

OVERVIEW OF THE MAGSAT PROGRAM

The Magsat project, the background leading to its inception, and its mission objectives are briefly described, followed by summaries of plans for studies of regional geology and geophysics, geomagnetic field modeling, and the inner earth.

PROJECT DESCRIPTION

The purpose of the Magsat project was to design, develop, and launch a satellite to measure the near-earth geomagnetic field as part of NASA's Resource Observation Program. It was intended to provide precise magnetic field measurements for geoscientific investigations by:

- Accurately describing the earth's main magnetic field for charting and mapping applications and for investigating the nature of the field source. This will provide more accurate magnetic navigation information for small craft, will trace more accurately the magnetic field lines for the near-earth magnetosphere, will separate the magnetic field into crustal and external field contributions, and will permit study of the earth's core and core-mantle boundary; and
- Mapping, on a global basis, the fields caused by sources in the earth's crust. This will contribute to our understanding of large-scale variations in the geologic and geophysical characteristics of the crust, and will in turn affect the future planning of resource exploration strategy.

BACKGROUND

Magsat is one of several integrated elements of the NASA Resource Observation Program that use satellites to study the earth's nonrenewable resources. One facet of this program is the use of space techniques to improve our understanding of the dynamic processes that formed the present geologic features of the earth and how these processes relate to phenomena such as earthquakes and to the location of resources.

One part of the Resource Observation Program is the measurement of the near-earth geomagnetic field. Before the satellite era, magnetic data from many geographic regions were acquired over periods of years by a variety of measurement techniques. However, for many regions such as the oceans and poles, data were either sparse or nonexistent.

Satellite measurements of the geomagnetic field began with the launch of Sputnik 3 in May 1958 and have continued sporadically in the intervening years. To date only the OGO-2, -4, and -6 satellites, which are the Polar Orbiting Geophysical Observatories (Pogo's), have provided a truly accurate global geomagnetic survey. These satellites operated between October 1965 and June 1971, and their alkali-vapor magnetometers provided global measurements of the field magnitude approximately every half second over an altitude range of 400 to 1500 km.

The satellite geomagnetic field measurements were intended for mapping the main geopotential field originating in the earth's core, for determining the long-term temporal or secular variations in that field, and for investigating short-term field perturbations caused by ionospheric currents. Analysis of data from the Pogo satellites disclosed that the lower altitude contains separable fields related to anomalies in the earth's crust, thus opening the door to a new class of investigations. Several geomagnetic field models and crustal anomaly maps based on the Pogo data have been published.

NASA established the Magsat program to provide the United States Geological Survey (USGS) of the Department of the Interior with data to be used in making magnetic field maps for the 1980 epoch. The program is managed by the Goddard Space Flight Center (GSFC) in cooperation with the USGS. Responsibility for spacecraft design, development, and testing was assigned to APL.

The Magsat data are expected to resolve directional ambiguities in both field modeling and magnetic anomaly mapping. Increased resolution, coupled with higher signal levels from anomalous fields, will overcome some of the shortcomings of the Pogo data and provide improved anomaly maps.

Magsat data will be correlated with other geophysical measurements. For example, the highly accurate determination of the earth's gravity field and geoid accomplished by both laser tracking of satellites and altimetry studies with geodetic satellites provides information about the density distribution within the earth's crust.

MISSION OBJECTIVES

The USGS, principal user agency for this mission, and other users from both U.S. and foreign governments, universities, and industry will pursue the following objectives:

- Obtain an accurate, up-to-date, quantitative description of the earth's main magnetic field. Accuracy goals are 6 nanoteslas ($1 \text{ nT} = 10^{-9}$ weber per square meter) root sum squares (rss) in each direction at the satellite altitude and 20 nT rss at the earth's surface in its representation of the field from the earth's core at the time of the measurement;
- Provide data and a worldwide magnetic field model suitable for USGS use in updating and refining world and regional magnetic charts;
- Compile a global scalar and vector map of crustal magnetic anomalies. Accuracy goals are 3 nT rss in magnitude and 6 nT rss in each component. The spatial resolution goal of the anomaly map is 300 km; and
- Interpret the crustal anomaly map in terms of geologic and geophysical models of the earth's crust for assessing natural resources and determining future exploration strategy.

MISSION PARAMETERS

The altitude of the Magsat measurements was dictated by a trade-off between two requirements: the lowest possible altitude is necessary for increasing the anomaly signals and their spatial resolution; a minimum satellite lifetime is necessary for obtaining adequate data distribution. On the basis of these requirements, the nominal perigee was about 350 km. The apogee was selected to provide the required lifetime. Although higher altitude data are less useful, data up to 500 km could be used in anomaly studies. Accuracy goals are determined by the fact that, based on experience with Pogo, the anomaly amplitudes at 300 km are expected to be in the range of 0 to 50 nT. To obtain the maximum anomaly resolution and signal strength, data were acquired as the orbit decayed below 300 km during the reentry phase.

The main field and anomaly measurements must be made in the presence of the perturbing fields from ionospheric and magnetospheric sources. Since the mission was conducted during a period of very intense solar activity, only approximately 20% of the data obtained at latitudes below 50° will be sufficiently free of these perturbations to yield the required accuracy. At latitudes higher than 50° even fewer data are usable. To achieve a 300 km global anomaly resolution, coverage is needed along grid lines that are no more than 150 km apart. The time required for achieving this anomaly resolution is estimated to be 10 days for perfectly quiet data or 50 days during periods of maximum solar activity. This time represents minimal cover-

age with no capability of averaging or statistical analysis. To provide a workable sample, data that are three times as dense are needed.

Before launch the desired lifetime of the mission was established as approximately 150 days. The actual lifetime was 225 days. This additional time provided a more than adequate statistical sample and increased the probability of obtaining "quiet day" coverage.

Data at all local times except for those between 0900 and 1500 are useful for anomaly studies. A dawn launch was chosen to obtain useful anomaly data on all portions of the orbit and to maximize power.

Originally, a 325 by 550 km orbit was proposed to provide an orbital lifetime of between 4 and 8 months. Because of the very high solar flux that was subsequently predicted during late 1979 and early 1980 (this flux increases the height of the atmosphere and leads to higher drag forces), the final selected orbit was 350 by 550 km. A four-stage Scout vehicle injected Magsat into a sunlit (dawn to dusk) sun-synchronous orbit. It was launched from the Kennedy Space Center Western Test Range, Vandenberg AFB, Calif., on October 30, 1979.

INVESTIGATION PLANS

To achieve the Magsat mission objectives, investigations are being carried out at GSFC and the USGS and by competitively selected principal investigators.

The GSFC investigations are those required for rapidly producing the principal mission products — spherical harmonic models of the main geopotential field and magnetic anomaly maps, analytic tools needed by other investigators (e.g., equivalent source models of the anomaly field), and development of preliminary crustal models of selected areas not being studied by other investigators.

The USGS will produce charts of both the United States and the entire earth; will develop sophisticated models of the main geopotential field using Magsat data along with appropriate correlation data, with particular emphasis on secular variation studies; and will develop crustal models of selected regions.

REGIONAL GEOLOGIC AND GEOPHYSICAL STUDIES

Magnetic anomaly data are useful for regional studies of crustal structure and composition, the usefulness including possible correlation with the emplacement of natural resources and guidance for future resource exploration. Magnetic anomaly maps based on aeromagnetic surveys are standard tools for oil and mineral exploration. A magnetic anomaly, as the term is used in this overview, is the residual field remaining after the broader-scale earth's field is removed. The removed field is usually computed from a spherical harmonic

model. The primary purpose of the regional studies is to identify subsurface geologic structures that may extend over distances and depths of a few kilometers and to help target specific areas for drilling or mining. Because of incomplete coverage and because of large temporal changes in background fields between the times when adjacent local surveys were made and when large local variations occurred, available aeromagnetic anomaly maps cannot effectively probe broad regional geological features. With the advent of the theory of plate tectonics, interest in identifying and mapping these broad regional features is increasing.

The anomalies measured by Magsat will reflect such important geologic features as composition, temperature of rock formation, remanent magnetism, and geologic structure (faulting, subsidence, etc.) on a regional scale. Magsat is therefore providing information on the broad structure of the earth's crust, with near global coverage.

Continental coverage will be most important for immediate economic applications. Magsat data will help to delineate the fundamental structure of the very old crystalline basement that underlies most continental areas. This structure will not necessarily parallel known younger trends.

Interpretation of the basic scalar anomaly map begins with the construction of a model of regional susceptibility contrasts. The inclusion of vector data will improve model accuracy. Vector data are then used to infer the magnetic-moment direction for each anomaly, permitting the presence of large-scale remanent magnetism to be distinguished from susceptibility contrasts. Correlative data, such as gravity anomalies and known geology, are used in interpretation so that the resulting geological and geophysical models closely resemble reality. These models will contribute substantially to our knowledge of the unexposed fundamental geology of the continents. Models yield information for both the shallow crustal features that are important to resource assessment and the deep features that relate to faulting and earthquake mechanisms.

One application of Magsat anomaly maps will be the long-range planning of mineral and hydrocarbon exploration programs. Such planning is concerned with delineating entire regions (frequently of subcontinental extent) that should be explored rather than with discovery of specific oil or mineral deposits. For example, in Australia serious exploration for oil began in areas that were known to have thick accumulations of sedimentary rock (i.e., sedimentary basins). Regional studies eventually narrowed the broad target areas to a few promising structures, which were then explored in detail.

Some idea of the relationship between the regional geology and mineralogy can be seen by noting that metallic mineral deposits are usually associated, either directly or indirectly, with igneous rocks. From a broader viewpoint, the distribution of such deposits is closely interrelated with regional

geology, such as structure, lithology, and depth of exposure. For example, copper deposits such as those of the southwestern United States are associated with a class of young granite intrusion that is, in turn, related to the Basin and Range Province, a large zone of block-faulting. In contrast, chromium occurs in large intrusions of iron-rich igneous rock of much greater age and completely different tectonic setting. A general factor that strongly affects both the formation of mineral deposits and the eventual discovery of their location is the crustal level at which they occur.

Because of these relationships, a sound knowledge of regional geology and geophysics is essential to the planning of mineral exploration and, generally, to the assessment of the mineral reserves of a region or country. Magsat is providing new information on crustal structure and composition over very large areas, including those in which bedrock is poorly exposed. Therefore, the data will be helpful in selecting the most promising areas for future mineral exploration and in determining the exploration strategy to be used. The full potential of the crustal anomaly measurements will not be realized for some time, but the near-term application of the initial results is obviously promising.

GEOMAGNETIC FIELD MODELING

One of the principal contributions of satellite magnetic field measurements to geomagnetism has been to make available a rapidly obtained global survey instead of conventional surface measurements that present the problem of the long-term, or secular, variation in the main geomagnetic field (which can amount to as much as 1% per year in some localities). In order to represent the global geomagnetic field accurately at any given instant, measurements must be made worldwide at nearly the same time. This can be achieved only by satellite observations and, even then, only by spacecraft that are in polar orbits and that are equipped with on-board tape recorders. In addition, accurate global representation of the secular variation requires periodic worldwide surveys. Magsat will furnish one such survey and, together with existing surface data, will permit accurate global representation of secular variation for the period beginning with OGO-2 to the demise of Magsat (October 1965 to June 1980).

Although Pogo data were global and taken over a short time, the limitation of measuring only the field magnitude resulted in some ambiguity in the field direction in spherical harmonic analyses. Magsat is eliminating this ambiguity by providing global vector data.

INNER-EARTH STUDIES

The radius of the earth is about 6378 km. Direct measurements in mines, drill holes, etc. are available only in the upper few kilometers of the crust. In particular, for information regarding the core

and mantle, the only sources of data are extruded geologic structures (upper mantle only), the gravity field of the earth, the rotation rate and polar motion, seismic measurements, and the magnetic field of the earth. Therefore, we must depend on only a few indirect measurements for information on more than 96% of the earth's volume.

To understand the tectonic processes that contribute to the dynamics of the earth's crust (i.e., plate motions, earthquakes, volcanism, and mineral formation), it is necessary to investigate the mantle and core in which these processes originate.

Characteristics of magnetic fields at and near the earth's surface (e.g., secular change, field reversals, and power spectra of magnetic-field models) have heretofore been used to infer properties internal to the earth. Combining Magsat data with earlier satellite surveys and with surface data from intervening times will permit more accurate determination of secular variation. This information can

be used to investigate changes of the fluid motions in the core that give rise to the field, properties of the core-mantle boundary that greatly affect fluid motions of the core, and the transmission of this temporarily varying field through the lower mantle.

When magnetospheric fields are time varying, they result in induced fields within the earth because of the finite conductivity of the earth. The characteristics of these induced fields are determined by the composition and temperature of the materials in the earth's mantle. At present the limiting factor in determining a precise conductivity profile within the earth with adequate spatial resolution is the accuracy possible in determining the external and induced fields. Although the ultimate usefulness of satellite vector measurements in these studies is not completely clear, preliminary results are encouraging, suggesting that Magsat vector measurements will enable a much more accurate analysis to be made.