IDENTIFICATION OF QUARRY BLASTS IN THE DEVA REGION (ROMANIA) USING SEISMO-ACOUSTIC ANALYSIS

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ABSTRACT

The updated Romanian Seismic Catalogue (ROMPLUS, Oncescu et al., 1999) has been contaminated over time by anthropic events, especially in the regions where quarries are exploited. This contamination can affect the interpreting and modelling of seismicity and geodynamics in specific areas. Therefore, a procedure to discriminate between tectonic earthquakes and anthropic events is required.

To eliminate misinterpretations, discrimination between earthquakes and quarry blasts has been proven very important for seismicity studies, hazard and seismic risk assessment, identification of soil structure and characteristics.

For this purpose, in the first step, a statistical analysis based on the depth interval, diurnal and weekly distribution of the events that occurred in the study area (Deva region, Central Transylvania) has been carried out. In the second step, events presumed as quarry blasts were validated using recordings of the Romanian infrasound arrays. A duo of detection-oriented software, recently developed by CEA/DASE and packaged in the extended CTBTO NDC-in-a-box, is used to investigate the infrasound signals: DTK-GPMCC and DTK-DIVA. The events identified as quarry blasts by meeting the discrimination criteria (statistical and association with infrasonic signals) are used as templates in the cross-correlation techniques applied for all events located in the Deva region between 2016 and 2018.

Keywords: ROMPLUS Catalogue, Seismo-Acoustic Analysis, Discrimination, Quarry Blast

INTRODUCTION

More than 29000 seismic events (magnitude Mw between 0 and 7.7) occurred on Romania's territory during 1900 – 2019-time intervals are listed in the ROMPLUS catalogue. The seismicity recorded before 1970 is mostly based on macroseismic observations and early seismic instrumentation. The distribution of epicentres (Figure 1) shows concentrations at the South-East Carpathians Arc bend and towards south-east, along South Carpathians and in the Banat area.

We assume that the relative large number of seismic events recently recorded in the Transylvania region is related to the enhanced coverage of the region with seismic stations and the capacity of the network to detect and locate the intense anthropogenic activity such as mining operating in the region.

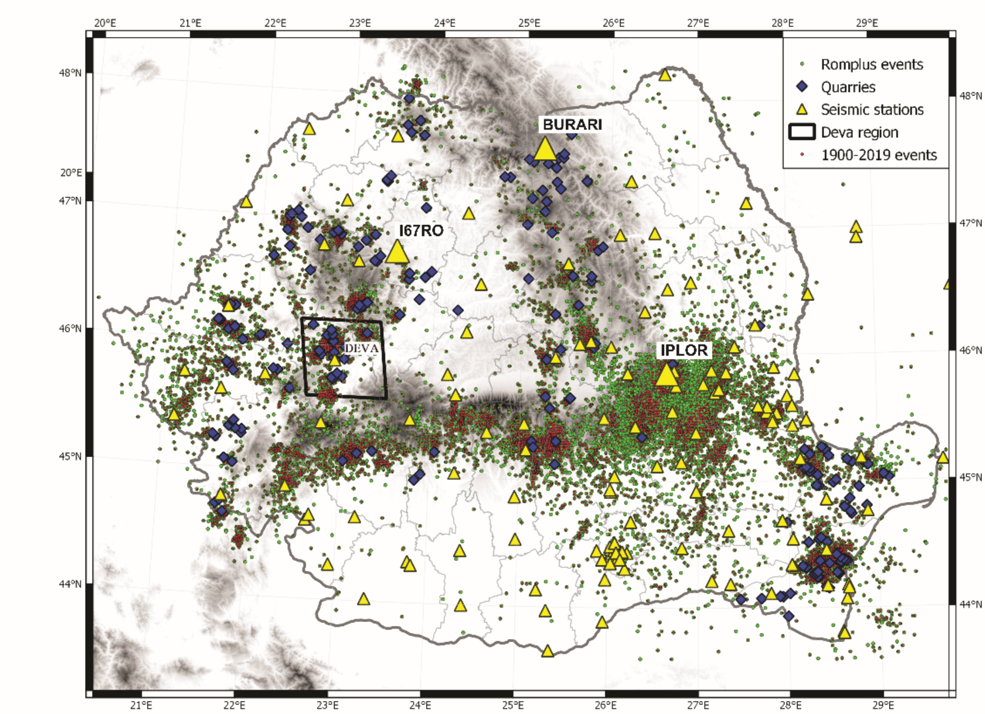

Figure 1 - The geographical distribution of the ROMPLUS events on Romania’s territory (green points). The black rectangle represents the considered study zone while the red points represent the events from ROMPLUS that fulfil the Borman criteria (Borman, 2013). I67RO, BURARI, IPLOR are the codes of Romanian infrasound stations

The seismic data used in this study were recorded between 2016 and 2018 by stations located at epicentral distances within a radius of 10 km around the quarries in the Deva region and surrounding areas. Statistically, it has been observed that most of the recorded events are localized inside a 10 km-radius circle around quarries, representing the typical distance for location errors in case of small and shallow-depth events.

According to Borman (2013), a seismic event could be considered as quarry blast if several criteria are fulfilled: it commonly occurs during working hours; magnitude is smaller than 3.0; depth is less than 5 km (as the quarry blasts occur on land or near the surface); Rayleigh waves are recorded in short time after the primary wave occurrence; P-wave generated by explosions is characterized by higher frequency range and compressional first motions along all directions.

However, for this study, we selected the events with depths up to 15 km because of possible inaccuracies in the event’s depth estimation. In fact, 57% of all events recorded between 1900 and 2019 in ROMPLUS catalogue (Figure 1) follow the magnitude (Mw < 3.0) and depth criteria (up to 15km) as stated above.

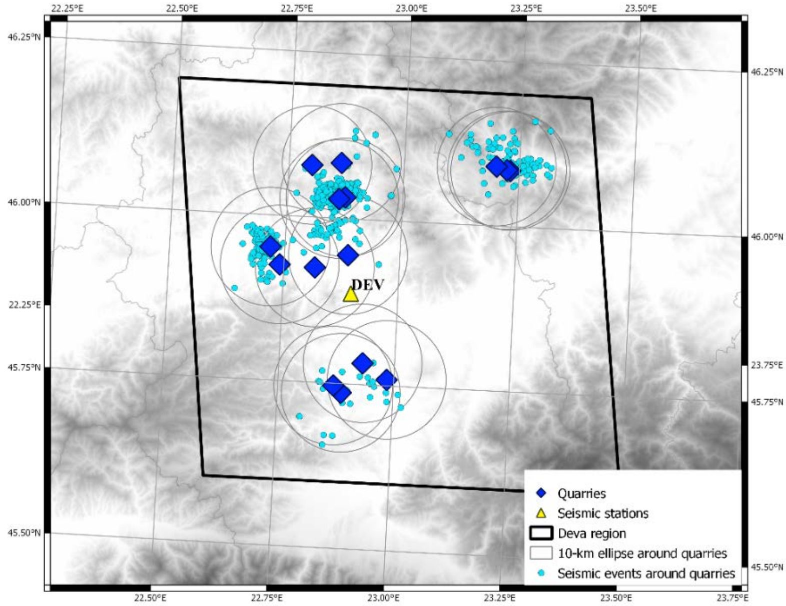

Figure 2 - Highlights of Deva region (yellow rectangle), active quarries used in this study (blue diamonds) and seismic events recorded in ROMPLUS during the 2016 – 2018 time interval (light blue dots). The waveforms recorded by Deva (DEV) station (yellow triangle) were used in the cross-correlation technique as templates.

Figure 2 shows the geographical distribution of the events located in the Deva region (yellow rectangle) between 2016 and 2018, which have been analysed in this study. 15 quarries activate in the region of Deva city and DEV seismic station. During 2016 – 2018-time interval, inside of the 10 km perimeter marked around these quarries, 480 events with magnitude Mw between 1.5 and 2.2 and depth between 1 and 22 km were located.

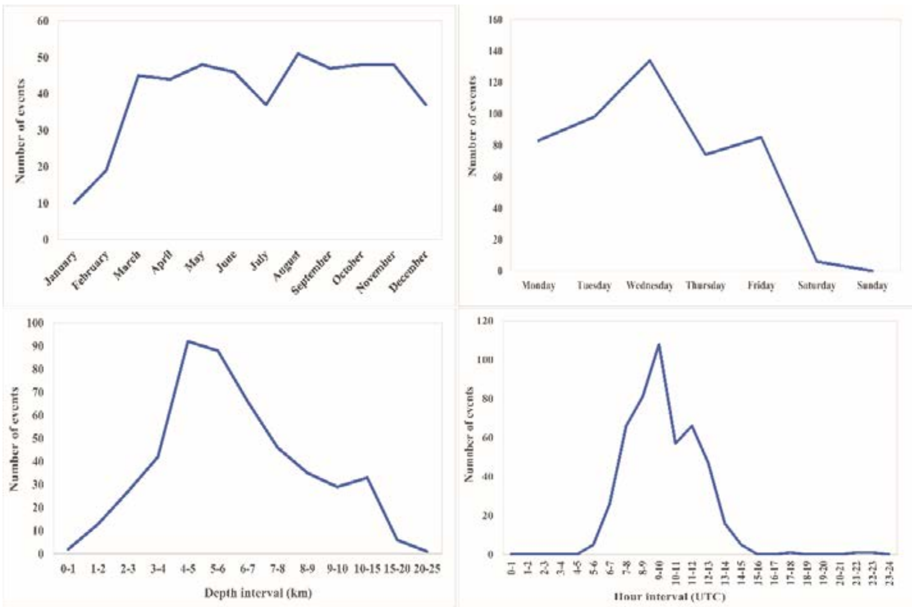

Figure 3 - Distribution of the events recorded in the Deva region between 2016 and 2018: diurnal (hour of the day) (up), weekly (day of the week) (middle), and on depth interval (down)

METHODS

a) Statistical analysis

The first step of our method of discrimination between tectonic earthquakes and quarry blasts is the statistical analysis: diurnal (hour of the day), weekly (day of the week) and depth distribution. The results are plotted in Figure 3.

The diurnal distribution shows that between 14:00 and 07:00 (UTC), the seismic activity in the area is almost absent and most seismic events occur during the daytime, from 07:00 until 14:00 UTC. Furthermore, the shape of most of the waveforms recorded during this time interval looks quite typical to quarry blasts.

b) Seismic waveform analysis

Throughout our study, we observed that for more than 60% of the events, the waveforms look quite similar to the quarry blasts shape. The position of the explosion points, at the surface or near the surface, as well as the detonation techniques used inside the quarries, could generate specific signal characteristics useful in the discrimination process (Figure 4).

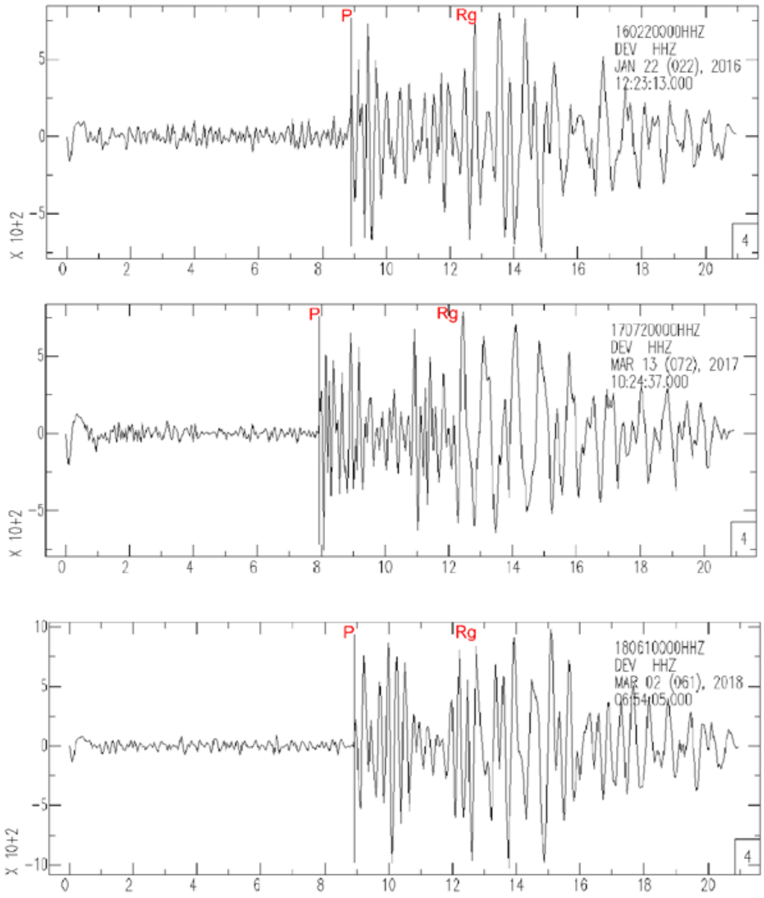

Figure 4 - Examples of waveforms associated with events considered as quarry blasts displayed with SAC software (Goldstein et al., 2003)

c) Infrasound waveform analysis

The data recorded by two infrasonic arrays (BURARI and I67RO) deployed in Romania during the 2016 – 2018 time interval were used in association with the seismic data in order to identify the blast events. Infrasonic waves generated by quarry blasts are characterized by sharp-onsets, with frequencies between 0.05 Hz and at least 20 Hz and with amplitudes ranging from a few mPa to more than 5 Pa (Campus and Christie, 2010).

BURARI infrasound array was installed in July 2016, in the northern part of Romania, under a joint effort between the National Institute for Earth Physics (NIEP) and AFTAC (USA). The station comprises four sites equipped with Chaparral Physics Model 21 sensors and distributed within a 1.2 km aperture. The seismic array (BURAR) is collocated with BURARI array (Ghica et al., 2017).

PTS portable infrasound array, I67RO, has been deployed between September 2016 and October 2018 as a collaboration between NIEP and PTS of the Preparatory Commission for CTBTO. The array consisted of four sites equipped with CEA/DAM MB2005 micro barometers and distributed within a 0.7 km aperture (Ghica et al., 2017).

Several seismic events in our study, located in the Deva region around quarries, could be associated, in terms of back azimuth and arrival time, with infrasonic detections of the BURARI and I67RO arrays. As the seasonally dependent stratospheric winds are an important factor strongly influencing the infrasonic wave propagation (de Groot-Hedlin et al., 2010), westward propagation during the summer season will significantly decrease the ability to detect infrasonic signals coming from a western azimuth. In this regard, most of the infrasonic detections could be observed between October and May.

Three examples of infrasonic signals detected by BURARI infrasound array and associated with acoustic events (quarry blasts) located in the Deva are shown in Figure 5.

d) Template matching and cross-correlation

The events considered as quarry blasts (Figure 6) from the previous steps (a, b, c) are used in cross-correlation analysis based on identifying technique of the events belonging to a cluster, i.e., the event waveform matching the reference explosion waveform and fulfilling the hour, week, and statistical depth criteria. The cross-correlation coefficient is both a measure of the similarities between pairs of events and a measure of the foci proximity of two events. In this study, we consider that a blast belongs to a quarry defined by a template event when the cross-correlation coefficient (CCF) is greater than or equal to 0.7.

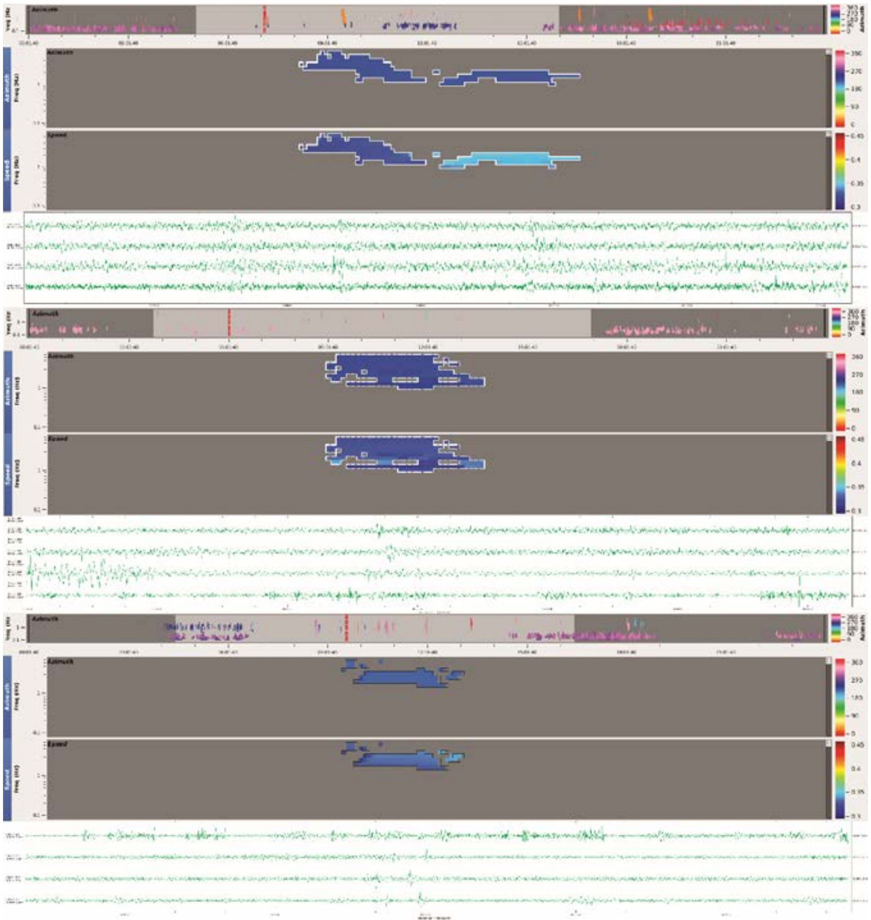

Figure 5 - Three examples of infrasonic signals detected by BURARI infrasound array and associated with acoustic events (quarry blasts) located in the Deva region. DTK-GPMCC detection panel (Cansi, 1995) is used to plot the infrasound detections and waveforms.

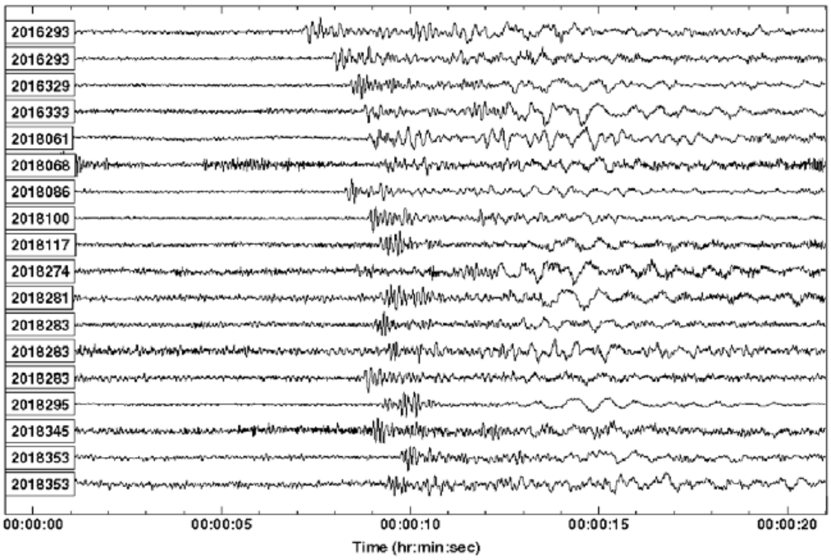

Figure 6 - Events selected as templates to be used for cross-correlation for Deva region quarry blasts using DEV (Deva) seismic station

We applied a cross-correlation window of 21 seconds on the vertical component recorded by the nearest station from the quarries, Deva seismic station (DEV) filtered with a Butterworth band-pass filter between 1 and 5 Hz. The cross-correlation techniques were applied for 18 template events, which were associated with the infrasonic signals observed with the Romanian infrasound arrays.

DISCUSSION AND CONCLUSIONS

In Deva region were studied 480 events. Diurnal distribution of the ROMPLUS events occurred in the Deva area (Figure 3) shows a clustering of these events (approx. 97%) in the 06:00 – 14:00 UTC hour-interval. This time correlates with the working hours and daylight. Based on the graphics showed in Figure 3, more than 97% of events could be considered as quarry blasts. Based on the analysis of the waveforms (visual inspection), 58% of the events located in the Deva region, within a 10-km perimeter around the quarries, could be considered quarry blasts. All 18 templates used in the cross-correlation process were matching some of the ~~other~~ events recorded in the quarries area; as a result, 34,2% of the analyzed events with CCF greater than 0.7 could be considered as quarry blasts.

The research conducted over time showed that it is easier to discriminate between events with magnitudes Mw above 4.0, while identifying the explosions among the small magnitude events is a challenging task. The seismicity of the Deva region based on the ROMPLUS catalogue is a combination between tectonic earthquakes and anthropic events. For this reason, the discrimination of natural and man-made events is of high interest.

Whenever BURARI and I67RO infrasound arrays detect acoustic signals that could be associated with seismic signals, they contribute to a more accurate identification of the quarry blasts. More than 35% of the events listed in the ROMPLUS catalogue for Deva region and used in this study show quarry blast characteristics.

The results of this study will be used to analyse the possible impact of the anthropogenic events that occurred in the area on the induced seismicity. Similar studies will be conducted in the future for all areas of the country to separate tectonic and anthropogenic events in the ROMPLUS catalogue.

Acknowledgements

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