ATOMIC WEAPONS RESEARCH ESTABLISHMENT

AWRE REPORT NO. O17/85

Some Seismic Results of an Underground Explosion at the Mururoa Test Site (Shot Report No. 6)

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FOREWORD

During the course of a speech to the United Nations on 5 December 1968, Ambassador William C Foster, United States representative on Committee I on disarmament, made the following statement:-

> "As demonstrated by activities such as these, the United States is continuing to devote considerable resources to seismic research so as to improve the capability to detect and identify underground seismic events. However, it is a fact that, with the existing technology, we are unable to gather all available seismic data at long distances. We are unable at such distances to detect or locate accurately all seismic events or to identify positively whether certain seismic signals come from earthquakes or man-made explosions.
>
> Fortunately, there is clearly a widespread desire - fully shared by the United States - for further advancement in seismic technology and for increased international exchange of information in this field.
>
> It is in keeping with this desire that I should like to present today a proposal which the United States considers could do much to advance objectives in these areas. The United States proposes that some underground nuclear explosions be conducted with the collateral objective that these serve as explosions for world-wide seismic investigation. This investigation is one in which all States with the appropriate seismic instrumentation could participate. Indeed, the success of this proposal would depend in large measure on the extent of world-wide participation in the collection and evaluation of the seismic data."

In keeping with the spirit of the statement by Ambassador Foster the UK from time to time publishes the seismological data it has available for particular underground explosions. The intention of these publications (which are referred to as "Shot Reports") is to provide seismological data from explosions of special interest such as those fired for engineering purposes at greater than normal depth and data for a selection of the explosions fired at those sites where many tests have been carried out. Most of the data included in the shot reports will be from recordings made at medium-aperture seismometer-array stations but if the opportunity arises data from other stations will be included.

A Douglas
MOD(PE)
BLACKNEST

13 November 1985

AWRE REPORT NO. O 17/85

ERRATA

Page 6, line 43 — Replace equation with

$$M_o = 4\pi\rho\alpha^2\psi(\infty) \tag{12}$$

Page 12 — Replace Table 4 with:

Station	Rise Time (s)	Duration (s)	$\psi(\infty)$ (m^3)	Seismic Moment ($\times 10^{15}$ Nm)
YKA	0.26	0.85	7685	6.76
WRA	0.32	1.35	3186	2.80
SAAS	0.34	1.10	8501	7.48
		mean	6457	5.68
	standard deviation		2862	2.52

Shot Report No. 1: P D Marshall, E W Carpenter, A Douglas and J B Young: "Some Seismic Results of the LONG SHOT Explosion". AWRE Report No. 067/66, HMSO.

Shot Report No. 2: P D Marshall: "Some Seismic Results of the MEDEO Explosions in the Alma Ata Region of the USSR". AWRE Report No. 033/70, HMSO.

Shot Report No. 3: D J Corbishley: "Some Seismic Results of the US GASBUGGY and RULISON Underground Nuclear Explosions". AWRE Report No. 046/70, HMSO.

Shot Report No. 4: P G Gibbs and C Blamey: "Some Seismic Results of 12 Underground Nuclear Explosions at the Nevada Test Site, USA". AWRE Report No. 032/72, HMSO.

Shot Report No. 5: P G Gibbs and C Blamey: "Some Seismic Results of the RIO BLANCO Explosion in the Colorado River Region, USA". AWRE Report No. 052/74, HMSO.

SUMMARY

This report provides seismological data from an underground explosion at the French Pacific test site at Mururoa recorded by seismological arrays in Australia, Brazil, Canada, India and the UK.

1. INTRODUCTION

Previous shot reports in this series have provided the seismological data on underground explosions in the USSR and USA. The French underground nuclear test site at Mururoa is situated on a Pacific island far from any continent and it may be of interest to seismologists to examine a suite of P-wave seismograms from an underground explosion there.

The explosion selected as an illustration was fired on 12 May 1984: table 1 gives the epicentral details as calculated by the National Earthquake Information Center Preliminary Determination of Epicentres Service. The processed records presented here are from five array stations at distances of between 80 and 145^{o} from the source; a distance range which includes P waves recorded in the teleseismic "source window" (1) and at distances where the P wave traverses the core of the Earth.

The arrays record ground motion using short-period (SP) seismometers which do not illustrate the full band width of an explosion-generated P wave. Much emphasis is now being placed on broad-band (BB) recordings which allow pulse shapes to be clearly seen (2,3). The SP records have been processed to provide usable BB recordings which facilitate interpretation of the seismograms.

2. SP DATA AND RESULTS

The seismograms presented here were recorded at five medium-aperture arrays of similar design. Figure 1 illustrates the layout of the arrays: the station co-ordinates are given in table 2. All the arrays use vertical-component Willmore SP seismometers (the response is shown in figure 2), the outputs of which are recorded on magnetic tape. Full details of these stations are given in reference (4).

Figure 3 is an azimuthal great-circle projection of the world, centred on the explosion epicentre, showing the relative positions of the arrays: the corresponding distances and azimuths are given in table 2. Note that three of the stations, WRA, YKA and SAAS, are within the 30 to 90^{o} "source window" for P waves. EKA and GBA are at distances where the first arrival is PKP.

Figure 4 shows the SP delay-and-summed (5) seismograms from the Mururoa explosion at the arrays. Table 3 lists the measurements made from these seismograms. The onset-time residuals are relative to travel-times computed using the PDE epicentre and the GEDESS computer program (6): ie, Jeffrey's-Bullen travel times corrected for the Earth's ellipticity. The amplitude (half peak-to-peak) and period quoted are measured on the largest signal in the first few cycles of the P wave. Body-wave magnitude, m_b is calculated using

$$m_b = \log(A/T) + B(\Delta) \qquad (7)$$

where A is amplitude in $m\mu$'s or nm's, T is period in seconds and $B(\Delta)$ is a distance correction factor. The Gutenberg-Richter correction (7) is used for P waves, unpublished corrections (Marshall, personal communication) are used for PKP.

3. BB SEISMOGRAMS

SP seismograms, by their band-limited nature, distort seismic pulse shapes. A much better representation of the true ground motion would be given by a BB instrument with the response illustrated in figure 2. A straight conversion from SP to BB would greatly decrease the signal-to-noise ratio: the SP pass-band was designed to exclude those frequencies where the natural Earth noise has large amplitude. Recently developed techniques (3), however, allow a conversion to be made with very little decrease in signal-to-noise ratio or distortion of the signal shape.

Figure 5 shows the phaseless broad-band (PBB) versions of the seismograms shown in figure 4. The PBB instrument response is the same as the BB response except that there are no instrumental phase shifts: this produces a non-causal filter that has minimal effect on pulse shapes (8). In addition to the conversion, each seismogram in figure 5 has been filtered using a single-channel Wiener filter (9), designed using the noise preceding the signal, and a filter that "puts back" a path attenuation of $t^* = 0.15$ s, correcting for the Earth's "baseline" attenuation (3).

In the P seismograms (WRA, SAAS and YKA) simple, positive pulses can be seen, as would be expected for an underground explosion source. Similar pulse shapes were not recoverable from the PKP records, even with additional filtering. Table 5 lists the measurements made on the three pulses: the rise time measures the steepness of the leading edge of the pulse (10); the pulse duration is taken as the time from the pulse onset to the return to the same amplitude level. The latter also defines the area under the pulse which, after correction for geometrical spreading (11), gives an estimate of the reduced displacement potential, $\psi(\infty)$. The seismic moment, M_o was calculated using

$$M_o = 2 \Pi \rho \alpha^2 \psi(\infty) \qquad (12)$$

where ρ and α are the density and P-wave speed of the source material (a basalt source medium was assumed, $\alpha = 5.0$ km/s, $\rho = 2.8$ g/cc).

4. ACKNOWLEDGMENTS

The recordings from the overseas stations were made possible by the co-operation of the Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Canada; the Australian National University, Canberra, Australia; and Bhabha Atomic Research Centre, Trombay, India; and the Department of Geosciences, University of Brasilia, Brazil (via the good offices of the Natural Environment Research Council).

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TABLE 1

Epicentral Details (NEIC, 1984)

Region:	Tuamotu Archipelago
Date:	12 May 1984
Origin Time:	17:30:58.3 UTC
Latitude:	21.852°S
Longitude:	138.961°W
Depth:	0 km
Magnitudes:	m_b 5.7 M_{sz} 3.8

TABLE 2

	Array Locations				Distances and Azimuths Relative to Mururoa		
	Array	Location	Geographic co-ordinates of crossover point		Distance	Azimuth	Back Bearing
			Latitude	Longitude	(degrees)	(degrees clockwise from North)	
1	WRA	Warramunga, Australia	19°56'52"S	134°21'03"E	79.9	253	110
2	SAAS	Brasilia, Brazil	15°38'06"S	47°59'29"W	85.2	105	249
3	YKA	Yellowknife, Canada	62°29'36"N	114°36'19"W	86.3	11	203
4	EKA	Eskdalemuir, UK	55°19'59"N	03°09'32"W	133.2	33	297
5	GBA	Gauribidanur, India	13°36'15"N	77°26'10"E	144.4	263	109

Array Operators

1 Australian National University, Canberra, Australia

2 Department of Geosciences, University of Brasilia, Brazil

3 Department of Energy, Mines & Resources, Ottawa, Canada

4 MOD(PE), Blacknest, UK

5 Bhabha Atomic Research Centre, Trombay, India.

TABLE 3

SP Measurements

Station	Onset Time (hh:mm:ss)	Residual (observed-computed)	Amplitude (mμ)	Period (s)	m_b
WRA	17:43:10.7	-0.1	7.9	0.84	4.67
SAAS	17:43:38.6	0.2	36.3	0.87	5.63
YKA	17:43:42.6	-0.1	58.0	0.82	5.75
EKA	17:50:18.3	-2.0	6.4	0.92	5.13
GBA	17:50:37.2	-0.7	6.5	0.69	4.72
			mean m_b		5.18
			standard deviation		0.50

TABLE 4

BB Measurements

Station	Rise Time (s)	Duration (s)	$\psi(\infty)$ (m^3)	Seismic Moment ($\times 10^{15}$ Nm)
YKA	0.26	0.85	7685	3.38
WRA	0.32	1.35	3186	1.40
SAAS	0.34	1.10	8501	3.74
		mean	6457	2.84
	standard deviation		2862	1.26

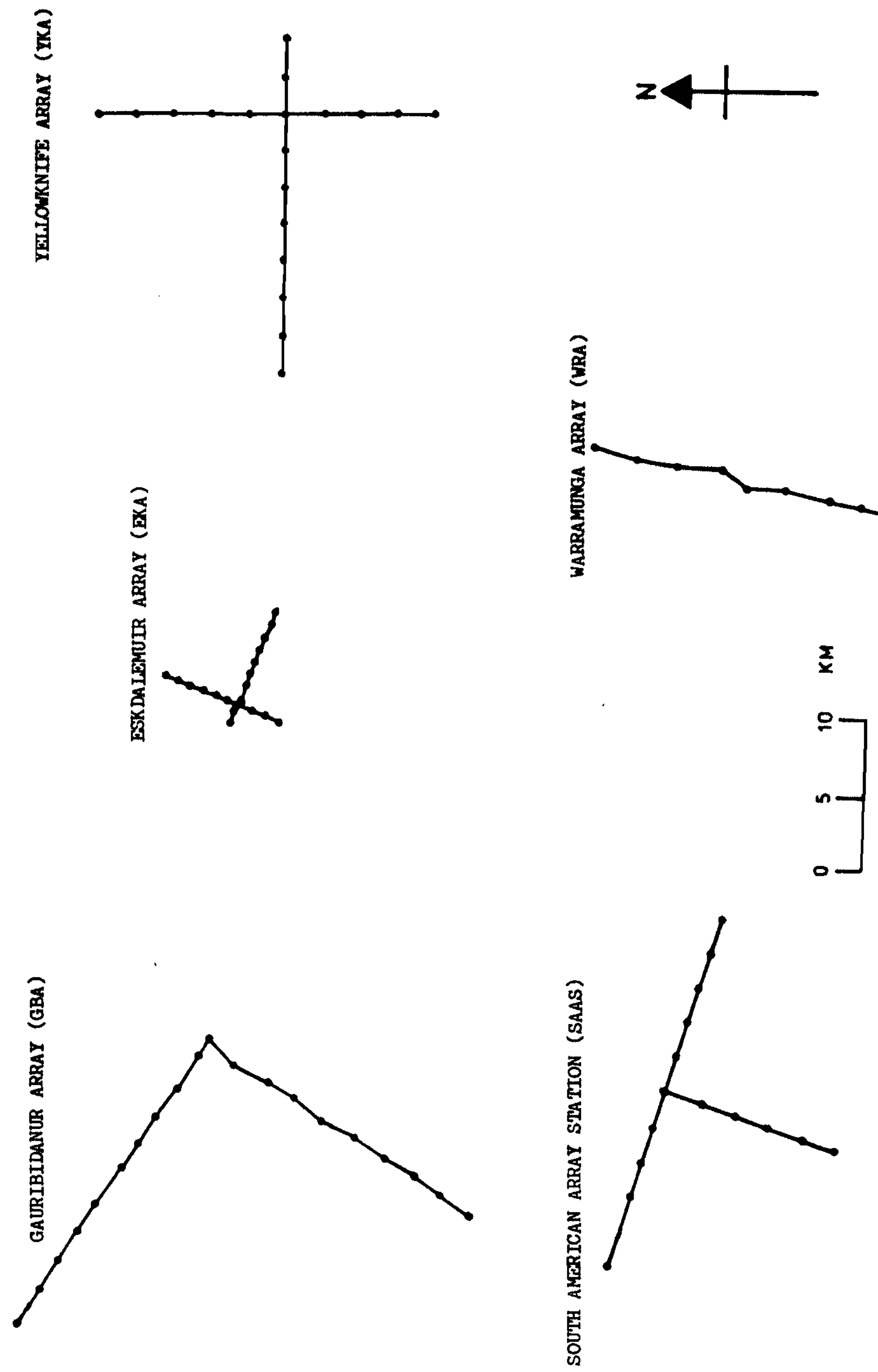

FIGURE 1. PLANS OF THE SHORT-PERIOD ARRAYS.

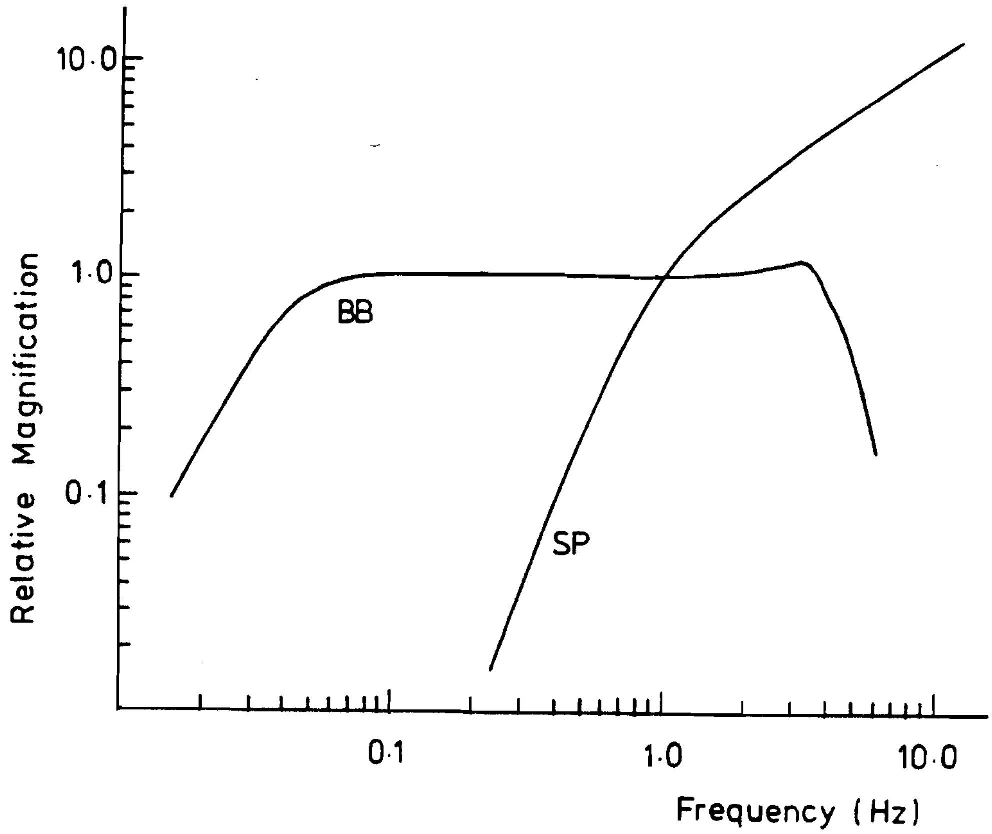

FIGURE 2. AMPLITUDE RESPONSE OF THE DISPLACEMENT BROAD-BAND (BB) AND ARRAY SHORT-PERIOD (SP) SEISMOGRAPHS.

Gains are normalised to unity at 1 Hz. The actual responses of the instruments deployed at the arrays can vary slightly at high frequencies from the response shown here.

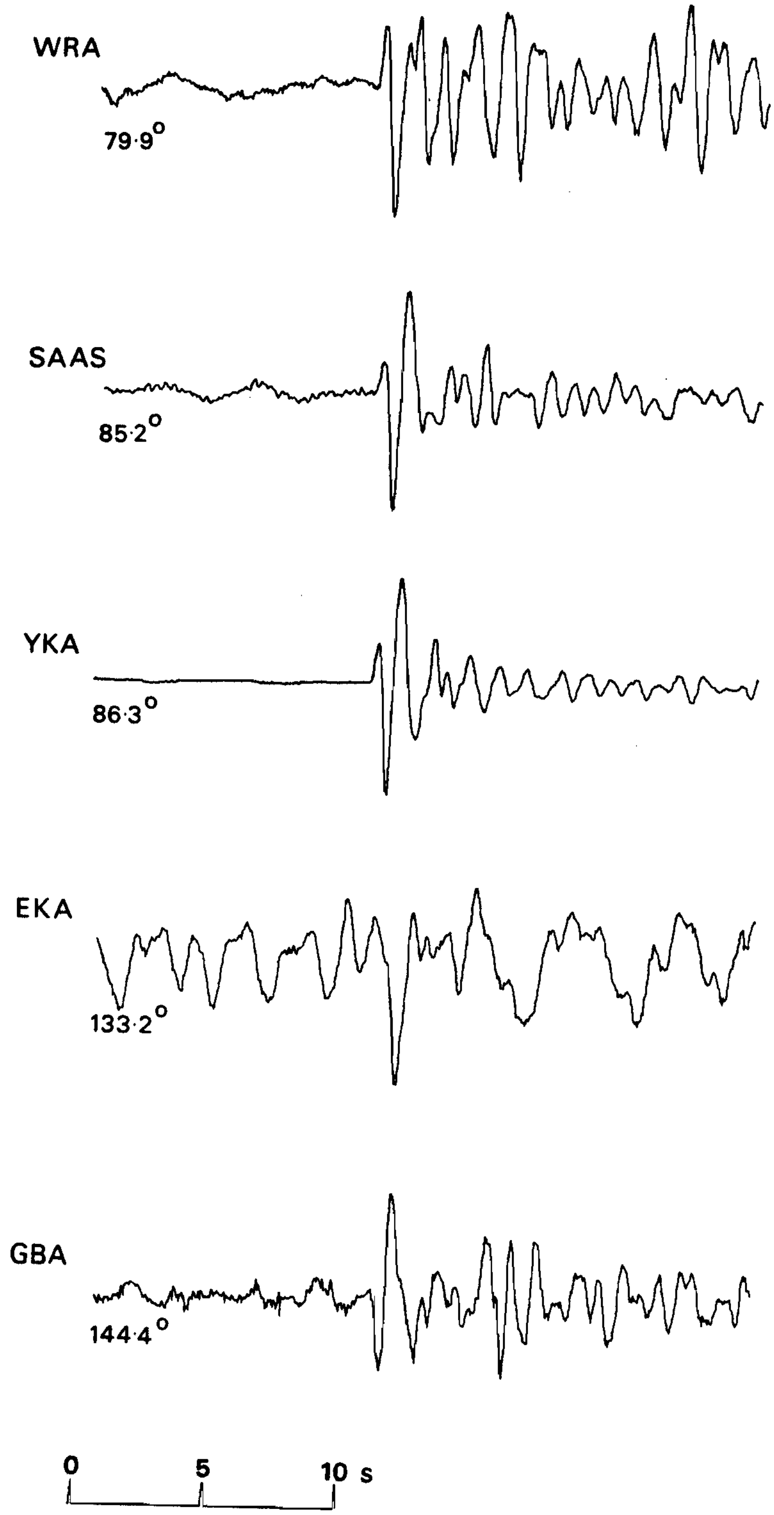

FIGURE 4. SHORT-PERIOD ARRAY-SUM SEISMOGRAMS FROM THE FIVE STATIONS.

(Gains are normalised for each channel).

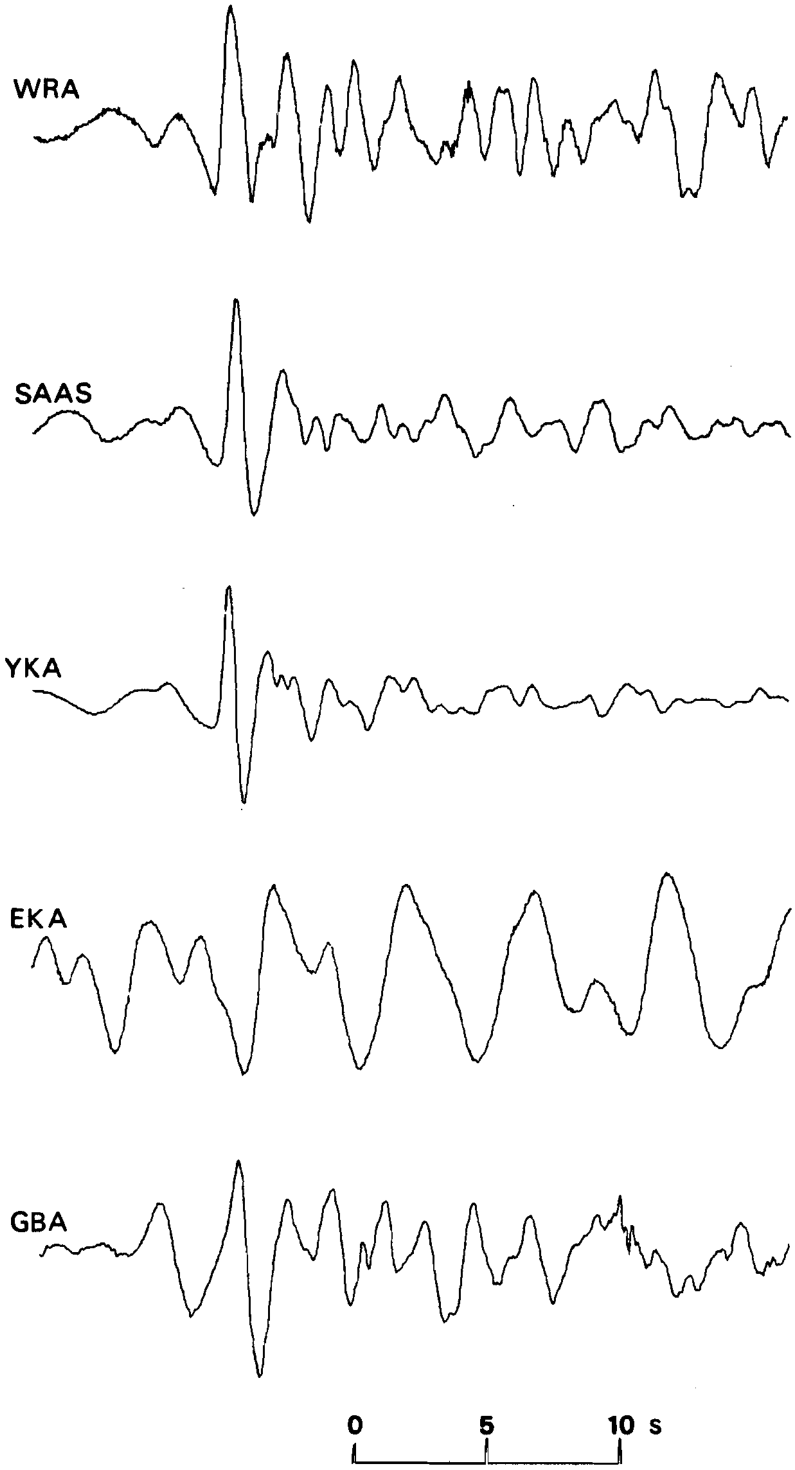

FIGURE 5. THE SEISMOGRAMS OF FIGURE 4 AFTER CONVERSION TO A PHASELESS BROAD BAND RESPONSE, WIENER FILTERING AND REPLACEMENT OF A T* OF 0.15.

(The GBA record has had an additional 0.1 to 5 Hz bandpass filter applied).

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See box on front cover

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Abstract

This report provides seismological data from an underground explosion at the French Pacific test site at Mururoa recorded by seismological arrays in Australia, Brazil, Canada, India and the UK.