GEOMAGNETIC ANOMALIES – POSSIBLE EARTHQUAKE PRECURSORS – LINKED WITH 2004 SIGNIFICANT SEISMIC ACTIVITY IN VRANCEA (ROMANIA)

D. ENESCU
National Institute for Earth Physics, P.O. Box MG-2, Bucharest-Măgurele, Romania

Received July 6, 2005

The association between a precursory geomagnetic anomaly and a Vrancea earthquake of moderate-to-high magnitude ($M_W = 6.3$) followed by weaker earthquakes ($M_W < 5$) was first proved in this paper. This finding extended to a broader magnitude range $3.7 \leq M_W \leq 6.3$ the conclusion of our earlier papers [1–6], i.e., that the great majority of Vrancea earthquakes of magnitudes $3.7 \leq M_W \leq 5.0$ were accompanied by observable precursory electromagnetic anomalies.

Right now, it seems that neither the precursor time nor the amplitude of the precursory magnetic anomaly can be linked reliably with the magnitude of the anticipated earthquake. Knowing the way electric resistivity varies ahead of an earthquake, we can assert that the earthquake-precursory growth in geomagnetic impedance is matched by an earthquake-precursory decrease of electric resistivity.

1. INTRODUCTION

Aimed at assessing the predictability of Vrancea earthquakes beyond the moment magnitude $M_W = 5$, the paper is an important extension of our previous research [1–6], which covered seismic events in the period from December 1997 to September 2004. While Vrancea earthquakes had never exceeded $M_W = 5$ for nearly seven years, they did so in October 2004, culminating with a seismic of $M_W = 6.3$ on October 27, 2004. Our chief objective in this paper consisted of showing that a precursory electromagnetic perturbation/anomaly was associated with that earthquake. We also indicated the extent to which that particular anomaly was linked with a relatively high increase in earthquake incidence shortly before and after the earthquake of $M_W = 6.3$.

2. WORKING DATA

The hypocentral coordinates of the Vrancea earthquake of October 27, 2004, were preliminarily determined as being: $\varphi^\circ = 45.8$ N; $\lambda^\circ = 26.7$ E; and

h = 100 km. The earthquake occurred at 23:34:36 h local time. According to an early estimate, it had a moment magnitude $M_W \approx 6.3$. Its macroseismic intensity was $I_o \approx VII$ as a maximum (on the Mercalli scale) and $I \approx VI$ in Bucharest. Further data with respect to Vrancea seismic activity in 2004 were taken from the seismic bulletins of the National Institute for Earth Physics.

As far as electromagnetic data were concerned, the geomagnetic ones were solely used. We explained earlier [3–6] why geoelectric data were not used in our papers. We used magnetic diagrams (magnetograms) of the geomagnetic field components $H_X$, $H_Y$, and $H_Z$, as recorded at Muntele Rosu Observatory in 2004, with $H_X$ and $H_Y$ – the horizontal components along the north-south direction and east-west direction, respectively, and $H_Z$ – the vertical component of the geomagnetic field.

3. GEOMAGNETIC DATA PROCESSING AND INTERPRETATION OF RESULTS

To process these data, we applied a method we had developed in our papers [3, 4] and used in our papers [4–6]. It took into account the time variation of the average daily ratio of the geomagnetic field vertical component $H_Z(t)$ and horizontal component $H_X(t)$ at a given point. We previously showed [3, 4] that:

$$\zeta(t) = \frac{B_Z(t)}{B_X(t)} \approx C + \left| \frac{\Delta B_Z(t)}{B_X(t)} \right|$$

where:

- $B_X(t) = \mu_0 H_X(t)$; $B_Y(t) = \mu_0 H_Y(t)$; $B_Z(t) = \mu_0 H_Z(t)$ are the components of the geomagnetic flux density, and $\mu_0$ is the magnetic permeability in vacuum ($\mu_0 = 1$);
- $\zeta(t)$ is the daily average of the ratio of $H_Z$ over $H_X$, or $B_Z$ over $B_X$, which is exactly the same thing;
- $\Delta B_Z(t)$ is the magnetic anomaly – possibly an earthquake precursor – caused by either or both of the two known natural electromagnetic phenomena, on which we rely for monitoring geodynamic processes (earthquakes and volcanoes);
- $P(t) = \left| \frac{\Delta B_Z(t)}{B_X(t)} \right|$ and also contains a most important component related to the magnetic storms appearing on the records;
- $C$ is a quantity that keeps almost constant over time intervals of up to one month or longer; it is expressed by the relation $C = \tan I'$, where $I'$ is the value of the geomagnetic inclination at the given point (i.e., Muntele Rosu Observatory) and is uninfluenced by potential perturbations/anomalies [3, 4].
The parameter $\eta(t)$ can also be defined, though much less rigorously, as

$$\eta(t) = \frac{|B_Z(t)|}{B_Y(t)}$$

(2)

It is worth mentioning that the ratios

$$\frac{B_Z(t)}{B_X(t)} \quad \text{and} \quad \frac{B_Z(t)}{B_Y(t)}$$

(3)

are also components of the geomagnetic impedance.

As we set out to investigate a potential link between the earthquake of October 27, 2004 ($M_W = 6.3$) and a geomagnetic anomaly with an earthquake precursory role, we first considered only the magnetic data of October 2004. For starters, we calculated the daily average of the ratio $\zeta(t) = \frac{B_Z(t)}{B_X(t)}$ and plotted it in Fig. 1. To make the diagram readable, we showed the particular day, month, and year at a few points on the abscissa. All of these indications refer to zero time of those days, except for earthquake marks, which obviously indicate the exact times when the quakes occurred. Every calculated value of the $\zeta(t)$ ratio on the diagram refers to midday time. The earthquake marks are accompanied by values of the moment magnitude $M_W$ and magnitude $M_D$ we calculated using the duration $D$ of every earthquake, as measured on the seismograms. Like in our previous papers [3–6], we drew a dashed line on the diagram parallel to the abscissa and the $\zeta(t) = C$ line. Strictly speaking, we don’t really know the quantity $C$. It is evident, though, that the dashed line nearly coincides with the $\zeta(t) = C$ line and highlights the perturbations $P(t)$ appearing in the time variation of the $\zeta(t)$ ratio.

Given the east-west orientation of axis $y$, the quantity $B_Y$ has such low values that they fall within the range of errors. The parameter

$$\eta(t) = \left| \frac{B_Z(t)}{B_Y(t)} \right|$$

would therefore be unreliable to use.

Since our previous studies had accustomed us to expect that about 87% of Vrancea earthquakes of magnitudes $M_D > 3.9$ should be preceded by anomalies of the ‘geomagnetic impedance’ $\zeta(t)$, we were quite surprised with our Fig. 1 showing none in the run-up to the earthquake of October 27, 2004. We therefore thought it necessary to consider the time variation of the parameter $\zeta(t)$ over a longer period than the one covered in Fig. 1. So, looking further back (Fig. 2), we noticed a quite substantial leap of $\zeta(t)$ in late July 2004, followed by several significant earthquakes, the most important of which occurred October 27, 2004.
Fig. 1. – The parameter $\zeta(t)$ for the period October 1–31, 2004; vertical streaks mark the occurrence times of Vrancea earthquakes of magnitudes $M_W \geq 4.0$ during this period.
Fig. 2. – Same as Fig. 1 for the period January 1 to December 31, 2004.
If we take a look at the diagram in Fig. 2 that shows the time variation of $\zeta(t)$ over the entire year 2004, we find a nearly perfect association between the Vrancea earthquakes of $M_W \geq 4.0$ occurring in this period and the precursory anomalies in $\zeta(t)$ variation. We thus had a geomagnetic anomaly preceding each of the three earthquakes of $M_W > 4.0$ occurring by the end of April. Next came a relatively quieter period, in which neither significant earthquakes nor any geomagnetic anomalies showed up until the end of June or early July 2004 (Fig. 2). An earthquake of magnitude $M_W = 4.3$ and the related precursory anomalies put an end to this period. Then a strong geomagnetic anomaly began, marked by an earthquake on July 22 (Fig. 2). The onset of this strong anomaly coincided with the early preparatory stage of a significant seismic activity in Vrancea that comprised several earthquakes of $M_W \geq 4.0$, including the seism of October 27, 2004 of $M_W = 6.3$ (Fig. 2).

To avoid overcrowding the diagram (Fig. 2), we dropped the condition that $M_D \geq M_o$ (where $M_o$ is 3.6 to 3.9, though usually $M_o = 3.9$) and only adopted the condition that $M_W \geq 4.0$, which likewise arose from the correlation of geomagnetic and seismic data.

A major magnetic anomaly had also been observed in conjunction with a previous cluster of Vrancea earthquakes in the first half of August 2002 [6], but we had no moderate-to-strong earthquake following in that case like we had on October 27, 2004, and this was reflected in the shape and parameters of the magnetic anomaly.

One might want to ascribe the strong geomagnetic anomaly occurring in late July 2004 (Fig. 2) to some failure in the geomagnetic recording system at Muntele Rosu leading to, say, a sudden leap in our records of the components $B_X$ and $B_Z$, but the magnetograms $B_X(t)$ and $B_Z(t)$ do not confirm any such failure. On the contrary, they prove this was a natural anomaly.

In our view, such anomalies/perturbations are the result of at least one of two categories of natural electromagnetic phenomena that are assumedly linked with geodynamic processes such as earthquakes and volcanoes. The natural electromagnetic phenomena in one category arise as the time variations of the externally originating geomagnetic field are induced into the earth. The physical-mechanical processes that take place in the focal zone in preparation of an earthquake can lead to, among other things, electrical resistivity changes, which in turn generate variations in electromagnetic field components, leading implicitly to changes in the ‘geomagnetic impedance’ $\zeta(t)$. These changes are illustrated by anomalies like those in Fig. 2.

Examples are provided in the literature of anomalies in the time variation of the electrical resistivity that have been seen to precede significant earthquakes. Some most reliable examples of this kind are to be found in the geoelectric
resistivity measurements Zhao and Qian [7] carried out uninterruptedly for 20 years in China, including before and after strong crustal earthquake such as the 1976 earthquakes in Tangshan (M = 7.8), Sungpan (M = 7.2), etc. These resistivity measurements were conducted at more than six different stations within at most 150 kilometers of the epicenters. Medium-term precursory decreases in resistivity involving precursor times of 1.5 to 3 years were found (see, for example, Fig. 3). Also detected were short-term precursory decreases, characterized by precursor times of 0.5 to 2 months (see, for example, Fig. 4).

Comparing data in Figs. 3 and 4 to those in Fig. 2, we see the earthquake-

Fig. 3. – Resistivity anomaly before the Tangshan earthquake observed at Baodi station (epicentral distance $\Delta = 80$ km); after Zhao and Qian (1994).

Fig. 4. – Accelerated anomalies in resistivity observed at Wudu station $(\Delta = 100$ km) before the Songpan earthquake and at Changlu station $(\Delta = 70$ km) before the Tangshan earthquake; after Zhao and Qian (1994).
precursory decreases in geoelectric resistivity $\rho(t)$ are matched by earthquake-precursory increases in geomagnetic impedance $\zeta(t)$. We also find that both earthquake precursors act not only in the short term, but in the medium term as well.

The presence of magnetic storms does not contradict our interpretation, because such storms deepen the external geomagnetic field variations and implicitly intensify the induction into the earth of the time variations of this field.

The natural electromagnetic phenomena in the other category are entirely of an internal origin, since they arise from changes in tectonic stress and the complex rock breaking and cracking mechanisms that are at work during earthquake preparation stages. Recent researches have confirmed that, under the growing action of tectonic stress, the deformed rocks in the preparation area of a major earthquake are capable of emitting a broad frequency range of natural electromagnetic waves. In our particular case (Fig. 2), we might have a combination of electromagnetic phenomena of both categories.

4. FINAL REMARKS

Summing up, we would like to underscore that:

1) This study confirmed and completed our previous finding [1–6] that observable precursory anomalies in the geomagnetic impedance $\zeta(t)$ precede the great majority of Vrancea earthquakes of magnitudes higher than 4. Taking into account the impedance $\eta(t)$ doesn’t make sense, because the component $H_y$ is parallel to the east-west direction.

2) It doesn’t seem we can for now establish a relation either between the precursor times and the magnitudes of the earthquakes they forerun, or between the amplitude of a magnetic anomaly and the upcoming earthquake magnitude. We did find, nonetheless, a relatively high precursor time increase for the Vrancea earthquake of October 27, 2004 ($M_W = 6.3$) as compared with the precursor times of earthquakes with $M_W \leq 5$.

3) The earthquake-precursory increase in geomagnetic impedance $\zeta(t)$ might correspond to an earthquake-precursory decrease in geoelectric resistivity $\rho(t)$.

4) The case shown in Fig. 2 along with a previous one in August 2002 [6] entitle us to hope that powerful Vrancea earthquakes will at some point become predictable, even though this predictability may involve a shift from “short term” to “medium term.”

5) It is recommended that earthquake prediction methods and observation data processing techniques diversify as much as possible.
REFERENCES
