J. Geophys. 42, 373–390, 1977

Journal of Geophysics

A Detailed Investigation of the Canadian Cordillera Geomagnetic Transition Anomaly

H. Dragert[1]* and G.K.C. Clarke[2]

[1] Earth Physics Branch, Gravity and Geodynamics, 1 Observatory Cres., Ottawa, K1A 0Y3 Canada
[2] Department of Geophysics and Astronomy, University of British Columbia, Vancouver, B.C. V6T 1W5, Canada

Abstract. Employing recently developed broad-band instrumentation, a geomagnetic depth-sounding study has been carried out investigating the detailed structure of the lateral conductivity discontinuity in the Cordillera geomagnetic transition zone along a profile between Clearwater, B.C., and Suffield, Alta. Analysis of data has revealed the presence of 3 conductive structures: 1) a near-surface conductor, which can be associated with the sediments of the Rocky Mountain Trench; 2) a parallel-striking lower-crust/upper mantle conductivity heterogeneity 40–50 km beneath the trench area, which can be associated with possible hydration or partial melting; 3) a second deep conductivity structure orthogonal to the previous structures, which is possibly associated with a buried Precambrian rift. The measured anomalous effect of the latter 2 conductors indicates that the induced current flow is not caused by local induction, but by local deflection of current patterns induced over a larger region.

Key words: Geomagnetic induction anomaly – Broad-band geomagnetic depth-sounding – Transfer function analysis – Canadian Cordillera crustal structure

Introduction

Over the past 10 years, various geomagnetic depth-sounding (GDS) and magnetotelluric (MT) studies (Hyndman, 1963; Caner and Cannon, 1965; Caner, et al., 1967; Caner, et al., 1971) have investigated the conductivity structure of the lower crust and upper mantle in western Canada. This work has established that a dominant geomagnetic feature for the Canadian Cordillera is the presence of a "low-I" zone ($I = |\Delta Z| / \{\Delta H^2 + \Delta D^2\}^{1/2}$), a region in which vertical field variations having periods less than 30 min are greatly attenuated compared to variations observed further east (see Fig. 1). The transition zone,

* Previously Dept. of Geophysics and Astronomy, U.B.C., Vancouver

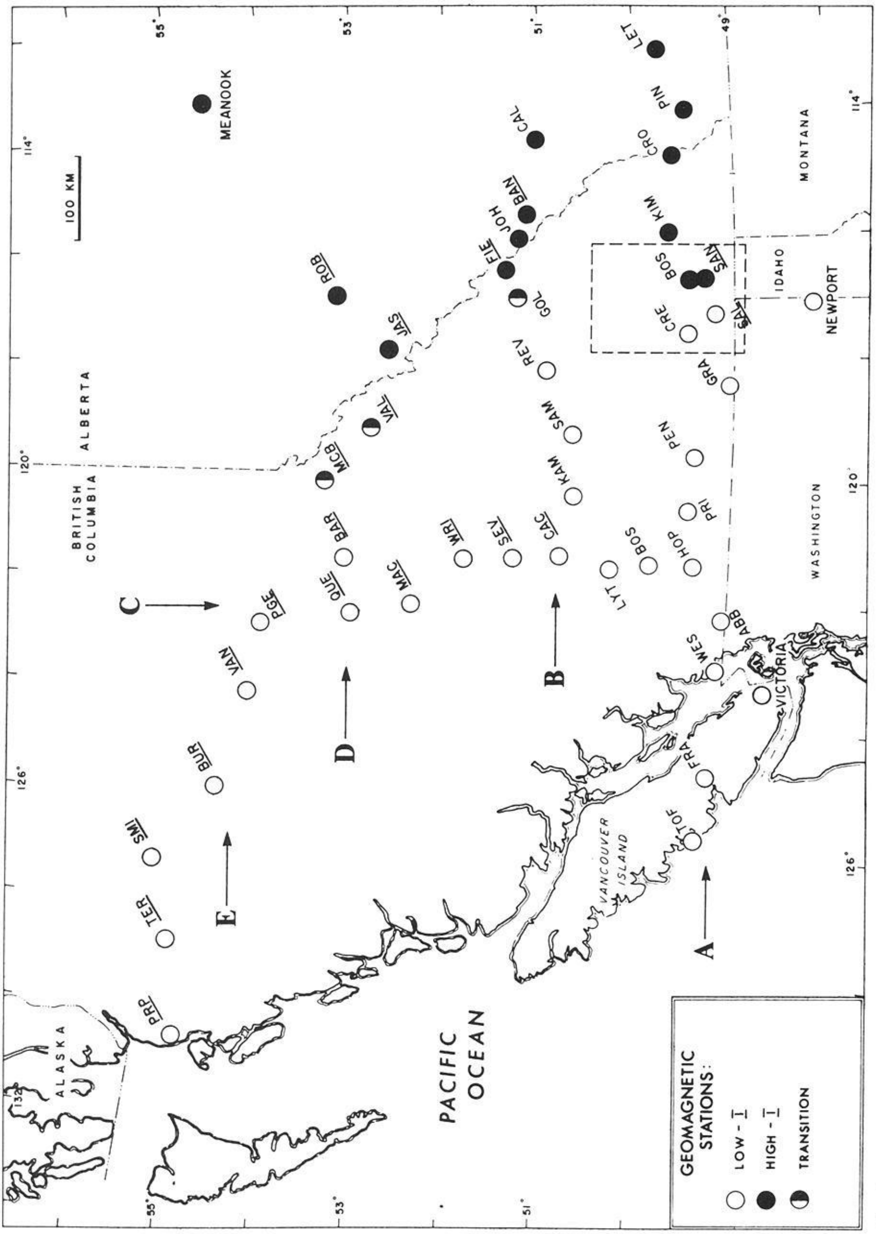
100 KM
ALBERTA
BRITISH COLUMBIA
MONTANA
IDAHO
WASHINGTON
ALASKA
PACIFIC OCEAN
VANCOUVER ISLAND
MEANOOK
ROB
JAS
VAL
MCB
FIE
JOH
BAN
CAL
LET
PIN
CRO
KIM
BOS
SAN
CRE
GOL
REV
SAM
KAM
PEN
GRA
SAL
NEWPORT
PRI
HOP
BOS
LYT
CAC
SEV
WRI
MAC
BAR
QUE
PGE
VAN
BUR
SMI
TER
PRP
WES
ABB
VICTORIA
FRA
TOF
A
B
C
D
E
55°
53°
51°
49°
114°
120°
126°
132°
GEOMAGNETIC STATIONS:
LOW - I
HIGH - I
TRANSITION

Fig. 1

where I not only increases sharply but also shows strong azimuthal dependence, has been found to follow roughly a line along the western front of the Rocky Mountains from 49° N to at least 54° N latitude (Caner, et al., 1971). Hence, this geomagnetic transition zone constitutes a large scale variational anomaly, marking a relatively abrupt lateral conductivity change in the lower crust or the upper mantle.

The primary purpose of this study was to investigate in greater detail the nature of the lateral conductivity changes encountered in this transition region.

Data Collection and Reduction

The instruments used in the field were of 2 types: 1) the Askania geomagnetic variograph Gv3; and 2) an electronic broad-band system recently developed by Caner and Dragert (1972). The instrumental characteristics pertinent to data analysis can be summarized as follows. The Askania film registrations allowed a time resolution of 30s and an amplitude resolution between 1 and 2γ within a dynamic range of about 55 db. The electronic system, using two overlapping frequency bands, produced magnetic tape records with a time resolution capability of 0.1 s, an amplitude resolution of 0.1γ, and a total dynamic range of 78 db (Dragert, 1974).

A geomagnetic depth-sounding profile of seven stations was operated for a period of two months during the fall of 1971. The location of the profile is shown in Figure 2 and the station identification detail is summarized in Table 1. Two obvious shortcomings of the chosen site locations could be mentioned at this point: 1) the average station spacing for the 4 broad-band sites ($\sim$60 km) is too large for accurate spatial resolution of possible short-period anomalies; and 2) the nature of the anomaly in this area is suspected to be three-dimensional (Caner, et al., 1971); thus, the quantitative interpretation of the data in terms of a best-fitting, two-dimensional, numerical model may be misleading. However, practical considerations such as the suitable protection of instruments, the accessibility of sites, the limited number of broad-band systems, the minimization of geomagnetic latitude effects, and the complete bracketing of the transition-zone anomaly, favoured the chosen profile location.

After preliminary editing of all data, simultaneous record sections with suitable continuous magnetic activity were chosen for analysis. For Band A, a digitizing interval of 1.00 min and record sections of 36 h were used, giving an effective period range of 5 to 180 min. Seven record sections or "magnetic events" recorded at all 7 stations were used for Band A analysis. Band B data were digitized using an interval of 2.50s and record sections of 100 min, resulting in an effective period range of 10–500s. Eleven events were used for Band B analysis, and these were naturally limited to the 4 broad-band systems.

Fig. 1. Location of GDS stations in western Canada up to 1970. Profile A are stations of Hyndman (1963) and Lambert and Caner (1965); Profile B and C are stations described by Caner et al. (1967); Profiles D and E are stations of Dragert (1970). The dashed rectangle identifies the area containing the 20-station network of Lajoie and Caner (1970). (After Caner et al., 1971)

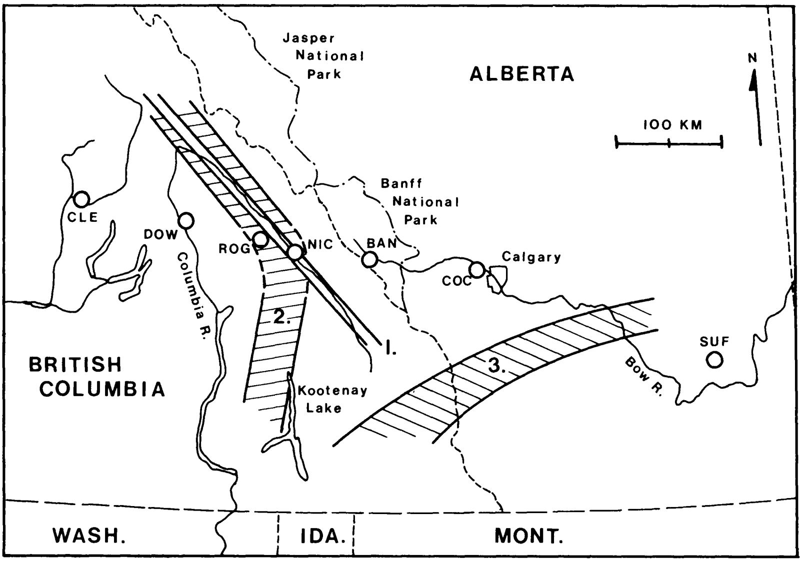

Fig. 2. Station locations for the field investigation of the geomagnetic transition-zone anomaly. The three indicated conductive structures deduced from this study are discussed in the conclusions

Table 1. Summary of station identification and location for the geomagnetic transition anomaly profile

Station	Geographic Long. (°W)	Location Lat. (°N)	Geomagnetic Lat. (°N)	Type of Instrument	Time of Operation
CLE (Clearwater)	120.0	51.6	57.9	Askania	Aug. 23–Nov. 16
DOW (Downie Creek)	118.2	51.3	58.0	Broad-band	Sept. 17–Nov. 11
ROG (Rogers Pass)	117.6	51.2	58.1	Broad-band	Sept. 17–Nov. 12
NIC (Nicholson)	117.0	51.3	58.3	Broad-band	Sept. 18–Nov. 12
BAN (Banff)	115.6	51.2	58.6	Broad-band	Sept. 19–Nov. 13
COC (Cochrane)	114.2	51.1	58.8	Askania	Sept. 20–Nov. 15
SUF (Suffield)	111.1	50.2	58.6	Askania	Sept. 20–Nov. 14

The type of magnetic activity and the quality of the data chosen for analysis of Bands A and B are illustrated in Figures 3 and 4 respectively, which display computer-drawn traces of digitized registrations. A closer examination of these figures reveals good spatial coherence of magnetic variations in both bands as well as anomalous behaviour of especially the Z component at stations such as BAN and COC.

Analysis Techniques

To handle the large quantities of data efficiently, the periodogram spectral approach (c.f. Jones, 1965) employing the Fast Fourier Transform (Cooley and Tukey, 1965) was used for spectral analysis. A variable-width Parzen window

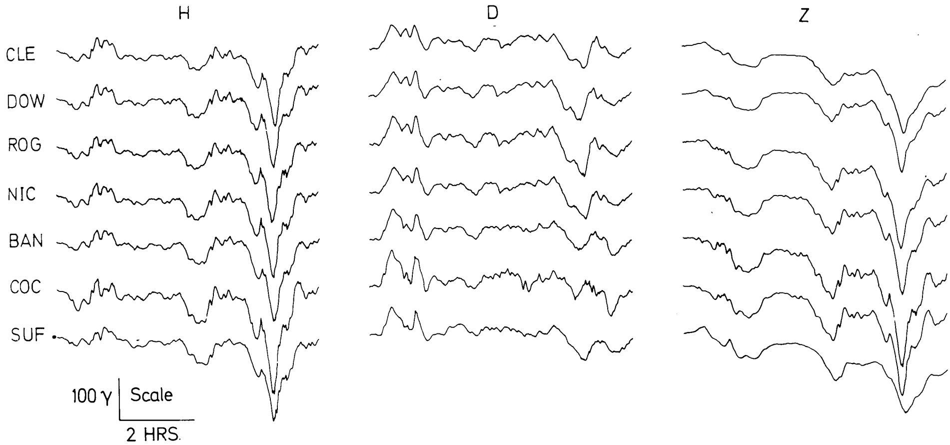

Fig. 3. Sample of digitized Band A data recorded simultaneously at all profile stations

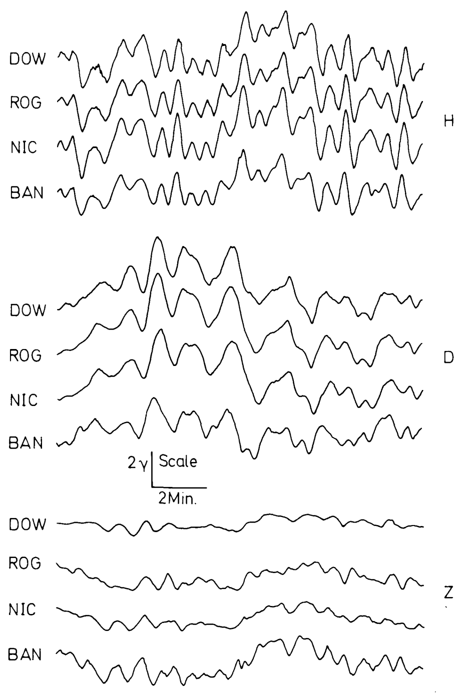

Fig. 4. Sample of digitized Band B data recorded simultaneously at the four broad-band stations

was used to convolve the raw power periodograms, yielding, as a function of frequency, smoothed spectral estimates of decreasing variance at a limited number of frequency bands having decreasing resolution. Figure 5 illustrates a normalized raw power spectral estimate and its smoothed form obtained by convolution with the Parzen window of varying width. Shown also are the extent of overlap between adjacent windows, and the change of window shape from low to higher frequencies. Such smoothed spectral estimates were

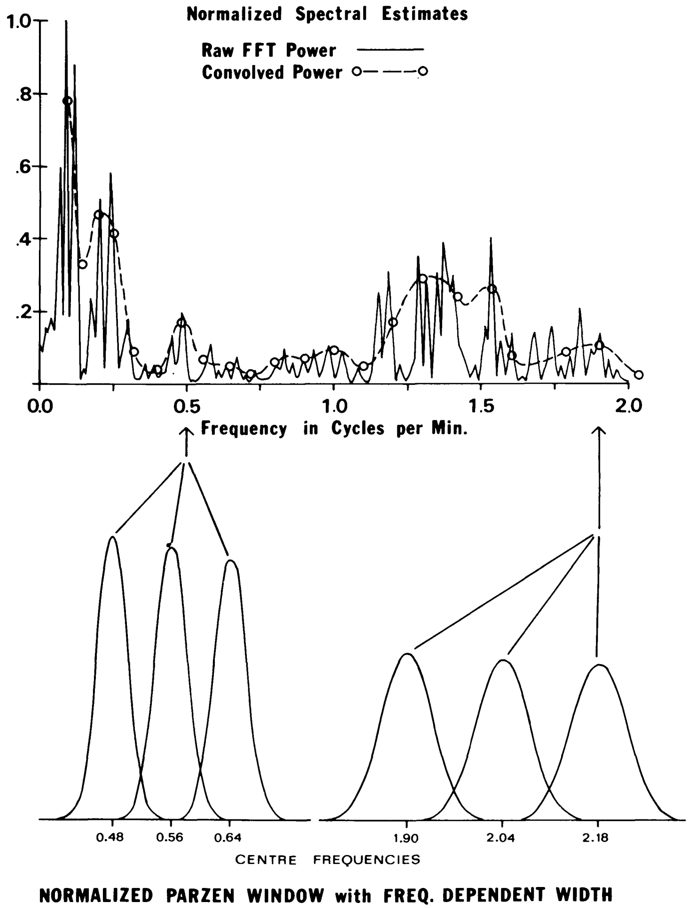

Fig. 5. An example of a periodogram spectral estimate calculated from the raw Fast Fourier Transform power, and its smoothed version obtained by convolution with a Parzen window of varying width

evaluated for each component and each storm event at all stations. To increase the stability of the spectral estimates even more, and to minimize possible time dependencies of these estimates, the component power and cross-power estimates were averaged over all analyzed events within each band at each station.

To determine the magnitude and phase of the anomalous field contributions at each station, 2 types of transfer functions were evaluated from the smoothed power and cross-power spectral estimates:

A. The Paired-Station Transfer Function Matrix, T

Under the assumption of a uniform source with infinite spatial wavelengths, the observed field variations, comprised of normal and anomalous field variations, can be statistically fitted to the frequency-domain relation (Schmucker, 1970)

$$\begin{pmatrix} H_A \\ D_A \\ Z_A \end{pmatrix} = \begin{pmatrix} h_H & h_D & h_Z \\ d_H & d_D & d_Z \\ z_H & z_D & z_Z \end{pmatrix} \begin{pmatrix} H_N \\ D_N \\ Z_N \end{pmatrix} + \begin{pmatrix} \delta_H \\ \delta_D \\ \delta_Z \end{pmatrix} \quad \text{i.e.} \quad \bar{F}_A = T \cdot \bar{F}_N + \bar{\Delta} \tag{1}$$

where

T = the transfer frunction matrix of 9 complex elements.

$\bar{F}_A$ = $(H_A,\ D_A,\ Z_A)$, the Fourier transform of the anomalous field; i.e., the field associated with lateral conductivity inhomogeneities.

$\bar{F}_N$ = $(H_N,\ D_N,\ Z_N)$, the fourier transform of the estimated normal field; i.e., the total field observed over a region of laterally homogeneous conductive structure.

$\bar{\Delta}$ = $(\delta_H,\ \delta_D,\ \delta_Z)$, the Fourier transform of a residual field containing uncorrelated parts of the anomalous components.

For this analysis, the field observed at a station well removed from the anomaly was taken to be representative of the normal field; hence the name "paired-station" transfer function matrix.

B. The Single -Station Vertical Transfer Function, T_Z

In the formulation of this simpler transfer function, only the vertical anomalous field is considered and 2 simplifying assumptions are made: 1) the anomalous field is produced by perturbations of only the *horizontal* normal field; and 2) there are no long term $H_N Z_N$ or $D_N Z_N$ correlations. Under these assumptions, the data observed at a single station are fitted to the relation (Cochrane and Hyndman, 1970).

$$Z_0 = z'_H H_0 + z'_D D_0 + \delta'_Z \tag{2}$$

where

T_Z = $(z'_H,\ z'_D)$, the vertical transfer function of two complex elements.

$(H_0,\ D_0,\ D_0)$ = the Fourier transform of the *observed* field.

δ'_Z = the Fourier transform of the vertical residual field.

It should be emphasized that Equation (2) uses the three field components observed at the same site; hence the name "single-station" vertical transfer function.

Both types of transfer functions express coherences or partial coherences between given field components. The formulation of T is more general, revealing anomalous perturbations of any normal field component as well as allowing for normal field component coherences; however, the complexity of its possible contributing factors (non-uniform source, change in normal field, and multiple anomalies) make a quantitative interpretation difficult. T_Z, on the other hand, is more easily computed and can be interpreted quantitatively by means of numerical modelling techniques; however, for the quantitative results to be meaningful, the simplifying assumptions for T_Z must be satisfied (Dragert, 1973a).

In the transfer function analysis of the data, a measure of confidence was established empirically by evaluating T_Z's and T's for each individual event and computing their standard deviations from the mean values.

Results of Analysis

A. Spectral Estimates

The smoothed spectral estimates for Bands A and B indicate that the "I-transition zone" is located in the vicinity of the Rocky Mountain Trench, as previously found by Caner et al. (1971). It must be added, however, that the power in Z at periods between 10 and 30 min is unexpectedly attenuated at the eastermost station SUF, which lies in an area previously thought to be a high-I region.

B. Single-Station Vertical Transfer Functions

Figure 6 illustrates the frequency dependence of the mean in-phase and quadrature components of T_Z for the short-period band at each station. The general tendency for increased deviations for periods less than 40 s is indicative of possible source non-uniformities. The features important to subsequent interpretation are:

(1) For sites recording the short-period band, DOW shows the least anomalous perturbations and hence is a logical reference site for normal field estimation.

(2) A reversal in anomalous Z occurs between ROG and BAN, with a corresponding reduction in anomalous Z at NIC.

(3) Generally, with increasing period, the quadrature components become more significant and a rotation towards the south is apparent for in-phase components.

Figure 7a and 7b illustrate the mean amplitudes and directions of the in-phase and quadrature components of T_Z for Band A, along with their computed standard deviations. The curves appear well-defined, and the increased deviations for periods greater than 45 min possibly reflect the greater variance (10–30%) of the spectral estimates at these frequencies. The real parts of the T_Z's appear to peak between 20 and 30 min periods at all anomalous sites except BAN where the maximum value occurs between 15 and 20 min periods. The following features are worth noting:

(1) Minimum anomalous vertical field contributions are observed at CLE and SUF, indicating either as possible candidates for a reference site. It should also be pointed out that the similarity of T_Z at CLE and SUF is quite striking

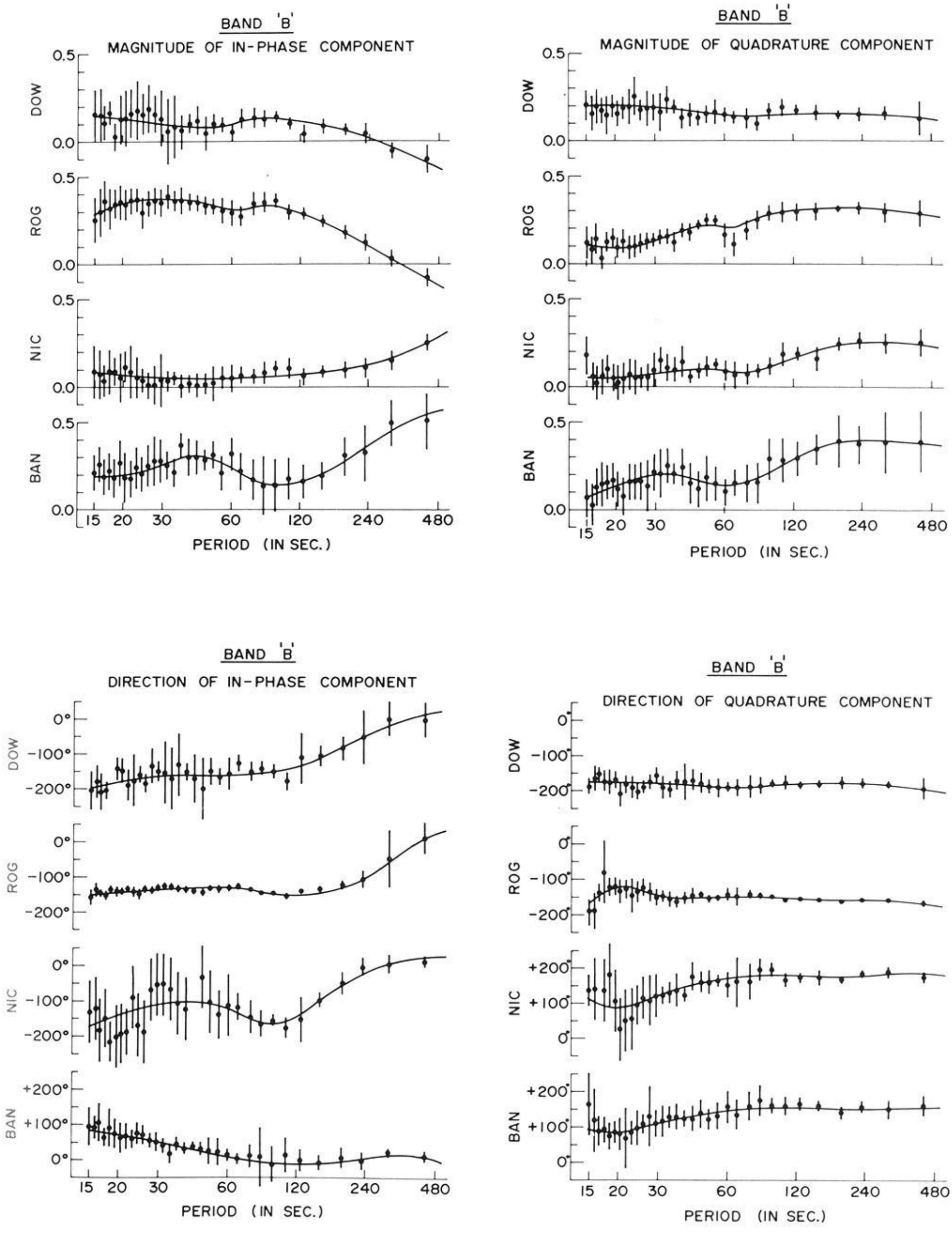

Fig. 6. Single-station transfer function amplitudes and directions for Band B. Directions are measured positive east of true north

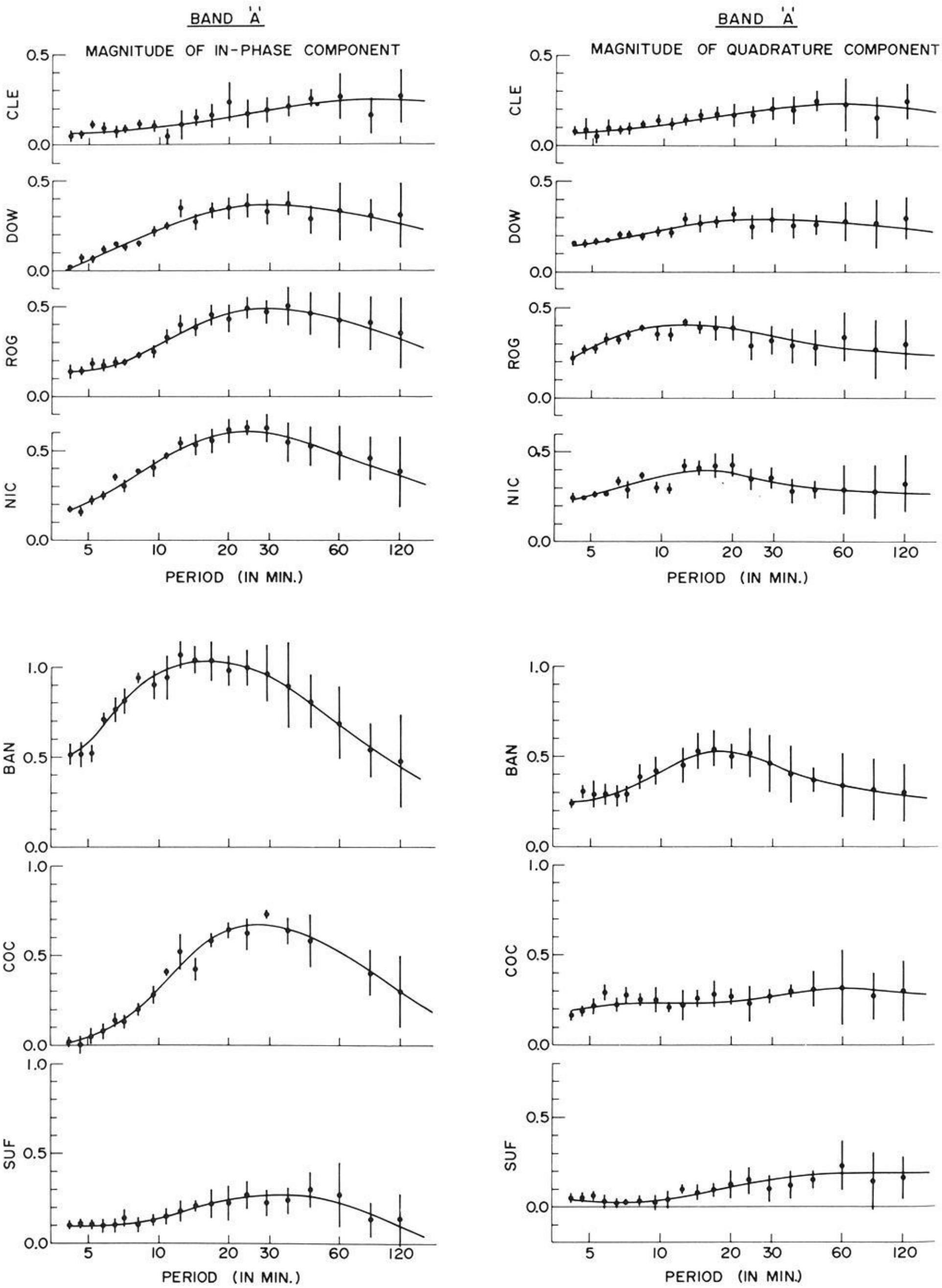

Fig. 7. a Single-station transfer function amplitudes for Band A

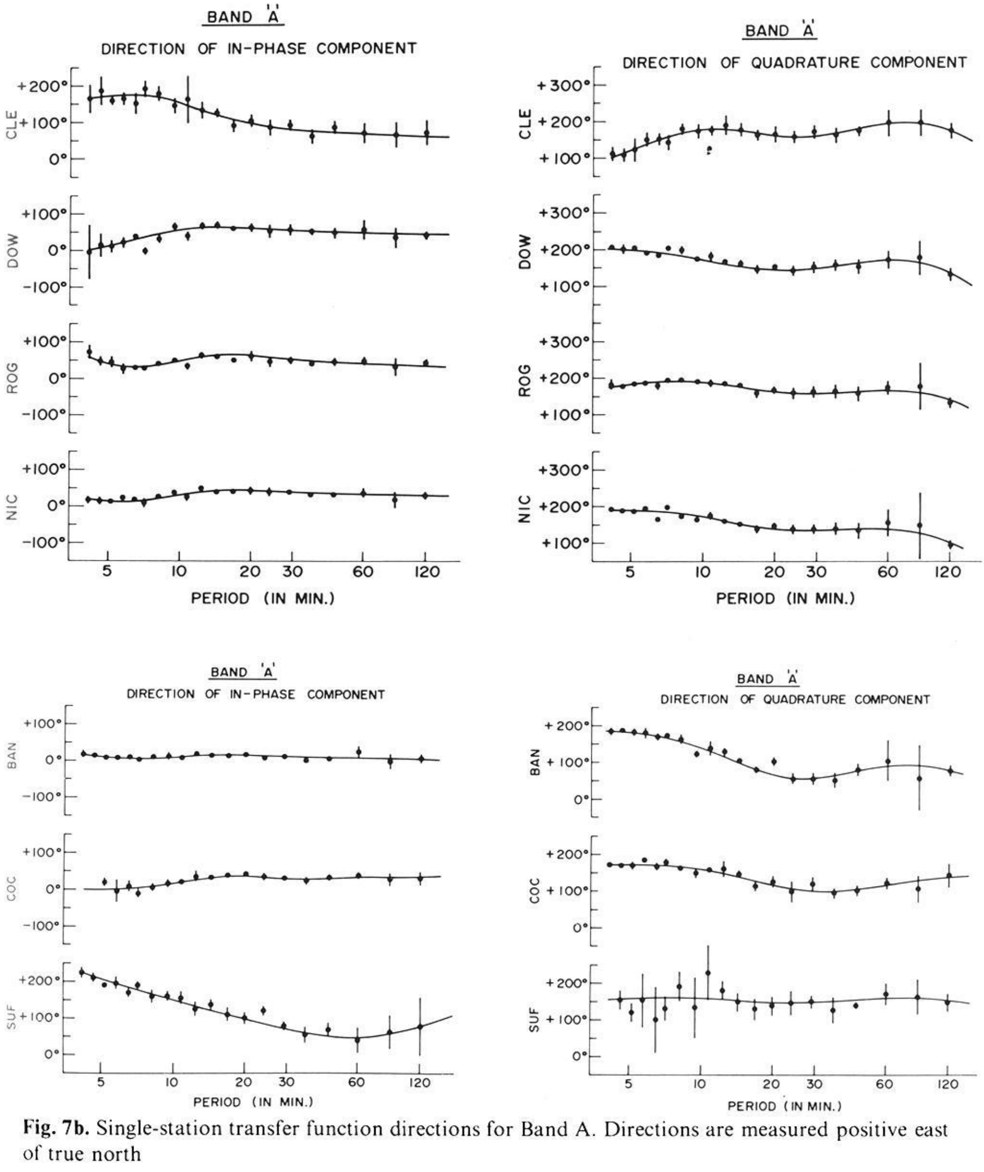

Fig. 7b. Single-station transfer function directions for Band A. Directions are measured positive east of true north

for two sites more than 600 km apart and supposedly located in quite distinct conductivity regions.

(2) No anomalous Z reversal is apparent across the transition zone for Band A.

(3) The in-phase and quadrature components are comparable in magnitude, and their directions tend to diverge with increasing period, indicating the presence of a three-dimensional conductivity structure.

(4) The directions of the in-phase components are dominantly southwest to south for all periods of this band.

C. Numerical Modelling for T_Z

Since the validity of the restrictive assumption for T_Z can be considered questionable, and a three-dimensional structure appears to be present, it follows that the observed anomaly cannot be interpreted in terms of an unambiguous, independent, two-dimensional conductivity model. Two-dimensional modelling techniques (Swift, 1971) were nonetheless applied using two previously proposed regional conductivity models (Caner, 1971; Camfield and Gough, 1975) in order to assess the validity of the principal features of each model for the area investigated. It was found that both models could account for barely one-half of the magnitude of T_Z, and both failed to account for the quadrature terms of T_Z. On the more positive side, a comparison of model transfer function curves with observed data indicated the following:

(1) A near-surface conductor with a depth extent of about 2 km must be present to account for the short-period T_Z response. Such a conductor has not been included in previous models.

(2) The frequency responses of the in-phase components of the T_Z's suggest a conductivity model intermediate to the Caner and Camfield-Gough models; that is, the 20 km thick conductive layer underlying the western Cordillera region is more likely to be at a depth of 40–50 km in the Trench area.

(3) The double-anomaly structure as observed by Camfield and Gough for the Idaho Panhandle is not resolved by the long-period data of this profile.

D. Paired-Station Transfer Function Matrices

No meaningful transfer matrices could be evaluated for Band B data. The scatter associated with the elements of T was often 70% of the estimated mean values or higher, and both vertical and horizontal transfer terms were erratic and ill-defined functions of frequency. Spatial non-uniformity of the source fields within this frequency band, and the instabilities encountered in complex-matrix inversion were perhaps major sources of this scatter.

However, for Band A, stable mean transfer matrices could be derived using the westernmost station CLE as arbitrary reference, although a scatter ranging between 20% and 60% of the average values was still present. Such a high error level in itselfs precluded a meaningful quantitative interpretation of the individual matrix elements. Furthermore, since the transfer matrices at all sites are evaluated with respect to an arbitrary reference field, it follows that the T's at each site will be affected by anomalous conditions at the reference site, by changes in the regional normal field, and naturally, by source nonuniformities. Data from a single profile of stations do not allow a separation of these effects, adding more uncertainty to a quantitative interpretation.

Nonetheless, the following qualitative observations were deemed significant:

(1) For periods greater than 15 min, the diagonal elements of T, shown in Figure 8, generally reflect a behaviour expected for the case of a reference site located over a horizontally-layered medium with higher conductivities at shallower depths (Dragert, 1973a); that is, these elements agree with the regional

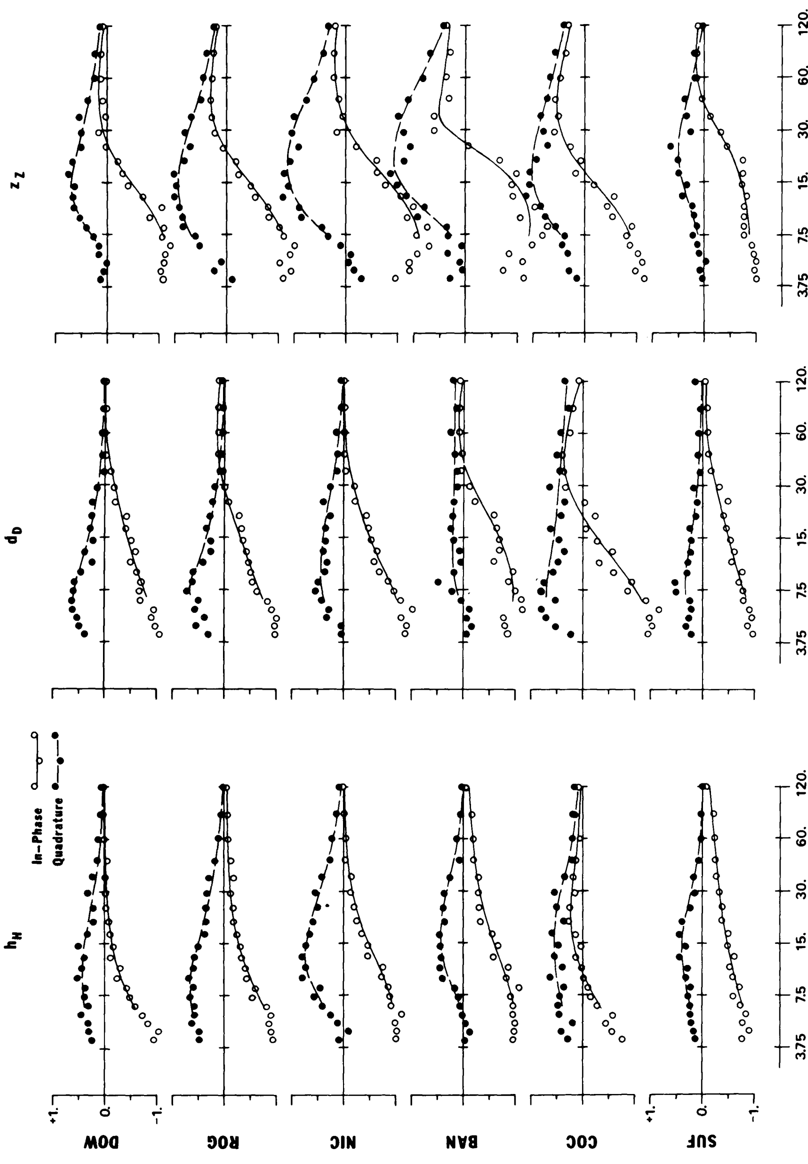

Fig. 8. Diagonal elements of the paired-station transfer matrix as functions of period (Band A) at each site

conductivity models proposed for this area. Only at BAN and COC does it appear necessary to invoke anomalous contributions to account for the changed pattern of the curves. It should be noted that due to the formulation, a lack of coherence between the analysis site and the reference site (CLE) will result in diagonal elements with in-phase and out-of-phase values of -1.0 and 0.0 respectively. This is illustrated by the trends at periods less than 7.5 min. The consistently large values of the quadrature parts of h_H, d_D, and z_Z in the period range of about 7–15 min as shown in Figure 8, possibly reflect changes in the phases of the normal field components.

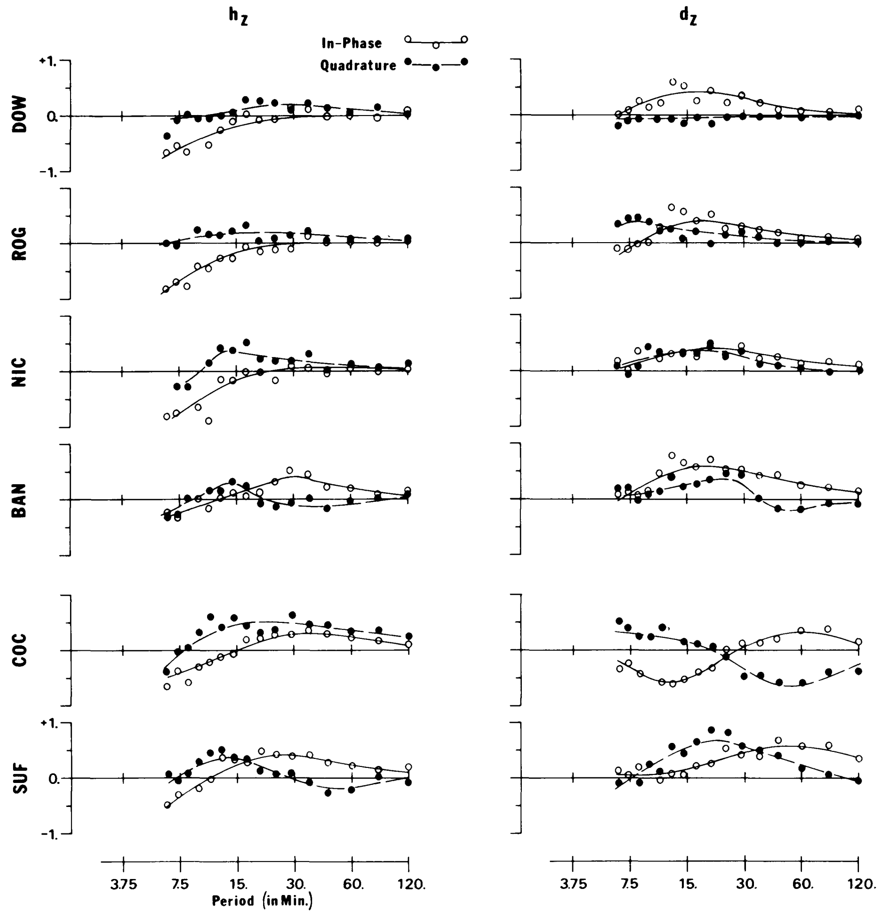

Fig. 9. Elements h_Z and d_Z of the paired-station transfer matrix as functions of period (Band A) at each site

(2) The transfer function elements h_Z and d_Z, shown in Figure 9, are characterized by ill-defined trends and an error scatter of over 50% from the mean values, reflecting the difficulty in obtained horizontal transfer function terms at anomalous sites referred to a "normal" site with little power in Z. It must be remembered that these elements exhibit the correlation of the horizontal field at a given site to the observed vertical field at the reference site. For the case of a uniform source field over a horizontally-layered medium, Z_N must be zero (Price, 1950); consequently, the reference field in this case is associated with a separate anomaly, source non-uniformity, or a channeled current system. The more clearly observable trends at COC and SUF are definite enough to call into question the simplifying assumptions for T_Z; that is, normal component coherences brought about through current channeling or systematic source configurations are probably biasing the single-station vertical transfer function.

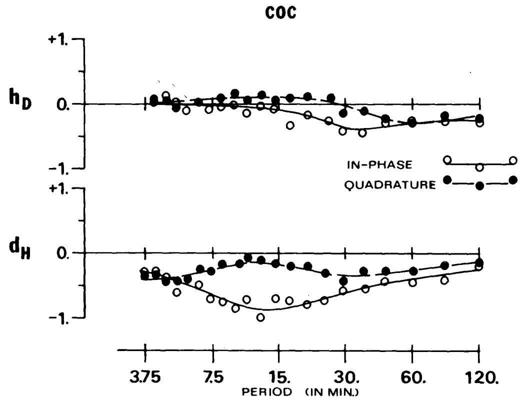

Fig. 10. Elements h_D and d_H of the paired-station transfer matrix as functions of period (Band A) at COC

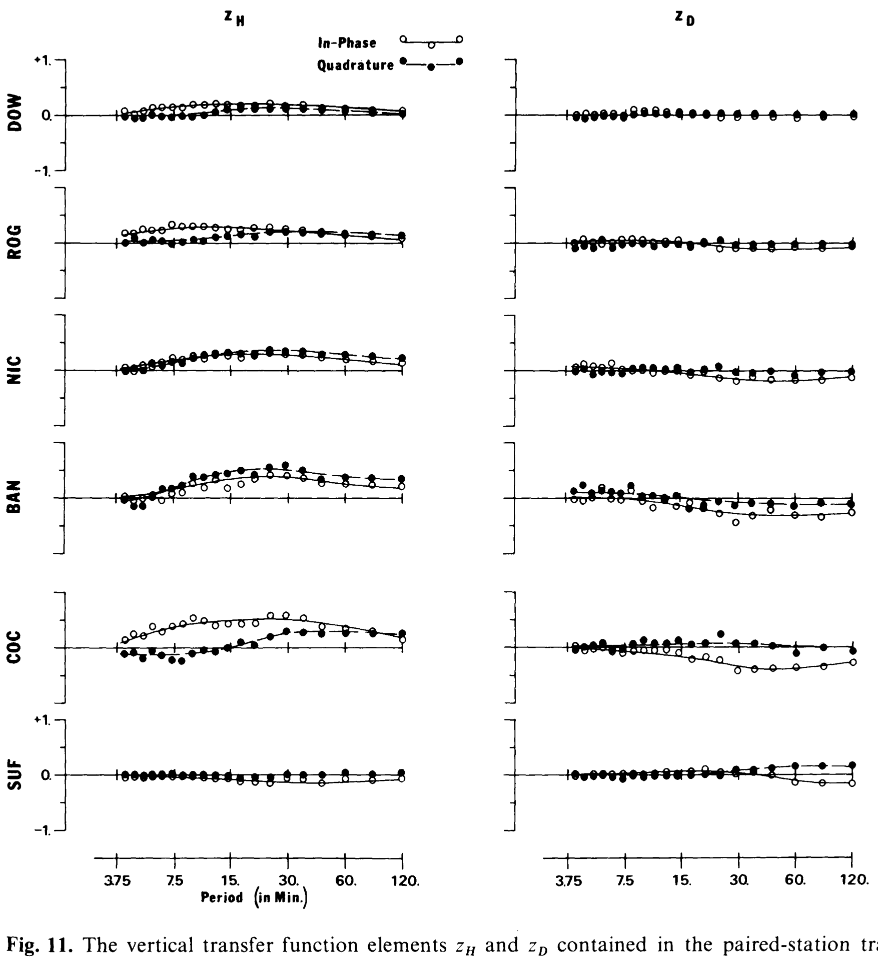

Fig. 11. The vertical transfer function elements z_H and z_D contained in the paired-station transfer matrix as functions of period (Band A) at each site

(3) Furthermore, at COC there are significant contributions to the observed horizontal field arising from the cross-terms h_D and expecially d_H (see Fig. 10). These terms are well-defined functions of frequency, having an average scatter of 20 to 30% about the mean. This unique anomalous condition at COC indicates the presence of a three-dimensional conductivity structure, one which appears to deflect H-induced currents almost 90 degrees.

(4) The vertical transfer function elements, z_H and z_D (see Fig. 11), contained in the matrix T show a behaviour in agreement with the single-station transfer function elements z'_H and z'_D (refer to Fig. 7). That is, maximum anomalous contributions are apparent at BAN and COC at periods of about 20 min. However, the anomalous peaks exhibited by z'_H and z'_D appear significantly larger and broader. Again, this could be indicative of systematic normal-field component coherences, which are regarded as anomalous contributions by the single-station vertical transfer function.

Interpretation and Conclusions

A probable but by no means unique interpretation of the observed data can be summarized as follows. (For a point by point interpretation of the individual spectral features, transfer function characteristics, and modelling results, see Dragert, 1973b.) In general terms, the geomagnetic I-transition zone between Revelstoke and Calgary marks the site of a three-dimensional conductivity structure which appears to be channeling or deflecting internal currents induced on a larger regional scale. In particular, three separate features are resolved (see Fig. 2):

1) The trench itself, most likely due to conductive sediments, acts as a near surface, two-dimensional conductor causing a spatial reversal of anomalous Z variations. The depth extent is of the order of 1–2 km and the conductivity roughly 0.1 ohm-m^{-1}. These values are not well defined due to the lack of spatial resolution of the limited number of broad-band stations.

2) *Within the limits of applicability of a two-dimensional model,* the conductive layer suggested by Caner and by Camfield and Gough to underlie the western Cordillera is probably at *or dips to* a depth of the order of 40–50 km beneath the trench . A thickness of about 15–20 km and a conductivity of 0.2 ohm-m^{-1}, adopted from the reference models, appear to agree with the observed data. Hydration or partial melting (Caner, 1970) along a thrust zone parallel to the crust/mantle interface appears as a likely cause of the enhanced conductivity of this layer which terminates beneath the transition zone. The Rocky Mountain Trench may therefore mark the eastern limit of the under-thrust.

3) A third conductive structure can be identified with a possible buried Precambrian rift in south-west Alberta (Kanasewich, 1968), which strikes almost perpendicular to the I-transition zone. The observed anomalous field directions in this study and from Cochrane and Hyndman's (1970) study indicate that this anomaly connects with the Kootenay anomaly along a line following this rift from Alberta into B.C. This implies that the Kootenay anomaly is not strike-slip caused as suggested by Lajoie and Caner (1970), but more likely

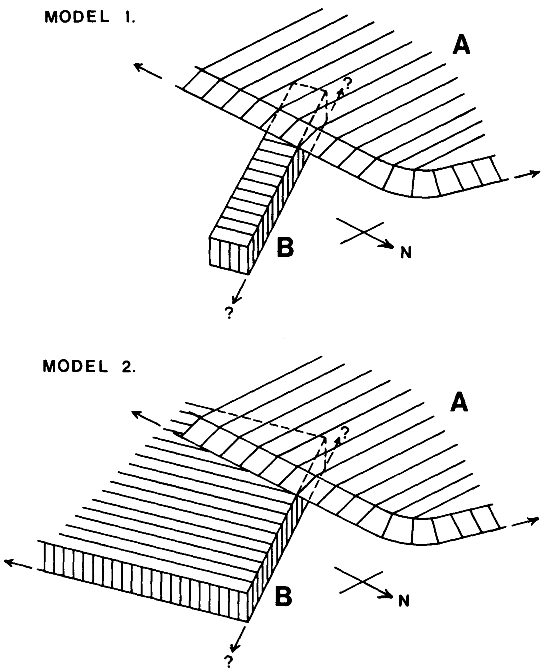

Fig. 12. Schematic diagrams of 2 simple three-dimensional conductivity structures which could account for the observed long-period transfer functions. Conductors A and B would correspond to conductive structures 2 and 3 respectively in Figure 2

associated with enhanced conductivities of evaporites suggested by Kanasewich to have been generated within the rift by syngenetic or hydrothermal deposition. Furthermore, it is possible that this rift marks the northern extent of a moderately conductive layer suggested by Camfield and Gough to underlie the Front Ranges and the Great Plains in the northwestern United States. The exact interrelation of the two deeper conductivity structures is not resolved, but a conductive connection appears likely.

From this summary it can be seen that the type of model required to represent the I-transition zone must be at least a simple three-dimensional model as suggested by the schematics of Figure 12, which are very similar to the speculative structural models suggested by Caner et al. (1971). These diagrams depict only possible deeper structures, and the actual transition anomaly in this region is further complicated by the presence of the surface conductor, the Rocky Mountain Trench, which has not been included in the model schematics. Either model could account for many of the observed features of the transfer matrices, and resolve some of the differences in the T and T_Z estimates.

In conclusion, the following general inferences from this small-scale study are emphasized:

(1) The extended frequency coverage of the broad-band system proved invaluable in the separation of the shallow trench conductor from the deeper inhomogeneities.

(2) The more general transfer function matrix is useful in obtaining a more comprehensive picture of all field component coherences and allowing an evaluation of the validity of the simpler transfer function assumptions.

(3) The results of this study indicate that not local induction but local deflection of regionally induced fields should often be considered in model interpretation.

Acknowledgements. This work was supported in part by Grant No. 66-9521 (G.K.C. Clarke) from the Defence Research Board of Canada. Personal financial support from the National Research Council of Canada for one of us (H.D.) is also gratefully acknowledged.

References

Camfield, P.A., Gough, D.I.: Anomalies in daily variation magnetic fields and structure under northwestern United States and southwestern Canada. Geophys. J. **41**, 193–218, 1975

Caner, B.: Electrical conductivity structure in Western Canada and petrological interpretation. J. Geomagn. Geoelectr. **22**, 113–129, 1970

Caner, B.: Quantitative interpretation of geomagnetic depth-sounding data in Western Canada. J. Geophys. Res. **76**, 7202–7216, 1971

Caner, B., Auld, D.R., Dragert, H., Camfield, P.A.: Geomagnetic depthsounding and crustal structure in Western Canada. J. Geophys. Res. **76**, 7181–7201, 1971

Caner, B., Cannon, W.H.: Geomagnetic depth-sounding and correlation with other geophysical data in western North America. Nature **207**, 927–928, 1965

Caner, B., Cannon, W.H., Livingstone, C.E.: Geomagnetic depth-sounding and upper mantle structure in the Cordillera region of western North America. J. Geophys. Res. **72**, 6335–6351, 1967

Caner, B., Dragert, H.: Instrumentation for wide-frequency-band (0.01–100 millihertz) geomagnetic induction work. Z. Geophys. **38**, 121–132, 1972

Cochrane, N.A., Hyndman, R.D.: A new analysis of geomagnetic depth-sounding data from Western Canada. Can. J. Earth Sci. **7**, 1208–1218, 1970

Cooley, J., Tukey, J.W.: An algorithm for the machine calculation of complex Fourier series. Math. Computation **19**, 297–301, 1965

Dragert, H.: A geomagnetic depth-sounding profile across central British Columbia, unpublished M.Sc. thesis, University of British Columbia, Vancouver, 1970

Dragert, H.: A transfer function analysis of a geomagnetic depth-sounding profile across central B.C.. Can. J. Earth Sci. **10**, 1089–1098, 1973a

Dragert, H.: Broad-band geomagnetic depth-sounding along an anomalous profile in the Canadian Cordillera, unpublished Ph. D. thesis University of British Columbia, Vancouver, 1973b

Dragert, H.: A field evaluation of Caner's broad-band geomagnetic induction instrumentation. J. Geophys. **40**, 121–129, 1974

Hyndman, R.D.: Electrical conductivity inhomogeneities in the earth's upper mantle, unpublished M.Sc. thesis, University of British Columbia, Vancouver, 1963

Jones, R.H.: A reappraisal of the periodogram in spectral analysis. Technometrics **7**, 531–542, 1965

Kanasewich, E.R.: Precambrian rift: genesis of strata-bound ore deposits. Science **161**, 1002–1005, 1968

Lajoie, J.J., Caner, B.: Geomagnetic induction anomaly near Kootenay Lake – a strike-slip feature in the lower crust? Can. J. Earth Sci. **7**, 1568–1579, 1970

Lambert, A., Caner, B.: Geomagnetic depth-sounding and the coast effect in Western Canada. Can. J. Earth Sci., **2**, 485–509, 1965

Price, A.T.: Electromagnetic induction in a semi-infinite conductor with a plane boundary. Quart. J. Mech. Appl. Math. **3**, 385–410, 1950

Schmucker, U.: Anomalies of geomagnetic variations in the southwestern United States. Bull. Scripps Inst. Oceanog., 13, University of California, 1970

Swift, C.M.: Theoretical magnetotelluric and turam response from two-dimensional inhomogeneities. Geophysics **36**, 38–52 1971

Received November 11, 1974; Revised Version October 4, 1976