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PART I. EXTENDED ABSTRACTS OF PAPERS PRESENTED AT THE CONFERENCE

1. STUDIES OF THE MAGNETIC PROPERTIES OF ROCKS

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One of our goals in ESL is to apply new techniques and instruments to the study of magnetic properties of rocks, increasingly important in several disciplines of geophysics and space physics. These fields include paleomagnetism, magnetic anomaly mapping, sediment stratigraphy, global tectonics, piezomagnetics, and the study of lunar and planetary origins.

Chemical Alteration

An ever-present question in paleomagnetism is whether the sample has or has not undergone any appreciable chemical alteration since it was originally formed or since it acquired its remanent magnetization. In this connection we are studying low-temperature oxidation processes (< 300°C), which may contribute to changes in magnetization intensity, in Curie temperature, and in mineral composition. Knowing how such changes occur in the laboratory will lead to conclusions about the reliability of many samples that manifest similar alterations in nature. As an example, we have found that remanence acquired during alteration at slightly elevated temperatures is proportional to the magnetic field applied at that time. One study involves attempts to reduce certain magnetic minerals in a furnace under zero magnetic field, to determine whether it is possible to expunge the contributions of secondary components and lay bare the original components of magnetization.

We are also working toward the elimination of chemical alteration in paleointensity studies. Heretofore it has been possible to obtain reliable paleointensity measurements only with the most highly oxidized samples. The experimental procedure involves subjecting a sample many times to temperatures as high as 700°C. To prevent heat-induced alteration, we have developed a controlled-atmosphere furnace which, with the aid of an oxygen-sensing electrolytic cell, enables us to produce any equilibrium condition necessary to inhibit alteration during the experiment. With these tools it becomes possible to use essentially any type of magnetic rock for paleointensity determinations. This equipment will also be used to study remanent magnetization as regards the relative effects of single- and multiple-domained grains, and the effect that eons of time could have on the magnetization.

Anisotropy of Susceptibility and Magnetism

Another area of study deals with certain questions concerning the effect of magnetic anisotropy on paleointensity measurements. Thus, is it crucial to know how the new remanence is acquired relative to the direction of the original remanence? And can we use the anisotropy of susceptibility to determine directions of lava flows, and in turn to locate unknown sources of these flows and to measure the directions of prehistoric ocean and river currents?

Magnetization of Sediments

We are using varved (layered) sediments to delineate prehistoric secular change of the geomagnetic field. A preliminary study of a 7 m column obtained from a glacially formed lake-bed approximately 50 km west of Boulder has yielded a reasonably detailed sequence of secular changes that occurred between 700 and 4000 years ago. Additional cores are being drilled in the same locality, to extend these data further back in time. It is hoped that dating can be matched between epochs of local glaciation and magnetic field changes. Since this type of clay-like sediment appears to be essentially unaltered, we are looking forward to using it for obtaining the first sediment-derived paleointensities.

Effects of Pressure on Remanence and Susceptibility

Continued interest in the possible exploitation of piezomagnetic effects as earthquake predictors has prompted us to begin research in the realm of stress- and strain-induced changes in the magnetic properties of rocks. For these studies we plan to use a three-component cryogenic magnetometer, surrounding a vessel capable of inducing hydrostatic and uniaxial compression on a sample. This new type of ultrasensitive magnetometer (10^{-13} tesla) will allow us to determine remanence and susceptibility in the very low pressure ranges (0.1 to 10 MN/m^2) previously inaccessible to measurement.

2. WHAT INFERENCES CAN BE DRAWN FROM THE MAGNETIC CHARACTERISTICS OF METEORITES?

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Students of cosmic and terrestrial physics are constantly seeking some record of ancient events. Paleomagnetism has been found to afford one of the best and most reliable geophysical means of studying and dating certain such events. Even though its uses are limited, the changing geomagnetic field as imprinted in the rocks has shed much light on the formation and subsequent movement of the continents and of the sea floor. Recently it was discovered that paleomagnetic techniques could likewise be applied to solar-system cosmology.

Lovering (1959), Stacey and Lovering (1959), and Stacey et al. (1961) were the first to measure remanent moments in meteorites. More recently, Banerjee and Hargraves (1971) and Brecher (1972) took up this work with studies on carbonaceous chondrites and thermal investigations of various types of meteorites. The research has thus far led to several conclusions. First, it appears that most (if not all) meteorites contain a stable, pre-impact remanent moment. Second, this seems to be mainly thermoremanence; that is, it was acquired during cooling of the magnetic minerals through their Curie temperatures. Third, the samples measured must at some time have been associated with a body having a magnetic field, such as a planet or the Sun. For the most part, details as to the actual source of remanence or the strength of the inducing fields have been lacking.

The study presently underway in ESL on rock magnetism has three purposes: (1) To determine the existence and strength of an early solar-system magnetic field and its role in planetary formation; (2) to study the magnetic properties of the various phases of nickel-iron minerals; and (3) to develop techniques suitable for paleointensity studies of lunar samples.

The work has thus far involved an attempt to measure the paleointensities of magnetic fields that existed early in the formation of the solar system. The experimental procedures include: (a) Heating the meteorite sample to increasingly higher temperatures, cooling from each step in zero magnetic field, and observing the decay of magnetization; (b) subsequent heating and cooling, but this time in a finite, known field, and observing the rate of acquisition of this new remanence; and (c) comparing rates of decay and re-acquisition of remanence at each temperature step and using their ratio to estimate the intensity of the paleofield.

The uniqueness of these measurements stems from our control of the surrounding atmosphere during heating, thus preventing oxidation or reduction of the magnetic minerals. This is arranged by causing a mixture of H_2 and CO_2 in a known ratio to flow around the sample in a completely closed system. Oxygen fugacities (or oxygen activity) as low as 10^{-30} N/m^2 (10^{-35} atmos.) are attainable by this technique. A special oxygen electrolyte probe enables us to monitor the fugacity throughout the experiment.

From these first results we have found two main intensity components. One occurs at 500°C and the other near 800°C. In the particular meteorite measured there are two remanence-carrying minerals--magnetite and a solid solution of nickel and iron. Since the higher-temperature remanent component (800°C) falls near the Curie temperature of nickel-iron, we must assume that the nickel-iron grains carry a remanent moment. On the other hand, magnetite has a Curie temperature of 570°C, but we see no major intensity component at that temperature. It can be concluded, however, that at some time subsequent to the formation of the magnetite, these grains were partially magnetized after being reheated to about 500°C in the presence of a magnetic field.

Our conclusions are as follows: (a) The nickel-iron grains were magnetized during condensation from the gaseous state and later were aligned with an ambient magnetic induction of at least 2000 nt during cold accretion into the meteorite body; and (b) at some later time in its history, the meteorite was reheated to at least 500°C and partially magnetized under 10,000 nt.

References

Banerjee, S. K., and R. B. Hargraves (1971), Natural remanent magnetization of carbonaceous chondrites, *Earth Planet. Sci. Let.* 10:392-396.

Brecher, A. (1972), Memory of early magnetic fields in carbonaceous chondrites, presented at Symposium on the Origin of the Solar System, Nice, April 1972.

Lovering, J. F. (1959), The magnetic field in a primary meteorite body, *Amer. J. Sci.* 257:271-275.

Stacey, F. D., and J. F. Lovering (1959), Natural magnetic moments of two chondritic meteorites, *Nature* 183:529-530.

Stacey, F. D., J. F. Lovering, and L. G. Parry (1961), Thermomagnetic properties, natural magnetic moments, and magnetic anisotropies of some chondritic meteorites, *J. Geophys. Res.* 66:1523-1534.

3. OROGENIES, POLAR WANDERING, REVERSALS, AND PLATE TECTONICS

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The "new global tectonics" has had a remarkably catalytic effect on the earth sciences, providing a framework for correlating diverse geophysical and geological processes. One such process is continental drift. There is now some evidence that the Mesozoic drift episode was not unique, and that North America and Southern Africa drifted independently of one another during the Precambrian (Spall, 1972). It now becomes instructive to look at the characteristics of the Mesozoic drift episode in an effort to suggest when previous drifts may have occurred.

We can point to five associations with the Mesozoic break-up. (1) When Dearnley (1966) tabulated over 3400 globally distributed isotopic age determinations, he found significant peaks in occurrence frequency at 180, 650, 1075, 1950, and 2750 m.y. The youngest one is at the Triassic-Jurassic boundary, contemporary with the break-up of the supercontinent Pangea (Dietz and Holden, 1970). (2) There is evidence for extensive basic igneous activity during the early Mesozoic (McDougall, 1963; Dietz and Holden, 1970) encompassing the Kaoko basalts and Karoo dolerites in Africa, the Ferrar dolerites in Antarctica, the Tasmanian dolerites in Australia, the Sierra Geral lavas in South America, and the Palisades sill in the eastern U.S. Such activity would be a natural accompaniment to the rupture of a continental mass and the evolution of an ocean (Dewey and Bird, 1970). (3) Briden (1966) concluded that during the Phanerozoic, the southern continents must have undergone short periods of rapid drift separated by quasi-static intervals of little or no drift, these being reflected in paleomagnetic pole positions. He identified Upper Carboniferous and Upper Permian rapid drift episodes, which we note may be related to the initiation of Mesozoic drift. (4) There is a fairly pronounced change in the *direction* of the Phanerozoic pole paths for both the northern and southern continents between Triassic and Jurassic times (Creer, 1970). (5) During the Late Paleozoic (230 to 290 m.y. ago), there was an interval of constant but reversed polarity (Irving, 1971), which as we now see bracketed the two periods of rapid polar shift observed by Briden (1966) and was a prelude to Mesozoic drift.

Using these associations we can then suggest that there may have been four earlier cycles of continental drift, as set forth below.

(1) *Beginning at 1000 to 1200 m.y.* The evidence for this comprises a peak at 1075 m.y. in the isotopic age distribution (Dearnley, 1966); a period of rapid shift and changes in direction in the North American pole path (Spall, 1971); a possible interval of constant normal polarity (Fahrig and Jones, 1968); and basic igneous activity in North America (Goldich, 1968; Fahrig and Jones, 1969), in South Africa (McDougall, 1963), in Scandinavia (Priem et al., 1968), and in Greenland (Burwash, 1969).

(2) *Beginning at 1600 to 1800 m.y.* This is suggested by an interval of rapid shift and a change in direction in both the North American and African pole paths (McElhinny et al., 1968; Spall, 1971) and by basic igneous activity in South America (Veldkamp et al., 1971), in Scandinavia (Priem et al., 1968; Neuvonen, 1970), and in Greenland (Burwash, 1969).

(3) *Beginning at 2000 to 2200 m.y.* This is suggested by rapid modifications in the polar motions for North America and Africa (McElhinny et al., 1968; Spall, 1971); by an age peak at 1950 m.y. (Dearley, 1966); and by the injection of extensive basic dike swarms in Canada (Payne et al., 1965), U.S. (Condie et al., 1969), Great Britain (Evans, 1963), and Greenland (Payne et al., 1965).

(4) *Beginning at 2500 to 2700 m.y.* The evidence for this consists of an age peak at 2750 m.y. and the injection of dike swarms in the U.S. (Condie et al., 1969), Canada (Gates, 1971), Greenland (Payne et al., 1965), and Australia (Evans, 1968).

It is interesting that the timing of these suggested cycles of continental drift is similar to that of long-term chelogenic cycles in the evolution of the continents proposed by Sutton (1963), as well as that of changes in the convection pattern of the lower mantle in response to the growth of the core (Runcorn, 1962).

References

Briden, J. C. (1966), Recurrent continental drift of Gondwanaland, *Nature* 215:1334-1339.

Burwash, R. A. (1969), Comparative Precambrian geochronology of the North American, European, and Siberian shields, *Can. J. Earth Sci.* 6:357-365.

Condie, K. C., A. P. Leech, and H. Baadsgaard (1969), Potassium argon ages of Precambrian mafic dikes in Wyoming, *Geol. Soc. America Bull.* 80:899-906.

Creer, K. M. (1970), A review of paleomagnetism, *Earth Sci. Rev.* 6:369-466.

Dearnley, R. (1966), Orogenic fold belts and a hypothesis of earth evolution, *in* L. H. Ahrens, ed., Physics and Chemistry of the Earth, Pergamon Press, vol. 7, pp. 1-114.

Dewey, J. F., and J. M. Bird (1970), Mountain belts and the new global tectonics, *J. Geophys. Res.* 75:2625-2647.

Dietz, R. S., and J. C. Holden (1970), Reconstruction of Pangea: Breakup and dispersion of continents, Permian to present, *J. Geophys. Res.* 75:4939-4956.

Evans, C. R. (1963), Geology of the Lochinver district, Sutherland, Ph.D. Thesis, Oxford.

Evans, M. E. (1968), Magnetization of dikes: A study of the paleomagnetism of the Widgiemooltha dike suite, Western Australia, *J. Geophys. Res.* 73:3261-3270.

Fahrig, W. F., and D. L. Jones (1969), Paleomagnetic evidence for the extent of Mackenzie igneous events, *Can. J. Earth Sci.* 6:679-688.

Gates, T. M. (1971), Improved dating of Canadian Precambrian dikes and a revised polar wandering curve, Ph.D. Thesis, M.I.T.

Goldich, S. (1968), Geochronology in the Lake Superior region, *Can. J. Earth Sci.* 5:715-724.

Irving, E. (1971), Nomenclature in magnetic stratigraphy, *Geophys. J.R.A.S.* 24:529-531.

McDougall, I. (1963), Potassium-argon age measurements on dolerites from Antarctica and South Africa, *J. Geophys. Res.* 68:1535-1545.

McElhinny, M. W., J. C. Briden, D. L. Jones, and A. Brock (1968), Geological and geophysical implications of paleomagnetic results from Africa, *Rev. Geophys.* 6:201-238.

Neuvonen, K. (1970), Paleomagnetism of the dike systems in Finland. 5. Remanent magnetization of the Ava intrusives, *Bull. Geol. Soc. Finland* 42:101-107.

Payne, A. V., H. Baadsgaard, R. A. Burwash, G. L. Cumming, C. Evans, and R. E. Folinsbee (1965), A line of evidence supporting continental drift, IUGS Upper Mantle Symposium, New Delhi, pp. 83-93.

Priem, H. N. A., F. G. Mulder, N. A. I. M. Boelrijk, E. H. Hebeda, R. H. Verschure, and E. H. Th. Verdurmen (1968), Geochronological and palaeomagnetic reconnaissance survey in parts of Central and Southern Sweden, *Phys. Earth Planet. Int.* 1:373-380.

Runcorn, S. K. (1962), Convection currents in the earth's mantle, *Nature* 195:1248-1249.

Spall, H. (1971), Precambrian apparent polar wandering: Evidence from North America, *Earth Planet. Sci. Let.* 10:273-280.

Spall, H. (1972), Did Southern Africa and North America drift independently during the Precambrian? *Nature* 236:219-221.

Sutton, J. (1963), Long term cycles in the evolution of the continents, *Nature* 198:731-735.

Veldkamp, J., F. G. Mulder, and J. D. A. Zijderveld (1971), Paleomagnetism of Suriname dolerites, *Phys. Earth Planet. Int.* 4:370-380.

4. DOES THE EARTH'S MAGNETIC FIELD HAVE A PREFERRED POLARITY?

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It is traditional to assume that every event in nature is interlinked with others by a cause-and-effect relationship. In contrast to this approach, we are investigating the questions: To what extent is Nature random, as regards the polarity changes of the geomagnetic field? Is there a preference for one polarity? And if so, does the preferred polarity represent a stable state to which the field always tries to return? We consider three approaches to this problem.

(1) *Lengths of time during which the field has maintained any polarity state.* Two segments of the geomagnetic reversal time scale are available. The more complete and detailed is that compiled from sea-floor spreading data by Heirtzler et al. (1968). Those authors identified 171 reversals in the last 70 to 80 m.y. Beyond 75 m.y. we must rely on continental rocks for polarity determinations. Here there are four main problems: (a) We seek a continuous record of field behavior, but for some parts of the geologic past there may be no available rock units; (b) to get the polarity-episode length we must use isotopic dating, a method for which the errors may preclude resolving the age to better than 10 percent; (c) the various proposed reversal time scales are not mutually consistent; and (d) there will be a human tendency to regard a short interval bracketed, for example, by two normal-polarity episodes as *entirely* normal, simply for lack of other data for the intervening sequence.

Using the Heirtzler reversal time scale, we see that the longest polarity intervals (longer than 1 m.y.) tend to be reversed; but on the other hand, the shortest intervals (shorter than 100,000 yrs) also tend to be reversed. The first of these observations implies that a reversed polarity is the more stable; yet the temporary changes, which might indicate instability, tend also to have the reversed polarity.

Applying a reversal time scale put forward by McElhinny and Burek (1971) for the Mesozoic to Russian data for the Paleozoic (Khramov and Sholpo, 1970), we analyzed the lengths of polarity intervals in the Phanerozoic. We arrived at the same conclusions (and the same conflict) as for the Cenozoic. Both the longest and the shortest intervals tend to be reversed.

(2) *Dispersion of the field.* A measure of perturbation in the geomagnetic field is given by α_{95} values. These are the error circles drawn about the mean direction of magnetization for a rock unit. These values include also uncertainties due to secular variation, measurement errors, tilting of the rocks, and errors in the magnetization process. To avoid this "noise" and investigate the dispersion of the field during either polarity, we considered only *related* rock sequences showing mixed polarities. It was believed that under this procedure any variables would have affected both polarities equally. We have tabulated in histogram fashion the α_{95} values from approximately 30 papers reporting mixed polarities from igneous intrusions, lava flows, and sedimentary sequences. By inspection, the α_{95} values for reversed rock units are much lower than for normal rocks. The mean α_{95} for rocks with reversed polarity is 5.0° and the mean during normal polarity is 7.1°. We therefore draw the tentative conclusions that there is less perturbation when the field is reversed than when it is normal, and that the reversed field is more stable.

(3) *Paleointensity measurements.* Relatively few determinations have been made of the intensity of the field in the geologic past. We compared polarity and equatorial paleointensity values from studies tabulated by Smith (1967, 1968) in two reviews of field intensity determinations. Although there are more values from rocks of normal polarity, these rocks exhibit a greater range in paleointensity than the reversed rocks (which peak at .40 oe). We tentatively suggest that this indicates greater perturbation in the normal state, and that the reversed field is more stable.

At present we can draw no firm conclusion as to whether one polarity state is more stable than the other. We have four pieces of evidence, not yet statistically proved, that the reversed field is more stable; and two that the normal is more stable.

References

Heirtzler, J. R., G. O. Dickson, E. M. Herron, W. C. Pitman, and X. Le Pichon (1968), Marine magnetic anomalies, geomagnetic field reversals and motions of the ocean floor and continents, *J. Geophys. Res.* 73:2119-2136.

Khramov, A. N., and L. Y. Sholpo (1970), Synoptic tables of USSR paleomagnetic data, transl. by E. R. Hope, Canadian Defence Board Pub. T 510R, Ottawa.

McElhinny, M. W., and P. J. Burek (1971), Mesozoic paleomagnetic stratigraphy, *Nature* 232:98-102.

Smith, P. J. (1967), Ancient geomagnetic field intensities--II, *Geophys. J.R.A.S.* 13:483.

Smith, P. J. (1968), Ancient geomagnetic field intensities--III, *Geophys. J.R.A.S.* 16:547.

5. A DISCREPANCY OF VERTICAL INTENSITY IN MODELS OF THE GEOMAGNETIC FIELD BASED ON SCALAR INTENSITY

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Earlier Indications of a Problem

Models of the geomagnetic field derived by analysis of satellite-observed scalar intensity (F) have been very successful in fitting F. However, some differences have been found in the surface vector fields computed from different satellite models (Cain, 1971; Benkova et al., 1971). Furthermore, Fabiano and Peddie (1971) found that the secular change of vertical intensity ($\dot{Z}$) at some equatorial observatories was poorly fitted by the satellite F model POGO (8/69).

The iterative analysis of F requires a subjective decision as to the initial model. To test the possible influence of this choice on the result, two analyses were performed on the same set of simulated noisy F for one epoch. The first one, using a good initial model, required six iterations to obtain a result stable to .0001 nt. For the second analysis, the initial coefficient g_1^0 was reduced by half, with small changes in the other initial coefficients. Nine iterations were required to get a stable result. The coefficients then agreed with those from the first analysis to better than .001 nt. This uniqueness evokes confidence in the analysis of scalar intensity. On the other hand, it has been reported (Hurwitz, 1972) that large Z discrepancies occur in the equatorial region, following the magnetic (dip) equator rather than the geographic equator.

Possible Basis of the Discrepancy

It is suspected (but not proved) that the Z discrepancy is inherent in the analysis of F. The reasoning follows: The expression for the residual v used in the least-squares analysis of F is, for iteration $(I + 1)$, for one data point

$$v = F_I + (\mathbf{F}_I \cdot \Delta\mathbf{F})/F_I - F. \qquad (1)$$

Here F is the measured scalar intensity, F_I is computed from the set of coefficients g_n^m, h_n^m available from the previous iteration, and the vector $\Delta\mathbf{F}$ is a linear function of the corrections Δg_n^m, Δh_n^m. The portion in parentheses is completely insensitive to that component of ΔF which is perpendicular to F_I. Thus it is perhaps not surprising to find the largest Z discrepancies in the vicinity of the dip equator (where ΔF perpendicular becomes ΔZ).

Assessment of the Extent of Impairment Likely

To scrutinize for the presence or absence of Z discrepancies, simulated noisy data X_S, Y_S, Z_S, F_S are computed, and F_S is used in place of F. After the last iteration (L), the discrepancy Z_D is computed from

$$Z_D = Z_S - Z_L,$$

where Z_L is derived from the final model.

I have made a few additional tests of this kind, searching for a scheme to eliminate or reduce the discrepancy. The random noise used had an approximately Gaussian distribution and a standard deviation of 10 nt from a zero mean. In the first test, a noisy data set was computed from 35 coefficients plus random noise. This data set was analyzed for 80 coefficients. It was determined that most of the Z discrepancy was contained in the first 35 coefficients. Discarding the last 45 coefficients of the 80-coefficient set does not appreciably reduce the discrepancy in Z along the dip equator.

In the second test, the same data set was used as in the first test, except that the 72 values of F_S at latitudes ±5° were omitted from the analysis. The Z discrepancy along the dip equator was slightly greater than when all 648 values were used. In a third test (with the complete data set), greater weight was given to the data at latitudes ±5°. This did not change the Z discrepancy.

In a fourth test, two models of different maximum degree were obtained from one set of simulated data. For the first model, 35 coefficients were obtained, For the second model, 80 coefficients were obtained. The second model gave a slightly better fit to F but the Z discrepancy was considerably worsened, as shown in Table 1.

This suggests that the improvement in the fit to F is to some extent obtained at the expense of the fit to Z (and perhaps to X and Y also).

Table 1. Comparison of Residuals from Models with Different Numbers of Coefficients

Number of Coefficients from *F* Analysis	*F* Residuals		*Z* Discrepancies	
	R.m.s.	Range	R.m.s.	Range
35	9.86 *nt*	62.2 *nt*	12.5 *nt*	86.8 *nt*
80	9.35	60.9	41.1	269.2

In a fifth test, the simulated noisy *F* data at latitudes ±5° were replaced by simulated noisy *X*, *Y*, and *Z* values. These vector data were treated as in a coupled *X*, *Y*, *Z* analysis. The coefficients that generated the test data were recovered to better than 0.6 nt, the r.m.s. being 0.3 nt.

For the final test of this series, no random noise was used. Instead, a simulated data set was computed from 80 coefficients and this set was analyzed for 63 coefficients. Thus, the contribution to the data set arising from the coefficients of degree 8 represents a sort of systematic noise. The standard deviation of the *F* residuals was 9.8 nt. The *Z* discrepancy was again concentrated along the dip equator and ranged from -563 nt to +282 nt.

Conclusion

The model from the analysis of noisy *F* fails to give the correct vertical intensity in the vicinity of the dip equator, despite its uniqueness with respect to the initial choice. This defect is reduced by including some vector data.

References

Benkova, N. P., S. S. Dolginov, L. O. Tyurmina, and T. N. Cherevko (1971), Comparison between the two satellite models, Izmiran and Pogo, *in* A. J. Zmuda, ed., World Magnetic Survey, 1967-1969, *Intl. Assn. Geomagnetism and Aeronomy, Bull.* 28, 158-163.

Cain, J. C. (1971), Geomagnetic models from satellite surveys, *Rev. Geophys. Space Phys.* 9:259-273.

Fabiano, E. B., and N. W. Peddie (1971), Evaluation of POGO (8/69): Mathematical model of earth's inner magnetosphere, *J. Geophys. Res.* 76:3816-3819. (See also Paper No. 8 of the present Review.)

Hurwitz, L. (1972), A basic flaw in models of the vector geomagnetic field derived from scalar intensity, U.S. Dept. Commerce, NOAA Tech. Rep. ERL 223-ESL 19, pp. 53-56. Supt. of Documents, Washington, D.C. 20402.

6. TIME-DEPENDENT LEAST-SQUARES ESTIMATION OF VERTICAL MAGNETIC DIPOLES AS SOURCES OF THE GEOMAGNETIC FIELD

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Background and Objective

In previous work (Alldredge and Stearns, 1969), the geomagnetic field was fitted by vertical magnetic dipoles, and its 5-yr secular change was described in terms of changing parameters of the dipoles. In the work here reported, we seek to determine the dipole parameters as functions of time over several epochs, in such a manner that interpolation and extrapolation of them will yield successive models that meet two criteria. These are: (1) The residuals will be small at places where the field is known; and (2) the migration and changing strength of the dipoles will describe the observed secular change reasonably well.

It might appear that the scheme already used would suffice, if it were merely applied independently to each epoch. Unfortunately, under this approach the extrapolated secular change for a given 5-yr interval may fail to fit the observed secular change; the r.m.s. residuals may reach 1000 nt, exceeding the secular change itself. To account for this shortcoming, one must examine the mathematical formulation of the problem and the subsequent numerical analysis required for its solution. The fitting requires least-squares solution of a set of simultaneous nonlinear equations, which are sufficiently overdetermined that the incidental errors become significant.

Applicable Techniques

If the model were linear in the parameters to be estimated, the contours of constant r.m.s. residuals would be ellipsoids; but with a nonlinear model the contours are distorted, depending on the severity of the nonlinearity, with constriction in some directions and elongation in others, so that the minimum may lie at the bottom of a long, curving trough. The situation is further complicated by the apparent broadness or flatness in the vicinity of the minimum, allowing some variability in the estimated parameters while the same r.m.s. residual is maintained. This may be inherent in the problem, perhaps owing to loss of precision and round-off errors. To achieve the desired solution, valid as a function of time, we need to accommodate the numerical solutions in such a way as to seek a minimum for each epoch that is in some way dependent on the parameters for previous epochs.

In this study an attempt is made to force into alignment the solutions of the problem at a succession of 5-yr steps, by iterating through time and using for each step estimates of the parameters obtained from the previous epochs. Thus, even though the minima will fall in different neighborhoods for each solution, they may be expected to form a time-dependent progression or alignment, leading to smooth progression of the dipoles on the sphere.

A numerical method (Marquardt, 1963) used in the previous work has been adapted to the present objective, so as to maintain the conditioning of the correction vector for the least-squares surfaces for each epoch under consideration. This is done by constraining the rate of convergence to be the same for all epochs. For a treatment of some of the mathematical detail, see Stearns and Alldredge (1970).

The data used are annual means from 80 observatories, the same selection used by Malin (1969), for the epochs 1942.5, 1947.5, etc., to 1962.5. (As an expedient in the present study, the main-field models as well as the secular-change values are governed by these data, though of course in any definitive treatment the main field should not be constrained solely by observatory data.) The data for 1952.5 were fitted by 21 vertical dipoles, situated at a common depth or radial distance. These dipoles served as initial estimates of parameters for the time-dependent iterations, but the depth was held fixed at its 1952.5 value. After the dipoles for 1957.5 were estimated by one iteration, the 1962.5 initial parameters were obtained by a linear extrapolation of the parameters of the two previous epochs. The iteration was continued with this linear extrapolation. At the end points 1942.5 and 1962.5, the iteration was turned around by using the negative extrapolated values from the previous extrapolation. The iteration at each interval was terminated when the r.m.s. residual became less than for the previous iteration at that epoch, since further iteration would defeat the time-dependent criterion.

Results Anticipated

The results obtained vary with the control exercised on the amount of allowable parameter change at each iteration. If only a moderate rate of constant change is allowed, the migrations of the dipoles do not seem to represent enough movement, but extrapolation for prediction purposes is very good. With parameters permitted to change at a maximum rate, the movement is very reasonable, but extrapolation is poor, being only within about 30 nt r.m.s. of that for the actual computed estimates. The computed r.m.s. values for the two approaches are about the same.

It is expected that an intermediate result can be achieved by suitable control over the rate of convergence of the iteration, so that the results will give reasonable source migrations and predictions.

References

Alldredge, L. R., and C. O. Stearns (1969), Dipole model of the sources of the earth's magnetic field and secular change, *J. Geophys. Res.* 74:6583-6593.

Malin, S. R. C. (1969), Geomagnetic secular variation and its changes, 1942.5 to 1962.5, *Geophys. J.R.A.S.* 17:415-441.

Marquardt, D. W. (1963), An algorithm for least squares estimation of nonlinear parameters, *SIAM J. Appl. Math.* 11:431-441.

Stearns, C. O., and L. R. Alldredge (1970), Convergence of iterative methods applied to large overdetermined linear and nonlinear systems of equations using least squares, U.S. Dept. Commerce, NOAA Tech. Rep. ERL 181-ESL 10, 12 pp., Supt. of Documents, Washington, D.C. 20402.

7. A SCHEME FOR THE RE-EXAMINATION OF THE EARLY SECULAR CHANGE OF MAGNETIC DECLINATION IN THE U. S.

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Shortcomings of Existing Patterns

For the interval from the earliest settlement down to about 1900 or 1905, the existing configurations of secular change of magnetic declination in the conterminous United States (as reflected in published tables and identically in the current computer programs) come from analyses that were done in the late 1800's by C. A. Schott. They embody an inherent constraint which, though reasonable for its time, has not been found valid in studies of recent intervals.

Schott's procedure was consonant with the limitations of the available data in the light of the then-prevailing concepts of secular change as being dominated by periodic influences. He assembled for a given local region the observed values of declination over the longest possible interval, and subjected them to a least-square reduction to obtain the trigonometric curve of best fit to all the data (with appropriate weighting) in that region. Under this approach, the available data were wisely not deemed to be sufficiently voluminous to warrant fitting functions with more detail than a simple sine curve. Each locality was treated independently of the others, and the procedure led to some rather large differences in secular-change rates at places not very far apart.

It has long been evident that the tables generated by the foregoing procedure fail to conform with our present understanding of the secular change in terms of spatially smooth isoporic patterns; hence, a chief objective of any new analysis should be to increase *spatial* smoothness but to discard the unsatisfactory former desideratum of extreme *temporal* smoothness. This objective has already been achieved for the more recent decades, in which the data were more plentiful and were treated by D. L. Hazard and his successors using a cartographic smoothing scheme.

Selection of a Technique

Several possible approaches might be considered for the older intervals. One method would involve reformulating Schott's localized curves of secular change in an effort to achieve greater temporal detail in each curve. But the data limitations (spottiness and noise) might well cause some spurious detail to appear and would almost certainly necessitate a degree of smoothness that would suppress some genuine temporal features, so that some of the information in the data would be ineffectual, and the shortcomings of the existing tables would be only partially overcome, if at all.

Another scheme would amount to spatial analysis of all the data, allowing the coefficients to change with time as in Cain's treatment of satellite data. But the data we must use, unlike Cain's, are sparsely and unevenly scattered for the earlier epochs, with a distribution that changes markedly with time; hence, such a treatment would likewise tend to obliterate short-term temporal fluctuations in the secular change (seeing especially that it would not give particular consideration to the data that are explicitly pertinent for secular change) and further would be likely to cause spurious secular-change features to appear, which would merely reflect the shifting patterns of data concentration.

A procedure is being developed to minimize these problems. The well established secular-change pattern for a selected 5 or 10 yr interval--the earliest such interval for which secular change is known from ample data--is to be modified for successively earlier intervals on the basis of less-voluminous but still pertinent paired sets of observations. Adjustment is contemplated to cause the cumulative changes for any sequence of short intervals to conform with appropriate long-term data that cannot be otherwise utilized. It is expected that most of the data assembled by Schott's efforts can thus be brought to bear on a modernized analysis of secular change, using a sort of computerized analogue of Hazard's cartographic approach. Corrections are contemplated to adjust the data for the effects of regional gradient and (using newer distribution data) for the contaminating influence of local anomaly, since in many cases the paired stations will not be identical in position. Substantial improvement in the older isoporic patterns is anticipated, even though it is clear that the data will not afford the same accuracy that was achieved in Hazard's work on later decades.

8. THE EVALUATION OF THREE SECULAR-CHANGE MODELS

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One of the classic difficulties in constructing accurate models of geomagnetic secular change has been posed by the irregular spacing of the data, particularly the spatial data gaps in the oceanic and circumpolar areas. It is hoped that satellite-borne magnetometers, affording global coverage in a matter of weeks, will ultimately solve this problem. Meanwhile, for surface and near-surface uses we continue to rely on the observatory annual means and (where necessary) on repeat-station data, as the standard for deriving global secular-change models and determining their accuracy. Consequently, a major criterion in this evaluation of models is the closeness of their fit to the rates of secular change derived from the curves of observatory annual means. A secondary criterion will be the agreement of a given model with other available ones. It is of special interest to express discrepancies in terms of cumulative errors over a 5 or 10 yr interval. We are still, of course, faced with the difficulty, sometimes the impossibility, of verifying the accuracy of models in regions distant from observatories and where there are large data gaps. But if a model displays broad patterns of high residuals near observatories, it is resonable to conclude that the model is defective in this respect.

Among the several extant models of secular change, three of special interest are evaluated here: The International Geomagnetic Reference Field (IGRF) for 1965; POGO 8/69; and the American World Chart model (AWC 70) for epoch 1970. All of these were derived by spherical harmonic analysis with first-derivative time terms--that is, the secular change is taken as linear over the entire stipulated interval of 5 yr or so. Both the IGRF and the AWC 70 models are of degree 8 (80 coefficients); POGO 8/69 is of degree 10 (120 coefficients) and was derived entirely from scalar (total-intensity) measurements made by satellites OGO 2, 4, and 6 during the interval from May 1965 through October 1968.

The secular-change charts for these models (not shown here) have several interesting features, especially those for rate of change of vertical intensity. In general, we note relatively low rates of change on all three charts between 40° and 80°N, and somewhat higher rates south of 40°S. The major differences appear in the midlatitudes, particularly when we compare POGO 8/69 with either AWC 70 or the IGRF. Numerical comparisons of calculated values from each model with the observatory data show up these and other differences more clearly. For AWC 70, it was found that $\Delta\dot{Z}$ was less than 25 nt/yr for *all* observatories. As to the other two models, Figures 1 and 2 show the distribution of $\Delta\dot{Z}$, which equals $\dot{Z}$(OAM) minus $\dot{Z}$(model). In figure 1, we note for the IGRF almost a dozen observatory locations where these $\Delta\dot{Z}$ residuals range upward from 25 nt/yr with a maximum of 55 nt/yr.

In figure 2, note that POGO 8/69 shows a predominance of relatively high residuals, all 65 nt/yr and more, in the region of the magnetic dip equator. A comparison of these residuals for points in the vicinity of the major POGO foci is shown in table 1, which also includes values of $\Delta\dot{I}$ and $\Delta\dot{H}$, the differences in the rates of change of dip and horizontal intensity. Here the good fit of AWC 70 is clearly shown, whereas the large discrepancies, particularly for the POGO 8/69 model, now appear to be very significant. For example, if one wishes to compute the secular change for a 5 yr interval in the region of Tatuoca, discrepancies of 1.5° in dip, 200 nt in horizontal intensity, and more than 700 nt in vertical intensity are indicated.

The magnetic declination is important for land-survey and navigational needs, so we need to know how well its secular change is described by the models. Figure 3 shows $\dot{D}$, the annual change of magnetic declination, from two of the models and from the U.K. world chart for 1970. The IGRF plot (not shown) compares well with the U.K. and AWC 70 plots. Here the discrepancies in the POGO model, for several regions in 10°N latitude, amount to accumulated differences of more than one-half degree over a 5 yr interval.

To summarize these evaluations:

(1) POGO 8/69 does not give reliable secular-change information for the vector components near the earth's surface. It has been suggested that special analytic solutions which take into account "noise" in the raw

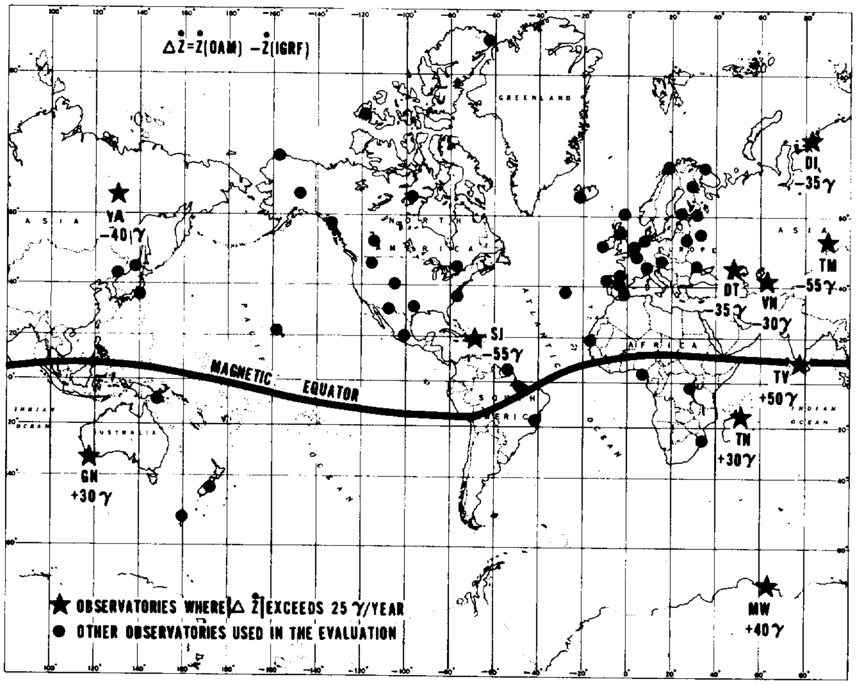

Figure 1. Distribution of Ż residuals (Observatory minus IGRF) in nanoteslas per year (γ/yr).

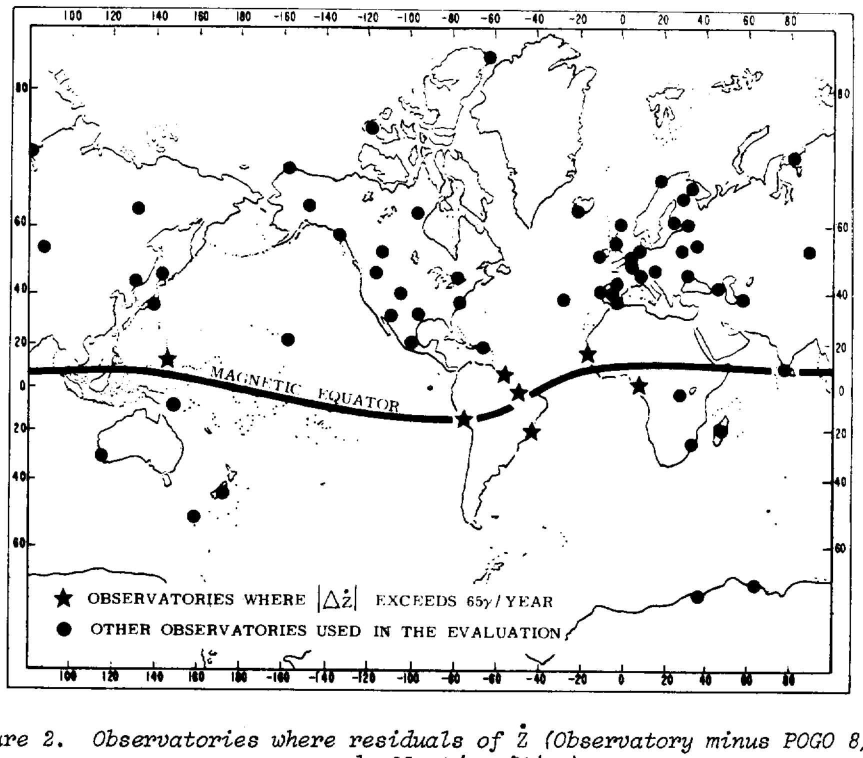

Figure 2. Observatories where residuals of Ż (Observatory minus POGO 8/69) exceed 65 nt/yr (γ/yr).

Table 1. Differences in Rates of Annual Change, OAM minus Model

	$\Delta\dot{I}$ *min/yr*			$\Delta\dot{H}$ *nt/yr*			$\Delta\dot{Z}$ *nt/yr*		
	POGO	IGRF	AWC	POGO	IGRF	AWC	POGO	IGRF	AWC
M'Bour	15	1	1	-28	5	9	129	-8	-6
Guam	7	0	1	-4	0	7	66	-3	6
Paramaribo	10	-1	0	51	-19	-2	-72	-11	4
Moca	8	-3	0	31	-2	0	78	-25	5
Tatuoca	-18	-1	1	40	-18	4	-143	-14	0
Vassouras	-16	1	-2	-38	6	17	-112	2	0

data might yield more accurate models. Some investigators, in ERL and EDS, are thinking about this approach. On the other hand, it has been suggested that if vector data rather than just total intensity were measured by satellite magnetometer, the resulting secular-change model would most likely be improved.

(2) For the IGRF, as has been pointed out elsewhere, several factors have conspired to make this model less accurate in secular change than had been anticipated. It is the mean of five other models of different degrees, some with both first and second time derivatives, each of which used a different data set for the analysis. As a result of averaging only the first 80 linear coefficients, an extra set of time derivatives for two of the constituent models had to be ignored, as well as ninth- and tenth-degree terms of one of the sets. Two other models had coefficients only to degree six, hence they made no contribution to the last 32 coefficients of the finally adopted degree-eight model.

(3) Finally, these comparisons have provided additional checks on the accuracy of the American World Chart model. These show that on the basis of available data and for near-surface uses, secular change computed from this model is more reliable and accurate than that from either the IGRF (1965) or POGO 8/69.

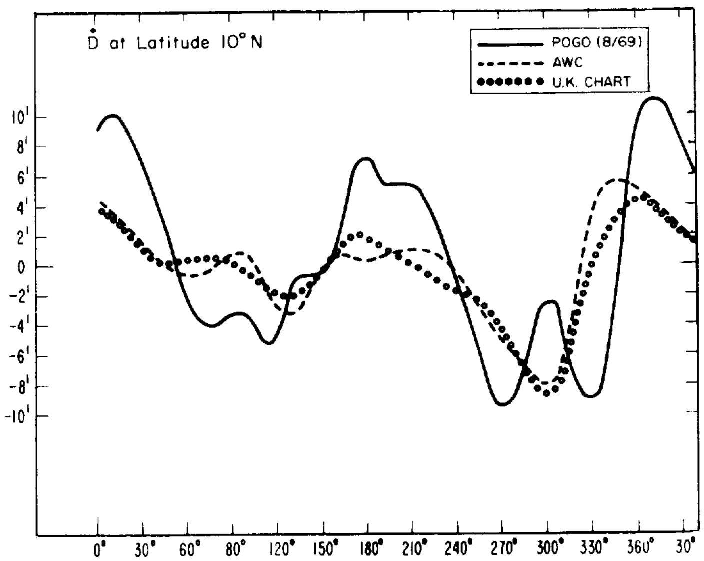

Figure 3. Annual change of magnetic declination (minutes/yr) according to three models.

9. RELATIONS BETWEEN GEOMAGNETIC MICROPULSATIONS OBSERVED SIMULTANEOUSLY IN THE MAGNETOSPHERE AND ON THE GROUND

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During the past decade, much study has been devoted to the function of ULF (ultra low frequency) waves in the physical processes occurring within the magnetosphere. A number of recent theoretical papers suggest the roles that such waves play in the dynamic behavior of radiation-belt particles, and they all emphasize the importance of knowing the characteristics of ULF waves in the magnetosphere. Ground-based studies provide an economical and flexible basis for studying the magnetospheric population of waves, but to test the theories and to determine the actual character of the waves, we must also study the waves *in situ* where they are presumed to originate. And to use the ground-based observations in the most meaningful way to study magnetospheric phenomena, we must carefully examine the relationships between the magnetospheric and ground observations. It must be remembered that ground-based observations are modified in complex ways by both ionospheric and ground currents, and the waves may be altered or reflected during their propagation from the equatorial region of the magnetosphere to the ground. It is thus clear that any opportunity to study correlated wave events in the equatorial region of the magnetosphere and on the ground affords valuable insight into the relations between the physical processes in the magnetosphere and their manifestations on the ground.

The most convenient way of characterizing such relations between magnetospheric and ground observations is by invoking the concept of a transfer function. Figure 1 schematically reviews the definition of a transfer function. The left panel shows the generalized situation, where an input $I(t)$ is subjected to an operation $T(\omega)$ to produce output $O(t)$. If one knows the transfer function of the process, the output may be determined for a known input. Conversely, given an output signal, we may then reconstruct the input signal.

The right panel gives the specification of the transfer function for the magnetospheric problem. A vector perturbation $\mathbf{B}_e(t)$ travels down the field line and is observed on the ground as a (modified) perturbation $\mathbf{B}_g(t)$. As vector quantities, the perturbations are related by a transfer matrix $T(\omega)$. Then knowing the transfer matrix $T(\omega)$, we may map the ground perturbation back to the equatorial region of the magnetosphere and reconstruct

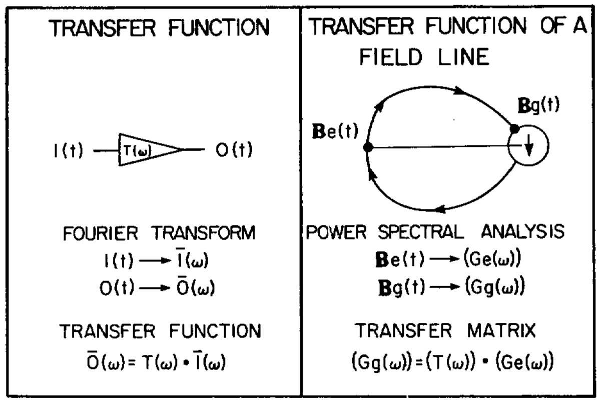

Figure 1. Definition of a transfer function.

the original perturbation. However, before a proper application of the transfer-matrix method can be made, certain complications must be compensated for. First, a given observation in the magnetosphere may be located anywhere within the flux tube containing the perturbation. Then the ground station observing the perturbation is also at an unknown location with respect to the flux tube and the adjoining ionospheric waveguide. (The magnetosphere-ground system is depicted in Figure 2). In addition, superimposed lower-frequency perturbations may move the flux tube

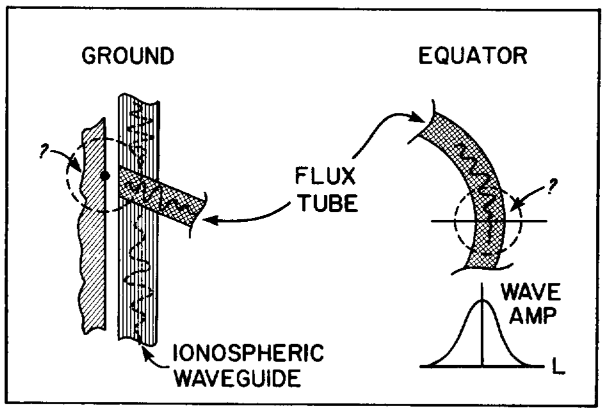

Figure 2. A flux-tube transition from magnetosphere to ground.

in the magnetosphere, so that the observing satellite may in effect move into and out of the region of interest. In view of the above complications, it is only by an orderly study of many coincident ground-magnetosphere events that we can definitively characterize the ground-magnetosphere transfer function.

The NOAA network of ground observatories provides an ideal data base for studying micropulsations. Several correlative studies are now under way, using the NOAA observatory data in conjunction with satellite observations in the magnetosphere. The studies cover the entire spectrum of micropulsation phenomena, and the results will be reported in a forthcoming series of papers.

10. THE AE INDEX-THE CONCEPT, SOME PROBLEMS, AND POSSIBLE IMPROVEMENTS

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Background

The Auroral Electrojet (*AE*) index was devised by T. N. Davis and M. Sugiura in 1966 to quantify geomagnetic activity in the auroral zones, particularly the effect of enhanced current in the eastward- and westward-flowing auroral electrojets. Such enhancements, intimately related to solar activity, are characteristic of magnetospheric substorms. At times, a surge of solar activity may increase the flux of particles in the solar wind, invert the north-south component of the interplanetary magnetic field, propagate a shock wave through the solar plasma, and cause a breaking and reconnection of geomagnetic field lines. This produces a complex system of magnetospheric and ionospheric electric currents. The earth's dipolar magnetic field serves to map the active, trapping region of the disturbed magnetosphere onto the polar ionosphere and upper atmosphere. This disturbed region of sun-earth coupling forms a band encircling each of the polar regions--the instantaneous auroral oval. Ionospheric auroral electrojets flowing along or just within this oval are the primary source of those surface magnetic fluctuations that are used to derive AE.

A high-latitude magnetic observatory in the early-morning sector near geomagnetic midnight will usually lie beneath the westward-flowing auroral electrojet and will record the effect of an enhancement in this ionospheric current as a negative magnetic bay in the horizontal field (H). A station in the evening sector, beneath the eastward electrojet, will show a corresponding increase in H above its quiet-time level. If at a given instant one could measure H at all points on the surface around the auroral oval and could subtract from each measured value the known quiet-time value at that location, then the range in the departures of H values from their respective undisturbed levels would be *AE* at that instant. In practice one can only derive a best estimate of *AE* from the records of a select group of high-latitude observatories.

Procedural Details

For the derivation of 1970 *AE*, we selected a network of 11 stations in the zone between 60° and 70°N geomagnetic (dipole) latitude. They were: Leirvogur, Narssarssuaq, Great Whale River, Fort Churchill, College, Barrow, Cape Uelen, Tiksi Bay, Cape Chelyuskin, Dikson Island, and Abisko. The H magnetogram traces from these observatories were digitized at 2.5-min intervals. A monthly reference level of H was computed for each station from values on the five international quiet days of each month. These quiet-day monthly means were subtracted from all the 2.5-min values, leaving a set of 11 time series $\Delta H(t)$. Superposition of plots of these 11 series yields a pattern of interwoven lines, contained between the upper and lower envelopes formed by the extreme values of ΔH. In the absence of other sources of magnetic fluctuation, the upper envelope amplitude (*AU*) is a measure of the current flowing in the eastward electrojet; and the lower amplitude (*AL*), that in the westward electrojet. Their difference (*AU* minus *AL*) is defined as *AE* for that instant. Another index *AO*, the mean of *AU* and *AL*, is related to the effect of the magnetospheric ring current at the auroral zones.

Both the latitude and longitude distributions of contributing stations are important. An event of short duration or limited spatial extent will be missed or imperfectly recorded if it affects only a segment of the electrojet falling between two stations. The largest longitude gaps in the 1970 *AE* network are between Fort Churchill and College and between Cape Uelen and Tiksi Bay. Also, expansion or contraction of the auroral oval with changing levels of activity may sometimes move it either below or poleward of the ring of stations used to derive *AE*. For this reason, the ideal station network would form a pattern of alternately higher and lower upper-latitude stations. In future *AE* derivations, we hope to supplement the 1970 network with meridional chains of stations.

As the 2.5-min *AE* indices are derived, they are plotted on daily graphs (see fig. 1). The pattern of three small discrete events followed by a larger substorm of 24 February 1970 is particularly well defined; it is the only such sequence of distinct substorms encountered during any day of 1970. (One similar day was noted in reprocessing 1965 *AE*.) The preceding day was the quietest of the month in terms of *AE*, although it was not one

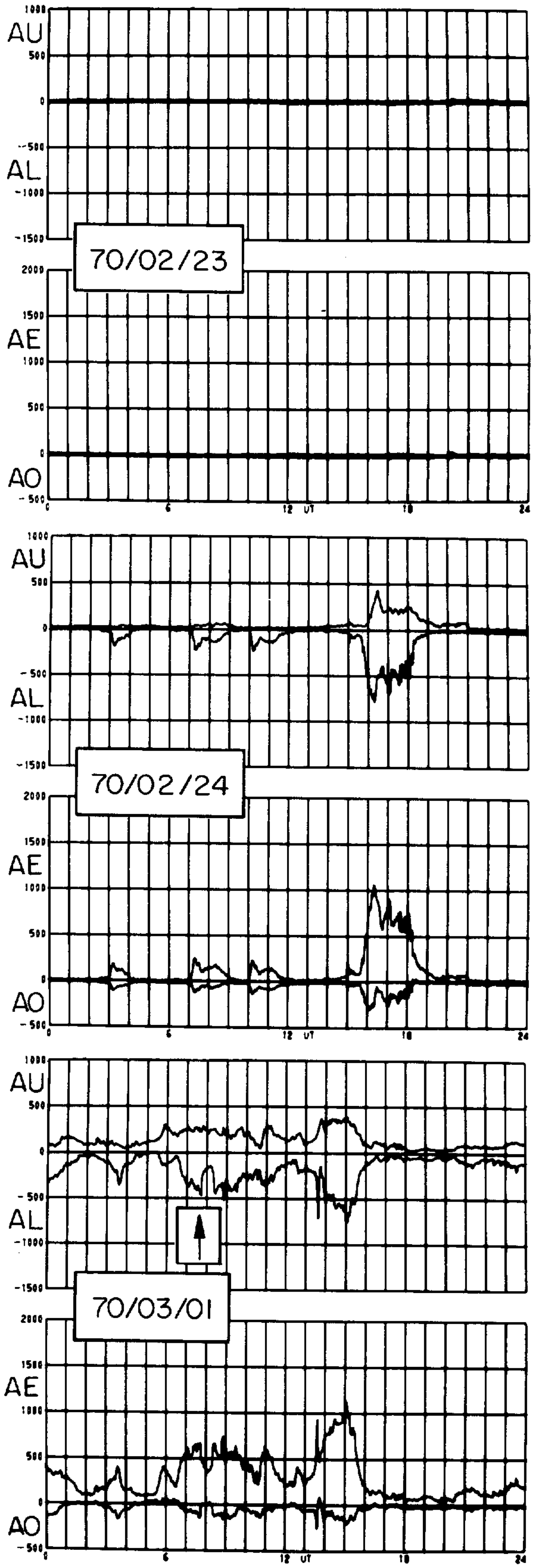

Figure 1. Daily graphs of AE indices. Ordinates in nanoteslas.

of the five international quiet days. We are studying features which might distinguish a quiet-*AE* day from a quiet day chosen on the basis of *Kp*.

Problems and Prospects

For any of several reasons, data may be missing from the magnetograms of a critically situated station, resulting in a "missing-data effect" as illustrated by the third day shown in figure 1 (see arrow). During the great magnetic storm of 8 March, we were reduced to deriving *AE* from a severely biased group of three stations, all in the western hemisphere.

Lack of calibration data for an observatory may preclude its use in computing *AE*. During the first week in January 1970, one station had a drifting *H* trace that led to erroneous initial values of *AE*, some 60 to 100 nt above their proper values for that week. Having neither calibration data nor auxiliary (storm) magnetograms for that station, we could only reject its data from our final derivation. After a 2-day interval of largely blank magnetograms, subsequent records showed the *H* variometer restored to operation with a stable base-line value, enabling the station to be used for the remainder of the year.

Another area of research for improving *AE* involves a study of the frequency with which each station contributes *AU* and *AL* values. Preliminary results confirm the latitude effect already mentioned; furthermore, we have encountered an apparent longitude or universal-time dependence as well.

This summary is based on a longer publication (Allen, 1972). We solicit response from users concerning further improvements in *AE* and inquiries as to the availability of the indices on magnetic tape or microfilm.

Reference

Allen, J. H. (1972), Auroral electrojet magnetic activity indices (AE) for 1970, U.S. Dept. Commerce, NOAA-EDS, WDC-A for Solar-Terrestrial Physics, Report UAG-22, Asheville, N.C. 28801, 146 pp.

11. THE PROLIFERATION OF GEOMAGNETIC ACTIVITY INDICES

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The title of this paper has a deliberately negative connotation, suggesting that too many indices are being circulated. Table 1 lists for each index its general purpose, its time resolution, the interval for which computations have been made, the magnetic observatories used in its derivation, and the sponsor or source of the index. There is obvious redundancy among many of the indices. For future research, there is a need for indices even better than those here listed. As an example, thus far we have none based on satellite data, though it is sometimes asserted that ground-based indices can monitor events at satellite altitudes.

The Moscow IUGG Assembly of 1971 included a symposium at which both current and proposed indices were discussed. Commission IV recommended changes in the content of the IAGA Bulletin 12 series (now the Bulletin 32 series.) Table 1 indicates which of the indices are currently so published.

At World Data Center A for Solar-Terrestrial Physics, we have files of most of the listed indices. Some are available not only in tabular form as single sheets or in publications, but also on microfilm or magnetic tape.

In the literature, it would appear that the indices most used are *AE*, *Dst*, *Kp*, and *Ap*. There is some reason to believe that *Kn*, *Ks*, *Km*, and *Aa* would be better for some correlations, because the stations are in middle latitudes and are more evenly spaced in longitude than the *Kp* stations. The *AE* index is valuable for auroral-region activity. *Dst* is used for indicating the ring-current disturbances, and especially for pointing out the main phase of individual storms.

There is growing interest in monitoring the sector crossings of the interplanetary field, and in the development of indices based upon solar-wind parameters.

Table 1. Geomagnetic Indices

Index	Purpose	Time Resolution	Interval Available	Number or Location of Stations	Sponsor or Source
AE	Substorm (auroral zone)	2.5 min or hourly	1957--1968 1970	11 (Northern auroral zone)	IAGA†
Dst	Ring current	hourly	1957--1970	Hermanus, Honolulu, San Juan, Kakioka	IAGA*
K	Individual station variation	3-hourly	1932 to date	All	IAGA
Kp	Planetary incidence of solar-wind particles	3-hourly	1932 to date	12	IAGA*†
Kn	Northern-Hemisphere activity	3-hourly	1964--1967 1969 to date	11	Mayaud *
Ks	Southern-Hemisphere activity	3-hourly	1964--1967 1969 to date	7	Mayaud *
Km	World-wide activity	3-hourly	1964--	18 (see *Kn* and *Ks*)	Mayaud *
Q	Individual stations, high-latitude (limited number)	15-min	1957 to date	Sodankyla and others	IAGA
ak	Station activity on linear scale	3-hourly	1932 to date	All	IAGA
Ak	Station activity on linear scale	daily	1932 to date	All	IAGA
ap	World-wide activity on linear scale	3-hourly	1932 to date	see *Kp*	IAGA *
Ap	World-wide activity on linear scale	daily	1932 to date	see *Kp*	IAGA*†
Aa	World-wide activity, antipodal stations	daily	1959--1967	Toolangi and Hartland	Mayaud
C	Character of days, individual stations	daily	1884 to date	All	IAGA
Ci	Character of days, international mean	daily	1884 to date	All	IAGA*†
Cp	World-wide activity	daily	1932 to date	see *Kp*	IAGA*†
C_9	World-wide activity	daily	1932 to date	see *Kp*	IAGA†
W	Intensity of equatorial electrojet	monthly	1922--1939	Huancayo	Bartels
u	Ring current	monthly	1872--1949	Equatorial stations	Bartels
u_1	Ring current (very severe storms removed)	monthly	1872--1930	Equatorial stations	Bartels
ΔHi	Station activity	hourly	1960-- ?	Huancayo	Chernosky
R	High-latitude variations	hourly	1964--1965	>65° Geomagnetic latitude	IAGA
Pc1	Pulsations	each event	1957--1968	Irkutsk	Sib. IZMIR Irkutsk
Sector crossings	Measures interplanetary magnetic field	calendar date	1972--	Thule, Resolute, Vostok	Wilcox
δ_H	Solar-wind particles	daily	1934--1967	7 Arctic, 5 Antarctic	AANII, Leningrad

† Published by EDS
* IAGA Bulletin 12 or 32

12. GEOMAGNETIC INFORMATION FOR INTERDISCIPLINARY STUDIES OF SELECTED COSMIC EVENTS

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Introduction

World Data Center A for Solar-Terrestrial Physics (WDC-A, STP) now encompasses the well known World Data Center A for Geomagnetism and thus collects and archives many kinds of geomagnetic data. Data are held from approximately 185 ground observatories, including microfilmed standard and rapid-run magnetograms, hourly values, and other data and indices reduced from the magnetograms and absolute observations. The Data Center also holds micropulsation data from many other ground-based stations and maintains records as well on related data held elsewhere, such as those on satellite observations of micropulsations and magnetospheric particles, and measurements of the magnetosphere by whistlers and VLF emissions, which are all held at WDC-A for Rockets and Satellites, NASA, Goddard Space Flight Center, Greenbelt, Maryland.

Data Catalogue

The Catalogue of Data on Solar-Terrestrial Physics of July 1971, UAG-15, lists the data holdings of the WDC-A, STP, as well as those of satellite data at WDC-A for Rockets and Satellites. It is soon to be superseded, however, by the 1972 issue. Users may obtain copies on request.

Monthly Publications

The Data Center publishes on a monthly schedule Part I (Prompt Reports) and Part II (Comprehensive Reports) of the "Solar-Geophysical Data" series. A Descriptive Text issued each February describes the data compiled in those reports, which contain geomagnetic information of interest to the scientific community.

Part I of "Solar-Geophysical Data" includes compilations for one and two months prior to publication data. The section for data one month previous contains Alert Periods issued by the Western Hemisphere Regional Warning Center of IUWDS, and also World-wide Geophysical Alerts. These include forecasts of geomagnetic storms or indicate that a storm was in progress on a certain date. As appropriate, the report may designate the storm as major ($Ap > 50$) or great ($Ap > 100$), and may indicate if unusual aurora was expected. This first section includes also interplanetary magnetic-field measurements from the Pioneer 8 and 9 magnetometer experiments, which are received from the NASA Ames Research Center; details are given in the Descriptive Text.

Two months after the month of observation, a table of geomagnetic activity gives the indices *Kp*, *Ci*, *Cp*, and *Ap* (see J. V. Lincoln, Paper 11 of this conference). The same table lists selected quiet and disturbed days. These data likewise appear in the Journal of Geophysical Research four months after the month of observation, along with the Ottawa solar flux measurements at 2800 Mhz and the Provisional Zürich Sunspot Numbers.

This section also contains a chart of *Kp* by solar rotations, received from Göttingen and usually showing eight rotation periods. The table of *Ap* indices for the previous 12 months, appearing below the chart, shows trends in magnetic activity. A graph of *Kp* for the entire year is published annually, along with a chart of the daily geomagnetic character figures *C9* and the 3-day mean sunspot numbers *R9*, likewise by solar rotations.

A list of principal magnetic storms published in "Solar-Geophysical Data" contains data from many observatories, grouped by storm. Another table presents sudden commencements and solar-flare effects as compiled by Father A. Romaña, using data from the world-wide network of magnetic observatories.

Reduced magnetograms prepared by S. I. Akasofu of the Geophysical Institute at College, Alaska, appear in Part II of "Solar-Geophysical Data" six months after the month of observation. For selected events they show the *H*-component traces from several observatories, all reduced to the same sensitivity and time scale. Since but few interesting events have occurred recently, the latest reduced magnetograms (for an event in December 1971) appeared in the June 1972 issue.

Upper Atmosphere Geophysics Reports

WDC-A, STP also publishes, on an irregular basis, Upper Atmosphere Geophysics (UAG)

Reports, with a varied content including the data catalogue mentioned earlier. Among the 19 UAG Reports thus far issued, six have covered geomagnetic storms, one being a three-volume compilation that dealt with the storm of March 8, 1970. J. H. Allen's discussion of *AE* indices (Paper 10 of this conference) involved magnetograms of that data which went off scale and presented data-reduction problems. In general, such UAG reports contain historical accounts of solar events, beginning with the development on the solar surface of the active region responsible for large particle-emitting flares, which then produce various geophysical phenomena. We are now compiling a report on the ground-level cosmic-ray increases of January 24 and September 1, 1971, and related geophysical phenomena, treated separately and by comparison.

Our latest UAG Report on magnetic phenomena (UAG-18), published in June of this year, is a study of polar-cap and auroral-zone magnetic variations by Kawasaki and Akasofu. It presents reduced magnetograms and AE indices for nine *DP-2* days in 1965.

The Data Center invites inquiries by letter, phone, and visit regarding its data holdings and publications. Contributors and users of the data on solar-terrestrial phenomena are welcome to make use of these facilities.

13. MAGNETIC SURVEYS IN THE EPICENTRAL AREA OF THE SAN FERNANDO EARTHQUAKE

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Background of Seismomagnetic Effect

Rikitake (1968) cites several instances of possible seismomagnetic change, some dating back to 75 yr ago, but finds most of them unconvincing; he notes that the magnitudes diminish steadily and radically with improved measurement techniques. Registrations extending over several years near the San Andreas fault have shown slight changes, possibly correlated with creep events and small earthquakes (Breiner and Kovach, 1968). Theoretical work (Talwani and Kovach, 1971) indicates that only 1- to 2-nt changes would have been likely to accompany those events. Though some of the existing data are highly suggestive, many seem equivocal. In Paper 15 of this conference, Hasbrouck and Allen report a 9-nt change observed at the time of and 3 km from an underground explosion.

Description of Surveys

This report compares a total-intensity survey made two weeks after the San Fernando earthquake of February 9, 1971 (M = 6.6) (O'Donnell and Kaufmann, 1971) with a similar repeat survey of April 1-7, 1972 (O'Donnell and Kaufmann, in press). For the initial survey, a base station monitored the total (scalar) intensity continuously, using a fluxgate instrument, and 32 other sites were occupied with an Elsec proton magnetometer as intended repeat stations. For the 1972 survey, a proton magnetometer with analog recording was used at the base station, and the occupations of repeat stations included a determination of the vertical gradient of scalar intensity at each site. At 20 of the sites, the gradient was so large (probably an account of magnetic inclusions in the station markers) that the expected error was unacceptable and it was necessary to reject the results obtained at these sites.

The standard deviation applicable to observations at a given site was ±1.7 nt, as determined by means of multiple observations at three different sites. The transient fluctuations were removed by referencing all measurements to the base station; however, very little activity other than ordinary daily variation was recorded during the actual time of the repeat observations. A recording for a typical day of each survey is shown in figure 1.

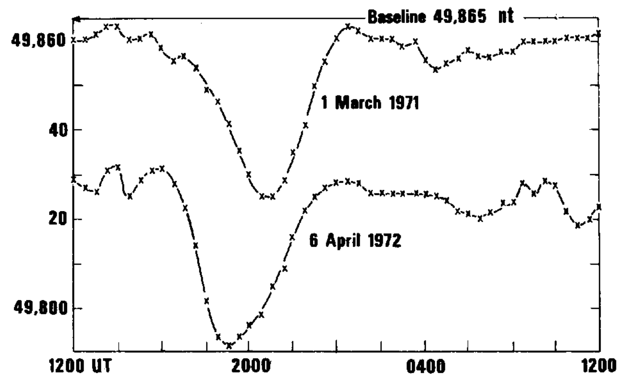

Figure 1. Typical recordings of scalar intensity at base station.

Discussion and Conclusions

Three sources of error in the measurements were high gradients, localized magnetic fields caused by unbalance currents in a 750-Kv d-c transmission line, and lateral inhomogeneity of the transient fluctuations. The first two effects were computed to be less than the standard deviation, while the third was estimated to be likewise negligible, as discussed in the longer report (O'Donnell and Kaufmann, in press).

During the 1971 survey, a 14-nt change took place between February 24 and March 3 at the Sand Canyon site, only 600 m from the base station. Within this interval at least nine aftershocks occurred in the epicentral vicinity, with magnitudes from 3 to 3.7 (Allen et al., 1971). The piezomagnetic effect requires a rock type with high magnetic susceptibility, but these two sites overlie 150 m or more of sedimentary formations; hence the 14-nt change would signify a much larger change closer to the igneous rock. Some of the sediments in the area could perhaps have a high susceptibility. The only known previous local magnetic survey in the area encompassed a tract of about 60 by 600 m, some 5 km south of our epicenter; the vertical component showed local irregularities of more than 5000 nt, thus indicating very high susceptibilities (Dehlinger, 1943). Another indication of this is the existence of numerous magnetite mines in the region. Furthermore, it has been estimated (Oakeshott, 1958) that this area contains California's largest known reserves of titanium ore, implying rock types with very high susceptibilities.

The repeat sites were rather closely clustered, so that they underwent a sensibly uniform but undifferentiated secular change, which must have combined with the presumably nonuniform seismomagnetic effect and with the errors already discussed to generate the observed differences between the values found in the two surveys. As an expedient for suppressing most of the uniform constituent, the change observed at the base station was in effect subtracted from those at the repeat sites to determine the final differences. These differences, shown in figure 2, range between -26 nt and -7 nt (exclusive of the base station). The change observed at the base station differs from that at the nearest repeat site by 23 nt, perhaps partly because of a lateral displacement of the base station between the two surveys (about 1 m). The secular change is provisionally estimated as -34 nt on the basis of the AWC 70 model promulgated in conjunction with NOAA's Environmental Data Services (see Paper 8 of this conference). In any event, the 19-nt spread between the two extreme values at repeat sites, as well as the 14-nt change detected during the first survey, is large enough to indicate a seismomagnetic effect. The probability that our observations could be repeated in the two surveys within ±5 nt is 99.7 percent, assuming a normal error distribution; hence the observed differences show a spread large enough to warrant further surveys.

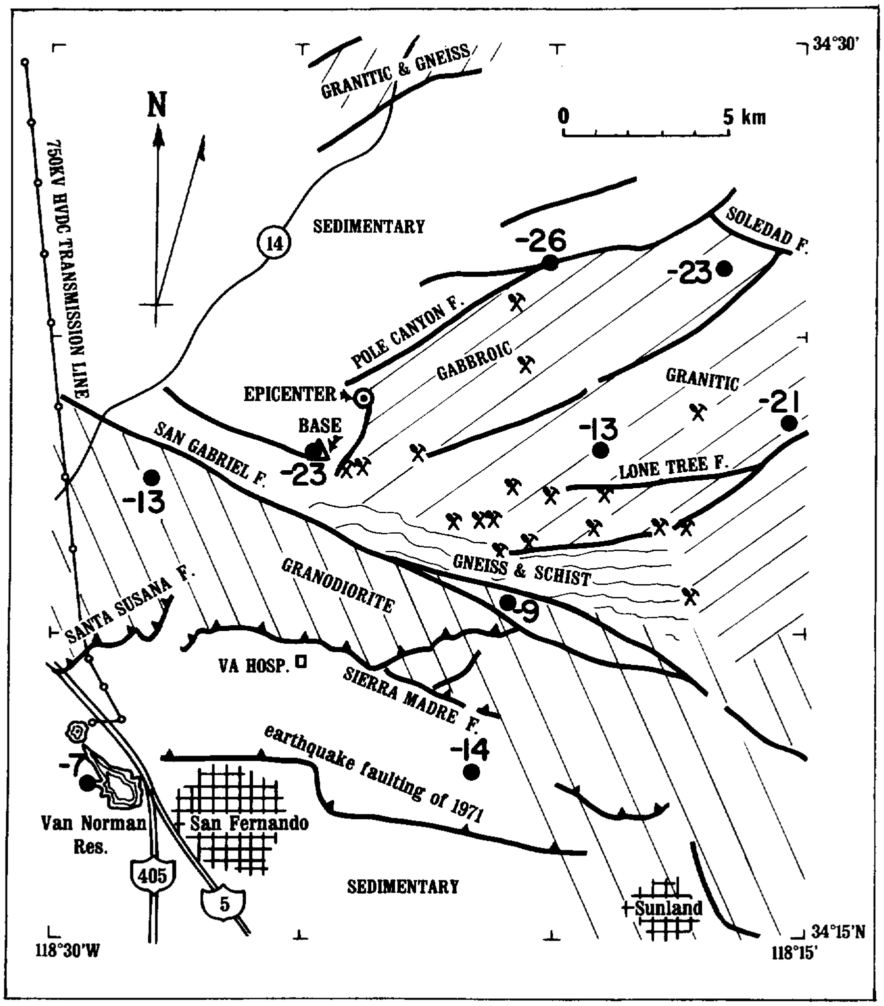

Figure 2. Map of survey area, modified from Oakeshott (1958 and 1971), with magnetic field changes indicated (see text).

It is recommended that other areas of high seismicity and susceptibility be similarly surveyed. The surveys could be repeated regularly and after seismic activity. If enough stations are used, the results could be interpreted quantitatively in terms of stress and rock magnetization. The repeat surveys should show areas where continuous magnetic recordings would be most useful for seismomagnetic detection. If such an effect is confirmed, one application would be the indirect measurement of creep or strain deep within the crust.

References

Allen, C. R., G. R. Engen, T. C. Hankes, J. M. Nordquist, and W. R. Thatcher (1971), Main shock and larger aftershocks of the San Fernando Earthquake, February 9 through March 1, 1971, *in* The San Fernando, California, earthquake of February 9, *U.S. Geological Survey Prof. Paper* 733, pp. 17-20.

Breiner, S., and R. L. Kovach (1968), Local magnetic events associated with displacement along the San Andreas Fault (California), *Tectonophysics* 6:69-73.

Dehlinger, P. A. (1943), A magnetic survey of Sand Canyon for placer deposits, San Gabriel Mountains, California, California Inst. Technology, M.S. Thesis (unpublished), pp. 1-21.

Oakeshott, G. B. (1958), Geology and mineral deposits of San Fernando Quadrangle, Los Angeles County, California, *Calif. Div. of Mines Bulletin* 172:1-147.

Oakeshott, G. B. (1971), The geologic setting, *California Geol.* Special Ed., April-May, 69-72.

O'Donnell, J. E., and H. E. Kaufmann (1971), Magnetic field survey of the San Fernando earthquake epicentral area, *in* The San Fernando, California, Earthquake of February 9, 1971, *U.S. Geological Survey Prof. Paper* 733, pp. 157-160.

O'Donnell, J. E., and H. E. Kaufmann (in press), Repeat magnetic field survey of the San Fernando earthquake epicentral area, *in* L. M. Murphy, Scientific coordinator, San Fernando, California, Earthquake of February 9, 1971, vol. 3, Geological and Geophysical Studies, U.S. Dept. Commerce, NOAA, ERL, Washington, D.C. 20402, Supt. of Documents.

Rikitake, T. (1968), Geomagnetism and Earthquake Prediction, *Tectonophysics* 6:59-68.

Talwani, P., and R. L. Kovach (1971), Theoretical studies and analysis of data from the San Andreas magnetometer array, Final Rept. E22-85-70G prepared for U.S. Dept. Commerce, NOAA, ERL, Boulder, Colo., 14 p.

14. PROGRESS REPORT ON DIMINUTION OF GEOPIEZOMAGNETIC NOISE DUE TO DAILY VARIATION

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and

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In the search for a magnetic-field expression of Aleutian strain episodes, total-field magnetometers were operated almost continuously from mid-September to mid-November 1971 on Amchitka Island, Alaska (fig. 1). At the Northwest and Southeast magnetic stations, located within several hundred meters of the similarly named NOAA--Colorado School of Mines strainmeter installations, magnetometers of 1/8 nt sensitivity were used. The Rifle Range magnetometer station was approximately 1 km WSW of the Galion Pit strainmeter site. Magnetometers of 0.5-nt sensitivity were operated there and at the Ben's Corner location. Digital data were acquired at all stations, and calibrations showed them to be accurate within 0.1 nt.

Upon our return to the Boulder Laboratories, these data were edited and conditioned for computer processing. Figure 2 shows the results obtained for October 19 at the Ben's Corner (upper trace) and Rifle Range (middle trace) stations. The lower trace is the synoptic difference amplified by a factor of two.

Characteristically, longer-period effects were not entirely removed by simple differencing. For example, differences in total magnetic field between station pairs exhibited interstation daily variations averaging approximately 13 nt between sites separated by 50 km and 1.5 nt between stations 6 km apart. Partial removal of diurnal effects was accomplished by developing sets of interstation

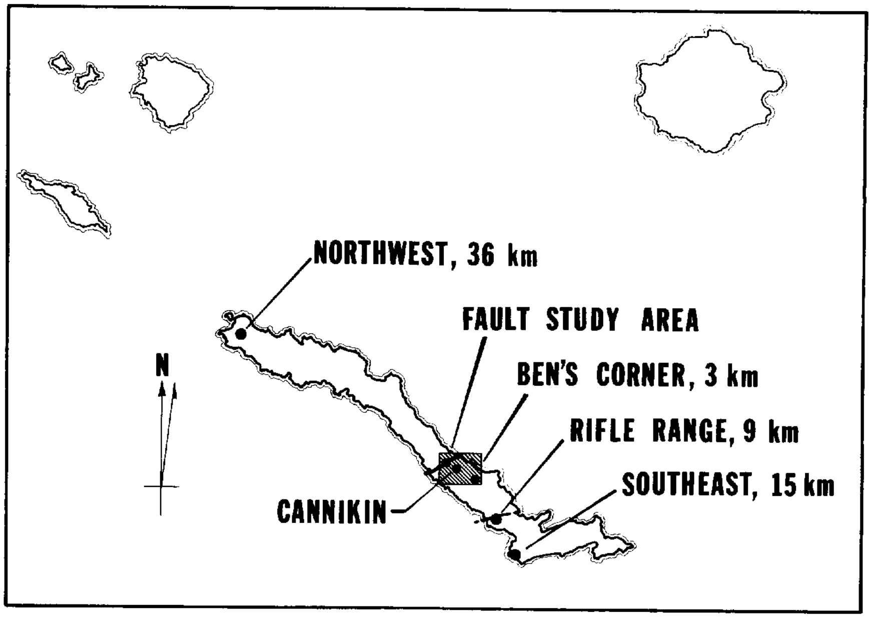

Figure 1. Index map showing location of four base-station magnetometers on Amchitka Island, Alaska. Distances are relative to Cannikin ground zero.

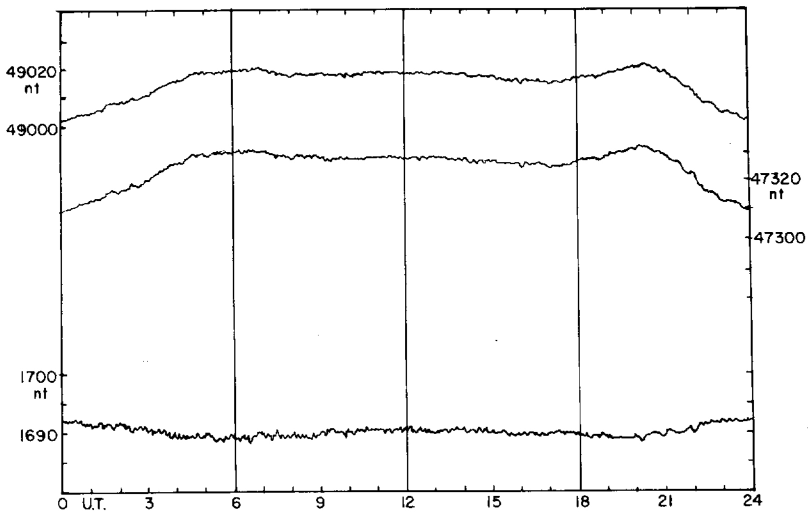

Figure 2. Total-field magnetic data from the Ben's Corner (upper trace) and Rifle Range (middle trace) stations for October 19, 1971. The lower trace shows the synoptic difference function between the two stations, on an expanded ordinate scale.

daily-variation curves for each station pair and then subtracting these values from the observed synoptic differences. Subsequent Fourier analysis of these corrected time series showed that the use of average daily-variation curves was almost 90 percent effective. These frequency analyses also showed that in addition to a residual solar-diurnal variation, two other spectral peaks appeared in the Northwest-Southeast difference function: One at 12.41 hours (the semidiurnal tidal component), and the other at 25.8 hours (the O_1 constituent of the lunar tide). Amplitude of all three peaks was approximately 1.4 nt. It is thus fairly certain that in an island environment, simple synoptic differencing between stations will probably be insufficient to reliably expose geopiezomagnetic effects of only a few nanoteslas. Considerably more data manipulation will be needed; and as has been indicated from our other work, three-component magnetometers will be required.

15. QUASI-STATIC MAGNETIC FIELD CHANGES ASSOCIATED WITH THE CANNIKIN NUCLEAR EXPLOSION

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The Cannikin underground nuclear explosion, detonated at $22^h\ 00^m$ UT on November 6, 1971, provided an opportunity to measure possible magnetic effects under controlled conditions. To detect shot-associated geopiezomagnetic effects, four proton total-field magnetometers were operated almost continuously for several months, and sets of preshot and postshot data were taken at 201 locations across and along the Teal Creek fault, whose surface trace passed within 1 km of ground zero. Within 30 sec after detonation, a magnetometer at 3 km from the shot recorded a 9-nt step increase in total magnetic field (fig. 1). Continuous difference recordings between the station at 3 km and one at 9 km, taken for eight days after the shot, showed an average increase of 7.2 nt in postshot-minus-preshot hourly values, thus showing that the observed change was apparently a lasting one.

Along a 0.5-km traverse, which crossed a portion of the fault centered 1.6 km from the epicenter, the postshot-minus-preshot differences fell off semisinusoidally from a high of +13 nt in the shot-contained block to a low of -11 nt in the distal block, except within the region extending 15 m on either side of the fault trace, where the static magnetic field decreased sharply by almost 15 nt (fig. 2).

A qualitative interpretation suggests that at the 3-km station the explosion caused either a residual compressive stress or an alteration of remanent magnetization. The geopiezomagnetic anomaly associated with the fault is best explained by postulating an increase and a decrease of remanent magnetization, produced respectively by compressive stresses parallel to the fault in the shot-contained block and by similarly oriented tensile stresses in the adjacent block.

A more detailed account is to be published in the December 1972 issue of the Bulletin of the Seismological Society of America.

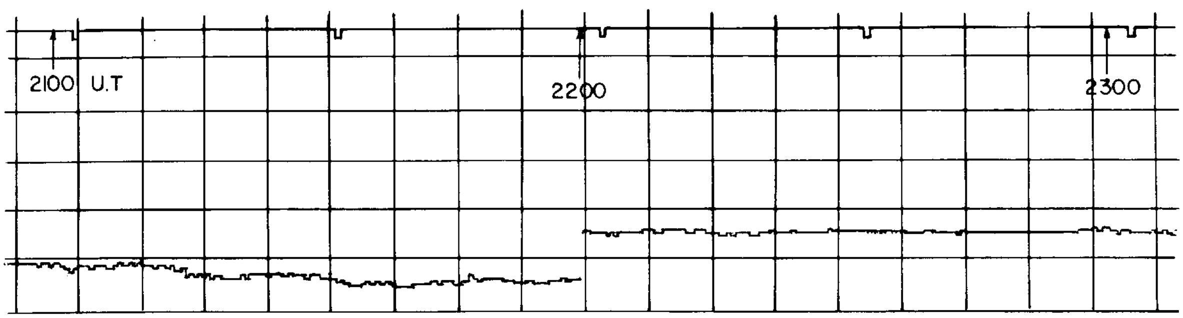

Figure 1. Part of the magnetogram recorded at the Ben's Corner station at the time of detonation. Ordinate scale is 10 nt between lines shown.

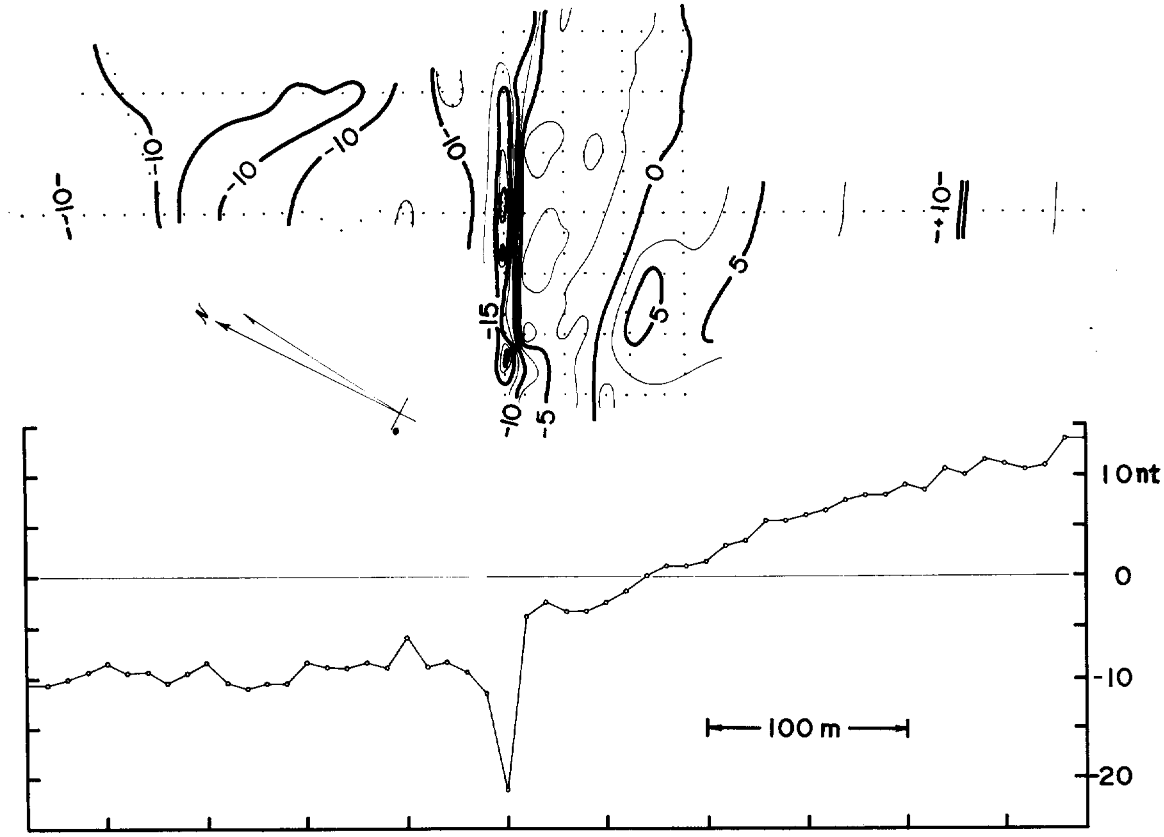

Figure 2. Contours of postshot-minus-preshot magnetic values obtained near the Teal Creek fault, and magnetic profile on longest line of the array. Station spacing, 10 m; contour interval, 2.5 nt. Center of mapped array is 1.6 km WNW of Cannikin ground zero.

16. A VECTOR AEROMAGNETIC SURVEY OVER NEAH BAY, WASHINGTON

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Program and Objectives

NOAA's mission in geomagnetism involves liaison with the Ames Research Center, vis-a-vis the latter's important role in the geomagnetic aspects of the NASA mission to foster and assess spacecraft studies of earth resources. Vector magnetic studies at Ames were initiated some three years ago when Ernest Iufer used existing spacecraft sensing elements in a triaxial magnetometer system, which was flown in a jet aircraft for the 1969 Auroral Expedition. The whole package was subsequently evaluated as a vector magnetometer for high-altitude applications in both aircraft and spacecraft, by flying a survey grid over a known magnetized body--a strip of pillow basalt in the vicinity of Neah Bay in the Strait of Juan de Fuca, Washington. The surface outcrops of the formation had been rather extensively mapped by Parke Snavely and Norman McCleod of the U.S. Geological Survey.

The next objective will be to define the unique merit of vector data in ascertaining the physical parameters of magnetic ore bodies. Upward continuation of the available data, both vector and scalar, will then be scrutinized to determine the economic feasibility of a minimum-altitude magnetometer satellite.

As a direct result of NOAA's cooperation with NASA/Ames through the Castle Rock Observatory, we were able to obtain the actual flight unit for a test of its long-term stability at the Fredericksburg Geomagnetic Center. This test has been under way for about eight weeks with promising results, and a second, similar magnetometer now being built by NASA will undergo extended evaluation by NOAA for ground recording applications.

Survey Equipment and Procedure

The vector aeromagnetic survey of July 1971 was conducted in a NASA/Convair 990 four-engine jet aircraft. For this flight, the only experiment aboard was that based on the vector magnetometer. The Iufer modification of the Ames fluxgate magnetometer flown on the IMP and Pioneer spacecraft provided a triaxial configuration featuring a feedback circuit with a closed servo loop. The resulting fully automated instrument offers remarkably high performance.

The total system comprised the magnetometer, fixed rigidly to the aircraft with a fiberglass tail boom; a Litton LTN-51 Inertial Navigation system; and a digital acquisition system. An RC-8 camera was provided by the Photogrammetry Division of NOAA/NOS several weeks before the flight. This system, planned to provide redundant data on attitude and position, became in fact an essential part of the survey.

To preclude loss of data, two different data-acquisition systems were used for this flight. As a primary system, the Iufer logger (which had been used on all earlier flights) relied on a single magnetic tape, recording at a rate of one sample every 3.2 sec; whereas the backup system, referred to as ADDAS, recorded data at a rate of one sample per second on two synchronized tape units, preventing data loss at this high speed. The ADDAS system also recorded the position and attitude data at a rate of 100 samples per second; as it turned out this was very important in the data reduction.

The flight was made at 440 km/hr and at 1520 m above the shores and waters of Neah Bay, keeping well clear of the terrain, which has nearly 600 m of relief. Within a 5-hr interval, a grid pattern was flown, comprising 16 short lines (34.7 km), 16 long lines (53.9 km), and four tie lines (54 km).

One of NOAA's significant contributions to the survey was the ground control arranged by sending a magnetic repeat survey party to Quillayute Airport, just south of the survey area. H. E. Kaufmann operated a temporary recording station there during the interval June 21-29, 1971. Unfortunately, the flight was delayed by inclement weather from June 23 until July 2, and Mr. Kaufmann's repeat schedule did not allow prolongation of the ground recording, so it was necessary to establish the component relationship between Quillayute and the nearest permanent observatory at Victoria, B.C. From the available magnetograms I determined this relation and was able to extrapolate for the field values existing at 1520 m above Quillayute during the overflight with which the survey commenced. The agreement with flight data was well within 100 nt in the components and 0.2 degree in D and I.

Analysis of Results

Removal of regional trends from the observed data was accomplished with the NOAA-developed world chart program (MC-811) using the AWC-70 model (see Paper 8 of this conference). I modified the program to facilitate its application to these data. NASA/Ames chose this model in preference to others such as the IGRF, with the concurrence of USGS personnel at Menlo Park.

Shortly after the flight, arrangements were made with a contractor to produce contour and perspective plots of the component data. The plots were delivered some six months later, but were found to depict fictitious data. Furthermore, delay in funding precluded any parallel checks on the data. Inasmuch as the faulty contours and the funding authorization came at about the same time, it was decided to perform an in-house analysis, to test whether the data met the stated criterion of 0.1° in attitude (translating roughly to 90 nt maximum through coupling) and to develop a messaged data tape that might be plotted by a contractor. The analysis commenced with the plotting of the data recorded on the low-speed logger, disclosing an irksome aperiodic spiking in the magnetic traces. A check of the coincident dropout points on the ADDAS system showed that the spiking originated in the low-speed data logging system, not in the magnetometer.

Plots of the roll and pitch uncovered two high-frequency modes that could not be traced either to the natural aircraft motions or to any of the magnetic components. They represented induced noise, as was confirmed by a display of similar information from a later flight. The attitude criterion was convincingly found to be satisfied when a graph of two overlapping profiles was produced; however, the pseudo-noise level has approached the stated values for some components.

At Mr. Iufer's request, I sought and found the computer-program errors responsible for the faulty contours. The most significant one was due to neglect of first-order terms in computing residual field components. The program had directly replaced the terms of the equation $F^2 = X^2 + Y^2 + Z^2$ with their respective residual values, assuming falsely that $\Delta F^2 = \Delta X^2 + \Delta Y^2 + \Delta Z^2$. The contractor had also misunderstood the effects of daily variation.

Some Collateral Benefits

The cooperation leading up to the Neah Bay survey has proved quite beneficial both to NASA and to NOAA. Certainly the benefits to the Castle Rock Observatory have been outstanding. Furthermore, an equipment configuration has been developed for use not only as an airborne system but also possibly at ground observatories.

17. MARINE ELECTROMAGNETIC INDUCTION

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Theory

Natural electromagnetic signals in the ocean with periods less than several years are due to sources external to the solid earth. Magnetic signals from the earth's core dominate for periods greater than four years. Time variations of the magnetic field, due to sources in or above the ionosphere, induce electric currents in the ocean and conducting mantle by means of the mutual inductive coupling between the ionosphere and the ocean and mantle. The dynamo action of the electrically conducting sea water as it moves in the geomagnetic field also induces oceanic electric currents. Observations of oceanic electromagnetic fields can therefore give information about the electrical conductivity structure of the mantle and the fluid motions in the ocean, provided the fields can be separated into parts of ionospheric and oceanic origin.

The electromagnetic equations can be reduced to a simple form because the oceanic part can most likely be treated by a thin-sheet approximation. In terms of the electric current stream function, defined by

$$-\mathbf{k} \times \nabla_0 \Psi_0 ,$$

$$\mathbf{I} = \mathbf{k} \times \nabla_s \Psi ,$$

the equation is

$$\nabla_s \cdot (\nabla_s \Psi / \sigma_0 d) - \partial B_z^i / \partial t = \partial B_z^e / \partial t + \nabla_s \cdot (\bar{\mathbf{V}}_s^* F_z) ,$$

where ∇_s is the horizontal gradient operator, σ_0 is the mean conductivity of the ocean, B_z^i is the induced vertical magnetic field generated by the electric currents in the ocean and mantle, B_z^e is the field due to ionospheric sources, F_z is the vertical geomagnetic field, $\bar{\mathbf{V}}_s^*$ is the conductivity-weighted mean velocity, and d is a depth related to the thickness of the thin sheet.

The terms of the equation from left to right are:

(a) The resistive term, which includes the lateral changes in surface conductivity or depth;

(b) the term that contains the self- and mutual-induction effects;

(c) the term for oceanic electric current induced by ionospheric sources; and

(d) the term for oceanic electric currents induced by barotropic fluid motion.

This last term separates into three parts in the following manner:

$$\nabla_s \cdot (\bar{\mathbf{V}}_s^* F_z) = -(F_z/d)\partial\zeta/\partial t + \bar{\mathbf{V}}_s^* \cdot \nabla_s F_z - (F_z/d)\bar{\mathbf{V}}_s^* \cdot \nabla_s d .$$

The three parts, reading from left to right, are:

(a) The term probably most important for tidal flow,

(b) the term most important for large-scale planetary waves, and

(c) the topographic term, whose importance is not well understood.

Separation

The separation of the fields into oceanic and ionospheric parts is accomplished by cross correlation of the electric field with the horizontal magnetic field. Because the latter is almost entirely produced by ionospheric sources, the ionospheric part of the electric field is the part that is coherent with the magnetic field, whereas the oceanic is the incoherent part. The factor that is estimated in order to carry out the separation is the transfer function. This factor is the ratio of the electric field to the magnetic field. It contains, in a compact form, all the information about the conductivity structure beneath the observation site.

This transfer function must be a smoothly varying function of frequency, enabling one to develop procedures to obtain smoothly varying estimates of the transfer functions. The procedure that has been used yields realistic estimates of mantle conductivity structure and surface conductivity, and given a measure of broad-scale barotropic ocean motion.

18. REAL-TIME DATA SYSTEM AT THE HIGH-LATITUDE MONITORING STATION AT ANCHORAGE, ALASKA

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The High-Latitude Monitoring Station (HLMS) located on Elmendorf AFB in Anchorage, Alaska, is one of two SEL field sites that feed real-time geophysical data into the Space Environment Services Center (SESC) in Boulder. The SESC is the operations group of the civilian Space Weather Service and works closely with the Aerospace Environmental Support Center (AESC) of the Air Weather Services at NORAD, which serves the military requirements.

Figure 1 is a block diagram of the HLMS data processing system. A small computer performs the routine reading, processing, and recording of the data, and sends out summary information to the SESC and AESC.

Signals are monitored from local sensors (magnetometers, HF radio receivers, and an auroral radar), from a riometer network (riometers located at Anchorage, Sheep Mountain, Paxson, College, and Fort Yukon), and from riometer and magnetometer sensors at a station operated by the Air Force Cambridge Research Laboratories near Thule, Greenland. The riometers at College and Fort Yukon are operated by the Geophysical Institute of the University of Alaska. Local sensor signals are sampled every 10 sec by an analog-to-digital converter. The riometer network and the Thule sensors are sampled four or five times per minute, using a device called a digital communicator, which can sample sequentially up to ten signals, can convert the signal voltages to digital numbers, and can send out the data in teletype code.

After the computer reads in the data they are smoothed, using programs that simulate a low-pass R-C filter of one- and five-minute time constants. Quiet-day curve (QDC) data are generated for riometer and magnetometer signals. Data values are recorded on magnetic tape for each sensor every minute from the 1-min filter, every 5 min from the

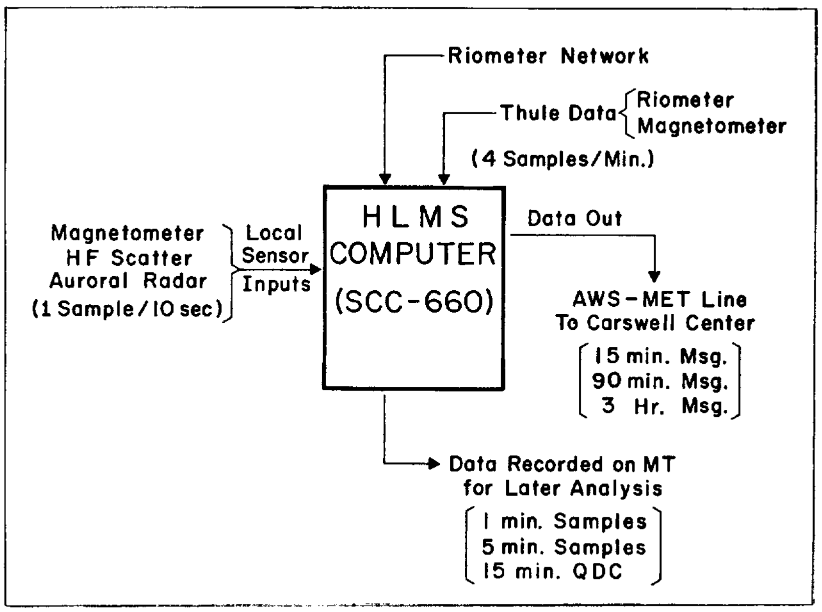

Figure 1. Data Processing at the High-Latitude Monitoring Station.

5-min filter, and every 15 min from the QDC data.

Summary messages are generated and transmitted via Air Weather Service lines to the SESC and AESC. A message sent out every 15 min summarizes the signal activity from the magnetometers, riometers, and HF receivers. The minimum and maximum of the Thule magnetometer signals are transmitted every 90 min for each component. Furthermore, the Anchorage magnetometer signal difference and a computed simulation of the *K* index are transmitted every 3 hr.

By using a small computer, the HLMS is able to process a large number of geophysical sensor signals and produce real-time results, such as magnetic perturbations in nanoteslas and *D*-region absorption in decibels below the normal quiet-day curve.

19. JOINT ARCTIC GEOMAGNETIC OBSERVATORY NETWORK

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During the past decade, it has been found that the auroral oval affords an important frame of reference for various magnetospheric and upper-atmospheric phenomena in high latitudes. It is eccentric, however, with respect to the dipole (or geomagnetic) axis. A meridional chain of geophysical observatories is therefore needed for most effectively monitoring these phenomena. The basic concept underlying a meridional chain is that it can "scan" the auroral oval once a day, like an azimuth-scan radar. Thus, if the stations are spaced about 200 km apart at most, between 65° and 75° geomagnetic latitude, there will always be one station very nearly underneath the auroral electrojet. In particular, such a chain is most useful in understanding the dynamics of the auroral oval, as well as in organizing the concurrent satellite data.

Magnetospheric studies are expected to peak in 1976-78 during the International Magnetospheric Survey (IMS), when satellite, rocket, and ground-based observations will be closely coordinated. This interval will see intensified demands for high-quality data from carefully selected chains of permanent and temporary stations equipped with standardized instruments.

Current and Proposed Operations

ESL has three Alaskan magnetic observatories, all with absolute control. They are at Barrow, College, and Sitka. The Space Environment Laboratory of ERL operates a three-component magnetograph at Anchorage without absolute control. The Geophysical Institute of the University of Alaska has been running old three-component fluxgate magnetometers on loan from NOAA, at Sachs Harbour and Bar Island, and is presently operating Schonstedt fluxgate magnetometers at Fort Yukon, Stevens Village, and the Poker Flats Launching Site.

The need for a better station distribution and for enhanced data quality prompts the proposal that NOAA/ERL enter into a cooperative geomagnetic effort with the Geophysical Institute and with Canadian authorities to operate a geomagnetic observatory network in Alaska and the Canadian Northwest Territory, as set forth in table 1.

Table 1. Proposed Joint Arctic Geomagnetic Network

Location	Geomagnetic latitude (deg)	Class*	Recording Features			
			On Site	Telemetered	Analogue	Digital
Mould Bay	79.1	1	Yes		Yes	
Sachs Harbour	75	2	Yes		Yes	Yes
Tuktoyaktuk	73.5	2	Yes		Yes	
Inuvik	70.4	2	Yes		Yes	Yes
Barrow	68.5	1	Yes	Yes†	Yes	
Arctic Village	68.4	2	Yes		Yes	
Fort Yukon	66.8	2		Yes†	Yes	
Poker Flats	65	2	Yes		Yes	
College	64.6	1	Yes	Yes§	Yes	Yes
Anchorage	61.0	2	Yes		Yes	
Sitka	60.0	1	Yes		Yes	
Kodiak	57.0	2	Yes		Yes	

*Class 1 with weekly absolute control, Class 2 without.

†To College Observatory.

§To Geophysical Institute.

Arctic Geomagnetic Center

The College Observatory will serve as the Arctic Geomagnetic Center (AGC) and will maintain general supervision of and responsibility for the network, in cooperation with the Geophysical Institute and Canadian authorities. It is proposed that the basic responsibility of the AGC be that of (a) acquiring the data, (b) making an initial examination of them, and (c) providing the technical supervision necessary to maintain quality control at all stations in the network. The data and records will be supplied to the Geophysical Institute, where the data from all the stations will be processed according to need, reduced to uniform time and sensitivity scales, and published jointly by the Geophysical Institute and NOAA/ERL, and/or otherwise distributed.

Dr. Syun Akasofu, Professor of Geophysics at the Geophysical Institute, and the Chief of the College Observatory will work jointly to operate the magnetic stations. Installation and operation of magnetometers at field stations will be a shared responsibility between AGC and the Geophysical Institute. The College Observatory and the Geophysical Institute have between them a complete range of facilities and skills. A main strength of this proposal is that it affords a mechanism to provide more and better magnetic data in a cost-effective approach that combines existing capabilities. Neither organization alone can hope to perform the work proposed here without a major funding increase; however, by a joint operation a relatively small increase in available funding will provide a radically improved data-collection program.

Arctic Geomagnetic Advisory Committee

To insure that the network will meet the general and specific needs of NOAA/ERL, of the Geophysical Institute, of the Canadian authorities, and of the scientific community, it is proposed that a small Arctic Geomagnetic Advisory Committee be formed initially to make recommendations at least annually on existing and future geomagnetic-related data services and research. On the basis of the annual review, the Committee will be responsible for improving the usefulness of the data from the observatory chain in conjunction with rocket and satellite projects. If necessary, the Committee should recommend supplemental locations for temporary observing sites, interspersed between the permanent observatories, for specific projects.

20. DEVELOPMENT OF GEOMAGNETIC INSTRUMENTS IN THE EARTH SCIENCES LABORATORIES AT BOULDER

Dale L. Vance
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Boulder, Colorado 80302

Current instrumental development work is primarily in the paleomagnetic area. A low-speed spinner magnetometer is being developed for work with fragile rocks that could not withstand the stress of rapid spinning. It utilizes state-of-the-art components to yield a direct read-out of the direction and intensity of magnetization of a sample. The spin rate is 10 hz, as compared with 155 hz for the older spinner. The system uses a low-noise transformer and pre-amplifier, made by Princeton Applied Research.

The existing system for demagnetizing rock samples has a single coil energized with ac, producing a 60 hz magnetic vector that increases and decreases along one axis, and a mechanical system to rotate the sample about three axes at the center of the coil. During this rotation, the a-c field is gradually reduced to zero. The rotating system is made of phenolic material and is rather fragile and thus slow. It requires up to 20 min to demagnetize a sample, and yields resolutions of 10° or more.

A new system under development will utilize a 3 khz field rotating in a plane, as a vector of constant magnitude (within .05 percent) during any given revolution. This is achieved by energizing two coils with signals of the same frequency but 120° apart in phase. By rotating the rock about a single axis orthogonal to those of the coils and then gradually reducing the magnitude of the applied field, we are able to demagnetize with 1° resolution in all orientations.

21. GEOMAGNETIC DIGITAL OUTPUT--DIRECT VERSUS INDIRECT

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Boulder, Colorado 80302

Distinction Between the Two Methods

Some of our digital magnetic observatory results are obtained by a direct method, via a digital magnetograph with machine-readable output; and some by an indirect method, via scaling of magnetograms and application of appropriate calibration factors. The direct one (even with the raw data expressed in arbitrary units) obviates the scaling, permits finer time resolution, and serves as a test bed for the future development of devices yielding absolute values directly.

NOAA has fostered both methods, though both are viewed as temporary expedients. NASA's Goddard Space Flight Center broached in 1963 a need for world-wide data in machine-readable form, to be taken at a high sampling rate. Under constraints on time, budget, and expertise, there was no choice but to work from the magnetograms. A sampling interval of 2.5 min was adopted, and the project was begun, using special semi-automatic machines built for scaling the traces. Many problems have arisen from the diversity of magnetograms and formats and from other conditions (Svendsen, 1969), but the project has continued to this day, following essentially the same procedure (Cain et al., 1966).

Some Problems with the Direct Method

As of the present time the direct method, notwithstanding its strong appeal, is more complex than the name implies. Since current interest centers on this method, we give here some detail of our experience with it.

An automatic digital magnetograph (Kuberry, 1972) requires expertise in trouble-shooting and in maintaining its exotic, newly developed components such as flux-gate and rubidium sensors, electronic clocks, digital counters and circuits, current supplies, and incremental recorders. Special software is needed to read the tapes (their spurious noises cannot always be handled by I/O routines), as well as other software and expertise for processing and file maintenance. The indirect method involves many of the same problems, but the scaling machines are simpler, and they may be operated in an office environment.

We are currently processing direct digital data from four observatories as shown in table 1. (The University of Kiruna has been kind enough to supply us with their results regularly.)

The ASMO was developed around an alkali-vapor sensor. Such sensors, as well as flux-gates, yield relative rather than absolute values and are subject to practical constraints on the biassing fields, so that we have digital magnetograph components that must be calibrated (obtaining "base-line values") like those of a conventional magnetograph. Monitoring of the base-line values, necessary for computation of the final output, is also helpful in diagnosing malfunction. We have had much trouble with drifting constant-current supplies, and even more with tilting of the coils.

Base-line control is, of course, dependent on the frequency and quality of absolute observations. The Castle Rock instrument piers are sited on a steep, unstable hillside, causing problems with both the ASMO and the absolute instruments. The site is not easily accessible to the observer, and the available absolute instruments are less than satisfactory. For various reasons we have not found it possible to overcome or avoid the siting

Table 1. Direct Digital Data Currently Flowing to EDS

Observatory	Instrument	Record From	Elements Recorded	Sampling Interval (sec)
Fredericksburg, Va.	Flux-gate	Magnetic Tape	D,H,Z	10
Castle Rock, Calif.	ASMO	Magnetic Tape	D,I,F	10
Dallas, Tex.	ASMO	Paper Tape	D,I,F	60
Kiruna, Sweden	----	Paper Tape	X,Y,Z	60

problems, and the observer deserves much credit for minimizing the consequences of his difficult situation. Even Fredericksburg, on level ground, has shown evidence of tilt. Until recently, base-line values of the Fredericksburg instrument drifted so rapidly that we were unable to assess sensor stability.

All three of the NOAA instruments may on occasion produce spurious values, owing to artificial disturbance or electronic failure, or in the case of the ASMO's to deterioration of a sensor. Whereas scalings obtained under human control require but little judgment to spot and eliminate artificial disturbance, in automatic processing this step is so costly that it is deferred until 2.5-min values are available, when it requires scanning 24 rather than 360 values per hour.

Like other sophisticated electronic gear, our three instruments have had frequent component failures, resulting in excessive down time--partly because of personnel shortages, but chiefly because of lack of spare parts. The Castle Rock observer lives at a distance, a circumstance that prolongs some of the record gaps; and there is no conventional magnetograph for filling them in. On the other hand, scaling machines too have occasionally been out of service, causing delays in processing but no loss of record.

Preparation of Data for Use

Tape processing requires several passes through the computer. (Paper tapes demand special care.) The first step converts the data to standard format. A 1098-character tape record, with data in original units, permits handling all data with a single set of programs. Some of these are: File maintenance, time and data correction, base-line computation, validation, and absolute-value computation. Cost factors have restricted the use of the validation program (which compares adjacent values and prints out sequences marked by excessive differences) and have confined the computation of absolute values to the shorter 2.5-min tapes.

Delay in processing, a frustration to the observatory engineer, often stems from a computer problem such as excessive turn-around time, a programming language change necessitated by changed computer hardware, or lesser annoyances like excessive tape marks or short tape leaders. Under the present set-up, Dallas values should normally be available within three months, Castle Rock results somewhat later for they must await final corrections to QHM's

Outlook for the Future

In NOAA we shall continue to offer to the geophysical research community machine-readable, digital magnetic results from a selected worldwide network of observatories. At present few countries can afford the expensive, direct digital systems. Since geographical location is paramount in the selection, we expect that the vast majority of the 2.5-min values to be deposited in our data bank will continue for a long time to be obtained by the indirect method. This lengthy procedure currently costs as much as $6500 per observatory-year. (The figure may soon diminish fractionally, with the use of a more fully automatic scaling device.) However, obtaining the same kind of data by the direct method is likewise a complicated process, as the experiences described above demonstrate--and the cost is even higher, so long as the development stage continues. Nevertheless, we are confident that the bugs will be worked out, the costs will come down, and the future will bring a worldwide network of standard digital magnetometers--not the breed we now have, but on-line station magnetometers directly producing absolute values.

References

Cain, J. C., F. Eleman, S. J. Hendricks, H. Meyers, W. Paulishak, and K. L. Svendsen (1966), U.S. Coast and Geodetic Survey – NASA Geomagnetic Data Reduction Program, X-612-66-11, NASA Goddard Space Flight Center, Greenbelt, Md., 29 pp.

Kuberry, R. W. (1972), A Report on NOAA Automatic Observatory Systems, U.S. Dept. Commerce, NOAA Tech. Rept., ERL 223-ESL 19, pp. 43-47, Supt. of Documents, Washington, D.C.

Svendsen, K. L. (1969), Transformation of Analog Records to Digital Form, Intl. Assn. Geomagnetism Aeronomy *Bul.* 26:104 (abst.)

22. QUALITY CONTROL AND RELIABILITY PROGRAM FOR OBSERVATORIES

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The quality control and reliability program (QCRP) applies statistical techniques to test the continuity of base-line and scale-value determinations, yielding a quantitative estimate of their reliability at a chosen level of confidence in terms of accuracy, precision, and limits of systematic error. The estimates of precision may be used to prepare control charts for spotting various manifestations such as: Gross blunders, unexplained shifts in average base-line and scale values, changes in precision, gradual drifts, and rapid cyclic fluctuations.

It is proposed to implement this program at observatory level in order to maintain control on a current basis and give immediate feedback to the observer in charge, for use in the search for systematic or accidental error.

The program has been tested in two ways. First, it was applied at one observatory to assess its completeness and utility and the work load it imposed on observatory personnel. The results proved to be particularly useful in the search for systematic error, and the work load was about 8 man-hours per month.

Second, the reliability portion of the program was applied to all NOAA-ESL standard observatories, to test it over a wide range of environmental and operating conditions. Table 1 shows the *a priori* or expected precision in terms of standard deviation, expressed in nanoteslas of induction (corresponding to gammas of field intensity). These estimates are based on the maximum likely observer error in reading instrumental verniers, thermometers, count, etc. Table 2 gives estimates of precision in terms of standard deviation for each observatory's base-line values observed during the first half of 1972. The columns on the left show the number of months included and the average frequency of the determinations. Four measures of standard deviation were taken for each magnetic element, namely: w, the within-occasion standard deviation; b, the between-occasion standard deviation (a measure of the variation between successive sets of measurements); m, the monthly standard deviation of n sets of measurements about their mean; and o, the overall standard deviation of the monthly mean values about their grand mean for the stated interval. The test indicates that the program may be applied without difficulty to diverse observatories with differing equipment and operating conditions.

Table 1. A-Priori Standard Deviations

Observatory	B_D	S_D	B_H	S_H	B_Z	S_Z
	nt	*nt/mm*	*nt*	*nt/mm*	*nt*	*nt/mm*
Barrow	0.67	0.054	4.6	0.150	2.9	0.078
Boulder	0.09	0.003	0.05	0.017	0.5	0.027
College	0.12	0.010	1.5	0.055	0.8	0.008
Dallas	0.09	0.002	0.6	0.007	0.6	0.016
Fredericksburg	0.06	0.002	0.4	0.012	0.3	0.019
Guam	0.09	0.002	1.0	0.012	0.8	0.031
Honolulu	0.06	0.002	0.4	0.018	0.4	0.031
Newport	0.12	0.005	0.7	0.020	0.6	0.027
San Juan	0.06	0.024	0.3	0.009	0.4	0.023
Sitka	0.14	0.010	1.9	0.046	1.7	0.079
Tucson	0.05	0.002	0.3	0.024	0.5	0.037

These estimates may be intercompared in order to test actual against expected precision, under ideal conditions; and the other estimates of precision may be intercompared to determine how the constituent processes change with time. The gross differences among the observatories reflect differing equipment and sensitivities and differing amplitudes of activity, rather than shortcomings of the observatory operation.

Table 2. Standard Deviation of Base-line Values

Observatory	Mos.	Sets per mo.	B_D				B_H				B_Z			
			w	*b*	*m*	*o*	*w*	*b*	*m*	*o*	*w*	*b*	*m*	*o*
			nt	*nt*	*nt*	*nt*	*nt*	*nt*	*nt*	*nt*	*nt*	*nt*	*nt*	*nt*
Barrow	5	6	0.40	3.0	4.4	19.4	1.6	5.8	7.5	47.0	3.0	9.7	7.6	10.6
Boulder	5	6	0.12	0.2	0.1	0.1	0.5	1.4	1.3	4.8	0.5	1.4	1.3	4.8
College	5	8	0.11	0.1	0.2	0.3	1.0	1.5	2.5	15.0	0.3	2.2	3.6	5.6
Dallas	5	9	0.09	0.2	0.2	0.1	0.7	1.6	1.8	1.8	0.5	1.3	1.7	5.2
Fredericksburg	5	8	0.08	0.2	0.2	0.4	0.1	0.5	0.7	3.0	0.9	0.3	0.5	2.2
Guam	6	9	0.07	0.1	0.1	0.2	0.7	0.7	0.8	3.9	0.7	1.2	1.2	4.0
Honolulu	6	8	0.04	0.1	0.2	0.2	0.1	1.4	1.7	2.1	0.1	0.7	0.6	3.1
Newport	6	9	0.13	0.1	0.2	0.3	0.3	0.6	0.5	1.6	0.1	0.5	0.6	1.8
San Juan	6	9	0.09	0.1	0.4	2.0	0.4	1.5	1.6	2.3	0.2	0.9	1.1	1.9
Sitka	5	8	0.14	0.2	0.3	0.3	0.8	1.1	1.9	6.0	0.6	2.1	2.6	9.3
Tucson	5	9	0.04	0.04	0.04	0.04	0.1	0.4	0.5	0.8	0.7	0.6	0.8	3.8

GEOMAGNETIC RESEARCH IN NOAA

PROGRAM

Monday, 24 July, 1:30 P.M.

Leroy R. Alldredge.................Introductory Remarks

PALEOMAGNETISM, MAIN FIELD, AND MAGNETIC VARIATIONS

Joe H. Allen -- Chairman

Donald E. Watson............Studies of the Magnetic Properties of Rocks

Donald E. Watson............What Inferences can be Drawn from the Magnetic Characteristics of Meteorites?

Henry Spall..................Orogenies, Polar Wandering, Reversals, and Plate Tectonics

Henry Spall and Donald Gester
..................Does the Earth's Magnetic field have a Preferred Polarity?

Louis Hurwitz................A Discrepancy of Vertical Intensity in Models of the Geomagnetic Field based on Scalar Intensity

Charles O. Stearns and Leroy R. Alldredge
..................Time-dependent least-squares Estimation of Vertical Magnetic Dipoles as Sources of the Geomagnetic Field

David G. Knapp...............A Scheme for the Re-examination of the Early Secular Change of Magnetic Declination in the U.S.

E. B. Fabiano................The Evaluation of Three Secular-change Models

Joseph N. Barfield..........Relations between Geomagnetic Micropulsations observed simultaneously in the Magnetosphere and on the Ground

Tuesday, 25 July, 8:00 A.M

MAGNETIC VARIATIONS, SEISMOMAGNETISM, AND MARINE MAGNETISM

Donald E. Watson -- Chairman

Joe H. Allen................The AE Index -- the Concept, some Problems, and possible Improvements

J. Virginia Lincoln.........The Proliferation of Geomagnetic Activity Indices

H. Coffey....................Geomagnetic Information for Interdisciplinary Studies of Selected Cosmic Events

J. E. O'Donnell.............Magnetic Surveys in the Epicentral Area of the San Fernando Earthquake

W. P. Hasbrouck and J. H. Allen
..................Progress Report on Diminution of Geopiezomagnetic Noise due to Daily Variation

W. P. Hasbrouck and J. H. Allen
..................Quasi-static Magnetic Field Changes Associated with the Cannikin Nuclear Explosion

Leroy W. Pankratz............A vector Aeromagnetic Survey over Neah Bay, Washington

Gaylord R. Miller............Telluric Electric Measurements at the Pacific Oceanographic Laboratory

George Peter.................Marine Magnetic Research at the Marine Geology and Geophysics Laboratory, 1971-1972

Barrett H. Erickson..........The Marine Geomagnetic Program at the Pacific Oceanographic Laboratory

Tuesday, 25 July, 1:30 P.M.

MAGNETIC OBSERVATORIES AND DATA HANDLING

Barrett H. Erickson -- Chairman

C. E. Hornback..............Real-time Data System at the High-latitude Monitoring Station at Anchorage, Alaska

John B. Townshend...........Joint Arctic Geomagnetic Observatory Network

Dale L. Vance...............Development of Geomagnetic Instruments in the Earth Sciences Laboratories at Boulder

K. L. Svendsen and R. E. Glacken
.................Geomagnetic Digital Output--Direct versus Indirect

John D. Wood................Organizational Structure for Geomagnetic Operations within ESL

Lanny R. Wilson.............Quality Control and Reliability Program for Observatories

PART II. A SPECTRUM OF GEOMAGNETIC ADVANCES

This section summarizes for the year ending June 30, 1972, those ESL activities that are not reflected in the papers given at the conference but are represented in activity and progress reports in the files. Appended is a list of publications and contributions on geomagnetism authored or sponsored by staff members of ESL and of other NOAA entities and issued during the same interval. Many of the activities of NOAA staff members depicted in last year's review (Watson, 1972) are of continuing concern, whether or not they are explicitly covered in the present volume. Papers given at the 15th General Assembly of I.U.G.G. in Moscow are mentioned in the present list of publications (references to IAGA Bul. 30 and 31) in so far as the work to which they pertain is not otherwise represented either in the present review or in the previous one.

DEVELOPMENTS AND INVESTIGATIONS BY MEMBERS OF THE GEOMAGNETIC GROUPS

Compiled by Philip J. Taetz

Ames Flux-gate Magnetometer

Staff members have worked closely with personnel of NASA's Ames Research Center in the development of an Ames-designed flux-gate magnetometer. In May, a prototype was shipped to the Fredericksburg Geomagnetic Center for testing and evaluation. One important aim of the work is to determine the suitability of the instrument for observatory operations. Design and operational changes suggested by FGC are to be incorporated into improved models of the Ames magnetometer.

Winter Anomaly Program

During January and February, the Fredericksburg Geomagnetic Center participated in a NASA program at Wallops Island, Virginia. FGC not only supplied *K* and *Ak* each day to 10 AM, but also estimated real-time values through 1 PM. The objective is to account for the winter anomaly in the ionospheric *D* region, possibly due to meteorological activity or to the energetic particle precipitation that accompanies some magnetic storms. The study involves several other ground experiments along with the FGC data.

Proton-ASMO Development

A set of ASMO coils was supplied to Geometrics, Palo Alto, California, for installation in an "automatic standard magnetic observatory" instrument using a proton sensor. The completed prototype has been received at Fredericksburg, for testing and evaluation of the concept.

Antarctic Operations

Proposals have been submitted to the National Science Foundation to continue the observatory operations at the present South Pole station. Informal negotiations have also been conducted with NSF concerning geomagnetic operations at the New South Pole Station, scheduled to be occupied in 1975, and at the Unmanned Geophysical Observatories (UGO's) that NSF plans to deploy in Antarctica. Formal proposals are in preparation.

Continental Drift

Paleomagnetism, having developed the first convincing evidence for continental drift and sea-floor spreading and thus initiated the new global tectonics, is returning now to what it can do best -- delineating large-scale movements of crustal plates over long intervals of geological time. This requires that pole paths be set up for each continent, by linking together isotopically dated pole positions.

Once the pole paths have been drawn for each continent, it is then necessary to compare them, to get some indication of the relative positions of the continents in the past. A comparison has been made of the Precambrian pole paths for North America and Africa. Using rotation coordinates according to Bullard's computer fit of the continents around the Atlantic, the two pole paths could not be superimposed. In fact, the shape of the paths is basically different. From this it can be concluded that continental drift occurred also during the Precambrian, and that it was not a unique event in the earth's past.

Analysis of a Magnetotelluric Sounding

Many workers are using MTS data to define geologic structure through electric conductivity anomalies in the earth's crust and upper mantle, although there have been recent reports in the literature of poor agreement in repeating the MTS experiments.

Analysis of an MTS at the Fredericksburg Geomagnetic Center has shown considerable scatter among the tensor impedance quantities in eleven different data sets (see pp. 33-36 of last year's report). In an effort to gain a better understanding of the scatter in these data, the telluric vertical current was measured in a 12 m drill hole. A common assumption in MTS work is that the vertical current is zero. These data will be used in theoretical studies to see whether the plane-wave assumptions are sufficiently satisfied. The scatter is also being reviewed to see whether or not the impedances are a function of solar time, or of micropulsation activity. A paper presently undergoing in-house review prior to publication shows clearly that the electrode noise did not affect the MTS results.

This analysis will be useful to show how much variation should be expected in computed impedance values. MTS values are routinely done by considering the impedance to be constant in time, hence they use only one data set at each recording site.

Lava Stripping Project

Magnetic anomalies of interest in exploration can be masked by flows of basic lavas. The aim of the lava-stripping project is to remove the magnetic effect of the lavas by techniques based on a consolidated study of airborne, ground, and laboratory observations. To evaluate the efficacy of the procedures, a test area containing a magnetically isolated volcanic feature (Amboy Crater, California) was selected. Initial investigations were conducted of the magnetic susceptibilities of the lavas and of the surrounding playa-lake sediments of the test area, and a geologic reconnaissance was made of the region.

Geomagnetic Source Studies

A study of methods of analyzing archival data for secular change led to the rewriting of an existing program so as to assign weights to the observation equations dependent on completeness of the data at each observation point. Also under study is the effect of station distribution on the coefficients of the spherical harmonic analysis, looking toward methods of compensating for the effect.

An intensive editing of the 1835 data set was undertaken and the results will soon be published, along with a new analysis of the data.

A manuscript was prepared for a contribution to the forthcoming Volume 13 of "Methods in Computational Physics". It deals with radial-dipole and other mathematical models of geomagnetic field sources.

A brief study of dislocation models was made in preparation for the Cannikin shot (see Part I, paper no. 15).

Some study was devoted to schemes for improvement and evaluation of models, looking toward revision of the International Geomagnetic Reference Field.

Other projects that are well under way but were not much advanced during the year are the boundary-value problem at the interface between the earth's mantle and liquid core, and a numerical solution for the velocity field and magnetic field within the core.

Magnetic Units and Quantities

Further work has been accomplished on a study of magnetic units and quantities, which is pertinent to forthcoming recommendations of an IAGA working group.

Miscellaneous

Other activities include a study of aliasing as it impinges on the use of digital magnetic observatory results, and the preparation of advisory memoranda on various proposals looking toward changes in the scope or character of the geomagnetism program in NOAA.

PUBLICATIONS

Alldredge, L. R. (1972), Report of the General Secretary, *in* Transactions of the 15th General Assembly, *Intl. Assoc. Geomagnetism Aeronomy Bull.* 31:3-8.

Allen, J. H. (1972), Status report: Auroral electrojet (AE) indices for 1970, U.S. Dept. Commerce, NOAA, EDS, NGSDC, Boulder, 20 pp.

Allen, J. H., and P. L. Bender (1972), Narrow line rubidium magnetometer for high accuracy field measurements, *J. Geomag. Geoelect.* 24:105-125.

American Congress on Surveying and Mapping (1972), U.S. National Cartographic Report for 1969-72, *Surveying and Mapping* 32:369-391, esp. 371-373.

Cain, J. C., R. S. Sweeney, and E. B. Fabiano (1971), Secular-change coefficients and their connections for the I.G.R.F., *Intl. Assoc. Geomagnetism Aeronomy Bul.* 30:281 (abst.)

Campbell, W. H. (1971), Introduction to solar-terrestrial activity for geomagnetic studies, Part I. The sun and solar wind, U.S. Dept. of Commerce, NOAA Tech. Rept. ERL 218-ESL 18, 16 pp, Supt. of Documents Washington, D.C.

Campbell, W. H. (1972), A search for an ionospheric dynamo current effect of the galactic X-ray ionization, *Planet. Space Sci.* 20:61-72.

Campbell, W. H. (1971), Sidereal-time variation of the geomagnetic field, *Intl. Assoc. Geomagnetism Aeronomy Bul.* 30:395 (abst.)

Campbell, W. H., and T. C. Thornberry (1972), Propagation of Pc-1 hydromagnetic waves across North America, *J. Geophys. Res.,* 77:1941-1950.

Emilia, D. A., D. F. Heinrichs, J. Brakl, C. S. Clay, and P. A. Rona (1972), Re-interpretation of a magnetic anomaly on the continental rise off Cape Hatteras, *J. Geophys. Res.,* 77:377-379.

Fabiano, E. B. (1971), Magnetic surveys, *in* U.S. National Report, 1967-1971, *EOS* 52:195-197.

Fabiano, E. B., and S. J. Cain (1971), Coverage by land, sea, and airplane surveys, 1900-1967, *in* A. J. Zmuda, ed., World Magnetic Survey 1957-1969, *Intl. Assoc. Geomagnetism Aeronomy Bul.* 23:94-98.

Fabiano, E. B., and N. W. Peddie (1971), Evaluation of POGO (8/69) mathematical model of earth's inner magnetosphere, *J. Geophys. Res.* 76:3816-3819.

Fabiano, E. B., and N. W. Peddie (1971), The International Geomagnetic Reference Field--a new evaluation, *Intl. Assoc. Geomagnetism Aeronomy Bul.* 30:281 (abst.)

Glacken, R. E. (1971), New computer-derived magnetic activity indices based on power, *Intl. Assoc. Geomagnetism Aeronomy Bul.* 30:152, 298 (abst.)

Hasbrouck, W. P., and J. H. Allen (1972), Quasi-static magnetic field changes associated with the Cannikin nuclear explosion, Geol. Soc. Amer. *Abstracts with Program* 4(3): 166. For later abstract see Paper 15 of the present Review.

Helsley, C. E., and H. Spall (1972), Palemagnetism of 1140 to 1150 million-year diabase sills from Gila County, Arizona, *J. Geophys. Res.* 77:2115-2128.

Kawasaki, K., and S. I. Akasofu (1972), A study of polar cap and auroral zone magnetic variations, U.S. Dept. Commerce, NOAA, EDS, Rept. UAG-18, 24 pp.

Larsen, J. C. (1971), Tidal and low frequency oceanic induced electric fields, *Intl. Assoc. Geomagnetism Aeronomy Bul.* 30:198 (abst.)

Larson, E. E., D. F. Watson, and W. Jennings (1971), Regional comparison of a Miocene geomagnetic transition in Oregon and Nevada, *Earth Planet. Sci. Lett.* 11:391-400.

Matsushita, S., and W. H. Campbell (1972), Lunar semidiurnal variations of the geomagnetic field determined from the 2.5-minute data scalings, *J. Atmos. Terr. Phys.* 34:1187-1200.

Perkins, D. M., T. Watanabe, and S. H. Ward (1972), Relations between geomagnetic micropulsations and magnetotail field changes, *J. Geophys. Res.* 77:159-171.

Spall, H. (1972), Did southern Africa and North America drift independently during the Precambrian? *Nature* 236:219-221.

Spall, H. (1972), On the remanent magnetism in Precambrian llanite and Town Mountain granite from Llano County, Texas, *Tex. J. Sci.* 23:479-496.

Spall, H. (1972), Paleomagnetism and Precambrian continental drift, *Proc. Intl. Geol. Congress,* 24th, Sec. 3, Tectonics, pp. 172-179.

Spall, H., and H. C. Noltimier (1972), Some curious magnetic results from the Precambrian granite, *Geophys. J.R.A.S.* 28: 237-248.

Stassinopoulos, E. G., and G. D. Mead (1972), ALLMAG, GDALMG, LINTRA: Computer programs for geomagnetic field and field-line calculations, NASA, National Space Science Data Center, NSSDC 72-12, 56 pp. (p. L-3 gives Hurwitz's coefficients of the 1970 AWC model discussed on p. 13 herein.)

Svendsen, K. L. (1971), Remarks on computer-derived magnetograms, *Intl. Assoc. Geomagnetism Aeronomy Bul.* 30:274 (abst.)

Talwani, P., and R. L. Kovach (1971), Theoretical studies and analysis of data from the San Andreas magnetometer array, Final Rept. E22-85-70G, prepared for U.S. Dept. Commerce, NOAA, ERL, Boulder, Colorado, 14 pp.

Tarpley, J. D. (1971), The O_1 component of the geomagnetic lunar-daily variation, *J. Geomag. Geoelect.* 23:165-179.

Tarpley, J. D., and B. B. Balsley (1972), Lunar variations in the Peruvian electrojet, *J. Geophys. Res.* 77:1951-1960.

Tarpley, J. D., and S. Matsushita (1971), The effect of a lunar-time electrostatic field on sporadic E, *Intl. Assoc. Geomagnetism Aeronomy Bul.* 30:201 (abst.)

Van Zandt, T. E., W. L. Clark, and J. M. Warnock (1972), Magnetic apex coordinate system for the ionospheric F-2 layer, *J. Geophys. Res.* 77:2406-2411.

Watson, D. E., ed. (1972), A review of geomagnetism research in NOAA, 1970-1971, U.S. Dept. Commerce, NOAA Tech. Rept. ERL 223-ESL 19, 69 pp., Supt. of Documents, Washington, D.C. 20402.

Wood, J. D. (1971), Geomagnetic observatories at Byrd and South Pole stations, *Antarctic J. of U.S.* 6:228.

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A REVIEW OF GEOMAGNETIC RESEARCH IN NOAA, 1971-1972

David G. Knapp, Editor

Introduction

The third annual review of geomagnetic research in NOAA was conducted at Boulder on July 24-25, 1972. The sessions were again organized by the Environmental Research Laboratories (ERL) under the immediate direction of Dr. Leroy R. Alldredge, Director, Earth Sciences Laboratories. Participants included representatives of several related activities in NOAA, particularly those components of the Environmental Data Service (EDS) that are involved in geomagnetism. This conference was the first such review to be held since the full implementation of the 1971 reorganization under which the geomagnetic functions of the former U.S. Coast and Geodetic Survey (now the National Ocean Survey) became part of the joint responsibility of ERL and EDS. (Physical transfer of staff and equipment from Rockville, Maryland to Boulder, Colorado was effected during the weeks following September 1, 1971.) Other groups represented at the meetings either by presented papers or by attendance of personnel were the Space Environment Laboratory, the Atlantic Oceanographic and Meteorological Laboratories, the Pacific Oceanographic Laboratories, the National Ocean Survey (all NOAA entities), the National Aeronautics and Space Administration, the U.S. Atomic Energy Commission, the National Science Foundation, and the Cooperative Institute for Research in the Environmental Sciences.

Of the 28 papers presented at the 2-day conference, 22 are represented by extended abstracts. In addition, a plan was implemented to incorporate another section in this report to depict somewhat more fully the scope of geomagnetic studies in ESL that were not brought out in the papers actually given at the sessions. This second part has been compiled by Commander Philip J. Taetz of the NOAA Commissioned Corps, who has been working with the Earth Sciences Laboratories since August 1972.

The several findings, proposals, and recommendations advanced by the authors of some of the papers should be taken only as such, and their inclusion in this volume does not imply their adoption or endorsement as official policy.

Among the several manuscripts there was some disparity in the use of units of measurement, and the editor has adopted the policy of converting to SI units (Système International) wherever possible. This necessitated the substitution of the nanotesla (nt) for the time-honored "gamma" (γ), which has been discouraged as a non-SI unit. The more conservative reader will perhaps elect to read "gamma" wherever he sees "nt". (For the rationale of this change see pp. 62-63 of the report on last year's corresponding Review, cited on p. 50 below as Watson, 1972.) As regards the spelling of doubtful place names, the editor has chosen to follow the guidance established by the U.S. Board on Geographic Names.

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