IN SEARCH OF SEISMIC PRECURSORS OF THE DESTRUCTIVE 10 NOVEMBER 1940 VRANCEA EARTHQUAKE

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Within the Vrancea intermediate-depth seismogenic body, there is included a distinct cluster of hypocenters that correspond to a small number of moderate earthquakes. The latter have a narrow magnitude range $(4.8 \le m_b \le 5.1)$ and most of their focal mechanisms are of reverse fault type, with the compression (P) axes oriented parallel to the strike of the seismogenic body. Notably, two of these events, in 1973 and 1983, have occurred within a time-window systematically placed 3 to 4 years in advance of the Vrancea major shocks of 1977 and 1986. Hence, each of the two indicated moderate seismic events can be assumed to have been a precursor of one of the destructive earthquakes. The present investigation tried to identify, within a 4 years' time-interval preceding another destructive Vrancea earthquake that took place on November 10, 1940, moderate magnitude earthquakes that would display characteristics compliant to those of the presumed precursors of the 1977 and 1986 major events. The earthquakes catalogue published by Shebalin et al. (1998) and the focal mechanisms catalogue published by Radulian et al. (2002) were used to this purpose. Out of the six events recorded by the indicated earthquakes catalogue over the 4 years interval that preceded the November 10, 1940 shock, three had focal mechanisms inconsistent with those of the presumed precursor events of 1973 and 1983. For the remaining 3 events of the 1936-1940 period, no focal mechanisms are so far available, and other characteristics (magnitude, hypocenter location) are not fully compliant with those expected for the precursor of a major earthquake. But some of the observed inconsistencies could be due to the poor recording and processing capabilities of the seismic network operating in the late 1930-ies. It is therefore desirable to deploy efforts for extracting additional information from existing records of the concerned moderate earthquakes, in order to further elucidate the issue of precursory seismicity patterns associated to the destructive event of November 10, 1940.

Keywords: seismic precursors, hypocentral depth, focal mechanism, Vrancea.

1. INTRODUCTION

Strong earthquakes (magnitudes > 7) are known to occur in the Vrancea area (e.g., Ismail-Zadeh *et al.*, 2012), within a seismogenic body (Fig. 1) that extends comprehensively over the 60-180 km depth interval, while its lateral extent is quite small (70×25 km).

It has been noticed (Mitrofan *et al.*, 2016) that across the concerned lithospheric deformation domain, the seismic energy release is not uniform. Four distinct clusters become apparent when considering, for instance, the hypocenter locations (Fig. 1b) provided by the National Earthquake Information Center (NEIC) catalogue for all recorded Vrancea earthquakes of strong and moderate magnitude (which we arbitrarily established as $m_b \ge 4.8$). Among the identified clusters, an upper positioned one ("Upper Diagonal Cluster" – hereafter UDC) includes both M > 7 earthquakes occurred in Vrancea (Oncescu & Bonjer, 1997) during the NEIC catalogue recording period (which has started in 1965). Each of those two earthquakes, of 1977 and 1986, had reverse fault focal mechanisms (Oncescu, 1987) with the *compression (P) axes* oriented *perpendicular to the strike of the seismogenic body*.

Another cluster, which occupies the lowermost position within the seismogenic body ("Lowermost Cluster" – hereafter LMC), was noticed to display several features which could be relevant in terms of strong earthquakes forecasting:

a. That cluster hosted only a small number of events (4), all of moderate magnitude $(4.8 \le m_b \le 5.0)$.

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b. Three of those events had reverse fault focal mechanisms (Oncescu, 1987) with the *P-axes* oriented *parallel to the* *seismogenic body strike* (the remaining event was of normal fault type - which is extremely rare for Vrancea region).



Figure 1 – Locations of intermediate-depth Vrancea earthquakes for which the NEIC catalogue indicated $m_b \ge 4.8$. a. Map view. b. Vertical cross-section along the strike (N50°E) of the Vrancea seismogenic body.

- c. All three events with reverse fault focal mechanism have occurred during the 1973–1983 time interval, which is partially superimposed on the occurrence interval (1977–1986) of the destructive (M > 7) Vrancea earthquakes; and notably, no similar earthquakes subsequently occurred within the LMC.
- d. 3 to 4 years before each of the strong Vrancea earthquakes of 1977 and 1986 (in 1973 and 1983, respectively), a moderate magnitude event with focal mechanism displaying P axes parallel to the seismogenic body strike has occurred within the LMC.

Overall considered, the indicated characteristics could imply that two of the three moderate earthquakes ($4.8 \le m_b \le 5.0$) having occurred in the LMC and which had reverse fault focal mechanisms with P-axes parallel to the seismogenic body strike, had been precursors of strong (M > 7) Vrancea earthquakes. If this was true, one cannot exclude the possibility that the other instrumentally recorded destructive Vrancea earthquake, that took place on 10 November 1940, had also been preceded by a forerunner event located in the LMC.

Looking for such a relationship seems yet to be quite difficult and subject to uncertain results, if one takes into account the much poorer seismic recording and processing capabilities of the equipment that existed before 1940. A catalogue which nonetheless appeared to be suitable for attempting to identify possible seismic precursors that took place in the LMC prior to the 10 November 1940 earthquake was that published by Shebalin et al. (1998). By using that compilation, together with the focal mechanisms catalogue published by Radulian et al. (2002), we tried to identify if any relevant information was currently available on possible seismic forerunners occurred in the late 1930-ites and which would obey the patterns recognized for the presumed seismic precursors of the years 1973 and 1983.

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2. MATERIALS AND METHODS

The catalogue compiled by Shebalin *et al.* (1998) includes seismic events that took place until the end of the year 1990 in Central and Southeastern Europe, and implicitly, also the Vrancea earthquakes which had preceded the major shock of 10 November 1940.

We started by comparing the data included in the Shebalin *et al.* (1998) catalogue with the NEIC catalogue data. To this purpose, all Vrancea events occurred during the time interval 1965–1990 at intermediate depths (60–180 km) and which had $m_b \ge 4.8$ were retrieved from the NEIC catalogue. All those earthquakes were also included in the Shebalin *et al.* (1998) compilation; in contrast, not all NEIC-recorded events with $m_{\rm b} < 4.8$ were reported by Shebalin *et al.* (1998) too.

Fig. 2a illustrates the differences between the epicentral positions indicated for the same event by the Shebalin *et al.* (1998) and the NEIC catalogues. In Fig. 2b there are illustrated analogous differences, between the corresponding hypocenter positions plotted in a vertical cross-section along the seismogenic body strike (N50°E).



Figure 2 – Earthquake locations provided by the NEIC catalogue are compared with the same events locations indicated by the Shebalin *et al.* (1998) compilation. a. Map view. b. Vertical cross-section along the strike (N50°E) of the Vrancea seismogenic body.

In Table 1, the parameters provided by the NEIC catalogue for the moderate magnitude earthquakes occurred within the LMC, are

compared with the corresponding parameters provided for the same events in the compilation of Shebalin *et al.* (1998).

Table 1

Main parameters of the moderate-magnitude $(4.8 \le m_b \le 5.1)$ Vrancea earthquakes occurred within the LMC over the time interval 1965–1990. Location and magnitude information retrieved from the NEIC catalogue can be compared with the corresponding information provided by the Shebalin *et al.* (1998) compilation. Focal mechanism information is from Oncescu (1987).

| Date | latitude N | | longitude E | | depth (km) | | mb | | Catalogue | Focal | P-axis |
|-----------------|------------|-------|-------------|-------|------------|-------|-----|---------|-----------|-----------------|----------------------------|
| | | error | | error | | error | | error | | mechanism | orientation |
| | | | | | | | | | | type | |
| Oct 23, 1973 | 45.689 | | 26.496 | | 174 | | 4.9 | | NEIC | | parallel to the |
| | 45.70 | ±0.1 | 26.55 | ±0.1 | 170 | ±5 | 5.1 | ±0.3 | Shebalin | thrust faulting | seismogenic body strike |
| Oct 2, 1978 | 45.725 | | 26.479 | | 164 | | 5.0 | | NEIC | | parallel to the |
| | 45.72 | ±0.05 | 26.57 | ±0.1 | 164 | ±5 | 4.9 | ±0.2 | Shebalin | thrust faulting | seismogenic body strike |
| Jan 25, 1983 | 45.667 | | 26.606 | | 163 | | 4.8 | | NEIC | | parallel to the |
| | 45.7 | ±0. | 26.6 | ±0. | 1 | +5 | 4 | ± 0 | Shebal | thrust faulting | seismogenic |
| | 2 | 05 | 8 | 05 | 60 | ±J | .9 | .3 | in | | body strike |

3. RESULTS AND DISCUSSION

According to Fig. 2b, the hypocenter locations indicated by the Shebalin *et al.* (1998) compilation are consistent with the hypocenters distribution in four distinct clusters (as identified based on the NEIC catalogue – Fig. 1b); and in particular, the isolated position of the LMC,

where the presumed precursor events have occurred, is clearly noticeable.

Our next step consisted in identifying in the Shebalin *et al.* (1998) compilation the intermediate-depth Vrancea earthquakes that occurred within a time-interval of about 4 years prior the major event of 10 November 1940 (Table 2).

Table 2

Main parameters of the intermediate-depth Vrancea earthquakes recorded by the Shebalin *et al.* (1998) catalogue over the time-period which had preceded by about 4 years the major event of 10 November 1940. Focal mechanism information is from Radulian *et al.* (2002).

| Date | latitude N | | longitude E | | depth (km) | | mb | | Ms | | Focal mechanis m type | P-axis orientation |
|--------------|------------|-------|-------------|-------|------------|-------|-----|-------|-----|-------|-----------------------------|---|
| | | error | | error | | error | | error | | error | in type | |
| Nov 1, 1936 | 45.6 | ±0.2 | 26.73 | ±0.2 | 150 | ±30 | 4.5 | ±0.5 | | | ? | ? |
| Jan 26, 1937 | 45.8 | ±0.2 | 26.6 | ±0.2 | 120 | >30 | 4.9 | ±0.7 | | | ? | ? |
| Jul 13, 1938 | 45.78 | ±0.2 | 26.66 | ±0.2 | 120 | ±10 | | | 5.1 | ±0.3 | strike-slip | normal to the seismogenic body strike |
| Sep 5, 1939 | 45.78 | ±0.1 | 26.74 | ±0.1 | 140 | ±10 | 6.1 | ±0.3 | | | ? | ? |
| Jun 24,1940 | 45.76 | ±0.1 | 26.58 | ±0.1 | 115 | ±10 | | | 5.0 | ±0.3 | thrust faulting | normal to the seismogenic body strike |
| Oct 22, 1940 | 45.9 | ±0.1 | 26.5 | ±0.1 | 140 | ±30 | 6.2 | ±0.3 | | | thrust faulting | normal to the seismogenic body strike |

In this respect, it is worth outlining a particularity of the November 10, 1940 destructive earthquake: its hypocenter was not located (Fig. 3b) within the UDC (as were the hypocenters of the strong earthquakes of 1977 and 1986), but rather in the "Lower Diagonal Cluster" (LDC). Also in the LDC fall even the shallower hypocentral depth values of 133 and 135 km, reported for the 1940 earthquake by Radu (1979) and Constantinescu & Mârza (1980), respectively. Hence, if viscoelastic stress transfer was responsible (as hypothesized in Mitrofan et al., 2016) for the long-range interaction between the presumed precursor events occurred in the LMC and the subsequent strong Vrancea earthquakes, the distance over which such transfer occurred could have been smaller in the case of the 1940 event than in the case of the earthquakes of 1977 and 1986. And consequently, the precursor time interval could

have been shorter than the 3-4 years recorded in the case of the 1977 and 1986 events.

Out of the six seismic events listed in Table 2, focal mechanism solutions are available (Radulian et al., 2002) only for three of them. Two of those solutions indicate reverse faulting with *P*-axes normal to the strike of the Vrancea seismogenic body, whereas for the third event (which actually had the most poorly constrained solution) strike-slip faulting was indicated, with the *P*-axis also normal to the seismogenic body strike. Since none of the three solutions is similar to those assumed to be characteristic to the precursor events occurred in the LMC (namely reverse faulting, with *P*-axes parallel to the seismogenic body strike), only three earthquakes are left as candidates for possible precursors: in fact, the three earthquakes for which no focal mechanism solutions are currently available.



Figure 3 – Locations provided by the Shebalin *et al.* (1998) catalogue for intermediate-depth Vrancea earthquakes that took place during the time-intervals 1965–1990, and November 1, 1936 – November 10, 1940. a. Map view.
b. Vertical cross-section along the strike (N50°E) of the Vrancea seismogenic body.

Among the latter three earthquakes, the September 5, 1939 one is the only whose timelag to the November 10, 1940 event is smaller than 3–4 years: this circumstance would be in accordance with the above-mentioned hypothesis, that the viscous stress transfer took a

shorter time to proceed than in the case of the 1977 and 1986 major earthquakes. The reported focal depth (140 km) of the 1939 earthquake is relatively close to the LMC depth range; however, according to the estimated depth uncertainty (±10 km), it is unlikely that the actual depth of the hypocenter could reach the LMC depth domain (Fig. 3b). And at the same time, the reported magnitude ($m_b = 6.1\pm0.3$) falls outside the range assumed to be characteristic to the precursor events occurring in the LMC ($4.9 \le m_b \le 5.1$).

The January 26, 1937 event appears to "score" better, when one considers:

- a. its lower reported magnitude ($m_b = 4.9$), comparable to that of the assumed precursor earthquakes of 1973 and 1983, and
- b. the large uncertainty (> 30 km) to which its hypocenter depth determination was subject – which could indicate the possibility that the hypocenter was actually deeper than 160 km, being hence positioned within the LMC (Fig. 3b).

Moreover, the time lag to the November 10, 1940 event falls within the 3 to 4 years range, similar to the time lags that separated the assumed precursors of 1973 and 1983, from the subsequent strong earthquakes of 1977 and 1986, respectively.

The November 1, 1936 earthquake seems to be the one that displays the best match between its estimated hypocentral depth, and the LMC depth range (Table 2, Fig. 3b). However, its magnitude ($m_b = 4.5\pm0.5$) is slightly smaller than the range $4.9 \le m_b \le 5.1$, assumed to be characteristic to the precursor events occurring in the LMC. Moreover, the time-lag to the November 10,1940 shock exceeds (just by a few days) 4 years.

Hence, of the three previously discussed "candidate" earthquakes, none is fully complying with the characteristics of the assumed precursors of the 1977 and 1986 major events. It is difficult to establish which of the noticed inconsistencies mirror actual relevant differences, and which are just a consequence of the poorer recording and processing capabilities of the late 1930-ies seismic network. It is therefore desirable to deploy further efforts for attempting to extract additional information (especially focal mechanisms, if possible) from existing records of the concerned earthquakes of 1936, 1937 and 1939. Such an approach could eventually validate (or invalidate!) the assumption that one of those events had been a precursor of the November 10, 1940 destructive earthquake.

4. CONCLUSIONS

Possible seismic precursors of the strong (M > 7) Vrancea earthquakes of 1977 and 1986 have been previously identified relying on several specific features: (i) hypocenter location (in particular depth > 160 km) within a narrow cluster inside the overall seismogenic body; (ii) narrow magnitude range ($4.8 \le m_b \le 5.1$); (iii) focal mechanisms indicating exclusively reverse faulting with compression (P) axes parallel to the seismogenic body strike. Moreover, each of the major earthquakes of 1977 and 1986 was preceded, within a time-interval that systematically ranged between 3 and 4 years, by one such precursor event.

In a quest for a possible similar seismicity pattern, that could have also preceded the strong Vrancea earthquake of November 10, 1940, we made use of the catalogue of Shebalin *et al.* (1998) and of the focal mechanisms catalogue of Radulian *et al.* (2002). When compared to the NEIC data base, the Shebalin *et al.* (1998) compilation was shown to include all Vrancea events occurred during the time-interval 1965–1990 and for which NEIC indicated $m_b \ge 4.8$; moreover, no severe location and magnitude differences existed between the two indicated catalogues.

Out of the six events recorded by the Shebalin *et al.* (1998) compilation within the four years' time interval prior to the major earthquake of November 10, 1940, three can be disregarded, since their focal mechanisms were not of reverse fault type with P-axes parallel to the seismogenic body strike.

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Each of the three remaining earthquakes (November 1, 1936, $m_b = 4.5$; January 26, 1937, $m_{\rm b} = 4.9$; September 5, 1939, $m_{\rm b} = 6.1$), for which focal mechanism solutions are not currently available, only partly complies with the characteristics displayed by the presumed precursors of the 1977 and 1986 destructive events. One must however take into account that some of the observed inconsistencies could be due to the poor recording and processing capabilities of the seismic network operating in the late 1930-ies. Therefore, efforts aimed to extract additional information from existing records of the concerned earthquakes could further elucidate the issue of precursory seismicity patterns associated to the destructive event of November 10, 1940.

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