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AEROMAGNETIC PROCESSING TECHNIQUES AT THE KANSAS GEOLOGICAL SURVEY

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Introduction

The purpose of this paper is to present some aeromagnetic data quality control and display techniques that may be useful at the National Geophysical Data Center (NGDC). These techniques were developed at the Kansas Geological Survey (KGS) during processing of approximately 92,000 line-kilometers of raw aeromagnetic data recently acquired in Kansas and Arkansas. This report is not a complete description of the KGS data acquisition and reduction procedures, but rather emphasizes quality control procedures that are relatively simple and generally applicable to other aeromagnetic data sets. Although some commercial contractors have processed orders-of-magnitude more data, very little detailed information on processing techniques has been published.

The KGS airborne aeromagnetic system consists of a Geometrics G-806 proton precession magnetometer, a Geometrics G-704 Data Acquisition System, a Cipher 70 digital magnetic tape recorder, a Sperry RA-227 radar altimeter, an Automax G-2 35mm camera with a 30 m film magazine, and a solid-state intervelometer built by KGS personnel. The magnetic sensor, housed in an aerodynamically stabilized "bird," is trailed 30 m from the aircraft. For the data reported on here, the system was flown in a Twin Beech D-18 aircraft and the magnetometer was operated at ±1 nT sensitivity and two second sampling rate.

This system digitally records on magnetic tape, at two second intervals, the magnitude of the total magnetic field, time, ground clearance, camera fiducial number and other bookkeeping information. The camera is triggered by the magnetometer at a rate appropriate for continuous or near-continuous coverage of the flight path. The fiducial number and time are recorded simultaneously on film and magnetic tape for subsequent correlation of flight-path coordinates with magnetic field measurements. Navigation was accomplished by visual sighting along section roads.

The flight path film was used to identify landmarks 10 to 20 km apart on 1:125,000 scale county road maps. The longitude and latitude coordinates of the landmarks (fiducial points) were digitized and written to magnetic tape. The uncertainty of fiducial point location on the ground is estimated to be ±90 m. The fiducial coordinates tape was merged with the magnetic field tape for initial assignment of longitude and latitude to all magnetic measurements.

Interpretation of the Kansas aeromagnetic data has been reported on elsewhere (Yarger, 1981 and 1983).

Flight Path Errors

To check for bad fiducial points, resulting from incorrect location on map or incorrect digitization, aircraft velocity profiles are examined for each flight line (figure 1). Since the camera is triggered by the magnetometer at some multiple of two seconds (determined by the flight operator), each fiducial point is correlated with a particular magnetometer measurement and time of measurement. This permits the calculation of the aircraft ground speed along the profile. A bad fiducial point is easily detected as a discontinuity in velocity (an impossible sudden change in aircraft velocity). Depending on flight conditions, this method is sensitive to fiducial point location errors greater than 100 to 200 m along the flight path. Bad fiducial point location along the flight path is easily diagnosed as an offset high-low velocity pair. In the example shown in figure 1, the fiducial point location is in error by 500 m to the east resulting in a sudden change in calculated velocity of 24 km/hr. These locational errors, if not corrected, will create false gradients along the magnetic profile.

This procedure should be applicable to any existing aeromagnetic data set, as long as the time for each measurement is available. It is most sensitive to velocities calculated between fiducial points, but should also work for velocities calculated between arbitrary measurement locations. Any good aeromagnetic data set should pass this simple requirement of a smoothly varying velocity profile.

Reversed Profiles

It is common practice to fly a profile in opposite directions to check for heading errors (i.e., errors due to aircraft body metal and eddy currents). A reversed profile is also very useful for determining the correct distance between the camera field of view and the sensor location (figure 2). In a towed bird system the location of the magnetic field measurement may be 30 m or more behind the center point of the field of view. Not only is there a spatial separation between camera and sensor, there is usually a time separation. In our system the magnetic measurement pulse triggers the camera which then fires 120 milliseconds later. This time delay adds 8 m to the actual spatial separation between the field of view and sensor for an aircraft velocity of 240 km/hr. Figure 3 exhibits a method for determining the true distance between fiducial point location and sensor location. The root-mean-square (rms) of the difference in magnetic field between reversed profiles is calculated for a series of distance increments (shifts) added to the along-flight coordinates of one of the profiles. If the latitude-longitude assignments for the profiles flown in opposite directions are correct, then the rms difference should be a minimum for zero relative shift. The plot in figure 3 is from the first reversed profile flown in Kansas, and revealed an error of approximately 55 m in our latitude-longitude assignment algorithm. Comparison of reversed profiles also gives us a feel for how well a particular profile can be reproduced. In this example the original profile was reproduced to within 8 nT RMS. The reversed profile was corrected for a 4.5 nT/hour diurnal drift, which was determined by least squares comparison to the original profile. The rms minimum for the profiles, with no drift correction applied, was 12 nT, but yielded approximately the same minimum position of -55 m.

In theory, the position of the towed bird, relative to the aircraft, is velocity dependent. For our typical aircraft ground speeds ranging between 210 km/hr and 270 km/hr, the change in horizontal distance between the bird and aircraft appears to be only a few meters.

This procedure could be applied to any aeromagnetic data set with reversed profiles. It is an important test of flight path recovery procedures and should be a requirement for all aeromagnetic surveys.

Temporal Variation Corrections

The KGS uses a relatively simple method of correcting for temporal variation in the magnetic field which does not require the use of a base station. The underlying assumption is that the magnetic field variation during flight is a smoothly varying low order polynomial in time. The polynomial coefficients are determined by minimizing tie line-flight line intersection residuals using least squares. The details of this approach have been presented elsewhere (Yarger, et al., 1978) and will not be reproduced here. Additional experience with this method has dictated a few procedural changes which are incorporated in the following discussion.

The procedure begins by first applying a zero order correction to all tie lines, then to all flight lines. This is referred to as zero order/zero order (0/0) leveling and is simply a DC level shift in the magnetic field applied to each flight and tie line. Before further least squares adjustment, the intersection residuals were "corrected" by searching for the minimum intersection residual within a 150 m radius (the estimated uncertainty in the flight path mapping procedure) from the originally mapped intersection location. This procedure, which we call roving the intersection, is particularly effective for the horizontal magnetic field gradients of $\geq$30 nT/km. Intersections located in areas of smaller gradients will often find a minimum at the limit of the search radius. This usually does not represent a true minimum, but is a result of slight level differences between tie lines and flight lines. We follow the rule of thumb that a minimum residual must occur at a radius less than the maximum search radius, otherwise the unroved intersection residual is used. Roving replaces the earlier procedure of ignoring large residuals in high gradient areas (Yarger, et al., 1978).

At this point, rms residuals for each line are calculated for all orders in time up to fifth order. The maximum order required for each line is chosen as the smallest order above which there is no significant decrease (greater than one nT) in the rms residual for the line. The maximum order required for individual lines generally ranges from zero to fifth order.

Table 1 summarizes the results of applying this temporal variation correction procedure to three data sets that were flown and reduced independently. The western Kansas data was acquired along 350 km east-west flight lines spaced 3.2 km apart (figure 4). The Arkansas Survey covered an irregularly shaped area (figure 5) with east-west flight lines spaced 1.6 km apart. Application of 0/0 leveling reduced the original residuals, which ranged from 25 to 87 nT, to a range of 9 to 12 nT. Roving reduced the residuals to approximately 6 nT. Higher order fits further reduced the residuals to 3 nT. It is clear that a large portion of the original rms residuals is due to level differences between lines. For some regional analyses of aeromagnetic data, a 0/0 leveling scheme (or other equivalent leveling scheme) is probably sufficient. This procedure can also be extended beyond fifth order to achieve smaller residuals, if desired.

Although no base station data were available, several tests of this procedure demonstrate that the higher order terms are related to actual magnetic field temporal variations. Probably the most convincing example is the plot appearing in Figure 6 for a data set in northeastern Kansas consisting of 345 intersections. The k index is designed to measure temporal variations in the magnetic field (Lincoln, 1967). The value of k depends on the difference between the highest and lowest deviation from a smooth diurnal variation within a three hour period. Higher k values imply more amplitude variation or higher frequency content in the temporal variations. The least squares drift determinations are consistent with this. The percentage of flight lines requiring more than a first order fit is roughly proportional to the k index (Figure 6).

Gridding

Gridded aeromagnetic data should measure, when possible, the true gradients along the measured flight lines. The graphics system software SURFACE II (Sampson, 1978) provides close monitoring of this problem by using the ERANALYSIS option. However, both gridding programs we tried, SURFACE II and Calcomp, tended to subdue steep horizontal gradients. We finally settled on a gridding procedure for Kansas that takes advantage of the very regular flight pattern (Figure 4).

The locations of the grid nodes, 160 meter spacing east-west by 3200 m north-south, was determined by requiring a minimum rms residual in the north-south difference between the flight line coordinates and the grid coordinates. The resulting rms residual was approximately 225 m which is about twice the uncertainty of the flight path coordinates. In other words, the nearly regular flight grid was rectified to an exact grid and was achieved by translating the measurement location an average of 225 m in the north-south direction. This method preserves exactly the along flight horizontal gradients, but introduces small systematic errors in the north-south coordinates. This procedure would be applicable to any survey done with very regularly spaced flight lines.

Maps

Black and white variable gray level maps (or density maps) provide a fast and inexpensive look at the data. The traditional contour map is appropriate and desirable for formal publications, but is a relatively expensive and time consuming process. Using the PCONTOUR option in SURFACE II, density maps are generated by the KGS on a Decwriter IV terminal connected to a Data General MV/8000 minicomputer. The quickly generated density maps greatly facilitate the determination of optimum filter parameters. The turn-around time for performing a filtering operation on a 216 by 216 grid and printing the resulting filtered map is approximately one hour. Density maps of the unfiltered Kansas aeromagnetic map and of a high frequency-pass filtered map are exhibited in figures 7 and 8. These are photo-reductions of variable density maps printed on standard computer output paper.

Conclusions

The accuracy of flight path mapping can be easily tested during original processing, but also "after the fact" for existing aeromagnetic data sets. Incorrectly mapped points along the flight path appear as discontinuities on a calculated airplane velocity profile. Comparison of profiles flown in opposite directions reveals systematic errors in the flight path recovery procedure. A least squares approach, which does not require base station data, can be applied to tie line-flight line intersections to determine temporal magnetic corrections. Any gridding procedure used should provide information on how well the original data is honored. Printer generated variable density maps provide a quick and inexpense alternative to traditional contour maps.

Acknowledgements

Alan Martin provided excellent assistance in compiling some of the information for this report.

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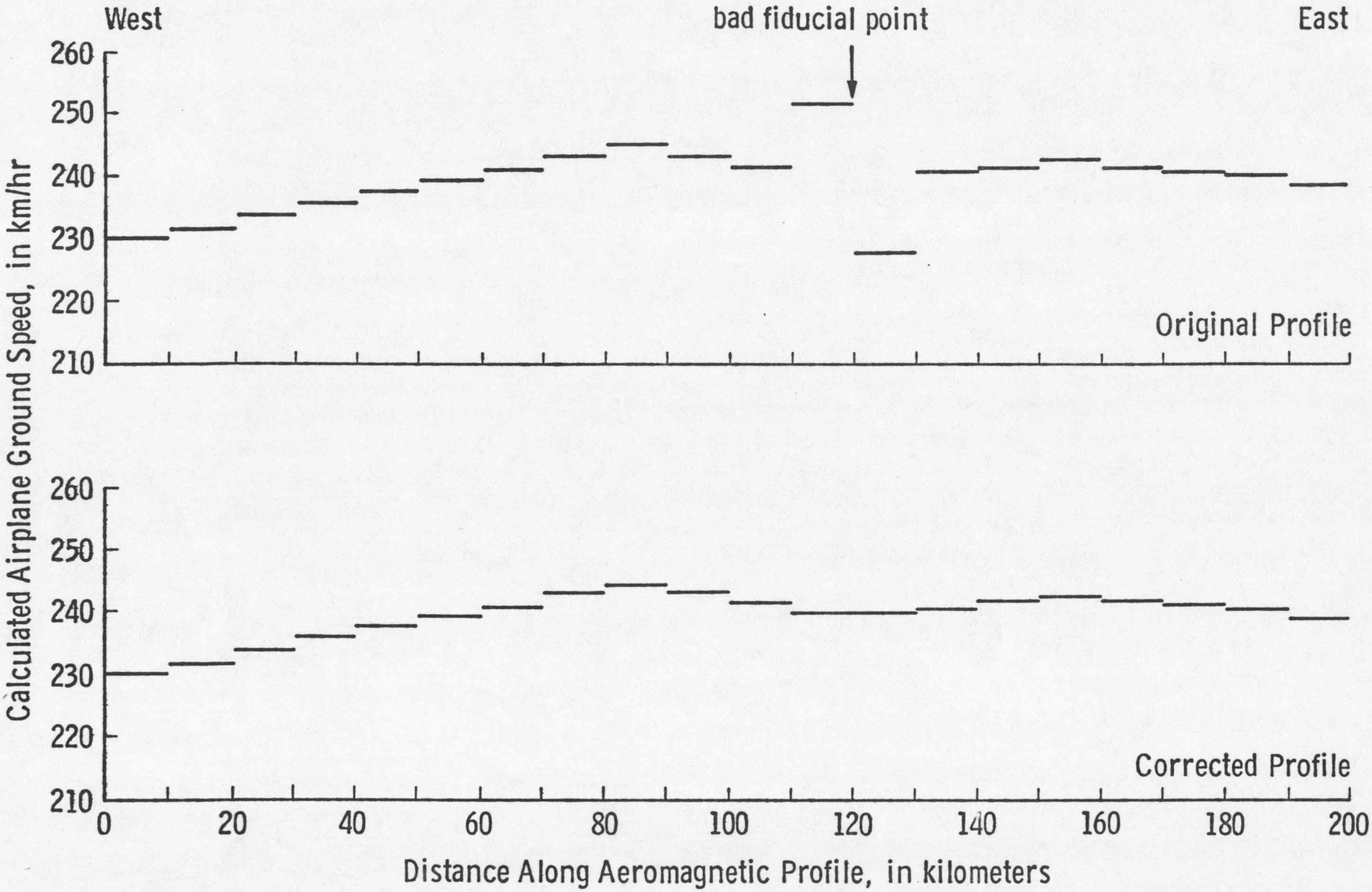
RMS	S.W. KANSAS 553 INTERSECTIONS	N.W. KANSAS 556 INTERSECTIONS	S.E. ARKANSAS 709 INTERSECTIONS
Original	37.2	87.5	24.6
add 0/0 leveling	12.3	11.6	8.6
add roving	6.1	5.9	--
add 5/5 fit	2.5	3.1	3.0

Table 1. Tie line-flight line intersections residuals in nanoteslas

Figure Captions

1. Generalized airplane velocity profile with fiducial points mapped every 10 km. A mapping error of 500 meters to the east causes velocity discontinuity at locations 110, 120 and 130 km's on the upper graph. The smoothly varying velocity profile on lower graph is obtained after correcting the bad fiducial point at the 120 km location.
2. Distance between camera field of view and sensor. Analyses of the same aeromagnetic profile flown in opposite directions will determine the correct distance.
3. Root-mean-square of the difference in magnetic field between reversed 320 km aeromagnetic profiles in eastern Kansas. A systematic error in flight path mapping is revealed because the minimum does not occur at zero relative shift.
4. Flight path map for Kansas aeromagnetic survey; flight paths are approximately 350 km long in both eastern and western Kansas. They overlap somewhat in central Kansas.
5. Flight path map for southeastern Arkansas aeromagnetic survey.
6. Percentage of flight lines requiring more than a first order polynomial drift correction versus the magnetic k index. Based on 345 intersections in northeastern Kansas.
7. Aeromagnetic map of Kansas. Photo reduction of variable density map generated by SURFACE II and printed on a Decwriter IV terminal.
8. High frequency pass-filtered map of Kansas aeromagnetic data generated by SURFACE II and printed on a Decwriter IV terminal. The continuous black line outlines a zone of low amplitude which corresponds to non-magnetic Precambrian sediments.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bad fiducial point
East
260
250
240
230
220
210
Original Profile
260
250
240
230
220
210
Corrected Profile
Calculated Airplane Ground Speed, in km/hr
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20
40
60
80
100
120
140
160
180
200
Distance Along Aeromagnetic Profile, in kilometers

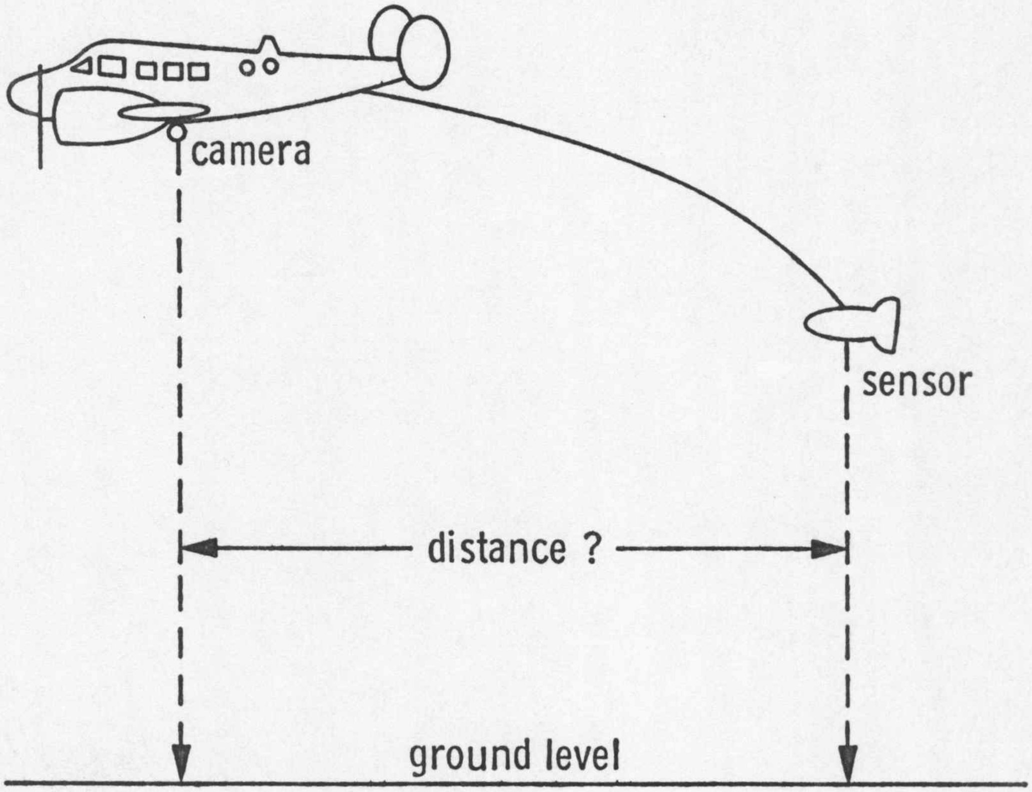

Fig. 2

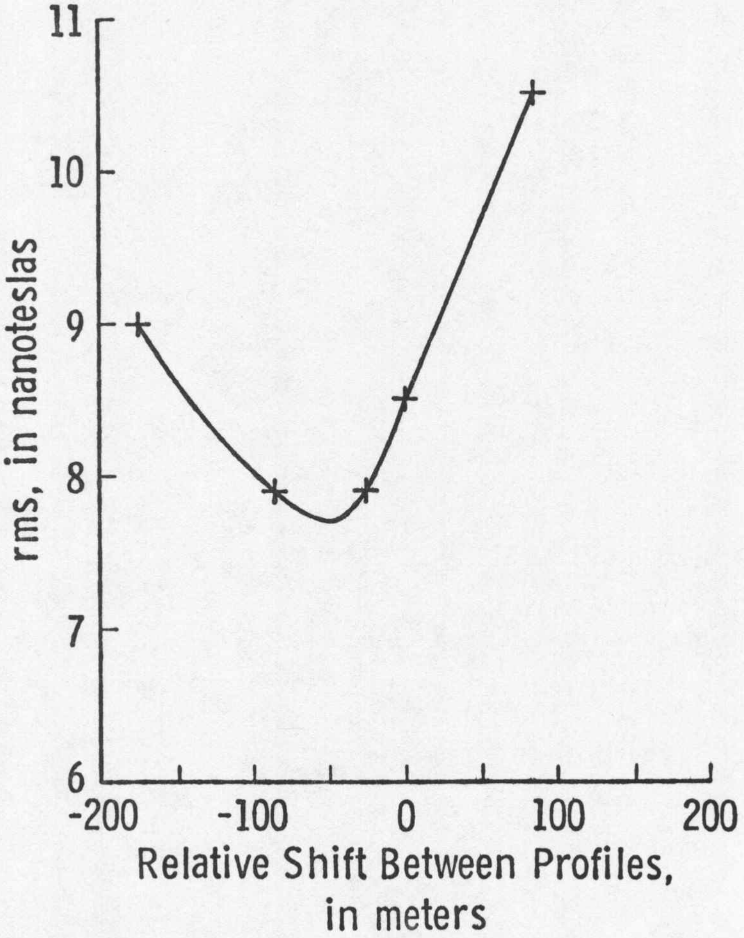
11
10
9
8
7
6
rms, in nanoteslas
-200
-100
0
100
200
Relative Shift Between Profiles,
in meters

Fig. 3

FLIGHT PATHS FOR AEROMAGNETIC MAP OF KANSAS

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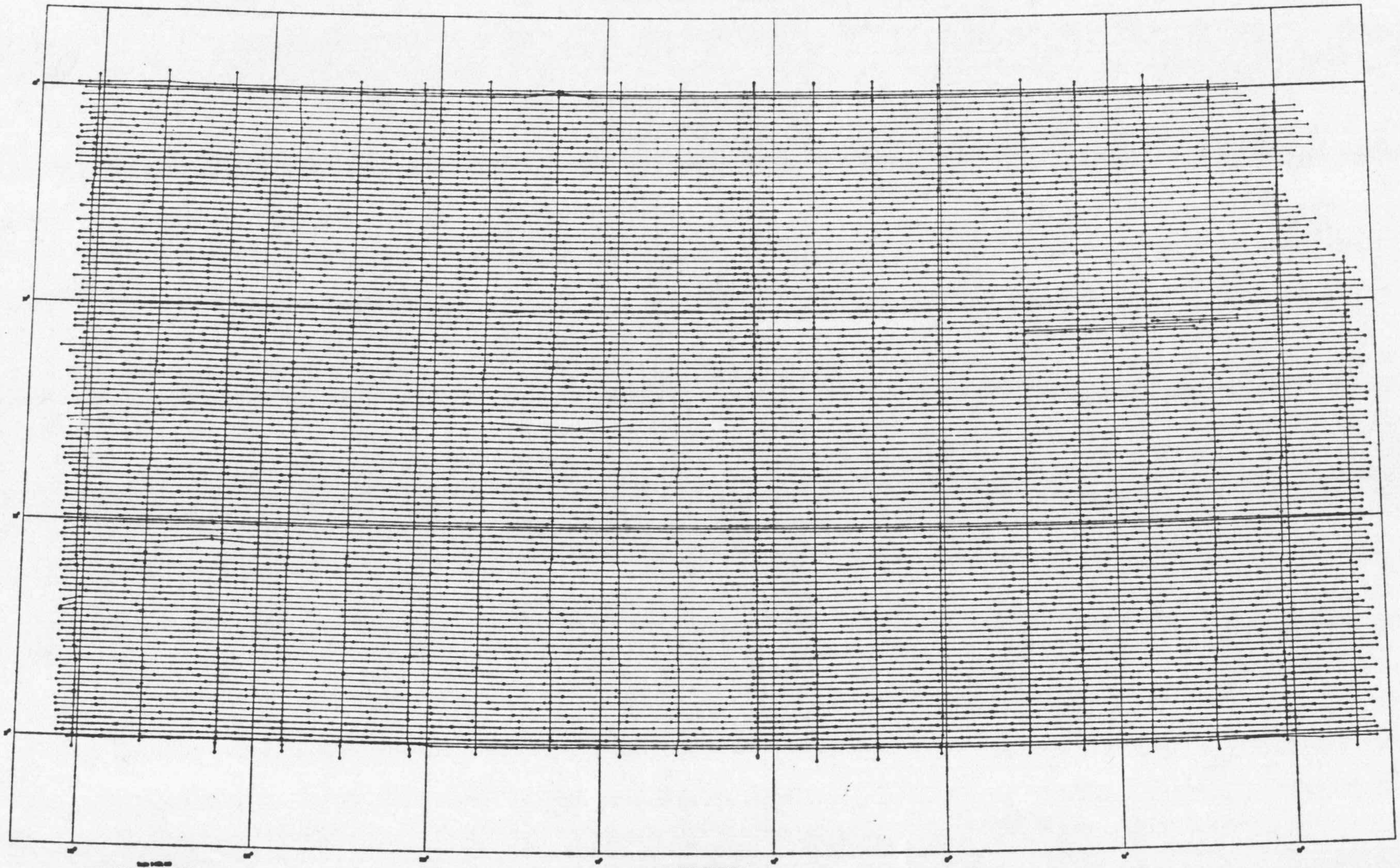
OPEN FILE SEPT. 1, 1980



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Further information [illegible]

Publications Sales
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[illegible] Avenue "A", Campus West
Lawrence, Kansas [illegible]

Lambert Conformal Conic Projection
Standard Parallels [illegible]
Flown during [illegible]
Flight lines flown east-west with two mile spacing.
Tie lines flown north-south with twenty mile spacing.

Supported principally by the Kansas Geological Survey. Supported, in part, by Special Appropriation from the Kansas Legislature for an Automated Resource Evaluation System, by the U. S. Geological Survey, Department of the Interior, under U. S. G. S. Grant No. [illegible], by the U. S. Nuclear Regulatory Commission under Contract No. [illegible], and by the Department of Energy under Grant No. [illegible].

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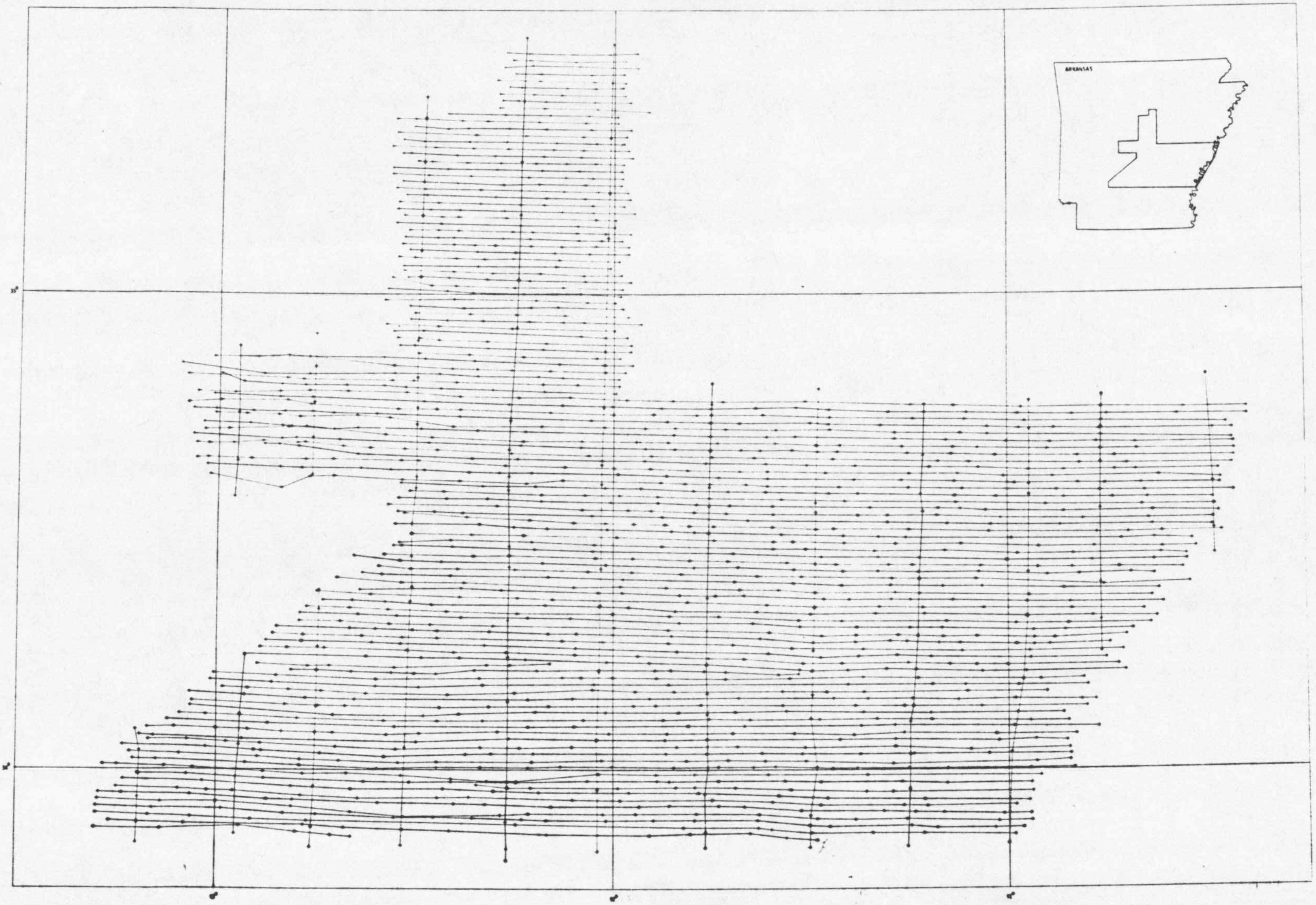
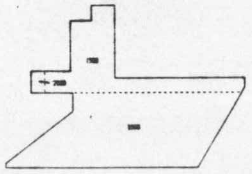
AEROMAGNETIC FLIGHT PATHS IN SOUTHEASTERN ARKANSAS



Index Map

Flight Elevation In Feet Above Sea Level



Lambert Conformal Conic Projection
Standard Parallels 33° And 45°

Aeromagnetic Survey Flown And Compiled By
H. Yarger, A. Martin, R. Sealey, And K. Ng
Kansas Geological Survey
The University Of Kansas - Campus West
Lawrence, Ks. 66045

For Norman L. Williams
Arkansas Geological Commission
Vardelle Parham Geological Center
3815 West Roosevelt Road
Little Rock, Arkansas 72204
Under State Of Arkansas Contract # [illegible]

Scale 1:250,000
1 Inch Equals Approximately 4 Miles
5 0 5 10 Miles
5 0 5 10 15 Kilometers

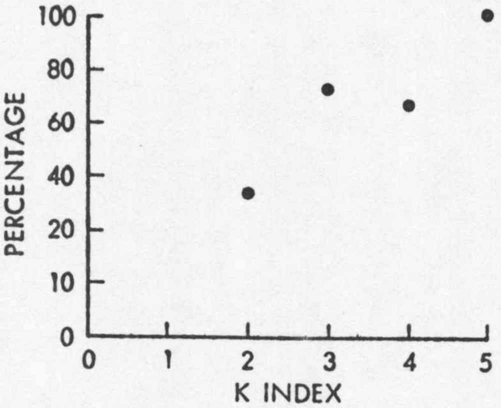


Fig. 6

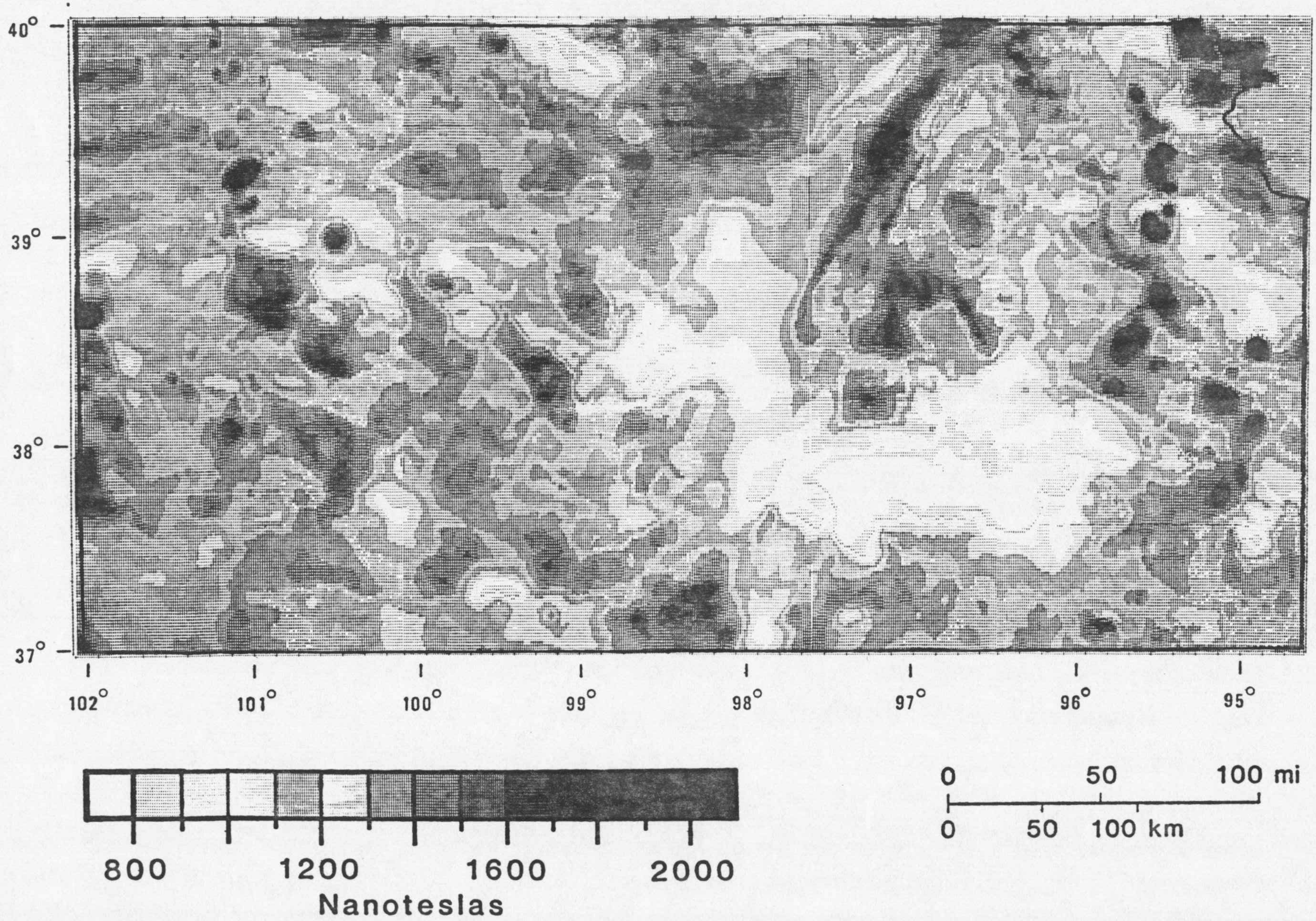

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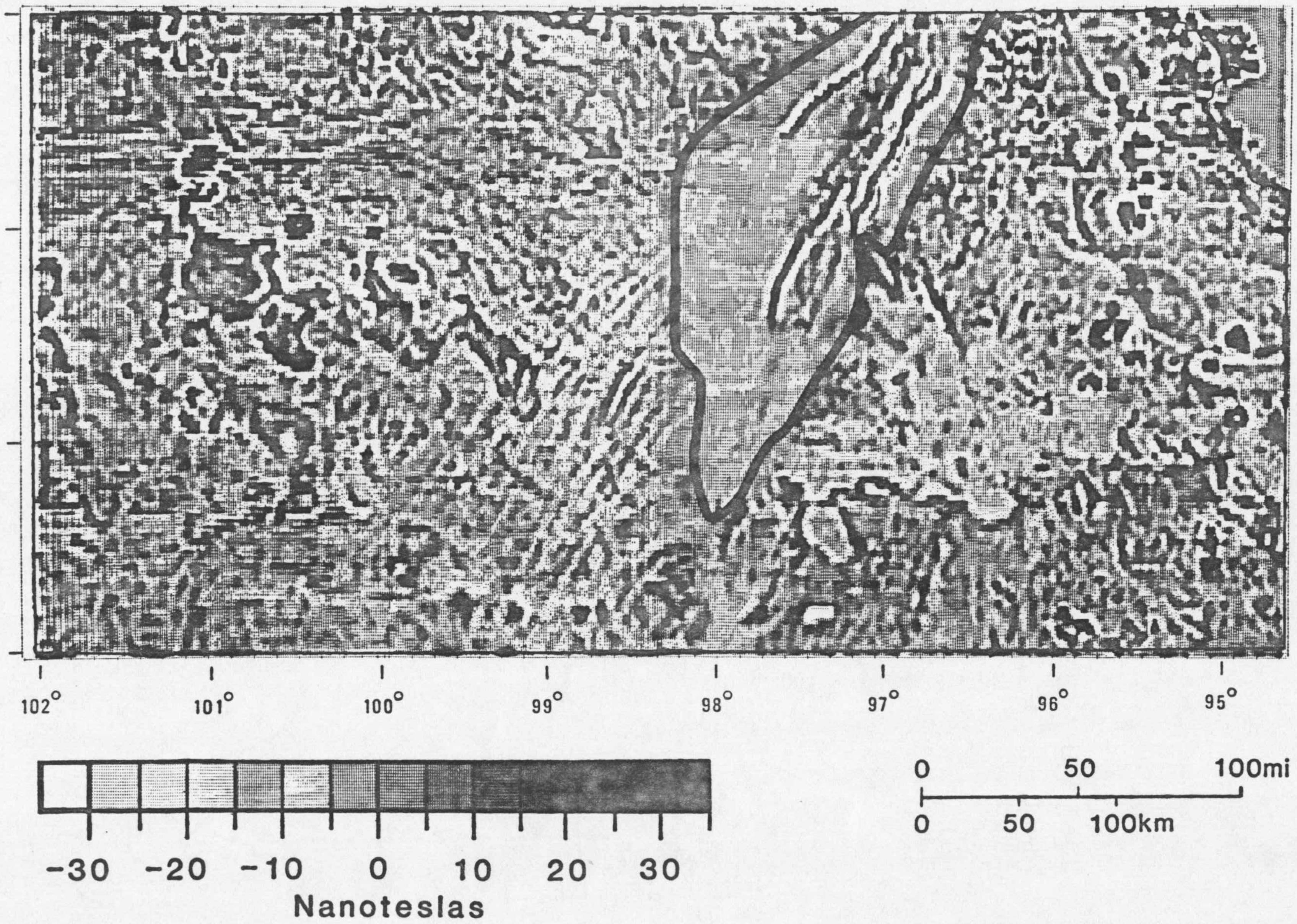
Fig. 7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