Acta Geodaet., Geophys. et Montainst. Acad. Sci. Hung. Tomus 11 (3—4), pp. 347—376 (1976)

INDUCTION STUDIES IN RIFTS AND OTHER ACTIVE REGIONS

R. HUTTON

DEPARTMENT OF GEOPHYSICS, UNIVERSITY OF EDINBURGH, UNITED KINGDOM

Induction studies undertaken in rifts and other active zones during the past few years are reviewed with special attention being paid to recent work in East and South Africa. The complementary nature of the geomagnetic and magnetotelluric techniques and the differences in interpretation which result from examination of data of different frequency coverage are both illustrated in the discussion. In view of the non-unique nature of the interpretation of most induction studies at the present time, no attempt is made to correlate conductivity profiles with tectonic activity. The paper concludes with suggestions for the extension of current work *a)* in a manner which should provide more unique conductivity interpretations and *b)* to parts of the world-wide rift system in which such studies have not yet been initiated.

Introduction

From the title of this paper, it would appear that the task of the reviewer should be *(a)* to define what is meant by the terms 'Rifts' and 'Active Regions', *(b)* to give an account of recent induction studies in these regions and *(c)* to attempt to collate the results of these studies in such a way that they would increase our understanding of the internal processes responsible for the characteristic features of these regions. For a number of reasons, this discussion will fall very short of these objectives.

Problems arise at the very outset when one finds, in the literature, that the term 'rift valley' has been used to describe widely differing ranges of geomorphological or tectonic situations. It was introduced by GREGORY [37] to describe what he called the 'Great Rift Valley' of East Africa. He used it in the sense of 'a relatively narrow space due to subsidence between parallel fractures resulting from horizontal *tension*'. More recently it has been used by BOTT [17], GARLAND [29], MO'CONNELL [57], PRESS and SIEVER [65], and others in the same sense and restricted primarily to *major* regions of *present-day* earth movement. A much wider connotation is however implied by some other authors (e.g. MILANOVSKY [56]) and includes regions of *suspected ancient analogues* of recent rift zones. The Symposium on The World Rift System [45] held in Ottawa in 1965 included some papers in which this broader interpretation of the term was accepted and at least one in which strike-slip faulting rather than normal faulting was the accepted origin. Figs 1 and 2 show the world-wide

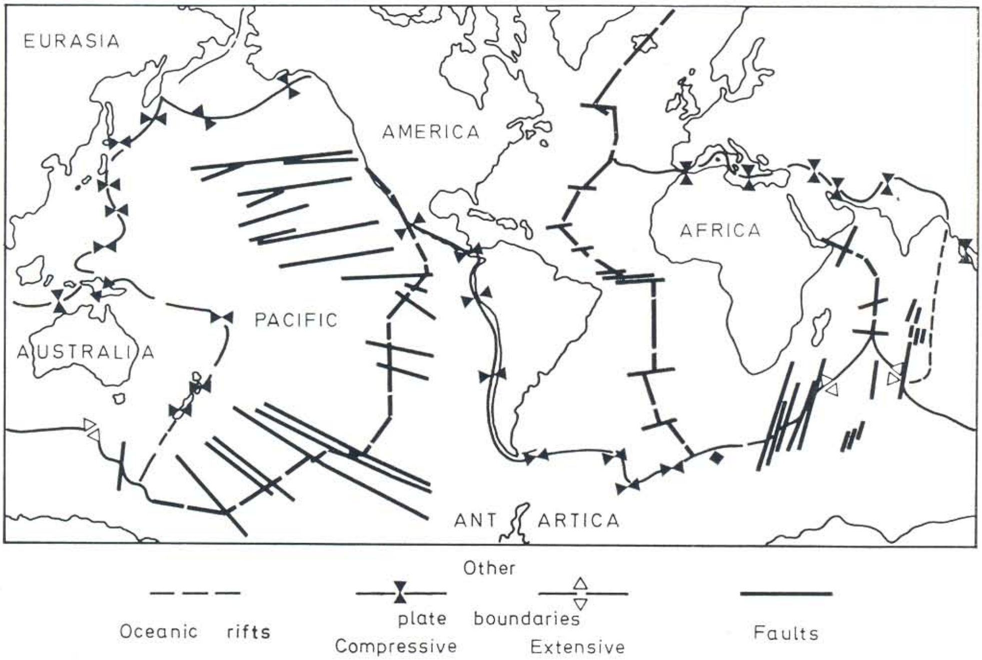


Fig. 1. World-wide plate tectonic pattern — 6 plate model (after LE PICHON et al. [52])

distributions of rifts in both the narrower and broader senses. Fig. 1 also indicates the location of present-day movement according to the simple 6-plate model and thus the main currently 'active' regions associated with both accreting and consuming plate boundaries.

For the purpose of this paper, regions of both recent and past rifting and other forms of tectonic activity are considered in a geographical context with special attention to recent induction studies in Africa. The discussion of fieldwork in active regions is followed by some suggestions on the manner in which the association of conductivity anomalies with tectonic processes might be approached.

With regard to the induction studies themselves, there are several factors which contribute to the difficulty of searching for common features which can be associated with specific tectonic processes. On surveying the literature one finds major differences, between the studies reported, in

(i) the characteristics, particularly of frequency coverage, of the induction technique employed

(ii) the areal extent of the fieldwork, e.g. single or multistation, linear or two-dimensional, and the station spacing

(iii) characteristics of the inducing field, such as amplitude, spatial gradients and polarization

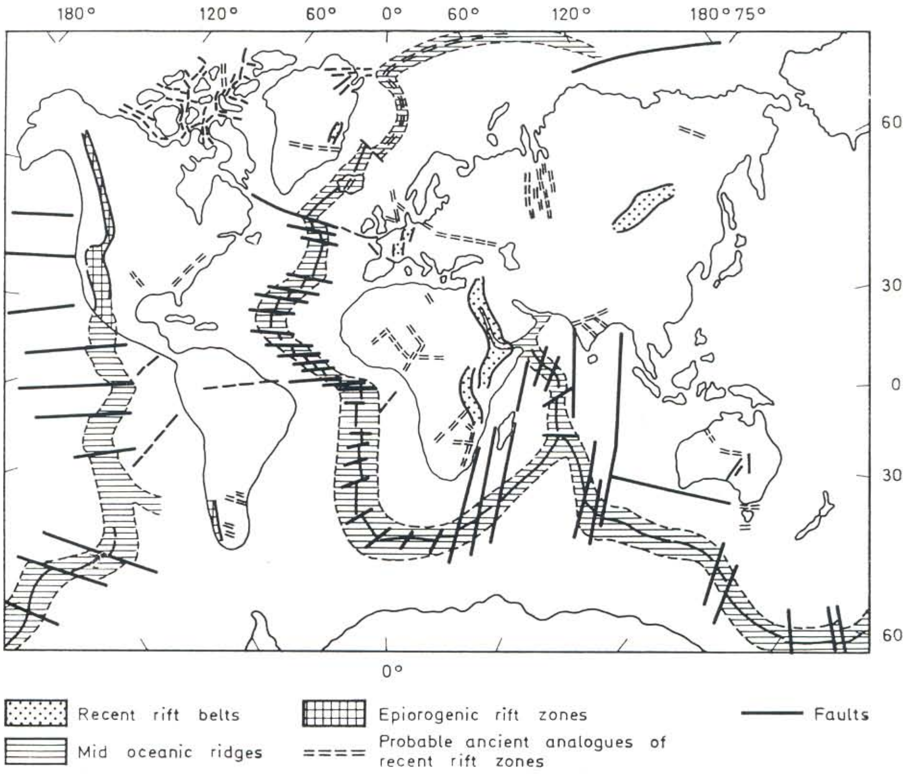


Fig. 2. Position of rifts and related zones — including probable ancient analogues of recent rift zones (after Milanovsky [56])

(iv) the data processing techniques employed
(v) the severity of the data acceptance criteria
(vi) the presentation of error estimates, and
(vii) the degree of non-uniqueness of data interpretation.

Despite the problems involved, this is perhaps an opportune stage to attempt to review the nature of the results currently available from at least some of the major zones of rifting and tectonic activity, to note the shortcomings in the data already available and to consider how best these can be overcome in future studies. Relevant induction studies undertaken prior to the Workshops in Edinburgh and Ottawa have been well reviewed by Gough [33] and Garland [30]. The studies discussed in this paper will concentrate on subsequent work or on regions not covered by presentations at the previous Workshops. The publications of recent symposia on 'Multidisciplinary Studies of Unusual Regions of the Upper Mantle' at the Madrid IAGA Assembly [67], on 'East African Rifts' at the Moscow IUGG General Assembly [31] and on 'Electromagnetic Induction Studies of Tectonic Regions' at the Kyoto IAGA Assembly [68] also contain many interesting papers on this subject.

Africa

The location of recent induction studies in Africa is shown in Fig. 3 in relation to the major tectonic features of that continent. Since the publication of the preliminary G.D.S. study in the Gregory Rift by BANKS and OTTEY [9] and of the abstracts of a number of reports of work in Africa presented at the Ottawa workshop, several major field projects have been completed.

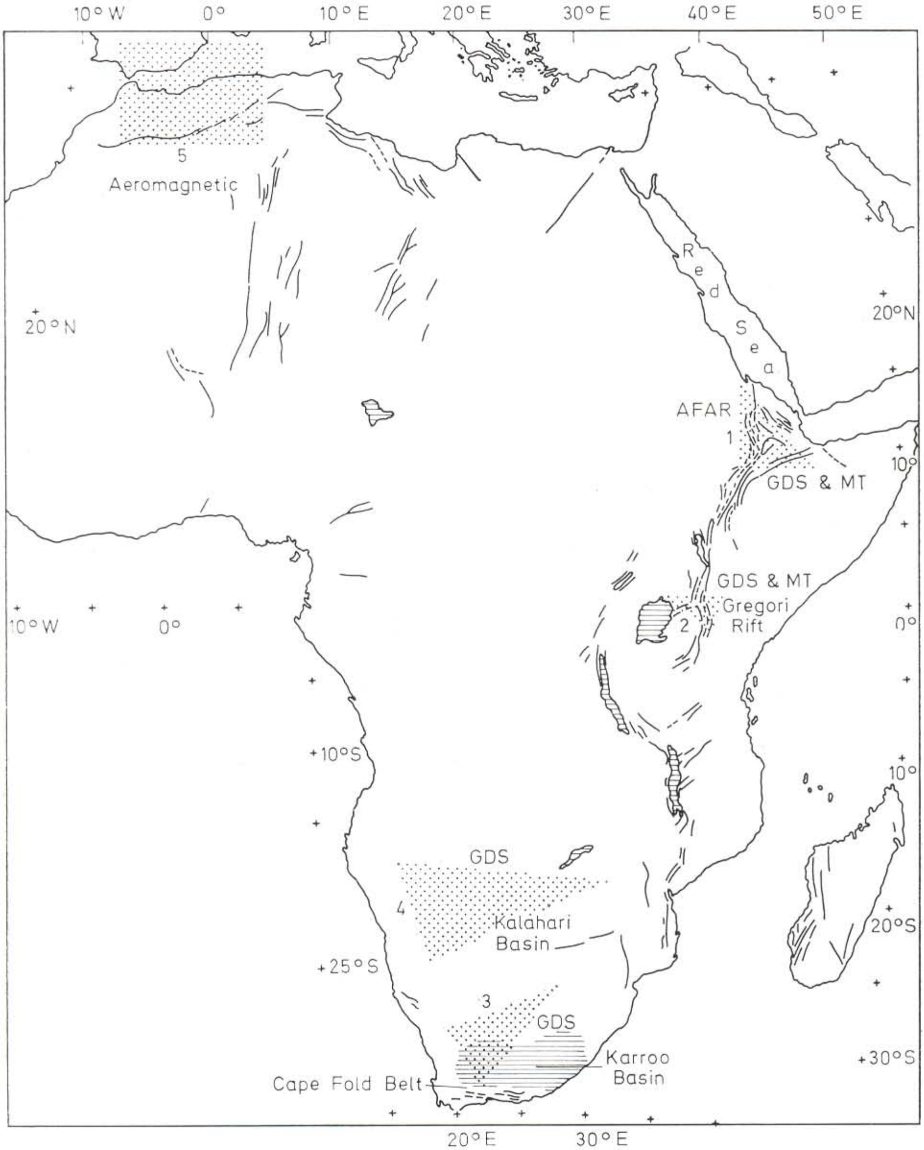


Fig. 3. The location of recent induction studies in Africa in relation to the Great Rift Valley

These include two magnetometer array studies in South Africa [35, 24, 22], a magnetometer array study [11] and a magnetotelluric study [72,73] in Kenya and the detection of an anomaly in the Western Mediterranean from analysis of aeromagnetic survey data [51]. Magnetometer array and magnetotelluric studies have also been undertaken in Ethiopia. **Berktold** et al. [14] summarized the results of these investigations in the Afar Depression and main Ethiopian Rift at the Ottawa Workshop and a fuller account of the magnetotelluric work has been given by **Berktold** [15]. Unfortunately a full account of the analysis of the magnetometer array study is not yet available; but the main results from both these induction studies, as reported at Ottawa, were *(a)* an anomalously high conductivity ($> 10^{-1}$ S m^{-1}) at a depth between 100 and 300 km in the southern part of the Afar Depression — indicated by the large induction vectors pointing into the anomaly in the period range 10 min to 3 hours and *(b)* an unexpectedly high conductivity under the W. Plateau below latitude 12 °N. In the absence of actual data, these results are illustrated schematically in Fig. 4(a) and are intended to indicate the directions and amplitudes of the induction vectors for the whole period range studied. **Beamish** [11] has now provided a full report of the array study, using 23 magnetometers undertaken in Kenya by the University of Lancaster group under **Banks**' supervision. He has examined his results, using a variety of methods such as mean real and imaginary induction arrows, mean maximum and minimum response functions, **Banks**'s [8] complex demodulation technique for estimating spectral densities and transfer functions and an extension of **Bailey** et al.'s [10] hypothetical event technique. For ease of comparison with the results of the other African array studies, **Beamish**'s transfer functions will be discussed here, although he himself regards the contoured maps of vertical and horizontal anomalous fields resulting from a hypothetical horizontal field as being superior to conventional transfer function methods in a three-dimensional conductivity situation. As an example of his maximum and minimum transfer functions, those for the period band 8—16 minutes are illustrated in Fig. 4(b). Similar transfer functions obtained by **Rooney** [72] in this region for a period of 1000 seconds are also presented in this figure. To explain both the results plotted in this figure and also the observed anomalous fields in general, **Beamish** has proposed three distinct regions of enhanced conductivity for the area studied.

a) A rift axial conductor located within the *crust,* terminating about 1 °S.

b) An extensive upper mantle conductor to the east of the main rift faults, striking approximately parallel to them. This has an ill-defined southern boundary which probably strikes eastwards.

c) A crustal conductor to the NE of Nairobi. It is suggested that its curved boundary near the eastern rift faults produces a current concentration effect and hence the very large response functions observed in this region.

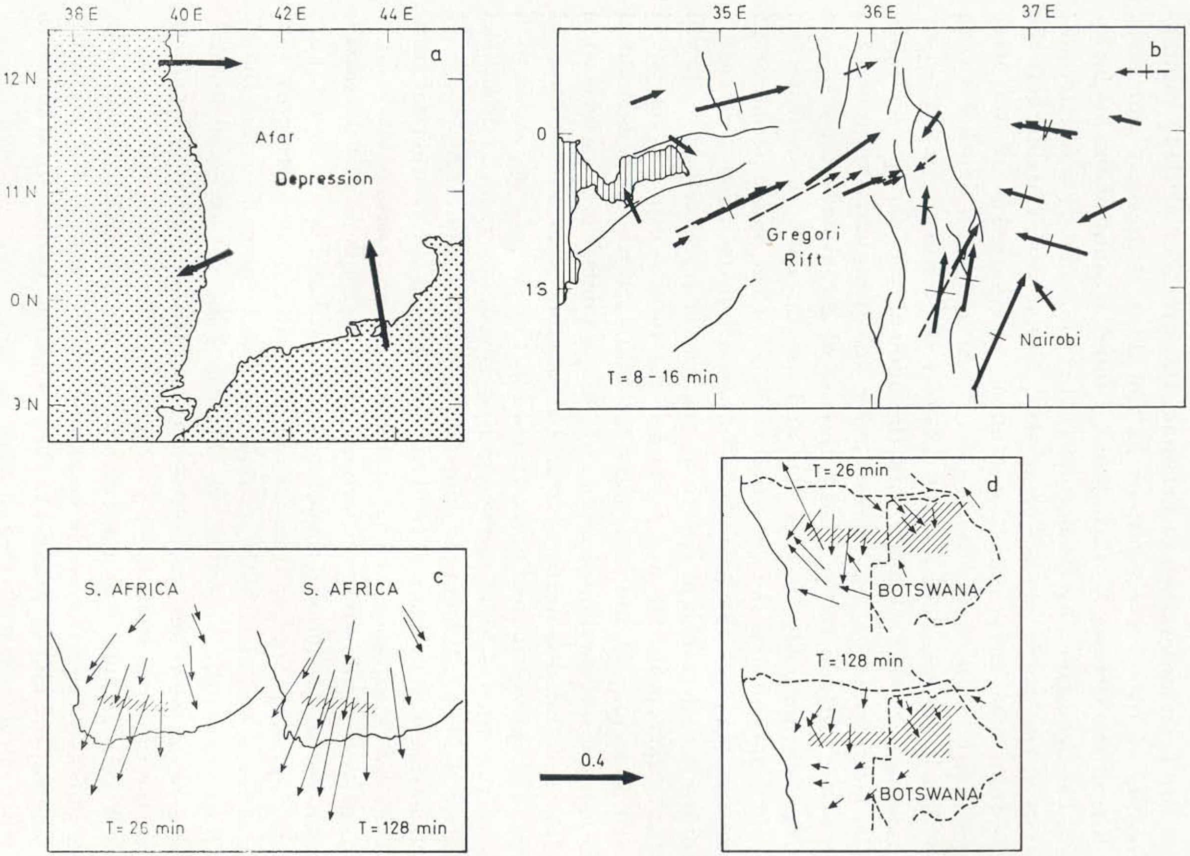


Fig. 4. Transfer functions obtained from induction studies in Africa. *a)* Schematic diagram of transfer functions in Afar region for periods 10 min to 3 hours (after Berktold et al. [14]). *b)* Maximum and minimum response functions in Kenya ——— for $T = 8$—16 min (after Beamish [11]), - - - - - for $T = 1000$ sec. (after Rooney [72]). *c)* Real transfer functions for $T = 26$ min and $T = 128$ min in S. Africa (after de Beer [22]). *d)* Real transfer functions for $T = 26$ min and $T = 128$ min in S.W. Africa, Botswana and Zambia (after de Beer [22]). Note that the vectors are all plotted on the same scale but that the regions are not

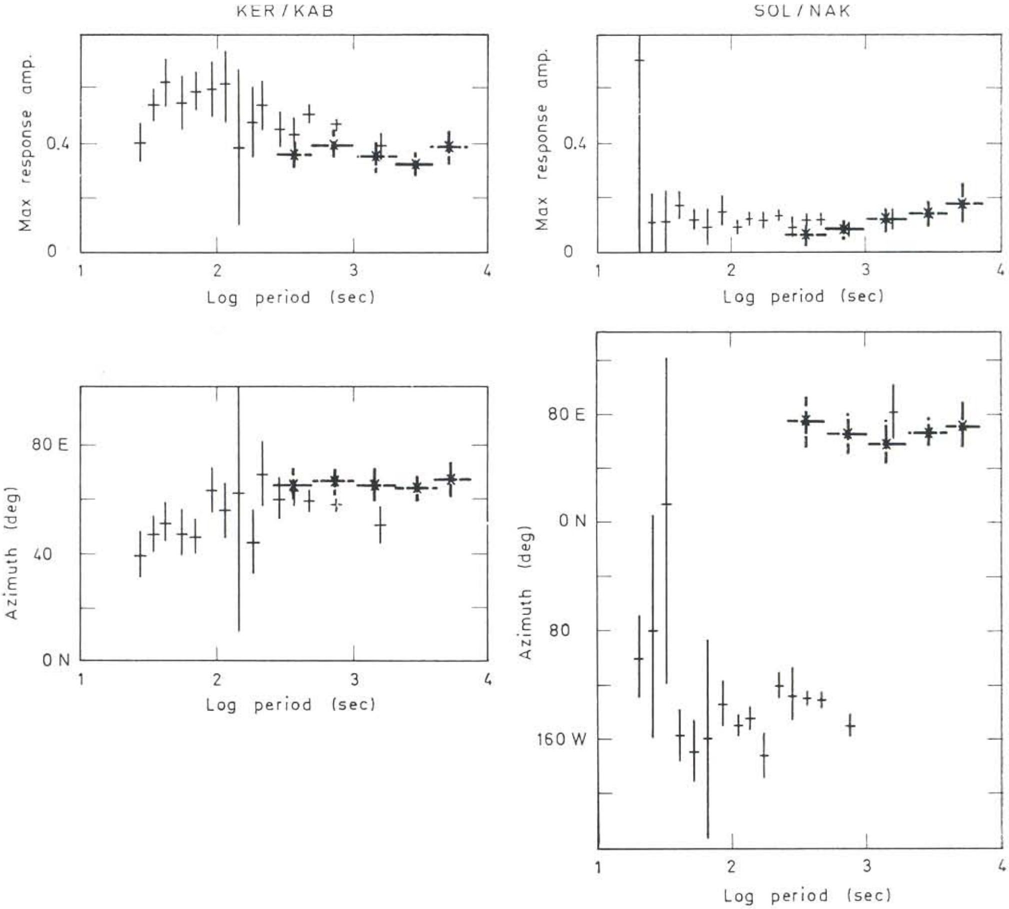


Fig. 5. The frequency dependence of real induction vectors obtained around the Gregory Rift Valley — compiled from the data of BEAMISH [11] and ROONEY [72]. ROONEY's results for Kericho (KER) — a site approximately 70 km west of the Rift Valley — and BEAMISH's results for the near-by site of Kabianga (KAB) have been used in the KER/KAB graphs; for the SOL/NAK graphs, ROONEY's results for the Rift Valley site of Solai (SOL) have been plotted along with BEAMISH's Rift Valley results from the nearby site of Nakuru (NAK)

Using the modelling programmes of PASCOE and JONES [58], he attempted to model the results along the equatorial profile, regarding them as representing a two-dimensional situation. From a total of about 2000 models considered, he reached the following general conclusions:

(i) that the anomalous vertical and horizontal magnetic fields can be satisfactorily modelled by two distinct regions of enhanced conductivity provided that, for the longest periods, allowance is made for resistive current channelling.

(ii) one of the two conducting regions is at a depth of 20—35 km beneath the Rift axis. Its conductivity is 10^{-1} Sm^{-1} and its width is more than 20 km greater than the separation of the bounding faults of the Rift.

(iii) the second conductor has a conductivity of 0.5×10^{-2} Sm^{-1}. Its western edge is about 60 km east of the eastern escarpment, its upper surface is at a depth not less than 150 km, its minimum thickness is about 100 km and its lateral extent greater than 100 km. Reference to ROONEY's magnetotelluric study is limited here to those parts of his study which best complement BEAMISH's study and those where there is significant divergence in actual observations, data analysis techniques and interpretation. Of the 14 sites at which magnetic and telluric observations were recorded in the period band 10—1000 seconds, 11 of these were located along the same equatorial traverse for which BEAMISH undertook his two-dimensional modelling. Considering the magnetometer data first, it should be noted that ROONEY's observations covered a period range which overlapped with that of the magnetometer array study as shown by the response functions for $T = 1000$ seconds plotted in Fig. 4(b). They also provided response functions down to 10 seconds. There is in general very good agreement in amplitude between the two sets of response functions but the slightly greater parallelism of the functions obtained by ROONEY may be due to his adoption, as one of his acceptance criteria, of a predicted coherency > 0.7 for measured Z as against the 0.5 used by BEAMISH. Figure 5 collates the maximum response function amplitudes and azimuths obtained by the two studies for representative locations — one towards the western extremity of both studies, KER/KAB and one within the rift itself, SOL/NAK. At these stations, the continuity of the values illustrates how well the two projects have *complemented* each other. Attention is also drawn to several points of interest in these and other plots of the frequency dependence of the transfer functions and phases, viz.:

a) The very low values for all periods at the rift station SOL/NAK suggest a conductor beneath the station from near surface to mantle depths.

b) The very large values and the direction of response at KER/KAB, especially for the shorter periods, can be interpreted as resulting from the influence of the Kavorindo Rift and Lake Victoria. At longer periods they result from the more distant effect of the Gregory Rift.

c) At the rift station LON, the increase in response for periods greater than several hundred seconds from very low values to about 0.4 suggests that the conductor terminates at shallower depths than at SOL and that LON is near the southern extremity of the rift axial conductor.

d) The decrease in response at NAN to very small values at the very long periods may support the proposal of a conductor at depth beneath this station or may indicate a gradual volume integrated rate of change of conductivity towards the east.

In his thesis ROONEY emphasizes the problem of interpreting anisotropic magnetotelluric data, especially for stations on the resistive side of a vertical conductivity discontinuity where the more useful apparent resistivities are probably the $\varrho_{\min}$ estimates. As a result he concentrates on the interpretation of his MT sounding curves for the Rift Valley stations where the apparent resistivities are predominantly isotropic and have minumum scatter; he discusses his MT results along the equatorial traverse in a qualitative manner only. He also attempted limited mathematical modelling of his results using the two-dimensional modelling programmes of **Jones** and **Pascoe**. His deductions differ considerably from those reported by **Beamish** in that he finds that his MT data for the Rift Valley are broadly consistent with a conductor ($\sigma \sim 10^{-1}$ Sm^{-1}) extending from a depth *less than 15 km to depths greater than 40 km.* He finds that neither a surface conductor only nor a single conductor at depths > 15 km fits the apparent resistivity data or satisfies the frequency dependence of the induction response data and concludes that the magnetotelluric data provide evidence — which is for the first time independent of other geophysical or geological data — for the existence of high conductivities at depths corresponding to the upper mantle below the Gregory Rift Valley. Both **Rooney** and **Beamish** interpret the upper mantle conductor under the rift valley in terms of partial melting and **Rooney** considers that the high conductivity he has detected there at upper crustal depths may require high temperatures and water saturation of the crust.

In his review at the Ottawa Workshop, **Garland** illustrated the correspondence between **Banks** and **Ottey**'s conductivity model and their summary of seismic and gravity information for an equatorial traverse of the Gregory Rift. As **Fairhead** [28] has more recently published additional gravity data for Kenya, it is interesting to examine the correlation between his gravity contours and the more extensive magnetometer data now available. Figure 6 shows **Fairhead**'s Bouguer anomaly over the Eastern rift contoured at 200 g.u. intervals, with **Beamish**'s maximum response functions of Fig. 4(b) superimposed. **Fairhead** interprets this regional gravity anomaly in terms of an upward thinning of the lithosphere and replacement by low density asthenosphere in a zone striking east of north and of width 350 ± 50 km. Thus the gravity data and, as shown by several authors (e.g. **Sundaralingham** [75]; **Long** et al. [53]) the seismic data support the deduction from the electromagnetic induction studies that the anomalous upper mantle beneath the rift is in a state of partial melt. It can be seen that the Longonot—Nairobi area lies to the S-W of the maximum gravity anomaly in a region with marked space gradients in the gravity field both parallel and perpendicular to the strike of the Rift Valley. As the skew factor of the magnetotelluric impedance tensor was found to increase rapidly at LON with increase in period, indicating an increasing departure from 2-dimensionality, it is suggested that the anomalous directions and abnormally large response functions in this area may be

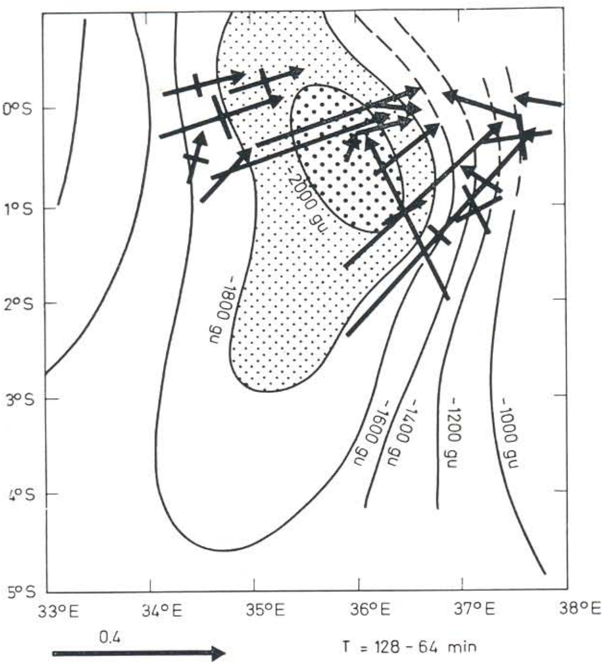


Fig. 6. The regional Bouger anomaly contours for Kenya (after Fairhead [28]) with induction vectors superimposed

caused by a very rapid increase in depth to the top of the asthenosphere in this region accompanied by considerable curvature of the depth contours of the asthenosphere surface.

The first magnetometer array study in S. Africa [35] was discussed at the Ottawa Workshop by Garland. He drew attention to Gough's (1973) suggestion that the east-west striking anomaly detected by this study, being associated with a negative isostatic gravity anomaly, may be the result of an east-west linear plume. This suggestion has since been rejected by de Beer and van Zijl [23] who argue that the Beattie Ridge magnetic anomaly, which lies to the north of and is parallel to the Cape Fold Belt and the conductivity anomaly, cannot be explained in terms of the linear plume hypothesis. They prefer the hypothesis that the induction anomaly is due to a compositional difference between the lithosphere in the Kalahari craton and the younger lithosphere further south, the Cape Fold Mountains resulting from a continent—continent collision and the long linear Beattie magnetic anomalies from the subduction of large slabs of oceanic crust near the continental margin. De Beer [22] has attempted to model the Cape Fold Belt anomaly using the two dimensional programmes of Jones and Pascoe (1971, 1972) although, as can be seen from the induction vectors plotted in Fig. 4(c) the array covered

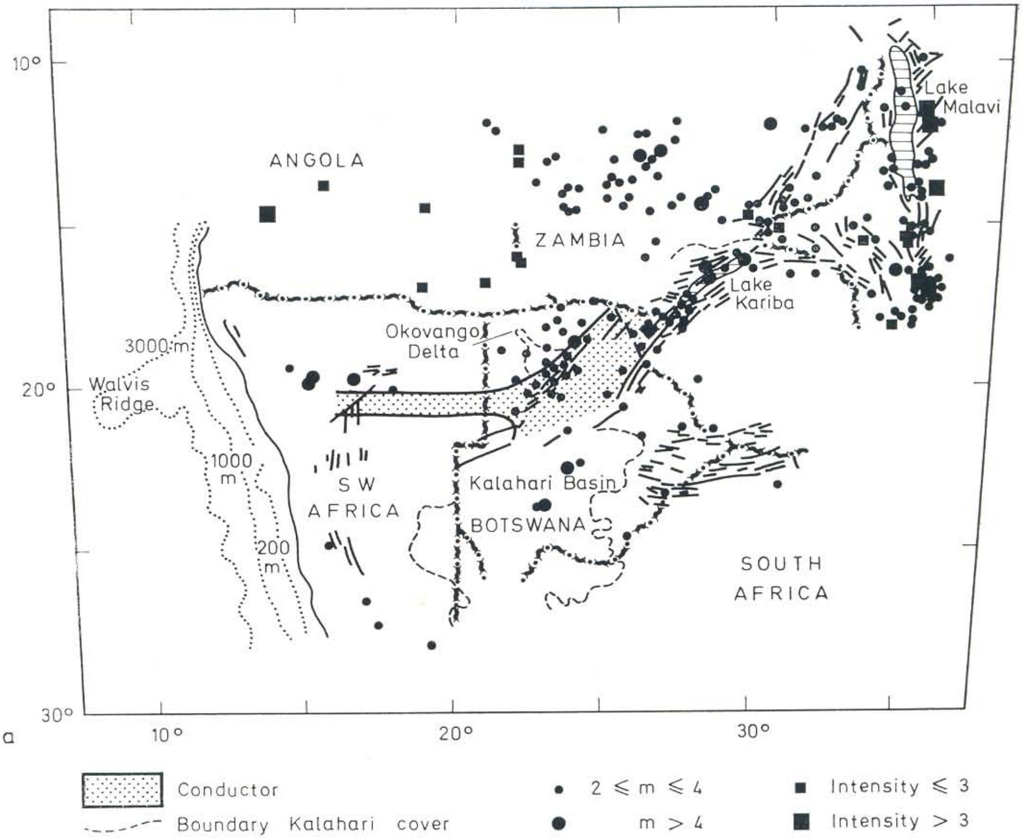


Fig. 7a, b The conductor proposed by DE BEER et al. [24] in relation to seismicity and tectonics of southern central Africa. Small dots, $2 \leq m \leq 4$; large dots, $m > 4$. Small squares, intensities ≤ 3

only about half the width of the anomaly. He examined 35 different models, using near surface resistivity values which had been determined from deep structural electrical investigations, deep drillings and seismic reflection work. For none of the models computed could he match the observed frequency response by the model calculations, and he concluded that the anomaly could only arise by induction in a two-dimensional structure if an amplifying effect due to current concentration or constructive interference were assumed. The results of the second magnetometer array study in S. Africa, presented in a progress report at the last Workshop, have now been discussed more extensively [24, 22]. The real and imaginary induction vectors from this study for periods 26 and 128 minutes are shown in Fig. 4(d). The proposed zone of concentrated induced electric currents at crustal depths, deduced from these and other sets of transfer functions, from magnetograms, from maps of Fourier

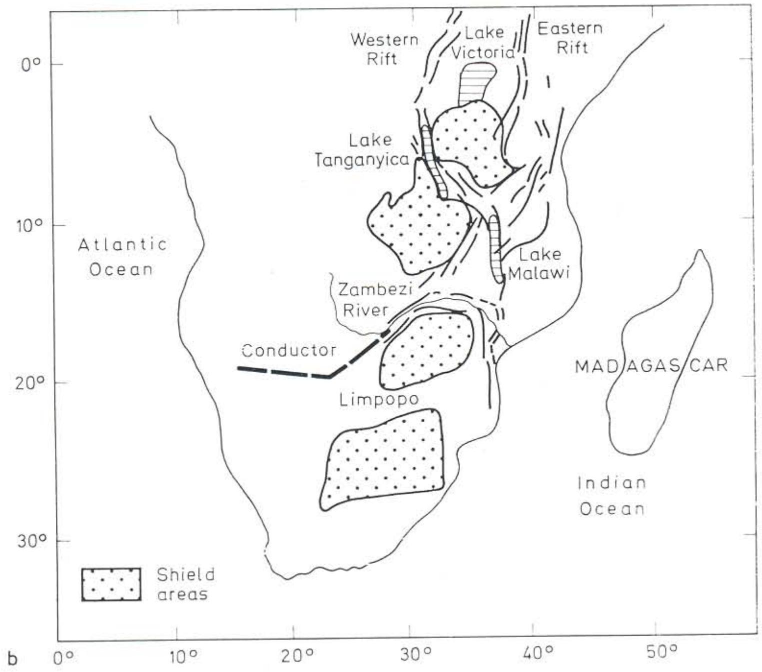


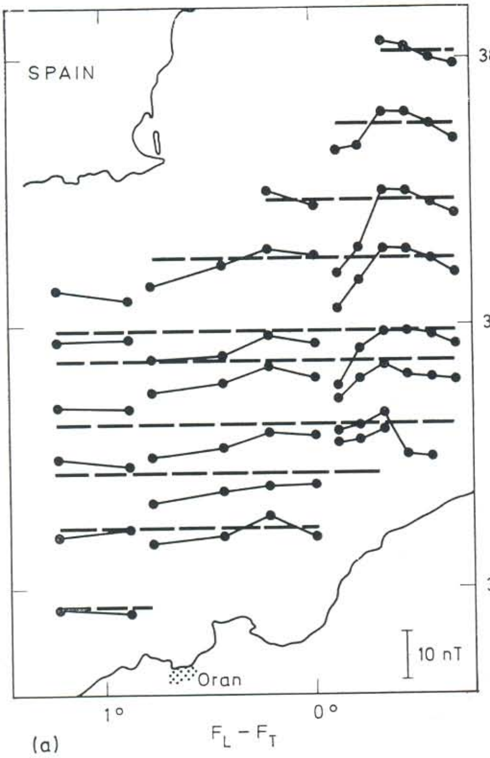
Fig. 7b

transform amplitudes and from profiles of normalized anomalous fields, is also indicated in these maps. In South-West Africa, where the conductor is covered by the array, the width of the anomaly is less than 100 km but when it curves north-eastward in Botswana, the conductive zone is wider, perhaps as much as 250 km. De Beer et al. [24] considered all available geophysical and geological evidence from the area to deduce that the conductive zone detected by this study is an extension of the African Rift system along old weak zones in the lithosphere. The evidence they consider is illustrated on the maps — Figs 7 a and b — where it can be noted that the location of the proposed conductor is associated with seismicity and faults, especially from Kariba to the Okavanga delta. They suggest that the Kalahari cover may obscure evidence of fractures along the westward arm which strikes in the direction of the Walvis Ridge. Goslin et al. (1974) have proposed that the Ridge is either a transformfault or some tectonic process following an older line of weakness. At this stage, it is interesting to examine together the maps of transfer functions from the four recent array studies in Africa — Fig. 4. It will be noted from the relative amplitudes of the transfer functions that in all studies, except that in South-West Africa and Botswana, anomalous current distributions are indicated over the whole period range studied, indicating, anomalous conductivities exist to upper mantle depths in the Afar Depression, in Kenya and near the Cape Fold Belt. Further, in these latter two regions, the existence of transfer functions as large as 0.5—0.7 suggests that acceptable interpretations must involve 3-dimensional modelling and perhaps current channelling also.

The final African study to be considered employs a completely different and novel technique in that by very careful analysis of the differences in the values of the total field intensity F, measured with an optical pumping magnetometer at the cross points of the flight and tie lines of an aeromagnetic survey, it has been possible to examine transient variations in F with periods in the range from several minutes to several hours. The possibility this technique opens up for the study of lateral variations in conductivity under the seas is very attractive in view of the experimental difficulties and expense of more conventional sea-bottom techniques. Le BORGNE and Le MOUEL [50, 51] have discussed their data reduction procedures in their recent publications. An example of the results of their examination of aeromagnetic survey data from the Western Mediterranean is given in Fig. 8 a. The transient variation anomaly which is clearly seen in this figure was also detected from the data on other days and has led the authors to the interpretation — illustrated in Fig. 8b — that there is an anomalous conducting channel, probably in the upper mantle, striking ENE-WSW through the Alboran Sea. They also suggest that it might be linked with the upper mantle conductor in North Morocco proposed by KIEFER following a study of geomagnetic variation data from total field measurements at Ouezzane and Kanoul and, H, D and Z variations at the observatories of Averroes and San Fernando and discussed more fully at the Sopron Workshop [55]. Le BORGNE and Le MOUEL draw attention to the association of their proposed conductivity anomaly and a recent study of the distribution of earthquake epicentres. It suggests a complex system of plate boundaries in the area. There are several lineations apparent in a 250 km wide seismically active zone and the proposed deep conductor is parallel to, but off-set from, one of them.

Eurasia

Reviews of the many induction studies which have been undertaken in this region prior to the present decade have been published by UNTIEDT [79] for Central and Southern Europe, by ADAM [2, 3] for the Carpathian Basin, by PĚČOVA et al. [59] for Czechoslovakia and are included in LAW and RIDDIHOUGH's [49] discussion of the tectonic environments of the geomagnetic variation anomalies. Very useful references, particularly to work in the USSR and Eastern Europe, are also to be found in recently published monographs



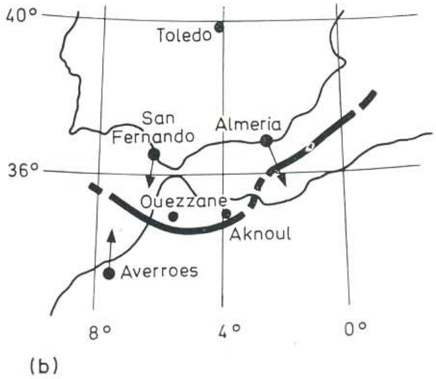


Fig. 8a. The differences $F_L - F_1$ observed on lines flown across the W. Mediterranean on August 25 and 26

Fig. 8b. Location of proposed deep seated conductor (after LE BORGNE and LE MOUEL [51])

by PORSTENDORFER [61] and ROKITYANSKY [71], in KELLER's [46] survey of the literature on electrical properties of the Earth's crust and in PRAUS's (1975) presentation at the Grenoble Assembly to the IAGA interdivisional working group on relations between external and internal fields. For the Baikal Rift, a very comprehensive bibliography of geophysical studies reported in Russian has been prepared by VLADIMIROVA [80].

At the Ottawa Workshop, Garland discussed the results of induction studies in the Rhinegraben by WINTER [81] and HAAK et al. [38] pointing out the association between seismic low velocity layers in the lower crust and upper mantle in the graben and a conducting layer ($\sigma \sim 3 \times 10^{-2}$ Sm^{-1}) at a depth of 20—30 km and thickness up to 90 km. LOSECKE [54] and SCHEELKE [74] obtained somewhat similar interpretations for their data from the same region. REITMAYR [66] has now completed the analysis of a combined MT and GDS study along a profile perpendicular to the graben and to the south of the profile of the previous studies (Fig. 9 a). For the telluric and magnetotelluric observations at sites 50 km to the west and 100 km to the east of

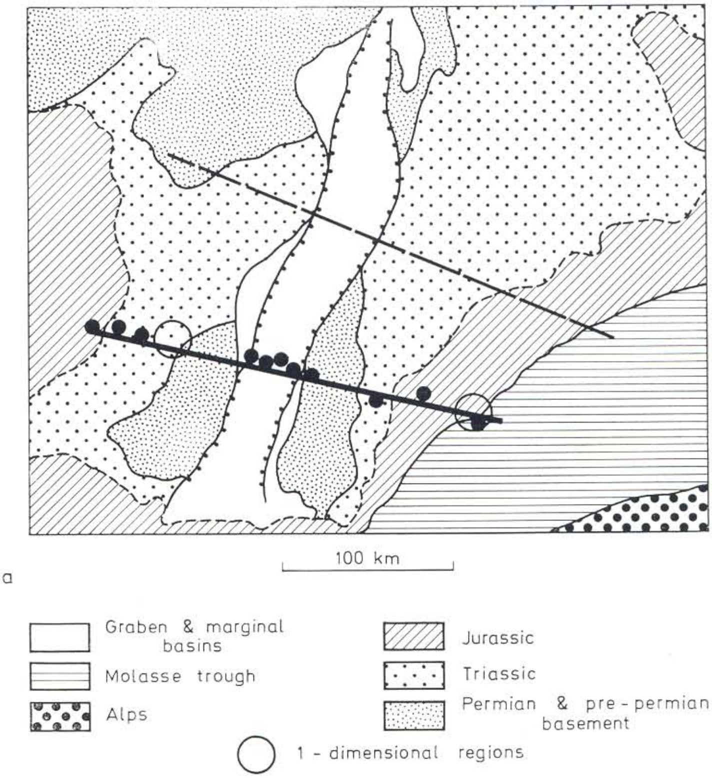


Fig. 9a. Location of Reitmayr's induction studies across the Rhinegraben

the graben Haak and Reitmayr [39] found that they could satisfactorily employ Cagnaird's method of interpretation or Schmucker's 1-dimensional inversion technique. Reitmayr then used the best model obtained in this way as a starting point for two-dimensional modelling of the induction vectors across the profile. He found that he could not get reasonable agreement between observed and model values unless he introduced below the graben itself an additional conductor ($\sigma \sim 2 \times 10^{-2}$ Sm^{-1}) at depths of 25—45 km and width a few tens of kilometres. Its exact geometry could not be resolved as can be seen from his most acceptable model — Fig. 9 b. None of his probable models suggests conductivities as great, or as at as shallow depths, as has been found in the Kenyan or Ethiopian Rifts. His models are, however, in reasonable agreement with those which satisfy observations made over the more northern Rhinegraben profile.

Recent seismic investigations of the Rhinegraben rift system ([26], Illies [44]) suggest that the depth to the crust-mantle boundary in the region covered by Reitmayr's study increases from about 25 km within the rift itself

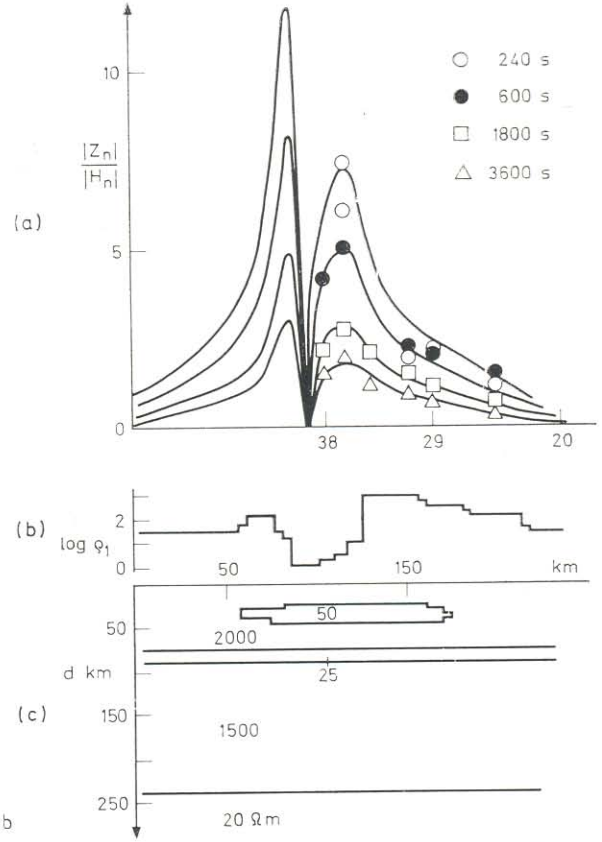


Fig. 9b. Conductivity model for the S. Rhinegraben (after Reitmayr [66])

to about 28 km at the profile's eastern extremity. It would be of interest to know whether the agreement between these values and the model structures discussed by Reitmayr are coincidental or not.

As references to the many induction studies in the USSR are available elsewhere, only a few reports in the English language are mentioned here. As seen in a simplified tectonic map of the region — Fig. 10, two of the studies discussed by Keller [46] are concerned with induction studies across the Baikal Rift Zone. The results of the very extensive magnetotelluric soundings discussed by him and by Berdichevskiy [13] are summarized in Table I, together with those from profile CC to the north-east of Lake Baikal and from a meridional profile across the eastern part of the South Caspian Depression. The importance of careful study of anisotropic magnetotelluric apparent resistivities is illustrated by comparison of the longitudinal and transverse ϱ_a versus $\sqrt{T}$ curves obtained in projects 3 and 5 — Figs 11 a and b. The interpretations are also illustrated in this Figure and are based on the E-polariza-

Table I

Results of Magnetotelluric Soundings in the Lake Baikal Region and South Caspian Depression

Project Location	Investigators	Results	Remarks
1. Profile E–E Fig. 10	Portnyagin [62]	Conducting layer at depths of 34 to 50 km	Tensor impedances?
2. Profile E–E Fig. 10	Pospeev et al. [63]	Depth to conducting layer in mantle decreases from 120—130 km to the west to 30—60 km near Lake Baikal	Tensor impedances?
3. Profile C–C Fig. 10	Berdichevskiy et al. [12] Berdichevskiy et al. [13]	A conducting layer at depths of 15—19 km and a second at depths ≥ 250 km	Interpreted upper conducting layer which coincides with Conrad discontinuity as due to presence of water liberated during dehydration in granitization of rocks at these depths. Interpretation based on longitudinal MTS curves
4. Profile A–A Fig. 10	Gornostayev [32]	Distance from Rift Depth of Conducting layers 500—350 km 100 km only 350—120 km a) 40—60 km b) 200—250 km 120—0 km a) 10—20 km b) 140 km	Tensor impedances? The conducting layer at shallow depths in the Rift attributed to partial melting associated with high heat flow
5. Meridonial Profile across the South Caspian Depression and Kara-Kum Plateau	Berdichevskiy et al. [13]	A conducting layer at a depth of 40—60 km terminating on the transition from the South Caspian Depression to the Kara-Kum Plateau	Interpretation based on longitudinal MTS curves. The upper mantle conductor at 40—60 km attributed to partial melting-hypothesis supported by increased geothermal activity in Depression

tion data. For project 5, the interpretation is also supported by laboratory model studies.

The most recent and most comprehensive collation of GDS data for Europe as a whole has been undertaken by RITTER [70]. This includes reference to at least 15 projects reported within the past 5 years. Although

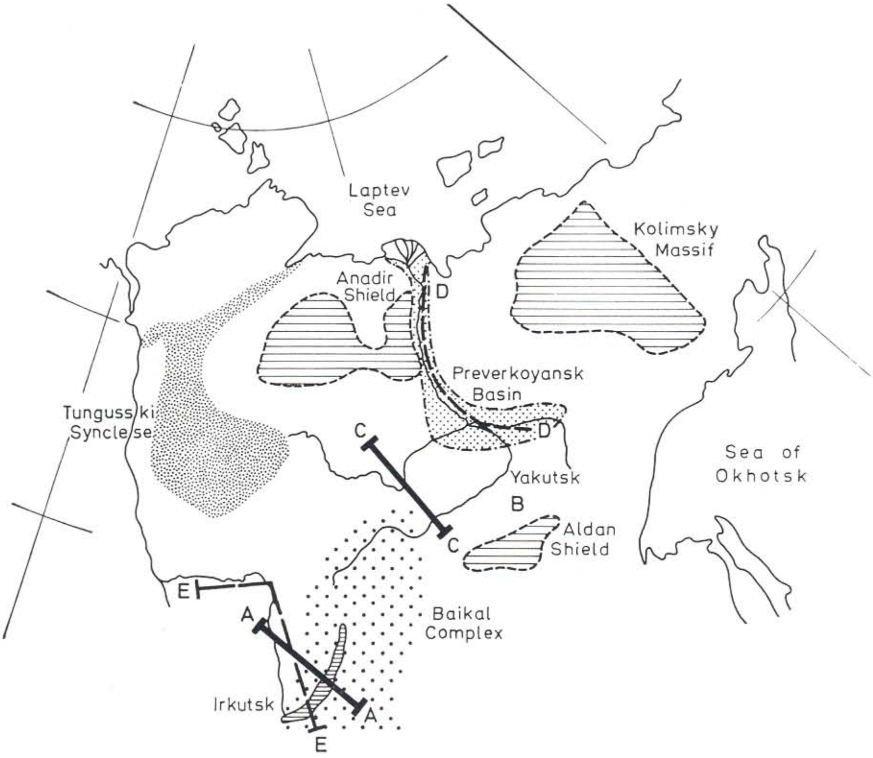
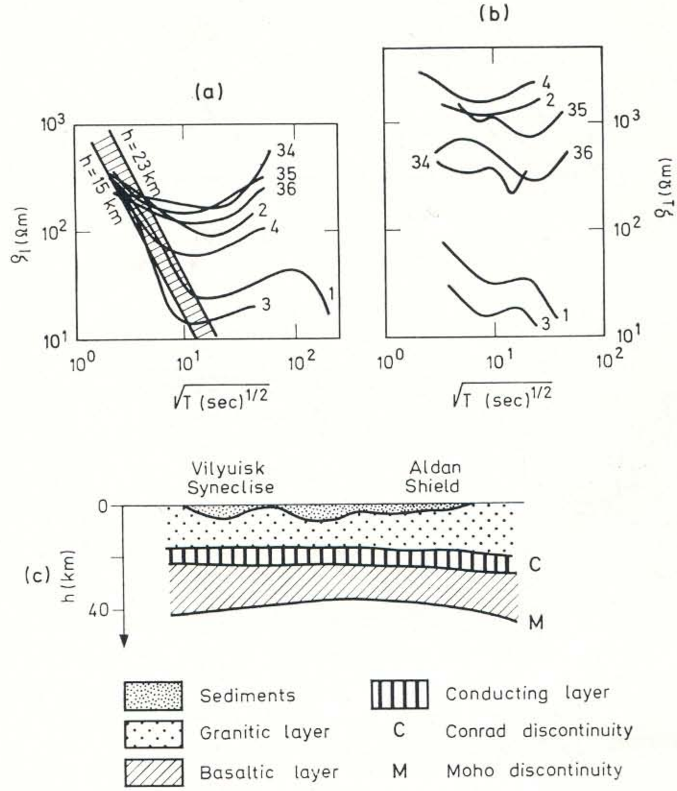


Fig. 10. Location of induction studies in the region of the Baikal Rift, U.S.S.R. (after KELLER [46])

he depicts the collated data on a map (his Fig. 2) on which the Wiese vectors and proposed conductivity anomalies are located, he draws attention to modelling problems resulting from the presence of vertical conductivity discontinuities and to the complications which could be associated with HURTIG et al.'s [43] hypothesis of convective heat transfer along deep faults. Fig. 12 a shows the location of the European anomalies — not the Wiese vectors — discussed by RITTER. It also contains a schematic representation of the location of the rifts in the northern European seas, as derived from seismic soundings. Consideration of the effect of these troughs may be important in the interpretation of induction studies in this region. Fig. 12 b shows the close association of regions of high heat flow and the location of the Rhinegraben and North German conductivity anomalies. Extensive magnetotelluric soundings in Hungary by Ádám and his colleagues [1, 3, 4] have similarly been interpreted as indicating a correlation between an upper mantle conductor at a depth of 45—85 km in a region of abnormally high heat flow. They also refer



a

Fig. 11a. Apparent resistivity versus $\sqrt{T}$ curves for Yakutsk profile

to the strong anisotropy exhibited by the MT data at most sites. Figure 13 a shows the results of *(a)* a deep seismic sounding of the region, *(b)* the heat flow studies and *(c)* the MT interpretation. Figure 13 b is an interesting schematic illustration of their suggested mechanism for the evolution of the Pannonian Basin, viz. *a*) the subduction of 2 plates at the margins of a microplate *b*) the accumulation of heat due to friction causing partial melting in the upper mantle *c*) the rise of the partially melted material, with it breaking through in a few places but generally resulting in subcrustal erosion and d) the isostatic sinking of the thinner crust. Praus et al.'s presentation at Grenoble

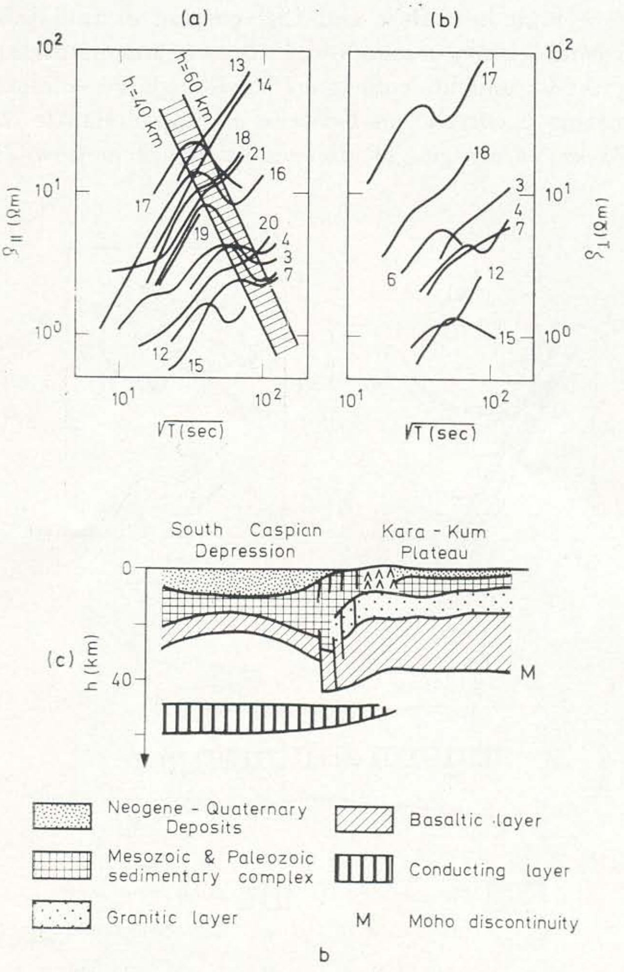


Fig. 11b. For South Caspian depression (after Berdichevskiy et al. [13])

covered the most recent of the intensive GDS and MT studies in the Western Carpathians—these were located along two profiles through Poland and Czechoslovakia along which deep seismic sounding had been undertaken. In general, they found it difficult to interpret the MT data due to their anisotropy, although they found both ϱ_a curves were one order of magnitude less than for other sites at one station along each of the two profiles. They separated the GDS data into internal and external parts and used techniques developed by Jones's group, and also by their own groups, to attempt to model their data for the E-polarization case, but were not completely successful in obtaining good agreement at all frequencies. Discussion of relevant new work in other Eur-

Fig. 12a. A map of Europe showing (i) the location of the conductivity anomalies indicated by available Weise vectors (after RITTER [70]) and (ii) a schematic representation of the position of the rifts in the North Sea as suggested by seismic investigations

asian countries cannot be included in this paper but publications of papers contributed to the Sopron Workshop will complement this review in this respect and will also provide information about the most recent work in the regions to which reference has been made.

Other regions

GOUGH [33, 34] and GARLAND [30] have previously reviewed, in relation to tectonic processes, the extensive induction studies which have been undertaken in Japan, the Peruvian Andes, Iceland, Western North America, Eastern Canada and Southern and Eastern Australia. A more detailed review of electrical conductivity under Western North America in relation to heat flow, seismology and structure has also been published by **Gough** [36]. Reference to these regions is thus restricted here to work relevant to the topic of this paper and published within the past two years. For the sake of brevity, the results are presented in tabular form — Table II.

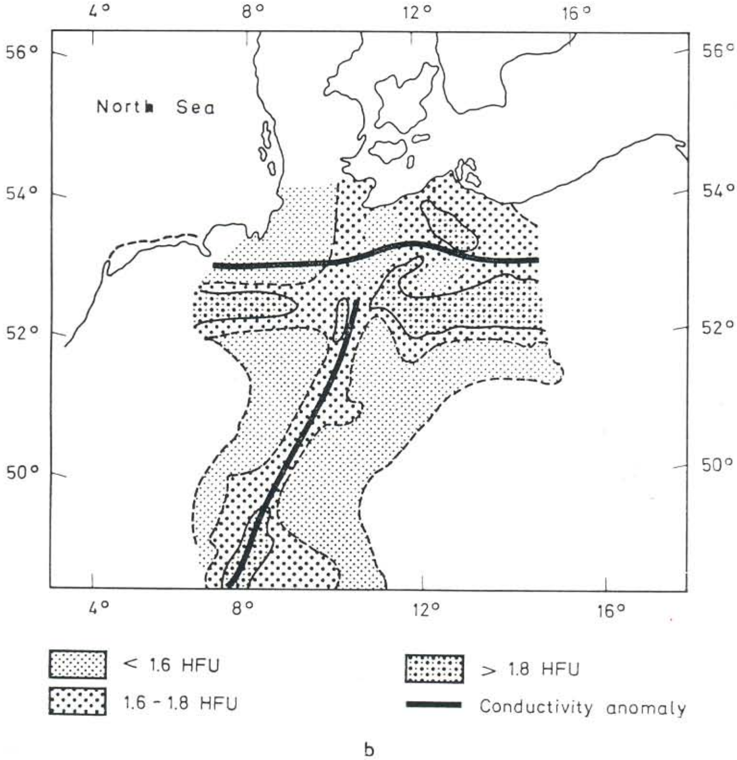


Fig. 12b. Location of heat flow anomalies in Europe with the axes of the conductivity anomaly (after **Hurtig** et al. [43])

It is also interesting to recall the results of two of the studies previously reviewed, in view of their correspondence with the results of the recent investigations in East Africa. In the first case, induction studies in Iceland [40, 77] have indicated at certain sites a conductivity of the order of 3×10^{-2} Sm^{-1} extending from depths less than 5 km to upper mantle depths — an interpretation comparable to that suggested by **Rooney** for the Gregory Rift Valley and **Berktold** for the Afar Region of Ethiopia. Secondly, the apparent resistivity versus period curves obtained by **Tammemagi** and **Lilley** [76] from a magnetotelluric traverse of the Adelaide Geosyncline and the in-phase induction vectors obtained from a two-dimensional array study of the same region

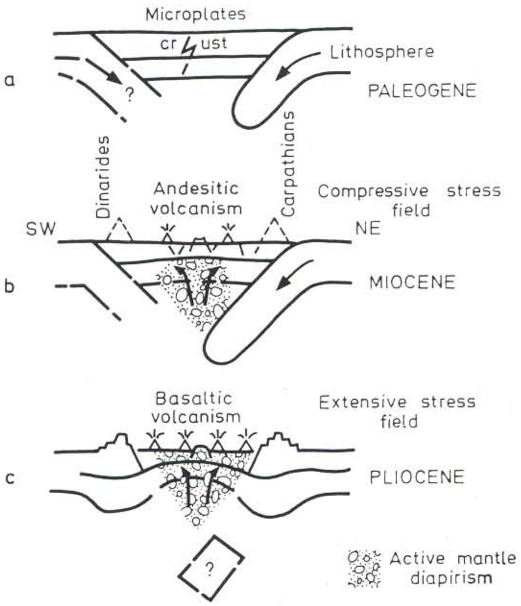


Fig. 13a, b, c Schematic diagram of the evolution of the Pannonian Basin (after ADAM et al. [4])

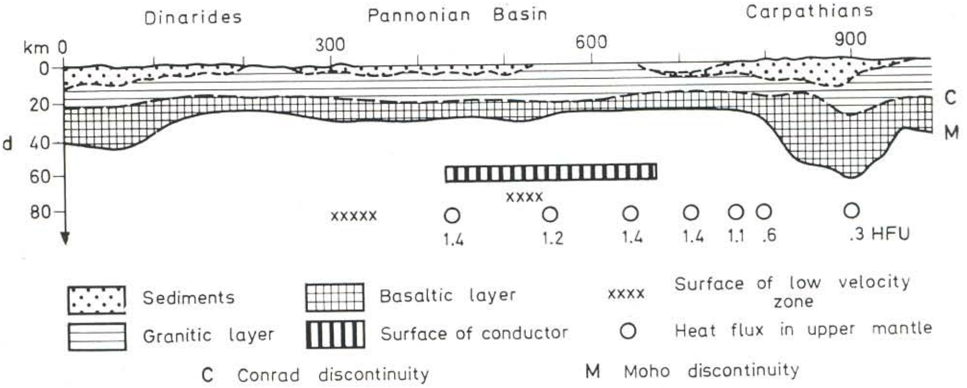


Fig. 13d Collation of the results of seismic, heat-flow and induction studies along a profile across the Pannonian Basin

by GOUGH et al. [36] show some striking similarities with the results of the recent Kenyan MT and GDS projects. It would be interesting to check whether the range of possible models suggested for the latter region would also satisfy the Australian data.

Table II

Notes on Some Recent Induction Studies in the American Continent and Japan

1. *Atlantic Canada:* MT and G.D.S. study [21]

   Main results: In phase and quadrature transfer functions presented for 13 stations for periods from 5—120 min. MT data also given but not possible to interpret due to strong anisotropy.

   Remarks: Transfer function modelling suggests a highly conductive deep crust and mantle under the Apalachian system with preferred interpretation that anomalous conductivity arises from hydration processes associated with low grade tectonic subsidence.

2. *Western Canada:* MT and G.D.S. study [25]

   Main results: Paired station transfer functions and single station vertical transfer functions presented for 7 sites in the region of the Rocky Mountain trench for periods of 5—120 min. In phase and quadrature induction vectors plotted for 15 sec to 120 min.

   Remarks: The trench acts as a near surface 2-D conductor, depth 1—2 km and $\sigma \sim \sim 10^{-1}\,\mathrm{Sm}^{-1}$. The conducting layer proposed by Caner and Gough to underly the western Cordillera appears to be at or *to dip to* 40—50 km beneath the trench. A third conductor strikes perpendicular to the I-transition zone and appears to be associated with a possible buried Precambrian rift.

3. *North American Central Plains:* G.D.S. 2-D array study [5]

   Main results: Maps of horizontal field polarizations and Fourier transform amplitudes and phases presented for several periods for 41 stations between latitudes 42° and 54°N and longitudes 98° and 109°W.

   Remarks: The North American Central Plains crustal anomaly [20] was found to continue northward to within 90 km of the exposed Canadian Shield where it is parallel to the strike of fold belts and fault zones in metamorphic rocks. It is postulated that it may be linked in the south with the mantle conductor under the Southern Rockies and that the linear crustal structure now mapped over 1800 km may be a major continental fracture zone.

4. *S. America:* G.D.S. Studies *a)* 2-D array and *b)* linear array [6, 7]

   Main results: a) Argentina—Chile: Vertical transfer functions increase towards the coast for periods between 15 and 60 min.

   b) Chile—Bolivia: Vertical transfer functions vary in amplitude across the array with maxima at the extremities.

   Remarks: Progress report.

5. *North-West U.S.A. and South-West Canada:* G.D.S. 2-D array study [19]

   Main results: Magnetograms presented from 31 stations between latitudes 44° and 51°N and longitudes 100° and 121°W for a magnetically quiet 5-day period. Maps of amplitudes and phases of Fourier transforms prepared from this data for periods of 8, 12 and 24 hours and also for 25—1440 min for the vertical component.

   Remarks: The North American Central Plains anomaly persists in the Z but not the Y component at periods of 8 and 12 hours. At 24 hours the amplitude maps show features not apparent at shorter periods. These are attributed to induction by X of currents in the highly conducting upper mantle under the Basin and Range province to the south and the variable transmission of the fields due to these currents through the electrically heterogeneous upper mantle and crust. To the west of the Northern Rockies, a best fit conductivity profile has a conductive layer 15 km thick, in a depth range 50—100 km which is not present in the Great Plains profile.

6. *East Central U.S.A.:* G.D.S. linear array [27]

   Main results: The real part of the normalized vertical field variations at periods of 16 min and 1 hour are plotted as functions of distance from the continental margin — for 1 hour corresponding values are given for other coasts. The "coast effect" in Eastern U.S.A. is surprisingly small and there is a marked Z reversal *inland* from the coast.

   Remarks: The results have been interpreted in terms of 2-D conductivity models. The data could not be modelled satisfactorily with conductors confined to the upper mantle. The best fitting model for all periods consisted of a conductor in the middle to lower crust with σ increasing from 5×10^{-2} under the Coastal Plains to 5×10^{-1} Sm^{-1} under the continental craton. The results support the idea of LAW and RIDDIHOUGH [49] that anomalies in tectonically inactive regions may indicate ancient zones of orogeny and subduction.

7. *Hawaiian Islands:* Magnetic and electric field observations on Oahu Island over 22 months [48]
   Main results: The E and B transfer functions are estimated in the frequency range 0.1 to 12 c.p.d. and by the use of polynomials are constrained to vary smoothly with frequency. The harmonics of the daily variation and the tidal variations are excluded from this representation.
   Remarks: As the island effect is found to be frequency independent with zero phase shifts for frequencies less than 6 c.p.d., one-dimensional inversion techniques can be applied. A conductivity versus depth profile with a near surface σ of 8×10^{-2} Sm^{-1} increasing to $8\times10^{-1}\,\mathrm{Sm}^{-1}$ at 700 km fits all the observations. At 330—380 km, there is a definite zone of enhanced conductivity which may be associated with a mantle plume. For depths more than 100 km conductivities $> 5\times10^{-2}$ Sm^{-1} have also been obtained recently for the north-west Atlantic Basin [60].

8. *Japan:* Theoretical modelling [69]
   Results: Numerical estimation of electromagnetic response of a conductive half-space with a triangular depression in its surface.
   Remarks: This model appears to be in good agreement with the characteristics of the observed geomagnetic variations of periods of a few tens of minutes. It is not claimed as unique but it is claimed that the value of conductivity beneath the Japan arc must be lower than that under the adjacent seas.

9. *Long Valley, California:* Audio magnetotelluric study [42]
   Results: Measurements of magnetic and telluric variations at 25 sites in the Long Valley caldera where extensive geothermal studies were being made. The equipment operated in the 8—18,000 Hz range and the results were presented in the form of contoured maps of apparent resistivity at specific periods.
   Remarks: Two linear zones of low resistivity were outlined by this study — these correlate with known hot springs in the area. There was generally good agreement with the results of other methods. While the conductors were well located, the depth resolution was poor — no interpretation in terms of a layered structure was attempted in view of the anisotropy apparent in the observations at most sites.

10. *Eastern Canada:* Magnetotelluric study [47]
    Main results: Magnetotelluric observations are reported from 16 sites from a region including part of the Canadian Shield and the Appalachian system. Apparent resistivity values in the major and minor axis co-ordinate system, skew values, phase estimates, azimuths etc. are plotted over the approximate period range 100—3,000 sec for each station.
    Remarks: Interpretation is based on 2-D modelling for profiles *a)* perpendicular to the St. Lawrence River, *b)* in N. W. Newfoundland and *c)* across Prince Edward Island. This leads to a resistivity section for the whole region from the Grenville shield across the Appalachians. Beneath the Shield, the lower crust is relatively conductive and the upper mantle resistive while in the S. E. Appalachians the upper mantle is the more conductive. The boundary between the 2 profiles lies to the S.E. of the Shield boundary and may be associated with the site of a proto-Atlantic ocean.

Discussion

At this stage, an attempt could, and perhaps should, be made to order the results and deductions of the studies discussed in this review. There appears to be little doubt that there are associations between tectonic processes and the existence of conductivity anomalies in the crust, in the upper mantle, or in both, as has been suggested — normally in a tentative manner — by many authors. However, in view of the problems generally associated with the interpretation of induction studies — listed in the introduction to this paper —, it is considered unwise at the present time to search for conductivity profiles which may be characteristic of a particular type or age of tectonic activity. Instead, it is suggested that previous studies should be extended in such a manner as to provide as unique conductivity interpretations as possible independent of other considerations. For this purpose, a suggested plan of action is as follows.

a) A GDS survey should be undertaken with preferably a two-dimensional array of magnetometers so that spatially variable source fields can be accounted for.

b) Wide-band magnetotelluric sounding should be made in locations — indicated by the array study — suitably distant from lateral inhomogeneities. Audiomagnetotelluric or d.c. sounding at the same sites and the operation of satellite telluric stations as recommended by HERMANCE and THAYER [41] would aid the interpretation of the MT data. All three components of the magnetic field should be recorded so that analysis of the magnetic data alone could compliment that of the magnetotelluric sounding.

c) The interpretation of the data should account for *all* the data obtained, e.g. the frequency dependence of the amplitude *and* phase of the transfer functions.

d) One- or two-dimensional modelling of the data should only be undertaken for locations where there is satisfactory evidence, e.g. from the magnitude of the skew factor, that it is valid. The temptation to present a model for the results obtained from an induction study is understandable but even although it may be accompanied by a statement of its non-uniqueness, there is a danger that it will be carried forward in the literature as the real situation. The author does not claim originality for these proposals, but considered them sufficiently important to merit repetition. With these ideas in mind, it might be useful to conclude with some suggestions — again using the African continent as the example — of future work which would assist us to achieve the goal of satisfactorily correlating conductivity structure with the tectonic processes. To complement the work already completed in Kenya, further magnetotelluric measurements should be undertaken, especially in the period ranges less than 10 seconds and greater than 1000 seconds, at stations within the rift valley itself. This would enable more precise conductivity profiling at these important locations. Wide-band induction studies — both G.D.S. and MT — are required in Northern Kenya to link the existing studies from Kenya and Ethiopia and also further south of the equator to link up with the magnetometer array studies already completed and planned for Southern Africa. Magnetotelluric traverses across the anomalies already detected in that southern region would assist in locating their depth more precisely. Finally, induction studies should be initiated in other parts of Africa, e.g. the Hon graben, Libya, the Benue Valley, Nigeria and the Akwapim region of Ghana, where the grabens have controversial association with the world-wide rift system [44, 18, 16, 77].

Acknowledgements

The author wishes to acknowledge helpful comments on this manuscript from her colleagues both at the University of Edinburgh and at the University of Alberta. She is particularly indebted to Professor D. I. Gough for the excellent facilities provided during her study leave at the Institute of Earth and Planetary Physics, University of Alberta where the preparation of the paper was undertaken.

REFERENCES

1. Ádám, A.: Appearance of electrical inhomogeneity and anisotropy in the complex electrical exploration of the Carpathian Basin. *Acta Geod. Geoph. Mont. Hung.*, 4 (1969), 187—197.
2. Ádám, A.: Some results of the magnetotelluric survey in the Carpathian basin and its complex interpretation. *J. Geomag. Geoelec.*, 22 (1970), 223—234.
3. Ádám, A.—Verő, J.: Das elektrische Modell des oberen Erdmantels im Karpatenbecken. *Acta Geod. Geoph. Mont. Hung.*, 5 (1970), 5—20.
4. Ádám, A.—Stegena, L.—Kis, K.: Magnetotelluric, geothermic and paleomagnetic investigations in Hungary. *Acta Geod. Geoph. Mont. Hung.*, 9 (1974), 183—190.
5. Alabi, A. O.—Camfield, P. A.—Gough, D. I.: The North American Central Plains anomaly. *Geophys. J. R. astr. Soc.*, 43 (1975), 815—833.
6. Aldrich, T.—Bannister, J. R.—del Pozo, S.—Salgueiro, R.—Beach, L.: Electrical conductivity studies in South America—Chile—Bolivia, Carnegie Inst. Washington Yearbook, 1975, 292—293.
7. Aldrich, T.—Casaverde, M.—Bannister, J. R.—Beach, L.: Electrical conductivity studies in South America—Argentina—Central Chile. Carnegie Inst. Washington Yearbook, 1975, 291—292.
8. Banks, R. J.: Complex demodulation of geomagnetic data and the estimation of transfer functions. *Geophys. J. R. astr. Soc.*, 43 (1975), 87—101.
9. Banks, R. J.—Ottey, P.: Geomagnetic deep sounding in and around the Kenya Rift Valley. *Geophys. J. R. astr. Soc.*, 36 (1974), 321—335.
10. Bailey, R. C.—Edwards, R. N.—Garland, G. D.—Kurtz, R.—Pitcher, D.: Electrical conductivity studies over a tectonically active area in Eastern Canada. *J. Geomag. Geoelec.*, 26 (1974), 125—146.
11. Beamish, D.: A geomagnetic deep sounding array study of East Africa .Ph. D. Thesis, University of Lancaster. U. K. 1976.
12. Berdichevskiy, M. N.—Borisova, V. P.—Bubnov, V. P.—Vanyan, L. L.—Feldman, I. S.—Yakovlev, I. A.: Anomalous electrical conductivity in the Earth's crust in Yakutia. *Fizika Zemli*, 10 (1969), 43—49.
13. Berdichevskiy, M. N.—Vanyan, L. L.—Feldman, I. S.—Porstendorfer, G.: Conducting layers in the Earth's crust and upper mantle. *Gerlands. Beitr. Geophysik*, 71 (1972), 187—196.
14. Berktold, A.—Bennett, D. J.—Angenheister, G.—Dziewonski, A.—Gouin, P.—Haak, V.—Porath, H.: The distribution of the electrical conductivity in Eastern Ethiopia (Afar Depression and Main Rift) Abst. Second Int. Workshop on E. M. Induction, Ottawa, 1974.
15. Berktold, A.: Magnetotelluric measurements in the Afar areas. Proc. Int. Symposium on the Afar Region and Related Rift Problems. (Pilger, A. and Rosler, A., Ed.), Schweizerbart—Stuttgart, 1975, 66—79.
16. Blundell, D. J.: Active faults in West Africa. *Earth and Planet. Science Letters*, 31 (1976), 287—290.

17. Bott, M. H. P.: The Interior of the Earth, E. Arnold (Publishers) Ltd., London 1971, 316 pp.
18. Burke, K.—Whiteman, A. J.: Uplift, Rifting and the Break up of Africa in Implications of Continental Drift to the Earth Sciences (Tarling, D. H. and Runcorn, S. K. Ed.), Academic Press, London 2 1973, 735—755.
19. Camfield, P. A.—Gough, D. I.: Anomalies in daily variation magnetic fields and structure under north-western United States and south-western Canada. *Geophys. J. R. astr. Soc.*, 41 (1975), 193—218.
20. Camfield, P. A.—Gough, D. I.—Porath, H.: Magnetometer array studies in north-western United States and south-western Canada. *Geophys. J. R. astr. Soc.*, 22 (1971), 201—221.
21. Cochrane, N. A.—Hyndman, R. D.: Magnetotelluric and magnetovariational studies in Atlantic Canada. *Geophys. J. R. astr. Soc.*, 39 (1974), 385—406.
22. de Beer, J. H.: Magnetometer array studies and electrical conductivity in Southern Africa. Ph. D. Thesis, University of Alberta, Canada 1976.
23. de Beer, J. H.—van Zijl, J. S. V.: Plate tectonic origin for the Cape Fold Belt. *Nature*, 252 (1974), 675—676.
24. de Beer, J. H.—Gough, D. I.—van Zijl, J. S. V.: An electrical conductivity anomaly and rifting in southern Africa. *Nature*, 225 (1975), 678—680.
25. Dragert, H.: An interpretation of the Canadian Cordillera geomagnetic transition anomaly. Protokoll über das Kolloqium Erdmagnetische Tiefensondierung. *Grafrath*, 1974, 78—103.
26. Edel, J. B.—Fuchs, K.—Gelbke, C.—Prodehl, C.: Deep structure of the southern Rhinegraben area from seismic refraction investigations. *J. Geophys.*, 41 (1975), 333—356.
27. Edwards, R. N.—Greenhouse, J. P.: Geomagnetic variations in the eastern United States: evidence for a highly conducting lower crust? *Science*, 188 (1975), 726—728.
28. Fairhead, J. D.: The structure of the lithosphere beneath the Eastern Rift, East Africa, deduced from gravity studies. *Tectonophys.*, 30 (1976), 269—298.
29. Garland, G. D.: Introduction to Geophysics, W. B. Saunders Co., Philadelphia, London and Toronto, 1971, 420 pp.
30. Garland, G. D.: Correlation between electrical conductivity and other geophysical parameters. *Phys. Earth Planet. Int.*, 10 (1975), 220—230.
31. Girdler, R. W.: Ed. East African Rifts. *Tectonophys.*, 15 (1972), Nos 1/2
32. Gornostayev, V. P.: On deep geoelectric model of Pribaikalia. *Geol. i geofiz.*, 6 (1972), 68—101.
33. Gough, D. I.: The geophysical significance of geomagnetic variation anomalies. *Phys. Earth Planet. Int.*, 7 (1973), 379—388.
34. Gough, D. I.: Possible linear plume under southernmost Africa. *Nature Phys. Sci.*, 245 (1973), 93—94.
35. Gough, D. I.—de Beer, J. H.—van Zijl, J. S. V.: A magnetometer array study in Southern Africa. *Geophys. J. R. asrt. Soc.*, 34 (1973), 421—433.
36. Gough, D. I.—McElhinny, M. D.—Lilley, F. E. M.: A magnetometer array study in Southern Australia. *Geophys. J. R. astr. Soc.*, 36 (1974), 345—362.
37. Gregory, J. W.: The Great Rift Valley, J. Murray, (Publisher), 1896.
38. Haak, V.—Sengpiel, K. P.—Berktold, A.—Greinwald, S.: The telluric method: results of the measurements along a profile across the Rhinegraben between Stuttgart and Kaiserlautern. Graben Problems (Illies, J. H. and St. Mueller, Ed.), Schweizerbart—Stuttgart. 1970, 235—238.
39. Haak, V.—Reitmayr, G.: The distribution of electrical resistivity in the Rhinegraben area as determined by telluric and magnetotelluric methods. Approaches to Taphrogenesis (Illies, J. H. and Fuchs, K., Ed.), Schweizerbart—Stuttgart. 1974, 366—369.
40. Hermance, J. F.: An electrical model for the sub-Icelandic Crust. *Geophys.*, 38 (1973), 3—13.
41. Hermance, J. F.—Thayer, R. E.: The telluric–magnetotelluric method. *Geophys.*, 40 (1975), 664—668.
42. Hoover, D. B.—Frischknecht, F. C.—Tippens, C. L.: Audio-magnetotelluric sounding as a reconnaissance exploration technique in Long Valley, California. *J. Geophys. Res.*, 81 (1976), 801—809.
43. Hurtig, E.—Oesberg, R. P.—Ritter, E.—Grunthall, G.—Jacobs, F.: Studies of the crustal structure in the northern part of Central Europe. *Gerlands Beitr. Geophysik.*, 84 (1975), 317—325.
44. Illies, J. H.: Graben Tectonics as related to Crust-Mantle Interaction. Graben Prob-

lems (Illies, J. H. and St. Mueller, Ed.). Schweizerbart — Stuttgart 1970, 4—27.

45. Irvine, T. N.: Ed. 'The World Rift System' Geol. Survey of Canada, Paper 1966, 66—14.
46. Keller, G. V.: Electrical Properties of; the Earth's Crust, Colorado School of Mines, Golden, Colorado 46 (1971).
47. Kurtz, R. D. — Garland, G. D.: Magnetotelluric measurements in Eastern Canada. *Geophys. J., R. astr. Soc.*, 45 (1976), 321—347.
48. Larsen, J. C.: Low frequency (0.1—6.0 cpd) electromagnetic study of deep mantle electrical conductivity beneath the Hawaiian Islands. *Geophys. J. R. astr. Soc.*, 43 (1975), 17—46.
49. Law, L. K. — Riddihough, R. P.: Geophysical relation between geomagnetic variation anomalies and tectonics. *Can. J. Earth Sci.*, 8 (1971), 1094—1106.
50. Le Borgne, E. — Le Mouel, J. L.: La variation diurne de l'intensite du champ magnétique terrestre au dessus du Golfe de Gasgogne. *Ann. de Geophys.*, 27 (1971), 433—445.
51. Le Borgne, E. — Le Mouel, J. L.: A conductivity anomaly in the Western Mediterranean. *Geophys. J. R. astr. Soc.*, 43 (1975), 939—956.
52. Le Pichon, X. — Francheteau, J. — Bonnin, J.: Plate Tectonics. Developments in Geotectonics, 6 Elsevier — Amsterdam, London, New York, 1973.
53. Long, R. E. — Backhouse, R. W. — Maguire, P. K. H. — Sundaralingham, K.: The structure of East Africa using surface wave dispersion and Durham seismic array data. *Tectonophys.*, 15 (1972), 71—81.
54. Losecke, W.: Ergebnisse magnetotellurischer Messungen bei Speyer. Graben Problems (Illies, J. H. and St. Mueller, Ed.), Schweizerbart — Stuttgart. 1970, 242—244.
55. Menvielle, M.: The Northern Morocco conductivity anomaly. Abst. Third Int. Workshop on E. M. Induction, Sopron, 1976.
56. Milanovsky, E. E.: Continental rift zones: their arrangement and development. *Tectonophys.*, 15 (1972), 65—70.
57. O'Connell, R. B.: Geological development of the rift system of Eastern Africa. *Geol. Soc. Amer. Bull.*, 83 (1972), 2549—72.
58. Pascoe, L. J. — Jones, F. W.: Boundary conditions and calculation of surface values for the general 2-dimensional electromagnetic induction problems. *Geophys. J. R. astr. Soc.*, 27 (1972), 179—193.
59. Pecova, J. — Petr, V. — Praus, O.: Depth distribution of the electrical conductivity on the Czechoslovak territory. *J. Geomag. Geoelec.*, 22 (1970), 235—240.
60. Poehls, K. A. — Von Herzen, R. P. — Gough, D. I.: Electrical resistivity structure beneath the North-west Atlantic Ocean. *Geophys. J. R. astr. Soc.*, 47 (1976), 331—346.
61. Porstendorfer, G.: Principles of magnetotelluric prospecting. Geoexploration Monograph Series 1 No. 5, 1975, 118 pp. Gebrüder Borntraeger — Berlin-West, Stuttgart.
62. Portnyagin, M. A.: On anomalous electrical conductivity at crust-mantle boundary in the Irkutsk amphitheatre. *Geologia i Geofizika*, 12 (1968), 93—100.
63. Pospeev, V. J. — Mikhalevsky, V. J. — Gornostayev, V. P.: Results of measurements with the magnetotelluric method in East Siberia and the Far East: In: Magnetotelluric Method for Studying the Structure of the Crust and Upper Mantle. 1969, 139—149. Nauka Press.
64. Praus, O. — Pecova, J. — Petr, V. — Pec, K. — Jankowski, J. — Szymanski, A.: Anomalous induction, in the Carpathians. IAGA Abstracts, General Assembly IUGG, Grenoble.
65. Press, E. — Siever, R.: Earth. W. H. Freeman and Co., U.S.A. 1974, 945 pp.
66. Reitmayr, G.: An anomaly of the upper mantle below the Rhinegraben studied by the inductive response of natural electromagnetic fields. *J. Geophys.*, 41 (1975), 651—658.
67. Rikitake, T.: Ed. Multidisciplinary studies of unusual regions of the upper mantle. *J. Geomag. Geoelec.*, 22 (1970), Nos 1—2.
68. Rikitake, T.: Ed. Symposium on electromagnetic induction studies of tectonic regions. *J. Geomag. Geoelec.*, 26 (1974), No. 2.
69. Rikitake, T.: A model of the geoelectric structure beneath Japan. *J. Geomag. Geoelec.*, 27 (1975), 233—244.
70. Ritter, E.: Results of geoelectromagnetic deep sounding in Europe. *Gerlands Beitr. Geophysik*, 84 (1975), 261—273.
71. Rokityanskyi, I. I.: Investigation of electrical conductivity anomalies by the method of magnetovariational profiles. Naukova Dumka, Kiev 1975.
72. Rooney, D.: Magnetotelluric measurements across the Kenyan Rift. Ph. D. Thesis, University of Edinburgh, U. K. 1976.
73. Ronney, D. — Hutton, V. R. S.: A magnetotelluric and magnetovariational study of the Gregory Rift Valley, Kenya. *Geophys. J. R. astr. Soc.*, 50 (1977) (in press).

74. Scheelke, I.: Magnetotellurische Messungen im Rheingraben und ihre Deutung mit zweidimensionalen Modellen. Gamma 20. Inst. Geophys. Meteorol. Tech. Univ. Braunschweig. 1972.
75. Sundaralingham, K.: Seismic investigation of the crust and upper mantle of East Africa'. Ph. D. Thesis, University of Durham, U. K. 1971.
76. Tammemagi, H. Y.—Lilley, F. E. M.: A magnetotelluric traverse in southern Australia. *Geophys. J. R. astr. Soc.*, 31 (1973), 433—445.
77. Thayer, R. E.—Hermance, Z. F.—Bjornsson, A.: Electrical Structure of the Crust in north-central Iceland. Abstr. Second International Workshop on Electromagnetic Induction in the Earth, Ottawa, 1974.
78. Turner, D. C.: The sedimentary cover in Nigeria. In 'Tectonics of Africa', 1971, 403—405. UNESCO, Paris.
79. Untiedt, J.: Conductivity anomalies in Central and Southern Europe. *J. Geomag. Geoelec.*, 22 (1970), 131—150.
80. Vladimirova, G. A.: List of publications on the Baikal Rift Zone (in Russian). Report SE-2, geodynamics International, 9 (1976), 7—16. World Data Center A for Solid Earth Geophysics, NOAA, Boulder.
81. Winter, R.: Der Oberrheingraben als Anomalie der elektrischen Leitfähigkeit untersucht mit Methoden der Erdmagnetischen Tiefensondierung. Dis. Math-Naturwiss. Fak. Univ. Göttingen. W. Germany, 1973.

ИНДУКЦИОННЫЕ ИССЛЕДОВАНИЯ В ОБЛАСТИ РИФТОВ И ДРУГИХ АКТИВНЫХ РЕГИОНОВ

Р. ХУТТОН

РЕЗЮМЕ

В обзоре рассматриваются индукционные исследования, проведенные в области рифтов и других активных зон, с особым вниманием на исследования, проведенные в Восточной и Южной Африке в прошедшие годы. Дополняющий друг друга характер геомагнитных и магнитотеллурических исследований, а также проявляющаяся в интерпретации разница, происшедшая из-за различия частотных диапазонов двух методов, одинаково участвуют в изложении. Поскольку ныне результаты большинства индукционных исследований еще не могут быть интерпретированы однозначно, автор не делает попытки для сопоставления профилей проводимости с тектонической активностью. Дуется предложение для распространения настоящих работ для того, чтобы а) стала возможной более однозначная интерпретация проводимости, б) проводились измерения над системой рифтов мира на местах, где они до сих пор еще не были начаты.