ATOMIC WEAPONS ESTABLISHMENT

AWE REPORT NO. O 6/90

Some Seismic Results from the US-USSR Joint Verification Underground Nuclear Explosions

(Shot Report No. 7)
(UK UNCLASSIFIED)

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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

LIST OF PUBLISHED SHOT REPORTS

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. O 67/66, 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. O 33/70, HMSO.

Shot Report No. 3: D J Corbishley: "Some Seismic Results of the US GASBUGGY and RULISON Underground Nuclear Explosions". AWRE Report No. O 46/70, 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. O 32/72, 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. O 52/74, HMSO.

Shot Report No. 6: R C Stewart and Penelope J Warburton: "Some Seismic Results of an Underground Explosion at the Mururoa Test Site". AWRE Report No. O 17/85.

SUMMARY

This report provides basic seismological data from two nuclear explosions, known as the Joint (US-USSR) Verification Experiment (JVE), detonated underground at Nevada USA and Shagan River, E Kazakhstan (USSR) and recorded at four medium aperture seismometer array stations which provide data to the UK National Data Centre at AWE Blacknest. Short period array summed and deconvolved seismograms are presented together with arrival time data, magnitudes and source parameters determined from the deconvolved seismograms.

1. INTRODUCTION

In an attempt to resolve outstanding technical problems of verifying compliance with a threshold test ban treaty limiting the yield of underground nuclear explosions to 150 kton or less, the US and the USSR agreed to conduct calibration explosions at their respective test sites. The yield of the explosions was to be in the yield range of 100 to 150 kton and both parties were given access to the test site to conduct agreed experiments in yield determination. These calibration explosions are known as the Joint Verification Experiment (JVE).

The two nuclear tests are of interest to the UN Ad Hoc Group of Scientific Experts (AHGSE) which meets twice a year at the UN Geneva to consider co-operative measures to detect and identify seismic disturbances. At the 26th Session of the AHGSE held in Geneva in mid-1988 delegates were asked to make available to the group the seismological data and recordings from their national stations of the JVE explosions. In response to this request seismological data from the explosions recorded at seismometer array stations which send their data to the UK National Data Centre at Blacknest have been analysed and are presented within this report.

The first explosion, conducted in the Pahute Mesa area of the US Nevada Test Site (NTS), was detonated on 17 August 1988. The USSR test was conducted at the Shagan River area of E Kazakhstan on 14 September 1988. Epicentral details of the explosions reported by the US National Earthquake Information Centre (NEIC) Preliminary Determination of Epicentres (PDE) are given in table 1. The seismograms presented here are from array stations located at distances between 25 and 130^{o} from the source. The arrays record ground motion using short-period (SP) seismometers which do not illustrate the full band-width of explosion generated P-waves. Much emphasis is now placed on broad-band (BB) recordings which allow P-pulse shapes to be clearly seen (1,2,3). The SP recordings have been deconvolved to produce BB seismograms which are used to determine the rise time and duration of the P-pulse together with its area which is used to determine ψ_∞ the long term level of the reduced displacement of the source. The magnitude m_b of each explosion is given together with the surface wave magnitude M_s determined from the seismograms located at the Eskdalemuir (EKA) array in Scotland.

2. SP DATA AND RESULTS

The SP seismograms presented here are recorded by four medium-aperture arrays of similar design. The arrays are located at EKA, Yellowknife (YKA) Canada, Gauribidanur (GBA) India and Warramunga (WRA) Australia. A diagram of the array configurations is given in figure 1. The arrays are equipped with vertical component Willmore Mk II seismometers (the response is given in figure 2) the outputs of which are recorded on magnetic tape. Full details of the arrays and their recording systems are given by Mowat and Burch (4).

The locations of the arrays with respect to the test sites are given in figures 3 and 4 which are azimuthal great-circle projections of the world centred on the test sites showing the relative positions of the arrays. The distance and azimuth of each station-explosion pair is given in tables 2 and 3. For the USSR explosion all stations lie within the 30 to 90° "source window" (5). Only EKA lies within the source window for the US explosion, YKA is at 25° and direct P is the first arrival but both GBA and WRA are located beyond the source window and the first arrival has propagated through the mantle and outer core of the earth.

The SP delayed and summed (6) seismograms are given in figures 5a to 9a. The arrival times are compared to the Jeffreys-Bullen (7) predicted travel time and residuals determined. The amplitude of the P-wave is used to determine the magnitude m_b where

$$m_b = \log_{10}(A/T) + B(\Delta) + SC$$

where A is the zero-peak amplitude of the P-wave in nanometres, T its period in seconds and $B(\Delta)$ is the Gutenberg and Richter (8) distance dependence term. SC is a station correction term which has been determined for the four arrays for explosions at Shagan River (9) but not for explosions at Nevada. For waves which have traversed the core a distance correction term determined by Marshall (personal communication) has been used.

The travel times, residuals and magnitudes for the two explosions are given in table 3.

3. BROAD BAND SEISMOGRAMS AND RESULTS

SP seismograms, by their band-limited nature, distort the shape of the P wave pulses. A better representation of ground motion at the receiver is given by a BB instrument with the response shown in figure 2. A simple conversion from SP to BB generally decreases the signal to noise ratio; the SP pass band is designed to exclude the large amplitude low frequency microseisms. However techniques are available (10) which allow conversions to be made with little decrease in signal to noise ratio or distortion of the P-wave pulse shape.

Using the SP-BB techniques available phaseless BB (PBB) seismograms have been produced for P-waves recorded in the source window from the JVE explosions and are presented in figures 5b to 9b. The PBB instrument response is the same as the BB response except that there are phase shifts introduced due to the instrument (11) however, the filter is non-causal and gives rise to precursors to the pulse. In addition to the SP-BB conversion each seismogram has been filtered using a Wiener filter designed to the pre-signal noise and passed through an additional filter which attempts to correct the seismogram for the effects of attenuation over the transmission path (12). The attenuation filter is based on t* (the ratio of the travel time to Q the specific quality factor), the values of t* used are 0.15 s for the USSR explosion (13) 0.35 s for Nevada to EKA (14) and 0.5 s for Nevada to YKA (15). The attenuation corrected BB trace is an estimate of the pulse radiated from the source region.

From the PBB t*-corrected seismograms illustrated in figures 5c to 9c some basic parameters which are related to source size are measured. The parameters selected are: the rise time and duration of the initial pulse (16) and the area of the pulse which after correction for geometrical spreading and amplification at the free surface at the recording station is used to determine ψ_∞ (3). To improve the estimation of ψ_∞ account must be taken of how the noise interferes with the seismic pulse. This is particularly true for the low signal to noise ratio recordings of US explosions at NTS and recorded at EKA (15). The area measured on each seismogram is represented by the shaded area in figures 5c to 9c.

The final step is to calculate the seismic moment M_O which is defined as

$$M_O = 4\pi\rho V^2\psi_\infty \quad (17)$$

where ρ is the density and V the P wave speed of the source material. To calculate M_O the value of ψ_∞ determined from the area of the BB P-wave must be corrected for the effects ρ and V at the source and receiver. Carpenter (12) has shown that

$$\psi_\infty = [2G(\Delta)]^{-1} \left[\frac{\rho_O V_O}{\rho_1 V_1}\right]^{\frac{1}{2}} A_O$$

is the best estimator of the long term level of the reduced displacement potential where $\rho_O V_O$ are receiver region values and $\rho_1 V_1$ are the source region values of density and P-wave speed. For explosions in hard rock such as granite

$$\left[\frac{\rho_O V_O}{\rho_1 V_1}\right]^{\frac{1}{2}} \text{ is approximately equal to 1.}$$

The corrected values of ψ_∞ are given in table 5, the values of ρ and V used for the two source regions and the array locations are given in table 4.

4. LONG PERIOD SEISMOGRAMS

The Rayleigh waves generated by the two JVE explosions were recorded on the long period vertical component seismometer at EKA. The response of this narrow band seismometer is given in figure 2. The seismograms are reproduced in figure 11 and the amplitude and period of the peak arrival of the surface wave train are given in table 3. The surface wave magnitude M_S is calculated using the Marshall and Basham formula (18).

5. ACKNOWLEDGMENTS

The recordings analysed in this report were possible due only to the efforts of the staff at the array stations and to the co-operation of the Earth Physics Branch, Dept of Energy Mines and Resources, Ottawa, Canada; the Australian National University, Canberra, Australia and the Bhaba Atomic Research Centre, Trombay, India. Their help in providing the recordings is gratefully acknowledged.

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TABLE 1

Epicentre Details (NEIC, PDE)

Region:	Nevada (Pahute Mesa)
Date:	17 August 1988
Origin time:	17:00:00.0
Latitude:	37.297°N
Longitude:	116.307°W
Depth:	0 km
Magnitudes:	m_b 5.5

Region:	Eastern Kazakh SSR (Shagan River)
Date:	14 September 1988
Origin time:	03:59:57.4
Latitude:	49.821°N
Longitude:	78:796°E
Depth:	0 km
Magnitudes:	m_b 6.1 M_{sz} 4.6

TABLE 2

		Geographic co-ordinates of crossover points		Distances and Azimuths Relative to Nevada			Distances and Azimuths Relative to Eastern Kazakh, Shagan River		
				Distance	Azimuth	Back Bearing	Distance	Azimuth	Back Bearing
Array	Location	Latitude	Longitude	Degrees	(degrees clockwise from North)		Degrees	(degrees clockwise from North)	
1 WRA	Warramunga, Australia	19°56'52"S	134°21'03"E	116.9	264.7	57.6	85.0	128.9	327.6
2 YKA	Yellowknife, Canada	62°29'36"N	114°36'19"W	25.3	1.9	183.2	67.5	6.7	350.7
3 EKA	Eskdalemuir, UK	55°19'59"	03°09'32"W	71.6	33.6	309.6	47.4	309.8	60.6
4 GBA	Gauribidanur, India	13°36'15"N	77°26'10"E	127.8	343.0	13.9	36.1	182.2	1.5

Array Operators

1 Australian National University, Canberra, Australia

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

3 MOD(PE) Blacknest, UK

4 Bhabha Atomic Research Centre, Trombay, India

TABLE 3

SP and LP Measurements made on Seismograms

(a) Short Period

Test Site	Station	Arrival Time	Residual (s) (observed-computed)	Amplitude (nm's)	Period (s)	m_b	Station correction	Final magnitude m_b
Nevada	YKA	17 05 27.1	-1.7	34	0.9	5.54[1]	-	5.54
	EKA	17 11 21.7	-2.8	30	0.9	5.40	-	5.40
	GBA[2]	17 19 07.8	0.1	7	0.9	(5.31)	-	5.31
	WRA	TAPE ERROR - NO DATA						
Shagan River	GBA	04 07 02.2	-0.9	225	0.9	6.01	-0.03	5.98
	EKA	04 08 35.5	-0.9	196	0.8	6.35	-0.37	5.98
	YKA	04 10 56.0	-0.7			OVERLOADED		
	WRA	04 12 35.8	-0.3	127	0.6	6.36	-0.28	6.08

(b) Long Period

Test Site	Station	Arrival Times		Amplitude (nm's)	Period (s)	Surface Wave Magnitude M_s
		Onset	Maximum			
Nevada	EKA	17 39 14	17 42 19	128	18	4.10
Shagan River	EKA	04 24 41	04 30 00	391	18	4.20

(1) Determined using calibrated data for explosions at Nevada recorded at YKA (15) $\log_{10}(A/T)_{bc} = 1.04\ m_b - 4.20$.

(2) Measurements made of 1-2 Hz filtered array sum seismogram.

TABLE 4

Density and P Wave Speeds at the Test Sites and at the Seismometer Arrays

Region	ρ $grm.cm^{-3}$	V $km.sec^{-1}$
Nevada (USA)	2.20 (1)	2.70 (1)
Shagan River USSR	2.70 (2)	5.70 (2)
EKA (19)	2.80	6.14
YKA (20)	2.67	5.64
WRA (21)	2.80	5.60
GBA (22)	2.80	5.60

(1) Above water table at Pahute Mesa, Nevada, USA

(2) Granitic type material, Shagan River, USSR

TABLE 5

Summary of Results derived from BB Deconvolved Seismograms

Test Site	Station	Risetimes (s)	Duration (s)	ψ_∞ (m^3)	$\psi_\infty corr$ (m^3)	Seismic Moment (x 10^5 nm)
Nevada	EKA	0.18	0.85	4634	7877	8.68
	YKA	0.17	0.65	2660	4235	4.67
Shagan River	EKA	0.26	0.65	17548	18600	20.50
	GBA	0.26	0.65	10801	10909	13.53
	WRA	0.17	0.50	12155	12277	12.02

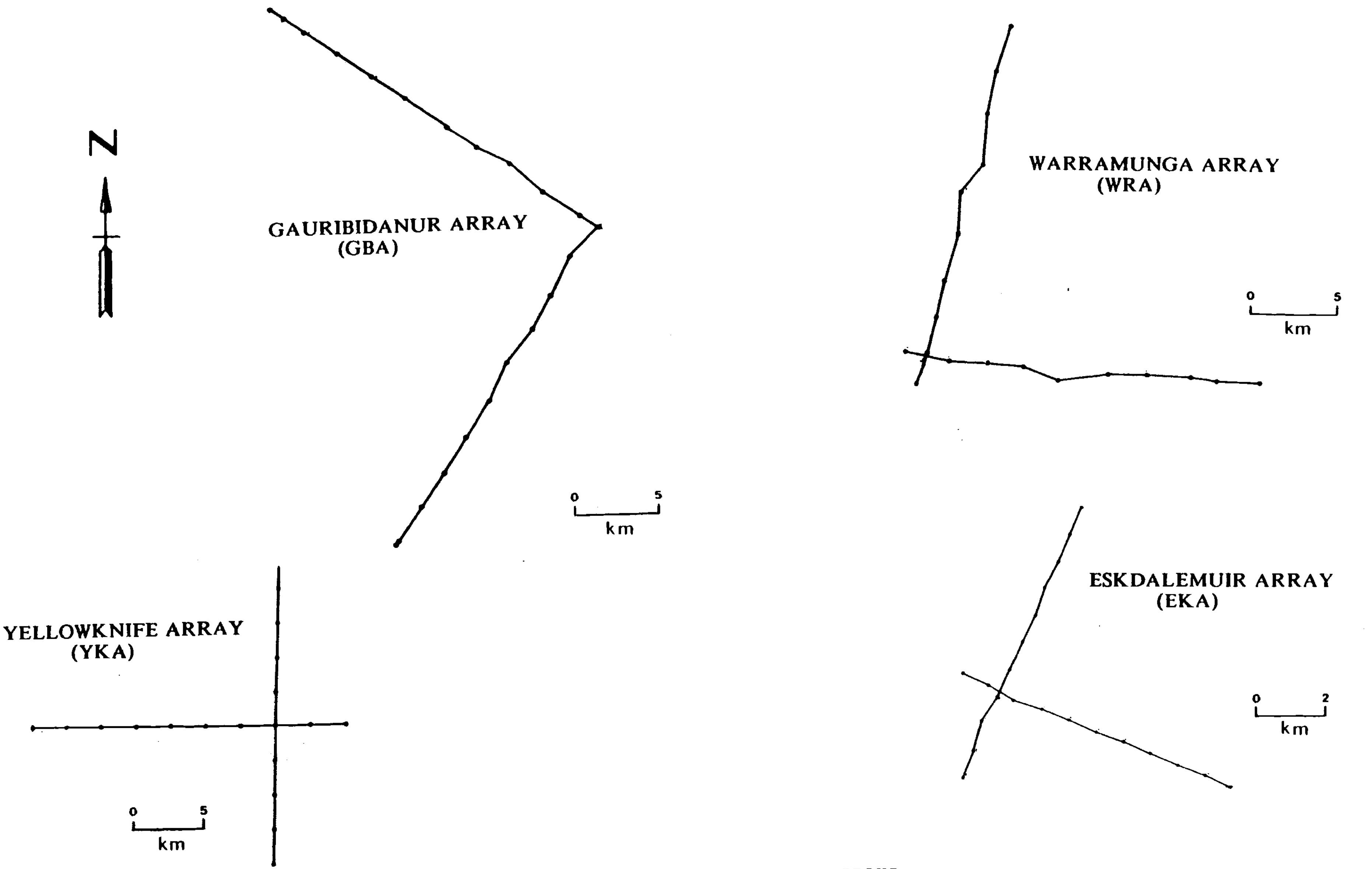


FIGURE 1. PLANS OF THE SHORT-PERIOD ARRAYS

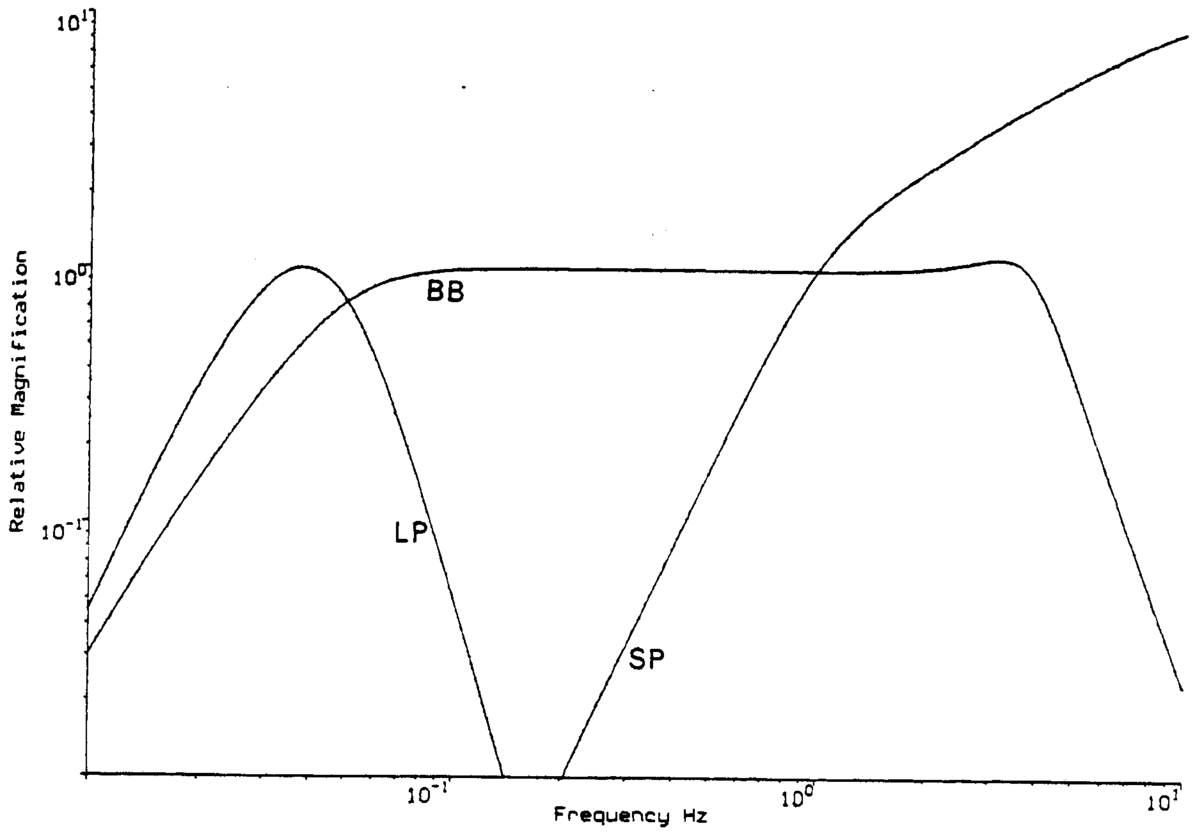


FIGURE 2. AMPLITUDE RESPONSE OF LONG-PERIOD NARROW BAND (LP), DISPLACEMENT BROAD-BAND (BB) AND ARRAY SHORT-PERIOD (SP) SEISMOGRAPHS

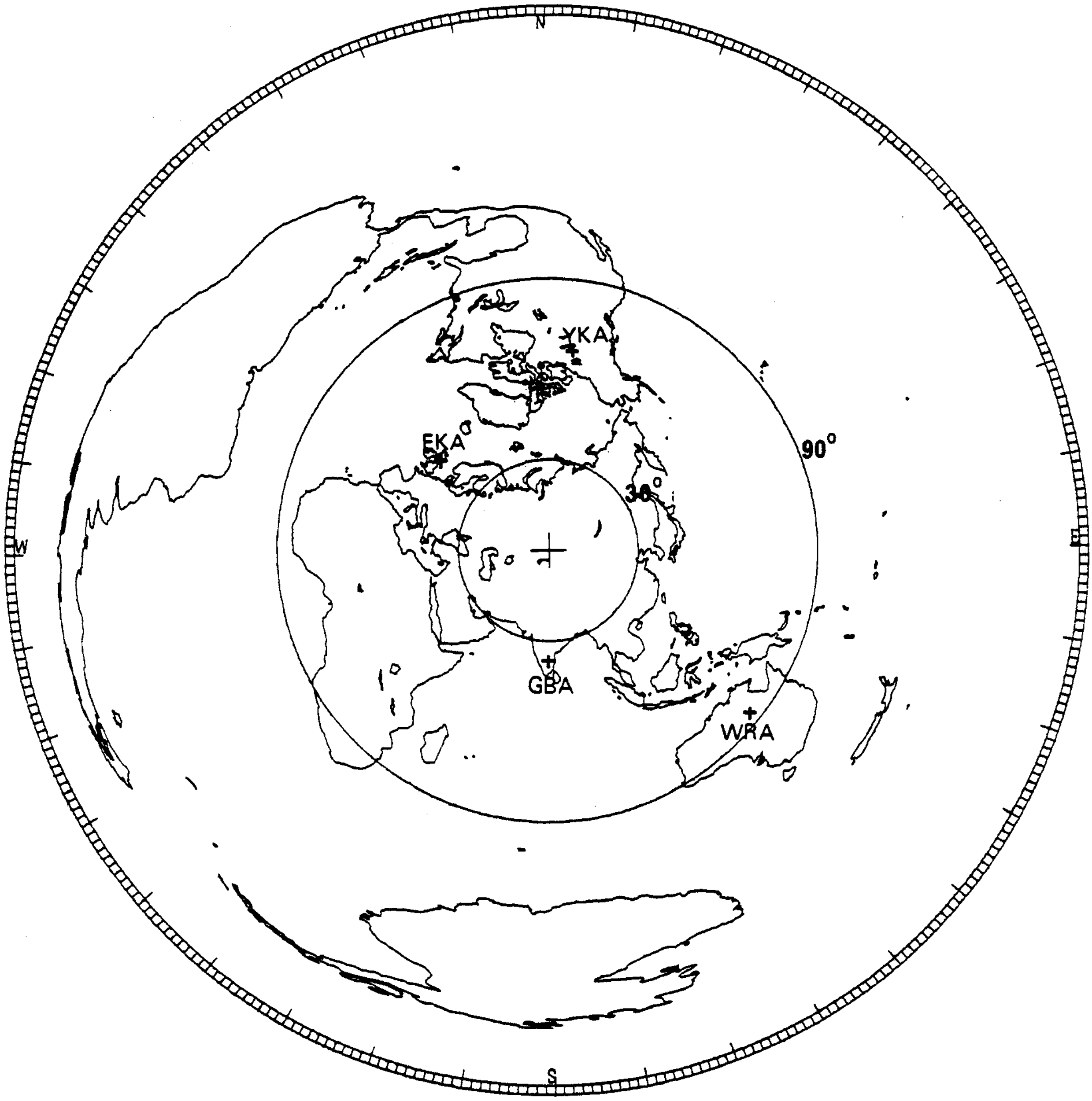


FIGURE 3. EPICENTRAL DISTANCE - AZIMUTH PROJECTION OF THE WORLD, CENTRED ON THE SHAGAN RIVER, EASTERN KAZAKHSTAN TEST SITE. (THE LOCATIONS OF THE FOUR ARRAYS ARE SHOWN)

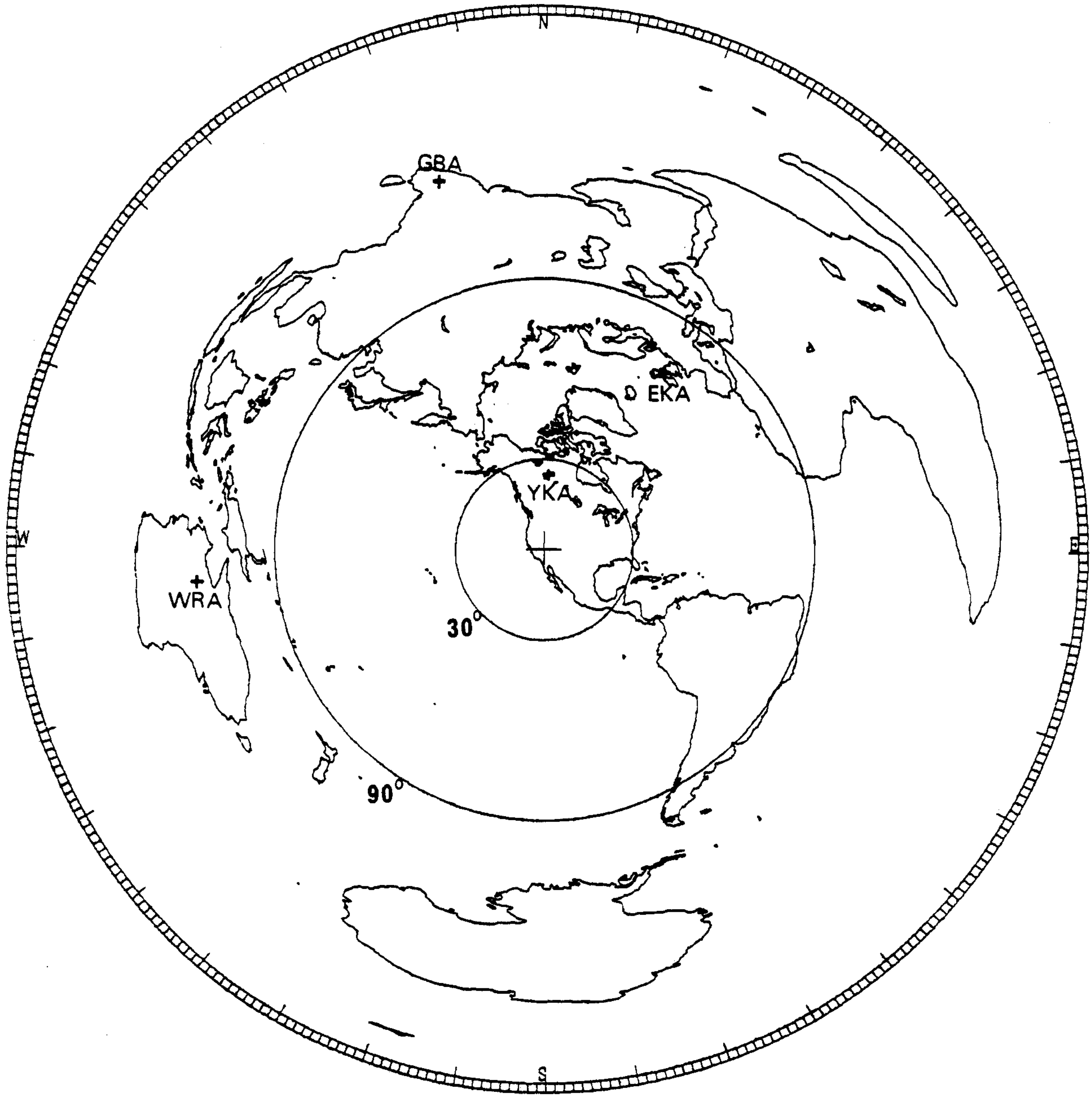


FIGURE 4. EPICENTRAL DISTANCE - AZIMUTH PROJECTION OF THE WORLD, CENTRED ON THE NEVADA TEST SITE. (THE LOCATION OF THE FOUR ARRAYS ARE SHOWN)

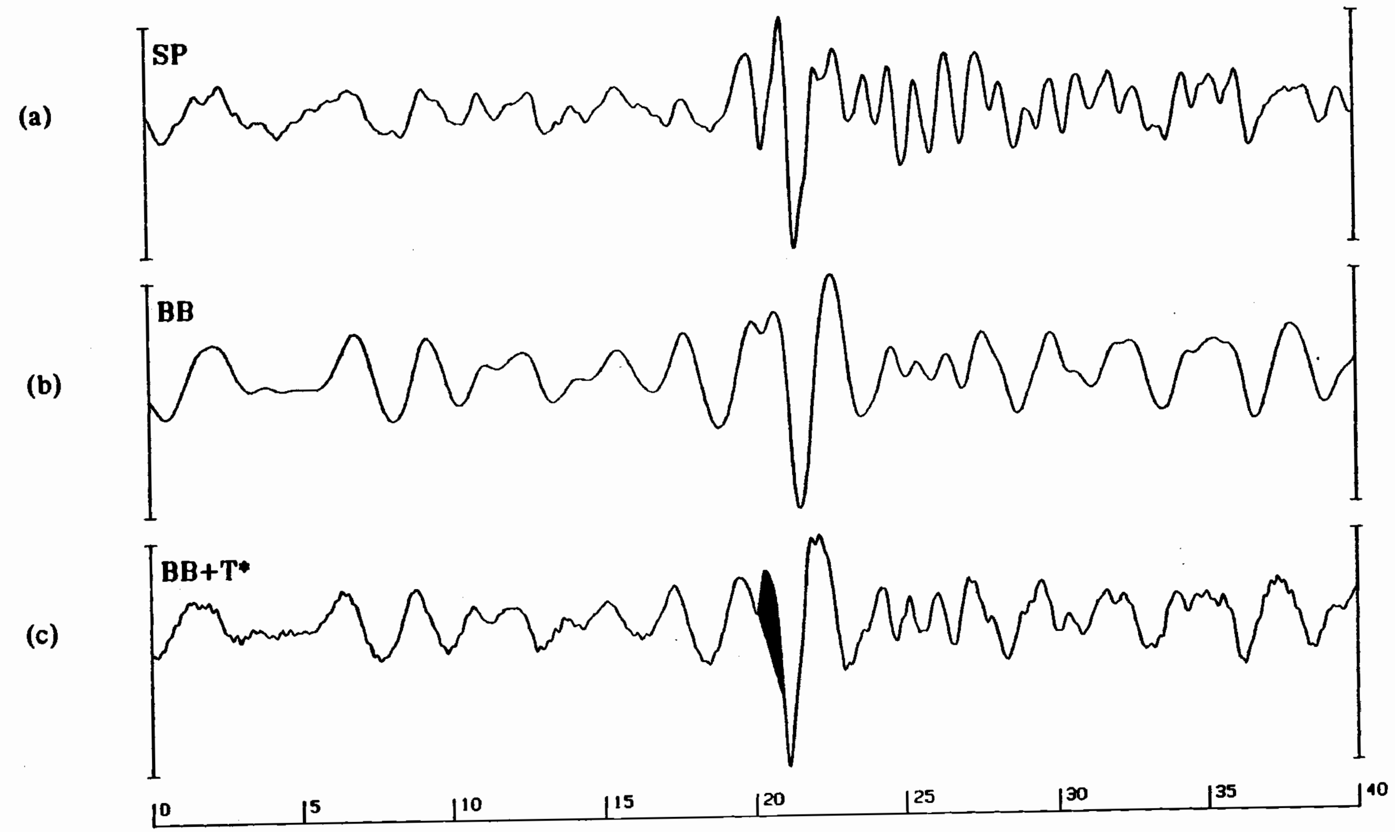


FIGURE 5. ARRAY SUM SEISMOGRAM - NEVADA TEST SHOT RECORDED AT EKA

(a) Short Period
(b) SP after conversion to a phaseless Broad Band response
(c) As (b) plus Wiener filtering and replacement of a t* of 0.35

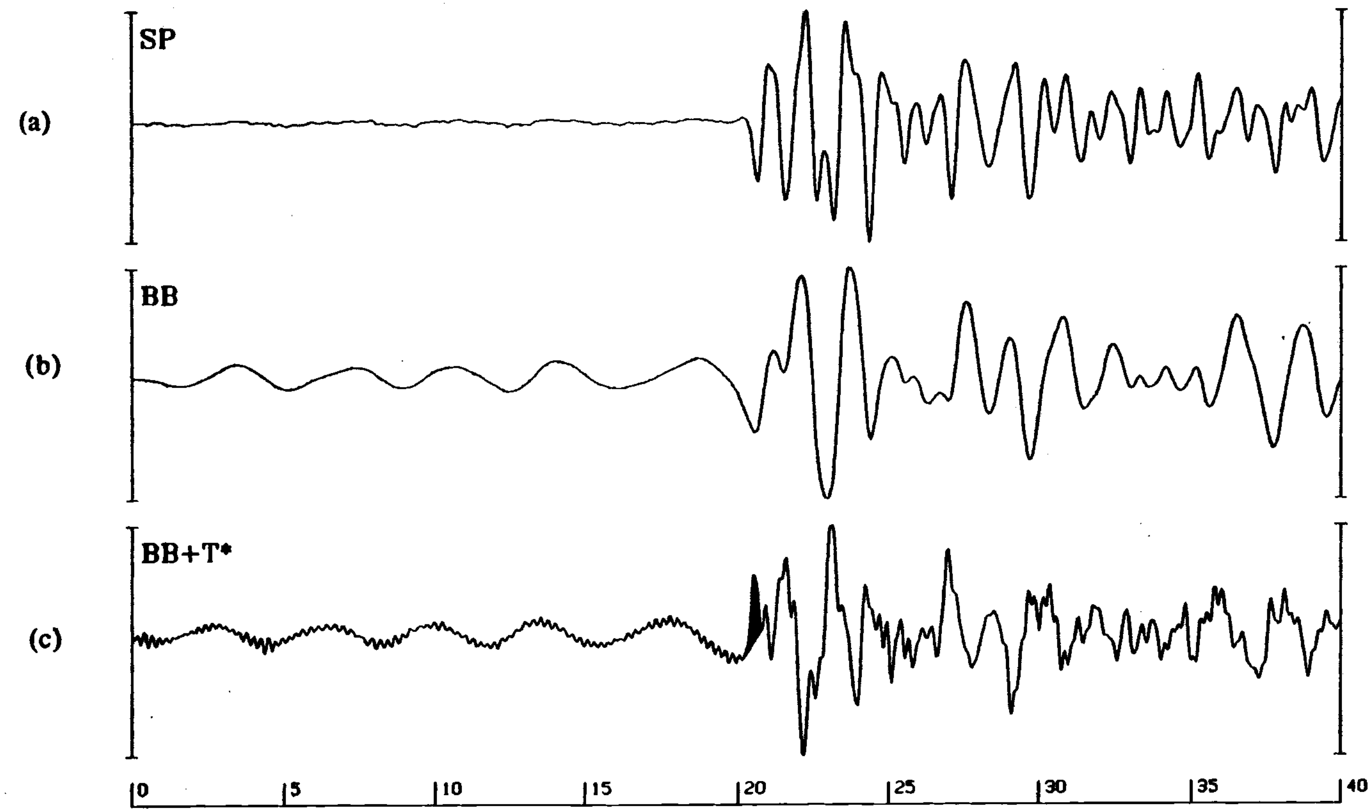


FIGURE 6. ARRAY SUM SEISMOGRAM - NEVADA TEST SHOT RECORDED AT YKA

(a) Short Period
(b) SP after conversion to a phaseless Broad band response
(c) As (b) plus Wiener filtering and replacement of a t* of 0.5

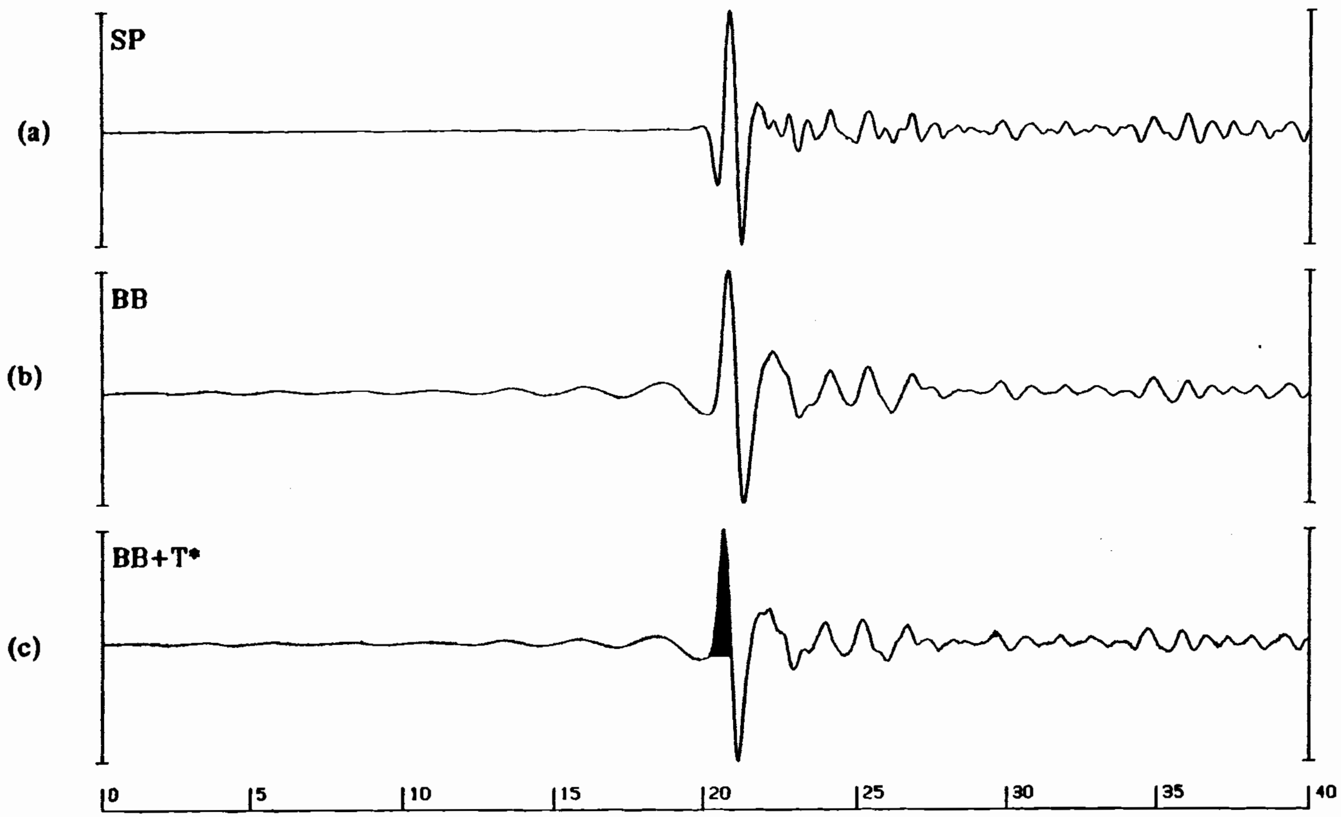


FIGURE 8. ARRAY SUM SEISMOGRAMS - SHAGAN RIVER TEST SHOT RECORDED AT GBA

(a) Short Period
(b) SP after conversion to a phaseless Broad band response
(c) As (b) plus Wiener filtering and a replacement of a t* of 0.15

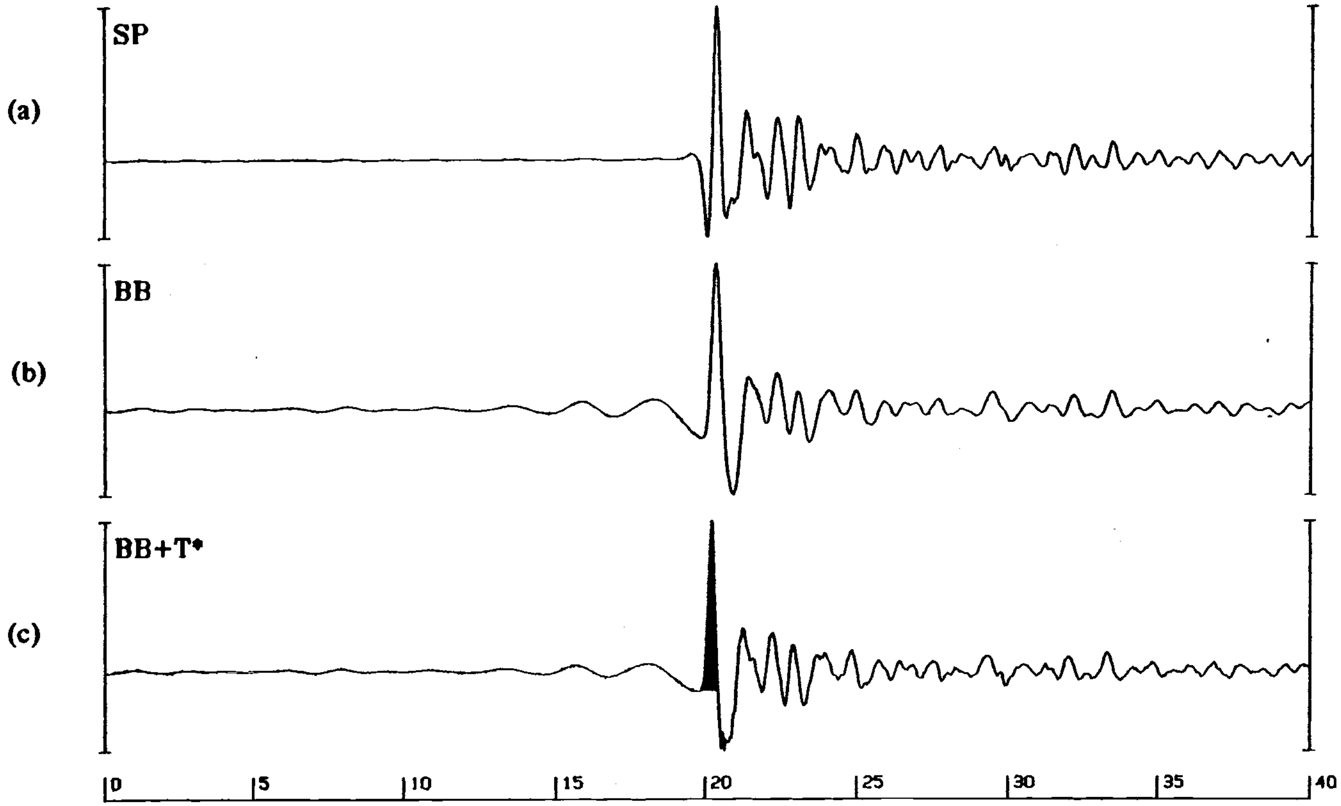
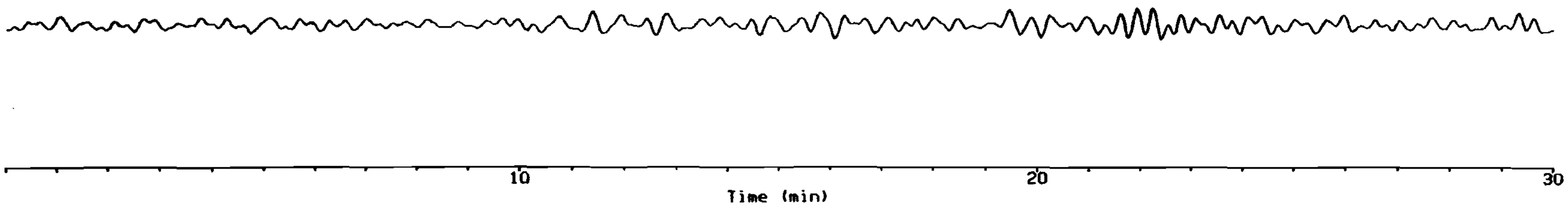
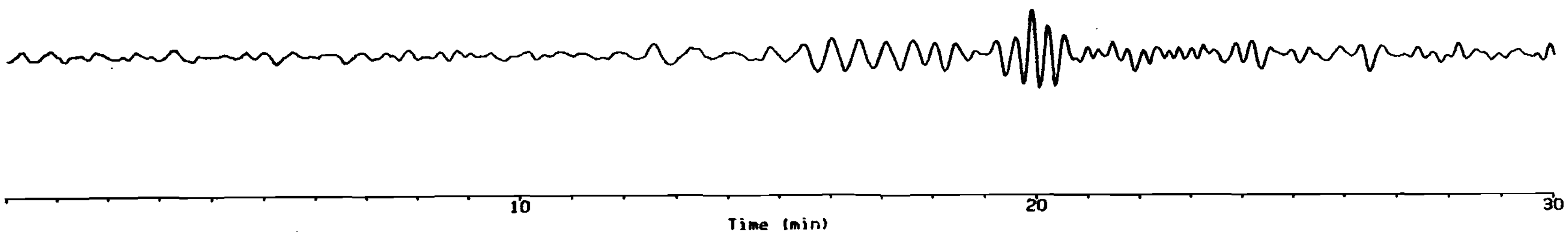


FIGURE 9. ARRAY SUM SEISMOGRAMS - SHAGAN RIVER TEST SHOT RECORDED AT WRA

(a) Short Period
(b) SP after conversion to a phaseless Broad band response
(c) As (b) plus Wiener filtering and replacement of a t* of 0.15



NEVADA



SHAGAN RIVER

FIGURE 10. LONG-PERIOD SEISMOGRAMS RECORDED AT EKA

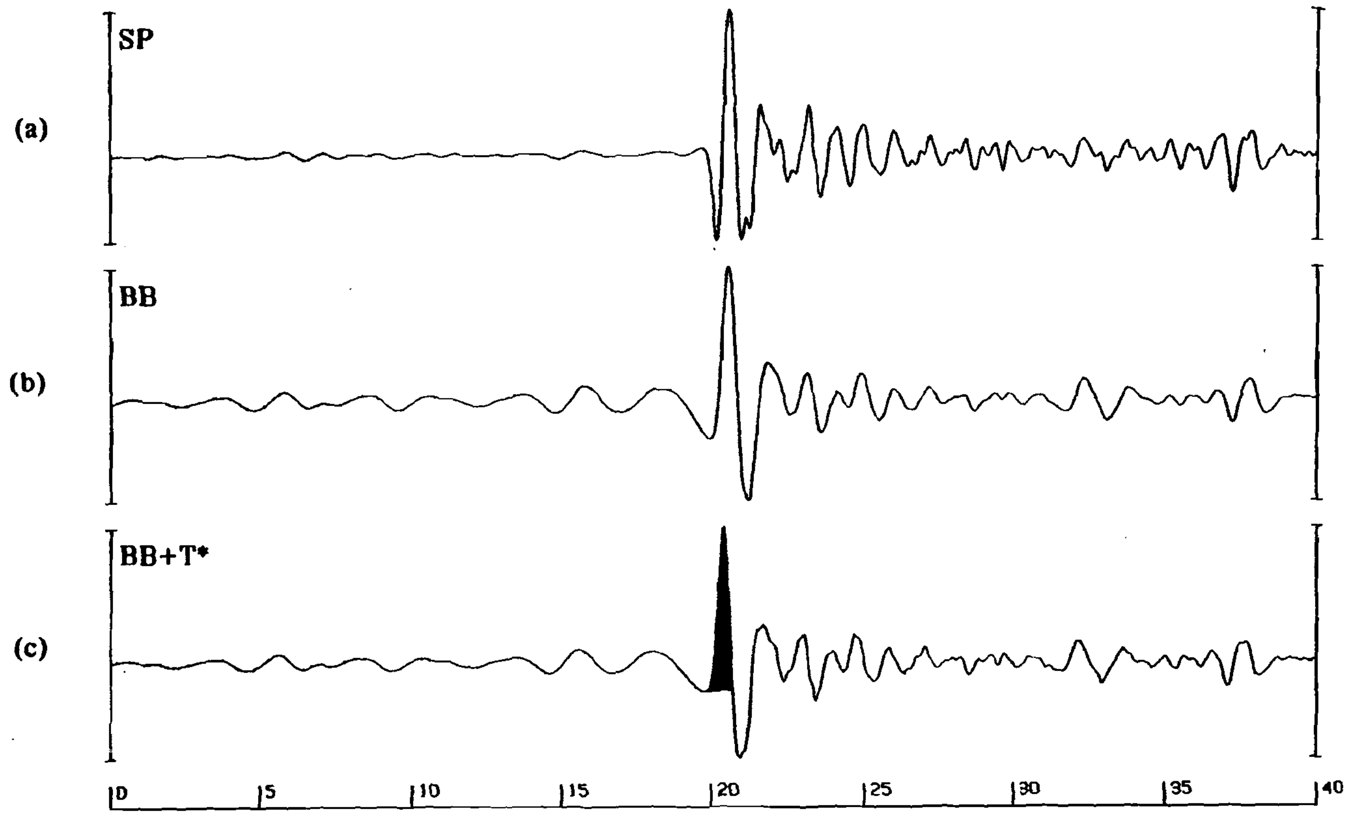


FIGURE 7. ARRAY SUM SEISMOGRAMS - SHAGAN RIVER TEST SHOT RECORDED AT EKA

(a) Short Period
(b) SP after conversion to a phaseless Broad Band response
(c) As (b) plus Wiener filtering and replacement of a t* of 0.15

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