BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD

BMR RECORD No. 85/13

GEOMAGNETIC WORKSHOP
Canberra,
14-15th May 1985

PROGRAMME AND ABSTRACTS

Compiled by
C.E. Barton, F.E.M. Lilley, W.Prohasky and A.J.McEwin

BMR RECORD No. 85/13

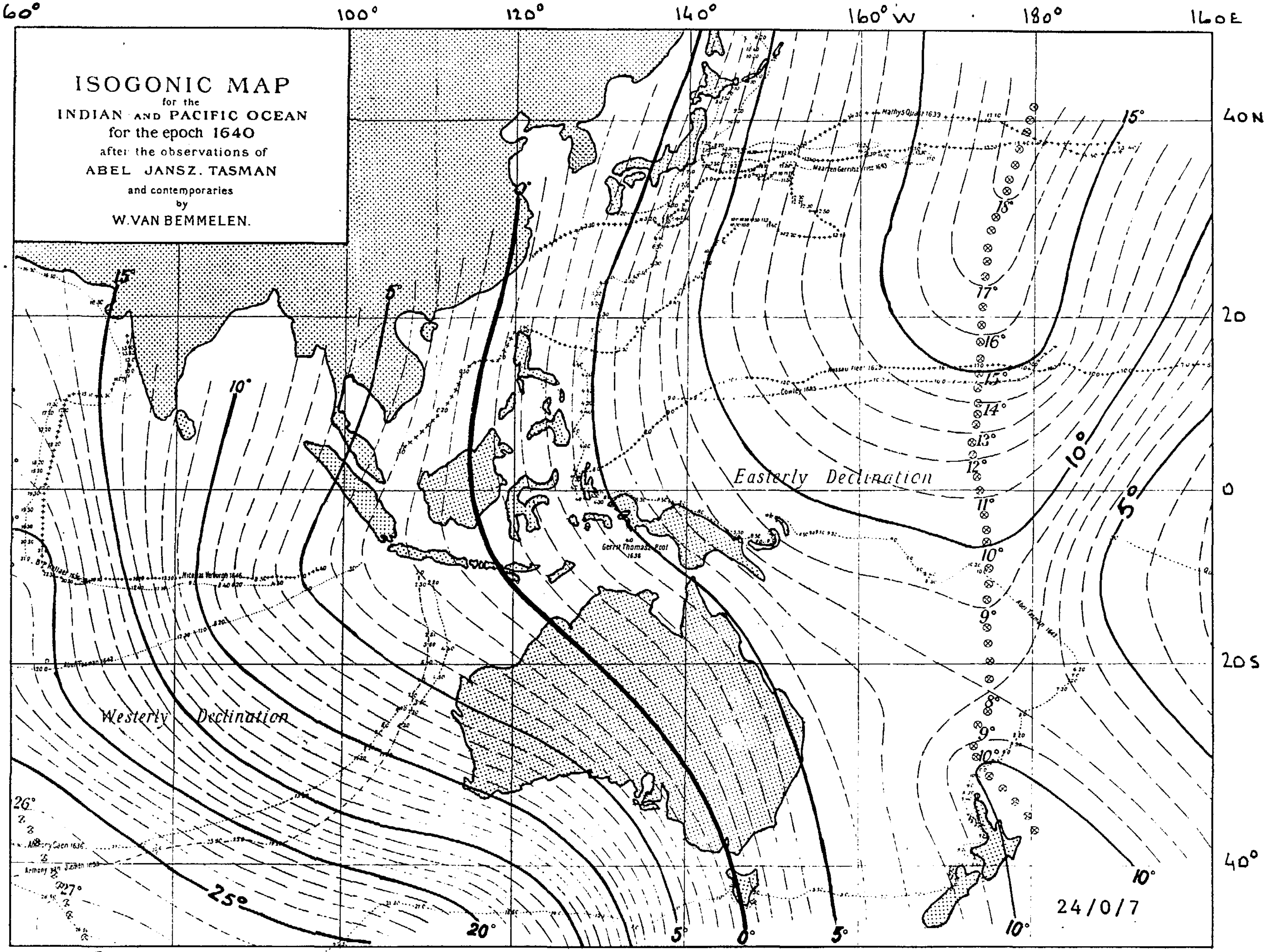
GEOMAGNETIC WORKSHOP
Canberra,
14-15th May 1985

PROGRAMME AND ABSTRACTS

Sponsored by: Specialist Group on Solid Earth Geophysics,
Geological Society of Australia

Organized by: Bureau of Mineral Resources, and
Research School of Earth Sciences, ANU

Compiled by
C.E. Barton, F.E.M. Lilley, W.Prohasky and A.J.McEwin



60°
100°
120°
140°
160° W
180°
160 E
40 N
20
0
20 S
40°
ISOGONIC MAP
for the
INDIAN AND PACIFIC OCEAN
for the epoch 1640
after the observations of
ABEL JANSZ. TASMAN
and contemporaries
by
W. VAN BEMMELEN.
Easterly Declination
Westerly Declination
15°
10°
5°
0°
20°
25°
26°
27°
17°
16°
15°
14°
13°
12°
11°
10°
9°
8°
Matthys Quast 1639
Maarten Gerritsz Vries 1643
Nassau Fleet 1625
Cowley 1683
Gerrit Thomasz. Pool 1636
Abel Tasman 1643
Abel Tasman 1642
Nicolaas Verburgh 1646
Anthony Caen 1636
Anthony van Diemen 1633
24/0/7

2

CONTENTS

FOREWORD

Historically, the Australian region, including Australian Antarctic Territories, has always played an important role in the study of geomagnetism, due largely to its position in the southern hemisphere. The earliest recorded magnetic observations in the region were made by European mariners, principally Abel Tasman (frontispiece) and subsequently James Cook, for whom a knowledge of the magnetic declination was of great value in navigation. One of the first magnetic observatories in the world was established in Van Diemen's Land (now Tasmania) as early as 1840, only two years after Gauss' first spherical harmonic analysis of the geomagnetic field, and demonstration of the need for a global network of observatories for describing the Earth's magnetic field.

Observatory and magnetic survey work initiated by George von Neumayer and also by the Carnegie Institution of Washington set the basis for geomagnetic studies in the region, which have continued to the present day. Together with New Zealand, Indonesia, Papua New Guinea and neighbouring islands the region covers one eighth of the earth's surface. It contains both the South Magnetic and Geomagnetic Poles, and an Australian Antarctic station is situated beneath the south polar cusp.

This workshop serves as a focus for the continuing, active role played by Australian and New Zealand scientists in the field of geomagnetism. The program of talks highlights the causes, effects and applications of geomagnetic phenomena ranging from those related to motions in the Earth's liquid core to those generated within the magnetosphere.

The meeting has been organized jointly by the Bureau of Mineral Resources and the Australian National University, under the sponsorship of the Specialist Group on Solid Earth Geophysics (SG^2) of the Geological Society of Australia.

We would like to thank the Director of the BMR, Prof. R.W. Rutland, and the Director of the Research School of Earth Sciences, Prof. K. Lambeck for the support of their respective organizations, Dr. M.W. McElhinny who has enthusiastically supported the idea, and all who have helped in the organization of this meeting, particularly Patricia Burrell, David Edwards, Adrian Hitchman, Peter Hopgood, Andrew McEwin, Timothy Nieminen, Wendy Prohasky, Joseph Salib and Michael Vernon.

C.E.B & F.E.M.L.
Canberra, May 1985

PROGRAMME

Tuesday 14th May, 1985

(speaker's names are undelined) — Abstract on page

09.00 am	Registration - Jaeger Building, Research School of Earth Sciences, ANU.	
10.00	Welcoming remarks by the organizers.	
10.15	Opening message by Prof. D.I. Gough, President of IAGA.	
10.30 am	TEA	
10.50	*K.D.Cole:* Solar wind induced geomagnetic pulsations and fluctuations.	20
11.15	*B.J.Fraser:* The use of geomagnetic pulsations in determining magnetospheric plasma properties.	28
11.40	*F.Menk, B.J.Fraser, C.Ziesolleck:* Propagation of Pc3-4 pulsations at low latitudes.	54
12.05	*R.J.Stening:* Solar and lunar magnetic tides at midnight.	72
12.30 pm	LUNCH at University House.	
02.00	*D.E.Winch:* The geomagnetic field and Sq.	86
02.30	*E.C.Butcher:* Variations in the magnetic declination on abnormal quiet days.	10
03.00	*M.R.Ingham, D.I.Gough & D.K.Bingham:* Conductive structures under the Canadian Cordillera.	43
03.30 pm	TEA	
04.00	*F.H.Chamalaun:* Geomagnetic deep sounding of the Java Trench subduction zone.	13
04.30	*W.D.Parkinson: & R.Hermanto:* The Tamar conductivity anomaly.	68
05.00	*A.White & P.R.Milligan:* Geomagnetic variation anomaly on Eyre Peninsula, South Australia.	82
08.00 pm	ORIENTAL MAGNETO-BANQUET at the Emperor Court Restaurant, Yarralumla Shopping Centre, Canberra. (transport provided from the Cellar Bar, University House).	

6

Wednesday 15th May, 1985

09.00 am	*F.E.M.Lilley*: The study of geomagnetic induction physics.	47
09.20	*I.J.Ferguson*: The Tasman Project of seafloor magnetotelluric exploration.	24
09.40	*N.L. Bindoff*: Oceanographic effects in geomagnetism.	8
10.00	*H.A.Roeser, v.Gebhardt, W.Weigel & K.Hinz*: Transition from rifting to sea-floor spreading: the magnetic slope anomaly off Morocco.	70
10.30 am	TEA.	
11.00	*P.J.Hill*: Seafloor spreading and magnetization in the Southern Ocean.	32
11.30	*B.D.Johnson*: Processing of satellite magnetometer data.	30
12.00	*J.C.Dooley*: Ground control of satellite observations of the geomagnetic field.	21
12.30 pm	GROUP PHOTOGRAPH outside the Jaeger Building.	
	LUNCH at the Black Mountain palaeomagnetic laboratory (transport provided).	
02.00	*D.H.Tucker, I.Hone & W.Anfiloff*: The airborne-magnetic map of Australia: problems, expectations and applications.	78
02.30	*G.V.Haines & L.R.Newitt*: A geomagnetic reference field for Canada1985.	66
03.00	*C.E.Barton: & A.J.McEwin*: International and Australian geomagnetic reference fields.	6
03.20	*P.L.McFadden*: The origin of the main field.	50
03.50 pm	TEA and concluding remarks by the organizers.	
04.10 pm	SUNSET VISIT to the Canberra Magnetic Observatory (transport provided, free geo-gluhwein, return at 6.15 pm. via the airport).	

7

Estimating the Three-Dimensional Structure of the Electrical Conductivity of the Earth

R.S. Anderssen,

CSIRO Division of Mathematics and Statistics,
GPO Box 1965, Canberra, ACT 2601

One way to assess the three-dimensional structure of the electrical conductivity of the Earth is to piece together as a mosaic the results from local studies. In part, the construction of such mosaics is the motivation for local studies. On the one hand they supplement the information available from an averaged global model; on the other they define limits on the range of applicability of global models.

Another way is to use available world-wide geomagnetic data to identify global features in the Earth's transient magnetic field, and to then derive using these features averaged three-dimensional electrical conductivity models. Numerous approaches have been suggested and applied from the same difficulties: the complexity of the Earth's geomagnetic field consisting of the external and internally induced transient field coupled with the internally generated permanent and transient fields: the erratic sparse nature of the available geomagnetic data; the need to stabilize in some appropriate way the inherent improperly posedness of the underlying mathematical model of electromagnetic induction which relates the observational data to the electrical conductivity. The obvious manifestations of these difficulties is the failure of the various methods to yield reasonably consistent models for the electrical conductivity.

In fact, about their only common feature is the conclusion that electrical conductivity increases abruptly at a depth somewhere between 400 and 750km. There is no agreement on either the size or the rate of the increase of this change. In addition, many of the resulting features of published models are artifactual consequences of the inversion techniques used (e.g. predetermined depth or shape of the abrupt change), though this fact is invariably ignored when models are compared.

More sophisticated global three-dimensional modelling of the electrical conductivity structure of the Earth would therefore appear to be inappropriate at this stage; not only because of the abovementioned lack of consistency among published studies, but also because, mathematically, the nature of the electromagnetic induction problem does not permit a tomographic decomposition of geomagnetic data in a manner being successfully applied to seismic data to determine the elastic wave properties of individual three-dimensional cells within the Earth (cf. Anderson and Dziewonski (1984)). This fact relates directly to the difference between the physical processes (and hence mathematical models) involved (cf. Cleary and Anderssen (1978)).

An electromagnetic counterpart to the use of tomography in seismology would appear to be the use of as much data as possible to accurately determine local three-dimensional structure which is then pieced together as a mosaic to define the global structure. Another counterpart could be based on the interpretation of the individual spectral components in a Fourier analysis of the Earth's transient magnetic field.

8

The former approach is crucial to a better understanding of the electromagnetic induction problem for the Earth. It would help clarify to what extent the abovementioned inconsistency among models is related to the three-dimensional variation in the electrical conductivity of the Earth. If Earth structure is as three-dimensional as recent seismic evidence suggests, then some of the inconsistency must simply reflect the geographic variability within the data used, in the sense that, locally, each data set see a totally different electrical conductivity profile as a function of depth.

In addition, if the conclusions from seismic tomography prove to be correct, then global averaging (i.e. radial symmetric modelling) of the electrical conductivity structure is of limited utility except in generating a reference model.

For such reasons, a detailed comparison of one-dimensional transfer function models derived from geomagnetic data at various geographic locations around the Earth is being undertaken.

References

Anderson, D.L., and Dziewonski, A.M., (1984), Seismic Tomography, Scientific American 251 (1984), 58-66.

Anderssen, R.S., Devane, J.F., Gustafson, S.-A. and Winch, D.E., (1979) The qualitative charactyer of the global electrical conductivity of the Earth, Phys. Earth Planet Int. 20(1979), 15-21.

Cleary, J.R. and Anderssen, R.S., (1979) Seismology and the internal structure of the Earth, Chapter 5 in The Earth: Its Origin, Structure and Evolution (Ed. M.W. McElhinny) Academic Press, London, 1979.

Parker, R.L., and Whaler K.A., (1981) Numerical methods for establishing solutions to the inverse problem of electromagnetic induction, JRG 86 (1981), 9574-9584.

9

AUSTRALIAN AND INTERNATIONAL GEOMAGNETIC REFERENCE FIELDS.

C.E. Barton and A.J. McEwin, Bureau of Mineral Resources, Canberra.

By the mid 1960's there was general recognition of the need for an internationally accepted mathematical model of the Earth's main field and its secular variation. Such a model would provide a standard for the trend surface for studies of magnetic anomalies, field residuals of external origin, the external form of the main field, the location of conjugate points, studies of the long-term behaviour of the main field and testing models for its origin. It was recognized that such a global model was attainable, although there was little prospect of agreement about higher order terms, representing regional and local detail of the field (Zmuda, 1971).

In 1968, the International Association of Geomagnetism and Aeronomy (IAGA) finally adopted the International Geomagnetic Reference Field, IGRF 1965. This was a series of spherical harmonics, to degree and order 8 (n=m=8), to describe the geomagnetic potential of the main field for epoch 1965.0, together with a similar model for the secular variation (n=m=8) to be used for extrapolation of the main field between epochs 1955.0 and 1975.0. However, by the early 1970's, departures of the field from predicted values were unacceptably large for many purposes. Accordingly, a new secular variation model (n=m=8) was adopted by IAGA for the interval 1975.0 to 1980.0, to be continuous with IGRF 1965 extended to epoch 1975.0.

Main field and secular variation observations, which take some years to accumulate, are extrapolated forward in time so that IGRF models are available in the year of the nominal epoch. Retrospective analysis of a data set centred about a given epoch provides a more accurate model of the field which is unlikely to undergo further revision. Such models are referred to as Definitive Geomagnetic Reference Fields (DGRF's). At the Edinburgh meeting of IAGA in August 1981, the following models were adopted:

- DGRF 1965 : main field model for 1965.0 (n=m=10)
- DGRF 1970 : main field model for 1970.0 (n=m=10)
- DGRF 1975 : main field model for 1975.0 (n=m=10)
- for intervening epochs (1965.0 to 1975.0) the main field is derived by linear interpolation between the DGRF coefficients.
- PGRF 1975 (Provisional GRF) : a main field model for the interval 1975.0 to 1980.0 defined by linear interpolation between the coefficients of DGRF 1975 and IGRF 1980 (below).
- IGRF 1980 : main field model for 1980.0 (n=m=10), together with a secular variation model (n=m=8) for the interval 1980.0 to 1985.0.

Note that IGRF 1980 is not continuous with IGRF 1975 extended to epoch 1980.0; PGRF 1975 supercedes IGRF 1975, and will itself be superceded when a definitive model for 1980.0 is adopted. The suite of models adopted at Edinburgh defines the main field continuously from 1965.0 to 1985.0

At the forthcoming IAGA Assembly in Prague (August 1985), agreement will be sought on a main field and secular variation model for IGRF 1985, and also definitive models for epochs 1945.0, 1950.0, 1955.0 and 1960.0. In the meantime, national groups are evaluating candidate models using their own regional data.

There are two future magnetometer-bearing satellite missions, currently under review by N.A.S.A., which would have a far reaching effect on new global and regional models of the geomagnetic field. First is the Magnetic Field Explorer (MFEx), a high altitude (550km) polar orbiting satellite with a proposed launch date during the next solar minimum, 1987-1988. The primary objective is to make observations of the Earth's main and external magnetic fields during a three year period. The second proposed mission, the Geopotential Research Mission (GRM), would make observations of both gravity and magnetic fields at a very low orbit of approximately 160 km. for approximately 6 months, to study gravity and magnetic anomalies of crustal origin. The hoped-for launch date is 1992.

Until regular satellite observations of the main field and its secular variation can be maintained, Australia and its neighbours will remain important contributors of data for global models. Furthermore, because of the lower density of observations in the southern hemisphere, particularly in the oceans, global field models are less well constrained here than in the northern hemisphere. Thus IGRF and DGRF models are less likely to give a very accurate picture of regional magnetic fields in these southern hemisphere regions, and hence there is a continuing need for regional magnetic surveys.

Apart from scattered observations collected by early mariners (e.g. Abel Tasman, 1640 - see frontispiece to this volume), the first systematic magnetic survey in Australia was conducted by George Balthazar von Neumayer (1869), while Director of the Flagstaff Observatory in Melbourne. Since its inception in 1946, the BMR has continued this work, producing a series of magnetic field charts for the Australian region (Dooley, this volume, p.22) based on data obtained from first-order observations - accuracy 5nT or 0.5minutes of arc. Permanently marked repeat stations used in the course of BMR first-order magnetic surveys are shown in Figure 1 of Milligan (this volume, p.62). A number of the stations still in use today were established by the Carnegie Institution of Washington magnetic survey in 1912-1913 (Bauer and Fleming, 1915).

The name Australian Geomagnetic Reference field (AGRF) was first used to describe a modification of IGRF 1965 for the Australian region (Petkovic, 1974; Petkovic and Whitworth, 1975; Dooley, this volume, p.22). A magnetic survey of the Australian region, including Papua New Guinea, Irian Jaya and islands in the adjoining oceans, has recently been completed. Modelling of this data using an orthogonal polynomial technique is in progress. The resulting set of models of the magnetic elements and their secular variation will be termed the Australian Geomagnetic Reference Field (AGRF) 1985. The models will contain more detailed information about the field than was represented by the fourth-degree polynomials used for the 1980.0 charts. Future effort is being directed towards reprocessing earlier data using the same technique to produce Definitive AGRF models for post-war epochs. These models will provide suitable baselines for processing localized magnetic survey data to obtain magnetic anomaly information, and will serve as a basis for studies of the long-term behaviour of the geomagnetic field.

It is plausible to assume that non-transient features of the geomagnetic field with wavelengths greater than the size of major continental blocks originate from within the core, or reflect gross heterogeneity in the core-mantle system. Conversely, magnetic anomalies with spatial extent significantly less than the depth to the core-mantle boundary (approx. 3000 km) may be attributed to crustal magnetization. Although there is no consensus regarding the highest degree harmonic of the core field that can be detected at the Earth's surface, figures in the range 12 to 16 have been suggested. The higher value translates to surface features with wavelengths of about 2500km. The size of Australia (about 40^0) corresponds to a 9th degree spherical harmonic, whereas the mean spacing between first-order magnetic survey repeat stations of about 350km corresponds to a 57th degree harmonic. Thus even the lowest harmonic of the AGRF may contain a significant crustal component. IGRF and DGRF models of the global field have been restricted to low degree and order (8 or 10, although a candidate model for the 1985 IGRF, WC85, goes to n=m=12), and therefore provide our best estimate of the main (core) field. Systemmatic differences between the AGRF and IGRF/DGRF models for given epochs therefore provide a measure of very long wavelength crustal magnetic anomalies in the Australian region.

References

Bauer, L.A. and J.A. Fleming (1915). Land magnetic observations 1911-1913 and reports on special researches. Researches of the Dept. Terrestrial Magnetism, Vol. 2, Carnegie Institution of Washington, Pubication No. 175, 142-160.

Petkovic, J.J. (1974). Magnetic secular variation in the Australian region. In: Annual Summary of Activities, BMR Report 190, 51-53.

Petkovic,J.J. and R.Whitworth (1975). Problems in secular variation in the Australian region. EOS Trans. A.G.U., 56, 51-53.

Neumayer, G.B. von (1869). Results of the magnetic survey of the colony of Victoria executed during the years 1858-1864. Published by Mannheim, printed by J. Schneider.

Zmuda,A.J., editor (1971). World Magnetic Survey 1957-1969. IAGA Bull. No.28, Paris IUGG.

Oceanographic effects on the Geomagnetic Field

N.L. Bindoff

Research School of Earth Sciences
Australian National University

Three classes of ocean water movements are identified as significant sources of motionally induced electromagnetic (EM) fields in the frequency range 10^{-3} - 10^{-2} cph. These are : (i) the barotropic steady state and mesoscale eddies, (ii) tides, and (iii) internal waves particularly at the inertial frequency. Other water motions may contribute significant EM fields such as tsunami, when present (Larsen 1971), surface waves and the dispersive wave observed by Law (1983). The electric field components are more sensitive to the motional induction than the magnetic components since the magnetic field is a spatial average of electric currents. The vertical component of the electric field (VEF) is not contaminated by ionospherically induced signals and represents a purely oceanographic signal. When the ratio of ocean stream width (D) to ocean depth (h) is large (i.e. $D/h \gg 1$) the VEF can be approximated by

$$E_z = -V_{east} \times B_{north}$$

where Veast is the east-west velocity of the local fluid (Harvey 1972, Malkus and Stern 1952). The interpretation of the horizontal components of the electric field is more complex. The horizontal components of the electric current are in general non-zero and depend on the velocity field, and, in the time varying case, on the conductivity structure of the mantle. The degree of mutual induction depends on the ratio of skin depth (δm) of the mantle and the length scale (D) of the ocean current flow (Sanford 1971). Small $\delta m/D$ ratios indicate a strong coupling between mantle and ocean movements.

The conductivity structure and velocity structure are the geophysical targets of ocean bottom EM experiments. Thus, for interpretations, some authors assume the depth averaged horizontal current (J) is negligible and obtain

$$E = -V \times F$$

where, E, V are the vertically averaged, conductivity weighted components of the electric field and velocity field respectively. The validity of this relation is critically dependent on the electrical linkage through the sea floor and is only strictly true for an insulating crust and time independent streams.

Power spectral analysis of VEF data, collected as part of the Tasman Project of Seafloor Magnetotelluric Exploration shows the significance of internal waves, mesoscale currents and tides at the ocean bottom. The amplitudes of the spectrum of the internal waves (including the inertial waves) and tides are 1 - 3 orders of magnitude less than the amplitudes due mostly to ionospheric sources, measured by the horizontal electric fields for the frequency range .05 - 20 cph. The large powers observed in the horizontal components of the electric field are inferred to be due to mesoscale currents for frequencies $< 10^{-3}$ cph. Such large energies are negligible in the power spectrum for magnetic variations recorded by ocean bottom magnetometers for the same frequencies. This result indicates that curl$\underset{\sim}{E}$ is small, and that these long period electric fields are due to ocean movements. The spectra for magnetic variations from this project show enhancement of spectral lines at tidal frequencies (M2) when compared with land data.

References

Cox, C., J. Filloux and D. Cayan, 1976. Electromagnetic Observations during Mode -I: Sea Floor Electric Field and Transport. Polymode News 14, August 27.

Harvey, R. 1972. Oceanic Water Motions Derived from the Measurement of the Vertical Electric Field, Hawaii Institute of Geophysics Report, May 1972.

Larsen, J.C. 1971. The Electromagentic Field of Long and Intermediate Water Waves, Journal of Marine Research, 29, 28-45.

Law, L.K. 1983. Marine Electromagnetic Research, Geophysical Surveys 6, 123-135.

Longuet-Higgins, M.S., M.E. Stern and H. Stommel. 1954. The Electrical Field Induced by Ocean Currents and Waves; With Applications to the Method of Towed Electrodes, Pap. Phys. Oceanography and Meteorology, Vol XIII, No.1, 1954.

Malkus, W.V.R. and M.E. Stern. 1952 Determination of Ocean Transports and Velocities by Electromagnetic Effects. Journal of Marine Research 11 No. 2 97-105.

Sanford, T.B. 1971. Motionally Induced Electric and Magnetic Fields in the Sea. Journal of Geophysical Res. 76, 15, 3476-3492.

14

Variations in the Magnetic Declination on Abnormal Quiet Days

E.C. Butcher

Department of Physics
La Trobe University
Bundoora, Victoria, Australia, 3082

For stations on the poleward side of the S_q focus the minimum in H on quiet days occurs near 1100 LT. In fact, on about 80% of quiet days, the minimum occurs between 0830-1330 LT. Such days were termed 'normal quiet days' (NQDs) by Brown and Williams (1969) whereas those days where minimum occurs outside this time range were termed 'abnormal quiet days' (AQDs). It has been shown that when AQDs occur, the amplitude of the normal H variation is significantly reduced and the daily minimum is formed by a magnetospheric substorm event. The reduction in the H variation is caused by a current which flows in the ionosphere, in a West-East direction on both sides of the focus, and therefore causes an increase in the amplitude of H at stations on the equatorward side of the focus (see Fig. 1). The strength of this current has been found to be dependent on the polarity of the IMF, it being larger on days when the IMF is away from the sun (A-days) than when it is toward the sun (T-days). This current also affects the position of the Sq focus, causing it to move poleward on AQDs, the effect being greatest on A-days.

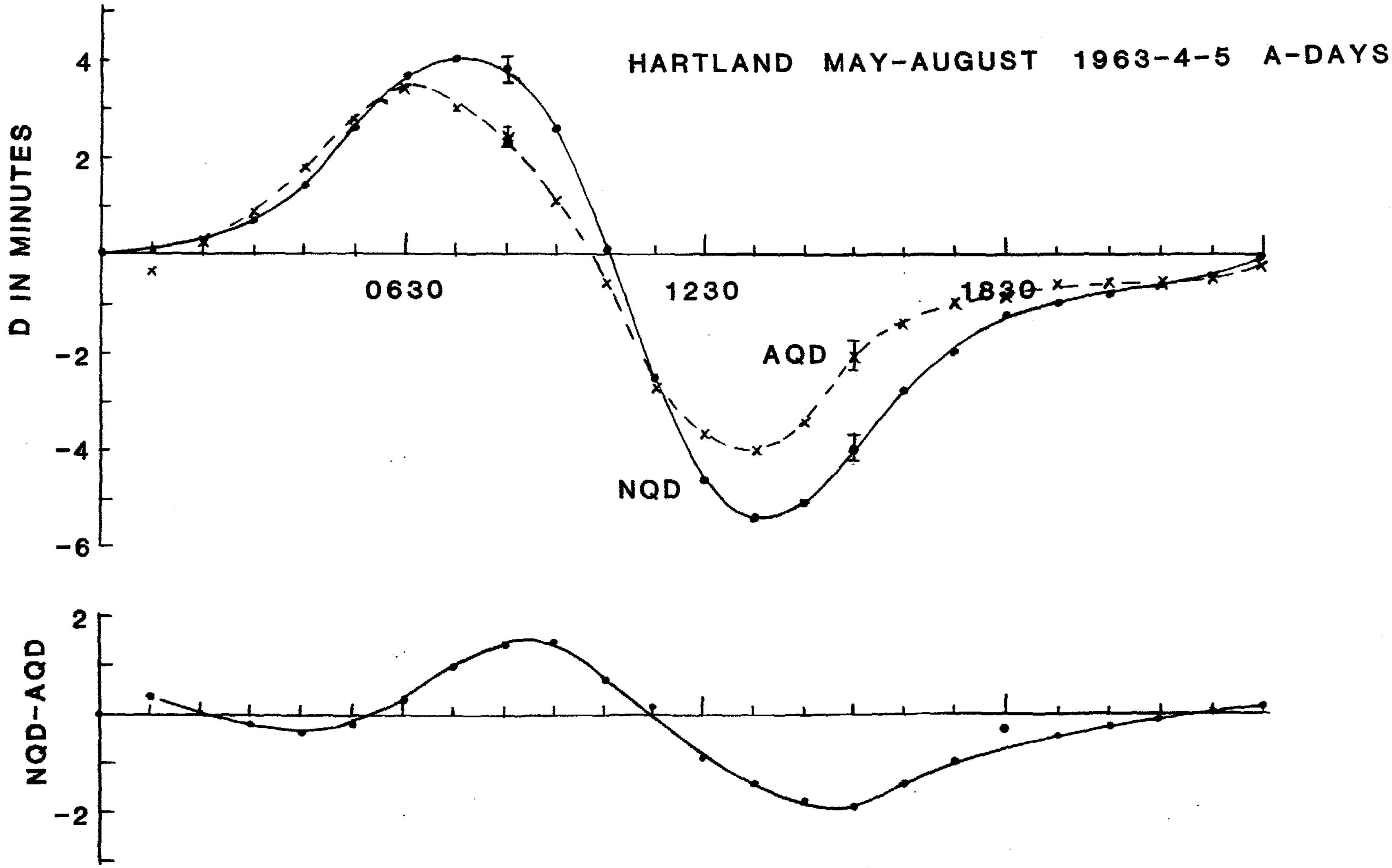
The source of this current is not known. Takeda (1982) has suggested that the source of this current is a field-aligned current at high latitudes which leaks equatorward and eastward before exiting as a field-aligned current. If this is the case, this should cause an equatorward current in the morning and a poleward current in the afternoon. Such currents should manifest themselves in the declination data. Declination data has been analysed and compared on NQDs and AQDs and it will be shown that on AQDs on A-days there is a poleward current in the morning and an equatorward current in the afternoon, the opposite to that predicted by Takeda. The effect does not appear to be present on T-days (see Fig. 2). Possible sources for this current will be discussed.

References

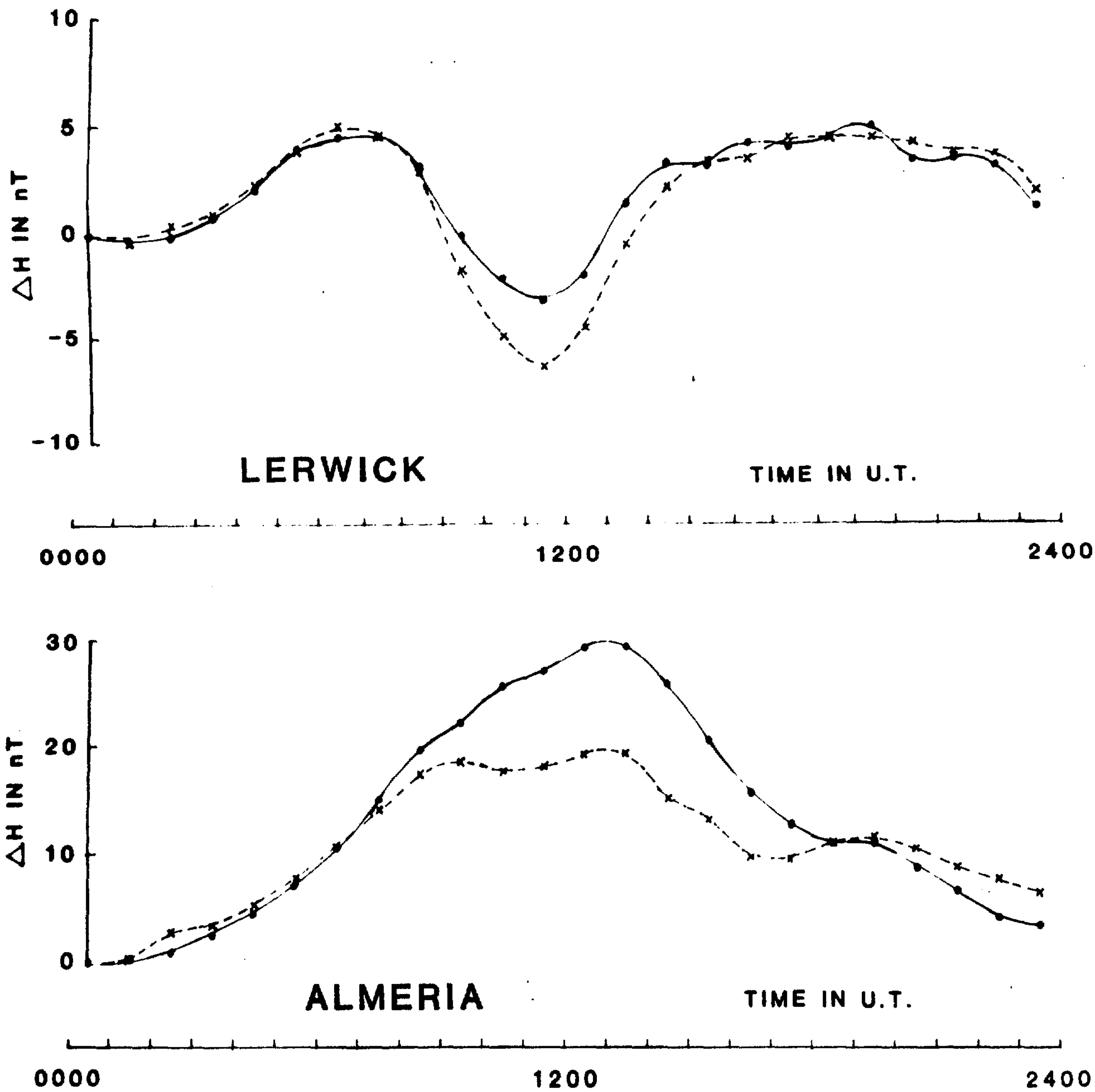
Brown, G.M., and Williams, W.R., (1969) Some properties of the day-to-day variability of S_q (H) Planet. Space Sci. 17, 455-470.

Takeda, M., (1982). Three-dimensional structure of ionospheric currents produced by field aligned currents. J. Atmos. Terr. Phys. 44, 695-701.

15


HARTLAND MAY-AUGUST 1963-4-5 A-DAYS
D IN MINUTES
4
2
-2
-4
-6
0630
1230
1830
AQD
NQD
NQD-AQD
2
-2

NOV-FEB 1963-4-5



17

GEOMAGNETIC DEEP SOUNDING OF JAVA TRENCH SUBDUCTION ZONE

F.H. Chamalaun
School of Earth Sciences,
The Flinders University of South Australia, Bedford Park,
South Australia.

Because of the complex tectonic setting of an island arc subduction zone, which involves marked changes in temperature and lithologies at depth, one might expect subduction zones to be associated with significant G.D.S. Anomalies. This is the case In Japan (Rikitaki and Honkura, 1973) and in Peru (Schmucker, 1973). In both cases the heat rising above the descending slab (Uyeda and Rikitaki, 1970, Gough, 1973) and the resistive upper part of the slab (Garland, 1975) have been suggested as possible causes for the observed anomalies. Jones et al (1981) showed that the temperature distribution could be significant, and presented the G.D.S. anomaly for three different thermal models.

In 1981 twelve magnetometers of the type described earlier (Chamalaun and Walker, 1982) were deployed for nine weeks in western Java, to determine the G.D.S. signal associated with the classical subduction zone of the Java trench. The induction arrows (Figure 1A) are directed towards the coast, and at 1 hour periods, decrease in lengths from about 1.0 at the coast to about 0.2 some 130 km land inwards. Little evidence was found for near surface conductors, such as might be associated with currently active volcanoes.

If the transfer functions are plotted as a function of distance from the coast, using the 2000 meter bathymetry contour (rather than the trench) as origin, the decay is found to be indistinguishable from that found at 'young tectonic' continental margins, such as those in California (Schmucker, 1970), the east (Bennett and Lilley, 1974) and south coast of Australia (White and Polatajko, 1978). A similar normal coast effect was observed by Aldridch et al (1972) for the southern portion of the Peru-Chile trench in Chile.

From the West Java and Chile results it would appear that neither the expected temperature contrasts, nor the presence of a more resistive upper slab, are by themselves necessarily sufficient to modify the normal coast effect.

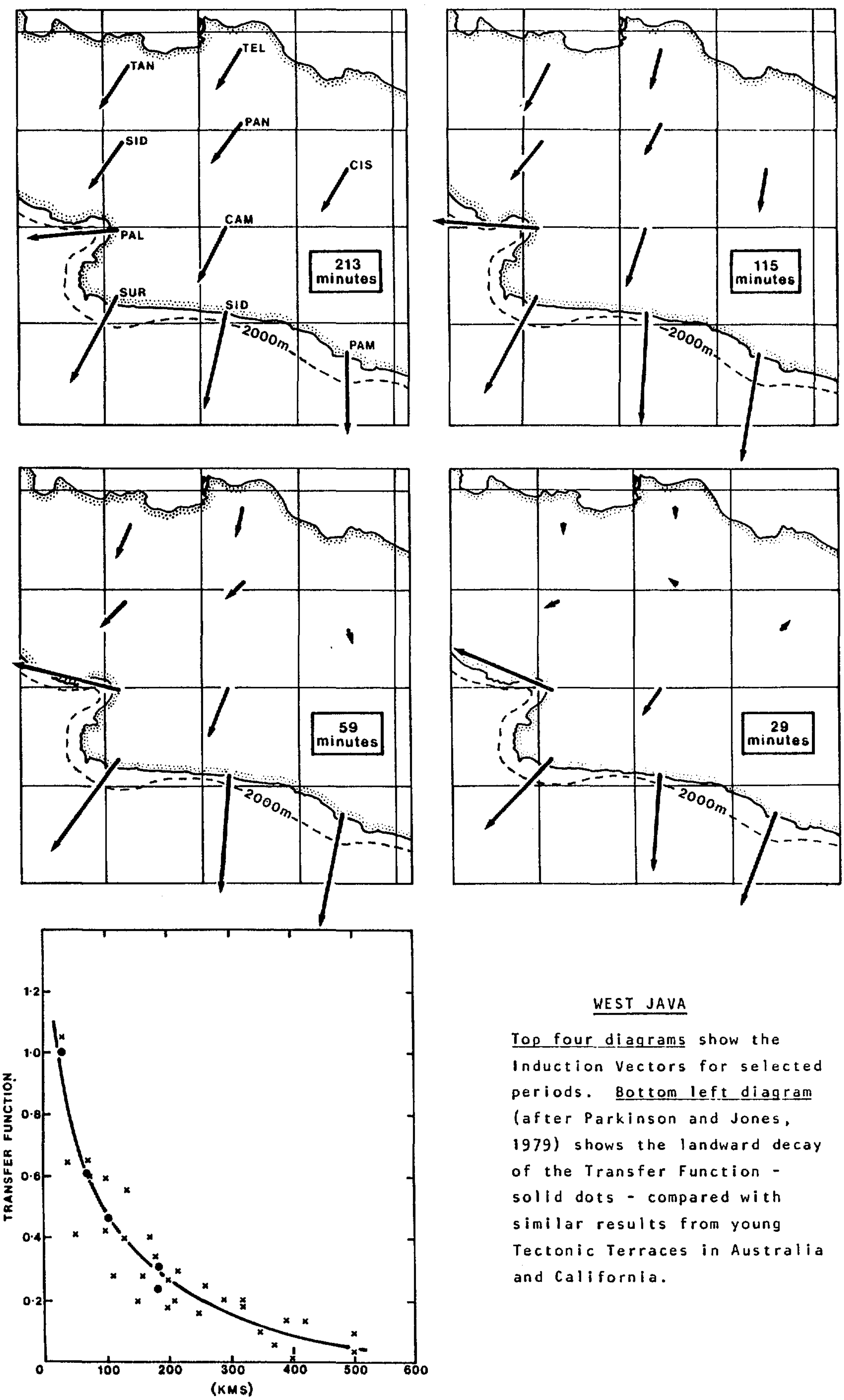
References

ALDRIDCH, T., Carnegie Inst. Wash. Yearb. 71/72, 317, 1972.
BENNETT, D.J. and LILLEY, F.E.M., Geophys. J.R.A. Soc., 37, 191-206 1974.
CHAMALAUN, F.H. and WALKER, R., J. Geomag. Geoelectr., 34, 491-507, 1982
GARLAND, G.D., Phys. Earth Planet. Interiors, 10, 220-230, 1975.
GOUGH, D.I., Phys. Earth Planet Interiors, 7, 379-388, 1973.
JONES, F.W., PASCOE, L.J., RAMASWAMY, V. and SYDORA, L.J., J.G.R., 86, 10870-10874, 1981.
PARKINSON, W.D. and JONES, F.W., Reviews Geophys. Space Phys, 17, 1999-2015, 1979.

18

RIKITAKI, T. and HONKURA, Y., Phys. Earth Planet Interiors, 7, 203-212, 1973.
SCHMUCKER, U., Bull. Scripps Inst. Oceanogr., 13, 1-165, 1970.
SCHMUCKER, U. et al., Phys. Earth Planet Interiors, 7, 365-378, 1973.
UYEDA, S. and RIKITAKI, T., J. Geomag. Geoelectr., 22, 75-90, 1970.
WHITE, A. and POLATAJKO, O.W., J. Geomag. Geoelectr., 30, 109-120, 1978.

19



WEST JAVA

Top four diagrams show the Induction Vectors for selected periods. Bottom left diagram (after Parkinson and Jones, 1979) shows the landward decay of the Transfer Function - solid dots - compared with similar results from young Tectonic Terraces in Australia and California.

20

THE FLINDERS ARRAY MAGNETOMETER

F.H. Chamalaun,
School of Earth Sciences,
The Flinders University of South Australia,
Bedford Park, S.A.

The use of arrays of magnetometers in geomagnetic deep sounding studies has two major advantages. The first is that a large area can be covered quickly reducing the need for repeat visits which is particularly important for terrains with difficult access. The second advantage is the opportunity to analyse single events of favourable polarization recorded simultaneously over a large area.

Array magnetometers should be: cheap, such that 20 or 30 can be constructed with a modest budget; they should be robust and small for easy installation; their power consumption should be low and data capacity large enough to allow some 3 months of unattended data recording; data should be digital so that the whole recording period will be available for rapid processing and analysis.

The first array magnetometer, of which more than 100 are now in use was developed by Gough and Reitzel (1967). It has proved to be highly successful and has been mainly responsible for the upsurge in G.D.S. studies in the past decade. The Gough-Reitzel magnetometer uses a classical design, with magnets suspended from torsion fibres and recording on photographic film.

Recent advances in digital electronics and microprocessors have made it possible to design a digital array magnetometer, using fluxgate sensors, for the same cost as the Gough-Reitzel magnetometer. Such an array magnetometer was designed and built at Flinders University (Chamalaun and Walker, 1982), and 25 magnetometers have been used in seven array studies over the last 4 years.

The Flinders magnetometer is a selfcontained sealed unit (60 cm x 20 cm) which uses three orthogonal fluxgate sensors. Power consumption is reduced by careful selection of components, and by switching the unit off between measurements. The signal is converted by an A/D converter pair. The heart of the unit is a microprocessor which controls the data acquisition sequence, applies a data compression algorithm and writes the data from memory to a cassette tape. Using a 1 minute sampling interval, data are written in one hour blocks every hour, and the total recording period is 100 days. The sampling rate is switchable between 10 seconds and 1 minute and can further be varied by software. Although absolute calibration is probably not better than ±80 n Tesla, the full field values for each sensor are recovered from the data. Hence the instrument need not be orientated in the field except for verticality. At present the instrument is operated with 1 n Tesla resolution; has noise

21

level of less than .5 n Tesla, and when burried a drift of less than 5 n Tesla per 30 days. Data loss, arises mainly from the taperecorder, but is generally less than 4 or 5 hours in 100 days.

We are currently designing a new prototype which will have solid state memory, for greater data integrity; a cmos micro with much reduced power consumption and greater (8k) program capacity; a programmable clock for added flexibility in varying sampling rates; a 16 bit A/D converter to reduce chip count and ring cores to improve signal to noise ratio. As the cost of memory chips is falling rapidly we expect the overall cost of the magnetometer to be about the same as the current one, while retaining the same capacity (100 days at 1 minute). In addition we are investigating using existing data sets and computer simulation, the feasibility of changing the data acquisition method from one in which the sampling rate is constant, to one in which the sampling rate is varied according to the rate of change of the magnetic field.

References

Chamalaun, F.H. and Walker, B., J. Geomag. Geoelectr. 34, 491-502, 1982.

Gough, D.I. and Reitzel, J.S., J. Geomag. Geoelectr. 19, 203-215, 1967/

22

EXTENSION OF THE FLINDERS RANGES ANOMALY

F.H. Chamalaun
School of Earth Sciences
Flinders University of South Australia,
Bedford Park, South Australia

The first large scale Geomagnetic Deep Sounding Array study in Australia, was conducted by Gough et al (1972, 1974), using a widely spaced array across the Flinders Ranges in South Australia, stretching from the West Australian border and into Victoria. A significant conductor was detected and interpreted to run north-south parallel to the main grain of the Flinders Ranges.

Between 1982 and 1984 three closely spaced arrays were deployed (see Figure 1), to delineate the Flinders Ranges anomaly in detail. The first array covered the Central Flinders Ranges and showed (Chamalaun, 1985) that the anomaly followed the Houghton anticline to the east. The second array traced the anomaly southward, where it enters St.Vincents Gulf between Wallaroo and Port Victoria. In both these studies the conductor effect is masked by the coast effect. A third array was deployed near Lake Frome, and this showed the anomaly to change to a northerly trend. The coast effect in the Lake Torrens sector is much less, and the anomaly is observed only at high frequencies.

The evidence favours a narrow and relatively shallow (<10 km) crustal anomaly. The anomaly however cuts across tectonic terrains suggesting that the current follows different tectonic units. In the north near Lake Frome it appears to follow the western edge of the Arrowie basin and associated basement highs. Where these abut the Olary Arc of the Flinders Ranges, the current enters the Calanna beds, which it follows along the Houghton anticline. In the south it seems to follow the NE-SW fault pattern out into the St. Vincents Gulf.

It is speculated that the northerly extension is likely to follow the western margin of the Cooper basin and may, via the Birdsville basement high, link up with the south west Queensland anomaly discovered by Woods and Lilley (1979, 1980).

References

CHAMALAUN, F.H., Phys. Earth Planet Int. 37., 174-182, 1985.

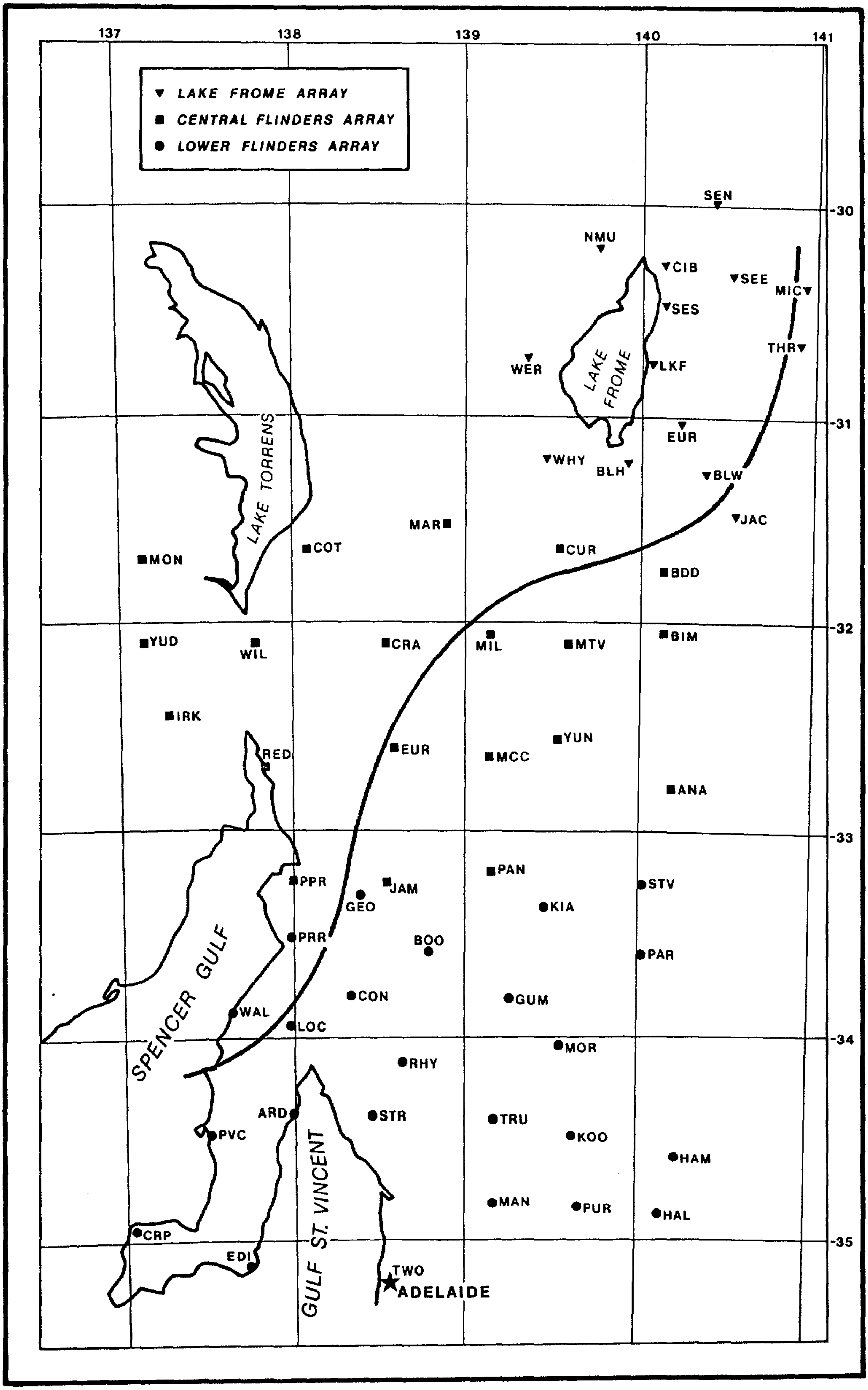
GOUGH, D.I., LILLEY, F.E.M. and MC ELHINNY, M.W., Nature,239, 88-91. 1972.

GOUGH, D.I., MC ELHINNY, M.W. and LILLEY, F.E.M., Geophys. J.R.A. Soc., 36, 345-362, 1974.

WOODS, D.V. and LILLEY, F.E.M., J. Geomag. Geoelectr., 31, 449-458, 1979.

WOODS, D.V. and LILLEY, F.E.M., Geophys. J. R. A. Soc., 62, 675-689, 1980

23


137
138
139
140
141
-30
-31
-32
-33
-34
-35
▼ LAKE FROME ARRAY
■ CENTRAL FLINDERS ARRAY
● LOWER FLINDERS ARRAY
SEN
NMU
CIB
SEE
MIC
SES
THR
WER
LAKE FROME
LKF
EUR
WHY
BLH
BLW
JAC
LAKE TORRENS
MAR
COT
CUR
MON
BDD
YUD
WIL
CRA
MIL
MTV
BIM
IRK
RED
EUR
MCC
YUN
ANA
PPR
JAM
PAN
STV
GEO
KIA
PRR
BOO
PAR
SPENCER GULF
CON
GUM
WAL
LOC
MOR
RHY
ARD
STR
TRU
PVC
KOO
HAM
GULF ST. VINCENT
MAN
PUR
HAL
CRP
EDI
TWO
ADELAIDE

24

Solar Wind Induced Geomagnetic Pulsations and Fluctuations

K.D. Cole

Department of Physics
La Trobe University
Bundoora, Victoria, Australia, 3083

The solar wind generates geomagnetic pulsations by direct interaction with cold plasma of ionospheric origin in the geomagnetic field. The wind also induces changes in the energetic particle populations of the magnetosphere which cause further pulsations. In this paper the upper limit of the period of pulsations is taken as about five minutes.

This paper concentrates on geomagnetic fluctuations of periods in excess of about five minutes which are induced by the action of the solar wind. The distribution of the fluctuations as functions of geomagnetic latitude and in different epochs of magnetic disturbance will be shown. The associations of the fluctuations with magnetospheric phenomena such as the ring current and plasmapause will be indicated.

25

Ground Control of Satellite Observations of the Geomagnetic Field

J.C. Dooley

Measurements of the vector magnetic field over Australia were made at about 8000 stations over Australia, mainly during the period 1967 to 1975 (Dooley and McGregor, 1982); these measurements comprised the Third-order Regional Magnetic Survey. The distribution of the measurement sites is shown in Fig. 1. One of the objectives of this survey was to improve the representation of the field for the production of magnetic charts; however it also provides an opportunity to study long wavelength anomalies associated with crustal features.

Another set of vector data over the continent is provided by the MAGSAT project. Anomalies of crustal origin have successfully been extracted from satellite magnetic data and analysed for various parts of the world; for Australia, so far only the scalar field has been used. The limit of resolution of anomalies from satellite data appears to be at a wavelength of about 250 km. It is expected that combined use of the satellite and ground data should improve the resolution, and also enable better treatment of systematic errors present in one or other data set but not in both. The use of vector data should improve the prospects of determining the directions of magnetisation of the anomalous bodies.

Two-dimensional Fourier analysis appears to be the most appropriate method for analysis of the data sets over the continental region. It has been shown that distortion due to assumption of a flat Earth over a region of the sphere of radius up to about 30^{o} is only about 2%. More serious errors are likely to arise from truncation of the third-order data at the continental boundary. Such errors may be reduced by using vector data from the U.S. Project Magnet, along profiles flown over the oceans adjacent to Australia during the period 1957 to 1963. About 5700 observations have been selected in the region bounded by latitudes 10^{o}N and 90^{o}S, and longitudes 80^{o}S and 180^{o}E.

In order to study crustal anomalies, it is necessary to remove a main field component from the observations. Because of the number of years over which the observations were made, it is also necessary to apply appropriate secular variation corrections to the third-order and Project Magnet data. As the variations amount to several hundred gammas, it becomes important to select an appropriate model, preferably a mathematical model suitable for computer use because of the large number of observations.

Main field and secular variation models for the region are based on magnetic observatory recordings, and on observations at field stations throughout Australia and on nearby islands, these being repeated at intervals of 5 to 10 years. There are about 60 such stations in Australia, known as first-order stations.

Global models of the magnetic field, in the form of spherical harmonic series, are produced every five years by the International Association of Geomagnetism and Aeronomy (IAGA). The first of these, the International Geomagnetic Reference Field for 1965, gave a reasonable representation of the

26

field over Australia at that epoch, but the predicted secular variation proved to be wrong in this area. The model for 1980 incorporated satellite observations, and is more accurate than the previous models. In addition, IAGA in 1981 adopted definitive models (DGRF) for 1965, 1970, and 1975.

Although IGRF and/or DGRF models provide magnetic charts for the Australian region, they are weighted heavily in favour of the northern hemisphere - at least before 1980 - because of the larger number of observatories and field observations there. Therefore it has been found advisable to produce charts specifically for the Australian region using local and regional data. Charts for all vector components have been produced by the Bureau of Mineral Resources (BMR) for 1957.5, 1970, and 1980, and for declination only for 1942.5, 1955.5, 1960.5, and 1965.0. Each of these charts included a predicted secular variation model.

The 1980 BMR charts were based on fourth-order polynomials in latitude and longitude, fitted to the observed values for D, H, and F corrected to 1980.0 by a graphically derived secular variation; the secular variation was also fitted with a polynomial. A comparison of this model with global spherical models was made by McGregor et al (1982). Previous charts were derived and contoured manually. Recently these contour maps have been digitised and polynomials have been fitted to the digital values.

Another model was derived by the Marine Geophysical Survey Group when it was found that the IGRF 1965 model was inappropriate for applying secular variations in this area; this was called the Australian Geomagnetic Reference Field (AGRF). It is spherical harmonic series, and is based on global data, but paying particular attention to fitting the available data in the Australian region. It includes quadratic time coefficients for secular variation.

For the proposed Fourier analysis of vector data over the Australian region, the data required are the orthogonal field components X, Y, and Z (in the north, east, and vertical directions) over a "square" area on the sphere; an origin at 25°S, 135°E seems appropriate, and the area should extend to 3.2 Mm in each direction from the origin. To examine the problem of appropriate models to produce such a data set, plots were made of observed field values, together with those derived from the above models, for X, Y, and Z, for all observatories and first-order stations in the region. For various reasons none of the models is entirely satisfactory for deriving the secular variation corrections.

The DGRF models are a substantial improvement on the earlier IGRF models, but are not altogether appropriate for the region; moreover they are available only from 1965 onwards, and thus do not cover the period of the Project Magnet surveys. An attempt was made to overcome this by using a quadratic secular variation model for the field from 1900 to 1965 derived post hoc by Fougere (1969), to project backwards from the 1965 DGRF values. This appears to be reasonably consistent with observed values earlier in the century; however nearly all plots show a distinct break in gradient at 1965.

The BMR polynomial models in general do not represent the field well in the outer parts of the region. An area of applicability is defined, mainly for the 1980 models, outside which the polynomials should be used with caution, if at all; however for some of the earlier models, even this area

27

is too large. There are large time gaps in the series of three-component charts. Polynomials for D, H, and F are not easily converted to X, Y, and Z, and the scale of the east coordinate, being degrees of longitude, varies with latitude.

The AGRF was plotted from 1955 onwards, and gives a reasonable fit to the observed values for the earlier part of the period, but starts to diverge from observed values and the more recent models about 1975.

The selected approach is to use the AGRF model as a first approximation, and to plot the differences between this and observed values for observatories, and for selected field stations where good continuity of three-component data is available. These plots should indicate the nature of any correction required to the AGRF secular variation, possibly a spline function with coefficients varying smoothly spatially. For the main field, a merge between the 1980 BMR model over most of the area, with the 1980 IGRF to extend this outside its area of applicability, is proposed.

There may be some advantages in using a coordinate system with one axis aligned along average magnetic north for the region, particularly if total intensity data were to be incorporated at a later stage.

References

Dooley, J.C., and McGregor, P.M. (1982), 'Correlative geophysical data in the Australian region for use in the MAGSAT Project'. Bull. Aust. Soc. Explor. Geophys., 13, 63-67.

Fougere, P.F. (1969), J. Geomag. Geoelectr., 21, 685.

McGregor,P.M., Winch, D.E., and McEwin, A.J. (1982), 'A preliminary assessment of international geomagnetic reference field models for Australia', J. Geomag. Geoelectr., 34, 411-416.

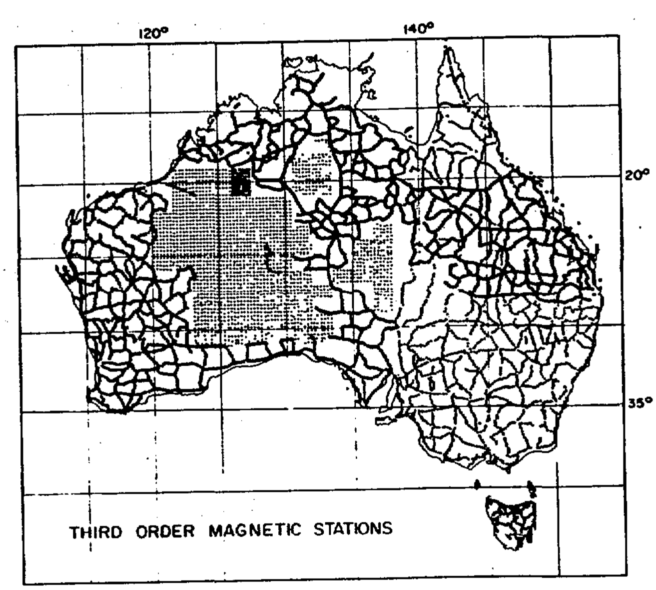


FIGURE 1.
Third-order regional magnetic station distribution.

28

The Tasman Project of Seafloor Magnetotelluric Exploration

I.J. Ferguson
Research School of Earth Sci ences
Australian National University, GPO Box 4, Canberra, ACT 2601

Introduction

This paper is based on geophysical measurements made along a line of nine recording sites crossing the deep seafloor of the Tasman Sea. Simultaneous measurements were also made on the Australian continent, on an extension of the seafloor line inland (Fig. 1).

The floor of the deep ocean is a remote and a technically hostile environment in which to operate. The observations described here were made possible by special highly developed instruments brought to Australia from Scripps Institution of Oceanography, California. The instruments all free-fall to the seafloor, where they record continuously for a pre-set period (acting as temporary geophysical observatories).

Several different kinds of geophysical recordings were made in this study. Magnetometers were used to measure (temporal) fluctuations in the three components of the magnetic field. A second kind of instrument measured fluctuations in the two components of the natural horizontal electric (telluric) field. In addition, a third instrument type measured fluctuations in the vertical electric field and a fourth recorded the ambient water temperature.

The magnetic and horizontal electric field recordings enable a magnetotelluric (MT) study to be made. These data as well as those from the other instruments have many applications for oceanographic studies as well as for solid-earth geophysics.

Seafloor Magnetotellurics

In the same manner as for land based MT studies seafloor magnetotelluric (SFMT) studies involve relating fluctuations in the horizontal magnetic field to the induced horizontal electric field, in order to investigate the underlying electrical conductivity structure. There are a number of characteristics unique to seafloor magnetic and horizontal electric field recordings.

Firstly, the electric field contains a significant component of signal induced by movements in the surrounding, conducting sea water. This signal is present at a wide range of frequencies; at long periods the signal is induced by eddies and ocean currents, at diurnal and semidiurnal periods it is induced by tides and at shorter periods it is induced by internal waves and ocean turbulence. The second difference from land recordings is that at the seafloor, the magnetic fluctuations at higher frequencies have been significantly attenuated from sea-surface values by the conducting sea water.

These effects limit the possible range of frequencies that may be used in SFMT. Even under optimum recording conditions this window extends over

29

only 2.5 decades, from periods of 10 minutes to periods of 2 days. Depending on the actual conductivity structure this means conductivity information will be obtained for depths from tens to possibly hundreds of kilometers.

Previous SFMT studies have been located mainly in the Pacific Ocean. These studies commenced around 1970 and have produced valuable information regarding the presence and depth of an asthenospheric layer. Such a layer is believed to be characterized by a partially molten region of high electrical conductivity.

The Tasman Experiment

The observing period of the present experiment was approximately 114 days, from early December 1983 until the end of March, 1984. The instruments were deployed and retrieved during two cruises of the naval oceanographic ship HMAS COOk. The instruments were lifted overboard using a crane, released, and then allowed to fall through water depths of 4000-5000 m to the seafloor. Figure 2 shows the deployment of an ocean-bottom instrument. Approximately four months later, according to a present timer, the instruments released a ballast tripod and floated to the surface for retrieval, transmitting radio signals to aid in their location.

This paper is concerned particularly with the SFMT data from site 4 in the Central Tasman Sea (Fig. 1). This site lies near the fossil spreading ridge that produced the Tasman Sea 80-60 my ago. The site also lies close to a line of seamounts that trends meridionally through the Tasman Sea.

Magnetotelluric Analysis

The horizontal magnetic and electric field components from site 4 were Fourier Transformed, band averaged, and analysed to produce an impedance tensor. The band averaging was arranged such that spectral lines near tidal frequencies were grouped and then omitted from further analysis. Further examination of coherences between components, indicated that the impedance tensor was only accurately resolved for periods between 10 hours and 20 minutes.

This narrow frequency range is due to the active nature of the ocean off Eastern Australia. Large-scale warm water eddies are carried down by the Eastern Australian ocean current and propagate across the line of the sites. The passage of such an eddy may be visually correlated with the commencement of a long period disturbance on the site 4 horizontal electric field recordings.

For site 4 the impedance tensor is highly skewed and anisotropic. The skewness is however frequency independent, and as such, could be produced by a near surface distortion of electric currents. A simple differential rotation of the electric data with respect to the magnetic data produces a "corrected" tensor that is consistent with a two dimensional electrical conductivity structure.

The magnitude and phase values for the principal axes of this tensor are shown in Fig. 3. Considerable anisotropy exists between the two axes, suggesting significant differences in electrical conductivity in the directions of the major and minor axes (10^{o} and -80^{o} clockwise from magnetic

30

north respectively). The phase differences between the two components suggest that this anisotropic conductivity varies with depth.

For comparison with the Tasman data, the impedance tensor derived for a site near the Pacific Rise, an active spreading ridge off Mexico is also shown. It may be noted that for longer periods an "average" impedance for the site 4 data is of comparable magnitude to the impedance near the Pacific Rise. Furthermore at higher frequencies, the site 4 impedance is significantly lower than the impedance near the Pacific Rise.

Interpretation

The similar magnitude of the impedance at site 4 in the Central Tasman Sea with that near the Pacific Rise suggests comparably large electrical conductivities in the earth's mantle. In addition the lower impedance of site 4 components at higher frequencies (as well as the very low values for phase at these frequencies) suggests that at some relatively shallow depth ($\lesssim$80km) the conductivity in the Central Tasman is higher than beneath the Pacific Rise.

Such an electrical conductivity value for the mantle beneath the Tasman Sea is unexpectedly high. One would generally expect such high conductivities to be associated with more tectonically active regions. The apparent two dimensionality of the conductivity at site 4 means that for a more complete understanding of the conductivity structure the data analysis for the surrounding sites will need to be completed. The high value of electrical conductivity may be a result of thermal effects associated with the seamount chain passing near the site.

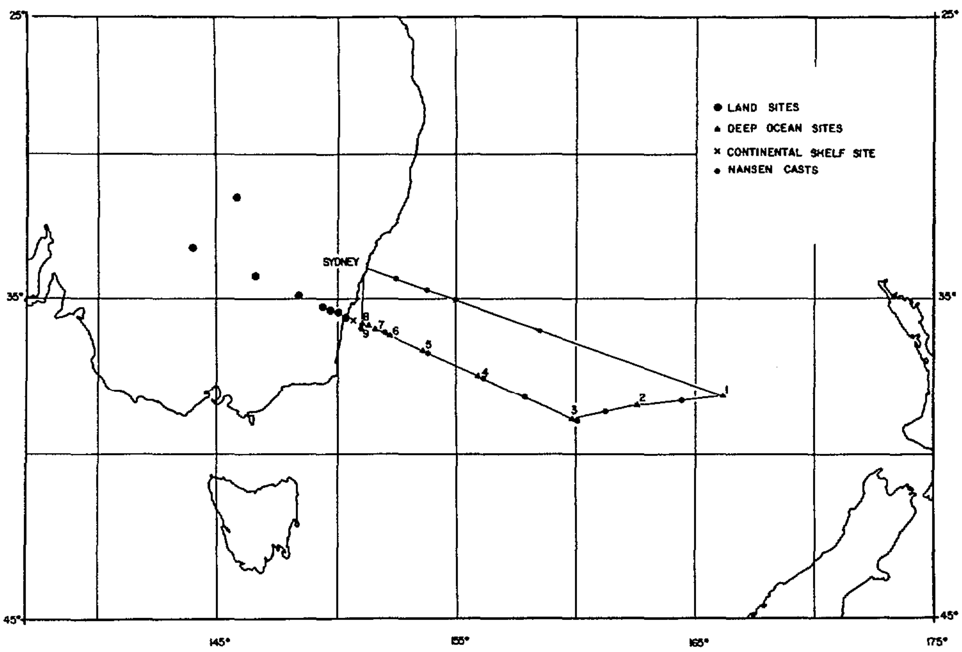


Fig. 1

Fig. 1 Map of the Tasman Project of Seafloor Magnetotelluric Exploration. Numbers mark the main sea-floor observation sites.

Fig. 2. Deployment of a sea-floor magnetometer from the deck of the naval oceanographic ship HMAS COOK. This instrument, developed by J.H. Filloux of the Scripps Institution of Oceanography, measures fluctuations in three components of the natural geomagnetic field, recording unattended on the sea-floor for periods up to four months.

Fig. 3 Impedance tensor results for site SIO 4 Tasman Sea, and for the Pacific Rise at 12 ° N off Mexico.

27 a

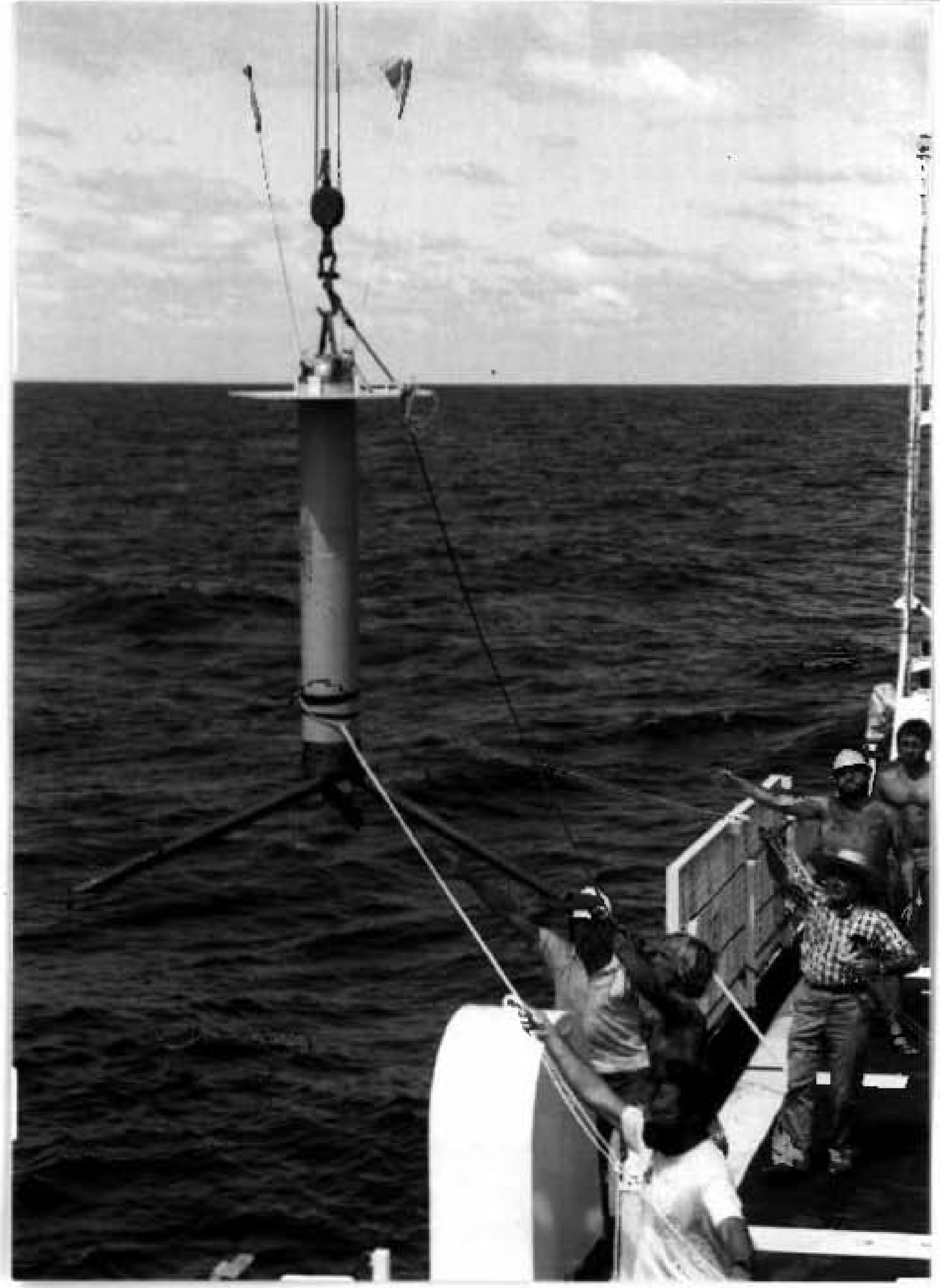


Fig. 2.

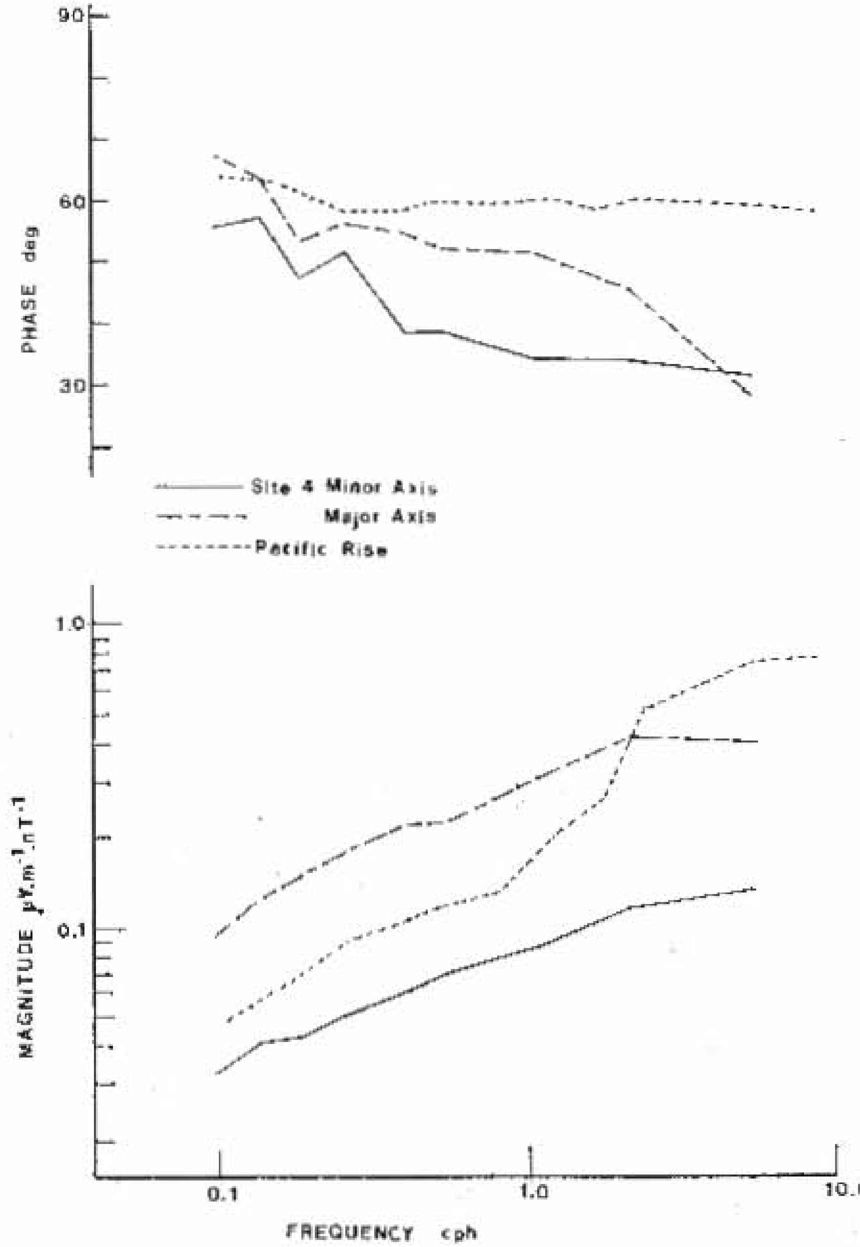


Fig. 3

103

THE USE OF GEOMAGNETIC PULSATIONS IN DETERMINING MAGNETOSPHERIC PLASMA PROPERTIES

B.J. Fraser
Department of Physics
University of Newcastle N.S.W. 2308

The existence of cold or cool heavy ions in the magnetospheric plasma of the earth has been known since early GEOS-I ion composition experiment results in 1977 (Geiss et al., 1978). Helium (He^+) and oxygen (O^+) relative concentrations of up to 50% of the total ion concentration were found. The reliability of these particle concentrations are difficult to estimate. Unresolved wave modulations, giving rise to plasma flows and other problems including spacecraft charging, make concentration measurements difficult. Mauk (1984) has recently shown by computer simulation that particle concentrations measured in association with linear interaction between a wave and He^+ ions may be artificially inflated by an order of magnitude. An extremely simple and sensitive measure of heavy ion (He^+, O^+) relative ion concentrations may be made using the bounding surfaces associated with the propagation of ion cyclotron waves in a multicomponent cold plasma. Obviously, measurements can be made only in the presence of ion cyclotron wave energy which occurs in the Pc1-2 geomagnetic pulsation frequency range (0.1-5 Hz).

The purpose of this paper is to present the properties of ion cyclotron waves seen by magnetometers on board the ATS-6 geostationary spacecraft at L = 6.6 and interpret them in terms of simple multicomponent cold plasma propagation theory. This leads to the application of wave diagnostic techniques to determine relative He^+ and O^+ ion concentrations.

A typical dynamic spectrum recorded by ATS-6 is illustrated in Figure 1. It can be seen that the wave spectrum is organized by the He^+ cyclotron frequency (f_{He}). Two four month data sets of similar events are available, one from 1974 when ATS-6 was situated 12°N of the geomagnetic equator and the other when the spacecraft was on the geomagnetic equator. Figure 2 shows polarization ellipticity plotted as a function of wave frequency normalized to the equatorial proton cyclotron frequency (f_H). The $\lambda = 12°$ data are mapped back

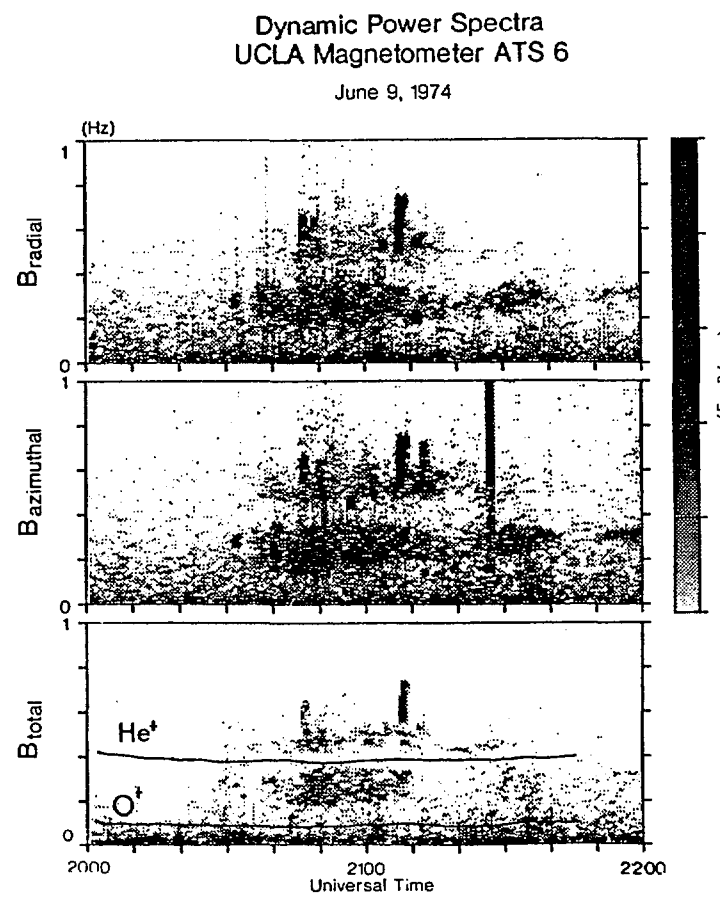


Fig. 1. Dynamic spectra of a Pc1 ion cyclotron wave event observed off the equator by ATS-6. The lines in the bottom panel indicate the local oxygen and helium cyclotron frequencies.

34

to the equator using the Olsen-Pfitzer 1977 geomagnetic field model. The He^+ slot is apparent in both plots by the absence of data points around f_{He}. For the $\lambda = 0^o$ data most waves are LH polarized with some almost linear cases observed. Off the equator the wave regime above f_{He} changes character to almost completely linear polarization. Below f_{He} the waves remain LH with the exception of a small linear group in the frequency range (0.1-0.2) f_H, which is just above the oxygen cyclotron frequency (f_O). These linearly polarized waves observed off the equator indicate the presence of O^+ in the thermal plasma (Fraser and McPherron, 1982). O^+ with concentrations comparable to or greater than He^+ has been observed in the thermal plasma at synchronous orbit (Geiss et al., 1978).

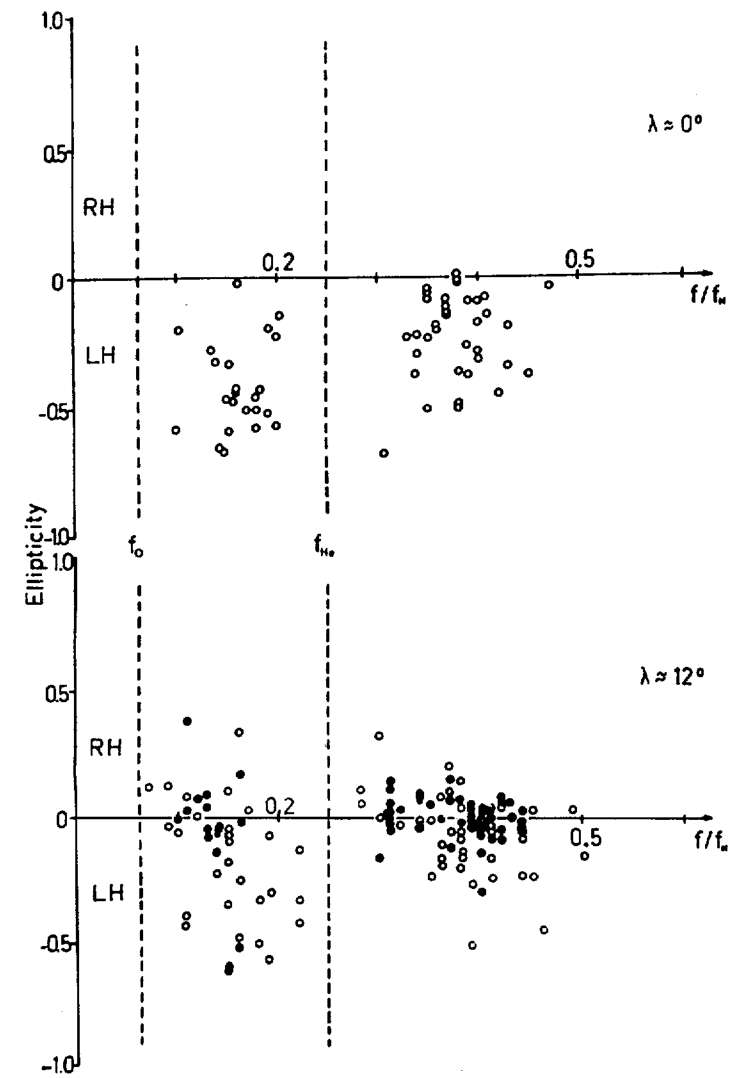


Fig. 2. Wave ellipticity variation with normalized frequency over the data recording intervals indicated in Figure 1. The solid data points indicate the first two months of data off the equator.

Current models suggest that ion cyclotron wave amplification is initiated off the equator and waves propagate along the field line direction with increasing f/f_H towards the equator and then with decreasing f/f_H into the opposite hemisphere. As the waves propagate away from the equator their characteristics are affected by multicomponent plasma bounding surface properties associated with resonances, cutoffs and polarization reversals. Using these properties a simple model can be invoked to adequately explain all the ion cyclotron wave properties observed by ATS-6.

Knowledge of the critical frequencies associated with the wave resonances and cutoffs provides a simple method to determine relative cold heavy ion concentrations in the vicinity of the spacecraft. The most accurately determined critical frequency from wave spectra is the crossover frequency defined by a polarization reversal. The distribution of He^+ concentrations determined from ATS-6 ion cyclotron waves observed off the equator in 1974 and on the equator 1975 assuming a two-ion plasma (H^+, He^+) are plotted in the histograms in Figure 3. He^+ concentrations are generally < 10%, a result which is in agreement with linear theoretical calculations of wave spectra (Roux et al., 1982). It also appears that very low He^+ concentrations are seen less frequently at the equator. The technique may be extended to a three ion plasma (H^+, He^+, O^+) for the simultaneous determination of He^+ and O^+ concentrations. There is still a lot of quantitative work to be done and it is anticipated that further understanding of wave propagation models will lead to the extension of diagnostic studies.

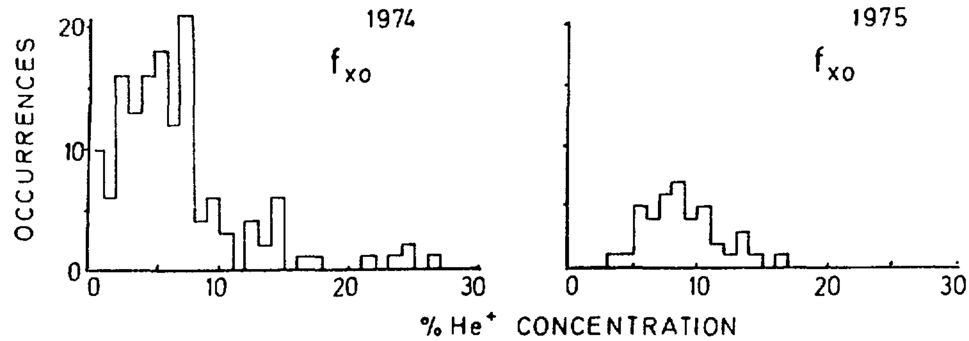


Fig. 3. Distribution of He^+ concentrations determined from the crossover frequency (f_{xo}) off the equator (1974), and on the equator (1975).

Fraser, B.J., and McPherron, R.L.: 1982, J. Geophys. Res., **87**, 4560.

Geiss, J., Balsinger, H., Eberhardt, P., Walker, H.P., Weber, L., and Young, D.T.: 1978, Space Sci. Rev. **22**, 537.

Mauk, B.H.: 1984, EOS, **65**, 263.

Roux, A., Perraut, S., de Villedary, C., Gendrin, R., Kremser, G., Korth, A., and Young, D.T.: 1982, J. Geophys. Res., **87**, 8174.

Processing of Satellite Magnetometer Data

B. David Johnson

Centre for Geophysical Exploration Research,
Macquarie University

The magnetic field observed at distances ranging from 350 to 500 kilometres above the earth is a combination of fields due to several different sources.

Electrical currents flowing in the outer core of the earth cause the main magnetic field of the earth which varies in amplitude from 30000 to 50000 nanotesla. The main field has time variations of the order of hundreds to thousands of years and spatial variations of the order of hundreds to thousands of kilometres.

Electrical currents in the ionosphere cause magnetic field disturbances ranging from tens to thousands of nanotesla in amplitide. These ionospheric disturbances have time variations ranging from milliseconds to days and spatial variations varying from metres to hundreds of kilometres. The ionospheric disturbances are particularly large in the auroral zones near to the north and south magnetic poles.

Electrical currents in the magnetosphere form a ring current system around the earth, at a distance of several earth radii, which give rise to magnetic field disturbances typically up to 50 nanotesla in amplitude. These magnetospheric disturbances have time variations of the order of a day and spatial variations of several thousands of kilometres.

After removal of the main magnetic field and the ionospheric and magnetospheric disturbances, the residual magnetic field is the required signal and is due to variations in the magnetisation of rocks within the crust of the earth. This crustal component of the magnetic field is a few tens of nanotesla in amplitude at satellite altitudes, and has spatial variations of hundreds to thousands of kilometres. The crustal component has essentially no time variations and therefore is separable, in theory, from the other components in spite of its relatively low amplitude. In practice, the data distribution in space and time does not permit complete modelling of the time varying disturbances. In addition, there is an overlap between the spatial frequencies of the core and crustal field components.

Annual, Semi-Annual and Solar Cycle Variations in Sq, and Ring Current Effects

F.H. Hibberd
University of New England

The difference of H at two magnetic observatories on the same meridian, but having longitudes equatorwards and polewards of the latitude of the Sq focus, yields a measure of Sq intensity largely free from disturbance. This is because the Sq variations are of opposite sign at the two observatories whereas the disturbance variation, having the same sign and roughly equal magnitudes, almost cancel each other in the difference. As a consequence, data from all days may be used to study Sq, rather than from quiet days alone, and this results in improved time resolution so that Sq is easily examined from month to month and the seasonal variation of Sq is clearly delineated.

Data from pairs of observatories in both the northern and southern hemispheres have been examined and it is found that as well as an annual variation of the range of Sq, with a maximum in local summer and a minimum in local winter, there is also a substantial semi-annual variation with equinoxial maxima. There is no corresponding semi-annual variation in the electrical conductivity of the E region of the ionosphere. It is suggested that the semi-annual variation in Sq is driven by the observed semi-annual variation in the thermospheric neutral temperature (though the origin of the temperature variation is not known). The differencing procedure also yields a clear delineation of the solar cycle variation of Sq.

There is also a clear annual variation of several gammas in the midnight values of H (previously reported by other workers). This variation appears to exist at all hours and is not restricted to midnight hours. It is not an Sq variation (i.e. is not of ionospheric origin) but appears to be due to an annual north-south motion of the ring current arising from the inclination of earth's rotation axis with respect to the plane of the ecliptic. It is concluded that this non Sq variation does not affect the validity of taking midnight values as the base-line from which to measure Sq.

38

Seafloor Spreading and Magnetization in the Southern Ocean

P.J. Hill, Bureau of Mineral Resources, GPO Box 378, Canberra ACT 2601

An extensive network of magnetic survey lines now extends over the Southern Ocean (Fig 1). Measurements of total field have been made by ship, aircraft and at high altitude from satellites. However, because of the vastness of the region, coverage is mainly still at reconnaissance level - with some areas such as the Antarctic continental margin very sparsely mapped. Exploration by oceanographic institute research vessels equipped with towed magnetometers began in the early 1960's. The first surveys providing systematic coverage were made between 1968 and 1972 by the "Eltanin', generally along north-south oriented lines spaced at about $5^{O}C$ of longitude. From these data, Weissel & Hayes (1972) were able to map the overall magnetic anomaly lineation pattern of the Southern Ocean seafloor, develop a tectonic framework for the region and outline the development of the Australia - Antarctica separation. They placed the onset of seafloor spreading at Magnetic Anomaly (M.A.) 22. Cande & Mutter (1982) have since produced a revised interpretation, putting the initiation of spreading at about M.A. 34 (85 m.y.) with much slower spreading rates prior to M.A. 18 time. Veevers (in prep.), in an analysis of all available data, concurs with Cande & Matter's interpretation of an early phase of slow spreading, but has refined the time of initiation to 96 m.y.

BMR has been active in the acquisition of magnetic and other geophysical data over the Southern Ocean. Between 1971 and 1973, the southern continental margin of Australia was surveyed at a line spacing of about 50 km. More recently, digital data acquisition systems were installed aboard the Danish polar supply ship 'Nella Dan' for survey work during the ANARE summer programs of 1979-82. About 110,000 km of magnetic data were collected during Southern Ocean transits between eastern Australia and the Australian Antarctic bases of Mawson, Davis and Casey, and during voyages out to sub-Antarctic Macquarie Island (Stagg & others, 1983a). More extended coverage was achieved in the region of the southern Kerguelen Plateau and offshore from the Antarctic stations while participating in multi-disciplinary scientific programs, and during a dedicated geophysical survey of the Prydz Bay area (Stagg & others, 1983b). Earlier in 1980 BMR used the 'Cape Pillar' to conduct a significant magnetic/bathymetric survey of waters around Heard Island and along the Heard-Western Australia transits (Tilbury, 1981). BMR's activity in the Southern Ocean will continue in 1985 with a major geophysical/geological investigation of the Kerguelen Plateau. This cruise, to begin in March, will be aboard the 'Rig Seismic' - BMR's new 72 metre research ship. It is hoped to acquire a better understanding of the origin of the plateau and its basic structure and stratigraphy. Is it underlain by oceanic or continental crust? What crustal differences are there between the northern and southern parts of the plateau? Is there any further evidence for a ridge crest jump at M.A. 24 time? How does the Kerguelen Plateau fit into the India/Australia - Antarctica reconstructions? The magnetic data may help to answer some of these questions.

Project Investigator-1, a low-level aeromagnetic survey flown over the Australian-Antarctic Discordance (AAD) of the SE Indian Ridge, has added considerably to knowledge of the seafloor tectonics of this anomalous zone - characterized by relatively deep and disrupted seafloor topography (Fig 2 & 3). The survey was a co-operative project between the United States Naval

39

Research Laboratory (NRL) and the Australian Defence Science and Technology Organization (DSTO). Two Orion aircraft were used to cover a 1000 km section of the ridge and north-south flight lines spaced about 20 km apart. Coverage extended north to M.A. 7 (25.5 m.y.) and south to M.A. 6 (19.5 m.y.). vogt et al. (1983) have interpreted the crenulated geometry of the AAD as having deve loped from a combination of continuous asymmetric spreading and propagating rifts which caused sudden changes in transform offset. The propagators are postulated as having been driven by asthenospheric flow toward the AAD from adjacent parts of the spreading axis to the east and west. The observed change in transform trend between 7 and 4 m.y., indicating adjustment to a new plate rotational pole, may have initiated the propagating rifts. A series of six colour charts depicting the main results of Project Investigator-1 have been prepared, and will be published by BMR in the near future. The charts illustrate revised plate tectonics of the Southern Ocean region, interpreted magnetic lineations of the AAD, seafloor ages and structures, magnetic profiles, magnetic anomaly contours and bathymetry.

In 1974 the BMR derived an Australian Geomagnetic Reference Field (AGRF) for the Australian region which was intended primarily for reduction of marine magnetic data to residual (anomaly) values. This AGRF was adopted in preference to the existing 1965 IGRF because of obvious discrepancies between predicted and observed secular variation patterns, and the problems this was creating, particularly in margin magnetic data from different surveys. Examination of Southern Ocean magnetic data acquired during 1978 to 1982 indicates major differences between the observed regional field and that calculated by the AGRF formula. The discrepancy is particularly severe in the region between Kerguelen Plateau and the AAD, where the AGRF is up to about 1000 nT less than the observed regional total field. These differences are caused by extrapolation of the secular variation beyond the time interval for which the AGRF is applicable. For these more recent surveys, later models of the global field and its secular variation should be used for the reduction of marine magnetic data. For example, PGRF 1975-80 and IGRF-1980 models (Peddie, 1982), which are based partly on MAGSAT data, provide very good fits to the observed total-field marine data. Furthermore, difinitive models of the global field (DGRF's) have been defined for 1965, 1970 and 1975 based on retrospective analysis of a complete data set (Peddie, 1982). these require evaluation for their suitability for replacing the initial AGRF model for the reduction of early survey data.

The open ocean areas have always presented a problem in studying and modelling the global secular variation because of the lack of land-based magnetic stations and observatories. Magnetic data has been collected in the Southern Ocean for more than two decades over a network of criss-crossing tracks. By comparing magnetic values recorded at track intersections, useful estimates of secular variation over the region can be obtained. Statistical analysis would be required to take into account limitations imposed by navigational inaccuracies and geomagnetic diurnal/storm variations for which precise corrections cannot be made.

BMR's 'Rig Seismic' is equipped with a magnetic gradiometer, rather than the single sensor that has commonly been used for oceanographic research in the past. This means that much of the short-term, time-varying component in recordings can be separated from anomalies of geological origin. This is a significant improvement in survey areas such as the Southern Ocean where

40

nearby base stations cannot be set up. Removal of temporal variations, or direct use of magnetic gradients enhances the usefulness of automatic computer interpretational techniques such as Werner deconvolution. Furthermore, the isolated temporal data are available for the study of external fields, and induction effects over oceanic regions.

References

Cande S. & Mutter, J., 1982 - A revised identification of the oldest seafloor spreading anomalies between Australia and Antarctica. Earth Planet. Sci. Lett. 58, 151-160.

Peddie, N.W. 1982 - International Geomagnetic Reference Field: the Third Generation. J. Geomag. Geoelectr., 34, 309-326.

Stagg, H.M.J., Ramsay, D.C., & Whitworth, R., 1983a - Recent BMR magnetic surveys of the Southeast Indian Ocean. In R.L. Oliver, P.R. James, & J.B. Jago (Eds). Antarctic Earth Science, Aust. Acad. of Sci., Canberra, 384-386.

Stagg, H.M.J., Ramsay, D.C., & Whitworth, R., 1983b - Preliminary report of marine geophysical survey between Davis & Mawson stations, 1982. In R.C., Oliver, P.R. James, J.B. Jago (Eds). Antarctic Earth Science, Aust. Acad. of Sci., Canberra, 527-532.

Tilbury, L.A. - 1981. 1980 Heard Island expedition: marine geophysical operations and preliminary results. BMR Rec. 1981/16 (unpub.)

Veevers, J.J. in prep. - Breakup of Australia and Antarctica estimated as mid-Cretaceous (96 Ma) from magnetic anomalies at the continental margin. Submitted to Earth Planet. Sci. Lett.

Vogt, P.R., Cherkis, N.Z. & Morgan, G.A. 1983 - Project Investigator-1 : evolution of the Australia-Antarctic Discordance deduced from a detailed aeromagnetic study. In Oliver, R.L., James, P.R. & Jago, J.B. (ed.), Antarctic Earth Science. Australian Academy of Science, Canberra, 608-614.

Weissel, J.K. & Hayes, D.E., 1972 - Magnetic anomalies in the southeast Indian Ocean. Am Geophys. Union, Ant. Res. Ser., 19, 165-196.

41

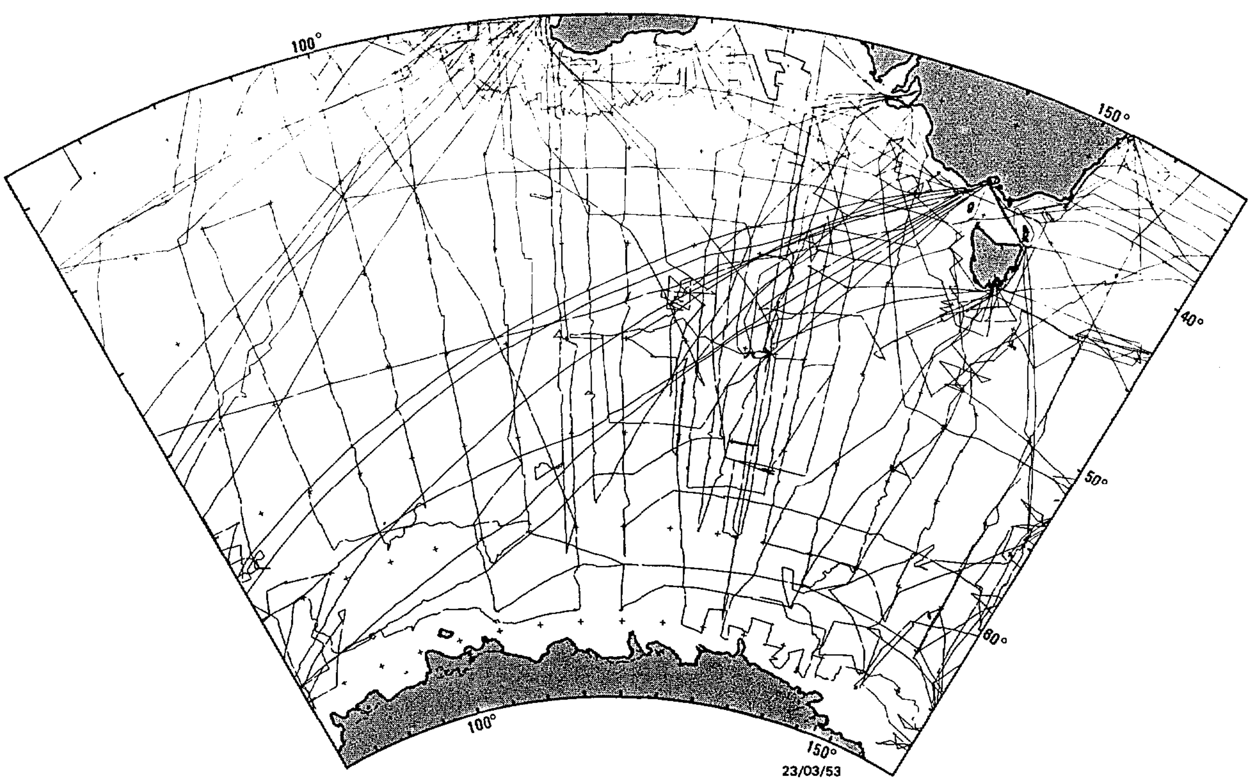


Figure 1 Southern Ocean research vessel tracks. Magnetic data are available over almost the entire network. BMR's continental margin survey lines are omitted for clarity.

42

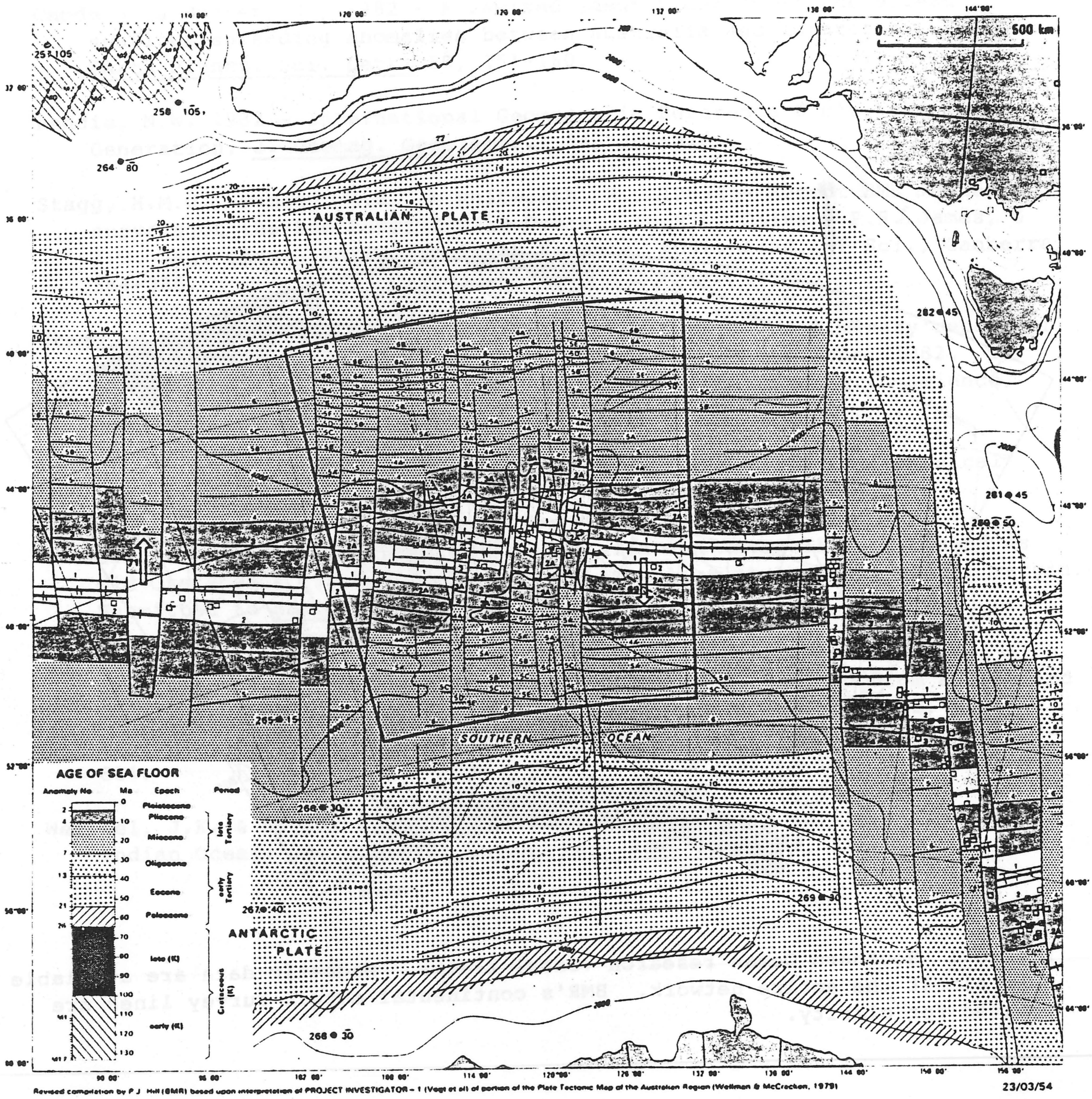


Figure 2 Revised tectonic map of the Australian - Antarctic Discordance, Southern Ocean.

Interpretation from Vogt, Cherkis and Morgan (1983). The region bounded by the solid line was surveyed during Project Investigator-1.

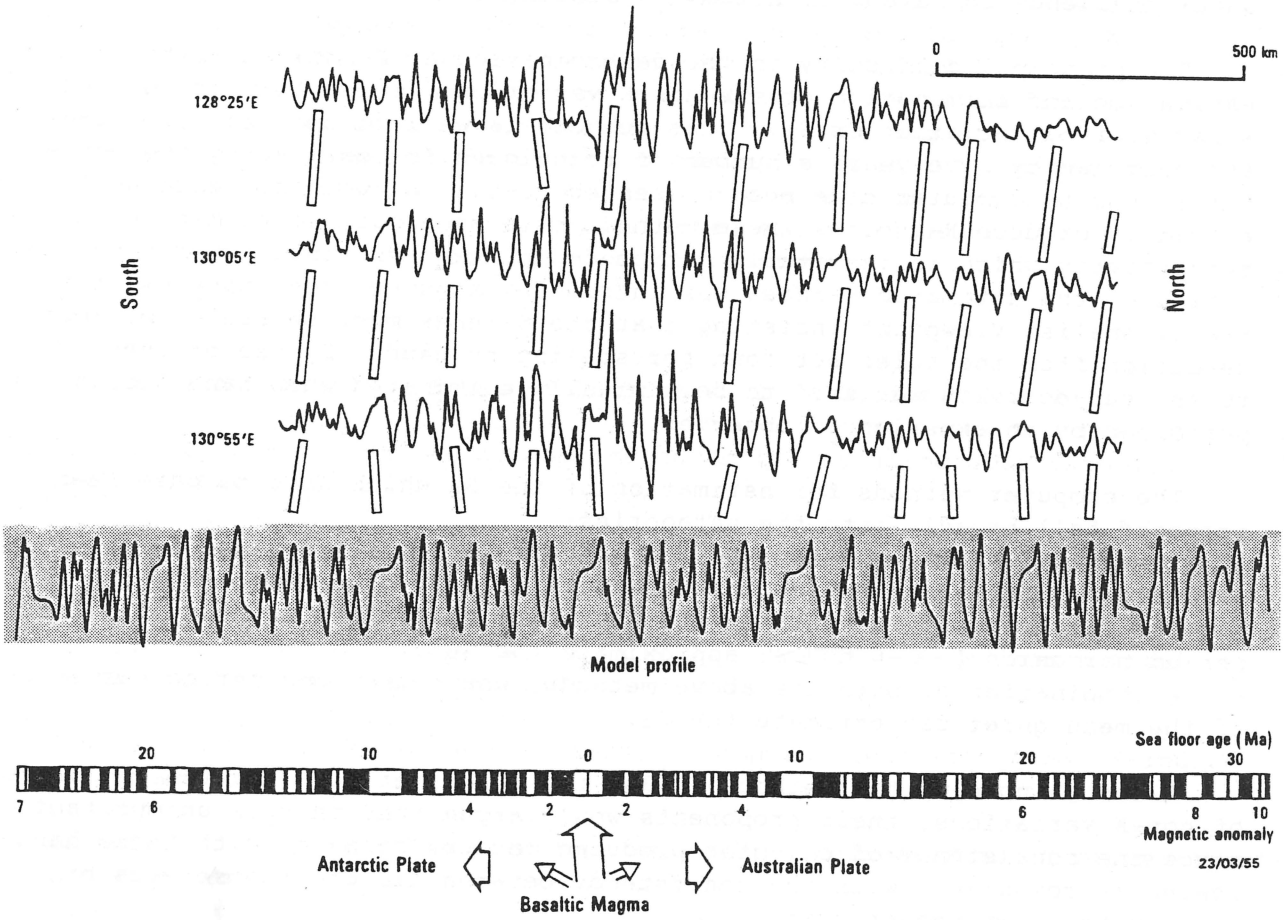


Figure 3 Aeromagnetic profiles across the Australian - Antarctic Discordance, showing strong correlation with the model based on the geomagnetic reversal timescale.

On The Determination of K-indices by Computer

P.A. Hopgood
Division of Geophysics
Bureau of Mineral Resources
Canberra, ACT

In 1939 the K-index was proposed to classify the range of geomagnetic variations, and was soon adopted internationally to become the most widely used of all geomagnetic indices. Traditionally the K-index has been scaled manually by experienced observers. However, since the introduction of automatic digital geomagnetic observatories and the universal accessiblity of computers, the traditional method of scaling K-indices has increasingly come under challenge in favour of automated scaling.

The principal difficulty in the determination of K-indices is the estimation and elimination of the non-K variations, in particular the regular solar diurnal variation or S_R. This subject is well documented: (1) Over the past twenty-five years a number of techniques for estimating the non-K variations by computer have been presented (2-5). As well as reducing the effort to produce K-indices these methods have been said to eliminate the subjectivity which is inevitably introduced by hand scaling. Ever since the notion of the automatic K-index was introduced argument has ensued with the traditionalist viewpoint insisting that the K-index must be scaled without deviation from the rules set down for scaling by hand. By use of these rules, subjectivity was said to be virtually eliminated when hand scaling is performed by an experienced observer.

The computer methods for estimation of the S_R which have to date been proposed fall broadly into the categories:

- the use of nearby quiet days from which a mean quiet day and S_R is estimated which is assumed appropriate for the day to be scaled;
- the filtering of the data on the day to be scaled and assuming the long period harmonics (3-6 hours) approximate the S_R;
- a combination of both the above methods, where the long period harmonics of the mean quiet day estimate the S_R.

Although none of the methods follow the rules set down for the estimation of non-K variations, their proponents would argue that this is unimportant since the consistency of computer produced indices compared with those hand-scaled is comparable with the consistency between different observers hand scaling the same magnetogram.

Of the described techniques to estimate the S_R by computer, those which utilize nearby quiet days, seem, in principle, the least satisfactory, retaining vestiges of the so called "iron-curve" method (6); They are unable to take proper account of the day-to-day variability in S_R; and still have an element of subjectivity in the choice of nearby quiet days. Alternatively, the method of filtering the data on the day to be scaled and approximating the S_R by long period harmonics, whilst not utilizing information from nearby quiet days, cannot be corrupted by them either. The method does assume however that the S_R and K-variations have non-overlapping frequency spectra.

An harmonic analysis method to estimate the S_R has been applied to both quiet and disturbed magnetic conditions at the new digital magnetic observatory at Charters Towers, Australia. By consideration of power spectra it was found that during magnetically quiet conditions there was little power in both the H and D geomagnetic components, at periods less than around 4 hours (Fig 1) and this could be considered a convenient period at which to separate the non-K from the K-variations. Applications to magnetically disturbed periods proved the criterion to be inadequate since it become evident that K-variations did exist with periods greater than that of cut-off, leading to the underestimation of some K-indices (See Fig 2). Increasing the cut-off period leads to their overestimation during quiet periods.

It is concluded that, unless the definition of the computer generated version of the 'K-index' is re-defined then its determination by computer must more closely follow the traditional criteria as used in hand-scaling. To this end it is suggested that a functional expression for the S_R be defined, the parameters of which are allowed to vary within limits appropriate to the station and perhaps the ambient magnetic conditions as determined by the variance. Such a scheme is in principle similar to the harmonic analysis approach, the only difference being that a more specific function would be fitted, which also would have constraints on its parameters. The analogy with the 'experienced observer' is in the choice of function and limits of variability of its parameters.

References:

(1) Mayaud, P.N., (1967) - Atlas of Indices K, IAGA Bulletin No. 21.

(2) Alldredge, L.R., (1960) - A proposed automatic standard observatory, J. Geophys. Res., 65, 3777.

(3) Van Wijk, A.M. and Nagtegaal, T., (1977) - K measurements by computer, J. Atmos. Terr. Phys., 39, 1447.

(4) Rangarajan, G.K. and Murty, A.V.S. (1980) - Scaling K-indices without subjectivity, IAGA News, 19, 112.

(5) Riddick, J.C. and Stuart W.F., (1984) - Computer generated quasi K-indices, IAGA news, 22, 91.

(6) Bartels, J., (1957) - The technique of scaling indices K and Q of geomagnetic activity, Ann. Int. Geophys. Year, 4, 215.

46

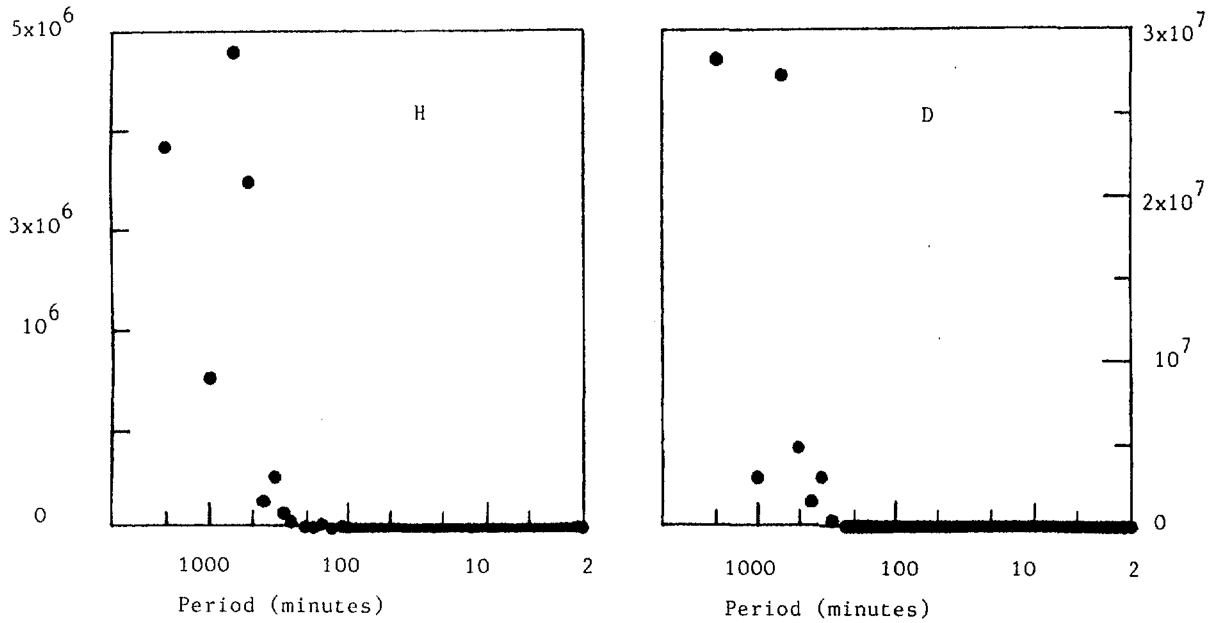


Figure 1. Power-spectra of geomagnetic variations in H and D components on a quiet day (4 Feb. 1985) at Charters Towers.

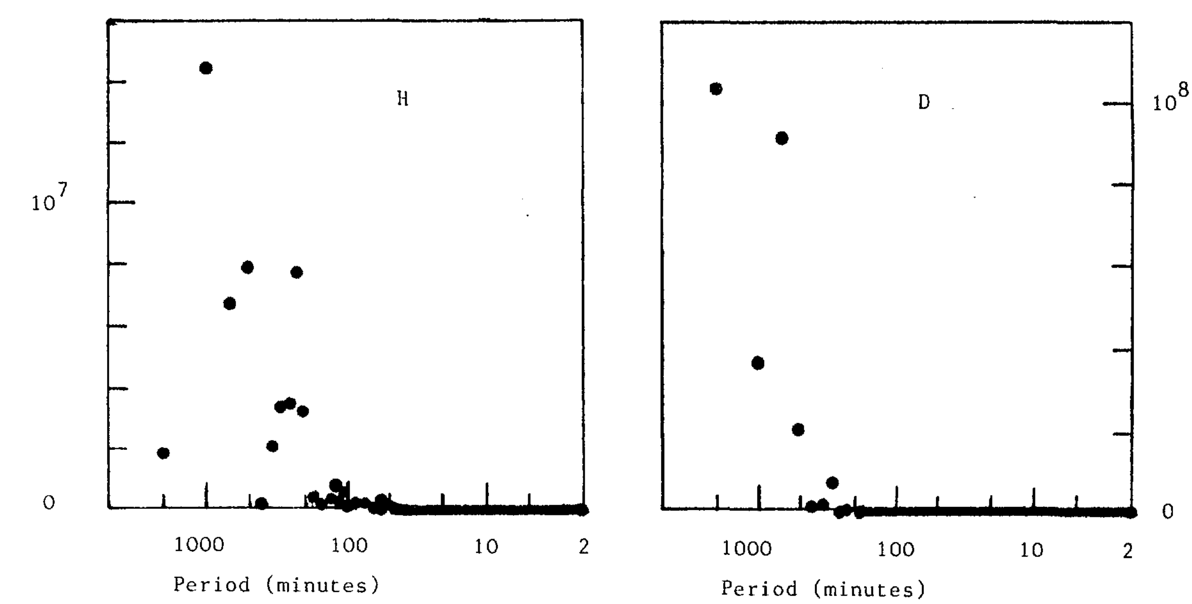


Figure 2. Power-spectra of geomagnetic variations in H and D components on a disturbed day (9 Jan. 1985) at Charters Towers.

47

Geomagnetic Induction Studies in Central New Zealand

Malcolm Ingham

Physics Department and Research School of Earth Sciences,
Victoria University of Wellington, New Zealand

A series of magnetovariational and magnetotelluric studies are currently under way in central New Zealand. These include :

(1) A magnetovariational study of the lower part of the North Island.

(2) An investigation into the channelling of induced currents through Cook Strait.

(3) A magnetotelluric traverse across the Wellington region.

(4) A magnetotelluric investigation of a known seismic boundary in the Egmont-Ruapehu region.

The magnetovariational results obtained to date (Ingham 1985a) indicate that at periods of 3000 seconds and above the main factor affecting geomagnetic variations on the north side of Cook Strait is the presence of induced currents in the Pacific Ocean. However, there is evidence of the channelling of these currents through the Strait. This has been clearly demonstrated by Boteler, Kaiser and Ingham (1985) by means of simultaneous measurements of the magnetic field on either side of the Strait and the voltage in a cable across the Strait.

At shorter periods local induction in the waters of Cook Strait still affects sites close to the Strait but at distances of around 60 km away variations can be quite well modelled by two-dimensional structure.

Other magnetovariational results are the identification of conductivity anomalies across the Wellington region and further north close to Mounts Egmont and Ruapehu. The former is supported by preliminary magnetotelluric measurements in the region (Ingham, 1985b) which show a large conductivity contrast possibly associated with one of the major faults in the region. The latter anomaly may be linked with a known region of attenuation of high frequency seismic waves and is also under investigation using magnetotelluric sounding.

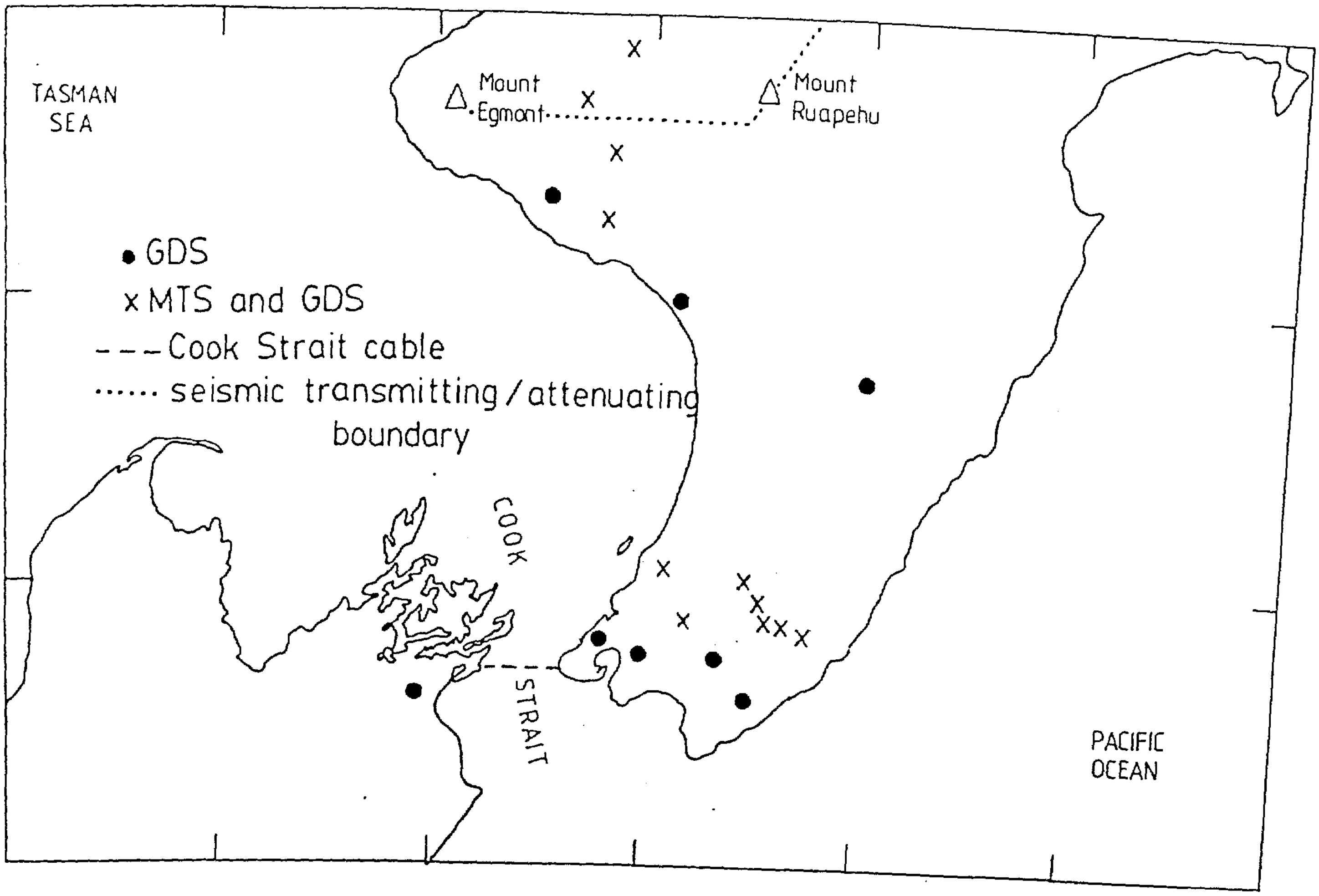
References

Boteler, D.H., Kaiser, A.B., and Ingham, M.R., 1985. Direct observation of channelling of induced currents. Submitted to Geophys. J.R.astr.Soc.

Ingham, M.R., 1985a. Magnetovariational measurements in the Cook Strait region of New Zealand. Phys. Earth Planet. Int., in press.

Ingham, M.R., 1985b. Magnetotelluric measurements in the Wellington region New Zealand. Journal of Geology and Geophysics, in press.

48


TASMAN SEA
Mount Egmont
Mount Ruapehu
• GDS
x MTS and GDS
- - - Cook Strait cable
······ seismic transmitting / attenuating boundary
COOK
STRAIT
PACIFIC OCEAN

49

CONDUCTIVE STRUCTURES UNDER THE CANADIAN CORDILLERA

M.R. Ingham[1], D.I. Gough[2] and D.K. Bingham[3]

[1] Victoria University of Wellington, New Zealand
[2] University of Alberta, Edmonton, Canada
[3] Alberta Environment, Edmonton, Canada

Three major structures of high electrical conductance have been mapped and investigated by means of large arrays of three-component recording magnetometers. The first array was deployed during 1980 and covered an area of 500,000 km^2 at a station spacing of about 150 km, with correspondingly low resolution. This array served to locate anomalies in the magnetovariation fields, two of which were mapped and studied by means of arrays with stations 50 km apart, each covering about 50,000 km^2, during 1981. These are denoted the 1981A and 1981B arrays.

The "discovery" array of 1980 gave preliminary maps of three structures, all detected previously with linear arrays of magnetometers by others. A large regional conductive layer, in the upper mantle and lower crust, covers much of the Cordillera of Canada southwest of the Rocky Mountains tectonic province, where it attenuates the vertical component of magnetovariation fields. Fig. 1 illustrates this attenuation at a period of 25 minutes. We call this conductive layer the Canadian Cordilleran Regional (CCR) conductor. Its conductance is of the order of 10^{4}Siemens.

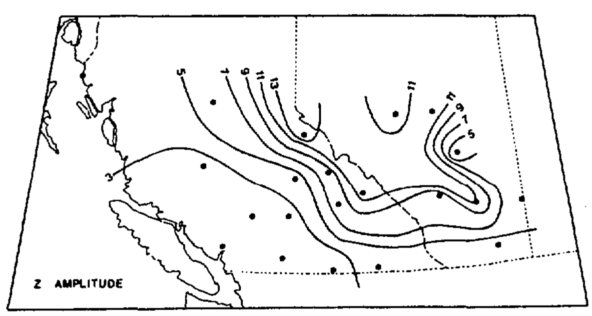


Fig. 1. Fourier transform amplitude at period 25 min of the vertical component, Z, of a magnetovariation event recorded by the 1980 array. (Gough et al., 1982)

The CCR conductor is bounded along its northeastern edge by the pre-Mesozoic craton of North America. Near that edge the conductor thickens and produces large local anomalies in all three components of the fields, in the Rocky Mountain Trench near latitude 53°N. Two stations of the 1980 array detected this anomaly, but could not define its shape: it appears near the centre of the northernmost line of stations in Fig. 2.

50

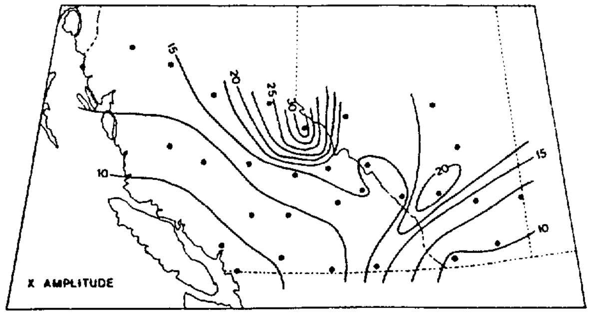


Fig. 2. Fourier transform amplitude at period 15.5 min. of the north-south horizontal component, X, of a magnetovariation event recorded by the 1980 array. (Gough et al., 1982)

The 1981A array was centred on this anomaly. It revealed the presence of very large induced currents flowing under the Rocky Mountain Trench and even more under the Main Ranges of the Rockies. Fig. 3 shows the Northern Rocky

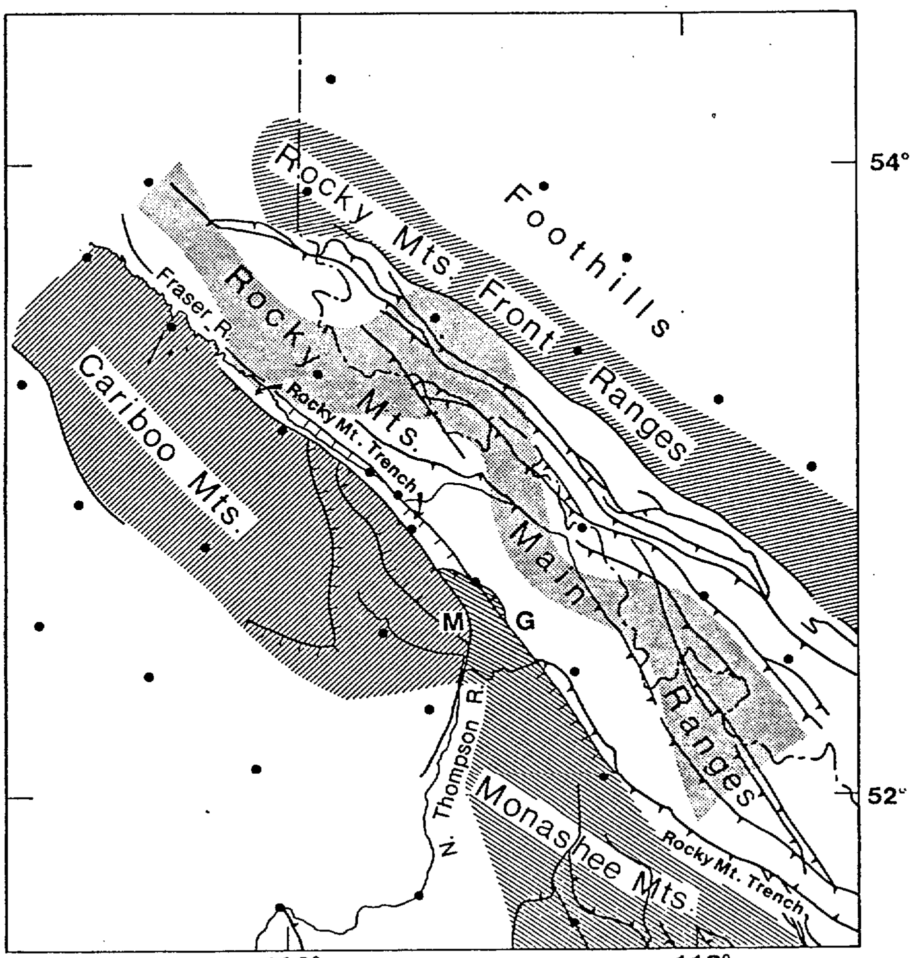


Fig. 3. Stippling shows the location of the Northern Rockies conductive ridge along the northeastern edge of the Canadian Cordilleran Regional conductor. The CCR conductor is not shown, but fills half of the map southwest of the NR conductor. (Bingham et al., 1985)

Mountains (NR) conductor as located by the technique of artificial event analysis, applied to transfer functions from horizontal to vertical components estimated from adequate samples of variation events. The location of the NR conductor was unexpected: by general consent the Rocky Mountain tectonic belt is part of the Precambrian craton of North America, and was expected to be resistive. It appears that the edge of the craton has been invaded by a very good conductor. The CCR conductor is correlated in position with a well developed low-velocity layer for S waves in the upper mantle, with a thin lithosphere and with high heat flow. It probably represents a layer of upper mantle containing a molten fraction. If the Northern Rockies structure at the edge of the CCR is similarly composed, or consists of saline water associated with melt lower down, then recent uplift of the Rockies would find a ready explanation. The obvious test is to measure the heat flux, but this is very difficult in a mountain range full of water with considerable vertical components of velocity.

Conductive ridges resembling the NR conductor are known to underlie the Southern Rockies of Colorado and the Wasatch Front mountains of Utah, as thickenings of the general conductive upper mantle beneath the Basin and Range and Colorado Plateaux tectonic provinces of the western United States. In the Canadian Cordillera as in the Basin and Range province, a variety of geophysical evidence strongly indicates the presence of partial melt as the cause of the conductive layer.

The third major conductive structure produces an elongated magnetovariation anomaly striking northeast to southwest across southern Alberta and the southeastern corner of British Columbia. Fig. 2 shows the anomaly in the amplitude of the north-south horizontal component of an event recorded by the 1980 array. This anomaly has been studied by means of the 1981B array, whose much more detailed maps show that the earlier array gave a fairly good account of the position of this structure. It continues the dominant strike of structures in the Precambrian basement beneath the sedimentary basin of Alberta, across strike of the Rocky Mountains. Over part of its length it coincides with a lower crustal rift valley identified by Kanasewich in 1968, from the earliest deep crustal seismic reflection study extended by means of gravity and magnetic anomalies. However the conductor and the rift as traced by Kanasewich diverge near Calgary, and their association is debatable. The identity of the Southern Alberta - British Columbia (SABC) conductor is unknown. A thermal origin seems unlikely, since any tectonic association would be of Precambrian date. It could consist of an accumulation of conductive minerals.

52

It must have a very large conductance, as it responds strongly to inducing fields with periods as long as 90 minutes. Even without knowing what the conductive structure is, it has tectonic importance in pinning the Purcell Anticlinorium of southeastern British Columbia to the Precambrian craton and so locating the boundary between the old craton and the terranes added to the continent in Mesozoic times.

Numerical modelling calculations are in progress on both the NR and the SABC conductive structures.

References

Bingham, D.K., D.I. Gough and M.R. Ingham, Conductive structures under the Canadian Rocky Mountains, Can. J. Earth Sci., March, 1985.

Gough, D.I., D.K. Bingham, M.R. Ingham and A.O. Alabi, Conductive structures in southwestern Canada: a regional magnetometer array study, Can. J. Earth Sci., 19, 1680-1690, 1982.

53

The Study of Geomagnetic Induction Physics

F.E.M. Lilley
Research School of Earth Sciences
Australian National University
G.P.O., Box 4, Canberra, 2601, Australia

The phenomenon of geomagnetic induction

Fluctuating electric currents flowing external to the earth in the ionosphere, the magnetosphere, and beyond act as primary source fields to cause electromagnetic induction in the solid earth. Secondary electric currents (or 'eddy currents') are thus induced to flow in the earth's oceans, crust, and upper mantle. The horizontal distances over which the primary and secondary currents flow are of the order of thousands of km.

The flow patterns of the secondary currents are controlled by the electrical conductivity structure of the earth. The phenomenon of natural geomagnetic induction may thus be exploited to study the electrical conductivity structure of the earth from the surface down to depths of order hundreds of km.

Two horizontal length scales

There are two important horizontal length scales to the phenomenon of geomagnetic induction. One length scale is the horizontal distance over which the source field can be considered to be uniform. The other length scale is the horizontal distance over which the geological structure can be considered to be laterally uniform. The relative sizes of these two length scales indicate whether induction taking place can be approximated as 'one dimensional', for which geological structure is horizontally layered relative to source field non-uniformity, or 'two or three-dimensional', for which source fields may be considered uniform relative to geologic non-uniformity.

Whether the induction taking place is one-dimensional, or two or three dimensional, affects strongly the geophysical characteristics which will be observed in field observations, and also affects strongly the style of the geophysical information which can be obtained by interpretation of the observations.

Geomagnetic induction approximated as being one-dimensional

In a one-dimensional situation, observed data may be interpreted to give a vertical profile of electrical conductivity varying with depth into the earth. The data may be observed by single-site magnetotelluric instruments, which measure the horizontal components of the fluctuating magnetic field, and of the fluctuating electric field at the earth's surface. On a larger (but still continental) scale, observations of the fluctuating magnetic field with arrays of recording magnetic variometers may be interpreted by the 'horizontal spatial gradient' method to give profiles of electrical conductivity with depth. Such arrays themselves detect the horizontal length scale of the geological structure, and also obtain a measure of the non-

54

uniformity of the primary source fields. On a global scale, the interpretation of magnetic fluctuation data from the world-wide network of magnetic observatories has traditionally been in terms of an earth in which electrical conductivity varies with radius only, and so is 'one-dimensional'.

Geomagnetic induction in two-dimensional and three-dimensional geological structures

The most spectacular geomagnetic induction observations are those from situations where the induced secondary or eddy electric currents flowing in the ground are strongly concentrated along particular paths. Such paths must be geological structures of increased electrical conductivity and are referred to as 'conductivity anomalies'. In such cases it is not uncommon for the vertical component of the magnetic fluctuating field to be reversed between two different observing sites perhaps only tens of km apart in horizontal distance.

The mapping of electrical conductivity anomalies in the earth is thus a method for obtaining geological information not available by other means. For much of the earth (including Australia) the work is just commencing, with large parts of continents not yet explored for their basic electrical conductivity structure. Exploration of the ocean basins is even more at a pioneering stage, involving as it does the extra technical challenge of making electromagnetic fluctuation measurements on the deep-sea floor.

An example and an application

Figure 1 shows the areas covered by major magnetometer array studies in Australia, and the main regions of anomalous geomagnetic induction mapped by them. Some further electrical conductivity anomalies are now known, notably in South Australia and Tasmania. Figure 2 shows simultaneous records of a simple magnetic substorm event as recorded at the sites of the 1977 array in western Queensland (carried out by D.V. Woods). The fluctuation signals in the amplitude of the total magnetic field, denote F, have been computed from the other scalar components observed : north, east, and vertically downwards. Figure 2 shows that across the array area, even between sites only tens of km apart, there are major differences in the vertical component (Z) of the fluctuations, which carry across to the total field amplitude (F).

One application of such data (besides its fundamental use in mapping earth conductivity structure) is to the procedures of accurate magnetic surveying, especially airborne and seaborne. Accurate magnetic surveys are important both in the exploration for minerals, and also of sedimentary basins for structures of possible hydrocarbon significance. Because such surveys measure the steady part of the earth's magnetic field (arising from crustal magnetisation) fluctuations in the field from the process of geomagnetic induction are a spurious signal to be removed. Such removal may be carried out by subtracting a base station record made simultaneously with that of the moving survey instrument, but only if fluctuations at the base station and at the survey instrument are expected to be the same. Such information is precisely that supplied by observations as in Fig. 2. In places, in Australia, base station and survey instrument may correctly be separated by distances of the order of one hundred km. In other places, and notably near coast-lines, significant errors may be introduced by base station to survey instrument distances of as little as 10 km. Knowledge of

55

the geomagnetic induction patterns of a continent and of its coastal seas allow such errors to be minimised.

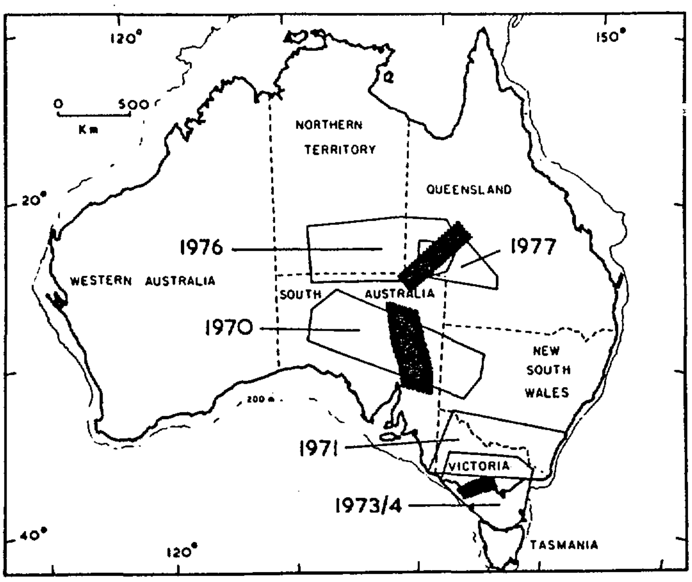


FIGURE 1

Areas covered by magnetometer array studies in Australia. Hatched regions mark the zones of strongest spatial non-uniformity in magnetic fluctuation patterns. In addition a 'coast effect' may be expected to be present everywhere around the edge of the continental shelf. The areas away from the marked zones are not necessarily regions of completely uniform magnetic fluctuation patterns.

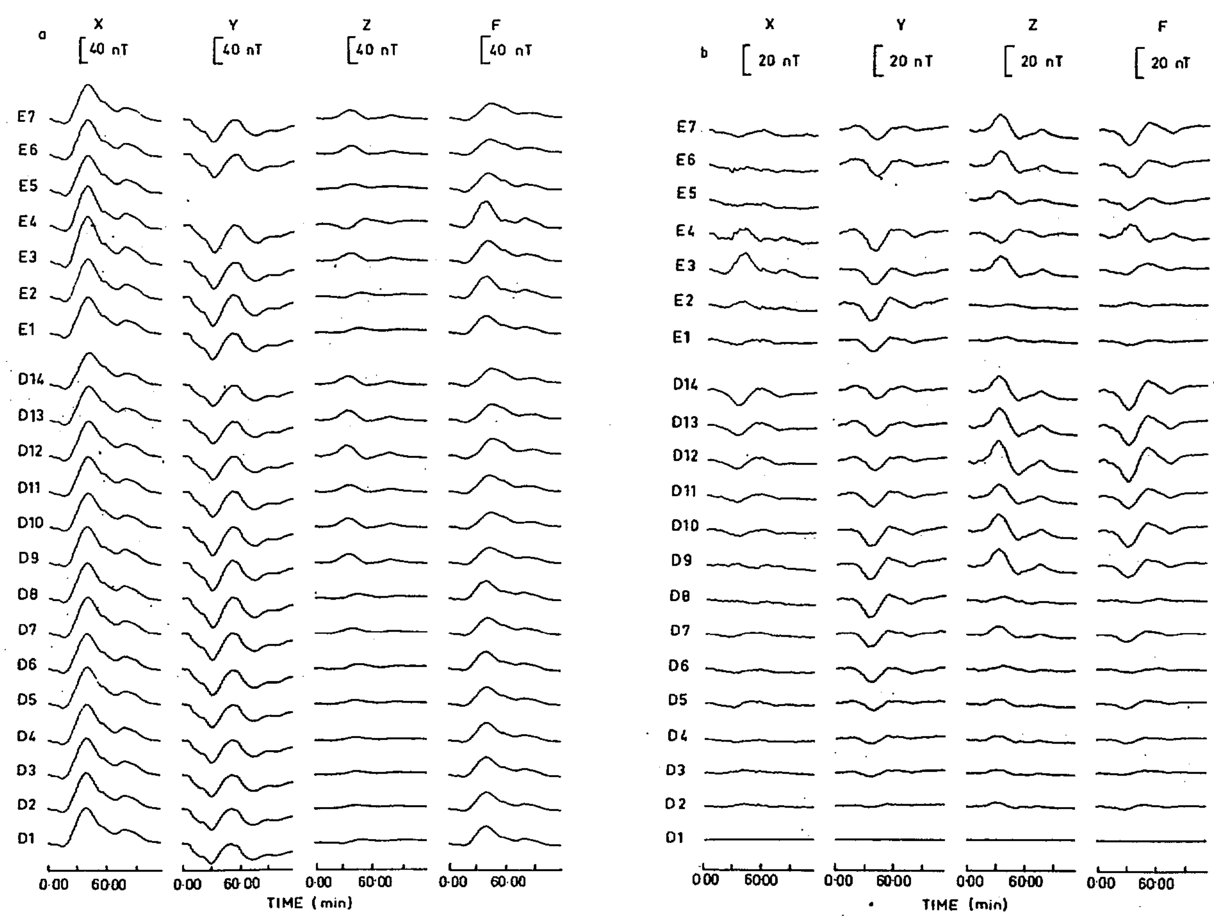


FIGURE 2 **(a) Stacked profiles from the observations of the 1977 array of a magnetic substorm event commencing at 1105 h on 13 September 1977 UT and lasting for 115 min. (b) The difference profiles for the same event, obtained by subtracting the records of station D1 from all other station records.**

56

Geomagnetic Workshop

Canberra, 14-15 May 1985

The Origin of the Main Field

P.L. McFadden

Geophysics Division, Bureau of Mineral Resources,
GPO Box 378, Canberra, ACT 2601, Australia

Early in the twentieth century Einstein described the problem of the origin of the earth's magnetic field as being one of the five most important unsolved problems in physics. Since then, major advances have been made and it is now generally accepted that the main field originates from some form of dynamo process taking place in the earth's outer core. However, the "dynamo problem" has not yet been solved and remains one of the mo st challenging mathematical problems ever formulated. Significant progress was made during the 1950's and 1960's with the nearly axisymmetric model developed by Braginsky and the mean-field concept instituted by Krause and Radler. Since then dynamo theorists have continued to search for ways to simplify the problem - unfortunately, without much success.

The history of man's attempt to solve the problem of the origin of the main field will be outlined and the development and present state of dynamo theory will be discussed. Finally, brief mention will be made of the ways in which palaeogeomagnetism can be used to constrain the dynamo problem.

57

BMR Photoelectronic Magnetographs

P.M. McGregor and K.J. Seers
Bureau of Mineral Resources, Canberra

New magnetic observatories in Australia are being equipped with commercial digital fluxgate magnetographs, but where appropriate buildings and classical instruments already exist, BMR-designed and developed devices (the MPE-1, horizontal and the MPE-2, vertical) are being added to provide visible charts and digital records.

The MPEs work on the force-balance principle: when the Earth's field varies, the couple exerted on a suspended magnet is counteracted by a couple from an opposite artificial field. The latter is produced by a null-detector/electronic-servo system, and the servo voltages are measures of the field variations.

BMR's first MPEs have been based on the QHM for horizontal components, and the La Cour Godhavn Z balance for vertical intensity. But in princiiple the servo system could be fitted to any suitably modified classical variometer.

Two MPE systems have been operated at Mawson and Macquarie Island Observatories since 1984. Results show that they have resolutions and noise levels better than 0.2 nT, and their long-term stabilities are as good as those of the La Cour variometers they have replaced. At present they have no temperature compensation, but it is an easy matter to provide magnetic (or electronic) compensation.

The main engineering features of the design follow.

A lateral effect photodiode senses the position of the light beam reflected from the magnet mirror. Unlike split photocells, this device gives a differential current output which is linear with respect to the deflection of the light spot. Several centimetres of active surface length ensure a wide dynamic range and keep the feedback loop operating for relatively large magnetic deflections.

A high-brightness LED is used for the light source. The peak emitted wavelength at 660 nm is visible for ease of setting up, and is less than 30% down on the peak response of the photodiode which lies in the near IR at 880 nm. The main advantage of a LED light source, however, is its ability to be switched rapidly, so permitting the light beam to be chopped. A chopping frequency of 220 Hz allows the input amplifier stages to be a.c. coupled, thereby eliminating the effects of drift and low frequency noise. After amplification, a synchronous demodulator converts the signal to d.c.

The optical gain is kept constant by an internal feedback loop which controls the LED brightness. The electronic gains within the main feedback loop are all tightly controlled; so the overall loop gain remains constant and the closed-loop response is predictable.

An integrator is included in the forward path of the feedback loop to ensure that the magnet remains in a true null position (i.e. a Type 1 control system with zero steady-state error) for any field within the instrument's range of plus or minus 1 000 nT around the baseline field.

58

The QHM and **Z**-balance possess a very underdamped second order transfer function (Q > 100). When this is combined with an integrator, the resulting third order system has a very low stability margin when feedback is applied.

The problem was to design a system which remains stable for a loop gain ranging from zero (at turn on) to a value sufficiently high to give the desired closed-loop response, and to tailor this response so that the system is well-behaved for step field changes, e.g. when a calibration pulse is applied. The frequency response must also remain high enough to follow the normal field variations. A complication lies in the fact that the response of a QHM or **Z**-balance is determined by its magnet and suspension characteristics, and may vary from unit to unit. Furthermore, the natural period of a given QHM varies inversely as the square root of the field component along the magnet axis. At a given location, the magnet is oriented at right angles to the field component being measured, so the natural period depends on location and orientation.

The feedback loop is stabilized by incorporating two lead-lag compensation networks. The compensation time constants were calculated to ensure stability at low gain even by a hypothetical mechanical damping factor of zero. It can be shown that this can be achieved if the compensation time constants are set proportionally to the magnet's natural period. When initially setting up at a new location or in a new orientation, the natural period is measured and four equal resistances are adjusted accordingly.

Thus the closed-loop transfer function is normalized with respect to the magnet's natural period. The compensation networks and loop gain were designed such that the damping factor of the complex closed-loop system poles is about 0.7, so ensuring no overshoot or ringing in the transient response. For a QHM having a natural period T seconds, the 10% to 90% rise time in closed loop is 3.2T seconds and the -3 dB frequency response is approximately 0.8/T Hz.

The dynamic range of the instrument is determined by the voltage swing available from the amplifiers in the feedback loop, and by the overshoot to a step input which occurs after the second compensation stage (in the feedback network and therefore not apparent at the output). The loop gains have been distributed such that these factors limit the steady-state range to plus and minus 1 000 nT around the initial baseline field, and the maximum input field step is limited to 770 nT from the baseline field.

The gain and phase margins (measures of stability), which are also determined by the design of the compensation networks, are 19.3 dB and 44 deg. respectively.

Work is continuing on improved amplifier design and electronic temperature compensation.

59

A MODEL OF THE EARTH'S MAGNETIC FIELD SUITABLE FOR REGIONAL USE

J.D. McKnight and L.A. Tomlinson
P.E.L. Geophysical Observatory, DSIR, New Zealand

INTRODUCTION

A model of the earth's magnetic field, suitable for use over a limited area of the earth's surface is described. Coefficients for this model are derived from local observations consisting of observatory results, field measurements and aeromagnetic data. A process of deriving the coefficients has been devised which avoids problems with the stability of the solution. Finally, a system is described which allows the automated plotting of charts, based on the model. On the charts, the resolution is independent of the projection or scale being used.

MATHEMATICAL FORM OF THE MODEL

The model used to represent the normal or main field is a set of three polynomials, first used by Reilly and Burrows, 1973. The three components (X, Y and Z) are each expressed as quadratic functions of latitude, longitude and time; e.g:

$$Z = a_z + b_z t + \tfrac{1}{2}c_z t^2 + d_z xt + e_z yt + f_z x + g_z y + \tfrac{1}{2}h_z x^2 + \tfrac{1}{2}i_z y^2 + j_z xy$$

where x, y and t are latitude, longitude and time relative to an arbitrary position and epoch. Similar expressions are used for X and Y. This mathematical form is completely empirical. It has sufficient flexibility to model the field over a limited region. The order of the polynomial could be extended but the quadratic form has been found adequate for the New Zealand region. In principle, it might be thought better to use a spherical harmonic model, but the fitting of coefficients to such a model from observations of a limited geographical extent leads to instabilities in the coefficients if the data base is changed slightly. Although the quadratic polynomials cannot truly represent the magnetic field, it is possible to constrain them by imposing the condition that there is no vertical current flow at the earth's surface. This condition is that the vertical component of CURL B = 0. If the easterly component is expressed as

$$Y = \text{SEC}\,\Theta\,(a_y + b_y t + \tfrac{1}{2}c_y t^2 + d_y xt + - -),$$ where Θ is the latitude,

instead of just a polynomial, the above constraint reduces to

$$e_x = -d_y,\ g_x = -f_y,\ i_x = -j_y,\ j_x = -h_y.$$

This reduces the number of independent coefficients from 30 to 26.

DERIVATION OF COEFFICIENTS

There are four categories of observations available for use in the derivation of the coefficients in the model: observatory mean values; repeat stations; field observations; and aeromagnetic data from "Project Magnet" flights.

When a computerised method is being considered to derive the coefficients from the data, it is tempting to consider each observation as being equally valid, and hence assign equal weights. In practice this does not work

60

well. The observatory results, whether monthly mean or annual mean values are used, unduly influence the spatial terms, and similarly the field observations unduly influence the time terms. As a result it has been found best from experience to divide the evaluation of the coefficients into three separate steps.

Firstly, the coefficients of the terms dependent only on time are derived solely from the Eyrewell Observatory values. Since the major use of the model is to produce declination charts for navigation purposes, the data are weighted according to time of observation, giving reduced weight to earlier observations. The form given to the weighting function is a negative exponential, $\exp^{-t/T}$. The time constant T needs to be chosen with care. Examination of the observatory mean values shows a smooth trend which can be well represented by a parabolic polynomial. Superimposed on the smooth trend are minor fluctuations, in particular some with quasi periods up to 30 or 40 years. Too short a time constant results in fitting to very recent data, resulting in a fit which is overly influenced by these fluctuations. This leads to a rapid divergence between the model and the actual field with time. If too long a time constant is chosen, the quadratic form of the time dependence is inadequate for representing the smooth trend. A time constant of at least 30 years has been found to be acceptable. The work of Reilly and Burrows used a 20-year time constant and the model was found to give a very poor extrapolation with time although the model fitted the previous decade well.

The next step is to determine the coefficients for the xt and yt terms. Observations from only the repeat stations are used in deriving these coefficients, since using such sites allows the separation of the secular variation from any local anomaly at the site. The secular variation at the Eyrewell Observatory is subtracted from the observations at the field sites. This can be done either by subtracting the function $a_z + b_z t + \frac{1}{2} c_z t^2$ from the field observations, or by subtracting the actual observatory values. It has been found preferable to subtract the actual observatory values, since this gives a more linear residual secular variation at the field sites. This is because the polynomial expression for the field at Eyrewell does not include the minor perturbations from a smooth trend. For each of the repeat stations a linear rate of change relative to the Eyrewell Observatory is obtained, and then these are used to determine the coefficients of the position dependent secular variation terms in the polynomial expressions for the field. (i.e. d_x, e_x, d_y, e_y, d_z and e_z. Note the constraint that $e_x = -d_y$) Because of the constraint, the components cannot be dealt with separately and the function that is minimised in a least squares fitting is

$$(O_{xi} - C_{xi})^2 + (O_{yi} - C_{yi})^2 + (O_{zi} - C_{zi})^2$$

where O_{xi} is the i^{th} observed value in the X component and C_{xi} is the calculated value from the polynomial expression. Several remote observatories are included with the repeat stations in this part of the analysis. The annual mean values are treated as individual observations. In the fitting procedure, the same time weighting function is used as for the secular variation at Eyrewell. No spatial weighting function is used for these terms since the distribution of the repeat stations has been chosen to be as uniform as possible.

61

Finally, the data from all stations are used to derive the remaining coefficients in the polynomials. As in the determination of the position dependent secular variation coefficients, the values at the Eyrewell Observatory are subtracted from the field station values. The residuals then consist of the sum of secular variation and position dependent effects relative to the Observatory. The secular variation effects are removed using the coefficients just found, and the coefficients of the purely position dependent terms (e.g. f_Z, g_Z, h_Z, i_Z, j_Z) are determined from the remaining values. A least squares fitting of the same form as that described above is used. The "Project Magnet" aeromagnetic data are weighted by a factor of 0.5 to allow for the greater uncertainties associated with air-borne measurements. The same time weighting function used previously, is used in the determination of these coefficients. However, more care has had to be taken with the spatial weighting of observations. Stations are not distributed uniformly, and some stations provide a large number of observations while others provide only one. The object of a weighting function in this case should be to balance the contributions of regions containing a large number of observations with those from regions in which observations are sparse. The method adopted is to treat each observation at each station individually. Then to determine the weight for a particular observation, the great circle distance 'd' to every other observation is determined and the function $\exp^{-(d/K)^2}$ is evaluated, where K is a scale distance, typically 5°. The mean value of this function over all observations is found and the reciprocal of this mean value is the weight for the original observation.

PRODUCTION OF CHARTS

The information contained in the mathematical model of the field can be conveniently displayed in the form of contour charts of the various field components and their secular variations. The mathematical form of the model lends itself to simple computer plotting of these contours. The program that has been produced to do this plotting has the feature that all calculations within it are done in terms of the Cartesian coordinates of the plotter itself. This means that the plotting program can handle a variety of field models, map projections and scales, but the accuracy of the finished chart is still expressed in terms of the chart itself. Contours are found where they cross the boundaries of the chart, or meridians in the case of enclosed contours. Once found, each contour is drawn as a series of straight line segments which do not depart from the true position by more than a preset limit. This limit is in terms of distance on the actual chart and not in terms of geographical distance.

In the plotting program currently in use, options are available to allow the inclusion of coastlines, a choice between Mercator and Lambert projections and either a spherical harmonic (global) or polynomial (local) field model.

REF Reilly, W I and Burrows, A L
The Geomagnetic Field in New Zealand at Epoch 1970.5
NZ DSIR 1973 (Bulletin 211)

62

PROPAGATION OF Pc3-4 PULSATIONS AT LOW LATITUDES

F.W. Menk, B.J. Fraser, C. Ziesolleck and P.W. McNabb
Physics Department, University of Newcastle, N.S.W. 2308.

Magnetic pulsations are ultra-low frequency (ULF) oscillations in the geomagnetic field with periods of order 1-1000 seconds. These pulsations are manifestations of hydromagnetic waves generated in the magnetosphere by a variety of physical processes and instabilities. Pc3-4 waves fall in the period range 10-150 seconds and appear to be produced by resonant oscillations of the earth's magnetic field lines, generally driven by the solar wind as it flows around the magnetosphere. Figure 1 shows a schematic representation of these interaction regions.

At synchronous orbit the Pc3-4 waves exhibit harmonic structure characteristic of a driven resonance[1,2]. This structure can be used to deduce the properties of the magnetospheric particles which are distributed along the particular oscillating field line. Furthermore, there is a correlation between the occurrence of Pc3-4 waves and properties of the solar wind[4-7]. This indicates the energy source of the pulsations may lie in the solar wind. Recording Pc3-4 pulsations at ground stations thus provides a means of continuously monitoring the state of the magnetospheric plasma and the solar wind.

A puzzling feature of ground observations of Pc3-4 pulsations is that they may be seen at very low and high latitudes as well as at middle latitudes[8,9]. High latitude stations map to regions of the magnetosphere external to the plasmapause (Fig. 1), while low latitude stations correspond to regions inside. The plasmapause forms a boundary in the magnetospheric plasma representing a sharp increase of over two orders of magnitude in plasma density. Thus field lines mapping to low latitudes

63

originate in a higher density region than those projecting to high latitudes. The plasmapause may act as a reflecting boundary to waves propagating in the outer magnetosphere, making it difficult for sufficient wave energy to penetrate to drive field line resonances within the plasmasphere. However, these waves are observed virtually every day at low latitudes.

At this stage, observations of wave phase and polarization characteristics at low latitudes have yielded contradictory results, and their propagation to these latitudes is not well understood. Several authors[10-14] have reported propagation of signals away from the local noon meridian and left handed polarization in the prenoon sector (right handed postnoon) when viewed in the direction of the ambient geomagnetic field lines. This is consistent with the generation of the waves by field line resonances, in the vicinity of the plasmapause at middle latitudes, driven by the Kelvin-Helmholtz instability at the magnetopause. However, the observed signal amplitudes at low latitudes do not agree with the expected damping rate of externally excited hm waves inside the magnetosphere[15]. Furthermore, it is not clear how significant wave energy can propagate from the magnetopause and across the plasmapause to couple with resonant field lines at low latitudes[16].

Conversely, some studies[17-19] have indicated the presence of long azimuthal wavelengths and propagation towards the noon meridian at low latitudes. These results are inconsistent with the Kelvin-Helmholtz instability model.

It has been recently suggested[20] that there may be two main sources of daytime Pc3-4 pulsations. Boundary waves may be generated in the Pc3-4 range near the magnetopause and penetrate into the outer magnetosphere. This would be a source of high latitude pulsations. Upstream waves in the

64

foreshock region may be transmitted across the magnetosheath and magnetopause deep into the magnetosphere where they are observed as compressional Pc3-4 waves at synchronous orbit[21]. The compressional waves may then propagate further into the inner magnetosphere and couple with transverse waves which exhibit field line resonance behavior[22]. Eigen frequencies would be determined mainly by local plasma parameters and the magnetospheric structure and would be observed on the ground as low latitude Pc3-4 pulsations.

In order to clarify some of these aspects, a new project to investigate the spatial characteristics of low latitude Pc3-4 geomagnetic pulsations has commenced. Data will be recorded along a latitudnal chain of field stations across eastern Australia, over the L-value range 1.3 to 2.7 (approx. 29^{o} - 53^{o} geomagnetic latitude). Figure 2 shows the locations of these recording sites with respect to geographic, geomagnetic and L-shell coordinates. Initially, Pc3-4 recording stations will be established at LN, NC, DB and WM. The array follows an earlier one deployed for studying the propagation of Pc1(0.1-1 Hz) and the longitudinal phase structure of Pc3 pulsations. Phase and polarization measurements across the network will also yield information on pulsation characteristics around the region of the maximum Alfven velocity in the magnetosphere, situated near L = 1.5. This will link hitherto unexplained Japanese observations which are restricted to latitudes corresponding to L < 1.7. The station locations chosen represent a compromise between the ideal case, lying on the geomagnetic meridian, and prevailing geographic and geological conditions such as accessibility and uniform ground structure.

Recording equipment is designed to facilitate economic handling of data. Orthogonally oriented induction coil systems will be linked via dual

65

mode amplification systems to microcomputers which store data in digital form on floppy disc. Timing at each site will be provided by an appropriate chronometer. During the initially planned few months of operation the stations will require only periodic attention to monitor operation and change discs. The NC station will form a reference station and will be equipped with a fluxgate magnetometer and chart recorders in addition to the digital Pc3-4 and Pc1 systems.

REFERENCES

1. Takahashi, K., McPherron, R.L. and Hughes, W.J. Multispacecraft observations of the harmonic structure of Pc3-4 geomagnetic pulsations, J. Geophys. Res., 89, 6758, 1984.

2. Hasegawa, A. Tsui, K.H. and Assis, A.S. A theory of long period magnetic pulsations, 3, local field line oscillations, Geophys. Res. Lett., 10, 765, 1983.

3. Yumoto, K. and Saito, T. Nonlinear resonance theory of Pc3 magnetic pulsation, J. Geophys. Res., 87, 5159, 1982.

4. Greenstadt, E.W., McPherron, R.L. and Takahashi, K. Solar wind control of daytime, midperiod geomagnetic pulsations, Adv. Earth Planet. Sci., 11, 89, 1981.

5. Gul'elmi, A.V. Diagnosis of the magnetosphere and interplanetary medium by means of pulsations, Space Sci. Rev., 16, 331, 1974.

6. Greenstadt, E.W., Mellott, M.M., McPherron, R.L., Russell, C.T., Singer, H.J. and Knecht, D.J. Transfer of pulsation-related wave activity across the magnetopause: Observations of corresponding spectra by ISEE 1 and 2, Geophys. Res. Lett., 10, 659, 1983.

7. Russell, C.T., Luhmann, J.G., Odera, T.J. and Stuart, W.F. The rate of occurrence of dayside Pc3,4 pulsations: The L-value dependence of the IMF cone angle effect, Geophys. Res. Lett., 10, 663, 1983.

8. Campbell, W.H. Natural electromagnetic field fluctuations in the 3.0 to 0.02 cps range, Proc. IEEE, 51, 1337, 1963.

9. Jacobs, J.A. and Sinno, K. World-wide characteristics of geomagnetic micropulsations, Geophys. J. Roy. Astron. Soc., 3, 333, 1960.

10. Samson, J.C., Jacobs, J.A. and Rostoker, G. Latitude dependent characteristics of long-period geomagnetic micropulsations, J. Geophys. Res., 76, 3675, 1971.

11. Rostoker, G., Samson, J.C. and Olson, J.V. Latitudinal and longitudinal variation of Pc4,5 pulsations and implications regarding source mechanisms, Adv. Earth Planet. Sci., 11, 1, 1981.

12. Olson, J.V. and Rostoker, G. Longitudinal phase variations of Pc4-5 micropulsations, J. Geophys. Res., 83, 2481, 1978.

13. Fraser, B.J. and Ansari, I.A. The spatial characteristics of low latitude Pc3 geomagnetic pulsations, Proc. 7th Symp. on Coordinated Obs. of Ionos. and Magnetos. in Polar Regions, Natl. Inst. Polar Res., Tokyo, Feb. 1984.

14. Kuwashima, M., Sano, Y., and Kawamura M. On the geomagnetic pulsation Pc (part III) - spectral and polarization characteristics of middle and low latitude Pc3, Mem. Kakioka Mag. Obs., 18, 1, 1979.

15. Southwood, D.J. Magnetopause Kelvin-Helmholtz instability, magnetospheric boundary layers, ESA-SP 148, 483, 1979.

16. Lanzerotti, L.J., Medford, L.V., Maclennan, C.G., Hasegawa, T., Acuna, M.H. and Dolce, S.R. Polarization characteristics of hm waves at low geomagnetic latitudes, J. Geophys. Res., 86, 5500, 1981.

17. Mier-Jedrzejowicz, W.A.C. and Southwood, D.J. Comparison of Pc3 and Pc4 pulsation characteristics on an east-west mid-latitude chain of magnetometers, J. Atmos. Terr. Phys., 43, 911, 1981.

18. Mier-Jedrzejowicz, W.A.C. and Southwood, D.J. The east-west structure of mid-latitude geomagnetic pulsations in the 8-25 mHz band, Planet. Space Sci., 27, 617, 1979.

19. Green, C.A. The longitudinal phase variation of mid-latitude Pc3-4 micropulsations, Planet. Space Sci., 24, 79, 1976.

20. Yumoto, K., Saito, T., Akasofu, S.-I., Tsurutani, B.T. and Smith, E.J. Propagation mechaism of daytime Pc3-4 pulsations observed at globally coordinated stations, to appear in J. Geophys. Res., 1985.

21. Yumoto, K. and Saito, T. Relation of compressiona hm waves at GOES 2 to low-latitude Pc3 magnetic pulsations, J. Geophys. Res., 88, 10041, 1983.

22. Kivelson, M. and Southwood, D.J. Resonant ULF waves: a new interpretation, to appear in Geophys. Res. Lett., 1985.

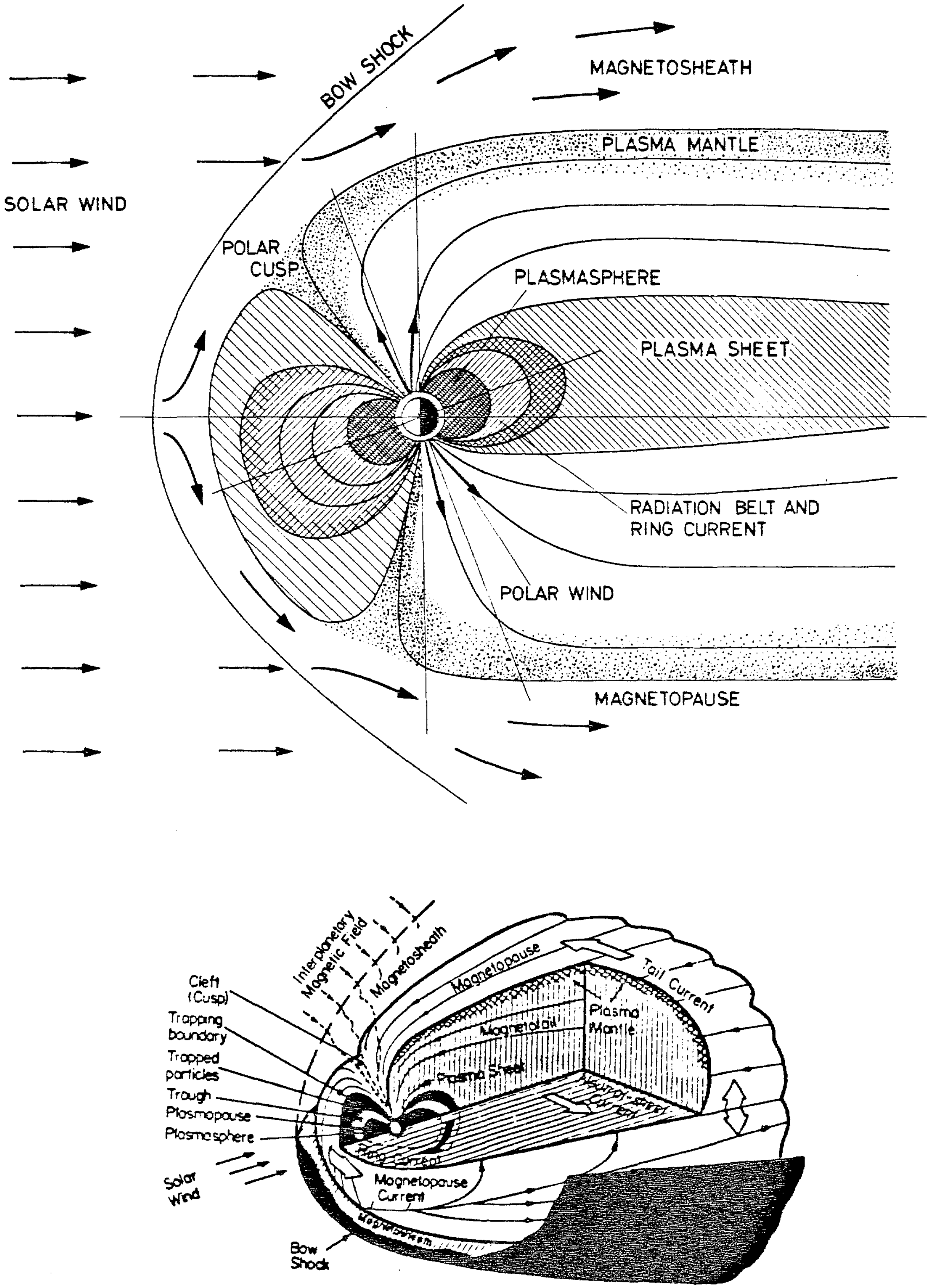


Fig. 1. Diagrammatic representations of the magnetosphere showing main features and regions.

68

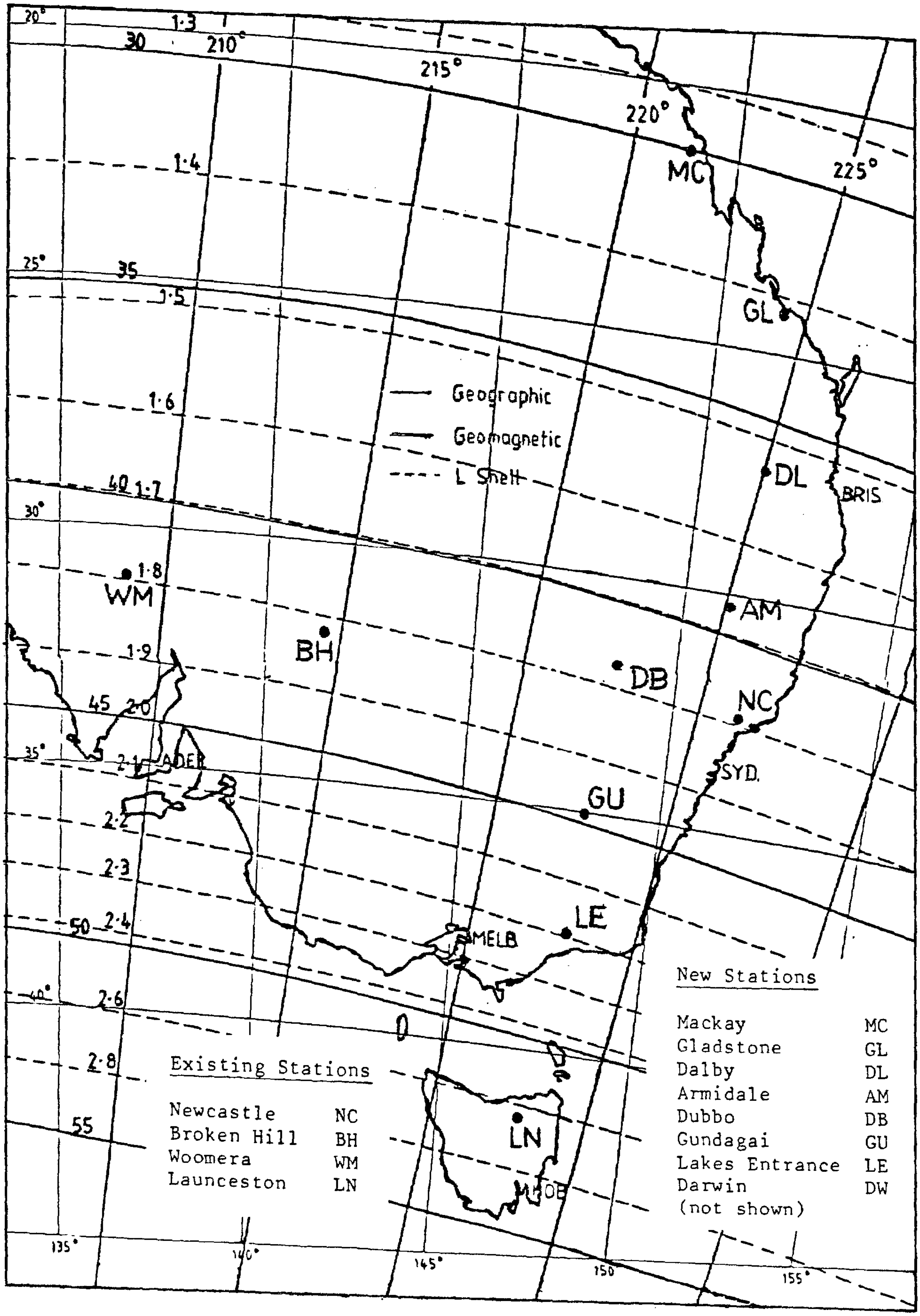


Fig. 2. Pc3-4 recording stations of the University of Newcastle latitudinal and meridional low latitude networks.

69

THE SPATIAL PATTERN OF THE DAILY MAGNETIC VARIATION OVER AUSTRALIA, WITH APPLICATION TO THE CORRECTION OF MAGNETIC SURVEY DATA.

Peter R. Milligan

Bureau of Mineral Resources,
Division of Geophysics,
G.P.O. Box 378,
Canberra City,
A.C.T. 2601

Time variations of the Earth's geomagnetic field, with periods of a few seconds to the daily variation, can introduce errors of up to tens of nanoteslas into magnetic survey data (Lilley, 1982; Riddihough, 1970). These errors may be removed either by rapid looping methods similar to those used in gravity surveys, or, as is more usually the case, by subtracting from the survey data the record of a continuously monitored ground station. This latter method usually works well if the survey is undertaken relatively close to the base monitor, but when the distances involved become of the order of several hundred kilometers, as they may in aeromagnetic surveying in Australia, the assumption of uniform variations on this scale may not be valid. Since magnetic surveys are not usually undertaken on days of strong disturbance of the geomagnetic field, the main errors will arise from pulsation events (I.Hone, D.Pridmore, pers.comm.), and from the daily variation, which is further considered here.

Spatial non-uniformities in the daily variation can arise either from irregularities in the ionospheric current systems producing the primary external field, or from secondary fields produced by currents induced in the ground by the primary field. In general, the normal daily variation differs between observation sites with a simple local-time phase dependence, as the Earth rotates beneath the source currents, which remain stationary with respect to the sun, and with a smooth latitude dependence observed in the amplitude (Lilley, 1982).

Several anomalous zones have been defined in Australia by Lilley (1982,1984), using arrays of magnetometers. The effects are most noticeable for short period events of up to a few hours duration, but significant lateral variations in the diurnal field are visible in the records from near Cobar, where current-channelling is postulated within the near-surface formations. The coast effect across south-east Australia is also prominent in the daily variation (Bennett and Lilley, 1973). Anomalous zones in northern South Australia and south-west Queensland are most obvious for short-period events, and this is true again for the more southerly regions of South Australia, which have now been mapped in some detail (White and Polatayko, 1978,1985; White and Milligan, 1985; Chamalaun, 1985). It is interesting that a very strong anomaly at short periods on southern Eyre Peninsula, South Australia (White and Milligan, 1984) appears to have negligible effect on the daily variation. There are, however, still large areas of Australia, particularly in Western Australia, the Northern Territory, and eastern Queensland, where geomagnetic variation studies using arrays of magnetometers have not been undertaken; hence geological effects on the magnetic variations are unknown for these regions.

Some information regarding the spatial distribution of the daily variation across Australia is available from recordings made by the Bureau of Mineral Resources (BMR) as part of their first-order magnetic surveys for the production of epoch maps of the seven geomagnetic elements. Records of H, D, Z and F are available for at least two days in succession from a network of more than 60 repeat sites across Australia (Figure 1). Although this data has not been simultaneously recorded, variations at each site may be compared with observatory data from Gnangara, Port Moresby, Toolangi and Canberra to give an estimate of the spatial distribution across Australia. As Lilley and Parker (1976) point out, the analysis of one day may be used to compare variations between two different sites, even though it may not give a reasonable estimate of the average daily variation at a single location.

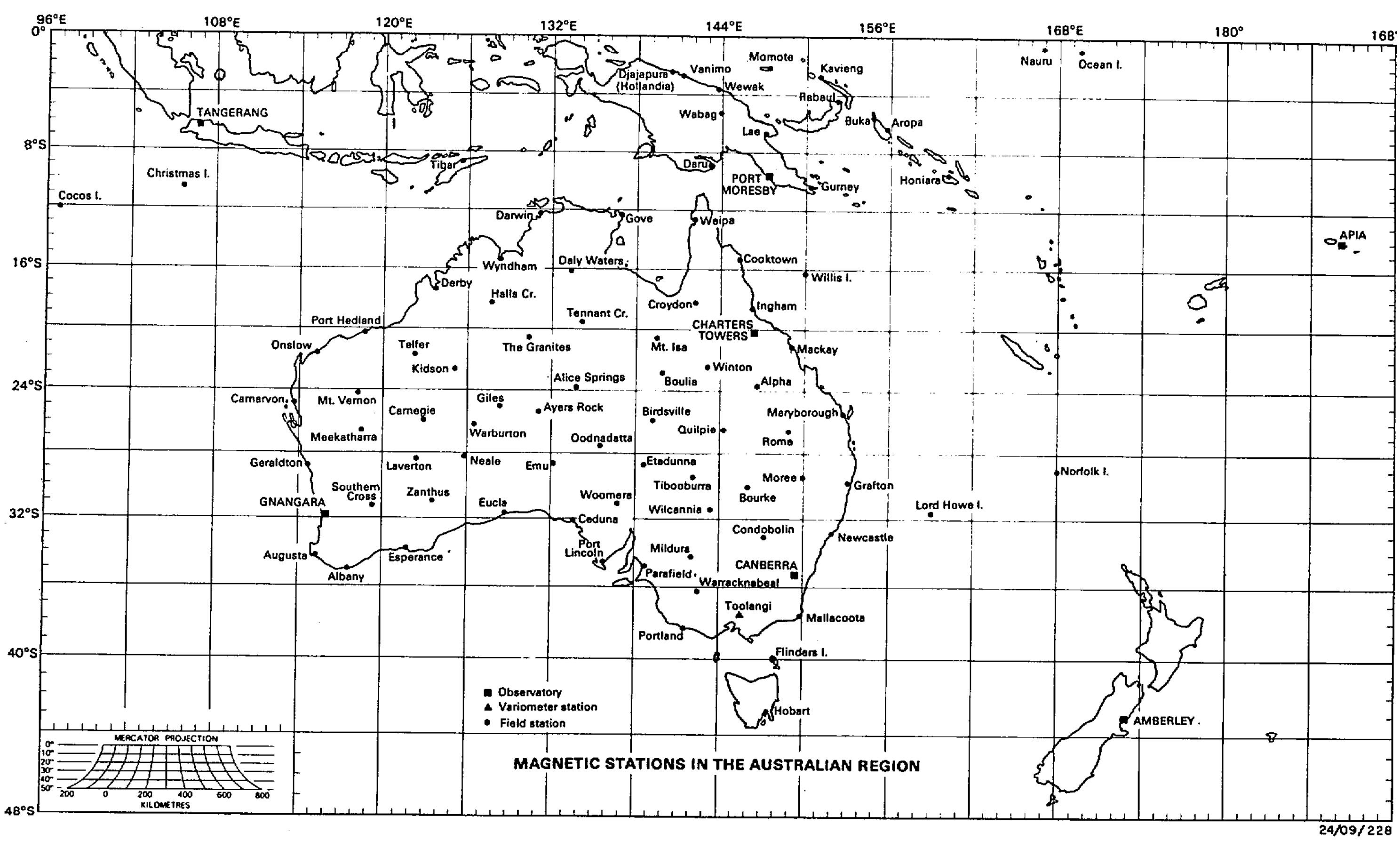


FIGURE 1. Current first-order magnetic sites, variometer station and magnetic observatories for the Australian region.

Riddihough (1971) compared the records of seven sites across Ireland with the corresponding total field records derived from Valentia Observatory. He found that the errors involved in assuming uniformity in the daily variation lie between ±2 and ±6 nanoteslas, with the maximum station separation of the order of 300 Km. Daily variations at each site were found to be highly correlated with those at the observatory, and it was concluded that while both time and amplitude differences affect the errors in reduction of magnetic survey data, the time variations have much less effect than the amplitude variations. A consistent geographical pattern of amplitude differences was contoured for Ireland, and subsequently used as a basis for estimating errors involved in reducing magnetic survey data. Srivastava (1971) described a similar analysis for the east coast of Canada, using both correlation analysis in the time domain, and comparison of Fourier amplitude and phase values, from several days of continuous data.

It is proposed that similar analyses be undertaken for Australia using the first-order data available, and supplemented, where possible, by selected data available from the base monitors of aeromagnetic surveys. These analyses should complement the information already available from the previously mentioned array studies, the usefulness of which for magnetic survey reduction has already been suggested by Lilley (1982,1984). First-order stations are reoccupied on average once every five years, with variometer recording having commenced about 1965. Thus the variability of station differences can be tested over several epochs. It may be that Australia can be divided into northern and southern zones on either side of the 40°S dip latitude, which is the approximate focus of the Sq current system. Sq variations in F and H are reversed in northern and southern Australia about this line, the position of which is very variable from day to day (McGregor, 1979). If an average latitudinal effect can be removed from the correlated data, it may be possible to produce a map which mainly reflects changes in the expected pattern of the daily variation across Australia due to geology. Figure 2 illustrates the high degree of correlation obtainable for selected days of total field measurements between Canberra Observatory and Mildura (similar latitude) and Moree (similar longitude). The spatial resolution is limited by the large average spacing between the first-order sites (approx. 500 Km.). Future large-scale array experiments across Australia will help define better the influence of geology and tectonics on the geographical pattern of the daily variation, and also short-period variations.

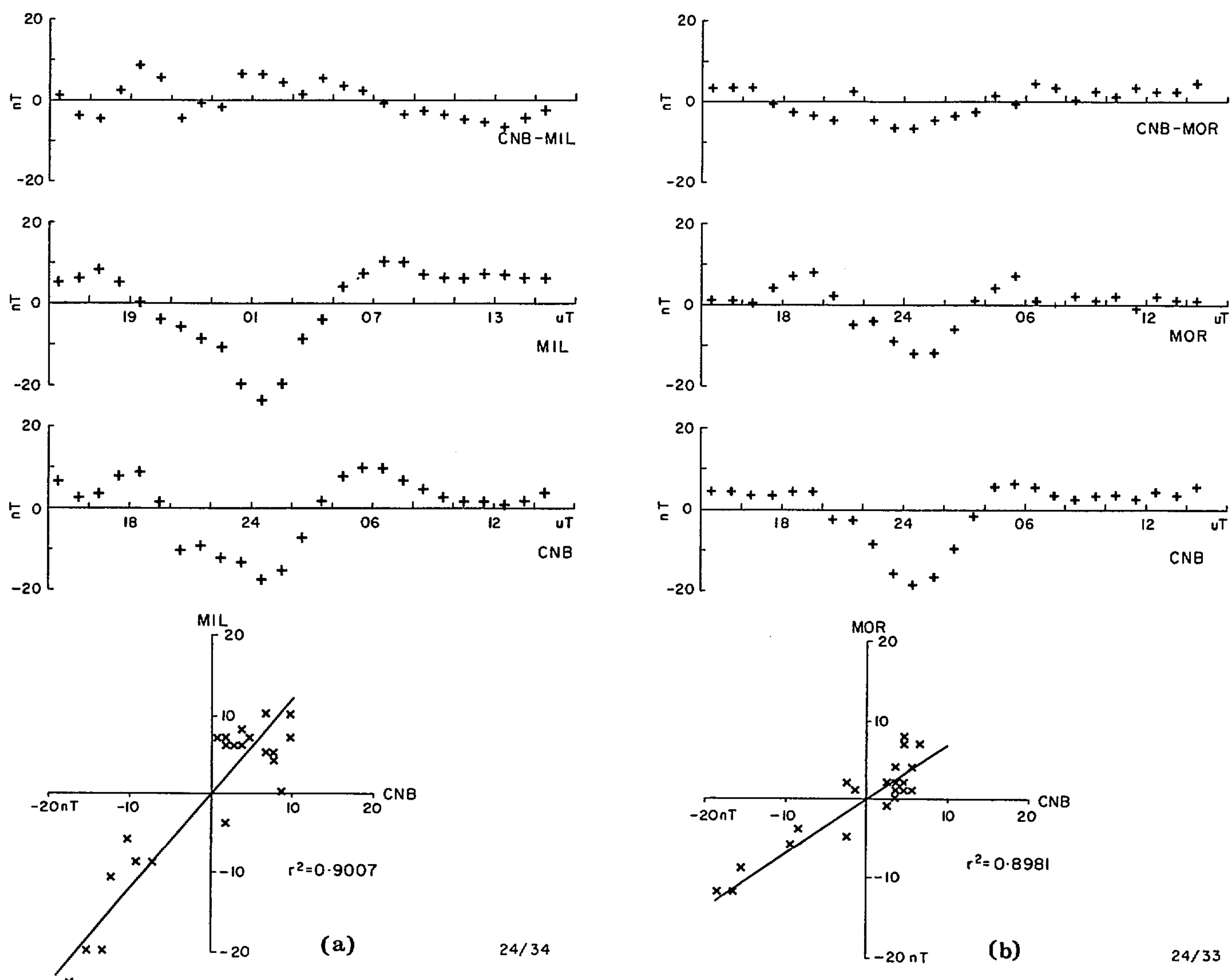


FIGURE 2. Examples of total field daily records of hourly means from (a) Mildura and (b) Moree compared with the corresponding records from the Canberra Observatory. The high degree of linear correlation is indicated.

REFERENCES.

BENNETT,D.J. and F.E.M.LILLEY, An array study of daily magnetic variations in southeast Australia, J. Geomag. Geoelectr., 25, 39-62, 1973.

CHAMALAUN,F.H., Geomagnetic deep sounding experiment in the central Flinders Ranges of South Australia, Phys. Earth Planet. Inter., 37, 174-182, 1985.

LILLEY,F.E.M., On the spatial pattern of magnetic fluctuations in the Cobar area, N.S.W., Exploration Geophysics, 15, 79-83, 1984.

LILLEY,F.E.M., Geomagnetic field fluctuations over Australia in relation to magnetic surveys, Bull. Aust. Soc. Explor. Geophys., 13, 68-76, 1982.

LILLEY,F.E.M. and R.L.PARKER, Magnetic daily variations compared between the east and west coasts of Australia, Geophys. J. R. astr. Soc., 44, 719-724, 1976.

McGREGOR,P.M., Australian magnetic observatories, BMR J. Aust. Geol. Geophys., 4, 361-371, 1979.

RIDDIHOUGH,R.P., Diurnal corrections to magnetic surveys - an assessment of errors, Geophys. Prospecting, 19, 551-567, 1971.

SRIVASTAVA,S.P., Diurnal variation of the total magnetic field along the east coast of Canada, Earth Planet. Sci. Letters, 10, 423-429, 1971.

WHITE,A. and O.POLATAJKO, The coast effect in geomagnetic variations in South Australia, J. Geomag. Geoelectr., 30, 109-120, 1978.

WHITE,A. and O.POLATAYKO, Electrical conductivity anomalies and their relationship with the tectonics of South Australia, Geophys. J. R. astr. Soc., 80, 757-771, 1985.

WHITE,A. and P.R.MILLIGAN, A crustal conductor on Eyre Peninsula, South Australia, Nature, 310, 219-222, 1984.

WHITE,A. and P.R.MILLIGAN, Geomagnetic variations across the southern Adelaide Geosyncline, South Australia, J. Geomag. Geoelectr., in press, 1985.

'Serpentine Emission' at the High Latitude Station Davis (17-23 September 1981)

R.J. Morris

Australian Antarctic Division, Department of Science
Kingston, Tasmania, 7150

K.D. Cole

Department of Physics, La Trobe University
Bundoora, Victoria, 3083

Almost a decade has passed since Gul'elmi and Dovbnya (1974) introduced the high latitude class of magnetic pulsations known as 'Serpentine Emission'. The purpose of this paper is twofold; firstly to present new morphological results of SE observed at Davis, Antarctica and secondly, to stimulate further experimental and theoretical interest by pulsation researchers. Analyses presented include the first cited amplitude-time structure of SE along with maximum entropy power spectra and digital sonagrams. SE polarizations are investigated and a limited diurnal morphological survey is presented.

74

A GEOMAGNETIC REFERENCE FIELD FOR CANADA 1985

by

G.V. Haines and L.R. Newitt

Division of Seismology and Geomagnetism
Earth Physics Branch
Energy Mines and Resources
Ottawa, Canada

The recently developed technique of spherical cap harmonic analysis (SCHA) is ideally suited for the analysis of potential fields over a portion of a sphere. SCHA is a regional analog of ordinary spherical harmonics involving associated Legendre functions of integral order but non-integral degree, and insures that the curl and divergence of the magnetic field vector are zero (Haines, 1985a). The method has been used to produce a Canadian Geomagnetic Reference Field for 1985 (CGRF1985) and the associated series of magnetic charts.

The primary data set consisted of Canadian vector aeromagnetic survey data collected between 1965 and 1976 and contained approximately 120000 half-minute averages gathered along 600000 kilometers of flight tracks. Line spacings varied from 37 km to 74 km and altitudes from 3 km to 5 km. The data from each survey were averaged in cells approximately 127 km on a side both to reduce the number of data to a manageable number for analysis and to reduce the possibility of aliasing. A total of 4350 averaged component-observations were obtained in this manner.

The aeromagnetic data provided adequate coverage over Canada and some adjacent areas, but did not cover the entire area of the spherical cap. They were, however, supplemented by the recent and important Magsat satellite data. The Magsat data used consisted of a subset of the quiet-time data used by Haines (1985b) to produce a Z anomaly map of the region north of 40 N. They were decimated to give a uniform areal coverage, eliminating the extremely dense coverage near the pole which was a result of the satellite's polar orbit. A total of 5622 component observations were retained, with a nominal spacing of 150 km.

All data were updated to 1985 using a model of the secular variation in Canada between 1960 and 1985, produced using SCHA (Haines, 1985c). It is estimated that updating errors were less than 50 nT.

The IGRF 1980, updated to 1985, was subtracted from the updated aeromagnetic and satellite data. Next, positional co-ordinates were transformed from geodetic to geocentric, and were rotated to a co-ordinate system with a pole at 65 N, 85 W, the centre of a spherical cap whose 30 degree radius took in all of Canada and adjacent areas.

75

A spherical cap harmonic analysis was performed on the combined data set, with the Magsat and aeromagnetic data being given equal weight. A spatial index of K=16 was chosen, corresponding to ordinary spherical harmonic degrees up to 49. This should allow the depiction of features with a scale size of approximately 800 km. An expansion to K=16 comprises 259 coefficients, although only 95 were found to be statistically significant at an F level of 4. The scatter, or standard error of estimate, of all data to the model was 63 nT.

The main field components are obtained by adding the IGRF at 1985 to the residual field derived from the SCHA. This composite is called the Canadian Geomagnetic Reference Field 1985. Magnetic charts of five components of the magnetic field were produced by computer contouring an equally spaced array of values computed from the CGRF.

Incorporation of the secular variation model into the CGRF makes the model valid for the period 1960 to 1985 with extrapolation to 1990 possible. The annual change shown of the chart is the average secular variation over the five year lifetime of the chart.

The Canadian Geomagnetic Reference Field has been produced because many users find that the information given by a national model is both more timely and more accurate than the information available from world models. Information on declination is most frequently requested, and is used in the production of topographical, aeronautical, hydrographical and many other charts published by Canadian federal and provincial charting agencies. Accurate declination information is also needed by a multitude of other orginizations, especially the petroleum industry who use bore-hole compasses for directional drilling.

References

Haines, G.V., Spherical cap harmonic analysis, J. Geophys. Res., March, 1985a.

Haines, G.V., Magsat vertical field anomalies above 40 N from spherical cap harmonic analysis, J. Geophys. Res, March, 1985b.

Haines, G.V., Spherical cap harmonic analysis of geomagnetic secular variation over Canada 1960-1983, J. Geophys. Res, submitted, 1985c.

76

<u>The Tamar Conductivity Anomaly</u>

W.D. Parkinson and R. Hermanto

University of Tasmania
Hobart, Tasmania, 7000

The Tamar Lineament follows an approximately straight line from near the mouth of the Tamar River to near the Tasman Peninsula. The pre-Carboniferous geology is very different on the two sides of this line. On the north-east side Devonian sediments are of deep water facies, typified by the Mathinna Beds. On the south-west side Devonian and older sediments are of shallow water origin, such as the Owen conglomerates and Gordon limestone. The granites in the north-east side are slightly older than those on the south-west side. There are also geophysical differences. The magnetic anomaly structure is smoother in the north-east and earthquakes are less frequent. This paper reports a striking conductivity anomaly coinciding with the Tamar Lineament.

Magnetic fluctuations within a certain period band are usually found to be polarised so that the vectors representing them lie in a plane. The plane is often horizontal, but if it is inclined at an appreciable angle it indicates a gradient of conductivity underground, the plane tilting upward towards the better conductor. This can be indicated on a map by an "induction arrow" whose direction is the direction of upward tilt, and whose length indicates the angle of tilt.

Field measurements have been made in Tasmania with 3-component EDA fluxgate magnetometers and Memodyne digital cassette recorders. Only two instruments are available so the technique of deriving and plotting induction arrows has been used rather than that of synoptic contour plots. It is found that all the induction arrows in eastern Tasmania point towards the Tamar Lineament, indicating that it is the location of a linear conducting body.

Superimposed on the effects of such a conductor is the effect of the oceans surrounding Tasmania. At long periods, of the order of 100 minutes or more, the effect of the oceans dominates, and all induction arrows point towards the SSE. As the period decreases induction arrows at sites to the north-east of the Tamar Lineament turn to a WSW direction and those at sites to the south-west of the Lineament turn to an ENE direction, both pointing towards the Lineament for periods less than 30 minutes. The effect of the oceans is more marked near the east and south coasts, where the effect is superimposed on the effect of the conductivity anomaly. Thus, for example, at Fingal, about 30 kms from the east coast, the induction arrow points almost south, even for short periods.

Professor Dosso and Dr Nienaber of the University of Victoria, British Columbia, have made a physical model in which the induction in sea water is simulated for Tasmania with its surrounding oceans and Bass Strait (Dosso et al., 1985). This has enabled us to evaluate, and to a certain extent compensate for, the effects of the oceans.

A striking feature of the anomaly is that it extends a great distance to the west. The influence is clearly visible at Bronte Park, in the centre of

77

the island. It appears to be wider in the north where its western limb may curve to the west passing under Deloraine and Mole Creek. However, because of the effect of Bass Strait, this is difficult to verify. However, along most of its length it is sufficiently close to a two-dimensional structure that it can be modelled as such. We have used the Jones and Pascoe program to search for models that approximate the field results. We have been aided in this by two magneto-telluric studies carried out by Nathan Bindoff (1983) and Jacques Sayers (1984). These show that the conducting body is shallow and very conducting, i.e. a depth of 2 kms and a conductivity of between 1 and 2 S/m. Using these restraints the best fitting models consist of a rather thin (3 km thick) highly conducting (2 S/m) body either dipping or tapering to the west and with a total width of about 30 kms in the central part and up to 70 kms further north.

Some geologists, e.g. Powell (1984), consider that the Tamar Lineament is part of what has been called the "Tasman Line", which consists of rifts and transform faults. It runs from near Cairns through the Flinders Ranges, then via a transform fault (the "Gambier-Beaconsfield fracture") to Bass Strait and thence southward as the Tamar Fracture Zone. It is considered to represent the eastern margin of the Australian continent in Cambrian times. An interesting feature of this concept is that practically all the important conductivity anomalies found in Australia lie on or near this Tasman Line.

It is not easy to identify the cause of the high conductivity associated with the Tamar anomaly. The presence of semi-conductors, except possibly graphite, is precluded by the absence of a significant magnetic anomaly coinciding with the conductivity anomaly. The shallow depth makes the presence of graphite unlikely and a sufficiently high temperature is out of the question. The most likely cause seems to be fractured rock saturated with highly conducting fluids. Archie's Law suggests that a porosity of 20% to 40% is necessary with a fluid conductivity of the order of 10 S/m. Fluids with such a high conductivity have been reported, but are generally confined to oilfields.

Bindoff N. (1983) Thesis, University of Tasmania

Dosso H.W., Nienaber W. and Parkinson W.D. (1985), Phys. Earth Planet. Int. (in press)

Powell C., (1984) in PHANEROZOIC EARTH HISTORY OF AUSTRALIA ed. J.J. Veevers, Oxford University Press

Sayers J., (1984) Thesis, University of Tasmania

The transmission from rifting to sea-floor spreading - magnetic slope off Morocco

H.A.Roeser (BGR Hannover), V. Gebhardt (Univ. Hamburg),
W. Weigel (Univ. Hamburg), K. Hinz (BGR Hannover)

In many cases, passive continental margins are paralleled by a prominent magnetic anomaly, the so-called "slope anomaly". Off the Atlantic coast of Morocco, the slope anomaly (named S1) varies along strike considerably in amplitude and shape (Fig.). The variations are correlated to changes in the magnetic character of the subsided and fractured continental crust eastward of the slope anomaly where we observed lineated magnetic anomalies which are nearly parallel to S1. Seaward of S1 the anomalies are generally much weaker. They are also parallel to the slope anomaly, however less continuous.

The change of the magnetic signature at S1, and the fact that it is the strongest anomaly indicate that it marks the continent-ocean boundary. This is supported by the reflection seismic data which shows oceanic character for the crust seaward of the slope anomaly. Over the slope anomaly itself the reflectors reveal a most irregular pattern. Landward diapiric structures dominate the continental slope. The most prominent of these "diapirs" coincides with a magnetic anomaly. Due to model calculations the source body must lie within the structure.

S1 cannot be interpreted as an edge effect. Instead a body with high magnetization is necessary. Refraction seismic measurements resulted in velocities of 7 km/s and 8 km/s at shallow depth at the place of the required body. Thus the crust is neither continental nor typical oceanic in character. We interprete it as sea-floor spreading crust influenced by the cold continental crust adjacent to the rift at the beginning of the drift phase.

Similar conditions exist at large-offset fracture zones where the mid-ocean ridge abuts cooler oceanic crust. Often the magnetization is lower at fracture zones than for typical oceanic crust, only in some cases it is higher. Likewise at many continental margins magnetic slope anomalies are not observed. The existence, or lack of a magnetic slope anomaly might provide important insights into the processes governing the begin of sea-floor spreading.

79

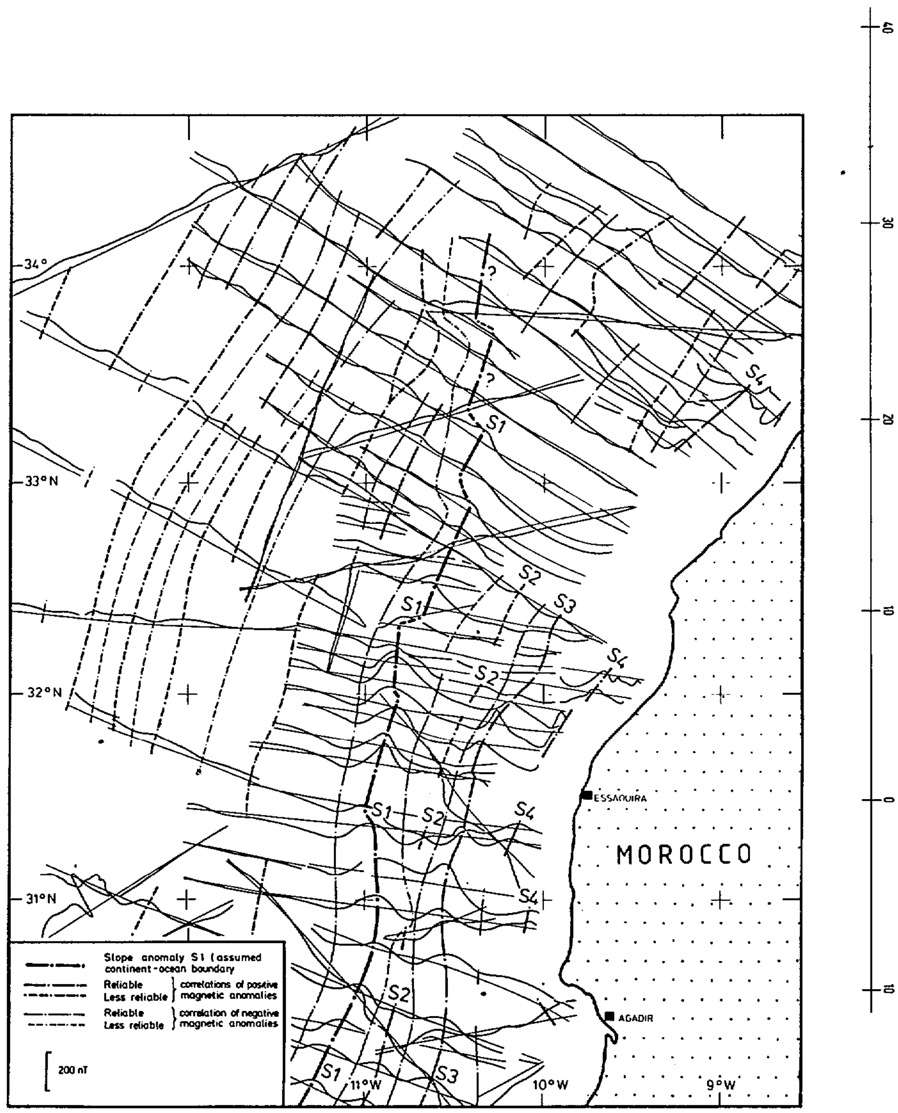


Figure 1. Total intensity anomalies of the Earth's magnetic field around the Atlantic continental margin of Morocco

SOLAR AND LUNAR MAGNETIC TIDES AT MIDNIGHT

Robert J. Stening

School of Physics, The University of N.S.W.
Kensington N.S.W. 2033

1. Solar Tides

The method of WINCH (1981) is used to extract the annual and semiannual components in the magnetic elements starting with hourly values. A series of coefficients of the form $A_{kn}\sin(nt+kh+\lambda_{kn})$ are obtained for n=1 to 4 and k=-2 to +2. Here t is the local time and h is the longitude of the mean Sun (giving variation with season). These 20 coefficients can then be used to reconstitute the daily variation curve for any season h. Here we are interested in the variation of the midnight (t=0) values with season.

The data used to derive the coefficients are hourly values for 1964 and 1965 with the 5 disturbed days of each month omitted. At sunspot minimum this will correspond to relatively quiet conditions.

In Figure 1 the variation with season of the midnight values of the horizontal component of the magnetic field H is plotted for selected stations. The main point to notice is the large enhancement of this variation at the dip equator (equatorial electrojet stations). The variation at Huancayo is more than 3 times that at Tatuoca or Fuquene and that at Trivandrum is more than 2.5 times that at Alibag. Addis Ababa also shows a large variation.

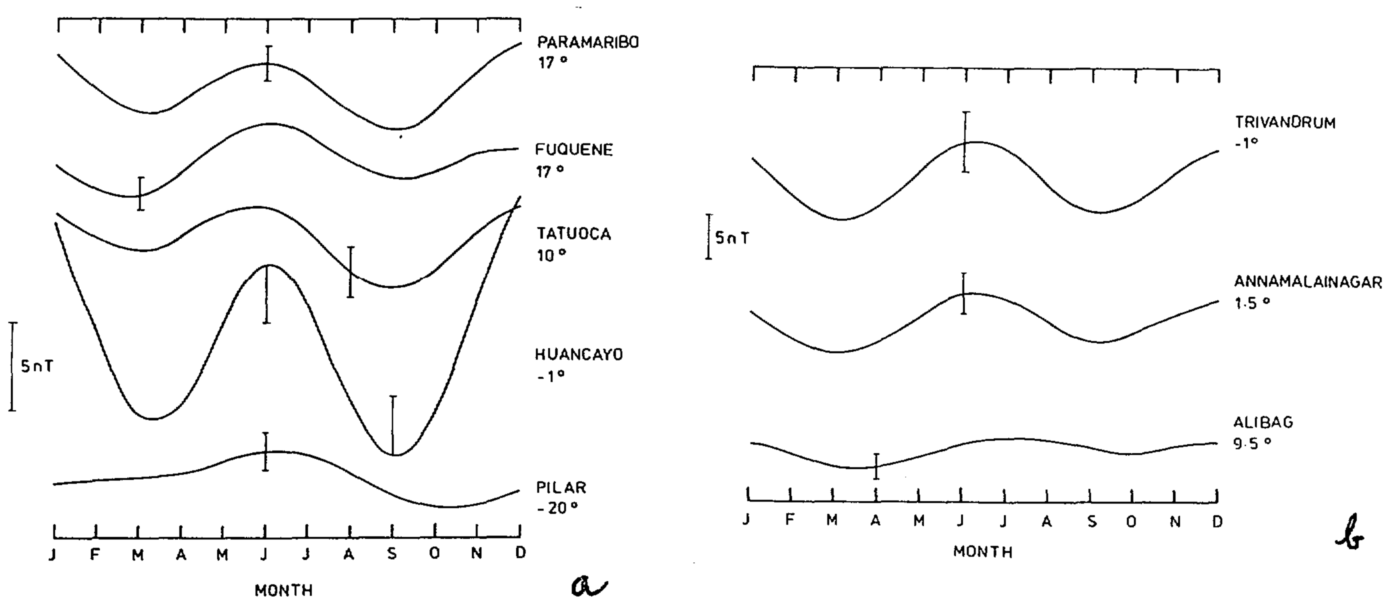


Figure 1: Midnight values of the solar variation of H (a) American sector (b) Indian sector.

The form of the variation, with maximum at solstices and minima at equinoxes, is similar to that obtained by CAMPBELL (1981). But the analysis of Campbell does not yield the large enhancement at the dip equator. He finds a more gradual fall off in amplitude of this variation with latitude and so is able to explain it in terms of the latitudinal movement of a ring current on the tail side of the magnetosphere at a distance of about 2 Earth's radii ($2r_e$).

81

While this mechanism may be responsible for some of the observed semi-annual variations at midnight, the dip equator enhancement suggests that there must also be a contribution from a westward equatorial electrojet. Note also that, as the dayside electrojet is stronger at Huancayo than at Trivandrum, so also it appears the night electrojet is similarly stronger (a seasonal change of 15.0 nt at Huancayo and 8.9 nT at Trivandrum).

The suggestion of a nighttime electrojet of this magnitude poses problems. The nighttime conductivity in the E region is generally considered to be only about 1/40 of the daytime value. Furthermore at sunspot minimum the results of FEJER et al (1979) indicate that F region vertical drifts (and so electric fields) are also smaller at night than during the day (though the reverse appears to be true at sunspot maximum). This effect is discussed in STENING (1981). Thus if the daytime electrojet yields 100 nT for ΔH on the ground (a typical value for 1964-65), then the nighttime jet should only give about 2 nT which is far short of that indicated by the results presented here. Some of the deficit will be made up from currents flowing in the F region (RISHBETH, 1981) but it is not clear how much.

Solar Tide in Z

The season variations in the vertical component Z of the geomagnetic field are shown in Figure 2. The form of the variations is again similar to

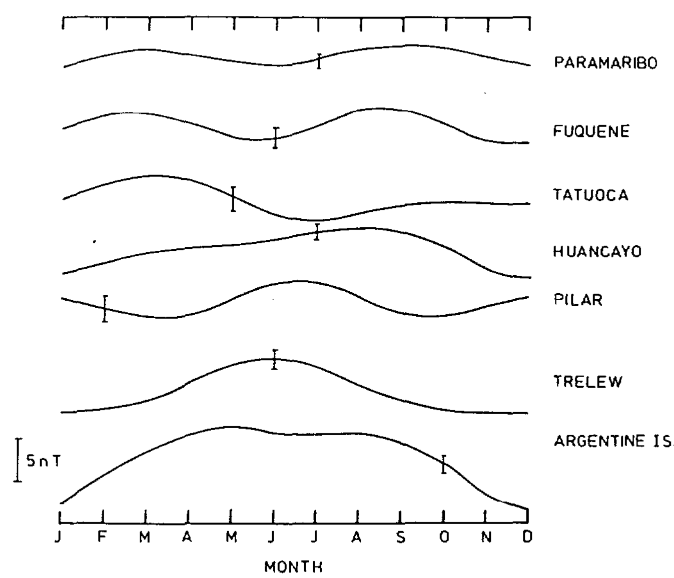


Figure 2: Midnight values of the solar variation of Z in the South American sector.

that obtained by CAMPBELL (1981) but in this case the amplitudes are smaller, e.g. at Huancayo Campbell finds a difference of 8.5 nT between June and December while I find the largest change is 5.7±0.9 nT with maximum in August. At 10° Campbell finds 12.8 nT while I find only 4.7±1.3 nT at Tatuoca. Campbell uses a much smaller data set with only 37 of the quietest days in 1965 selected. By contrast my analysis at Huancayo includes 592 days for H and 299 days for Z. It is hard to understand how my analysis, which includes "less quiet" days, gives a smaller seasonal variation than that of Campbell, especially if the movement of the ring current position is responsible.

82

2. Lunar Variations

The midnight value of the lunar geomagnetic variation has been used by MALIN (1970) to deduce the "oceanic component" on the assumption that ionospheric contributions will be negligible at midnight. SCHLAPP (1977) has shown that there are appreciable seasonal variations in the midnight lunar magnetic variation of Z at Honululu very similar to that shown in Figure 3.

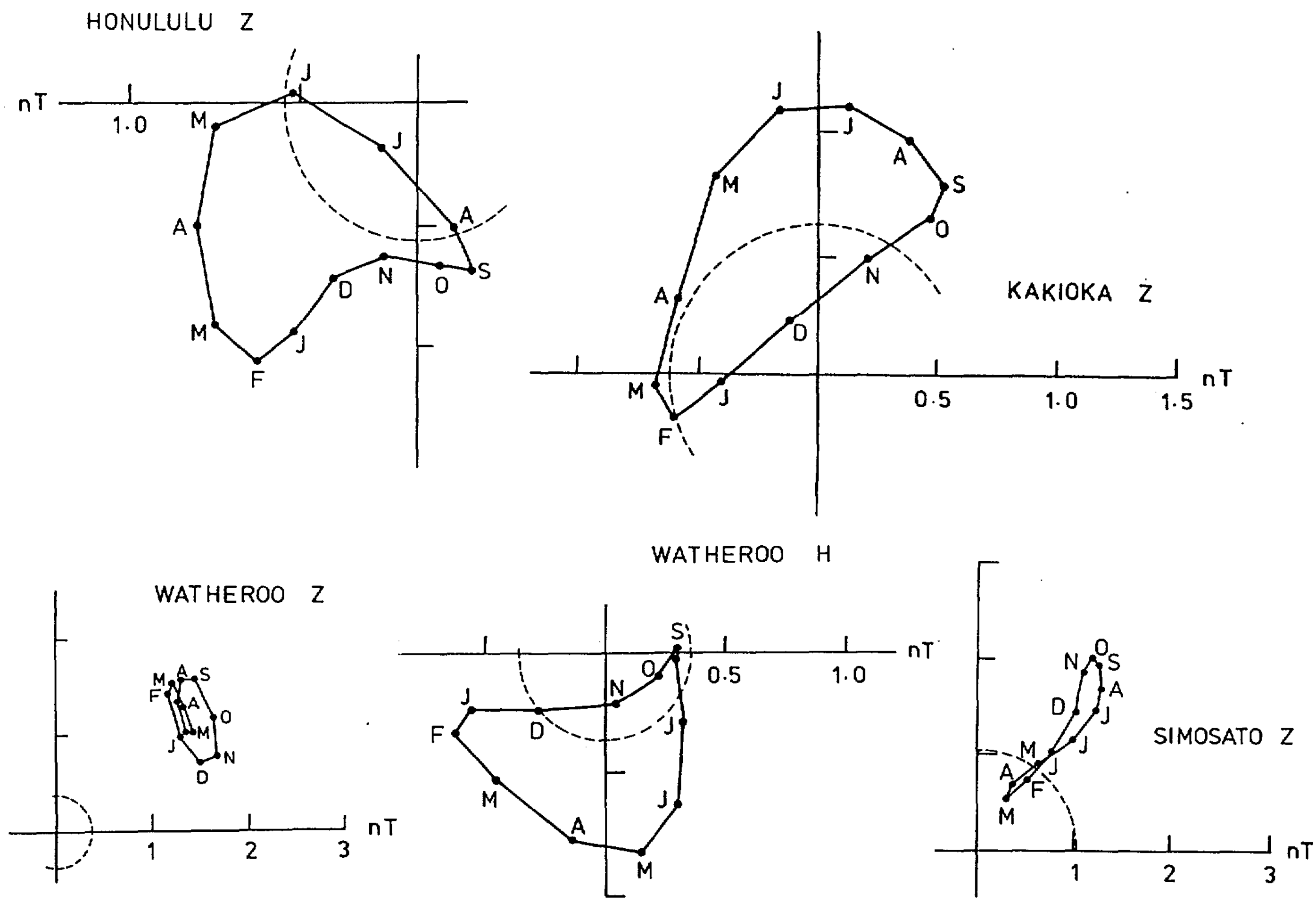


Figure 3: Phase and amplitude variation with season of lunar midnight values at various stations.

Schlapp uses 37 years of data so that all points are statistically significant. this result may be interpreted as either
(i) a constant M_2 tide plus an O_1 component or
(ii) a seasonally varying M_2 tide.
Schlapp adopts the former explanation because the phase progression is that of a diurnal tide.

If this variation is of oceanic origin, it implies that the O_1 component of the ocean-generated geomagnetic tide has a similar magnitude to the M_2 component. But observations show that the O_1 component is only about 3% of the M_2 component of the tide in ocean heights. Seasonal variations of ocean tides are also small (2 to 3%). It therefore seems unlikely that the seasonally varying part of this geomagnetic tide is of oceanic origin. Other examples of lunar midnight tides varying with season are also shown in Figure 3. The

Watheroo results use coefficients taken from WINCH and CUNNINGHAM (1972) derived from 40 years of data, while the other stations use only 2 years of data (1964-65). One can find other results similar to Honululu (as Kakioka Z) while others show a variation of amplitude only with season (Simosato Z) or virtually no variation (Watheroo Z).

An understanding of these lunar midnight tides must await an even more comprehensive analysis.

Acknowledgement

Dr. D.E. Winch kindly provided the coefficients from his extensive analysis and also assisted with many helpful discussions.

References

CAMPBELL, W.H., J. atmos. terr. Phys. 43, 607-616, 1981.

FEJER, B.G., FARLEY, D.T., WOODMAN, R.F. and CALDERON, C., J. geophys. Res. 84, 5792-5796, 1979.

MALIN, S.R.C., Geophys. J.R. astr.Soc. 21, 447-455, 1970.

RISHBETH, H., J. atmos. terr. Phys. 43, 387-392, 1981.

SCHLAPP, D.M., J. atmos. terr. Phys. 39, 1453-1457, 1977.

STENING, R.J., J. geophys. Res. 86, 3543-3550, 1981.

WINCH, D.E., Phil. Trans. Roy. Soc. Lond. A303, 1-104, 1981.

WINCH, D.E. and CUNNINGHAM, R.A., J. geomag. geoelectr. 24, 381-414, 1972.

84

Geomagnetic Disturbance Forecasting at the Ionospheric Prediction Service

R. J. THOMPSON
Ionospheric Prediction Service
Department of Science
P.O. Box 702
Darlinghurst, NSW, 2010, Australia

The Ionospheric Prediction Service (IPS), a branch of the Department of Science, provides routine frequency predictions for users of HF communications within Australia and the Asian-Pacific region. To supplement this service, IPS operates the Sydney Regional Warning Centre which has the responsibility for providing forecasts of geomagnetic disturbances and associated ionospheric disturbances. Examples of this latter group of users are people involved in geophysical surveying for minerals; pipeline authorities interested in minimising corrosion in long pipelines; and electrical authorities interested in preventing damage to power transmission grids. Satellites can also be damaged, or even lost completely, through solar-induced disturbances to the sun-earth environment and so the coming launch of Australia's domestic satellites is expected to increase the demand for IPS Radio and Space services in this direction.

Most, if not all, geomagnetic and space disturbances originate in the sun. The particular sources generally thought to be associated with disturbances are solar flares, disappearing filaments and solar coronal holes.

Solar flares are sudden outbursts of radiation over a wide band-width of wavelength ranging from X-rays right through to the radio end of the spectrum. Major flares can also accelerate charged particles which, if they reach the earth, produce a geomagnetic disturbance.

Solar filaments are thin, relatively cool, dense structures suspended above the solar chromosphere by magnetic fields. Large filaments may remain relatively unchanged for several months but, at times, become active and disappear abruptly and completely. The disappearance of a large, suitable oriented filament is found to be correlated with a terrestrial disturbance some time later.

Coronal holes are extended regions of lower than average density and temperature in the solar corona and are the sources of high speed solar wind which can produce disturbances to the terrestrial magnetic field. Coronal holes are often long-lived and produced sequences of disturbances spaced at intervals of 27 days, the apparent rotation period of the sun.

Forecasts of terrestrial disturbance require timely and continuous observations of the sun both at optical and at radio wavelengths. To provide these observations, IPS maintains close data exchange links with similar overseas organisations and operates several solar observatories within Australia. In addition, IPS has collaborative arrangements with Australian universities and the CSIRO to obtain solar data from their observatories.

At Culgoora in northern NSW, IPS has an optical observatory which maintains a routine patrol for solar flares. The staff at the Culgoora

85

observatory also operates the Culgoora radiospectrograph which was built by the CSIRO Division of Radiophysics. The instrument provides vital information on the movement of clouds of charged particles moving out through the solar corona.

At Learmonth in the north-west of Western Australia, IPS jointly operates a solar optical and radio observatory with the United States Air Force. Data from optical and radio patrols at Learmonth are sent routinely to the USAF forecast centres and to the IPS Sydney Regional Warning Centre.

In addition to requiring timely observations of the sun, forecasts of terrestrial disturbances require an understanding of those solar events which are likely to produce disturbances. To this end IPS has a continuing interest in undertaking research in solar-terrestrial relationships. Current topics being studied include: the association of solar filament disappearances and geomagnetic disturbances; the prediction of disturbances from solar coronal holes observations; and seasonal effects in geomagnetic disturbances.

The services produced by IPS for geophysical users are as follows:

- Warnings, usually issued by telex, of impending disturbances.
- A Monthly Summary of solar and geophysical data.
- A recorded telephone message updated daily or more frequently when required.
- specialist advice upon request.

Details of these services are given in the IPS Handbook - H8 or can be obtained by writing to:

Assistant Secretary,
Ionospheric Prediction Service,
P.O. Box 702,
DARLINGHURST, 2010

or by phoning (02) 269 8613.

86

The new Magnetic Map of Australia: applications and expectations and problems

Vadim Anfiloff, Ian Hone, David Tucker
Division of Geophysics
Bureau of Mineral Resources
Canberra ACT

Airborne magnetic surveying has been in progress in Australia since 1951, and a first pass cover may be completed by about 1990. Approximately 50 percent of the surveys will provide digital data and the others will have provided analogue recorded profiles and hand reduced contours. It is our intention to publish standard scale pixel maps and provide a digital database for general use from all suitable data.

Three types of maps will be produced:

1. Total Magnetic Field Pixel Map (greyscaled)

2. Total Magnetic Field Pixel Map (colour scaled)

3. Total Magnetic Field Pixel Shadow Map (greyscaled)

Scales of the maps will be 1:1 000 000 and 1:2500 000. The 1:1000 000 series maps will cover the same areas as the standard 1:1000 000 topographic series, and the 1:2500 000 series will consist of six maps covering Australia.

Prototype Pixel maps of three areas have been produced by image processing techniques, and we have identified various problems associated with:

1. integrating data from surveys flown at different times with different specifications;

2. preserving the integrity of the original data;

3. tying into the AGRF, and ascertaining the correctness of very long wavelength anomallies;

4. interpretation of the diverse information available in pixel maps.

On a regional scale, inaccuracies may result from generation and propogation of errors during matching of data from different surverys, the previous introduction of distortions by removal of various, sometimes not well described, regional gradients and reference fields, and the changing of the geomagnetic field with time. Long airborne calibration and check traverses will be flown, and appropriate tying in with the AGRF is highgly desirable. Completion of these tasks will itself involve solution of numerous difficult problems.

87

The new maps can provide an objective base for developing and testing ideas on the geological framework of Australia, and will give an opportunity for new and comprehensive interpretation of Australia-wide and relatively local areas. They permit the assembling and presentation of very large scale data sets with minimal loss of detail, and enable easy recognition of the form and texture of the magnetic field. The maps reveal both large and small scale features which are difficult to recognise in contour and profile presentations.

Long wavelengths are relevant to deep structures and large crustal blocks, and short wavelength anomalies (width of 500 metres) allow analysis of near surface patterns. While most short wavelength anomalies have been attenuated, some can still be seen with amplitude as low as one to two nanoteslas.

So far interpretation of the new maps has been directed towards relatively local areas. Various applications in interpretation are becoming evident and already the new maps have provided a major improvement in the amount and quality of information obtained from interpretation.

Compared with the existing contour maps, the pixel maps show a dramatic improvement in resolution and in definition of sources at the scale used. This improvement is partly because we are able to represent more effectively the dynamic range of the data, but more so because we are able to take advantage of the ability of the human eye to distinguish subtle changes of intensity, colour, and hue. An example of the improvement is provided in the Albany 1:1 000 000 greyscale pixel map, which provides considerable information on dykes and lithostratigraphy.

One prominent feature disclosed by the Albany magnetic data is the ab undance of long linear magnetic anomalies indicating a pervasive system of magnetic sources crossing the Sheet area, much of which has little outcrop. The linear anomalies are interpreted as magnetic basic dykes, and five times as many of these can be interpreted from the pixel map than from contour maps and profiles. The dykes, some of which extend for more than 500 km across the Yilgarn Shield, have probably at some time exercised a strong control on paleodrainage. As such they could present a t arget for deposits of alluvial heavy minerals.

A second prominent feature evident on the Albany magnetic map is a broad belt of anomalies about 20 km wide across the bottom of the area. Close inspection of this belt shows that it consists of quite remarkably subparallel narrow curvilinear magnetic anomalies. The belt is wrapped around a relatively quite zone with a few lozenge-shaped narrow anomalies scattered about.

The belt of narrow curvilinear anomalies is interpreted as being caused by steeply dipping metasediments fringing a large granite pluton in the south; the lozenge-shaped anomalies appear to represent preserved roof pendants of folded metasediments. The interpretation of the granite pluton is supported by the presence of a gravity low that coincides with the magnetic quiet zone, and some scattered granite outcrops on geological maps. What is clear in the new pixel presentations is the prominence of the contact along the northern side and the apparent simplicity of the preserved folds of metasediments. The enveloping of the metasediments indicates that the granite was intruded upwards into a belt of sediments in the Albany Mobile Belt. A few scattered mineral occurrences in this area of extensive cover suggest that it may be of great interest for exploration.

Geomagnetic Variation anomaly on Eyre Peninsula
South Australia

Antony WHITE and Peter R. MILLIGAN*

School of Earth Sciences,
The Flinders University of South Australia
Bedford Park, S.A. 5042

A systematic study of the coast effect in South Australia (White & Polatajko 1978, 1985; White & Hopgood 1979) revealed the existence of a conductivity anomaly on Eyre Peninsula. Significant deflections of the transfer function vectors at periods around one hour indicated a telluric current concentration flowing SW-NE up the peninsula. This prompted a more detailed study in the southern part of the peninsula where a total of 40 magnetometer stations have been occupied with spacing as close as 5 km (White & Milligan, 1984).

Field recordings were taken between July 1982 and January 1983. Analysis of the data to produce transfer function vectors relating the vertical to the horizontal field variations shows that, while the coast effect is present, there is obvious evidence of a strong linear telluric current flow within the crust in a direction directly away from the ocean.

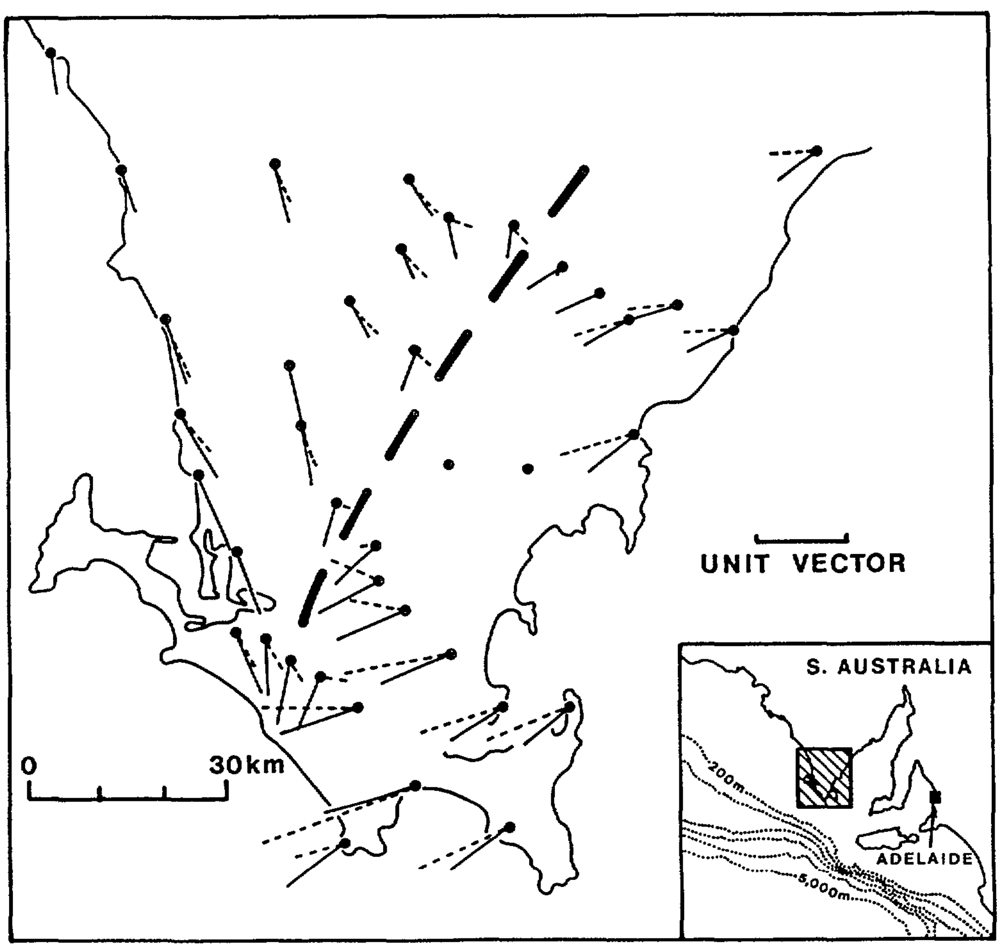


Figure 1. Transfer function vectors (in-phase) for periods of 2 hrs (solid lines) and 0.25 hrs. (dashed lines). The large dashed line indicates the axis of the proposed conducting zone.

---

*Present address: Division of Geophysics, Bureau of Mineral Resourses, G.P.O. Box 378, Canberra, A.C.T. 2601.

Figure 1 displays the in-phase transfer function vectors for two periods, 2 hrs and 0.25 hrs ; following normal convention the direction of the vectors has been reversed. It is apparent that both sets of vectors are responding to a telluric current flow whose axis lies close to the position indicated by the large dashed line in Figure 1. At the higher frequency the effect is more pronounced with vectors on each side of the axis pointing almost directly towards it. Furthermore the vector amplitude reduces to very small values near the axis and the closeness of the station spacing demonstrates that the zone of enhanced conductivity in which the telluric current is flowing must be both narrow and shallow.

There is a strong enhancement of the horizontal D field (which is almost at right angles to the direction of telluric current flow). The contours in Figure 2a are based on data from the stations shown, and are related to the D field at station PL by the equation

$$D\ (\text{anomalous}) = [\,D(\text{total}) - D(PL)\,]/D(PL)$$

for 1 hour period. Enhancement of the D field is frequency dependent; for the daily variation there is no noticeable enhancement, while for 20 minutes period the enhancement for the most southerly stations overlying the conducting zone is greater than a factor of 3. Figure 2b shows contours of the vertical field derived from hypothetical event analysis (Bailey et al., 1974) for 1 hour period. The orientation of the unit horizontal field is parallel with the deep ocean waters and at right angles to the conducting zone, thus minimizing the coast effect and maximising the conductivity anomaly effect. Taken together the D and Z contours of Fig. 2a and 2b are consistent with a concentration of telluric current channelled within a narrow zone of enhanced electrical conductivity. The axes defined by the two sets of contours do not exactly coincide, indicating that there may be some asymmetry of the zone. It appears also that the zone may broaden and/or deepen to the NE. Using a simple retangular channel model with uniform current density as given by Wilhjelm and Friis-Christensen (1974) the best fitting model for profile AB (Figure 3a) defines a conducting zone 12 km wide with upper and lower bounds 6 km and 20 km depth as shown in Figure 3b. (dashed lines).

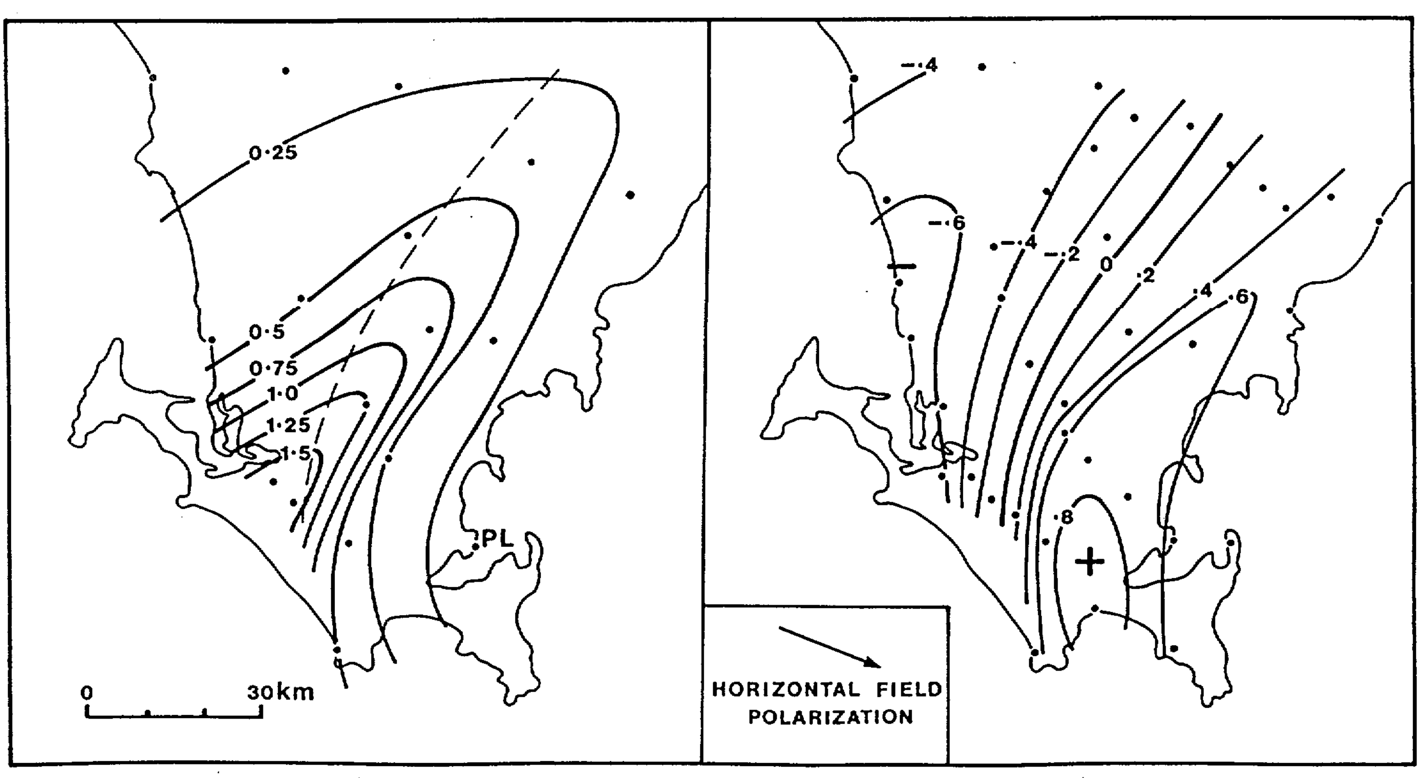


Figure 2. a) Contours of anomalous D field variations relative to Port Lincoln (PL) for 1 hour period.
b) Hypothetical event analysis contours of Z for unit horizontal field in the direction shown (1 hour period).

91

There is a strong correlation of the conducting zone with the fault-like gradient on the western side of the Bouguer gravity anomaly shown in Figure 3a. A simple 2 dimensional model (Lockwood, 1977) has been used to fit the gravity profile along AB and this is shown in Figure 3b. The model uses a 2 km square grid with a variable density contrast ascribable to each grid square. In the model shown a single density contrast of 0.16 g/cm^3 was used and this gave rise to the irregularly shaped bodies as shown. The best fitting model of a rectangular conducting channel described above is superimposed on Figure 3b for comparison.

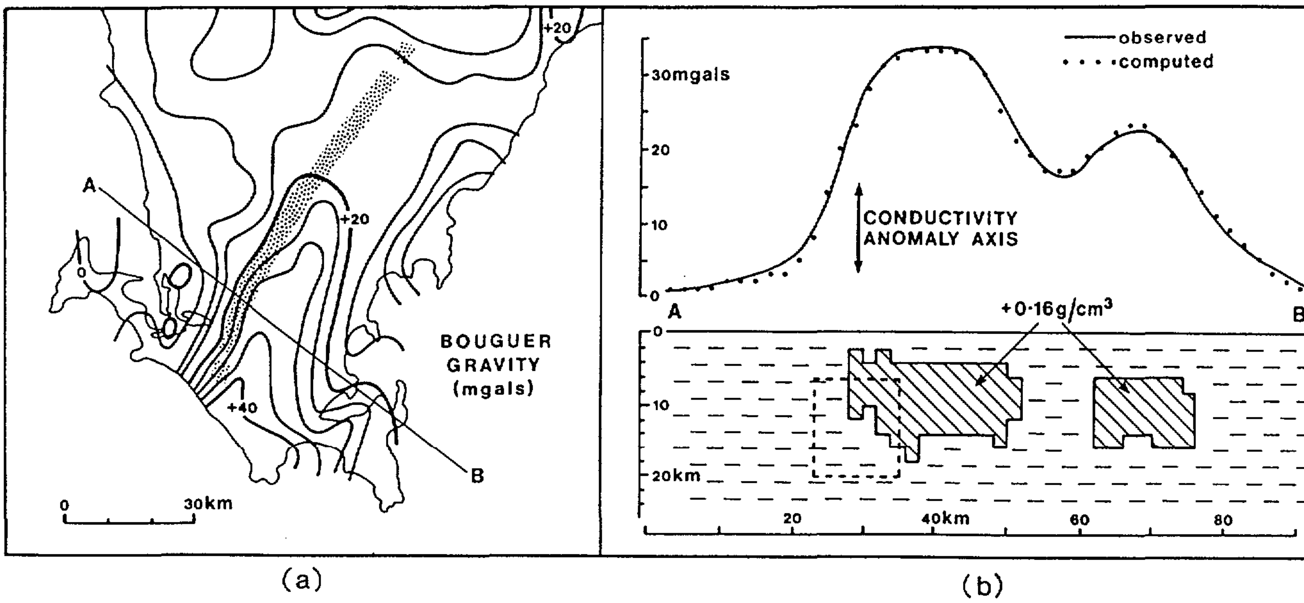


Figure 3. a) Bouguer gravity contours. The axis of the proposed conductivity zone is shown, and the profile AB is that used in Figure 3b.
b) The two dimensional gravity model for profile AB. The dashed line indicates the best fitting model of a rectangular conducting channel having uniform current density.

Although these models are preliminary and conceptually simple their strong correlation indicate a major geological feature coincident with the proposed conducting zone. The basement rocks are largely granite gneisses of the Sleaford and Lincoln complexes and the denser bodies are presumably basic intrusives. They could possibly have been emplaced during the Kimban orogeny (1820-1580 Myr).

There is no direct correlation of the proposed conducting zone with mapped geology. Major parallel structures run up the eastern coastline of the peninsula. The visible deformations are due to the Kimban orogeny (Parker and Lemon, 1982) and lie within the metasiltstones and schists of the Hutchison group. It is possible that the conducting zone lies within a major crustal shear or fracture marking the western limit of the Kimban tectonism. Graphite occurs within the Hutchison but no significant current channelling is observed along its outcrop axis. It is more likely that the conducting mechanism is associated with strongly saline groundwaters within the proposed fracture or shear zone.

This research was supported by funds granted by the Australian Research Grants Scheme and the Flinders University Research Committee.

92

References

Bailey, R.C., Edwards, R.N., Garland, G.D., Kurtz, R. & Pitcher, D., 1974. Electrical conductivity studies over a tectonically active area in eastern Canada. J. Geomagn. Geoelect., 26, 125-146.

Lockwood, K., 1977. A geophysical assessment of the Outer Band Arc with emphasis on gravity measurements in Eastern Timor, unpublished M.Sc. Thesis, Flinders University, Bedford Park, S.A. 5042.

Parker, A.J. & Lemon, N.M. 1982. Reconstruction of the Early Proterozoic stratigraphy of the Gawler Craton, South Australia, J. geol. Soc. Aust., 29, 221-238.

White, A. and O.W. Polatajko , 1978. The coast in geomagnetic variations in South Australia. J. Geomagn. & Geoelectr. 30, 109-20.

White, A. and O.W. Polatajko , 1985. Electrical conductivity anomalies and their relationship with the tectonics of South Australia, Geophys. J.R. Astr. Soc. 80, 757-771.

White, A. and D.N. Hopgood , 1979. The island and coast effect in geomagnetic variations around St. Vincent Gulf, South Australia. J. Geomag. Geoelectr. 31, 479-84.

White, A. and P.R. Milligan , 1984. A crustal conductor on Eyre Peninsula, South Australia, Nature 310, 219-222.

Wilhjelm, J. and Friis-Christensen, E. 1974 . The Igdlorssuit geomagnetic variation anomaly in the rift-fault zone of northern West Greenland. J. Geomagn. and Geoelectr. 26, 173-189.

93

THE GEOMAGNETIC FIELD AND Sq

D.E. Winch

Department of Applied Mathematics,
University of Sydney, Sydney N.S.W., 2006

The process of conductivity modelling using results for internal and external components of daily magnetic variations and their seasonal changes gives consistently poor results from Sq at 1 cpd and from L at both 1 and 2 cpd. One possible way of proceeding is to assume that there are small terms of internal origin at these frequencies that are not part of the induction process, and to use conductivity models based on other daily variation terms to provide estimates of their amplitude and phase. Studies of local midnight values that extend the work of Malin (1977) on lunar magnetic variation midnight values should also help to determine the extent of magnetic variations of internal origin generated directly by the ocean dynamo. Work by Ashour and Price (1965) on night-time earth currents associated with the daily magnetic variations needs to be included in such studies.

Interpretation of the physics of the standard theory of induction as set down by Chapman and Whitehead (1923), and Lahiri and Price (1939) can also be improved, using, for example, the poloidal and toroidal vector field representation used so successfully by Bullard and Gellman (1954) in their studies of the main field. The induction equation can be written:

$$\nabla^2 B_o + \mu_o \sigma \alpha B_o = - \mu_o (\nabla\sigma) \times E_o + \alpha \nabla \times P_o$$

where the time dependence of magnetic, electric and electric polarization fields is specified by:

$$B = B_o e^{\alpha t}, \quad E = E_o e^{\alpha t}, \quad P = P_o e^{\alpha t}$$

The equation, together with the boundary conditions, can be considered in terms of poloidal and toroidal representations of the vector fields. When the conductivity σ depends upon the radius only, the inducing poloidal magnetic variation gives rise to a purely poloidal magnetic field in the conducting sphere; the inducing and induced fields are associated with toroidal current systems. However, when the conductivity σ is not uniform over a spherical surface, then the induction equation for B includes a toroidal component of $\nabla\sigma \times E_o$, which will be balanced by the toroidal form of $\alpha \nabla \times P_o$ associated with a poloidal polarization electric field.

The special functions $j_n(\sqrt{ikr})$ required to represent the radial dependence on the induced fields can be set down exactly in terms of trigonometric and exponential functions. Real and imaginary parts of the ratios j_n/j_{n-1} for $n=1,2,3,4,$ can also be set down exactly. These expressions will be compared with the power series and asymptotic series used by Chapman-Whitehead and Lahiri-Price.

Q4

Attention is drawn to the use of equator symmetric seasonal variation terms of magnetic variations in induction studies and also to the mathematical form of magnetic disturbance used by Chapman and Whitehead in the studies as a means of providing further electromagnetic response functions for the Earth, for the purpose of conductivity modelling.

References:

Ashour, A.A. and Price A.T., 1965 Night-time earth currents associated with the daily magnetic variations, *Geophys. J. R. Astr. Soc., 10,* 1-15

Bullard, E.C. and Gellman, H. 1954 Homogeneous dynamos and terrestrial magnetism. *Phil. Trans. Roy. Soc. Lond. A, 247* 213-278.

Chapman, S., and Whitehead, T.T. 1922 The influence of electrically conducting material within the earth on various phenomena of terrestrial magnetism. *Trans. Camb. Phil Soc.,22,* 463-482

Lahiri, B.N. and Price, A.T., 1939 Electromagnetic inudction in non-uniform conductors, and the determination of the conductivity of the Earth from terrestrial magnetic variations. *Phil. Trans. Roy. Soc. Lond. A., 237,* 509-540.

Malin, S.R.C. 1977 Ocean effects in geomagnetic tides. *Annls géophs.* 33, 109-114.

Electromagnetic Induction study of the Kapuskasing Structural Zone Using an Array of Magnetic Variometers

Dennis V. Woods,

Michel Allard,

Department of Geological Sciences,
Queen's University,
Kingston, Ontario, K7L 3N6

As part of the Lithoprobe Phase I project, a large-scale electromagnetic induction investigation has been carried out over the Kapuskasing Structural Zone (KSZ) using an array of 30 magnetic variometers. The instruments recorded three components of geomagnetic field fluctuation for an eight week period in July and August, 1984. Analysis of the data, which primarily involves comparisons of the simultaneously recorded fluctuations between stations, has lead to the following observations and tentative conclusions:

1) The magnetograms reveal a general uniformity of response across the area, suggesting that the conductivity contrast between the KSZ high grade metamorphic rocks of lower crustal origin and the surrounding greenstone-granite terrain is relatively low.

2) Indications of an anomalous response in the immediate vicinity of the Ivanhoe Lake Cataclastic Zone (ILCZ), primarily from comparisons of the Fourier transformed magnetic fluctuations at relatively high frequency, suggest that the ILCZ may be locally conductive.

3) A strong response observed along the most northerly line of stations, which is coincident with the Highway 11 transportation corridor, is most likely due to electromagnetic induction and the concentration of currents in the buried Trans-Canada gas pipeline.

Further analysis and interpretation of the recorded data over a wider frequency range, combined with induction arrow and numerical modelling techniques, will further clarify these conclusions.

96

Registered and associated participants.

Robert S. Anderssen,	Department of Mathematics & Statistics, C.S.I.R.O., G.P.O. Box 1965, Canberra, ACT 2601	062-81 5059
Vadim Anfiloff	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9228
Mike Barbetti,	NWG Macintosh Centre for Quaternary Dating, Madsen Building, University of Sydney, Sydney, NSW 2006	02-692 3993
Charles E. Barton,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9611
Nathan Bindoff,	Research School of Earth Sciences, Australian National University, Canberra, ACT 2600	062-49 4517
Eric Butcher,	Physics Dept., La Trobe University, Bundoora, VIC 3083	03-478 3122 x 2645
Francois H. Chamalaun,	School of Earth Sciences, Flinders University, Bedford Park, SA 5042	08-275 2319
David Clark,	CSIRO Division of Mineral Physics, P.O. Box 136, North Ryde, NSW 2113	02- 887 8666
Keith D. Cole,	Physics Department, La Trobe University, Bundoora, VIC 3083	03-479 2735
Peter Crosthwaite,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9779

97

Patrick Cunneen,	Aerodata Holdings Ltd. 1029 Wellington Street, West Perth, WA 6005	09-322 1799
James C. Dooley,	c/o Bureau of Mineral Resources, and 66 Hawker Street, Torrens, ACT	062-86 2145
Brian J.J. Embleton,	CSIRO Division of Mineral Physics, P.O. Box 136, North Ryde, NSW 2113	02- 887 8666
Ian J. Ferguson,	Research School of Earth Sciences, Australian National University, Canberra, ACT 2600	062-49 3424
Brian J. Fraser,	Physics Department, University of Newcastle, Newcastle, NSW 2308	049-68 0401
D. Ian Gough,	Institute of Earth and Planetary Physics, University of Alberta, Edmonton, CANADA T6G 2J1	
Peter Gregson,	Mundaring Geophysical Observatory (BMR), Hodgson Street, Mundaring, WA 6073	09-95 1555
R. Hermanto,	Geology Department, University of Tasmania, P.O. Box 252-C, Hobart, TAS 7001	
Frank H. Hibberd,	Physics Department, University of New England, Armidale, NSW 2351	067-73 2389
Peter J. Hill,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9253
Adrian Hitchman,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9321

98

Rodney Home, Dept. of History & Philosophy of Science,
Melbourne University,
Parkville, VIC 3052 03-341 6556

Ian Hone, Bureau of Mineral Resources,
P.O. Box 378,
Canberra, ACT 2601 062-49 9306

Peter Hopgood, Bureau of Mineral Resources,
P.O. Box 378,
Canberra, ACT 2601 062-49 9306

Malcolm Ingham, Physics Department,
Victoria University of Wellington,
Private Bag,
Wellington, N.Z. 64-4-72 1000 x 2824

B. David Johnson, School of Earth Sciences,
Macquarie University,
North Ryde, NSW 2113 02-88 9106 / 9220

John A. Kennewell, Learmonth Solar Observatory,
P.O.Box 200,
Exmouth, WA 6707 099-49 1472

Chris T. Klootwijk, Bureau of Mineral Resources,
P.O. Box 378,
Canberra, ACT 2601 062-49 9324

F. E. M. (Ted) Lilley, Research School of Earth Sciences,
Australian National University,
Canberra, ACT 2600 062-49 4174

Michael W. McElhinny, Bureau of Mineral Resources,
P.O. Box 378,
Canberra, ACT 2601 062-49 9267

Andrew McEwin, Bureau of Mineral Resources,
P.O. Box 378,
Canberra, ACT 2601 062-49 9320

Phil McFadden, Bureau of Mineral Resources,
P.O. Box 378,
Canberra, ACT 2601 062-49 9653

99

Peter McGregor,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9392
Noel Mattocks,	Tesla-10 Pty. Ltd., 41 Kishorn Road, Applecross, WA 6153	09-364 8444
Frederick Menk,	Physics Department, University of Newcastle, Newcastle, NSW 2308	049-68 5334
Peter R. Milligan	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9111
Larry R. Newitt,	Div. Seismology & Geomagnetism, Earth Physics Branch, E.M.R., 1 Observatory Crescent, Ottawa, CANADA K1A 0Y3	1-613-995 5545
Alfio Parisi,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9253
W. Dudley Parkinson,	c/o Geology Department, University of Tasmania, Box 252-C, Hobart, TAS 7001	002-202481/284068
Norman W. Peddie,	Branch of Global Seismology & Geomagnetism, U.S. Geological Survey, Box 25046 M.S. 964, Denver, CO 80225	1-303-234 5497
Haralds F. Petersons,	Mathematics Department, Australian National University, Canberrra, ACT 2600	062-`49 2907
Wendy Prohasky,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9358

102

Hans A. Roeser,	B.G.R., Stillweg 2, D-3000 Hannover 51, WEST GERMANY	49-511-643 2799
Joseph Salib,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9322
Grahame Sands,	Aerodata Holdings Ltd., 1029 Wellington Street, West Perth, WA 6005	09-322 1799
Phil Schmidt,	CSIRO Division of Mineral Physics, P.O. Box 136, North Ryde, NSW 2113	02- 887 8873
Kevin Seers,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9500
Merren Sloane,	Research School of Earth Sciences, Australian National University, Canberra, ACT 2600	062-49 3424
Robert J. Stening,	School of Physics, University of NSW, P.O. Box 1, Kensington, NSW 2033	02-697 4584
Richard Thompson,	Ionospheric Prediction Service, P.O.Box 702, Darlinghurst, NSW 2010	02-269 8613
Lester A. Tomlinson,	D.S.I.R. Geophysical Observatory, P.O. Box 2111, Christchurch, NEW ZEALAND	64-3-79 1540
David H. Tucker,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9216
Peter Wellman,	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9340

101

Anthony White,	School of Earth Sciences, Flinders University, Bedford Park, SA 5042	08-275 2213
Roy Whitworth	Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT 2601	062-49 9252
Dennis E. Winch,	Applied Mathematics Dept., University of Sydney, NSW 2006	02-692 3235
Dennis V. Woods,	Dept. Geological Sciences, Queen's University, Kingston, Ontario, CANADA K7L 3N6	1-613-547 2840
Christian W. S. Ziesolleck,	Physics Department, University of Newcastle, Newcastle, NSW 2308	049-68 0401

102