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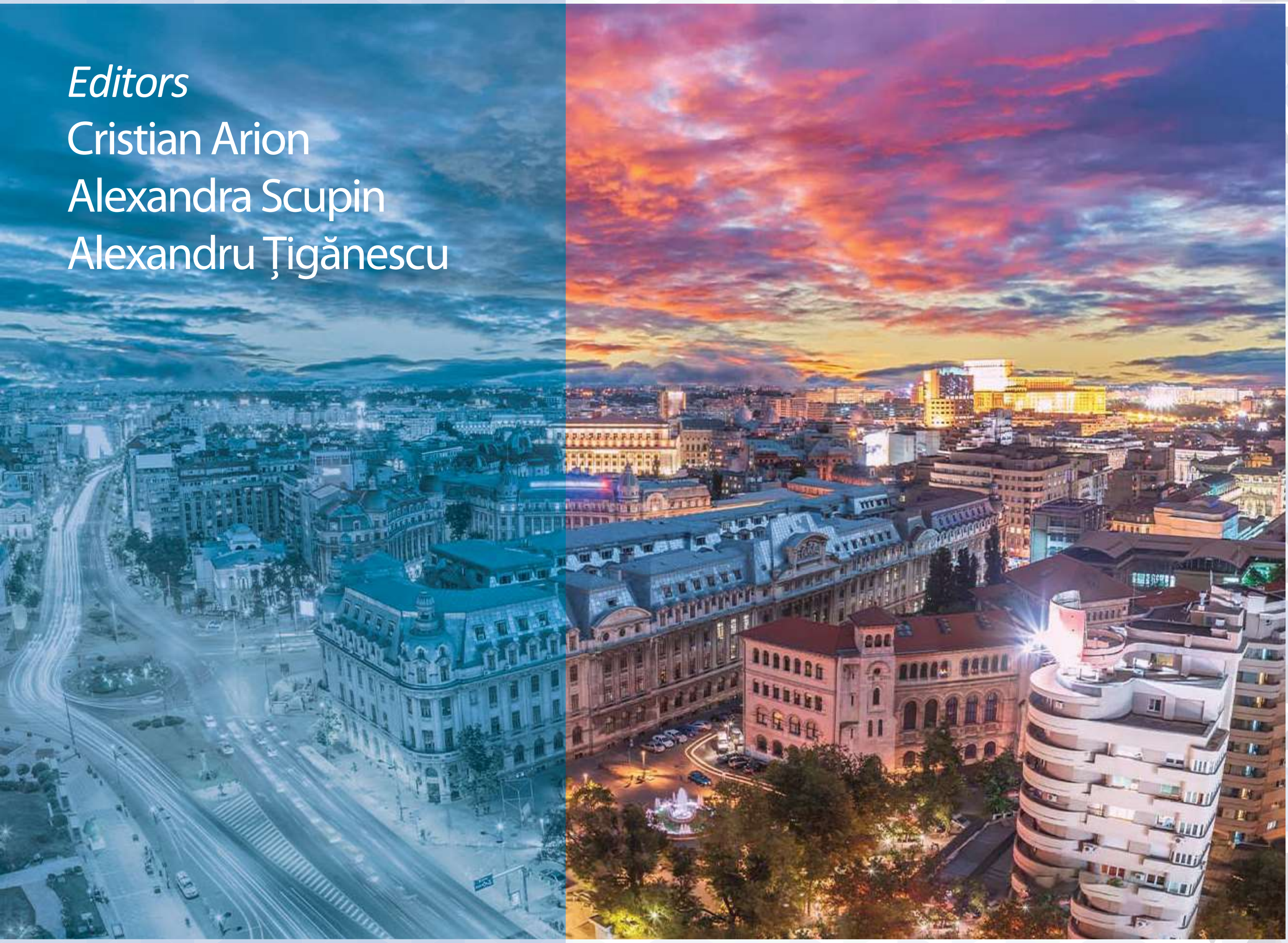

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In search of activated faults in the Petrinja (Croatia) earthquake sequence of 2020–2021

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Abstract: Preliminary locations of over 12,700 earthquakes in the Petrinja (Croatia) earthquake sequence (2020–2021) reveal that a number of smaller faults were activated in the first five months after the main strike-slip rupture along the Petrinja fault (mainshock M_w = 6.4). Unlike the nearly vertical Petrinja fault, most of the smaller faults dip to the NE, and can be related to reverse faulting mechanisms. The cross-sections through the epicentre clouds also point to a large area around the mainshock's hypocentre where the density of aftershocks foci is rather low, thus indicating nearly complete stress release by the main event. Most of the aftershocks occurred in two well-defined clusters below this region, and to the SE of it. Focal mechanism solutions for 50 events from the sequence ($2.6 \leq M_w \leq 6.4$) show that the largest ones are characterized by strike-slip sources, but a considerable number of nearly pure dip-slip solutions were also found. The inferred orientations of the P-axes (SW–NE to SSW–NNE) are rather consistent, with only a few exceptions.

Keywords: Aftershock locations, focal mechanisms, active faults

1. Introduction

The Petrinja earthquake sequence started on 28 December 2020 with a foreshock of moment magnitude M_w = 4.9. The devastating mainshock (M_w = 6.4) occurred a day later causing wide-spread destruction in the greater epicentral area, including the city of Petrinja itself. The year of 2020 was the first year of the Covid-19 pandemic, which significantly hindered activities of seismologists related to field work and temporary seismic network installation. Unfortunately, the density of stations in the vicinity of the mainshock's epicentre was rather low, which was significantly improved on 4 and 5 January 2021 when a small mobile pool of six stations was installed in cooperation with Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Udine, Italy. As Dasović et al. (2020) and Stipčević et al. (2021) have shown, data from this network reduced average standard errors of hypocentral depths by a factor of about four. Starting in late January 2021, an additional network of 36 stations was installed by the Croatian Seismological Survey. The analyses of DInSAR interferograms have shown that maximum horizontal ground displacements caused by this earthquake reached about ±45 cm (Fig. 1).

Herewith we present preliminary results of analyses of all available seismic data collected in the first five month of the series duration. In particular, we show and briefly comment on hypocentral locations, and the first-motion polarity focal mechanisms obtained thus far, and point to possibly activated faults illuminated by this series of earthquakes.

2. Earthquake locations

Recorded digital seismograms were analysed by an experienced seismologist, who hand-picked about 220,000 phase arrival times for over 12,785 earthquakes as shown in Fig. 1. Hypocentres were located using the Hyposearch program (Herak, 1989), adapted to handle source-specific station corrections as explained by Herak et al. (2021). A bulk of events occurred within the main epicentral cloud stretching NW–SE for about 20 km. Apart from the main group, significant activity is also recorded to the NE and SW of Petrinja in the NE-wall of the Petrinja strike-slip fault, to the NNW of Glina in the SE fault wall, as well as about 10 km to the N of the main cluster.

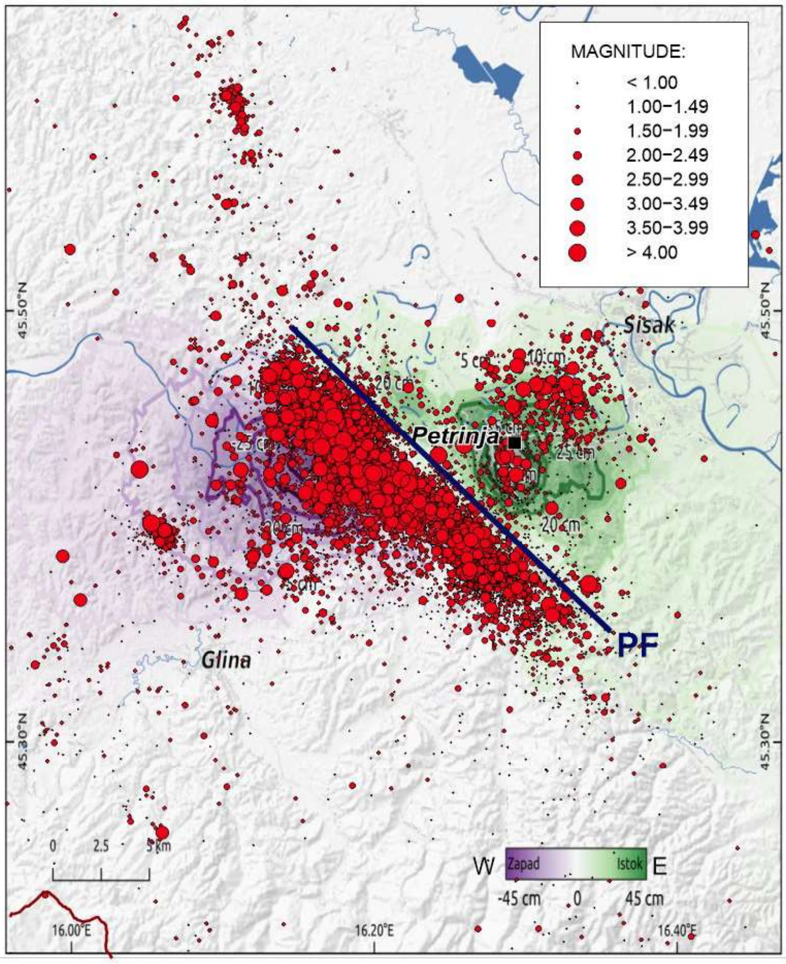

Fig. 1 – The first five months of seismicity, 28 December 2020 – 27 May 2021. Epicentres of 12,785 located events are shown overlain over the DEM of the greater epicentral area and the unwrapped DInSAR interferogram (M. Govorčin, personal communication, 2021) showing horizontal E–W coseismic displacements of the Earth's surface. PF – rough estimate of the surface projection of the causative strike-slip Petrinja fault dividing areas with net displacements towards the east and the west.

Fig. 2 presents only the best-located earthquakes characterized by the minimal number of onset-times used for location and the standard error for depth, as well as the maximal allowed azimuthal gap. The threshold values were less restrictive for the initial eight days (until 4 January 2021, when the first mobile network was deployed), than for the remaining period (see Fig. 2 caption for detail). In the lower part of the figure, four depth cross-sections are presented. The main fault is clearly seen to be almost vertical, extending to the depth of about 20 km (cross-sections B and C). The profiles A and C suggest that smaller faults dipping to the NE exist on both sides of the main rupture. The longitudinal section (D in Fig. 2) through the main aftershock cloud reveals that most of the small events occur in two well defined volumes – the one in the NW part at depths between 10 and 18 km, dipping gently towards SE, and the south-eastern one between 5 and about 13 km depth.

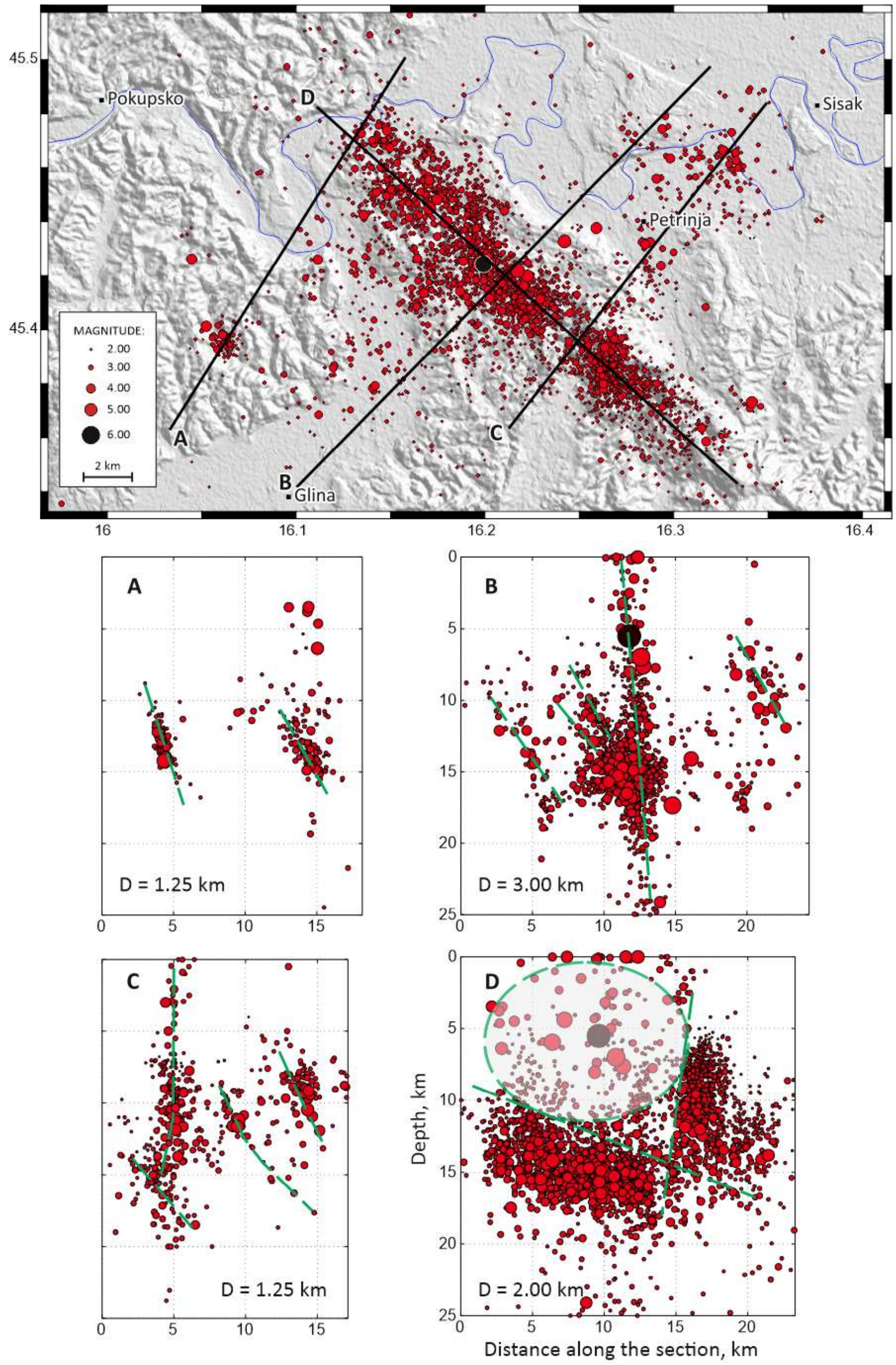

Fig. 2 – *Top:* Best located epicentres of earthquakes which occurred in the first five months of the Petrinja sequence (28 December 2020 – 27 May 2021). Mainshock is shown as black circle. The events shown were located using $N_{min} \geq 14$ (<u>8</u>) phase onset times, with the standard error for the depth $\sigma_h \leq 2.0$ (<u>3.5</u>) km, and azimuthal gap $\gamma \leq 90°$ (<u>150°</u>) which occurred after (<u>before</u>) 4 January 2021 when the first mobile seismic network was installed in the epicentral area. *A–D:* vertical cross-sections shown in the map above. The half-width *D* of the corridor around each profile is indicated in the corresponding subplot. Green dashed lines accentuate possible activated faults and block boundaries. The semi-transparent ellipse in D roughly corresponds to the ruptured area of the Petrinja fault in the mainshock.

The fault surrounding the mainshock's focus (green ellipse in Fig. 2D) is characterized by comparatively few foci, mostly of the early aftershocks. This area probably corresponds to the main rupture where the largest part of the stress was released by the mainshock. The boundaries of this region towards the two aforementioned clusters of foci are rather sharp and well defined.

3. Focal mechanisms

First-motion polarity focal mechanisms for 50 earthquakes of the Petrinja sequence are shown as lower hemisphere equal-area projections in Fig. 3. Clearly strike-slip solutions prevail for the largest events, but pure reverse faulting, sometimes with some strike component, is also found.

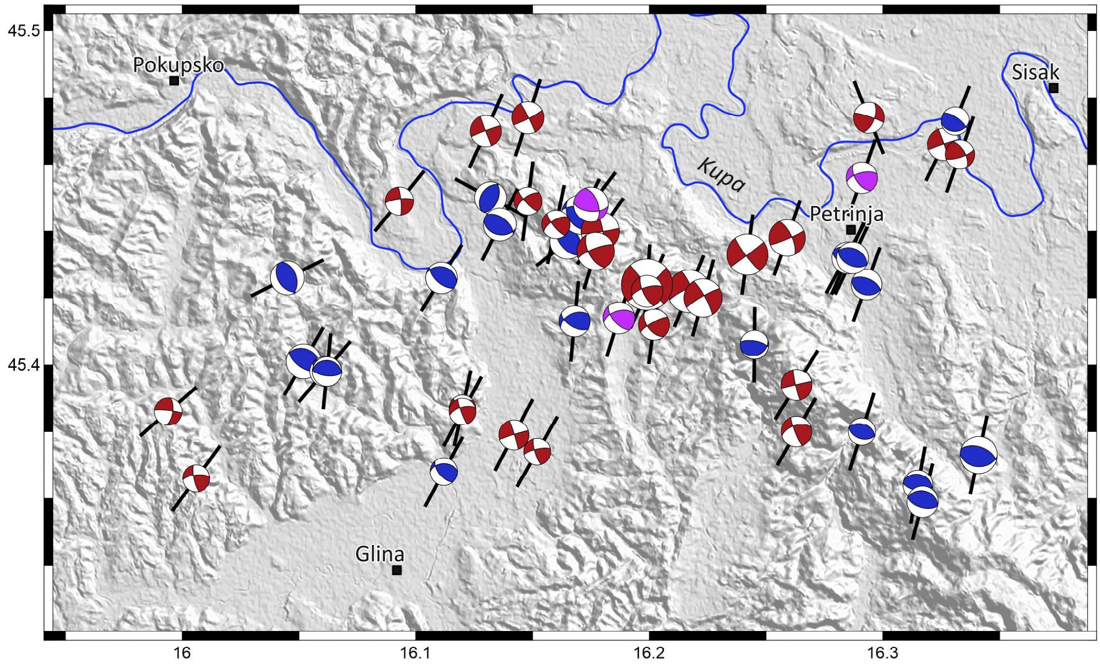

Fig. 3 – First-motion polarity focal mechanisms (lower hemisphere equal-area projection) for events in the first year of the Petrinja sequence. Red, blue and violet compressive quadrants correspond to predominantly strike-slip, reverse, and transpressive mechanisms, respectively. The beach-ball sizes are scaled with the magnitude ($2.6 \leq M_w \leq 6.4$). Black lines are oriented along the strike of the P-axes.

The dip-slip faulting mostly correspond to smaller faults outside the body of the main cluster, of which some may readily be associated with possible faults imaged by the hypocentral distribution in Fig. 2. The inferred P-axes consistently strike SW–NE to SSW–NNE, with only a few exceptions that were probably caused by local perturbation of the tectonic stress field as a result of stress redistribution after the mainshock rupture.

4. Conclusions

The preliminary results presented herewith are encouraging. After most of the aftershocks in later sequence will be located using further improved velocity models and better-defined source-specific station corrections, we hope to be able to provide valuable data to constrain the pattern of activated faults, and characterise seismotectonic environment of the greater Petrinja area.

Acknowledgements

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