CNWRA 98-001

# CNWRA GROUND MAGNETIC SURVEYS IN THE YUCCA MOUNTAIN REGION, NEVADA (1996 – 1997)

*Prepared for*

**Nuclear Regulatory Commission**
**Contract NRC-02-97-009**

*Prepared by*

**Center for Nuclear Waste Regulatory Analyses**
**San Antonio, Texas**

**January 1998**

CNWRA 98-001

# CNWRA GROUND MAGNETIC SURVEYS IN THE YUCCA MOUNTAIN REGION, NEVADA (1996–1997)

*Prepared for*

**Nuclear Regulatory Commission**
**Contract NRC-02-97-009**

*Prepared by*

**S.L. Magsino, C.B. Connor, B.E. Hill, J.A. Stamatakos, P.C. La Femina, D.A. Sims, and R.H. Martin**

**Center for Nuclear Waste Regulatory Analyses**
**San Antonio, Texas**

**January 1998**

# ABSTRACT

The purpose of this intermediate milestone is to disseminate ground magnetic data collected by Center for Nuclear Waste Regulatory Analyses (CNWRA) staff in the Yucca Mountain region (YMR) between April 1996 and June 1997. These data were collected to support the Nuclear Regulatory Commission (NRC) in the analysis of volcanic and tectonic hazards to the proposed high-level radioactive waste repository at Yucca Mountain.

Data from 14 surveys in the YMR are contained on a CD ROM attached to this report. These data are formatted as Arc/Info export files, text data files, postscript files showing magnetic maps of each survey area, and text files describing each survey. This CD ROM can be read by most computers. Nevertheless, the easiest and fastest way to read this CD ROM is to use a UNIX operating system.

# CONTENTS


| Section | | Page |
|---|---|---|
| FIGURES | | iv |
| ACKNOWLEDGMENTS | | v |
| 1 | INTRODUCTION | 1 |
| 2 | CD ROM DISK | 1 |
| 3 | METHODS | 3 |
| | 3.1 DATA COLLECTION | 3 |
| | 3.2 DRIFT CORRECTIONS/DATA REDUCTION | 3 |
| | 3.3 DATA RESOLUTION | 4 |
| 4 | AREAS SURVEYED | 6 |
| | 4.1 1996 CRATER FLAT SURVEY | 6 |
| | 4.2 AMARGOSA "ANOMALY A" SURVEY (1996) | 8 |
| | 4.3 NORTHERN CONE SURVEY (1996) | 8 |
| | 4.4 STEVE'S PASS SURVEY (1997) | 11 |
| | 4.5 ALICE SURVEY (1997) | 14 |
| | 4.6 NORTHERN FORTY-MILE WASH SURVEY (1997) | 14 |
| | 4.7 JACKASS FLAT SURVEY (1997) | 17 |
| | 4.8 KANE SPRING SURVEY (1997) | 17 |
| | 4.9 BABY HUEY SURVEY (1997) | 17 |
| | 4.10 WINDY WASH SURVEY (1997) | 22 |
| | 4.11 SOUTHWEST NORTHERN CONE SURVEY (1997) | 22 |
| | 4.12 SOLITARIO CANYON SURVEY (1997) | 22 |
| | 4.13 SOUTHERN CRATER FLAT SURVEY (1997) | 25 |
| | 4.14 PORKCHOP SURVEY (1997) | 25 |
| 5 | SUMMARY | 25 |
| 6 | REFERENCES | 30 |

# FIGURES


| Figure | | Page |
|---|---|---|
| 1-1 | Location of magnetic surveys | 2 |
| 3-1 | Typical magnetic drift observed at the base station | 5 |
| 4-1 | Magnetic map of Crater Flat (1996) survey | 7 |
| 4-2 | Magnetic map of Amargosa Anomaly "A" | 9 |
| 4-3 | Magnetic survey north of the Amargosa Anomaly "A" survey | 10 |
| 4-4 | Magnetic map of Northern Cone survey | 12 |
| 4-5 | Steve's Pass magnetic survey | 13 |
| 4-6 | Detail of the Steve's Pass magnetic survey | 15 |
| 4-7 | Magnetic map of Alice survey | 16 |
| 4-8 | Magnetic map of northern Forty-Mile wash survey | 18 |
| 4-9 | Magnetic map of Jackass Flats survey | 19 |
| 4-10 | Magnetic map of Kane Springs survey | 20 |
| 4-11 | Magnetic map of Baby Huey survey | 21 |
| 4-12 | Magnetic map of Windy Wash survey | 23 |
| 4-13 | Magnetic map of southwest Northern Cone survey | 24 |
| 4-14 | Magnetic map of Solitario Canyon survey | 26 |
| 4-15 | Magnetic map of Southern Crater Flat survey | 27 |
| 4-16 | Profile across the Porkchop anomaly, collected on an approximately N-S traverse at 534100 E | 28 |
| 4-17 | Profile across the Porkchop anomaly, collected on an approximately N-S traverse at 533400 E | 29 |

# ACKNOWLEDGMENTS

This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the Nuclear Regulatory Commission (NRC) under Contract No. NRC-02-97-009. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards (NMSS), Division of Waste Management (DWM). The report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC. Technical review by Michael P. Miklas and programmatic review by Budhi Sagar improved this report. Annette Mandujano provided editorial assistance.

# QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

**DATA:** CNWRA-generated original data contained in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Sources for other data should be consulted for determining the level of quality for those data.

**ANALYSES AND CODES:** EarthVision (Version 4.0.1) and Arc/Info (Version 7.0.2) computer codes were used for analyses contained in this report. These are commercial computer codes and are not controlled under the CNWRA Software Configuration Procedures as set forth in FAR 52.227-14 and FAR 52.227-19. Arc/Info macro language code and C code written for this project are controlled under the CNWRA Software Configuration Procedures.

# 1 INTRODUCTION

Yucca Mountain, the proposed site of the first high-level radioactive waste repository in the United States, lies within a central Basin and Range Province of the North American Cordillera. This region is geologically active and the area about Yucca Mountain is no exception. During the Quaternary, the Yucca Mountain region (YMR) has been the site of small-volume basaltic volcanic eruptions, faulting, and historical seismicity. This activity suggests that geologic hazards associated with the tectonic setting of Yucca Mountain must be assessed, as further volcanic eruptions and faulting at the site pose a potential risk of noncompliance of the site with environmental standards designed to protect the public health and safety during the performance period of the repository.

The Nuclear Regulatory Commission (NRC) has identified several key technical issues (KTIs) related to geologic hazards at the site. These KTIs include the Igneous Activity (IA) KTI, concerned primarily with volcanic hazards to the proposed repository and the Structural Deformation and Seismicity (SDS) KTI, primarily concerned with the faulting and seismicity in the site region during the performance period of the repository. Many of the technical activities related to these KTIs during 1996–1997 are described in Nuclear Regulatory Commission (1996a,b).

The purpose of this report is to make available ground magnetic data collected in the YMR by staff of the Center for Nuclear Waste Regulatory Analyses (CNWRA) between 1996 and 1997. These data were collected to support resolution of the IA and SDS KTIs. During 1996 and 1997, CNWRA staff conducted 14 separate ground magnetic surveys in the YMR. Locations of these surveys are shown in figure 1-1.

# 2 CD ROM DISK

A CD ROM disk accompanies this report. This CD contains ground magnetic data collected in the YMR of Nevada by the CNWRA staff. Data from 14 surveys are included in this CD ROM disk. They are:

1) Crater Flat (1996)
2) Alice (1997)
3) Amargosa Desert (1996)
4) Baby Huey (1997)
5) Jackass Flat (1997)
6) Kane Spring (1997)
7) Northern Forty-Mile Wash (1997)
8) Northern Cone (1996)
9) Porkchop (1997)
10) Solitario Canyon (1997)
11) Southern Crater Flat (1997)
12) Steve's Pass (1997)
13) SW Northern Cone (1997)
14) Windy Wash (1997)

A separate directory exists for each survey. Each directory contains the following:

- An Arc/Info (v. 7.0.2) export file (*.e00) with raw data, drift corrected data, international geomagnetic reference field (IGRF) corrected data, and dates and times of data collection.

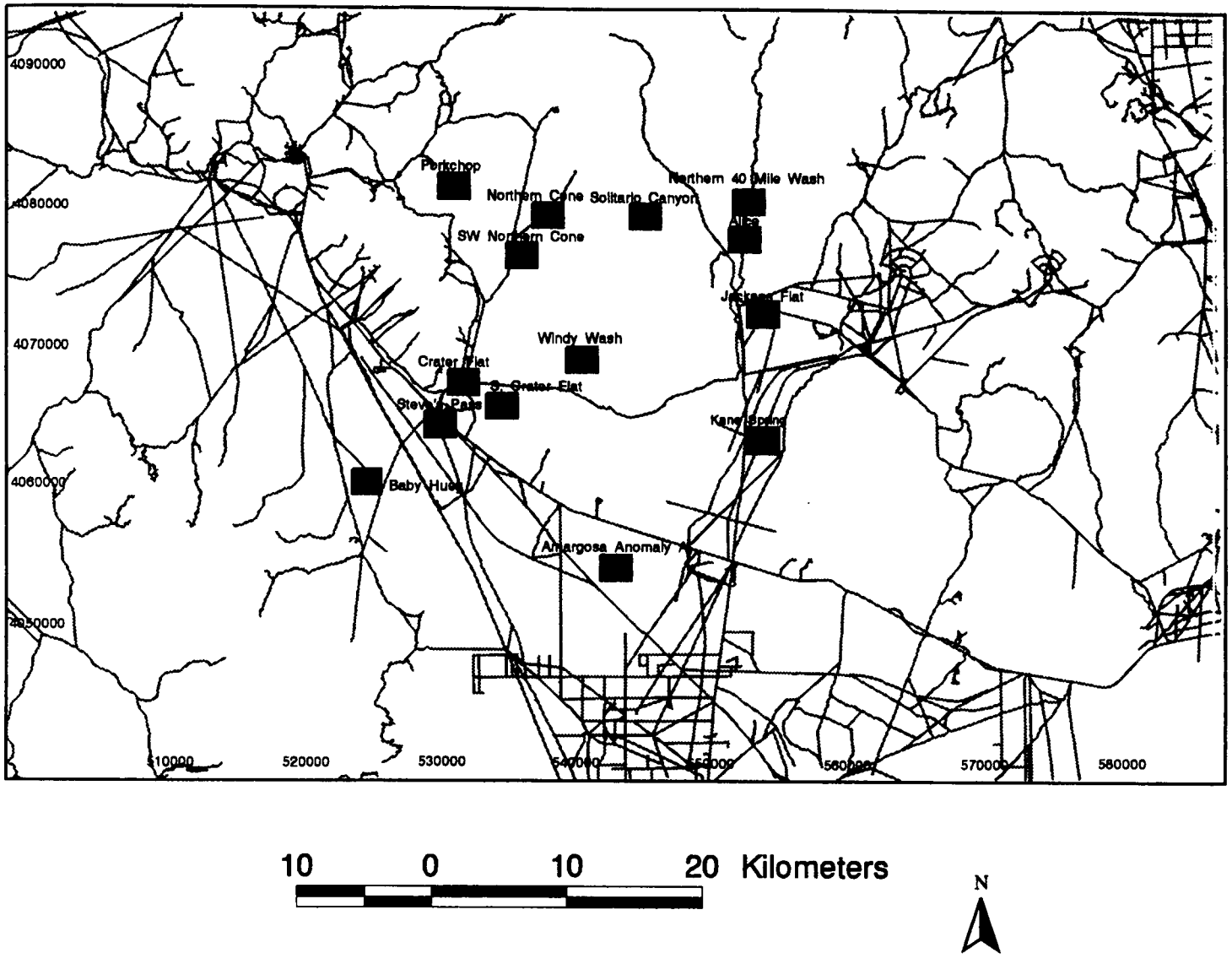


Figure 1-1. Location of magnetic surveys

These files can be accessed by creating a workspace within Arc/Info and running the import command.

- A *.dat file containing the Northing, Easting, and IGRF corrected data in an x,y,z format. This file can be read by most word processing programs.

- An encapsulated postscript file (*.ps) with a map of the data gridded and contoured using EarthVision. This postscript file can be opened using Ghostview, Showcase, or similar postscript readers installed on UNIX operating systems.

- A directory contents explaining within which coordinate system (e.g., Universal Transverse Mercator [UTM], NAD 83) the survey was conducted, the names of the files within that directory, and details about the Arc/Info coverages. This file can be read by most word processing programs.

The CD ROM disk can be read using UNIX, Windows NT, and MacIntosh operating systems. For full use of the data contained on this disk, it is recommended that a UNIX operating system be used and ARC/Info workspaces be created for each of the Arc/Info export files. If Arc/Info is not available, it is possible to read the *.dat files as simple text files. These text files can be used to plot, grid, and contour the data sets in packages like Geosoft Oasis Montaj, Surface III, Surfer, Geophysical Mapping Tools, and EarthVision.

# 3 METHODS

## 3.1 DATA COLLECTION

The ground magnetic surveys were conducted using a Geometrics model G-858 optically pumped cesium-vapor magnetometer. This magnetometer provides data repeatability in areas of high magnetic gradient and is capable of collecting data at a much greater sampling rate than many other types of magnetometers. Magnetic readings were made with the G-858 at 1- or 2-sec intervals. Sensor height was approximately 1 m above the ground surface for all surveys.

The magnetometer was interfaced to a differential global positioning system (DGPS), which collected position information every second. Real time differential corrections were made on position data and sent, via RS232 cable, as a string in National Marine Electronics Association (NMEA) protocol to the magnetometer and stored with magnetic measurements. During the surveys, one person carried the magnetometer and a second person carried the DGPS. The base station for these surveys included a proton-precession magnetometer (Geometrics model G-856), set to continuously record diurnal variation in the magnetic field, and the DGPS base station, consisting of a global positioning system (GPS) receiver and telemetry.

## 3.2 DRIFT CORRECTIONS/DATA REDUCTION

Positional information was reduced to true map coordinates by positioning the DGPS base station at known benchmarks or by tying the base station to benchmarks in the region by DGPS surveying. Magnetic readings, time, position, and elevation were stored in the magnetometer memory and downloaded to a laptop computer at regular intervals.

Ground magnetic values presented in this report use drift corrected values from which the IGRF has been subtracted. An example of typical diurnal variation is shown in figure 3-1. Diurnal variation from one day to the next was accounted for by comparing data collected at the same location on different days. After drift correction, the IGRF corrected value was calculated for each station (Malin and Barraclough, 1981).

## 3.3 DATA RESOLUTION

Although error associated with the cesium-vapor magnetometer is on the order of 0.1 nT, total error in the surveys is typically 1 nT due to position error. Error may be as much as 10 nT in areas of high magnetic gradient, as in areas of basalt cover. Error is introduced to the magnetic data in four ways:

- Change in instrument sensitivity
- Diurnal variation in the magnetic field
- Error in the GPS location
- Survey technique.

Change in instrument sensitivity refers to change in the value of the magnetic field measured by the magnetometer, exclusive of external factors. Instrument drift in magnetometers is very low, $<<$ 0.1 nT/day. Change in instrument sensitivity was monitored during most surveys by sampling the magnetic field at up to seven wooden stakes located in close proximity to one another. Readings were collected at each of these stakes in rapid succession and the difference between readings at successive stakes calculated. These difference values were compared before and after surveys were made. In all cases, it was determined that differences changed by less than 0.9 nT.

Diurnal variation in the Earth's magnetic field results from changes in conductivity of the upper atmosphere during the day. These temporal changes are on the order of 30–50 nT and vary in amplitude over distances of 100 km or more. Therefore, it is necessary to monitor diurnal variations in the intensity of the magnetic field using a base station located at the survey site. Drift observed at the base station is subtracted from the field observations. Error is introduced into this drift correction because drift is interpolated between readings at the base station. Maximum rates of change in the magnetic field during these surveys was $<$ 0.004 nT/s with 95 percent confidence. Thus, at a 3 min sampling rate, interpolation error is most likely maximum at 90 sec and could be as much as 0.36 nT. This assumes that maximum rates of change in the magnetic field are well represented by the variance in observations. Sampling was not conducted during magnetic storms, which produce greater rates of change in the magnetic field.

The ground resolution of the DGPS varies among the surveys. For three surveys conducted in 1996, Crater Flat, Northern Cone, and Amargosa Anomaly A, radio technical commission for maritime (RTCM) services DGPS corrections were made. RTCM data quality yields a horizontal position $\pm$ 5 m of actual location 95 percent of the time. The remaining 11 surveys were completed using radio technical - 20-cm (RT-20) DGPS resolution. GPS positions are $\pm$ 20 cm of actual location 95 percent of the time in RT-20 surveys.

Several conditions can occur during surveys that dilute the precision of DGPS measurements. Loss of communication between one or more satellites and the GPS receiver (loss of lock) occasionally results in position errors. Since the status of the telemetry network is displayed on the GPS receiver

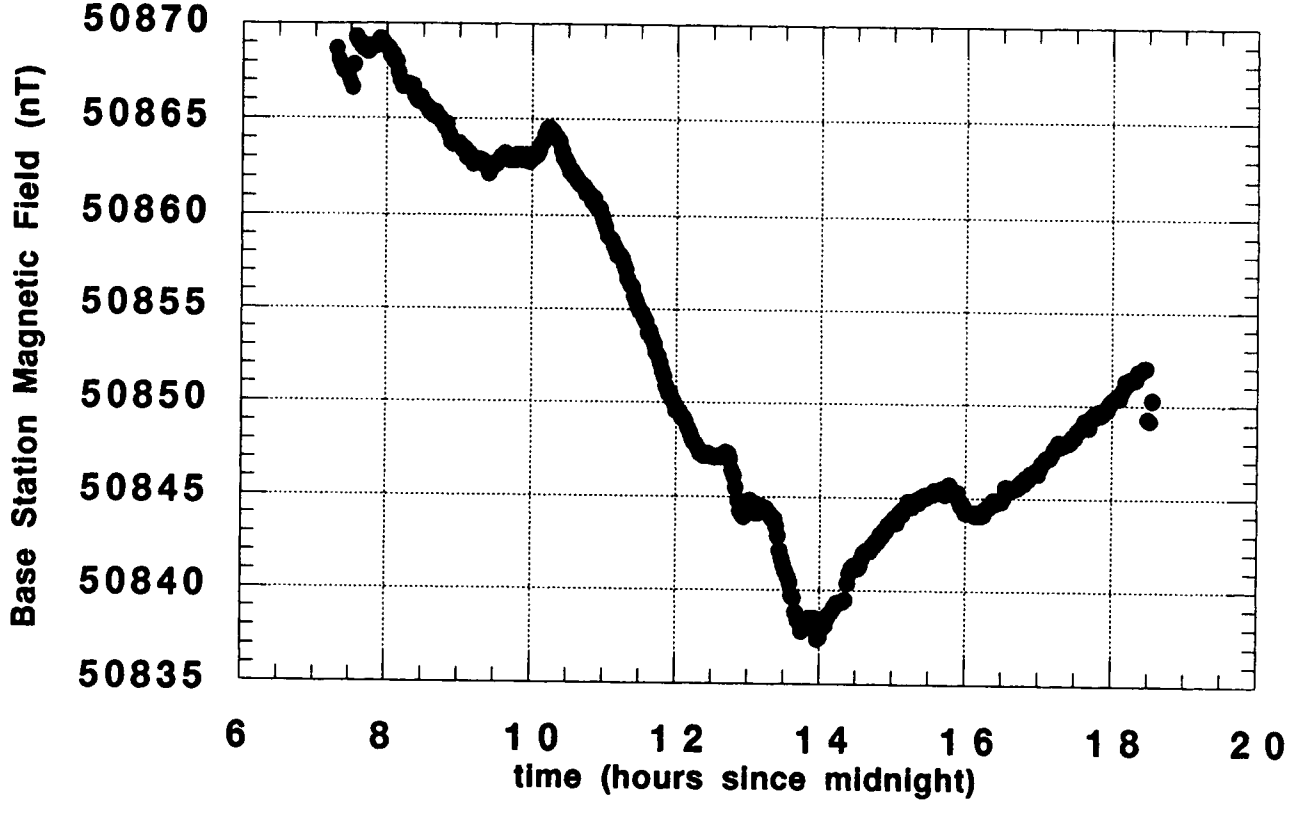


Figure 3-1. Typical magnetic drift observed at the base station. Data collected June 12, 1997.

during surveying, data are not collected during loss of lock. Momentary loss of lock not noticed by the DGPS operator during data collection is easily recognized during post-processing within a geographic information system (GIS) and such data are deleted. Upsets in the radio telemetry between the base station and the survey party can also result in positional errors. These errors can also be noted in the field, during data collection, or during post-processing.

Additional positional error results from survey technique. Collection of ground magnetic data requires one person to carry the magnetometer and a second person to carry the DGPS receiver and antenna. Thus, the magnetometer sensor and the DGPS antenna are separated by a distance of 3–4 m during the survey. This offset distance is necessary to avoid biasing the magnetic readings with the small magnetic field associated with the DGPS equipment. Because the person carrying the magnetometer walks in front of the person carrying the DGPS antenna, offset in the position information is partly corrected by correlating magnetic readings with DGPS readings collected 1–2 sec after the magnetic readings are collected. Nevertheless, a total position error resulting from survey design may be as much as 4 m. Combining this error with error resulting from the DGPS position, magnetic features such as the boundaries of buried lava flows are located within $\pm$ 9 m for the RTCM surveys and $\pm$ 4.2 m for the RT-20 surveys.

Position errors influence the absolute error in magnetic values depending on the local magnetic gradient. Typical local magnetic gradients are 0.1 to 1.0 nT /m. Thus, a $\pm$ 9-m position error results in an error in the magnetic value at a given map location of 0.9 to 9.0 nT. Therefore, maximum errors on these surveys are considered to be 10 nT, except on very near-surface basaltic lava flows, on which the magnetic gradients can be much steeper.

# 4 AREAS SURVEYED

The 14 magnetic surveys each consist of 3,000 to 70,000 magnetic measurements. Line spacing varied between 25–500 m, depending on the wavelength and complexity of observed anomalies.

## 4.1 1996 CRATER FLAT SURVEY

Crater Flat is a structural half-graben where small-volume basaltic volcanism has repeatedly occurred since large-volume silicic volcanism ended during the mid-Miocene. Deposition of young alluvial sediments has partially or completely buried volcanoes in the southern part of the basin, obscuring the volcanic history of the area. Two Quaternary cinder cones, the Little Cones, are exposed in the northern portion of the survey area, with lava outcrops extending approximately 400 m south of the Little Cones. The survey area covers approximately 6 $km^2$ immediately surrounding and south of the Little Cones between UTM coordinates (533500, 4066000) and (536500, 4070000). Figure 4-1 is a magnetic anomaly map showing gridded and contoured results of the ground magnetic survey. The Little Cones (figure 4-1) and surrounding lava flows are seen as short-wavelength, very high-frequency predominantly negative anomalies on the map. Magnetic data indicate the buried flows extend approximately 1 km beyond flows exposed at the surface. These flows are buried 15–30 m beneath a nearly featureless alluvial plane (Connor et al., 1997). So, rather than being incongruously small volcanic features compared to nearby cones, the Little Cones and their lava flows exemplify the final stages of inundation and burial of two young cinder cones in an actively subsiding basin (Stamatakos et al., 1997a). The magnetic map also shows a striking positive anomaly approximately 2 km south of the Little Cones. This anomaly had been previously observed on aeromagnetic maps (Kane and Bracken, 1983; Langenheim and Ponce,

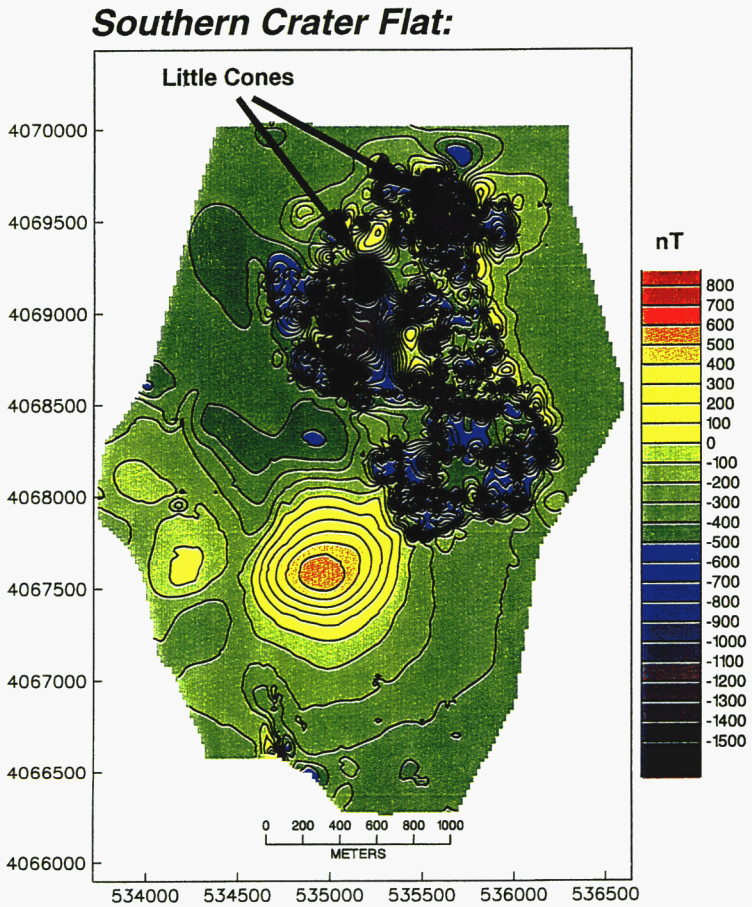


**Figure 4–1. Magnetic map of Crater Flat (1996) survey. Contour interval is 100 nT.**

1995). The anomaly has a peak-to-peak amplitude of 1100 nT, with positive and negative peaks separated by 750 m. The negative portion of this anomaly is truncated by anomalies associated with the Little Cone lava flows. The polarity, size, and symmetrical nature of this anomaly indicate that it is caused by an older, completely buried volcano. A third prominent magnetic feature was discovered near outcrops of Miocene basalt. This feature is a linear magnetic anomaly extending from the southern end of the survey area to the north-northwest for approximately 500 m (figure 4-1). The anomaly is probably caused by a shallow dike associated with the Miocene basalts (Connor et al., 1997).

## 4.2 AMARGOSA "ANOMALY A" SURVEY (1996)

Five anomalies were identified in Amargosa Valley by Langenheim et al. (1993) as potential buried volcanoes or related igneous features. Of these anomalies, Amargosa "Anomaly A" (figure 4-2) is the most complex and difficult to interpret from aeromagnetic maps. Anomaly A is of great interest because of its proximity to the Lathrop Wells cinder cone, the youngest volcano in the YMR, and because it is the closest of the Amargosa Valley anomalies to the proposed repository site. With these factors in mind, a ground magnetic survey of Anomaly A was completed to constrain its origin and to better resolve its distribution in the subsurface. The survey area covers approximately 20 $km^2$ within UTM coordinates (543500E, 4051000N) and (547000E, 4060000N). The map of magnetic data collected over Amargosa Anomaly A delineates three separate anomalies associated with shallowly buried, reversely magnetized rock (figure 4-2). These anomalies are distributed over 4.5 km on a northeast trend, and each has an amplitude of 70–150 nT. The identification of the northeast trend of Anomaly A is a key result of this survey. The trend is similar to the alignment of five Quaternary cinder cones in Crater Flat and to the Sleeping Butte cinder cones, a Quaternary vent alignment 40 km to the northeast. Although the age of the Amargosa Valley alignment is not known, it suggests that development of northeast-trending cone alignments is a pattern of volcanism that has persisted through time in the YMR and supports the idea that future volcanism may exhibit a similar pattern (Smith et al., 1990). Although the character of these anomalies can be partially resolved with aeromagnetic data (Langenheim et al., 1993), trenchant details that are important to volcanic hazard analyses and tectonic studies of the region emerge from the ground magnetic survey. Such details include the character of the southernmost anomaly, which has a smaller amplitude than those to the north but is nonetheless distinctive, and the northeast-trending structure within the negative portion of the central anomaly, which mimics the overall trend of the alignment. The ground magnetic data also enhance the small positive anomalies north of each of the three larger amplitude negative anomalies, reinforcing the interpretation that Anomaly A is produced by coherent basalt edifices with strongly reversed remanent magnetizations (Connor et al., 1997).

This survey was extended north of highway U.S. 95 as far as the southern outcrops of the lava flows from Lathrop Wells volcano (figure 4-3). Short-wavelength anomalies on the northern part of this map are a result of normally magnetized lavas from Lathrop Wells. A +70 nT anomaly is located south of these lavas. This anomaly is roughly circular in shape and approximately 1 km in diameter. This anomaly may result from an isolated block of buried tuff or basalt.

## 4.3 NORTHERN CONE SURVEY (1996)

Northern Cone, located in Crater Flat approximately 8 km from the repository site, is the closest Quaternary volcano to Yucca Mountain. Its proximity to the site of the proposed repository makes the structural setting of Northern Cone of particular interest in volcanic hazard assessment. Surveying was conducted primarily along east-west trending lines 100 m apart over rugged alluvial topography. The

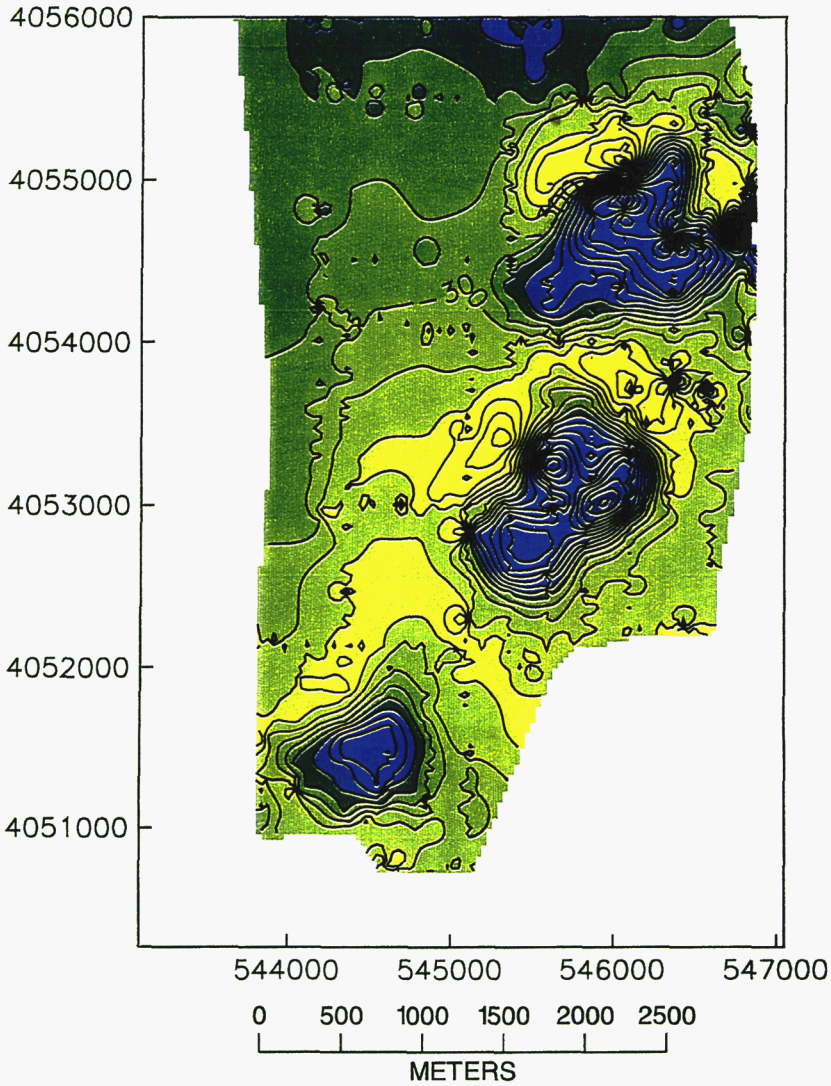


**Figure 4–2. Magnetic map of Amargosa Anomaly "A". Contour interval is 10 nT.**

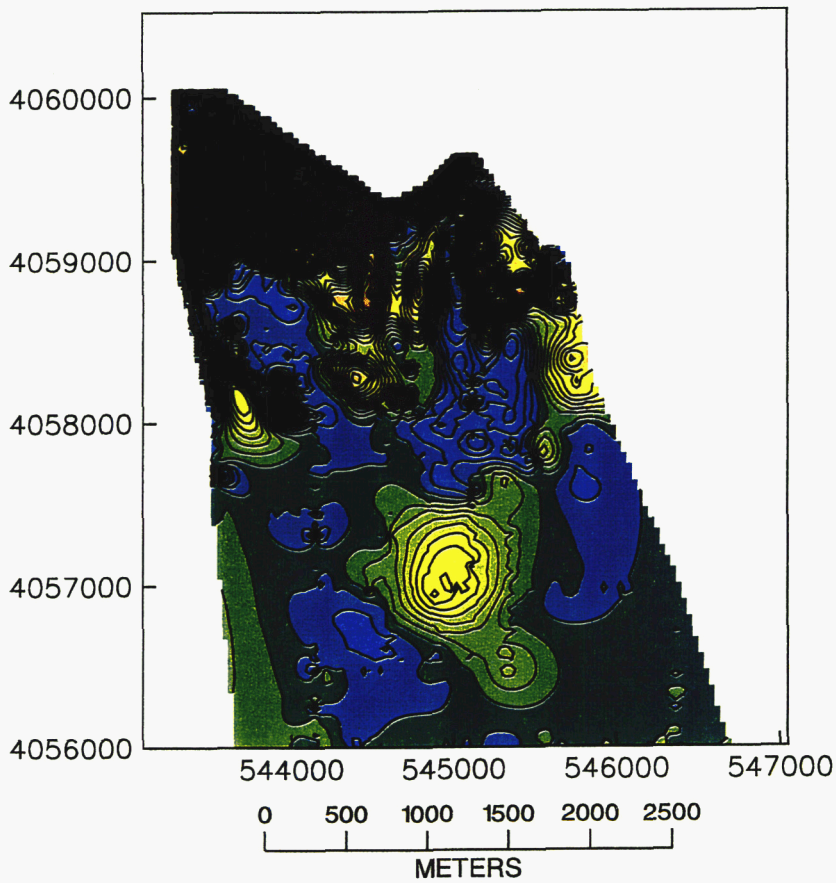


**Figure 4–3. Magnetic survey north of the Amargosa Anomaly "A" survey. Contour interval is 10 nT.**

survey area covered approximately 5 $km^2$ immediately surrounding Northern Cone. Gridded and contoured ground magnetic data over the Northern Cone area are presented in figure 4-4. The magnetic anomaly map is superimposed over topography, roads, and mapped faults (Frizzell and Schulters, 1990). Northern Cone consists of approximately 0.4 $km^2$ of highly magnetized (10–20 $Am^{-1}$) lava flows, near-vent agglutinate, and scoria aprons resting on a thin alluvial fan. Large-amplitude, short-wavelength anomalies were observed over the cone.

No evidence of northeast-trending structures was discovered that could directly relate Northern Cone to the rest of the Quaternary Crater Flat cinder cone alignment. Instead, prominent linear anomalies surrounding Northern Cone trend nearly N-S and have amplitudes of up to 400 nT. These anomalies likely result from offsets in underlying tuff across faults extending beneath the alluvium (Connor et al., 1997). The relationship between faults and Northern Cone becomes clear when the ground magnetic map is compared with topographic and fault maps (Frizzell and Schulters, 1990; Faulds et al., 1994). The N-trending anomalies at Northern Cone roughly coincide with mapped faults just north of the survey area that have topographic expression resulting from large vertical displacements. These mapped faults and the faults inferred from the magnetic map are all oriented north to north-northeast, trends favorable for dilation and dike injection in the current stress state of the crust. Thus, the Northern Cone magnetic survey further supports the idea that volcanism on the eastern margin of Crater Flat was localized along faults (Connor et al., 1997).

## 4.4 STEVE'S PASS SURVEY (1997)

The Steve's Pass survey was conducted over a 27 $km^2$ area immediately south of Bare Mountain and Steve's Pass. Other than a few outcrops of quartz latite lavas and tuff, the area is completely covered with alluvium. The complex nature of aeromagnetic anomalies over the area, including the highest amplitude aeromagnetic anomaly along the Quaternary Crater Flat volcano alignment, makes this area particularly interesting.

Figure 4-5 is a ground magnetic anomaly map of the survey area. Notable features include a linear northwest-southeast trending ground magnetic anomaly truncating two N-trending, curvilinear anomalies. Stamatakos et al. (1997b) interprets the first of these anomalies as part of an active first-order fault extending from south of Beatty, Nevada, to southernmost Bare Mountain and bending southward along the western edge of the Amargosa gravity trough. Stamatakos et al. (1997b) and Slemmons (1997) named this fault the Carrara Fault. The magnetic expression of the Carrara Fault is most apparent in the features it offsets. A −1700 nT anomaly with a horizontal distance of 400 m between positive and negative peaks lies along the Carrara Fault, where this fault truncates N-trending curvilinear anomalies. The amplitude and wavelength of this −1700 nT anomaly is consistent with buried basaltic lavas in the area and is interpreted to be a buried basaltic volcanic center, the Carrara Fault Basalt. This anomaly is elongated parallel to the trend of the fault. Some rotation or displacement may have occurred given the geometry of the magnetic anomaly.

A smaller anomaly with peak-to-peak amplitude of 1700 nT, and horizontal distance between peaks of 50 m, is located 400 m south of the Carrara Fault Basalt. The anomaly is also caused by a reversely magnetized body. No apparent displacement or rotation of this body has occurred. This, and the Carrara Fault Basalt, lie in alignment with 1.0 Ma basaltic cones in Crater Flat, also reversely magnetized, likely extending the Crater Flat volcanic alignment to 16 km in length.

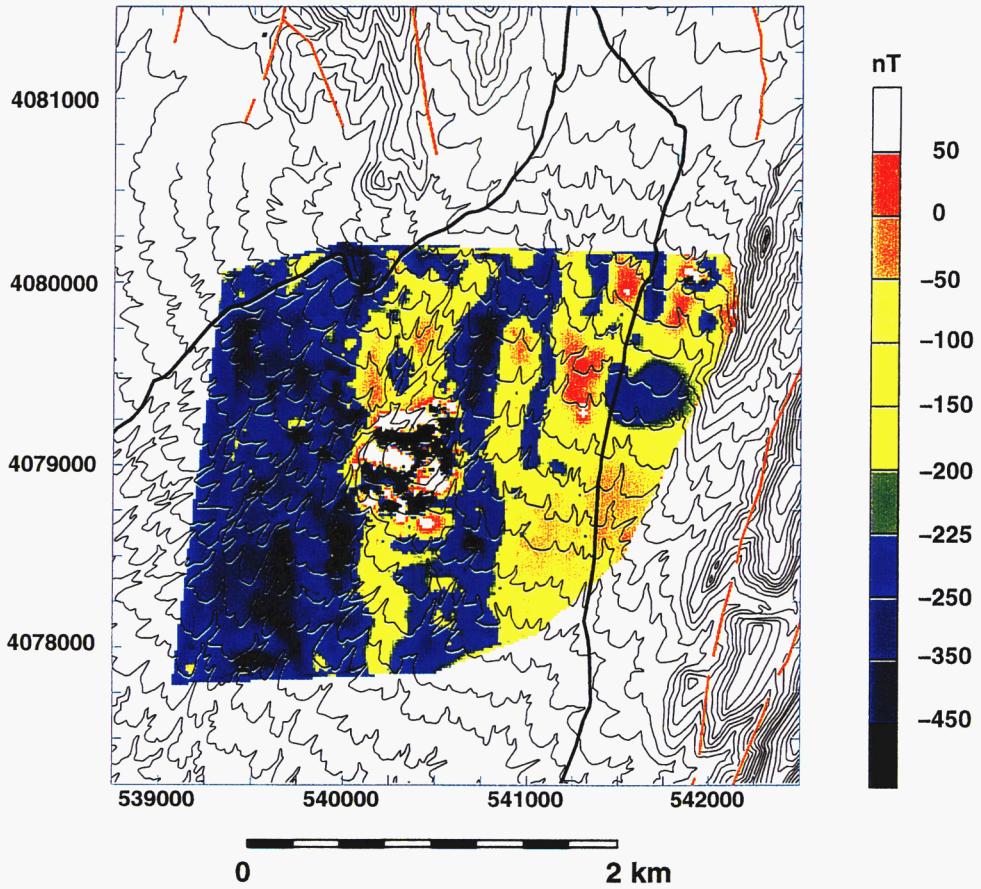


**Figure 4–4. Magnetic map of Northern Cone survey. Contour interval is 50 nT.**

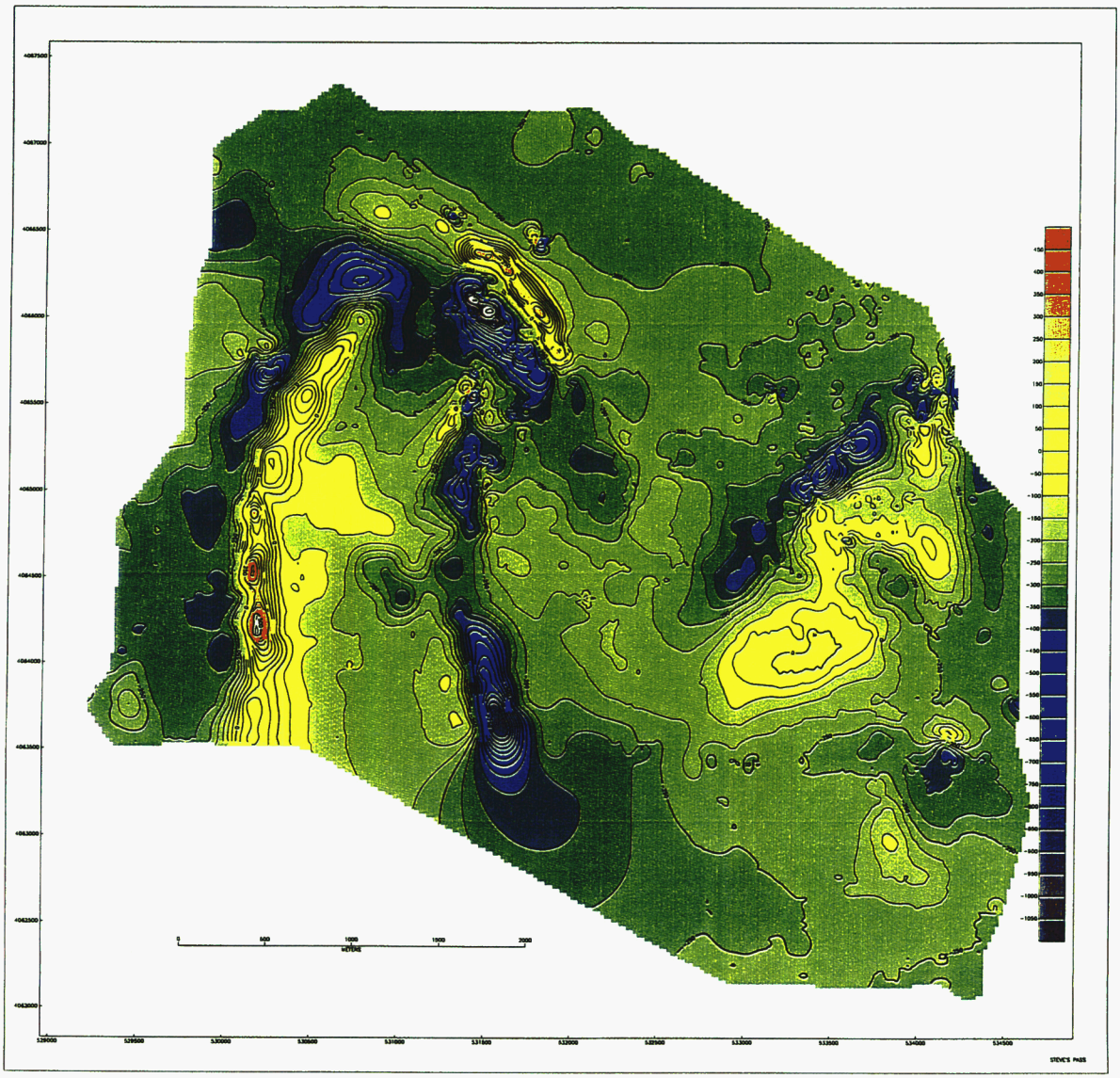

**Figure 4–5. Steve's Pass magnetic survey. Contour interval is 50 nT.**

The above mentioned N-trending curvilinear anomalies have similar length and trend, but opposite polarities, and are both truncated at the Carrara Fault. The western curvilinear anomaly results from normally magnetized rock, has a peak-to-peak amplitude of 950 nT, and extends at least 2.5 km south of the Carrara Fault, probably continuing beyond the survey area. Parallel to this anomaly, approximately 1200 m to the east, is an anomaly with a peak-to-peak amplitude of 750 nT, produced by reversely magnetized rock. Both anomalies bend northeast approximately 1 km south of the Carrara Fault anomaly. Both anomalies are asymmetric in cross-section in the southern part of the map and become more symmetric as they curve to the north, possibly a result of the changing trend of the anomalies with respect to magnetic north. If these anomalies represent faults, the change in symmetry may be caused by greater throw on the faults in the north, closer to the Carrara Fault. Stamatakos et al. (1997b) suggest these parallel anomalies are produced by the edges of faulted blocks of highly magnetized Miocene silicic tuff or porphyry flows.

A third magnetic anomaly, possibly produced by buried basalt, lies in the southeastern part of the survey area and is detailed in figure 4-6. This is a symmetric reverse magnetic anomaly with a peak-to-peak amplitude of 360 nT separated by a horizontal distance of 150 m. The causative body is buried completely within alluvium and has a shape similar to a vertical cylinder, such as might result from erosion of a volcanic neck. This body is either of basaltic origin or is produced by a block of tuff which has slid off from the north. This latter interpretation requires, however, that no rotation of the tuff block occurred during transport to its present location.

The complex positive anomaly patterns observed in the northeast portion of figure 4-5 are related to Miocene quartz latite lava flows which crop out in the northern part of the map. Displacement in these anomalies is possibly caused by the Carrara Fault.

## 4.5 ALICE SURVEY (1997)

The Alice survey area covers 0.5 $km^2$ in Forty-mile Wash, just east of Alice Ridge between UTM coordinates (554200E, 4078600N) and (554800E, 4080400N). The area is characterized by somewhat rough alluvial topography and is bounded on the east and west by ignimbrite outcrops. This area was chosen for detailed investigation because aeromagnetic anomalies indicated the possible presence of basalts.

The most obvious feature on the ground magnetic map is a complex, high-amplitude, negative anomaly in the central part of the survey area (figure 4-7). Peak-to-peak amplitude of the anomaly is 800 nT, and the horizontal distance between positive and negative peaks is 200 m. The rest of the map is characterized by complex anomalies with amplitudes up to 200 nT of varying wavelength. Because of the nature of the anomalies and the presence of ignimbrite or tuff outcrops on either side of Forty-mile Wash, we attribute these anomalies to the presence of tuff beneath the alluvium. The "noisy" character of some contour lines is caused by randomly oriented blocks of magnetized rock within the alluvium. Some of the anomalies on this map may be caused by basaltic rocks, but ground magnetic data indicate that a shallowly buried volcanic center is not present in this area.

## 4.6 NORTHERN FORTY-MILE WASH SURVEY (1997)

The Northern Forty-mile Wash survey was conducted over a 1 $km^2$ area within Forty-mile Wash, northeast of Alice Ridge. The survey area is 700 m north of the northern boundary of Alice survey

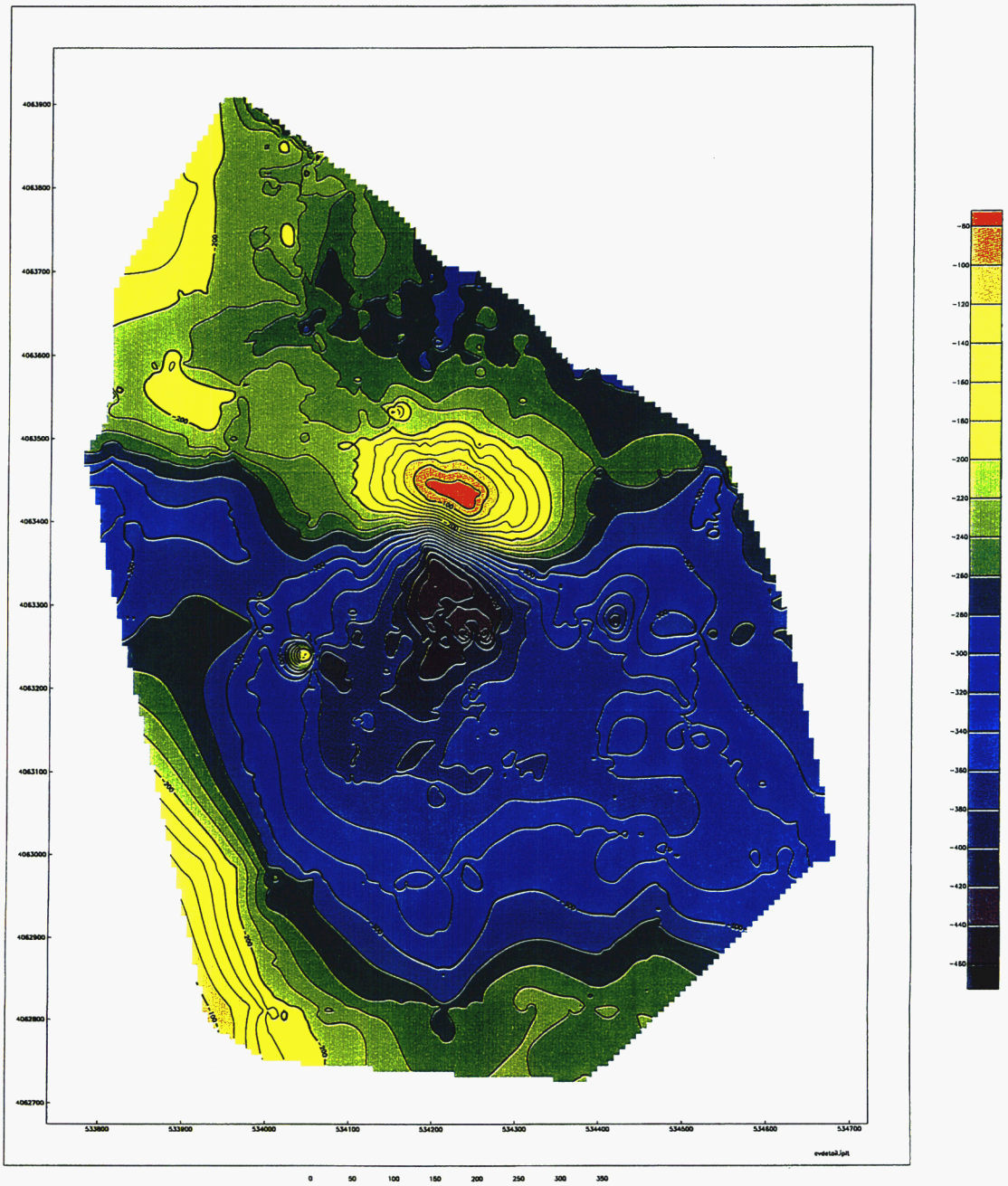


**Figure 4–6. Detail of the Steve's Pass magnetic survey. Contour interval is 20 nT**

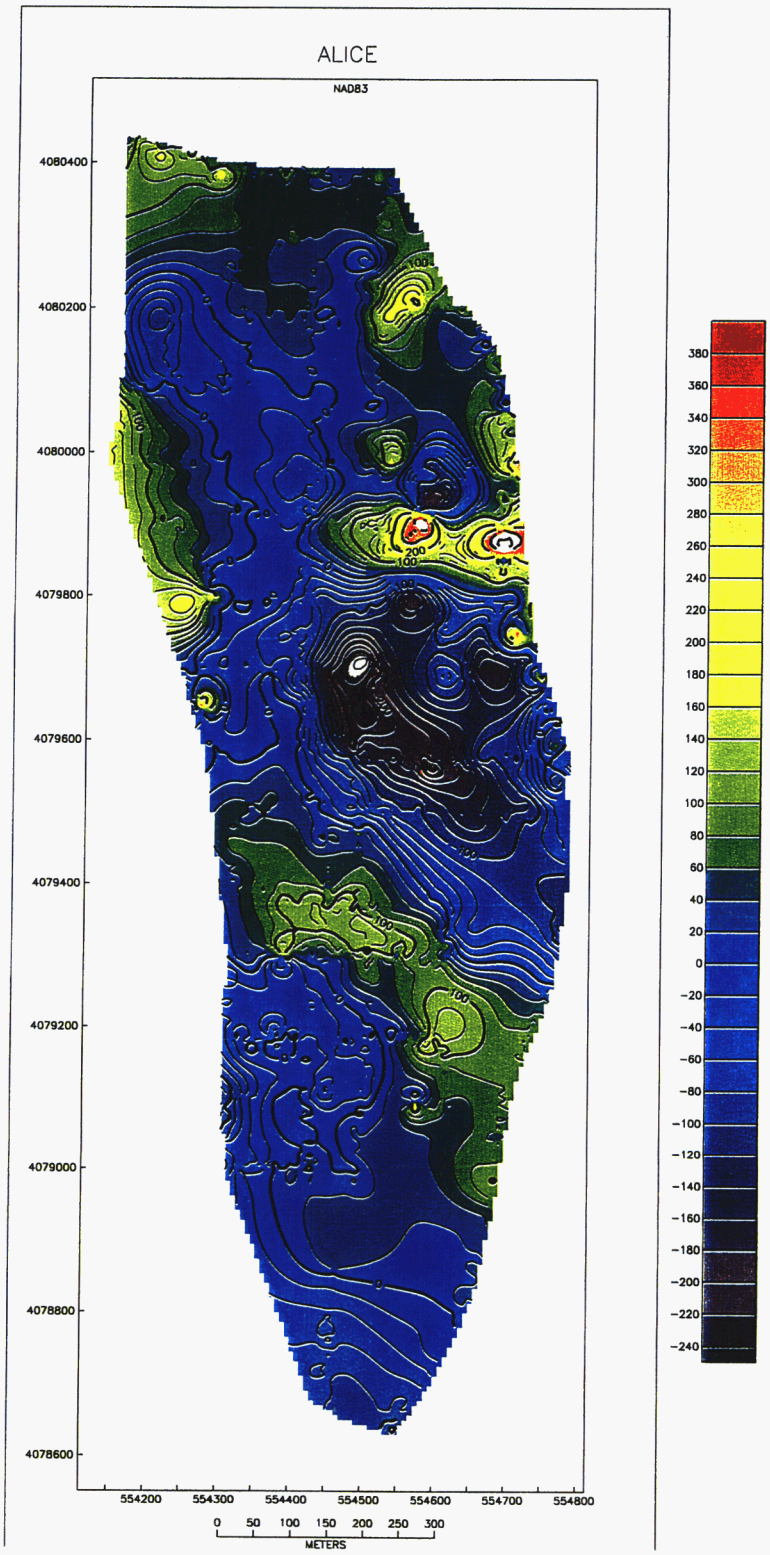


**Figure 4–7. Magnetic map of Alice survey. Contour interval is 20 nT.**

and is located between UTM coordinates (554200E, 4081100N) and (555500E, 4082300N). The area is characterized by rugged alluvial topography bounded on both sides of the wash with rhyolitic ignimbrites. Like the Alice survey, this area was chosen for detailed investigation because of aeromagnetic anomalies indicative of the possible presence of basalts. Anomalies in this area (figure 4-8) are large-amplitude, short-wavelength, and complex in map pattern. Amplitudes range from 900 to 1500 nT, somewhat larger than the anomalies mapped near Alice Ridge, but are of similar wavelength (approximately 200 m peak-to-peak). As in the Alice Ridge area, these anomalies are attributed to ignimbrite beneath the alluvium.

## 4.7 JACKASS FLAT SURVEY (1997)

The Jackass Flat survey was conducted within Jackass Flat, an alluvial fan with very little topographic relief. The survey covered a 1.8 $km^2$ area between UTM coordinates (555400E, 4072000N) and (556400E, 4073800N). This investigation took place to determine the nature of an isolated aeromagnetic anomaly within this alluvial fan. The survey consisted of five N-S traverses spaced 200 m apart. The most obvious feature on the resulting ground magnetic map (figure 4-9) is a long wavelength, -50 nT anomaly. The observed ground magnetic anomaly has none of the magnetic character of a shallow basalt, nor does it resemble the magnetic anomaly shown on aeromagnetic maps. The causative body of the ground magnetic anomaly is interpreted to be a deep feature, possibly related to topography of the magnetic basement. Re-examination of the aeromagnetic anomaly suggests that it is an artifact caused by error in flight line position, and does not represent a geologic body.

## 4.8 KANE SPRING SURVEY (1997)

The Kane Spring survey covers a 2.5 $km^2$ area in Jackass Flat, west of Little Skull Mountain between UTM coordinates (554800E, 4062600N) and (556600E, 4065200N). The area is covered with alluvium with little topographic gradient. The area was investigated because of complex aeromagnetic anomalies along the N-trending Gravity Fault, north of aeromagnetic anomaly "B" (Langenheim et al., 1993). No surface expression of the Gravity Fault exists in the region. The ground magnetic anomaly map (figure 4-10) is dominated by NNE-trending anomalies with a peak-to-peak amplitude of approximately 150 nT. These anomalies are likely the result of offset of reversely magnetized ignimbrites across a west dipping N-trending normal fault. No evidence of shallow buried basalt was found in the Kane Springs area.

## 4.9 BABY HUEY SURVEY (1997)

The Baby Huey survey covers a 2 $km^2$ area located in the Amargosa Desert, southwest of Bare Mountain, between UTM coordinates (526200E, 4059800N) and (527600E, 4062000N). This area was investigated to better delineate an aeromagnetic anomaly. The aeromagnetic anomaly was of particular interest because it is located along the southwest extension of the Crater Flat Quaternary cinder cone alignment. The survey was conducted over flat alluvium. The main feature on the resulting ground magnetic map (figure 4-11) is an oval shaped, 80 nT positive anomaly. Magnetic contrast on the southeastern edge of the anomaly is more abrupt where it is immediately adjacent to a very low amplitude (20–30 nT), N-trending structure transecting the length of the map. The positive anomaly may represent a block of ignimbrite displaced on a fault. Based on the horizontal magnetic gradient of the anomaly, the tuff may be thinning to the north, or displacement on the fault is greater in the north. There is no indication of shallowly buried basalt in this area.

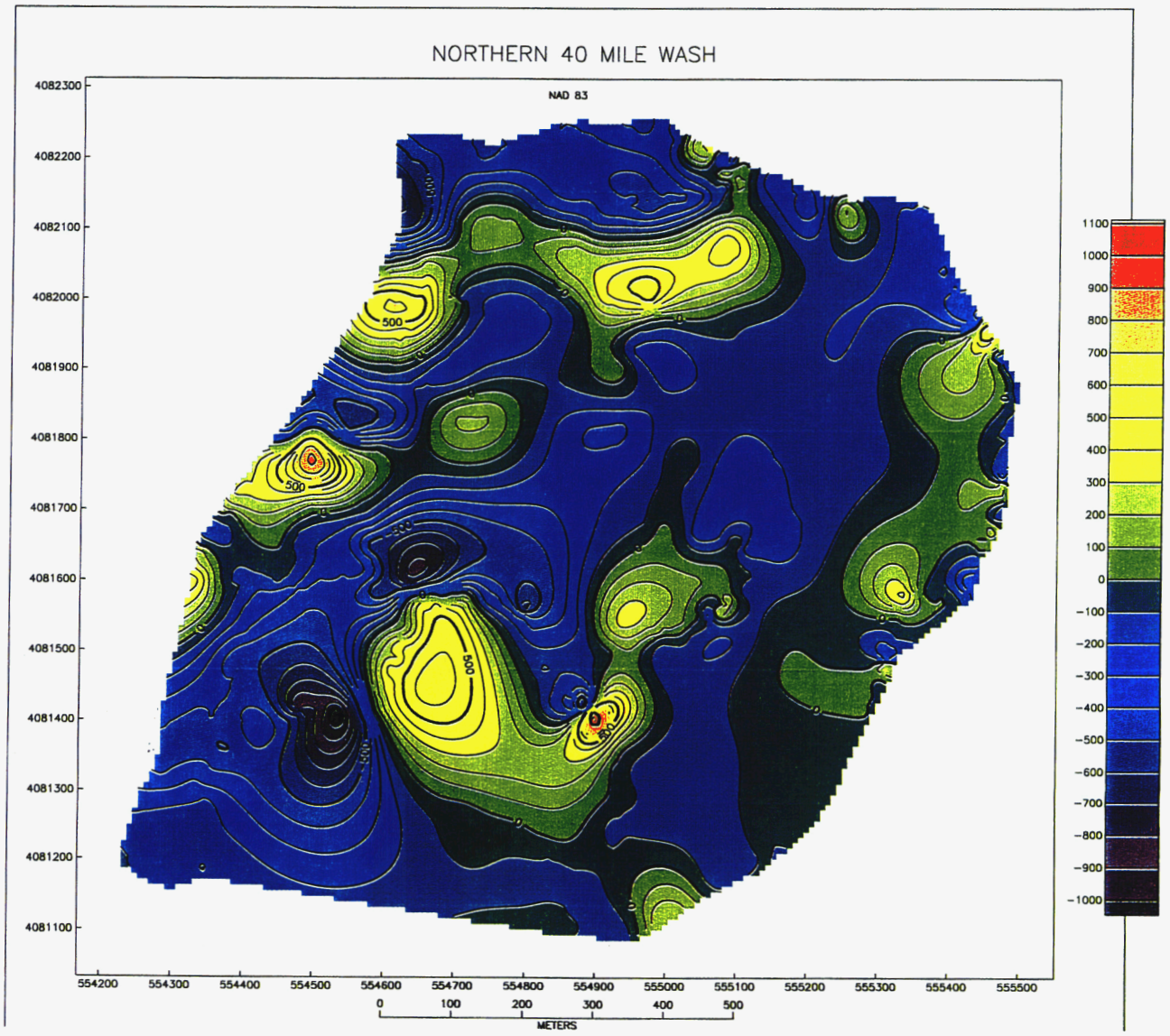


**Figure 4–8. Magnetic map of northern Forty–Mile wash survey. Contour interval is 100 nT.**

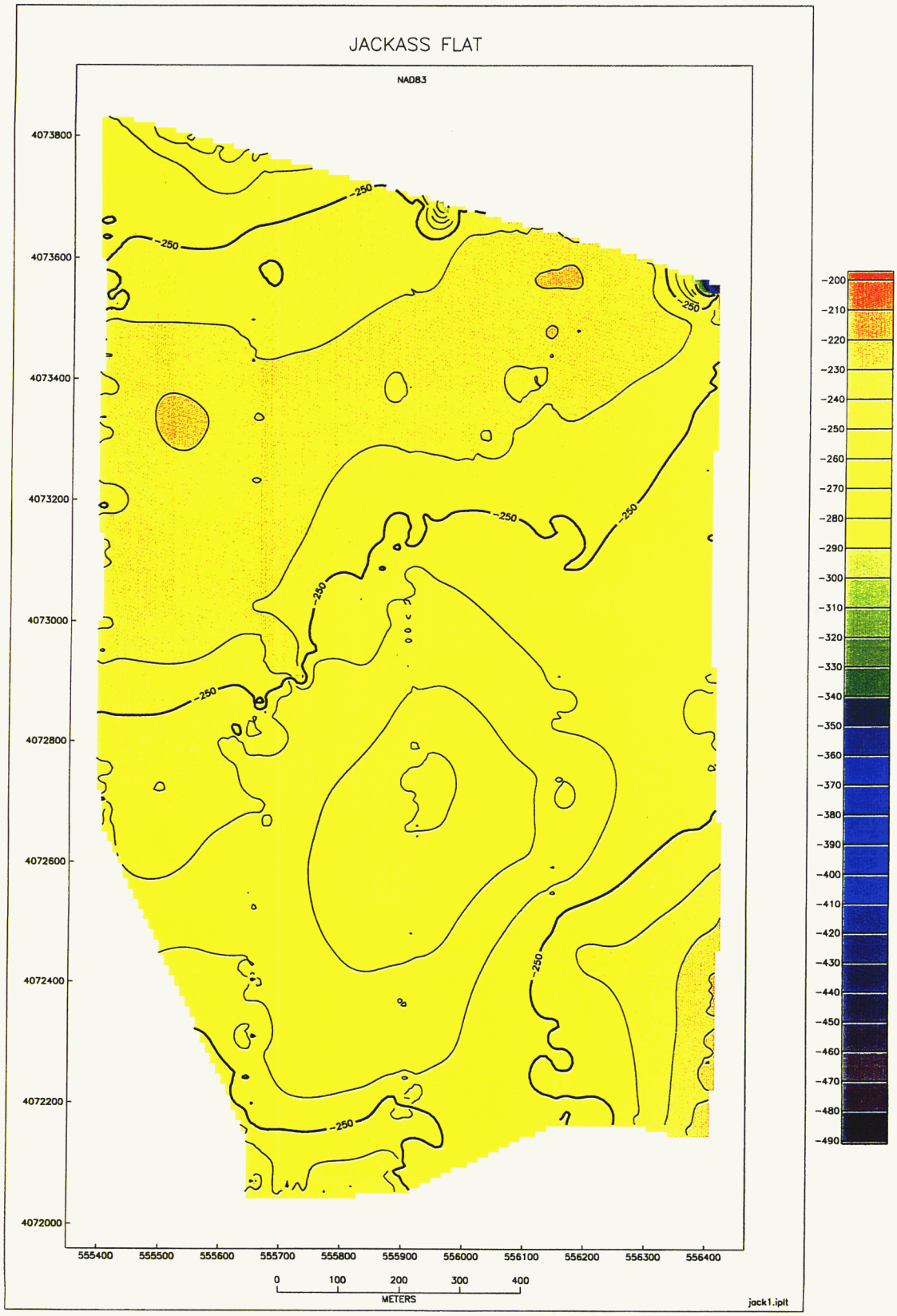


**Figure 4–9. Magnetic map of Jackass Flats survey. Contour interval is 10 nT.**

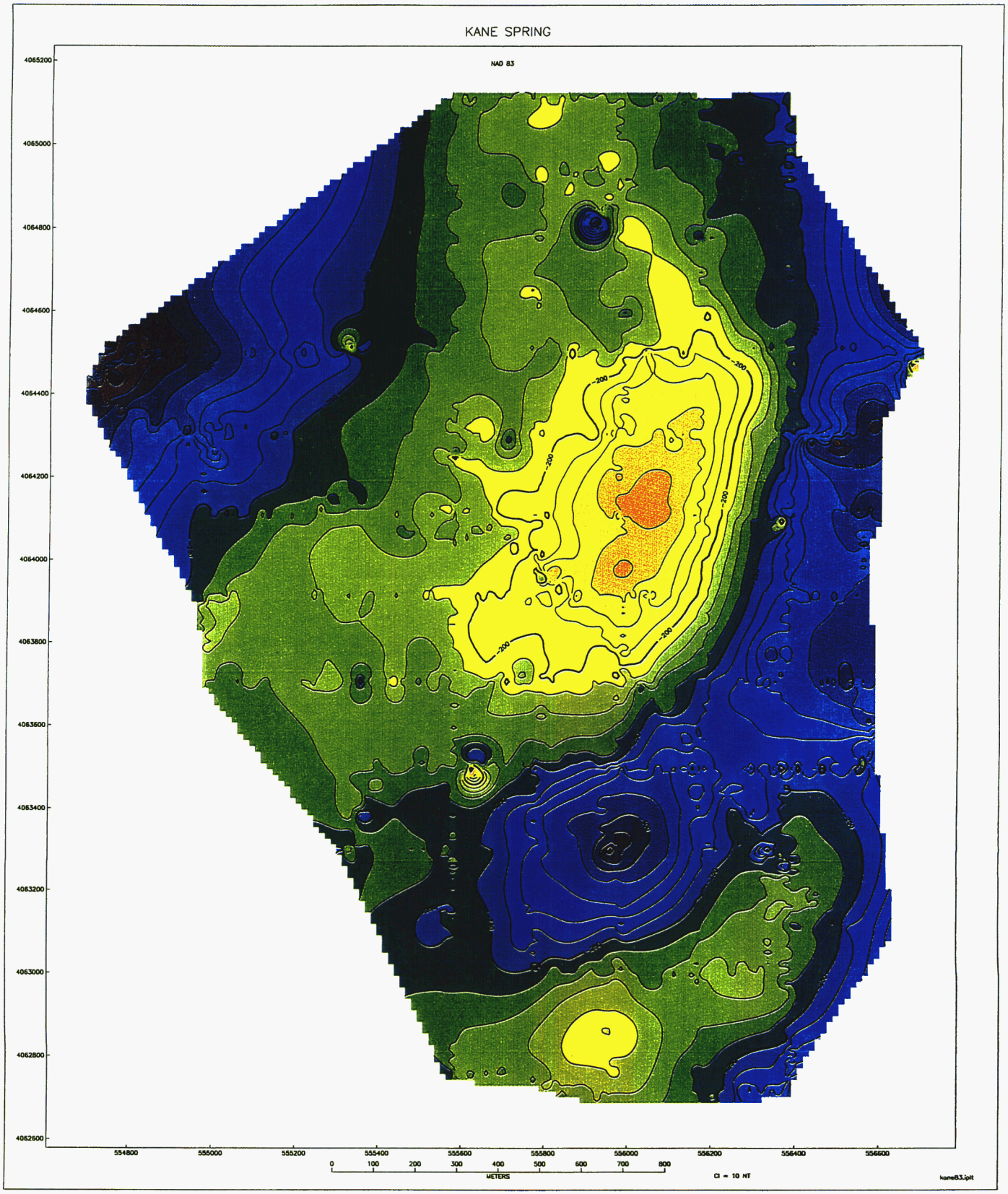


**Figure 4–10. Magnetic map of Kane Springs survey. Contour interval is 10 nT.**

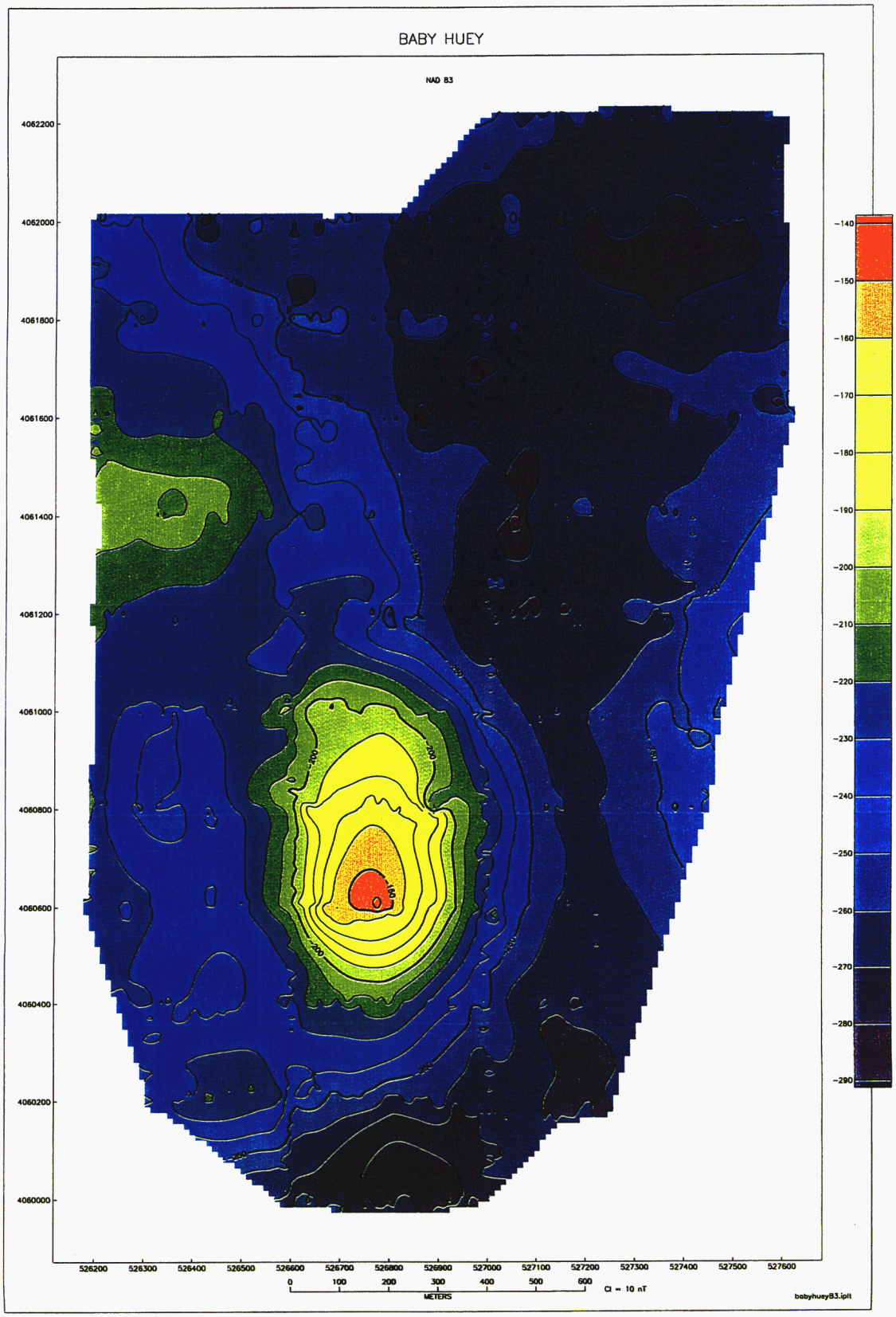


**Figure 4–11. Magnetic map of Baby Huey survey. Contour interval is 10 nT.**

## 4.10 WINDY WASH SURVEY (1997)

The Windy Wash survey covers an 8 $km^2$ area within Windy Wash, adjacent to Yucca Mountain. This area was investigated in order to characterize the relationship between Pliocene Basalts in southern Crater Flat and geologic structures, such as the Crater Flat and Windy Wash faults. The survey covers the area between UTM coordinates (541200E, 4068200N) and (543800E, 4070200N). This area consists of Pliocene basalts exposed on the Windy Wash and Crater Flat footwalls, separated by relatively flat alluvium. The magnetic map (figure 4-12) shows a complex pattern of short-wavelength, large-amplitude anomalies associated with exposed basaltic lavas and the Crater Flat and Windy Wash faults. The Crater Flat fault manifests itself as a 1000 nT anomaly produced by offset of reversely magnetized basalt in the western half of the map area. Basalt outcrops on the Crater Flat footwall are characterized by extremely high horizontal magnetic gradients. Similarly, the Windy Wash fault appears on the eastern edge of the map as a N-trending, 1000 nT anomaly, most conspicuous at the edge of the lava outcrop.

The Crater Flat footwall basalts extend 600–1,000 m east of the Crater Flat fault, based on the frequency and character of mapped anomalies. East of the buried basalts, the wavelength of magnetic anomalies increases abruptly, indicating an increase in the thickness of alluvium. Furthermore, the rocks buried at these greater depths are normally magnetized. This is best seen at the north edge of the lava flow along a WNW-trending lineament which indicates the position of the north edge of the rock unit. These data indicate the existence of a normally polarized body, basalt or tuff, located tens of meters below the Windy Wash alluvium. This finding suggests that the basalts exposed along the Windy Wash and Crater Flat faults are not part of the same lava flow. The WNW-trending lineament may indicate the position of an additional fault, or mark the northern edge of a normally polarized lava flow.

## 4.11 SOUTHWEST NORTHERN CONE SURVEY (1997)

The Southwest Northern Cone survey covers a 1 $km^2$ area, approximately 2.5 km southwest of Northern Cone and 3 km north of Black Cone. The survey was located between UTM coordinates (537200E, 4076600N) and (539000E, 4078600N). Surveying was conducted along a grid of NS and EW trending lines spaced 200 m apart over alluvial topography to characterize a magnetic anomaly discerned on aeromagnetic maps. Numerous low-amplitude, short-wavelength features over the map reflect the presence of randomly oriented highly magnetized rock within the alluvium. Prominent in the center of the resulting ground magnetic map (figure 4-13) is an anomaly with a peak-to-peak amplitude of 250 nT and a horizontal distance between peaks of 600 m. The most striking feature of this anomaly is the relationship between the positive and negative portions of the anomaly. The positive portion of the anomaly is of similar magnitude to, but higher horizontal gradient than, the negative portion of the anomaly, and appears to be wrapped around the northeast corner of the negative portion of the anomaly. This anomaly is the result of a buried body of reversely magnetized rock, likely basalt or tuff, that is tilted or thins to the northwest. This magnetized body may have also rotated in a clockwise direction since acquiring remanent magnetization.

## 4.12 SOLITARIO CANYON SURVEY (1997)

The Solitario Canyon survey was conducted over the Solitario Canyon fault in order to map the magnetic anomalies associated with a known basaltic dike. Surveying was done within UTM coordinates (547100E, 4079400N) and (547450E, 4081000N). The dike, exposed in a trench in the northwestern-most

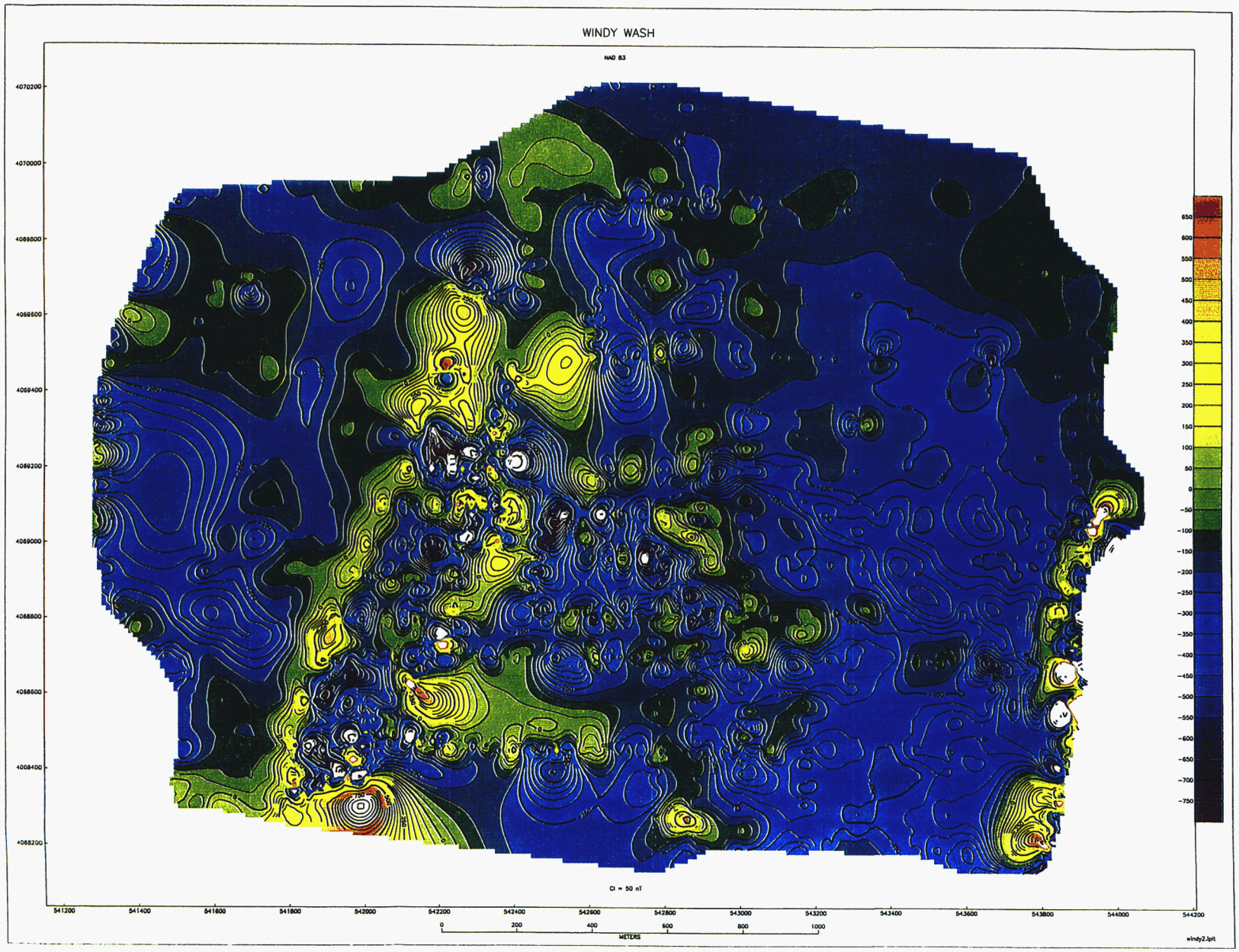


**Figure 4–12. Magnetic map of Windy Wash survey. C ontour interval is 50 nT.**

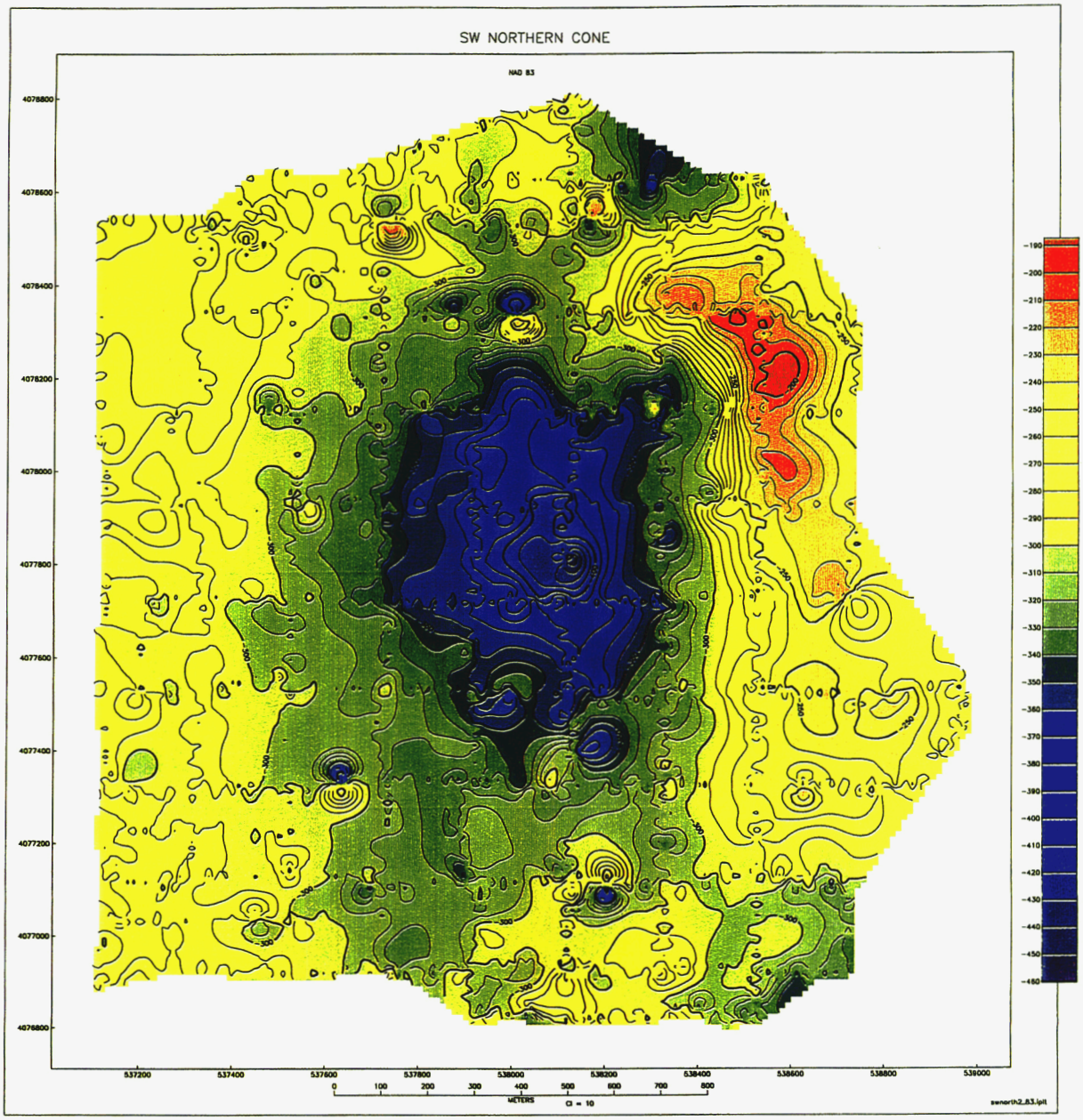


**Figure 4–13. Magnetic map of southwest Northern Cone survey. Contour interval is 10 nT.**

part of the survey area, is dated to be 10.6 Ma and is approximately 3 m wide where exposed in the trench. Intermittent basalt outcrops were located up to 200 m south of the trench. The anomaly associated with this dike is reversely polarized, has a very short wavelength, and a peak-to-peak amplitude of approximately 800 nT (figure 4-14). Transecting the entire length of the ground magnetic map is a north-south trending, short wavelength, reversely polarized anomaly with an amplitude of approximately 300 nT. Intermittently over this anomaly, particularly notable in the southeast corner of the map, are areas of higher wavelength, similar in character to that produced by the known basaltic dike. The entire north-south structure has a wavelength and amplitude consistent with a basaltic dike and may represent a dike within the the Solitario Canyon fault. The anomaly, however, may be produced solely by the fault.

## 4.13 SOUTHERN CRATER FLAT SURVEY (1997)

The 1997 Southern Crater Flat survey was conducted in the deepest part of the Southern Crater Flat Basin, east of the 1996 Crater Flat Survey. The area covers approximately 2.8 $km^2$ between UTM coordinates (535800E, 4065400N) and (537800E, 4067400N). Surveying was done along primarily N-trending lines spaced 200 m apart over flat alluvium. This area was chosen for detailed investigation to characterize ambiguous aeromagnetic anomalies mapped in two previous surveys across this area. The resulting ground magnetic map (figure 4-15) shows several long-wavelength anomalies with amplitudes of between 70 and 150 nT. These anomalies are likely caused by structures within the magnetic basement and are not the result of near surface features.

## 4.14 PORKCHOP SURVEY (1997)

Two roughly N-trending traverses were conducted within northern Crater Flat. These traverses were done to ascertain whether an aeromagnetic anomaly (the Porkchop) located over this area is of volcanic origin. The eastern ground magnetic profile, figure 4-16, is approximately 3.5 km long. This profile shows a normally polarized anomaly having a peak-to-peak amplitude of 420 nT and a horizontal distance of 1,200 m. This profile is characteristic of that produced by a horizontal body of magnetized rock beneath the surface. Figure 4-17 shows the resulting ground magnetic profile of the western traverse. The traverse is approximately 3 km long. The southern half of the survey is relatively smooth with a symmetrical 200-nT, reversely polarized anomaly with a horizontal distance of 150 m between peaks. The northern half of the survey is characterized by higher-frequency, very-high-amplitude anomalies associated with exposed ignimbrite.

# 5 SUMMARY

Fourteen ground magnetic surveys were conducted in the YMR between April 1996 and June 1997 by CNWRA staff. These surveys identified faults and buried volcanoes in the YMR. These and related data will be used to evaluate geologic hazards at the proposed Yucca Mountain high-level radioactive waste repository.

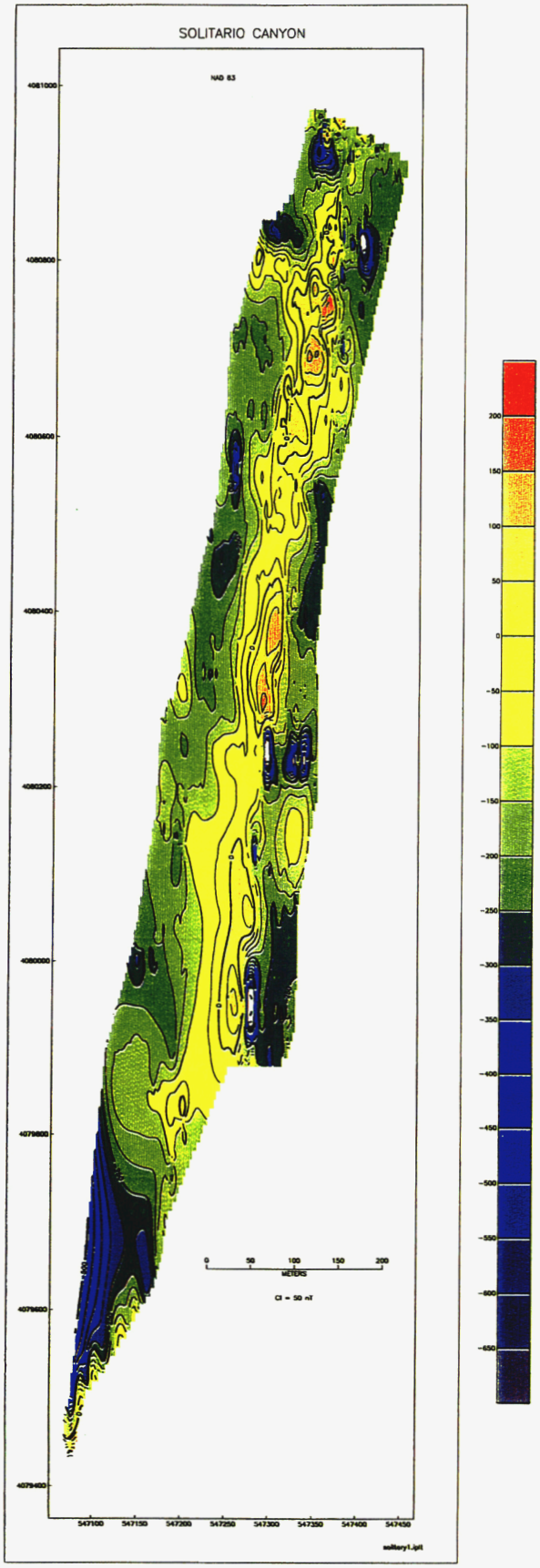


**Figure 4–14. Magnetic map of Solitario Canyon survey. Contour interval is 50 nT.**

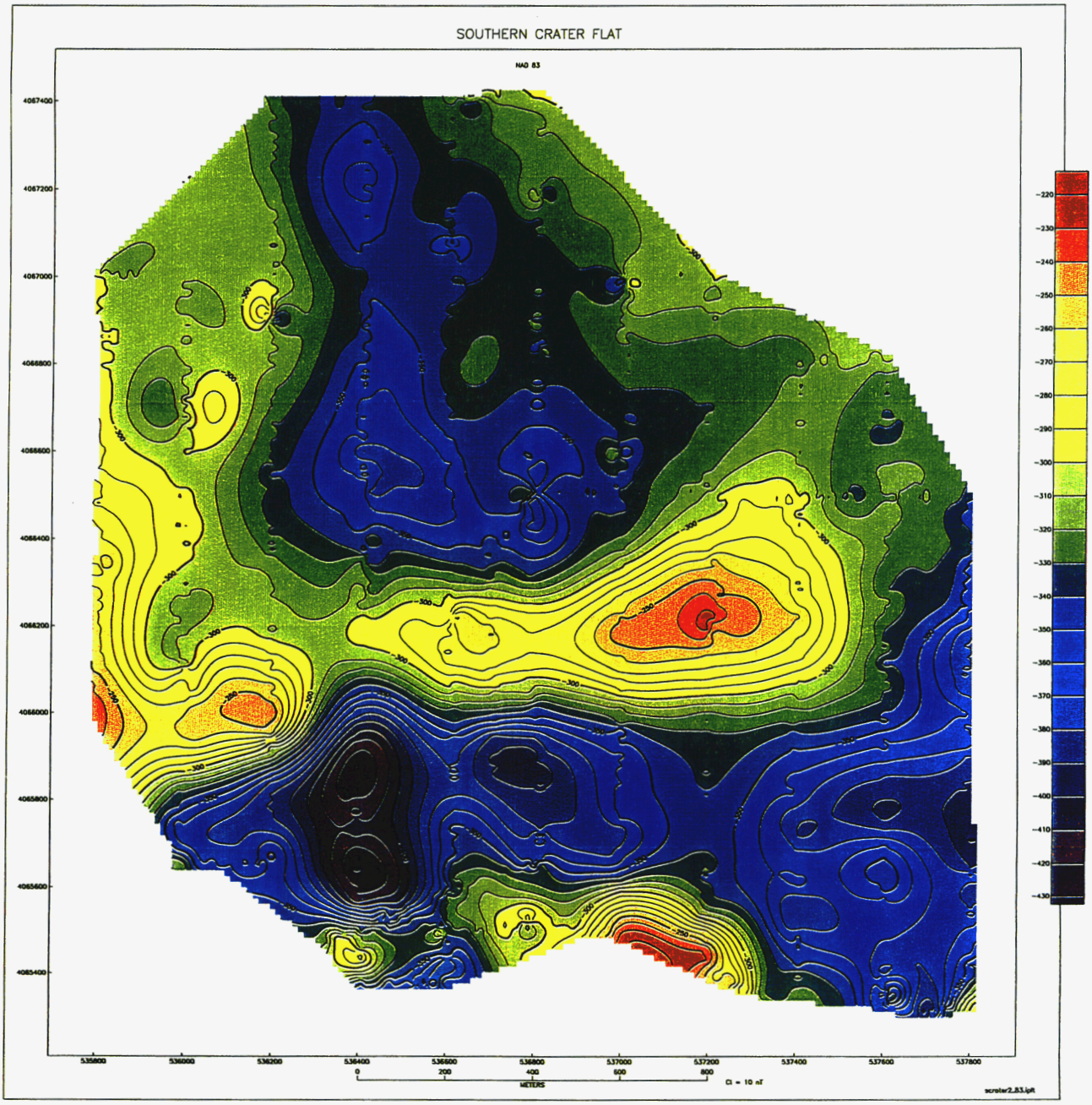


**Figure 4–15. Magnetic map of Southern Crater Flat survey. Contour interval is 10 nT.**

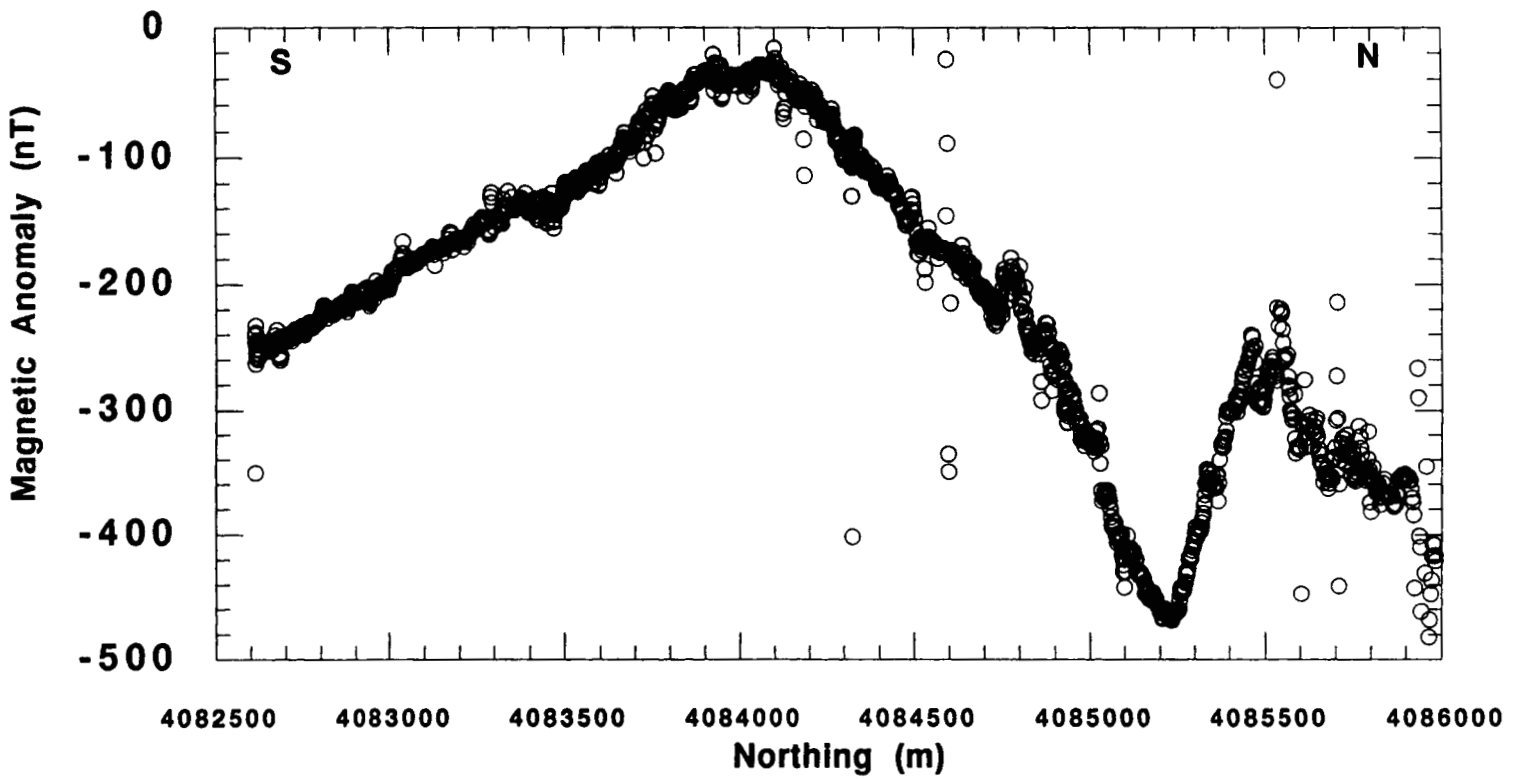


**Figure 4-16. Profile across the Porkchop anomaly, collected on an approximately N-S traverse at 534100 E**

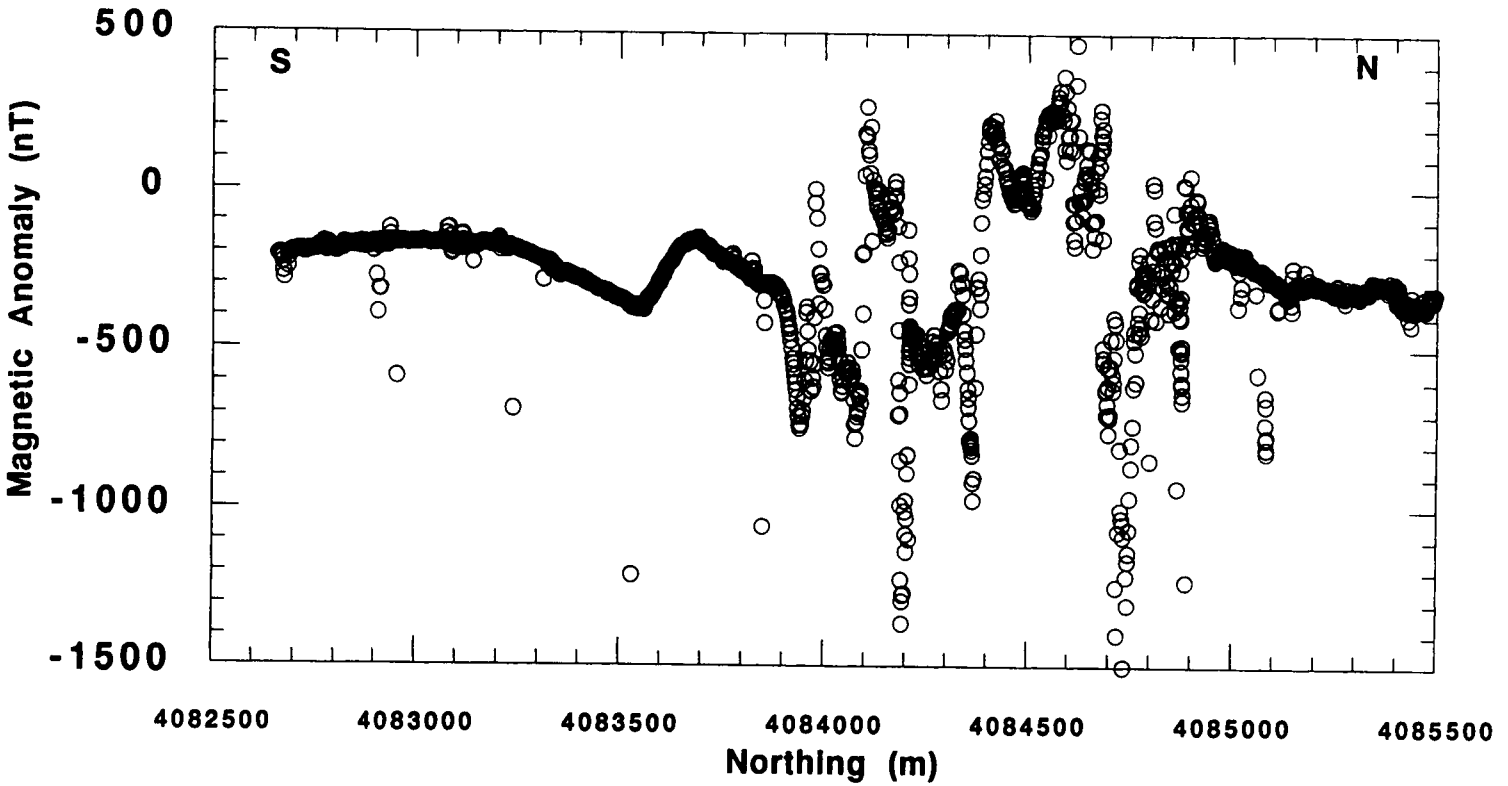


**Figure 4-17. Profile across the Porkchop anomaly collected on an approximately N-S traverse at 533400 E**

# 6 REFERENCES


Connor, C.B., S. Lane-Magsino, J.A. Stamatakos, R.H. Martin, P.C. La Femina, B.E. Hill, and S. Lieber. 1997. Magnetic surveys help reassess volcanic hazards at Yucca Mountain, Nevada. *Eos, Transactions of the American Geophysical Union* 78(7): 73, 75–78.

Faulds, J.E., J.W. Bell, D.L. Feuerbach, and A.R. Ramelli. 1994. *Geologic map of the Crater Flat area, Nevada*. Nevada Bureau of Mines, Geologic Map 101.

Frizzell, V.A., Jr., and J. Schulters. 1990. *Geologic map of the Nevada Test site, southern Nevada*. U.S. Geological Survey Miscellaneous Investigations Map I-2046.

Kane, M.F., and R.E. Bracken. 1983. *Aeromagnetic map of Yucca Mountain and surrounding regions, southwest Nevada*. U.S. Geological Survey Open-File Report 83-616.

Langenheim, V.E., and D.A. Ponce. 1995. Depth to Pre-Cenozoic basement in southwest Nevada. *Proceedings of the Sixth Annual International Conference on High-Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 129–131.

Langenheim, V.E., K.S. Kirchoff-Stein, H.W. Oliver. 1993. Geophysical investigations of buried volcanic centers near Yucca Mountain, southwestern Nevada. *Proceedings of the Fourth Annual International Conference on High-Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 1,840–1,846.

Malin, S.C., and D.R. Barraclough. 1981. An algorithm for synthesizing the geomagnetic field. *Computers and the Geosciences* 7: 401–405.

Nuclear Regulatory Commission. 1996a. Igneous Activity. *NRC High-Level Radioactive Waste Program Annual Progress Report, Fiscal Year 1996*. NUREG/CR-6513, No. 1, CNWRA 96-0IA. Washington, D.C.: Nuclear Regulatory Commission.

Nuclear Regulatory Commission. 1996b. Structural Deformation and Seismicity. *NRC High-Level Radioactive Waste Program Annual Progress Report, Fiscal Year 1996*. NUREG/CR-6513, No. 1, CNWRA 96-0IA. Washington, D.C.: Nuclear Regulatory Commission.

Slemmons, D.B. 1997. Carrara Fault, in southwestern Nevada from paleoseismic, geologic, and geophysical evidence: Implications to the earthquake hazards and tectonics near Yucca Mountain, Nevada. *Eos, Transactions of the American Geophysical Union* 78: F453.

Smith, E.I., T.T. Naumann, D.L. Feuerbach, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: Implications for volcanic risk assessment*. First International Conference on High-level Waste Management, pp 81-99. La Grange Park, Il: American Nuclear Society.

Stamatakos, J.A., C.B. Connor, and R.H. Martin. 1997a. Quaternary basin evolution and basaltic volcanism in Crater Flat, Nevada, from detailed ground magnetic surveys of the Little Cones. *Journal of Geology* 105: 319–330.

Stamatakos, J.A., C.B. Connor, B.E. Hill, S.L. Magsino, and D.A. Ferrill. 1997b. The Carrara Fault in southwestern Nevada revealed from detailed gravity and magnetic results: Implications for seismicity, volcanism, and tectonics near Yucca Mountain, Nevada. *Eos, Transactions of the American Geophysical Union* 78: F453.

CNWRA 98-001 CNWRA GROUND MAGNETIC SURVEYS IN THE YUCCA MOUNTAIN REGION, NEVADA (1996 – 1997)