

NORTH AMERICAN CENTRAL PLAINS CONDUCTIVITY ANOMALY GOES EAST

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Abstract. The North American Central Plains electrical conductivity (NACP) anomaly has been known for almost two decades, and its influence on palaeotectonic models of the North American continent has been significant. Magnetometer array studies have located the structure in a gross sense, but there has not been, until now, a comprehensive magnetotelluric (MT) survey of it. In this letter we report on the preliminary interpretation of data from thirty-five MT sites recorded along a 400 km East-West profile just north of the US-Canadian border. We show that the anomaly at this latitude is 75 km farther east of the location previously mapped by the array studies. Modelling indicates that the conductive body has its top surface at about 10 km depth and appears to be anticlinal in shape. The profile also extends sufficiently east that it traverses another previously known electrical structure, referred to herein as the TOBE anomaly. We consider briefly other geophysical and geological data for the region, and tentatively infer that the NACP structure is terminated to the east by the interpreted southern extension of the Tabbernor fault/fold system, and that the TOBE anomaly is an expression of the known southern extension of the Thompson nickel belt, both beneath Phanerozoic sediments of the Williston Basin.

Introduction

The largest and most enigmatic continental-scale structure discovered to date by electromagnetic induction studies is, unequivocally, the North American Central Plains conductivity (NACP) anomaly. First detected in data from a geomagnetic deep sounding (GDS) magnetometer array experiment conducted during 1967 (Reitzel et al., 1970), Gough and colleagues in later arrays (Camfield et al., 1971; Alabi et al., 1975) defined an elongated feature (shaded zone in Fig. 1) running from the Southern Rockies at 41° latitude almost to the exposed Churchill Province of the Canadian Shield at 54° latitude. Handa and Camfield (1984) undertook a profile of GDS stations at 56°-57° latitude (Fig. 1) in an attempt to extend knowledge of the NACP structure into the exposed Churchill Province, and in an analysis of data from the "Churchill" profile of the Canadian International Magnetospheric Study magnetometer deployment, Gupta et al. (1985) interpreted observed reversals in the vertical magnetic field component between two stations (BKC and GIM, Fig. 1) as indicative of the possible eastward extension of the NACP structure to beneath Hudson Bay.

Camfield et al. (1971) suggested that the high electrical conductivity of this structure was possibly associated with conductive minerals such as graphite in schistose rocks in the basement beneath the Great Plains, and Camfield and Gough (1977) presented a hypothesis that the anomaly represents a Proterozoic plate boundary. The NACP

structure certainly is of major importance to both geophysicists and geologists who attempt to deduce Archean and Proterozoic tectonic models of this region of North America, and obviously any proposed model that does not generate such a major electrical conductivity feature is untenable. The NACP anomaly has been used as the basis for defining the edge of the Wyoming craton by some, and as the edge of the Churchill Archean Platform by others. Tectonic models, and also extrapolations of Precambrian geology beneath the Williston Basin, that consider that NACP structure have been presented recently by, for example, Peterman (1981), Dutch (1983), Green et al. (1985), Burwash and Frost (1986) Klasner and King (1986), and Van Schmus et al. (1986). Also, one of the COCRUST seismic refraction profiles was designed to probe directly the anomaly (profile "C" of Hajnal et al., 1984). Accordingly, it is of great importance that the precise location of the NACP structure be known, and that its characteristics (depth, thickness, conductivity) be defined.

U.S. data from the magnetometer array studies apparently defies quantitative two-dimensional (2D) modelling in terms of conductive structure (Porath et al., 1971; Alabi et al., 1975), which led those authors to consider that the anomaly concentrated current induced elsewhere. Jones (1983), in his review on "the problem of current channelling", expressed surprise at this supposed defiance, given that the length of the NACP (>2000 km) far exceeds

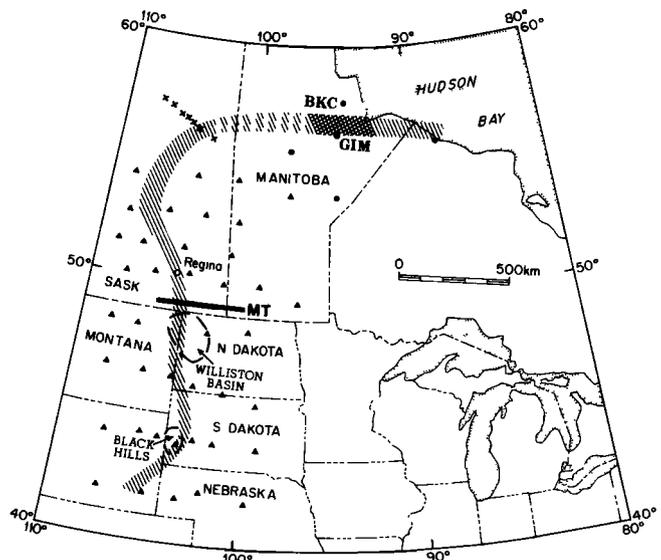


Fig. 1 Map of North America showing the locations of Alabi et al.'s array magnetometers (triangles), Handa and Camfield's magnetometer profile (crosses), Gupta et al.'s IMS chain of magnetometers (dots, and BKC and GIM), and our MT profile (solid line). The shaded area is the location of the North American Central Plains conductive body as mapped by the magnetometer work

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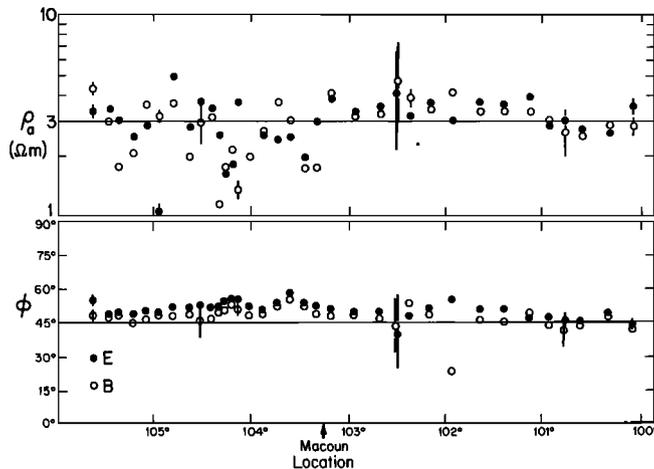


Fig. 2 The E-polarization (dots) and B-polarization (open circles) MT apparent resistivities and phases at a period of 1 s from all 35 MT locations.

the skin-depth in the "host" medium at all periods shorter than about 1 hour (for a "host" of 1000 Ωm), and Handa and Camfield (1984), Gupta et al. (1985) and ourselves are able to obtain satisfactory 2D models that are consistent with observations in Canada.

In order to obtain a more accurate quantitative model of the NACP structure, and also of another known electrical structure to its east detected by Rankin and Kao (1978) and referred to herein as the TOBE anomaly (for Thompson Belt), data were recorded along a 400 km East-West profile located just north of the US-Canadian border (Fig. 1). In this letter, we present some of the data from the profile and interpret it in a preliminary manner, and we briefly discuss the possible significance of the NACP and TOBE structures to the geology of the region.

Data and Preliminary Interpretation

High quality remote-reference MT data were obtained at 35 sites along a 407 km East-West profile at $49^{\circ} 20'$ latitude (Fig. 1). The electromagnetic field components in the period range 0.0026 – 1820 s (frequency range 384 – 0.00055 Hz) required for remote-reference magnetotelluric (MT) observations were measured and processed by a PHOENIX MT system. The quality of the estimated responses was very high, except at frequencies close to 60 Hz and its odd-order harmonics, and, in general, the estimated standard errors were smaller than the symbols used

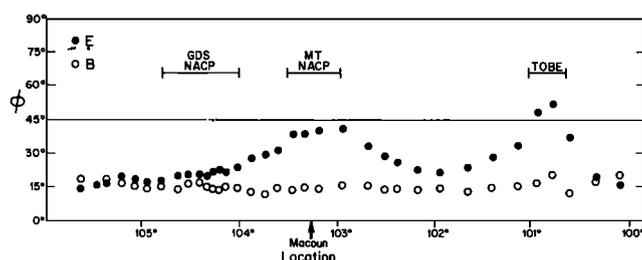


Fig. 3 The E-polarization (dots) and B-polarization (open circles) MT phases at a period of 100 s from all 35 MT locations. The bar labelled GDS-NACP indicates the location of the NACP anomaly from Alabi et al.'s array observations. The other two bars indicate the NACP and TOBE anomalies from this work.

to plot the data (see Figs. 2 and 3). Apart from "static-shift" problems (discussed below), the MT responses from all locations were one-dimensional (1D) from the highest frequency of 384 Hz down to 0.25 Hz (4 s period). At lower frequencies, the two sets of information which describe current flowing along the anomaly (E-polarization) and current flowing across the anomaly (B-polarization) diverge, rather dramatically at some locations.

We are of the opinion that many of the apparent resistivity curves are "static-shifted". Static-shift is a DC-like phenomenon that is due to a very local near-surface inhomogeneity that affects the potential of one electrode of the pair such that the apparent resistivity curve plotted on a log-log scale is shifted upwards or downwards by the same factor at all frequencies. Without any additional information, it is not possible to account for this effect at any given single location. The phases of the two impedances, E-polarization and B-polarization, remain unaffected, but the vital absolute depth information given only by the level of the apparent resistivity curves is lost.

Figure 2 illustrates the E-polarization and B-polarization apparent resistivity and phase responses at a period of 1 s. It can be seen that the phases in both polarizations are equal to one another at every location (with the exception of one site just to the east of 102° longitude where the estimates are obviously noise-degraded at this period when compared to the neighbouring ones), whereas the apparent resistivities differ from each other. This phase equality was true at all locations for all frequencies in the range 384 – 0.25 Hz. Static-shift appears to be a greater problem at sites along the western half of the profile than for sites along the eastern half. Note that the lack of response at this period to either of the two anomalies infers that neither are "shallow" structures.

At 100 s period (Fig. 3), it is immediately obvious that the E-polarization phases are indicative of two distinct conductivity structures. The westernmost of these anomalies — the NACP anomaly — is a broad feature with a maximum phase response at approximately 103° longi-

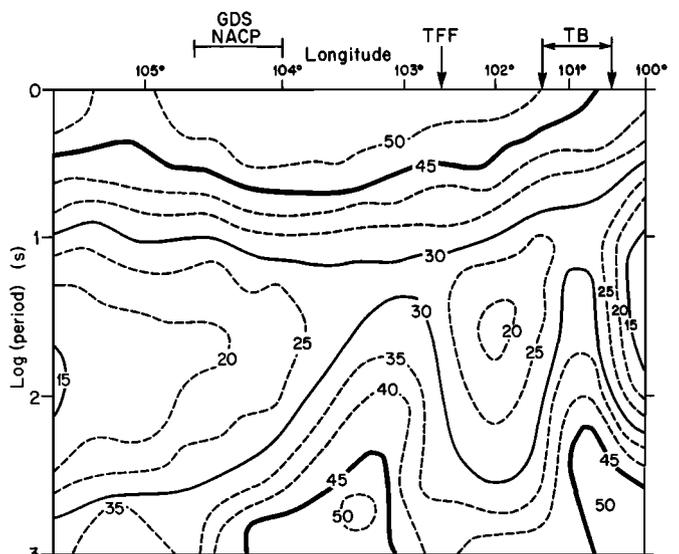


Fig. 4 Pseudo-section of the E-polarization phases from 1 s to 1000 s (note that the ordinate axis is not regular). Also shown are the surface locations of the NACP anomaly, from Alabi et al.'s interpretation of magnetometer array data, and of the Tabernor fold/fault system (TFF) and Thompson belt (TB), from Green et al.'s interpretation of static aeromagnetic map compilation.

tude, whereas the eastern anomaly — the TOBE anomaly — is much narrower and is centred at approximately $100^{\circ} 45'$. The B-polarization phases appear to be almost totally insensitive to the presence of either of these anomalies. This indicates that the structures are "thin" in an electromagnetic sense, i.e., less than 10 km, such that currents flowing perpendicular to them are little perturbed by them. It is apparent that at the location of the NACP structure mapped by Alabi et al. (1975) there is no significant anomalous phase response.

The variation of the E-polarization phase responses with period are illustrated in the pseudo-section of Fig. 4 (note that the abscissa is not regular). The migration of the upper 45° contour to shorter periods from west to east is an indication of the thinning Phanerozoic sediments of the Williston Basin. The anomalous phase response at 103° longitude migrates slightly westwards with increasing period, inferring a structure that dips to the west. The phase response of the TOBE anomaly infers a more vertical structure. Certainly, there is no marked response at the location of the NACP structure as mapped by the GDS array observations.

The E-polarization and B-polarization apparent resistivity curves from locations directly above the NACP and TOBE structures overlie each other at all frequencies higher than 0.25 Hz, inferring that there is little, or no, "static-shift" effect at these sites. At 103° longitude, 1D modelling of the E-polarization MT responses indicates a conducting zone to a depth of $\approx 2650 (\pm 70)$ m, which correlates well with the depth to the top of the Lower Palaeozoic formations at a nearby borehole of 2600 m (Hutt, 1963; see also Paterson, 1975). Above the TOBE structure, the base of the conducting zone is at a depth of $\approx 1250 (\pm 200)$ m, which also correlates extremely well with the depth to the top of the Lower Palaeozoic formations of ≈ 1280 m (Norris et al., 1982). The present conclusion is that the Lower Palaeozoic formations do not have a high electrical conductivity compared to the Upper Palaeozoic and Mesozoic sediments, and accordingly that the MT data can resolve well the depth to the base of the latter, represented in this region by the Ashern dolomite. The electrical structure of the Williston Basin will be the subject of a later paper.

Discussion

In this letter we have shown that the NACP structure at a latitude close to the US-Canadian border is some 75 km east of the location defined by the coarse GDS array study of Alabi et al. (1975). It must be emphasised that this does not automatically imply that the structure at other latitudes is also erroneously located. The evidence from the Fourier maps of Alabi et al. (1975) is that the structure is perhaps more vertical and of higher areal conductance (width \times thickness \times conductivity) south of the US-Canadian border than north of it. Rankin (pers. comm.), continuing westwards the profile of Rankin and Kao (1977), has recently recorded MT data at fifteen locations at approximately $49^{\circ} 40'$ latitude between 102° - 104° longitude, and also finds anomalous responses at stations at 103° . MT profiles that traverse the structure need to be undertaken at other latitudes.

The aeromagnetic anomaly compilation for this region presented by Green et al. (1979, his Fig. 5) shows a high gradient in magnetic field (≈ 300 nT change) over a very short distance (≈ 6 km) at a longitude of approximately $102^{\circ} 35'$. This feature was suggested by Green et al. (1979) to be an expression of the southern extension of the Tabbernor fault/fold system buried beneath the thick Phanerozoic sediments of the Williston Basin. If this ex-

trapolation is correct, then the Tabbernor fault/fold system (Fig. 4, TFF) could represent the eastern termination of the NACP structure. Preliminary 1D and 2D modelling indicates that the top of the NACP structure is at a longitude of 103° and at a depth of about $10 (\pm 0.5)$ km, and that it is anticlinal in shape. However, the structure appears to have no seismic signature in the interpretation of refraction data by Hajnal et al. (1984), and more recently by Morel-à-l'Huissier (pers. comm., 1986). The position of the NACP structure from the MT data is now directly below the Weyburn high heat flow anomaly reported by Majorowicz et al. (1986), not to its west. Thus, we have another occurrence of a high geothermal gradient in Palaeozoic sediments above the location of a crustal conductor (see Lam et al., 1982, Ingham et al., 1983, and Majorowicz et al., 1984).

The TOBE anomaly was earlier discovered by Rankin and Kao (1978) in their interpretation of data from a profile of nine MT sites further north ($49^{\circ} 45'$ latitude, 100° - 102° longitude), and, in terms of its effect on MT parameters at 100 s, it is obviously narrower and more vertical than is the NACP structure. A southern extension of the Thompson nickel belt beneath the Phanerozoic sediments was originally suggested by Green et al. (1979) from their aeromagnetic data compilation, and this is now known to be correct (Klasner and King, 1986). From the aeromagnetic lineations of Green et al. (1979), it is apparent that the TOBE anomaly appears to be well bounded on both edges by the eastern and western extents of the Thompson belt (Fig. 5, TB). Preliminary modelling indicates that the top of the structure is at a depth of $2.1 (\pm 0.4)$ km, which is to be compared with a depth of 2.4 km presented by Rankin and Kao (1978), and that it is of less than 5 km in width. The Precambrian basement at this location is at a depth of ≈ 1750 m (Norris et al., 1982), which implies that this anomaly could be at the base of the Phanerozoic formations, but present modelling indicates that there must be some 300-500 m of more resistive material between the top of the structure and the base of the Phanerozoic.

It is of interest to note that 1D interpretations of stations from the westernmost end of the profile, at which the E-polarization and B-polarization MT responses are equal to one another at all periods, imply a lower crust of some 150 Ω m. This is in a region with a lower crust of compressional wave velocity ≈ 7.2 km/s (Hajnal et al., 1984; Morel-à-l'Huissier, pers. comm., 1986). Thus, the electromagnetic and seismic parameters for the lower crust in this region agree with the definition of Type II, or "Intermediate", crust in the speculative classification system introduced by Jones (1981), and imply that it is composed of shield edge rather than shield centre material.

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