SHALLOW (< 55 KM) SEISMIC ACTIVITY TRIGGERED ALONG THE MARASESTI-GALATI-BRAILA LINEAMENT IN RESPONSE TO THE MAJOR SUB-CRUSTAL EARTHQUAKES OF VRANCEA AREA

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Introduction

Earthquake triggering is the process by which stress changes associated with an earthquake can induce or retard seismic activity in the surrounding region, or trigger other earthquakes at great distances. In the case of the *sub-crustal* seismogenic volume of Vrancea area, a Coulomb Failure Stress analysis has been performed by Wustefeld (2003), and Wuestefeld *et al.*, (2003), in order to determine whether the major ($6.9 \leq Mw \leq 7.4$) seismic events which had occurred in that region during the last 70 years had been independent, or if they had been triggered by the preceding large earthquakes. More recently, Radulian *et al.* (2007, 2008) have noticed that the *intermediate-depth* Vrancea earthquakes exhibited a non-random distribution of their hypocenters, a setting which could not be explained by stress transfer associated to a simple mechanical rupture process. By performing a seismicity pattern analysis, the latter authors additionally inferred that the strong earthquakes in the upper part of the Vrancea *sub-crustal* seismogenic volume (such as the 1977 earthquake, or the 1990 earthquake) seem to have been generated in response to the preceding large shocks having occurred below (in 1940 and in 1986, respectively); all in all, there was inferred that the seismicity configuration at shallower depths (including the crust) should correspond to that particular triggering mechanism.

In the following, we provide new evidence that at shallow (crustal) levels, a significant seismic activity is triggered in response to the major earthquakes generated at intermediate-depth in Vrancea area. The crustal region which we identified as being concerned by that seismic triggering processes is located along the so-called "Marasesti-Galati-Braila Lineament" (MGBL).

Investigation approach

The seismic sensitive area of MGBL has been initially mentioned by Raileanu *et al.* (2007) as being included - together with other two distinct sub-domains, "Ramnicu Sarat" and "Vrancioaia" – within the broader domain where the *crustal* earthquakes of Vrancea area occur: the latter domain surface projection essentially overlies the Vrancea *sub-crustal* earthquakes zone, yet also extending farther to the east and to the southeast.

For each of the above-indicated sub-domains (*Ramnicu Sarat*, *Vrancioaia* and *MGBL*), we have specified conventional boundaries (Fig. 1). Our zonation was essentially based on a visual inspection of the epicenters clustering, while also taking into account the homogeneity of the seismic activity. There were considered the $Mw \geq 2.5$ seismic events with hypocentral depths < 55 km, which the ROMPLUS catalog (available at http://infp.infp.ro/catal.php) listed over the 20 years time-interval that spanned from 1975 to 1994: during that period, there have occurred the 3 most recent destructive earthquakes (1977, 1986, 1990, with moment magnitudes 7.4, 7.1 and 6.9 respectively) of the intermediate-depth seismic region of Vrancea.

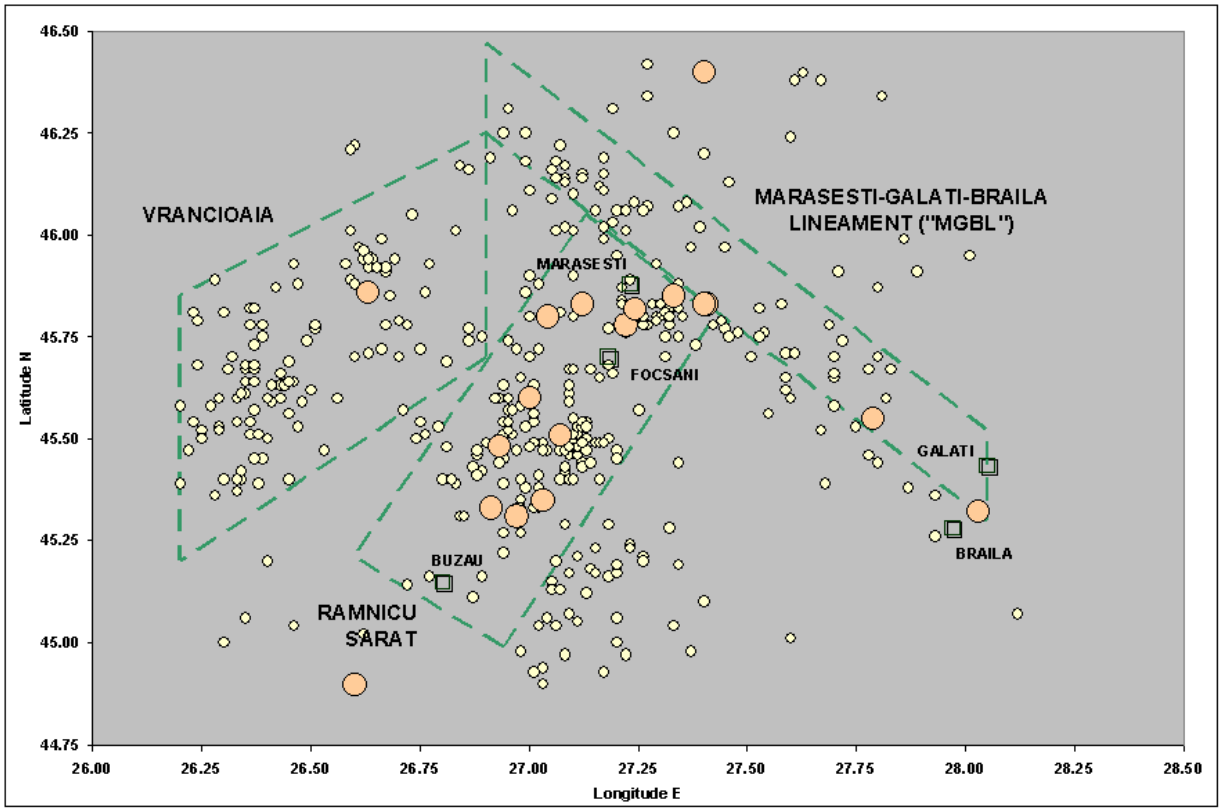

Fig. 1. Epicenter map of the Vrancea *crustal* earthquakes. Small, light-yellow dots indicate events with 2.5 ≤ Mw ≤ 3.4; larger, orange dots indicate events with 3.5 ≤ Mw ≤ 4.5. Crustal seismicity sub-zones - *RAMNICU SARAT*, *VRANCIOAIA* and the *MARASESTI-GALATI-BRAILA LINEAMENT* (*MGBL*) – are bounded by green polygons.

The moment magnitudes (Mw) that the ROMPLUS catalogue indicated for the earthquakes recorded in the MGBL *crustal* domain have been used to construct the corresponding cumulative Benioff strain release diagram (the "Benioff curve", Fig. 2).
An analogous Benioff curve has also been constructed for the Vrancea *intermediate-depth* earthquakes: in that case, from the ROMPLUS catalog there were retrieved the seismic events that complied with the hypocenter-depth requirement (≥ 55 km), and with the completeness criterion (Mw ≥ 2.8) that Enescu *et al.* (2008) stipulated for the intermediate-depth Vrancea earthquakes catalog. As expected, the obtained Benioff curve was largely similar to that constructed by Scordilis (2006), who yet utilized a different, composite catalog, and addressed only intermediate-depth Vrancea earthquakes with Mw ≥ 4.8.
The two considered domains – the *crustal* MGBL domain, and the Vrancea *sub-crustal* earthquakes domain - are subject to highly contrasting seismic energy release rates (Radulian et al., 2007). That circumstance would have made direct comparison of their Benioff curves difficult. Therefore, the raw values of the cumulative strain have been divided, for each of the two distinct domains, with the corresponding cumulative strain value recorded by the end of the considered time interval (such diagrams are designated by Mantovani *et al.*, 1987, as "autonormalized").

Discussion and conclusions

Fig. 2 illustrates the seismic energy release regime in the *sub-crustal* domain of Vrancea area, as compared to the contemporary energy release recorded in the MGBL *crustal* sub-zone. There can be noticed that several months/tens of months after each major *sub-crustal* event (of 1977, 1986 and 1990 respectively), an accelerating moment release (AMR) was recorded in the *crustal* seismicity of the MGBL. Alternatively, over the long time-spans which separate

those episodes of increased seismicity, the two Benioff curves display gentle slopes which are, moreover, essentially similar. In addition, the only significant seismic events ($3.4 \leq Mw \leq 4.4$) of the MGBL area (Fig. 2) belong to the 3 episodes of AMR.
Previously, by comparing an analogous pair of Benioff curves, Mantovani *et al.* (1987) had conjectured that the large earthquakes located on the western margin of the ADRIA plate were triggered by the major events which had occurred, a few years earlier, on the opposite (eastern) boundary of the same tectonic plate. Similarly, the overall setting recorded in Vrancea area suggests that each of the 3 destructive *intermediate-depth* earthquakes having occurred between 1975-1994, has triggered a significant seismic activity at shallow (*crustal*) depths in the MGBL domain.

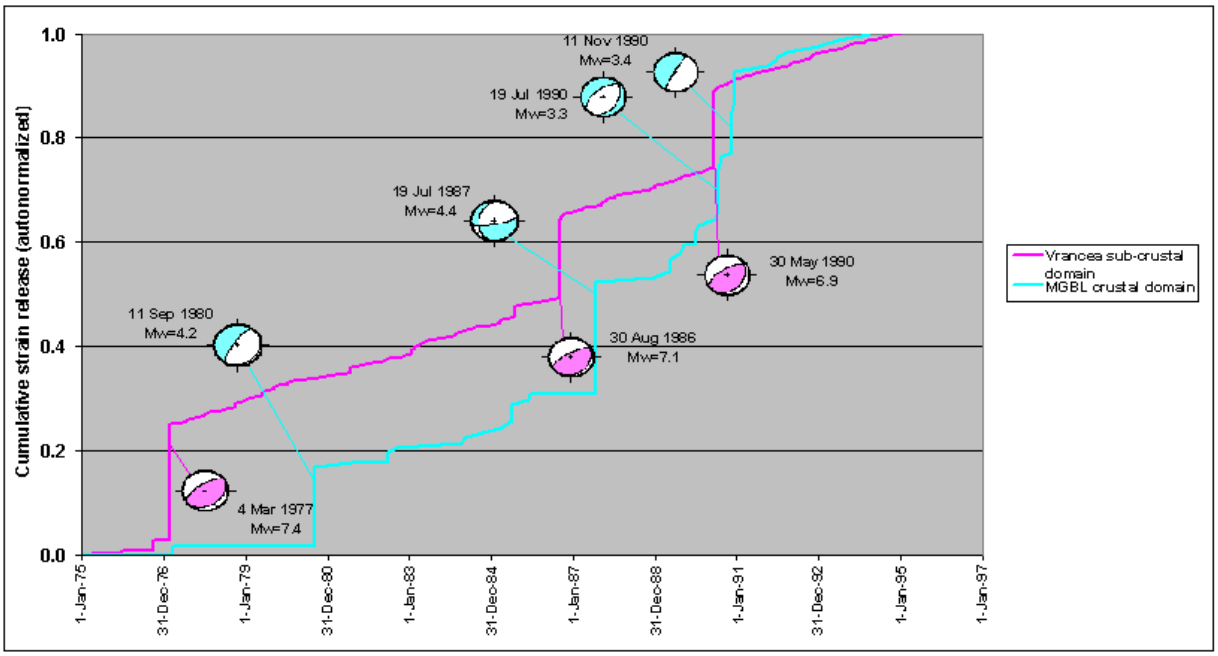

Fig. 2. Benioff strain release diagrams (autonormalized) constructed for the Vrancea *intermediate-depth* seismic domain (magenta), and for the MGBL *crustal* domain (light blue). Beach-balls indicate focal mechanisms: magenta - for the major *intermediate-depth* earthquakes; light blue – for the MGBL main *crustal* events that occurred in the aftermath of the three *intermediate-depth* destructive earthquakes.

Sandu and Zaicenco (2008) provided focal mechanisms (Fig. 2) for the main *crustal* events which had occurred along the MGBL in the aftermath of the *intermediate-depth* destructive Vrancea earthquakes (the same *crustal* events are, in fact, the only ones to be recorded along the MGBL during the 1975-1994 time-interval by the USGS PDE catalog, available at http://earthquake.usgs.gov/earthquakes/eqarchives/epic/epic_rect.php). Notice that all the available fault-plane solutions have their slip-planes striking NE-SW (Fig. 2), i.e. in the same direction as the slip-planes of the corresponding *intermediate-depth* earthquakes (the latter focal mechanisms were retrieved from http://www.globalcmt.org). There is, however, a significant difference: while the *intermediate-depth* (~ 90-135 km) earthquakes mechanisms always indicate SE-NW directed compression, the mechanisms of the considered MGBL *crustal* earthquakes suggest that along the same direction, at shallow (~ 0-20 km) depths, extension stresses are basically operating. This is an overall pattern which appears to occur at least during the increased *crustal* seismicity episodes, which follow the major *intermediate-depth* Vrancea earthquakes.

A thermo-mechanical model addressing subduction processes in the Carpathians bend zone (Cloetingh *et al.*, 2004) seems to provide some physical insights concerning the above-noticed regime of opposing stresses: on the one hand, SE-NW compression is postulated at large depth, where earthquakes are generated by the contact between a lower plate slab, in accelerated descent, and a detached mantle lithosphere segment belonging to the overriding plate; on the other hand, in the upper part of the lower plate, crustal tilting and normal-faulting are favored along the Peceneaga-Camena fracture zone, that latter major fault being the one which was inferred to account, according to Raileanu *et al.* (2007), for the MGBL seismic activity.

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