Induction arrows in Eastern Tibet

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Summary

In 3 observatories of eastern Tibet enormously large tippers were recorded. The authors of this discovery explained the result with a simple uniform rectangular conductor enclosed in poorly conducting half-space. However, real Earth contains highly conducting upper mantle, which reduces the anomalous fields more than two times for periods >1000 s. We analyze the possibilities of obtaining large amplitudes of the anomalous field in the conditions of the real Earth (with a conductive mantle) and come to the conclusion that this is possible only with Super-Channeling effect. It occurs in an elongated non-uniform conductor in a place where the lengthwise conductance G is less than G in moderately remote along strike parts of the anomaly.

Keywords: induction arrow, electrical conductivity anomaly, channeling

Introduction

In eastern Tibet, large-scale motions of the Earth crust occur. For their explanation crustal flow channels were proposed. To constrain the pattern of the flow geophysical data are necessary and electromagnetic studies are the promising tool for this purpose. One of such studies was made in the article (Xu et al 2023). The most remarkable result presented in it was the discovery of unusually large induction arrows, twice as large as the worldwide maximum obtained before, and they are located exactly in the area of crustal flows. Consider the article in some details.

54 geomagnetic observatories of Chinese network were carefully processed for 2008-2019 years and tippers (VTF, induction arrows) were estimated at 16 periods in 300 - 10000 s interval. Unusually large tippers with magnitude >3 were discovered at three observatories CBT, JGU and MLA in eastern Tibet. The authors of (Xu et al 2023) compiled a model: 1000 km long, 100 km wide, 10 km thick conductor (Figure 1) at the depth of 5 km in highly resistive ρ_e=10000 Ohm·m half-space and obtained tipper magnitudes >3.

However, the authors ignored the high conductivity of the Earth's mantle, which has been reliable established over the past 1.5 centuries, and the most precisely determined with the use of both the observatory and satellite data in (Kuvshinov et al 2021). We calculated the anomalous field from this model with and without a conducting mantle – the tipper's values differ by ≈2.5 times. Therefore, for realistic Earth (with conducting mantle) the model of (Xu et al 2023) does not explain the experimental data on large tippers.

All great arrows are directed to west (in Wiese convention). We supposed that anomalous body plunges along an eastward-inclined plane of Jinshajiang suture zone; the western edge of the anomaly most likely is located at shallow depths. Trying to find a model explaining the large tippers, we increased the conductivity of the western end of the anomaly by orders of magnitude. As a result, the frequency characteristic maximum shifted to periods 10^4 -10^5 s, but even then the magnitude of the calculated tippers did not exceed 1.5.

Physics of anomalous field formation.

Anomalous currents in a conducting body arise due to local electromagnetic induction inside the body, as well as due to the conductive redistribution (and concentration/channeling) of currents induced in the host medium on the large territory comparable with the external source size. Analytical solutions for a cylinder and a sphere are presented as an infinite series. The first term is proportional to the applied electric field (it forms the conductive anomaly), the second one – to the magnetic field – it forms the magnetic eddy-type anomaly. The latter cannot exceed 1. The magnitude of the conductive type anomaly depends on the anomaly shape, on the conductivities of enclosing medium σ_e and the anomalous body σ_i. Analysis of natural situations showed that conductive type anomalies are predominate for elongated conductors, and a corresponding theory was developed for them (Rokityansky 1982, p. 247-277, 290-307). The frequency characteristics of the conductive type anomalous field b can be presented as follows

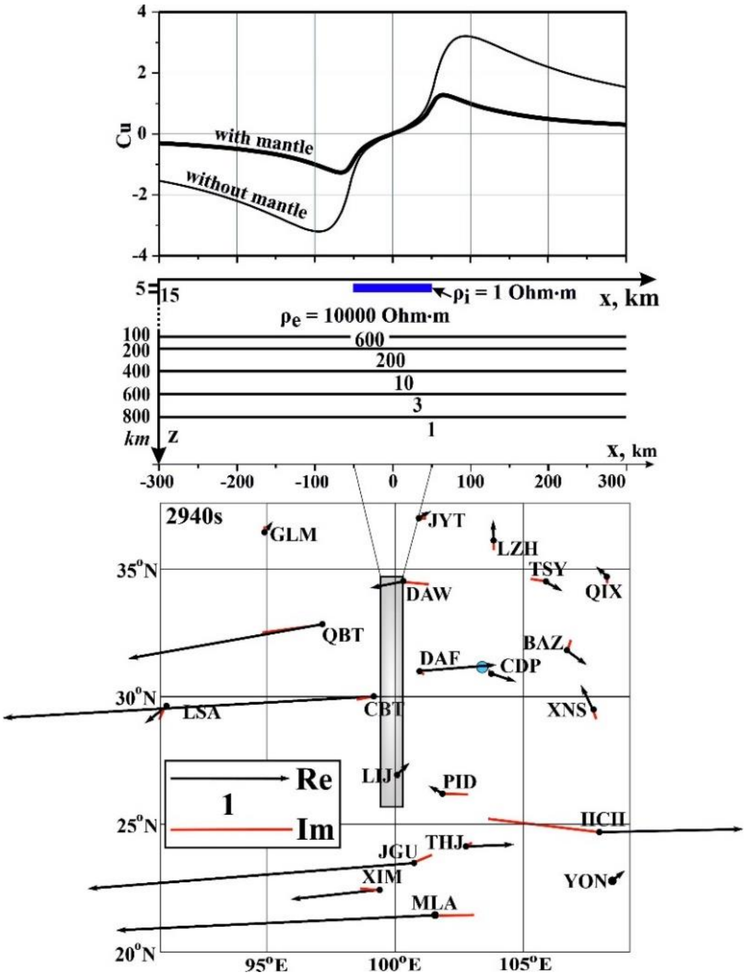
$$b(r,T) = A(r) \cdot V(T) \cdot \zeta_N(T) \qquad (1),$$

where *A* depends on geometric factors, V(T) ($0 \le V \le 1$, V = 1 corresponds DC) describes the degree of filling of the conductor by anomalous currents (result of the skin-effect inside the anomalous body), V is a non-decreasing function of period. ζ(T) is the normal 1D impedance of the given region or global, a priori studied by GDS-MTS soundings. It is a decreasing function of the period, so its product with function V has a maximum at some period T_0. The position T_0 is closely related to the total lengthwise conductance:

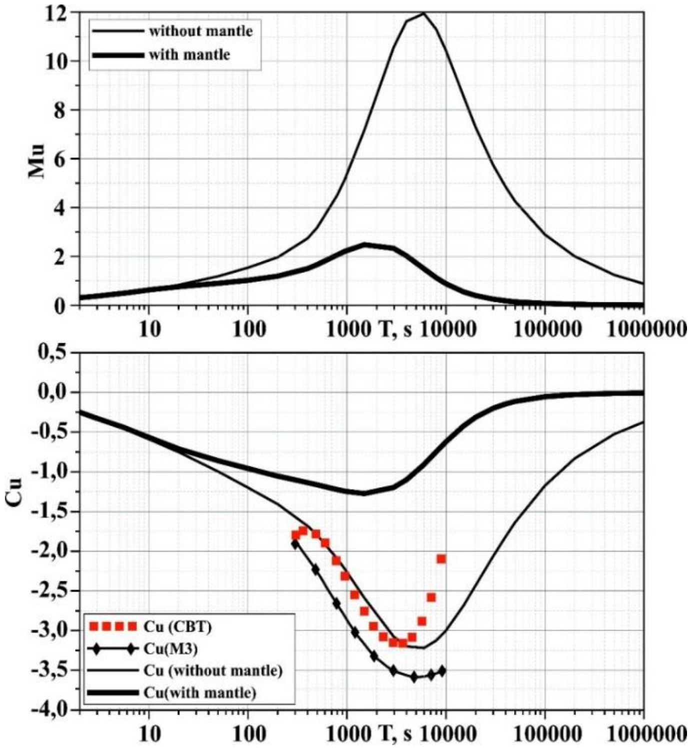
$$G\left[S\times m\right]=Q\cdot\sigma_i \qquad (2)$$

where Q is the cross-section area of the anomalous conductor σ_i. Numerous calculations carried out in the 1970s, generalized in (Rokityansky 1982), and recently repeated at the modern level, established the relationship between G and T_0:

$$G\left[S\times m\right]=5\cdot10^4\cdot\left|T_0\left[s\right]\right|^{1.2} \qquad (3),$$



← **Figure 1. At the bottom.** Induction arrows in Wiese convention on the SW China map reconstructed from Figure 2 in (Xu et al 2023). The gray rectangle 1000km×100km in the center nearby observatory CBT (≈20km from it) represents the main component of 3D electrical conductivity anomaly given in (Xu et al 2023) for explanation of «Enormously large tipper» in CBT and for our 2D calculations, two of which are presented in upper graph. **At the top.** 2D modeling over the conductor with cross-section 100km×10km over realistic normal deep cross-section *with* a well conducting upper *mantle* (presented by 5 layers from the data of Kuvshinov et al. 2021) and *without mantle*.



← **Figure 2.** Frequency characteristics of the real anomalous horizontal magnetic tensor Mu and the real tipper Cu. 16 red squares are the tippers measured at observatory CBT, curve Cu(M3) with rhombs is the result of 3D modeling (all from Figure 8 in (Xu et al 2023)). The curves from 2 to 10^6 s are our 2D calculations of the models in Figure 1, upper part.

Over uniform half-space, the slope of ζ(T) is equal -45°. Over the real Earth, due to the worldwide increase in the electrical conductivity of the Earth's mantle with depth, the slope is equal ≈-53°. Accordingly, for the uniform half-space the degree over To in Eq.3 will be 1, for the real Earth -1.2. Eq. 3 was obtained from the data with T_0 = 500-5000 s and can be applied only for this interval.

Dispersion relations.

At the period T_0, the anomalous fields and the induction arrow become real C = Cu, the imaginary induction arrow Cv passes through zero changing sign. For shorter periods $T < T_0$, Cu and Cv are parallel, for longer periods $T > T_0$ they are anti-parallel. It is valid for $e^{-i\omega t}$ time factor, for $e^{+i\omega t}$ it is vice versa. When mentioning dispersion relations, reference is usually made to the work of (Marcuello et al 2005), although these relations were presented earlier in the work of (Rokityansky 1975) and repeated in (Rokityansky 1982).

Frequency characteristics (FC).

In Figure 2, FCs for observatory CBT are presented. The short curves for periods 300-10000 s are taken from Figure 8 in (Xu et al 2023), the long curves for periods 2-1000000 s are our 2D calculations. The curves for our Cu (without mantle) and their Cu(M2) almost coincide (within 10%) and both have a very slow long-period decay. All observed frequency responses have a significantly steeper long-period decay, as can be seen in Fig.2 on the observed curve Cu(CBT) and calculated Cu(with mantle). The extreme of the latter is shifted to the shorter periods in contrast with observed curve. To match their T_0, it is necessary to increase the conductivity of the model by approximately two times. However, obtaining the observed magnitude of the anomalous field is a much more difficult problem.

2D-Channeling (2D-C).

In horizontally layered Earth, external ionosphere-magnetosphere source induces only horizontal currents, uniform in a homogeneous layer of σ_e. Let us place in the layer a 2D anomaly of increased conductivity σ_i elongated along x-axis. The current inside the anomaly increases, while in host medium it decreases by the same amount. Has there been a channeling of current? Certainly. The preserved parallelism of the current lines does not show it visually/explicitly, but the appearance of the anomalous magnetic fields around conductor does. The electric field Ex in well-conducting anomaly is less than in poorly conducting enclosing medium, but at $T>T_0$ the difference decreases and in DC limit Ex is the same in both the anomaly and the host medium. It is inherent only to 2D case, which is a central/basic one.

Under-Channeling (U-C) (conductor is shorter than 2D).

Consider the elongated anomaly of limited length Lx. The case is studied by mathematical and physical modeling. Current lines flow from host medium into the conducting body - visual channeling, but it is weaker than in 2D case. Then the limited length anomaly creates incomplete channeling. The electric field Ex in the well-conducting anomaly is always, at all periods, less than in poorly conducting enclosing medium.

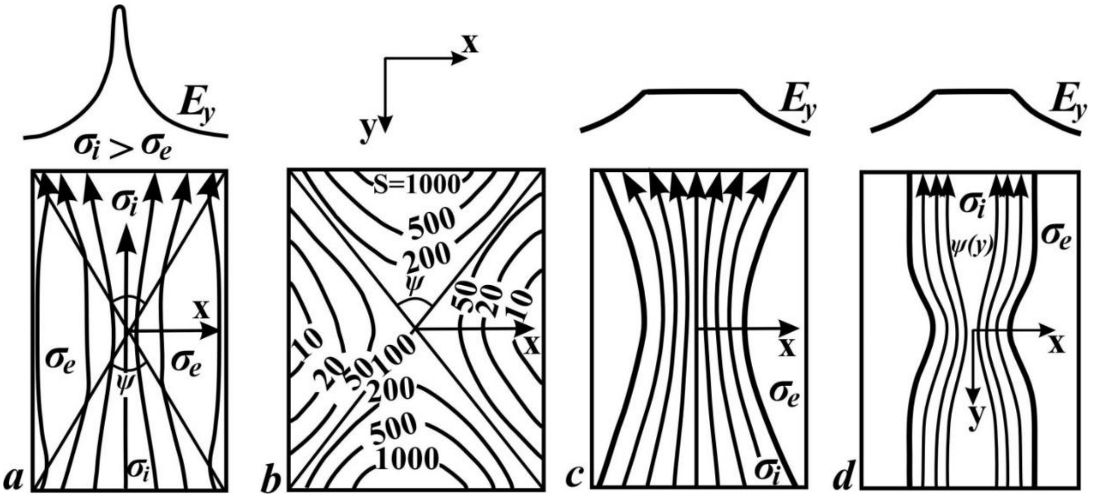


Figure 3. Structures of Superchanneling: a) sectorial, b) saddle-like presented by longitudinal conductance S of upper conducting layers, c) narrowing of a good conductor, d) narrowing in a cylinder. ψ is the angle of compaction and de-compaction of the currents given by arrows: in figures a) and b) ψ is constant, in figures c) and d) it is variable and equals zero in the center, in figure d) also in the lower and upper sections of the model d). Electric field is given for the central profile y=0.

Super-Channeling (S-C) – case opposite to the U-C.

It occurs when in place of observation the lengthwise conductance G is less than G in moderately remote along-strike x parts of the anomaly. This phenomenon is also known as the strait effect observed between two islands or land areas. It arises in a 4-sectorial structure (Figure 3a), when two opposite sectors have low conductivity and the other two have high conductivity. A similar phenomenon is seen in the saddle-like structure (Figure 3b), it arises when river crosses a mountain ridge, e.g. Rhine Graben crosses crystalline massifs Schwarzwald and Vogesen (Rokityansky 1982, s.221-229.).

In the S-C areas, the electric field Ex inside the conductor is larger at periods $T>T_0$ than in the enclosing host medium despite of its much lower conductivity. It was supported by physical modeling in a tank installation (Rokityansky 1989). To our knowledge, S-C has not been quantitatively studied anywhere and presents a challenge for 3D modeling. We propose to start modeling with the model of a cylinder shown in Figure 3d and vary Gmin/Gmax, length and angle of the zones compaction and de-compaction $\psi(y)$. In any case, it yields the regularities of Super Channeling. It is precisely on this way the problem of the nature and quantitative description of the “enormously large tippers” can be solved.

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Abbreviations

2D - Two-dimensional
2D-C – 2D Channeling
3D – Three-dimensional
C - tipper, or induction arrow, or VTF
Cu – real part of tipper C
Cv – imaginary part of tipper C
DC – direct current
GDS – Geomagnetic deep sounding method
G - total lengthwise conductance of the anomaly $G = Q \cdot \sigma_i = Lx \cdot Lz \cdot \sigma_i$
L – dimensions of the anomaly with conductivity σ_i
Lx – width of the anomaly in the direction of the anomalous magnetic field
Ly – length of the anomaly in the direction of the applied electric field
Lz – thickness of the anomaly
MTS – Magnetotelluric sounding method
S-C – Super-Channeling
T_0 – period where Cu has a maximum, and Cv pass throw 0 changing sign
U-C – Under-Channeling