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## Investigation of Seismograms of North Korean Nuclear Explosion of September 3, 2017 Recorded by the Sakarya University and Kandilli Observatory Seismic Stations

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### Abstract

A nuclear test was done on September 3, 2017 in North Korea. This activity is regarded as a nuclear test based on both CTBTO analysis and the statement of the official North Korean news agency. The type of explosion was announced as a fusion based thermonuclear hydrogen bomb. Preliminary solution of CTBTO International Data Center (IDC) reported the origin time, epicenter coordinates and magnitude as 03:30:01 UTC, 41.3°N 129.1°E, and mb 6.1. U.S. Geological Survey (USGS) determined these parameters as 41.343°N, 129.036 °E and body wave magnitude, mb 6.3.

In this study the seismograms of September 3, 2017 North Korean nuclear test recorded by the Sakarya University and Kandilli Observatory seismic stations were investigated. As we observed the first motion polarity is upwards for the explosion records but the first motion polarity is downwards for the April 14, 2014 Japan earthquake records.

Also we statistically analyzed the North Korean nuclear explosions and some teleseismic earthquakes near Japan by using mb/Ms values. Linear discriminant function (LDF) was used to discriminate teleseismic events and nuclear explosions. The discrimination success percentage is 100 % in this study.

**Keywords:** nuclear explosion, North Korea, explosion and earthquake discrimination, waveform, P wave.

### 1. INTRODUCTION

Artificial explosions using powerful explosives are carried out for military or industrial purposes in the world. Nuclear explosions or quarry blasts for industrial purposes made anywhere in the world are recorded by seismic recording stations around the world.

The location, the depth and the time of blasting of an explosion can be precisely calculated. These calculations are the same as determination of an

earthquake location and the time. For accurate calculation of nuclear explosions a dense and specially designed seismic array is needed. Especially United States (TXAR), Germany (GERE), Turkey (BRTR) and some other countries have such groups of seismic stations. This kind of seismic station groups can observe nuclear explosions made around the world. At the same time, due to the special distribution geometries, the location and other physical properties of the earthquakes can also be accurately calculated. As well as the station groups, the national earthquake network of each

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country plays an important role in the observation of these explosions. Some countries in the world, the United States, western European countries and Turkey have come together within the framework of the Comprehensive Test Ban Treaty Organization. The aim of these member countries is to identify nuclear explosions anywhere in the world and to provide international exchange of data collected from seismic station groups.

The earthquake and large scale explosion data collected from seismic station groups can be used for economic, strategic, military, engineering and scientific purposes.

Various analysis techniques can be used to discriminate explosion and earthquakes recorded at the seismic recording stations. The earthquake and nuclear explosion events occur from different energy sources. While faults are formed cracking of the earth's crust by pairs of opposite forces, the explosions are formed by a force mechanism in which almost equivalent forces are applied in all directions (Figure 1).

In this study, 3 September 2017 North Korean nuclear explosion's digital seismograms recorded at Sakarya University and Boğaziçi University Kandilli Observatory and Earthquake Research Institute are interpreted. Also the North Korean nuclear explosions and some teleseismic earthquakes near Japan are analyzed statistically using mb/Ms ratio.

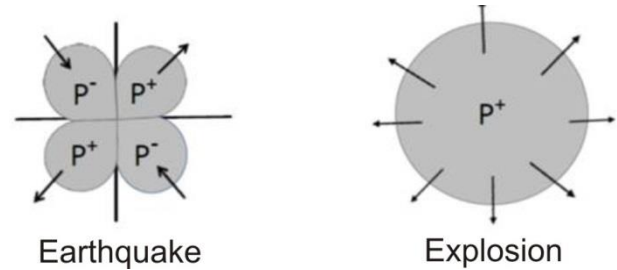


Figure 1. Comparison of the complicated radiation pattern of an earthquake source (left side) and nearly isotropic radiation pattern of an explosion source (right side)

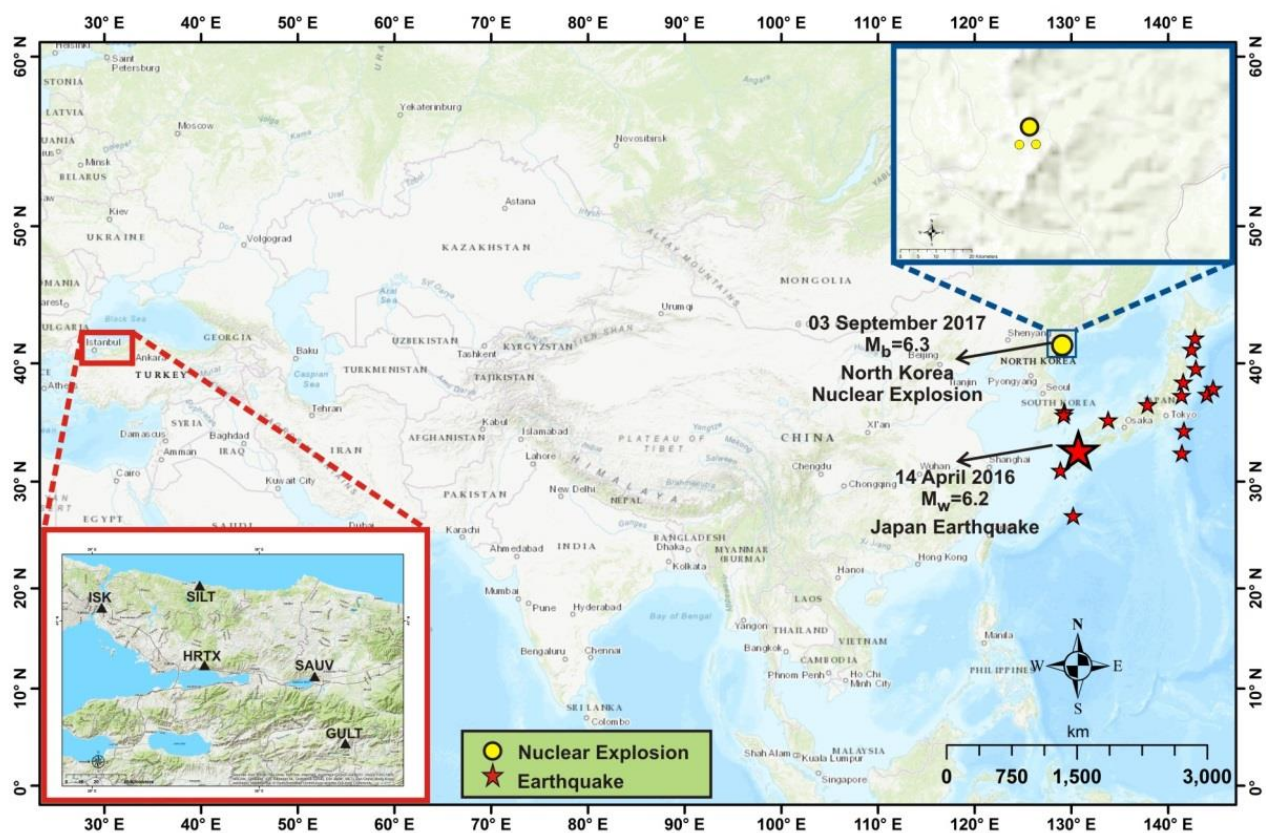


Figure 2. Map showing the locations of three North Korean nuclear explosions and some earthquakes near Japan. The recording seismic station locations are given in the inset map

## 2. EXPLOSION PARAMETERS

On September 3, 2017, the Democratic People's Republic of North Korea carried out a nuclear test

(Figure 2). Type of bomb used in this nuclear test was announced as a fusion-based thermonuclear hydrogen bomb.

Preliminary solution of CTBTO International Data Center (IDC) reported the origin time, epicenter

coordinates and magnitude as 03:30:01 UTC, 41.3°N 129.1°E, and mb 6.1. U.S. Geological Survey (USGS) determined these parameters as 41.343°N, 129.036 °E and body wave magnitude, mb 6.3 respectively. A second seismic event at the same location with magnitude (mb 4.1) was recorded eight minutes after the explosion by the USGS. The cause of this event is considered to be either related to the collapse of the explosion chamber or a triggered landslide. The nuclear test that occurred on 3 September 2017 is the largest one up to now in that region. The recommended amount of explosive for nuclear explosion on 3 September 2017 is 251 kt TNT  $\pm$  187kt TNT [1].

### 3. DISCRIMINATION OF EARTHQUAKES AND EXPLOSIONS

Seismologists have examined the differences in the amplitude and the spectra of the waveforms of the seismic records to reveal the differences between earthquakes and explosions [2-9]. The amplitude and frequency characteristics of the surface and the body waves obtained from nuclear explosions or quarry blasts are different from the earthquakes. Kim and Richards [10] analyzed nuclear explosion records in North Korea on October 9, 2006 and compared these records with earthquakes and known chemical blasting records. In this study, P/S spectral ratios obtained from earthquake, chemical explosion and nuclear explosion records are plotted for eight discrete frequency values. This distribution was analyzed by linear discriminant function (LDF). The Pg/Lg spectral ratio is an effective method for classifying earthquakes and explosions in North Korea and China.

Figure 3 shows the seismic waveforms of the nuclear test done in North Korea on 3 September 2017 at SAUV, SILT, GULT, HRTX and ISK stations. SAUV station belongs to the Department of Geophysical Engineering of Sakarya University and SILT, GULT, HRT and ISK stations belong to the Kandilli Observatory and Earthquake Research Institute Regional Earthquake-Tsunami Monitoring Center (KOERI-RETMC). It can be seen that the first motion polarity is upward at all stations looking at the waveforms recorded at these stations. The reason is a force mechanism in which approximately equivalent forces in each direction are applied (Figure 1). When the waveforms of the nuclear explosion are examined, it is seen that the P wave amplitude is very large

and dominates over the seismogram. S wave phase is not seen. This feature of the seismogram is used to distinguish explosions from earthquakes.

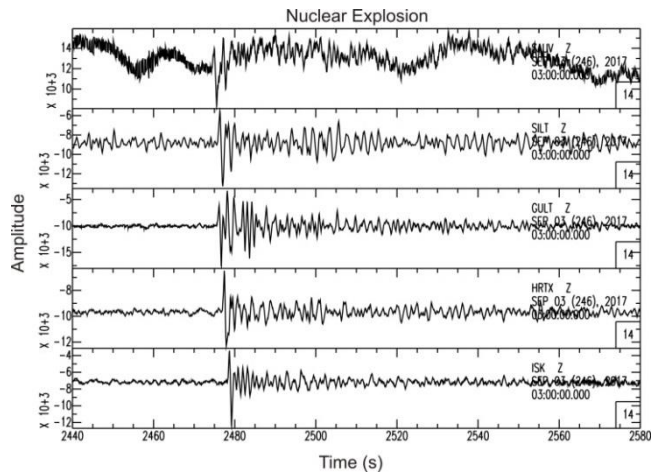


Figure 3. Seismograms of September 3, 2017 North Korean nuclear explosion

In Figure 4a, waveforms at different stations of an earthquake that occurred in Japan on April 14, 2016, Mw 6.2, are given. Although the first motion polarity of an earthquake can be upwards or downwards, in this study we see the first motion polarity downwards at all earthquake records in Figure 4b. Because the seismic stations located at almost the same azimuth degree. Both S waves and surface waves are well seen in earthquake records. In Figure 4a, the amplitude of surface waves is dominant in the records of April 14, 2016 earthquake.

Due to the shallow depth of the source, surface waves can also be seen in the explosion records, but the energies are low. Surface waves are used as an important criterion to distinguish earthquakes and explosions [11].

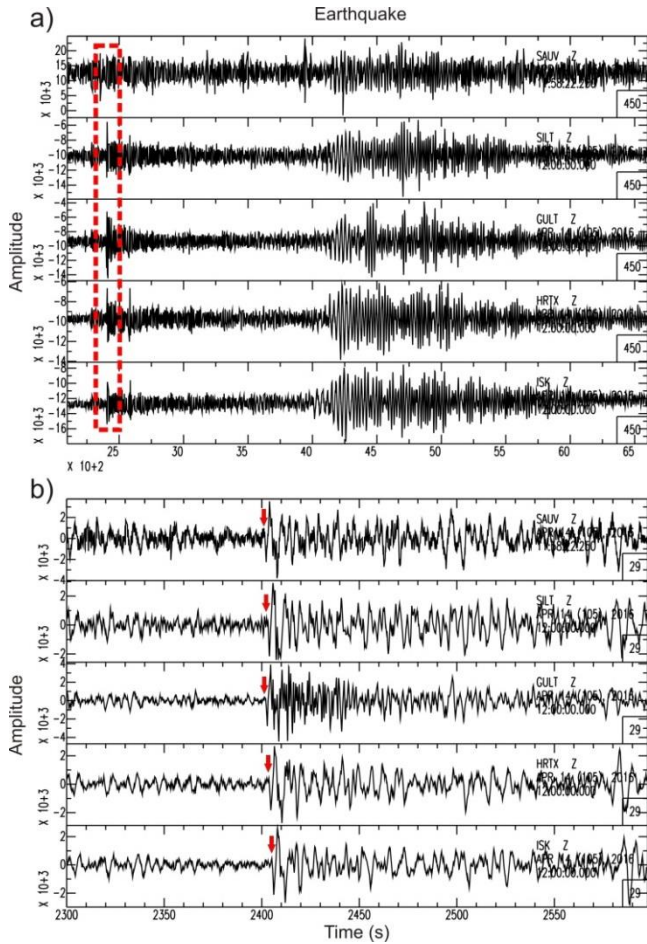


Figure 4 a. Seismograms of April 14, 2016 earthquake in Japan, b. Expanded version of the beginning of seismogram shown in the above figure

The frequency domain characteristics of the September 3, 2017 North Korean explosion and April 14, 2016 Japan earthquake are given in Figure 5 a, b, c and d. Figure 5 a, b, c and d show the North Korean explosion and Japanese earthquake spectrograms for GULT and SAUV stations respectively.

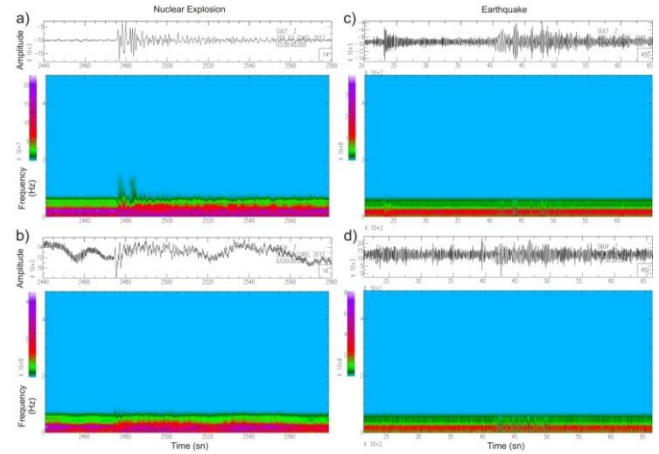


Figure 5 a, b, c and d. This figure show the North Korean explosion and Japanese earthquake spectrograms for GULT and SAUV stations respectively. Purple color represents high energy contents, red medium, whereas dark green and blue colors represent low energy contents

Table 1. List of seismic events that were used in this study

Date	Orjin Time	Latitude (°N)	Longitude (°E)	h (km)	m <sub>b</sub>	M <sub>s_20</sub>	Type
2018.01.24	10:51:19	41.103	142.433	31	6.1	6.2	Earthquake
2017.11.15	05:29:32	36.074	129.280	10	5.4	5.2	Earthquake
2017.11.09	07:42:11	32.521	141.438	12	5.7	5.6	Earthquake
2017.10.06	03:59:32	37.503	144.020	9	6.3	5.9	Earthquake
2017.09.20	16:37:16	37.981	144.660	11	6.1	5.9	Earthquake
2017.09.03	03:30:01	41.332	129.030	0	6.3	5.1	Explosion
2017.07.26	10:32:57	26.898	130.184	12	5.9	5.4	Earthquake
2016.11.21	20:59:49	37.399	141.387	9	6.6	6.9	Earthquake
2016.11.11	21:42:59	38.497	141.568	42	5.6	5.6	Earthquake
2016.10.21	05:07:22	35.374	133.809	5.6	5.9	6.2	Earthquake
2016.09.23	00:14:34	34.462	141.637	10	5.9	6.4	Earthquake
2016.09.12	11:32:55	35.781	129.216	13	5.5	5.2	Earthquake
2016.04.15	16:25:06	32.791	130.754	10	6.4	7.3	Earthquake
2016.04.14	12:26:35	32.788	130.704	9	5.8	6.1	Earthquake
2016.01.14	03:25:33	41.972	142.781	46	6.5	6.2	Earthquake
2016.01.06	01:30:01	41.300	129.047	0	5.1	3.8	Explosion
2015.11.13	20:51:31	31.001	128.873	12	6.3	7.0	Earthquake
2015.02.16	23:06:28	39.856	142.880	23	6.2	6.6	Earthquake
2014.11.22	13:08:18	36.641	137.880	9	6.2	6.2	Earthquake
2013.02.22	02:57:51	41.299	129.004	0	5.1	4.0	Explosion

Spectrograms show how the frequency content of the signal changes with time. Seismic Analysis Code (SAC) was used to obtain these figures. When we look at the explosion and the earthquake

spectrograms we see the frequency content of the explosion spectrogram is little bit larger (~ 1.5 Hz) than the earthquake spectrogram (~0.8 Hz) for GULT station. The frequency content for SAUV

station is low and less than 1 Hz for both the explosion and the earthquake. Hammer et al. [12] and Allmann [13] show that the frequency content of the quarry blast seismograms examined in their data groups is lower than the earthquakes. In these figures, purple color represent high energy contents, red medium, whereas dark green and blue colors represent low energy contents.

Traditionally, mb/Ms discrimination (the amplitude of high frequency P waves and long period surface waves) is used for teleseismic events [14, 15]. Therefore, in this study, we used mb/Ms for discrimination of teleseismic earthquakes and North Korean explosions. The seismic events that used in this study are given at Table 1. Three of them are the North Korean explosions. Other seismic events are earthquakes occurred near to Japan. We obtained mb and Ms magnitude values from USGS web site. The mb/Ms ratio plotted versus mb values of the teleseismic events is given in Figure 6.

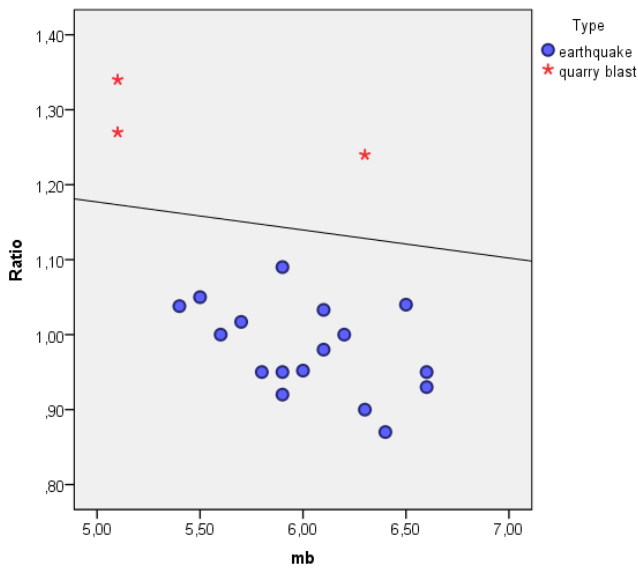


Figure 6. mb/Ms ratio versus mb for North Korean explosions and teleseismic earthquakes. The discrimination line has been determined from a linear discrimination function (LDF) for events in Table 1

The discrimination line is obtained using SPSS software. We obtained good results using mb/Ms magnitude ratio. These statistical values are given in Table 2. The classification percentage is 100% for the discrimination of teleseismic events and the North Korean nuclear explosions.

Table 2. The results of the discrimination analysis between North Korean nuclear explosions and teleseismic earthquakes

Type	Predicted group membership		Total	
	Earthquake (E)	Quarry blast (QB)		
Original	E	17	0	17
Count	QB	0	3	3
%	E	100	0	100
	QB	0	100	100

#### 4. RESULTS

1. When the North Korean nuclear explosion records of September 3, 2017 are examined, it is found that the P wave is the dominant phase on the seismogram.
2. In all station records for explosion the first motion direction is always upwards.
3. Looking at the frequency content of the September 3, 2017 North Korean nuclear explosion records, it appears that low frequencies are dominant.
4. In this study the mb/Ms ratio was used for discrimination of teleseismic earthquakes and North Korean nuclear explosions.
5. Statistical analyses method (linear discriminant function, LDF) was used to discriminate teleseismic earthquakes and North Korean nuclear explosions.
6. The discrimination percentage is obtained as 100 % in this study.

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