USGS-OFR--82-932

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Aeromagnetic measurements in the Cascade Range and Modoc Plateau of northern California -- Report on work done from June 1, 1980, to November 30, 1980

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Open-File Report 82-932

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Project Information

This report was prepared under Grant No. 14-08-0001-G-623 to Oregon State University from the U.S. Geological Survey's Geothermal Research Program, with Dr. Richard Couch of the School of Oceanography as the Principal Investigator. The period of the grant was from June 1, 1979, to October 31, 1981. Objectives of the grant were as follows: (1) To obtain high-quality aeromagnetic data over a 30,000-square-kilometer area in the Cascades and Modoc Plateau of northern California and (2) to analyze the data in terms of structure, volcanic centers, regional trends, Curie-temperature isotherm depths, and the implications concerning the geothermal energy potential of the area. The data obtained during the course of this project and described in this report are on file in the National Geophysical Data Center (NGDC) of NOAA in Boulder, CO.

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Abstract

Aeromagnetic measurements made along flightlines oriented east-west and spaced at 1.6-km intervals and along lines oriented north-south and spaced at 8-km intervals, over approximately 30,000 square km of northern California, exhibit crossing errors of less than 5 nanoTeslas. The measurements show short-wavelength magnetic anomalies associated with near-surface volcanics over and east of Lassen Peak and over and north of Mt. Shasta and the Medicine Lake Highlands, longer wavelength anomalies over the Modoc Plateau, and very long wavelength anomalies over the northernmost part of the Great Valley and the easternmost metamorphic rocks of the Klamath Mountains. Anomaly patterns exhibit northwest-southeast trends over the Modoc Plateau and a marked change in character at the juncture of the plateau and the Klamath Mountain and Great Valley complexes.

Research Objective

Figure 1 outlines an area of approximately 30,000 square kilometers that extends from the Oregon-California border at 42° N. latitude to south of Lassen Pk. at 40°15' N. latitude and approximately between 121°45' and 122°45' W. longitude. This area encompasses the southern Cascade Mountain Range, the adjoining Modoc Plateau including the Medicine Lake Highlands, and the northern terminus of the Great Valley, and the easternmost flank of the Klamath Mountains. The objectives of this study are: to obtain precise aeromagnetic measurements in the region; to delineate the magnetic anomalies associated with the Cascade Range and the transition region between the Cascade Range and the basin and range structures east of the Cascades; to determine the depths to the magnetic sources; and to estimate the depths of the Curie-point isotherm in the region. These analyses will assist in the geologic and tectonic interpretation of the region and provide data to help assess the geothermal resource potential of the region. This report describes the location and accuracy of the aeromagnetic measurements, and briefly describes the observed total-field magnetic anomalies.

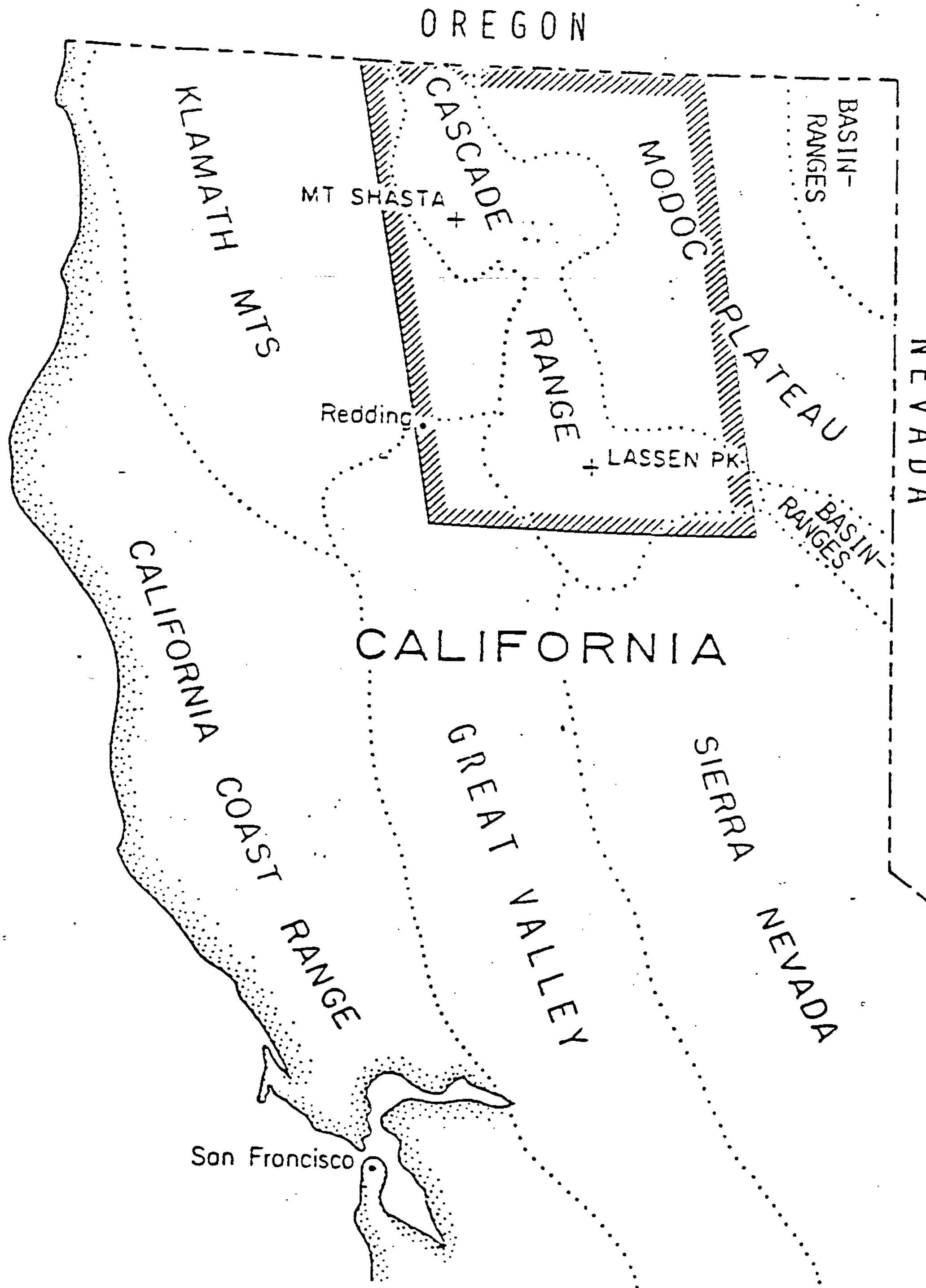
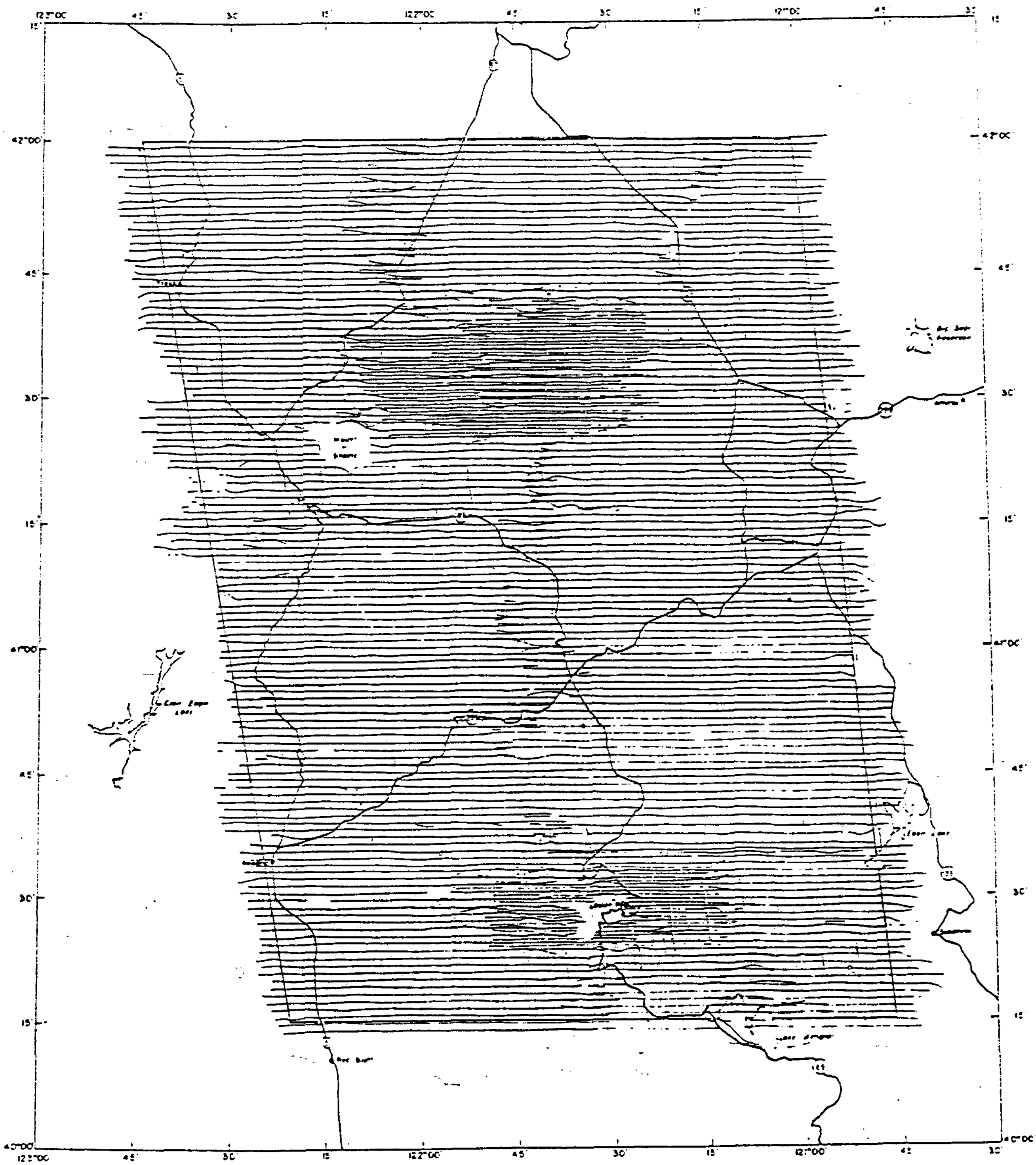


Figure 1. Northern California physiographic provinces and aeromagnetic survey location (outlined by shading).

Aeromagnetic Measurements

During June, July, and August 1980, magnetic measurements were made over northern California in the area between 40°15' and 42° N. latitude and 120°45' and 122°45' W. longitude. Figure 1 outlines the aeromagnetic survey area, and figures 2, 3, and 4 show the flightlines along which over 25,000 km of aeromagnetic data were obtained. The measurements were made with a twin-engined Piper Aztec aircraft flying at approximately 240 km/hr (150 mph). A 2-second data sample rate yielded a data point spacing, along the flight lines, of approximately 130 meters. The survey yielded over 200,000 measurements of the Earth's magnetic field at accurately located positions.

Figure 3 shows the flightlines at 2,740 meters (9,000 feet) altitude above sea level (ASL) over the survey area. East-west lines spaced at 1-mile (1.6-km) intervals and north-south lines spaced at 5-mile (8 - km) intervals were flown over the entire area. In addition, 0.5-mile (0.8-km) spaced east-west lines were flown over the Medicine Lake Highlands east of Mt. Shasta and in the Lassen Peak area in the southern part of the survey area. East-west lines spaced 0.5 mile (0.8 km) apart were also flown over the summit area of Lassen Peak at 3,353 meters (11,000 feet) altitude. Figure 3 shows these lines. Figure 4 shows lines flown at 4,527 meters (15,000 feet) over the summit of Mt. Shasta. These lines were spaced 0.5 mile (0.8 km) apart. The higher density of data in these areas of current interest should allow for a more detailed analysis of these areas in future studies.

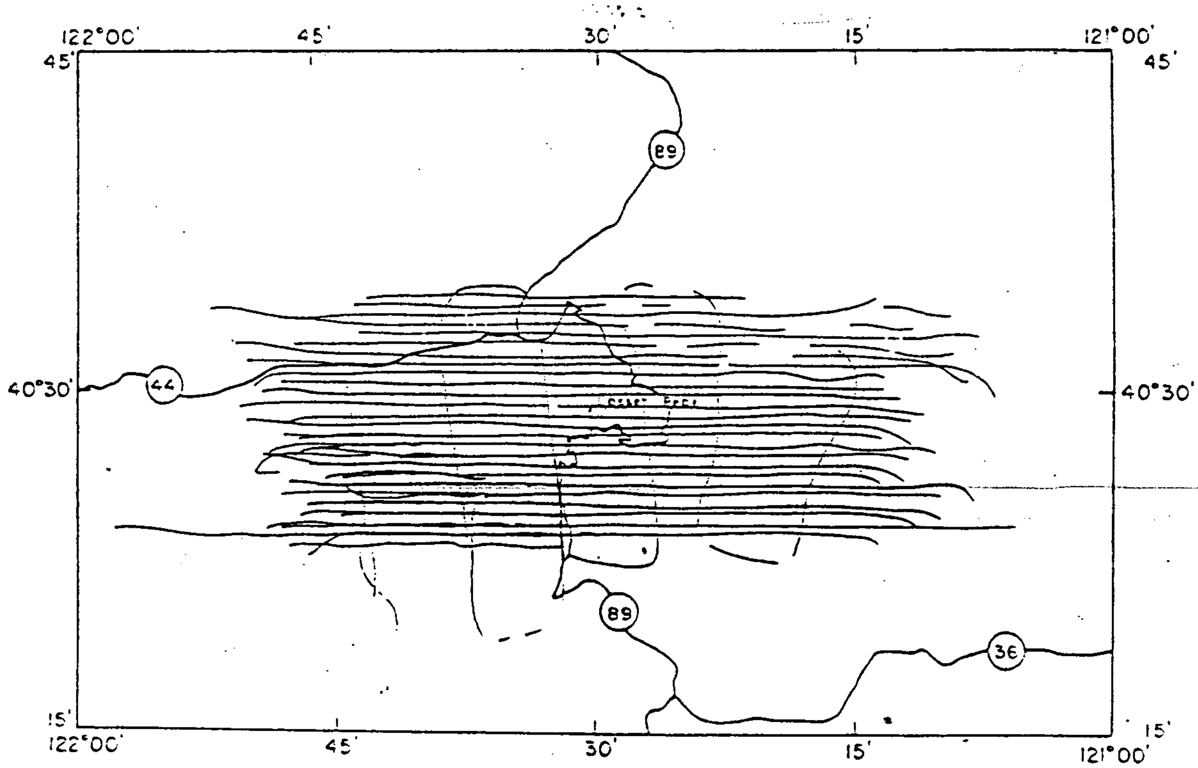


CALIFORNIA CASCADES AEROMAGNETIC FLIGHT LINES

FLIGHT ELEVATION 9000 FEET

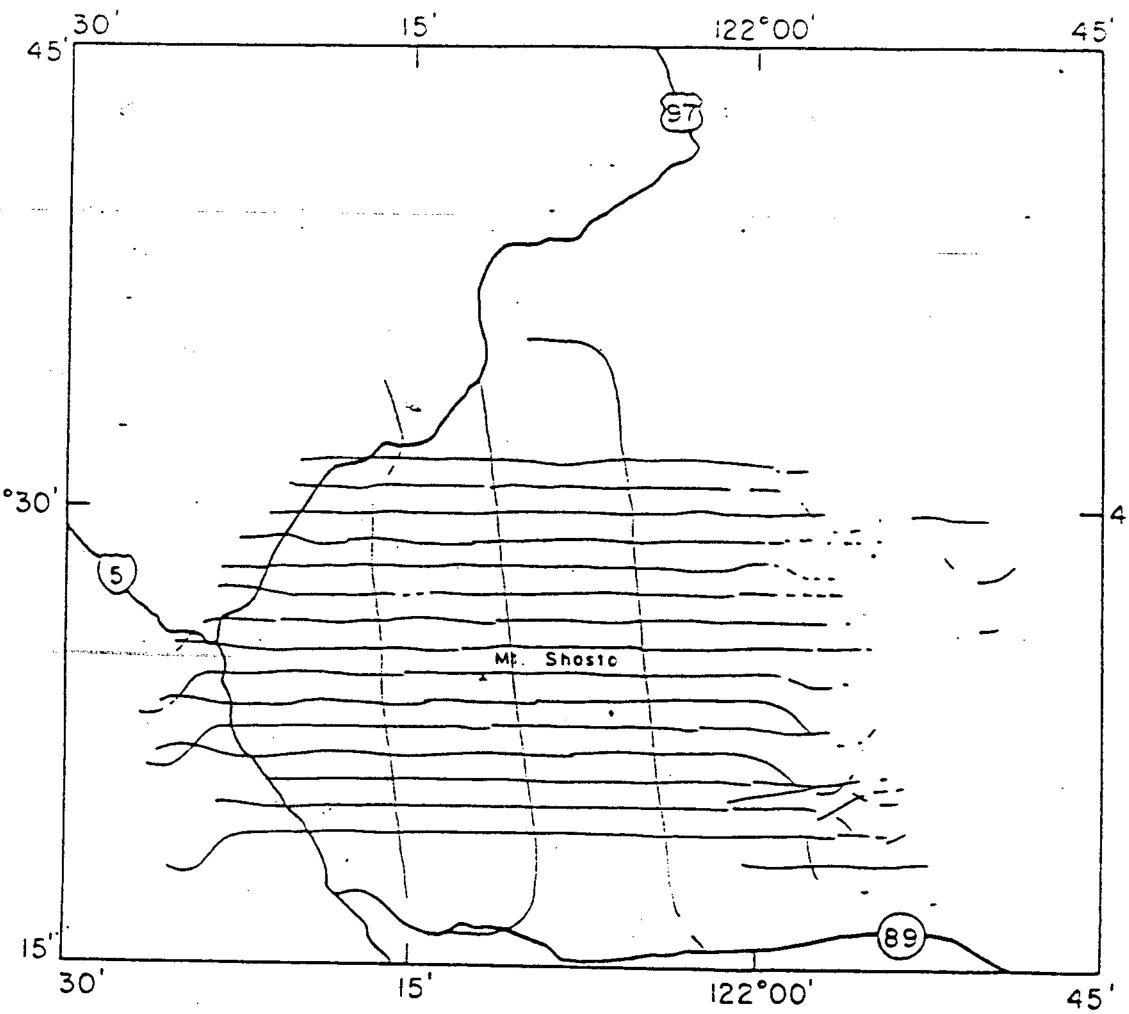
OREGON STATE UNIVERSITY, NOVEMBER 1980

Figure 2



LASSEN PK.
AEROMAGNETIC FLIGHT LINES
FLIGHT ELEVATION 11,000 FEET
OREGON STATE UNIVERSITY, NOVEMBER 1980

Figure 3.



MT. SHASTA
AEROMAGNETIC FLIGHT LINES
FLIGHT ELEVATION 15,000 FEET
OREGON STATE UNIVERSITY, NOVEMBER 1980

Figure 4.

Data Processing and Magnetic-Anomaly-Map Preparation

Field processing of the aircraft acquisition system data consisted of reading and checking the field tapes for data errors, converting altitudes to feet and filling in any missing altitude data by linear interpolation, and making plots of magnetic measurements and radar pressure altimeter readings. Field processing of base station data included checks for time-sequence or data errors, plots of magnetic and pressure altitude variations, and smoothing both altitude and magnetic data with a five-point moving average filter. The filtered base-station data supplied diurnal pressure altitude and magnetic variation corrections for the flight data. The magnetic and altimetric data from each flight were plotted in profile form to further check for errors. Finally the base reference value of 53,113 nanoTeslas (nT) was subtracted from each magnetic reading to form a diurnal variation correction for the magnetic measurements taken in the aircraft. Subsequently all the data were processed to make the data tapes compatible with the Eclipse system at Oregon State University (OSU).

At OSU the aircraft data and base-station data from each flight were merged. The navigation ranges were converted to State Plane Coordinates (California North zone) and subsequently to latitude and longitude for each magnetic reading. Data points missing navigation points were located by interpolation. Finally, magnetic-anomaly values were calculated, using the equation:

$$A(x,y) = M(x,y,t) - D(t) - R(x,y)$$

where A is the anomaly value, M is the measured value of the total magnetic field at time t, D is the diurnal variation at time t, and R is the regional magnetic field. The regional magnetic field R was determined from the International Geomagnetic Reference Field of 1975 (International Association of Geomagnetism and Aeronomy, 1976) updated to the survey time and then modified to allow anomaly values in this survey to match anomaly values in the survey adjacent to the northern boundary (McLain, 1981; R. Couch and M. Gemperle, 1981, unpub. data).

The following equations give the regional field values in nT used in this survey:

$$\text{Regional (9000 ft ASL)} = 50{,}166.083 + (1.03900598 \times 10^{-3})(x) - (0.473232 \times 10^{-10})(x^2) + (1.57310835 \times 10^{-3})(y) - (0.575790 \times 10^{-10})(y^2)$$

$$\text{Regional (11000 ft ASL)} = 50{,}394.592 + (0.830215 \times 10^{-3})(x) + (1.52514 \times 10^{-3})(y)$$

$$\text{Regional (15000 ft ASL)} = 50{,}338.478 + (0.855628 \times 10^{-3})(x) + (1.47816 \times 10^{-3})(y)$$

where x and y are in State Plane Coordinates.

A simple statistical analysis of the differences at survey flightline crossings yielded an estimate of the RMS (root mean square) uncertainty of the final magnetic-anomaly values. Figures 5, 6, and 7 each show a graph of the crossing errors for the 9000; 11000-and 15000-ft ASL surveys, respectively. Tables 1, 2, and 3 list the corresponding statistics. The RMS uncertainty per line attributes one-half of the mistie to each of the flightlines used in calculating the uncertainty, i.e.,

$$\text{RMS uncertainty per line} = \text{RMS mistie}/\sqrt{2}.$$

The RMS uncertainties per line for these surveys are 4.7, 4.0, and 1.3 nT, respectively. These low values reflect the excellent navigation control and the careful monitoring of the diurnal changes. Estimates of the components of the uncertainty are:

1nT	resolution of the airborne magnetometer
1nT	resolution of the base-station magnetometer
1-2nT	diurnal correction
1-2nT	x-y position determination in low-gradient areas
1-2nT	z position determination in low-gradient areas.

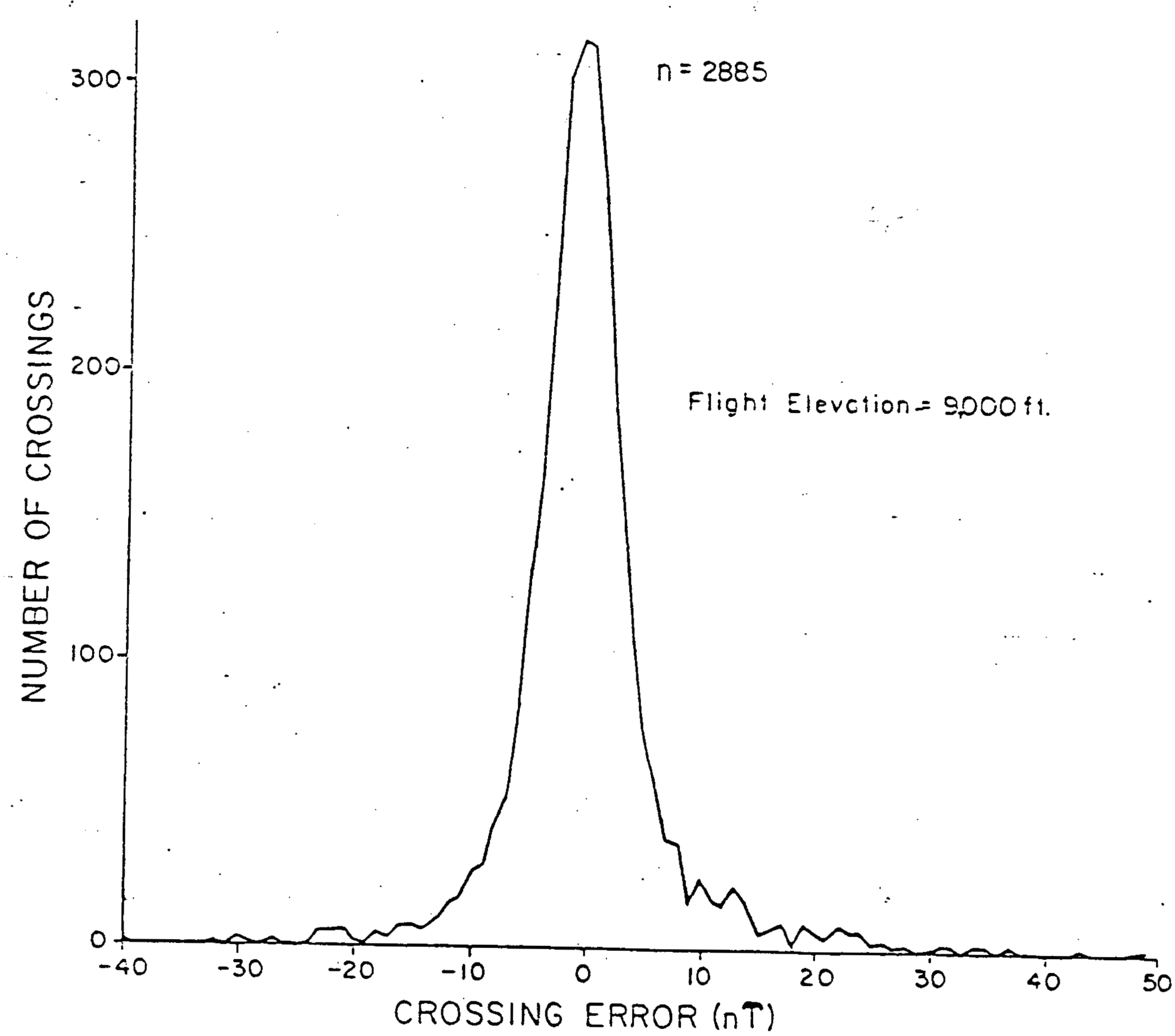


Figure 5.

Graph of 2,885 crossing errors calculated for the northern California 9,000-foot ASL aeromagnetic survey.

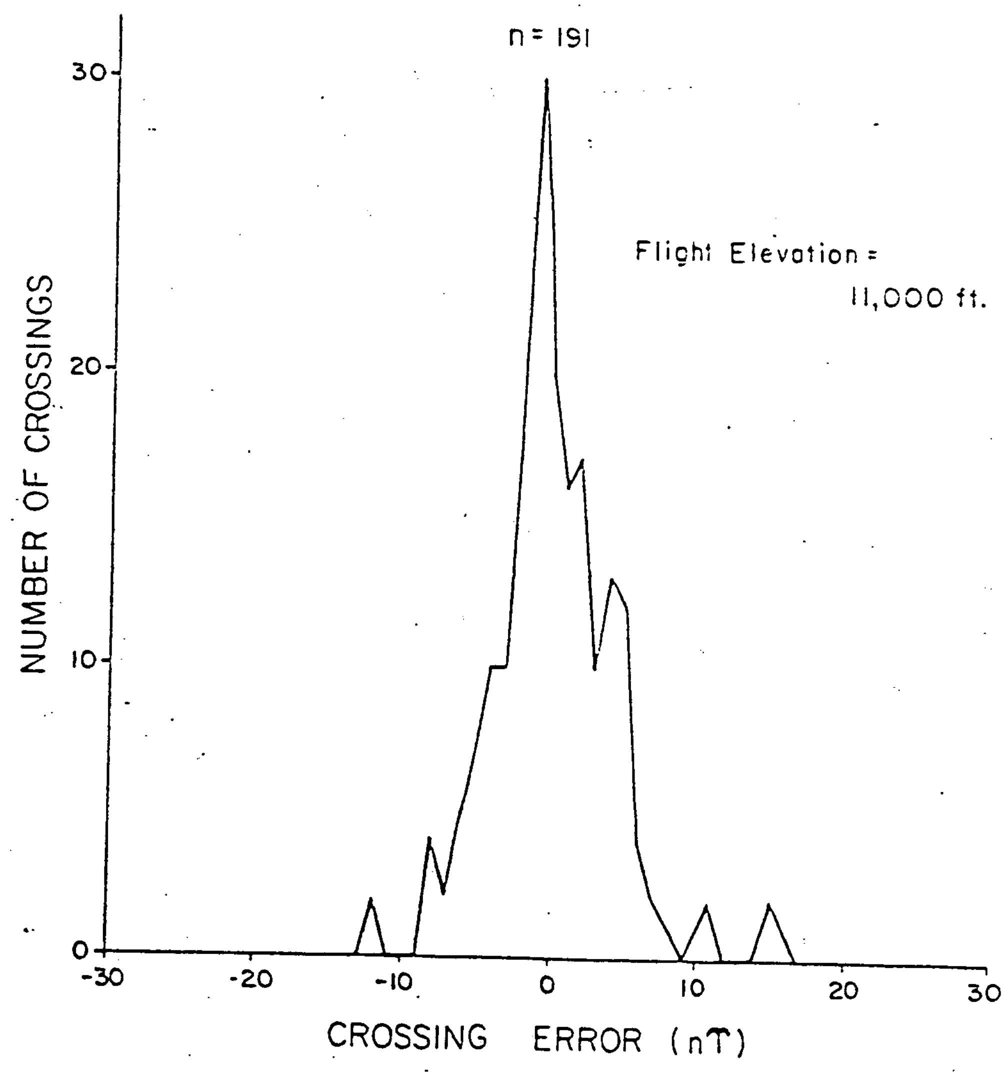


Figure 6.

Graph of 191 crossing errors calculated for the Lassen Peak 11,000-foot ASL aeromagnetic survey.

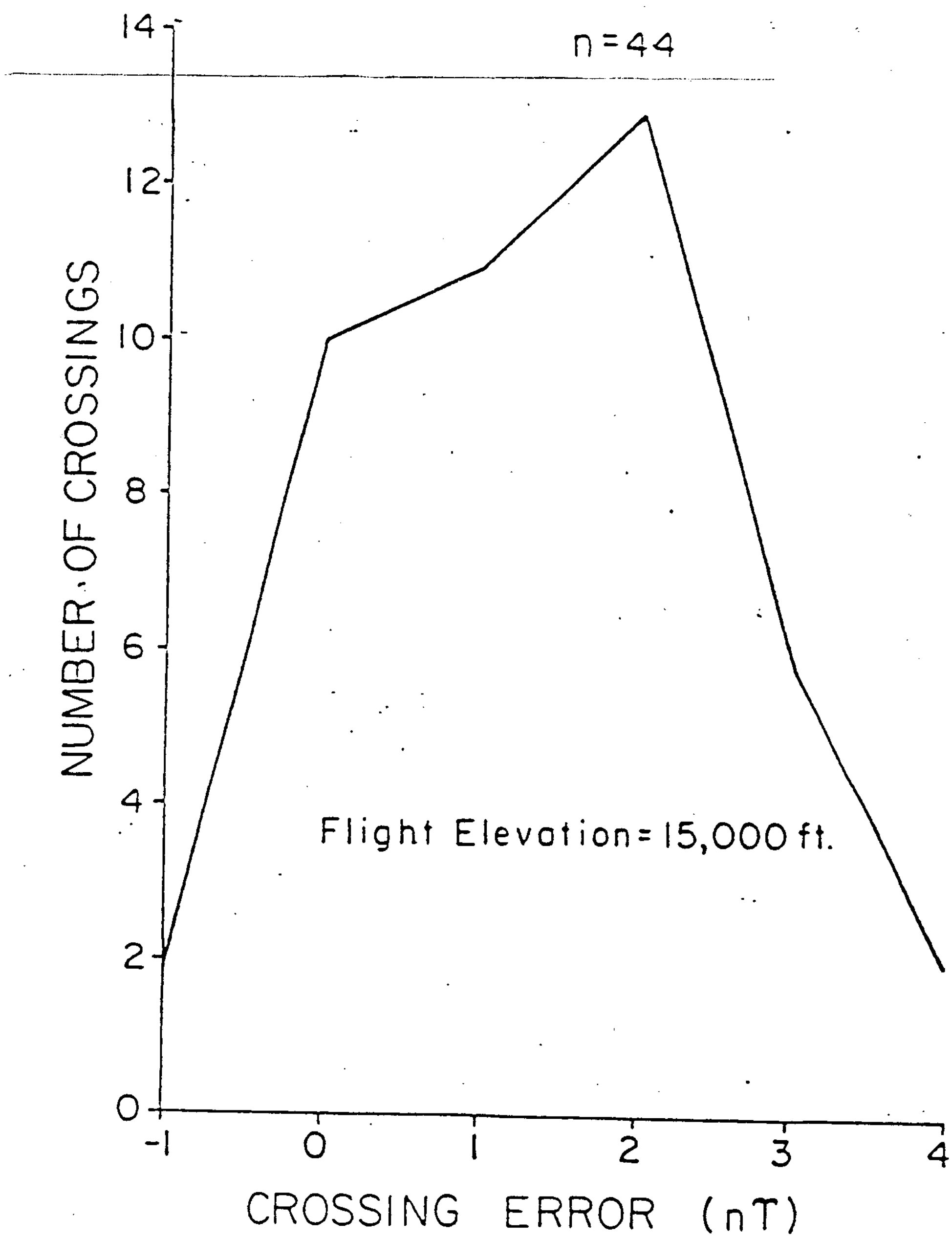


Figure 7.

Graph of 44 crossing errors calculated for the Mt. Shasta 15,000-foot ASL aeromagnetic survey.

Table 1. Northern California 9,000 ft ASL survey crossing error statistics.

Total Crossings	2885
Mean	0 nT
Median	-1 nT
Mode	-1 nT
RMS	6.6 nT
RMS uncertainty per line	4.7 nT

Table 2. Northern California 11,000 ft ASL survey crossing error statistics.

Total Crossings	191
Mean	0 nT
Median	0 nT
Mode	-1 nT
RMS	5.7 nT
RMS uncertainty per line	4.0 nT

Table 3. Northern California 15000 ft ASL survey crossing error statistics.

Total Crossings	44
Mean	1nT
Median	1nT
Mode	2nT
RMS	1.9 nT
RMS uncertainty per line	1.3 nT

Magnetic Anomalies of Northern California

Figure 8 shows a topographic map of the northern California aeromagnetic survey area.* The contour interval is 1,000 feet and heavy contours occur at 5,000 and 10,000 feet elevation. Mt. Shasta, 14,162 feet in elevation, near 41°15' N. lat. and 122°15' W. lon. rests on elevated terrane that extends east-northeastward and forms the Medicine Lake Highlands and northward towards the Oregon border along the axis of the Cascade Range. In the southwestern part of the survey area, the Sacramento River flows through Redding and into the north end of the Great Valley of California. Shasta Lake, between Redding and Mt. Shasta, occupies part of the dendritic drainage that flows southwestward from the highlands about and north and east of Mt. Shasta. The axis of the Cascade Range strikes approximately south-southeast just east of Mt. Shasta and through Lassen Pk. near 40°30' N. lat. and 121°30' W. long. The Modoc Plateau, with elevations generally between 4,000 and 5,000 feet, shows only relatively subdued relief with a general northwest-southwest orientation (Macdonald, 1966).

Paleozoic and Mesozoic sedimentary and volcanic rocks, in places strongly metamorphosed, form the deeply dissected structures of the Klamath Mountain complex between Redding and Mt. Shasta in the western part of the survey area. Granitic rocks, mainly of Mesozoic age, intrude the older sedimentary and volcanic rocks. Cenozoic volcanic rocks that form the Modoc Plateau overlap the older Klamath Mountain rocks immediately north and east of Mt. Shasta and west of Lassen Pk. Cenozoic continental sedimentary rocks and alluvial deposits of the

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* Figures 8 and 9 are available at 1:250,000 scale in U.S. Geological Survey Open-File Report 82-198 (Couch, 1982).

TOPOGRAPHIC MAP

CASCADE MOUNTAIN RANGE, NORTHERN CALIFORNIA

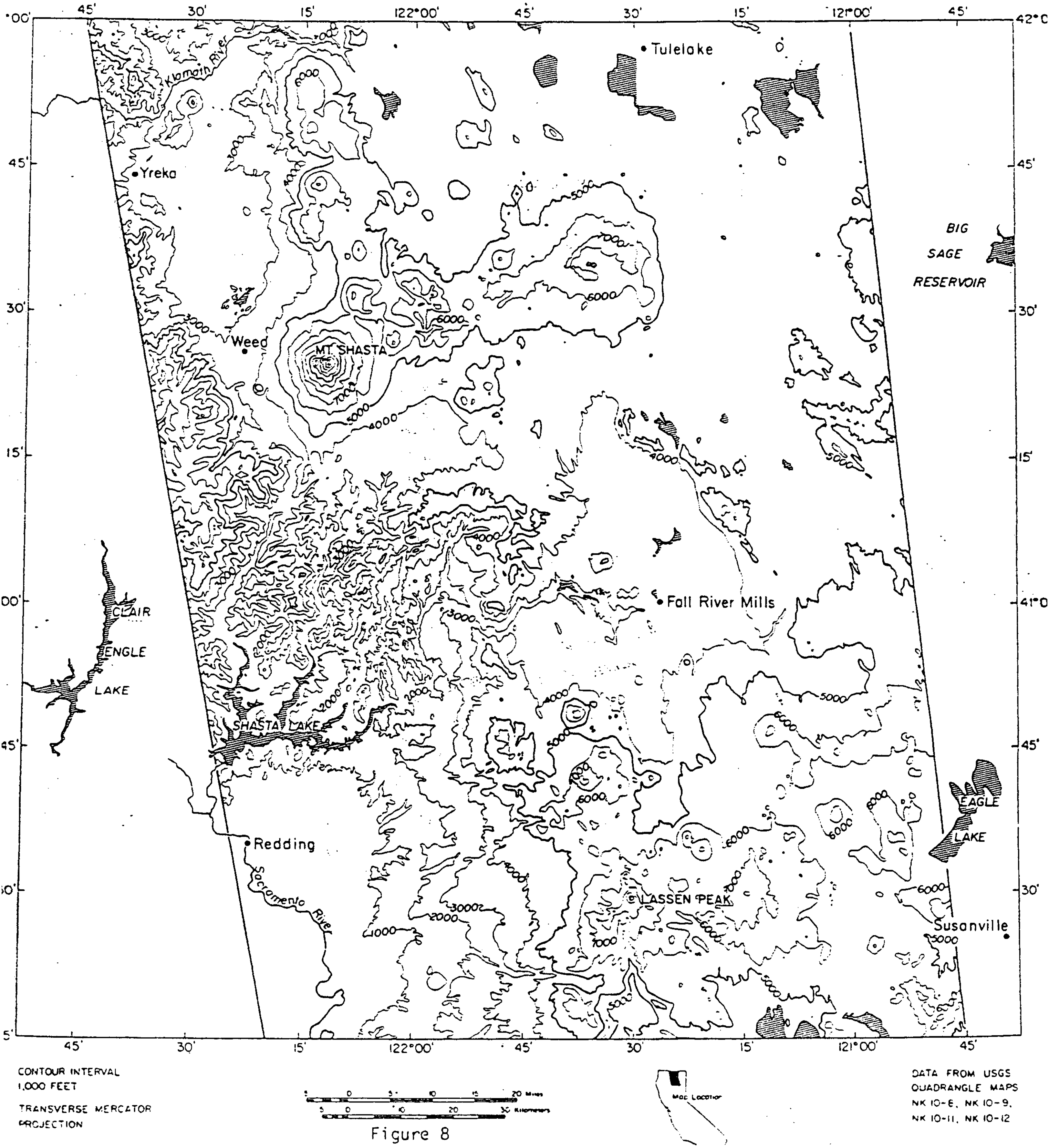


Figure 8

This map is available at 1:250,000 scale. See U.S. Geological Survey Open-File Report 82-198 (Couch, 1982).

Great-Valley overlap the Paleozoic and Mesozoic rocks of the Klamath Complex south of Redding, California. The old rocks of the Klamath belt dip eastward beneath the Modoc Plateau and the Great Valley and are thought to extend northeastward into Oregon and southeastward toward the Sierra Nevada (Irwin, 1966).

Figure 9 shows the total field magnetic-anomaly map of the northern California survey area. The contour interval is 100 nanoTeslas, and heavy contours occur at 500 nT intervals. Mt. Shasta and Lassen Pk. extend above the 9,000-foot flight elevation of the map and generate "holes" in the map. Figure 10 shows the magnetic-anomaly map of Lassen Pk. and the area immediately about Lassen Pk. based on measurements made at a flight elevation of 11,000 feet. The contour interval is 50 nT, and heavy contours occur at 0, ± 250, - 500 and, - 750 nT. Figure 11 shows the magnetic anomaly map of the Mt. Shasta area based on measurements at a flight elevation of 15,000 feet. The contour interval is 25 nT, and heavy contours occur at 0, ± 125, ± 250, and - 375 nT.

Two prominent circular positive anomalies occur in the vicinity of Mt. Shasta. The westernmost positive anomaly, with an amplitude greater than 175 nT, occurs near the peak of Mt. Shasta whereas the easternmost positive anomaly, with an amplitude greater than 325 nT, occurs over a secondary cone near the base of Mt. Shasta on the east side (fig. 1). The amplitude of this anomaly at the 9,000-foot flight elevation, as shown in figure 9, is greater than 2,300 nT.

A marked negative anomaly of less than 800 nT, as observed at 9,000 feet elevation, occurs immediately northeast of the large -

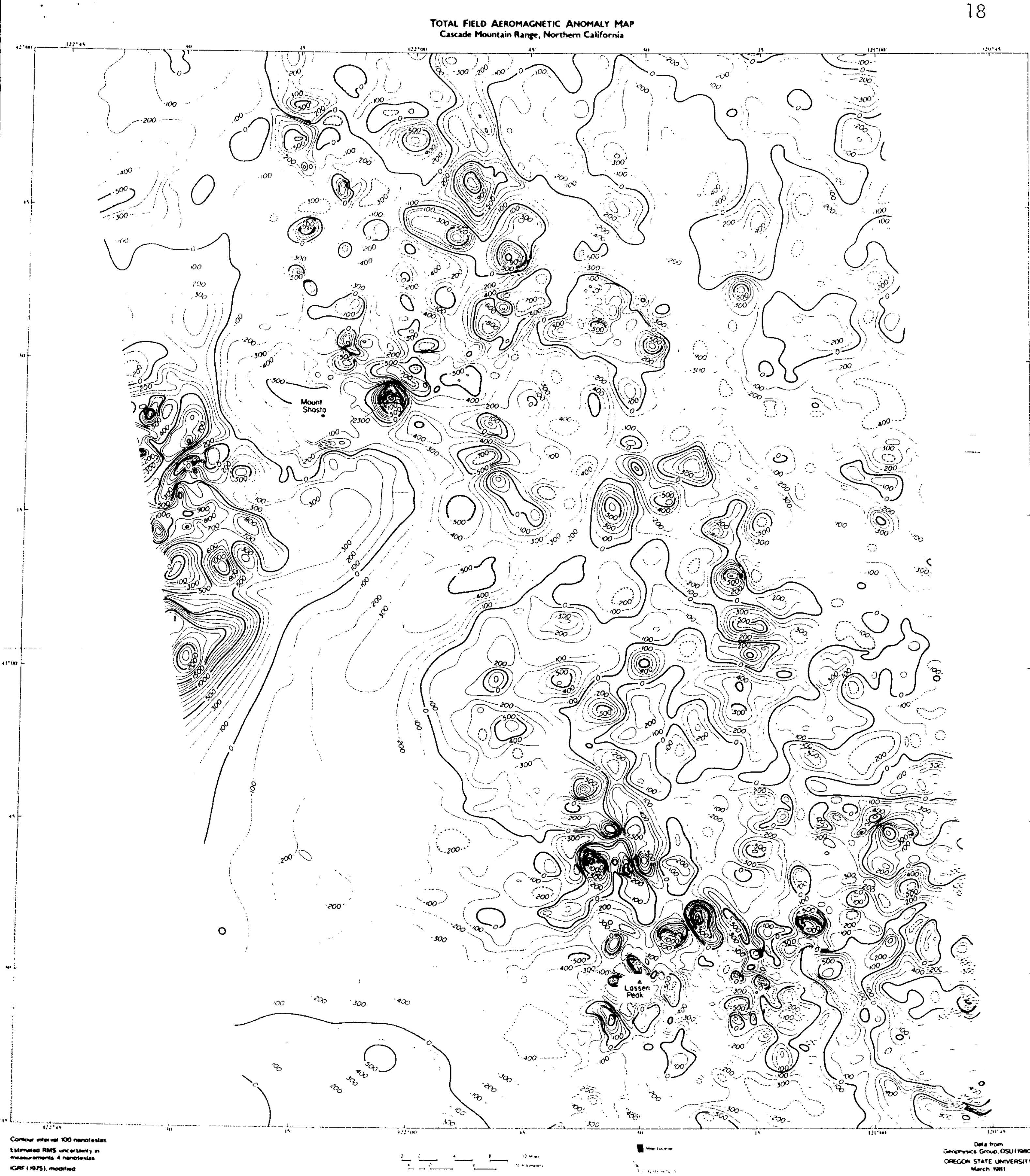
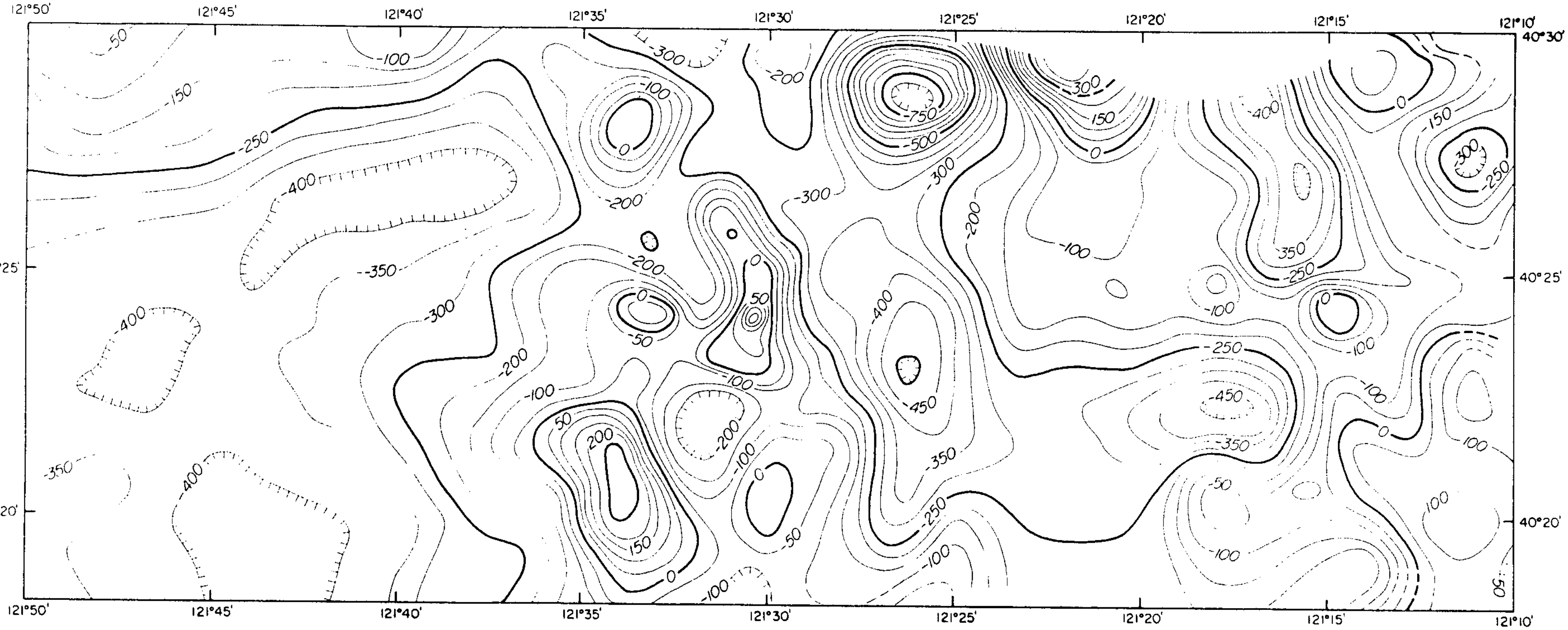


Figure 9.

This map is available at 1:250,000 scale. See U.S. Geological Survey Open-File Report 82-198 (Couch, 1982).



Contour interval 50 nanoteslas
Estimated RMS uncertainty in measurements 4 nanoteslas
IGRF (1975), modified
Flight elevation 11,000 feet

TOTAL FIELD AEROMAGNETIC ANOMALY MAP
Lassen Peak Area, Northern California

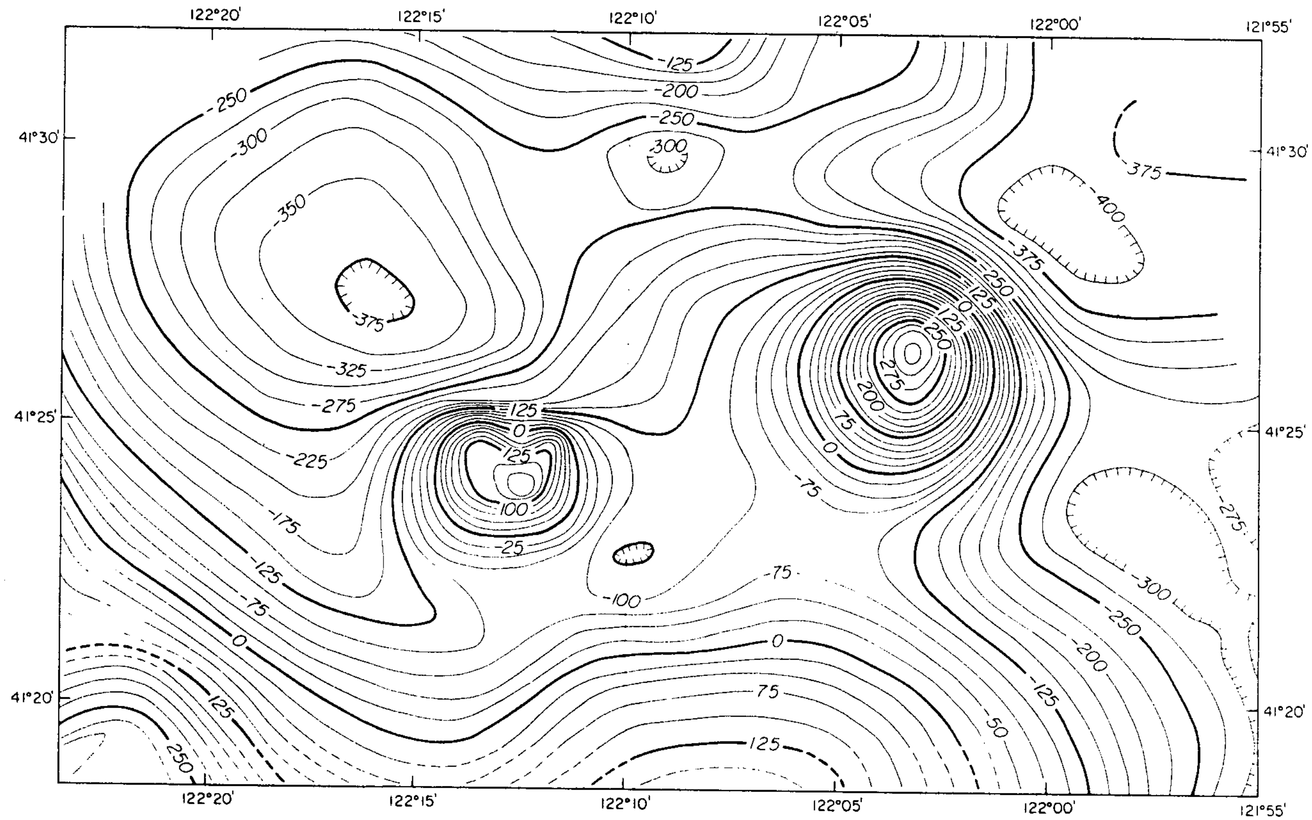
SCALE 1:250,000

1 0 1 2 3 4 Miles
1 0 2 4 Kilometers

Transverse Mercator Projection

Data from
Geophysics Group, OSU (1980)
OREGON STATE UNIVERSITY
April, 1981

Figure 10.



Contour interval 25 nanoteslas
Estimated RMS uncertainty in measurement 4 nanoteslas
IGRF (1975), modified
Flight elevation 15,000 feet

TOTAL FIELD AEROMAGNETIC ANOMALY MAP
Mount Shasta Area, Northern California

SCALE 1:250,000
1 0 1 2 3 4 Miles
1 0 1 3 5 Kilometers
Transverse Mercator Projection

Map Location
NORTHERN CALIFORNIA

Data from
Geophysics Group, OSU (1980)
OREGON STATE UNIVERSITY
April, 1981

Figure 11.

amplitude, nearly circular, positive anomaly on the east side of Mt. Shasta. The positive anomaly shows a greater decrease in amplitude than the negative anomaly when the flight elevation increases from 9,000 feet (figure 9) to 15,000 feet (figure 11); hence, the source of the negative anomaly is deeper than the source of the positive anomaly. If the anomaly pair is due to a dipole source body, the body is normally polarized and dips northeastward at less than 64°, the approximate dip of the Earth's dipole field in northern California. Alternatively the anomalies reflect a positively polarized source body on top of a reversely polarized regional base.

A very broad, low-amplitude, negative magnetic anomaly located in the vicinity of Redding and the area east of Redding extends north toward Shasta Lake and then toward the northeast north of the lake. The anomaly generally coincides with the mapped Mesozoic sedimentary and volcanic rocks of the Klamath Mountain complex, and the long wavelength components of the anomaly appear to be present "beneath" the short-wavelength components of the Cascade Mountains southeast of Mt. Shasta. The western edge of the negative anomaly appears to delineate the eastward extent of the intrusive granitic and ultramafic rocks of the Klamath Mountains.

Two lineaments are apparent in the magnetic-anomaly map of figure 9. One lineament strikes northwest from near 41°00' N. lat., 120°45' W. long. to 42°00' N. lat., 122°00' W. long. and separates the intermediate-wavelength magnetic anomalies of the northeastern Modoc Plateau from the short-wavelength anomalies of the Cascade Range and southern Modoc Plateau. The second lineament strikes northwest from near 40°15' N. lat., 120°55' W. long. toward Mt. Shasta. Both lineaments suggest changes or discontinuities in the basement structure. The southern lineation may be due to an extension of the Honey Lake Fault toward the northwest beneath the young volcanics of the Modoc Plateau. The magnetic anomalies also suggest several northeast-southwest lineations between Mt. Shasta and Mt. Lassen that may be related to trends of the Klamath Mountain Complex beneath the Cenozoic volcanics of the Cascade Range.

The Klamath Mountain Complex west of Mt. Shasta is a region of predominantly positive magnetic anomalies. The anomalies are large in amplitude and exceed 2,200 nT southwest of Mt. Shasta. The Mesozoic and Paleozoic age and degree of metamorphism of the rocks in this region suggest that a large part of the magnetic character of the rocks in this region is due to induced magnetization.

The Medicine Lake Highlands appear as an area of relatively low amplitude positive anomalies (with respect to the flight elevation above the volcanic rock) superimposed on a region of negative anomalies.

The Cascade Mountain Range appears on the magnetic anomaly map of figure 9 as composed of numerous short-wavelength, high-amplitude somewhat circular positive and negative anomalies. These small high amplitude anomalies mark the locations of volcanic vents, intrusions and hyabyssal bodies of Tertiary to Recent age. The anomaly pattern of the Cascade Range appears diminished near 41° N. latitude where the Klamath Mountain Complex and the northern extension of the Great Basin extend eastward.

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