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Morphological Features in the Structure of Geomagnetic Variations in Relation to Earthquakes in Vrancea

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Abstract

On example of the Vrancea seismic zone, the correlation between geomagnetic field disturbances and earthquakes is shown. The geomagnetic situation was studied for more than 200 earthquakes during the period 1988-1996. The significant statistical material has demonstrated that the polar sub-storms and their middle-latitudinal manifestation is a trigger mechanism for realization of the seismic energy in Vrancea. The release of seismic energy is related to abrupt changes (gradients) in H-component of geomagnetic field. The energy class of the earthquake is connected with the amplitude of the change in H-component. The differences between durations of near-midnight polar sub-storms preceding earthquakes on various depths have been determined. Taking into account the temporal interval from maximum of sub-storm up to the shock, the connection between geomagnetic disturbances and earthquakes is always positive. The time interval between maximum of polar sub-storm and earthquake is correlated with the depth of the earthquake.

1. Introduction

The Sun – interplanetary space – magnetosphere – ionosphere – atmosphere – Earth's tectonosphere chain is a complicated open dynamic nonlinear system wherein high-energy effects cause a complex of processes. In this context, the seismicity phenomena of the Earth should be considered as a part of the whole Sun-Earth system. The relation between seismicity and processes in the Sun-Earth chain is still ambiguous, but most of the researchers tend to their positive correlation. The studies of regional seismicity with the solar activity, the amplitude of the Earth tides, the Earth's rotation rate, etc. show the influence of these processes on the stressed state of the Earth's crust with subsequent activation of seismic activity. Some authors show that the changes in the underground water level, the ionosphere parameters, the electromagnetic and the geomagnetic field, the electrical conductivity of rocks, the radon emanation, etc. should be considered as precursors of seismic events (Rikitaky 1979, Sidorin 1992, Sobolev 1993).

The problem of relationship between seismicity and geomagnetic activity is under discussion as well. Many scientists searched for a relationship between geomagnetic storms and tectonic events. But the processes of transformation of solar flare energy into the energy of tectonic processes are still not clear. The influences of magnetic storm with sudden commencements on seismicity have been discussed in (Sobolev *et al.* 2001). The studies of technogenic impulse electrical signals when the number of the seismic events tended to increase 3-4 days after the impulse passing were the premise to the above said (Tarasov *et al.* 1999). The duration of activation was several days and its area reached some hundreds km. As far as the energy pumped into the Earth is by several orders smaller than the released seismic energy, the trigger mechanism of the influence has been taken into consideration.

An assumption on the trigger mechanism of the effect of the magnetic disturbance (magnetic storms) on the seismicity in Kirghizia, Kazakhstan and Caucasus (with the maximum effect in 2-7 days after disturbance) was discussed by Sobolev *et al.* (2001) and Zakrzhevskaya and Sobolev (2002). However, the correlation was not evident that the magnetic storm could be considered as the cause of tectonic events. The positive or negative effects were explained by different geological structures of the regions.

One of the mechanisms of the effect of magnetic storms on seismicity may be electro-osmotic phenomena in the rock massif (Kormiltsev et al. 2002). The electro-osmotic fluid flow induced by magnetic storms generates anomalous porous pressure which could be the triggering of the tectonic event. As this effect is small, the correlation between the magnetic field variations and tectonic processes will be weak.

In this paper we consider that most of the earthquakes are a result of stress discharge which slowly accumulated in different parts of the crust and upper mantle. We study the correlation between geomagnetic field disturbances and earthquakes on the example of the concentrated seismicity zone (Vrancea, South Carpathian region). The aim of this article is to show how the reaction of the stress-strained medium responds to geomagnetic disturbances (morphological features in the geomagnetic variation structure).

2. Initial Data

The geomagnetic situation was studied for more than 200 earthquakes with intermediate-depth hypocenters beneath Vrancea zone during the period of 1988-1996. The Vrancea zone is considered as one of the classical examples of concentrated seismicity (Martin *et al.* 2005). The deep-foci earthquakes zone is elongated as a narrow band of 90 km length and 25 km width. The earthquake foci are placed both in the Earth's crust and in the upper mantle in 100-180 km depth. The deep-foci shocks characterized by high seismic energy reach a magnitude M > 7.

The seismicity of the Carpathian region has been described in detail by Kutas *et al*. (2001). For the Vrancea zone the total seismic energy was determined from year to year, with maxima due to the greatest earthquakes in 1977, 1986 and 1990. We examined the geomagnetic situation during the period 1988-1996, but did it separately for deep-foci earthquakes (sub-crust) and crust ones (shallow) in conformity with Seismological Bulletins of Ukraine. We have analyzed more than 150 deep-foci and ca 60 crust shocks in Vrancea zone. The energy class of the shocks (K) and the foci depth (h, km) were taken as the seismic characteristics.

The analyses of geomagnetic variations in relation to earthquakes were carried out from Yastrebovka (45.5ºN; 34.1ºE) and Korets (50.6°N; 27.2°E) magnetic observatories data. The morphological features of the variations were studied by the changes of the amplitude of the H-component of the geomagnetic field.

3. Results

Earlier analysis of one of the strongest earthquakes in Vrancea (30.05.1990) showed that the release of seismic energy was related to abrupt changes (“gradients”) in H-component of geomagnetic field (Sedova *et al*. 2001). The concept of the “main gradient” – the greatest change in the horizontal H-component which may precede the shock in the interval from several days or more, and the “gradients” − changes in the horizontal H-component 1-2 days before the shock − were described by Sedova *et al*. (2001) and Bakhmutov *et al*. (2006). The connection between deep-foci earthquakes in Vrancea and preceding geomagnetic disturbances was determined, while the seismic events themselves occur mainly on weakly disturbed and quiet days (85%), and only 15% of the events took place on geomagnetic disturbed days ($\sum Kp > 30$). The crust shocks are related to sudden commencement storms. The geomagnetic activity determined by Kp-indices in relation to seismicity in the Vrancea zone is always positive when considering the time intervals from the “gradient” to the shock (Bakhmutov *et al*. 2006). The time interval τ from the “main gradients” in the geomagnetic field to the deep-foci earthquakes varies from several days to one month and more (Fig. 1a) while τ from “gradients” to the shallow shocks is most often several hours, and rarely exceeds two days (Fig. 1b).

An analysis of the geomagnetic situation in 1988-1996 showed that the release of seismic energy is connected with definite morphological features in the magnetic field variation spectrum rather than with the geomagnetic activity as a whole. For the Vrancea zone, about 90% of shocks are associated with the near-midnight polar substorms and their middle-latitudinal manifestation. Figure 2 presents the distribution of substorms (H-component of the geomagnetic field) depending on the time before shallow and sub-crust earthquakes. The maximum of substorms is 20-24UT (22-02LT).

An example of the mid-latitudinal manifestation of polar substorms during the quiet background of the geomagnetic field is given in Fig. 3. The shock of 18.04.1993 at 02:03 UT (K = 9.9, h = 150 km) is preceded by the substorm of 17.04 with the maximum in the H-component at about 18:00 UT. The amplitude of the substorm was digitized from a base line, conventionally taken as a normal field (zero level).

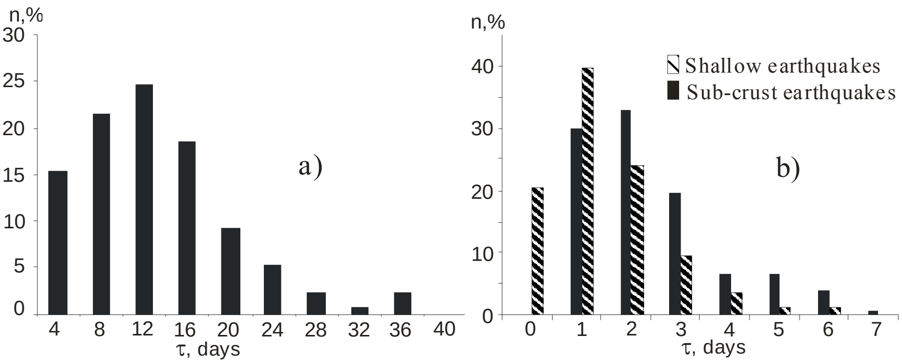

Fig. 1. The time interval τ from "main gradients" to sub-crust earthquakes (a); from the "gradients" preceding the sub-crust and shallow shocks in Vrancea (b).

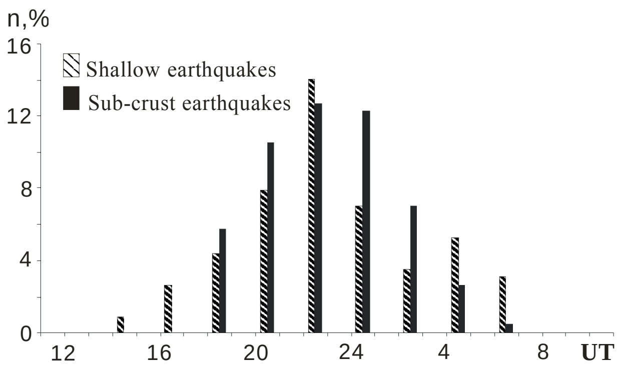

Fig. 2. Daily substorms distribution before the shallow and sub-crust earthquakes in the Vrancea zone for the period 1988-1996.

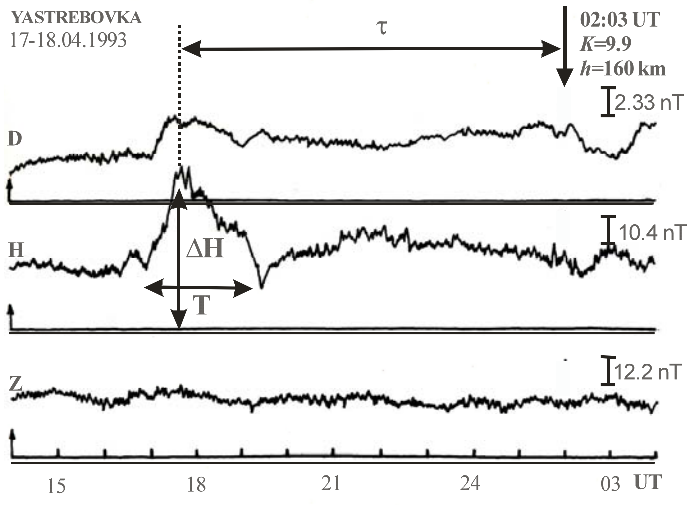

Fig. 3. A copy of the magnetograms from 17-18.04.1993, magnetic observatory Yastrebovka.

For the whole period of studies the earthquakes intensity in Vrancea is rather stable within the range of $K = 9 - 11$ both for the deep-foci earthquakes and for the crust shocks. The weaker shocks ($K < 9$) were 5.3%, and the shocks with $K > 11$ attain 7.6%. The main distribution of the energy class K of sub-crust earthquakes for 1988-1996 and the mean statistical values of the amplitudes of the H-component at the maximum of magnetic polar substorm's development preceding the shock are shown in Fig. 4. In spite of the rather narrow limits of the earthquake's intensity changes, their linear dependence on the substorm amplitude ΔH is clear, particularly if the main seismic events of 04.03.1997 ($K = 15.8$) and 30.05.1990 ($K = 16$) are included in the diagram.

Before the shallow earthquakes, the ΔH amplitudes are 50-80 nT which are comparable with amplitudes of substorms occurring before the deep-foci earthquakes (Fig. 5a). Before the deep-foci shocks the amplitude range is wider and $\Delta H = 90 - 110$ nT in 10% of events. An analysis of the duration (T, min) of the midnight polar substorms preceding the shallow and sub-crust earthquakes shows that they are different (Fig. 5b). In most cases sub-crust earthquakes were preceded by substorms with $T > 60$ min while before shallow shocks $T \leq 60$ min.

We obtained a common linear dependence of the foci depth and the duration T of the midnight polar substorms both for the deep-foci and for the crust shocks (Fig. 6a). This result agrees with the geodynamic model of the Vrancea zone which is a localized downwards narrowing crater-shaped structure for which the notion of crust-mantle discontinuity (estimated depth of 50-60 km) may be considered as a conventional one (Chekunov 1980, Martin *et al*. 2005).

The time interval between the maximum of polar sub-storm and the earthquake is correlated with the depth of earthquake foci (Fig. 6b). The deeper the earthquake focus h, the longer the delay time τ. As shown in (Bakhmutov *et al*. 2006) the time interval τ depends both on the geomagnetic field disturbance and on the mean annual level of geomagnetic activity. The abrupt changes in the geomagnetic field during the magnetic storm may notably shorten the time interval τ (to 4-7 hours) which affects the linearity between τ and foci depth h.

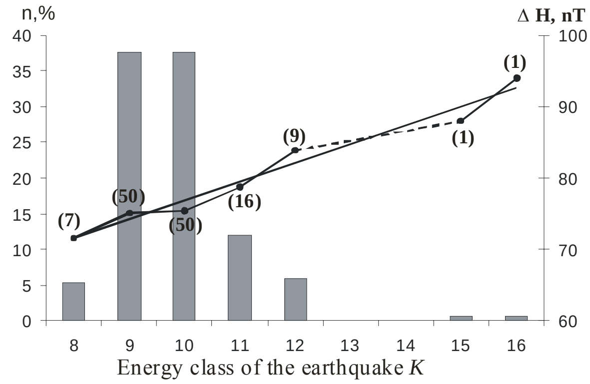

Fig. 4. The distribution of the energy class K of sub-crust earthquakes for 1988-1996 and the mean values of the amplitudes of the H-component at the maximum of the polar substorm's development. The amount of earthquakes is given in parentheses.

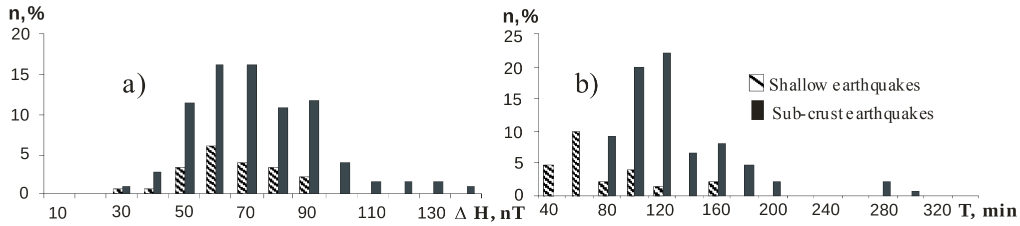

Fig. 5. The amplitudes (a) and the duration (b) of the magnetic polar substorm preceding the shallow and sub-crust earthquakes.

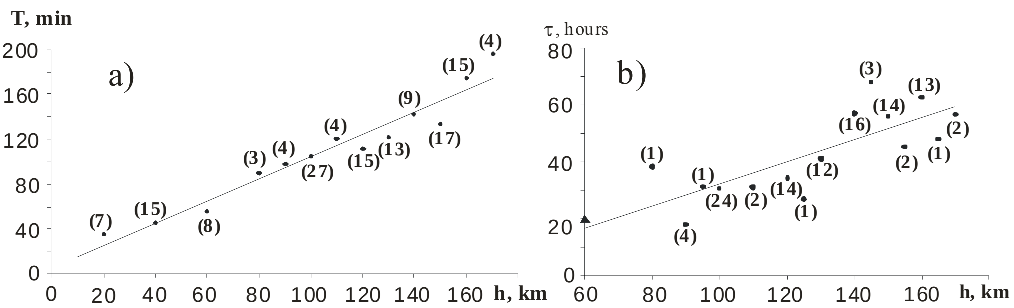

Fig. 6. The dependence of the earthquakes foci depths on the substorms duration (a) and the time interval τ for sub-crust earthquakes (b). Triangles denote the average time interval τ for the shallow shocks. The amount of earthquakes is given in parentheses.

4. Discussion and conclusion

As noted above, more than 90% of shocks recorded in the Vrancea zone are associated with the mid-latitudinal manifestation of the near-midnight polar substorms. The substorms manifested themselves both against the quiet geomagnetic field background and during magnetic storms. As a substorm reflects a complex of magnetospheric and ionospheric phenomena where the main factor is an increase of the auroral electrojet, each substorm has individual features due to the high dynamics of electrojet currents. On the other hand, the geomagnetic storm is the sum of the *Dst* variation, the disturbed diurnal variation and the irregular variation. The last one specifies the various character of the storm. There are relatively slow changes of the magnetic field lasting from several minutes to several hours which are superposed by faster fluctuations. The irregular variation spectrum is independent of the geomagnetic storm intensity (Afanasyeva *et al*. 1972).

A storm is featured by a decrease of the H-component in middle and low latitudes related to the ring current development. The relation between the processes responsible for the geomagnetic storms and substorms cannot be explained unambiguously (Gelberg *et al*. 2000). We are not discussing the mechanism of these processes.

Taking into account the temporal interval from maximum of sub-storm up to the shocks, the connection between geomagnetic disturbances and earthquakes is always positive. We systematized the changes (“gradient”) in the magnetic field related with polar substorm by three main types (groups): (1) the isolated near-midnight polar substorm occurs against a quiet background of the geomagnetic field; (2) the substorm precedes the main phase of the magnetic storm; (3) the substorm is manifested during the attenuation of the *Dst* variation.

The second and third types of changes of the H-component are called the “direct” and the “inverse” ones, respectively. The sudden commencement storms should be separated against the polar substorms into another group.

The other “gradients” in the magnetic field are rare and not related to the substorms, e.g. a recurrent storm with a sudden commencement, an anomalous behavior of the diurnal H-component changes when the *Sq* variation is not expressed (the field level is very high or low) but there are no substorms, etc. All of these events do not exceed 10%.

In accordance with this classification for each deep-focus Vrancea earthquake, the geomagnetic field behavior preceding the shock was determined. The three distinguished types correspond to 90% of shocks. When there are no substorms we have no records of deep-foci earthquakes in Vrancea at all.

The processes may be presumed as a triggering mechanism by Sobolev *et al.* (2001), when “pumping in” of energy into the Earth’s crust occurs during the magnetic storm and it is subsequently released at the earthquake. In addition, the detected regularities of substorms at their midlatitudinal manifestation should be considered as estimations of the “pumped in” energy.

In summary, we emphasize that the seismicity in the Vrancea zone is connected with a definite type of geomagnetic disturbances, such as midlatitudinal manifestation of a near-midnight polar substorm. The abrupt changes (“gradient”) in geomagnetic field (H-component) related to the maximum of the polar substorm precedes the seismic energy discharge – the seismic event occurs at a definite time interval τ after the substorm. The time interval τ from the maximum in the substorm development to the shock is associated with the earthquake focal depth. The energy class of the earthquake is connected with the amplitude of the H-component changes (during near-midnight polar substorm manifestation). Definite morphological signs preceding realization of seismic energy have been detected in the geomagnetic variation spectrum. They are systematized for different types, three of which correspond to 90% of seismic events. The effect of the magnetic disturbance on the seismic energy release is always positive taking into consideration the temporal interval from sub-storm up to the shocks. The results do not contradict the assumption of a triggering mechanism of the magnetic storm effect on the seismicity but suggest a definite contribution of the substorms which are manifested at middle latitudes.

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