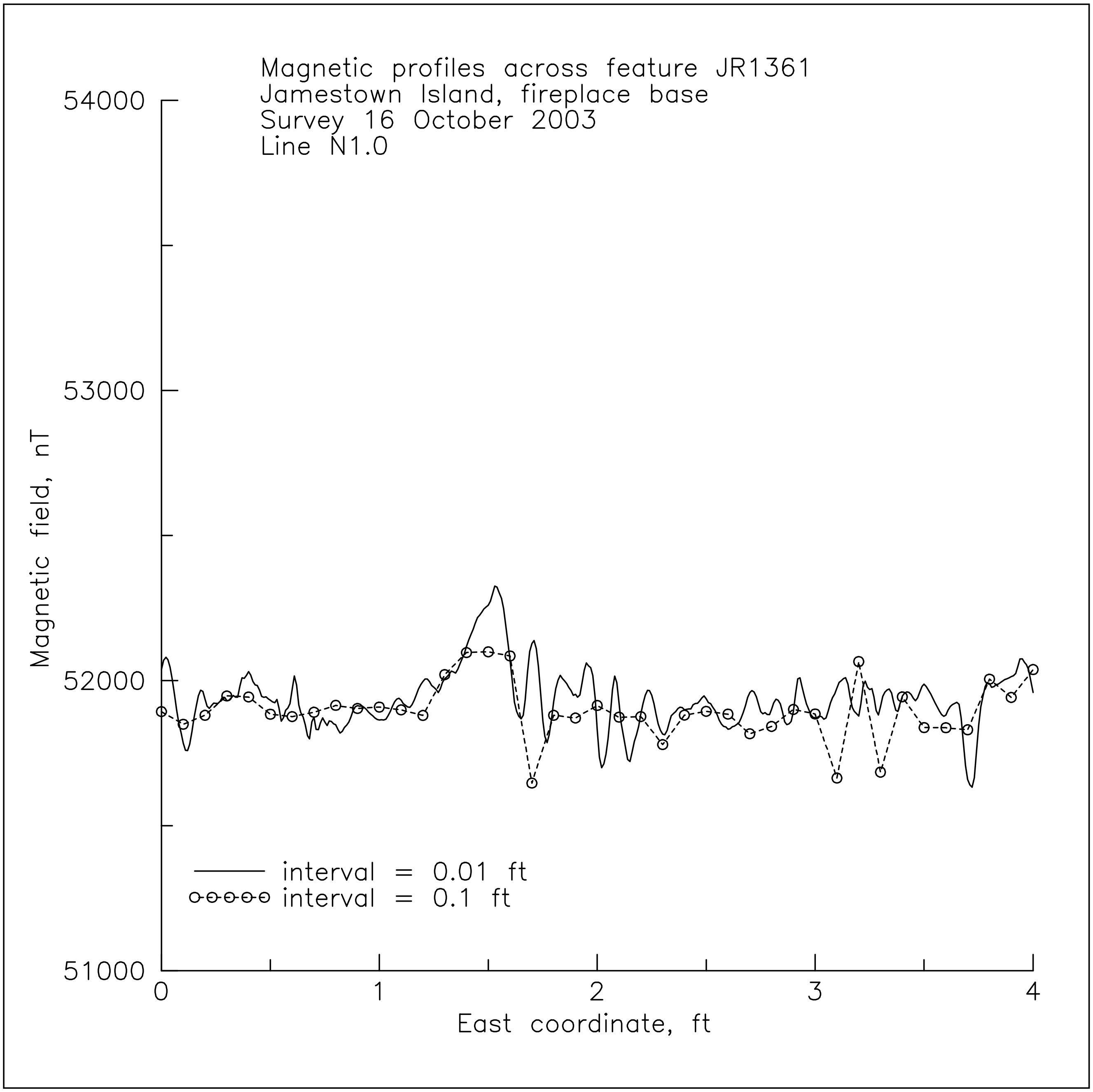

Figure 4: Another pair of magnetic profiles. These measurements were made on line N1.0 ft, which is 1 ft to the north of the edge of the excavation. The high readings near E1.5 are at brick 2 in the map of Figure 1.

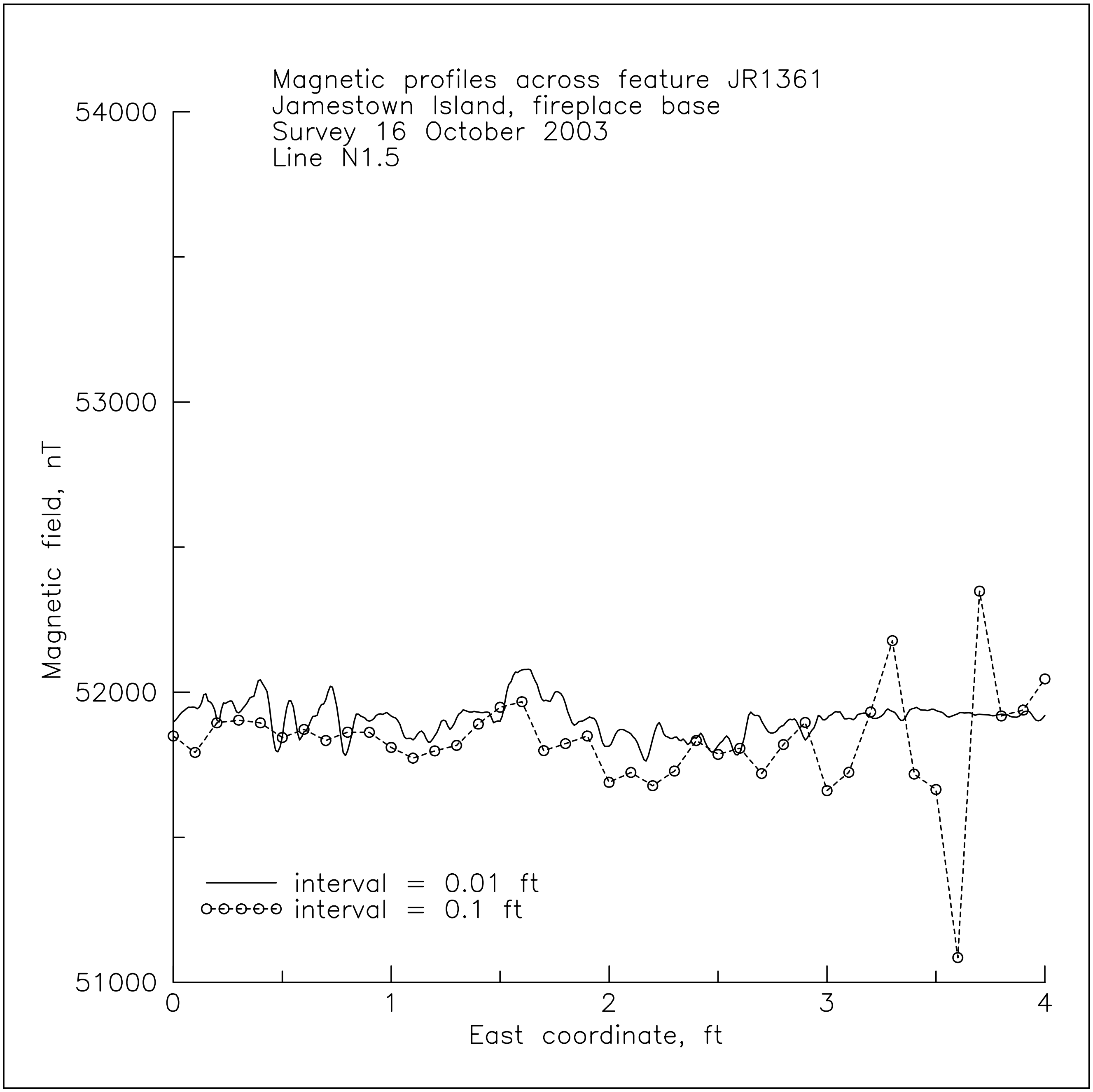

Figure 5: Magnetic profiles of line N1.5 across the fireplace. Little was detected on this line. The irregularities on the dashed line at the right end are caused by moving iron tools in the excavation that was to the east.

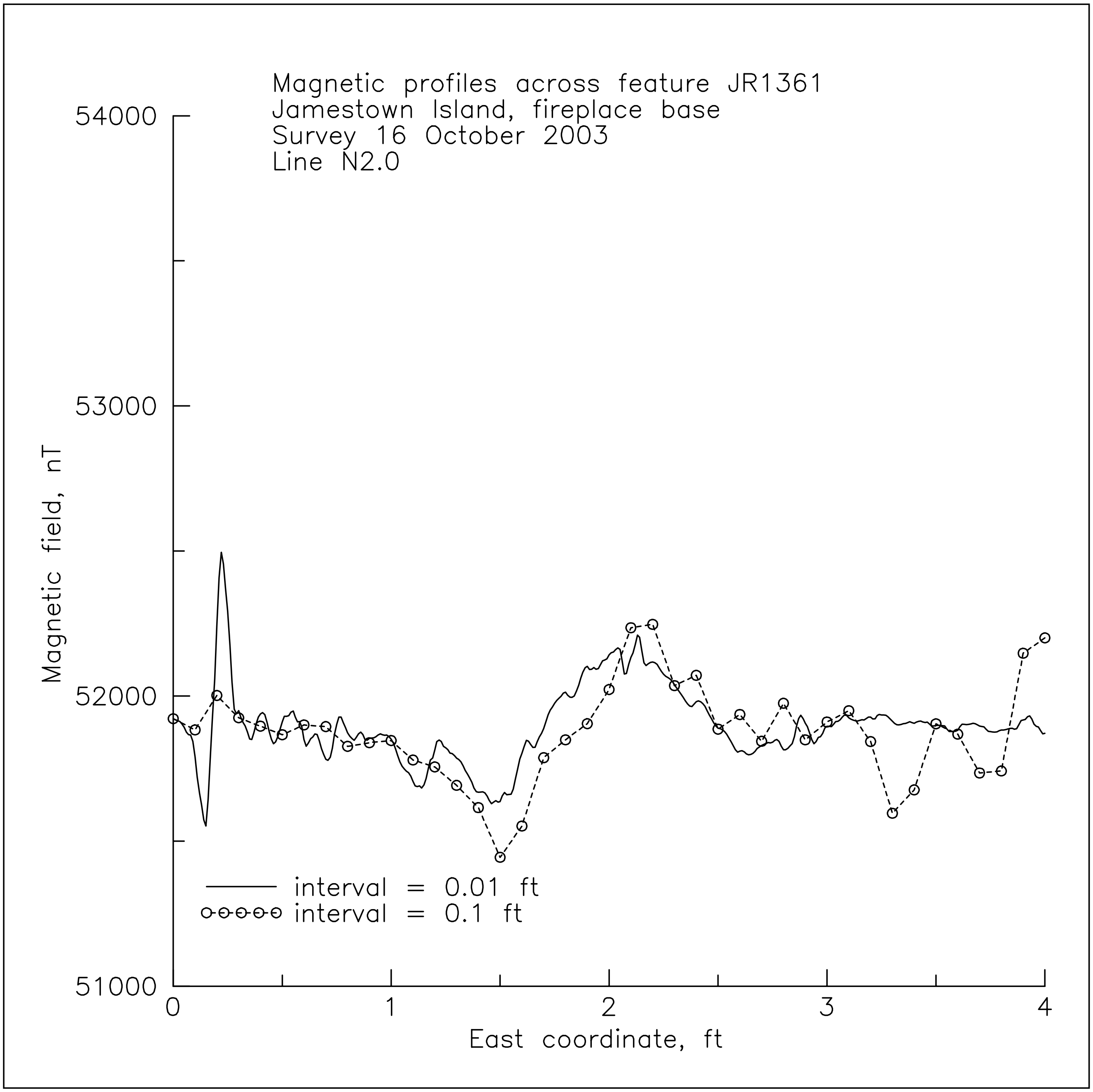

Figure 6: The magnetic effect of two bricks. On this line, brick 3 causes the low readings near E1.5, while brick 4 causes the high readings near E2. The large swing of the solid line curve near E0.2 has an unknown origin, but it is not caused by an underground feature.

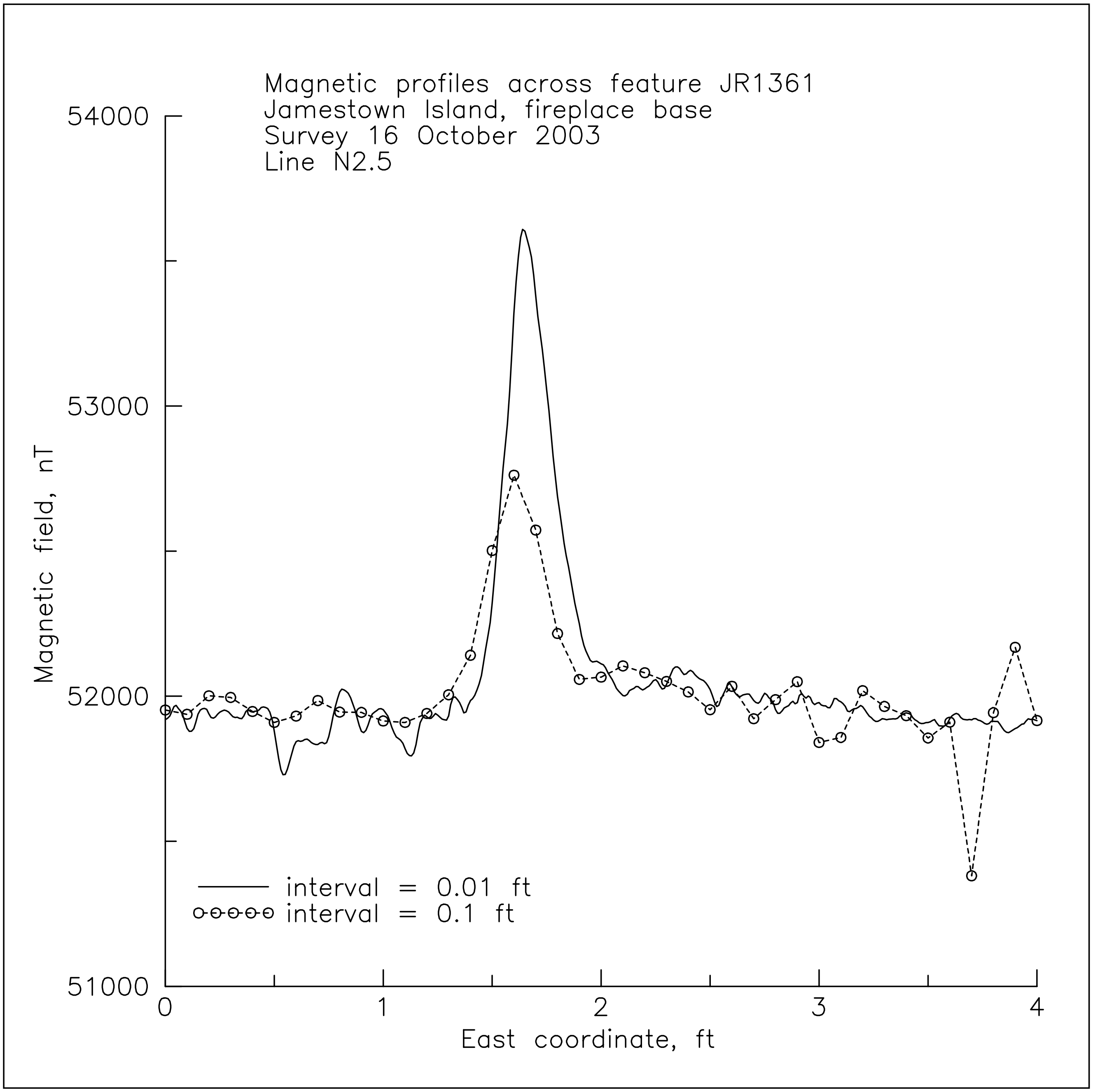

Figure 7: The most magnetic brick. The large peak near E1.7 is caused by brick fragment 1; it is much more magnetic than any of the other bricks in this fireplace base. The difference in the amplitudes of the magnetic anomaly on the two curves may be due to differences in spatial resolution; one set of readings was made at intervals of 0.1 ft while the other set was at 0.01-ft intervals.

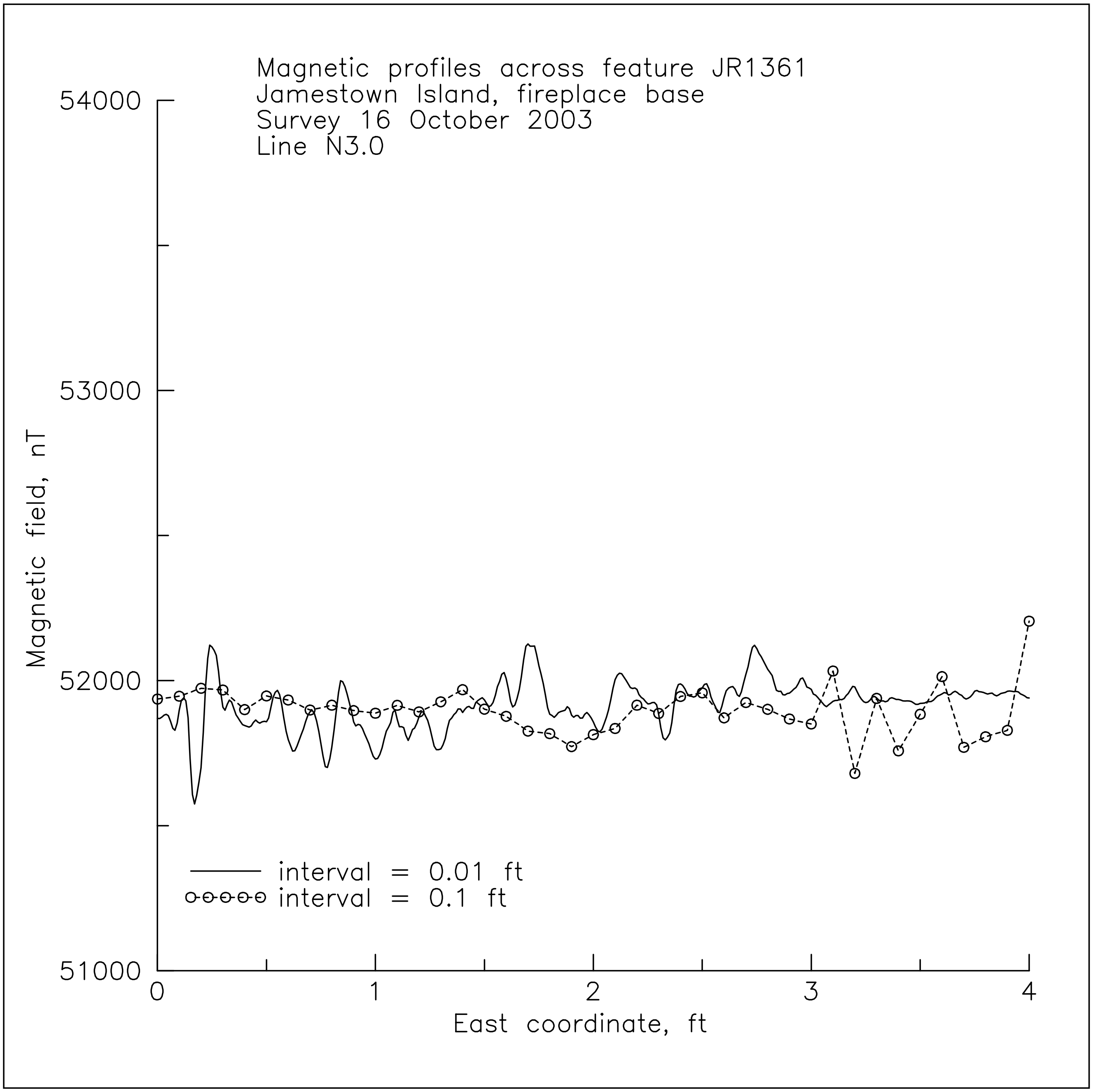

Figure 8: The final magnetic profiles. While this line crosses a brick at E1.3, that brick was not detected by the magnetic survey. This is evidently because this brick is not very magnetic; it must be about as magnetic as the surrounding soil.

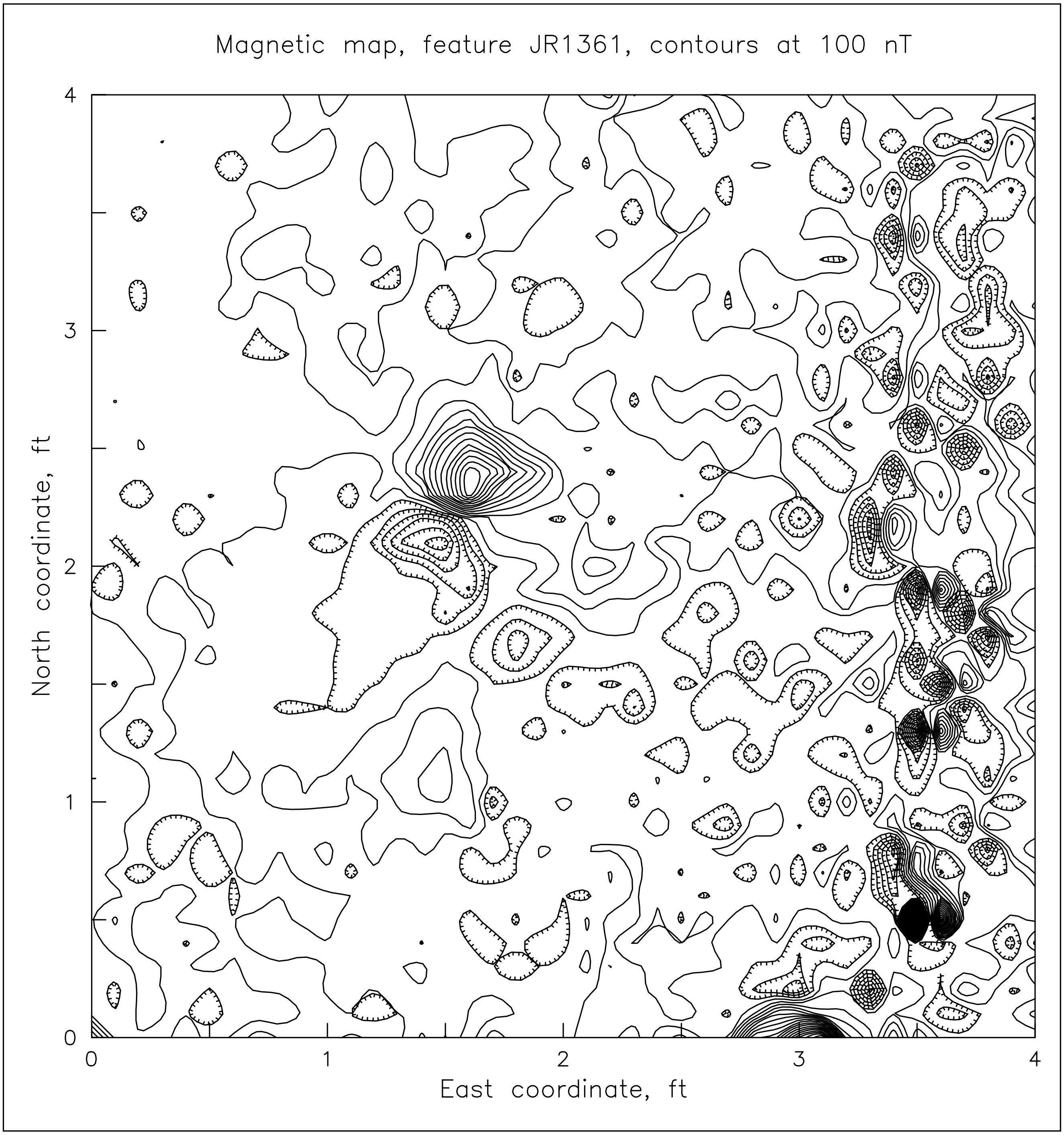

Figure 9: The magnetic map. The magnetic sensor was at a height of 0.053 ft (0.63 inch) above the brick surface and the measurement spacing was 0.1 ft. The interval between the contour lines is 100 nT. Enclosed low values have contours with tick marks along them. The band of complex anomalies on the right is caused by moving iron tools that were nearby.

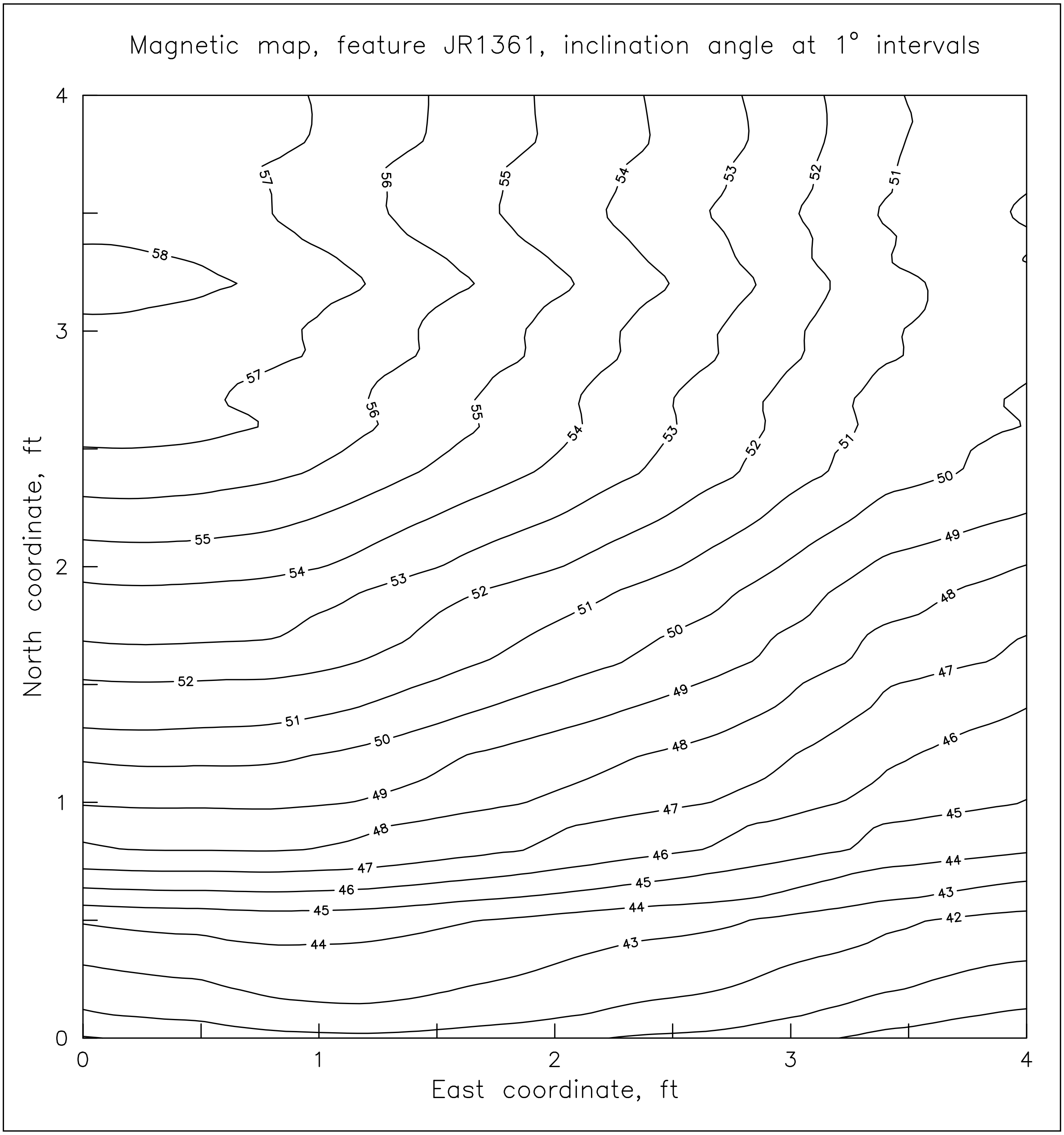

Figure 10: The inclination or dip of the magnetic field in the 4-ft square. The numbers show the angle, in degrees, below the horizontal. Without magnetic features, the dip of the earth's field should be about 66^o at Jamestown. The angle is much less at the southern side of the square; this is likely due to the effect of the magnetic soil in the unexcavated ledge to the south.

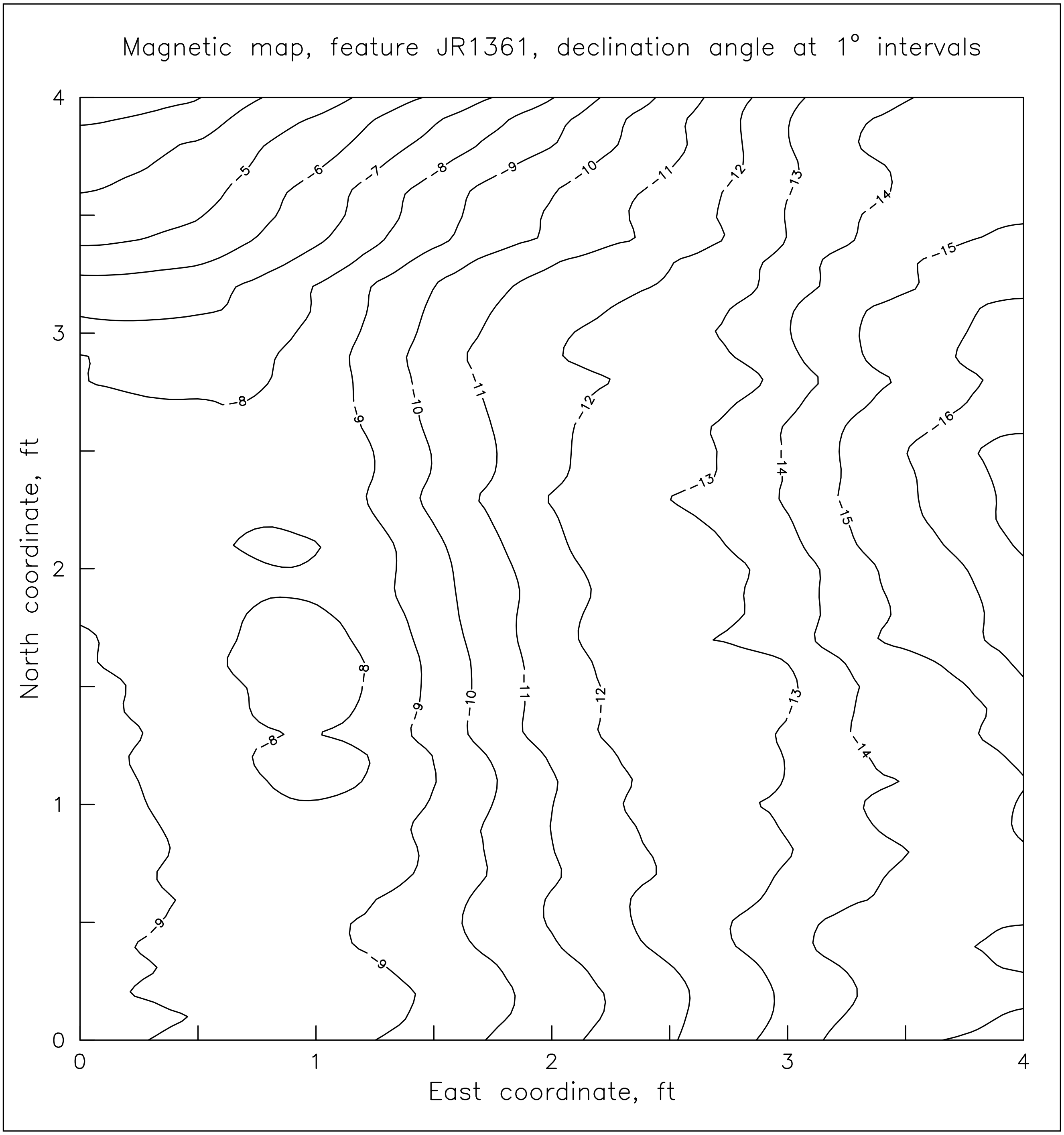

Figure 11: The grid declination of the magnetic field in the square. It varies over a range of about 12^{o} in this area. The cause of this pattern has not been studied. The negative numbers mean that the local direction of magnetic north is to the west of grid north.

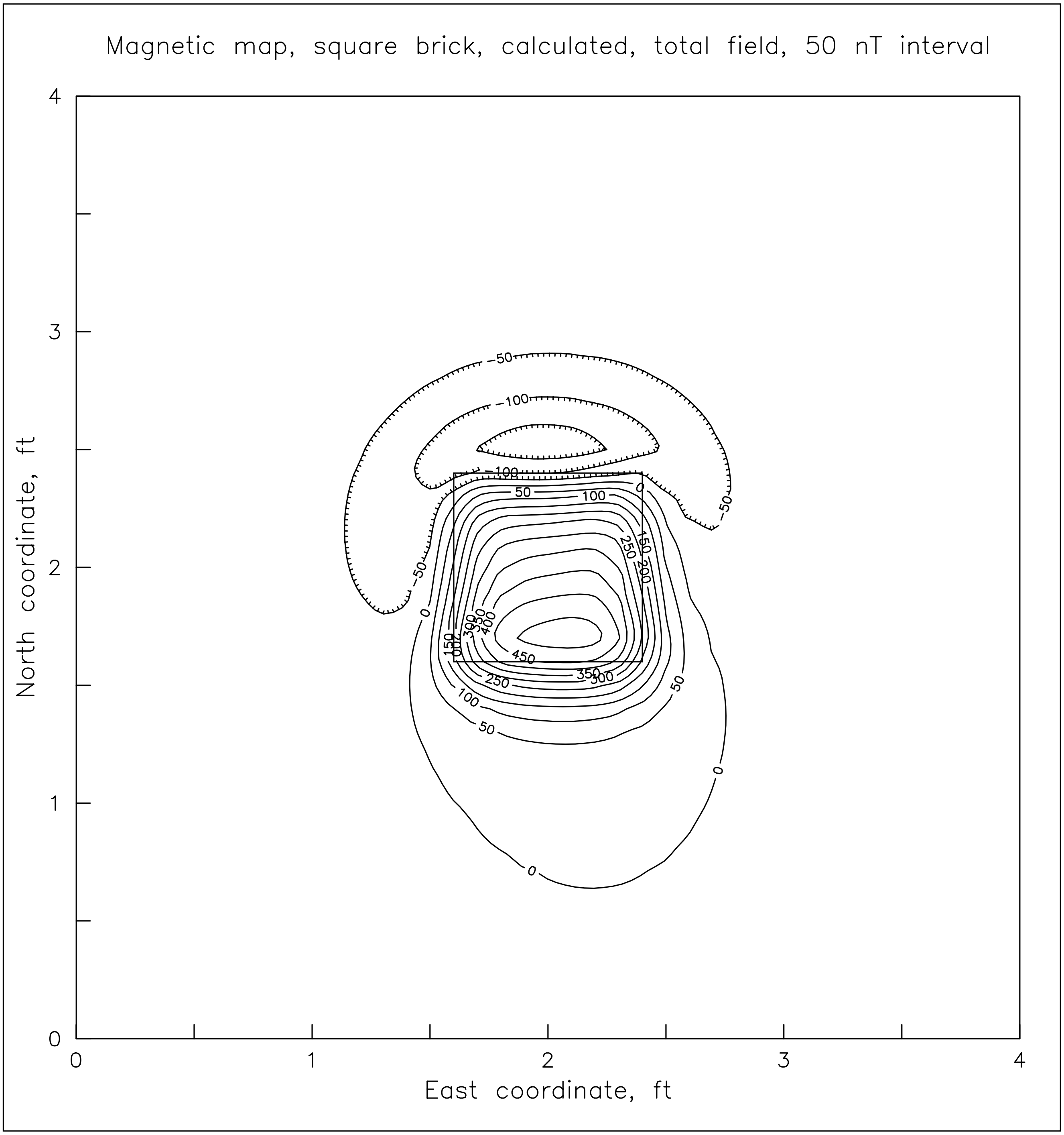

Figure 12: The calculated magnetic map of an approximated brick. The brick is outlined with a square, and is 0.8 ft on a side. This brick has been assumed to have been fired in place, and this causes the magnetic low to be north of the brick. In the measurements of Figure 9, brick 1 has its low to the south; this means that it was not fired in place and was not remagnetized in the fireplace.

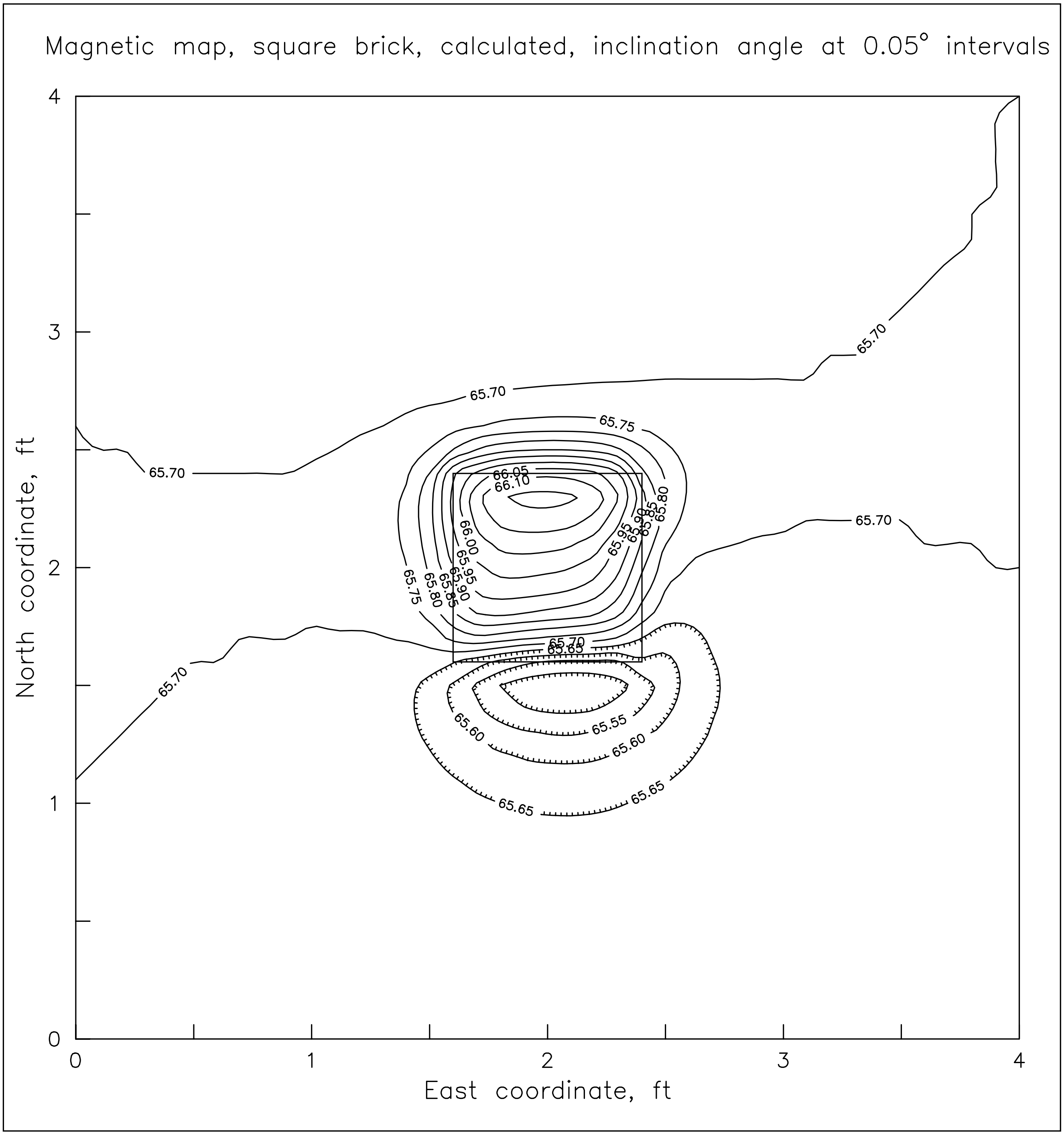

Figure 13: Calculations of the inclination angle of the magnetic field that would be measured over a brick. Again, a square locates the brick. The magnetic field dips to a steeper angle over this brick. This is to be expected if there is no self-demagnetization within the brick.

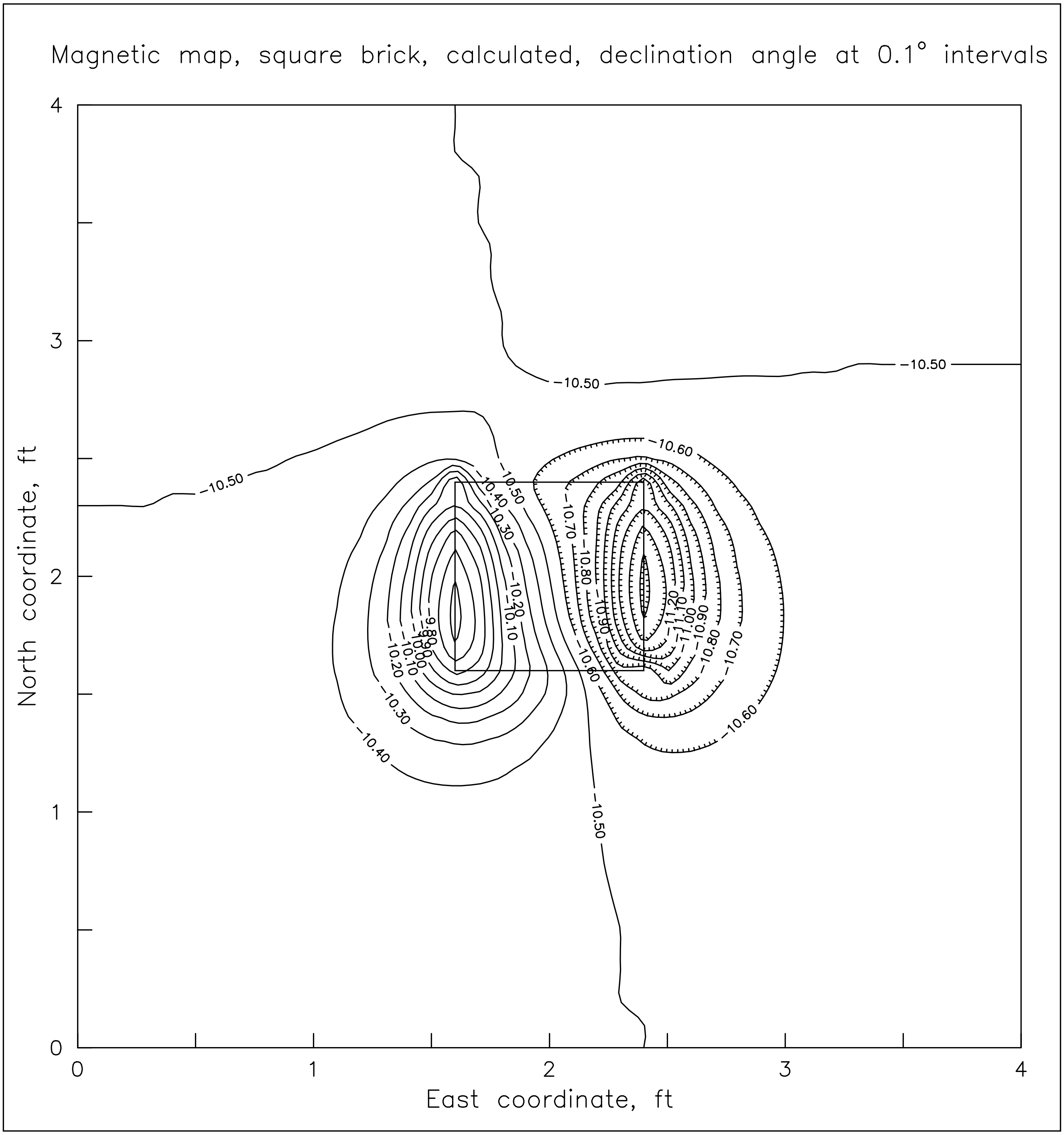

Figure 14: The grid declination angle of the magnetic field over the brick. This pattern means that a magnetic compass that was set on the brick would have its direction of north angled toward the north-south midline of the brick. This angular pattern has indeed been measured over magnetic objects.

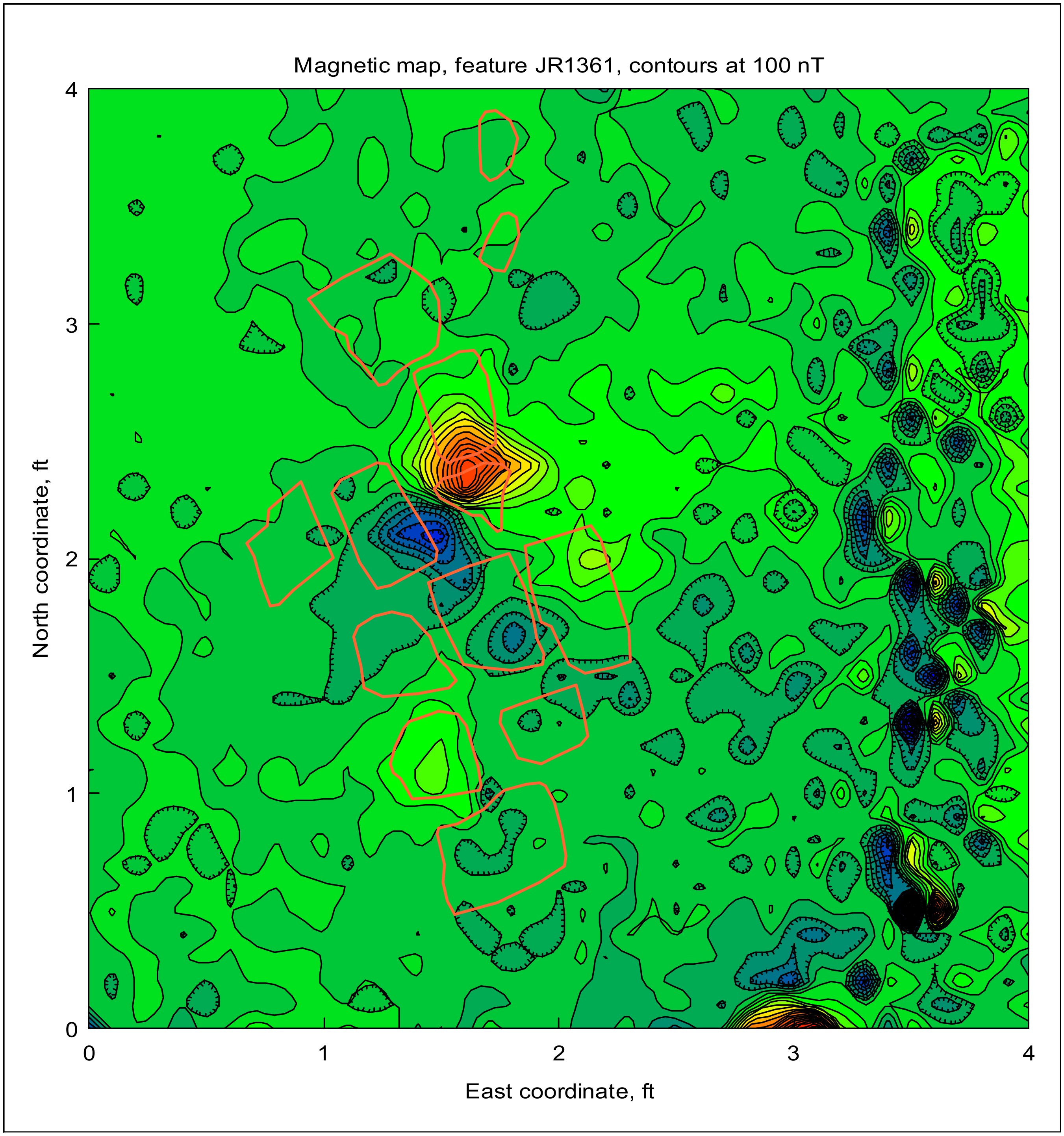

Figure 15: The magnetic map. Cool colors (such as blue) show low values while warm colors (red) are highs. The adjacent pair of high and low values near E1.5 N2.2 are caused by a brick fragment that is very magnetic. This triangular fragment is indicated in Figure 1 to the left of the circled 1. The bricks are outlined with red lines; while a few of these were moderately magnetic, most were not detected.