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Search for a possible electromagnetic coupling between a transatlantic communication cable and the magma chamber in the mid-Atlantic ridge

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Abstract. A linear correlation analysis study is reported between geomagnetically induced voltage variations on the transatlantic TAT-6 telecommunications cable and magnetic field fluctuations recorded at two stations located on the mid-Atlantic ridge and its prolongation, Leirvogur, Iceland, and Crozet in the Indian Ocean. Interpretations are complicated by lack of knowledge of the scale sizes of geomagnetic fluctuations. For the cable voltage data set available, no definite correlations between the voltage and the magnetic fluctuations from stations on the ridge can be claimed. Surprisingly, however, good correlations are observed in some frequency bands between the two stations Leirvogur and Crozet, although the stations are not conjugate and are at vastly different geomagnetic locations.

Key words: Induction – Cable – Atlantic – Midocean ridge

Introduction

Submarine transoceanic communication cables are among the longest man-made electromagnetic systems. They interact with the natural electromagnetic environment, essentially becoming a portion of it in such a manner that they can be likened to large and very expensive experimental tools. As such, they are especially suited for monitoring environmental electromagnetic phenomena. An extensive discussion for such potentialities has been given by Meloni et al. (1983), while the incorporation of such cables within the natural telluric current environment has been recently discussed by Lanzerotti and Gregori (1984).

This paper concerns a statistical investigation of the variations in the powering voltage recorded on the American coast (see Fig. 1) of the transatlantic cable TAT-6 (Green Hill, Rhode Island, to Saint Hilaire de Riez, France; ~6,300 km). The cable can be depicted as an insulated conductor, powered by a DC voltage of +5200 V on the American coast and by a DC voltage of −5200 V on the European coast in order to maintain a constant current (~650 mA) to the repeaters. Data were recorded in May 1980 and have formed the basis of investigations by Medford et al. (1981) and by Lanzerotti et al. (1982), wherein additional details can be found on the experimental arrangements and on the data base.

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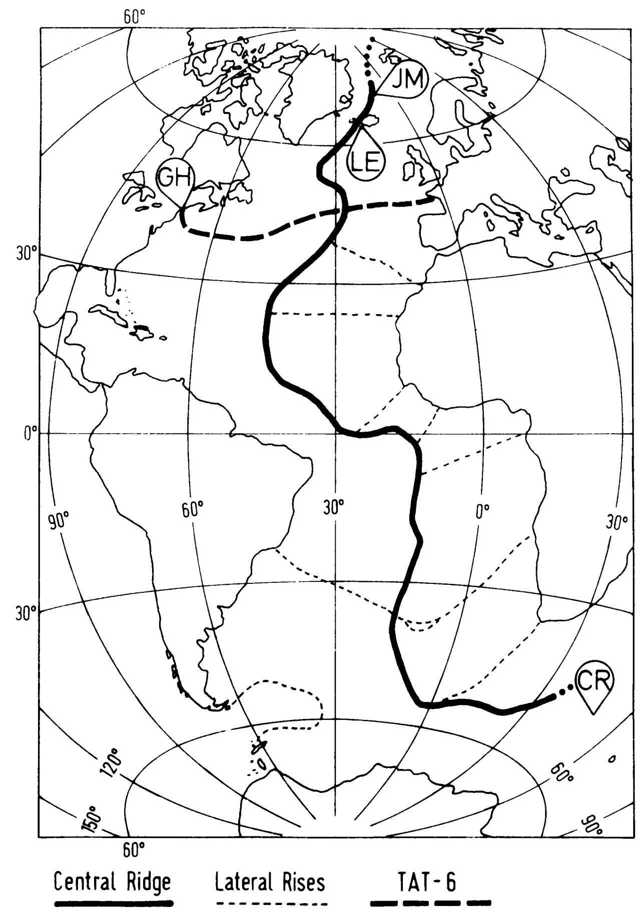

Fig. 1. Relative approximate location of TAT-6 cable across the North Atlantic (*dashed line*); mid-Atlantic ridge (*solid line*); three standard geomagnetic observatories (JM = Jan Mayen, LE = Leirvogur and CR = Crozet); and GH = Greenhill, being the American terminal of TAT-6

One of the items of particular interest to geophysical investigation using a transatlantic cable involves the possibility of an actual electromagnetic coupling between the cable and the magma chamber which is generally believed to be a few kilometres below mid-oceanic ridges (Menard, 1969; Nisbet and Fowler, 1978; Kusznir, 1980, and references therein). The existence of such a high conductivity region has been discussed by Gregori and Lanzerotti (1982), where it was concluded that such a magma chamber in the mid-Atlantic ridge might be equivalent to ~ 1000 man-made communication cables in parallel (the South Pacific mid-oceanic ridge magma chamber might correspond to $\sim 10^4$ such communication cables in parallel).

Therefore, it might be expected that, unless the cable and the currents in the magma chamber are precisely perpendicular, there would be an electromagnetic coupling between the two conductors, which are separated at closest approach by only a few kilometres of oceanic crust.

This paper is concerned with a first attempt to search for the existence of such a coupling. The spatial scale of geomagnetic variations of any period plays a crucial, critical role in this investigation. This present study basically searches for correlations between the TAT-6 voltage variations and the records from two standard geomagnetic observatories located on the mid-Atlantic ridge in the northern (Leivorgur) and southern (Crozet) hemispheres (see Fig. 1). Also, magnetic data were acquired at Green Hill during the interval of cable measurements. An important point for the analysis is to attempt to distinguish between phenomena which are to be interpreted just in terms of correlations on the planetary scale of the external *Sq* field, and those phenomena which can be interpreted in a different way, such as in terms of an electromagnetic coupling between TAT-6 and the magma chamber.

Such a study as that reported here has significant limitations, just because of the difficulty of observation. The possible presence of a magma chamber acknowledges that the Earth has a two- (or three-) dimensional structure. Conventional array studies via magnetotelluric (MT) and/or geomagnetic depth sounding (GDS) would be the optimum way to approach such an investigation. Obviously, the logistics of such an attempt in a deep ocean environment are formidable (although some work is in progress in studying the East-Pacific rise; see, for example, Spiess et al., 1980; Young and Cox, 1981; Law, 1983). Further, the upper mantle and crust of the Earth itself, being a conductor (although certainly not as good as the suspected magma chamber), can carry currents from a more distant locale to the region of measurement.

Surprisingly, experimental knowledge on the spatial scale of the external geomagnetic field is at present poorly known over a wide frequency range. Only the *Sq* field (periods $T = 24$ h plus a few low-order higher harmonics) have been investigated rather systematically (e.g. Mayaud 1965a, b; Riddihough, 1968; Schlapp, 1968, 1973, 1976; Greener and Schlapp, 1979; Schlapp and Mann, 1983; Sato, 1965; Campbell, 1976; Matsushita, 1967; Anderssen et al., 1979). These wavelengths are not of specific concern in the following investigation. At shorter periods the literature on scale sizes is sparse and the problem basically requires systematic and extensive investigations (refer, e.g., to Davidson and Heirtzler, 1968; Lanzerotti et al., 1977; Southwood and Hughes, 1978).

The investigation presented here is intended to be a first approach to the coupling problem, primarily to focus on the frequency bands where further investigations may be warranted. The next section contains a brief description of the method of analysis. The subsequent two sections deal with the results found for variations 20 min $< T \lesssim 1.5$ h and 1.5 h $\lesssim T \lesssim 4$ h, respectively. Variations of longer periods cannot be used, as far as the present analysis is concerned, because they are related to the spatial scale of the *Sq* variability on the planetary scale.

The data base and the method of analysis

The data base is composed of different records collected simultaneously on 15 days of good cable records in the interval 1–18 May, 1980 (inclusive). The different records are (refer to Fig. 1):

i) The TAT-6 voltage recorded at the American terminal (Green Hill, Rhode Island, 41.4°N, 71.7°W geographic), showing a diurnal amplitude variation of ~ 12 V, as discussed by Medford et al. (1981);

ii) The three geomagnetic field components recorded by a magnetometer at Green Hill (GH);

iii) The three geomagnetic field components recorded by a standard observatory magnetometer at Leivogur (LE);

iv) The three geomagnetic field components from the geomagnetic observatory of Crozet (CR), located on the Crozet archipelago, close to the prolongation of the mid-Atlantic ridge within the Indian ocean.

All data sets have been used at a 10-min sampling interval. The complete data base consists of the 10 data sequences (one for TAT-6, plus the three magnetic components for GH, LE and CR). Each such data set has been divided into 15 subsets, each covering one day. Each data subset has been processed with a Fast Fourier Transform (FFT) to obtain the amplitude of the data variations at each of the frequency components with periods from $T =$ 24 h through $T = 24$ h/72 = 20 min (20 min is the Nyquist limit, for 10-min sampling rate). For each given period, a regression analysis (e.g. Edwards, 1979; Chambers et al., 1983) was performed between the amplitudes of two of the ten data subsets. We stress that for this initial investigation, we have used only the amplitudes from the FFT analyses, neglecting the phases. This is, of course, only an approximation to the classical MT relationship (derived for use for much shorter separations of the electric field sensor probes).

An example of such a regression analysis is shown in Fig. 2, where the TAT-6 voltage (TATV) is regressed with the *H*-component magnetic field variation at GH (GHH) at a period of 1 h 33 min. In this regression plot, the correlation coefficient is found to be 0.77. For the 15 data points, this indicates a probability $< 0.1\%$ of obtaining such a relationship by chance. The correlation coefficients were obtained in a similar manner for the TAT-6 voltage regressed with all three magnetic field components from all three stations.

After obtaining the correlation for all the relevant frequencies, they were plotted as a function of period as shown in Figs. 3–8. In each of the figures, three sets of points are designated by either +, O or Δ corresponding to the correlations with, or between, the *H*-components, *D*-components and *Z*-components, respectively. The solid line connects the average value of the correlation for each period among the corresponding points +, O and Δ at that period (frequency). It is certainly not rigorously correct to average correlation coefficients referring to the different components. As such, the solid "average" lines drawn in Figs. 3–8 should be viewed only as providing an indication of where to focus attention on those periods with a generally higher of lower correlation. In Figs. 3–8 the horizontal lines drawn at $R = 0.5$ signify a correlation coefficient significant at the

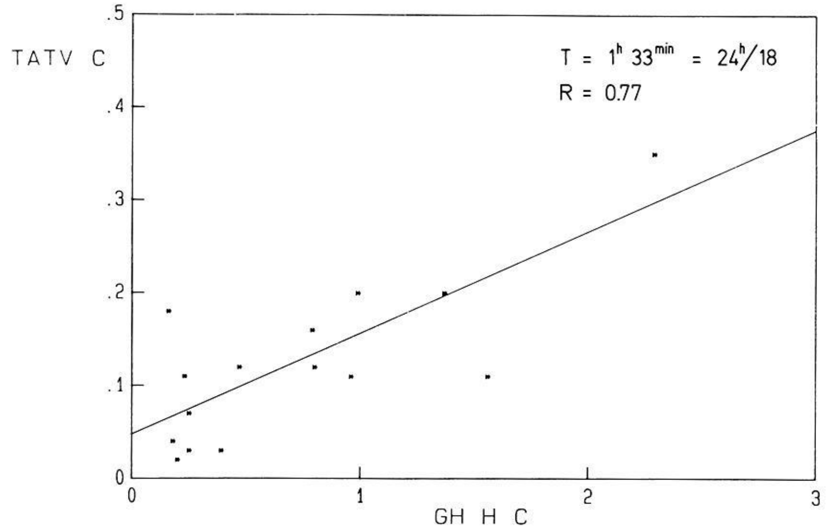

Fig. 2. Example of a regression analysis between the TAT-6 voltage (TATV) and the *H* geomagnetic component recorded at GH (GHH) for the variation period 1 h 33 min. The linear regression line has a correlation coefficient $R = 0.77$

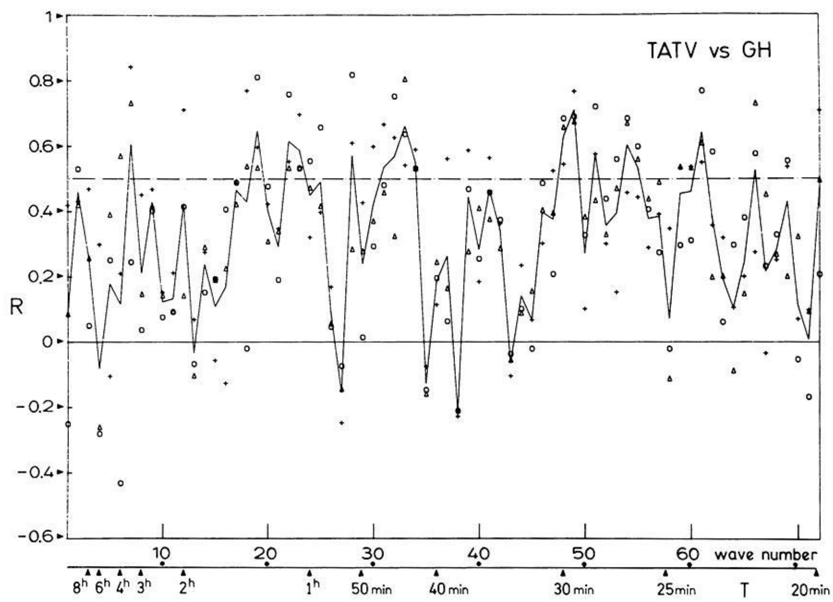

Fig. 3. Linear correlation coefficients *R* vs period for regression analyses between TATV and GHH (+); TATV and GHD (O); TATV and GHZ (Δ). The *solid line* connects the "average" value of *R* at each period. The *horizontal dot-dash line* is drawn as a visual aid at $R = 0.5$

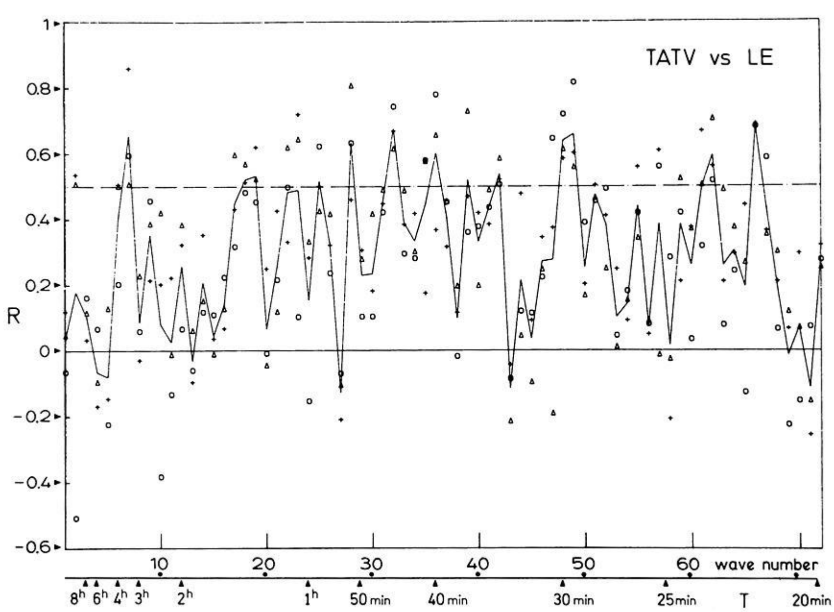

Fig. 4. Similar to Fig. 3: correlations between TATV and the three geomagnetic components at LE

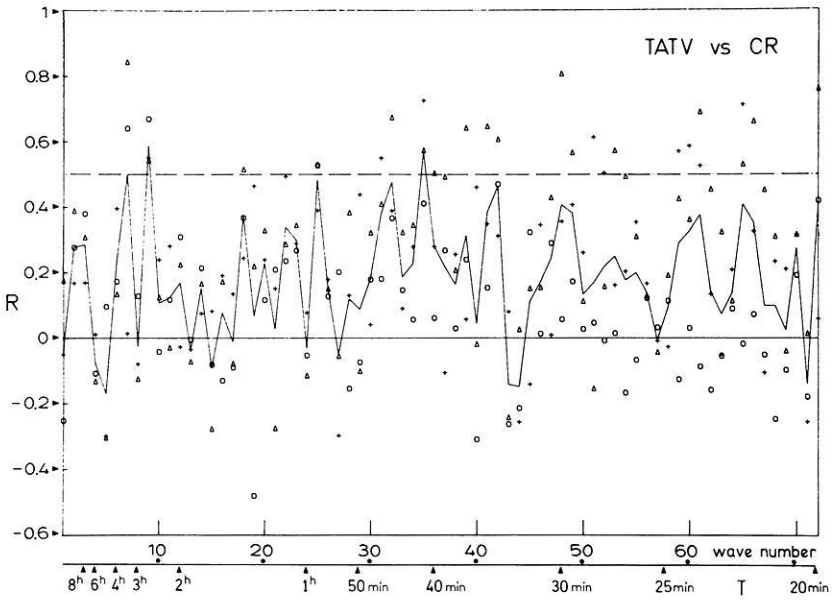

Fig. 5. Similar to Fig. 3: correlations between TATV and CR

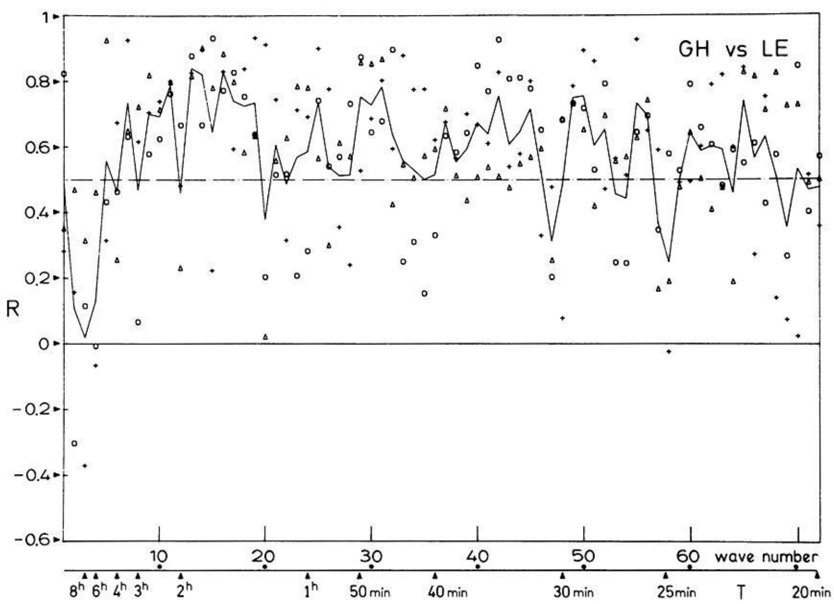

Fig. 6. Similar to Fig. 3, with the points +, O and Δ designating correlations between GHH and LEH, GHD and LED, and GHZ and LEZ, respectively

~5% level for the 15 points entering into each correlation plot.

The shorter period range ($T \lesssim 1.5$ h)

Consider the period range 20 min $< T \lesssim 1.5$ h. The sets of correlated variables TATV-GH (Fig. 3), TATV-LE (Fig. 4) and GH-LE (Fig. 6) show a reasonably "good" correlation in this range. This effect is likely related to the spatial scale of the external source in this period band, a source which is apparently sufficiently wide so as to span a major portion of the area covered by TAT-6, including GH and LE. In fact, Figs. 5 and 7, in comparison with Figs. 3, 4 and 6, show how poorly CR correlates with either TATV or GH in this period band. There would, however, appear to be a correlation, at ~1% level, and hence the possible existence of a coupling, between LE and CR (Fig. 8).

On the basis of the results, we tentatively conclude that no relevant electromagnetic coupling is evident within this period range between TAT-6 and the mid-Atlantic ridge.

The longer period range ($T \gtrsim 1.5$ h)

Consider the period range 1.5 h $\lesssim T \lesssim 4$ h. A generally reasonably "good" correlation at ~1% level is found in all of Figs. 3–8, although the correlations between magnetic components are better than between the TAT voltage and the magnetic components.

In fact, considering only the correlations involving the *H* components, the correlations between CR and either TATV or GH are rather poor, unlike the correlations between CR and LE which are rather good.

The results in this frequency range suggest a planetary-mode correlation in the external field, which appears slightly enhanced for CR and LE, presumably depending upon their coupling via the ridge. As far as the cable is

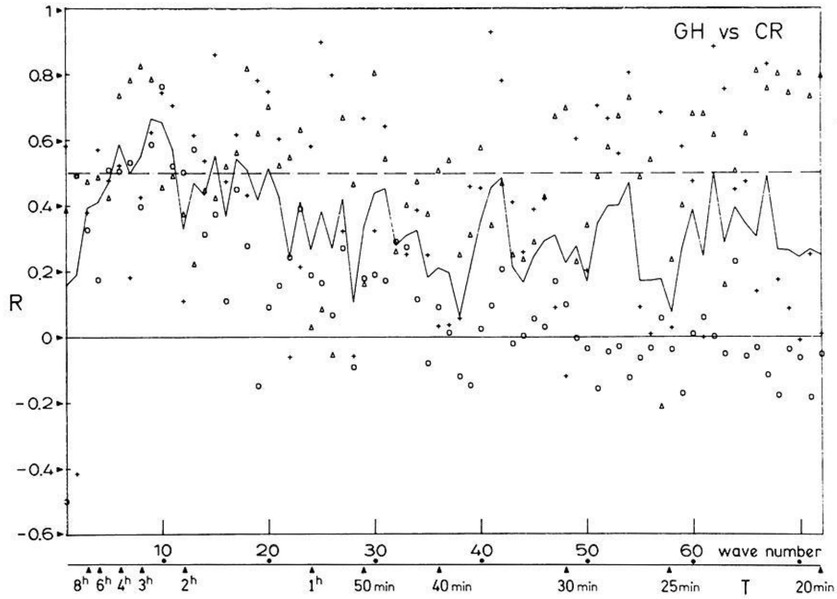

Fig. 7. Similar to Fig. 6 for the stations GH, CR

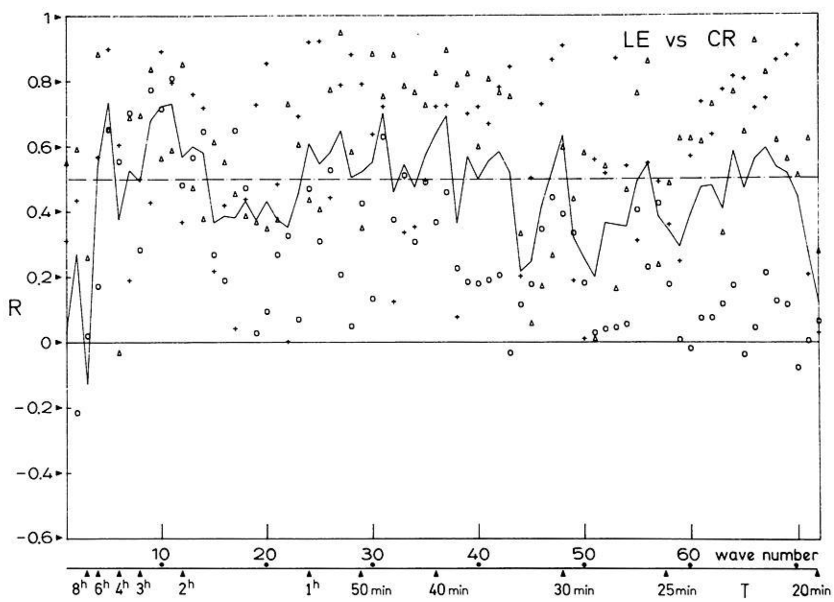

Fig. 8. Similar to Fig. 6 for the stations LE and CR

concerned in this period range, either no coupling exists between the cable and the ridge, or, if such a coupling exists, it plays a minor role.

For $T > 4$ h the correlations should more suitably be investigated by considering the detailed pattern of the *Sq* fields. Differently stated, the results appear, on an intuitive ground, more likely to be related to planetary-scale phenomena than to coupling with the mid-Atlantic.

Conclusions

Although the statistical results presented in the above suggest little coupling between currents possibly flowing in the mid-Atlantic ridge and the TAT-6 cable, it is premature to state a definitive conclusion concerning the coupling. More extensive investigation, using other geomagnetic observatories (e.g. Jan Mayen, see Fig. 1) along the ridge would be required. In addition, a longer time series of data would be highly desirable. A longer time series together with more sophisticated analyses would allow more rigorous statistical conclusions to be drawn. Some of these improved procedures and techniques are presently being implemented for future investigations using other cable systems.

A very rough idea of the magnitude of the current that must be flowing in the magma chamber to produce an observable effect can be estimated as follows. Assume that the current in the ridge is a line current. In actuality, of course, the magma chamber has a finite cross-sectional area. Kusznir (1980) mathematically modelled the thermal evolution of the oceanic crust spreading from a ridge. For a spreading rate of 1 cm $year^{-1}$ in the Atlantic, he obtained a rhomboidal cross-sectional area for the chamber of $\sim 5.3\ km^2$.

We also assume that the cable and its return path is oriented parallel to the magma chamber current flow, with the cable separated 5 km from the line current. The area of the cable current path was determined by Medford et al. (1981) from analysis of the *Sq* response of the cable to be $\sim 10^6$ km^2. Therefore, from a Biot-Savart law calculation, a 1-V change in the cable potential would require $\sim 4 \times 10^3$ A flowing in the ridge chamber (a current density of ~ 0.8 mA/m^2 in an area the size computed by Kusznir [1980]). This would be a lower limit on the current in as much as a change in orientation of the cable from parallel would reduce the coupling into the circuit path.

However, notwithstanding all the above limitations, the present analysis presents some evidence that, within the period range 20 min $< T <$ 24 h, an electromagnetic coupling between TAT-6 and the mid-Atlantic ridge can exist at most only in the range of $T \sim 2$–3 h, and this evidence is only for the station at LE. On the contrary, an interesting, tentative suggestion is found that the ridge may perhaps be able to "couple" geomagnetic observations located close to it which, in the study here, are LE and CR. It is unlikely that the correlations observed between these two stations is a "conjugate" phenomena, in that the conjugate point to LE, an auroral-zone station at the geomagnetic drift shell $L \sim 6.1$, is in the vicinity of Syowa Station in the Antarctic. In contrast, CR is at $L \sim 1.6$ and $\sim 11°$ east of the Syowa longitude. This latter, somewhat surprising finding, is being vigorously pursued further at present.

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