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Some Seismic Results of the MILROW Underground Nuclear Explosion

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SUMMARY

MILROW, a large yield nuclear device, was detonated underground on Amchitka Island in the Aleutians and recorded at the four UKAEA sponsored arrays. The preliminary results from the four short period arrays and the analysis of the surface wave train from MILROW and from an earthquake in the Aleutian Isles recorded at Blacknest are presented. The JED [1] technique for epicentre location and the results of spike filtering the short period signal to identify the free surface reflection pP are also presented.

1. INTRODUCTION

On the 2nd October 1969 at 2206 hours GMT a nuclear device was detonated on Amchitka Island in the Aleutian Islands. This event was given the code name MILROW.

This was the second underground explosion on the island that was detected by many seismograph stations around the world; the first was LONGSHOT, October 1965 [2].

This report is aimed at providing some basic data obtained from the UKAEA sponsored arrays and some results of the initial analysis of this data provided by the underground explosion MILROW.

2. SHOT DETAILS (REF: USCGS PDE CARD 64-69)

Code name MILROW

The shot coordinates and firing time

51°25'01.6" N

179°10'56.3" E

Depth = 3900 ft relative to ground zero

Time 2nd October 1969 220600.0 hours GMT

Seismic magnitude $m_b = 6.5$

$M_s = 5.0$

The medium in which the explosion was fired is not known at present, also the yield of the weapon has not been announced.

3. UKAEA SPONSORED ARRAY RESULTS

Four linear arrays of AWRE design [3] were operating at the time of MILROW. These were:-

Eskdalemuir, Scotland	EKA	55°19'59.0"N 03°09'33.0"W
Yellowknife, Canada	YKA	62°29'34.3"N 114°36'16.5"W
Gauribidanur, India	GBA	13°36'15.0"N 77°26'10.0"E
Warramunga, Australia	WRA	19°56'32.8"S 134°21'15.8"E

The P waves from the MILROW explosion were recorded at all four stations. The signal overloaded all recording systems except for a strong motion channel at EKA. A summary of the array data is given in table 1.

TABLE 1

The Amplitude and Arrival Time Data from the Four UKAEA Sponsored Arrays

Station	Δ°	Arrival Time GMT	Amplitude A/T, mμ/s	Magnitude
YKA	36	221301.6	Overloaded	> 6.1
EKA	74	221732.6	562	6.6
WRA	81	221815.6	Overloaded	> 6.2
GBA	87	221843.4	Overloaded	> 6.2

The strong motion channel at EKA is illustrated in figure 1. One point worthy of mention is the absence of a precursor to the initial P wave on the YKA record which was present on the record from the LONGSHOT [2] explosion of 29th October 1965, located approximately 5 km north of the MILROW epicentre. This difference in the character of the onsets is illustrated in figure 1.

4. EPICENTRE LOCATION OF MILROW AND SOME NEARBY EARTHQUAKES

The arrival times of MILROW recorded by stations reporting to the USCGS and used in conjunction with the joint epicentre location program JED [1] have provided an excellent opportunity for testing the accuracy of the JED technique.

The method estimates station (time) corrections, epicentres and origin times for several events simultaneously and gives a better location than the standard method of considering each event individually. It has already been shown [4] to be ideally suited for locating events within a small area relative to one event which is restrained at fixed coordinates. In the present study either LONGSHOT alone, or LONGSHOT and MILROW, were restrained to true coordinates and the following experiments carried out.

4.1 Earthquake epicentres

With both LONGSHOT and MILROW restrained a series of about 40 earthquakes were located relative to these two events. The earthquakes are from the suite used in the relocation method described in the LONGSHOT Report [2].

The results are shown in figure 2 which gives the positions of the earthquakes as quoted by the USCGS and their relocated positions using JED.

The Lilwall and Douglas 1969 travel times were used without any station corrections being applied. Other travel time curves locate LONGSHOT between 23 - 26 km north-north-west of the true shot point and the epicentres of earthquakes in this region given by the USCGS could be similarly in error. The JED method halved the epicentral error of LONGSHOT to between 11 - 14 km [5]. By restraining LONGSHOT and MILROW to their correct positions it is seen that the relocated (JED) epicentres move 10 - 30 km south-east of the USCGS locations. It is also noted that one earthquake, with arrivals recorded only at North American stations, has moved 25 km south-west of the USCGS location.

4.2 Flexible container shot

This explosion occurred on 6th September 1968 at a calculated time of 020709.5 hours GMT, and was the controlled explosion of 340 tons of TNT at a depth of 3000 ft. USCGS PDE Card No. 73-68 gives $m_b = 4.5$ and the approximate coordinates of 51°9'N and 178°24.4'E. The epicentre relocated relative to the restrained MILROW and LONGSHOT epicentres are marked F in figure 2 and details are given in table 2.

4.3 MILROW epicentre

Together with 40 Aleutian Island earthquakes, MILROW was relocated by JED relative to the fixed coordinates of LONGSHOT, treating it in the same way as an earthquake in section 4.1. The location error was 1.65 km north-west of the true shot point and is indicated by point A on figure 3. The new positions for the earthquakes were negligibly different from those calculated by restraining both MILROW and LONGSHOT epicentres.

The proximity of the LONGSHOT site to that of MILROW makes it ideally suited for use as a calibration event for MILROW. The latter was relocated using only arrival times from 53 stations that recorded both explosions. The calculated epicentre was 0.10 km in a direction north-east of the true shot point and is indicated as B in figure 3.

Figure 3 also shows the epicentres of MILROW and LONGSHOT calculated from the arrival time data recorded by the 4 UKAEA array stations and using Flinn's [6] epicentre program with the Lilwall and Douglas travel times.

The locations obtained for the two events were:-

LONGSHOT	51.304° ± 0.84N	179.229° ± 1.29E
MILROW	51.402° ± 0.60N	179.223° ± 0.92E

TABLE 2

Calculated Epicentres and 95% Joint Confidence Areas

Event	Date	Origin Time		Latitude	Longitude	Error, km	95% Confidence Area, km^2	Number of Stations
MILROW (A)	2nd October 1969	TRUE	220600.0	51.417N	179.182E			
		JED	220559.6	51.424N	179.161E	1.65NW	216	68
MILROW (B)		JED	250559.8	51.418N	179.183E	0.10NE	42	53
Flexible Container	6th September 1968	USCGS	020709.5	51.2N	178.4E			
		JED	020714.0	51.222N	178.539E	12.52NE	737	23

A similar experiment to locate LONGSHOT [2], but using Bolt's epicentre program yielded the calculated epicentre

LONGSHOT 51.38°N 17.28°E

5. IDENTIFICATION OF FREE SURFACE REFLECTION

MILROW was exploded at a depth of 1177.1 m and produced a free surface reflection pP, with phase reversal. The interference of this phase with the P onset can be seen as an inflexion in the second cycle of the strong motion record at EKA (figure 4(a)).

The exact arrival time of the pP phase cannot be established from this record. The effect of the mantle through which the rays have travelled is to attenuate the high frequencies, and the seismogram is also distorted by the instrument response of the receiver. A spiking filter was constructed [7] to remove these two effects from the observed seismogram, leaving a record that represents just the source function and the effects of source layering. Identification of reflections in the source area then becomes far easier. Figure 4(b) shows the deconvolved record on which is marked the P and pP arrivals, with a separation (t) of 1.74 s.

From a knowledge of the overburden velocity (v) at the shot site, the depth of the event (h) can be calculated, as approximately $h \approx v(t/2)$.

No information has so far been published about the medium in which the shot was fired. However, from the known depth and the P - pP delay time, the overburden velocity is calculated to be 1.36 km/s. This velocity is considerably less than the 3.38 km/s measured in the vicinity of the LONGSHOT site. It is noted in figure 4(b) that there is a further reflection 1.00 s after the P arrival which may represent a reflection from a intermediate layer between the shot point and the surface. Until details of the site geology are known no detailed interpretation can be made.

6. SURFACE WAVES

The Rayleigh waves generated by the MILROW explosion were recorded on a long period vertical component seismograph at Blacknest, (51°22'N, 01°11'W). The amplitude-frequency response of this seismometer is given in figure 5, and the Rayleigh wave train recorded on this instrument is given in figure 6.

The shape of the Rayleigh wave amplitude spectrum can be used to indicate the nature of a seismic source [8] and has been used to separate earthquake and explosion sources [9]. The Rayleigh wave train from the MILROW explosion was digitised and Fourier analysed, the absorption effects of the transmission path and the instrumental response were removed from the smoothed spectrum by point wise division. The resultant smoothed spectrum is given in figure 7 which represents an estimate of the source spectrum. (No account has been taken of source depth or layering at the source.)

Just to illustrate the spectral differences between explosions and earthquakes, a shallow earthquake from the same region was selected at random and analysed in the same way as the explosion. The result is plotted in figure 7 for comparison with the explosion. No correction was made for the effects of source depth in either event. The effect of source depth is negligible in the case of the very shallow explosion ($h < 5$ km) but for earthquakes which occur at greater depths ($h < 700$ km) the effect is very pronounced on the surface wave train. As an earthquake source gets deeper the Rayleigh wave amplitude spectrum peaks at lower frequencies, this means that the peak of the earthquake spectrum moves away from the peak of the explosion spectrum and has the effect of increasing the separation between earthquake and explosion source spectra. In figure 7 the high frequency explosive source is clearly separated from the earthquake source which is comparatively richer in low frequencies.

The $m_b:M_s$ relationship is also used to discriminate between earthquakes and explosions. The surface wave magnitude M_s [10] was determined from the Rayleigh wave train from the MILROW explosion recorded at Blacknest and was found to be 4.52. This very low value of M_s from an event with a short period magnitude $m_b \approx 6\frac{1}{2}$ is in agreement with previous $m_b:M_s$ results from explosive sources [2,11] and identifies MILROW as an underground explosion.

7. ACKNOWLEDGMENTS

The recordings at the overseas stations were made possible by the cooperation of the Dominion Observatory, Ottawa, Canada; the Bhabha Institute for Atomic Research, Trombay, India; and the Australian National University, Canberra, Australia.

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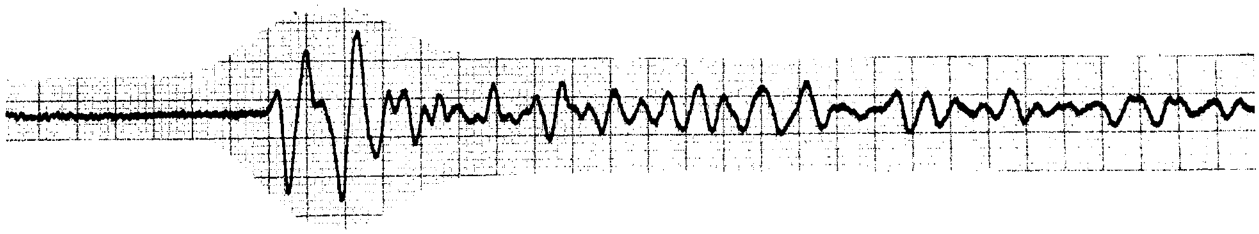
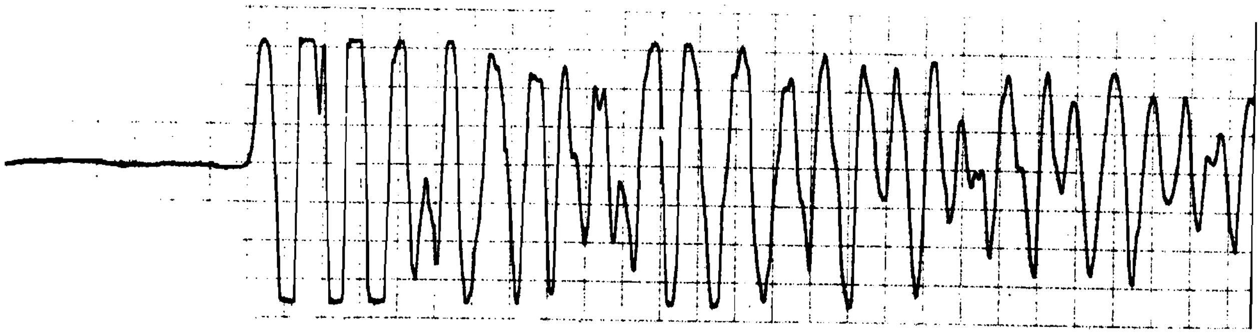
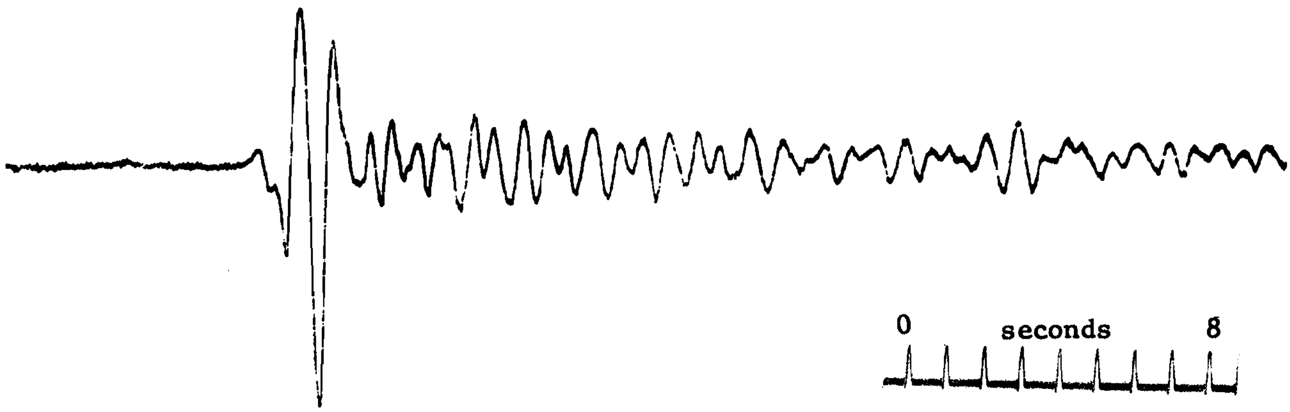


(a) MILROW - Strong Motion Vertical EKA



(b) MILROW - Sum-All Vertical YKA (Overloaded)



(c) LONGSHOT - Sum-All Vertical YKA showing Presence of Precurser

WRA and GBA Recordings of MILROW were Overloaded

<u>FIGURE 1. SHORT PERIOD P RECORDS OF MILROW AND LONGSHOT AT UK ARRAYS</u>

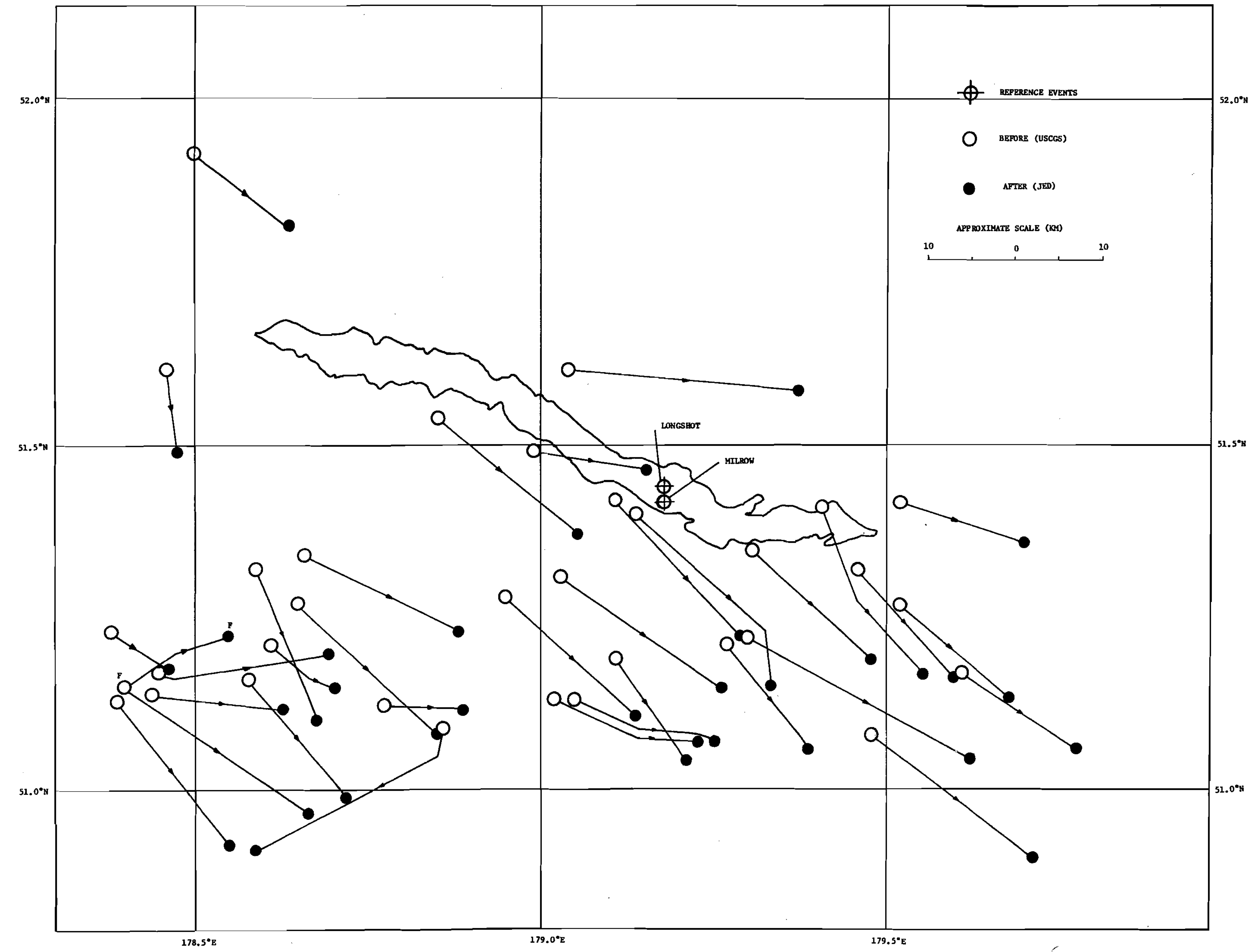


FIGURE 2. RELOCATION OF EARTHQUAKE EPICENTRES IN THE REGION OF AMCHITKA ISLAND

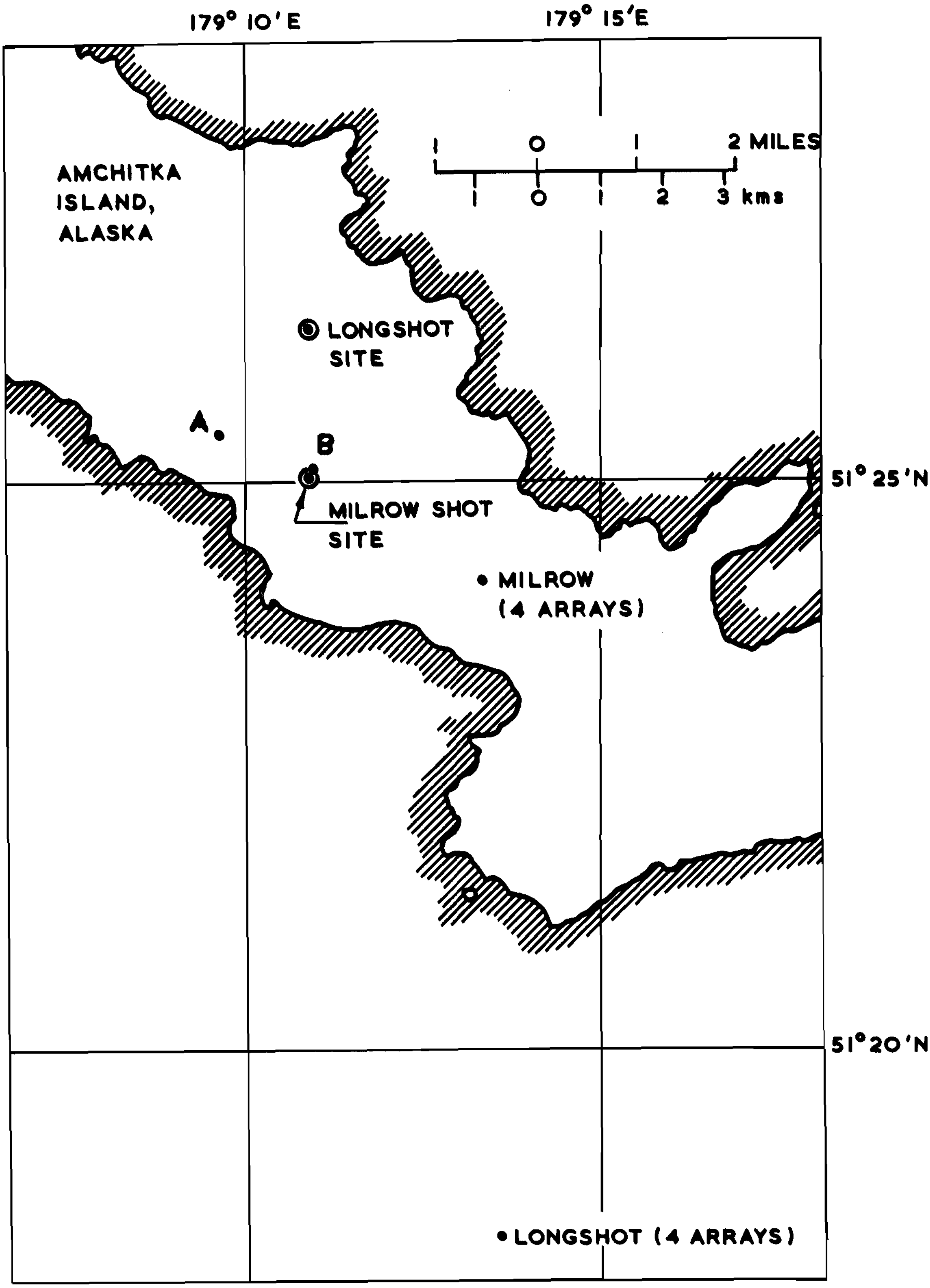


FIGURE 3. LONGSHOT AND MILROW TRUE AND CALCULATED EPICENTRES

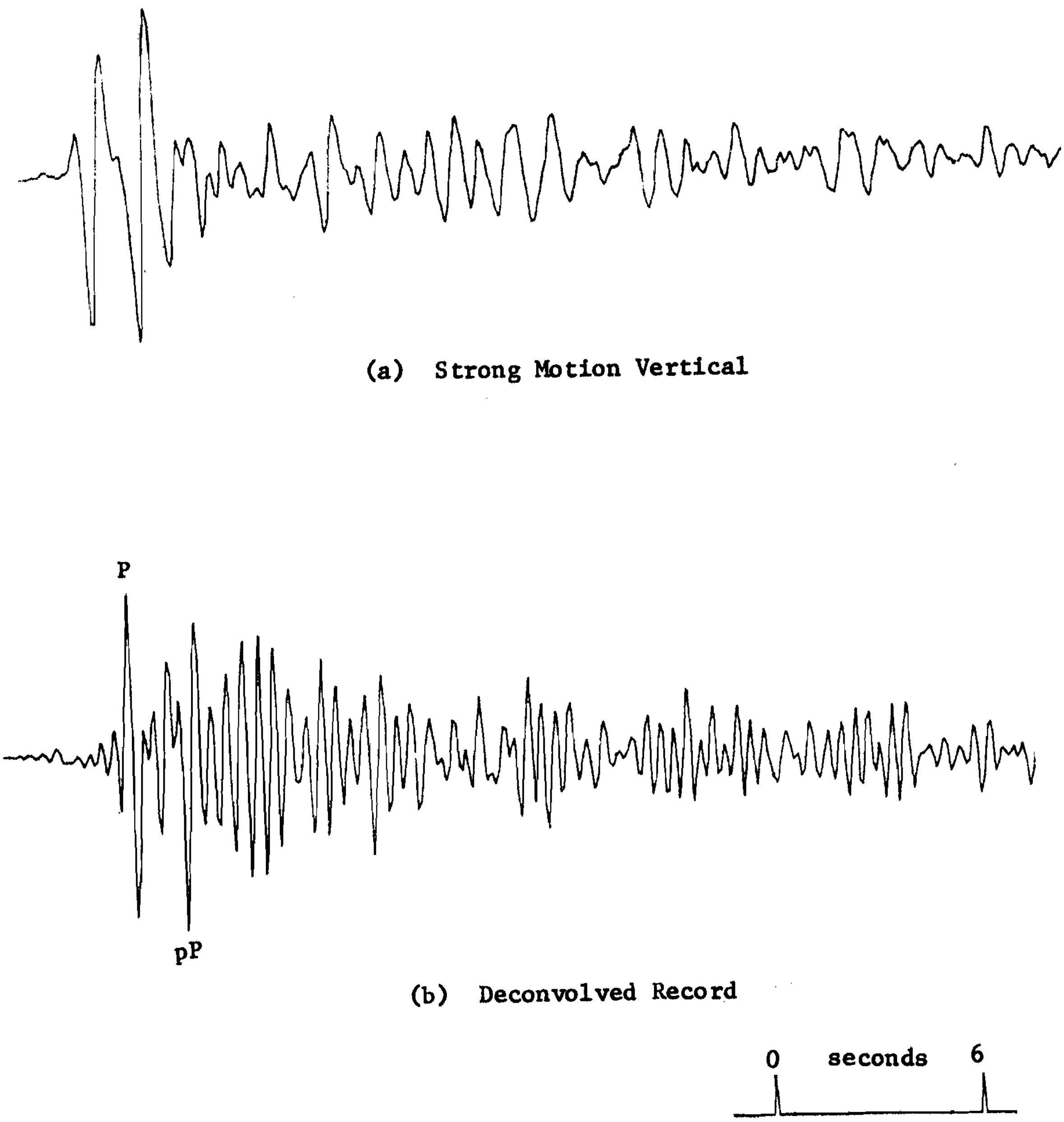


FIGURE 4. STRONG MOTION AND DECONVOLVED RECORD OF MILROW (2nd OCTOBER 1969, 220600.0 GMT h = 1.18 km RECORDED AT EKA). IDENTIFICATION OF FREE SURFACE REFLECTION

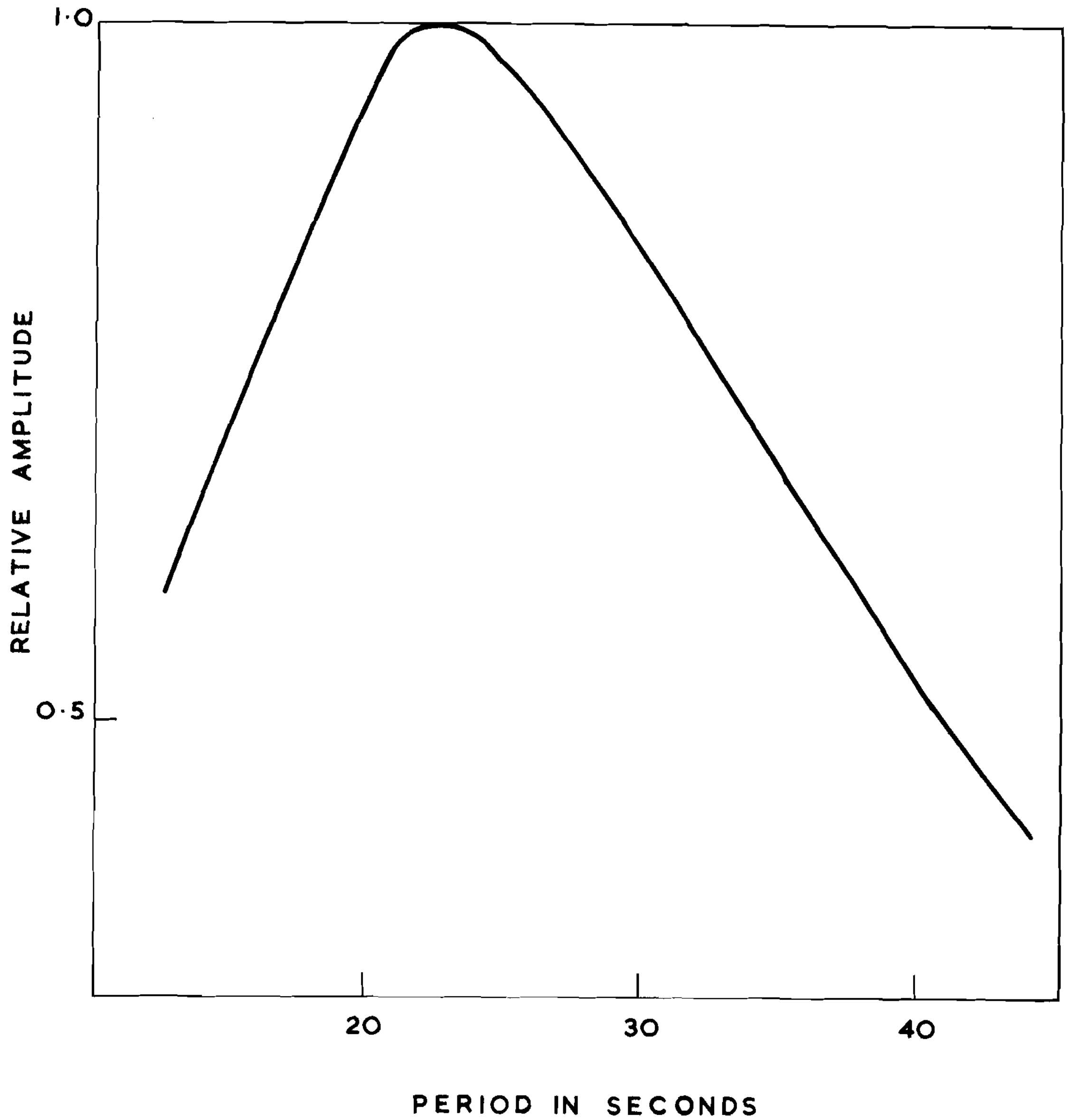


FIGURE 5. AMPLITUDE RESPONSE OF L.P. SEISMOMETER AT BLACKNEST

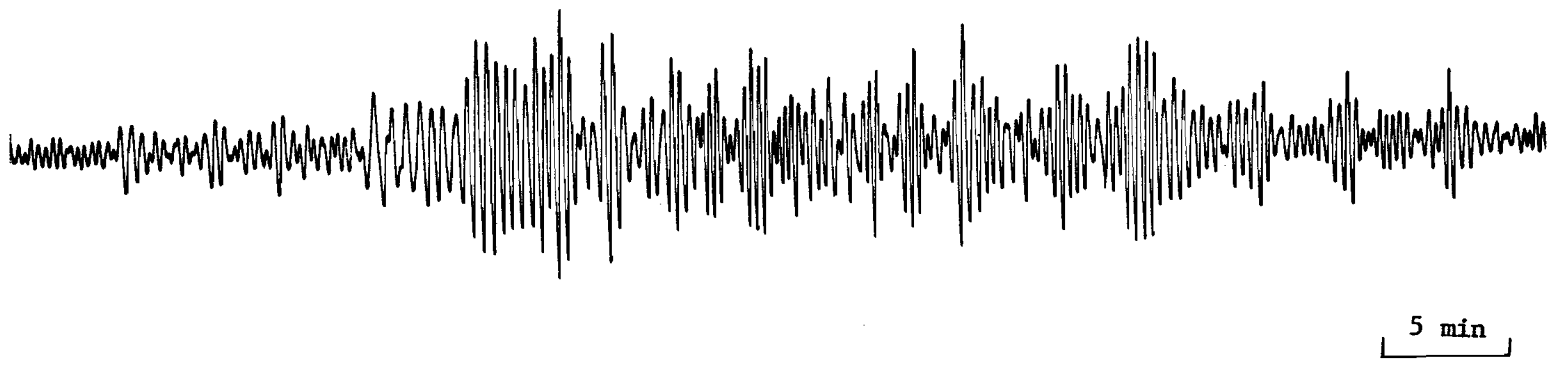


FIGURE 6. SURFACE WAVES (LR) RECORDED FROM MILROW EXPLOSION AT BLACKNEST

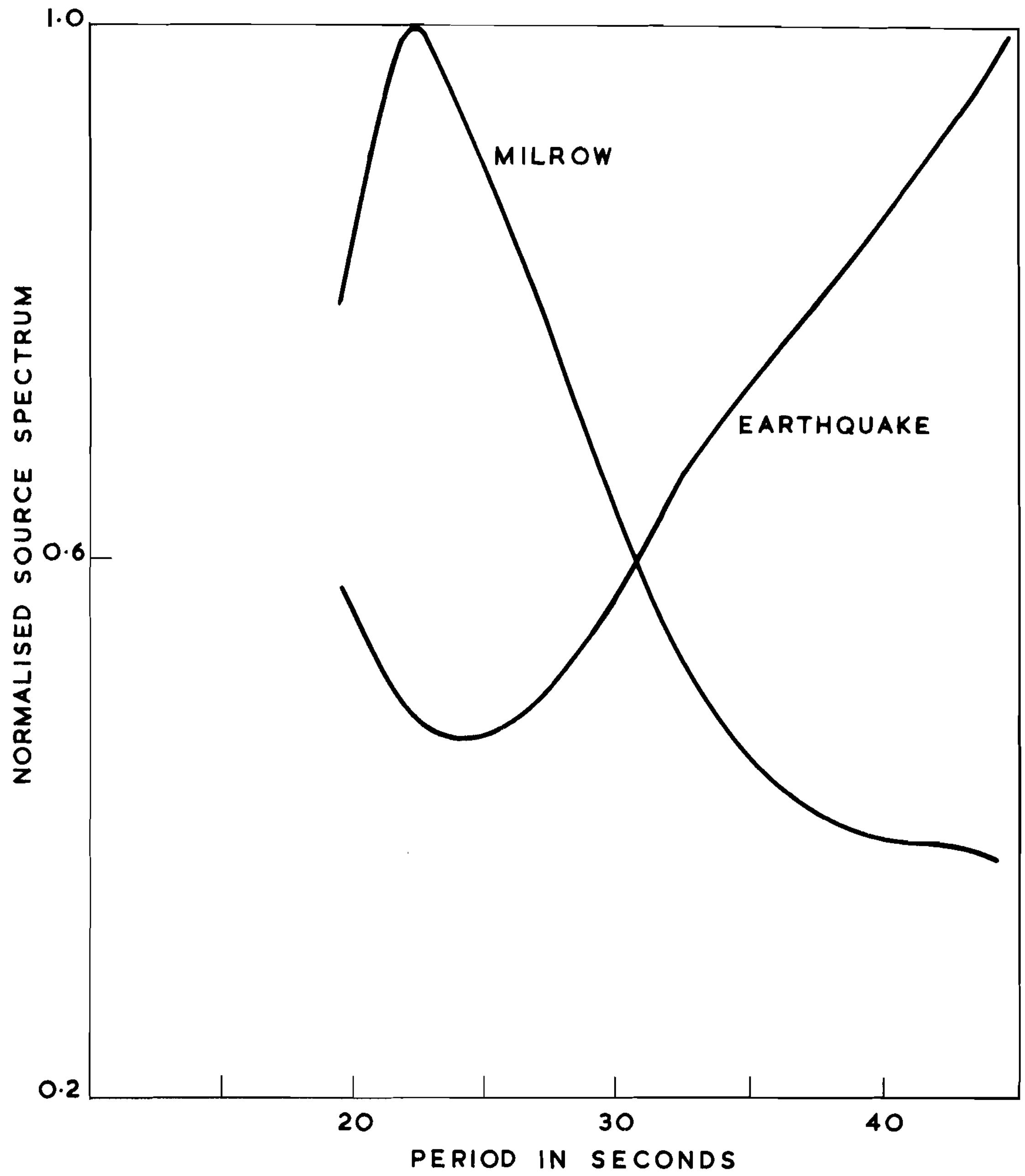


FIGURE 7. ESTIMATED SOURCE SPECTRA FOR MILROW AND AN ALEUTIAN ISLAND EARTHQUAKE