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# Some Seismic Results of the LONG SHOT Explosion

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W5 LONGSHOT:W91.54
W91.54:550.343
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## SUMMARY

LONG SHOT, with a predicted yield of 80 kton, was detonated underground on Amchitka Island in the Aleutians and recorded at Eskdalemuir, Yellowknife (Canada), Gauribidanur (India) and Tennant Creek (Australia). The results of processing of the array records are presented, and compared with the results from many other stations. The location of the epicentre is also discussed.


## 1. INTRODUCTION

On the 29th October 1965 at 2100 hours GMT a nuclear device of 80 kton yield was detonated underground on Amchitka Island in the Aleutian Islands. The event was widely recorded by many seismograph stations around the world. The analysis of the resulting data is still in progress; this report is aimed only at providing some basic data and indicating some of the problems worth further study.

## 2. SHOT DETAILS

Code name LONG SHOT.

The shot co-ordinates and firing time [1]

$51^{\circ}\ 26'17''$N

$179^{\circ}\ 10'57''$E

Depth = 2303 ft, relative to ground zero

2100 00.1 hours GMT on 29th October 1965.

The explosive was fired in an andesite still [1].

The yield was predicted as 80 kton, no estimate of the actual yield has yet been published.

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1. "LRSM LONG SHOT 29th October 1965". Seismic Data Laboratory Report No. 133. Defense Documentation Center, Cameron Station, Alexandria, Virginia, USA

## 3. UK ARRAY RESULTS

Four linear arrays of AWRE design [1] were operating at the time of the LONG SHOT explosion. These were:-

| | |
|---|---|
| Eskdalemuir, Scotland | 55° 19′ 59.0″ N 03° 09′ 33.0″ W |
| Yellowknife, Canada | 62° 29′ 34.3″ N 114° 36′ 16.5″ W |
| Gauribidanur, India | 13° 36′ 15.0′ N 77° 26′ 10.0″ E |
| Tennant Creek, Australia | 13° 56′ 32.8″ S 134° 21′ 15.8 E |

Very good signals were obtained at all four stations, although at Gauribidanur the signal was so large that there was slight overloading of the recording system on some of the recording channels. The UKAEA seismology group forecast of the magnitude of LONG SHOT was $m_b = 6.0$. The LRSM shot report [2] gives a mean magnitude $m_b = 5.97 \pm 0.48$.

The array records have each been processed by the velocity filtering techniques employed as standard processing at Blacknest [3]. The four "sum-all" signals (formed by phasing and summing all seismometers for each array) are shown together in Figure 1 and a full set of Eskdalemuir processed records are shown in Figure 2.

The four records of the initial P pulse shown in Figure 1 are very coherent. The only "anomaly" is the precursor on the Yellowknife record. A precursor has also been observed on the record obtained at the LRSM station, Jasper, Alberta (JPAT) at a similar range and it may prove to have some connection with the velocity-depth structure of the earth at a depth of about 800 km. The basic arrival time and amplitude data for the four arrays is given in Table 1.

For comparison with the recorded data in Figure 1, Figure 3 gives the basic predicted wave shape and amplitudes for the four arrays.

## 4. RECORDS OF THE WWSS NETWORK

Following the LONG SHOT explosion the United States Coast and Geodetic Survey (CGS) collected and published amplitudes and arrival times from the many stations which recorded it. In much of our work we have found that results are more consistent if the data are read by one person, and LONG SHOT provided an excellent opportunity for comparing the readings collected by the CGS with those read at Blacknest.

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1. C. G. Keen, J. Montgomery, W. H. H. Mowat, J. E. Mullard and D. C. Platt: (November 1965) "British Seismometer Array Recording Systems". Radio and Electronic Engineer, 30, 5
2. "LRSM LONG SHOT 29th October 1965". Seismic Data Laboratory Report No. 133. Defense Documentation Center, Cameron Station, Alexandria, Virginia, USA
3. F. E. Whiteway: (January 1965) "The Recording and Analysis of Seismic Body Waves Using Linear Cross Arrays". Radio and Electronic Engineer, 29, 1.

Table 2 gives the basic data for those stations where independent estimates are given. For observed arrival times there is no ambiguity about what is measured, but for amplitude measurements the situation is not so clear cut. The Blacknest measurements refer to the one half of the peak-to-peak amplitude in the first few cycles (see Figure 4 for illustration).

At Blacknest a computer program Gedess [ 1 ] is widely used for calculating basic travel time parameters. In particular the program computes the expected arrival times at various stations for events whose epicentral locations are given by the USCGS. The basic input data are the Jeffreys-Bullen travel time data. The LONG SHOT data gave an opportunity for comparing the Gedess predictions with the values for the same parameters as calculated by the USCGS program. In Table 2 the Blacknest "calculated" results and the USCGS calculated data are compared. The two sets of data are almost identical.

## 5. EPICENTRE LOCATION

Arrival times read from earthquake records are used to determine the epicentre of the event. The accuracy of present techniques has been the subject of much discussion because of its relation to the question of the area an on-site inspection team would have to survey in order to confirm the nature of an unidentified event. LONG SHOT has given an excellent opportunity of testing epicentral location techniques. As an example, Table 3 gives some epicentral solutions obtained using Bolt's program. In the near future these epicentres will be redetermined using the more refined program of Flinn [ 2 ] which gives confidence limits on the solutions.

An interesting variant is to locate events relative to some specific well-recorded event. If the specific event is an explosion whose location is known the determination becomes absolute, for an earthquake or large explosion whose epicentres are not known the location remains relative, although there is always the possibility that data on the true epicentre of an explosion will become available.

The technique is as follows, particular reference being made to LONG SHOT as an illustration:-

Knowing the location of LONG SHOT, the program used for epicentre determination is used to predict arrival times at the various recording stations. For each recording station the difference between the observed and computed arrival times gives a station (LONG SHOT) correction. These station corrections are then subtracted from the arrival

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1. J. B. Young: "A Computer Program Gedess for Prediction of Seismic Wave Arrival Times". Report in preparation.
2. E. A. Flinn: (February 1965) "Confidence Regions and Error Determinations for Seismic Event Locations". Review of Geophysics, 3, 1

times of earthquakes with epicentres in the vicinity of LONG SHOT. The epicentre program is then run (using the LONG SHOT co-ordinates as a first estimate) with the corrected data as input. This gives an epicentre relative to LONG SHOT which should be more accurate than a free run with the uncorrected data.

As an example about 50 Aleutian earthquakes have been relocated. Figure 5 shows their positions as quoted by the USCGS, and their relocated positions using the LONG SHOT travel time corrections.

In the near future it will be possible to give confidence regions for each solution by using Flinn's program. We believe this technique to be of the utmost value to seismology and recommend that well recorded explosions be regarded as standards. The question which needs answering is how far does an earthquake have to be from the explosion before the corrections became invalid? Put another way, are the corrections virtually functions only of the recording station or are they at least in part due to the path and hence azimuthally dependent?

## 6. SURFACE WAVES

Evidence collected to date on surface waves recorded from underground explosions and earthquakes indicates a significant difference in the amount of energy in the surface waves recorded from the different types of sources. Using Båth's method [1] of determining the magnitude $M_s$ of an event from the Rayleigh wave, the magnitude at Eskdalemuir of LONG SHOT was $M_s = 4.7$. This is over an order of magnitude lower than one would expect from an earthquake of the same body wave magnitude and from the same region.

A plot of earthquake and underground explosion values of $M_s$ against the USCGS published event magnitude $m_b$ (determined from short period records) is given in Figure 6. LONG SHOT is plotted with other underground explosions and it should be noted that they fall significantly below the earthquake data with considerably less scatter about a mean slope than the earthquakes. The scatter on the earthquake data is probably due to the asymmetrical radiation pattern of earthquakes; the reduced scatter of data for explosions is consistent with the symmetric radiation of energy from an explosive source. Using data from the LRSM Shot Report [2] the average $M_s$ value was found to be 4.76 compared with an average $m_b$ of 5.97 giving an $m_b$ - $M_s$

1. M. Båth: (1954) "The Problem of Earthquakes Magnitude Determination." BCIS Series A, Travaux Scientifique, Fasc. 19, 5-63
2. "LRSM LONG SHOT 29th October 1965". Seismic Data Laboratory Report No. 133. Defense Documentation Center, Cameron Station, Alexandria, Virginia, USA

a difference of 1.21. Thirlaway and Carpenter [1] using Båth's equation to measure $M_s$ and Gutenberg and Richter's method [2] of measuring $m_b$ predicted for an explosion in hard rock (e.g., granite) a difference of between $m_b$ and $M_s$ of 1.2 - very close to that recorded for LONG SHOT.

## 7. ACKNOWLEDGMENT

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

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1. H. I. S. Thirlaway and E. W. Carpenter: (February 1966) "Seismic Anomalies, Travel Times, Amplitudes and Pulse Shapes." Proceedings of the Vesiac Study Conference, Willow Run Laboratories. Report No. 4410-99-X
2. B. Gutenberg and C. F. Richter: "Magnitude and Energy of Earthquakes." Annali di Geofisica, IX, 1-15

TABLE 1

DATA FROM THE ARRAYS

| Station | $\Delta^o$ | P Arrival Time | Amplitude A/T, $m\mu/s$ | Magnitude |
|---|---|---|---|---|
| EKA | 73.6 | 21 11 32.4 | 208 | 6.18 |
| YKA | 36.1 | 21 07 02.0 | 282 | 6.04 |
| GBA | 86.7 | 21 12 43.6 | (Overloaded) | Estimated 6.4 (Overloaded) |
| WRA | 81.2 | 21 12 14.6 | 156 | 6.00 |

TABLE 2

| Station Code | Distance $\Delta^o$ | Travel Times | | | | | | Amplitude Data | |
|---|---|---|---|---|---|---|---|---|---|
| | | CGS Calculated, min | s | Gedess Calculated, s | CGS Observed, s | Blacknest Observed, s | | Blacknest A/T, mμ/ s | Ratio $\frac{\text{Blacknest}}{\text{CGS}}$ |
| AAM | 62.3 | 10 | 26.1 | 25.8 | 21.0 | 20.5 | | 180 | 0.95 |
| ADE | 93.1 | 13 | 16.6 | 16.6 | 15.0 | 15.3 | | 60 | 2.00 |
| ALQ | 54.3 | 09 | 30.6 | 30.2 | 27.0 | 26.6 | | 185 | 0.93 |
| ATL | 68.4 | 11 | 05.4 | 05.2 | 00.4 | 00.5 | | 150 | |
| BEC | 79.5 | 12 | 09.9 | 09.7 | 05.8 | 05.7 | | 160 | 0.61 |
| BOZ | 44.6 | 08 | 16.0 | 15.7 | 11.9 | 11.9 | | 245 | 2.80* |
| BUL | 141.2 | 19 | 32.7 | 32.7 | 24.0 | 23.8 | | | |
| CAR | 96.2 | 13 | 31.6 | 31.3 | 28.5 | 27.6 | | 60 | 0.82 |
| COR | 38.2 | 07 | 23.0 | 22.8 | 21.7 | 20.7 | | | |
| DAL | 61.6 | 10 | 21.5 | 21.4 | 18.5 | 18.0 | | 190 | 0.56 |
| GUA | 46.8 | 08 | 33.3 | 33.3 | 28.5 | 28.5 | | | |
| HNR | 62.9 | 10 | 30.0 | 30.1 | 27.0 | 27.0 | | 180 | 0.97 |
| IST | 84.3 | 12 | 34.8 | 34.6 | 30.0 | 30.2 | | | |
| KIP | 34.8 | 06 | 54.7 | 54.7 | 53.9 | 53.2 | | 541 | 29.8* |
| LON | 38.0 | 07 | 21.4 | 21.2 | 18.4 | 18.1 | | 75 | 1.04 |
| NOR | 46.9 | 08 | 33.6 | 33.3 | 30.0 | 30.0 | | 23 | 0.75 |
| NUR | 66.5 | 10 | 53.4 | 53.1 | 48.3 | 48.6 | | 60 | 0.88 |
| RAR | 74.7 | 11 | 43.0 | 43.1 | 39.0 | 39.9 | | | |
| RCD | 50.4 | 09 | 01.0 | 00.7 | 56.0 | 56.0 | | | |
| SHI | 86.7 | 12 | 46.9 | 46.5 | 43.1 | 43.1 | | | |
| SJG | 90.4 | 13 | 04.9 | 04.7 | 01.3 | 01.9 | | 90 | 1.23 |
| TUC | 53.4 | 09 | 24.0 | 23.7 | 20.7 | 20.6 | | 184 | 1.00 |
| VAL | 76.7 | 11 | 54.2 | 53.9 | 51.0 | 51.4 | | 128 | 0.82 |
| WES | 68.4 | 11 | 05.0 | 04.8 | 59.8 | 59.8 | | 200 | 1.07 |
| WIN | 148.0 | 19 | 44.3 | 44.3 | 42.9 | 42.1 | | 108 | 1.00 |

*It would appear that the amplitude quoted in the Earthquake Data Reports (A USCGS publication) is the peak-to-peak amplitude in millimetres from the record, not the actual amplitude in millimicrons.

## TABLE 3

### Longshot Epicentre Location Results

| | | |
|---|---|---|
| Long Shot Epicentre | 51.44°N | 179.18°E |
| Bolt's Program Using | | |
| (a) USCGS Published Data | 51.66°N | 179.11°E |
| (b) WWSSN Data Read at Blacknest | 51.60°N | 179.12°E |
| (c) Stations Used in (b) Using Published Arrival Times | 51.61°N | 179.04°E |
| (d) 4 UKAEA Array Stations | 51.38°N | 179.28°E |

LONG SHOT — AMCHITKA, ALEUTIAN ISLANDS. 29 OCTOBER 1965

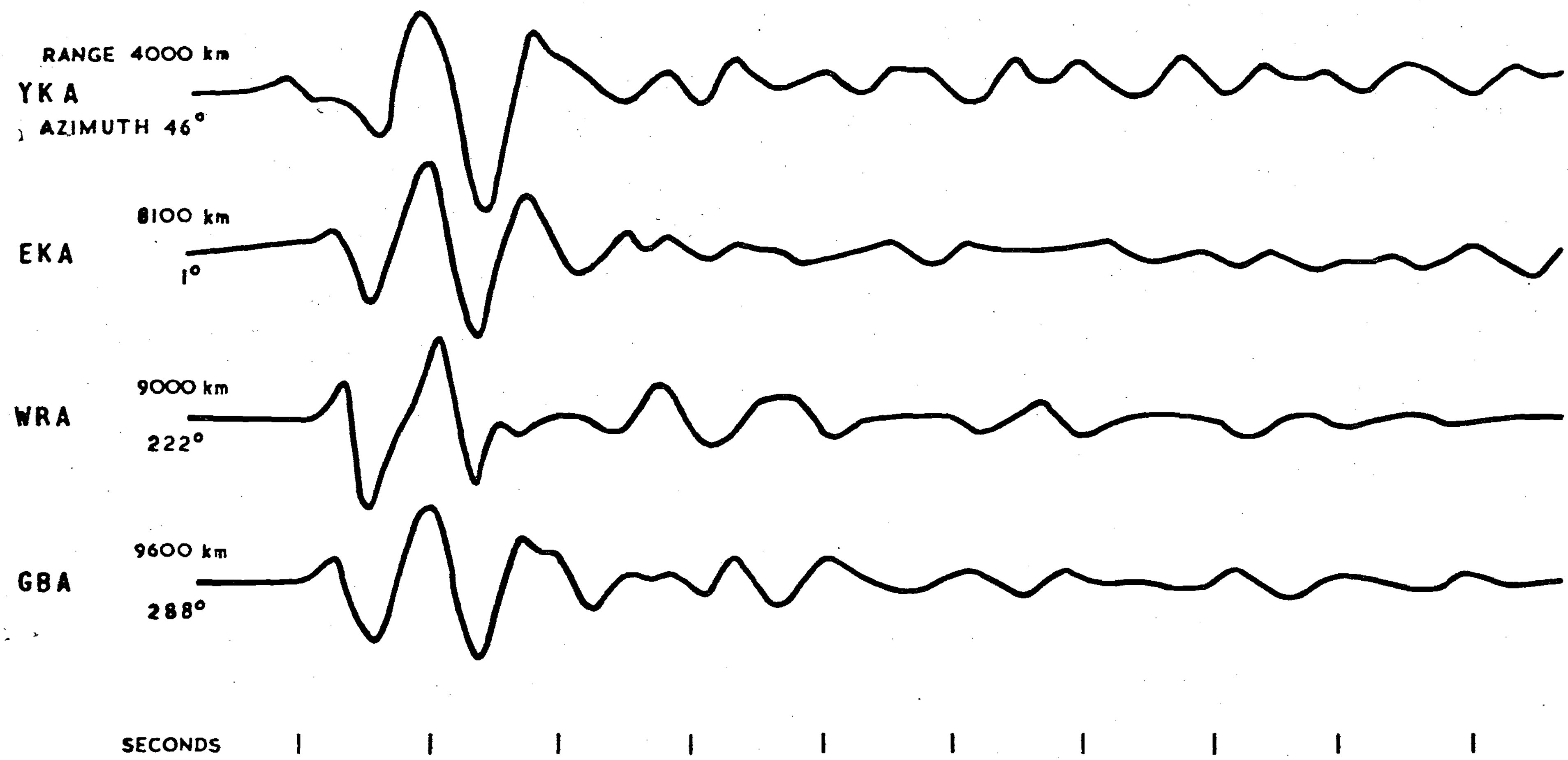


FIGURE I. FOUR UKAEA SPONSORED ARRAY SUM ALL LONG SHOT RECORDS

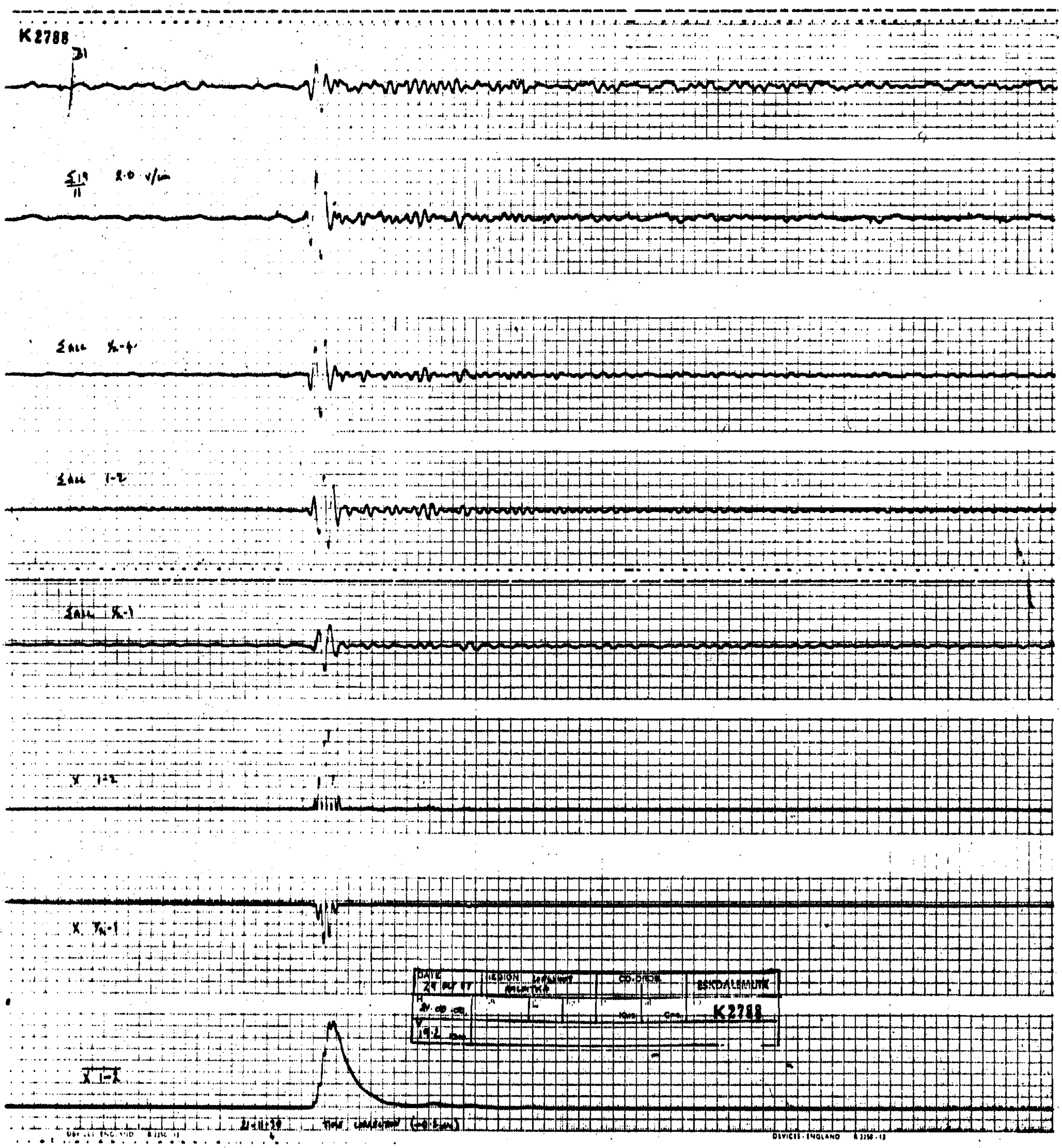

FIGURE 2. ESKDALEMUIR PROCESSED RECORD OF LONG SHOT EVENT

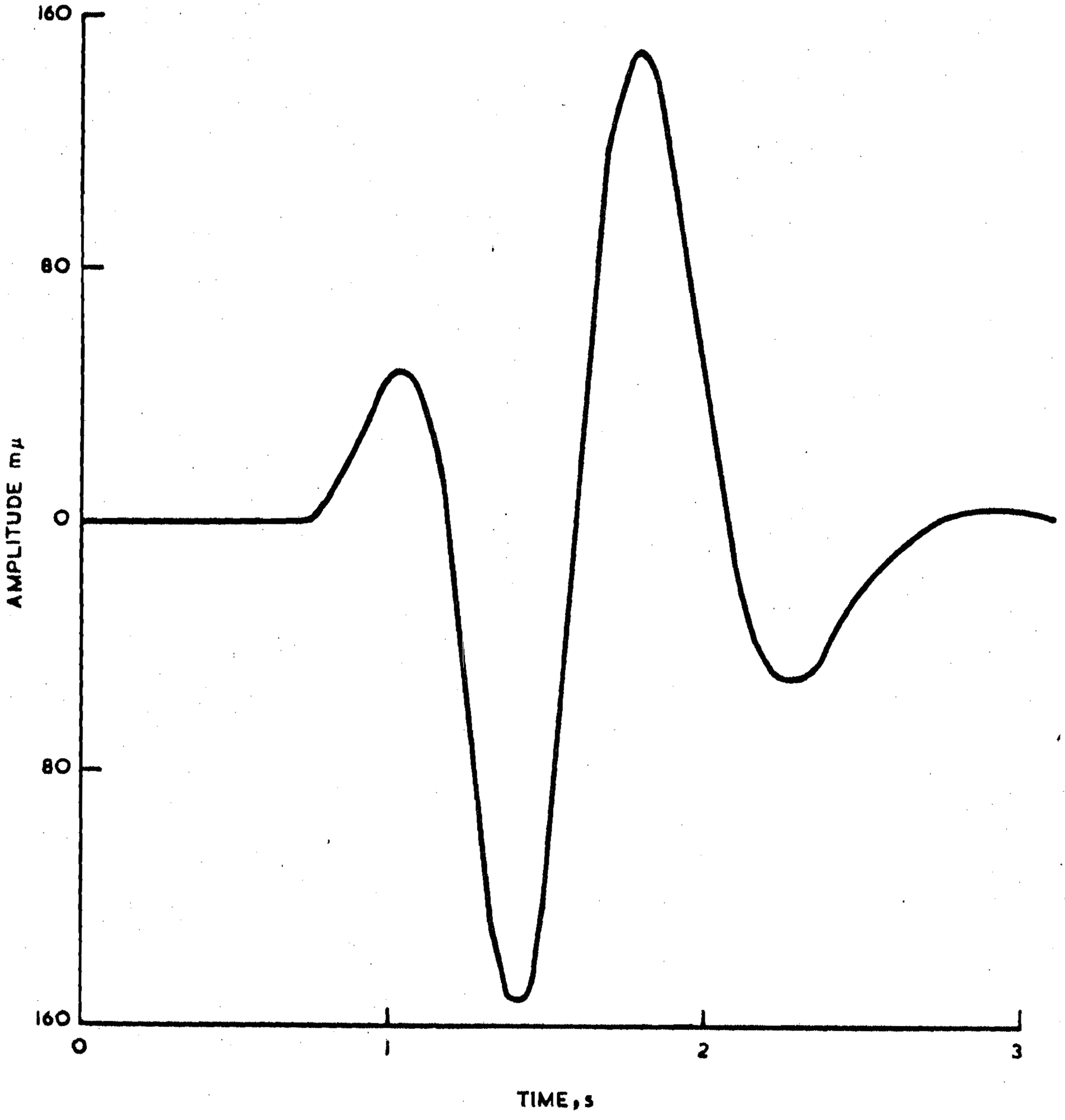


FIGURE 3. CALCULATED SIGNAL AT Δ = 60°, SOURCE 80 kton IN GRANITE, RECEIVER ALSO ON GRANITE

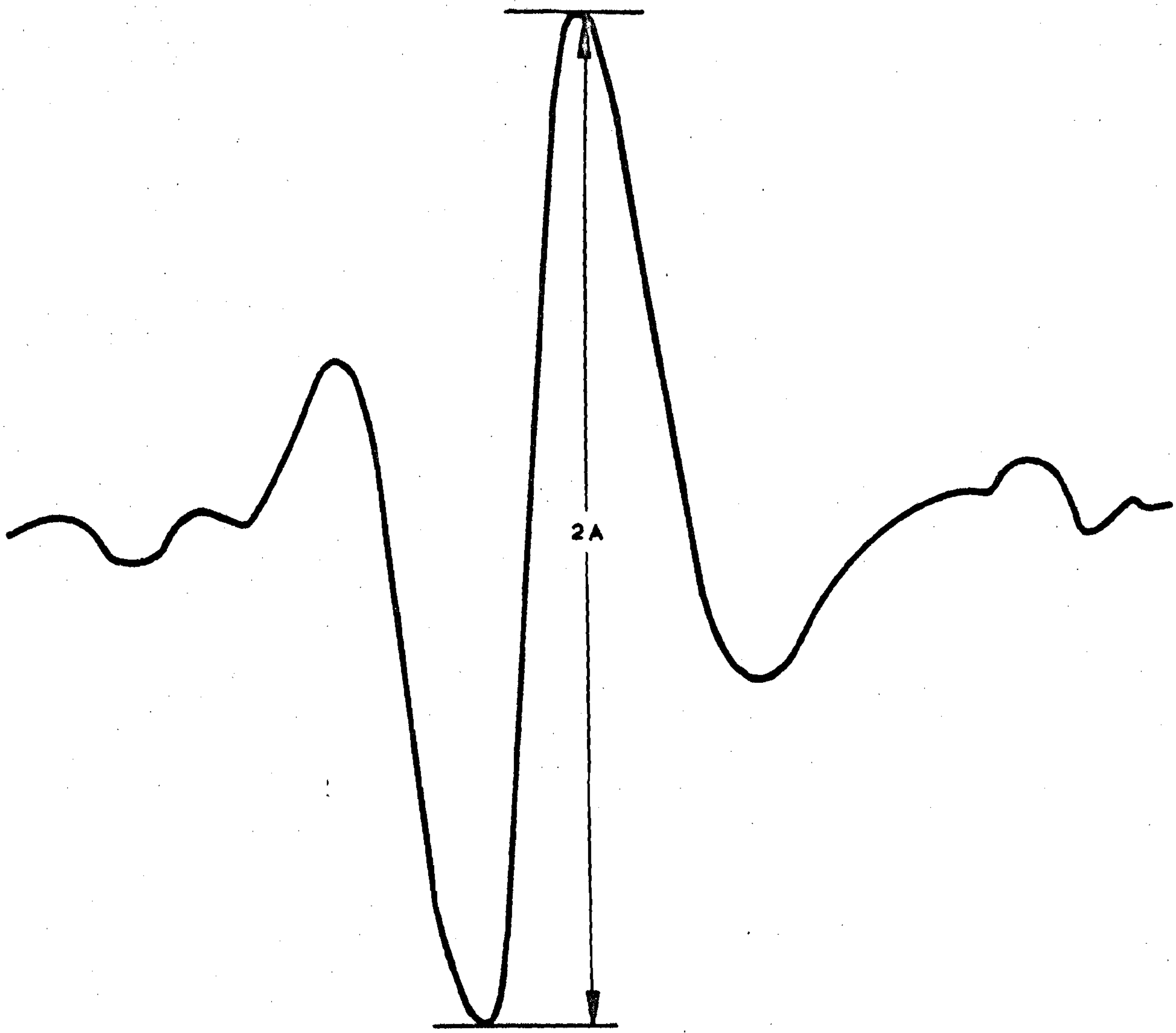


FIGURE 4. ILLUSTRATES THE PORTION OF THE P WAVE USED TO DETERMINE THE AMPLITUDE A FOR CALCULATING THE MAGNITUDE

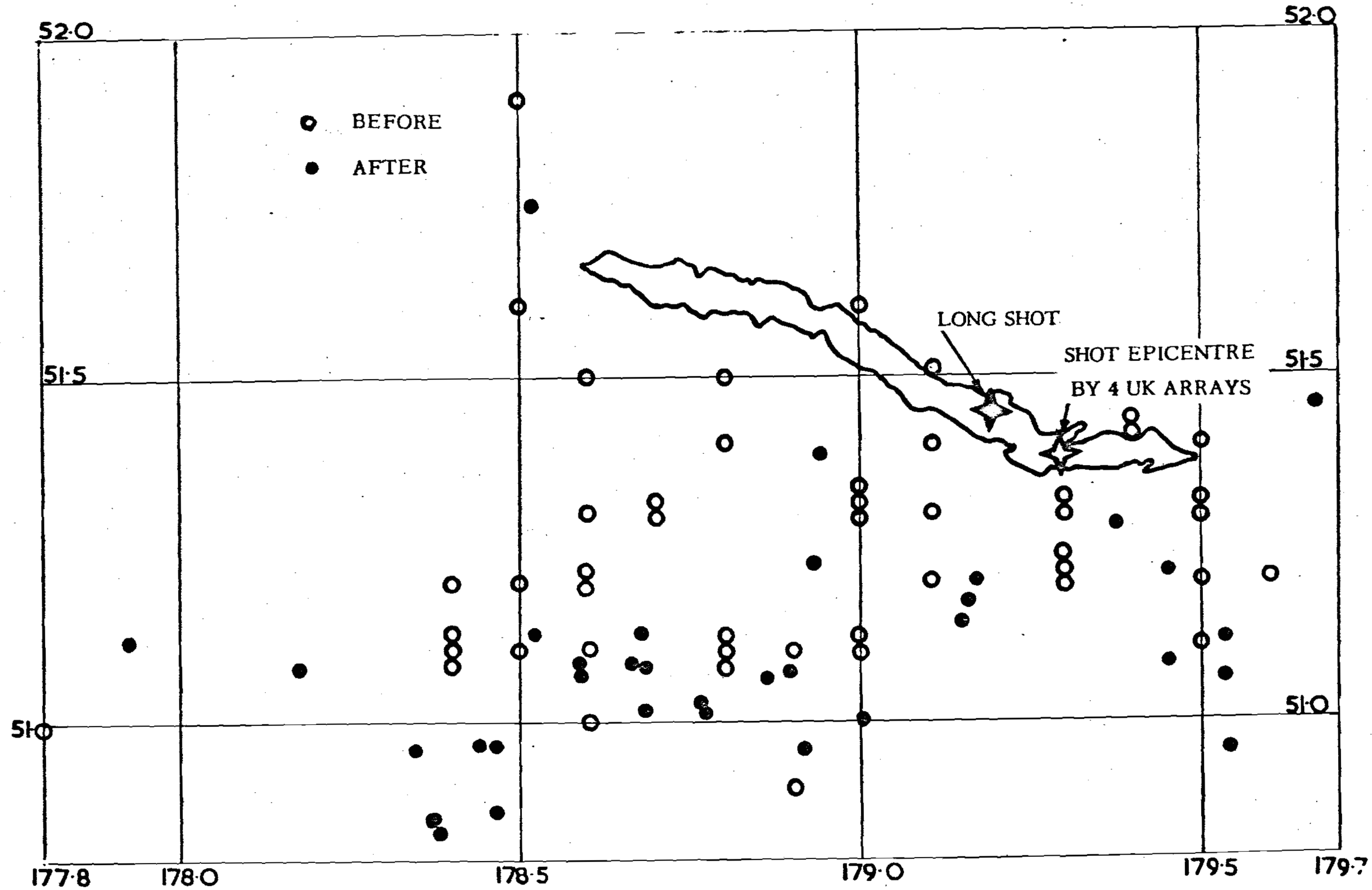


FIGURE 5. RELOCATION OF EARTHQUAKE EPICENTRES IN THE REGION OF AMCHITKA ISLAND

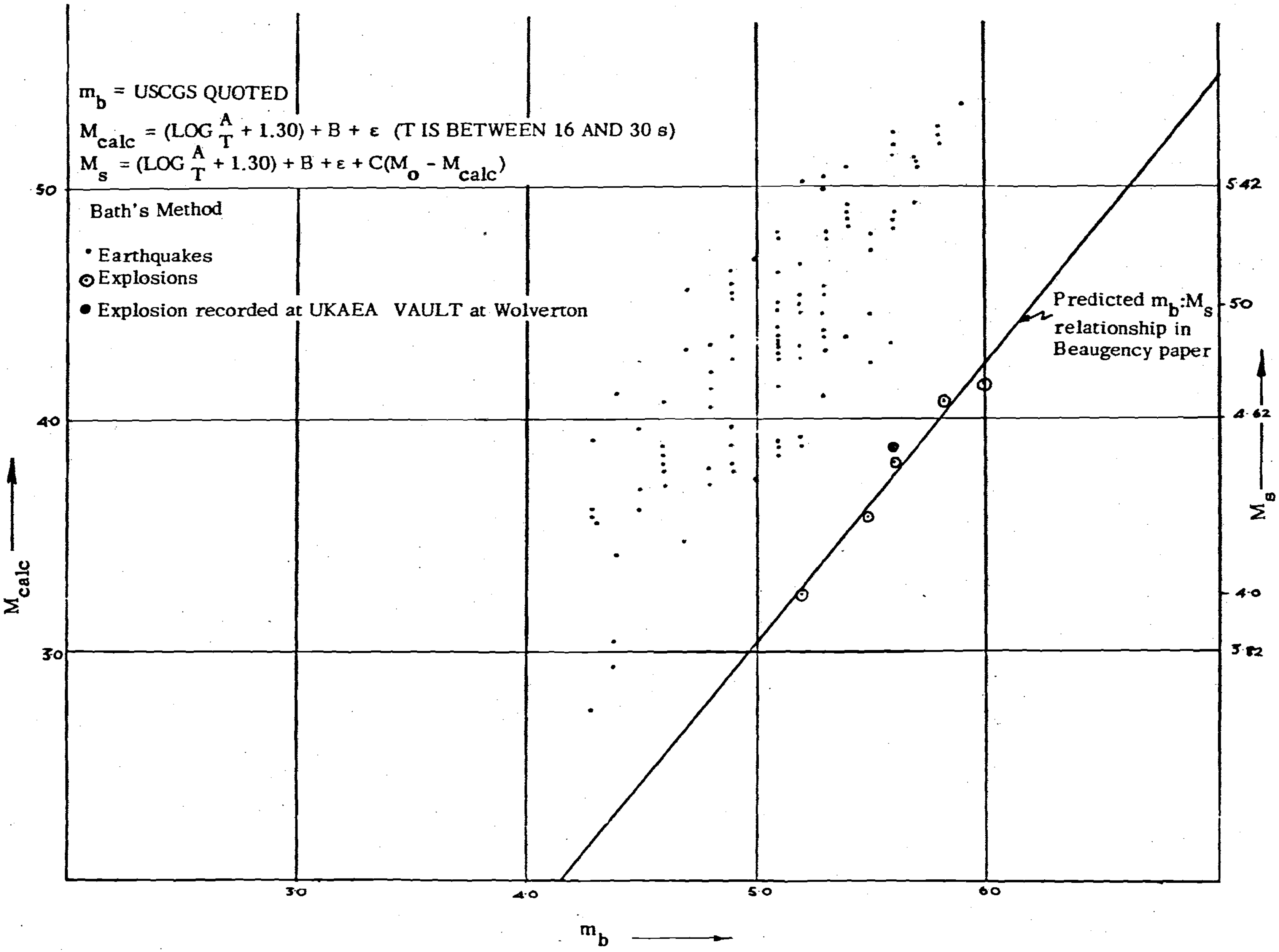


FIGURE 6. $M_s$ AGAINST $m_b$ FOR EARTHQUAKES AND EXPLOSIONS RECORDED AT EKA, WITH BEAUGENCY [6] PREDICTION