PROJECT REPORT

FIXED-WING AEROMAGNETIC SURVEY

Amargosa Desert / Death Valley,
San Gregorio North / Point Sur / Hollister / Moss Landing, and
Bodie-Aurora District,
Nevada and California, USA
1999

CONTRACT # 99CRCN0013

for

UNITED STATES GEOLOGICAL SURVEY

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I. INTRODUCTION

Sander Geophysics Limited (SGL; see *Appendix I* for a company profile) conducted high resolution aeromagnetic surveys in three separate areas located in Nevada and California for the United States Geological Survey between August 4th and December 21st, 1999. A total of 55,780 line kilometres were flown for the project.

The Amargosa Desert / Death Valley survey was conducted over an area located along the border of central California and southern Nevada between August 4th and September 20th. Forty-three sorties, including test flights, were required to complete data acquisition in the survey block for a total of 23,333 line kilometres.

The San Gregorio North / Point Sur / Hollister survey was conducted over an area along the central California coast between October 1st and November 3rd. Thirty sorties, including test flights, were required to complete data acquisition in the survey block for a total of 10,729 line kilometres. In addition to the original contracted survey blocks, the area between the San Gregorio North and Hollister blocks, referred to here as the Moss Landing Block, was also flown to the same specifications as the rest of the survey. The total size of the San Gregorio North / Point Sur / Hollister survey including Moss Landing is 11,729 line kilometres.

The Bodie-Aurora District survey was conducted along the border of central California and northern Nevada between November 4th and December 21st. Fifty-six sorties, including test flights, were required to complete data acquisition in the survey block for a total of 20,718 line kilometres.

II. SURVEY AREAS

The locations of all the survey blocks are illustrated in *Figure 1*.

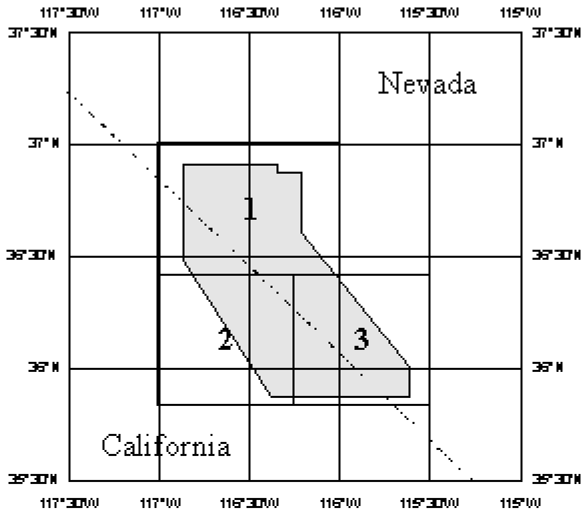
AMARGOSA DESERT / DEATH VALLEY

The survey area straddles the California/Nevada border, with the southern end of the survey approximately 30 km west of the city of Las Vegas. The survey area follows the Pahrump and Amargosa Desert valleys from close to the town of Jean north-westward to the town of Beatty. The valley floors are flat and arid with salt flats and scrubby vegetation, lying at altitudes of 2,000 to 3,000 feet. The Spring Mountains, which reach 6,384 feet, lie between the survey block and Las Vegas to the east, but the rugged, steep sided Amargosa, Greenwater and Funeral Mountains, which reach 6,703 feet, are mainly within the survey block on the west side, and the Nopah Range Mountains which reach 6,384 feet lie entirely within the survey. In addition, a small part of Death Valley near Furnace Creek is also within the survey on the west side, where altitudes lie just below sea level only 15 km from the crest of the Funeral Mountains ridge line.

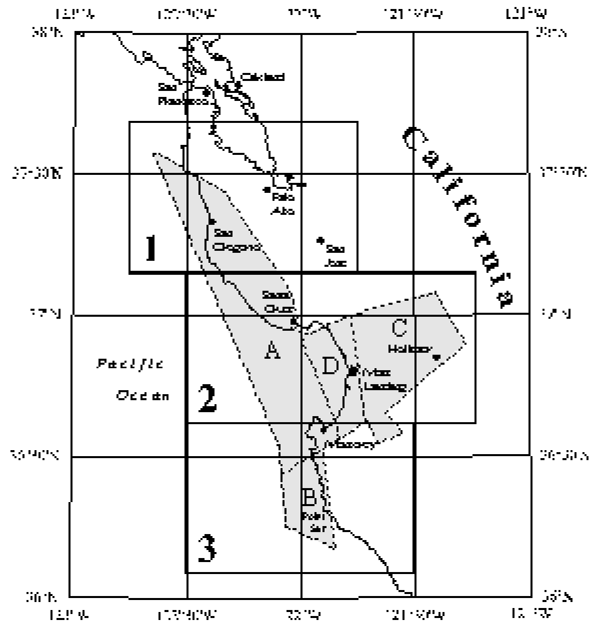
The following coordinates, in the WGS-84 datum, define the survey area:

36:54.8978N	116:52.5535W
36:52.4981N	116:21.5526W
36:35.9985N	116:13.1522W
35:52.4997N	115:37.5508W
36:29.9984N	116:52.5532W
36:54.8981N	116:21.5527W
36:52.4982N	116:13.1524W
35:59.9995N	115:37.5508W
35:52.4994N	116:22.5520W

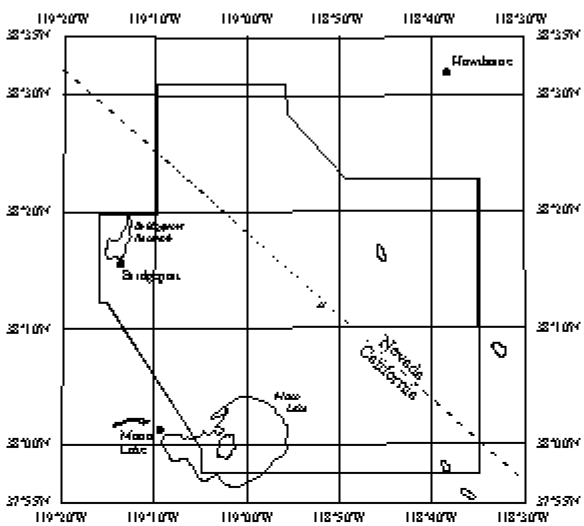
Figure 1
SURVEY AREA LOCATIONS



Amargosa - Death Valley Survey



San Gregorio North, Point Sur, Hollister
And Moss Landing Survey



Bodie - Aurora District Survey

SAN GREGORIO NORTH / POINT SUR / HOLLISTER

This survey consists of three separate blocks plus an additional area between blocks referred to as follows:

Block A	San Gregorio North
Block B	Point Sur
Block C	Hollister
Block D (between Blocks A & C)	Moss Landing

The survey area lies along the central California coast, extending from Half Moon Bay near San Francisco to Point Sur south of Monterey Bay. The northern part of the survey area (the north part of Block A) consists of the western half of the Santa Cruz Mountains and the immediate area offshore. The mountains reach an altitude of 2,680 feet within the block 10 km from the shoreline, and climb to 3,231 feet just outside the survey boundary. The mountains are heavily wooded with tall pines and redwood trees, and are sparsely populated with isolated homes and some small towns.

The central part of the survey area (the south part of Block A, Blocks C and D) encompasses all of Monterey Bay including the coastal towns of Santa Cruz, Monterey and Carmel. The survey extends onshore to include the low, flat farmland around Watsonville and Salinas, and beyond to the Santa Clara Valley around Gilroy and Hollister. The hills are wooded, but the valleys have been cleared revealing farmland.

The south part of the survey (Block B) consists of the coastal strip from Point Lobos near Carmel to Point Sur, and the adjacent area offshore. The coastline here is steep, rugged and forested.

The following coordinates, in the WGS-84 datum, define the survey area:

Blocks A, C and D	
37:34.5772N	122:38.2532W
36:57.7151N	122:19.2142W
36:32.2938N	122:05.7915W
36:31.6039N	121:54.4152W
36:37.4199N	121:42.6149W
36:32.9060N	121:39.5888W
36:39.3679N	121:38.1009W
37:04.8614N	121:24.7869W
36:55.5116N	121:59.7989W
37:06.1751N	122:03.7939W

Blocks A, C and D (cont'd)	
37:34.2662N	122:39.0392W
36:46.9574N	122:13.3639W
36:26.2099N	122:05.1014W
36:33.7099N	121:50.2091W
36:33.0440N	121:39.9548W
36:35.0420N	121:33.2827W
36:53.9837N	121:16.7405W
36:59.9774N	121:46.9214W
37:03.3672N	122:02.3838W
37:26.0105N	122:20.1926W

Block B	
36:10.4004N	121:51.1988W
36:15.2662N	122:03.8892W
36:26.2099N	122:05.1014W
36:31.6039N	121:54.4152W

BODIE-AURORA DISTRICT

The survey consists of a single block in the mountains and hills immediately east of the central Sierra Nevada. The terrain is rugged, sparsely vegetated, and largely unpopulated. The peaks reach a height of 11,320 feet at Mount Bryant just outside the survey area, and the valleys lie as low as 6,500 feet around Mono Lake, half of which can be found within the survey area on the south side.

The following coordinates, in the WGS-84 datum, define the survey area:

38:19.0952N	119:09.6083W
38:30.6950N	119:09.6084W
38:30.6951N	118:55.9081W
38:28.1451N	118:55.9080W
38:22.5453N	118:49.4578W
38:22.5454N	118:34.9074W
37:57.5958N	118:34.9071W
37:57.5956N	119:04.9079W
38:00.0455N	119:04.9079W
38:12.3952N	119:15.0083W
38:12.3952N	119:15.9084W
38:19.0951N	119:15.9085W

III. SURVEY EQUIPMENT

SGL's Britten-Norman Islander, registration C-GSGX was used to fly the entire survey. A full list of survey equipment and their serial numbers can be found in *Appendix II*. SGL provided the following instrumentation for this survey:

AIRBORNE DATA ACQUISITION SYSTEM

- *Sander NavDAS*

The NavDAS is the latest version of airborne data acquisition computers developed by SGL. It records and displays all incoming data on a flat panel screen. Data is recorded 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.

AERIAL AND GROUND MAGNETOMETERS

- *GEOMETRICS model G-822A*
- *SCINTREX model G3*

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.

AUTOMATIC AEROMAGNETIC DIGITAL COMPENSATOR (AADC)

- *RMS model AADC 4000 MkII*

The RMS compensator is a 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

- *GPSNAV software*
- *NovAtel 3951R GPS card receiver*
- *OMNISTAR 6300 DGPS 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.

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*
- *Sander Digital Barometric Pressure Sensor*

The TRT radar altimeter has a resolution of 0.5 metre, an accuracy of 1 percent and a range of 1 to 10,000 feet. The barometric pressure system has a resolution of 2 metres, an accuracy of +/-4 metres, and a range of 1 to 30,000 feet.

SURVEY AIRCRAFT

- *Britten-Norman Islander BN-2B (C-GSGX)*

The Islander is an all metal, high-wing, twin-engine, short take-off and landing aircraft powered by two fuel injected Lycoming engines that drive constant speed, fully feathering propellers. The aircraft has fixed tricycle landing gear, extendable flaps and manually adjustable trim tabs on the rudder and elevator. The aircraft is equipped with de-icing equipment and sufficient avionics for IFR flight. The electrical system has been modified to reduce the magnetic field variations around the aircraft.

The aircraft has an aluminium and composite 2.5 metre tail stinger designed to accommodate the magnetometer sensor and wiring. There is a camera hole in the belly and provisions for numerous other survey and navigation systems. The airplane has Canadian registration C-GSGX and the entire aircraft and survey system conform to Canadian Aeronautical Regulations. A complete description of the aircraft is given in *Appendix III*.

GROUND DATA ACQUISITION SYSTEM

- Sander GND-ACQ

The ground data acquisition computer records all the incoming data and displays it 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. Data are recorded 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.

DATA PROCESSING EQUIPMENT AND SOFTWARE

a) PRO-10 200 MHz computer with 1 GB Iomega Jaz drive, 8 mm Exabyte tape drive, Yamaha 4xs recordable CD drive and Viewpanel VPA138 monitor,
b) Toshiba Tecra 500 CDT laptop computer and a Hitachi MX laptop computer,
c) Fujitsu DL3450 printer,
d) Hewlett Packard Deskjet 1000C colour printer,
e) Sony KV-8AD10 Trinaton colour TV, and
f) Phillips VCR-457/77 VCR .

IV. SURVEY SPECIFICATIONS

FLIGHT LINE SPECIFICATIONS

Amargosa Desert / Death Valley		
	Traverse	**Control**
Line spacing:	400 m	2000 m / 2300 m
Line direction:	east-west	north-south
Survey altitude:	150 m min. clearance, differential GPS	

The survey consists of 289 east-west oriented traverse lines and 52 orthogonal control lines. Control line spacing was initially set at 2,000 metres and lines 101 to 107 were flown at this spacing. Control line spacing was increased to 23,00 metres to compensate for the addition of three extra lines, and lines 118 to 152 were flow at this spacing. The three extra lines (1.00 to 3.00) each consist of several segments and were flown continuously from point to point in waypoint mode.

San Gregorio North / Point Sur / Hollister		
	Traverse	**Control**
Line spacing:	536 m	5360 m & 7580 m
Line direction:	247° & 355°	337° & 309°
Survey altitude:	150 m min. clearance over sea, differential GPS 245 m min. clearance over land, differential GPS	

The original contracted survey consisted of three separate blocks A, B and C as described above. Blocks A and C were flown with traverse lines oriented at 247° and control lines spaced 5,360 metres orthogonal to the traverse lines and parallel to the western boundary of Block A. Blocks A and C are separated by a gap approximately 15 kilometres wide, referred to here as the Moss Landing Block or Block D. Survey lines from Block A were extended to the east across Block D into Block C and all three blocks were flown together. After completion of the survey USGS purchased the Block D data, creating a single area from Blocks A, C and D. The combined blocks consist of 261 traverse lines and 17 orthogonal control lines.

Block B was flown with 34 traverse lines oriented at 355° and 4 non-orthogonal control lines spaced at 7,580 metres and oriented at 309°. The lines were set at this orientation to avoid flying perpendicular to the steep cliff line in order to allow the aircraft to fly as close to the sea surface as practical. Block B was flown as a separate block despite being adjacent to Block A because of the difference in line directions. Data from Block B is merged with data from the other blocks in processing (see below).

Bodie-Aurora District		
	Traverse	**Control**
Line spacing:	150 m	1500 m
Line direction:	north-south	east-west
Survey altitude:	150 m min. clearance, differential GPS	

The survey consisted of 399 north-south oriented traverse lines, and 42 orthogonal control lines.

A list of all planned lines for all surveys with their coordinates are given in *Appendix IV*. A survey log with the coordinates of the lines flown and their flight numbers is enclosed in *Appendix V*.

TERRAIN CLEARANCE AND DRAPE SURFACE

A pre-planned drape surface was prepared for each survey to be used to guide the aircraft over the topography in a consistent manner as close to the minimum clearance as possible. The drape surface was prepared using 1:250,000 scale Digital Elevation Model (DEM) data obtained from United States Geological Survey FTP site (http://edcftp.cr.usgs.gov/pub/data/DEM/250/). The following map sheet files were used:

Amargosa Desert / Death Valley
death-e.dem
death-w.dem
vegas-w.dem
kingm-w.dem
trona-e.dem

San Gregorio North / Point Sur / Hollister
sanfr-e.dem
sancr-e.dem
sanjo-w.dem
mont-w.dem

Bodie-Aurora District
walker-e.dem walker-w.dem marip-e.dem marip-w.dem

In each case the data was merged into a single map, and trimmed to the survey boundary plus a 7.5 kilometres beyond the boundary to allow the aircraft to achieve the drape before coming on line. The topography was then smoothed based on the climbing and descending capabilities of the Britten-Norman Islander survey aircraft as follows; 7.5 percent climb/descent at sea level declining to 5.8 percent climb/descent rate at 10,000 feet. The minimum terrain clearance was then added to the smooth drape surface. The clearance was set at 150 metres for all surveys, except for the onshore portion of the San Gregorio North / Point Sur / Hollister survey which was set at 245 metres.

Modifications were made to the terrain model for the San Gregorio North / Point Sur / Hollister survey to take into account various restrictions on the height to be flown as follows:

a) An amount of 95 metres was added to all land data in the digital terrain model to allow for the difference in minimum clearance between the onshore and offshore parts of the survey. This approach allowed the drape program to generate a smooth transition between the two clearance heights, and then a single shift of 150 metres was applied to the entire survey after smoothing.

b) Areas designated as “congested” by the San Jose FSDO (see below) were flown at 1000 foot clearance. The digital terrain model was modified by adding a further 61 metres to the terrain over these areas (in addition to the 95 metres added above) prior to smoothing and addition of the 150 metre clearance.

c) Areas designated as “sensitive” by the Monterey Bay National Marine Sanctuary (see below) were flown at 1,000 feet above mean sea level (MSL) within 1 nautical mile of the centre of the designated sites. The digital terrain model was modified by adding 156 metres to the MSL height at the sites and substituting this value in the terrain prior to smoothing and addition of 150 metre clearance.

Production flights for the San Gregorio / Point Sur / Hollister block began with climb and descent rates that were too steep for the Islander to maintain. As a result, the aircraft was too low in hilly areas up to and including flight 6. Since the data collected provided greater detail than would have been the case using the correct climb and descent rates, it was agreed along with the technical inspector that these lines would not be re-flown.

The Las Vegas FSDO also required that a minimum clearance of 1000 feet be maintained over congested areas in the Amargosa Desert / Death Valley survey area (see below). However, the areas involved were small and the requirement was handled during flight by the pilot's own judgement rather than pre-adjusting the drape. No adjustments were required for the Bodie-Aurora survey.

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 second;
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 second.

TECHNICAL SPECIFICATIONS

The following technical specifications were adhered to:

a) *Flight path following*

Deviations from the planned paths not to exceed 50 percent of the flight line spacing. Gaps between adjacent flight lines not to exceed 1.5 times the designated flight line spacing for more than 2 linear miles (3.2 km). Flight path deviation and line gap data for all surveys is provided in *Appendices VI* and *VII*.

b) *Drape surface following*

Pre-planned drape surface to be maintained within 100 metres, safety permitting. Drape surface following statistics are provided in *Appendix VIII*.

c) *Geomagnetic diurnal variation*

Airborne survey data not acceptable when gathered during magnetic storms or short-term disturbances of magnetic activity at the ground station used, that exceed the following:

1. Monotonic changes in the magnetic field of 5 nT in any 5 minute period.
2. Pulsations having periods of 5 minutes or less shall not exceed 2 nT.
3. Pulsations having periods between 5 and 10 minutes shall not exceed 4 nT.
4. Pulsations having periods between 10 and 20 minutes shall not exceed 8 nT.

The period of the pulsation is defined as the time between adjacent peaks or troughs. The amplitude of a pulsation is one-half the sum of the positive and negative excursions from trough to trough or peak to peak.

d) *Airborne magnetometer*

Total intensity magnetometer to have a resolution of 0.1 nT or better. Values to be obtained along flight lines at intervals no greater than 10 metres (see *Appendix IX* for statistics on the speed of the aircraft). Error envelope due to turbulence and internal magnetometer noise not to exceed +/- 0.1 nT for more than 10 percent of any flight line.

e) *Ground station magnetometer*

One or more ground station magnetometers to be located within 100 miles (161 km) of all survey points. Each station to be run continuously at a single location with a resolution of 0.2 nT or better, absolute control of 0.2 nT or better and a noise envelope of less than or equal to 0.1 nT. The location(s) to be free of man made noise greater than 1 nT. Sample rate to be less than or equal to 15 second intervals.

f) *Flight path recovery*

GPS receivers to have an update rate of no less than one reading/second Differential flight path recovery to be processed to provide positions to 10 metres. GPS accuracy data is provided in *Appendix X*.

g) *Video tape of the ground track*

Video tape of the ground track of the aircraft to be made at sufficient quality to permit recovery of the flight path. In level flight the viewing angle of the camera not to be more than 2 degrees from vertical. Video tape to be annotated to permit correlation with flight records, flight path maps and digital tapes.

All re-flights performed due to out of specification data is listed in *Appendix XI*. Some ease from specification (g) was permitted by the technical inspectors; all lines lacking video coverage are listed in *Appendix XII*.

V. SYSTEM TESTS

MAGNETOMETER CALIBRATION

Calibration of the aircraft magnetometer systems was carried out at Bourget, Ontario, on July 23rd, 1999. The results of the calibration flight are presented in *Figure 2*. The absolute error was -1.0 nT. The average heading errors were found to be 0.3 nT in the north-south direction and -1.3 nT in the east-west direction. The poor result in the east-west direction was due to the strong diurnal variations that occurred that day. The diurnal correction was carried out using data from the NRCan ground station in Ottawa, spaced at 1 minute intervals. This data sampling rate proved to be insufficient. As a result, a heading error test was carried out in the field on the 4th August 1999 using the intersection of lines 1030 and 105 of the Amargosa Desert / Death Valley survey in an area of low relief and anticipated low magnetic gradient. Each direction was flown twice. The results of this test are as follows:

Heading	X m	Y m	Field nT	Error nT	Mean Error nT
WEST EAST	615944 615944	3982222 3982219	50350.79 50351.27	-0.48	0.48 (east-west)
WEST EAST	615930 615930	3982222 3982219	50350.64 50351.12	-0.48	
SOUTH NORTH	615944 615930	3982222 3982222	50351.19 50351.45	-0.26	0.26 (north-south)
SOUTH NORTH	615944 615930	3982219 3982219	50351.12 50351.38	-0.26	

The heading errors were found to be small and remarkably consistent.

AADC COMPENSATION

Compensation tests determine the magnetic influence of aircraft manoeuvres and the effectiveness of the RMS AADC compensator to mitigate these effects. A compensation flight was performed at the start of each survey area because of the different geomagnetic fields and flight line orientations found among them. Several additional compensation flights were required due to magnetic sensor changes in the aircraft stinger. For each compensation flight the aircraft performed sets of three pitches (+/-5 °), rolls (+/-10°), and

Figure 2

AEROMAGNETIC SURVEY SYSTEM CALIBRATION AT BOURGET, ONTARIO

Aircraft type : Britten-Norman 2B Islander
Registration : C-GSGX
Organization : Sander Geophysics Limited
Pilot : Randy Forwell
Co-Pilot : Malcolm Imray
Instrument Operator : Mark Ovenden
Observer : n/a

Date : July 23rd 1999
Height flown : 500 feet
Magnetometer type : GEOMETRICS G-822A
Compensator: RMS AADC II
Sampling rate : 10/s
Data acquisition system : Sander ADAC computer
Camera : video
Camera sampling rate : continuous

Dir	Line #	GMT	Total field Aircraft T1	Grnd Stn Prev Min T2	Grnd Stn Subs Min T3	Interpolated Reading T4	Calculated T5	Error Value T6	Variation from Average
N	2	5:07:36 PM	55,691.4	56,247.9	56,249.5	56248.1	55691.1	0.3	1.3
S	1	4:56:35 PM	55,685.9	56,243.7	56,244.1	56243.7	55686.7	-0.8	0.2
E	6	4:47:03 PM	55,690.2	56,247.9	56,248.1	56248.0	55691.0	-0.8	0.2
W	5	4:43:31 PM	55,690.1	56,248.6	56,248.3	56248.6	55691.6	-1.5	-0.4
N	4	5:22:37 PM	55,694.6	56,252.7	56,252.8	56252.7	55695.7	-1.2	-0.1
S	3	5:11:43 PM	55,692.3	56,249.9	56,250.4	56250.0	55693.0	-0.7	0.3
E	8	4:52:17 PM	55,686.9	56,244.7	56,244.8	56244.8	55687.8	-0.9	0.1
W	7	4:49:23 PM	55,687.7	56,248.2	56,247.3	56247.4	55690.4	-2.7	-1.7
							Total :	-8.3	
							Average:	-1.0	

Average North-South Heading Error : 0.3 gammas

Average East-West Heading Error : 1.3 gammas yaws (+/-5°), while flying in the four flight line directions specific to the current survey at high altitude over a magnetically quiet area. A solution to compensate for the noise generated by the manoeuvres is determined by the AADC and the efficacy of the solution is tested by repeating the same set of manoeuvres. The total compensated signal noise resulting from the twelve manoeuvres, referred to as the figure of merit (FOM) is calculated from the maximum peak to peak value resulting from each manoeuvre. The results of all compensation flights, and the flights for which each solution was used, is shown below.

Date	FOM	Used for Production Flights
August 4th	1.18	Amargosa Desert / Death Valley, 3-24
Sept 3rd	1.125	Amargosa Desert / Death Valley, 26-43
Oct 3rd	1.25	San Gregorio North etc. Blocks A, C & D, 1-11
Oct 17th	1.34	San Gregorio North etc. Blocks A, C & D, 13-30
Oct 17th	0.925	San Gregorio North etc. Block B, 20-21
Nov 9th	1.01	Bodie-Aurora District, 7-35
Dec 1st	0.99	Bodie-Aurora District, 41-56

Compensation flight test plots can be found in *Appendix XIII.*

INSTRUMENTATION LAG

The system lag on the aircraft was checked by analysing two sets of data flown in opposite directions (east and west) at 150 metres above ground over two different, distinct anomalies in the Amargosa Desert / Death Valley survey. The well-defined anomalies allowed the determination of the lag between the positional data and the magnetometer data as follows:

Date	Line	Lag
Sept 11th	1010	0.70
Sept 23rd	1174	0.68

The average lag was found to be 0.69 second and the delay was subsequently corrected during data compilation.

RADAR ALTIMETER CALIBRATION

The radar altimeter in the aircraft was tested on August 4th, by flying at altitudes of 300, 500, 700, 900, 1100, and 1300 feet AGL over the airport runway at Henderson Executive Airport, Las Vegas, Nevada. The height of the runway was determined by a slow taxi over the length of the runway on August 23rd, and was found to be 742.46 metres. The resultant radar altimeter versus differentially corrected GPS heights converted to MSL altitude and minus the runway height are shown in *Figure 3*. The plot of the radar calibration data points revealed a close approximation to a straight line with a slope of 1.017131, indicating good calibration of the radar altimeter, and intercept on the y-axis (radar altimeter) of -1.57.

The radar altimeter calibration was checked by analysing data collected on October 20th from part of line 104.00 of the San Gregorio North / Point Sur / Hollister survey where it climbs and descends over the ocean. A five point running average was applied to the radar altimeter and differential GPS height data (height with respect to MSL), which were then re-sampled from a 0.5 second frequency to a 2.5 second frequency (ie. every 5th data point). The data is plotted in *Figure 4*, revealing a straight line with a slope of 1.004841, confirming that the calibration of the radar altimeter was good. The non-zero y-axis intercept (-9.37 m) reflects the difference between the sea surface at the time of the flight and MSL.

Figure 3

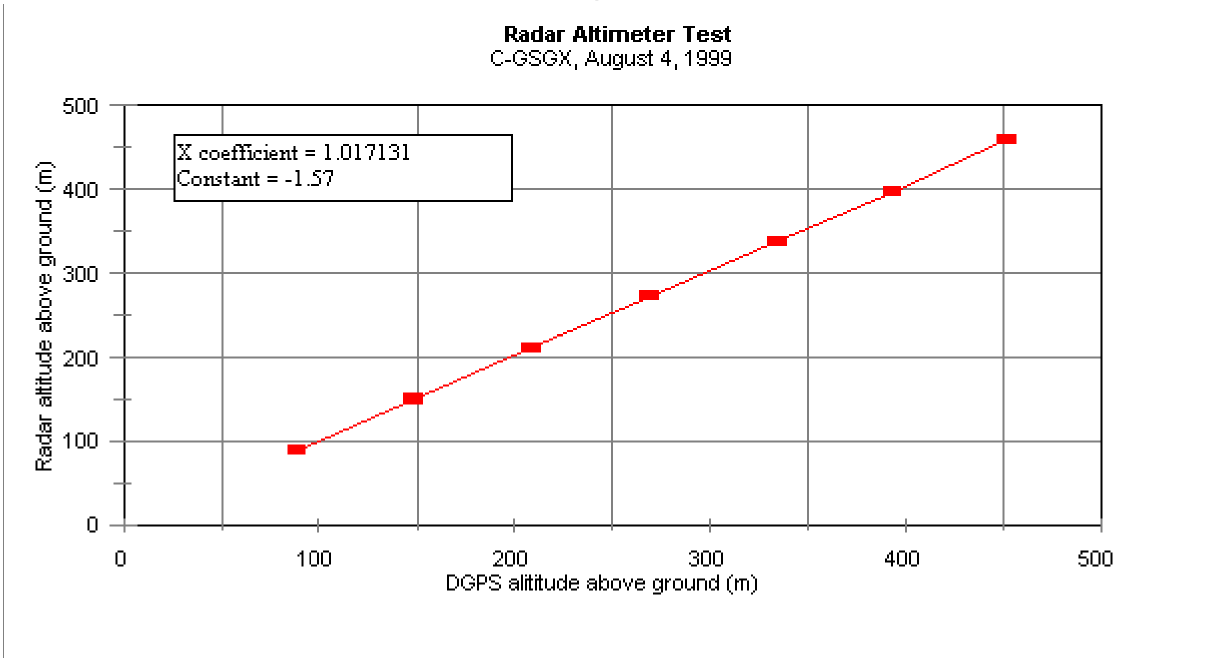
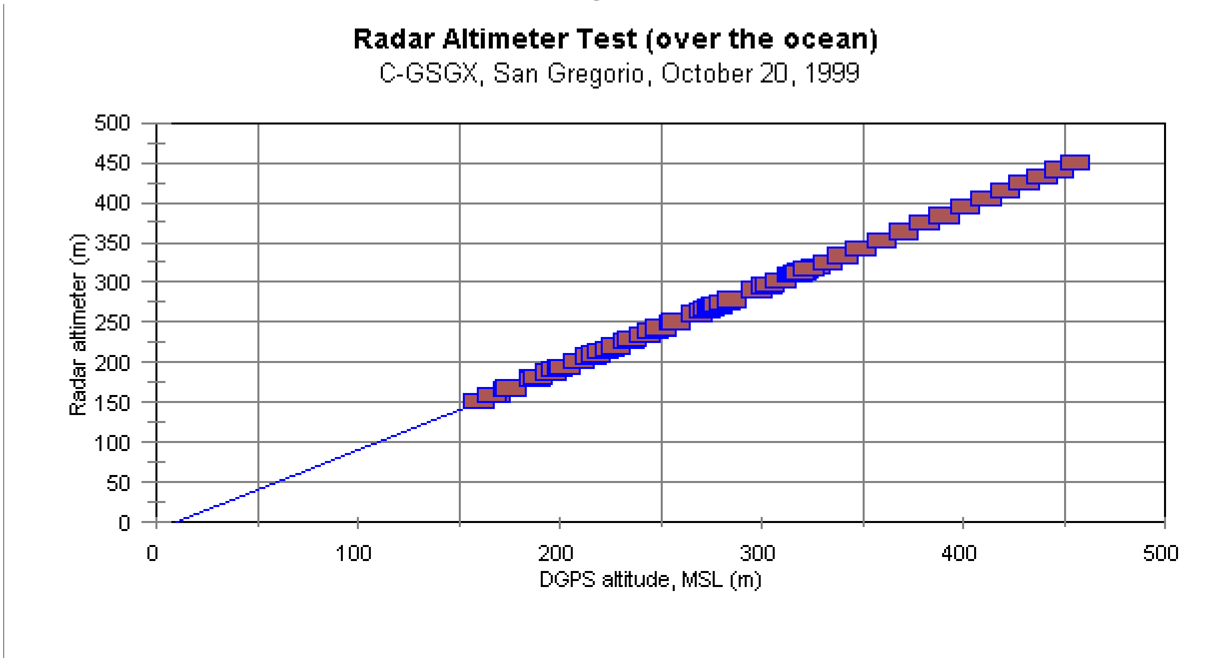


Figure 4



VI. FIELD OPERATIONS

The Project Summary for each survey area can be found in *Appendix XIV*. A copy of all weekly field reports from all areas can be found in *Appendix XV*. Flight logs can be found in *Appendix XVI*.

AMARGOSA DESERT / DEATH VALLEY

Operations were conducted from Henderson Executive Airport located immediately to the south of Las Vegas, Nevada, close to the southeast corner of the survey block but outside the survey boundary. A field office was established in a portable office unit at the airport, and two adjacent spaces were rented in a shade hangar for the Islander. The ground station computer was set up in the maintenance facility at the airport, with the GPS antenna was placed on the roof. The ground station magnetic sensor pole was erected in the area between the maintenance facility and the runway.

The location of the base station was determined using data from Julian day 215 (day 215 of the year), and differentially corrected using the IGS Station GOL2 (Goldstone, 60 miles north of Barstow, California) as the monitor reference station. Data for GOL2 was downloaded from the NASA/JPL FTP site (bodhi.jpl.nasa.gov/pub/pro/y1999/d215). The location of GOL2 was obtained from gol29906.log downloaded from the internet at http://igscb.jpl.nasa.gov/igscb/station/log. The position of the ground station GPS antenna after differential correction was:

Latitude (WGS-84):	35:58.6499 N
Longitude (WGS-84):	115:08.2733 W
Elevation (GRS-80 ellipsoid):	708.7956 m

The northwest corner of the survey area was more than 100 miles (161 km) from the base station at Henderson Airport. Therefore, a remote ground station was established at the Angel's Ladies Ranch at Beatty, Nevada, close to the northwest corner of the survey and inside the survey boundary. The remote ground station computer was set up in a shed at the back of the ranch, with the GPS antenna on the roof. The remote ground station magnetic sensor pole was erected on the hill to the north of the shed. The remote station was set up for continuous measuring of the magnetic field and GPS time only. For part of the time, GPS position was also recorded (flights 16 to 26) but this data was not used for differential correction of the flight path. Remote ground station data is available for all but the final three flights (41, 42, 43) due to a loss of power. The position of the remote ground station GPS antenna (non-differential) was:

Latitude (WGS-84):	36:56.5486 N
Longitude (WGS-84):	116:43.676 W
Elevation (GRS-80 ellipsoid):	1032.47 m

Comparison plots were made of the magnetic field, measured at the two stations. The high degree of correlation observed in the phase and amplitude of the high frequency diurnal events, recorded at the two stations, indicated that data from either station could be used to carry out the diurnal correction of the airborne data from anywhere in the survey block.

Permission to conduct the survey was granted by Gerry Gavette of Las Vegas FSDO but a waiver to fly below 1000 feet over the congested areas (i.e. towns) within the survey area, was unattainable. A map defining these areas was prepared by the field crew, and it was agreed that a 1000 foot clearance should be maintained over the marked areas (Pahrump, Shoshone and Beatty). This was achieved by non-automated draping using the pilots judgement where the automatic drape brought the aircraft too low over the towns.

Part of the survey block lies within Death Valley National Park. No special permission was required to fly in the park, but the administration (Mr. Ed Forner, Assistant Chief Ranger) was notified of SGL's activities.

The northeast corner of the survey block is within the Nevada Test Site (NTS), including parts of restricted areas R-4808N, R-4808S and R-4807A. These areas lie outside the jurisdiction of the F.A.A. Therefore, special permission to operate within the NTS was required and obtained from the U.S. Department of Energy through the Nye County Nuclear Waste Repository Project Office (Mary Ellen Giampoli, tel. 702-875-4594). A time window to operate in the NTS was granted from August 31st to September 3rd inclusive, and this was extended until September 5th at the request of the SGL field crew. All production in the NTS was completed during this time. No cameras were allowed on board the aircraft, therefore there is no video for this data. For security purposes, the aircraft was required to land at Desert Rock military base for inspection prior to entry into the NTS every day. No post flight inspection was required.

Permission to operate within the NTS had been obtained prior to starting the survey, but became invalid as a result of legislation passed by the US government at the time of mobilization. The new permissions were not granted until much of the survey outside the NTS had been flown. The time frame granted to fly inside the NTS did not allow for full lines (including the parts outside the NTS) to be flown. As a result, flight lines were broken along the boundary of the NTS. All broken traverse or control lines, including those broken due to weather or re-flights, start and end at control lines or traverse lines.

As expected, the hot climate, in southern Nevada, in summer restricted survey flying to the cooler mornings. Increasing heat and turbulence through the day prevented survey flying on all but a couple of afternoons, and only one production flight was possible per day. In addition, there were seven days when no survey flying was possible due to active thunderstorms. Some flights were cut short for the same reason.

SAN GREGORIO NORTH / POINT SUR / HOLLISTER

Operations were conducted from Watsonville Municipal Executive Airport located in Watsonville, California, located in the centre of the survey block. A field office was established in the office buildings attached to the Watsonville Aviation Hangar. The aircraft was parked on the ramp close to Watsonville Aviation, and maintenance facilities were made available by Watsonville Aviation. The ground station computer was set up in a trailer parked in a field adjacent to the airport runway on the northwest side. The trailer belonged to Mr. Benson, who also farmed the field. Power was supplied from Mr. Benson's home nearby. The GPS antenna was located on the roof of the trailer, and the ground station magnetic sensor pole was erected in the field which was not in use at the time.

The location of the base station was determined using data from Julian day 286, differentially corrected using the IGS Station GOL2 (Goldstone, 60 miles north of Barstow, California) as the monitor reference station. Data for GOL2 was downloaded from the NASA/JPL FTP site (bodhi.jpl.nasa.gov/pub/pro/y1999/d286). The location of GOL2 was obtained from gol29906.log downloaded from the internet at http://igscb.jpl.nasa.gov/igscb/station/log. The position of the GPS antenna of the ground station after differential correction was:

Latitude (WGS-84):	36:56.046324 N
Longitude (WGS-84):	121:47.6862 W
Elevation (GRS-80 ellipsoid):	16.958 m

Since the entire survey area was within 100 miles (161 km) of the base station, no remote base station was required.

Permission to conduct the survey was granted by Mike Barnett of San Jose FSDO. A waiver to fly below 1000 feet over congested areas (i.e. towns), within the survey area, was unobtainable. A map defining these areas was prepared by the field crew, and it was agreed that 1000 foot clearance over the marked areas (Half Moon Bay, Santa Cruz, Watsonville, Gilroy, Hollister, Salinas, Monterey and Carmel) should be maintained. This was achieved by adjusting the digital terrain model used for the drape surface as described above.

Much of the survey area lies within the Monterey Bay National Marine Sanctuary (MBNMS). Permission was granted to operate at 500 feet above sea level within the MBNMS by Scott Kathey with the following exceptions:

a) 800 feet minimum clearance to be maintained over Elkhorn Slough.

b) 1000 feet above MSL to be maintained within 1 nautical mile of the following ecologically sensitive locations:

Devil's Slide	37°35'50''N	122°31'10''W
Año Nuevo Island	37°06'30''N	122°20'40''W
Point Lobos	36°31'23'N	121°57'15''W
Castle Rocks	36°22'30''N	121°54'33''W
Hurricane Point	36°21'24''N	121°54'27''W

In addition, SGL were required to coordinate activities over Devil's Slide, Año Nuevo Island and Pescadero Point (37°14'40"N 122°25'05"W) with Edward Euber of the Gulf of the Farallones National Marine Sanctuary who arranged to place observers on the ground during operations.

A report on SGL's activities in the MBNMS was submitted to the office in Monterey in December '99 in compliance with the operation permission granted.

A small part of Block A, and much of Block B, lies within the California Sea Otter Refuge which runs along the coast south of Monterey. Permission to operate at 500 feet above MSL within the refuge was obtained from Lt. Carmel Babich of the California Department of Fish and Game.

The busy airport at Monterey lies within the survey block. The air traffic controllers were visited at the control tower in order to establish good coordination of survey flights through the approaches and over the runway.

Coastal fog was the main factor effecting the production rate. Fog and low cloud occurred mostly in the mornings, lifting and burning off toward mid-day. Only four days were completely lost due to poor visibility, but numerous other flights were delayed and double flights were only occasionally possible. Another day was lost when the only remaining production, for the survey block, passed through an active parachute drop zone near the town of Marina on the coast of Monterey Bay.

Problems were encountered with the provision of real-time GPS corrections from the Omnistar unit when flying several kilometres offshore. No data was flown offline as a result, and the problem was solved by arranging for special coverage that allowed for the transition between land and sea.

BODIE-AURORA

Operations were conducted from Yerington Municipal Executive Airport located in Yerington, Nevada, located north of the survey block. A field office was established in the Sorensen Hangar, and space was rented in the hangar for the Islander. The ground station computer was set up in a shed at the Cook's farm on Green Acres road just east of the airport. The GPS antenna was located on the roof of the shed, and the ground station magnetic sensor pole was erected in an adjacent field which was not in use at the time.

The location of the base station was determined using data from Julian day 312, differentially corrected using the IGS Station GOL2 (Goldstone, 60 miles north of Barstow, California) as the monitor reference station. Data for GOL2 was downloaded from the NASA/JPL FTP site (bodhi.jpl.nasa.gov/pub/pro/y1999/d312). The location of GOL2 was obtained from gol29906.log downloaded from the internet at http://igscb.jpl.nasa.gov/igscb/station/log. The position of the ground station GPS antenna after differential correction was:

Latitude (WGS-84):	39:00.046885 N
Longitude (WGS-84):	119:09.2959 W
Elevation (GRS-80 ellipsoid):	1313.410 m

Since the entire survey area was within 100 miles (161 km) of the base station, no remote base station was required.

Permission to conduct the survey was granted by Clarence Bohartz of Reno FSDO. A waiver to fly as low as 500 feet above any towns within the survey area was granted, although no large urban areas were affected anyway. Notification of SGL's activities was provided to the Sheriff of Bridgeport (the only significant town within the survey) in accordance with the provisions of the waiver. In addition, permission was obtained to fly over the Hawthorne Army Depot ordinance detonation site "New Bomb" at restricted area R-4811. Flights were permitted at all times, except between 11:30 to 15:00 Tuesday through Wednesday, subject to confirmation on the day of the flight due to the possibility of non-regularly scheduled detonations. Coordination was arranged with Louis Delmonica and Vicki Coll at the Army Depot.

The weather remained unseasonably dry and clear throughout almost the entire duration of the survey. Production was regularly interrupted by strong winds and turbulence, often associated with passing weather fronts, which are a feature of the area just to the east of the Sierra Nevada. Production was restricted on some days, two flights returned with no production, and no flight was attempted on four other days as a result of high winds. Double flights were performed on the majority of days, although flight durations were short (rarely longer than 4 hours) due to the high fuel burn at high altitude.

FIELD PERSONNEL

The following technical personnel of SGL participated in field operations:

Amargosa Desert / Death Valley		
Project Manager:	Reed Archer	
Field Operations Manager/ Data Processor:	Martin Bates	
Pilot-in-Command:	Randy Forwell	(flights 1-28)
	Nick Taylor	(flights 22-43)
Copilot/Aircraft Maintenance Engineer:	Brian Clarke	

San Gregorio North / Point Sur / Hollister		
Project Manager:	Reed Archer	
Field Operations Manager/ Data Processor:	Martin Bates	
Pilot-in-Command:	Nick Taylor	(flights 1-8)
	Jan Kristiansen	(flights 1-3 & 9-17)
	Todd Lewis	(flights 2-30)
	Randy Forwell	(flights 18-30)
Copilot/Aircraft Maintenance Engineer:	Brian Clarke	(flights 1-3)
	Simon Worswick	(flights 2-30)

Bodie-Aurora District	
Project Manager:	Reed Archer
Field Operations Manager/ Data Processor:	Martin Bates
Pilot-in-Command:	Randy Forwell
	Todd Lewis
Copilot/Aircraft Maintenance Engineer:	Simon Worswick

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 the SGL head office in Ottawa. *Figure5* summarizes the steps involved in processing the data obtained from the survey.

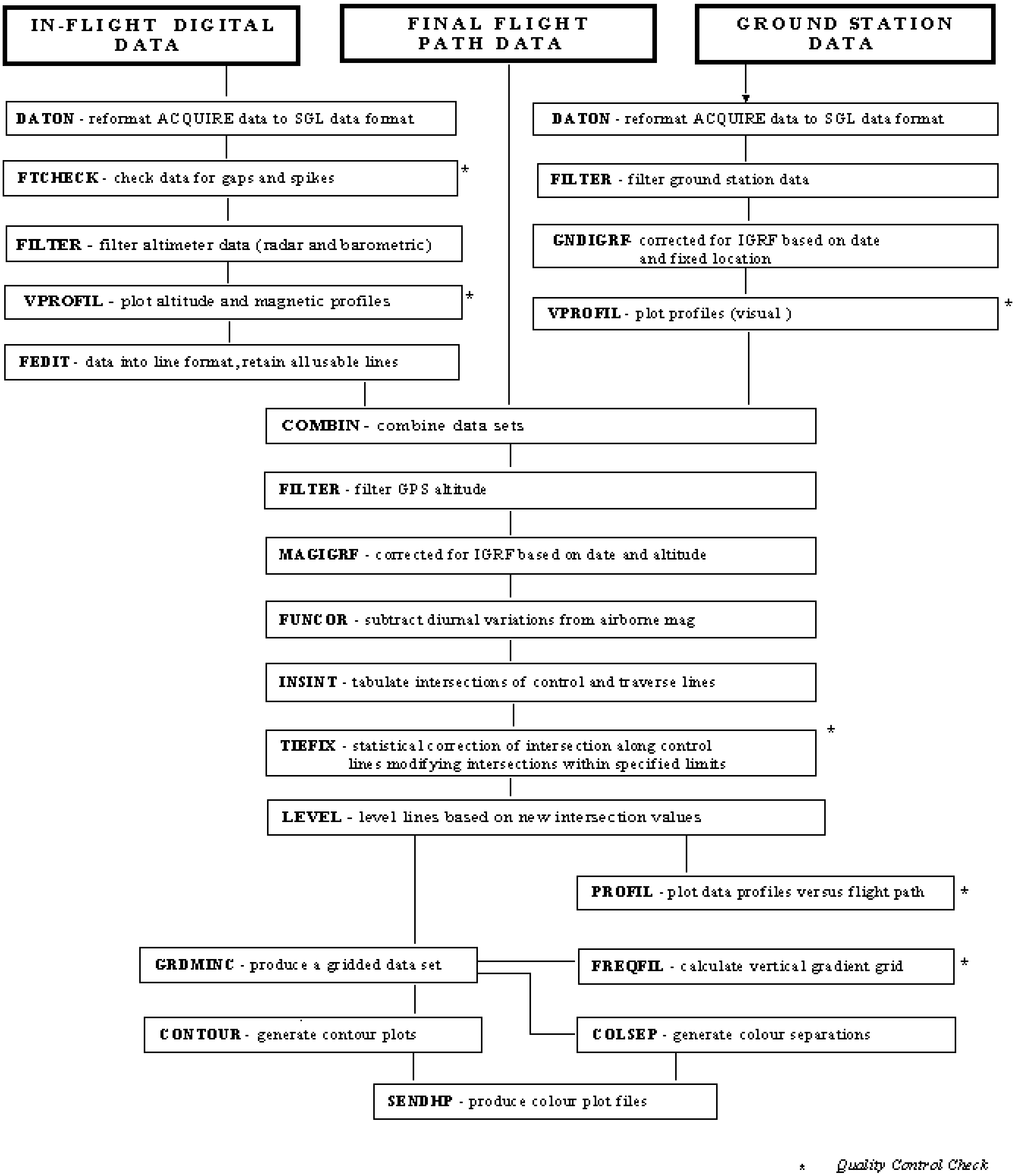
DAILY FIELD PROCEDURES

The following procedures took place on a daily basis:

a) Inspection of flight analog trace, noting noise or interference on magnetic data, and checking all data channels (air and ground magnetic, 4th difference of air magnetic data, radar and barometric altimeter, GPS).
b) Inspection of ground station magnetic data for diurnal activity and interference.
c) Check time synchronization of airborne and ground station data files.
d) Check DGPS data for continuity of coverage, accuracy of position, and number of satellites used.
e) Generation of an untrimmed flight path map for each sortie flown.
f) Check air data files for data gaps.
g) Screen profiles of radar and barometric altimeters.
h) Generation of trimmed flight path map (on line data only).
i) Check for deviation from planned flight lines.
j) Check for deviation from planned drape surface.
k) Check speed of aircraft for data coverage.
l) Screen profiles of drape surface, digital terrain model, DGPS altitude and calculated terrain.
m) Screen profile of ground station magnetometer data.
n) Screen profile of air magnetometer data.
o) Create multiple stacked profiles of magnetic data.
p) Check of video tape for gaps and picture quality.

Figure 5

MAGNETOMETER DATA PROCESSING



WEEKLY FIELD PROCEDURES

The following tasks were performed on a weekly basis:

a) Create multiple stacked profiles of radar altimeter
b) Produce grids of radar altimeter, barometric altimeter, DGPS height (MSL) and topography.
c) Examine altimeter intersection statistics.
d) Level magnetic data and inspect intersection statistics.
e) Inspect magnetic data grids (total magnetic intensity, 1st vertical derivative, 2nd vertical derivative).
f) Check remote ground station magnetic data and comparison with local ground station magnetic data (Amargosa Desert / Death Valley survey only).
g) Check distance between flight lines.

MAGNETOMETER DATA

Amargosa Desert / Death Valley

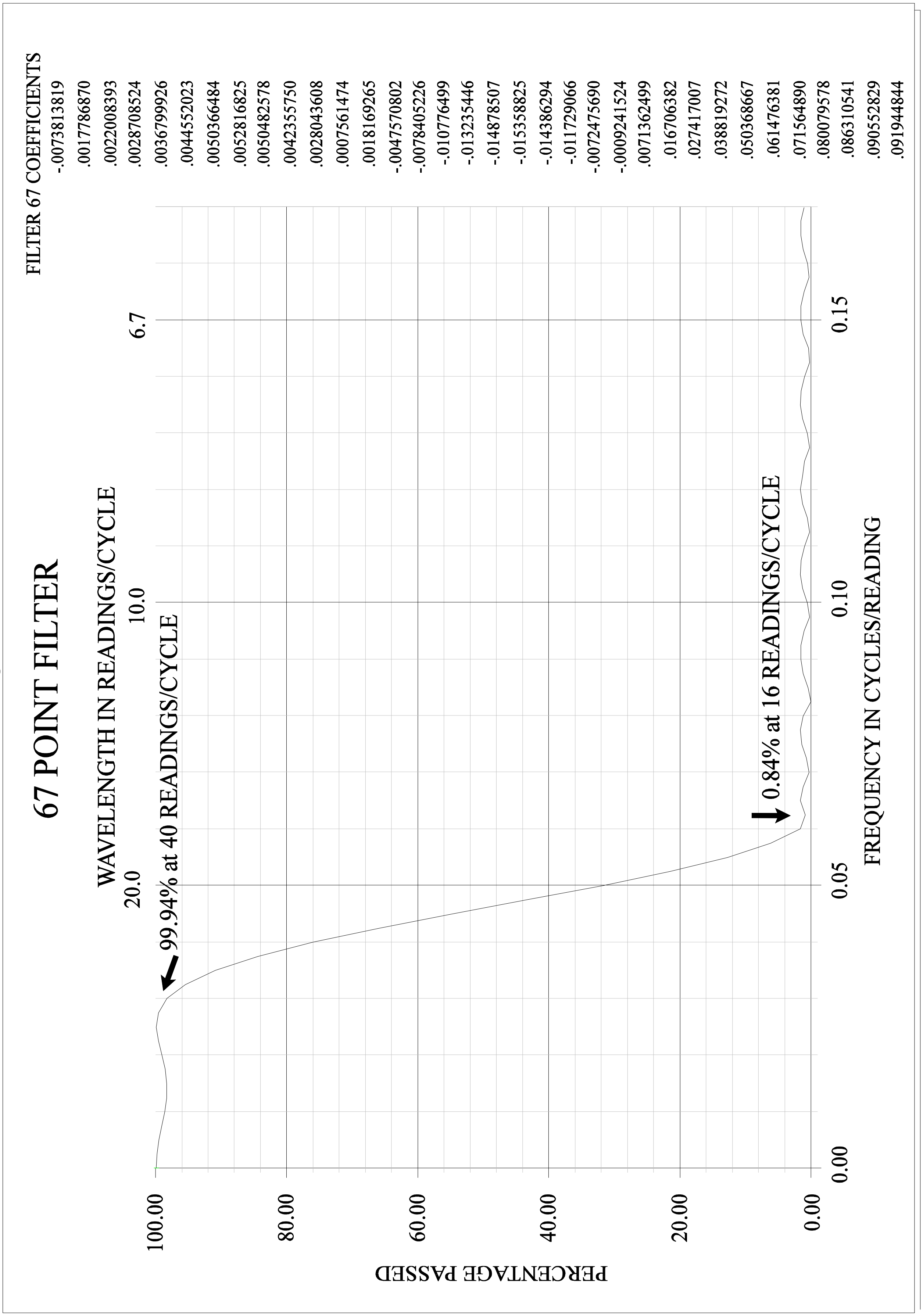
The airborne magnetometer data, recorded at 10 Hz, were plotted and checked for spikes or noise. No filtering of the airborne magnetic data was required. All ground station magnetometer data were filtered using a 67-point low pass filter (*Figure 6)* and corrected for the IGRF using the fixed ground station location (*see section VI - Field Operations*) and the recorded date for each flight. The airborne data is corrected for diurnal variations by removing the filtered and corrected ground station data. The data from the ground station at Henderson airport (the "local" ground station) was used to correct all data for this survey. The airborne magnetometer data was then corrected for the IGRF using the location, altitude and date of each point. IGRF values were calculated using the 1995 IGRF parameter file. The altitude data used for the IGRF correction are DGPS MSL heights filtered using a low pass filter with a ramp between 100 and 200 points applied to the data interpolated to 4 Hz.

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 each intersection point. Each control line was then adjusted by a specific constant magnetic value to minimize for each traverse line:

$$\Sigma|i - a|$$

where, i = (*individual intersection difference*)
a = (*average intersection difference for that traverse line*)

Figure 6


67 POINT FILTER
WAVELENGTH IN READINGS/CYCLE
20.0
10.0
6.7
99.94% at 40 READINGS/CYCLE
0.84% at 16 READINGS/CYCLE
PERCENTAGE PASSED
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.05
0.10
0.15
FREQUENCY IN CYCLES/READING
FILTER 67 COEFFICIENTS
-.0073813819
.0017786870
.0022008393
.0028708524
.0036799926
.0044552023
.0050366484
.0052816825
.0050482578
.0042355750
.0028043608
.0007561474
-.0018169265
-.0047570802
-.0078405226
-.010776499
-.013235446
-.014878507
-.015358825
-.014386294
-.011729066
-.0072475690
-.0009241524
.0071362499
.016706382
.027417007
.038819272
.050368667
.061476381
.071564890
.080079578
.086310541
.090552829
.091944844

The influence of anomalous intersections was avoided by calculating local average corrections over 9 intersections, and omitting intersection corrections that differ from the local average by more than 3.0 nT.

Adjusted control lines were then locally corrected to minimise the difference between individual corrections and the local average correction of the control line (“short- fix”) which result from residual diurnal variations along control lines. The local average correction value was determined over 11 intersections, and compared to the correction applied to the whole line. A correction is applied at the centre of a group of 11 intersections equal to the difference in these two values where the difference is significant (greater than 0.2 nT). Corrections for intersections between the centre points were determined by linear interpolation.

Further adjustments to levelling corrections were determined for individual intersections. Local averages were recalculated over 11 intersections, omitting clearly anomalous intersections as above. Intersection corrections differing from the local average by more than 3.0 nT were adjusted to bring them to the average. Levelling parameters were adjusted, and individual intersection corrections were adjusted, removed or added where appropriate. A total of 176 individual intersection corrections were employed, 18 of which were determined by visual inspection of the data.

The levelling procedure was checked by generating contour maps of the total magnetic intensity (TMI), inspection of 1^{st} and 2^{nd} vertical derivative grids, and plotting profiles of corrections along traverse and control lines to check for steep correction gradients.

Line levelling was carried out by a program which interpolates and extrapolates levelling values for each point, based on the two closest levelling values. After traverse lines have been levelled, the control lines are matched to them. This ensures that all intersections tie perfectly and permit the use of all data in the final grids.

Grids were generated using the minimum curvature method, with a 100 m grid cell size appropriate for the 200 m flight line spacing. 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).

San Gregorio North / Point Sur / Hollister

The airborne magnetometer data, recorded at 10 Hz, were plotted and checked for spikes or noise. All ground station magnetometer data were filtered using a 67-point low pass filter (*Figure 6)* and corrected for the IGRF using the fixed ground station location (*see section VI - Field Operations*) and the recorded date for each flight. The airborne data is corrected for diurnal variations by removing the filtered and corrected ground station data. The data from the ground station at Watsonville Airport were used to correct all data for this survey. The airborne magnetometer data was then corrected for the IGRF using the location, altitude and date of each point. IGRF values were calculated using the 1995 IGRF parameter file. The altitude data used for the IGRF correction are DGPS MSL heights filtered using a low pass filter with a ramp between 100 and 200 points applied to the data interpolated to 4 Hz.

Data from flights 24 and 25, on October 28th 1999 were effected by diurnal variations that appeared to be related to a particularly heavy oceanic swell generated by a major storm off the Oregon coast. Pulsations were recorded in the offshore data when flying in a westbound direction. The pulsations were not as obvious from lines flown eastbound, and were not recorded onshore either in the airborne data or at the ground station at Watsonville airport. Careful examination of the full data set revealed some other data, from other days, with a similar effect. A band pass filter with ramps between 30 to 60 points and 75 to 150 points was applied to 10 Hz data to isolate the diurnals, and was limited to the parts of lines affected by the diurnals. The diumal data was smoothed using a low pass filter with a ramp between 10 to 25 points to prevent artifacts from being introduced at the limit of the filtering, and the airborne data was corrected by subtracting the diurnals. A full list of the affected lines and the range over which they are filtered is given in *Appendix XVII.*

Levelling for Blocks A, C and D was carried out together, whilst levelling for Block B was carried out separately and then merged with the rest of the data. 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 each intersection point. Each control line was then adjusted by a specific constant magnetic value to minimize for each traverse line:

$$\Sigma|i - a|$$

where, i = (*individual intersection difference*)

a = (*average intersection difference for that traverse line*)

The influence of anomalous intersections was avoided by calculating local average corrections over 9 intersections, and omitting intersection corrections that differ from the local average by more than 5.0 nT for Block A, C and D by more than 3.0 nT for Block B.

Adjusted control lines were then locally corrected to minimise the difference between individual corrections and the local average correction of the control line ("short- fix") which result from residual diurnal variations along control lines. The local average correction value was determined over 7 intersections for all data sets, and compared to the correction applied to the whole line. A correction is applied at the centre of a group of 7 intersections equal to the difference in these two values where the difference is significant (greater than 0.2 nT). Corrections for intersections between the centre points were determined by linear interpolation.

Further adjustments to levelling corrections were determined for individual intersections. Local averages were recalculated over 7 intersections, omitting clearly anomalous intersections as above. Intersection corrections differing from the local average by more than 5.0 nT or 3.0 nT for Blocks A, C and D were adjusted to bring them to the average. Levelling parameters were adjusted, and individual intersection corrections were adjusted, removed or added where appropriate. A total of 59 individual intersection corrections were employed for Blocks A, C and D, 46 of which were determined by visual inspection of the data. A further 24 corrections were applied to traverse line data between intersections. Seventeen individual intersection corrections and 67 between intersection corrections were applied to the data from Block B, all of which were identified by visual inspection of the data.

The levelling procedure was checked by generating contour maps of the TMI, inspection of 1^{st} and 2^{nd} vertical derivative grids, and plotting profiles of corrections along traverse and control lines to check for steep correction gradients.

Line levelling was carried out by a program which interpolates and extrapolates levelling values for each point, based on the two closest levelling values. After traverse lines have been levelled, the control lines are matched to them. This ensures that all intersections tie perfectly and permit the use of all data in the final grids.

Grids were generated using the minimum curvature method, with a 200 m grid cell size appropriate for the 536 m flight line spacing. 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).

Data from Block B were merged with data from Blocks A, C and D by comparing data from the two sets in the overlap of the two data sets. Three false lines were created (see *Appendix XVIII*); one “overlap” line along the data overlap, and two further parallel “limiting” lines, one to the north entirely within Block A and one to the south entirely within Block B. A shift of -6.95 nT was applied to all data in Block B to minimise the average difference between the data sets along the overlap line. Data from Block B were then matched to data from Block A along the overlap line, and the correction at each intersection with the overlap line were linearly interpolated to zero along the flight lines of Block B to the intersection with the southern limiting line. A total of 34 further corrections were made at points on flight lines from both sets, identified by visual inspection of the data, and interpolated to zero at the north or south limiting lines as appropriate. Digital line data is delivered both in merged and un-merged forms. The final gridded data is made from the merged data set using the minimum curvature method as described above.

Bodie-Aurora

The airborne magnetometer data, recorded at 10 Hz, were plotted and checked for spikes or noise. No filtering of the airborne magnetic data was required. All ground station magnetometer data were filtered using a 67-point low pass filter (*Figure 6)* and corrected for the IGRF using the fixed ground station location (*see section VI - Field Operations*) and the recorded date for each flight.

The airborne data is corrected for diurnal variations by removing the filtered and corrected ground station data. The data from the ground station near Yerington Airport were used to correct all data for this survey. After flight 23 the ground station magnetometer and pole had to be moved to accommodate a new gate being installed at the Cook’s farm. A value of 11.5 nT was added to the ground station data for flights 1 to 23 to account for the variance in magnetic values at the different locations.

In flight 35, a magnetometer failure occurred necessitating the installation of a new magnetometer and a new compensation solution to be obtained. From flight 41 (next production flight after 35) to the last flight (flight 56) a value of 7 nT was added to the airborne magnetic data to reconcile the difference in magnetometers.

The airborne magnetometer data was then corrected for the IGRF using the location, altitude and date of each point. IGRF values were calculated using the 1995 IGRF parameter file. The altitude data used for the IGRF correction are DGPS MSL heights filtered using a low pass filter with a ramp between 100 and 200 points applied to the data interpolated to 4 Hz.

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 each intersection point. Each control line was then adjusted by a specific constant magnetic value to minimize for each traverse line:

$$\Sigma|i - a|$$

where, i = (*individual intersection difference*)
a = (*average intersection difference for that traverse line*)

The influence of anomalous intersections was avoided by calculating local average corrections over 9 intersections, and omitting intersection corrections that differ from the local average by more than 4.0 nT.

Adjusted control lines were then locally corrected to minimise the difference between individual corrections and the local average correction of the control line (“short- fix”) which result from residual diurnal variations along control lines. The local average correction value was determined over 11 intersections, and compared to the correction applied to the whole line. A correction is applied at the centre of a group of 11 intersections, equal to the difference in these two values, where the difference is significant (greater than 0.25 nT). Corrections for intersections between the centre points were determined by linear interpolation.

Further adjustments to levelling corrections were determined for individual intersections. Local averages were recalculated over 9 intersections, omitting clearly anomalous intersections as above. Intersection corrections differing from the local average by more than 4.0 nT were adjusted to bring them to the average. Levelling parameters were adjusted, and individual intersection corrections were adjusted, removed or added where appropriate.

The levelling procedure was checked by generating contour maps of the TMI, inspection of 1st and 2nd vertical derivative grids, and plotting profiles of corrections along traverse and control lines to check for steep correction gradients.

Line levelling was carried out by a program which interpolates and extrapolates levelling values for each point, based on the two closest levelling values. After traverse lines have been levelled, the control lines are matched to them. This ensures that all intersections tie perfectly and permit the use of all data in the final grids.

Traverse line parallel stripes due to persistent levelling problems were removed using decorrugation (micro-levelling) of the grid. Artificial anomalies parallel to traverse lines were targeted within a range of frequencies defined as being less than a given wavelength perpendicular to the traverse lines, and greater than a given wavelength parallel to the traverse lines. Places with high gradient did not require decorrugation so these areas were identified and eliminated from the decorrugation processing.

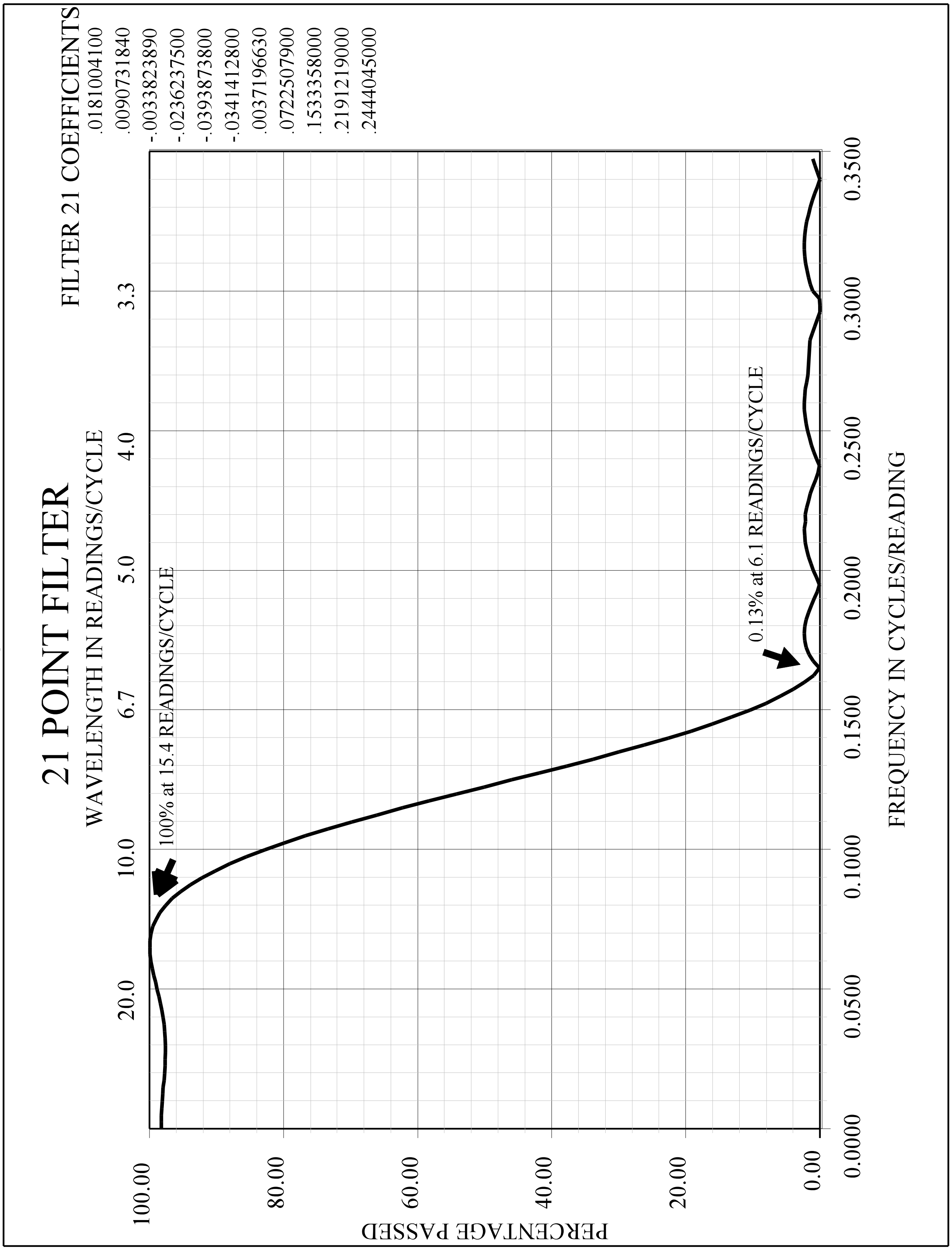
The wavelength of decorrugation across the traverse lines was 130 metres and along the lines at 300 metres. Decorrugation corrections determined from grid data were applied to the line data. These corrections were limited to +/- 2 nT. Decorrugation corrections were low-pass filtered in the one-dimensional frequency domain using a cosine tapered filter from 20 to 30 points on 0.1 second data to remove high frequency artifacts introduced by the decorrugation filter and smooth the transition to areas of the data which were not decorrugated.

Grids were generated using the minimum curvature method, with a 50 m grid cell size appropriate for the 150 m flight line spacing. 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 high frequency noise using a 21-point low pass filter (*Figure 7*). The filtered data were plotted and inspected for quality. The radar altimeter data were gridded using the minimum curvature method and the same grid cell sizes as used for the magnetometer data. Due to variations in aircraft attitude when flying in different directions in areas of steep terrain, radar altimeter values at control line/traverse line intersections do not always match. For this reason, the grids of radar heights are made from traverse line data only.

Figure 7


21 POINT FILTER
WAVELENGTH IN READINGS/CYCLE
FILTER 21 COEFFICIENTS
.0181004100
.0090731840
-.0033823890
-.0236237500
-.0393873800
-.0341412800
.0037196630
.0722507900
.1533358000
.2191219000
.2444045000
20.0
10.0
6.7
5.0
4.0
3.3
100% at 15.4 READINGS/CYCLE
0.13% at 6.1 READINGS/CYCLE
100.00
80.00
60.00
40.00
20.00
0.00
PERCENTAGE PASSED
0.0000
0.0500
0.1000
0.1500
0.2000
0.2500
0.3000
0.3500
FREQUENCY IN CYCLES/READING

BAROMETRIC ALTIMETER DATA

The barometric altimeter data was recorded at 4 Hz and after being checked for integrity the low pass filter 131A *(Figure 8)* was used to remove high frequency noise.

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 general data flow for GPSoft is illustrated in *Figure 9*.

The accurate location of the GPS antenna was determined using a permanent GPS reference station near Barstow, California (*see section VI - Field Operations*) to differentially correct the SGL ground station position data. This technique provides a final receiver location with an accuracy of better than 1 metre. The entire airborne data set was processed differentially using the calculated ground station location.

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

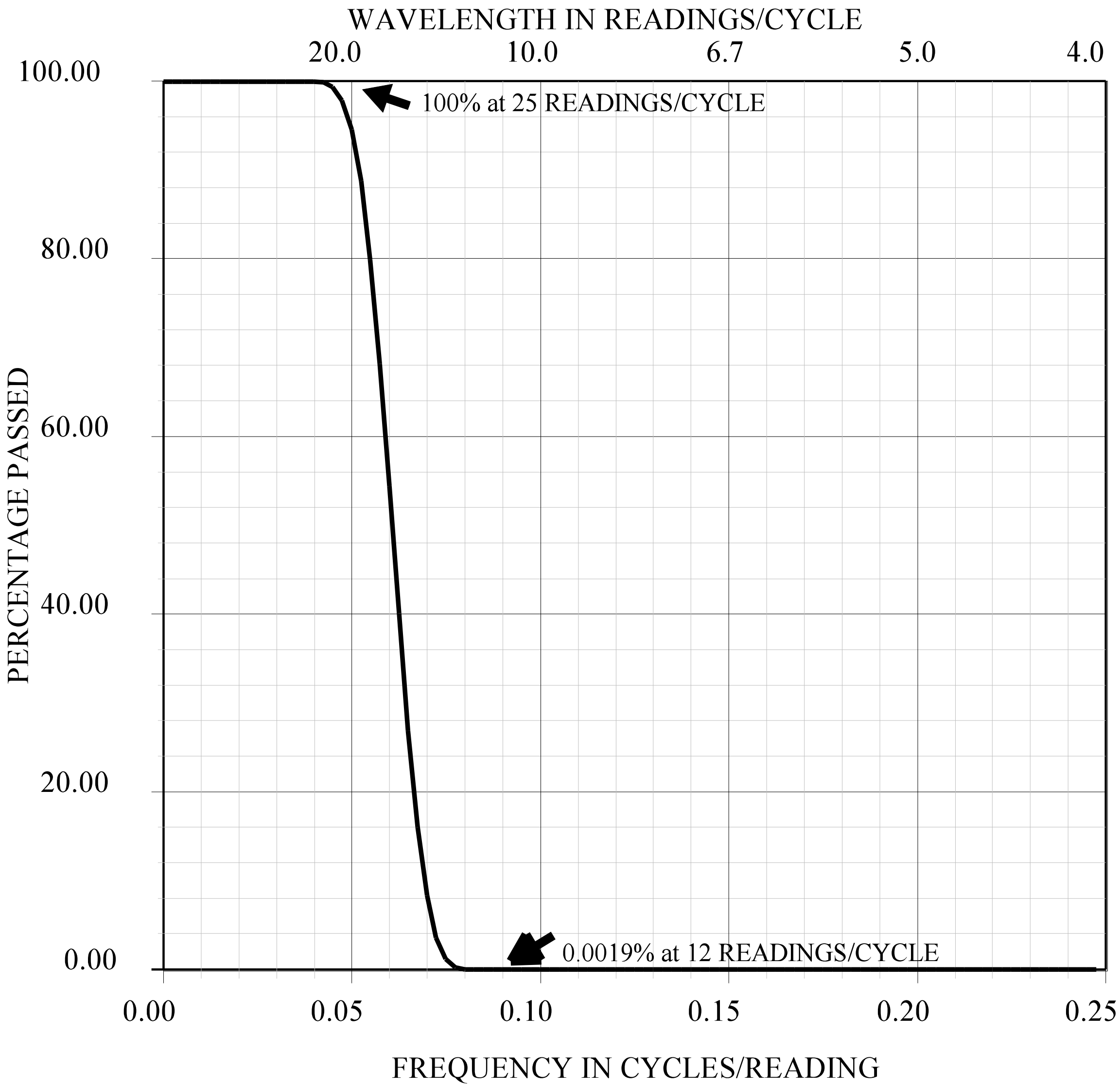
Ellipsoid:	International (Clarke-1866)
Semimajor axis:	6378206.4
1/flattening:	294.979
Shift to WGS-84:	dx = -8, dy = 160, dz = 176

Amargosa Desert / Death Valley & Bodie-Aurora areas:	UTM zone 11N, central meridian 117° west
San Gregorio North / Point Sur / Hollister area:	UTM zone 10N, central meridian 123° west

Elevation data were recorded in the WGS-84 datum and transformed to MSL using the OSU91A30 model.

Figure 8

131 POINT FILTER

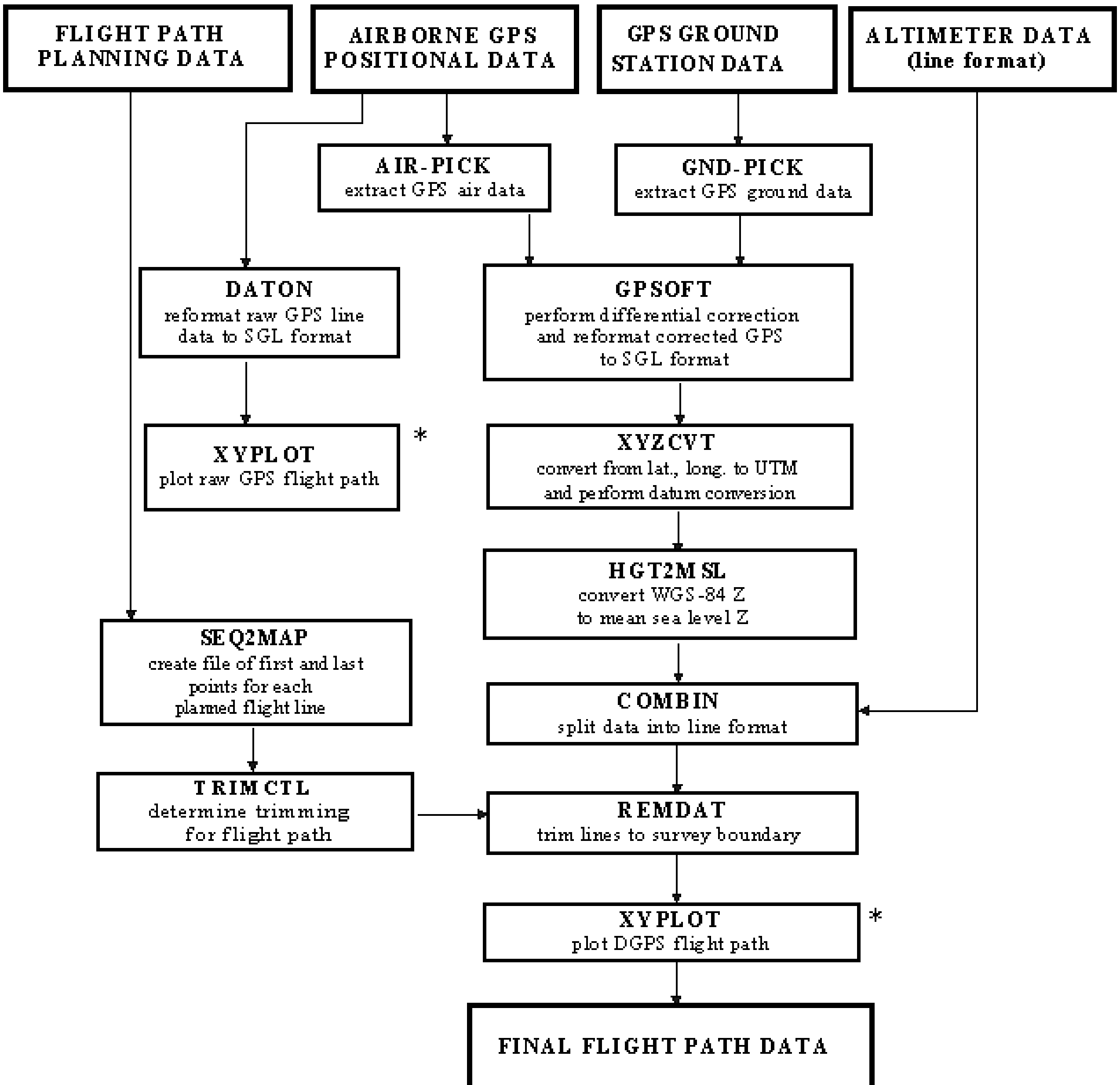


131 FILTER COEFFICIENTS

.0000260972	.0021227699	.0387007609
-.0000215508	.0013318287	.0587941859
-.0000347301	.0001445621	.0784115155
-.0000527685	-.0013145414	.0958773646
-.0000689586	-.0028486226	.1096397280
-.0000759605	-.0042091576	.1184433040
-.0000665814	-.0051298564	.1214721169
-.0000353316	-.0051298564	
.0000197128	-.0053688655	
.0000952014	-.0047555092	
.0001815251	-.0032317683	
.0002629864	-.0008823412	
.0003194901	.0020543574	
.0003296908	.0051990722	
.0002754251	.0080698676	
.0001466616	.0101432829	
-.0000539411	.0109319821	
-.0003079391	.0100689900	
-.0005805888	.0073862597	
-.0008235856	.0029746856	
-.0009813262	-.0027858964	
-.0010001866	-.0092349627	
-.0008396489	-.0154811362	
-.0004834514	-.0204909701	
.0000514538	-.0232082194	
.0007104261	-.0226897427	
.0014028256	-.0182407400	
.0020111249	-.0095306391	
.0024068490	.0033276342	
.0024719976	.0197483320	

Figure 9

POSITIONAL DATA PROCESSING



* *Quality Control Check*

DATA PROCESSING PERSONNEL

Data processing at head office was performed by the following SGL personnel under the supervision of Luise Sander:

Martin Bates	Veronique Lavoie
Chris Church	Jennifer Meyer
Carlos Cifuentes	Suzi Santaguida
David Kalviainen	

Cartographic work was performed by Jeff Kertesz.

VIII. FINAL PRODUCTS

DIGITAL DATA

Amargosa Desert / Death Valley

Two copies of the following files were delivered on CD-ROM:

README.TXT	ASCII line data file format description
AMAR.XYZ	ASCII line data for the whole project
READMEGD.TXT	GXF grid format description
TMI.GXF	GXF format total magnetic intensity grid (nT)
RAD.GXF	GXF format radar altimeter grid (m)

***Line Data*:** The digital data format is described in *Figure 10*a.

***Grid Data*:** The grids were delivered in GXF format. Header Information from the GXF files is as follows:

```
TOTAL MAGNETIC INTENSITY (or RADAR ALTIMETER)
NOVEMBER 25, 1999
DATUM NAD-27-USA, UTM ZONE 11N
SANDER GEOPHYSICS LTD
#POINTS
   1376
#ROWS
  1327
#PTSEPARATION
  100.0000
#RWSEPARATION
   100.0000
 #XORIGIN
  499000.00
#YORIGIN
  3964200.00
#SENSE
  1
#DUMMY
  -9999.000
#GRID
```

Figure 10a
ASCII DIGITAL DATA FORMAT
Amargosa Desert / Death Valley

FORMAT DESCRIPTION FOR AMAR.XYZ

Record length: 150 bytes

Channel	Contents	Columns	Format
Line identifier	lllllssqq (see below)	1-8	A8
Longitude NAD-27	decimal degrees	9-20	F12.6
Latitude NAD-27	decimal degrees	21-30	F10.6
UTM x NAD-27, Zone 11N	metres	31-39	F9.1
UTM y NAD-27, Zone 11N	metres	40-49	F10.1
Fiducial	seconds	50-58	F9.2
Year and Julian day	YYDDD	59-64	A6
Time of day	HHMMSS	65-71	A7
Radar height	metres	72-78	F7.1
Barometer height	metres	79-85	F7.1
GPS elevation (MSL)	metres	86-92	F7.1
Ground magnetics (IGRF corrected)	nT	93-101	F9.2
Remote magnetics (IGRF corrected)	nT	102-110	F9.2
Uncorrected TMI	nT	111-119	F9.2
TMI diurnally corrected	nT	120-128	F9.2
TMI IGRF removed	nT	129-137	F9.2
Final TMI (levelled)	nT	138-146	F9.2

Line identifier consists of line number, segment number and quadrant, (qq is left aligned).

Figure 10b
ASCII DIGITAL DATA FORMAT
San Gregorio North / Point Sur / Hollister

FORMAT DESCRIPTION FOR SGN-ALL.XYZ
Record length: 150 bytes

Channel	Contents	Columns	Format
Line identifier	lllssqq (see below)	1-8	A8
Longitude NAD-27	decimal degrees	9-20	F12.6
Latitude NAD-27	decimal degrees	21-30	F10.6
UTM x NAD-27, Zone 10N	metres	31-39	F9.1
UTM y NAD-27, Zone 10N	metres	40-49	F10.1
Fiducial	seconds	50-58	F9.2
Year and Julian day	YYDDD	59-64	A6
Time of day	HHMMSS	65-71	A7
Radar height	metres	72-78	F7.1
Barometer height	metres	79-85	F7.1
GPS elevation (MSL)	metres	86-92	F7.1
Ground magnetics (IGRF corrected)	nT	93-101	F9.2
Uncorrected TMI	nT	102-110	F9.2
TMI diurnally corrected	nT	111-119	F9.2
TMI IGRF removed	nT	120-128	F9.2
Un-merged Final TMI (levelled)	nT	129-137	F9.2
Merged Final TMI (levelled)	nT	138-146	F9.2

Line identifier consists of line number, segment number and quadrant, (qq is left aligned).

Figure 10c
ASCII DIGITAL DATA FORMAT
Bodie-Aurora

FORMAT DESCRIPTION FOR BODIE.XYZ
Record length: 150 bytes

Channel	Contents	Columns	Format
Line identifier	llllssqq (see below)	1-8	A8
Longitude NAD-27	decimal degrees	9-20	F12.6
Latitude NAD-27	decimal degrees	21-30	F10.6
UTM x NAD-27, Zone 11N	metres	31-39	F9.1
UTM y NAD-27, Zone 11N	metres	40-49	F10.1
Fiducial	seconds	50-58	F9.2
Year and Julian day	YYDDD	59-64	A6
Time of day	HHMMSS	65-71	A7
Radar height	metres	72-78	F7.1
Barometer height	metres	79-85	F7.1
GPS elevation (MSL)	metres	86-92	F7.1
Ground magnetics (IGRF corrected)	nT	93-101	F9.2
Uncorrected TMI	nT	102-110	F9.2
TMI diurnally corrected	nT	111-119	F9.2
TMI IGRF removed	nT	120-128	F9.2
Final levelled TMI	nT	129-137	F9.2
Final levelled & decorrugated TMI	nT	138-146	F9.2

Line identifier consists of line number, segment number and quadrant, (qq is left aligned).

San Gregorio North / Point Sur / Hollister

Two copies of the following files were delivered on CD-ROM:

README.TXT	ASCII line data file format description
SGN-ALL.XYZ	ASCII line data for the whole project
READMEGD.TXT	GXF grid format description
TMI.GXF	GXF format total magnetic intensity grid (nT)
RAD.GXF	GXF format radar altimeter grid (m)

Line Data**:** The digital data format is described in *Figure 10*b.

Grid Data**:** The grids were delivered in GXF format. Header Information from the GXF files is as follows:

```
TOTAL MAGNETIC INTENSITY (or RADAR ALTIMETER)
MARCH 07, 2000
DATUM NAD-27-USA, UTM ZONE 10N
SANDER GEOPHYSICS LTD
#POINTS
  813
#ROWS
  1002
#PTSEPARATION
  200.0000
#RWSEPARATION
  200.0000
#XORIGIN
  520000.00
#YORIGIN
  3981600.00
#SENSE
  1
#DUMMY
  -9999.000
#GRID
```

Bodie-Aurora

Two copies of the following files were delivered on CD-ROM:

README.TXT	ASCII line data file format description
BODIE.XYZ	ASCII line data for the whole project
READMEGD.TXT	GXF grid format description
TMI.GXF	GXF format total magnetic intensity grid (nT)
RAD.GXF	GXF format radar altimeter grid (m)

***Line Data*:** The digital data format is described in *Figure 10c*.

***Grid Data*:** The grids were delivered in GXF format. Header Information from the GXF files is as follows:

TOTAL MAGNETIC INTENSITY (or RADAR ALTIMETER)
APRIL 14, 2000
DATUM NAD-27-USA, UTM ZONE 11N
SANDER GEOPHYSICS LTD.
#POINTS
1511
#ROWS
1532
#PTSEPARATION
50.0000
#RWSEPARATION
50.0000
#XORIGIN
294350.00
#YORIGIN
4196900.00
#SENSE
1
#DUMMY
-9999.000
#GRID

MAP PRODUCTS

Amargosa Desert / Death Valley

Two laminated plots on clear film, of the following map products, were delivered:

At 1:250,000 - 1 map sheet for the entire survey area

- Total magnetic intensity contour map with flight lines superimposed

At 1:100,000 - 3 map sheets to cover the entire survey area

- Total magnetic intensity contour map with flight lines superimposed
- Radar altimeter contour map with flight lines superimposed

San Gregorio North / Point Sur / Hollister

Two laminated plots on clear film, of the following map products, were delivered:

At 1:250,000 - 1 map sheet for the entire survey area

- Total magnetic intensity contour map with flight lines superimposed

At 1:100,000 - 3 map sheets to cover the entire survey area

- Total magnetic intensity contour map with flight lines superimposed
- Radar altimeter contour map with flight lines superimposed

Bodie-Aurora

Two laminated plots on clear film, of the following map products, were delivered:

At 1:250,000 - 1 map sheet for the entire survey area

- Total magnetic intensity contour map with flight lines superimposed

At 1:100,000 - 1 map sheet to cover the entire survey area

- Total magnetic intensity contour map with flight lines superimposed
- Radar altimeter contour map with flight lines superimposed