U. S. DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

Digital aeromagnetic data from the Sandoval-Santa Fe, Belen, and Cochiti airborne surveys, covering areas in Rio Arriba, Sandoval, Santa Fe, Socorro, and Valencia Counties, New Mexico

by

U. S. Geological Survey[1], Sander Geophysics, Ltd.[2], and Geoterrex-Dighem[3]

Open-File Report 99-404

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DISCLAIMERS

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ABSTRACT

This CD-ROM contains digital data, image files, and text files describing the data formats and survey procedures for aeromagnetic data collected during three airborne geophysical surveys in New Mexico during 1997-1998. The Sandoval-Santa Fe survey covers the southern Española Basin and northern Albuquerque basins, including Española, the western part of Santa Fe, major portions or all of the lands of the Pueblos of San Juan, Santa Clara, San Ildefonso, Pojoaque, Nambe, Tesuque, Santo Domingo, San Felipe, Santa Ana, and Zia, and minor portions of the lands of the Pueblos of Cochiti and Jemez. The Belen survey covers the southern Albuquerque basin from just north of Belen to Bernardo on the south. The Cochiti survey primarily covers Cochiti Pueblo lands, west of Santa Fe. Sander Geophysics, Ltd. conducted the Sandoval-Santa Fe and Belen aeromagnetic surveys in 1998; Geoterrex-Dighem collected aeromagnetic data as part of the Cochiti time-domain electromagnetic survey in 1997. Image files of enhanced versions of the data can be viewed using a web browser at http://rmmcweb.cr.usgs.gov/public/mrgb/airborne.html.

DESCRIPTION OF DATA

This report describes aeromagnetic data collected from three geophysical surveys in the northern and southern Albuquerque and southern Española basins, New Mexico as part of U. S. Geological Survey (USGS) contributions to the multi-agency Middle Rio Grande Basin project (Bartolino, 1999). The overall objective of these surveys, in conjunction with other geologic, geophysical, and hydrologic studies is to improve the understanding of the geologic and hydrogeologic framework of the Middle Rio Grande Basin. This improved understanding will ultimately lead to refinements in the hydrologic model of the Basin.

Three geophysical surveys were flown during 1997-1998: the Sandoval-Santa Fe, Belen, and Cochiti surveys (fig. 1). The Sandoval-Santa Fe survey was conducted by Sander Geophysics, Ltd. for the USGS during November-December, 1998. The survey area covers the southern Española Basin and northern Albuquerque basins, including Española, the western part of Santa Fe, major portions or all of the lands of the Pueblos of San Juan, Santa Clara, San Ildefonso, Pojoaque, Nambe, Tesuque, Santo Domingo, San Felipe, Santa Ana, and Zia, and minor portions of the lands of the Pueblos of Cochiti and Jemez. The Belen survey was conducted by Sander Geophysics, Ltd. for the USGS during December, 1998. The survey area covers the southern Albuquerque basin from just north of Belen to Bernardo on the south. Aeromagnetic data for the Cochiti survey was acquired as part of a time-domain electromagnetic survey conducted by Geoterrex-Dighem for the USGS in February-March, 1997. The survey area primarily covers Cochiti Pueblo lands, west of Santa Fe.

The Sandoval-Santa Fe and Belen surveys were flown along east-west lines spaced 150 m apart and at a nominal altitude of 150 m above ground level (AGL). Further details of the flight specifications, survey procedures, and data processing are included in Appendix A. The Cochiti survey was flown along east-west lines spaced 400 m apart and at a nominal altitude of 73 m for the magnetometer. Further details of the flight specifications, survey procedures, and data processing are included in Appendix B. Projected coordinates for the flight-line data use a Universal Transverse Mercatur projection (Zone 13; central meridian 105^{o}W, North American Datum of 1927).

Grids of the magnetic and radar-altimeter data were constructed using a minimum curvature algorithm. Grid specifications are described in the gxfinfo.txt file listed below (Table 1). Grids in grid exchange format (.gxf) for the Sandoval-Santa Fe and Belen surveys were constructed using a 50-m interval by Sander Geophysics, Ltd. (Appendix A). Grids of the final magnetic data (excluding tie lines) that appear in other formats were constructed by the USGS using the minimum curvature program of Webring (1981). Grids for the Cochiti survey were constructed using a 100-m interval by the USGS in a similar fashion. The greater grid interval is commensurate with the wider line spacing of the Cochiti survey. The USGS grids of the final magnetic data were developed into color shaded-relief images using the program ERMapper[1]. A color shaded-relief image enhances many subtle details not apparent in standard displays. A sun angle of 270^o (west) and sun elevation of 60^o above the horizon were used in the shaded-relief algorithm for all images. The color scales were non-linear and are displayed on some of the images (see Table 1 and imginfo.txt file).

The files on this CD-ROM and the contents of the four folders (directories) are briefly explained in Table 1. The "readme.txt" file provides summaries of the contents of the CD-ROM and instructions for installing the Adobe Acrobat[1] reader necessary for viewing the .pdf files. The four folders (directories) are organized as follows. Files pertaining to this report are contained in the "report" folder; files pertaining to the gridded data are contained in the "grids" folder; files pertaining to the flight-line data are contained in the "linedata" folder; and files pertaining to the color shaded-relief images are contained in the "images" folder. In each folder, ASCII files with the extension .txt describe the format and contents of the data files. Read the .txt files before using the data files.

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[1]Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U. S. Geological Survey.

TABLE 1. FILE DESCRIPTIONS

FILE NAME	FORMAT TYPE	DESCRIPTION
readme.txt	ASCII text	Text file explaining how to start reading and using the files of this CD-ROM.
ar32e301.exe	Executable file	Self-extracting program to install Acrobat Reader 3.01 for viewing .pdf files. See readme.txt for instructions.
----REPORT folder----		
report.pdf	Portable document format	A file containing the text of this report, with hyperlinks to the appendices and figures shown by red boxes around text.
appenda.pdf	Portable document format	Appendix A - text only of the contractor's report on the Sandoval-Santa Fe and Belen surveys by Sander Geophysics, Ltd.
appendb.pdf	Portable document format	Appendix B - text only of the contractor's report on the aeromagnetic collection only for the Cochiti survey by Dighem-Geoterrex.
figloc.pdf	Portable document format	Figure 1 of report.pdf, showing locations of the survey areas.
----GRIDS folder----		
gxfinfo.txt	ASCII text	Description of grids with the extension .gxf and explanation of grid exchange format .
ssmag.gxf	Grid exchange format	Final levelled, decorrugated, total-intensity magnetic data for the Sandoval-Santa Fe survey, gridded by the contractor (Appendix A). See help file gxfinfo.txt
ssradar.gxf	Grid exchange format	Radar-altimeter measurements for the Sandoval-Santa Fe survey in meters, gridded by the contractor (Appendix A). See help file gxfinfo.txt
ssunlmag.gxf	Grid exchange format	Unlevelled, total-intensity magnetic data for the Sandoval-Santa Fe survey, gridded by the contractor (Appendix A). See help file gxfinfo.txt

TABLE 1. FILE DESCRIPTIONS - CONTINUED

bmag.gxf	Grid exchange format	Final levelled, decorrugated, total-intensity magnetic data for the Belen survey, gridded by the contractor (Appendix A). See help file gxfinfo.txt
bradar.gxf	Grid exchange format	Radar-altimeter measurements for the Belen survey in meters, gridded by the contractor (Appendix A). See help file gxfinfo.txt
bunlmag.gxf	Grid exchange format	Unlevelled, total-intensity magnetic data for the Belen survey, gridded by the contractor (Appendix A). See help file gxfinfo.txt
cmag.gxf	Grid exchange format	Final levelled total-intensity magnetic data for the Cochiti survey, gridded by the USGS (Webring, 1981). See help file gxfinfo.txt
cradar.gxf	Grid exchange format	Radar-altimeter measurements for the Cochiti survey in meters, gridded by the USGS (Webring, 1981). See help file gxfinfo.txt
cunlmag.gxf	Grid exchange format	Unlevelled, total-intensity magnetic data for the Cochiti survey, gridded by the USGS (Webring, 1981). See help file gxfinfo.txt
e00info.txt	ASCII text	Description of ARC export format .e00 (grid) files and use with ARC-compatible software.
ssmag.e00	ARC exchange format	Final levelled, decorrugated, total-intensity magnetic data for the Sandoval-Santa Fe survey, tie-line data removed, gridded by the USGS (Webring, 1981). See help file e00info.txt
bmag.e00	ARC exchange format	Final levelled, decorrugated, total-intensity magnetic data for the Belen survey, tie-line data removed, gridded by the USGS (Webring, 1981). See help file e00info.txt
cmag.e00	ARC exchange format	Final levelled total-intensity magnetic data for the Cochiti survey, tie-line data included, gridded by the USGS (Webring, 1981). See help file e00info.txt

TABLE 1. FILE DESCRIPTIONS - CONTINUED

----LINEDATA folder----		
ssminfo.txt	ASCII text	Description of the information contained in and format of the flight-line data file, ssmlines.asc, Sandoval-Santa Fe survey
ssmlines.asc	ASCII data	Final information from the contractor for the Sandoval-Santa Fe survey as sampled along the flight lines. See the file ssminfo.txt for description of file contents and format.
bminfo.txt	ASCII text	Description of the information contained in and format of the flight-line data file, bmlines.asc, Belen survey
bmlines.asc	ASCII data	Final information from the contractor for the Belen survey as sampled along the flight lines. See the file bminfo.txt for description of file contents and format.
cminfo.txt	ASCII text	Description of the information contained in and format of the flight-line data file, cmlines.asc, Cochiti survey
cmlines.asc	ASCII data	Final information from the contractor for the Cochiti survey as sampled along the flight lines. See the file cminfo.txt for description of file contents and format.
----IMAGES folder----		
imginfo.txt	ASCII text	Description of the files containing color shaded-relief images developed in ERMapper from the final total-intensity magnetic data.
ssmagimg.tif	Tagged image format	Color shaded-relief image without scales or text annotation for import by many graphics packages. When paired with ssmagimg.tfw in the same directory, the file can be imported into ARC/INFO and ARC/VIEW
ssmagimg.tfw	Geotif ASCII header file	See ssmagimg.tif
ssmagpic.gif	Graphics interchange format	Color shaded-relief image with map and color scales and latitude/longitude labels for standard graphics programs and web browsers.
ssmagpic.pdf	Portable document format	Color shaded-relief image with map and color scales and latitude/longitude labels for Acrobat readers, resized to fit an 11"x17" page.

TABLE 1. FILE DESCRIPTIONS - CONTINUED

bmagimg.tif	Tagged image format	Color shaded-relief image without scales or text annotation for import by many graphics packages. When paired with bmagimg.tfw in the same directory, the file can be imported into ARC/INFO and ARC/VIEW
bmagimg.tfw	Geotif ASCII header file	See bmagimg.tif
bmagpic.gif	Graphics interchange format	Color shaded-relief image with map and color scales and latitude/longitude labels for standard graphics programs and web browsers.
bmagpic.pdf	Portable document format	Color shaded-relief image with map and color scales and latitude/longitude labels for Acrobat readers, resized to fit an 11"x17" page.
cmagimg.tif	Tagged image format	Color shaded-relief image without scales or text annotation for import by many graphics packages. When paired with cmagimg.tfw in the same directory, the file can be imported into ARC/INFO and ARC/VIEW
cmagimg.tfw	Geotif ASCII header file	See cmagimg.tif
cmagpic.gif	Graphics interchange format	Color shaded-relief image with map and color scales and latitude/longitude labels for standard graphics programs and web browsers.
cmagpic.pdf	Portable document format	Color shaded-relief image with map and color scales and latitude/longitude labels for Acrobat readers.

ACKNOWLEDGEMENTS

We are very grateful to the Pueblos of Cochiti, Jemez, Nambe, Pojoaque, Santa Ana, Santa Clara, San Felipe, San Ildefonso, San Juan, Santo Domingo, Tesuque, and Zia for their permission to acquire data over pueblo lands and to the Bureau of Indian Affairs who helped fund the Sandoval-Santa Fe survey. The large areal extent of the Sandoval-Santa Fe and Belen surveys would not have been possible without the funding support of the New Mexico State Engineer's Office. We are also thankful to the people of Santa Fe, Española, Belen, and surrounding communities for their tolerance during the low-level flying over their homes and businesses.

REFERENCES CITED

Bartolino, J. R., 1999, U. S. Geological Survey Middle Rio Grande Basin Study—Proceedings of the Third Annual Workshop, Albuquerque, New Mexico, February 24-25, 1999: U. S. Geological Survey Open-File Report 99-203, 95 p.

Webring, Michael, 1981, MINC: A gridding program based on minimum curvature: U. S. Geological Survey Open-File Report 81-1224, 41 p.

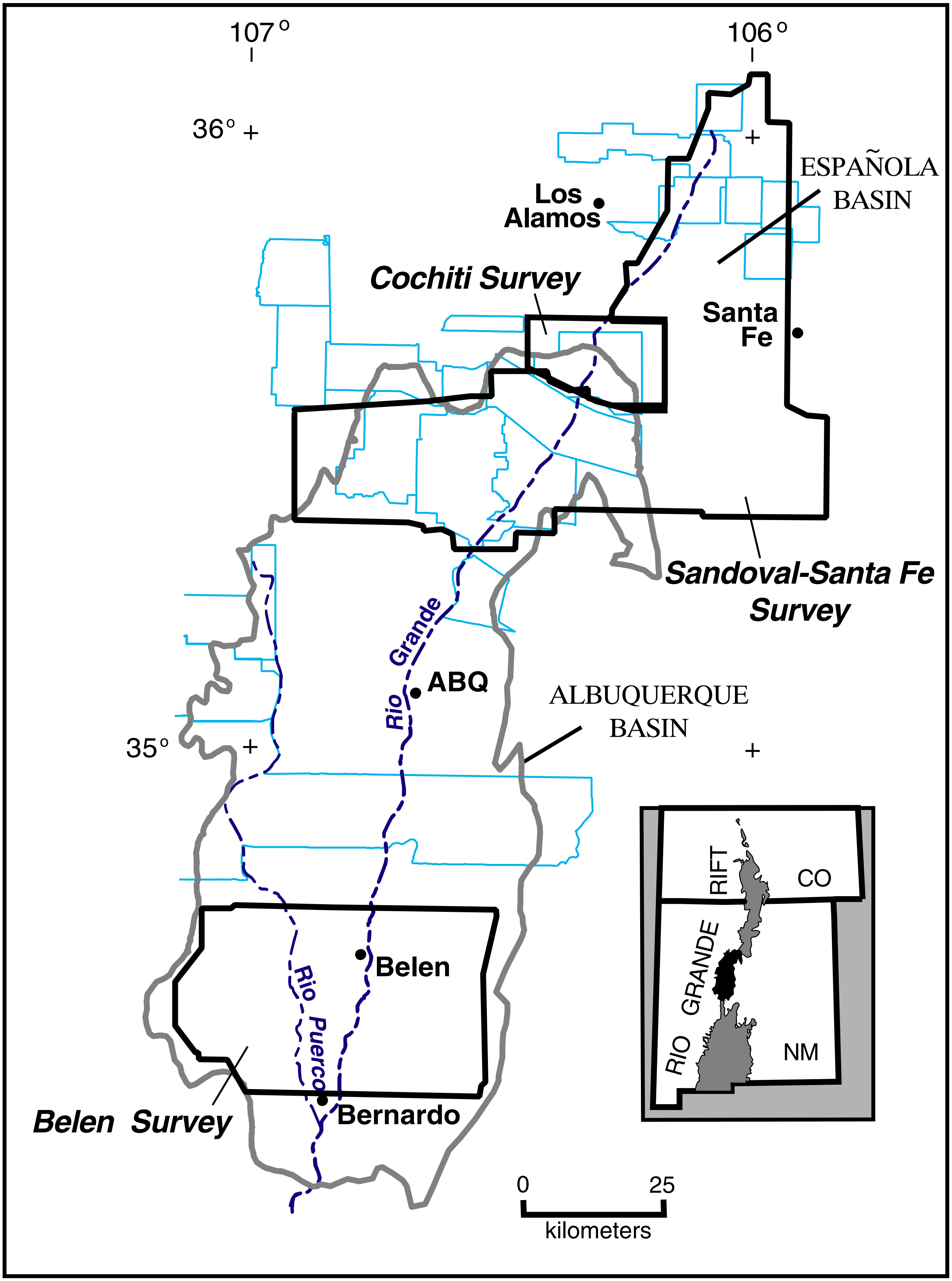

Figure 1. Location of the Sandoval-Santa Fe, Belen, and Cochiti geophysical surveys within the Albuquerque and Española basins. The Sandoval-Santa Fe and Cochiti surveys overlap. Pueblo lands are outlined in light blue. ABQ=Albuquerque. Inset shows the location of the Albuquerque basin within the Rio Grande rift in New Mexico.

APPENDIX A: REPORT BY SANDER GEOPHYSICS LIMITED

PROJECT REPORT

HIGH RESOLUTION AEROMAGNETIC SURVEY

CENTRAL NEW MEXICO (USA) - 1998

for

UNITED STATES GEOLOGICAL SURVEY

by

Sander Geophysics Limited
260 Hunt Club Road
Ottawa, Ontario K1V 1C1

Kelly O'Connor, B.Sc.

July 1999

TABLE OF CONTENTS

I. INTRODUCTION

Sander Geophysics Limited (SGL) conducted a high resolution aeromagnetic and radiometric survey in Central New Mexico for the United States Geological Survey. The survey was flown between November 1 and December 12, 1998. Fifty-one flights, totalling 34,386 line kilometres, over two survey blocks, were required to complete data acquisition for the survey.

II. SURVEY AREA

SANDOVAL - SANTA FE BLOCK (NORTH BLOCK)

The two survey areas abut to form a survey area in the shape of a mirror-image 'L, approximately 80 km in the north-south direction, and 100 km in the east-west direction. The southern border is 35 km south of Santa Fe and 20 km north of Albuquerque. The eastern border of the block is 15 km east of Santa Fe. The survey area contains rolling terrain surrounded by mountains to the east and west. The average elevation of the survey block is approximately 2000 m.

The following coordinates, in NAD-27-USA datum, define the survey area:

Corner	Latitude	Longitude
1	36:01.2500N	105:59.5000
2	36:01.2500N	105:57.0000
3	35:33.9500N	105:57.0000
4	35:31.2900N	105:52.1800
5	35:22.7800N	105:52.1800
6	35:22.7800N	106:06.0000
7	35:23.3700N	106:06.7100
8	35:25.3900N	106:09.2400
9	35:25.3900N	106:10.4700
10	35:23.2600N	106:11.5200

Corner	Latitude	Longitude
11	35:23.2585N	106:24.4878
12	35:20.8830N	106:24.4878
13	35:20.8830N	106:29.1142
14	35:19.2661N	106:29.1142
15	35:19.2661N	106:36.2008
16	35:20.8830N	106:36.4961
17	35:21.7431N	106:41.8110
18	35:21.7431N	106:55.5671
19	35:32.3687N	106:55.5671
20	35:34.1300N	106:32.0700
21	35:36.6100N	106:32.0700
22	35:36.6100N	106:28.1500
23	35:31.3800N	106:11.9900
24	35:31.2600N	106:10.6400
25	35:41.5000N	106:10.6400
26	35:41.5000N	106:17.7500
27	35:42.5802N	106:17.7500
28	35:55.0000N	106:10.0000
29	36:02.4000N	106:06.9300
30	36:06.3200N	105:59.5000

This block consists of 581 traverse lines oriented east-west, and 14 orthogonal control lines.

BELEN BLOCK (SOUTH BLOCK)

The survey block is rectangular, 50 km in the east-west direction by 35 km in the north-south direction, centred approximately on the town of Belen. The area is relatively flat with a ridge running north-south through the centre of the block. The average elevation of the survey block is approximately 1500 m.

The following coordinates, in NAD-27-USA datum, define the survey area:

Corner	Latitude	Longitude
1	34:32.3333N	107:08.3287W
2	34:36.3679N	107:01.6000W
3	34:44.1115N	107:01.6000W
4	34:44.1115N	106:30.6222W
5	34:37.7897N	106:32.3267W
6	34:32.3333N	106:31.9889W
7	34:27.3337N	106:31.8646W
8	34:26.0000N	106:33.5221W
9	34:26.0000N	106:59.7099W
10	34:29.6904N	107:02.3619W
11	34:29.6904N	107:05.5939W

This block consists of 224 traverse lines oriented east-west, and 6 orthogonal control lines.

III. SURVEY EQUIPMENT

Two aircraft were used for this survey, a CESSNA 402B UTILILINER, registration C-GCKB, and a CESSNA 404, registration C-GBWE. SGL provided the following instrumentation for this survey:

AERIAL AND GROUND MAGNETOMETERS

- *GEOMETRICS Model G-822A (402 and 404)*
- *SCINTREX Model G3 (Ground Station - Santa Fe and Belen) and GEOMETRICS model G-822A (Ground Station - Belen)*

Both the ground and airborne systems used a non-oriented (strap-down) optically pumped cesium split-beam sensor. These magnetometers have a sensitivity of 0.01 nT, or better, and a range of 20,000 nT. Sensor noise is less than 0.02 nT. The total field magnetic measurements are digitally recorded at intervals of 0.1 second in the airborne system and 0.5 second in the ground system.

The ground station in Belen was knocked down by heavy machinery during survey production, damaging the sensor. The Geometrics magnetometer was replaced at that point with the Scintrex G3 from the Santa Fe ground station.

AUTOMATIC AEROMAGNETIC DIGITAL COMPENSATOR (AADC)

- *RMS Model AADC 4000 MkII* (Cessna 402)
- *RMS Model AADC 4000 MkIII* (Cessna 404)

Both of the RMS compensator used are fully automatic, 27-term compensator systems utilizing 3-axis fluxgate magnetometers for heading information. Magnetic information is output to the serial port at a minimum of 0.1 second intervals, with a resolution of 0.001 nT. The system provides a complete real-time compensation of the aircraft manoeuvre noise.

NAVIGATION AND FLIGHT PATH RECOVERY SYSTEM

- *NovAtel GPSCard Receiver*
- *OMNISTAR 6300 Receiver*

Navigation and flight path recovery are provided by GPSNAV system which utilizes a NovAtel GPSCard 3951R 12-channel GPS receiver mounted in a 486-based navigation computer with a sampling rate of 1.0 second. In addition to providing essential positional data, the GPSNAV system is used to guide the pilot along the desired flight lines at the optimal flight altitude. The navigation computer processes real-time differentially corrected GPS (RTDGPS) data from the OMNISTAR 6300 system and compares that to the coordinates of a theoretical flight plan and flying surface.

AIRBORNE DATA ACQUISITION SYSTEM

- *Sander NavDAS*

The NavDAS is the latest version of airborne data acquisition computers developed by SGL. It records all incoming data and displays them on a flat panel screen. Recording is done on vibration tolerant IOMEGA JAZ cartridges. The time base (UTC) accuracy of the NavDAS system is automatically provided by the GPS receiver. The NavDAS incorporates a magnetometer sensor coupler, an altimeter converter and a GPS receiver.

GROUND DATA ACQUISITION SYSTEM

- *Sander GND-ACQ*

The ground data acquisition computer also records and displays all the incoming data on a flat panel screen. The computer is a portable PC-486 with a Sander Cesium Magnetometer Frequency Counter to process the signal from the sensor. The noise level of the base station magnetometer is less than 0.1 nT. Recording is done on the internal hard disk of the computer. The magnetic data are recorded at a rate of 0.5 second. The GPS ground data are recorded using the same format as the airborne data. The time base (UTC) of both the ground and airborne systems is automatically provided by the GPS receiver. Data acquired by the ground system are printed on a line printer before and during each flight. The entire ground data acquisition system is fully automatic and is set for unattended recording and printing.

GPS BASE STATION RECEIVER

- *NovAtel 3951R*

The NovAtel GPSCard 12-channel receiver forms an integral part of the Sander GND-ACQ system. It provides averaged position and raw range information of all satellites in view, at intervals of 1.0 second. It also provides comparative navigation data during all production flights, allowing differential GPS (DGPS) coverage for the entire project.

VIDEO CAMERA AND RECORDER

- *Panasonic NTS CCD WVD-5100HS*

The video camera is mounted in the floor of the aircraft and oriented in such a way as to look vertically below while in flight. An intervalometer and fiducial marking system required for flight path verification are incorporated. The video information was recorded on VHS video tapes for the entire survey. This information can be used to identify the sources of cultural noise in the magnetic data for later removal.

RADAR AND BAROMETRIC ALTIMETERS

- *TRT radar altimeter (Cessna 402 and 404)*
- *Sensotec digital barometric pressure sensor*

The TRT radar altimeter has a resolution of 0.5 m, an accuracy of 1% and a range of 1 to 10,000 ft. The barometric pressure system has a resolution of 2 m, an accuracy of ±4 m, and a range of 1 to 30,000 ft.

SURVEY AIRCRAFT

- *Cessna 402B (C-GCKB)*

SGL’s 402 is an all metal, low-wing aircraft powered by two Continental turbocharged engines that drive constant speed, fully feathering propellers. The aircraft is equipped with full de-icing equipment and sufficient avionics for IFR flight. The airframe was extensively modified to reduce the magnetic signature of the aircraft. For this project, the aircraft was configured with a single 2.5 m tail stinger made of a non-magnetic material to house the magnetometer sensor. The aircraft has a Canadian registration C-GCKB and with the aeromagnetic system installed conforms to Canadian Aeronautical Regulations.

- *Cessna 404 (C-GBWE)*

SGL’s 404 is an all metal, low wing, twin-engined aircraft powered by two turbocharged engines that drive constant speed, fully feathering propellers. The aircraft has fully retractable tricycle landing gear, extendable flaps and manually adjustable trim tabs on the primary controls for all three flight axes. The aircraft is equipped with full de-icing equipment and sufficient avionics for instrument flying. The aircraft has a rigid aluminum and composite material 2.5 m tail stinger designed to accommodate a magnetometer sensor and wiring. There is a camera hole in the belly of the aircraft and provisions for numerous other survey and navigation systems. The airframe has been extensively modified to reduce the magnetic signature of the aircraft by replacing ferromagnetic parts with those made from special non-magnetic stainless steel or aluminum. Several wiring changes have also been made to the electrical system to reduce the magnetic field variations around the aircraft.

DATA PROCESSING EQUIPMENT AND SOFTWARE

(a) Pentium 166 MHz, 3.8 Gb hard drive

(b) Toshiba 330CDT laptop computer, 266 MHz, 3.8 Gb hard drive

(c) HP1000 colour printer

(d) SGL data processing and imaging software

(e) GPS processing software

IV. SURVEY SPECIFICATIONS

DATA RECORDING

The following parameters were recorded during the course of the survey:

(a) Aircraft altitude as measured by the barometric altimeter at intervals of 0.25 second;

(b) Terrain clearance provided by the radar altimeter at intervals of 0.25 second;

(c) A continuous video tape record of the terrain passing below the aircraft;

(d) Airborne GPS positional data (latitude, longitude, height, time and raw range from each satellite being tracked), recorded at intervals of 1.0 s;

(e) Time markers synchronously impressed on the video and digital data;

(f) Airborne total magnetic field recorded with a 0.1 s sampling rate;

(g) Ground total magnetic field recorded with a 0.5 s sampling rate; and

(h) Ground based GPS positional data (latitude, longitude, height, time and raw range from each satellite being tracked), recorded at intervals of 1.0 s.

TECHNICAL SPECIFICATIONS

The following technical specifications were adhered to:

(a) *Geomagnetic diurnal variation*

Reflights would be required if the magnetic diurnal variation exceeded a maximum deviation of ± 5.0 nT from a curvilinear mean over two minutes, if the pulsations had periods of 5 minutes and exceeded 2 nT, if the pulsations had periods between 5 and 10 minutes and exceeded 4 nT or if the pulsations had periods between 10 and 20 minutes and exceeded 8 nT. Geomagnetic variations did not exceed these specifications during survey flying and thus no reflights were needed due to this specification.

(b) *High frequency noise*

Reflights would be required if the high frequency noise envelope on the aeromagnetic data exceeded 0.1 nT for more than 10% of any flight line. No lines were reflown due to this specification.

(c) *Deviation from theoretical flight path*

Reflights would be required if a gap greater than 1.5 times the nominal line spacing (150 m) between two adjacent lines occurred over a distance greater than 2 miles (3.2 km). No lines were reflown due to this specification.

(d) *Deviation from theoretical altitude*

The contract specified that the any deviations greater than ±20% from the specified survey height would be reflown. Six lines were reflown because altitude deviations exceeded this specification. The lines reflown were lines 1095, 1234, 1284, 1285, 1437 and 1545.

FLIGHT LINE SPECIFICATIONS

Sandoval - Santa Fe Block (North Block)

	Traverse	**Control**
Line spacing:	150 m	10 km
Line direction:	East-West	North-South
Survey altitude:	150m (500') AGL Differential GPS	

Belen Block (South Block)

	Traverse	**Control**
Line spacing:	150 m	10 km
Line direction:	East-West	North-South
Survey altitude:	150m (500') AGL Differential GPS	

The specified flying height for this project was 150 m above ground level. Due to the hills within the survey area and the mountains surrounding the survey, the preplanned drape surface contained numerous areas that would be flown above the minimum ground clearance. Thus, it was decided to fly the survey with a minimum ground clearance set to 120 m. This resulted in an average height above ground level of 204 m for the north block and 151 m for the south block.

V. SYSTEM TESTS

MAGNETOMETER CALIBRATION

Calibration of the Cessna 402 magnetometer system was carried out at Bourget, Ontario, on September 29, 1998. The average heading errors were found to be 0.2 nT in the north-south direction and 0.1 nT in the east-west direction. The absolute error was 0.3 nT.

Calibration of the Cessna 404 magnetometer system was carried out at Bourget, Ontario, on November 12, 1998. The average heading errors were found to be 0.2 nT in the north-south direction and 0.3 nT in the east-west direction. The absolute error was 0.7 nT.

AADC COMPENSATION

Compensation tests determine the magnetic influence of aircraft manoeuvres and the effectiveness of the RMS AADC compensator. Two compensation flights for the geophysical aircraft Cessna402B, C-GCKB were carried out over a magnetically quiet area close to Santa Fe, New Mexico on October 29 and 30, 1998. The aircraft performed pitches, rolls, and yaws, while flying in the four cardinal headings (North, East, South, West). The total compensated signal noise resulting from the twelve manoeuvres (referred to as the Figure of Merit -FOM) was 1.6 nT for the first compensation flight and 1.3 nT for the second. The solution determined during the second flight was used for all survey flights until the aircraft alternator was replaced on November 14. A third compensation was flown on November 15 with a FOM of 1.1 nT.

The magnetic compensation flight for the Cessna 404 was carried out in the same area close to Sante Fe on November 21, 1998. Problems with the aircraft alternators and voltage regulators caused them to be changed on November 23 and 24. Compensations were flown both days, with FOM's of 1.3 and 1.0 nT respectively. A voltage regulator was changed on November 30 after apparent alternator problems caused a flight to be aborted. The FOM determined during the compensation flight flown December 1 was 1.3 nT.

INSTRUMENTATION LAG

The system lags on both aircraft were checked during the magnetometer calibration flights by analysing two sets of data flown in opposite directions over a bridge in the Bourget test area. A well defined anomaly was obtained and allowed determination of the lag between the positional data and the magnetometer data. The lag was found to be 0.65 second for both systems and the delay was subsequently corrected during data compilation. It is not unexpected that the two systems have identical lag since the data acquisition systems and instrumentation are identical.

RADAR ALTIMETER CALIBRATION

The radar altimeter in the Cessna 402 was tested on October 8, 1998, by flying at altitudes of 300 ft, 500ft and 700 ft AGL over airport runway in Ottawa. The radar altimeter in the Cessna 404 was tested on November 9, 1998 by flying at altitudes 200 ft, 400 ft, 600 ft and 800 ft AGL over the Ottawa airport runway. The resultant radar altimeter and differentially corrected GPS heights were plotted on XY graphs. In both cases, the plot of the radar calibration data points is a close approximation to a straight line with a slope of 45°, indicating good calibration of the radar altimeter.

VI. FIELD OPERATIONS

Operations were conducted from the Santa Fe Municipal Airport located approximately 10 kilometres from downtown Santa Fe.

A field office was established in the Zia Aviation hangar at the airport.

The combined magnetic/GPS ground station was installed at the airport. The magnetic sensor was situated in a field next to the main Zia Aviation hangar while the GPS antennae was situated on the hangar roof. The position of the GPS antennae of the ground station was:

Latitude (WGS-84):	35:37.3048 N
Longitude (WGS-84):	106:04.8682 W
Elevation (wrt GRS-80) :	1919.10 m

A second combined magnetic/GPS ground station was installed at the Belen airport to record during the flights in the south block. The magnetic sensor for this ground station was located in a field adjacent to the Mountain Sun Aviation hangar and the GPS antennae was situated on the hangar roof. The position of the GPS antennae of the ground station was:

Latitude (WGS-84):	34:38.8282 N
Longitude (WGS-84):	106:49.7157 W
Elevation (wrt GRS-80):	1560.26 m

FIELD PERSONNEL

The following technical personnel of Sander Geophysics Limited participated in field operations.

Project Manager:	Reed Archer
Field Operations Manager:	Kelly O'Connor
Data Processor:	Kelly O'Connor
Pilot-in-command:	Saeed Solhdoost, Siegfried Hypolite Jan Kristiansen
Copilot:	Todd Lewis, John Maldonado
Aircraft Maintenance Engineer:	Bill Haggart

VII. DIGITAL DATA COMPILATION

All preliminary data compilation such as editing and filtering was performed in the field. Preliminary processing for on-site quality control was performed as each flight was completed. Final data processing and map production were performed at SGL head office in Ottawa.

MAGNETOMETER DATA

The airborne magnetometer data, recorded at 10 Hz, were plotted and checked for spikes or noise. Ground magnetometer data were de-spiked automatically using a filter and spiker. All ground station magnetometer data were then filtered using a 67-point low pass filter. Ground station magnetometer data were IGRF corrected using the fixed ground station location (see Field Operations) and the recorded date for each flight. The north block data was corrected using the Santa Fe magnetic ground station data , while most of the south block was corrected using the Belen magnetic ground station data. The Belen ground station did not function for a number of flights. A comparison of the recorded magnetic data for the two ground stations on days when both were functioning showed an excellent correspondence between the medium and short wavelength disturbances. Thus it was decided to use the Santa Fe magnetic ground station for the days when the Belen ground station was not functioning. The affected flights for which the Santa Fe ground station was used were flights 211, 215, 216, 217, 917, and 218.

The magnetic ground station sensor was re-installed approximately five metres from its original position. To compensate for the difference, 20 nT was added to the entire ground magnetic data set for flight 219, the only flight flown after the sensor was moved.

The airborne magnetometer data were corrected for diurnal variations by subtracting the ground magnetometer values and adding the average value back in, using all the flights. Intersections between control and traverse lines were determined by a program which extracts the magnetic, altitude, and X and Y values, of the traverse and control lines at the intersection point. Each control line was then adjusted by a specific constant value to minimize for each traverse line:

$$\Sigma|i - a|$$

where, i = (*Individual intersection difference*)
a = (*Average intersection difference for that traverse line*)

Line levelling was carried out by a program which interpolates and extrapolates levelling values for each point, based on the two closest levelling values. Both traverse and control lines were levelled, ensuring that all intersections tied perfectly.

After levelling, a decorrugation filter was applied to remove residual errors mainly due to altitude differences on adjacent traverse lines. Low frequency decorrugation corrections were calculated from the gridded data and applied to the line data. For the north block, the filter removed features with wavelength greater than 900 m parallel to the traverse line, and less than twice the line spacing perpendicular to the traverse lines. Corrections were limited to ± 3 nT. For the south block, the filter removed features with wavelength greater than 500 m parallel to the traverse line, and less than twice the line spacing perpendicular to the traverse lines. Corrections were limited from -2 nT to 1.5 nT. Control line data was matched to the corrected traverse line data to ensure identical magnetic values at all intersections.

Gridding was accomplished using the minimum curvature method, using a 50 m grid cell size. This method uses data from both control and traverse lines to create a two-dimensional grid equally incremented in X and Y directions. The algorithm produces a smooth grid by iteratively solving a set of difference equations, which minimizes the total second horizontal derivative, and attempts to honour input data (Briggs, I.C., 1974, Geophysics, v 39, no. 1).

RADAR ALTIMETER DATA

The terrain clearance measured by the radar altimeter in metres was recorded at 4 Hz. The data were filtered to remove the high frequency noise using a 67-point filter. The filtered data were plotted and inspected for quality.

POSITIONAL DATA

A number of programs were executed for the compilation of navigation data in order to reformat and recalculate positions in differential mode. SGL's GPS data processing package, GPSoft was used to calculate DGPS positions from raw range data obtained from the moving (airborne) and stationary (ground) receivers.

The final location of both GPS antennae was determined using a permanent GPS reference station in Pie Lake, New Mexico, to differentially correct the recorded positional data. This technique provides a final receiver location with an accuracy of ±1 m. The entire airborne data set was then reprocessed differentially using the recalculated ground station location.

Positional data were recorded in the WGS-84 datum and transformed to NAD-27-USA datum. Parameters for the datum are:

Ellipsoid:	International (Clarke-1866)
Semimajor axis:	6378206.4
1/flattening:	294.979
Shift to WGS-84:	dx = -8, dy = 160, dz = 176

UTM Zone 13N, Central Meridian 105° West

Elevation data were recorded in the WGS-84 datum and transformed to Mean Sea Level (MSL) using the OSU91A30 model.

APPENDIX B: REPORT BY GEOTERREX-DIGHEM

LOGISTICS and PROCESSING REPORT

of the

AEROMAGNETIC ACQUISITION

for the

AIRBORNE MAGNETIC AND GEOTEM ELECTROMAGNETIC MULTICOIL SURVEY (COCHITI SURVEY)

in

SANDOVAL and SANTA FE COUNTIES, NEW MEXICO

for the

U.S. GEOLOGICAL SURVEY

Job N^{o} 319
August, 1997
Ottawa, Ontario

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I

INTRODUCTION

From February 18th to March 9th, 1997, an electromagnetic and magnetic survey was flown by Geoterrex-Dighem on behalf of the United States Geological Survey. Three areas were flown, namely the Cochiti Pueblo, the Rio Rancho and the Rio Puerco blocks, in Bernalillo, Sandoval and Santa Fe counties, New Mexico. In all, 2338 line miles of data were collected.

The survey data was compiled and processed in the Geoterrex-Dighem Ottawa office and is presented as maps of the total intensity magnetics with flight path, and the terrain clearance, multiparameter profiles, conductivity-depth-transform grids for each survey line and digital archive files.

This processing report describes aeromagnetic acquisition of the Cochiti survey only.

II

SURVEY OPERATIONS

Location of the Survey Area

The Cochiti Pueblo block is located west of Santa Fe in Sandoval and Santa Fe counties.

The base of operation was Albuquerque, New Mexico.

Aircraft and Geophysical On-Board Equipment

Aircraft	CASA C-212 twin turbo-prop.
Operator	Geoterrex-Dighem
Registration	C-FDPP
Survey Speed	125 knots/145 mph/65m/sec.
Magnetometer	Scintrex Cs-2 single cell cesium vapour, towed-bird installation, sensitivity = 0.01 nT[1], sampling rate = 0.1 sec., ambient range 20,000 to 100,000 nT. The general noise envelope was kept below 0.5 nT. Nominal sensor height of 73 metres above ground.
Electromagnetic system	GEOTEM multicoil system
Digital Acquisition	Geoterrex-Dighem GEODAS.
Analog Recorder	RMS GR-33, showing the total magnetic field at 2 vertical scales, the radar and barometric altimeters, the time-constant filtered traces of the x-coil channels 1 to 12 and the on-time channel 20, the raw traces of the x and z-coil channel 1 and 12, the EM primary field, the powerline monitor, the 4th difference of the magnetics, the x and z-coil earth's field monitors and the fiducials.

[1] One gamma is equivalent to the S.I. unit nanotesla (nT).

Barometric Altimeter	Rosemount 1241M, sensitivity 1 foot, 1 sec. recording interval.
Radar Altimeter	TRT AHV-8, accuracy 2%, sensitivity one foot, range 0 to 2,500 feet, 1 sec. recording interval.
Camera	Panasonic colour video, super VHS, model WV-CL302.
Electronic Navigation	Sercel GPS receiver NR103, 1 sec. recording interval, with a resolution of 0.00001 degree and an accuracy of ±10 m.

Base Station Equipment

Magnetometer:	Scintrex H8 single cell split beam cesium vapour, mounted in a magnetically quiet area, measuring the total intensity of the earth's magnetic field in units of 0.01 nT at intervals of 1 second, within a noise envelope of 0.10 nT.
GPS Receiver:	SERCEL NR103 V2.3, measuring all GPS channels, for up to 10 satellites.
Computer:	Toshiba laptop, model T4600, 33 MHz, 486.
Converter:	Picodas, model MEP710 3/10901 GTS 780008.
Printer:	Kodak Diconix 150 plus.
Battery Backup.	

Field Office Equipment

Video Playback:	Panasonic Super VHS with an 8" BRULE Colour Monitor.
Computer:	Dell Latitude LM laptop with 800 MB hard drive.
Plotter:	Design Mate 24" Calcomp with multiple colours and pen types, quality - 2000 steps/inch.
Printer:	Hewlett Packard Deskjet 660C.
DAT Tape Drive:	Conner, 90 metre tapes (1300 MG).
Hard Drive:	Seagate 4 gigabyte

Survey Specifications

Altitude:	The survey was flown at a mean terrain clearance of 120 metres. Nominal height of magnetometer was 73 meters.

The altitude tolerance was limited to ±15 m, not to be exceeded over a distance greater than 3 km, unless required for safety or air regulations.

Traverse Lines: Spacing of 400 m, direction E-W.

The separation between flight lines was not to exceed 600 m over a distance greater than 4500 m.

Control lines: Spacing of 7250 m, direction N-S.

Diurnal variation: Acceptable variations were limited to 7.5 nT deviations from a one minute chord.

Noise levels: The noise level on the magnetic data was not to exceed ±0.25 nT over a distance greater than 3 km.
The noise level on the electromagnetic data was not to exceed ±30 ppm over a distance greater than 3 km, as displayed on the analogue traces of the late-time x-coil channels.

Lines or portions of lines flown during any of the above deviations were reflown. These reflights began and ended by crossing control lines and overlapping good data.

Survey Coverage

In the Cochiti area, 773 line miles of data were collected.

Tests and Calibrations (flown from the Sierra Vista airport, March 14, 1997)

System lag for the Magnetic and Electromagnetic response

A suite of lines were flown over a bridge, near the airport, along bearings 140^{o} and 320^{o}, and checked against the video positions to verify the system lag of the magnetic and EM response.

The average system lag from all passes were as follows:

Magnetics:	3.6 seconds
Electromagnetics:	4.0 seconds

GPS Accuracy check (cloverleaf)

The accuracy of the GPS navigation system and its synchronization with the on-board video system was verified by flying a cloverleaf pattern at survey altitude over the basestation GPS antenna, set-up at the Sierra Vista airport (Easting of 563741, Northing of 3495176, datum Clarke 1866).

Control from the video:

Pass	Dir	Altitude	Fiducial	Video Position
1	W	380 ft	61181.55	3 m N of mark
2	E	381 ft	61319.75	1 m N of mark
3	W	380 ft	61491.85	4 m N of mark
4	E	383 ft	61624.85	1 m S of mark
5	S	383 ft	61841.35	8 m W of mark
6	N	431 ft	61959.98	7 m E of mark
7	S	392 ft	62171.50	5 m W of mark
8	N	406 ft	62329.35	5 m E of mark

Results after post flight differential corrections applied:

Scatter of solutions inside an error box of 15 x 20 metres.
Offset of mean position from all passes relative to the mark is less than one metre.
Synchronization difference of the GPS position and the video image is 0.5 second.

Altimeter Calibration

A series of altitude passes were flown over the runway (elevation of 4612 feet above sea level), ranging from 300 to 800 feet terrain clearance, as monitored by the on-board radar altimeter.

Field Crew

The base of field operations was Albuquerque, New Mexico.

Pilots: G. Stonehouse, G. Mueller, D. Wiens, M. Mellett
Electronics Operators: D. Patzer, R. Penton, J. Moore
Engineer: R. Constapel
Geophysicist: R. Williams

Production Statistics

Flying for the Cochiti Pueblo, Rio Rancho, and Rio Puerco blocks was done between February 18th and March 9th, 1997.

Total production: 3762 km
Number of production flights: 16
Hours of production flying: 42.7 hours
Number of km/hour of production flying: 88.1 km/hr.
Number of km/average production flight: 235 km
Number of hours/average production flight: 2.7 hours
Number of days lost to:
- Equipment: 1
- Weather: 4.5
- Testing: 0.5
- Pilot training and/or rest: 5

III

QUALITY CONTROL AND COMPILATION PROCEDURES

In the Field

After each flight, all analog records were examined as a preliminary assessment of the noise level of the recorded data. Altimeter deviations from the prescribed flying altitudes were also closely examined as well as the general condition of the diurnal activity, as recorded on the base stations.

All digital data were verified for validity and continuity. The data from the aircraft and base station was transferred to the PC's hard disk. Basic statistics were generated for each parameter recorded; these included the minimum, maximum and mean values, the standard deviation and any null values located. Editing of all recorded parameters for spikes or datum shifts was done, followed by final data verification via an interactive graphics screen with on-screen editing and interpolation routines. Any of the recorded parameters could be plotted back at a suitable scale on the field pen plotter.

The quality of the navigation was controlled on a daily basis by recovering the flight path of the aircraft. The Trajecto correction procedure employs the raw ranges from the base station to create improved models of clock error, atmospheric error, satellite orbit, and selective availability. These models are used to improve the conversion of aircraft raw ranges to aircraft position. The Trajecto-corrected GPS was plotted back daily in the field on the pen plotter and checked for speed busts.

Checking all data for adherence to specifications was carried out in the field by the Geoterrex-Dighem field operations manager/data technician.

More details on the individual processing steps applied to each parameter are given in this report in Section V, Field Processing of the Data.

IV

DATA PROCESSING IN THE OFFICE

Flight Path Recovery

Data used: GPS positions recalculated from the recorded raw range data, differentially corrected and converted to UTM metres.

Final positions:

Projection: Universal Transverse Mercator
Central meridian: 109^{o}W
False Easting: 500,000 metres
False Northing: 0 metres
Scale factor: 0.9996
Spheroid: Clarke 1866

Altitude Data (Radar and GPS)

Noise editing: Alfatrim median filter used to eliminate the 2 high and 2 low values from the statistical distribution of a 9 point sample window.
Noise filtering: Triangular filters set to remove radar wavelengths less than 6 seconds and amplitudes below 25 feet; and GPS wavelengths up to 4 seconds and amplitudes up to 2.5 metres.
Gridding: A grid of the terrain clearance was produced from the radar altimeter values, as a general reference for evaluation of the survey results.

Diurnal magnetics

Noise editing: Alfatrim median filter used to eliminate the 2 high and 2 low values from the statistical distribution of a 9 point sample window.
Culture editing: Polynomial interpolation via a graphic screen editor.
Noise filtering: Triangular filter set to remove wavelengths of less than 4 seconds and amplitudes

up to 0.5 nT.
Extraction of long wavelength component: Low pass filter set to retain only wavelengths of greater than 50 seconds.

Magnetics

Lag correction: 3.6 seconds
Noise editing: 4th difference editing routine set to remove spikes of greater than 0.5 nT, followed by an alfatrim median filter eliminating 2 high and 2 low value from its calculation over a 9 point window.
Noise filtering: Triangular filter set to remove noise events having a wavelength of less than 0.5 second and an amplitude of less than 0.3 nT.
Diurnal subtraction: The long wavelength component of the diurnal (greater than 50 seconds) was removed from the data, prior to the levelling analysis.
Levelling: The levelling consisted of applying a micro-levelling routine to the gridded data to remove small residual effects. The difference in the gridded datasets before and after the application of the micro-levelling routine were computed and extracted along the original survey lines to be stored in the final line dataset as the final magnetic compensation values.
Regional: The regional values were computed from the 1995 coefficients for the date of 1997.16 at an elevation of 1900 m a.s.l.

V

FIELD PROCESSING OF THE DATA

Flight Path Recovery

1. Recover GPS data from base station.
2. Recover GPS data from aircraft file.
3. Combine base station and aircraft GPS data to a common file.
4. Apply differential corrections and compute Lat/Long fixes from the raw range data (TRAJECTOGRAPHY); GPS lag of 0.5 sec used.
5. Change spheroid from WGS84 to Clarke 1866 using the following offsets:

   Dx = 8 m
   Dy = -163 m
   Dz = -180 m

6. Convert Lat/Long fixes to UTM metres, using the following:

   Central meridian: 105^{o}W
   False Easting: 500,000
   False Northing: 0
   Scale factor: 0.9996
   Ellipsoid: Clarke 1866

7. Compute speed from resulting positions to check for irregularities, time gaps, etc.

Correction of Altimeter Data

1. Recover altimeter data from aircraft file.
2. Convert radar and GPS altitude data to feet and cm respectively.
3. Remove spikes from the radar and GPS data using an alfatrim median filter to isolate the 2 extreme values (high or low) of a statistical distribution based on a window of 9 points.
4. Apply triangular convolutions to the altimeter data; aimed at wavelengths of 4 seconds or less and amplitudes of 2.5 m, or less for the GPS and wavelengths of 6 seconds or less

and amplitudes of 25 feet or less for the radar.

Processing of Magnetic Data from the Base Station

1. Recover magnetic data from the base station.
2. Edit the ground data for spikes, isolating the 2 extreme values out of a 9 point distribution (alfatrim median filter).
3. Remove culture events (when applicable) by polynomial interpolation via a graphic display/editing routine.
4. Apply a triangular smoothing convolution, aimed at removing wavelengths of 4 seconds or less with amplitudes of 0.5 nT or less.
5. Extract long wavelength component of the data (greater than 25 seconds) with a low pass filter, to be subtracted from the air data.

Processing of Magnetic Data from the Aircraft

1. Recover data at full 10 samples/sec.
2. Adjust readings for a system lag of 3.6 seconds (36 samples).
3. Edit data for spikes using a fourth difference routine, set for spikes of greater than 0.5 nT.
4. Apply triangular smoothing convolution, aimed at removing wavelength of less than 0.5 seconds with amplitudes less than 0.3 nT.
5. Remove the long wavelength component of the diurnal data (greater than 25 seconds).
6. Add back the mean value of the diurnal field.
7. Grid the resulting magnetic values, image and check for irregularities.

Creation of Final Files

1. Processed positioning, altimeter, and magnetic data is cut-back from flight form to survey line limits, re-sampled and combined into a common file at 5 samples/sec.

Field Products

1. Preliminary total magnetic field contour map with flight path at 1:100,000 scale.