# Magnetic Survey of the Southern Portion of the Elbee Site (32ME408), Mercer County, North Dakota

By
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Midwest Archeological Center
Technical Report No. 110

NATIONAL PARK SERVICE
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**United States Department of the Interior**
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*Available*

Making the report available meets the criteria of 43CFR Part 7, Subpart A, Section 7.18 (a) (1).

## ABSTRACT

Between September 11 and September 15, 2006, Midwest Archeological Center (MWAC) staff conducted magnetic geophysical investigations at the Elbee Site (32ME408) within Knife River Indian Villages National Historic Site (KNRI). This was part of a multiple phase archeological project to assess the archeological record of the Elbee Site that has been dramatically impacted by erosion of the vertical cutbank along the Knife River in the northern portion of the site. Initially, a magnetic survey was conducted in the northern portion of the site by MWAC staff in 2002 (Volf 2002). The University of North Dakota archeological staff and students conducted a ground truthing phase in 2003 to investigate magnetic anomalies to confirm the presence or absence of significant archeological deposits in the threatened northern portion of the site. The magnetic survey indicated that the southern portion of the site had been severely impacted by the historic farmstead that was present on the site during the 19$^{th}$ and 20$^{th}$ century; however, a number of magnetic anomalies were identified as potential archeological features associated with the Native American occupation of the site during the prehistoric and historic periods. A total of 14,200 $m^2$ or 3.51 acres were surveyed during the geophysical investigations at the site.

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# 1. INTRODUCTION

Between September 11 and September 15, 2006, Midwest Archeological Center (MWAC) and Knife River Indian Villages National Historic Site (KNRI) staff conducted magnetic geophysical investigations at the Elbee Site (32ME408) within the Knife River Indian Villages National Historic Site in Mercer County, North Dakota (Figure 1). This was part of a multiple phase archeological project to assess the archeological record of the Elbee Site, which was dramatically impacted by erosion of the vertical cutbank along the Knife River in the northern portion of the site (Ellis 2006:32-36). Initially, a magnetic survey was conducted in the northern portion of the site by MWAC staff in 2002 (Volf 2002). The University of North Dakota (UND) archeological staff and students conducted a ground truthing phase in 2003 to investigate magnetic anomalies and confirmed the presence of significant archeological deposits in the threatened northern portion of the site (Toom et al. 2004). The authors also recommended that a magnetic survey be conducted on the southern portion of the site.

The geophysical survey techniques used during the investigations of the southern portion of the Elbee Site included a magnetic survey and a test of the potential of ground penetrating radar (gpr) techniques at the site (Figure 2). The magnetic survey was conducted with a fluxgate gradiometer. The ground penetrating radar survey was conducted with a gpr cart system with a 400 mHz antenna. The present report will discuss the results of the magnetic survey and the potential of ground penetrating radar surveys at KNRI. During the magnetic survey, Kasha Hanson and Ramon Jasso of the park maintenance staff assisted in setting out the geophysical survey grid corner hub stakes and moving the survey ropes during the project.

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## 2. ENVIRONMENTAL SETTING

The present project is located in the glaciated Missouri Plateau section of the Great Plains Province of the Interior Plains (Fenneman 1931:72-79). The project area is also located within the Rolling Soft Shale Plain of the Northern Great Plains Spring Wheat Land Resource Region (USDA 2006:145-146). The moderately dissected, rolling plain consists of glaciated old plateaus, with some local badlands, buttes, hills, and the occasional isolated mountains. Bedrock in the vicinity of KNRI include the Paleocene age Sentinel Butte and Bullion Creek formations of *poorly lithified sand, silt, silty clay, and clay with shale and lignite* (Lovick and Ahler 1982:38) covered with Quaternary glacial, eolian, and alluvial deposits. The Elbee Site (Figure 3) is located on the mid-Holocene age "A" terrace above the right bank of the Knife River with small portions in the southwest corner of the site located on the Pleistocene Hensler and Stanton terraces (Lovick and Ahler 1982:39-42; NPS 1986:49; Reiten 1983:9-13). The terrace deposits are layers of silty sand grading upwards to clayey silt and capped by wind blown silt. For additional information on the environmental setting, the reader is referred to Lovick and Ahler (1982:34-47) and Toom et al. (2004:1.1-1.7).

Soils within the Rolling Soft Shale Plain are dominated by Mollisols and Entisols (Foth and Schafer 1980:116-125; USDA 2006:146). The soils are more or less freely drained with ustic soil moisture and frigid soil temperature regimes. Parent materials in Mercer County have several different origins including glacial till and other glacial materials, weathered material from water sorted till, wind or water deposited sandy and loamy materials, alluvium, residual bedrock, and porcelanite (Wilhelm 1978:107). The soils formed under mid and short prairie grass vegetation. Depth to bedrock ranges from shallow to very deep. The project area lies within the Havrelon-Lohler soil association of *level, deep, well drained and moderately well drained soils formed in material weathered from alluvium* (Wilhelm 1978:10). The soils within the project area include the Straw loam (91B) located on three to six percent slopes on the Holocene "A" terrace, the Zahl-Williams loam located on nine to 15 percent slopes on the Pleistocene Hensler terrace, and the Parshall loam located on one to six percent slopes on the Pleistocene Stanton terrace (Lovick and Ahler 1982:39-42; Wilhelm 1978:27-30,59-60,96-97,101,105-106). The Straw loam soil in the project area consists of a deep, well drained, gently sloping to undulating soil located on the low terrace on the right side of the Knife River (Wilhelm 1978:59,101). Formed in material weathered from loamy alluvium, the soil has a moderate permeability, medium surface runoff, moderate shrink-swell potential, moderate frost action, and a high available water capacity (Wilhelm 1978:59). The soil pH ranges from neutral to moderately alkaline (Wilhelm 1978:101). The soil mapping unit comprises the majority of the present project area. The Zahl-Williams loam soils are deep, well drained soils on the glacial till uplands (Wilhelm 1978:27,105-106). The Zahl-Williams loam soils occur in the sloping southwestern part of the site. The Zahl soil formed in material weathered from calcareous loamy glacial till. The Williams soil formed in material weathered from loess over glacial till. The Zahl soil has a moderately slow permeability while the Williams soil has a moderate permeability in the subsoil and a moderately slow permeability in the substratum (Wilhelm 1978:28). The

Zahl-Williams loam soils have a medium to rapid surface runoff, moderate shrink-swell potential, moderate frost action, and a high available water capacity (Wilhelm 1978:28). The soil pH ranges from neutral to moderately alkaline (Wilhelm 1978:105-106). The Parshall loam soil is a deep, well drained, level to gently sloping soil located between the Zahl-Williams loam soils and the Straw loam soil in the southwestern corner of the geophysical project area (Wilhelm 1978:29,97). Formed on terraces, outwash plains, and upland swales (Wilhelm 1978:97), the soil has a moderately rapid permeability, slow surface runoff, low shrink-swell potential, moderate frost action, and a high available water capacity (Wilhelm 1978:29). The soil pH ranges from neutral to moderately alkaline (Wilhelm 1978:97). These resources provide the basis of the aboriginal subsistence of prehistoric times and the historic and modern Euroamerican farming economy.

The project area also lies within the Saskatchewan biotic province (Dice 1943:24-26). The semiarid mixed grass plains are dominated by a mixture of short and mid-height grasses, including western wheatgrass, needleandthread, green needlegrass, and blue grama (Brown 1985:45-53; Jones and Cushman 2004:35-40; NPS 1986:49-52; Shelford 1963:334; USDA 2006:146). Little bluestem, prairie sandreed, and side oats grama occur on shallow soils in the region. Other prairie vegetation throughout the region includes prairie rose, leadpland, and western snowberry. Green ash, chokecherry, and buffaloberry may be found along draws and narrow valleys. Strips of deciduous trees are most commonly found along larger stream channels (Brown 1985:48-49,53; Dice 1943:25; NPS 1986:49-52; Shelford 1963:309-313).

In the region, bison and pronghorn antelope roamed the open plains until the mid to late 1800s (Brown 1985:49-51; Jones and Cushman 2004:42-50; Shelford 1963:335). During the prehistoric and historic periods, white-tailed deer were present in the timbered areas along streams and slopes. Jackrabbits are common along with coyotes, prairie dogs, black-footed ferrets, badgers, mink, bobcats, and foxes (USDA 2006:146). Wolves were also important predators until exterminated from the region in the late 1800s. Numerous other mammals and rodents also inhabit the region (Brown 1985:52; Jones and Cushman 2004:42-50; NPS 1986: 49-52; Shelford 1963:334-336). Numerous species of birds inhabit the grasslands, the shrublands, and wooded areas of the region (Brown 1985:53; Jones and Cushman 2004:50-58; Shelford 1963:336). Gray partridge, sharp-tailed grouse, and prairie chicken represented some of the regional game birds, as well as migratory waterfowl, in both prehistoric and historic times. Numerous grassland and forest species of songbirds are present. Reptiles include several species of lizards, turtles, and snakes (Brown 1985:53; Jones and Cushman 2004:58-63; Shelford 1963:336). Amphibians are found in the prairies, forests, and wetlands (Brown 1985:53; Jones and Cushman 2004:58-63; Shelford 1963:336). Fish, including rainbow trout, walleye, smallmouth bass, bluegill, yellow perch, and northern pike, and fresh water mussels are found in the streams throughout the region (Jones and Cushman 2004:58-63; NPS 1986:49-52; USDA 2006:146). Insects and other invertebrates abound throughout the region with the grasshopper being one of the most abundant insect groups (Brown 1985:53; Jones and Cushman 2004:64-66; Shelford 1963:336-339).

The region has a semiarid continental climate characterized by large daily and annual variations in temperature (NPS 1986:53-54; Wilhelm 1978:1-2,124-125). The project area lies within the transition zone between the middle-latitude dry climatic zone (Trewartha and Horn 1980:360-364) and the cool-summer subtype of the temperate continental climatic zone (Trewartha and Horn 1980:302-311). Winters are very cold and the summers are hot. The annual average temperature ranges between 3 and 8°C (USDA 2006:146). Annual January temperatures average -13.3° C (Bavendick 1941:1046; Wilhelm 1978:124). The lowest recorded winter temperature is –46° C (Bavendick 1941:1046). Annual July temperatures average 20.2° C (Bavendick 1941:1046). The highest recorded summer temperature is 42.2° C (Bavendick 1941:1046; Wilhelm 1978:124). Annual precipitation averages between 35.5 to 45.5 centimeters (Bavendick 1941:1046; USDA 2006:146; Wilhelm 1978:124) with the majority falling from April through September. The average seasonal snowfall is 68.58 centimeters per year (Wilhelm 1978:124). The growing season averages 109 days with killing frosts occurring as late as May 28th in the spring and as early as September 14th in the fall (Bavendick 1941:1046; Wilhelm 1978:125). Hail may occur with summer thunderstorms. Blizzards are common during the winter. Recent droughts have tended to be severe (Bavendick 1941:1054). The sun shines approximately 74% of the time in the summer and 53% of the time in the winter (Bavendick 1941:1054; Wilhelm 1978:2). The prevailing winds are from the west-northwest with more southerly winds occurring in the summer (Bavendick 1941:1054; Wilhelm 1978:2). The annual relative humidity averages 68 percent.

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# 3. PREVIOUS INVESTIGATIONS AT THE ELBEE SITE (32ME408)

In 1974, the United States Congress authorized the establishment of the Knife River Indian Villages National Historic Site to commemorate the cultural history and lifeways of the Mandan and Hidatsa Indians and to preserve the archeological resources associated with the two native Northern Plains tribes. Since 1976, the National Park Service has conducted an extensive archeological and ethnohistorical program to document the archeological and historical resources within the park. A four-volume summary of the program provides significant information on the archeological research program's objectives, methodology, cultural history and ethnohistory of the region, analysis of the material culture, and interpretive results (Thiessen 1993). The regional prehistory and history is divided into five major cultural periods: Paleo-Indian (10,000-6000 B.C.), Archaic (6000 B.C. to A.D. 1), Woodland (A.D. 1 to A.D. 1000), Plains Village (A.D. 1000-1861), and Euro-American (A.D. 1861-present). A radiocarbon date of 440 ± 40 BP places the site in the Extended Coalescent variant of the Plains Village (Ahler et al. 2007:86). Additional information on the cultural history of the Knife River Indian Villages National Historic Site and surrounding region, including the synopsis of archeological investigations in the KRNI and vicinity prior to 1974, may be found in park documents and archeological reports (Ahler 1978a:1-31; Lehmer 197149-179; Lovick and Ahler 1982:47-84; NPS 1983:I/11-I/36,1999:1/18-21,2/1-5; SHSND 1990:3.1-3.42,5.1-5.51; Zedeño et al. 2006:23-42).

The Elbee Site (32ME408) was identified and recorded by a UND archeological crew in the Spring of 1978 (Ahler 1978b:14-16) during the investigations of a potential access road route and staging area for U.S. Army Corps of Engineers riverbank stabilization project at the Sakakawea Village Site (32ME11). The site was located within the boundary of the William Russell farm complex in Tract 01-112 (Taylor 1978). At the time of the 1978 UND archeological investigations, the southern portion of the site contained the farmhouse, garage, chicken coop, grain storage bin, and livestock barn (Figure 4). The house was located on the side slope of the Pleistocene terrace on the southwest side of the site. The buildings and structures were demolished and the materials were removed. The basement of the house was filled and contoured to the surrounding landscape.

Lovick and Ahler (1982:236-237) describe the Elbee Site as follows:

> *The Elbee site is a complex, multicomponent site located on the northernmost extremity of the A terrace surface in the southern part of the KNRI. The site boundary is defined by the edge of the A terrace on the east and north and by the gravel road on the west; the boundary is ill-defined and arbitrary to the south. The site area as defined is about 3.1 hectares (7.75 acres). The site was defined and surveyed by conventional reconnaissance techniques. At the time of the survey the site surface was covered with dense grass and weedy plants, and visibility was limited to a few trails and some eroded*

*areas on the terrace margin. The entire site surface appears to have been cultivated.*

*The most recent component at the site is attributed to the William Russel (sic) farm complex, several buildings of which stood on the southern part of the site and farther to the southwest. The southern part of the site is heavily littered with farmyard debris and recent historic artifacts within and immediately beneath the sod cover.*

*Several Plains Village period components exist at the site, as exposed and defined in salvage excavations conducted in 1978 in the path of a haul road to be constructed across the site … The plowzone contains a very dispersed scatter of Knife River ware ceramics and Euro-American trade materials such as beads and metal items which indicate use of the site in the historic period by peoples who were probably interacting with the villagers at nearby Sakakawea Village. A few trade artifacts were also noted on the surface at various places beyond the excavations. This component has been classified as a debris scatter belonging to the general Plains Village tradition.*

*The plowzone also contains the remnants of another, more prominent village period component assigned to the scattered village complex. Excavations revealed truncated storage pits, the remains of a circular house below the plowzone, and associated thin-walled, tool-decorated ceramics, all of which are part of the scattered village complex. These remains have been dated in the 15$^{th}$ and 17$^{th}$ century A.D… The 1938 aerial photographs of the area show several anomalies which could be additional circular houses at the site. One test unit at the site yielded yet another, earlier village age component in a buried humic horizon below the plowzone and about 30 cm below the present surface. The artifact content from this component is very meager, but it appears to represent a yet earlier scattered village complex component.*

*The earliest component at the site was detected as a concentration of patinated KRF flaking debris and fire-cracked rock eroding from a localized area on the eastern edge of the A terrace. Excavation there yielded an intact aceramic component in a paleosol buried ca. 1 meter below the level of the A terrace surface. A C-14 date of 2974 ± 66 radiocarbon years B.P. on non-cultural charcoal is the nearby Elbee bluff cutbank at a depth of 2.6 m below the surface provides a maximum age for this component of at the site.*

As indicated in the previous discussion of the site, a pedestrian reconnaissance of the project area revealed an artifact scatter across the mid-Holocene "A" terrace. Shovel tests along the potential route of the access road on the terrace indicated the presence of buried archeological materials. Additional archeological investigations were conducted in the summer of 1978, including a magnetic survey of a 3,600 $m^2$ block (Weymouth 1986a:18-28) encompassing both the proposed route of the service road and a major portion of the proposed construction staging area and subsequent excavations (Figure 4). The magnetic survey indicated the presence of numerous magnetic anomalies including a broad irregularly shaped series of anomalies of geologic origin and numerous small magnetic anomalies of varying amplitudes, which were caused by the presence of historic ferrous objects associated with the William Russell farm complex, Tract 01-112 (Ahler 1978:15; Lovick and Ahler 1984:236-237; Taylor 1978:KNRI-1548; Weymouth 1986a:18-28). There was, however, no correlation between the magnetic anomalies and the excavated archeological features, which consisted of cache pits, a circular row of post molds identified as a house structure, a hearth, an artifact concentration, and a pit (Ahler 1978:15-16, Volf 2002:1-2; Weymouth 1986a:18-28). Weymouth (1986a:18-28) concluded that the discrepancy may have resulted from large sensor to source distance used in the magnetic survey and the apparent non-magnetic contrast between the features and the surrounding soil matrix. Although the magnetic survey at the Elbee Site did not provide additional insight into the buried archeological resources at the site, the use of magnetic survey techniques at other sites at KNRI, including the three major village sites of Lower Hidatsa (32ME10), Sakakawea (32ME11), and Big Hidatsa (32ME12) provided significant information on site structure and feature patterning (Weymouth and Nickel 1977; Weymouth 1979a,1979b,1986b:352-355,1988). The 1978 archeological investigations were compiled in an edited volume by Stanley Ahler (1984) describing the site setting, the fieldwork, excavated features, and site chronology along with the analytical procedures and the analysis of the ceramics, stone tools, chipped stone debitage, faunal remains, and other artifacts.

In 2002, the Midwest Archeological Center staff conducted geophysical investigations at the Elbee Site as part of a project to *assess the archeological record of the northern part of the Elbee site that is being dramatically impacted by erosion of a vertical cutbank along the Knife River* (Volf 2002:1). Twenty-five complete and two partial 20 m by 20 m grid units were surveyed using a fluxgate gradiometer (Figure 4). Sixteen of the twenty-seven grid units were also systematically swept with a metal detector in order to identify and remove the modern farm related debris from the survey area. Three magnetic anomalies were identified for archeological excavations due to impending danger for bank erosion along the Knife River in the northern part of the geophysical project area (Volf 2002). Other identified magnetic anomalies were located in the southern part of the geophysical project area where the potential for active erosion was minimal.

Using the University of North Dakota's (UND) Archeological Field School participants, the Anthropology Research staff at the UND conducted evaluative archeological excavations at the Elbee Site in 2003 (Toom et al. 2004). Four small excavation blocks (i.e., 2 m by 2 m units) were excavated during the field season. Three of the blocks were placed over the three magnetic anomalies identified as being potentially threatened by the continued erosion of the Knife River bank (Toom et al. 2004:3.1). The fourth block was placed near the cut bank at the far northern end of the site. The ground truthing of the magnetic anomalies revealed two large undercut pits indicated by Anomaly A and Anomaly E in XU 1 and XU 2, respectively. Anomaly I located in XU 3 was identified as an oval shaped hearth (Toom et al. 2004:3.1-3.18). A linear magnetic anomaly noted in the magnetic survey data may represent the Big Hidatsa to Sakakawea trail (Toom et al. 2004:6.3). The authors concluded the report by indicating the combination of magnetic survey work and ground truthing excavations were so effective in the northern part of the site that they should be extended to the southern portion of the site.

## 4. GEOPHYSICAL PROSPECTION TECHNIQUES

Various geophysical instruments have been used by archeologists to locate evidence of past human activity. Magnetometers and soil resistance meters began to be employed on Roman sites in England during the late 1940s and early 1950s (Aitken 1961), and their use was the focus of considerable research in the 1960s and 1970s. During this period the archeological applications of additional instruments were explored (Aitken 1974, Clark 2000, Scollar et al. 1990, Tite 1972). While many of the early studies in England and Europe were very successful, it was some time before improvements in detector sensitivity and data processing techniques allowed a wide range of New World sites to be mapped. Virtually all the instruments used in non-invasive mapping of historic sites originated as prospecting devices for geological exploration. In general, cultural resource applications using geophysical instruments focus on weaker anomalies or smaller anomalies. It is important to emphasize that instruments employed in archeological geophysical surveys do not respond only to the desired cultural targets, and consequently feature detection depends greatly on the recognition of patterns that match the anticipated form of the cultural target. The challenge in archeological geophysics is to recognize the anomalies produced by the target features and sort them out from the "noise" produced by the responses from the surrounding matrix. The amount of data collected in any given area and the method of collection both affect one's ability to recognize the specific anomaly type or "signature" of the feature being sought.

Geophysical prospection techniques available for archeological investigations consist of a number of techniques that record various physical properties of earth, typically in the upper couple of meters; however, deeper prospection can be utilized if necessary. Geophysical techniques are divided between passive techniques and active techniques. Passive techniques are ones that measure inherently or naturally occurring local or planetary fields created by earth related processes under study (Heimmer and De Vore 1995:7,2000:55; Kvamme 2001:356). The primary passive method utilized in archeology is magnetic surveying. Other passive geophysical techniques include the measurement of earth's natural electrical fields, gravitational fields, radiometric measurement of radioactive elements, and thermal measurements of soil temperature changes. These passive methods with limited archeological applications include self-potential methods, gravity survey techniques, and differential thermal analysis. Active techniques transmit an electrical, electromagnetic, or acoustic signal into the ground (Heimmer and De Vore 1995:9,2000:58-59; Kvamme 2001:355-356). The interaction of these signals and buried materials produces alternated return signals that are measured by the appropriate geophysical instruments. Changes in the transmitted signal of amplitude, frequency, wavelength, and time delay properties may be observable. Active methods applicable to archeological investigations include electrical resistivity, electromagnetic conductivity (including ground conductivity and metal detectors), magnetic susceptibility, and ground-penetrating radar. Active acoustic techniques, including seismic, sonar, and acoustic sounding, have very limited or specific archeological applications. The active geophysical prospection technique used during the project was the ground-penetrating radar survey. The ground-penetrating radar utilizes electromagnetic signals.

## Magnetic Survey Techniques

A magnetic survey is a passive geophysical prospection technique used to measure the earth's total magnetic field at a point location (Bevan 1991,1998:29-43; Breiner 1973;1992:313-381; Burger 1992:389-452; Clark 2000:92-98,174-175; David 1995:17-20; Dobrin and Savit 1988:633-749; Gaffney and Gater 2003:36-42,61-72; Gaffney et al. 1991:6,2002:7-9; Hanson et al. 2005:151-175; Heimmer and DeVore 1995:13,2000:55-56; Kvamme 2001:357-358,2003:441, 2005:434-436,2006a:205-233,2006b:235-250; Lowrie 1997:229-306; Milson 2003:51-70; Mussett and Khan 2000:139-180; Nishimura 2001:546-547; Robinson and Çoruh 1988:333-444; Scollar et al. 1990:375-519; Telford et al. 1990:62-135; Weymouth 1986:343; and Witten 2006:73-116 for more details on magnetic surveying). Magnetometers depend upon sensing subtle variation in the strength of the earth's magnetic field in close proximity to the archeological features being sought. Variation in the magnetic properties of the soil or other buried material induces small variations in the strength of the earth's magnetic field. Its application to archeology results from the local effects of magnetic materials on the earth's magnetic field. These anomalous conditions result from magnetic materials and minerals buried in the soil matrix. Ferrous or iron based materials have very strong effects on the local earth's magnetic field. Historic iron artifacts, modern iron trash, and construction material like metal pipes and fencing can produce such strong magnetic anomalies that nearby archeological features are not detectable. Other cultural features, which affect the earth's local magnetic field, include fire hearths, and soil disturbances (e.g., pits, mounds, wells, pithouses, and dugouts), as well as, geological strata.

Magnetic field strength is measured in nanoteslas (nT; Sheriff 1973:148). In North America, the earth's magnetic field strength ranges from 40,000 to 60,000 nT with a inclination of approximately 60° to 70° (Burger 1992:400; Milsom 2003:55; Weymouth 1986b:341). The project area has a magnetic field strength of approximately 58,800 nT with an inclination of approximately 73.9° (Peddie 1992; Peddie and Zunde 1988; Sharama 1997:72-73). Magnetic anomalies of archeological interest are often in the ±5 nT range, especially on prehistoric sites. Target depth in magnetic surveys depends on the magnetic susceptibility of the soil and the buried features and objects. For most archeological surveys, target depth is generally confined to the upper one to two meters below the ground surface with three meters representing the maximum limit (Clark 2000:78-80; Kvamme 2001:358). Magnetic surveying applications for archeological investigations have included the detection of architectural features, soil disturbances, and magnetic objects.

Two modes of operation for magnetic surveys exist: 1) the total field survey and 2) the magnetic survey. The instrument used to measure the magnetic field strength is the magnetometer (Bevan 1998:20). Three different types of magnetic sensors have been used in the magnetometer: 1) proton free precession sensors, 2) alkali vapor (cesium or rubidium) sensors, and 3) fluxgate sensors (for a detailed description of the types of magnetometers constructed from these sensors see Aitken 1974; Clark 2000:66-71; Milsom 2003:58-62; Scollar et al. 1990:450-469; Weymouth 1986b:343-344).

The total field magnetometer is designed to measure the absolute intensity of the local magnetic field. This type of magnetometer utilizes a single sensor. Due to diurnal variation of the earth's magnetic field, the data collected with a single sensor magnetometer must be corrected to reflect these diurnal changes. One method is to return to a known point and take a reading that can be used to correct the diurnal variation. A second method is to use two magnetometers with one operated at a fixed base station collecting the diurnal variation in the magnetic field. The second roving magnetometer is used to collect the field data in the area of archeological interest. Common magnetometers of this types used in archaeological investigations include the proton precession magnetometer, the Overhauser effect magnetometer (a variation of the proton precession magnetometer), and the cesium magnetometer.

The magnetic survey is conducted with a gradiometer or a magnetometer with two magnetic sensors separated by a fixed vertical distance. The instrument measures the magnetic field at two separate heights. The top sensor reading is subtracted from the bottom sensor reading. The resulting difference is recorded. This provides the vertical gradient or change in the magnetic field. Diurnal variations are automatically canceled. This setup also minimizes long range trends. The gradiometer provides greater feature resolution and potentially provides better classification of the magnetic anomalies. Two commonly used gradiometers in archeological investigations are the cesium gradiometer and the fluxgate gradiometer. They are capable of yielding 5 to 10 measurements per second at an accuracy resolution of 0.1 nT (Kvamme 2001:358). Cesium gradiometers record the absolute total field values like the single sensor magnetometers. The fluxgate sensors are highly directional, measuring only the component of the field parallel to the sensor's axis (Clark 2000:69). They also require calibration (Milsom 2003:2003:61-62). Both cesium and fluxgate gradiometers are capable of high density sampling over substantial areas at a relatively rapid rate of acquisition (Clark 2000:69-71; Milsom 2003:60-62).

## Ground Penetrating Radar Survey Techniques

Ground-penetrating radar (gpr) is an active method that has recently achieved popularity in cultural resource management applications (see Annan 2005:357-438; Bevan 1991,1998:43-57; Clark 2000:118-120,183-186; Conyers 2004,2006:131-159,2007:329-344; Conyers and Goodman 1997; David 1995:23-27; Gaffney and Gater 2003:47-51,74-76; Gaffney et al. 1991:5-6,2002:9-10; Goodman et al. 2007:375-394; Heimmer and DeVore 1995:42-47,2000:63-64; Kvamme 2001:363-365,2003:442-443;2005:436-438; Lowrie 1997:221-222; Milson 2003:167-178; Mussett and Khan 2000:227-231; Nishimura 2001:547-551; Scollar et al. 1990:575-584; Weymouth 1986:370-383; and Witten 2006:214-258 for more details on ground-penetrating radar surveys). Although Bruce Bevan pioneered the archeological use of gpr a quarter-century ago (Bevan 1977; Bevan and Kenyon 1975), the cost of equipment and problems dealing with the massive amount of data produced by gpr surveys limited the number of archeological applications. Recently, Conyers and Goodman (1997) and Conyers (2004) have published introductions to gpr for archeologists, and Bevan (1998) has provided an excellent comparison of various radar antennas as applied to a consistent group of archeological features. Reductions in the cost of equipment and improvements in the software available for processing the voluminous data have helped to make gpr surveys more affordable and analysis more efficient.

Ground-penetrating radar uses pulses of radar energy (i.e., short electromagnetic waves) that are transmitted into the ground through the surface transmitting antenna. A short burst of radio energy is transmitted and then the strength of the signal received from reflectors a few nanoseconds after the pulse's transmission is recorded by the receiving antenna. The combination of time after transmission and strength of reflected signal provides the data used to create plan maps and profiles. The radar wave is reflected off buried objects, features, or interfaces between soil layers. These reflections result from contrasts in electrical and magnetic properties of the buried materials or reflectors. The contrasts are a function of the dielectric constant of the materials (Sheriff 1973:51). The depth of the object or soil interface is estimated by the time it takes the radar energy to travel from the transmitting antenna and for its reflected wave to return to the receiving antenna. The depth of penetration of the wave is determined by the frequency of the radar wave. The lower the frequency, the deeper the radar energy can penetrate the subsurface; however, the resulting resolution, or the ability to distinguish objects, features, and soil changes, decreases. These low frequency antennas generate long wavelength radar energy that can penetrate several tens of meters under certain conditions, but can only resolve larger targets or reflectors. The higher the radar wave frequency, the higher the resulting resolution but the depth penetration decreases. High frequency antennas generate much shorter wavelength energy, which may only penetrate a meter into the ground. The generated reflections from these high frequency antennas are capable of resolving objects or features with maximum dimensions of a few centimeters. A resulting tradeoff exists between subsurface resolution and depth penetration: the deeper the penetration then the resulting resolution is less or the higher the resolution then the resulting depth penetration is much shallower.

As the radar antenna system (transmitting and receiving antennas) is moved along the survey line, a large number of subsurface reflections are collected along the line. The various subsurface materials affect the velocity of the radar waves as they travel through the ground (Conyers and Goodman 1997:31-40). The rate at which these waves move through the ground is affected by the changes in the physical and chemical properties of the buried materials through which they travel. The greater the contrast in electrical and magnetic properties between two materials at the interface results in a stronger reflected signal. As each radar pulse travels through the ground, changes in material composition or water saturation, the velocity of the pulse changes and a portion of the energy is reflected back to the surface where it is detected by the receiving antenna and recorded by ground-penetrating radar unit. The remaining energy continues to pass into the subsurface materials where it can be reflected by deeper reflectors until the energy finally dissipates with depth. In a uniform soil, there would be little energy reflected (except at the air/soil interface), and the bulk of the energy would be absorbed within a short distance. Objects included in the soil or strata with contrasting electrical properties may result in reflection of enough energy to produce a signal that can be detected back at the antenna. The radar system measures the time it takes the radar pulse to travel to a buried reflector and return to the unit. If the velocity of the pulse is known, then the distance to the reflector or the depth of the reflector beneath the surface can be estimated (Conyers and Lucius 1996).

Actual maximum depth of detection also depends upon the electrical properties of the soil, the frequency of the antenna, and the contrast between the target and its matrix. Plan maps present the average signal strength across the grid during the selected time interval (e.g. 7.2 to 14.4 ns). Because these time intervals correspond with horizontal layers or slices of soil, they are called either time-slices or depth-slices. The analyst can set the span of the time-slice and consequently the thickness of the depth-slice. Ground-penetrating radar profiles illustrate a cross section through the soil with the ground's surface at the top of the image. The profile images are conceptually similar to what one would see when looking at the side of an excavated trench. The vertical scale used on the profiles can be marked in nanoseconds (ns) indicating the amount of time between the transmission of the radar pulse and the receipt of the reflected signal or in units indicating depth below the ground surface. The earlier reflections are received from targets nearer the surface and the later reflections are received from deeper levels or features. The velocity can be measured directly in the field in some cases, calculated from the form of strong hyperbolic reflections, or estimated by using values of similar soils.

The success of the survey is dependent on soil and sediment mineralogy, clay content, ground moisture, depth of burial, and surface topography and vegetation. The ground-penetrating radar signal can be lost or attenuated (i.e., quickly dissipated) in soils that have high moisture content, high electrical conductivity, highly magnetic materials, or high clay contents. Dry soils and sediments, especially those with low clay content, represent the best conditions for energy propagation. The soils at the project sites do contain a relatively high clay content but were relatively moist during the survey. A ground-penetrating radar survey, with its capability for estimating the depth and shape of buried objects, may be an extremely valuable tool in the search of grave shafts. At times, radar cannot profile deep enough or the strata may be so complex as to render the graves indistinguishable from the surrounding soil profile. Selection of the appropriate antenna frequency is also important in providing a good compromise between the depth penetration and resolution.

**MAGNETIC SURVEY OF ELBEE SITE**

## 5. GEOPHYSICAL SURVEY METHODOLOGY

The statement-of-work for the 2006 survey of the southern portion of the Elbee Site (32ME408) called for the use of magnetic survey techniques with a fluxgate gradiometer and the evaluation of resistivity, conductivity, and ground-penetrating radar survey techniques if time permitted the additional survey activities (Figure 4). The survey was to cover the area south of the geophysical survey block covered in 2002 (Volf 2002) which extended to the base of the Pleistocene terraces. The 2002 datum was relocated in the southwest corner of the 2002 project area at N500/E500 and used for the present magnetic survey. The geophysical grid was oriented 7° 45’ west of magnetic north. The geophysical grid units were established at the project location with a portable Ushikata S-25 Tracon surveying compass (Ushikata 2005) and 100 meter tape. The surveying compass was used to sight in the two perpendicular base lines and grid corners. Wooden hub stakes were placed at the 20-meter grid corners. Twenty-nine complete 20-meter by 20-meter and six partial 20-meter by 20-meter grid units were established on the southern portion of the site for a total project area of 14,200 $m^2$ or 3.51 acres.

Before the start of the geophysical survey, yellow nylon ropes were laid out on the grids. These ropes served as guide ropes during the actual data acquisition phases of the project. Twenty-meter ropes were placed along the top and bottom base lines connecting the grid corners. The survey ropes formed the boundaries of each grid during the data collection phase of the survey. Additional traverse ropes were placed a one-meter intervals across the grid at a perpendicular orientation to the base lines beginning with the line connecting the two wooden hubs on the left side of the grid unit. The ropes serve as guides during the data acquisition and in the development of the sketch map of the surface features (Figure 5). The 20-meter lengths of ropes are divided into 0.5 meter increments by different colored tape. One color (blue) is placed every meter along the rope with a different colored (red) tape placed at half-meter intervals. The use of different colored tape on the ropes provides a simple way to maintain one’s position within the geophysical survey grid unit as data are being collected. The geophysical data were therefore recorded in a series of evenly spaced parallel lines with measurements taken at regular intervals along each line resulting in a matrix of recorded measurements (Kvamme 2001:356; Scollar et al. 1990:478-488). Beginning in the lower left-hand corner of the grid, data collection occurred in a parallel (unidirectional) or zigzag (bi-directional) mode across the grid(s) until the survey was completed for each technique.

### Magnetic Survey Methodology

The magnetic survey was conducted with a Geoscan Research FM36 fluxgate gradiometer with a ST1 sample trigger (Figure 6)). The instrument is a vector magnetometer, which measures the strength of the magnetic field in a particular direction (Geoscan Research 1987). The two fluxgate magnetic sensors are set at 0.5 meters apart from one another. The instrument is carried so the two sensors are vertical to one another. Height of the bottom sensor above the ground is relative to the height of the surveyor. In the carrying mode at the side of the body, the bottom sensor is approximately 0.30 meters above the ground. Two readings are taken at each point along the survey traverse, one at the upper sensor and one at the lower sensor. The difference or gradient between the two sensors is calculated (bottom minus top) and recorded in the instrument's memory. Each sensor reads the magnetic field strength at its height above the ground. The gradient or change of the magnetic field strength between the two sensors is recorded in the instrument's memory. This gradient is not in absolute field values but rather voltage changes, which are calibrated in terms of the magnetic field. The fluxgate gradiometer does provide a continuous record of field strength. With a built-in data logger, the gradiometer provides fast and efficient survey data collection.

The gradiometer sensors must be accurately balanced and aligned along the direction of the field component to be measured. The zero reference point was established at N440/E540 grid corner and the balancing and alignment procedures were oriented to magnetic north. This point was selected where there were no noticeable localized changes in the digital display or by raising the instrument above the ground with the use of a plastic step stool. The readings should vary less than 2 to 3 nT. The balance control on the instrument was adjusted first. The balancing the instrument was conducted in the 1 nT resolution range to within a range of ± 1 nT. If the observed display readings went over the acceptable range, the balancing and alignment procedures were repeated until successful. The instrument was returned to the 0.1 nT resolution operating range and then zeroed at arms length over the operator's head. The operator's manual (Geoscan Research 1987:29-31) illustrates the steps involved in preparing the instrument for actual field data collection.

The survey of each traverse was conducted in a parallel or unidirectional mode beginning in the southwest corner or lower left-hand corner of each grid unit (Table 1). During the survey, data were collected at 8 samples per meter (0.125 m) along each traverse and at half-meter traverses across each individual grid unit resulting in 16 samples per square meter. A total of 6,400 measurements were recorded during the magnetic survey for each complete 20 m by 20m grid unit. With eight samples per meter and one-half meter traverses in the zigzag mode, it took approximately 30 minutes to complete a 20m by 20 m grid unit. The instrument's memory can hold data acquired from two grid units. At the end of the data acquisition of two grid units, the magnetic data from the survey were downloaded into the Geoscan Research GEOPLOT software (Geoscan Research) on a field laptop computer. It took approximately 26 minutes to download the data from memory of the gradiometer when it was full. The grid files were downloaded into the GEOPLOT software and a composite file created in GEOPLOT was reviewed in the field prior to the clearing of the gradiometer's memory.

## Ground Penetrating Radar Survey Methodology

The Geophysical Survey Systems, Inc. (GSSI), TerraSIRch SIR System-3000 ground-penetrating radar (gpr) system (Figure 7) is used for the evaluation of the potential use of gpr techniques at KNRI with a Model 5103 antenna, which operates at a nominal frequency of 400 mHz. The gpr profiles were collected along 0.5 meter traverses beginning in the southwest corner (N380/E580) of grid unit 23 (Table 2). The data were collected in the parallel or unidirectional mode with the operator returning to the same side of the grid to start the next traverse line. The gpr profiles were collected in the North or y direction. A total of 41 radar profiles were collected across the grid unit over 800 linear meters. With one-half meter traverses in the parallel mode, it took approximately 25 minutes to complete the 20m by 20 m grid in one direction. The data folder containing the profile line data were transferred to the laptop computer via the 512 mb compact flash card used to record the data in the TeraSIRch SIR-3000.

Ground-penetrating surveys generally represent a trade-off between depth of detection and detail. Lower frequency antennae permit detection of features at greater depths but they cannot resolve objects or strata that are as small as those detectable by higher frequency antennas. Actual maximum depth of detection also depends upon the electrical properties of the soil. If one has an open excavation, one can place a steel rod in the excavation wall at a known depth and use the observed radar reflection to calibrate the radar charts. When it is not possible to place a target at a known depth, one can use values from comparable soils. Reasonable estimates of the velocity of the radar signal in the site's soil can be achieved by this method. Using one of the hyperbolas on a radargram profile (Goodman 2004:76), the velocity was calculated to be approximately 4.1 cm per ns. For a time slice between 5 and 15 ns with the center at 10 ns (two way travel time), the approximate depth to the center of the gpr slice would be 20.5 cm. With a 50 ns window open, the total depth displayed was approximately 0.92 meters.

**MAGNETIC SURVEY OF ELBEE SITE**

## 6. DATA PROCESSING

Processing of geophysical data requires care and understanding of the various strategies and alternatives (Kvamme 2001:365; Music 1995; Neubauer et al. 1996). Drs. Roger Walker and Lewis Somers (Geoscan Research 2003) provide strategies, alternatives, and case studies on the use of several processing routines commonly used with the Geoscan Research instruments in the GEOPLOT software manual. Dr. Kenneth Kvamme (2001:365) provides a series of common steps used in computer processing of geophysical data:

> *Concatenation of the data from individual survey grids into a single composite matrix;*
>
> *Clipping and despiking of extreme values (that may result, for example, from introduced pieces of iron in magnetic data);*
>
> *Edge matching of data values in adjacent grids through balancing of brightness and contrast (i.e., means and standard deviations);*
>
> *Filtering to emphasize high-frequency changes and smooth statistical noise in the data;*
>
> *Contrast enhancement through saturation of high and low values or histogram modification; and*
>
> *Interpolation to improve image continuity and interpretation.*

It is also important to understand the reasons for data processing and display (Gaffney et al. 1991:11). They enhance the analyst's ability to interpret the relatively huge data sets collected during the geophysical survey. The type of display can help the geophysical investigator present his interpretation of the data to the archeologist who will ultimately use the information to plan excavations or determine the archeological significance of the site from the geophysical data.

### Processing Magnetic Data

Due to the limited memory capacity and changes in the instrument setup of the FM36 fluxgate gradiometer, the data were downloaded into a laptop computer after the completion of two grid units at the site. On the laptop computer, the GEOPLOT software was initialized and the data from the instrument was downloaded as grid data files on the laptop computer (Geoscan Research 2003:4/1-29). Each grid file contained the magnetic raw data obtained during the survey of the individual grids. The grid files were reviewed as a shade plot display (Geoscan Research 2003) for data transfer or survey errors. If no data transfer errors were observed, a composite of the data file(s) was created for further data processing. Generally, while in the field, the composite file was processed with the zero mean traverse routine and viewed on the laptop computer before the memory in the gradiometer was cleared. From this preliminary review of the collected data, the geophysical investigator could analyze his survey design and methodology and make appropriate survey decisions or modifications while still in the field.

In order to process the magnetic data, the grid files from the survey must be combined into a composite file. The first step in creating a composite file is to create a mesh template with the grid files oriented in the correct position in the overall survey of the site (Geoscan Research 2003:3/15-21). Once the grid files have been placed in the correct position in the mesh template, the composite file is generated. The master grid or mesh template is saved as a file for later modification as necessary.

After the creation of the composite file for the magnetic data collected at the site, the data may be viewed either as the numeric data values or as a graphic representation of the data (Geoscan Research 2003:5/2-3). The shade plot represents the data in a raster format with the data values assigned color intensity for the rectangular area at each measurement station. Data may be presented as absolute numbers, in units of standard deviation, or as a percentage of the mean. Several color and monochrome palettes provide different visual enhancements of the data. Trace plots of the data represent the data in a series of side by side line graphs, which are helpful in identifying extreme highs and lows in the data. The trace plots show location and magnitude.

Up to this point, we have been collecting the data and preparing it for processing and analysis. Inspection of the background should show the data as bipolar and centered on zero. There should be a broad range in the archeological anomalies with weak anomalies less than 1 nT, typical 1 nT to 20 nT anomalies, strong anomalies greater than 20 nT. If the anomalies are weak then reset the clip plotting parameter to a minimum of –2, a maximum of 2, and units to absolute. Then one should identify weak and strong ferrous anomalies, which often represent modern intrusions into the site such as localized surface iron trash, wire fences, iron dumps, pipelines, and utility lines. Geological trends in the data set should also be identified. Since gradiometers provide inherent high pass filtering, broad scale geological trends are already removed from the data set. If such trends appear to exist, there may be changes in the topsoil thickness, natural depressions, igneous dikes or other geomorphologic changes in the landscape. Final step prior to processing the data is to identify any defects in the data. These can range from periodic errors appearing as linear bands perpendicular to the traverse direction, slope errors appearing as shifts in the background between the first and last traverses, grid edge mismatches where discontinuities exist between grids, traverse striping consisting of alternating stripes in the traverse direction which most commonly occurs during zigzag or bi-directional surveys, and stager errors resulting in the displacement of a feature on alternate traverses (Geoscan Research 2003:Reference Card 3).

Initially, the spectrum function (Geoscan Research 2003:6/87-95) was applied to the data. The spectrum function provided analysis of the frequency spectrum of the data, splitting it into amplitude, phase, real, or imaginary components. The amplitude component was selected for the analysis to identify any periodic defects. These defects may have been the effects of cultivation (e.g., plow marks, ridge and furrow) or operator induced defects during data acquisition). It operated over the entire site data set. No periodic defects were noted in the data set.

The magnetic data were "cleaned up" using the zero mean traverse algorithm (Geoscan Research 2003:6/107-115). This algorithm was used to set the background mean of each traverse within a grid to zero, which removed any stripping effects resulting from "scan to scan instrument and operator bias defects" (Jones and Maki 2002:16). It also was useful in removing grid edge discontinuities between multiple grids. The algorithm utilized the least mean square straight line fit and removal default setting on over the entire composite data set. The statistics function (Geoscan Research 2003:6/101-102) was then applied to the entire magnetic data composite file for the southern portion of the site. The mean, standard deviation, and variance were used to determine appropriate parameters for the subsequent processing steps. The magnetic data ranged from –219.8 to 258.3 nT with a mean of 0.19 and a standard deviation of 17.573 after the application of the zero mean traverse algorithm. The data set is interpolated to produce a uniform and evenly spaced data matrix (Geoscan Research 2003:6/53-56). Increasing or decreasing the number of data measurements creates a smoother appearance to the data. The original matrix is an 8 x 2 matrix. The interpolate function requires three parameters: direction, interpolation mode and interpolation method. In the Y direction, the number of data measurements is expanded to yield an 8 x 4 data matrix. In the X direction, the number of data measurements are shrunk yielding a 4 x 4 matrix. The low pass filter was then used to remove high-frequency, small scale spatial details over the entire data set (Geoscan Research 2003:6/57-60). It was also used to smooth the data and to enhance larger weak anomalies. The composite data files were then exported to xyz data files for use in the SURFER 8 contouring and 3d surface mapping program (Geoscan Research 2003:5/4-7; Golden Software 2002).

In SURFER 8 (Golden Software 2002), the initial step is to view the xyz data file. Adjustments to the x and y coordinates were made to the data file. The x or Easting and the y or Northing coordinates was divided by four to yield the sample interval position at every 0.25 meters across the magnetic data set. The value 360 was added to the Northing coordinate and the value 500 was added to Easting coordinate values in order to express the results into the mapped site coordinate system. The data are sorted, using the data sort command, to check for GEOPLOT dummy values (i.e., 2047.5). The rows of data containing these values are deleted from the file. The data is saved as a new file containing the corrections.

In order to present the data in the various display formats (e.g., contour maps, image maps, shaded relief maps, wireframes, or surfaces), a grid must be generated (Golden Software 2002). The grid represents a regular, rectangular array or matrix. Gridding methods produce a rectangular matrix of data values from regularly spaced or irregularly spaced XYZ data. The gird geometry is defined for the project area. The minimum and maximum values for the X and Y coordinates are defined. These values represent the beginning and ending coordinates of the surveyed geophysical grid. The sample interval and traverse spacing are defined in the distance between data units under spacing. The number of lines should correlate with the number of traverses and samples per traverse. The Kriging gridding method was selected for processing the data. The Kriging method is very flexible and provides visually appealing displays from irregularly spaced data. The Kriging variogram components are left in the default values. The next step in the formation of the visual display of the data from the site is to apply the spline smoothing operation to the grid file. The operation produces grids that contain more round shapes on the displays. Due to the presence of unsurveyed areas along the edges of the rectangular survey area, a blanking file was constructed and applied to the grid file. The blanking file contains the X and Y coordinates used to outline the blanked portion of the grid, as well as, the number of parameter points and whether the blanking operation is located on the interior of the parameter points or on the exterior of these points.

At this point in the process, maps of the data may finally be generated (Golden Software 2002). Typically for geophysical surveys, contour maps, image maps, shaded relief maps, and wireframes may be generated. The image map is a rastor representation of the grid data. Each pixel or cell on the map represents a geophysical data value. Different color values are assigned to ranges of data values. The image map is generated. The map may be edited. The color scale is set with the minimum value assigned the color white and the maximum value assigned the color black. The data are also clipped to a range between -25 and 25 nT for better visual presentation of the image. The scale is a graduated scale flowing from white through several shades of gray to black. SURFER 8 has a several predefined color scales including the rainbow scale which is often used for the presentation of geophysical data or the investigator may create an color spectrum suitable for the project data. To complete the image map, descriptive text is added along with a direction arrow, a color scale bar, and map scale bar. Another way to represent geophysical data is with contour maps. Contour maps provide two dimensional representations of three dimensional data (XYZ). The North (Y) and East (X) coordinates represent the location of the data value (Z). Lines or contours represent the locations of equal magnetic value data. The distance or spacing between the lines represents the relative slope of the geophysical data surface. The contour map may be modified by changing the mapping level values in the levels page of the contour map properties dialog controls. Contour maps are useful in determining the strength of the magnetic anomalies as well as their shape and nature. The various types of maps can be overlain on one another and different types of data can be illustrated by stacking the displays within a single illustration. Both the image and contour maps were generated for the magnetic data (Figure 8).

## Processing Ground Penetrating Radar Data

The gpr radargram profile line data is imported into GPR-SLICE (Goodman 2004) for processing. The first step in GPR-SLICE is to create a new survey project entitled KNRI. The next step is to create the new information file, which identifies the names and location of the gpr profiles or radargrams, the number of profiles collected, the direction used to collect the profile, the beginning and ending coordinates for the easting and northing directions, the units per marker, the time window of 50 ns, 512 samples per scan, and 50 scans per marker. The radargram data is collected in 16 bit format. The profile data is transferred from the main folder into the raw folder. The 16-bit GSSI radargrams are converted for further processing. During the conversion process, the signal may be enhanced by applying gain to the radargrams. Once the conversion process is completed, the next step is to reverse the data in every other radargram to correct the zigzag collection mode in the field. This places the data in each of the radargrams in the same direction for further processing. The next step is to insert locational markers into the resampled radargrams. The GSSI SIR 3000 and the artificial markers button are selected to apply markers based on the total number of scans in the radargram. The show markers button allows one to view an example of a radargram with the artificial markers in place. The next step is to create the time slices of the data (Conyers and Goodman 1997; Goodman et al. 1995). The program resamples the radargrams to a constant number of scans between the markers and collects the time slice information from the individual radargrams. The number of slices is set to 20 slices. The slice thickness is set to 35 for a 3.42 ns slice to allow for adequate overlap between the slices. The offset value on the radargram where the first ground reflection occurs is used to identify the first radargram sample at the ground surface. The end sample is 512. The cut parameter is set to square amplitude with the cuts per mark set to 4 or every 0.25 meters. The radargrams are then sliced. The final step in the slice menu is to create the XYZ data file. The slice data is then gridded in the grid menu with the parameters set for the grid cell size, x and y search radii, the method of gridding (i.e., Krigging). A low pass filter may be applied to the combined dataset to smooth noisy time slices in this menu. At this point, one may view the time sliced radar data in the pixel map menu (Figure 9). The gain may be readjusted for any time slice or for the entire set of slices. The slices may also be saved in jpeg format or as SURFER grid files. The grid data is then interpolated to create additional slices for the creation of the 3D data set. The new interpolated grids are all normalized. The number of grids is now equal to 95 ((20-1)*5). The 3D data may be displayed as a series of z slices in the creation of a 3D cube with a bitmap output for animating the 3D cube. Time slices 13 (Figure 10) and 15 (Figure 11) from 27 to 30 ns and from 31 to 34 ns, respectively, illustrating the resulting gpr data from the gu23 survey area, were selected for further analysis and display.

The slice option provides the means to specify the number and type of plots either in time slices or depth slices. Times slices are generally used since gpr systems record the time for the radar or radio waves to travel to a target and return to the gpr unit. Depth has to be calculated before it can be used. Depth depends on the velocity of the wave to the target and back. Depth is determined by the following equation: $D = V \times T/2$ where D is depth (meters), V is velocity (meters/nanosecond), and T is the two-way travel time (nanoseconds). Velocity of the radar wave is determined by the dielectric permittivity of the material (Conyers and Goodman 1997:31-35; Sheriff 1973:51). Other physical parameters that affect the transmission of the radar wave include the magnetic permeability and electrical conductivity of the material. Increases or decreases in these parameters may increase the velocity, slow it down, or attenuate it so there is no reflected signal. In most heterogeneous soils, the various soil layers have differing affects on the velocity of the radar wave. The velocity may be estimated using velocity charts of common materials (GSSI 2003a:49-50) or by identifying reflections in gpr profiles caused by buried objects, artifacts, or stratigraphic soil/sediment layers (Conyers and Goodman 1997:107-135). The depth used in this report was calculated using a value of 0.041 m/ns.

## 7. DATA INTERPRETATION

Andrew David (1995:30) defines interpretation as a "holistic process and its outcome should represent the combined influence of several factors, being arrived at through consultation with others where necessary." Interpretation may be divided into two different types consisting of the geophysical interpretation of the data and the archaeological interpretation of the data. At a simplistic level, geophysical interpretation involves the identification of the factors causing changes in the geophysical data. Archeological interpretation takes the geophysical results and tries to apply cultural attributes or causes. In both cases, interpretation requires both experience with the operation of geophysical equipment, data processing, and archeological methodology; and knowledge of the geophysical techniques and properties, as well as known and expected archeology. Although there is variation between sites, several factors should be considered in the interpretation of the geophysical data. These may be divided between natural factors, such as geology, soil type, geomorphology, climate, surface conditions, topography, soil magnetic susceptibility, seasonality, and cultural factors including known and inferred archeology, landscape history, survey methodology, data treatment, modern interference, etc. (David 1995:30). It should also be pointed out that refinements in the geophysical interpretations are dependent on the feedback from subsequent archeological investigations. The use of multiple instrument surveys provides the archeologist with very different sources of data that may provide complementary information for comparison of the nature and cause (i.e., natural or cultural) of a geophysical anomaly (Clay 2001). Each instrument responds primarily to a single physical property: magnetometry to soil magnetism, electromagnetic induction to soil conductivity, resistivity to soil resistance, and ground penetrating radar to dielectric properties of the soil to (Weymouth 1986b:371).

### Interpretation of Magnetic Data

Interpretation of the magnetic data (Bevan 1998:24) from the project requires a description of the buried archeological feature of object (e.g., its material, shape, depth, size, and orientation). The magnetic anomaly represents a local disturbance in the earth's magnetic field caused by a local change in the magnetic contract between buried archeological features, objects, and the surrounding soil matrix. Local increases or decreases over a very broad uniform magnetic surface would exhibit locally positive or negative anomalies (Breiner 1973:17). Magnetic anomalies tend to be highly variable in shape and amplitude. They are generally asymmetrical in nature due to the combined affects from several sources. To complicate matters further, a given anomaly may be produced from an infinite number of possible sources. Depth between the magnetometer and the magnetic source material also affect the shape of the apparent anomaly (Breiner 1973:18). As the distance between the magnetic sensor on the magnetometer and the source material increases, the expression of the anomaly becomes broader. Anomaly shape and amplitude are also affected by the relative amounts of permanent and induced magnetization, the direction of the magnetic field, and the amount of magnetic minerals (e.g., magnetite) present in the source compared to the adjacent soil matrix. The shape (e.g., narrow or broad) and orientation of the source material also affects the anomaly signature. Anomalies are often identified in terms of various arrays of dipoles or monopoles (Breiner 1973:18-19). A magnetic object in made of magnetic poles (North or positive and South or negative). A simple dipole anomaly contains the pair of opposite poles that relatively close together. A monopole anomaly is simply one end of a dipole anomaly and may be either positive or negative depending on the orientation of the object. The other end is too far away to have an affect on the magnetic field.

Magnetic anomalies of archeological objects tend to be approximately circular in contour outline. The circular contours are caused by the small size of the objects. The shape of the object is seldom revealed in the contoured data. The depth of the archaeological object can be estimated by half-width rule procedure (Bevan 1998:23-24; Breiner 1973:31; Milsom 2003:67-70). The approximations are based on a model of a steel sphere with a mass of 1 kg buried at a depth of 1.0 m below the surface with the magnetic measurements made at an elevation of 0.3 m above the ground. The depth of a magnetic object is determined by the location of the contour value at half the distance between the peak positive value of the anomaly and the background value. With the fluxgate gradiometer, the contour value is half the peak value since the background value is approximately zero. The diameter of this contour (Bevan 1998:Fig. B26) is measured and used in the depth formula where depth = diameter – 0.3 m (Note: The constant of 0.3 m is the height of the bottom fluxgate sensor above the ground in the Geoscan Research FM36 were I carry the instrument during data acquisition. This value needs to be adjusted for each individual that carries the instrument.). The mass in kilograms of the object (Bevan 1998:24, Fig. B26) is estimated by the following formula: mass = (peak value - background value) * $(\text{diameter})^3/60$. It is likely that the depth and mass estimates are too large rather than too small, since they are based on a compact spherical object made of iron. Archeological features are seldom compact but spread out in a line or lens. Both mass and depth estimates will be too large. The archaeological material may be composed of something other than iron such as fired earth or volcanic rock. Such materials are not usually distinguishable from the magnetic data collected during the survey (Bevan 1998:24). The depth and mass of features comprised of fired earth, like that found in kilns, fireplaces, or furnaces could be off by 100 times the mass of iron. If the archeological feature were comprised of bricks (e.g., brick wall, foundation, or chimney), estimates could be off by more than a 1000 times that of iron. The location of the center of the object can also be determined by drawing a line connecting the peak positive and peak negative values. The rule of thumb is that the center of the object is located approximately one third to one half of the way along the line from the peak positive value for the anomaly. One should also be cautious of geophysical anomalies that extend in the direction of the traverses since these may represent operator-induced errors. The magnetic anomalies may be classified as three different types: 1) dipole, 2) monopole, and 3) linear.

There are numerous dipole and monopole magnetic anomalies in the data set from the southern portion of the Elbee Site (Figure 12). The examination of the image plot of the magnetic data from the southern portion of the Elbee Site provides an overall view of the density of the magnetic anomalies, which helps identify broad magnetic anomalies and trends. Individual anomalies are also identified and analyzed by looking at the contour plots of the magnetic data in each grid unit (Figures 13-47). Using a similar strategy that was developed by Volf (2002:5-7) for the northern portion of the Elbee Site, the magnetic anomalies are graded into groups of high interest or intermediate/low interest. The grades, according to Volf (2002:5),

> *are based upon characteristics of individual anomalies' contoured features such as shape, width, association with magnetic lows, magnitude, and profile. Anomalies graded high are similar to anomalies at other sites that when tested, were determined to be associated with prehistoric features (Volf 2000; John W. Weymouth, personal communication). Anomalies graded to be of intermediate interest display some degree of patterning indicative of being caused by prehistoric activities, but may also be caused by small metal artifacts, or metal objects that are oriented such that the negative component of the magnetic field does not register.*

The vast majority of the magnetic anomalies are related to ferrous materials deposited on the site during the period that the Russell farmstead was in operation. The southern part of the present magnetic survey area is highly impacted from the disposal of large quantities of ferrous based materials (i.e., baling wire, barbed wire, fencing staples, nails, building hardware, horse tack, cans, parts of farm implements, bricks, etc.). A number of potential prehistoric anomalies are present in the northern portion of the present geophysical survey area and along the edge of the terrace where the density of the historic debris does not mask the potential prehistoric features. Several groups of magnetic anomalies cluster around the location of farm buildings, including the house, garage, chicken coop, and grain storage bin, which were demolished by the National Park Service after the acquisition of the property (Figure 48). Farm lanes and possible fence lines appear as linear alignments of magnetic anomalies. One linear anomaly extends across the southern portion of the site from the terrace edge in the southeast corner of the magnetic survey block to the NPS gate and gravel service road. It is identified through a portion of the site as a linear depression or swale. The NPS grave service road is also represented by a linear set of magnetic anomalies. A linear anomaly consisting of two closely spaced parallel magnetic low regions occurs in the data near the northeast corner of the magnetic grid block in the southern portion of the site. This anomaly is connected to a linear anomaly noted by Volf (2002:6). Like the linear anomaly noted by Volf, there is no surface expression of the linear anomaly. Volf (2002:6) concluded that

> *Two possible explanations exist for this anomaly. One is that it is the result of the two-tracked road visible in the aerial photographs taken in 1964 (North Dakota State Highway Department, negative 2166 and 2167) and 1978 (KBM Inc. negative 1-36 dated 5-13-1978) of the area. The other is that it may represent an extension of the historic Sakakawea-Big Hidatsa Village trail (see Lovick and Ahler 1982: Figure 6), identified by Ahler in the 1978 UND excavations in the southern portion of the Elbee Site (Ahler 1984:32-33, Figure 2). It is also possible, but purely speculative, that*

*the two-track road follows the same path as the historic Sakakawea-Big Hidatsa Village trail at this location.*

The orientation and pattern of the linear anomaly fits the farm lane in the aerial photographs. Two adjacent curvilinear anomalies to the west of the farm lane anomaly may represent manifestations of the trail between the two village sites.

Volf (2002:5) also identified several "connect-the-dot" circles of magnetic anomalies ranging in diameter from 7 m to 26 m. Volf (2002:5-6) provides a case for the intermediate to low interest in this type of magnetic anomaly cluster based on the differences between these magnetic clusters and the magnetic signatures of earth lodges at other sites within the KNRI boundary:

*Speculation that the circles represent cultural causes (house structures) is tentative at best and they are judged to be of only intermediate to low interest due to a variety of factors. First, the connect-the-dot pattern is unlike other reported magnetic signatures for circular lodge remains within KNRI. At the Sakakawea Village site (32ME11), the magnetic response of the earthlodges is characterized by circular regions with lower than average magnetic values with a positive magnetic anomaly in the center (central fire hearth) (Weymouth and Nickel 1977, Weymouth 1988). None of the circles in the Elbee data possess those characteristics. At the Bogan site (14GE1) in Geary County, Kansas, eathlodges displayed an intact circular ring of slightly higher than average magnetic values with average background readings within the ring (*De Vore and Nickel 2004*). The circles identified at Elbee...do exhibit short arcs of slightly higher magnetic response or have numerous small monopolar anomalies that can form an arc. The interior magnetic readings are similar to the magnetic field outside the identified circles. Secondly, the circles are atypical of earthlodges found in the area in that they lack substantial interior anomalies and are larger in size. If the circles represent the outline of a house structure, it would be expected that there would be interior magnetic anomalies reflecting archeological features within the perimeter of the house, notably the presence of a central fire hearth. While anomalies of intermediate/low interest are indicated within three of the circles (Circles B, D, and E…), the identification of these individual anomalies was partially influenced by the circles. The anomalies within the circles ore of a size (in terms of size and magnitude) that they are very unlikely to represent fire hearths, which would be much larger in size and magnetic magnitude. The diameter of the circles is also problematic in that several of the circles are much larger that the ordinary size range of earthlodges. Finally, the circles ,ay simply be the result of random pattering of the numerous pieces of small metal remaining in the surveyed area and are purely coincidental in nature…a magnetic survey of an area immediately south of the are surveyed in 2002 was conducted in 1978 by MWAC staff.*

*Subsequent excavations within the surveyed area revealed the presence of a house structure approximately 12 m in diameter with several features within the house outline (Ahler 1984). No indication of a circular structure or anomalies was seen in that magnetic data.*

However, without additional archeological investigations of these anomalous areas, their true nature may go undetected. Seven clusters of this type of magnetic anomalies are also present in the magnetic data from the southern portion of the site. Although there may be more in the magnetic data from the project area that may relate to the prehistoric occupation of the Elbee Site, the dense concentration of historic farmstead related magnetic materials mask any manifestation of this anomaly type as well as other buried prehistoric features in much of the present project area. It is also possible that some archeological features are not detectable due to their low magnetic magnitude; feature shape, size, and content; and/or feature depth (Volf 2002:5).

## Interpretation of Ground Penetrating Radar Data

Analysis and interpretation of the gpr data may be conducted in several different ways. The individual radargrams for each profile line may be analyzed for hyperbolic reflections. The radargrams may be combined and processed to provide planar time slices of the data. The time slices may also be combined to form 3D cubes of the gpr data. The majority of the gpr radargrams show numerous small reflections along any given profile.

The ground penetrating radar data was collected in grid unit 23 in the southeastern portion of the project area. Time slices 13 and 15 at a depth of approximately 0.6 meters between 27 to 30 ns and at a depth of approximately 0.67 meters between 31 to 34 ns, respectively, contains linear and circular clusters of gpr anomalies. The larger gpr anomalous area is associated with the location of the magnetic connect-the-dots circle in the grid unit. The outline of the circle is highlighted by the presence of low amplitude strength reflections in both time slices. In time slice 13, two smaller concentrations of high amplitude strength reflections are located near the top of the larger circular anomalous area and near the bottom of the grid unit (Figure 49). In time slice 15 (Figure 50), the clusters are more elongated and cover more than twice the area as noted in time slice 13. Although it is possible that these gpr anomalous areas may represent prehistoric features, they may also represent the location natural features in the soil or more modern human activity at the site. The linear cluster of gpr anomalies are located in the swale of the farm lane, which passes through the site to the lower terrace above the Knife River. The low amplitude strength reflection appears to represent the location of the tracks of the farm vehicles and/or implements while the higher amplitude strength reflection indicated the sides of the tire or wheel ruts. In time slice 13, the linear anomalies are represented by extremely weak reflections. In time slice 15, the reflections are much stronger suggesting that the reflections are from the base of the compacted tracks. In time slice 15, there is also a parallel set of linear gpr anomalies in the upper northwest portion of the grid unit. The linear gpr anomalies consist of low amplitude strength reflections which also appear to be vehicular or implement tracks.

## Combining and Overlaying the Geophysical Data Sets

A different way of looking at the geophysical data collected during the investigations of the geophysical survey in grid unit 23 at the Elbee Ferry Site is to combine the two complementary data sets into one display (Figure 51). When a number of the different geophysical anomalies overlap, they suggest a strong correlation between the geophysical data and the buried archeological or natural features (Ambrose 2005; Kvamme 2007:345-374). There appear to be direct correlations between the geophysical anomalies associated with the larger circular anomalies in the gpr and the magnetic data sets. The farm lane two-track swale is also present in both data sets

In addition for looking at the complementary geophysical data set in grid unit 23, it is important to view the entire magnetic survey from the 2002 and the 2006 seasons (Figure 52). On first inspection of the combined magnetic data sets, it is clear that the southern portion of the site contains substantially more historic debris form the discarding of ferrous materials near the farm buildings and from the demolition of the buildings. The excessive amount of ferrous materials masks the detection of any prehistoric features in this portion of the site. Two-track farm access road and lanes to the fields and other portions of the farm are also evident in the magnetic combined data sets.

## 8. CONCLUSIONS AND RECOMMENDATIONS

Between September 11 and 15, 2006, the Midwest Archeological Center and Knife River Indian Villages National Historic Site staff members conducted geophysical investigations of the southern portion of the Elbee Site (32ME408) in Mercer County, North Dakota. The 2006 geophysical project was part of a multiple phase archeological project to assess the archeological record of the Elbee Site, which has been dramatically impacted by erosion of the vertical cutbank along the Knife River in the northern portion of the site. During the investigations, 14,200 square meters or 3.51 acres were surveyed with a Geoscan Research FM36 fluxgate gradiometer. Due to the large concentration of historic ferrous material on the site, a test was also conducted with the Geophysical Survey System Inc's TerraSIRch SIR-3000 ground-penetrating radar and 400 mHz antenna to determine the potential of other geophysical survey techniques at the site. Time did not permit the testing of resistance techniques. This report has provided an analysis of the geophysical data collected during five days at the Elbee Site (14BN111).

The magnetic data and the ground penetrating radar profile data from grid unit 23 from the southern portion of the site provided information of the physical properties (magnetic and ground-penetrating radar reflections) of the subsurface materials. Several magnetic and ground-penetrating radar anomalies were identified. There area several high magnetic dipoles as well as a number of weak magnetic dipoles. The strong magnetic dipoles represent large concentrations of magnetic iron, probably of recent or modern agricultural origin. Weak magnetic dipole and monopole anomalies may be associated with the prehistoric occupation at the site. The gpr data provided useful information concerning the buried archeological resources at the site. A gpr survey should be useful in situations where there id a high percentage of magnetic ground clutter caused by the disposal of historic ferrous materials.

Archeological excavations are needed to verify the nature and extent of the geophysical anomalies identified during the survey efforts. Generally, excavations can be more efficiently planned with the geophysical background data than through the use of traditional archeological excavation strategies; however, the discard of vast quantities of ferrous materials at the farmstead and from the demolition of the buildings has resulted in the masking of buried archeological feature associated with the prehistoric occupation of a majority of the area in the southern portion of the site. While individual anomalies and anomalous areas have been identified as potential prehistoric features and selected as potential candidates for archeological excavations, these anomalies are not the only possible archeological features within the project area at the site.

Finally, refinement of the archeological and geophysical interpretation of the survey data is dependent on the feedback of the archeological investigations following geophysical survey (David 1995:30). Should additional archeological investigations occur at the site investigated during this project, the project archeologist is encouraged to share additional survey and excavation data with the geophysical investigators for incorporation into the investigators' accumulated experiences with archeological problems. Throughout the entire geophysical and archeological investigations, communication between the geophysicist and the archeologist is essential for successful completion of the archeological investigations. It is also important for the investigators to disseminate the results of the geophysical survey and archeological investigations to the general public. It is especially important for the park staff to combine the results of the geophysical investigations into the park's interpretative presentations. It is through public support in funds and labor that we continue to make contributions to the application of geophysical techniques to the field of archeology.

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# TABLES

Table 1. Acquisition and instrumentation information for the gradiometer survey used in the grid input template.

| GENERAL | | | |
|---|---|---|---|
| Acquisition | value | Instrumentation | value |
| Sitename | knri | Survey Type | Gradiometer |
| Map Reference | | Instrument | FM36 |
| Dir. 1st Traverse | N | Units | nT |
| Grid Length (x) | 20 m | Range | AUTO |
| Sample Interval (x) | 0.125 m | Log Zero Drift | Off |
| Grid Width (y) | 20 m | Baud Rate | 2400 |
| Traverse Interval (y) | 0.5 m | Averaging | Off |
| Traverse Mode | Parallel | Averaging Period | 16 |

Table 2. Acquisition and instrumentation information for the ground-penetrating radar survey.

| | | | |
|---|---|---|---|
| GENERAL | | | |
| Acquisition | value | Instrumentation | Value |
| File Name | KNRI | Survey Type | GPR |
| Number of Profile Lines | 41 | Instrument | GSSI TerraSIRch SIR 3000 |
| Dir. 1st Traverse | N | Samples/scan | 512 |
| Grid Length (x) | 20 m | Bits/sample | 16 |
| Scans/meter | 50 | Scans/second | 100 |
| Grid Width (y) | 20 m | Meters/mark | 2 |
| Traverse Interval (y) | 0.5 m | Diel Constant | 8 |
| Traverse Mode | Zigzag | Antenna | 400 mHz |
| ACCESSORIES | | | |
| | Channel(s) | 1 | |
| | Range Gain (dB) | -20.0 26.0 31.0 43.0 | |
| | Position Correction | 0 ns | |
| | Vertical IIR LP N = 1F | 800 mHz | |
| | Vertical IIR HP N = 1F | 100 mHz | |
| | Position (ns) | 0 | |
| | Range (ns) | 50 | |

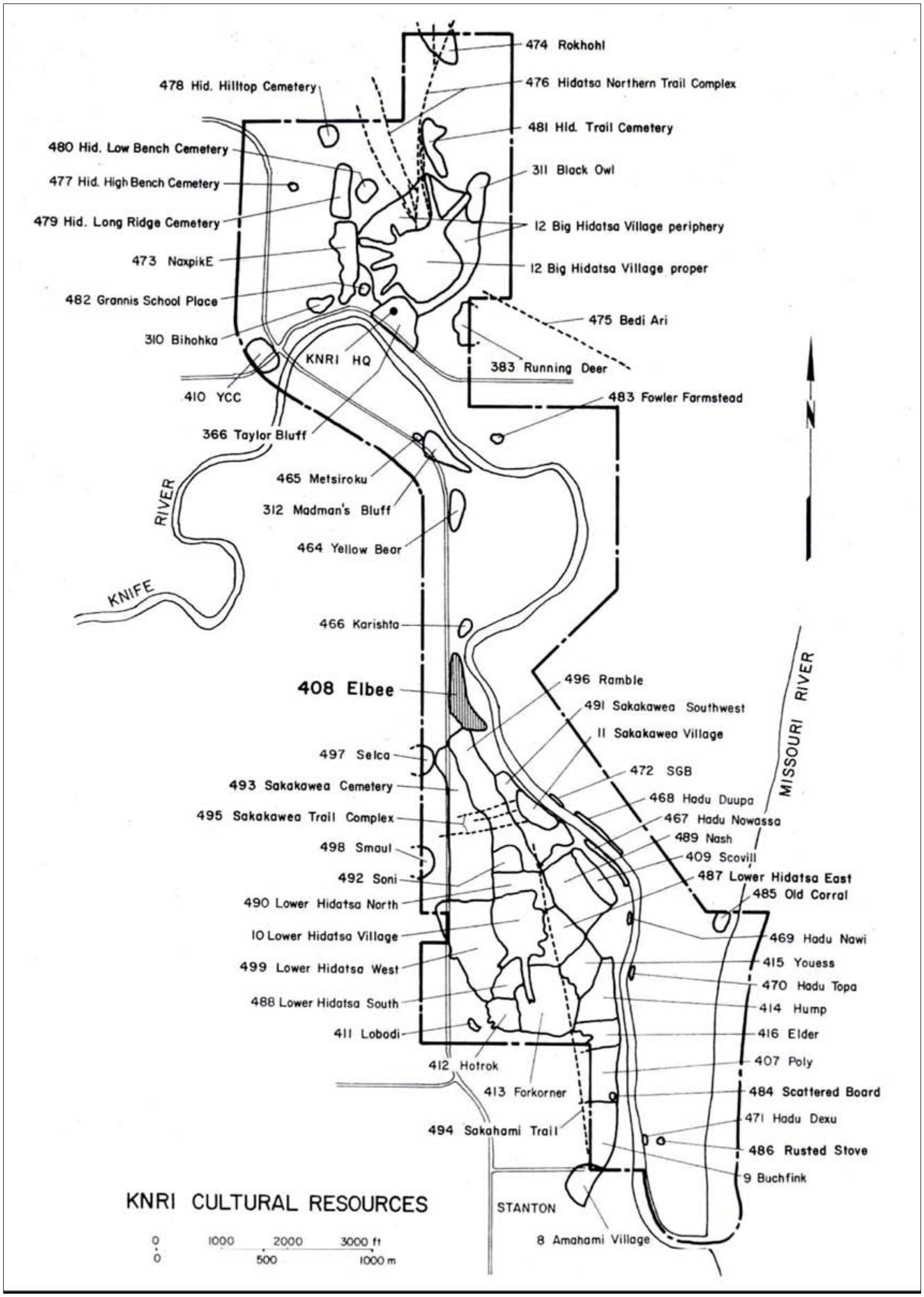
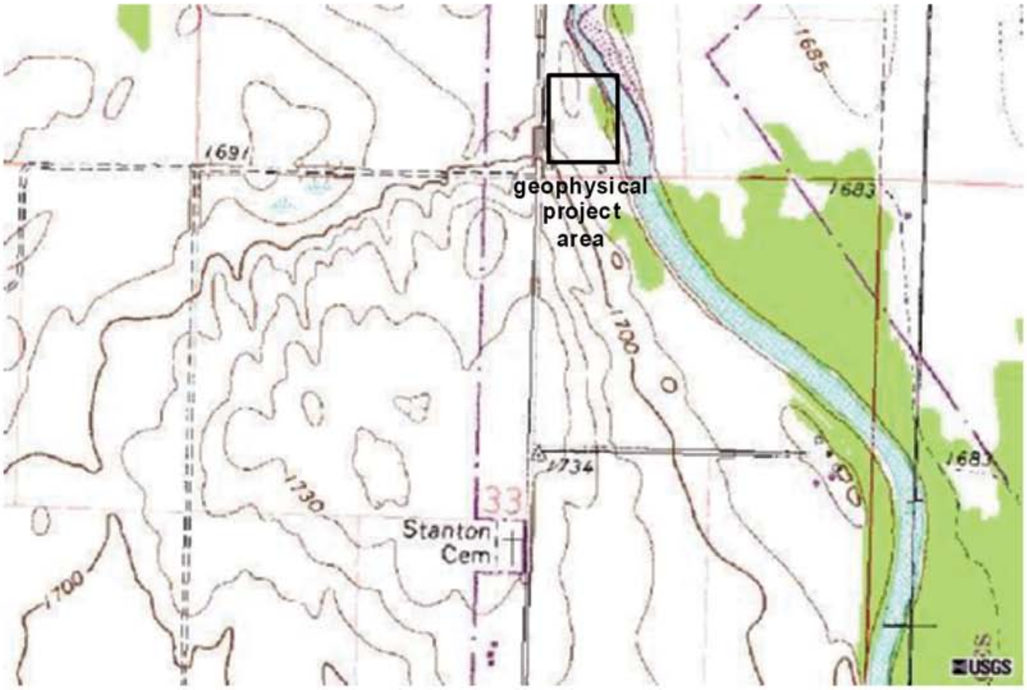



**Figure 1.** Location of the Elbee Site within Knife River Indian Villages National Historic Site, Mercer County, North Dakota.




a) USGS topographic map 1 km NE of Stanton, North Dakota (dated 01 Jul 1995)


b) USGS aerial photograph 3 km NE of Stanton, North Dakota (dated 27 Sep 1995)

**Figure 2.** Geophysical project area at the Elbee Site.

**a)** general view from southwest corner of the site (view to the east northeast)

**b)** general view of from southwest corner of the site (view to the north)

**Figure 3.** General view of the geophysical project area in the southern portion of the Elbee Site.

## MAGNETIC SURVEY OF ELBEE SITE

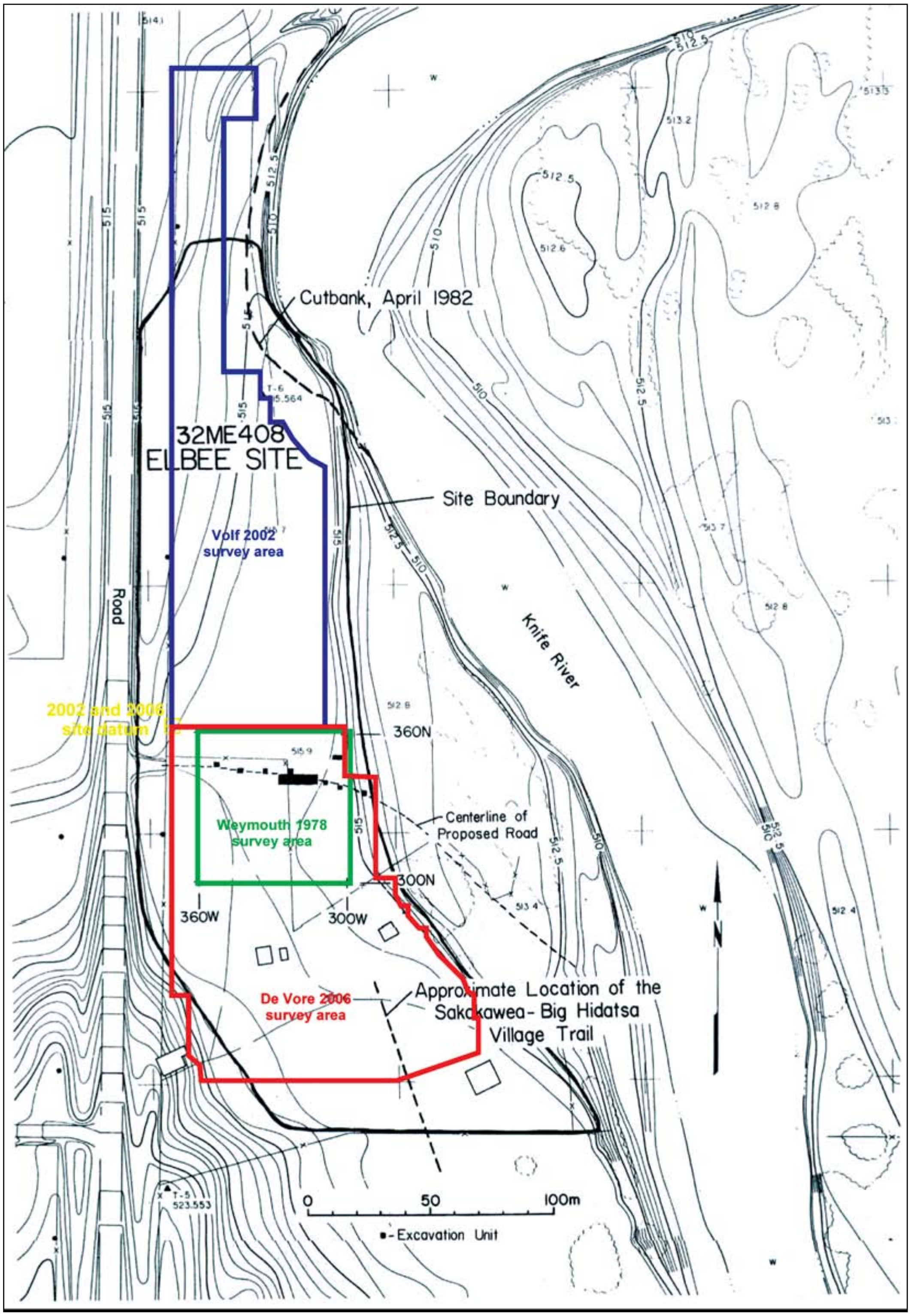



**Figure 4.** Elbee Site with the 1978, 2002, and 2006 geophysical project areas.

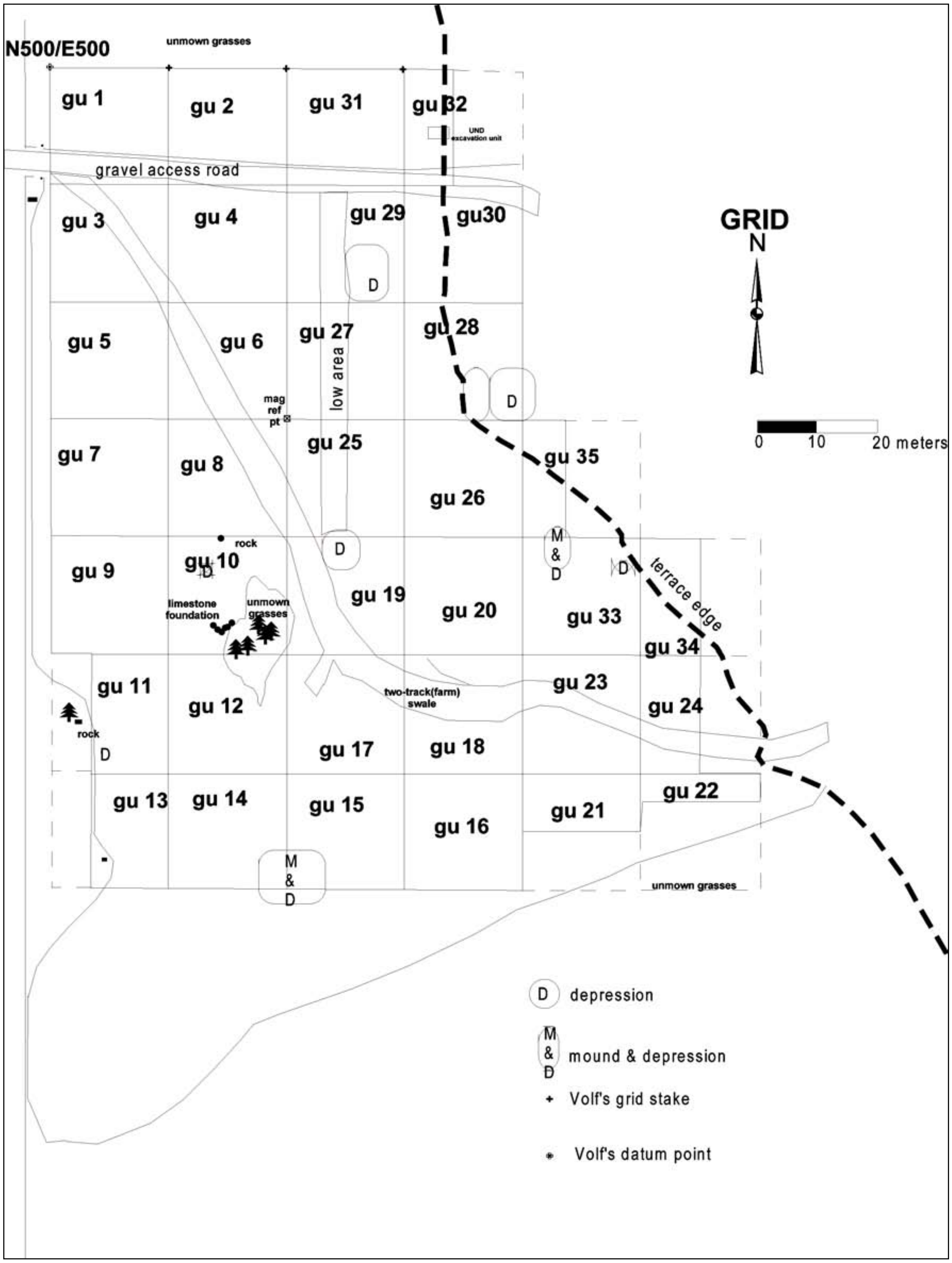



**Figure 5.** Sketch map of the geophysical survey area in the southern portion of the Elbee Site.

**Figure 6.** Conducting the magnetic survey with a Geoscan Research FM36 fluxgate gradiometer (view to the southeast).

**Figure 7.** The Geophysical Survey Systems, Inc. TerraSIRch SIR-3000 ground-penetrating radar system with a 400 mHz antenna (view to the east).

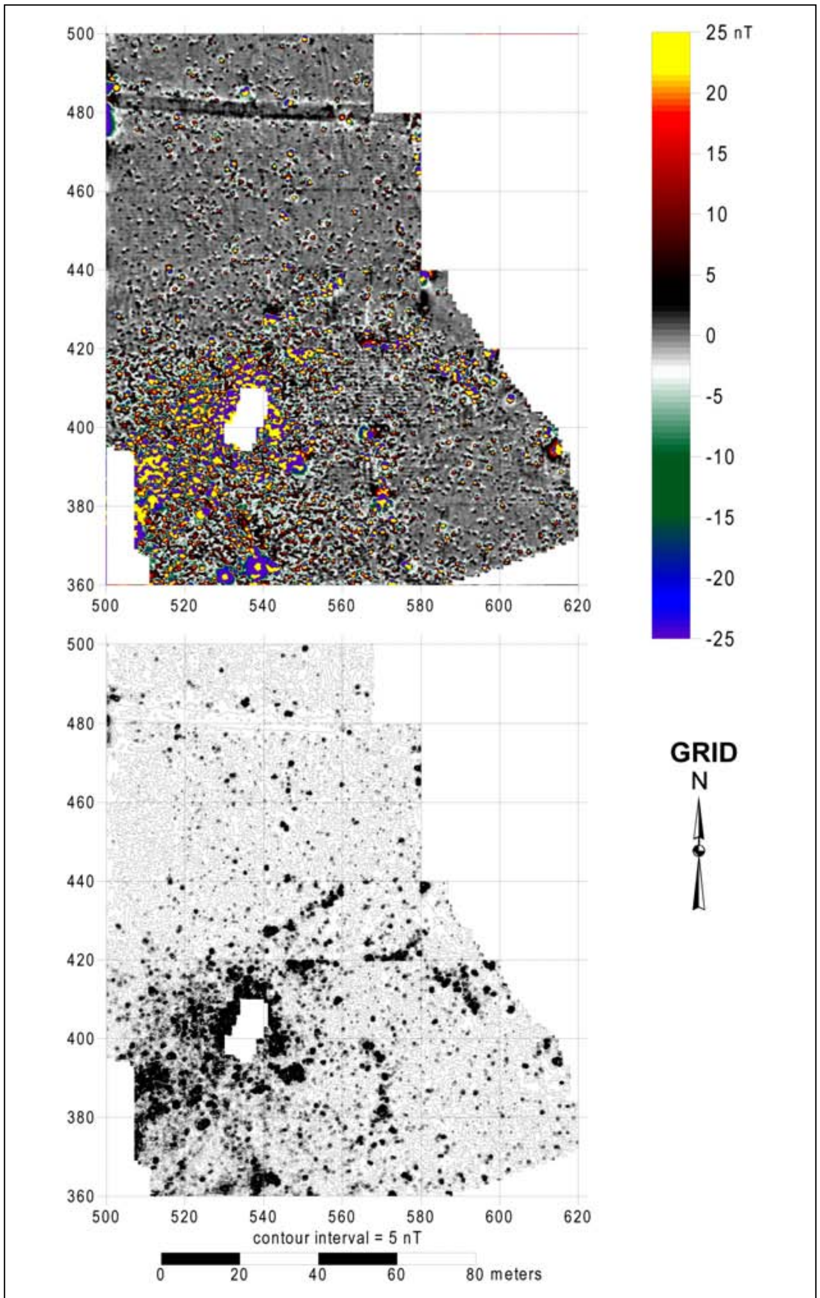



**Figure 8.** Magnetic gradient image and contour data plots.

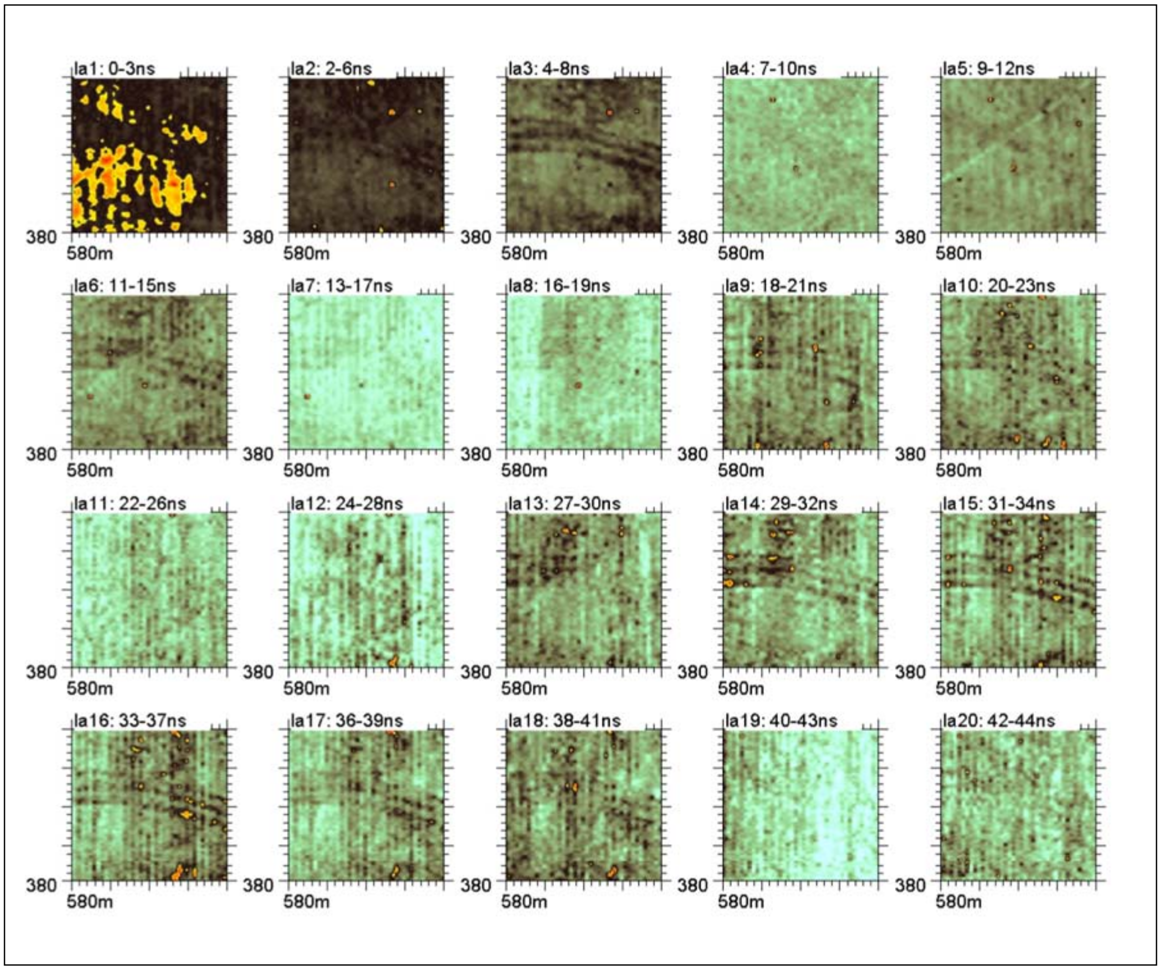



**Figure 9.** Time slices of the ground-penetrating radar profile data.vv

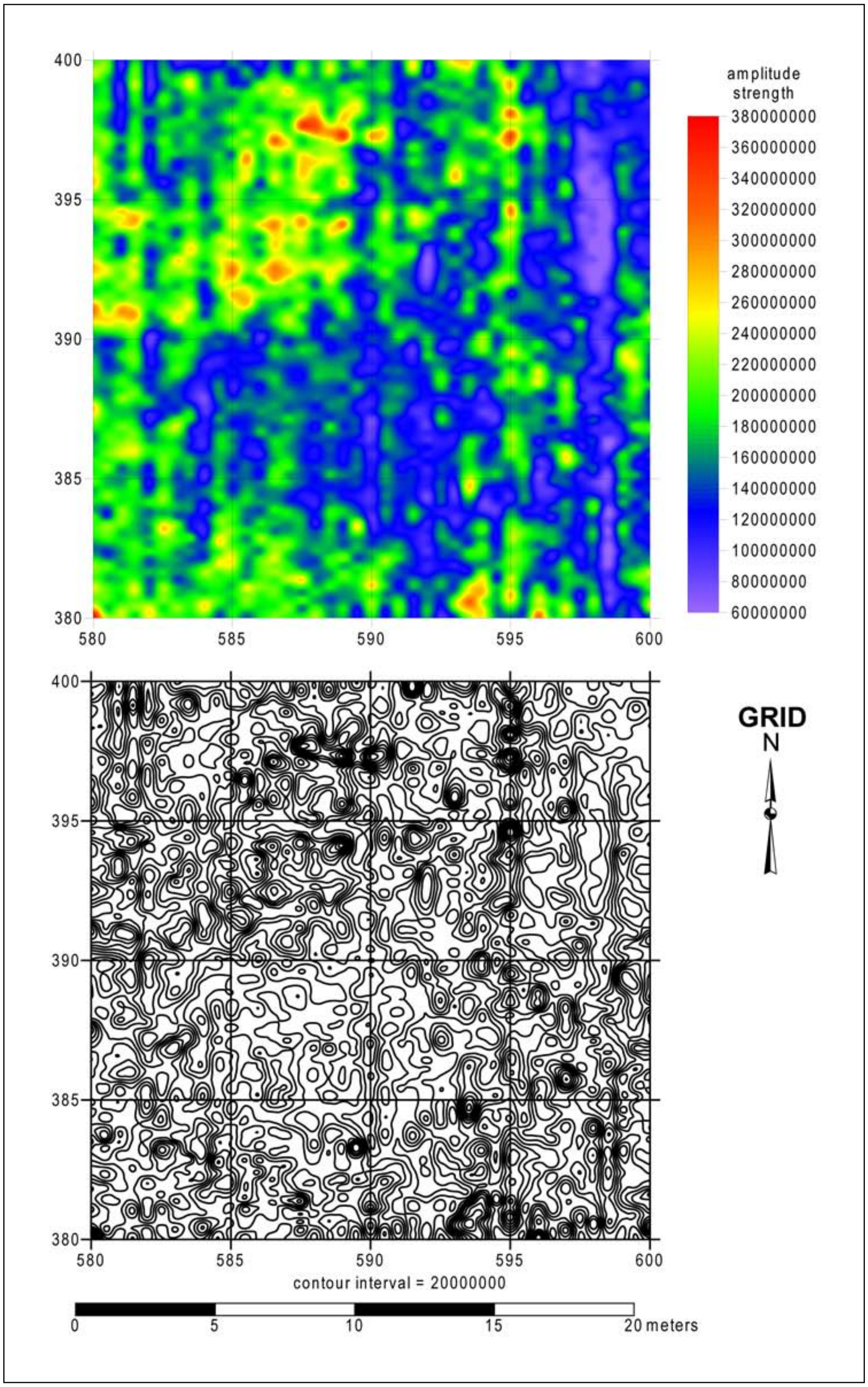



**Figure 10.** Time slice window 13 from 27 to 30 ns.

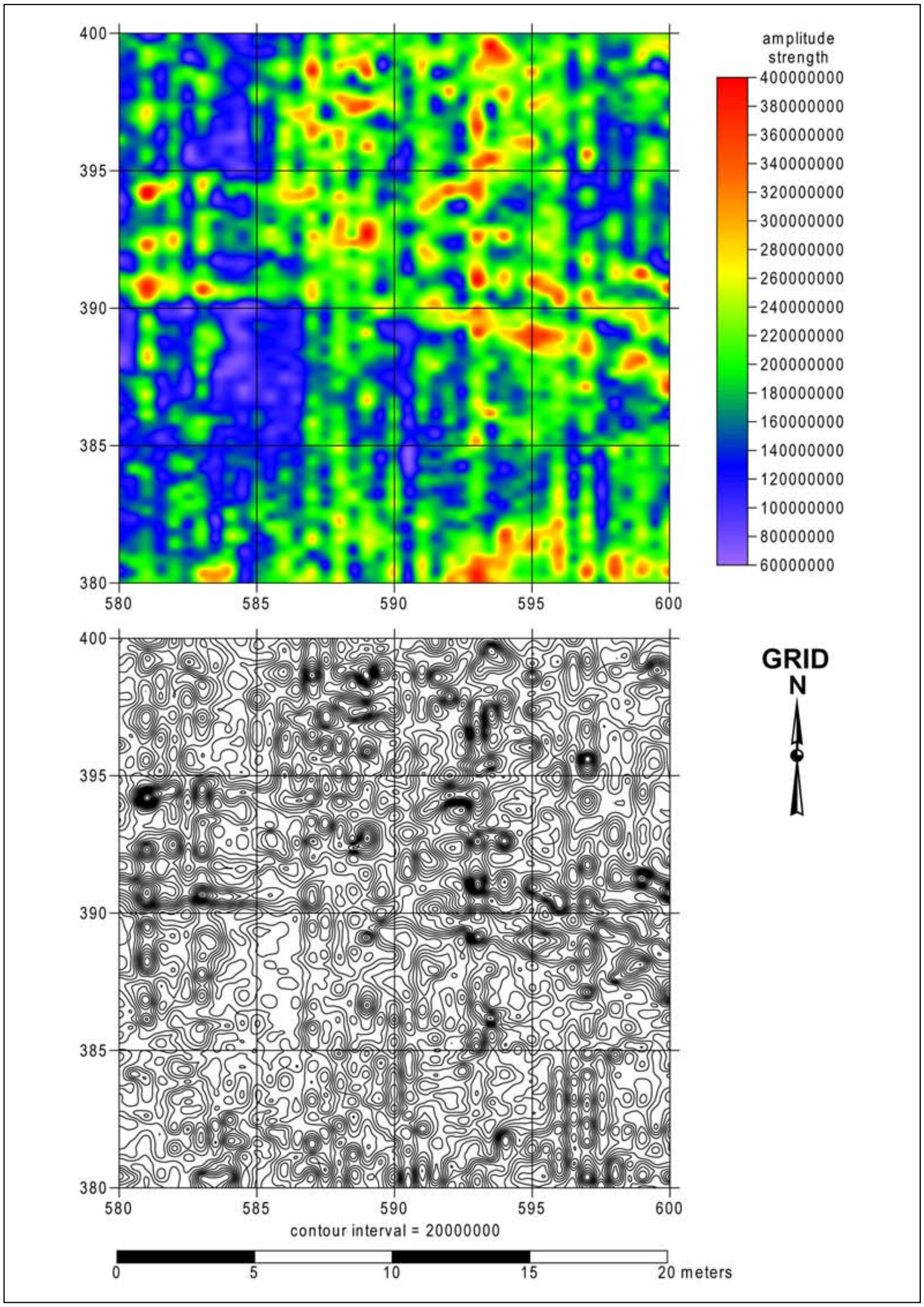



**Figure 11.** Time slice window 15 from 31 to 34 ns.

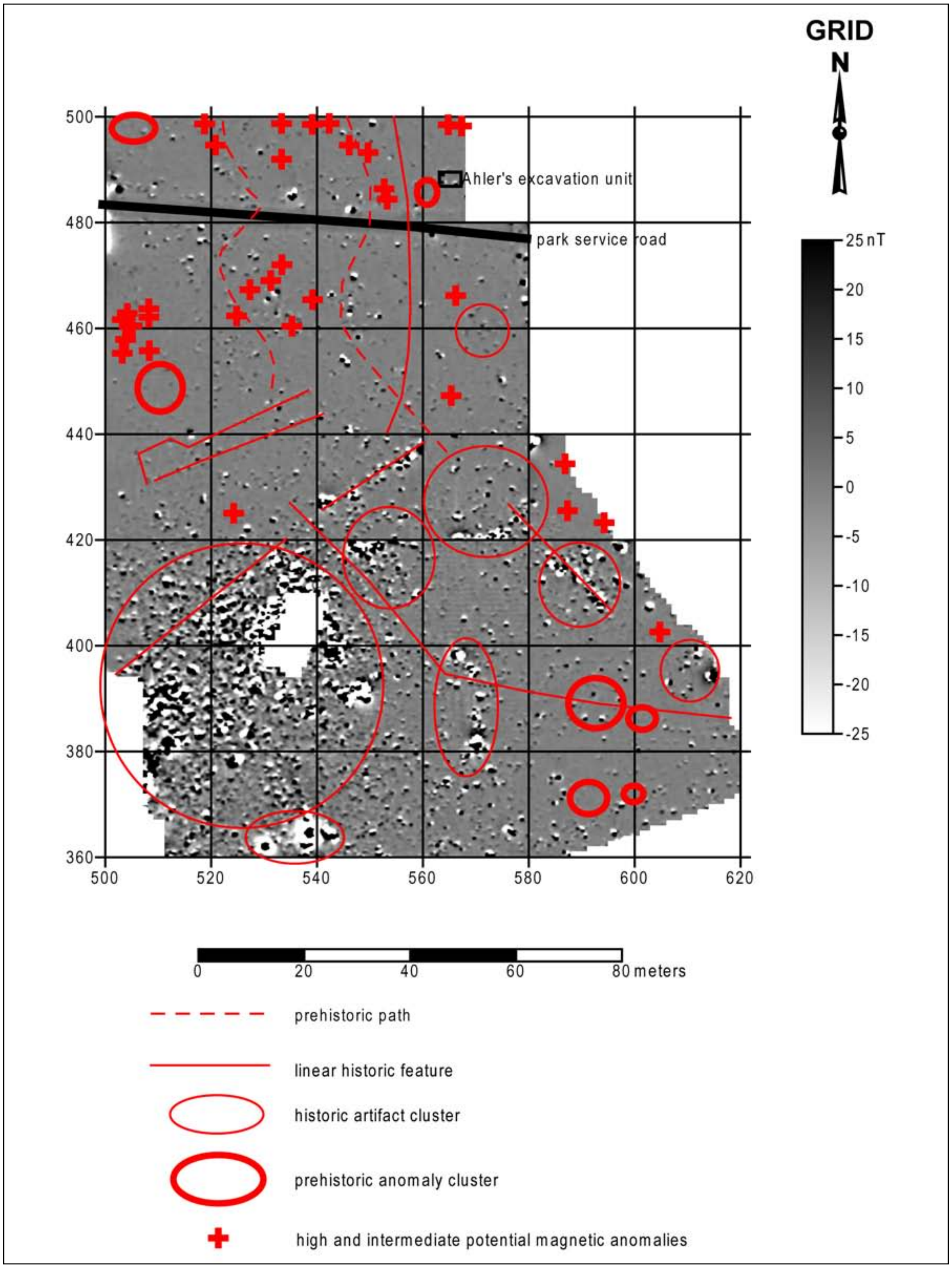



**Figure 12.** Magnetic gradient anomalies located within the geophysical project area.

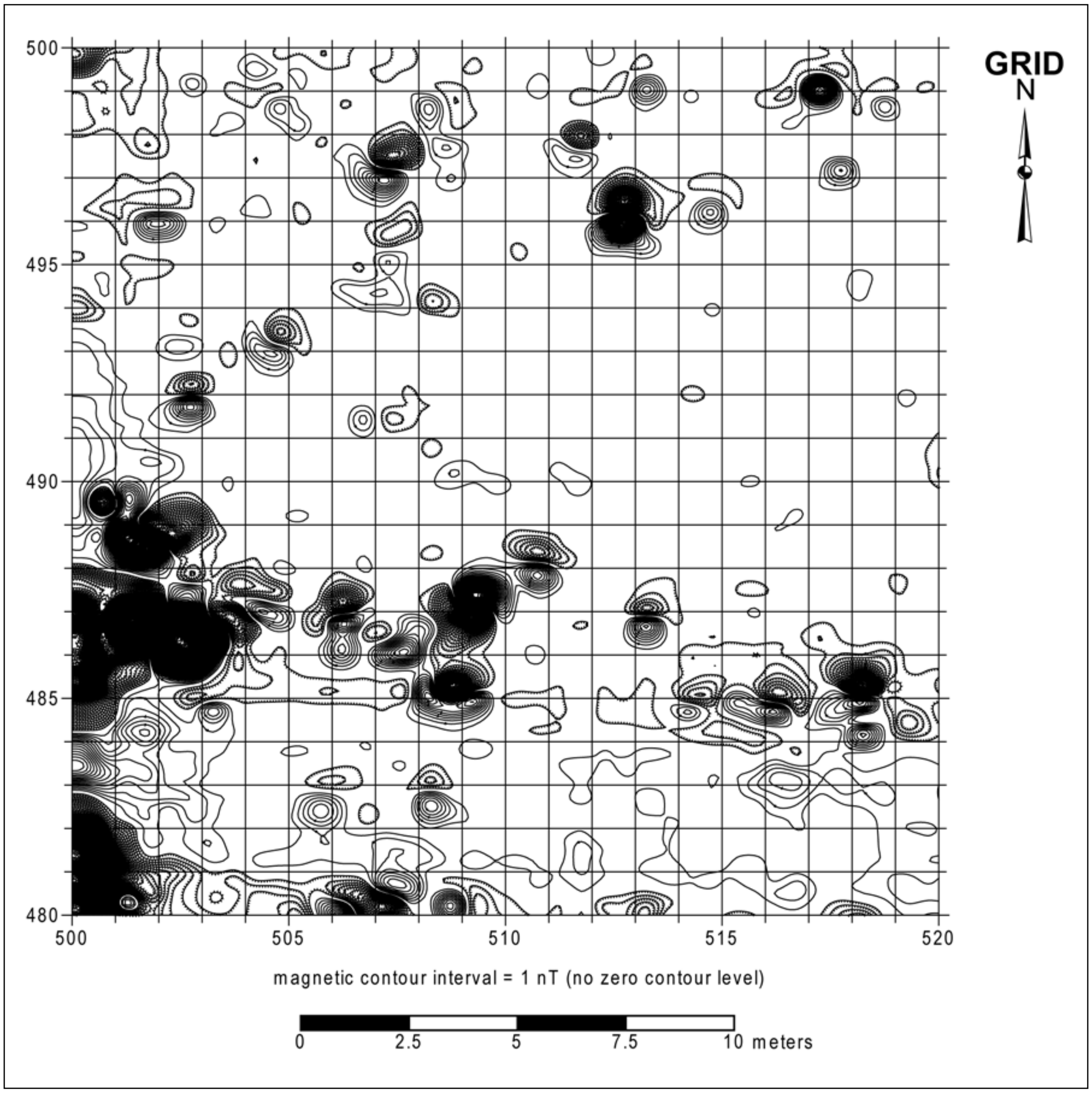



**Figure 13.** Magnetic contour plot of grid unit 1 (N480/E500).

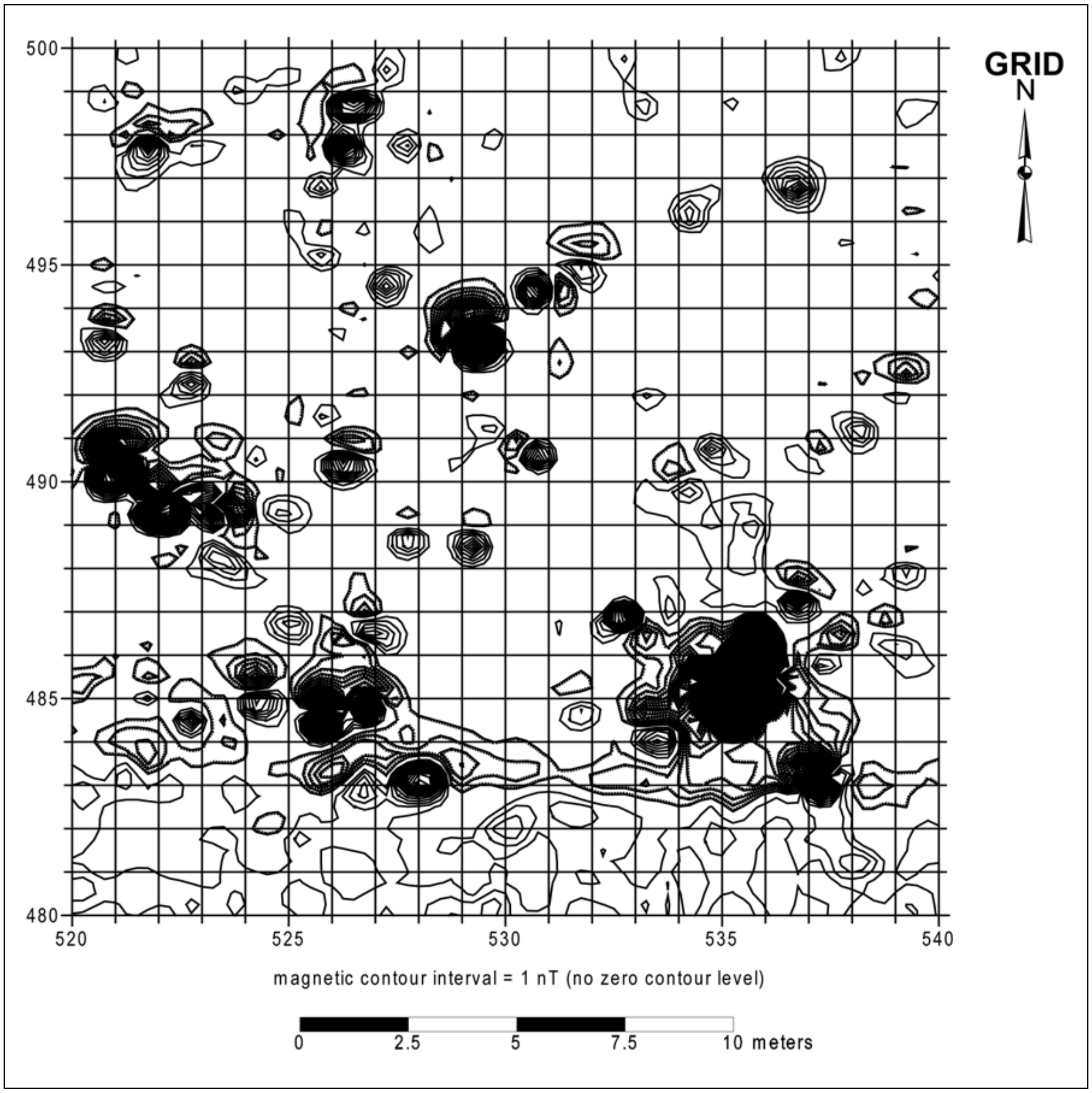



**Figure 14.** Magnetic contour plot of grid unit 2 (N480/E520).

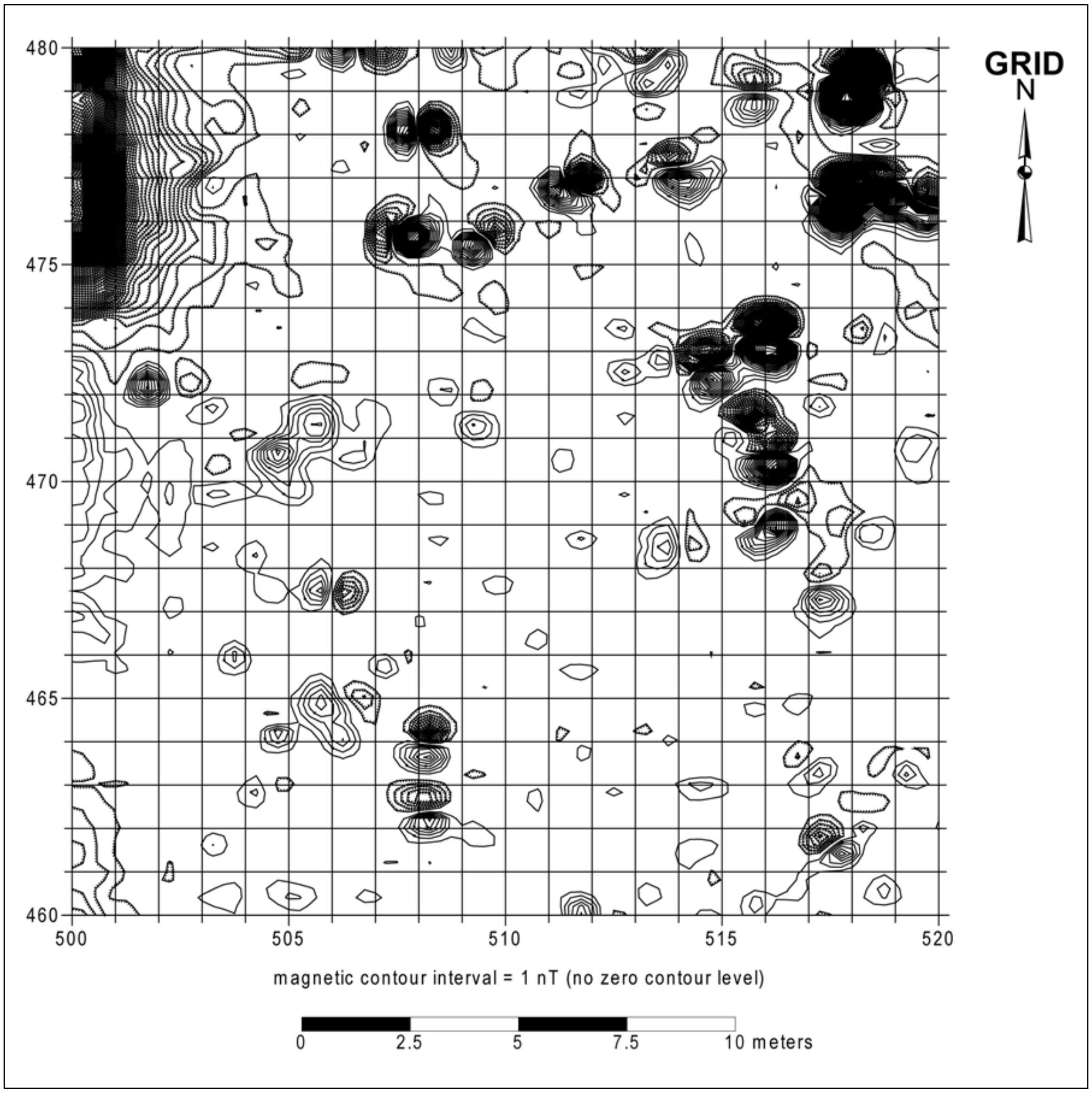



**Figure 15.** Magnetic contour plot of grid unit 3 (N460/E500).

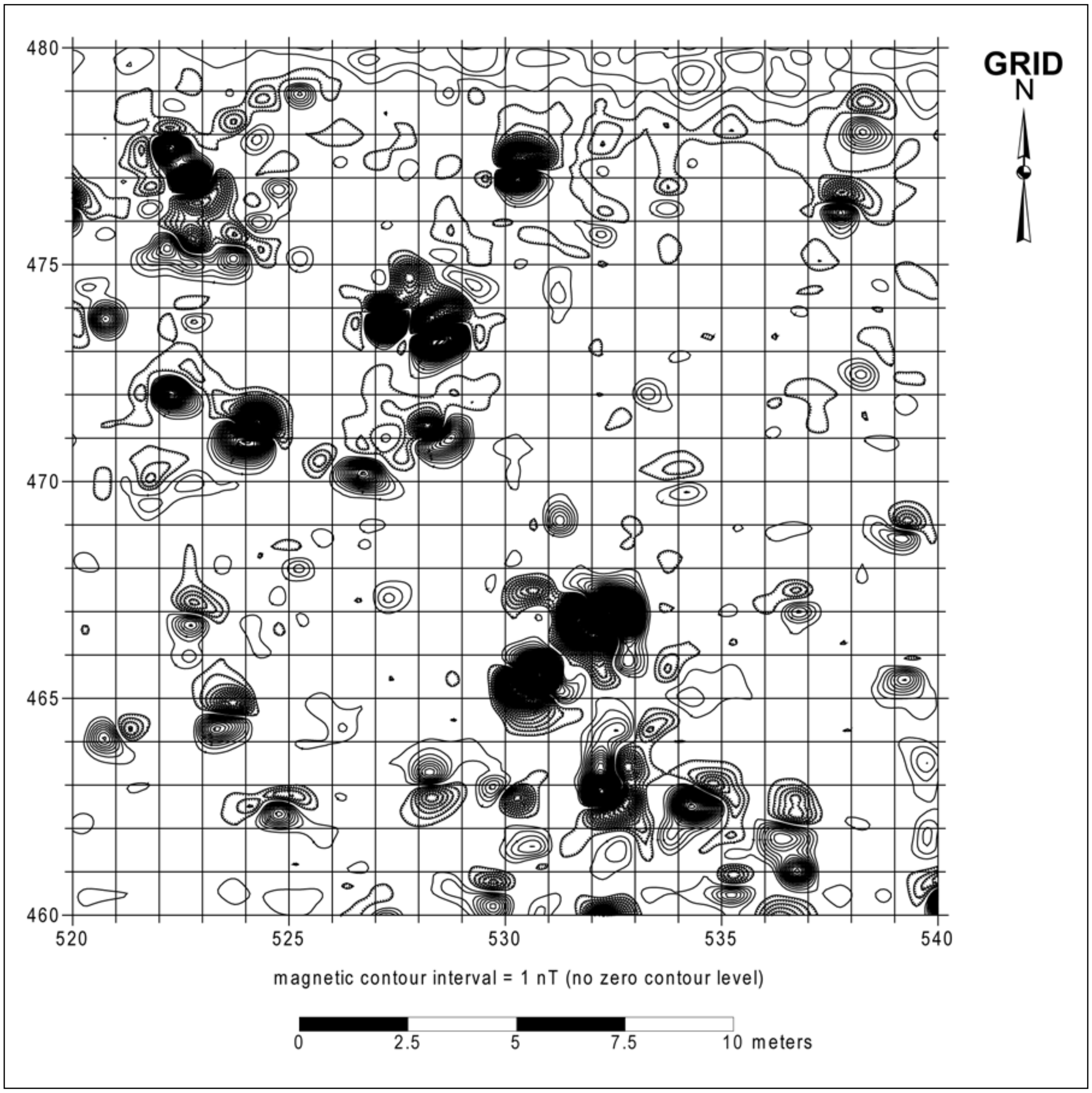



**Figure 16.** Magnetic contour plot of grid unit 4 (N460/E520).

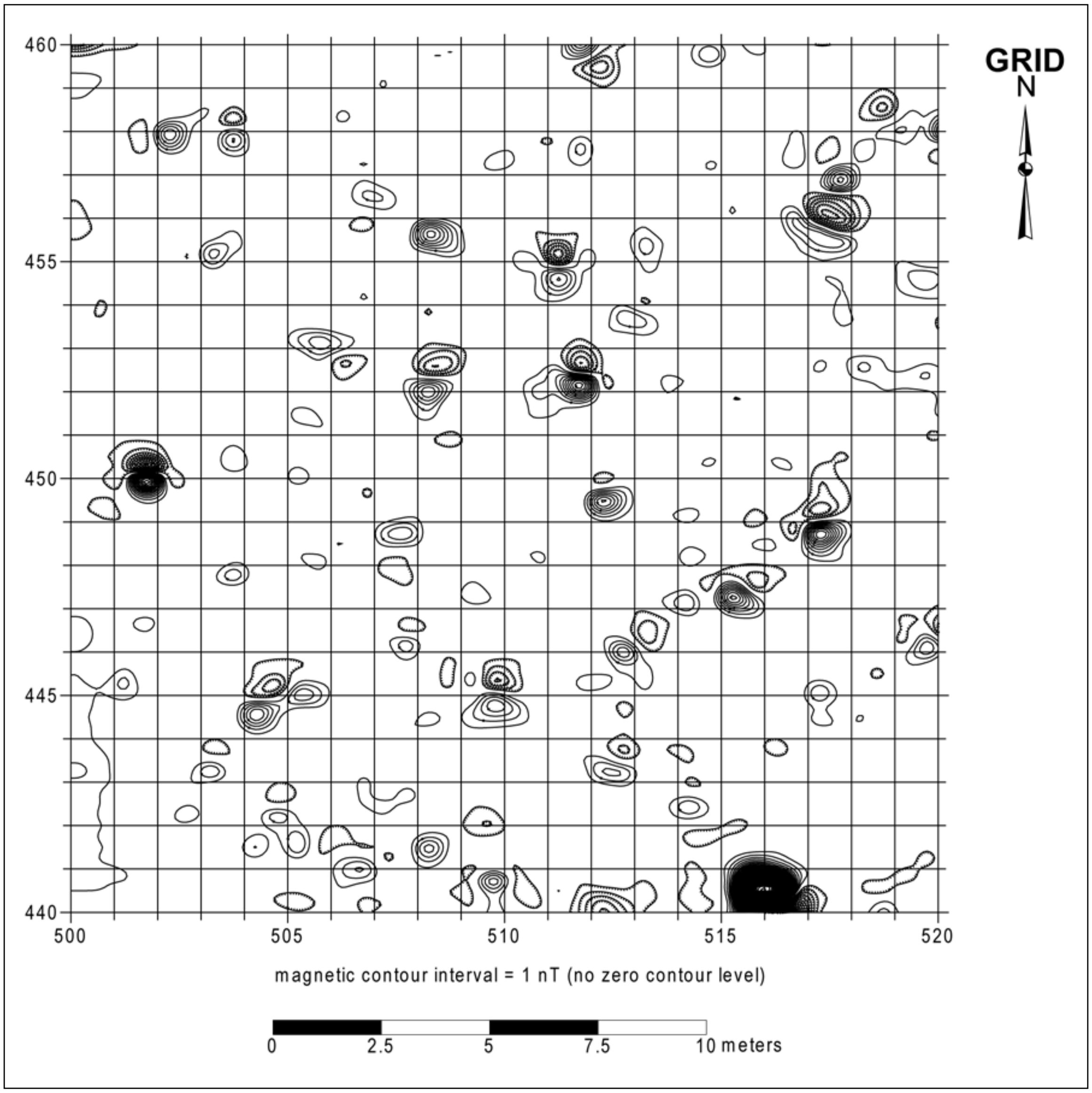



**Figure 17.** Magnetic contour plot of grid unit 5 (N440/E500).

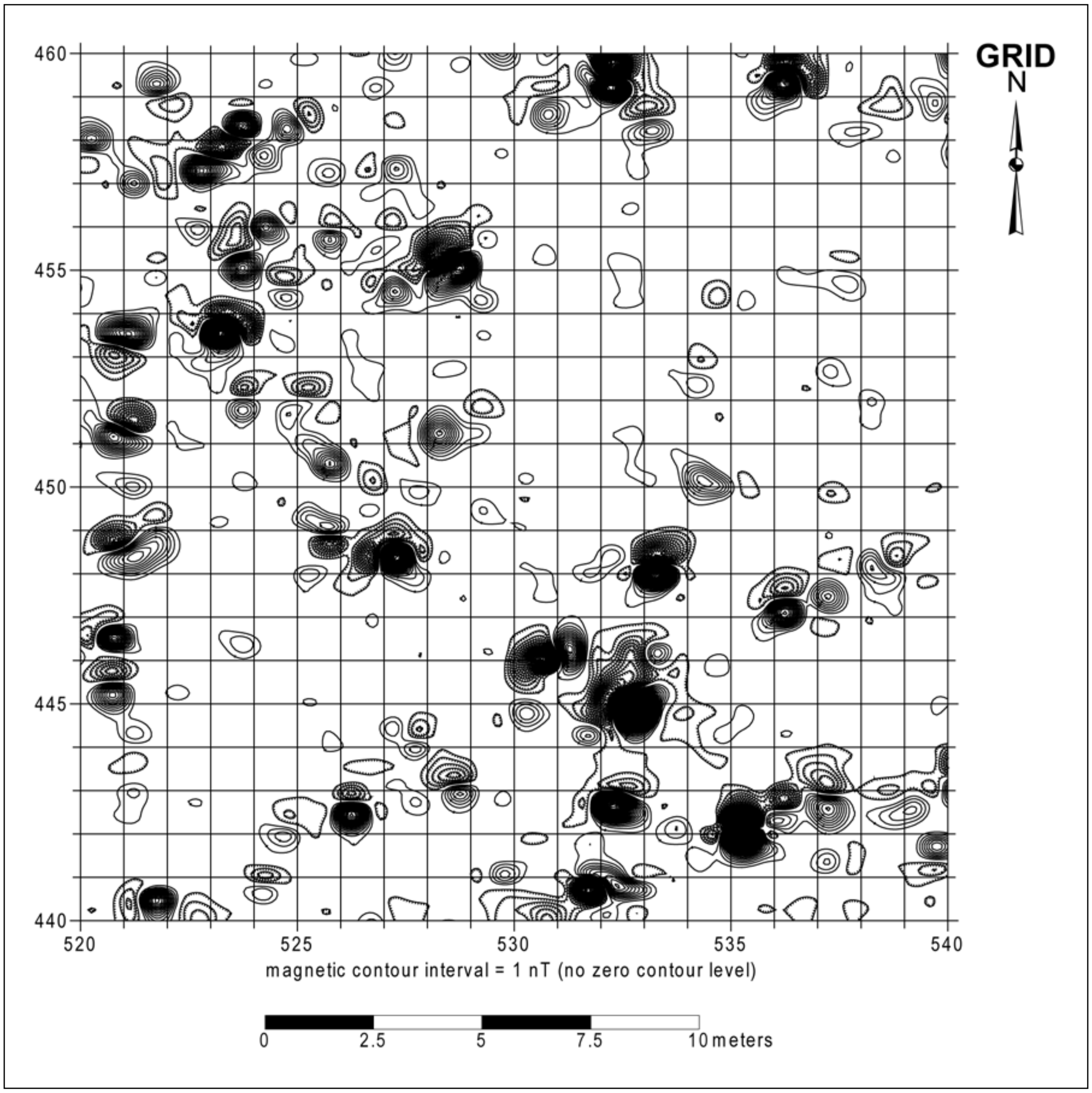



**Figure 18.** Magnetic contour plot of grid unit 6 (N480/E520).

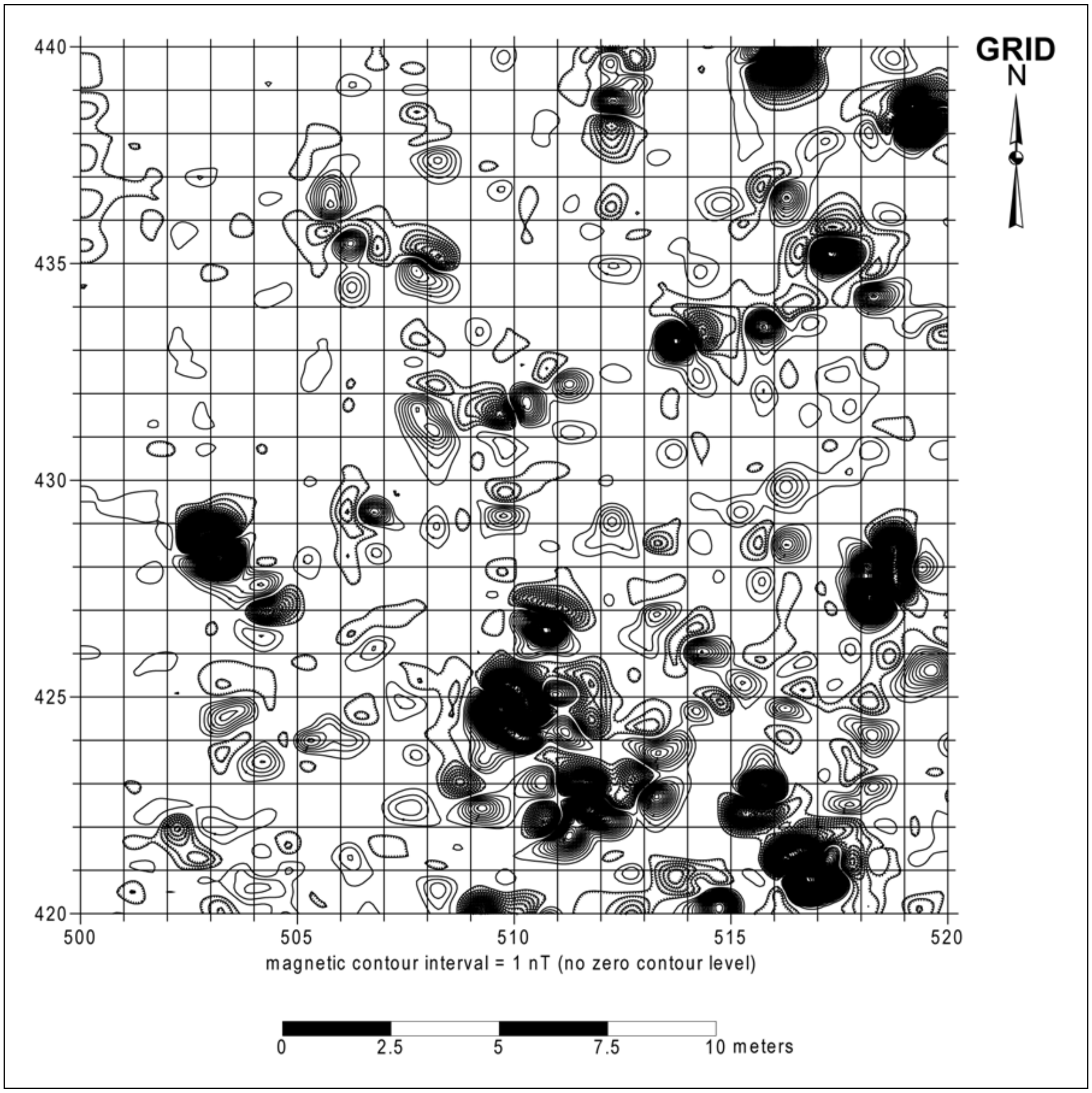



**Figure 19.** Magnetic contour plot of grid unit 7 (N420/E500).

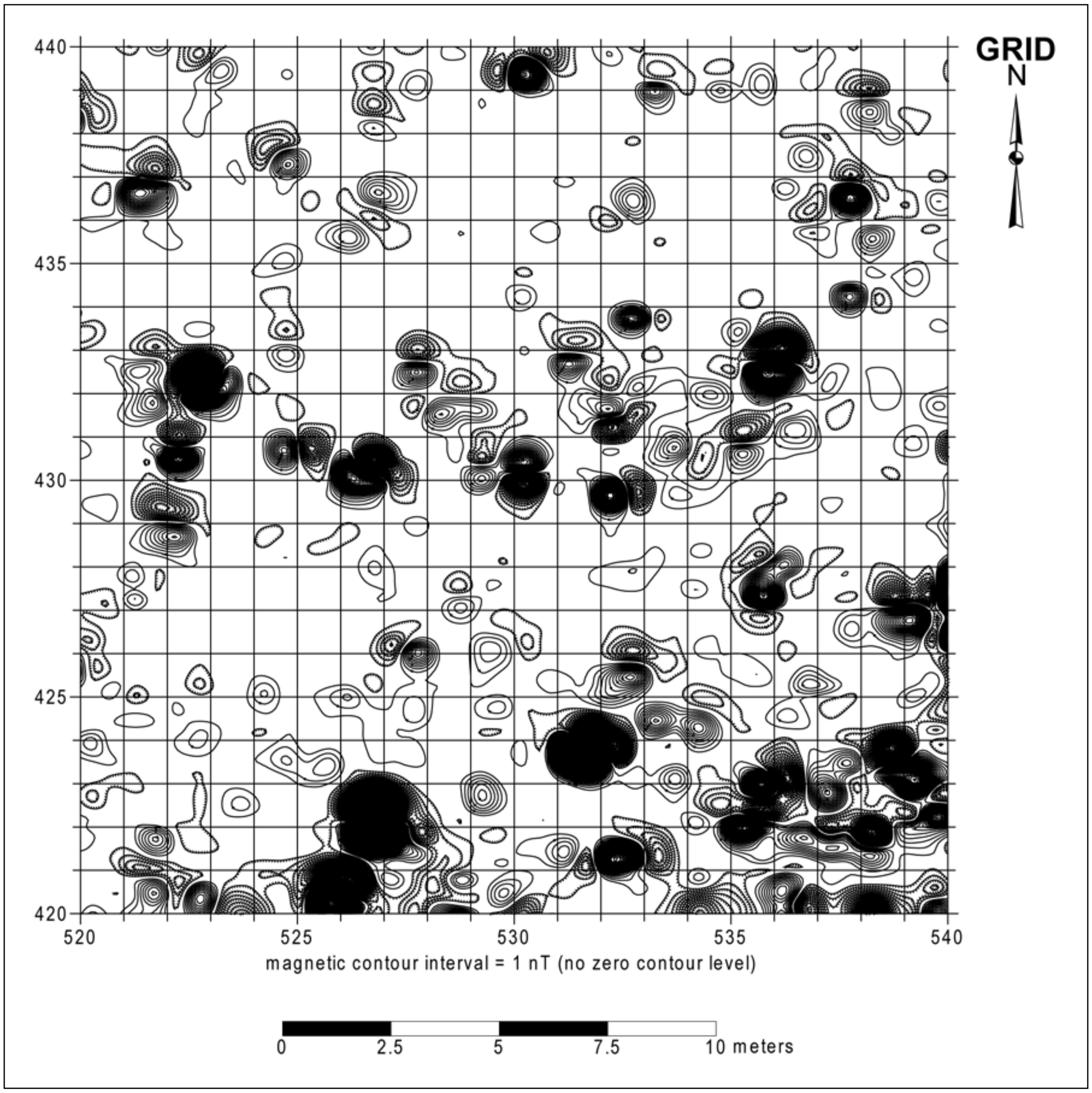



**Figure 20.** Magnetic contour plot of grid unit 8 (N420/E520).

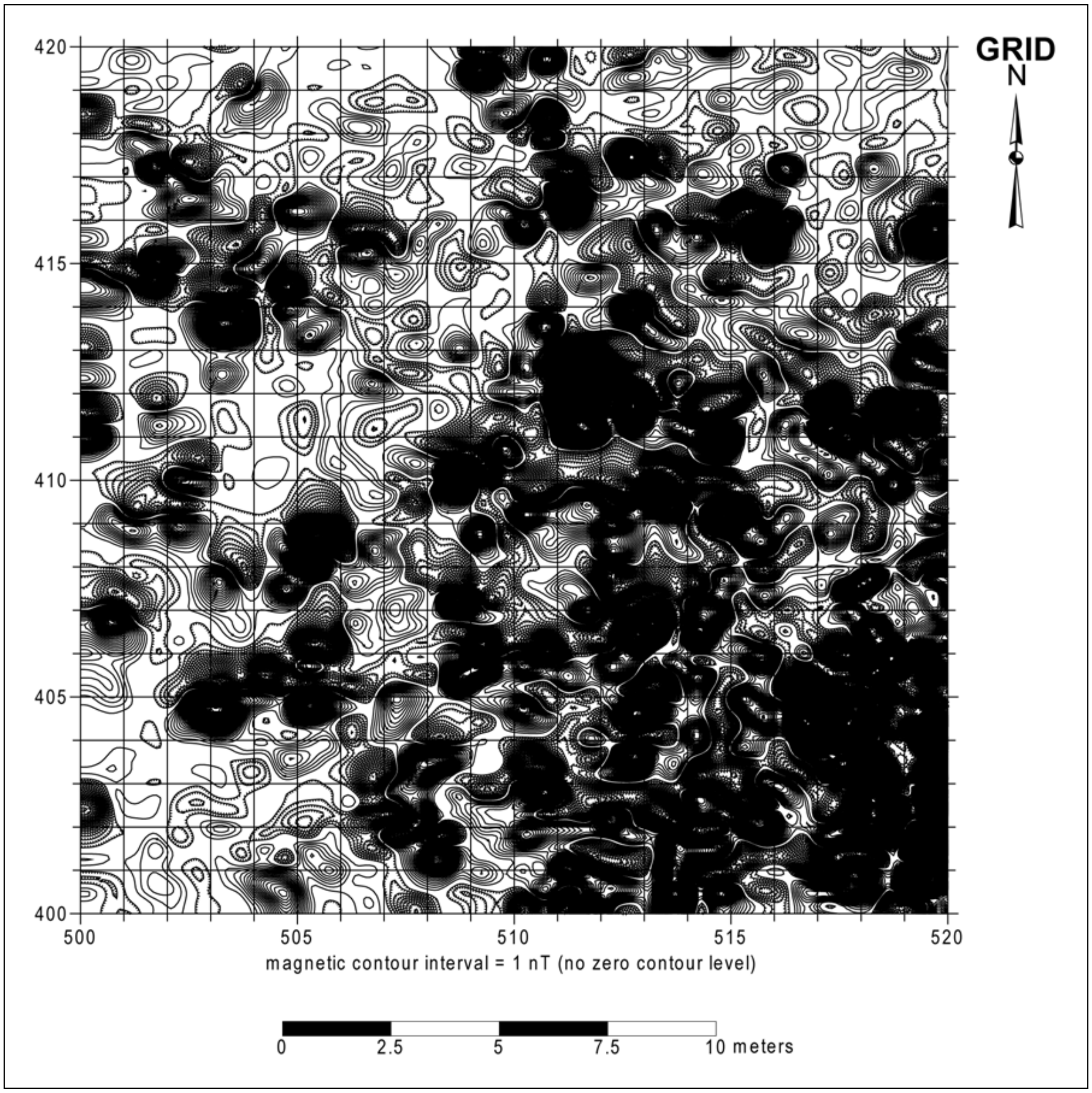



**Figure 21.** Magnetic contour plot of grid unit 9 (N400/E500).

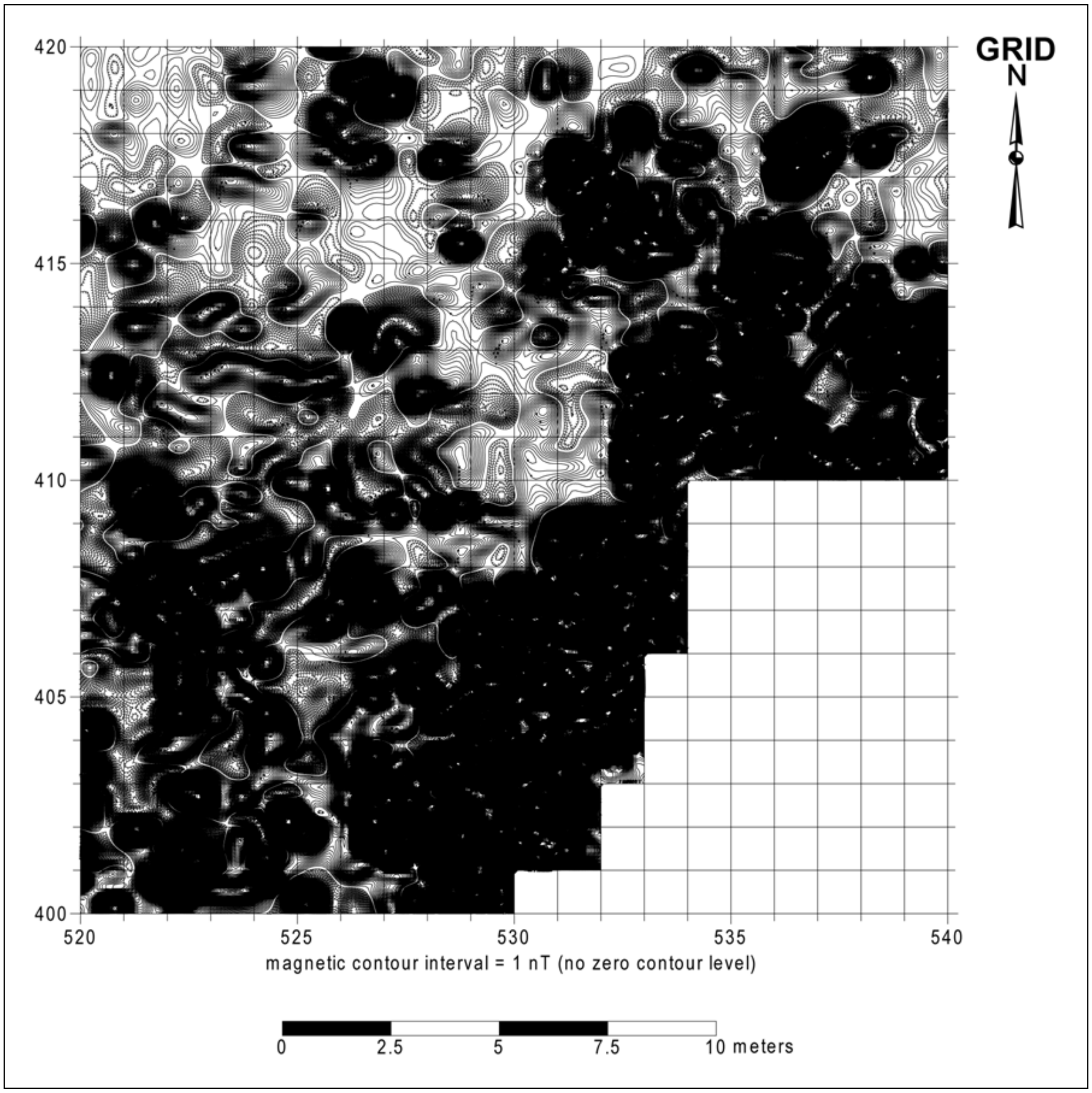



**Figure 22.** Magnetic contour plot of grid unit 10 (N400/E520).

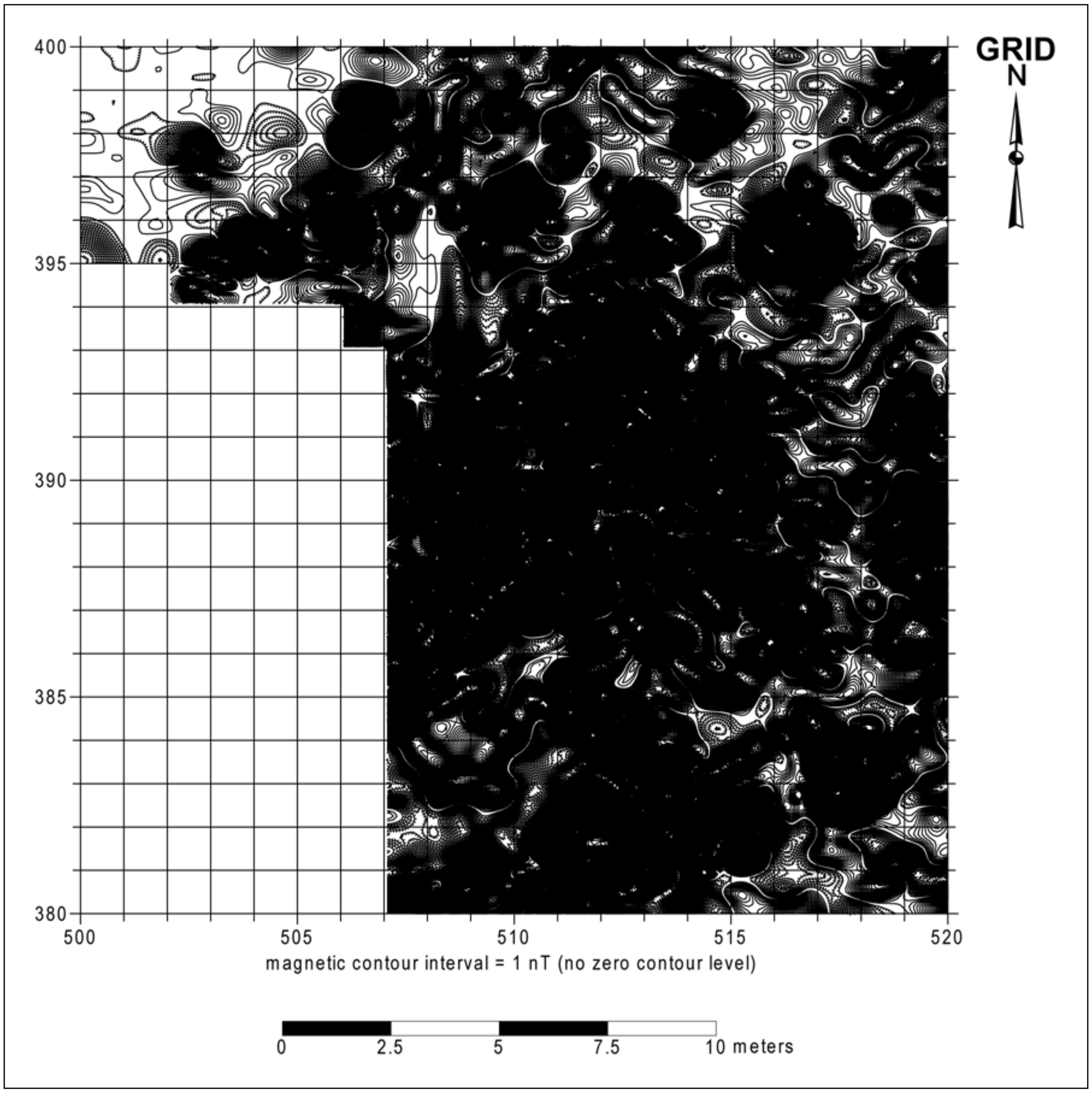



**Figure 23.** Magnetic contour plot of grid unit 11 (N380/E500).

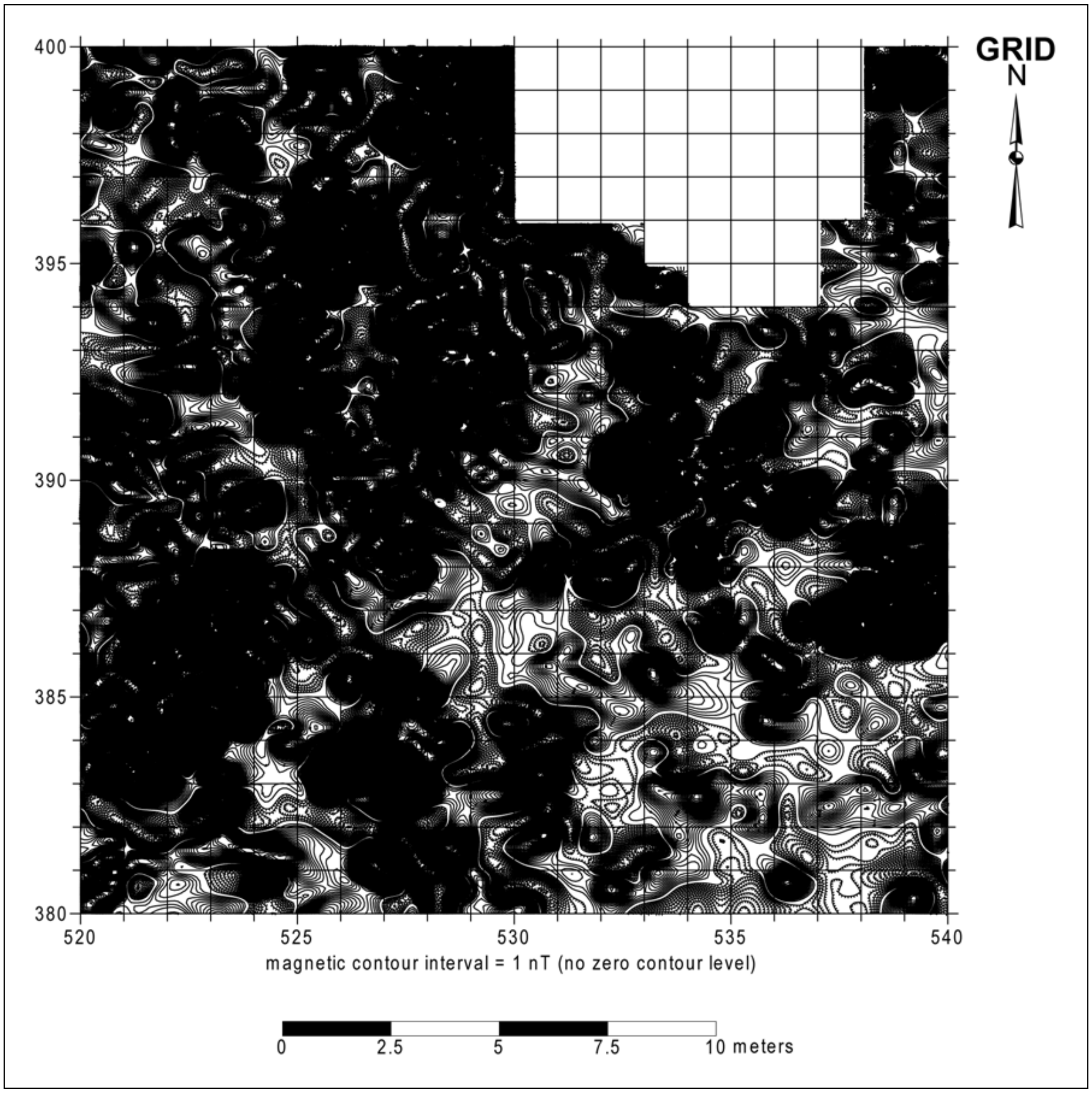



**Figure 24.** Magnetic contour plot of grid unit 12 (N380/E520).

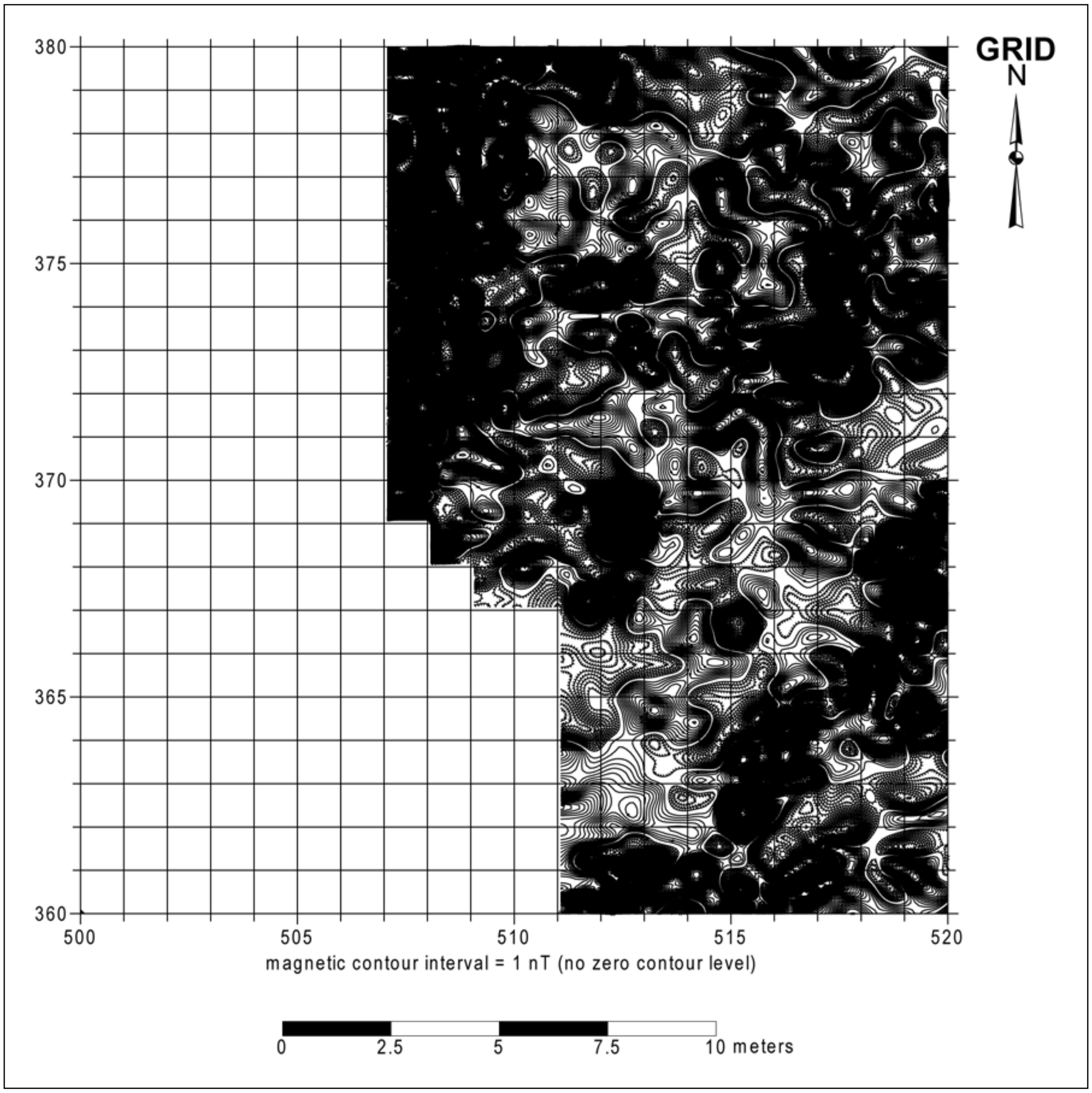



**Figure 25.** Magnetic contour plot of grid unit 13 (N360/E500).

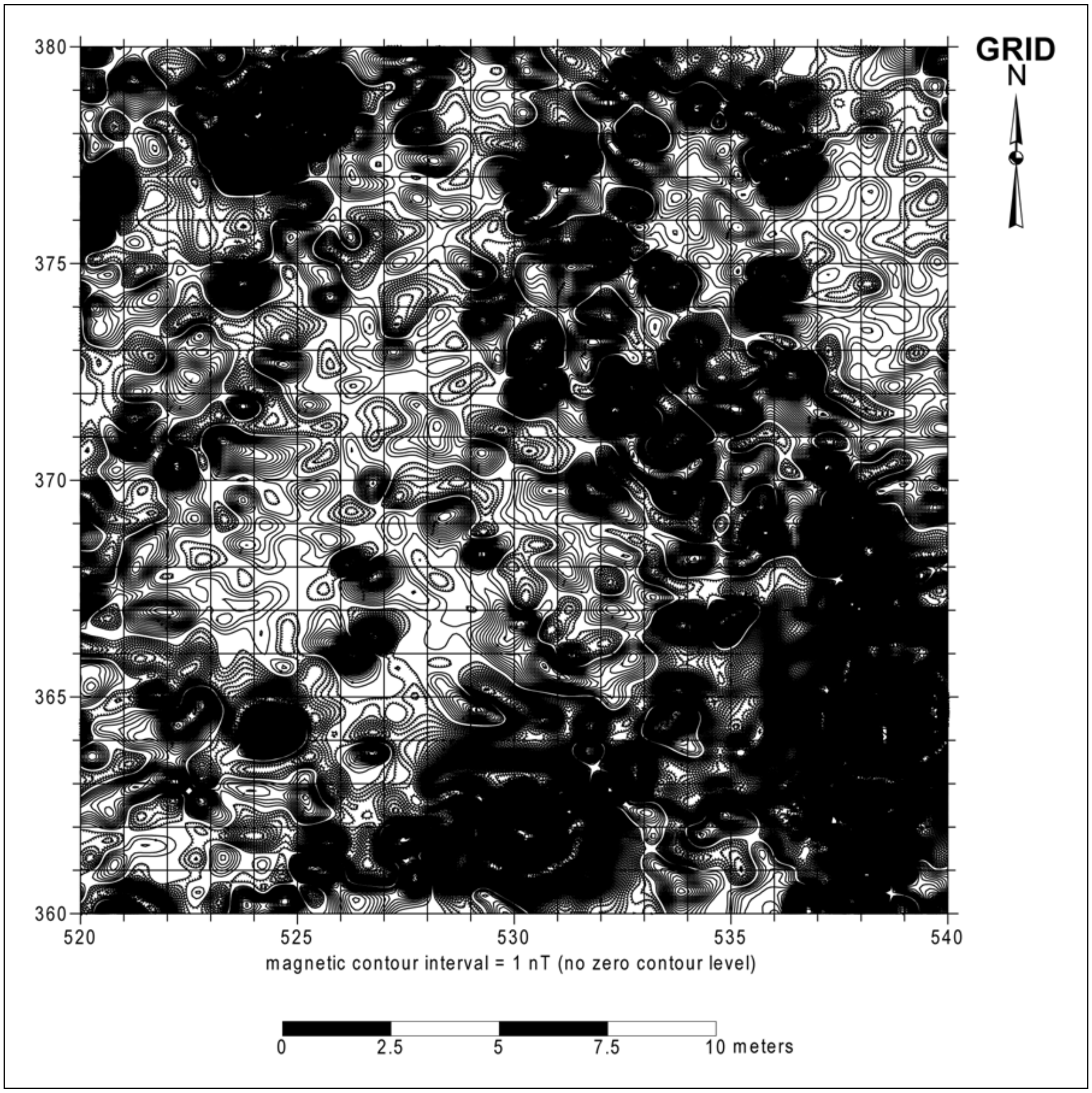



**Figure 26.** Magnetic contour plot of grid unit 14 (N360/E520).

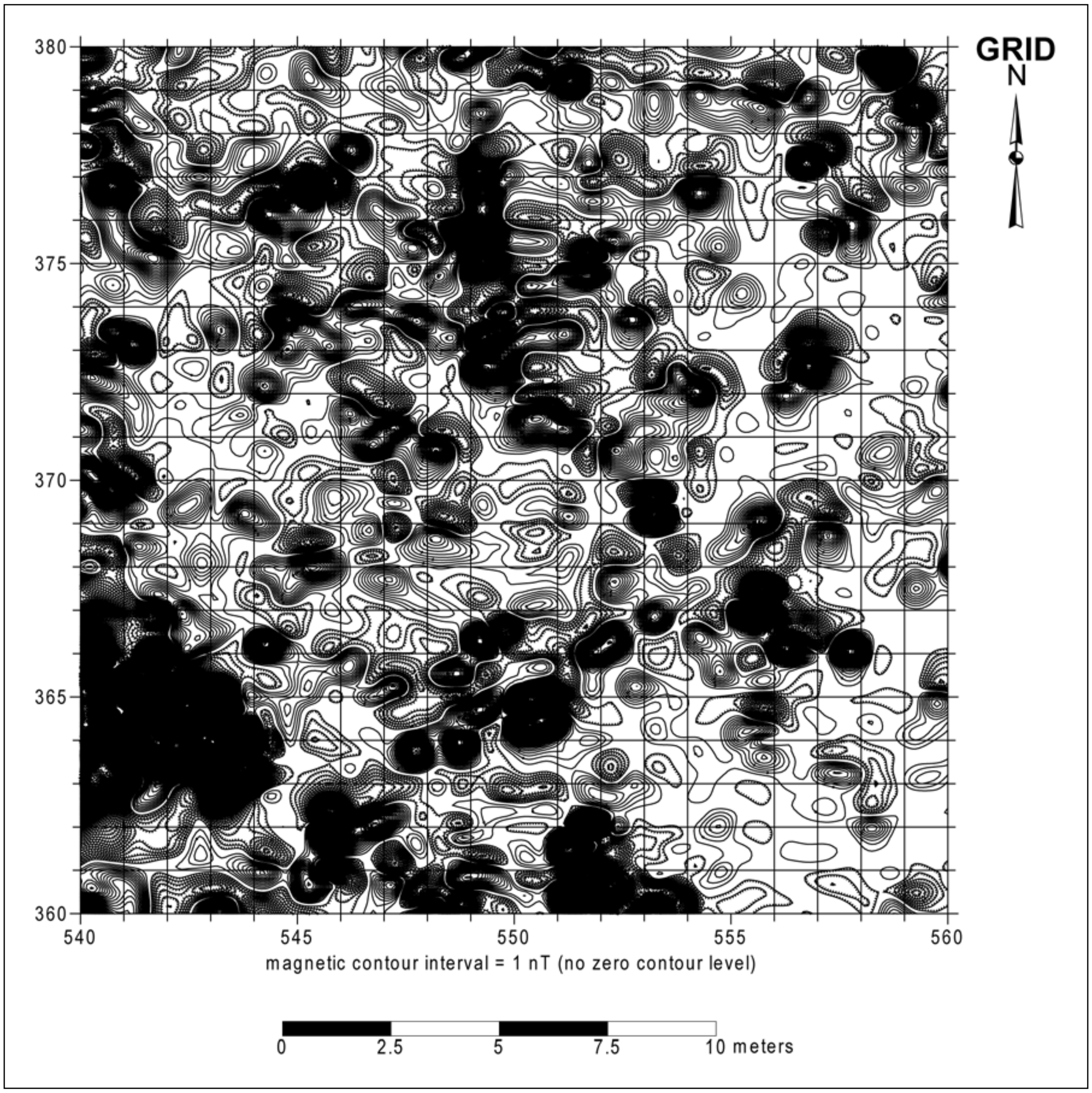



**Figure 27.** Magnetic contour plot of grid unit 15 (N360/E540).

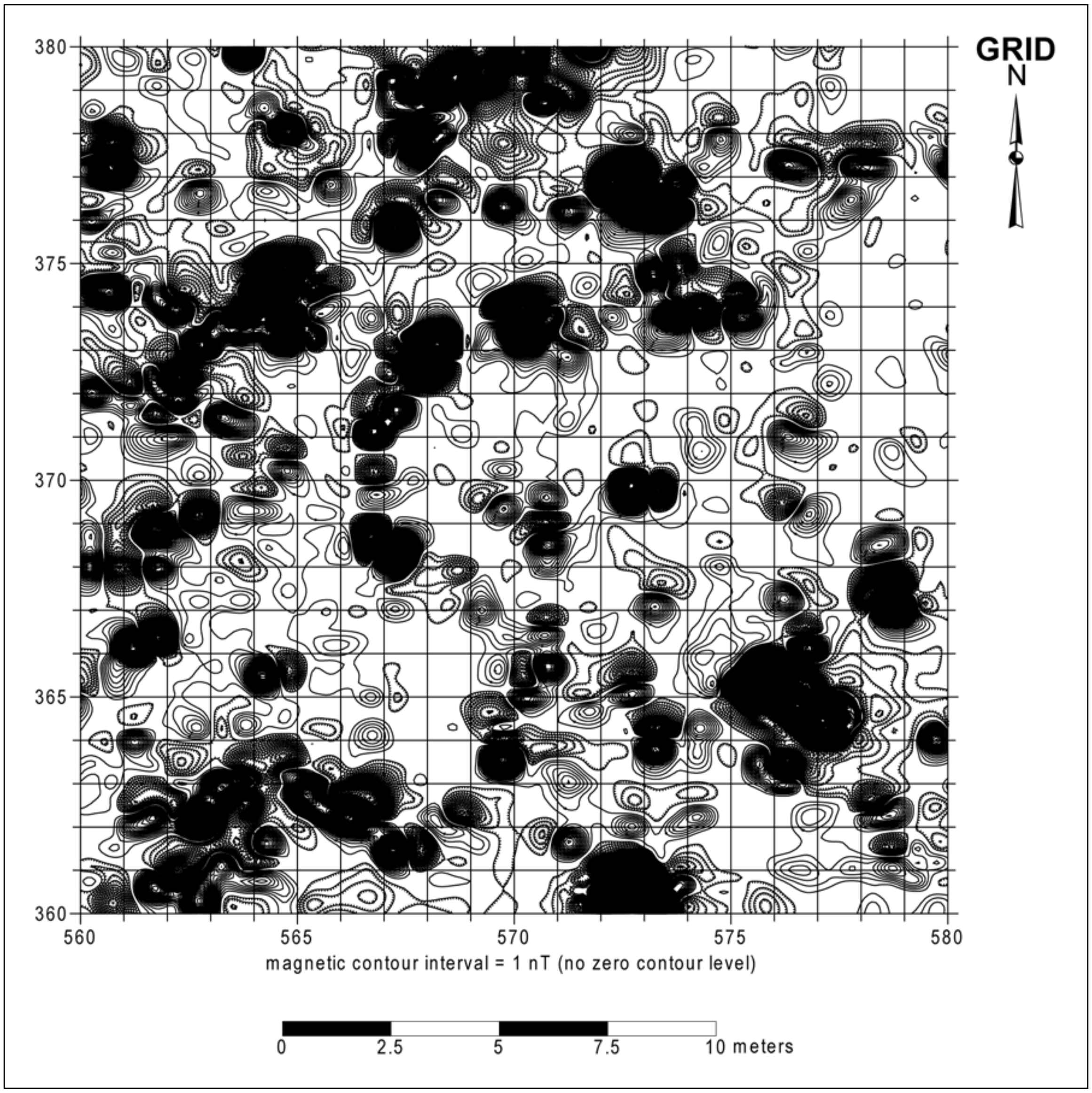



**Figure 28.** Magnetic contour plot of grid unit 16 (N360/E560).

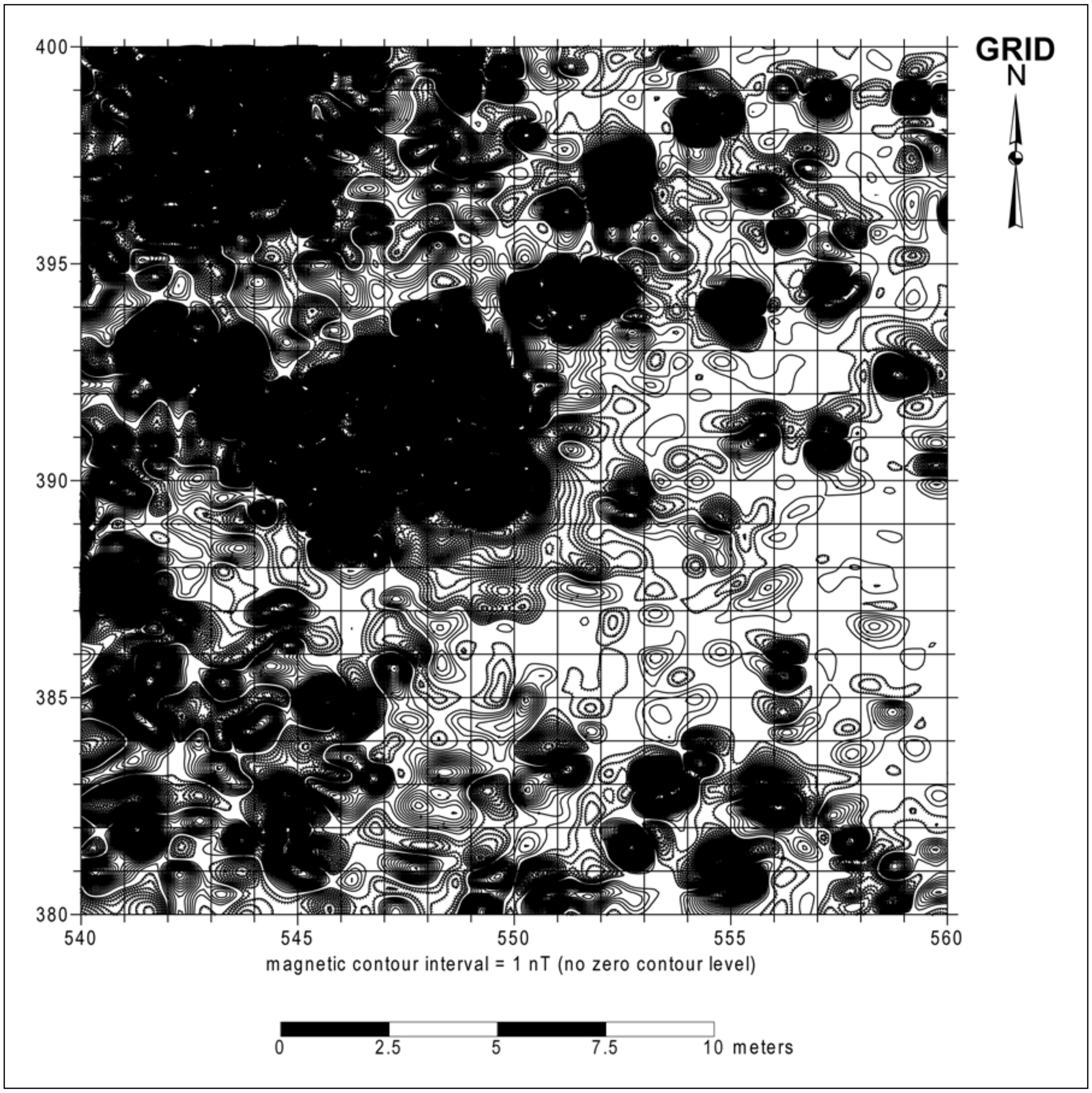



**Figure 29.** Magnetic contour plot of grid unit 17 (N380/E540).

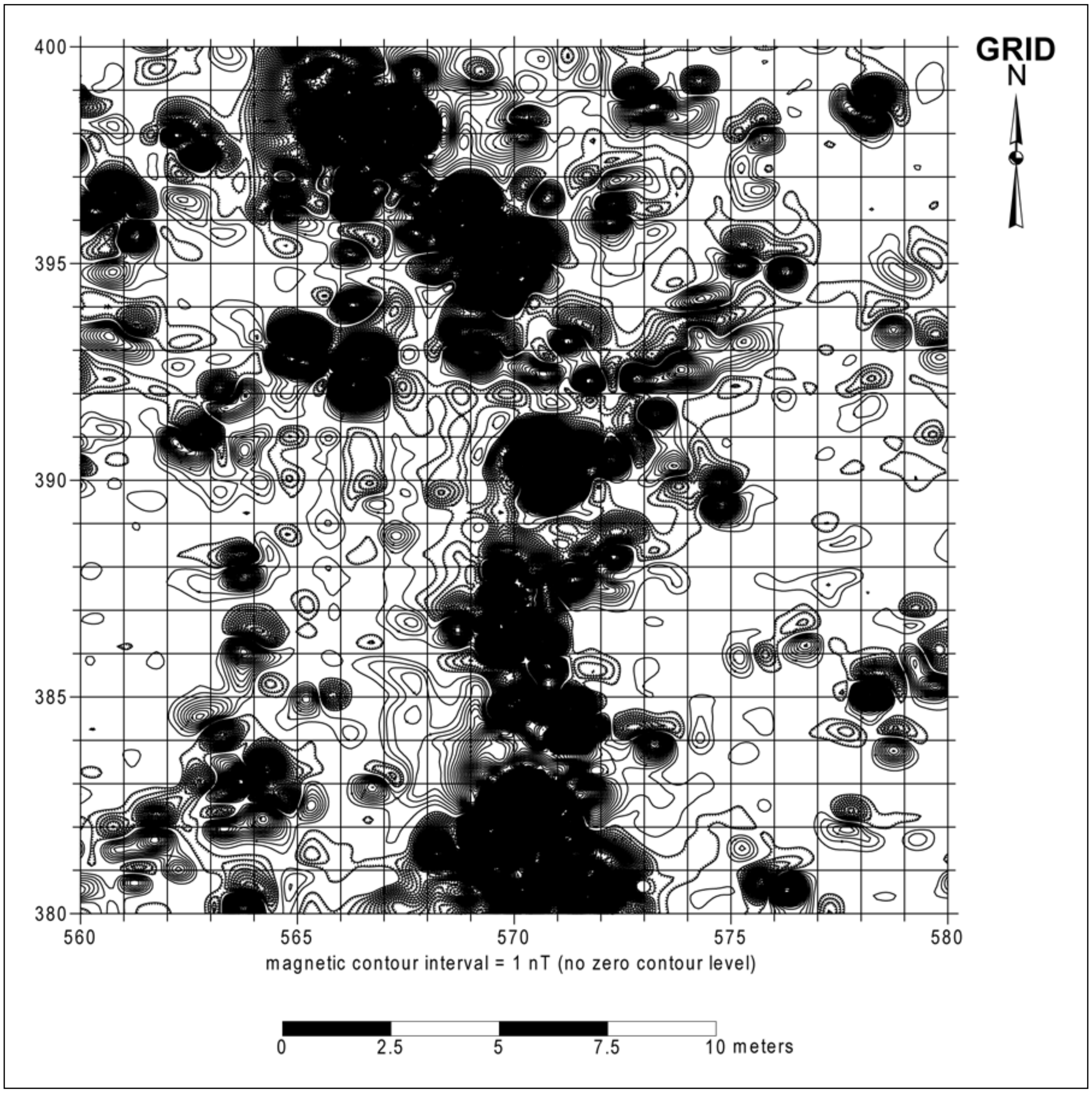



**Figure 30.** Magnetic contour plot of grid unit 18 (N380/E580).

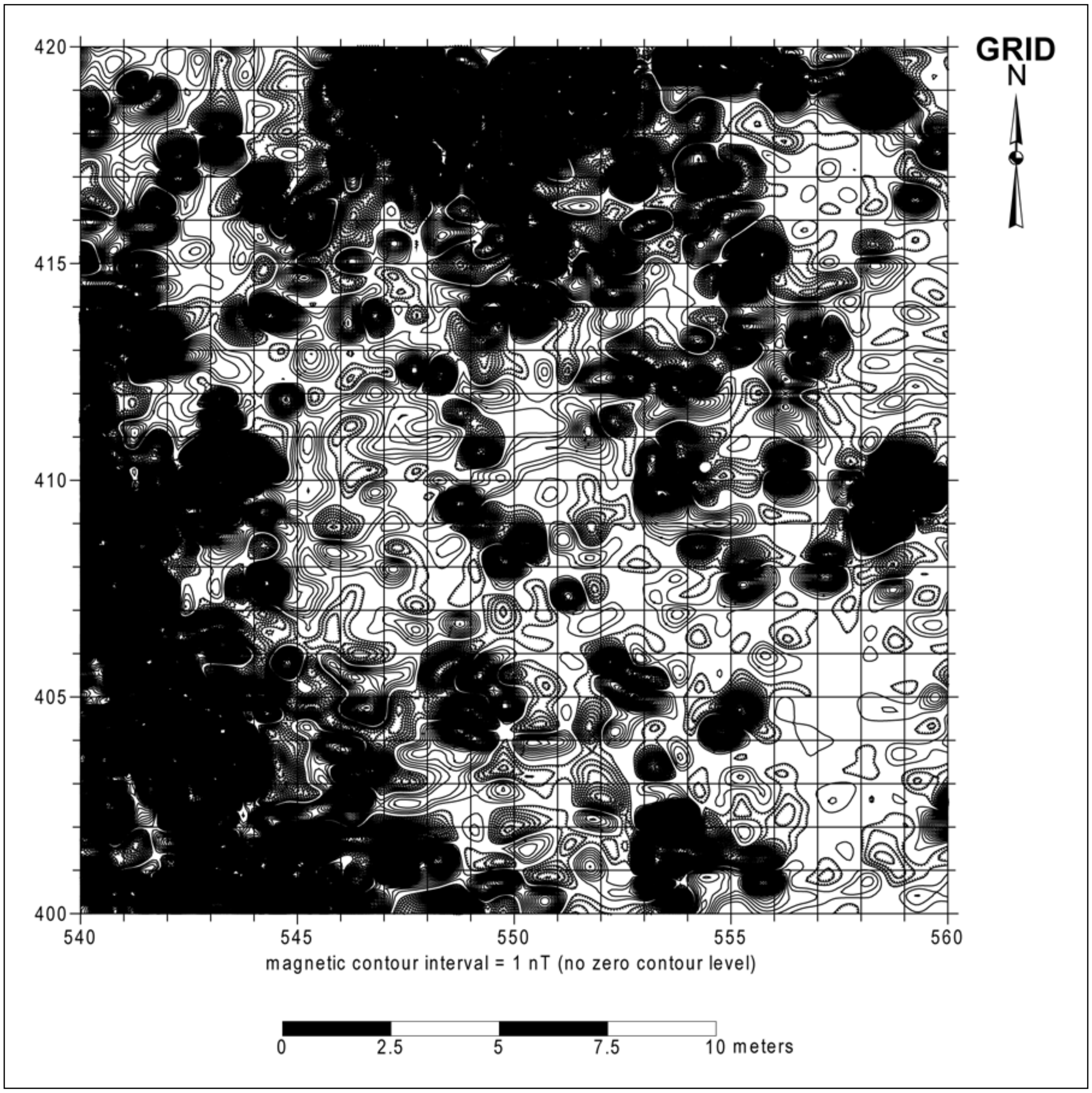



**Figure 31.** Magnetic contour plot of grid unit 19 (N400/E540).

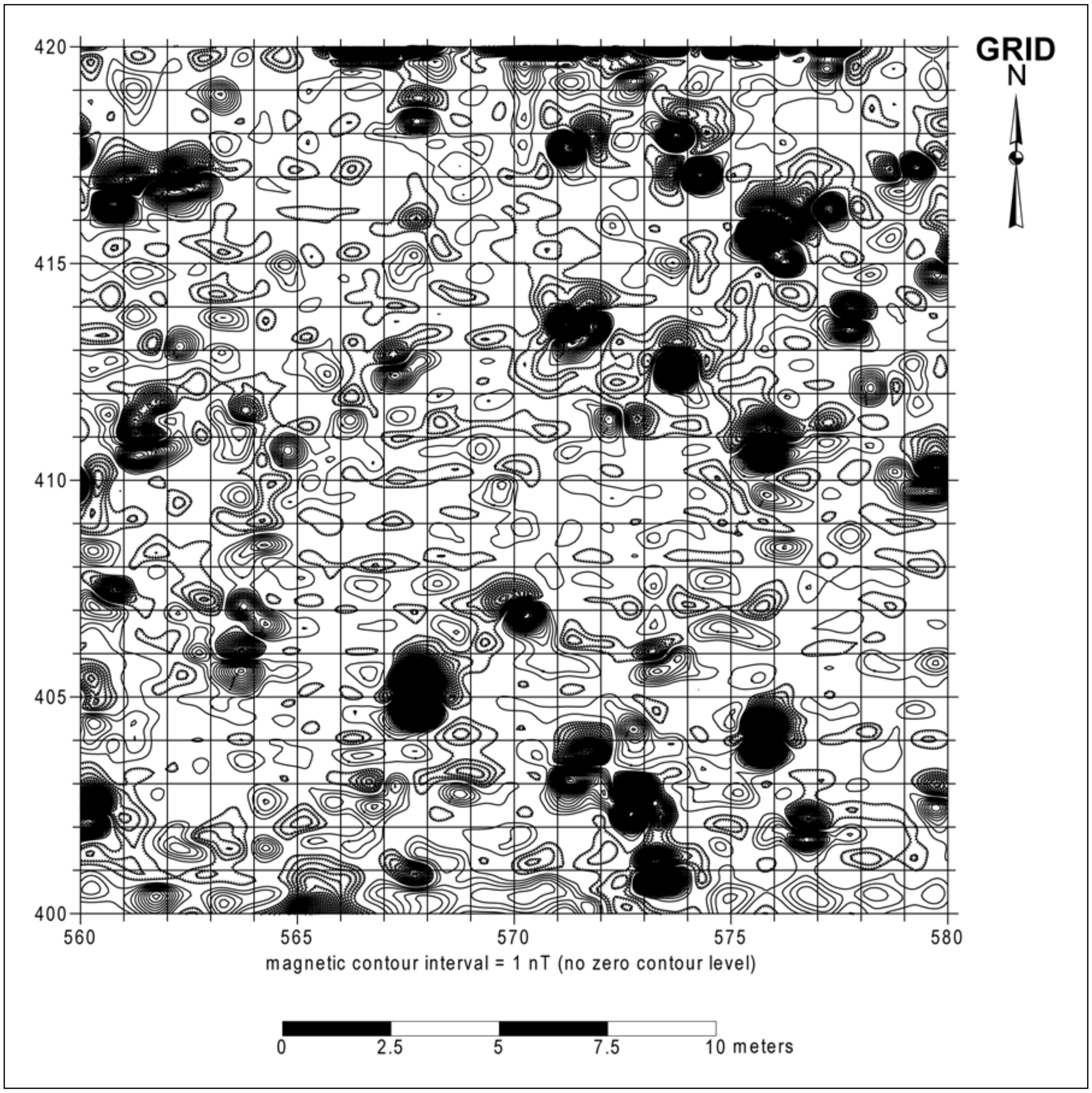



**Figure 32.** Magnetic contour plot of grid unit 20 (N400/E560).

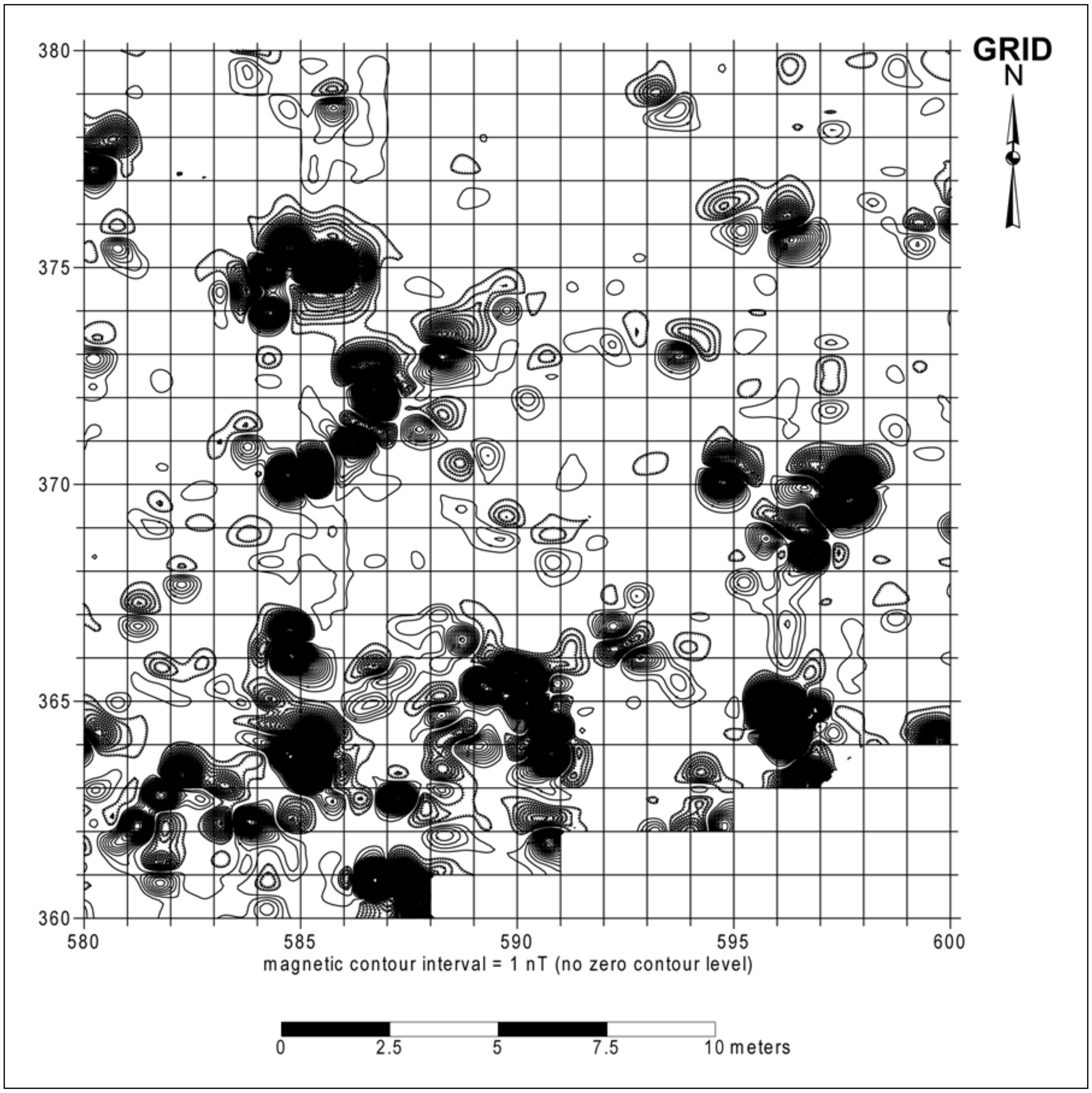



**Figure 33.** Magnetic contour plot of grid unit 21 (N360/E580).

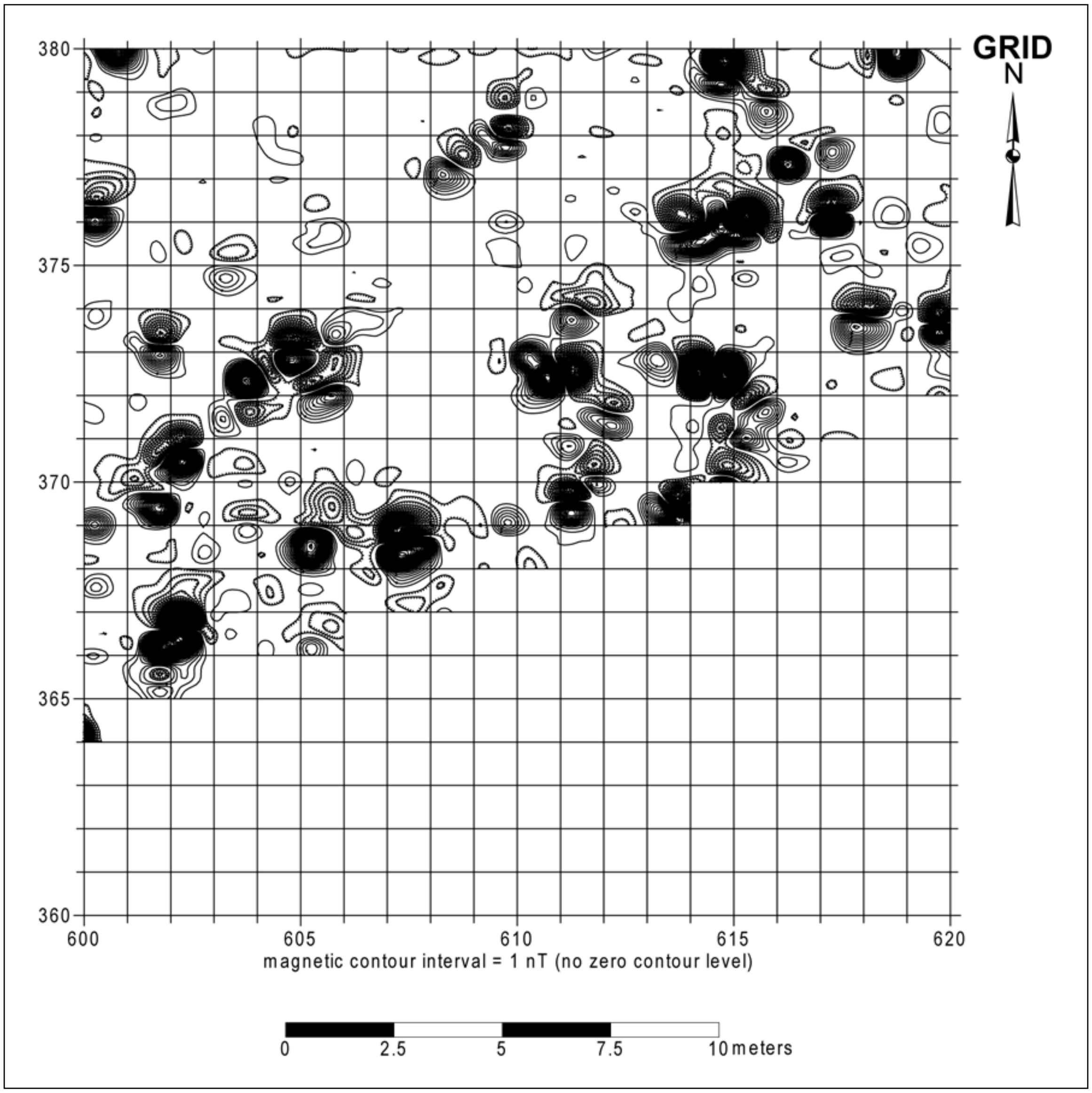



**Figure 34.** Magnetic contour plot of grid unit 22 (N360/E600).

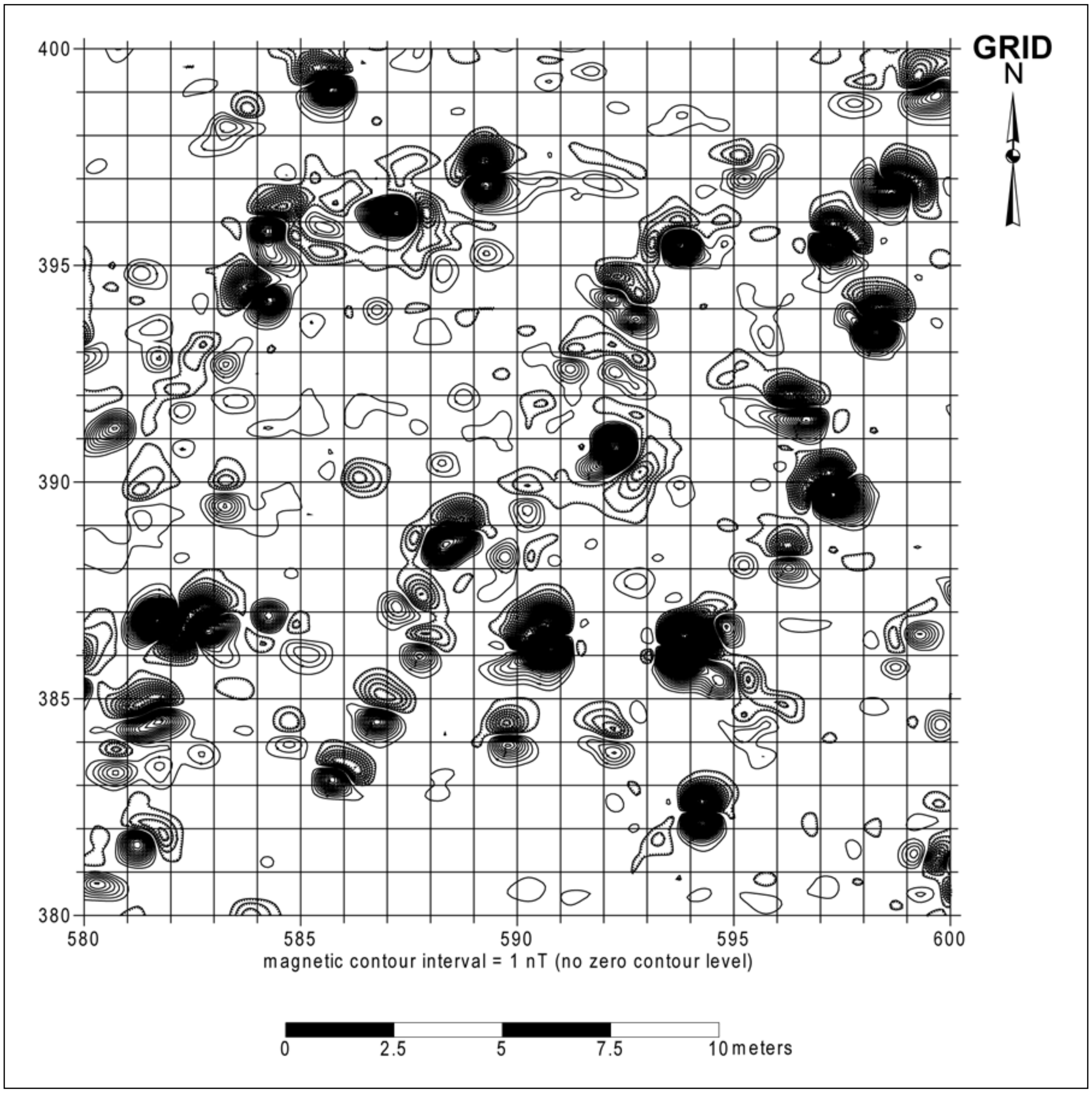



**Figure 35.** Magnetic contour plot of grid unit 23 (N380/E580).

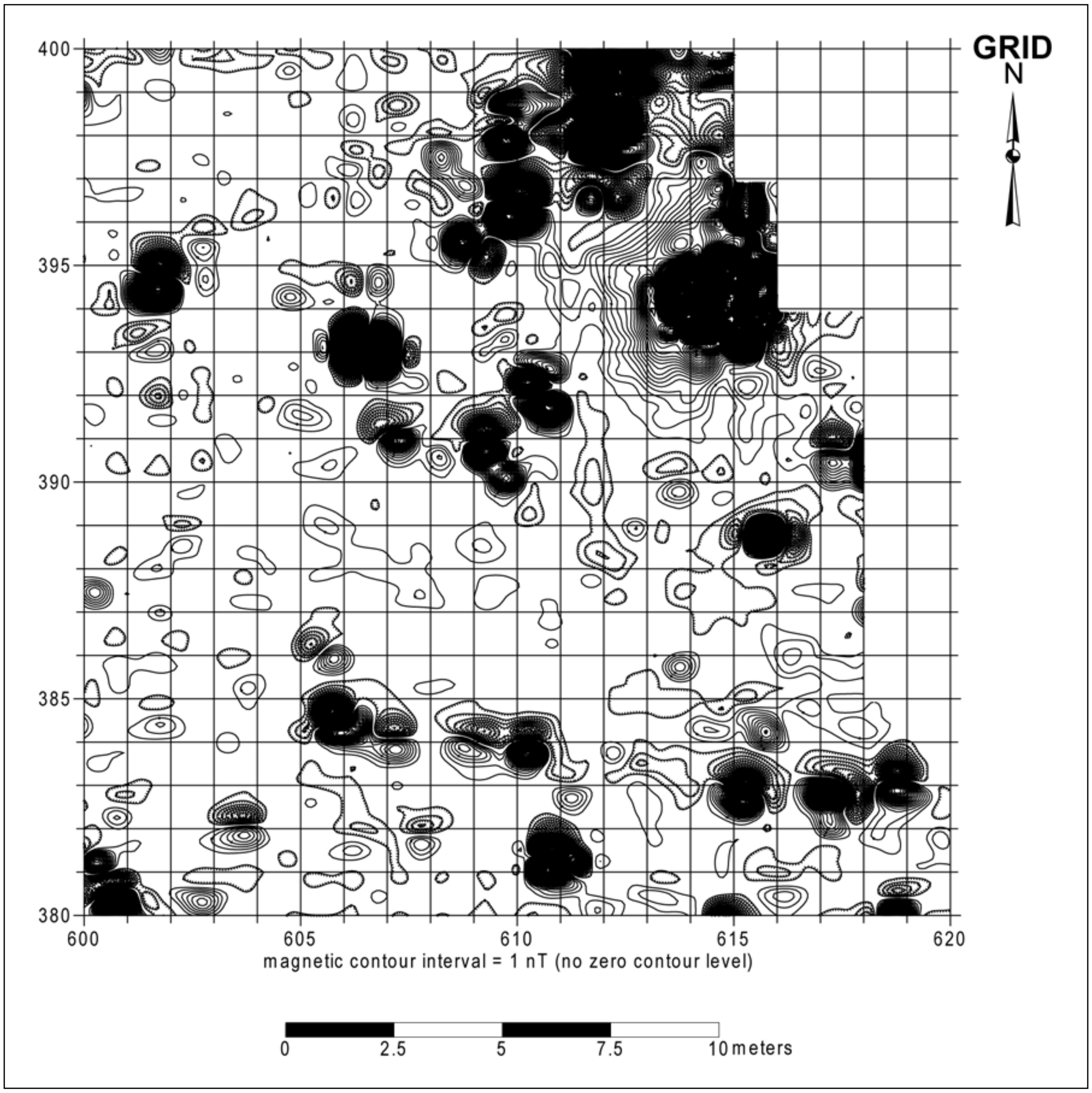



**Figure 36.** Magnetic contour plot of grid unit 24 (N380/E600).

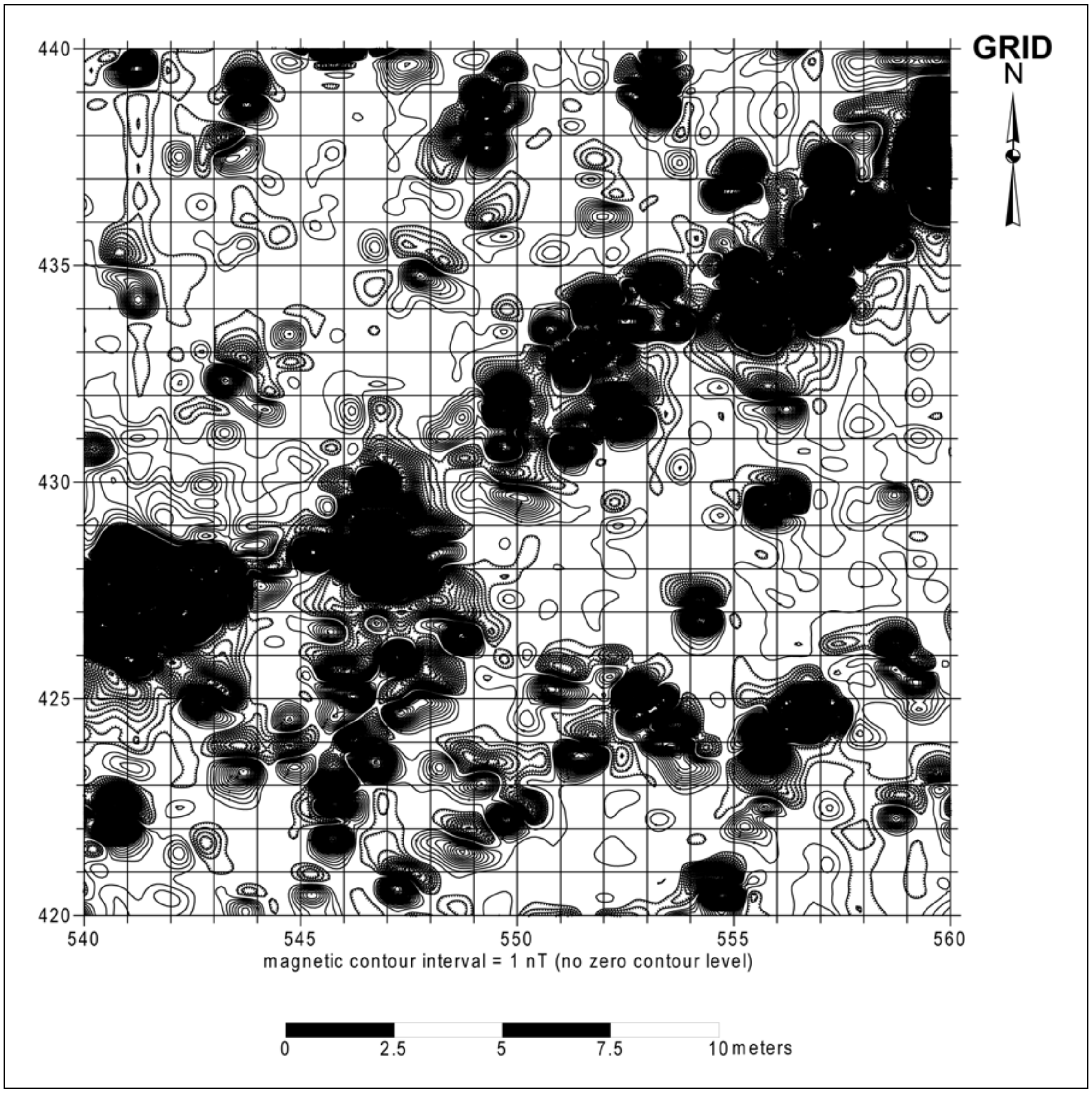



**Figure 37.** Magnetic contour plot of grid unit 25 (N420/E540).

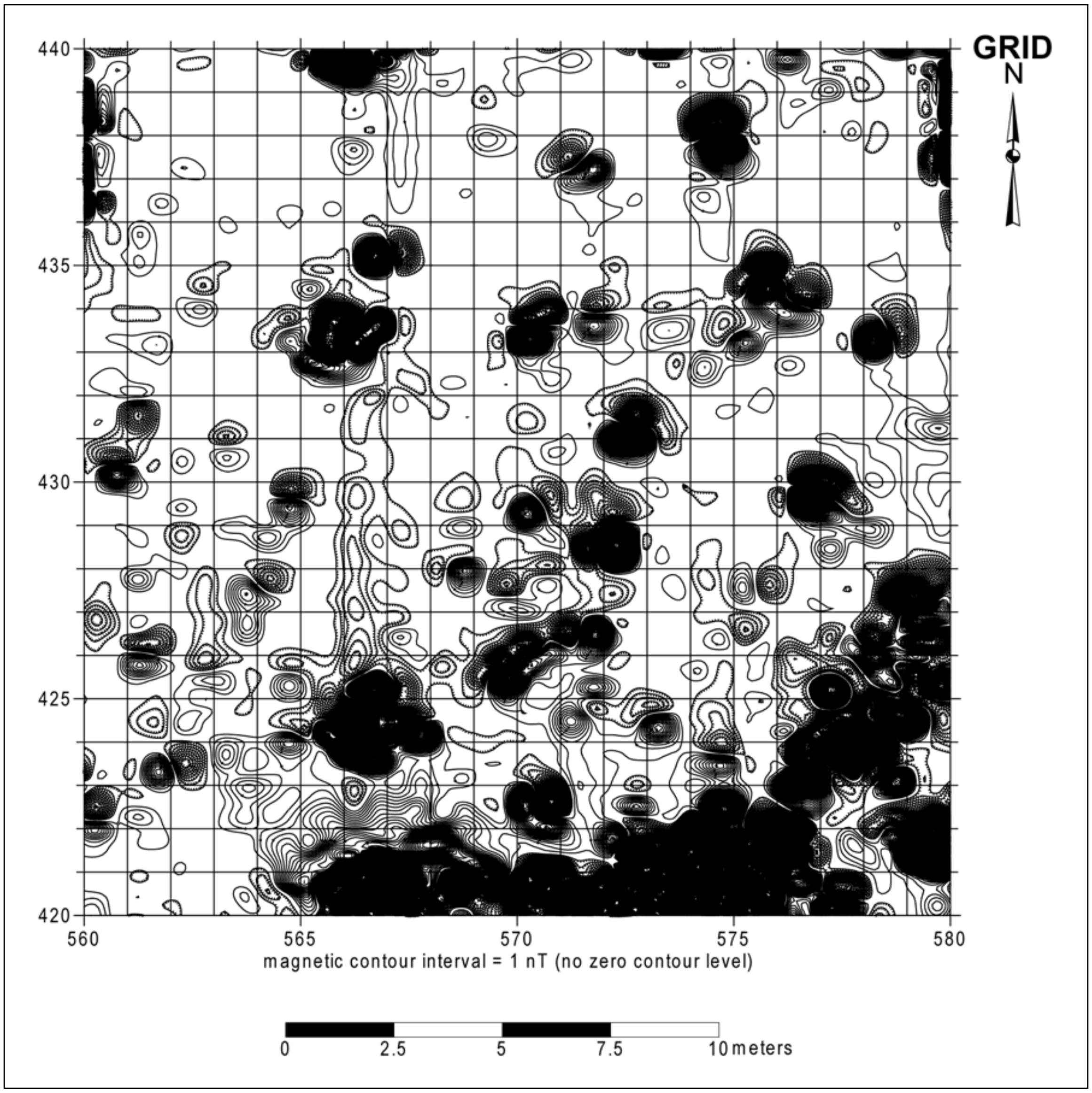



**Figure 38.** Magnetic contour plot of grid unit 26 (N420/E560).

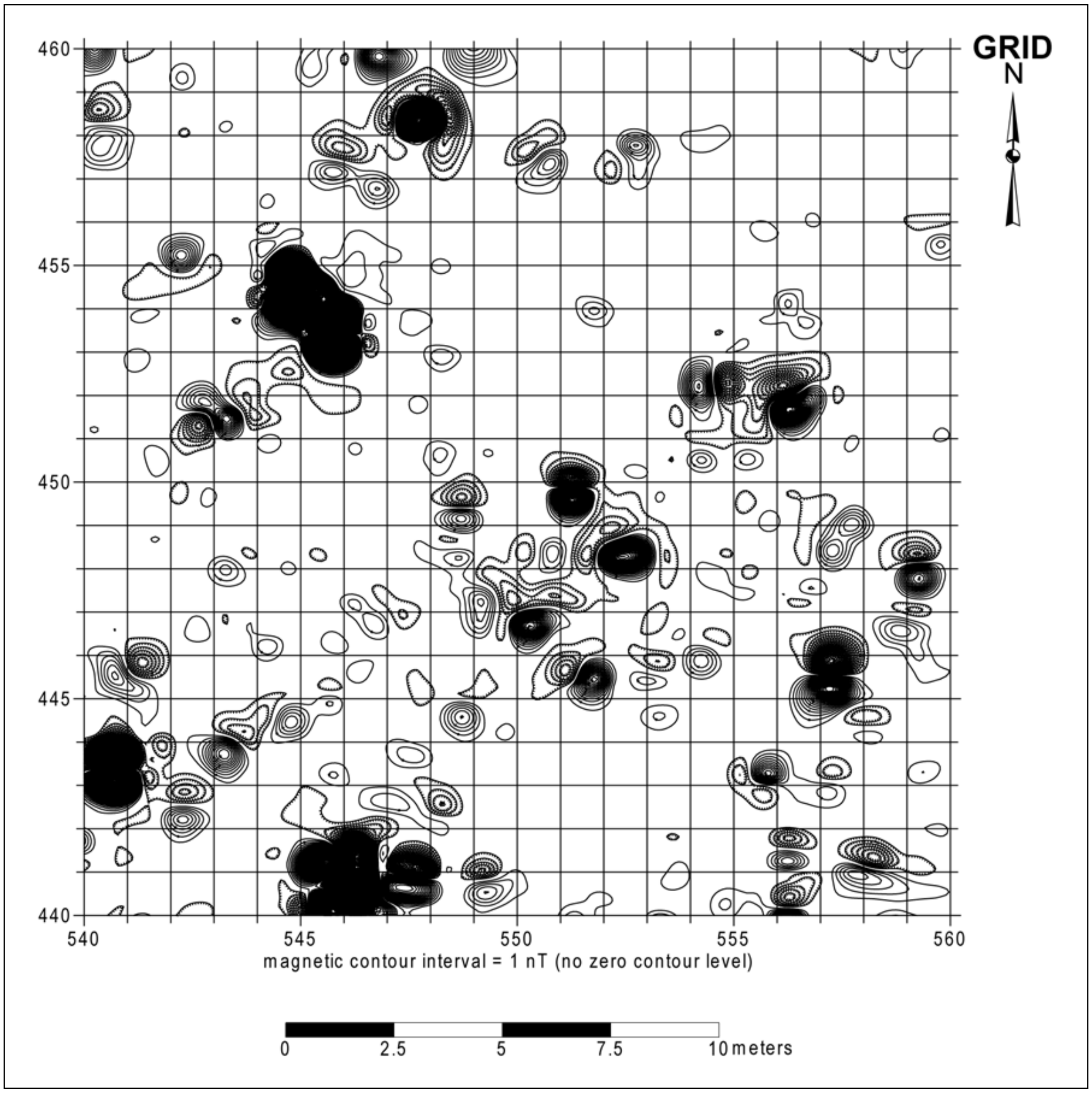



**Figure 39.** Magnetic contour plot of grid unit 27 (N440/E540).

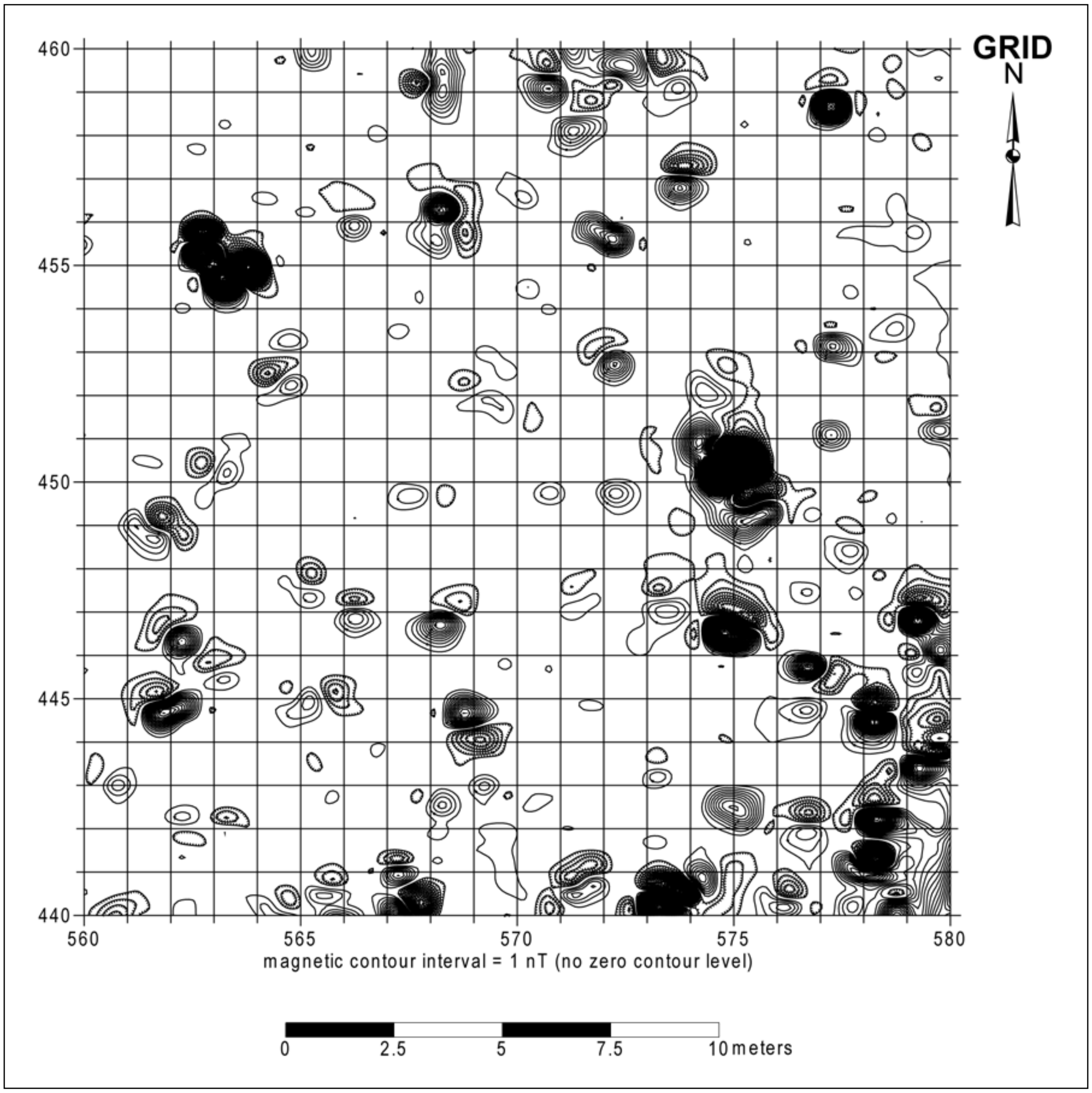



**Figure 40.** Magnetic contour plot of grid unit 28 (N440/E560).

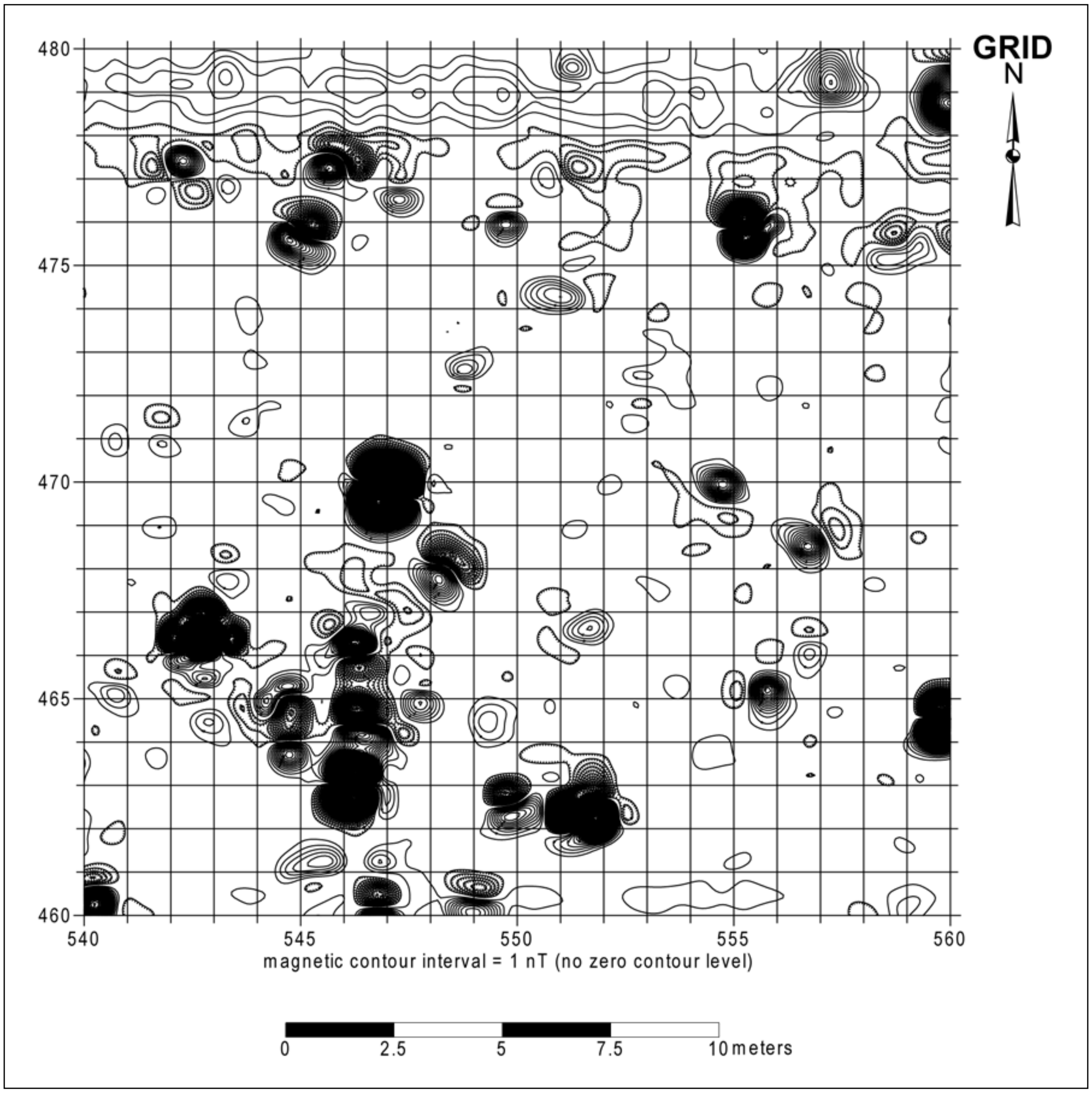



**Figure 41.** Magnetic contour plot of grid unit 29 (N460/E540).

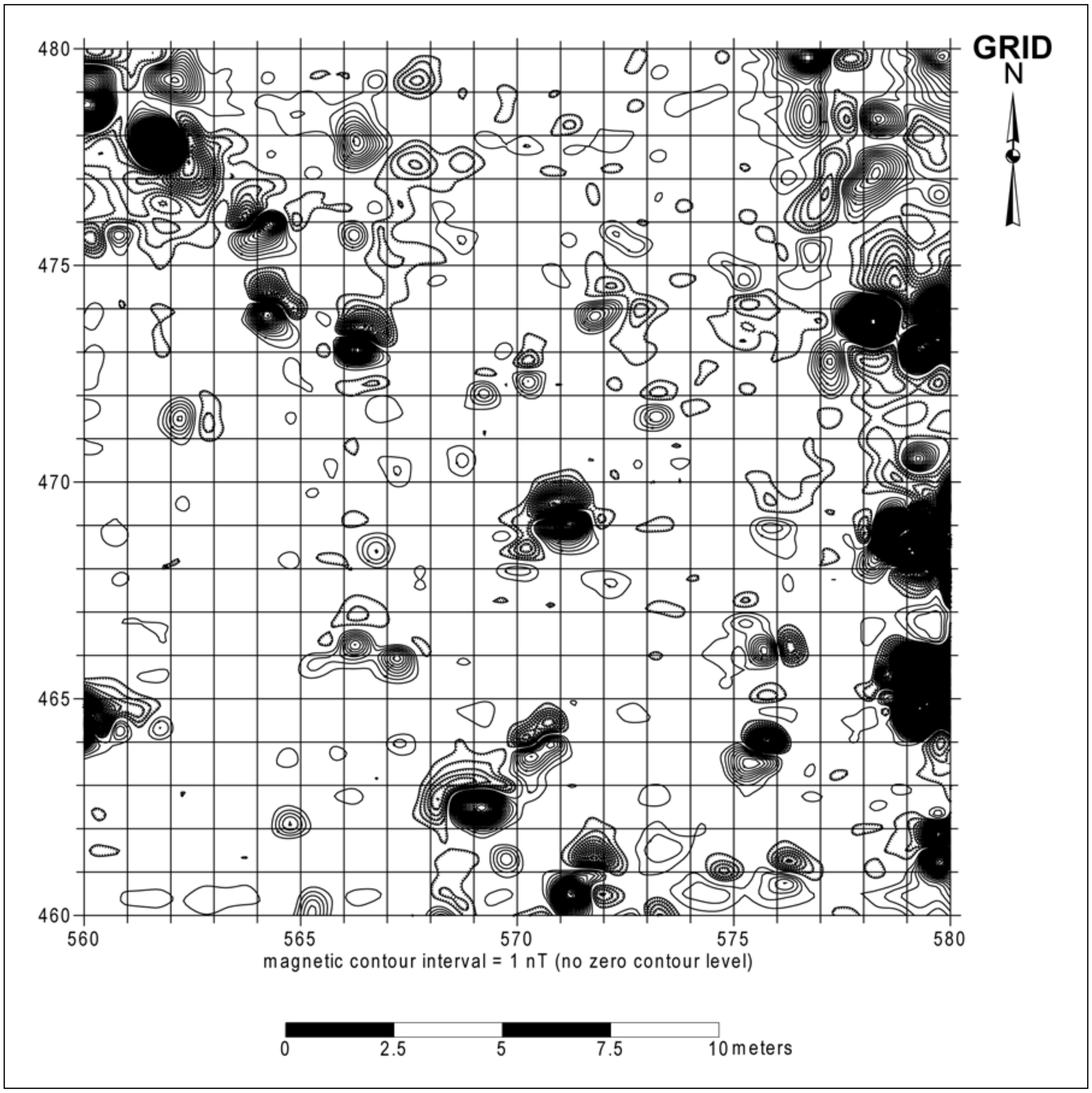



**Figure 42.** Magnetic contour plot of grid unit 30 (N460/E560).

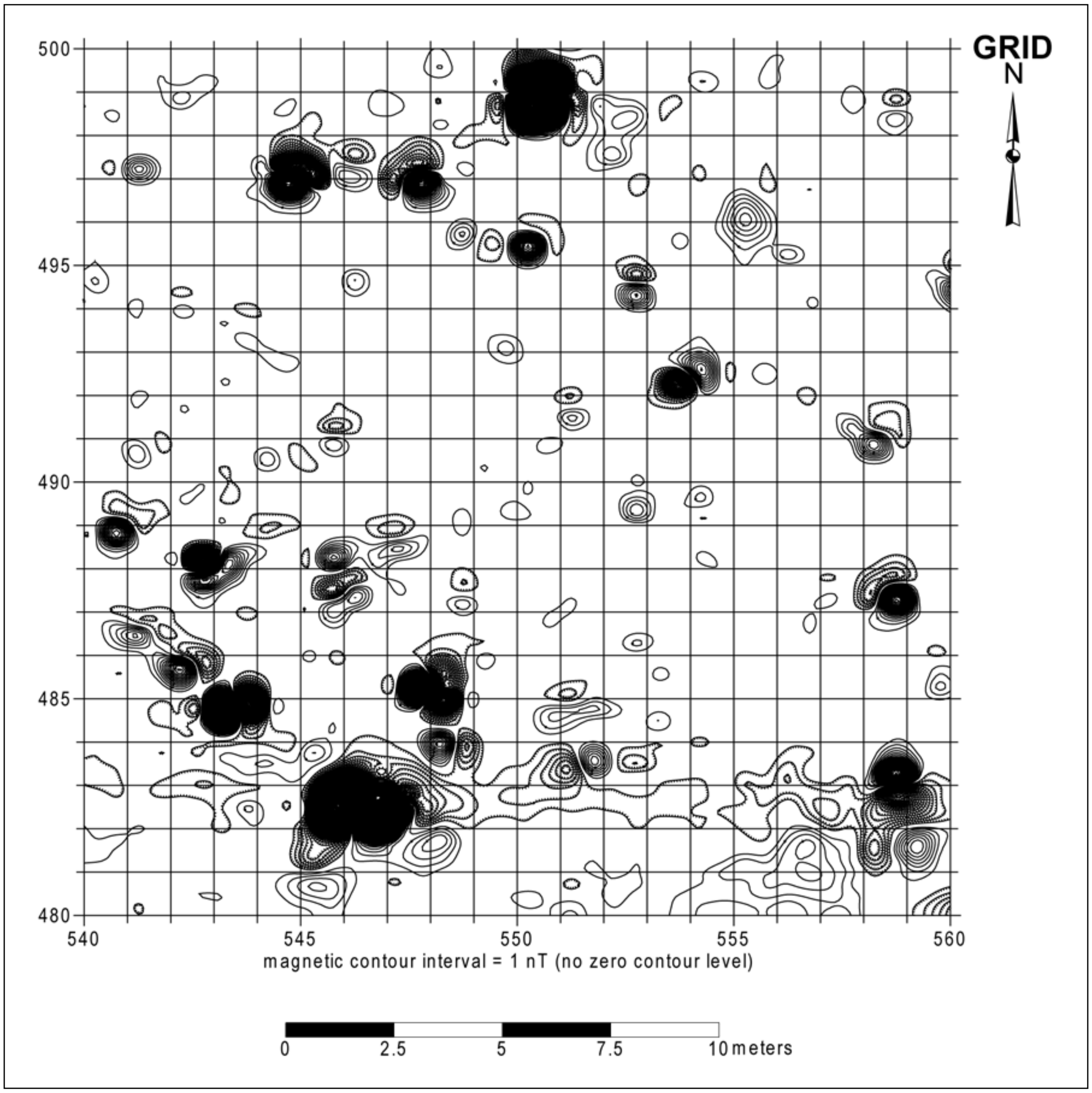



**Figure 43.** Magnetic contour plot of grid unit 31 (N480/E540).

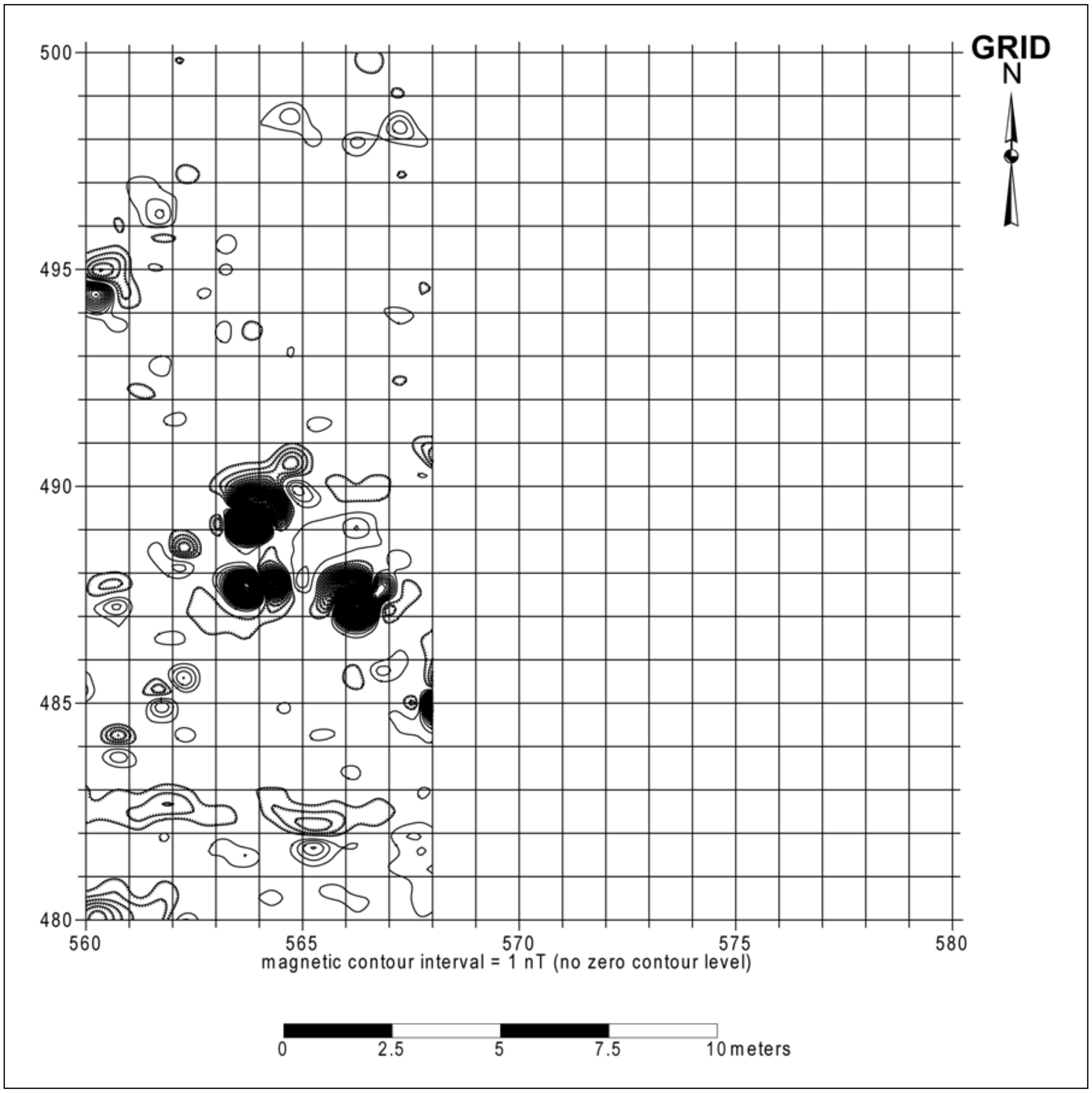



**Figure 44.** Magnetic contour plot of grid unit 32 (N480/E560).

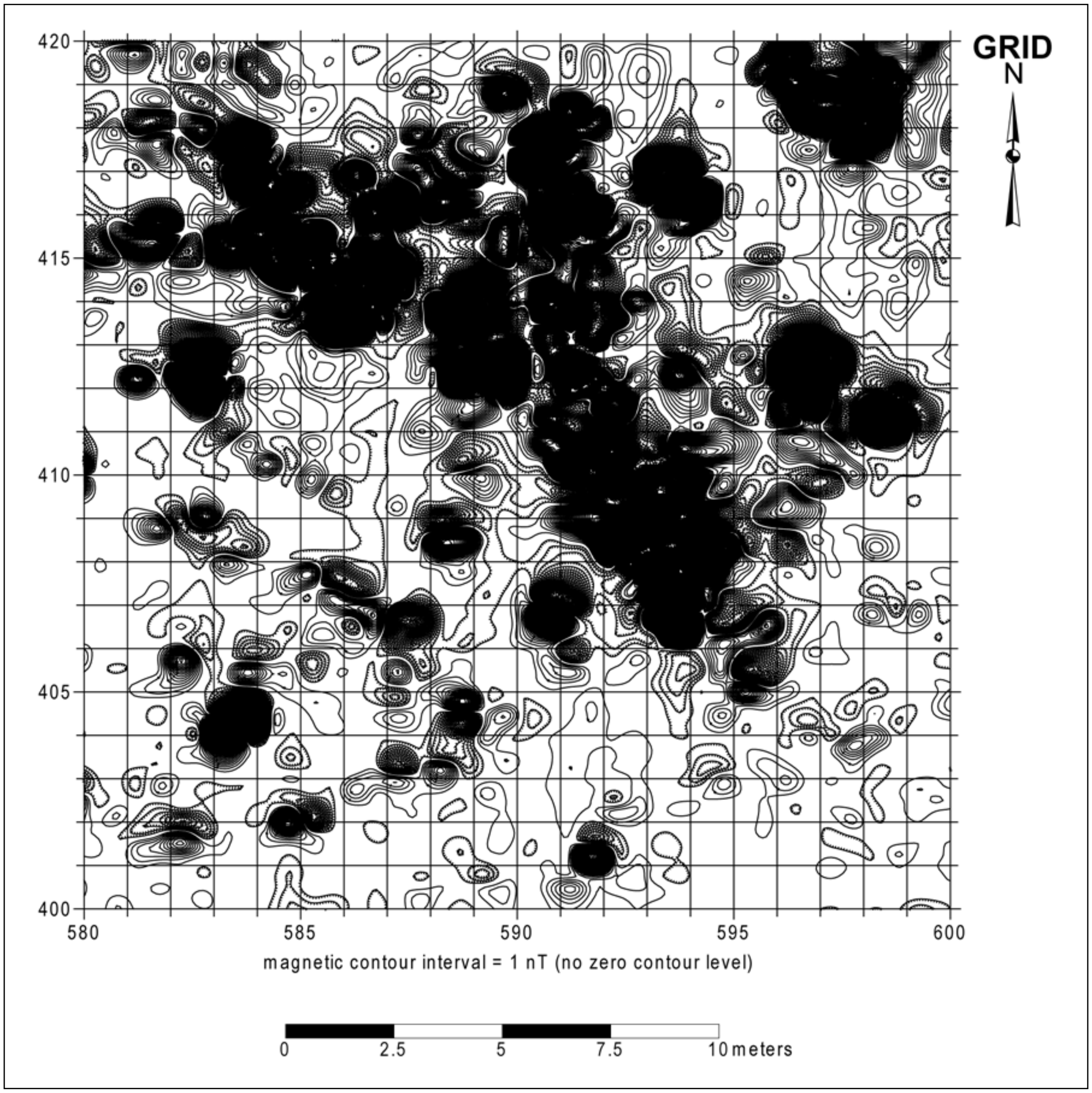



**Figure 45.** Magnetic contour plot of grid unit 33 (N400/E580).

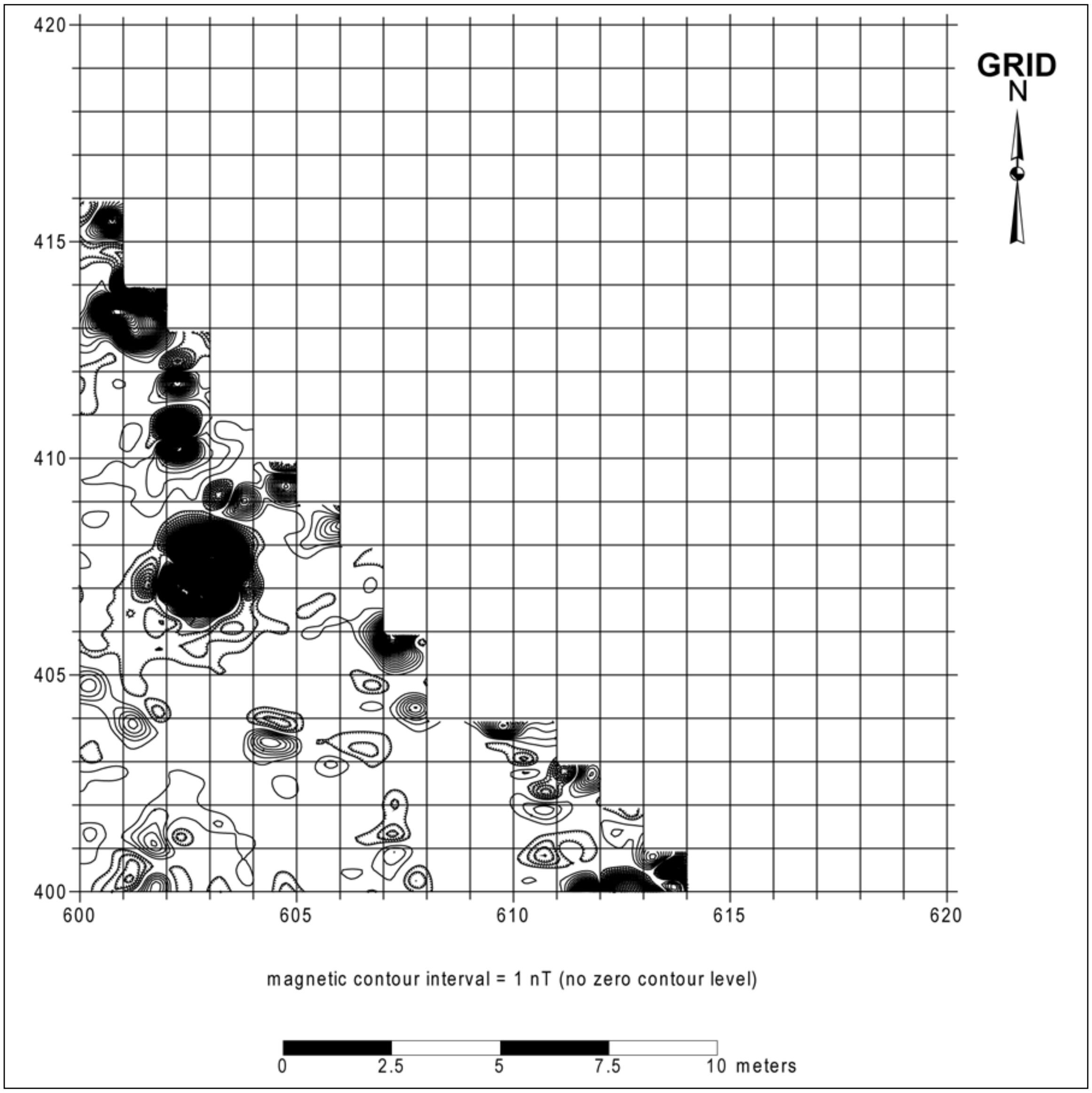



**Figure 46.** Magnetic contour plot of grid unit 34 (N400/E600).

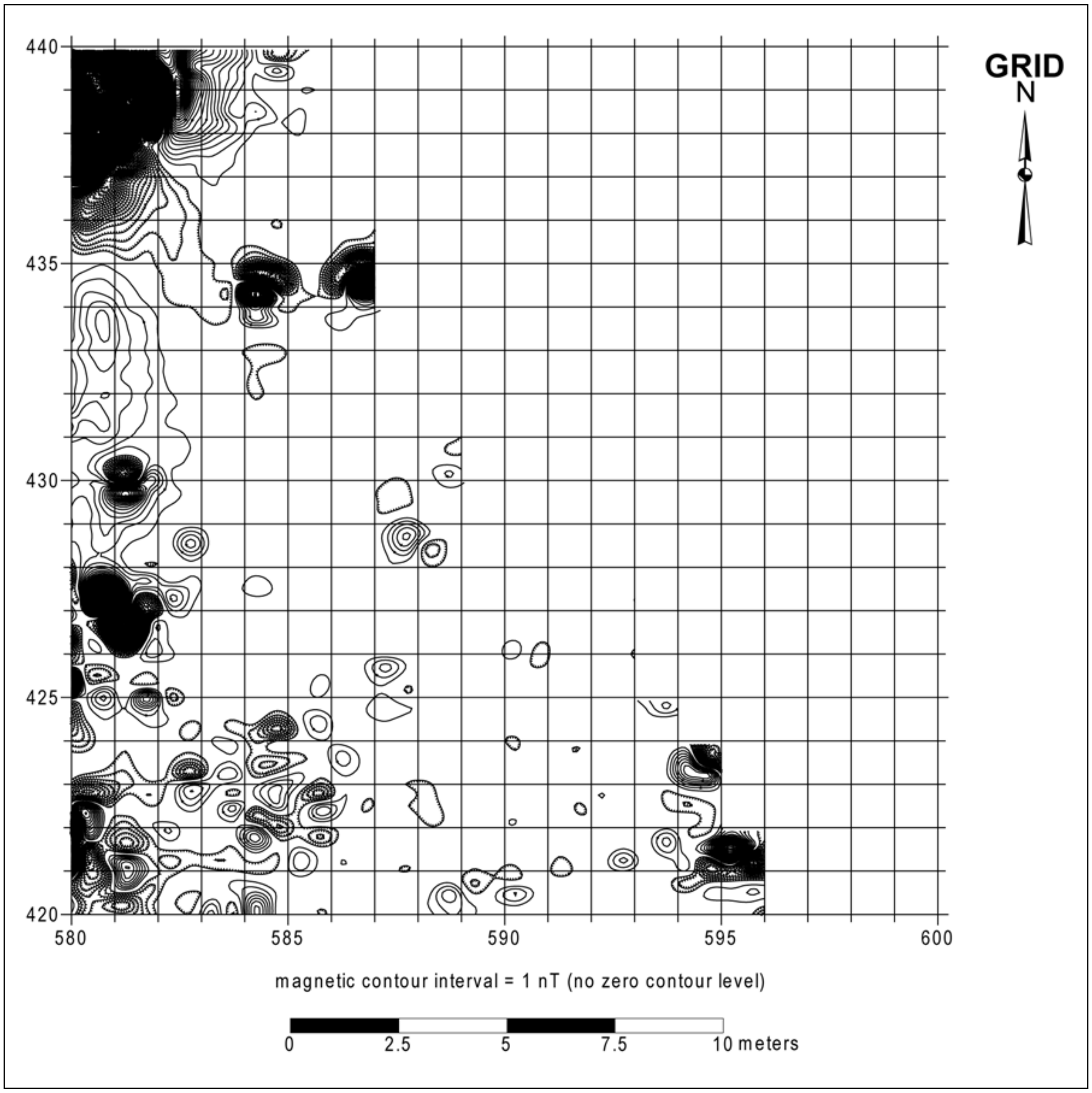



**Figure 47.** Magnetic contour plot of grid unit 35 (N420/E580).

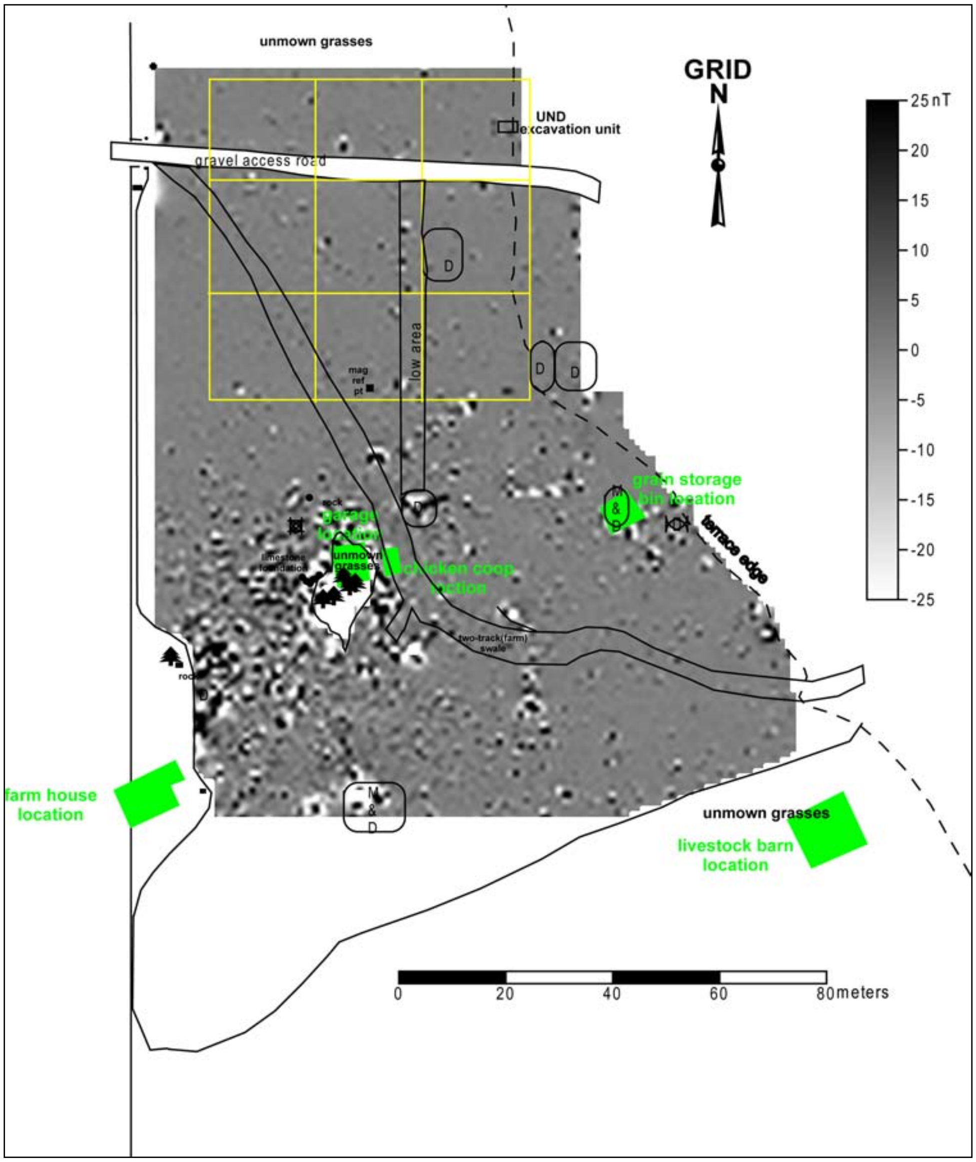



**Figure 48.** Location of Russell farm buildings and other farm related surface features.

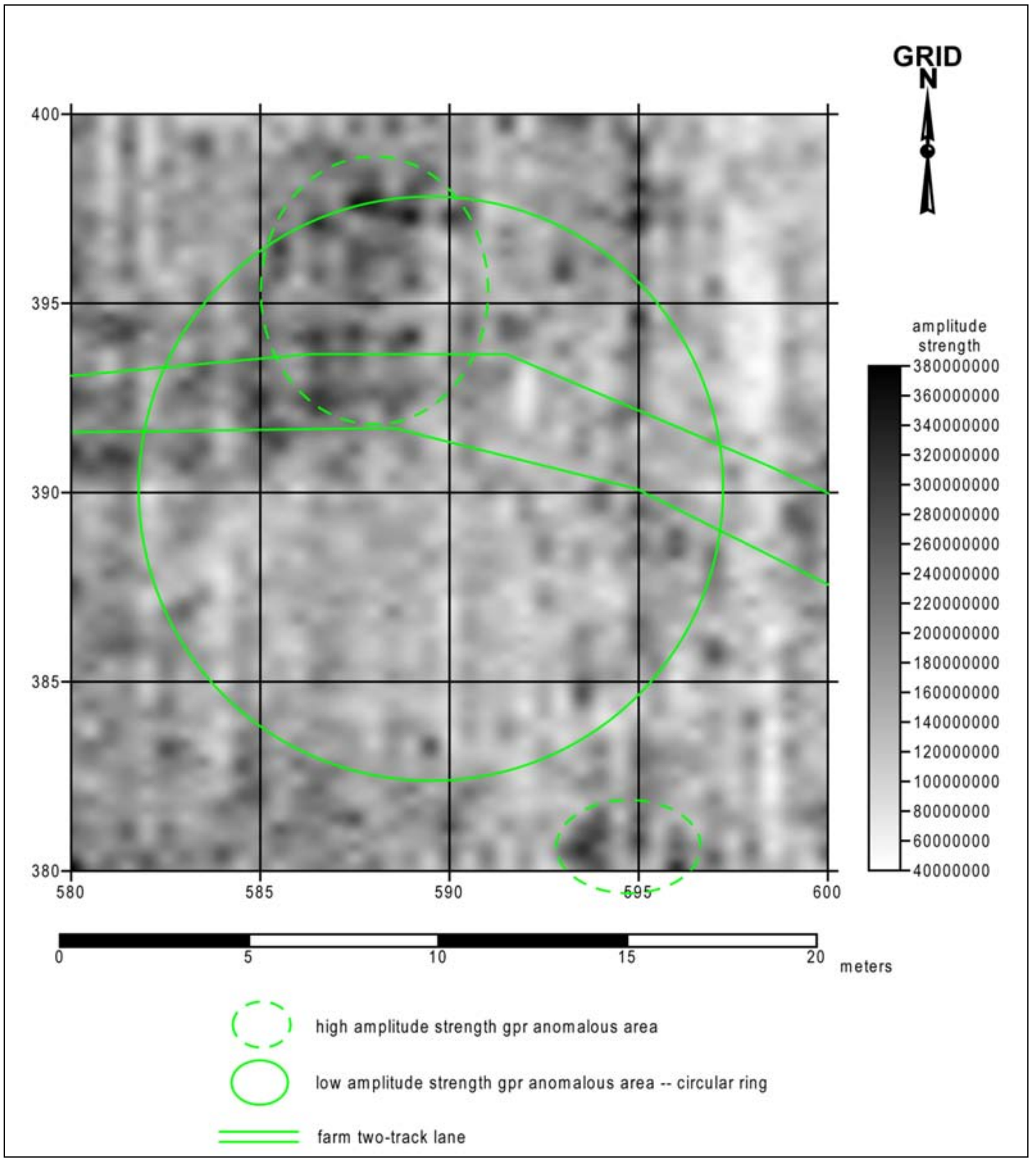



**Figure 49.** Ground-penetrating radar amplitude anomalies in time slice 13 located in grid unit 23.

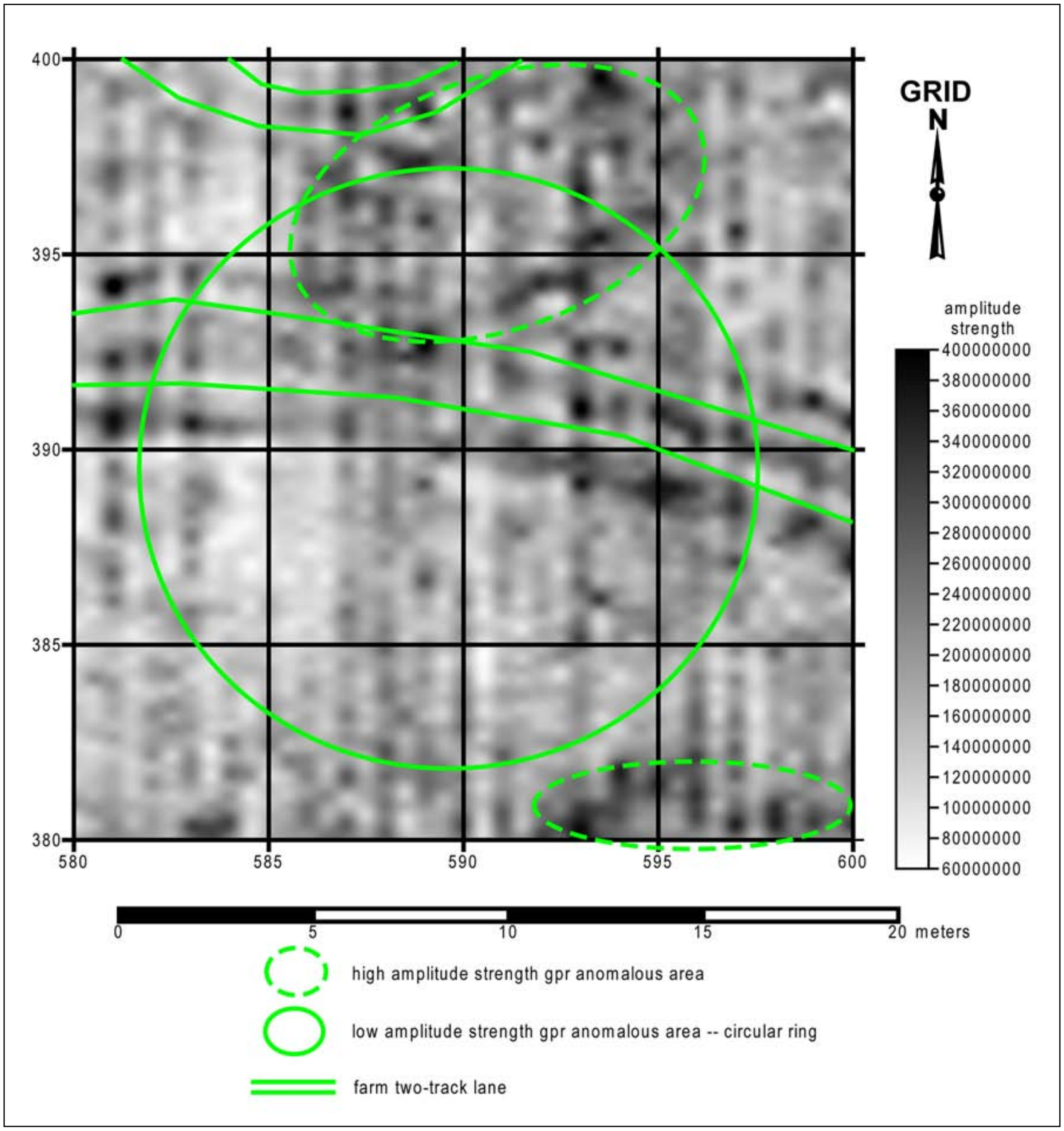



**Figure 50.** Ground-penetrating radar amplitude anomalies in time slice 15 located in grid unit 23.

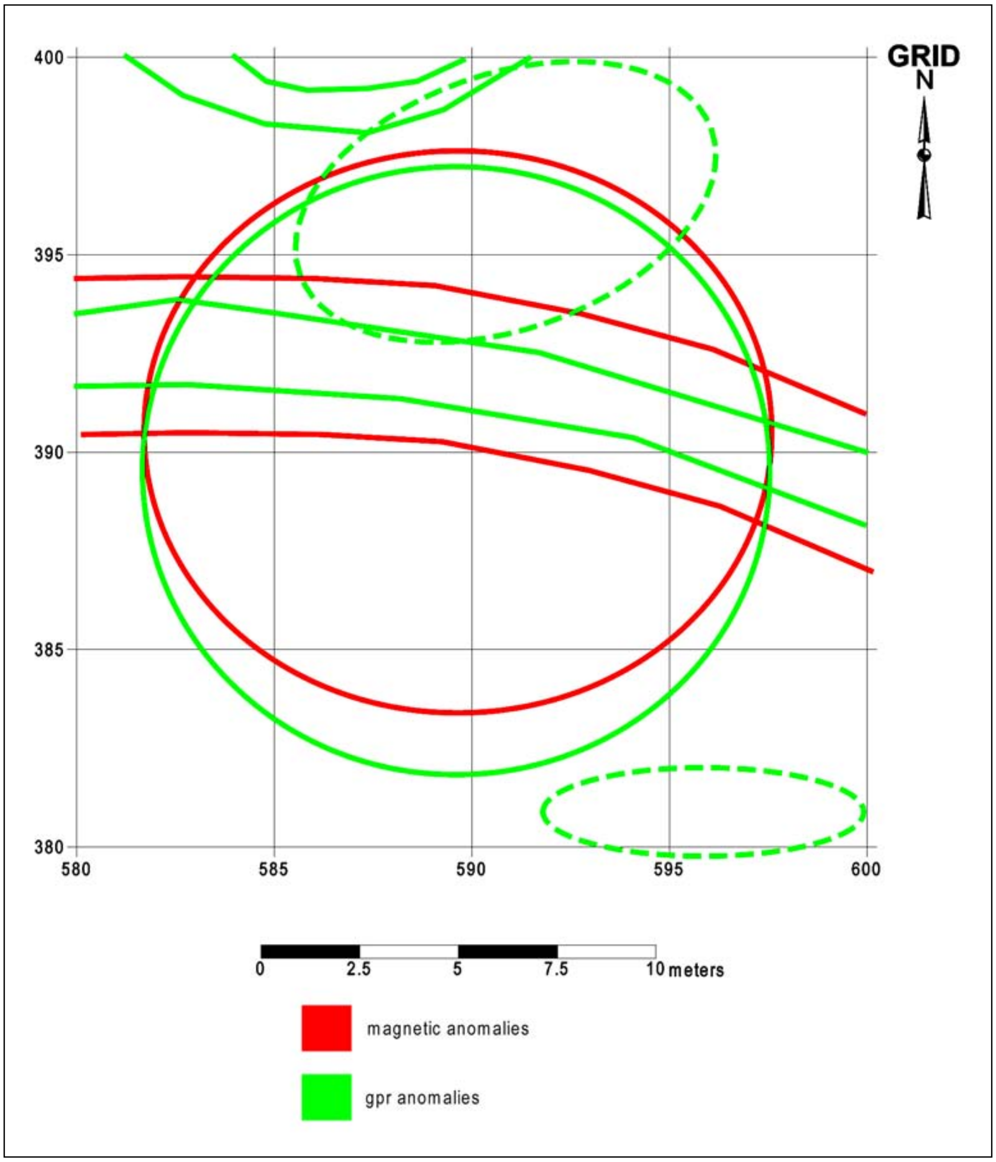



**Figure 51.** Overlay of magnetic and time slice 15 gpr anomalies in grid unit 23.

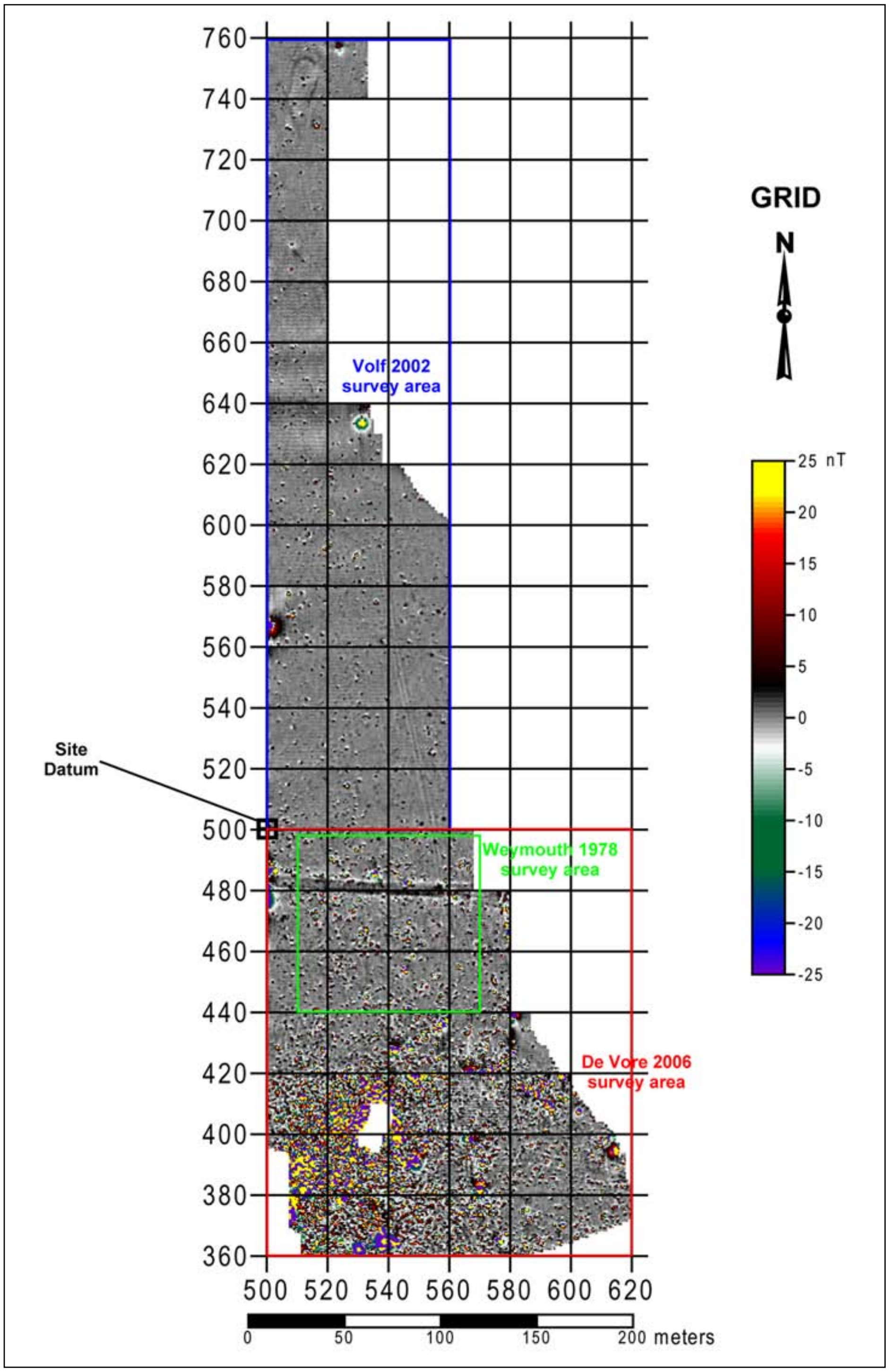



**Figure 52.** Combined magnetic data from the 2002 and 2006 field seasons at the Elbee Site.

**MAGNETIC SURVEY OF ELBEE SITE**