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*Full Length Research Paper*

# Spectral discrimination between mining blasts and natural earthquakes: Application to the vicinity of Tunçbilek mining area, Western Turkey

**Kekovalı K*, Kalafat D and Deniz P**

National Earthquake Monitoring Center, Kandilli Observatory and Earthquake Research Institute, Boğaziçi University 34684 Çengelköy, İstanbul, Turkey.

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**The objective of our paper is to develop time and frequency techniques to characterize mine or quarry blasts and discriminate these events from natural earthquakes. We are examining well documented mine blasts in the Kütahya Province in western Turkey that is an ideal case study since there are frequent confirmed routine mining blasts at Tunçbilek mining area. Particularly, Turkey's richest lignite reserve was detected with the statistical analysis include Tunçbilek region that has been undertaken by Kekovali et al. (2011). In this study, we used time and frequency domain analysis (S/P wave amplitude peak ratio, complexity, spectral ratio) of a set of known earthquake and mining blasts seismograms of 520 seismic events (2.3 ≤ Md ≤3.0) from Kandilli Observatory Earthquake Research Institute and National Earthquake Monitoring Center (KOERI-NEMC) seismic catalog between 2009 to 2011. Out of a total 520 records, 344 are related to probable mining blasts and 176 to earthquakes. However, a new approach estimated on Pe (power of event) value comprising of three variables (S/P wave amplitude peak ratio, complexity, spectral ratio) that can be suitable identification of quarry-mining blasts in the the seismic catalogs, is presented and discussed for Tunçbilek region in the study. In the discrimination analysis between the earthquakes and mining blasts showed that Pe analysis comprising of three variables (S/P wave amplitude peak ratio, complexity, spectral ratio) was used together to increase the reliability instead of the S/P wave amplitude peak ratio or complexity and spectral ratio in time-frequency domain. The classsification was obtained with acceptably high results of 99.6% using Pe analysis. For a future study, we suggested that this algorithm could be applied to different earthquake-mining regions that was developed independently in this study. Because of the presence of quarry-mining blasts among the earthquakes recorded by the KOERI-NEMC seismic network, the decontamination of the catalog is essential for a reliable seismic hazard assessment and understanding the seismogenic processes of Turkey.**

**Key words:** Earthquake, mining blast, amplitude discrimination, time-frequency domain.

## INTRODUCTION

Many researchers have used different methods in order to identify earthquakes from man-made explosions such as time- of –day analysis (Agnew, 1990; Wiemer and Baer, 2000; Taira and Tsumara, 2001; Gulia, 2010), amplitude ratios and time-frequency domain analysis (Gitterman et al., 1998; Koch and Fah, 2002; Horasan et al., 2009; Dahy and Hassib, 2010; Öğütçü et al., 2011). Previous work on determining blasting sources of Turkey has been undertaken by Kekovalı et al. (2011) who estimated potential mining and quarry areas from KOERI-NEMC seismic catalogs using statistical analysis, identified Tunçbilek, Eskihisar, Gümüşköy, Orhangazi, Şile, Gebze, Kemerburgaz and Soma locations of explosion contamination. Particularly, they also note that Tunçbilek area where caution or special attention is advisable is heavily contaminated with daytime quarry-

*Corresponding author. E-mail: kekovali@boun.edu.tr.

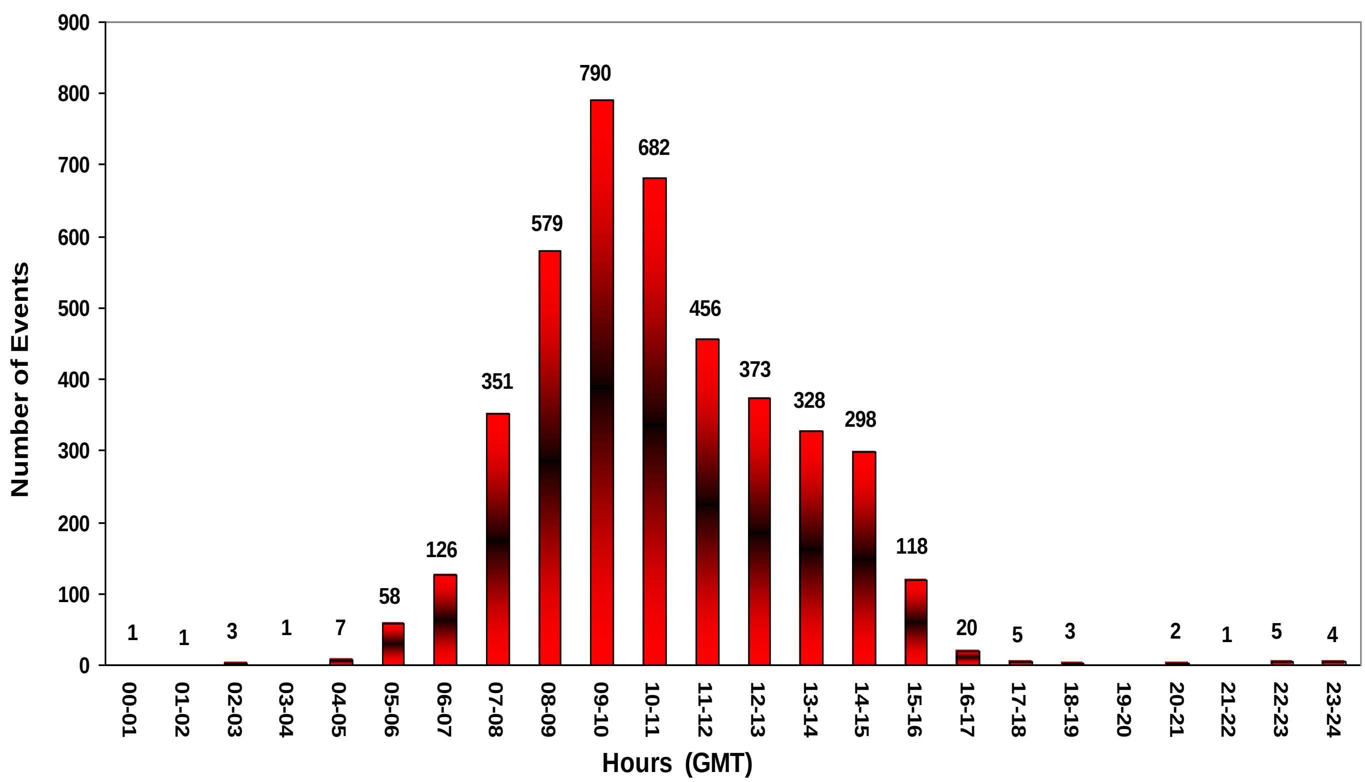



**Figure 1.** Histogram of the number of events with Md≤ 3.0 that occurred with a 15-km radius of the Tunçbilek mining area between 1970-2011.

mining blasts.

Turkey has very diverce mineral deposits due to its extremely complex geology. Blasting techniques, which have been used for a long time in Turkey, are economical and powerful tool in producing raw material in mining industries. Tunçbilek open-pit coal mine is located at the major underground mining basin of Kütahya Province in western region of Turkey. In this basin, hard coal extraction has been offically carried out by Western Lignite's Cooperation which is a subsidiary of the state-owned Turkish Hard Coal Enterprise (TKI). However, there are also many mining and quarry sites in different locations of Kutahya. In Tunçbilek basin, hard coal production started in 1940 and total production has reached 46 million ton between 1940 to 2008 according to TKI offical record (www.tki.gov.tr).

## DATA AND METHOD

Approxiamtely 33% of Turkey's lignite reserves occur in the western Anatolia lignite basins (Inaner and Nakoman, 1993). The research area is selected in Kutahya that is an active mining region with many types of mines and quarries that is also Turkey's top producer of hard coal. However, the region also has prevalence of natural seismicity due to active faults in Aegean Extensional Province such as Simav, Emet and Gediz faults. These factors make the region an ideal test bed for disrimination techniques examinated to seperate signals from earthquakes and mining blasts, including time - of – day analysis, amplitude ratios, and time-frequency domain analysis. In order to assemble a database containing natural and probable mining-related events, before the data selection step, we first determined the site of major mining and the sites of earthquake sources. The following factors were taken into consideration in determining of the study areas in the region.

a) Tunçbilek mining blasts that take place in western Turkey are ripple fire blasts in open pit mine. The geographic coordinates of the mining area was derived by satellite image from Google Earth program (http://earth.google.com/intl/en_uk/) and from the the mineral map of Turkey from MTA (General Directrorate of Mineral Research and Exploration). The information about blasting times on an average of fourty times monthly and the average amount of explosives varying from 20 to 20.000 kg were obtained formally by TTK from Tunçbilek region.
b) The statistical distribution of Tunçbilek events with Md≤ 3.0, with a 15-km radius of the Tunçbilek mining area between 1970 to 2011 that was recorded by KOERI-NEMC Network, in daytime and nighttime was investigated and effectively outlines regions of mining activity (where the dominant percentage of daytime events occur in regions of known mine locations). Figure 1 reveals that an unusually high number of daytime events are seen in the Tunçbilek mining area that is a likely sign of blasting activity. The number of events as a function of their occurrence hour shows a strong clustering at the working hours (05:00 to 17:00 hours GMT time) of the Tunçbilek mine. The number of nightly events is very low compared to the one of daytime events. Only a few events occurred

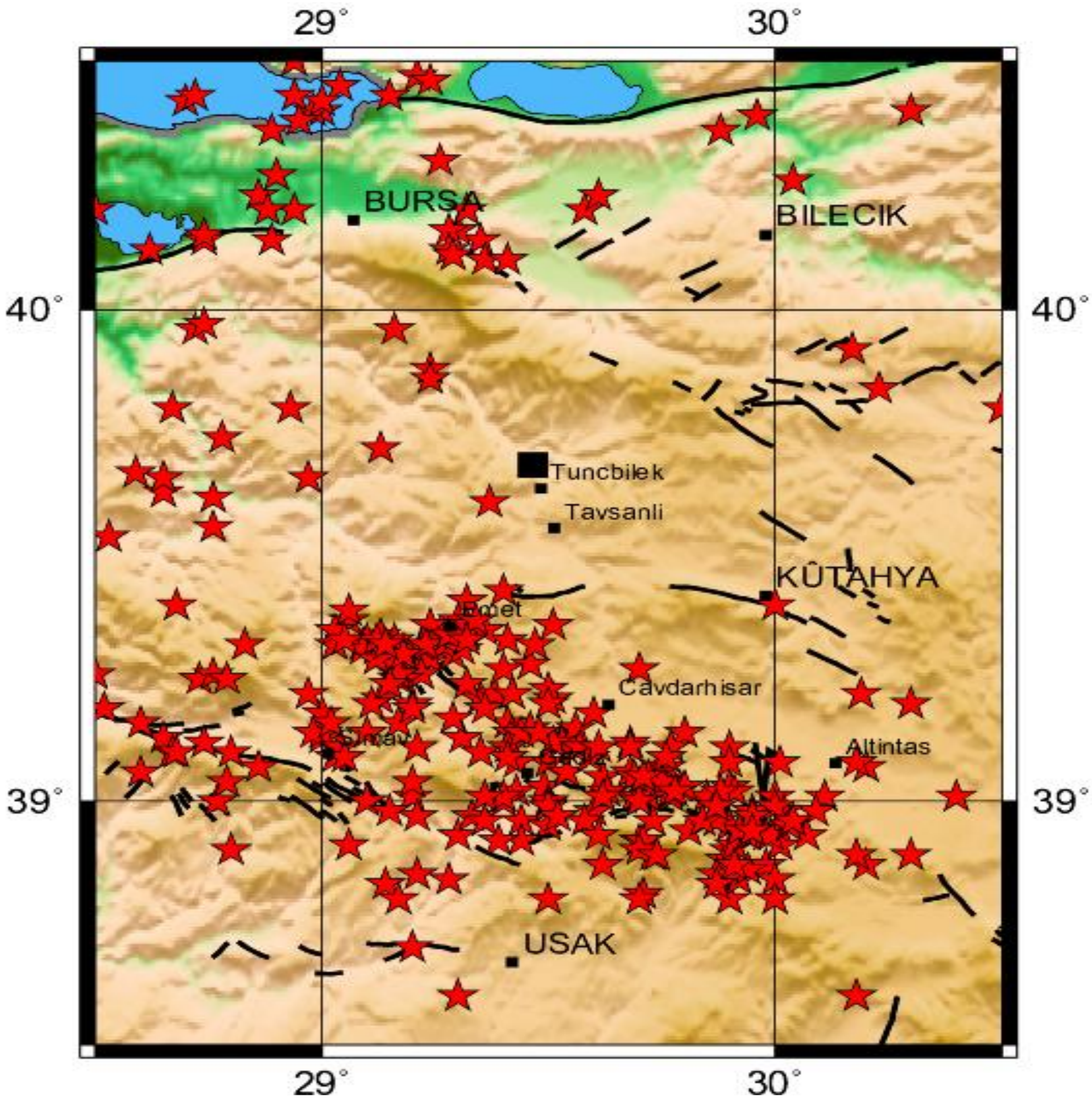



**Figure 2.** The seismic activity of the study region between 1970-2011 (M ≥ 4.0). The black box shows the Tunçbilek mining area.

at night that is unreliable location with regard to the errors in the epicenters before 2000.

The seismic activity of the Tunçbilek area and its vicinity has been investigated by using the earthquakes equal or greater than magnitude 4.0 that occurred with a 100-km radius of the Tunçbilek mining area for the time interval between 1970 to 2011 due to the data set is relatively uniform for western Turkey (Figure 2). The distance of the nearest earthquake to the mining area is 8 km that occurred at 1970 that is unreliable location with regard to the errors in the epicenters are within 0 to 15 km for earthquakes in Turkey since 1970's (Kalafat et al., 2007). Partricularly, the hypocentral distribution of the earthquakes outlines no earthquakes of magnitude 4.0 or large were located nearby Tunçbilek mining area since 1970's that shows occurring small events (Figure 2) are a likely sign of blasting activity.

c) Our study region is Kütahya in western Anatolia, is a part of the Agean Extonsional Province that is one of the most seismically active regions of Turkey. African, Eurasian, and Arabian plates are three major plates surround of Turkey, the motion between Africa and Eurasia is not taken on one plate boundary, but is carried by the motion of the Aegean and Turkish plates (Mc Kenzie, 1972; Dewey et al.,1973). Approximately E-W trending grabens and their basin-bounding active faults are the most prominent neotectonic features of Western Anatolia (Bozkurt, 2001). In additioan to E-W trending faults, which characterize the general tectonic regime of the western Anatolia, WNW-ESE trending Gediz and Simav Faults, as well as E-W trending Emet fault are believed to contribute much to the seismicity of the region (Tokay, 1979). Due to many of the mining-quarry blasts that took place in the study region, the other earthquake sources were selected taken into consideration the present–day tectonics occurred nighttime seismic events such as Simav, Emet and Gediz locations. In general, nighttime seismicity

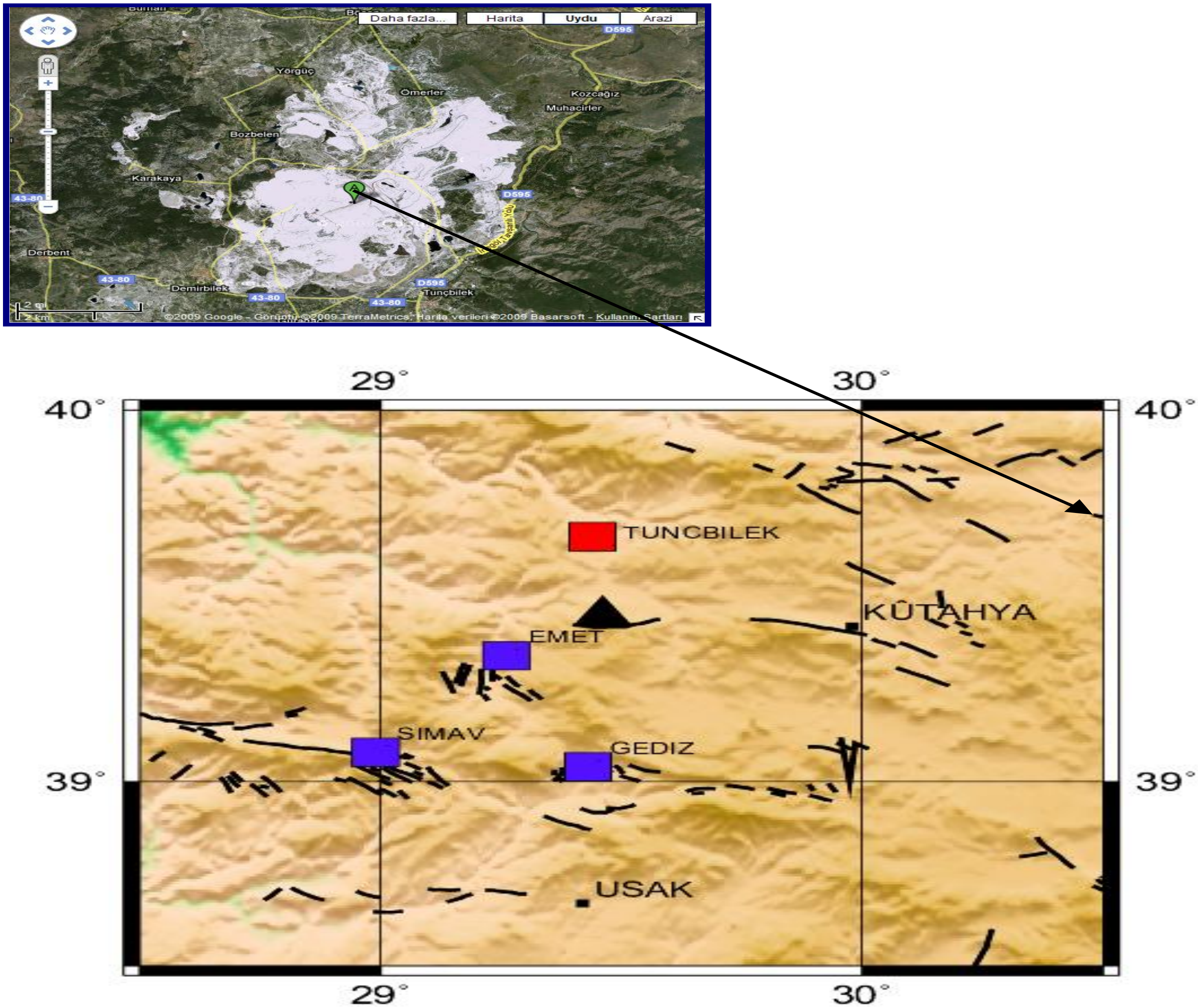


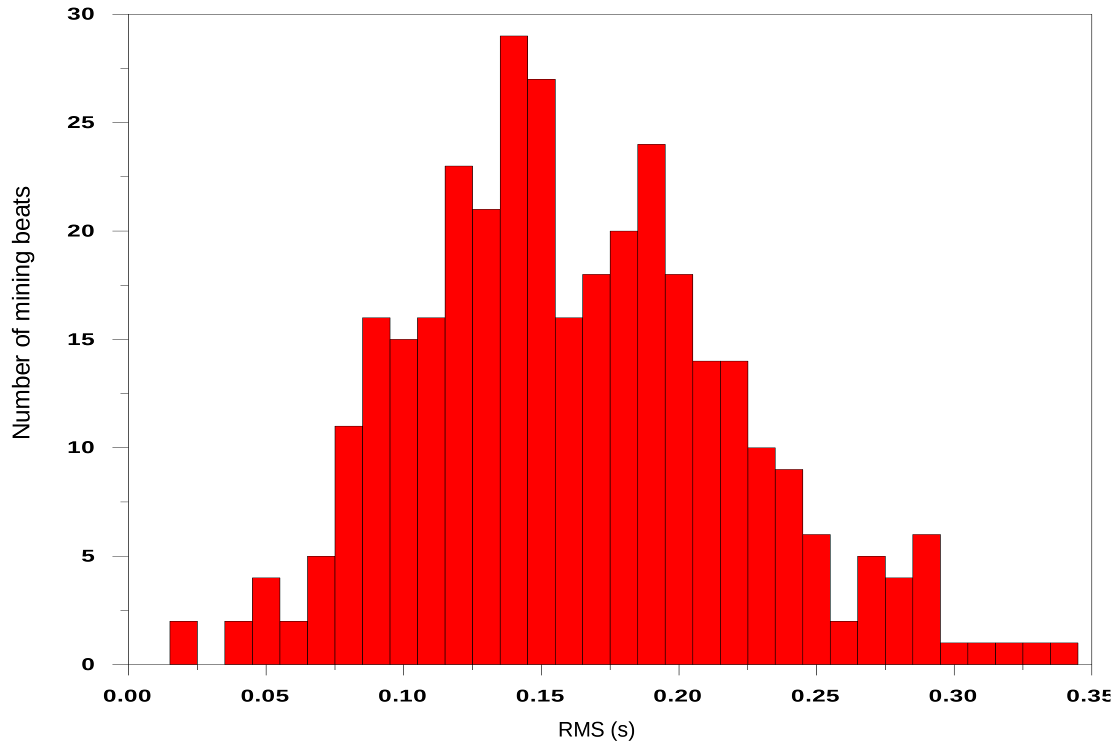

**Figure 3.** Map showing the study region (38.5 - 40.5 ºN latitude and 28.5 - 30.5 ºE longitude) and the sites of Tunçbilek mining area (red box; Tunçbilek mining area) determined satellite image and earthquake sources blue boxes; Simav,Emet,Gediz). The location of the Tavsanli (TVSB) seismic station (black triangle) used in the study for seismic analysis.

better reflects these tectonic trends that are presumably most earthquakes.

All data sets were gathered and divided into training and testing sets for each study region such as Tunçbilek, Simav, Emet and Gediz (Figure 3).The seismic events that occurred in the study area were recorded digitally by at least five P wave arrivals, of which at least one is an S wave arrival of KOERI-NEMC network for the years of 2009 to 2011. Although we started with an initial set of 539 events obtained by the first selection, our final data comprises 520 well-located events. We excluded approximately 3.5% of the data with root mean square (RMS) residuals larger than 0.35 sec and standard location errors (ERH and ERZ) larger than 5.0 km. In this study, we used re-evaluated data with residual RMS less than 0.34 s and uncertainties both in epicenter and depth less than 5 km. The accuracy of the location is a critical factor that is reliable for obtaining the best discriminant performance. If the selected data is not sufficiently reliable and robust, the performance of the applied approachments C, Sr and Pe could not be usefull because of inaccurate locations of mining blasts and earthquakes.

## RESULTS

The results of RMS travel- time residuals of the mining blasts and earthquakes is shown in Figure 4. The focal depths of the selected events are not deeper than 20 km that may not give a reliable indication for discrimination analysis because of the possible large inaccuracies in hypocentral depth estimation. Figure 5 shows the



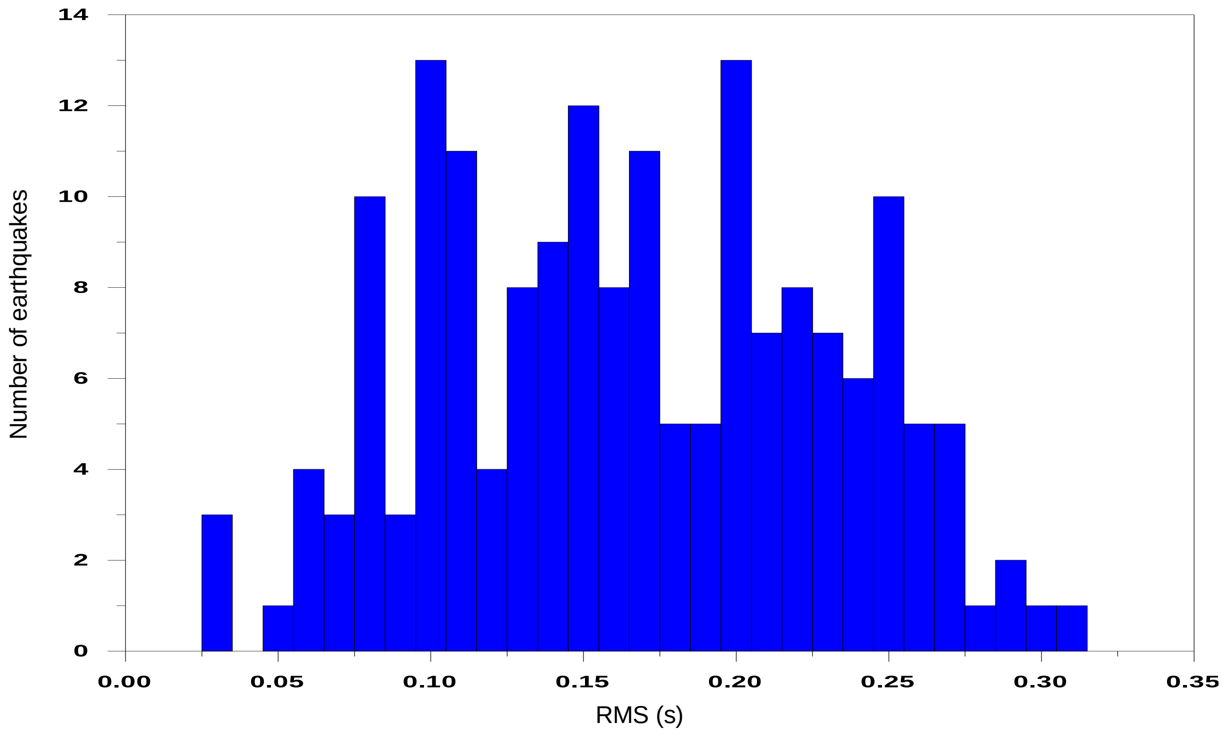




**Figure 4.** The histograms showing the distribution of travel-time residuals for probable mining blasts (a) and earthquakes (b).

magnitude-frequency distribution of the probable mining blasts and earthquakes with the duration magnitude intervals 2.3-3.0 and no events with magnitude 3 or more was observed with 15-km radius of the Tunçbilek mining area.

All waveform data were previewed and selected based on signal quality (no data dropouts) as well as on the ability to pick a first arrival (that is, signal-to-noise

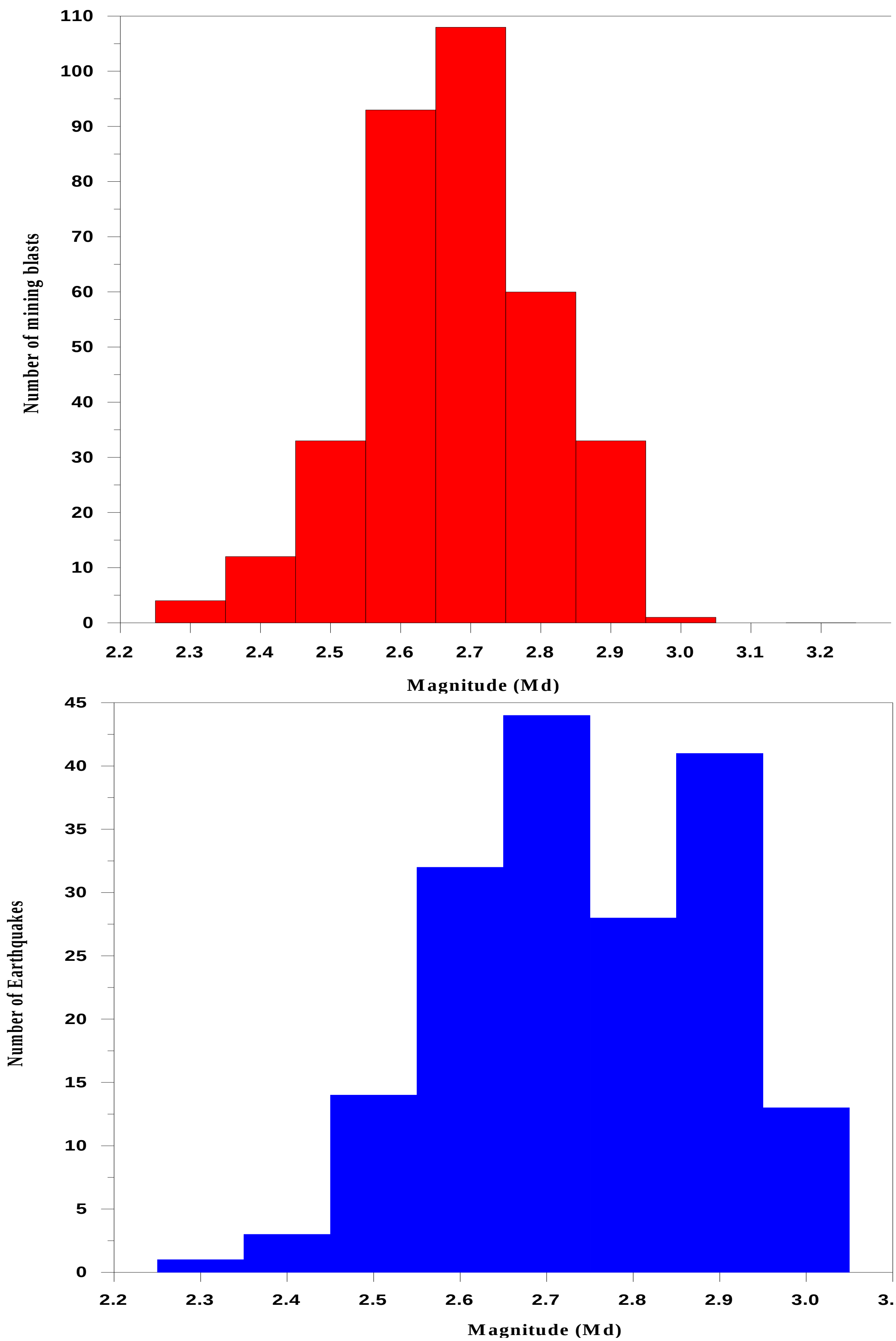



**Figure 5.** Magnitude frequency distribution of the probable mining blasts (a) and earthquakes (b) for the study areas between 2009-2011.

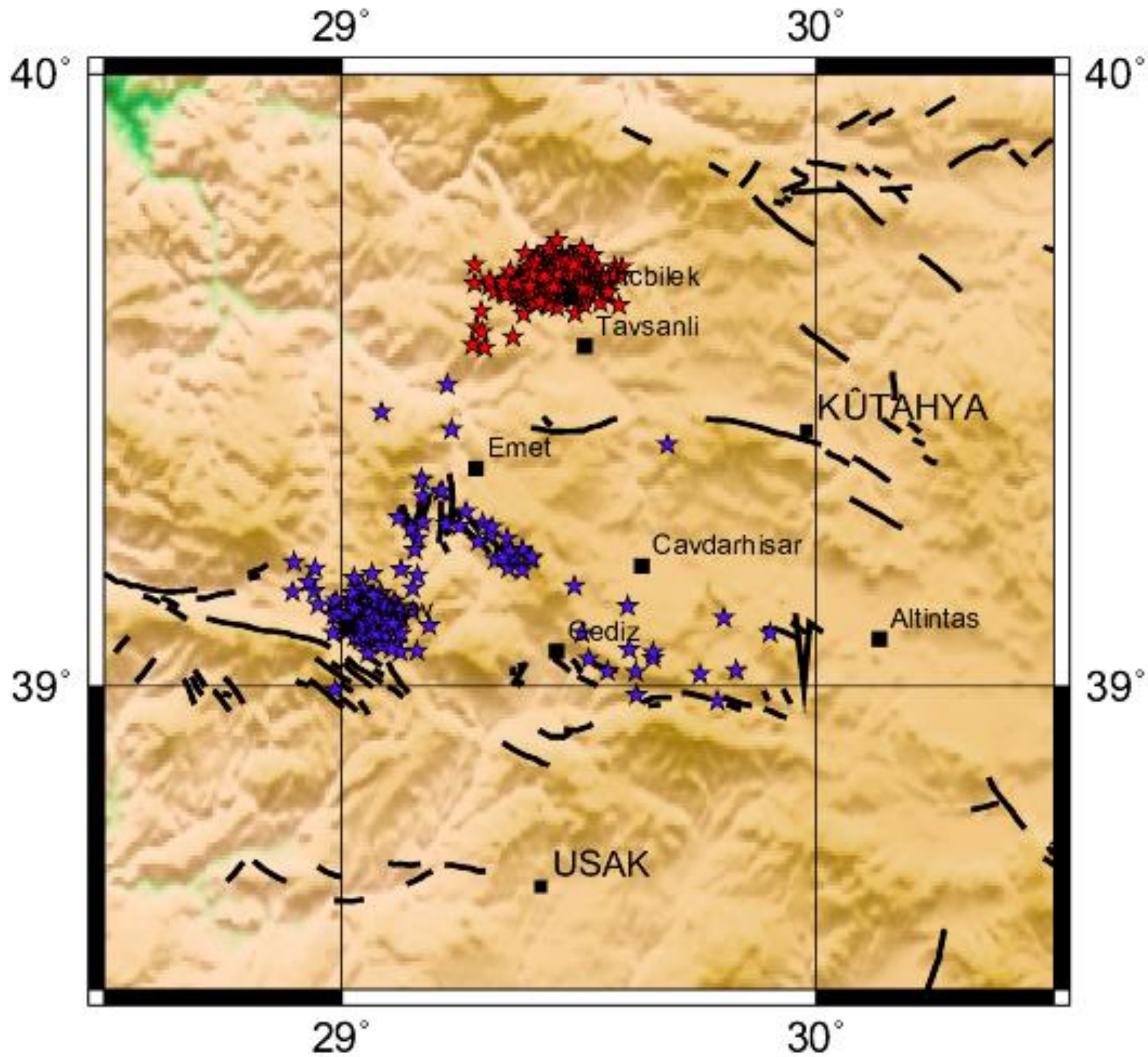



**Figure 6.** Locations of seismic events (red stars: probable mining blasts, blue stars: earthquakes) with Md≤ 3.0 used for discrimination analysis between 2009-2011.

quality). Among 520 seismic events used, 344 were located in Tunçbilek, 127 in Simav, 34 in Emet and 15 in Gediz (Figure 6). 344 are related to probable mining blasts and 176 to earthquakes. The relocated probable mining event distribution does not follow any fault segmentation however, the mostly nightime events (17:00 to 05:00 h GMT time) were seen nearby at identified Simav, Emet and Gediz fault segmentations in the study region.

In this study, discrimination method is applied to the identification of earthquakes and probable mining blasts are well recorded by the Tavşanlı (TVSB) seismic station that is the nearest station to Tunçbilek mining area in the region that was installed in 2009. We used the vertical components of the velocity seismograms from 520 seismic events that were recorded at the KOERI-NEMC Network, TVSB broadband station in Tavşanlı with a sampling rate of 50 Hz. Selected events that occurred approximately up to 30 km for Tunçbilek, 65 km for Simav, 30 km for Emet and 60 km for Gediz from TVSB station

## Discrimination methods

### *Amplitude discrimination*

We analyzed 344 probable mining blast waveforms and 176 earthquake waveforms, picking maximum amplitudes of Pg and Sg waves for the vertical component of the

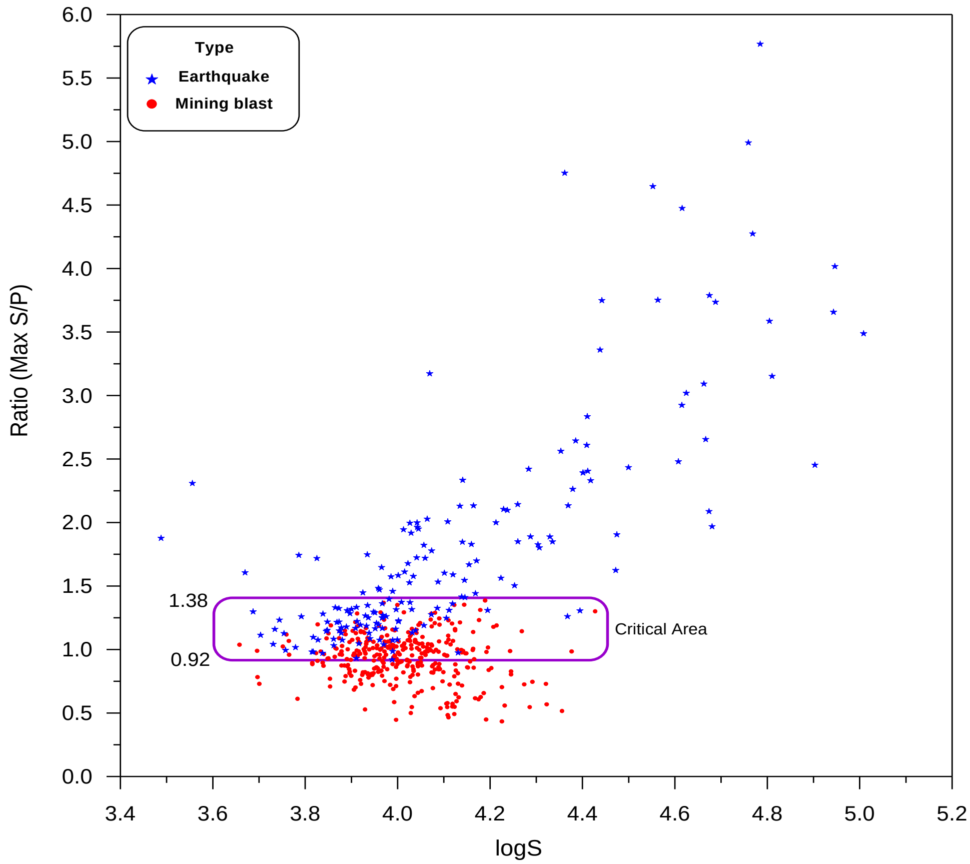



**Figure 7.** Maximum amplitude peak ratio of S to P ($R_{S/P}$) wave versus logarithm of maximum amplitude peak of S wave (log S) in time domain of the vertical component of the velocity seismogram of TVSB station for the study areas.

**Table 1.** Statistical information about amplitude ratio for the study areas.

| **Tunçbilek mining source** | | **Simav, Emet, Gediz Earthquake sources** | |
|---|---|---|---|
| Number of events | 344 | Number of events | 176 |
| $S_{max}/P_{max}$ | 1.3801 | $S_{max}/P_{max}$ | 5.7737 |
| $S_{min}/P_{min}$ | 0.4281 | $S_{min}/P_{min}$ | 0.9244 |
| Standard deviation | 0.1851 | Standard deviation | 0.889 |
| Arithmetic mean | 0.9329 | Arithmetic mean | 1.8066 |

velocity seismograms of TVSB station. Maximum amplitude measurements of Pg-Sg waves were determined using the automatic program that was developed in this study. The magnitude dependence of Sg/Pg ratios was reduced in the selecting of the same magnitude ranges for both mining events and earthquakes.

The discrimination plots for the maximum Sg/Pg amplitude ratios versus the logarithm amplitude of Sg wave is shown in Figure 7 for the study region. In general, there is a tendency for the amplitude ratios for the earthquakes to be higher than the quarry- mining blasts since the S wave amplitude on the seismogram is higher than the P wave amplitude. This usually occurs due to the isotropic character of the explosion sources, which generate mainly compressional P wave with S waves vanishing or being very weak.

The amplitude ratios for the mining blasts vary from between 0.42 to 1.38 and 0.92 to 5.77 for earthquakes (Table 1). The critical values area obtained in the 0.92 to 1.38 range from both mining events and earthquakes. In this area mining blasts overlaps with the the earthquake

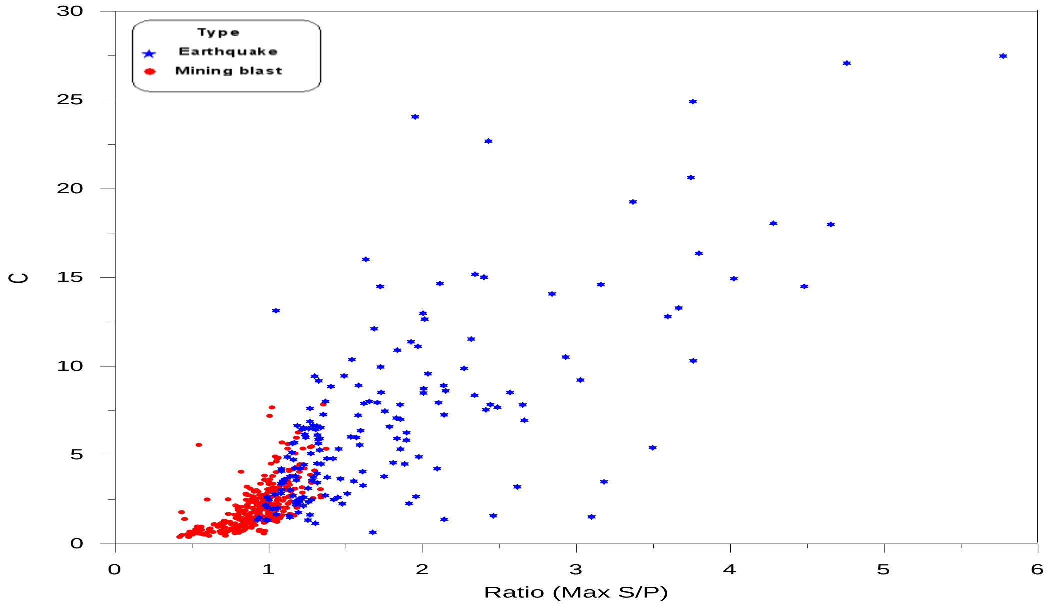



**Figure 8.** Maximum amplitude peak ratio of S to P ($R_{S/P}$) wave versus Complexity (C) of the vertical component of the velocity seismogram of TVSB station for the study areas.

populations is considerable. The results indicated that this is a poorly performing discriminant, the majority of events do not discriminate well that is evidenced by variability in Pg and Sg amplitudes that can be strongly dependent on recording site geology. Observations of Nuttli (1981), Gupta and Blandford (1983), and Taylor et al. (1989) have showed important overlap in the earthquake and explosion populations for Eurasia and in Western United States. On the other hand, some researchers have used S/P amplitude ratios effectively for distinguishing of quarry-mining blasts from earthquakes (Wüster, 1993; Bennett et al., 1989; Horasan et al., 2009; Öğütçü et al., 2011). Discrimination methods that are used reliably in one seismic region can often be effective in other regions due to different sources and geological settings and may cause differencies in the amplitude characteristics (Gilbert et al., 2007; Zeiler and Velasco, 2009). The main drawback of the S/P discriminant is that, because of signal-to-noise considerations, misidentification of the seismic phases and propagation are affected.

## Complexity (C) and spectral amplitude ratio (SR) analysis

Complexity and spectral amplitude values for the selected seismograms were calculated in the PITSA program using The Fast Fourier Transform (FFT) method that decomposes a signal into its constitutent frequency components (Scherbaum and Johnson, 1992).

The discriminant criterion was obtained from the plot of complexity (C) versus the spectral ratio of the seismogram (Sr) for the selected probable mining events and earthquakes in the study region. The following equation was used to complexity (Arai and Yosida, 2004)

$$C = \int_{t_1}^{t_2} S^2(t)dt \;/\; \int_{t_0}^{t_1} S^2(t)dt \qquad (1)$$

Where s(t) denotes the signal amplitude as a function of time (t) and C is the ratio of integrated powers of the vertical component of the velocity seismogram $s^2(t)$ in the determined time windows for mining blasts and earthquakes. As in earlier studies, frequencies and amplitudes of the seismic waves resulting from earthquakes and mining blasts are different. Particularly, using low and high time-frequency intervals, it is easier to identify how the energy is distributed and allows to estimate the fraction of the total signal energy at the time and frequency domain. Such cross-spectral measures may be attractive for the best discriminant performance. Therefore, different frequency bands were tested in order to find differences in spectral shapes between mining blasts and earthquakes in the study.

The limits of the integrals of C given using Equation 1 were determined by a trial estimation to finding the best performance. C values that is provided in the selected time windows ($t_1$-$t_2$: 3.5-8 s; $t_0$ is the onset time of P-wave for Tunçbilek, $t_1$-$t_2$: 3.5-8 s for Emet, $t_1$-$t_2$: 6-11 s for Simav and Gediz locations. We determined a long-time window length of about 25 s for the estimation of the complexity depending on the distance to the epicenter from the TVSB seismic station. Figure 8 shows the complexity versus the maximum S/P amplitude ratios for

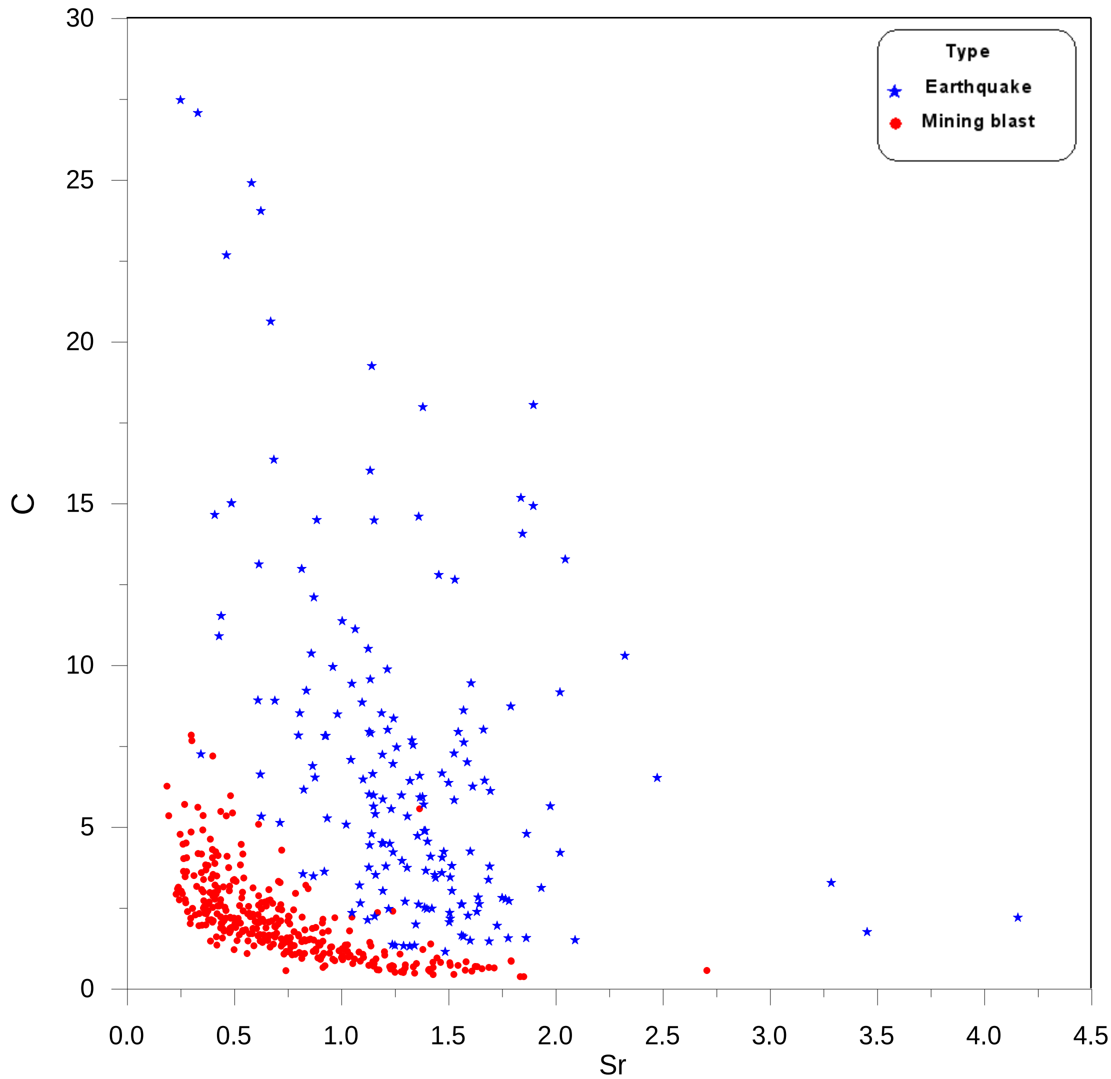



**Figure 9.** Plot of complexity (C) versus spectral ratio of the vertical component of the velocity seismogram (Sr) for the study areas.

investigated seismic events in the study region. In general C becomes larger for eathquakes than for probable mining blasts, since the P- wave amplitude on the seismogram is larger than the S - wave amplitude for mining blasts. Similar results were obtained by Horasan et al. (2009) and Öğütcü et al. (2010). However, the clear discrimination was not obtained of the mining blasts from earthquakes by both ratios.

Spectral ratio is probably the most promising discrimination method for classification of underground explosions from shallow earthquakes. The Sr parameter is calculated using the ratio of integrated spectral amplitudes a(f) of the seismogram in the selected frequency bands for mining blasts and earthquakes. The spectral ratio (Sr) between the high-frequency ($h_1$,$h_2$) and the low-frequency bands ($l_1$,$l_2$) can be represented as (Gitterman and Shapira, 1993);

$$Sr = \int_{h_1}^{h_2} a(f)df \;/\; \int_{l_1}^{l_2} a(f)d(f) \qquad (2)$$

The limits of the integrals of Sr were selected by comparing the low and high energy in the spectra of mining blasts and earthquakes. To find the frequency band where Sr discriminant is most efficent, we compared the variance of spectral estimates of the selected events in different frequency bands. We determined high frequency band, $h_1$-$h_2$: 5-10 Hz; low frequency band, $l_1$-$l_2$: 0-5 Hz for Tunçbilek mining area, $h_1$-$h_2$: 7-14 Hz, $l_1$-$l_2$: 1-7 Hz for Simav, Emet and Gediz locations. Figure 9 shows the complexity (C) versus the spectral ratio (Sr) for the seismic events in the study region. We observed that the mining blast and earthquake populations were not completely discriminated by both ratios. However, we conclude that

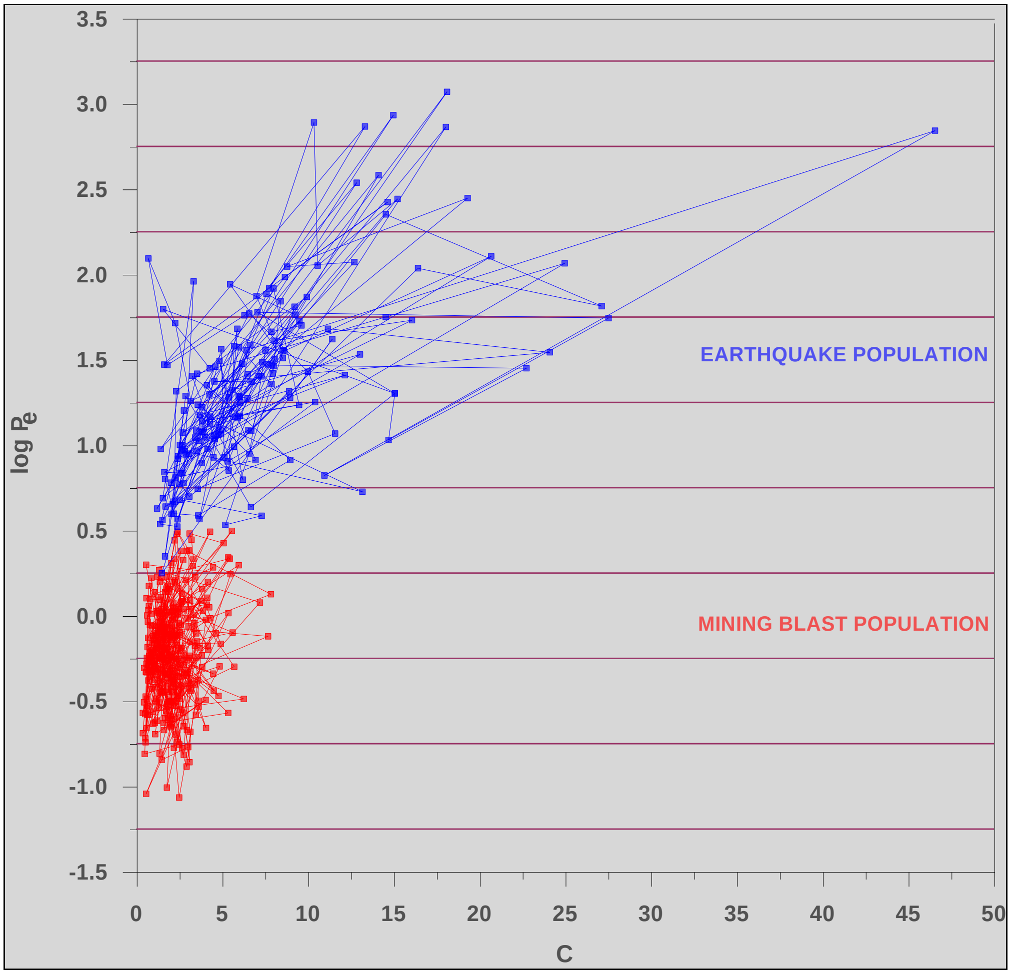



**Figure 10.** Plot of log Pe versus complexity (C) of the vertical component of the velocity seismogram of TVSB station for the study areas.

frequency domain analyses provided more reliable separation than amplitude discrimination in the study region.

## Multi- parameter discrimination; Pe (Power of event) analysis

Advances in data storage and computer capabilities make possible much more extensive analyses than have been performed in the past, which will provide a better picture of discrimination of mining blasts from earthquakes using spectral properties and amplitudes methods. In the determining of new approachment, four parameters (amplitude peak ratio, log S, complexity, spectral amplitude ratio) are widely used that estimated from time and frquency domain analyses of the vertical seismograms of TVSB station. The correlation among four parameters were tested statistically using different iterations in order to find the best classification of earthquake population from mining blast population. The statistical results of these parameters (arithmetic mean, standard deviation, the correlations and covariances between the parameters) were taken into consideration in determining the new algorithm developed in statistics, called the power of event (Pe).

We defined the best classification of a set of known mining blasts and earthquakes using the $R_{S/P}$ (Maximum amplitudes ratio), C (Complexity) and Sr ( Spectral Ratio) that can be represented as;

$$Pe = (R_{S/P})^2 \times C \times (Sr)^2 \quad (3)$$

In this algorithm, Pe value strengthened by taking the squares of the maximum amplitude ratio and spectral ratio of two identified populations. Figure 10 illustrates the correlation between the logarithmic Pe and complexity (C). To provide a comparable presentation of Pe values for mining blasts and earthquakes a logarithm scale is used. Pe values obtained in the 1.79 to 1186 range for

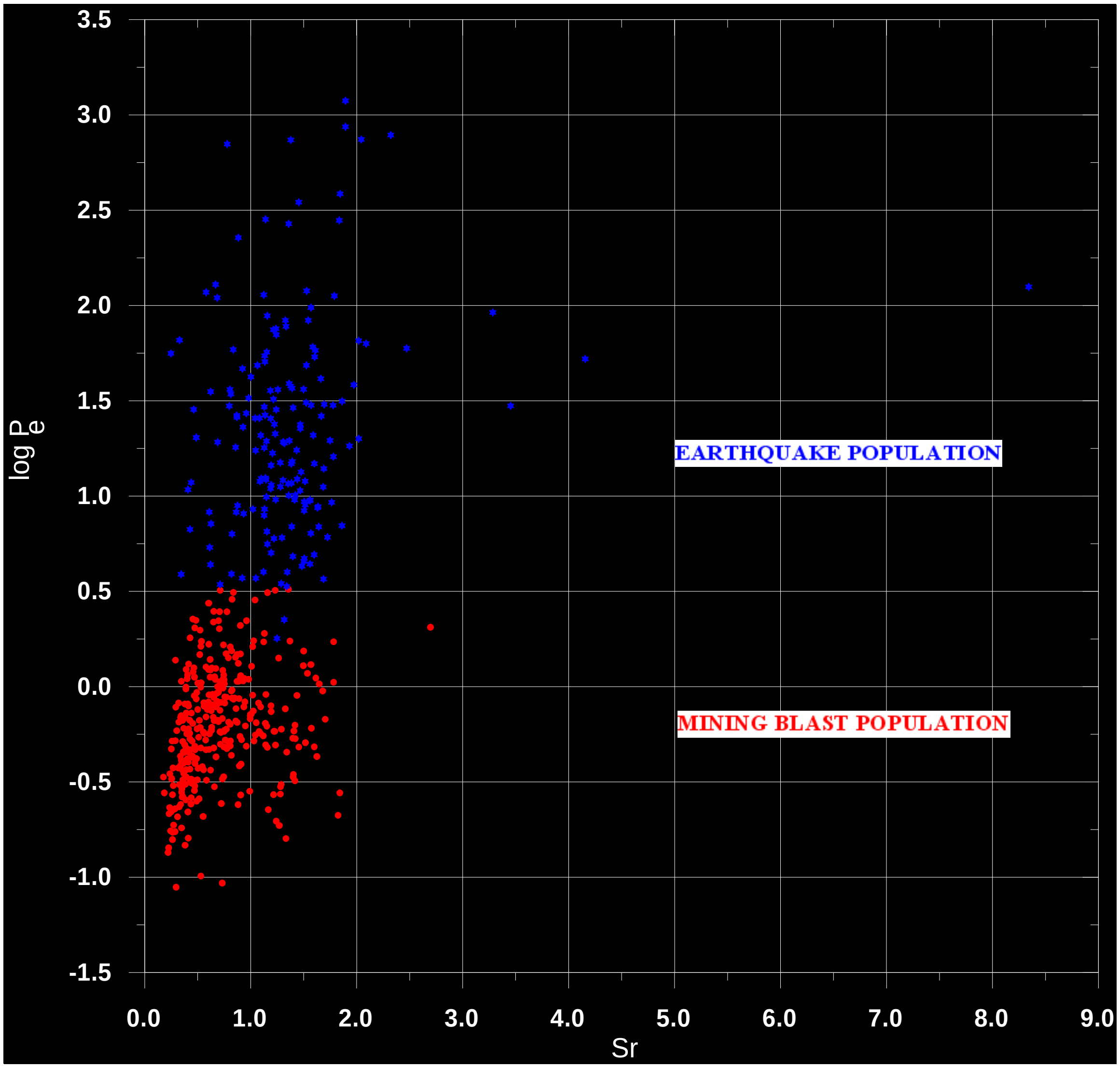



**Figure 11.** Plot of log Pe versus spectral ratio (Sr) of the vertical component of the velocity seismogram of TVSB station for the study areas.

earthquakes and 0.08 to 3.17 range for mining blasts. It was noticed that the two populations are almost seperated but only two earthquakes were located in the mining blast population.

The locations, signal qualities and time-frequency amplitudes of two misclassificated earthquakes were evaluated again in order to find the cause of them. Notwithstanding the differences, it appears that there is completely discriminant similarities between mining blasts and earthquakes. Figure 11 shows the plot of logarithmic Pe versus spectral ratio (Sr). Similar results were obtained, and it was observed that the two earthquakes which show low discriminate values were also misclassified as mining blasts using the Sr - log Pe analysis. Particularly, we observed that Pe becomes significantly bigger for earthquakes in comparison with mining blasts. Similar results were obtained using C- Pe and Sr-Pe analyses which is a good tie for the test of the reliability of the new algorithm. The discrimination was estimated with acceptably high results (99.6%) in the study areas.

## Conclusions

The performed research has important implications for the identification of mining blasts from the natural seismicity in the Kütahya Province where there is significant contamination of the KOERI-NEMC seismic catalog by mining blasts that may cause misinterpretation of the present-day tectonic in seismic hazard studies. The major advantage of the study, the overwhelming number

**Table 2.** The percentages of correct classification for the different methods used in this study for discrimination of mining blasts from earthquakes.

| Correlation | Percent correct identification (%) |
|---|---|
| Maximum amplitude (S/P) - Log S | 84 |
| Complexity (C) – Spectral ratio (Sr) | 95 |
| C- Log $P_E$ | 99.6 |
| Sr- Log $P_E$ | 99.6 |

of events classsified as mining blasts are restricted to Tunçbilek area where the known major mine is situated. On the other hand, time-of-day is not the sole criterion for discrimination, though it can be utilized in conjuction with satellite imagery and waveform analysis in time-frequency domain to further provide constraints on anomalously timed events. Therefore, data sets are created from all of the four regions such as Tunçbilek, Simav, Emet and Gediz that was used with different methodologies for the discrimination analysis of mining blasts from natural seismicity.

Firstly, we investigated Sg/Pg amplitude ratio discriminants using digital seismograms of TVSB broad-band seismic station. Following our methodology, we observed that the amplitude ratio discriminant is not useful in seperating mining blasts from earthquakes in the study region. We also note that the critical values obtained for discriminating earthquakes are 3-4 times higher than the mining blasts at the sime time, we found considerable overlap in earthquake and mining blast populations. These findings are also consistent with work by Nuttli (1981); Koch and Fah (2002); Taylor et al. (1989); Arrowsmith et al. (2007). They found that amplitude ratio measurements can not be sufficent for discriminating earthquakes from quarry-mining blasts because of the discrepancies of the local geology conditions and the source lithology of the studies sources.

Secondly, we investigated the correlation between the complexity (C) and spectral ratio (Sr) of both mining blasts and earthquakes in Tunçbilek region where we were able to show that the time-frequency discriminant seperated 95% of a certain type of mining blasts from the earthquake population. Although considerable overlap was not found for the mining blast and earthquake populations, they were not completely discriminated by both ratios.

In this study, a new aprroachment (Pe) were obtained using the peak amplitude ratio (S/P), complexity and spectral amplitude ratio for the discrimination analysis. Generally, the results of this research have shown that the new approachment could be all usefull for distinguishing mining blasts and earthquakes. The performance of the new approachment was checked by applying it to a set of known test events using C-LogPe and Sr-log Pe analyses. Given the high rate of success, on average about 99.6%, from the results obtained, the proposed Pe analysis appears to be an efficent and a reliable tool for discrimination of mining blasts from tectonic earthquakes (Table 2).

The data sets computed from the vertical component of waveform were recorded in Kütahya region at single station, located up to 60 km from the mining area and the signal qualities of the other seismic stations are poor up to 120 km that may be an important disadvantage of our study. For a future study, we suggest that classification accuracy can be increased by adding more seismic stations for different mining areas. The performance of the applied approachment (Pe) could have tested by the choice of different study regions and seismic stations. According to the KOERI-NEMC seismic catalog, seismic events in the Kutahya Province classified as earthquakes have been observed since 1970. Therefore, the seismic catalog is heavily contaminated with daytime mining blasts for this region. According to the results of this research, it is evident that identification of mining blasts and their removal from the KOERI-NEMC seismic catalog is essential in order to evaluate earthquake potential and seismic hazard of Tunçbilek region, western Anatolia.

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### REFERENCES

Agnew DC (1990). The use of time-of-day seismicity maps for earthquake/explosion discrimination by local networks, with an application to the seismicity of San Diego country. Bull. Seismol. Soc. Am. 80(3):747-750.

Arai N, Yosida Y (2004). Discrimination by short-period seismograms. International Institute of Seismology and Earthquake Engineering, Building Research Institute (IISEE), Lecture Note, Global Course, Tsukuba.

Arrowsmith SJ, Hedlin MAH, Arrowsmith MD, Stump BW (2007). Identification of delay-fired mining events using seismic arrays: Application to the PDAR array in Wyoming, USA. Bull. Seismol. Soc. Am. 97: 989-1001.

Bennett TJ, Barker BW, McLaughlin KL, Murphy JR (1989). Regional discrimination of quarry blasts, earthquakes and underground nuclear explosions. Final Report, GL-TR-89-0114, S-Cubed, La jolla, CA. p. 146.

Bozkurt E (2001). Neotectonics of Turkey- a synhthesis. Geodinamica Acta 14:3-30.

Dahy SA, Hassib GH (2010). Spectral discrimination between quarry and microearthquakes in southern Egypt. Res. J. Earth Sci. 2(1):1-7.

Dewey JF, Pitman WC, Ryan WBF, Bonnin J (1973). Plate tectonics and the evolution of the Alpine system. Geol. Soc. Am. B. 84:3137-3180.

Gilbert H, Velasco AA, Zandt G (2007). Preservation of Proterozoic terrane boundaries within the Colorado Plateau and implications for its tectonic evolution. Earth Planet. Sci. Lett. 258:237-248.

Gitterman Y, Shapira A (1993). Spectral discrimination of underwater explosions. Isr. J. Earth Sci. 42:37-44.

Gitterman Y, Pinky V, Shapira A (1998). Spectral classification methods in monitoring small local events by the Israel seismic network. J. Seismol. 2:237-256.

Gulia L (2010). Detection of quarry and mine blast contamination in European regional catalogues. Nat. Hazards 53:229-249.

Gupta I N, Blandford RR (1983). A mechanism for generation of short-period tarnsverse motion explosions. Bull. Seismol. Soc. Am. 73:571-579.

Horasan G, Güney A B, Küsmezer A, Bekler F, Öğütçü Z, Musaoğlu N (2009). Contamination of seismicity catalogs by quarry blasts: an example from İstanbul and its vicinity, northwestern Turkey. J. Asian Earth Sci. 34(1):90-99.

Inaner H, Nakoman E (1993). Lignite deposits of the western Turkey. Bull. Geol. Soc. Greece, 28(2):493-505.

Kalafat D, Güneş Y, Kara M, Deniz P, Kekovalı K, Kuleli S, Gülen L, Yılmazer M, Özel N (2007). A revised and extended earthquake catalogue for Turkey Since 1900 (M≥ 4.0). Boğaziçi University Library.

Kekovali K, Kalafat D, Kara M, Deniz P (2011). The estimation capability of potential mining and quarry areas from seismic catalog using statistical analysis, an application to Turkey. Int. J. Phys. Sci. 6(15):3784-3794.

Koch K, Fah D (2002). Identification of earthquakes and explosions using amplitude ratios; the Vogtland area revisited. Pure Appl. Geophys. 159:735-757.

Mckenzie DP (1972). Active tectonics of the Mediterranean region. Geophys. J. R. Astron. Soc. 30:109-185.

Nuttli OW (1981). On the attenuation of Lg waves in western and central Asia and their use as a discriminant between earthquakes and explosions. Bull. Seismol. Soc. Am. 71:249-261.

Öğütçü Z, Horasan G, Kalafat D (2011). Investigation of microseismic activity sources in Konya and its vicinity, central Turkey. Natl. Hazards 58:497-509.

Scherbaum F, Johnson J (1992). Programmable interactive toolbox for seismological analysis (PITSA). In: Lee WHK (ed), IASPEI Software Library, USA. 5:269.

Taira T, Tsumara K (2001). The identification and removal of artificial events from the JMA and Tohoku University earthquake catalogs, Zisin (J. Seismol. Society Jpn) 53:255-258 ,(in Japanese).

Taylor SR, Denny MD, Vergino ES, Glaser RE (1989). Regional discrimination between NTS explosions and earthquakes. Bull. Seism. Soc. Am. 79:1142-1176.

Tokay M (1979). Seismotectonic features of Gediz and its surrounding. Bull. Geol. Soc. Turkey 22:209-210.

Wiemer S, Baer M (2000). Mapping and removing quarry blast events from seismicity catalogs. Bull. Seismol. Soc. Am. 90(2):525-530.

Wüster J (1993). Discrimination of chemical explosions and earthquakes in central Europe- a case study. Bull. Seismol. Soc. Am. 83:1184-1212.

Zeiler C, Velasco AA (2009). Developing local to near-regional explosion and earthquake discriminants. Bull. Seismol. Soc. Am. 99:24-35.