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KSRS 자료를 이용해서 북한의 인공지하폭발의 탐지 및 분석
Detection and Analysis of the Artificial Underground Explosions in N. Korea using KSRS data.

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요약/Abstract

원격지진과 핵실험의 구별에 관한 연구는 많은 지진학자들에 의해서 연구되어 왔다(너틀리와 김, 1976;달만과 이스라엘슨, 1977;마세, 1981). 그러나 지역적인 미세지진과 인공지하폭발(진앙거리 400km보다 가까운)은 지진학적 관점에서 볼때 활발하게 연구되지 않았다. 더우기 최근 IAEA(국제 원자력기구)가 북한의 핵무기 개발을 명백하게 분석하는데 이 문제는 매우 중요하지만 한국에서 이런 종류의 연구는 전혀되지 않았다.

본 연구는 지난 6년동안 북한에서 발생한 인공지하폭발(약 100개)중에 KSRS자료를 이용하여 수행되었다. 방위각·외견입사각, 진앙거리 및 진앙 등은 단일 관측의 3성분자료를 이용하여 결정된다. 그리고 인공지하폭발의 탐지·진앙확인은 Polarization 기술과 주파수 필터링 방법으로 수행된다. 이 방법은 전환파(converted waves)를 정밀 분석할 수 있으며 비동질의 지각구조 모델을 결정하는데 크게 이용할 수 있다.

The discrimination studies between earthquakes and underground nuclear explosions have been carried out by various seismologists(Nuttli and Kim, 1976; Dahlman and Israelson, 1977; Masse, 1981). The discrimination between local microearthquakes and artificial underground explosions(epicentral distance not greater than 400Km), however, has not been actively studied so far in the light of seismological aspects. Futhermore this kind of research has never been performed in Korea even if it is of great importance for IAEA (International Atomic Energy Agency) to clearly analyze the military nuclear power of North Korea at present.

This research has been carried out by using some of the artificial underground explosions(about 100 events) have occurred in North Korea for the last six years. The azimuths, apparent incidence angles, epicentral distances and locations are determined using a single station of 3-component data. The detection, location and identification are performed through the polarization and the bandpass filtering. This technique can be also applied to study the inhomogeneous crustal structure finding the converted waves.

Introduction

It has been studied for long time that a seismologist determines to locate the hypocenter of the seismic event using normally well−distributed seismic stations. If the seismic stations are not distributed isotropically around the source, we can scarcely use the conventional method (HYPO71PC). The polarization method is the best for estimating any seismic sources using a single station and/or seismic array of 3−component data. In first motion study, we disregard the converted phases such as *Ps*, *sP*, taking into some multiple and/or decoupled events account from various signals of the seismograms(Clark and Pearce, 1988). There are a number of published studies(Magotra et al., 1987;Jurkevics, 1988;Kedrov and Outchinnikov, 1990;Kim, 1995) that examine the tasks of detection and initial processing of seismic signals at a single station or array.

It is difficult to determine the seismic parameter of the N. Korean events since we do not have the mutual data exchange programs and the poor distribution of the seismic stations in the Korean Peninsula. We applied a polarization method to KSRS data to determine the hypocentral parameters of the artificial underground explosions that occurred in N. Korea.

We tried to determine not only focal parameters of the underground artificial explosions in N. Korea but also the characteristics of the explosions such as verification of multiple explosions and/or decoupled explosions. This method is also useful for identifying converted waves(*pS* or *sP*) within the crust(Bataille and Chiu, 1991) to investigate the heterogeneity of the structure.

The Korean Seismological Research Station (KSRS) short period array was designed and implemented to aid in the detection and discrimination of Eurasian events. The KSRS SP array is positioned in Wonju about 110 kilometers southeast of Seoul and consists of 19 short−period vertical seismometers(See Fig. 1). It has an

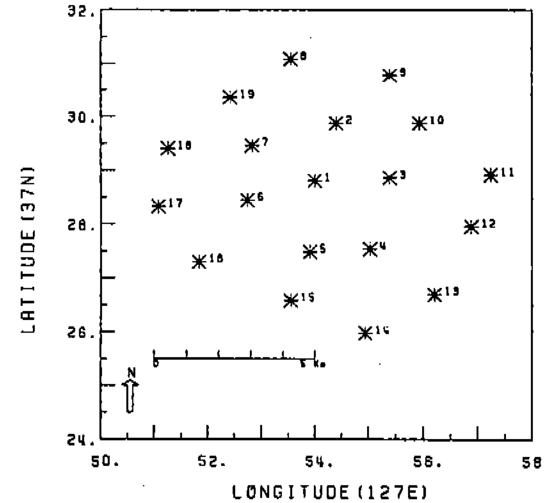


Fig. 1 Configuration of KSRS seismic Array.

apparatus of approximately 9km and the center 3−component seismometer is located at 37°29′14″N latitude and 127°55′24″E longitude. The three−components of low gain is 5k, whereas the three−component of high gain is 500k. The station gain at 1.0 Herts(Hz) is 0.488 milli−microns(mμ)/count(ct). An anti−aliasing filter eliminated energy above 5.0Hz. Sampling rate of 20 data points per second is used for all data.

This research is carried out by using artificial underground explosions of N. Korea which occurred in N. Korea for the period January 1988 to June 1988. The raw data of these events were collected at the KSRS stations of Wonju, Korea. Quantitative detectability estimates(Kim and Lee, 1995) demonstrate the applicability of the developed method may lead to good results in monitoring regional seismicity in spite of the poor distribution of the seismic station in the Korean Peninsula. In this study we retrieved only short−period records of 19 stations and the 3−component short period data of low and high gain. The locations of these explosions are determined using a 3−component data. It is most difficult for seismologists to detect micro−earthquakes and explosions in case of multiple and/or decoupled explosions that interfere the original signals by producing the composite traces of the signals(Kim, 1995). The multiple events are verified using the bandpass filter and polarization method for body waves, whereas the decoupled explosions are identified by analyzing of the predominant frequency contents of the events.

Analysis and Results

Fig. 2 and Table 1 indicate the locations and parameters of the artificial underground explosions in N. Korea for this study. The estimates of epicenters and epicentral distances of Table 1 were performed by means of the azimuth of the polarization method and S−P Tables of the Korea Meteorological Administration, representing epicenters in terms of latitude and longitude. Fig. 3 shows the output seismograms of N. Korean artificial underground explosions which were retrieved from KSRS. We can see clearly *Rg* waves of the fundamental Rayleigh mode for a and b, while we cannot see any *Rg* waves for c and d, which provide only high frequency signals compared to a and b. *Rg* waves are generally generated for the ordinary explosions where the source is located under the very shallow depth of the low velocity layer(e.g. alluvium) overlying basement. The results of multiple reflection for SV and SH waves within the interface or the surface demonstrate the generation of Lg waves and Rg waves(Kim, 1994). The predominant high frequency of the explosions may be attributed to the decoupled explosions due to the multiple reflection(reverberation) within the air or water filled cavity instead of the tamped explosions of the high energy release (Kim, 1995).

We can see the multiple explosions in Fig. 4. We can see three events in a of Fig. 4 which took place with each three second−interval. We observed two events in b of Fig. 4 that occurred with eignteen second−interval. The last example of Fig. 4 shows the twelve second−interval of two multiple explosions. The multiple explosions of c also provide the clear generation of *Rg* waves, which do not appear in a and b of Fig. 4. It should be noted that a and b of Fig. 4 have almost the same azimuth and locations, whereas c of Fig. 4 must have a different azimuth and different location since the azimuth and the epicentral distance of the respective two events are found to be different from each other according to the results of the polarization analysis. From Fig. 4, we show the outputs that were analyzed from the on−line analysis of seismic data. The first step is performed by the band pass filtering of 4∼8Hz to enhance the S/N for P waves except for S and surface waves. The first part of the second step is carried out rotating the AZ(epicenter to station) for P waves and the second part of the second step is done rotating BAZ(station to epicenter) for S and surface waves of the 2−dimension elliptical polarization. We can scarcely see shear waves

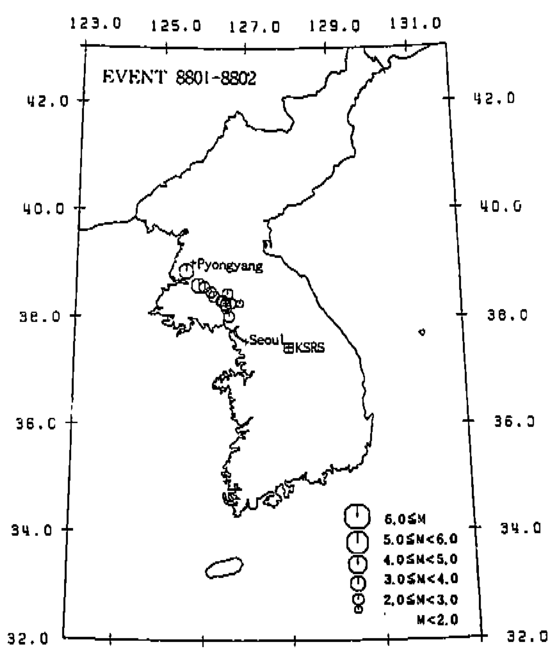
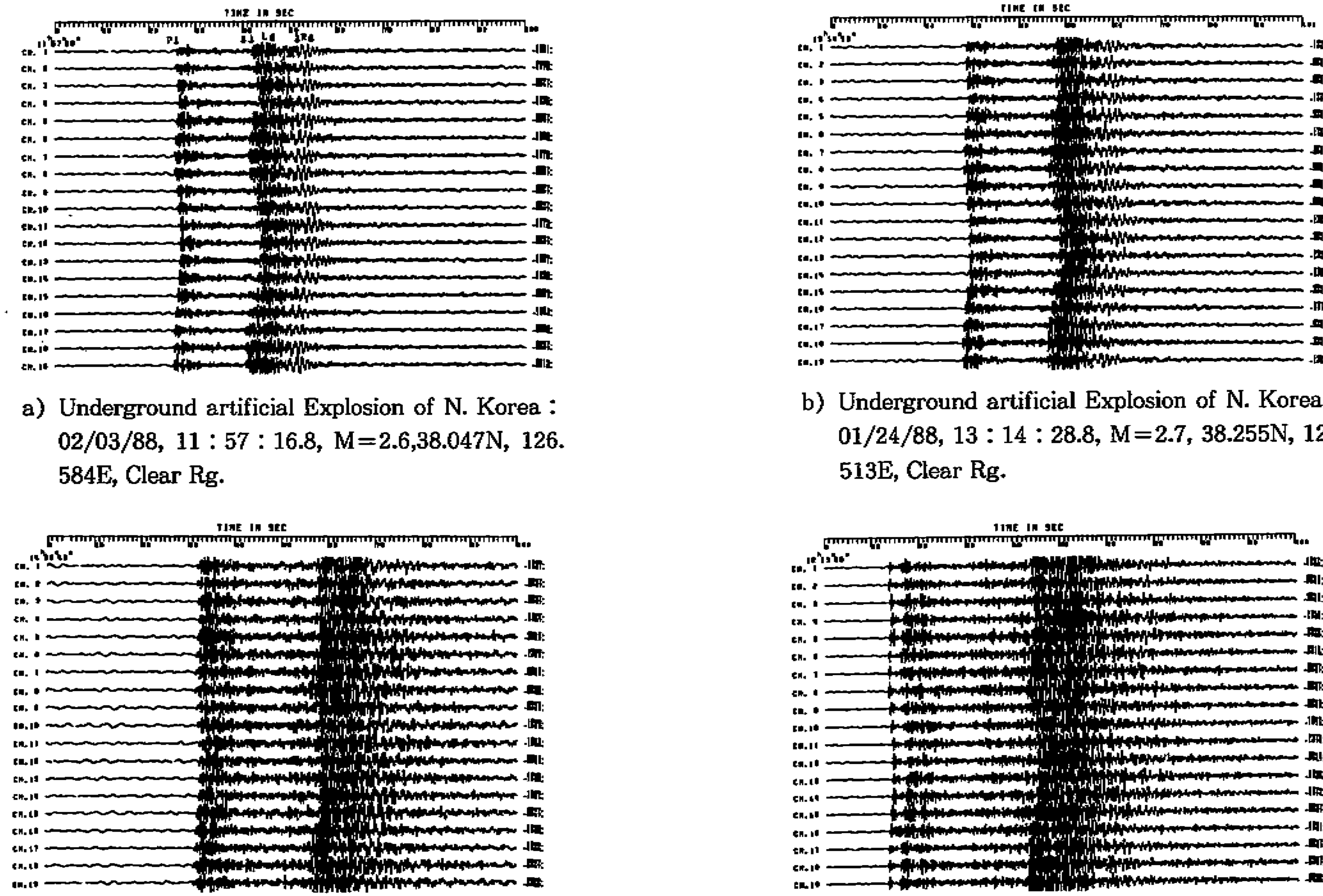


Fig. 2 The locations of underground artificial explosions in N. Korea determined by KSRS data.

Table. 1 The hypocentral parameters for the artificial underground explosions of N. Korea produced by KSRS data.

Event No.	O.T. M/D/Y H : M : S	Azimuth	App. Inc	Distance △(Km)	Epicenter Lat. Lon.	Magnitude (M)	Rg wave
LKSRS03	01/17/88 12 : 58 : 59.9	305.7	55.8	161.0	38.3 126.4	2.1	No
LKSRS05	01/18/88 12 : 25 : 25.3	300.3	58.1	150.1	38.3 126.5	2.4	No
HKSRS07	01/19/88 16 : 13 : 28.0	305.4	57.4	181.0	38.4 126.2	2.4	No
LKSRS09	01/24/88 13 : 14 : 28.8	305.0	57.9	147.9	38.3 126.5	2.7	Yes
LKSRS11	01/25/88 12 : 13 : 07.6	307.9	41.1	257.0	38.9 125.6	3.0	No
	01/25/88 12 : 13 : 10.5	301.1	62.1	266.0	38.7 125.3	–	No
	01/25/88 12 : 13 : 14.1	309.2	52.0	266.4	39.0 125.5	–	No
LKSRS13	01/26/88 12 : 43 : 46.3	303.8	52.8	141.0	38.2 126.6	1.8	Yes
HKSRS15–2	01/28/88 16 : 59 : 02.1	308.6	77.8	134.0	38.3 126.6	2.4	Clear
HKSRS19	01/28/88 16 : 59 : 32.8	309.2	54.1	189.0	38.5 126.2	2.4	No
	01/28/88 16 : 59 : 53.8	308.3	50.5	185.0	38.5 126.2	2.6	No
LKSRS21	01/29/88 17 : 00 : 35.3	306.8	37.5	206.0	38.6 126.0	2.6	Yes
LKSRS23	01/30/88 11 : 58 : 07.7	314.1	53.9	128.6	38.3 126.8	1.8	Clear
	01/30/88 11 : 58 : 14.9	281.2	70.2	127.3	37.9 126.5	2.0	Clear
LKSRS27	02/03/88 11 : 57 : 16.8	298.2	52.6	130.7	38.0 126.6	2.6	Clear
HKSRS29	02/03/88 16 : 18 : 45.8	312.9	58.1	161.0	38.5 126.5	2.4	Clear
LKSRS33	02/04/88 16 : 53 : 30.8	306.9	51.2	159.0	38.4 126.4	2.5	Clear
LKSRS35	02/05/88 14 : 59 : 41.0	305.6	36.7	218.0	38.6 125.9	3.0	No
LKSRS39	02/10/88 16 : 00 : 00.6	303.4	57.1	144.4	38.2 126.5	2.5	No



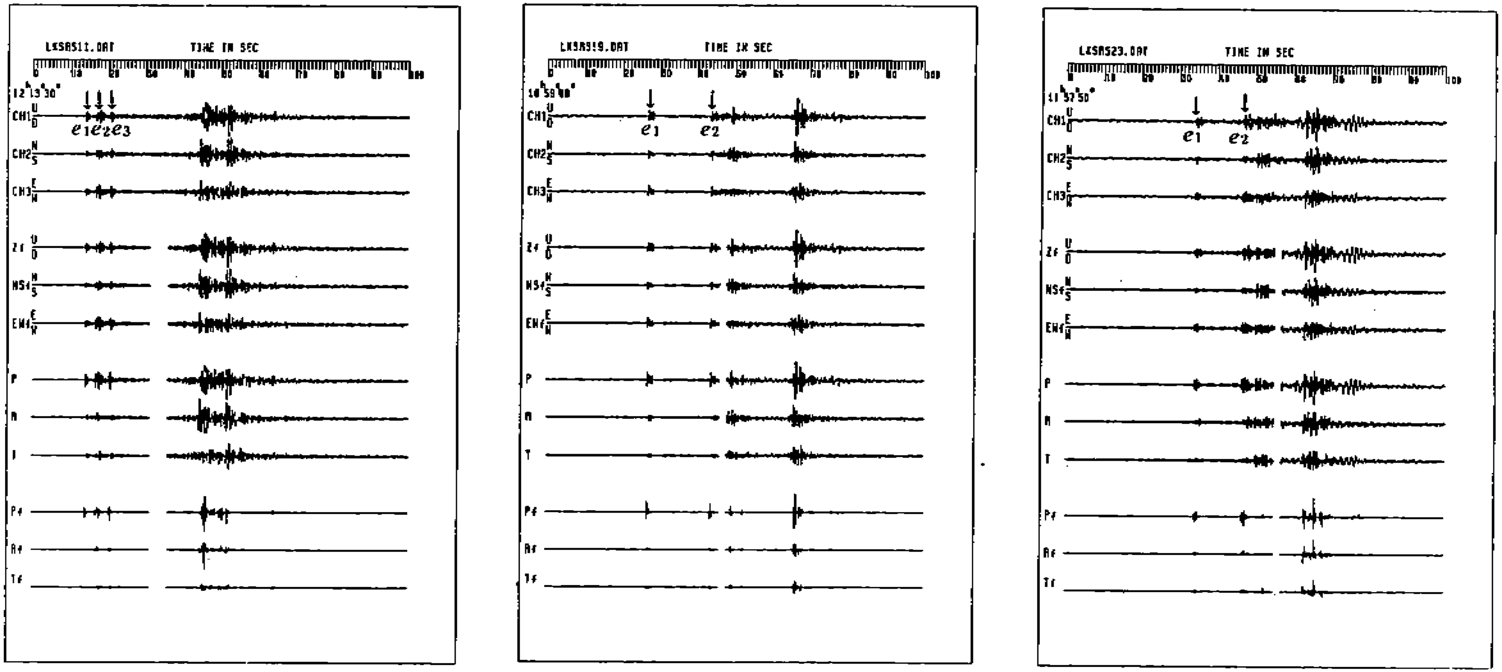
a) Underground artificial Explosion of N. Korea : 02/03/88, 11 : 57 : 16.8, M=2.6,38.047N, 126.584E, Clear Rg.

b) Underground artificial Explosion of N. Korea : 01/24/88, 13 : 14 : 28.8, M=2.7, 38.255N, 126.513E, Clear Rg.

c) Underground artificial Explosion of N. Korea : 01/25/88, 12 : 13 : 7.6, M=3.0, 38.896N, 125.555E, No Rg.

d) Underground artificial Explosion of N. Korea : 02/05/88, 14 : 59 : 41.0, M=3.0, 38.625N, 125.860E, No Rg.

Fig. 3 Seismograms of 19 KSRS seismometers with Rg waves (a,b) without Rg waves (c,d) for the artificial underground explosions of N. Korea

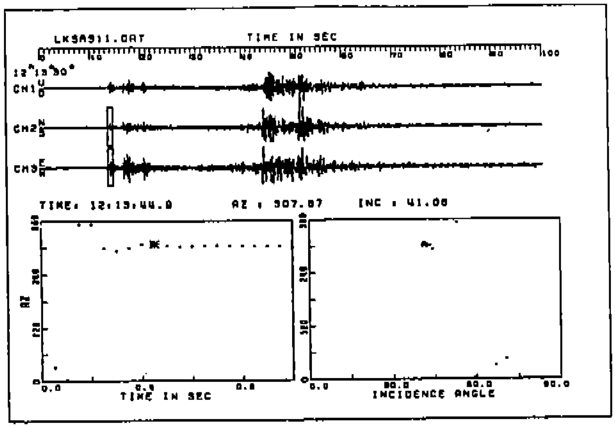


a) Multiple events of the underground artificial explosions in N. Korea : Multiple Events (3) 01/25/88, 12 : 13 : 7.6, M=3.0, 38.896N, 125.555E, No Rg.

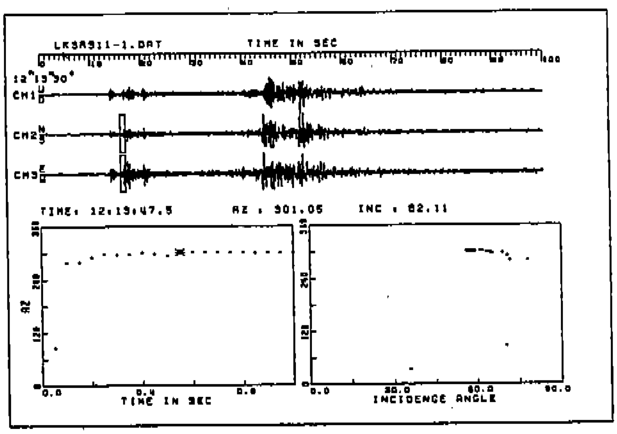
b) Multiple events of the underground artificial explosions in N.Korea : Multiple Events (2) 01/28/88, 16 : 54 : 31.7, M=2.7, 38.506N, 126.161E, No Rg.

c) Multiple events of the underground artificial explosions in N.Korea : Multiple Events(2) 01/30/88, 11 : 58 : 7.7, M=1.8, 38.301N, 126.842E, Clear Rg

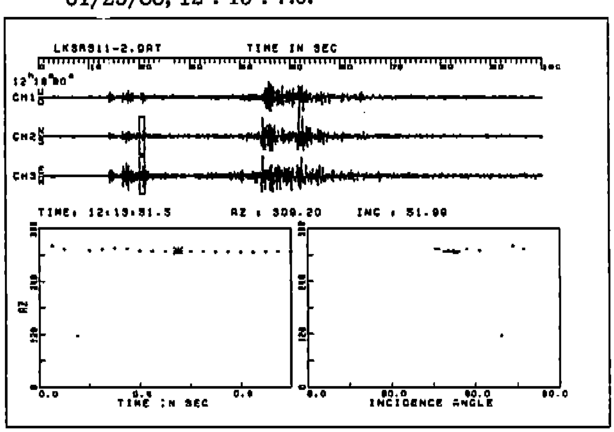
Fig. 4 Multiple explosions of 3-component KSRS are analyzed through bandpass filter(4-8Hz), polarization for P-waves and rotation, normalization for P, S and surface waves.



a) The first event of the multiple explosions for 01/25/88, 12 : 13 : 7.6.

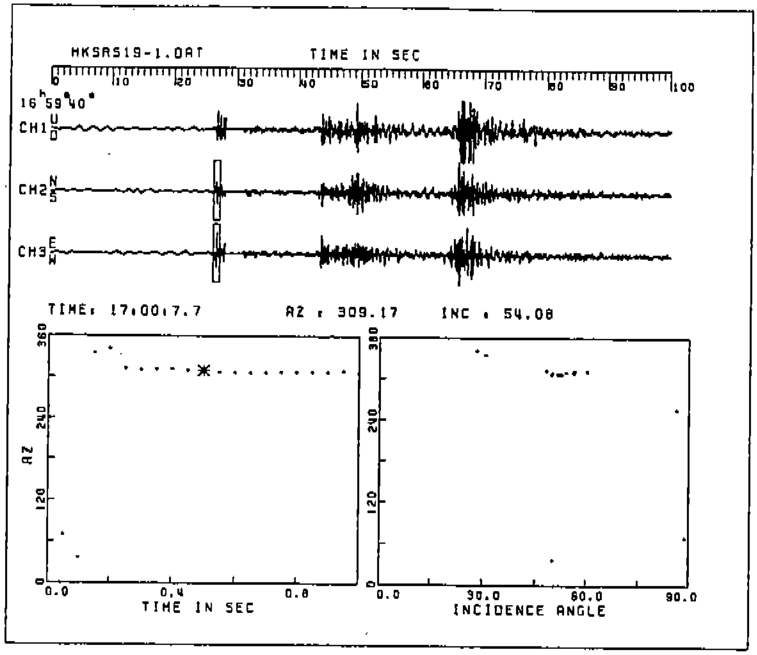


b) The second event of the multiple explosions for 01/25/88, 12 : 13 : 7.6.

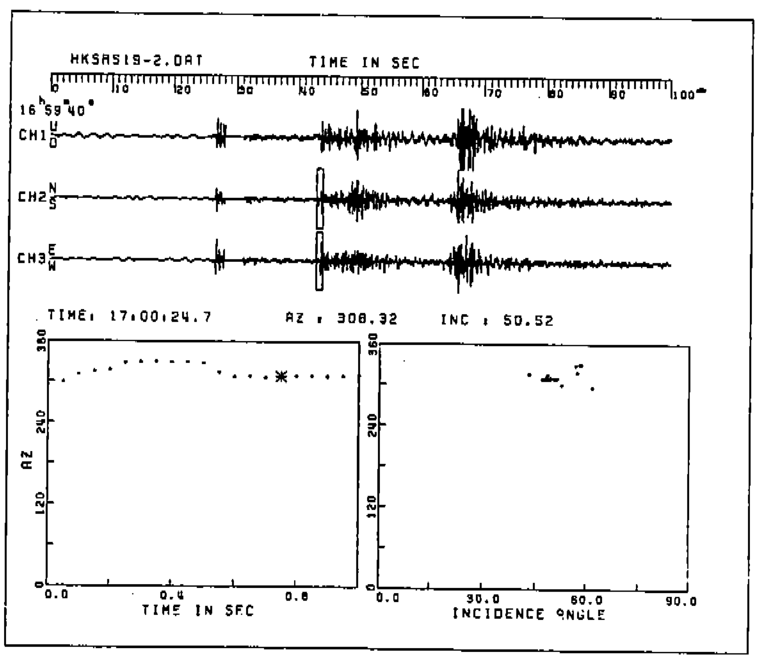


c) The third event of the multiple explosions for 01/25/88, 12 : 13 : 7.6.

Fig. 5 The identification of the multiple events using the polarization method for Jan. 25, 1988.

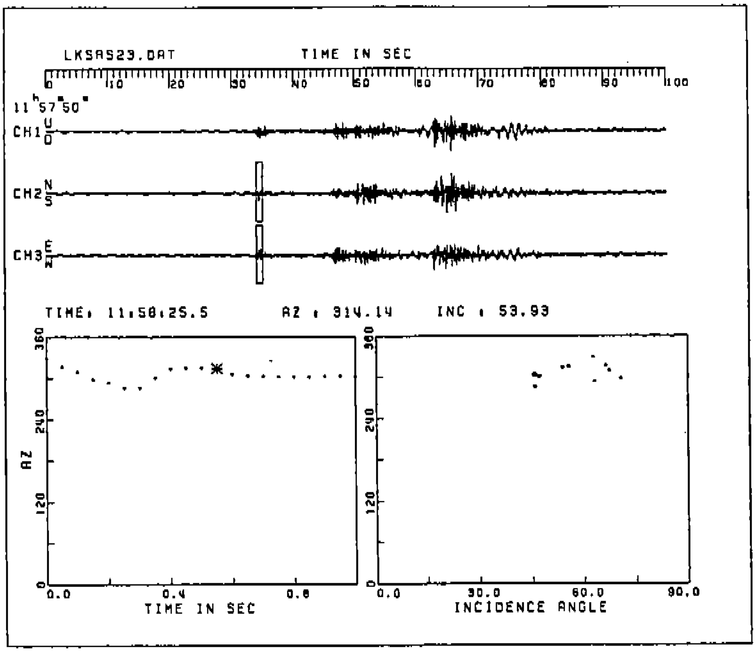


a) The first event of the multiple explosions for 01/28/88, 16 : 59 : 32.8

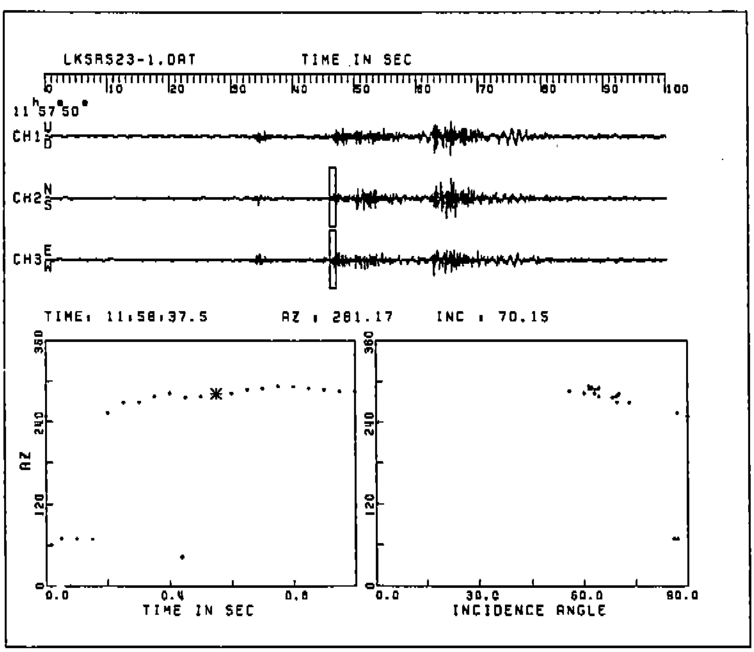


b) The second event of the multiple explosions for 01/28/88, 16 : 59 : 53.8

Fig. 6 The identification of the multiple events using the polarization method for Jan. 28, 1988.

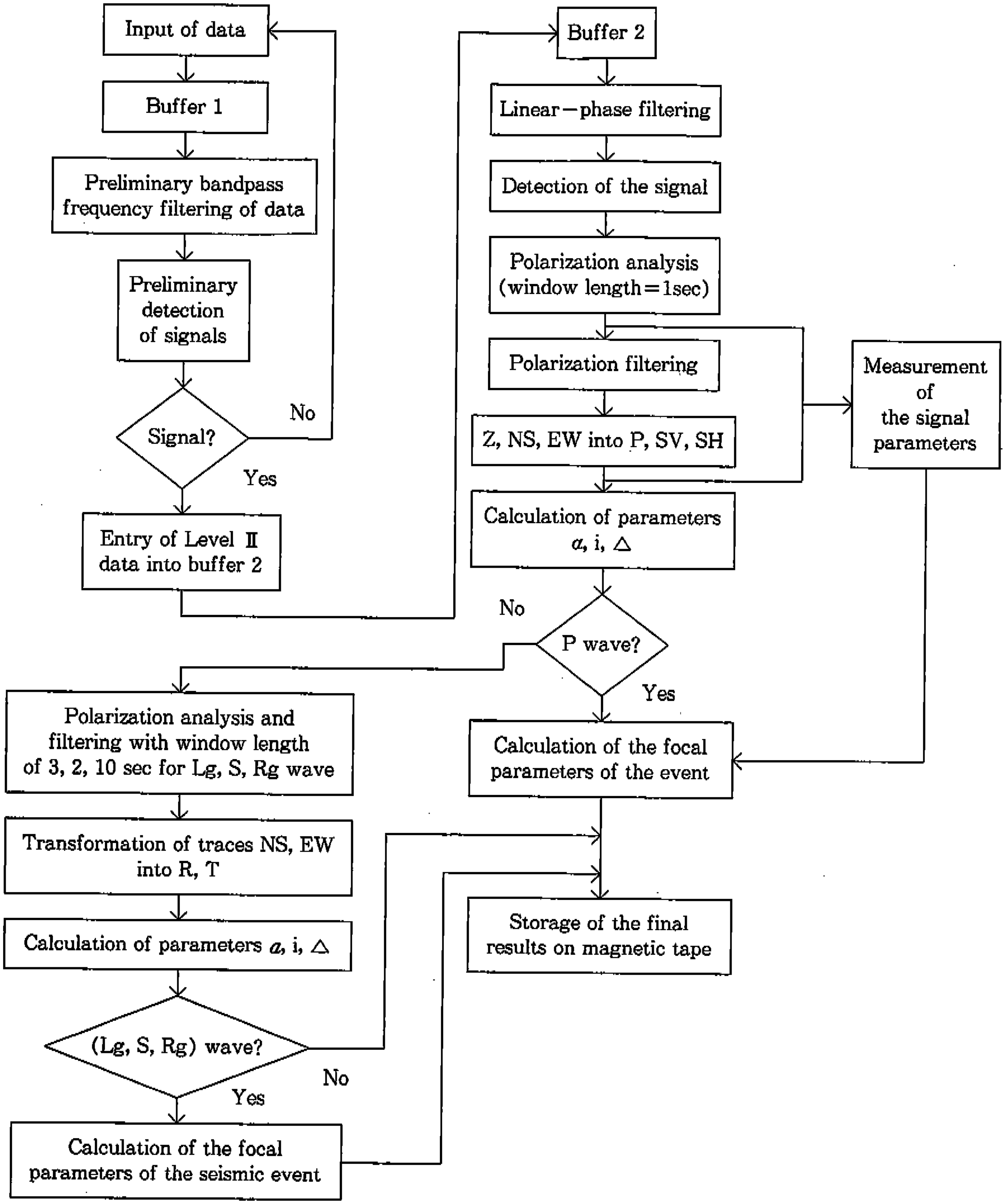


a) The first event of the multiple explosions for 01 /30/88, 11 : 58 : 7.7



b) The second event of the multiple explosions for 01/30/88, 11 : 58 : 14.9

Fig. 7 The identification of the multiple events using the polarization method for Jan. 30, 1988. Two multiple events are located in the different location.



* Period for Lg wave 0.5−6sec : for S wave 0.5−5sec : for Rg 5−15sec

Fig. 8. Flowchart of algorithm for Polariztion Method

and/or surface waves from this rotation since these events are explosions that do generate little shear and surface waves. The third step is to multiply the weighting function of the rectilinearity and/or planarity and directions for P and S(surface) waves in order to retrieve the clear waveforms of the events for the follow-up of event detectability. We can clearly see multiple explosions Figs. 5, 6 and 7 show the determination of azimuths and apparent incidence angles of multiple events for January 25, January 28, and January 30, 1988, respectively. The multiple events for January 25 and 28 are found to have almost the same azimuths, whereas those for January 30 are estimated as the different azimuths. These findings indicate that the location of the multiple explosions for January 30, 1988 must be different. The present study uses the characteristics of waveforms of P, S, and surface waves for phase association as outlined in the flow chart in Fig. 8.

Discussion and Conclusions

Regional S−type phases (*Sg, Sn, Lg*) recorded at 3−component stations are not generally considered to be very useful for backazimuth estimations because of their complex particle motion (Suteau−Henson, 1991, Jurkevics, 1988).

1. Polarization was found useful for phase detection and identification, and location using 3−component seismic data at a single station and/or an array.
2. The moving time window is selected at the best phase and/or frequency of the waveform i. e. the first motion of P−wave on−set. The choice of time windows and frequency intervals for extracting ploarization information can be made on the basis of the pure particle motion attributes.
3. The decoupled explosions are revealed by filtering, polarization, rotation and normalizing with the weighting function.
4. Normally it is not easy to tell converted phases and multiple events on the seismogram, but not difficult to tell them in care of use of several stations. The identifying converted waves from 3−component seismic data within the crust are very useful for determining the crustal structure and the strong lateral variation.
5. The sampling rate of KSRS is 0.05 sec (SPS =20), which is relatively low for the local micro−seismic events in the Korean Peninsula since its Nyguist frequency is 10 Hz. It seems that the appropriate sampling rate is 0.02 sec (SPS=50) in the Korea micro−seismicity studies.
6. Further improvements for detection, location and identification are derived from the frequency−wavenumber analysis(FVK) of beamforming configuration which if we spend a huge budget for a telemetry seismic array based on real−time seismology.

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