United Kingdom Atomic Energy Authority

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Some Seismic Results of the US GASBUGGY and RULISON Underground Nuclear Explosions

(Shot Report No. 3)

D.J. Corbishley

FOREWORD

During the course of a speech to the United Nations on 5th December 1968, Ambassador William C. Foster, United States representative in 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 worldwide 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 worldwide participation in the collection and evaluation of the seismic data."

One form of the United Kingdom contribution to the investigations will be Shot Reports which present the principal data recorded by the 4 seismological array stations sponsored by the UK Atomic Energy Authority and operated with the co-operation of the Dominion Observatory, Canada, the Bhabha Institute for Atomic Research, Trombay, and the Australian National University, Canberra.

As the opportunity occurs, the Shot Reports will be used to summarise data recorded from any interesting explosions on which full details of location, depth and yield are accessible.

S.D. Abercrombie
Senior Superintendent
Detection Systems

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

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

SUMMARY

GASBUGGY and RULISON were two nuclear explosions detonated underground by the United States AEC as part of Project Plowshare. These enterprises were carried out jointly with commercial companies to investigate the feasibility of releasing natural gas from comparatively impervious ("tight") strata.

This report presents the seismic results obtained from the four UKAEA sponsored arrays at Eskdalemuir (EKA), Scotland; Yellowknife (YKA), Canada; Gauribidanur (GBA), India and Warramuga (WRA) near Tennant Creek, Australia.

1. SHOT DETAILS

Code name		GASBUGGY (see reference [1])	RULISON (see reference [2])
Date		10th December 1967	10th September 1969
Origin time		1930 00.1 GMT	2100 00.1 GMT
Site	Latitude	36° 40' 40.4" N	39° 24' 21" N
	Longitude	107° 12' 30.3" W	107° 56' 53" W
Depth, relative to ground zero		4240 ft	8442 ft [3]
Geological medium		Shale	Sandstone
Yield		26 kt	40 kt [3]
Magnitude		4.53 ± 0.27	5.4

The USCGS Earthquake Data Report No. 81-67 gives the magnitude of GASBUGGY as 5.1.

2. UK ARRAY RESULTS

The four UK designed linear arrays [4] operating at the time of the explosions are:-

Eskdalemuir, Scotland (EKA) 55° 19' 59.0" N 3° 9' 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° 36' 10.0"E
Tennant Creek, Australia (WRA) 19° 56' 32.8" S 134° 21' 15.8"E

Both the Indian and Australian arrays are within the core shadow zone for teleseismic P arrivals from New Mexico and Colorado. The four velocity filtered records (formed by phasing and summing all seismometers for each array) [4]) are shown in figure 1 for GASBUGGY and figure 2 for RULISON. Both events were well recorded at YKA (though note that the distance Δ is less than 30°) and GASBUGGY gave a good P signal at EKA.

The basic arrival time and amplitude data for the four arrays is given in table 1. The arrays are situated to record signals from central Asia within the distance range 30° - 90°. The distances from both events in North America to GBA and WRA are greater than 120°, so the first arrivals are branches of the P signal which have traversed the core (PKP). These arrivals, which are given in table 1 refer to the main (D) branch of PKP.

TABLE 1

Data from the Arrays

GASBUGGY

Station	Δ°	P Arrival Time	Amplitude A/T, $m\mu s^{-1}$	Magnitude
YKA	26	19 35 36.6	8	4.33
EKA	68	19 40 59.3	21	5.33
WRA	124	(PKP) 19 49 1.0	26	Shadow zone
GBA	130	(PKP) 19 49 9.2	28	Shadow zone

RULISON

YKA	23	21 5 10.0	26	4.72
EKA	66	21 10 48.0	5	4.69
WRA	124	(PKP) 21 19 0.6	5	Shadow zone
GBA	127	Not detected		Shadow zone

3. DETECTION THRESHOLD

The detection of the two events at a teleseismic distance by EKA allows an estimate for the detection threshold at EKA to be made.

Both events were detonated at depths greater than is usual, so giving a first arrival that was unperturbed by the free surface reflection. The signal to noise ratio of the first arrival measured on the phased, summed and filtered 1 - 2 Hz channel (figure 1) was 9 for GASBUGGY (26 kt) and 6 for RULISON (40 kt) (figure 2). The latter signal being recorded at EKA when the microseismic activity was particularly high. The considerable improvement in the RULISON record obtained by phasing and summing all seismometers can be seen by comparing the top single seismometer channel (filtered 1 - 2 Hz) of figure 3 with the third trace which is the sum (filtered 1 - 2 Hz).

The signal to noise ratios of between 6 and 9 for events with yields between 40 and 26 kt, show EKA should be capable of detecting Plowshare experiments from North America down to 5 kt, provided that the coupling is similar to that for the deeply buried GASBUGGY and RULISON experiments.

4. DEPTH ESTIMATES

The unusually great depth below ground zero (8442 ft or 2.57 km) at which RULISON was detonated produced a free surface reflection, with phase reversed, which can be seen on the sum-all record at EKA (figure 2) arriving just over one second after the P arrival. The identification of this phase (pP) can be used to give an estimate of the depth (h) of the explosion if the velocity (v) of the overburden is known. If the pP - P delay time is T, then $h = vT/2$ approximately.

However, the identification of the exact arrival time of the pP phase is difficult as the phase has interferred with the P arrival. The seismograph is also a distorted version of the true source reverberations because of the attenuation by absorption of the mantle through which the waves have travelled, the layering in the vicinity of the recording seismometer, the instrumental effects of the seismometer itself, and by normal band filtering. These three effects have been estimated for teleseismic ray paths to EKA and a filter constructed to remove them from the observed seismograph [5]. The resultant record should then represent just the source function and the effects of the source layering.

The unfiltered sum-all record and the deconvolved record are shown in traces b and d of figure 3.

The maximum vertical displacement in the down direction is identified as the pP phase. Reflections at other layers at the source can also be identified. The delay time between P and pP is 1.57 s.

RULISON was detonated in the Mesaverde formation of sandstone and shales which is of upper cretaceous age, overlaid by later tertiary material. Compressional velocities vary between 3.0 - 3.5 cm/s [6] and assuming an average velocity of 3.3 km/s the delay time of 1.57 s yields a computed shot depth of 8500 ft, or 58 ft deeper than the known shot depth.

The high frequency content of GASBUGGY recorded at EKA is thought to be responsible for no satisfactory deconvolved record being obtained.

7. ACKNOWLEDGMENTS

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

REFERENCES

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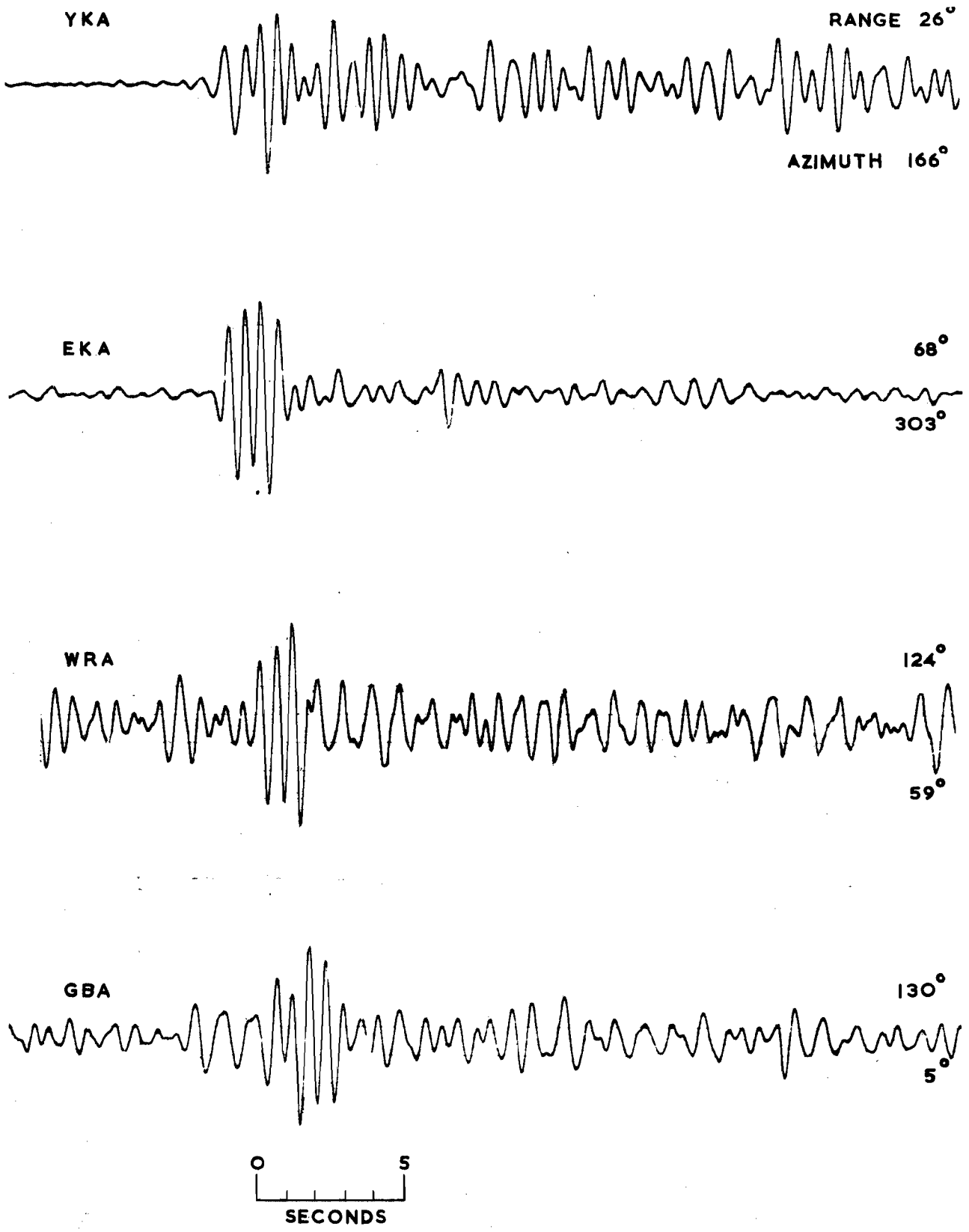


FIGURE 1. U.K.A.E.A SPONSORED ARRAY RECORDS OF GASBUGGY (10th DECEMBER 1967, H=1930·00 HRS): SUM-ALL FILTERED 1-2 Hz.

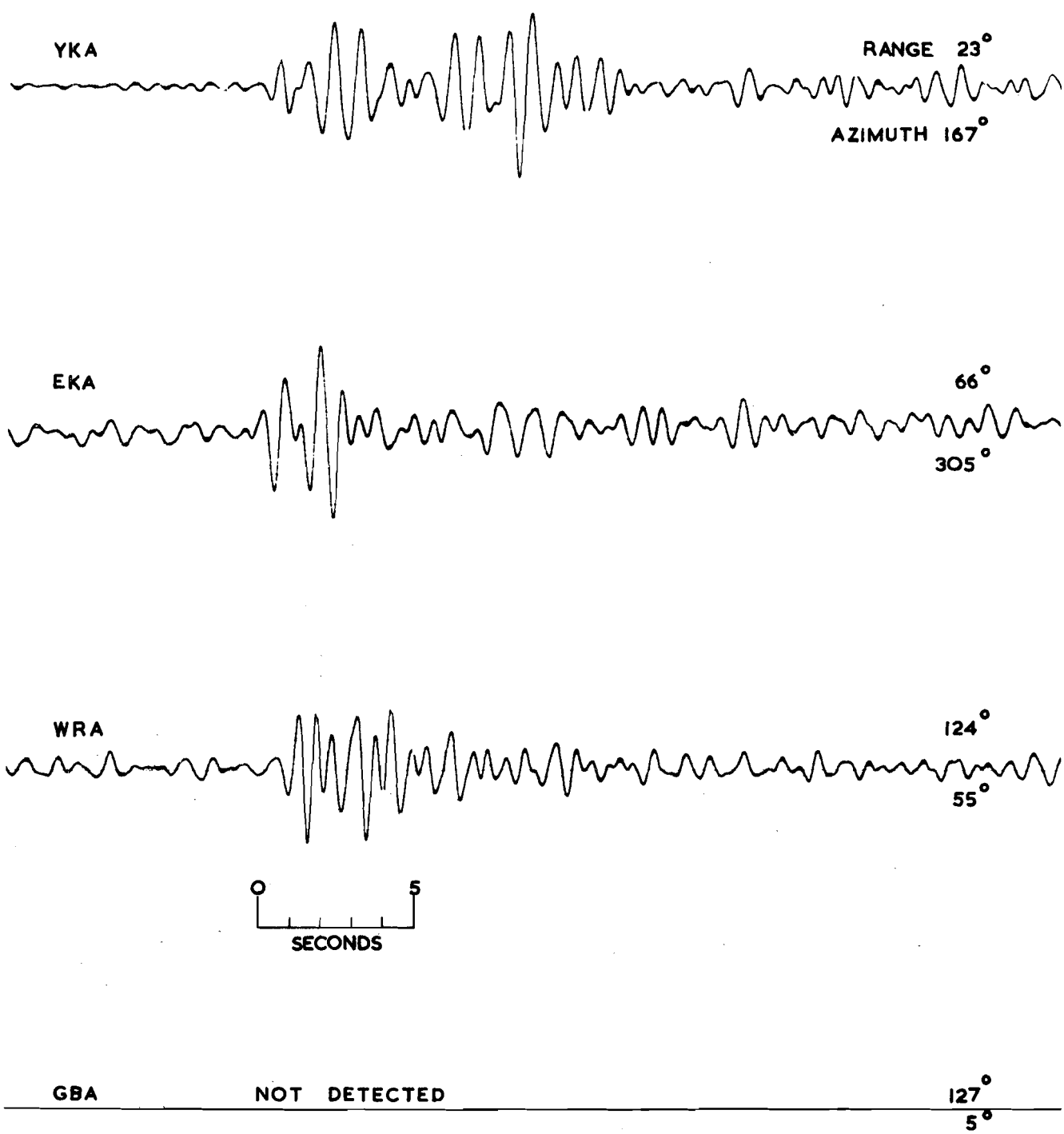
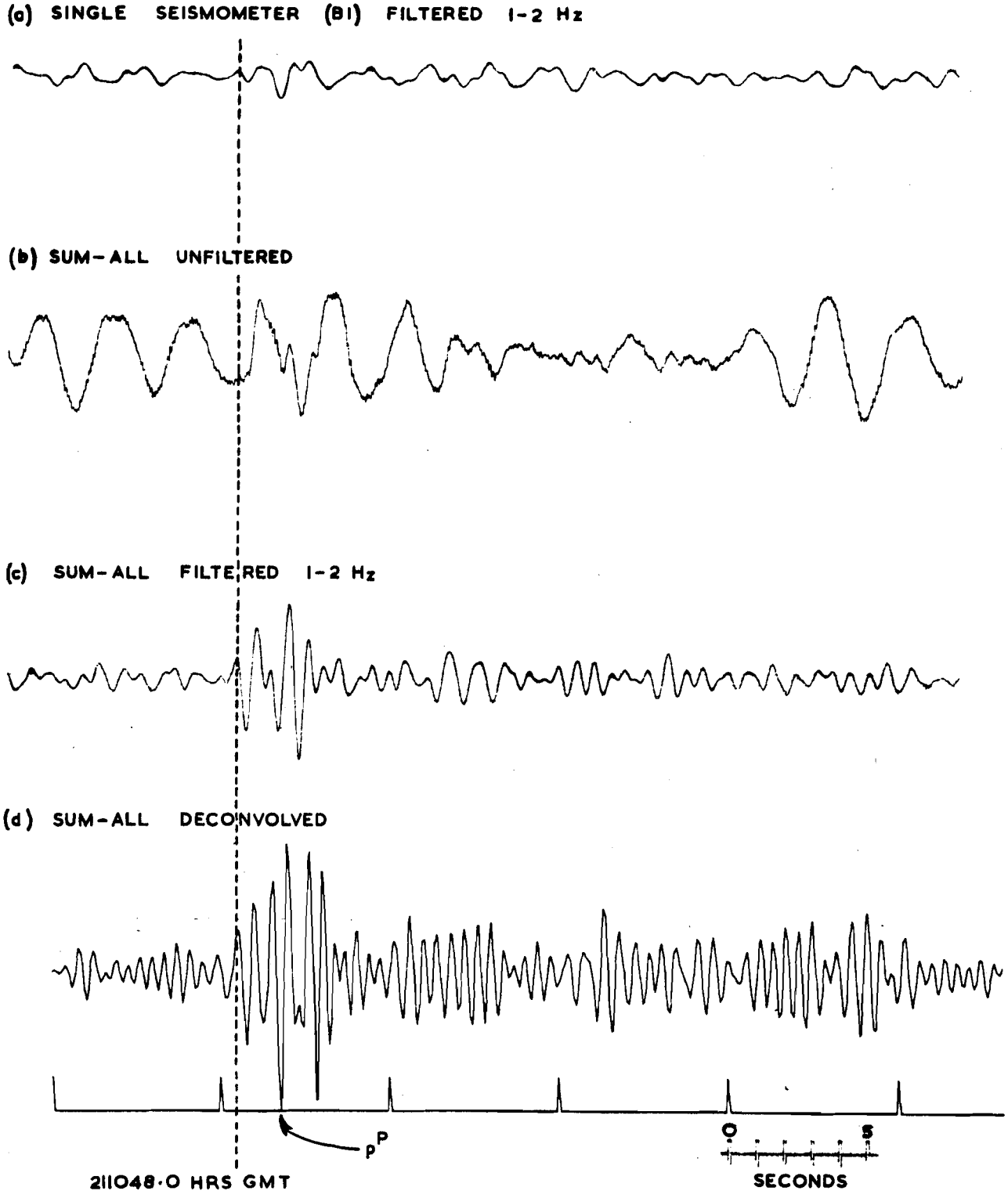


FIGURE 2. U.K.A.E.A SPONSORED ARRAY RECORDS OF RULISON (10th SEPTEMBER 1969, H=2100·00 HRS): SUM-ALL FILTERED 1-2 Hz



P-p^P DELAY = 1·57 SECONDS. CALCULATED DEPTH = 8500 FEET (v = 3·3 km/s)

FIGURE 3. DEPTH ESTIMATE FOR RULISON (DETONATED 2100·00 HRS GMT, 10th SEPTEMBER 1969) RECORDED AT EKA ARRAY