EARTHQUAKE ELECTROMAGNETIC PRECURSORS: EXPERIMENTAL EVIDENCE AND POSSIBLE FORMATION MECHANISM

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Abstract. Electromagnetic anomalies are often found to be the earthquakes precursors. The experimental evidence of these phenomena is given and their observed peculiarities are discussed. A possible model explaining both commonly accepted magnetic variations anomalies and contradicting them experimental facts is presented.

1. Introduction

The seismic hazards forecast is may be the most urgent scientific problem of our time. Especially earthquakes (EQ) prediction because of their high destructive force and undetermined location is important. Between different types of observed EQ precursors the electromagnetic ones seem to be the most reliable and the most often observed.

Numerous papers are published already both supporting and denying the existence of such precursors. Really, some times it happened that one time the EQ was preceded by clearly seen magnetic and/or electric activity of the peculiar structure and next time when the EQ occurs there are practically any signals, even for the some place, as, e. g., in the case of Loma-Prieta EQ [1]. Moreover, there are extremely few cases of really successful prediction of EQ using electric or magnetic precursory phenomena. This very poor success of the EQ predictions is the cause of the absence of the reliable theory of physical links between seismic activity and precursory effects of non-seismic nature, although a number of hypothesis are under discussion now. That is why any new experimental evidence of precursory events and attempts to explain them is a matter of great importance for the improvement of our knowledge of this problem.

The present paper is a further attempt to comment the observed experimentally facts and to propose a mechanism explaining the precursory events formation peculiarities.

2. Experimental evidence

One of the most widespread instruments for the monitoring of the EQ precursory signals are magnetometers. A set of LEMI type magnetometers produced by Lviv Centre of Institute of Space Research were installed at two sites in Japan and at three points in Ukraine starting from the year 1998. During this time there were some clearly identified cases when the relatively weak EQ (M ~ 4-4,5) occurring near the observation points were preceded about 1-2 days by anomalous behavior of the magnetic field fluctuations. Namely the decrease of the ratio of the vertical component amplitude B_z to the horizontal components amplitudes B_x and B_y was observed. Only the days with low magnetic activity ($K_p < 5$) were taken into consideration. The examples of experimental data for Matsushiro (Japan, EQ with M ~ 4.3, July, 1, 1998) and for Simeiz (Crimea, Ukraine, EQ with M ~ 4.4, October, 16, 1998) are given on Fig. 1, *a* and *b* correspondingly.

Some comments as to the observation time and analyzed frequency band are necessary. First, the analyzed frequency band - 0.01-0.03 Hz - was selected in the range of P_c4 natural magnetic field pulsation. If to compare the whole spectrum of such pulsation with the calculated value of the expected level of magnetic fluctuation (see calculations below), we can see that namely around P_c4 frequency region we have the best signal to noise ratio (Fig. 2). Moreover, as the experimental data show, the observation sites both in Japan and Ukraine are within intensely populated areas what makes it impossible to observe the relatively weak seismogenic signals at the background of artificial noises. Only the night time interval around 01.00 - 03.00 local time gives some hope to extract the magnetic signals of other than artificial nature. To this, P_c4 are mostly day-time pulsation with considerable drop of the amplitude during night time (see dashed line at Fig. 2 as estimation). It also implies that the observed precursory phenomena have to have enough long duration in order to detect them during the mentioned time interval, at least about 24 hours.

Other example of magnetic fluctuations obtained in Ukraine in three observation points - Razdolnoye, Simeiz and Zmeinyi -before the EQ with M ~ 4.0 occurring August, 7 and 9, 1999, near Taman peninsula (Russia) are given on Fig. 3. The obtained results are very peculiar: in two points - Razdolnoye and Zmeinyi - the observed magnetic anomaly had the signature as described below, although the distance from the epicenters to the observation places were about 250 and 400 km correspondingly. For the third point - Simeiz - although it was the closest to the epicenters (around 200 km), no anomaly of this type was observed. An attempt to explain all these experimental facts is made below.

3. Possible explanation models

It is rather commonly accepted for the moment that the B_z/B_h ratio (B_h is horizontal component of the magnetic field fluctuation) could be the signature allowing to discriminate the origin of the magnetic fluctuation. If B_z/B_h is considerably lower than unity this signal is attributed to the ionospheric source. And if B_z/B_h is close to unity the source is supposed to be in the lithosphere (see explanations in [2, 3]). But as it was experimentally shown upper, in the reality (as well as on the Fig. 1 of [3]) there is just opposite situation. Let us analyze it.

One of the possible generation mechanism for anomalous magnetic field on the earth surface may be associated with the change of local crust conductivity. Such a magnetic field may be generated, for example, by slow movement of the highly conductive layers (or soakage of highly conductive liquid into crust layers with low conductivity) before the earthquake. For such an anomaly with high conductivity the inductive current I equals

$$I = Bv\sigma S \tag{1}$$

where B is the Earth's magnetic field, v is the speed of fluid movement, σ is the conductivity of the fluid, S is the cross section area of the layer with moving fluid. (The Eq. (1) is an upper estimation because we consider the movement is perpendicular to the vector of magnetic field). If the diameter of the layer is much smaller than the distance to it (more than three times) then we may consider such a current as linear.

When the length of the moving layer l is much more than the distance to the point of observation ρ the next relation for anomalous magnetic field takes place

$$B_a = \mu_0 Bv\sigma S\,(2\pi\rho)^{-1} = 10^{-2} v\sigma S\rho^{-1}, \tag{2}$$

where B_a is in nanoteslas; the values in the right hand part of Eq. (2) are substituted in SI units.

The last equation was used to construct the estimation of signal level of this nature on Fig. 2 when the conductive layer is supposed to be at depths 30 and 40 km. This estimation shows the order of signal value that has to be detected.

Let us analyse the expressions for the components of anomalous magnetic field from such a source on the earth surface (Fig. 4):

$$B_y = B_a h \rho^{-1}$$
$$B_z = B_a y \rho^{-1} \qquad (4)$$

where h is the layer's depth, y is the horizontal displacement of observation point from vertical axis to the centre of layer in direction that is perpendicular to layer's axis. From Eqs. (2), (4) it follows

$$B_y = \mu_0 B v \sigma S h \, (2\pi\rho^2)^{-1}$$
$$B_z = \mu_0 B v \sigma S y \, (2\pi\rho^2)^{-1} \qquad (5)$$

From Eqs. (4), (5) it is clear that vertical component of magnetic field near vertical axis is zero. At increasing of distance y the value B_z also increases and when y will be close to h we obtain $B_z \sim B_y$. Because of the signal to noise ratio quickly decreases when y increases, it is possible to detect high B_z values from the lithospheric source only for big enough signals. Let us accept

$$B_{a0} = (S/N) B_N \, , \qquad (6)$$

where B_{a0} is the field at $y = 0$ (near the vertical axis), (S/N) is the signal to noise ratio, B_N is the environmental magnetic noise level. From Eqs. (5), (6) it follows that

$$B_y = (S/N) B_N \, h^2 \rho^{-2}$$
$$B_z = (S/N) B_N \, h y \rho^{-2} \qquad (7)$$

If we consider that

$$B_z / B_N \geq (S/N)_t \, , \qquad (8)$$

where $(S/N)_t$ is the threshold signal to noise ratio (the minimal (S/N) ratio that allows to detect the anomalous signal) then from Eqs. (7), (8) we may obtain desirable range of distances where B_z is detectable (see Table 1).

Table 1

$(S/N)/(S/N)_t$	1	1.5	2	2.5	3	4	5
$(y/h)_{min}$	-	-	1	0.5	0.38	0.27	0.21
$(y/h)_{max}$	-	-	1	2	2.6	3.7	4.8

If to take $(S/N)_t = 1.5$ then from Table 1 it follows that at $(S/N) \leq 3$ z component of magnetic field is undetectable. Thus the possibility of detection of horizontal and vertical components of magnetic field depends on signal to noise ratio and their ratio – on the position of observation point relatively to anomalous crust layer axis.

So, taking into account that the position of observation point for the cases illustrated on Fig. 1 was close to the epicenter, we obtained $B_z/B_y < 1$ as follows from the equation (5) for $y << h$.

The study of the geological structure of the Crimea peninsula region reveals that there is a shallow crustal conductive fold going as an arc from Taman peninsula just via Razdolnoye and Zmeinyi observation points, whereas Simeiz is outside of this fold so that the distance to its axes is greater than its depth. Then the model presented above well explains the obtained experimental data: pre-earthquake crustal stress provoked the conductive fluid movement along the fold and we observed the induced magnetic anomaly at the points close to the fold axis. The numeric estimation of the speed of the fluid movement gives very realistic and close to the reality results. Let us consider the conductivity of the moving layer σ = 10.5 - 5 $(\mathrm{Ohm}\cdot\mathrm{m})^{-1}$, cross section of the layer S ~ 10 x 10 km, depth h ~ 30 km and really observed signal on the Earth surface B_a ~ 0.5 nT. In this case the speed of fluid movements is obtained in limits (3 - 0.3) cm per second. In the reality, taking into account that fluid stream cross section can be still greater, this speed can be still lower what consides well with real geological situation.

Still one strong support of this model gives the work made by F. Freund [4]. It was discovered that even in the absence of the moving fluid the stressed state of the crust can generate in oxide/silicate minerals from peroxy defects the flux of highly mobile positive "holes". Once formed through peroxy dissociation when rocks at depth undergo changes in their stress state under tectonic load, they propagate through otherwise insulating minerals forming propagating conductivity changes or the current source close to the described upper.

4. Conclusion

The formation of precursory signals of electromagnetic nature during EQ preparatory stage is often observed. The stress state change of the crust under the tectonic load is commonly accepted as the main triggering mechanism of these signals. It is clear that great variability of Earth crust structure is the cause of different reply of the media to the stress, so giving different observed evidence of electromagnetic phenomena. To classify them and to develop a physical mechanism of their generation is of the first priority task for EQ monitoring.

The described mechanism of induced magnetic anomalies formation under the influence of currents in the crust provoked by stress changes explains rather well all observed peculiarities of such anomalies, as well as their possible absence if the observation points is not properly chosen. Still once a known fact is confirmed, that for the rise of EQ monitoring reliability the so called "zones-indicators" have to be carefully selected [5] and often these zones can be far enough from the epicenter, as, for example, experience in Greece shows. The further improvement of the eartquake monitoring reliability can be the simultaneous multiparametric observations based on the physically valid theoretic model of EQ formation.

References

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