Crustal magnetic anomalies

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Introduction

This Quadrennial Report departs in format from its predecessors. Earlier reports provided brief descriptions of the entire range of topics on "crustal magnetic anomalies." Following guidelines established by the AGU, we instead focus our discussion on only a few selected topics. Our abbreviated list of references reflects this restricted focus. A more comprehensive bibliography can be obtained from the authors as noted subsequently.

The past quadrennium was distinguished by a significant change in the scale and scope of crustal magnetic anomaly research. Advances in instrumentation, navigation, and data processing techniques resulted in increasing use of two-dimensional anomaly maps rather than profile data. Although maps are commonly used in aeromagnetic studies of continental areas, their use in the ocean basins has been limited until recently. The other important change has been a trend towards increased integration of magnetic anomaly data with gravity, seismic, geochemical, remote sensing, and geologic data to enhance the interpretation and reduce the ambiguity of magnetic field data.

With most of the magnetic anomalies in the ocean basins mapped to first-order, current studies are focusing on very detailed magnetic observations, mostly near the mid-ocean ridge axes. Detailed, three-dimensional magnetization distributions derived from marine magnetic anomalies are providing fundamental constraints on spatial and temporal variability in the physical and chemical characteristics of crustal magmatic accretion. Inferences concerning the accretion process obtained in these studies prove to be complementary to the larger, regional picture deduced from systematic variations in anomaly amplitude and from petromagnetic properties of basalt.

The traditional role of aeromagnetic studies over continental areas has been in establishing geologic and tectonic frameworks and in exploring for minerals and other commodities. The techniques established in these traditional investigations were applied during the past quadrennium to the identification and understanding of several critical geologic hazards. Some geologic hazards, such as the San Andreas fault in California, are clearly expressed at the surface and can be studied by geologic mapping...
and other surface-based methods. Most geologic hazards are not so easily accessible. The New Madrid seismic zone, for example, has no expression at the surface but nevertheless poses a continuing and potentially devastating threat to major population areas. The magnetic method is a relatively inexpensive way to learn about geologic hazards, such as seismically active faults, shallow magma chambers, and volcanic centers. Indeed, it may be the only way to study hazardous structures in places where they are concealed beneath young deposits, water, vegetation, and urban development.

Much attention has been directed recently toward removing residual external field contamination from the Magsat anomaly field. These efforts represent an important step toward realizing globally continuous, high-accuracy lithospheric anomaly fields that will undoubtedly furnish valuable constraints on understanding the genesis and evolution of the lower crust and large scale regional crustal processes. The satellite anomaly field continues to be a valuable resource in deciphering regional tectonic fabric and compositional variations.

Detailed Tectonic Histories

Spreading Rate Variations and Magnetic Telechemistry of the Seafloor Revisited

High-resolution studies of the oceanic magnetic anomaly pattern have become increasingly popular as tools for investigating the structure and dynamic evolution of the mid-ocean ridge system and as a means to understand the magmatic accretion process. Two-dimensional magnetic anomalies have been interpreted as reflecting chemical variations in the oceanic crust, as first suggested by Peter Vogt and G. Leonard Johnson in 1973 with the concept of “magnetic telechemistry”. Although questions remain concerning the character and stability of the source layer of marine magnetic anomalies, the anomaly pattern still offers a powerful means of studying accretionary processes through time.

Several key observations have been made recently that illuminate the underlying processes that control accretion. First, magnetization intensity has been shown to correlate with tectonic segmentation of ridge axes: higher anomaly amplitudes and magnetization intensities (obtained in inversions) have been observed at first- and second-order discontinuities (transform faults and overlapping spreading centers, respectively) on the southern mid-Atlantic Ridge (MAR) [Carbotte et al., 1991], the East Pacific Rise [Sempéř, 1991; Carbotte and Macdonald, 1992; Perram et al., 1993] the Juan de Fuca Ridge [Tivey, 1994], and at the Galapagos spreading center [Perram and Macdonald, 1994]. These higher-than-average magnetizations have been attributed to more highly fractionated (Fe-Ti) basalts at the segment tips. The larger degree of fractionation likely results from lower degrees of partial melting in smaller, deeper, and/or more disrupted magmatic sources at segment tips. An alternative hypothesis is that the total iron content of the erupted basalts between the segment centers and tips is controlled by variations
in heat and magma supply. The magnetic signature of the segment tips can be traced off-axis to map the propagation history of the discontinuities [Carbotte and Macdonald, 1992; Perram et al., 1993] and/or the waxing and waning of the magma supply [Grindlay et al., 1992; Carbotte and Macdonald, 1992].

A recent study related to the above observations but with much broader scope is that of Johnson and Pariso [1993]. These authors presented a new analysis of selected Deep Sea Drilling Project/Ocean Drilling Program rock magnetic results for crustal samples ranging in age from Cretaceous to present. They found a systematic variation in intrinsic magnetic properties with age that correlates with variations in oceanic crustal magnetization revealed by inversion of gridded magnetic anomalies [e.g., Sayanagi and Tamaki, 1992]. The magnetizations decrease to a low at ≈30 Ma, then increase again. Johnson and Pariso [1993] concluded, on the basis of several lines of evidence, that these trends are the result of gross variations in the amount of magnetic minerals in the crust. Magnetic minerals in Cretaceous crust, for example, are twice as abundant as in crust from certain other time periods. This intriguing conclusion, considered in concert with the above suggestion that magnetization variations within an individual segment are controlled by the magma flux rate and temperature, may suggest that either magma supply or temperature or both were unusually high during a period of 40 million years that roughly coincides with the Cretaceous Long Normal Period of constant geomagnetic polarity.

The second important observation to emerge from fine-scale anomaly studies is that detailed spreading rate histories, derived from inversion results, reveal the episodicity of the accretion process within and between segments, and its variability with time. Carbotte et al. [1991] documented a 20 percent variation in spreading rates across segment boundaries at the southern MAR indicating significant non-rigid plate behavior on the time scale of individual anomalies (≈ 0.8 million years). This observation should have important implications for assessing the instantaneous state of stress on faults, such as the San Andreas, for which a relative plate motion model averaged over several million years is commonly used.

Third, the response of the plate boundary to changes in plate motion can be quantified by the magnetically-determined evolution of discontinuities that develop to accommodate the new geometry [Macdonald et al., 1991]. The above studies all support the notion of the independence of individual spreading cells and the longevity of first- and second-order discontinuities. The magnetization variations associated with the discontinuities appear to be fixed with respect to the segments they bound (i.e., magnetic highs always occur at segment tips). Thus, mapping highly magnetized zones in older crust may reveal spatial and temporal variations in magma supply and variations in near- and far-field stresses at the boundary.

In another development, the spreading rate dependence of anomalous skewness (anomaly distortion that is unrelated to geomagnetic latitude) was documented in two studies [Roest et al., 1992; Dyment et al., 1994]. The latter study confirmed the
negative correlation between anomalous skewness and spreading rate seen in the former study and further found a transition to virtually no anomalous skewness at spreading rates above 50 mm/yr. These findings have important implications for the character of the magnetic source layer and the roles of faulting and magmatism in creating the oceanic crust and shaping its magnetic anomalies. One important implication is that paleopoles derived from anomaly skewness, especially for single plates, should be more reliable for faster spreading episodes.

**Continental Tectonics**

The tectonic histories of several continental regions were elucidated in greater detail as a result of the interpretation of higher resolution magnetic anomaly data sets in conjunction with gravity, seismic, and geologic data. These data sets were used to characterize the subsurface in order to develop a more accurate picture of the magmatic and deformational evolution of areas now hidden beneath sedimentary cover. Blakely and Jachens [1991] delineated the extension of the northern Nevada Rift into southern Nevada and mapped the thickness of sedimentary cover from a joint interpretation of gravity and magnetic data. They inferred that the mid-Miocene northern Nevada rift enhanced the strength of the crust, as demonstrated by its apparent immunity to later deformation that formed most of the sedimentary basins.

Holbrook et al. [1994] and Lizarralde et al. [1994] combined seismic reflection and refraction data with magnetic and gravity anomaly data to investigate the structure and evolution of the U.S. Atlantic continental margin. Holbrook et al. [1994] interpreted magnetic susceptibilities, inferred from modeling the East Coast and Brunswick magnetic anomalies using seismic constraints on crustal thickness, to indicate highly mafic material in the continent-ocean transition zone emplaced during rifting. An abrupt change in seismic and magnetic properties occurs at the landward edge of the 80-km wide transition zone, which results in the prominent Brunswick magnetic anomaly; a similar contrast in crustal properties is observed offshore Georgia, where an abrupt change to more mafic crust occurs seaward of this anomaly [Lizarralde et al., 1994]. The documentation of a thick volcanic sequence in the ocean-continent transition zone, equivalent in volume to large igneous provinces associated with plume heads but for which no evidence of a plume origin exists, implies that enhanced convection during rifting is responsible for this massive igneous event [Holbrook et al., 1994].

Finn [1994] produced a revised basement map of northeast Japan based on interpretation of a recently acquired high-resolution aeromagnetic data set, guided by drill hole, seismic, and gravity data. She mapped the extent of a buried and previously unrecognized Early Cretaceous batholith and inferred a large amount of tectonic erosion or thrusting at the margin in order to explain the lack of Cretaceous forearc deposits implied by the position of the paleo-magmatic arc. In a more contemporary setting, Blankenship et al. [1993] mapped an active volcano within the West Antarctic rift system beneath the West Antarctic Ice Sheet with combined airborne ice-penetrating radar, magnetic,
gravity, and altimetry data. Their interpretations, that volcanism is currently active and that the lithosphere participates in controlling ice sheet stability, will have important implications for the neotectonic and glacial history of West Antarctica.

Magnetic Studies of Geologic Hazards

Hazardous geologic structures, such as faults, volcanoes, and shallow magma reservoirs, often juxtapose lithologies with contrasting magnetic properties. Aeromagnetic techniques are naturally suited for the exploration of these structures where they may be concealed below the surface and pose a threat to society. A variety of studies conducted during the past quadrennium focused attention on this important application of the aeromagnetic method. Here we highlight only a few significant developments related to earthquakes and volcanoes.

Active Faults

Potential-field studies were conducted in seismically active regions throughout the world: in California [Jachens and Griscom, 1995], Oregon [Blakely et al., 1995], in the U.S. mid-continent [Hildenbrand et al., 1992; Hildenbrand and Hendricks, 1995], in eastern Canada [Goodacre et al., 1993; Mohajer, 1993; Thomas et al., 1993], in Colombia [Toto and Kellogg, 1992], along the Rhine graben [Prodehl et al., 1992], in Norway [Karplus et al., 1991], and in the Gulf of Aqaba [Alamri et al., 1991].

The Loma Prieta earthquake (M = 6.9) struck the San Francisco Bay Area in October 1989 killing 63 people and causing $5.9 billion in damages to public and private property throughout the region from San Francisco to Santa Cruz, California. Understanding this earthquake and its many aftershocks is critical to mitigating the effects of future earthquakes of the area. This understanding is complicated, however, because the Loma Prieta earthquake occurred in a region of significant geologic complexity.

Jachens and Griscom [1995] produced a comprehensive interpretation of the epicentral region of the Loma Prieta earthquake based on magnetic and gravity data and constrained by geologic and seismic information. Their modeling experiments show a San Andreas fault system that deviates significantly from a simple vertical boundary between two major plates. Aftershocks indicate that the deeper parts of the fault surface in the epicentral region dip steeply to the southwest, but potential-field data indicate that in the shallow subsurface magnetic sediments of Pliocene age are thrust northeastward beneath rocks on the northeast side of the San Andreas fault. A few kilometers south, the San Andreas is nearly vertical in the shallow subsurface, changing to a southwest dip farther south. Jachens and Griscom, [1994] concluded that most Loma Prieta aftershocks occurred along three major faults, the San Andreas, Zayante-Vergeles, and Sargent faults, and that the widely dispersed pattern of epicenters was the result of non-vertical and spatially variable surfaces on these faults.

The New Madrid seismic zone in the Mississippi embayment
was the site of a $M = 8$ earthquake in 1811 and is estimated
to be capable of producing a $M = 6$ earthquake on the order of
every 100 years. Located just 100 km from Memphis, Tennessee,
such an event could have devastating consequences. Most of the
seismicity of the New Madrid seismic zone occurs within the
Reelfoot graben, a presumed rift active during the Cambrian and
now entirely concealed beneath Upper Cretaceous and younger
sedimentary rocks. The graben is defined on the basis of aero-
magnetic and seismic-reflection data.

A specially designed aeromagnetic survey was flown over the
northern part of the New Madrid seismic zone to investigate the
Reelfoot rift and related structures [Hildenbrand et al., 1992;
Hildenbrand and Hendricks, 1995]. The survey was flown
just 91 m above ground along flight lines spaced 400 m apart.
The aeromagnetic data, after various enhancing operations, show
numerous linear features lying parallel to the New Madrid seismic
zone. These magnetic anomalies apparently reflect faults, but
the physical connection between faulting and magnetic sources
is complicated; namely, the sources of the anomalies lie at
depths of about 1 km within the relatively nonmagnetic sedimen-
tary overburden, several kilometers above the faulted basement.
Hildenbrand et al. [1992] concluded that the magnetic sources
may be igneous intrusions emplaced along the faults and into the
sediments. Alternatively, faulting may have promoted the growth
of magnetic minerals, either authigenic pyrrhotite or magnetite
altered from pyrite, in the overlying sediments. In any case, the
pattern of faults determined from the aeromagnetic data should
lead to new stress models for the New Madrid seismic zone.

Volcanoes

Studies of relatively young volcanic centers were conducted in
a variety of areas during this quadrennium: on the island of Hawaii
[Hildenbrand et al., 1993]; at Long Valley caldera, California
[Miyazaki, 1991a, 1991b]; at Portland, Oregon [Blakely et al.,
1995]; in New Zealand [Rout et al., 1993; Woodward and
Mumme, 1993]; and in West Antarctica [Blankenship et al.,
1993; Behrendt et al., 1991, 1994].

The ability of the magnetic method to define concealed structures
was perhaps best demonstrated by the aerogeophysical study
of the West Antarctic rift system conducted by Blankenship
et al. [1993]. Their study was part of the CASERTZ pro-
gram (Corridor Aerogeophysics of the Southeastern Ross Transect
Zone). They discovered a variety of spatially coincident features:
a depression in the surface of the West Antarctic ice sheet, a
peak in subglacial topography, a 600-nT positive aeromagnetic
anomaly, and a broad positive gravity anomaly. Blankenship
et al. [1993] concluded that these diverse data reflect an active
volcano, part of a 23-km-wide caldera situated at the base of the
ice. The depression in the surface of the ice sheet apparently is
caused by recent volcanism; i.e., increased heating by the volcano
at the base of the ice is matched by an increased flux of ice toward
the volcano from above. Such geothermal features potentially
could modify the dynamics of the West Antarctic ice sheet by, for
example, modifying the water supply available for saturating the
underlying sediments responsible for ice streaming. Monitoring the geothermal flux of the West Antarctic rift system and mapping its regional tectono-magmatic framework are important factors in understanding the position and character of ice streams and their control on ice sheet stability [Blankenship et al., 1993].

Hildenbrand et al. [1993] produced a comprehensive analysis of aeromagnetic data over the Island of Hawaii. Aeromagnetic data are useful here for delineating the lateral extent of shield structures, such as rifts, summit calderas, pit craters, and vent fissures. The active East Rift of Kilauea volcano is reflected in the aeromagnetic data but becomes especially clear when the regional anomaly caused by the topographic expression of the island is removed. Magnetic lows that parallel the rift may reflect chemical alteration of magnetic minerals by hydrothermal fluids. Using spectral analysis, Hildenbrand et al. [1993] determined that the magnetic lows originate at depths of about 1 km beneath the rift, just above a concentration of earthquake hypocenters at depths of 2 to 4 km thought to be caused by a magma conduit. Other linear magnetic lows may indicate the location of ancestral rifts on Hawaii.

Resource Issues

Magnetic methods have long played a secondary role in oil exploration, such as helping to define basement structures that control emplacement of hydrocarbons in overlying sedimentary basins. This quadrennium introduced several more direct applications. Near-surface magnetic anomalies often are seen associated with oil-producing regions. To improve our understanding of the sources of these anomalies, Reynolds et al. [1991] conducted a thorough rock magnetic and geochemical analysis of magnetic minerals from three well-known oil-producing areas of the United States. They found widely different petromagnetic settings at each locale, some involving authigenic magnetic minerals directly related to hydrocarbons. They concluded that both abiologic and biologic mechanisms can produce magnetic sulfide minerals (pyrrhotite, greigite, etc.) in some zones of hydrocarbon seepage. Alternatively hydrocarbons can reduce magnetization by replacing detrital magnetic minerals with nonmagnetic sulfide minerals. Thus a direct connection has been established between the presence of hydrocarbon and the nature of near-surface magnetic anomalies in sedimentary basins.

Andrew et al. [1991] made the strong pitch that hydrocarbon exploration should involve a synergistic combination of various kinds of data. They showed correlations between aeromagnetic lineations, Landsat lineaments, and vertical offsets in high-frequency seismic sections from Montana. They interpreted their observations as reflecting conjugate sets of lateral faults that evolved in a wrench system and that apparently have influenced the emplacement of hydrocarbons. Andrew et al. [1991] emphasized that many oil fields have near-surface magnetic anomalies, and elsewhere magnetic anomalies occur over regions with seismic characteristics often indicative of oil resources. For
these reasons, magnetic anomalies should play a larger role in identifying exploration targets.

In a similar vein, Sparlin and Lewis [1994] undertook a detailed investigation of a subtle (40 nT) aeromagnetic anomaly situated directly over the Omaha Oil Field in southern Illinois. They conducted a detailed ground magnetic survey of the region and produced a three-dimensional model for the source of the anomaly. They constrained their model with petromagnetic measurements, thin-section analysis, and drill information. They interpreted the anomaly as due to two ultramafic sills emplaced into the sedimentary section, one above the other. Together the sills have served as the structural closure necessary for hydrocarbon accumulation.

Oil was not the only exploration target in magnetic anomaly studies this quadrennium. Babu et al. [1991], for example, used magnetic anomalies to define the shape and extent of an aquifer in Hyderabad, India. The weathered layer over granitic terranes sometimes acts as an aquifer, with the base of the weathered layer (roughly 50 m deep in this locale) corresponding to the base of the aquifer. Babu et al. [1991] used spectral analysis of magnetic data to estimate the thickness of the weathered layer, under the premise that the weathered layer is relatively nonmagnetic with respect to the underlying, unweathered granite. With many such estimates, they were able to produce a map showing the topography on the base of the weathered layer. When compared with eight drill sites, their depth estimates were accurate to within an rms error of ±10.2 m.

Improved Satellite Anomaly Fields

Several efforts were directed towards characterizing external field contamination in low- and high-latitude satellite magnetic field (Magsat) data in order to produce higher accuracy lithospheric anomaly fields. Ravat and Hinze [1993] derived an empirical ionospheric correction for the equatorial region by computing dip-latitude averages of suites of profiles grouped in longitude, time, and altitude. Alsdoe et al. [1994] employed a Fourier wavenumber correlation filter to adjacent south polar passes to extract the spatially correlated signal associated with the lithospheric field from the temporally varying signal associated with the ionospheric and magnetospheric currents. Their analysis was carried out independently on dawn and dusk passes in four altitude bins which were then adjusted to a common altitude of 430 km and combined in a final correlation filtering step. Arkani-Hamed et al. [1994] applied a degree-correlation filter in the spherical harmonic domain to retain covariant harmonics in selected quiet passes of Pogo, Magsat-dawn, and Magsat-dusk data; the equatorial ionospheric correction of Ravat and Hinze [1993] was first removed from the Magsat data. Their three data sets were combined using two criteria for the correlation level, one stringent and one relaxed, which trade off signal-to-noise against signal power. These new maps all reveal the anomaly field with greater accuracy and smaller uncertainties;
as such they constitute a valuable resource for future geologic and geodynamic investigations, as well as a means of leveling individual aeromagnetic surveys for producing continent-scale maps. These new techniques provide a baseline scenario for analyzing future satellite magnetic field data and for merging them with existing data sets to further improve accuracy and resolution.

Lithospheric Magnetization Contrasts

Magsat data were used in many studies to investigate the regional extent and character of major continental and oceanic tectonic features. A fundamental problem in this regard is the apparent lack of a long-wavelength continent-ocean anomaly in many places, commonly explained in theoretical models as being caused by the spherical harmonic separation of the main field components. This expression of the continent-ocean boundary in Magsat data, or lack thereof, was the focus of several investigations.

Hinze et al. [1991] inverted 2° x 2° reduced-to-pole Magsat anomalies to determine effective susceptibility contrasts between thick continental crust and thin oceanic crust. By examining mean susceptibility contrasts between oceanic and continental regions, they hoped to determine if a simple binary distribution of regional magnetization existed; i.e., if the integrated magnetization of continental lithosphere is always greater than oceanic lithosphere. If so, the ocean-continent anomaly could be masked by the main field. The study found that, overall, the oceans have a wider range of susceptibility contrasts (with a significantly negative mean) compared to the continents. This supports the argument that harmonics generated by the ocean-continent anomaly overlap with the main field harmonics. Moreover, the more variable susceptibility of the oceanic crust can explain in part the global variability in magnetic contrasts across the continent-ocean transition seen in the Magsat anomaly field.

Bradley and Frey [1991] concluded that the positive contrast between Greenland and the Labrador Sea arises principally from the greater thickness of the continent rather than its greater susceptibility, indicating that anomalies over passive continent-ocean margins are edge-effects. Toft and Arkani-Hamed [1993] used forward models to derive an estimate of the magnetization contrast between the Precambrian microcontinent of Rockall Plateau and the induced magnetization of the surrounding North Atlantic oceanic crust. Their estimate, which they argued should represent an upper bound on contrasts at passive continental margins, is substantially lower than estimates from the margins of the Labrador Sea [Bradley and Frey, 1991] and the range of vertically-integrated magnetization contrast across ocean-continent boundaries that was obtained in a global survey by Counil et al. [1991]. The variations in these estimates partially reflect the different methods used to derive them, but they also may reflect the variation in magnetic contrasts across ocean-continent transitions, which is indicative of their rifting styles and histories.
Major magnetic contrasts of South America and Africa were studied by Ravat et al. [1992], who found a remarkable correspondence of magnetic anomalies across the reconstructed rifted continental margins and a negative relationship between anomaly amplitude and Mesozoic hotspot tectonism in the continent. This study and a study of the satellite anomaly pattern over Europe by Ravat et al. [1993] indicate that the intruded lower crust at continental rifts is dominated by weakly magnetized to nonmagnetic titanomagnetite. Ghideya et al. [1991] correlated Magsat anomalies with aeromagnetic data in West Antarctica and used constraints from both to infer the lateral extent and probable thickness of the magmatic arc complex of the Antarctic Peninsula. They also modeled a prominent ocean-continent boundary anomaly in the Weddell Sea as an extension of the seaward-dipping seismic reflector sequences observed offshore Dronning Maud Land, Antarctica.

These studies, while not definitive in their conclusions because of the accuracy and resolution of the Magsat data, do offer valuable insights into the processes which create and modify the crust, particularly the lower crust, where the sources of the anomalies are frequently presumed to reside. The satellite-altitude magnetic anomaly field can contribute to mapping deeply buried continental rifts, while the persistence of magnetic contrasts across the South America/Africa margins, inherited from the Gondwana configuration, indicates little alteration of the lower crust since break-up. The subject of magnetic contrasts at (passive) continental margins remains controversial but should yield to more systematic efforts to understand if and how long-wavelength continent-ocean anomalies are masked by overlapping core harmonics. Proper resolution of this problem will require acquisition of higher accuracy and higher resolution satellite anomaly fields. The magnetic structure of the continental margins, reflecting variations in magma supply and composition, is a valuable constraint on models of rifting and hotspot versus passive convection models of volcanism at rifts. The unique capability of satellite magnetic anomaly data to detect lower crustal magnetization and its sensitivity to lateral thermal gradients within the lithosphere argue in favor of acquisition and interpretation of higher accuracy and higher resolution satellite magnetic field data. As an indication of the popularity of this view, Taylor et al. [1992] reported on the results of a survey of industry geopotential field specialists involved in resource analysis; the respondents find Magsat data useful in their evaluations, and have expressed interest in future lower altitude magnetic field missions.

Workshops and Facilities

Representatives from the wide-range of geomagnetic disciplines met at a week-long workshop in Washington, D.C., during March 1992 to address the challenges and opportunities in geomagnetic research and to develop a plan of action to promote future discussion, interaction, and coordination. Crustal magnetic anomalies were an important theme of the workshop, and various recommen-
dations concerning the current state of, and future directions in, the study of crustal magnetic anomalies are expressed in the workshop report, entitled The National Geomagnetic Initiative [National Resource Council, 1993].

The National Geomagnetic Initiative identified a number of critical needs in order to promote future progress in these areas. Improving the consistency of the digital magnetic anomaly database for the U.S. emerged as a top priority. Consequently, a data task group was formed to develop a rationale and operational plan to upgrade the U.S. magnetic anomaly database. The task group prepared a report that provides an excellent review of the many and varied applications of magnetic anomaly research to problems in waste disposal and groundwater flow, earthquake and volcano hazards, land use and water management, and hydrocarbon and geothermal energy resources. The report, titled Rationale and Operational Plan to Upgrade the U. S. Magnetic Anomaly Data Base, is available from the National Research Council (contact Kevin Crowley, Board of Earth Sciences and Resources, National Research Council, 2001 Wisconsin Ave., NW, Washington, D.C. 20007).

The National Geomagnetic Initiative also found critical needs for the acquisition of higher-resolution data at all scales, from deep-tow marine surveys to satellite missions. A new geomagnetic satellite is needed at sufficiently low-altitudes to focus on lithospheric problems. A mid-depth-tow magnetometer package should be developed to improve resolution of seafloor anomalies and to enhance interpretation of high-resolution swath bathymetric surveys. These and other specialized data will provide for better characterization of the spatial distribution of crustal magnetization leading to improved understanding of important geodynamic processes, such as the evolution of sedimentary basins, continental rift zones, and midocean ridges. Such studies should go hand-in-hand with the development of new ways to analyze, interpret, and visualize magnetic data and with research to understand the fundamental processes of magnetization in oceanic and continental lithologies, especially at depth.

The Office of Polar Programs of the National Science Foundation recently made an aerogeophysical platform available as a research facility for use by the Antarctic earth-science community. This twin-engine plane, geared towards high-resolution surveying, carries a magnetometer, gravimeter, laser altimeter, ice-penetrating radar, and geodetic-quality GPS receivers. This facility demonstrates the increasing importance of aerogeophysical information, including aeromagnetic data, for solving problems in the earth sciences and glaciology.

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The following list of references are restricted to those cited in this report. A more comprehensive bibliography on the subject of crustal magnetic anomalies, published during 1991–1995 and written by both U. S. and non-U. S. authors, is available from the authors of this report. It is also available digitally in \textsc{LaTeX} format by sending electronic mail to blakely@gauss.wr.usgs.gov.


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