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Some Seismic Results from Soviet PNE Explosions

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CONTENTS

SUMMARY

Short period seismological array data from four medium aperture arrays have been analysed to estimate the location and depth of presumed underground explosions conducted as part of the Soviet programme of Peaceful Nuclear Explosions (PNE) during 1972 and 1973. No evidence is presented to confirm that these are explosions or that they are nuclear. The explosions considered here were detonated at locations which are in general aseismic and well away from the underground explosion test sites in Kazakh and Novaya Zemlya.

Yield estimates for the explosions are made based on the world-wide average m_b values determined from the P waves.

1. INTRODUCTION

In this report we give the results of the analysis of seismic body wave P phases recorded at four medium aperture arrays from seismic disturbances in what are otherwise aseismic areas of the Soviet Union. Several PNE explosions have been reported by Soviet delegates at IAEA. Vienna Conferences and Press and radio reports suggest that there are a number of explosions within the Soviet Union that are part of an intensive PNE programme. It is assumed that the explosions analysed here are all part of this Soviet PNE programme.

Whatever the purpose of these explosions, they are of considerable interest to seismologists simply because they generate widely recorded signals originating in tectonically quiescent regions of the world. The purpose of this report is to record the basic source data, the seismological parameters measured from the four arrays and any interesting features of these large explosions.

By comparing these parameters with the world-wide seismological data reported to the US Geological Survey Service we obtain an indication of the capacity of the network of four array stations to monitor compliance with a comprehensive test ban treaty.

2. STATIONS USED

The four array stations used in the analyses presented here are fully described by Mowat and Burch [1]. The locations of the arrays are:-

Eskdalemuir	(EKA)	Scotland	55°19'59.0"N	3°09'33.0"W
Yellowknife	(YKA)	Canada	62°29'34.3"N	114°36'16.5"W
Warramunga	(WRA)	Australia	19°56'52.0"S	134°21'03.0"E
Gauribidanur	(GBA)	India	13°36'15.0"N	77°26'10.0"E

Co-ordinates refer to the point where the two arms of the roughly L-shaped arrays cross.

Each array station is equipped with Willmore Mk II short period (T = 1 s) vertical component seismometers and the output of each seismometer is recorded, in analogue form, on magnetic tape at the station and then despatched by air mail to Blacknest MOD(PE) at AWRE, Aldermaston. The tapes are stored for two years and are then despatched to IGS, Edinburgh where they are edited to produce a library tape of seismic signals. The original tapes are then cleaned and returned to the array stations for re-recording.

3. LIST OF EXPLOSIONS

The explosions selected for this study are given in table 1; the epicentral data were taken from the Preliminary Determination of Epicentres (PDE) published by the United States Department of the Interior Geological Survey (USDI-GS), with the exception of one event, for which data were taken from the Bulletin of the International Seismological Centre (ISC).

TABLE 1

Epicentral Details of Explosions Used in this Study

Explosion Number	Date	Origin Time	Epicentre		PDE Number	m_b (USDI-GS)
			°N	°E		
1	11 April 1972	06 00 0.46	37.367	61.996	23-72	4.9
2	3 October 1972	08 59 57.8	46.848	45.010	58-72	5.8
3	1 November 1972	04 06 44.9	38.479	65.165	67-72	4.4
4	24 November 1972	09 59 57.8	51.843	64.152	71-72	5.2
5	15 August 1973	01 59 57.8	42.711	67.410	50-73	5.3
6	19 September 1973	02 59 57.2	45.635	67.850	56-73	5.2
7	20 August 1972	02 59 57.9	49.462	48.179	49-72	5.7
8	30 September 1973	04 59 57.5	51.608	54.582	58-73	5.2
9	21 September 1972	09 00 01.2	52.127	51.994	59-72	5.1
10	24 November 1972	09 00 08.0	52.779	51.067	73-72	4.7
11	9 July 1972	06 59 57.9	49.78	35.40	*	4.8*
12	28 August 1973	02 59 57.6	50.550	68.395	54-73	5.3
13	4 September 1972	07 00 03.6	67.689	33.445	52-72	4.6

*Epicentral data taken from the ISC Bulletin (this explosion was not reported by PDE).

The analyses of the seismograms are presented in section 10; the explosions have been arranged in groups associated with a particular tectonic region, so that those in similar geophysical environments can be readily compared with each other.

The number identifying each explosion is given in table 1 and the location of the explosions is illustrated in figure 1.

FIGURE 1. LOCATION OF SOVIET PNE EXPLOSIONS ANALYSED IN THIS STUDY

4. EPICENTRE LOCATION

Given the P wave arrival time at three or more stations from a seismic disturbance, it is possible to estimate the epicentre and origin time of the disturbance. As a rough test of the capacity of the four array network to locate seismic events, epicentres were independently estimated. Many digital programs exist to compute epicentral data; one used here is called SPUR and is described by Douglas et al. [2]. The results summarised in table 2 show a substantial capacity of the four arrays to locate Soviet explosions.

5. ESTIMATION OF SOURCE DEPTH

An estimate of the source depth is made from an analysis of the "spiked" seismogram. The "spiked" seismogram is produced by removing, from the delayed and summed best beam unfiltered array processed seismogram, the effect of the recording instrument and the absorption effects of the mantle portion of the total transmission patch. The absorption at each angular frequency ω is taken to be exp $(-\ \omega t^*/2)$, where $t^* = T/Q_{av}$, T is the P travel time source to receiver and Q_{av} is the average quality factor. t* between 0.1 and 0.6 is used (figure 8) and it is noteworthy that 0.1 or 0.2 - high Q_{av} - gives the better results. The "spiked" seismogram should show a series of impulses - or spikes - associated with the direct P wave and reverberations within the source and receiver layered structure, the largest of which should be the reflection of the P wave at the free surface above the shot point (pP). The free surface reflection "spike" should be negative, ie, opposite in direction to the direct P "spike" because of the reversal of phase at the free surface.

If the pP - P separation time can be estimated in seconds and assumptions made about the velocity structure above the shot point, it is possible to estimate the source depth using the simple relationship

$$\text{d (depth in kilometres)} = \frac{\text{V (velocity)} \times \text{(pP - P)}}{2} \text{ seconds.}$$

A full description of the spiking technique is given by Douglas et al. [3] and an example of its application is given by Marshall [4]. In this study estimates of depth have been made, where possible, and averaged to produce the depth estimates given in table 2. The velocity in the overlying rock has been assumed to average 2.75 km s^{-1} for this purpose. This is the "average" kind of figure to be expected in consolidated sedimentary rocks with a weathered top layer.

6. MAGNITUDE DETERMINATION

Short period body wave amplitudes and periods were used to calculate the magnitude m_b of each explosion at each array station according to the relationship defined by Gutenberg and Richter [5]:-

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

where A is the half peak to peak amplitude within the first few cycles of the P wave in nm and T is the period in seconds. $B(\Delta)$ is a distance normalising term which corrects for the effects of geometrical spreading and absorption of the wave. The magnitudes given in this report are measured on the delayed and summed processed signal. The average array magnitudes are given in table 2 and may be compared with the averages in table 1 from a much larger number of stations.

TABLE 2

Summary of Results

Explosion No.	Date	Approx. Origin Time	Array Location (Minimum Three Stations)		Shift in km E of N Relative to PDE Data		Average Array m_b	pP-P, s	Estimated Depth, m	Yield, kton (See Table 3)
1	11 April 1972	0600	37.234N	61.877E	18.2 km	215.6°	4.76	1.80	2500	11
2	3 October 1972	0900	46.782N	44.643E	29.0	255.0	5.54	0.72	1000	90
3	1 November 1972	0407	38.784N	65.580E	49.5	46.7	4.60		Very shallow	5
4	24 November 1972	1000	51.843N	64.152E	6.3	50.7	5.09	0.49	670	20
5	15 August 1973	0200	42.654N	67.834E	35.0	100.2	5.66	0.46	630	25
6	19 September 1973	0300	45.653N	67.599E	19.7	275.9	5.17	0.87	1200	20
7	20 August 1972	0300	-	-	-	-	6.00	0.61	840	70
8	30 September 1973	0500	51.699N	54.582E	14.5	314.2	5.28	0.43	600	22
9	21 September 1972	0900	52.125N	51.863E	9.0	268.9	4.94	0.36	480	18
10	24 November 1972	0900	-	-	-	-	4.78	0.40	550	7
11	9 July 1972	0700	-	-	-	-	4.73	1.80	2500	16
12	28 August 1973	0300	50.624N	68.490E	10.7	39.3	4.87	0.6	0 - 800	12
13	4 September 1972	0700	-	-	-	-	4.30	0.25	350	10

7. ESTIMATION OF YIELD

Empirical relationships have been determined between the seismic magnitude m_b and the yield Y in kilotons of underground nuclear explosions. However, variations occur in the relationship due to factors such as the response of the medium to non-elastic deformation, the water content, and the density and porosity of the rocks in which the explosion occurred. These are some of the factors which determine the amplitude and shape of the elastic wave which emerges from the source region. Another important factor determining the wave characteristic is the absorption within the upper mantle structure in the source region and likewise in the seismograph receiver region. It is for this reason that it is essential to establish source region amplitude corrections applicable to m_b before a good estimate of m_b, and hence yield, can be made.

It is possible to determine amplitude or magnitude residuals (ie, departures from the mean) for seismological stations and interpret these in terms of upper mantle absorption (Booth et al. [6]). The residual for an area can then be applied to the average magnitude as a correction factor to improve the estimate of m_b. This improvement in the final estimate of m_b should be particularly noticeable for explosions since they are radially symmetric sources. An example of how this technique may be used is given by Booth et al. For example, the regional effect of the Nevada Test Site (NTS) area is estimated by contouring the station residuals in the western United States and estimating the regional correction applicable to NTS. It is found to be (- 0.25) m_b units relative to the Aleutian Test Site area, which is (+ 0.33) m_b units, a difference of 0.58 magnitude units. So for an explosion of the same yield detonated at both locations the average world-wide magnitude m_b would be about 0.6 of a magnitude larger from the Aleutian explosion than from the NTS explosion. As a check on this we can use two 80 kton explosions, one MINIATA at NTS and the other LONGSHOT in the Aleutians. The average SP body wave magnitude of MINIATA is 5.5 and of LONGSHOT 6.1. The difference is 0.6 magnitude units as predicted by the regional magnitude differences. Applying the NTS correction to MINIATA we get m_b 5.75 and applying the correction for the Aleutians to LONGSHOT we get m_b 5.77. In this way the discrepancy between two sources of the same yield is eliminated. It does not remove the problem of the direct coupling between the medium and the explosive source. It would appear that the most significant factor in terms of medium coupling is whether the shot is above the water table or below it.

To determine regional magnitude corrections on a world-wide basis would require amplitude data from many points over the globe. Ideally the amplitude data from <u>every</u> seismological station around the world would be analysed. This would remove the problems of determining absolute base-line levels for different suites of data from widely separated areas. Because of the seismic wave propagation characteristics and especially the strong diffraction and refraction by the core of the Earth, this is not possible. However, it is possible to <u>estimate</u> the base-line level in such a way that relative corrections, applicable over virtually the whole world, can be determined.

As will be discussed in greater detail in a later publication, there appears to be a correlation between the amplitude residual at a station and the P velocity in the upper mantle (defined as the outer 650 km) beneath the recording station. An analysis of the station terms and Pn velocities gives the relationship:-

Station term = - (0.88 ± 0.28) Pn (velocity km s^{-1}) + (7.28 ± 2.28) (regional core).

Product moment correlation coefficient = - 0.78.

Number in sample = 28.

Student's t = 6.39.

The derivation of this relationship will be described in greater detail in the later publication mentioned above. For the present it is the graph from which this relationship was established which has been used to obtain the regional corrections given in table 3. In the virtual absence of amplitude data from 1 Hz short period recording systems in the USSR we have used this relationship between Pn and m_b regional corrections to estimate the regional corrections applicable to the USSR. This has been possible for most of the areas in which Soviet explosions have occurred because the results of very extensive deep seismic sounding experiments are published in the open literature giving Pn data over most of the USSR.

TABLE 3

Final Corrected PDE m_b and Yield

Explosion Number	PDE m_b	Regional Correction Applied	Depth Correction Applied	Corrected m_b	Estimated Yield, kton
1	4.9	- 0.05	+ 0.2	5.05	11
2	5.8	+ 0.15		5.95	90
3	4.4	+ 0.15	+ 0.2	4.75	5
4	5.2	+ 0.10		5.30	20
5	5.3	+ 0.10		5.40	25
6	5.2	+ 0.10		5.30	20
7	5.7	+ 0.15		5.85	70
8	5.2	+ 0.15		5.35	22
9	5.1	+ 0.15		5.25	18
10	4.7	+ 0.15		4.85	7
11	4.8	+ 0.20	+ 0.2	5.20	16
12	5.3	- 0.20		5.08	12
13	4.6	+ 0.20	+ 0.2	5.00	10

We are now left with the problem of relating magnitude to yield in an expression which is valid for any particular test site. Note that this still does not contain a correction for the coupling effect of the shot medium on seismic amplitudes.

If we use the very convenient relationship of Carpenter:

$$m_b = \log_{10} Y(kt) + 4.0 \ [7]$$

to relate m_b to yield on a global basis, we would have to adjust the NTS correction from - 0.25 to - 0.45 and the Aleutians correction from + 0.33 to + 0.13. This is permissible as the relative difference is not altered and we are concerned only with adjusting the base-line levels to make the technique applicable to world-wide data. Now consider the two explosions MINIATA and LONGSHOT and, using the formula above in conjunctions with these adjusted regional corrections, we can write

$$m_b - RC = \log_{10} Y + 4.0,$$

where RC is the regional correction, and observe that this is a relationship that gives consistent results, ie, for 80 kton, $m_b - RC = 5.9$. (The regionally corrected values for MINIATA and LONGSHOT respectively are 5.95 and 5.97.)

We now have to estimate RC for test sites within the USSR. Pasechnik [8] has published amplitude residuals, determined from French and US underground explosions, for stations in the Urals area and the Kazakh area of the Soviet Union. The relative residuals determined from 1 Hz seismograph systems indicate regional corrections of - 0.25 m_b and 0.0 m_b for the Urals and Kazakh respectively. Thus, we have regional corrections for the Urals - 0.25, Russian Shield (Kazakh) 0.0, Nevada Test Site - 0.45 and + 0.13 for the Aleutians area. These regional corrections correlate positively with Pn velocity and by reference to Pn velocities, we are able to adjust the base-line levels of the regional corrections and to use Carpenter's relationship between magnitude and yield.

We must also consider the effect of the depth of the explosion and the arrival time of pP (the free surface reflection) on the resultant amplitude of the direct P wave which is used to determine m_b. Most m_b:Y relationships were developed for sub-megaton explosions fired at depths where pP and P interfere constructively†. However, very shallow (surface) and deep explosions are commonly used for PNE and these will have no pP or a late arriving pP respectively. Consequently, for the same yield, very shallow and very deep explosions will give relatively smaller magnitudes. To compensate for this, a correction of 0.2 magnitude units is added to the magnitudes measured for such explosions. (The amplitude of the wave reflected at the free surface is a function of the reflection coefficient; this will cause depth correction factors to vary but the value used here, 0.2 m_b units, is a reasonable average estimate.)

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†Carpenter's m_b:Y relates to direct P amplitudes. By general consent and usage it has been applied to P + pP.

We can now write

$$m_b - RC + \text{depth correction} = \log_{10} Y + 4.0$$

This is the expression we have used to relate m_b to yield. The regional corrections and depth corrections are valid only if the P wave signal has a period around 1 second (± a factor of 2) and is recorded on conventional narrow band short period instruments. As the concept of regional corrections is developed, we can look forward to consistent estimates of seismic yield even when the explosion P waves are detected at one station only.

Ideally, yield would be related to m_b determined from a widely distributed fixed network of standardised seismograph stations. This may be possible with an operational network monitoring a CTBT but for the purposes of this report we use the m_b published by the USDI-GS NEIS (National Earthquake Information Service).

In table 3 the regional and depth corrections have been applied to the NEIS m_b for the suite of explosions selected for this report.

8. EXPLOSION ANALYSIS

8.1 The Scytho-Turanian Platform Area

Explosions numbered 1 to 6 are included in this area. Tectonically this area has been stable since the end of the Palaeozoic era. Shallow basins developed in Mesozoic and Cenozoic times, the maximum subsidence being between 5 to 10 km. The crust is about 40 km thick increasing to 45 km near the foldbelts. The structure of the crust is expected to be relatively uniform over a wide area and should be similar to the model shown in figure 2. The upper mantle velocity Pn is high, ranging from 8.1 to 8.3 km s^{-1}.

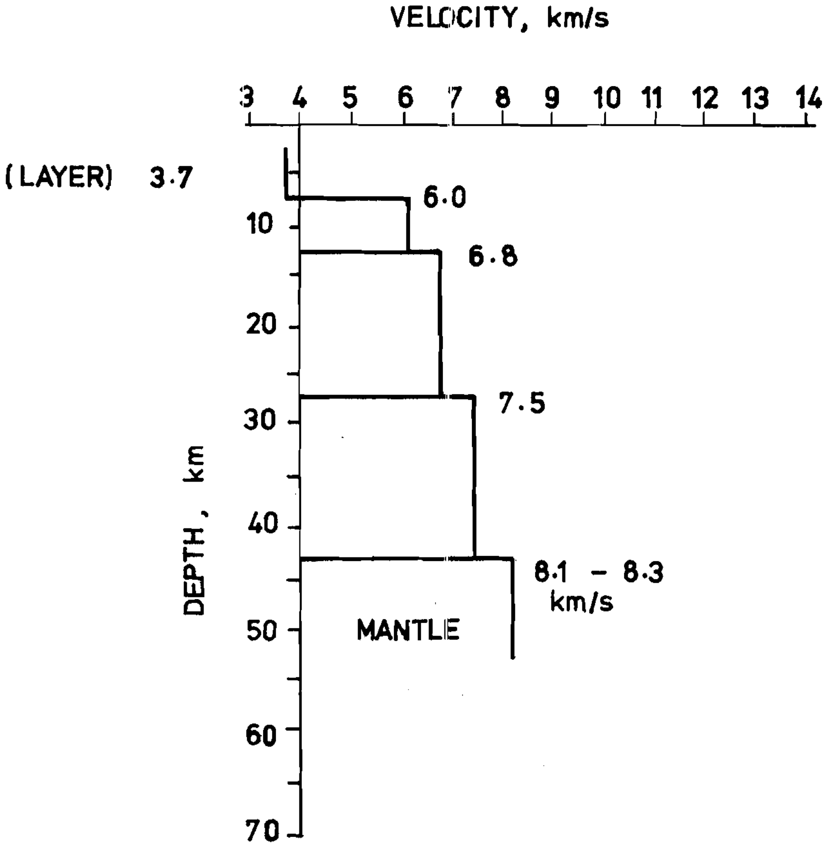

FIGURE 2 VELOCITY DEPTH PLOT FOR THE SCYTHO-TURANIAN PLATFORM

8.1.1 Explosion 1. 11 April 1972

This explosion occurred near Bayram-Ali in an area of known dry sediments which may give rise to low amplitude signals by decoupling very shallow explosions. The emplacement depth has been estimated to be 2.5 km so it is probably well coupled at this depth. The Pn velocity of 8.3 km s^{-1} in this region would suggest excellent transmission away from the area with little attenuation. Note the consistency in the magnitude at the four arrays; the amplitude at GBA is unusually high relative to the others since the structure beneath the Hindu Kush normally attenuates signals to GBA. It illustratés how critically dependent on the path is the signal amplitude; a change of only a few kilometers can produce dramatic variations in the signal wave form when crossing tectonically disturbed areas like this. As an example, explosions near Bukhara, some 200 km farther north, but equi-distant to GBA (Δ = 27.4°), give signals which are more attenuated and more complex because the rays must have passed through a more lossy section of the upper mantle beneath the Hindu Kush.

The yield estimated as described in earlier sections is 11 kton and the depth is 2.5 km.

TABLE 8.1.1

PDE DATA CARD NO. 23-72 | EXPLOSION NO. 1

Date: 11 April 1972 | Geographical Location: Turkman SSR

Epicentre: 37.367°N 61.996°E | Origin Time: 06 00 04.6

m_b 4.9

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	46.6	314.5	11.3	0.8	06 08 30.4	4.85
YKA	80.4	358.4	7.9	0.6	06 12 14.2	4.70
GBA	27.4	145.7	16.4	0.6	Code unreadable	4.71
WRA	88.7	116.3	4.4	0.8	06 12 56.2	4.76

Multiple Array Location: 37.23°N 61.88°E

Origin Time: 05 59 59.1 GMT

Average Array m_b: 4.76

Shift Relative to PDE Location: 18.2 km 215°E of N

Estimated Yield: 11 kton

Estimated Depth: 2500 m

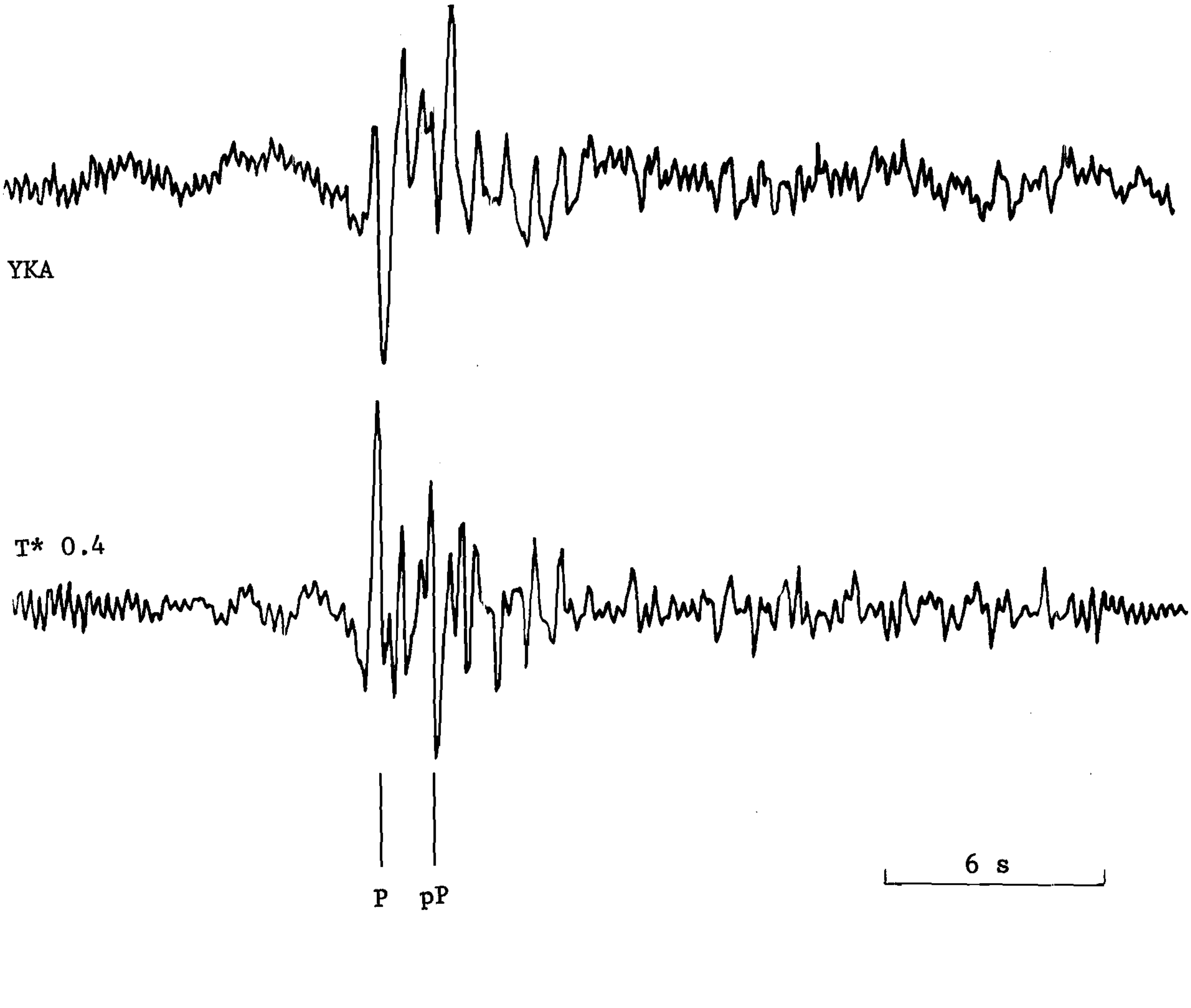

FIGURE 8.1.1. YELLOWKNIFE SUM-ALL UNFILTERED SEISMOGRAM AND THE SPIKE FILTERED RECORD INDICATING P AND THE FREE SURFACE REFLECTION pP

8.1.2 Explosion 2. 3 October 1972

This explosion occurred in an area of the Platform with known deposits of gas and oil and the estimated depth of 1000 m suggests that the explosion may be associated with gas-oil stimulation or storage experiment.

The Pn velocity in this region implies good seismic transmission but somewhat less than for the explosion near Bayram-Ali (No. 1). Note the longer average period of the P wave signals from this explosion relative to the other explosions in this tectonic region. This can be due to the larger yield - causing a spectral shift to longer periods - the dynamic response of the shot medium or on the Pn velocity evidence, greater attenuation immediately beneath the shot point. The yield is estimated to be 90 kton.

TABLE 8.1.2

PDE DATA CARD NO. 58-72

EXPLOSION NO. 2

Date: 3 October 1972

Geographical Location: South Western Russia

Epicentre: 46.848°N
45.010°E

Origin Time: 08 59 57.8

m_b 5.8

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	30.9	303.9	50.0	0.8	09 06 15.5	5.40
YKA	69.8	350.1	92.0	1.0	09 11 10.8	5.87
GBA	42.8	129.9	70.0	1.1	09 08 00.0	5.34
WRA		Core shadow: not processed				

Multiple Array Location: 46.78°N
44.64°E

Origin Time: 08 59 57.3 GMT

Average Array m_b: 5.54

Shift Relative to
PDE Location: 29 km 255°E of N

Estimated Yield: 90 kton

Estimated Depth: 1000 m

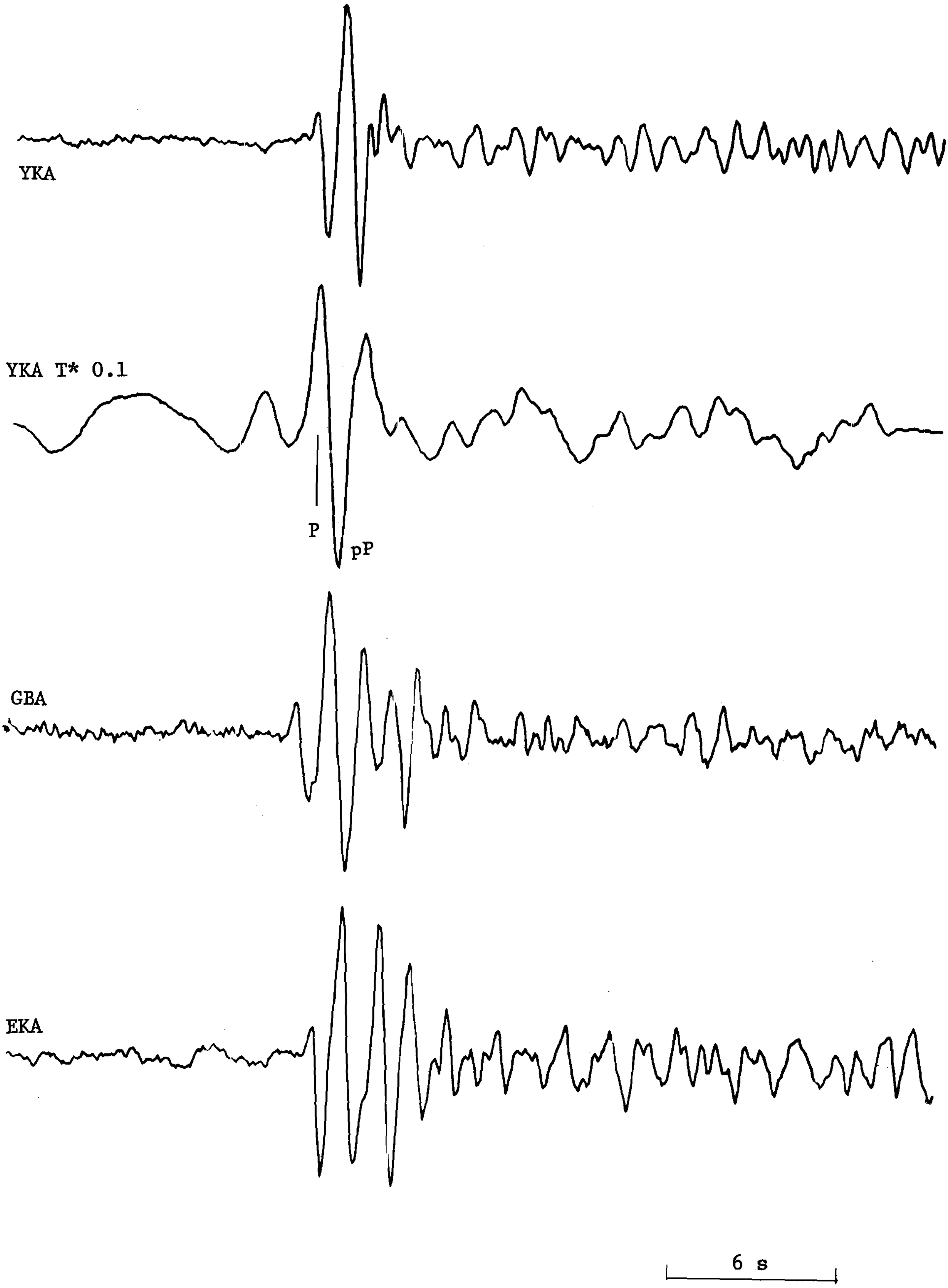

FIGURE 8.1.2. THE SUM-ALL ARRAY SEISMOGRAMS INCLUDING THE SPIKE FILTERED RECORD AT YELLOWKNIFE

8.1.3 Explosion 3, 1 November 1972

The location of this explosion is close to the Amu Darya River in an area of thick sediments. The shallow depth suggests that it may have been associated with dam or reservoir construction in the Amu Darya River area. The yield is 5 kton (nuclear) but similar amplitudes would be given by about $2\frac{1}{2}$ kton of chemical explosive. The magnitude of YKA is relatively low and it is interesting to note that the azimuth of the take off angle to YKA is such that the ray passes at a shallow depth beneath the mountainous region of Samarkand which may cause some attenuation either by scattering or absorption. (For explosion No. 1 as well as the Bukhara explosions the rays to YKA miss the Samarkand deep structure.)

TABLE 8.1.3

PDE DATA CARD NO. 67-72

EXPLOSION NO. 3

Date: 1 November 1972

Geographical Location: Uzbekistan

Epicentre: 38.479°N
65.165°E

Origin Time: 04 06 44.9

m_b 4.4

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	47.6	314.0	12.2	0.6	04 15 20.8	4.99
YKA	79.4	359.9	2.7	0.6	04 18 50.0	4.23
GBA	27.1	153.0	10.4	0.6	04 12 30.0	4.51
WRA	87.0	118.3	7.5	0.6	04 19 28.6	4.65

Multiple Array Location: 33.78°N
65.58°E

Origin Time: 04 06 42.0 GMT

Average Array m_b: 4.60

Shift Relative to
PDE Location: 49.5 km 46.7°E of N

Estimated Yield: 5 kton

Estimated Depth: Very shallow

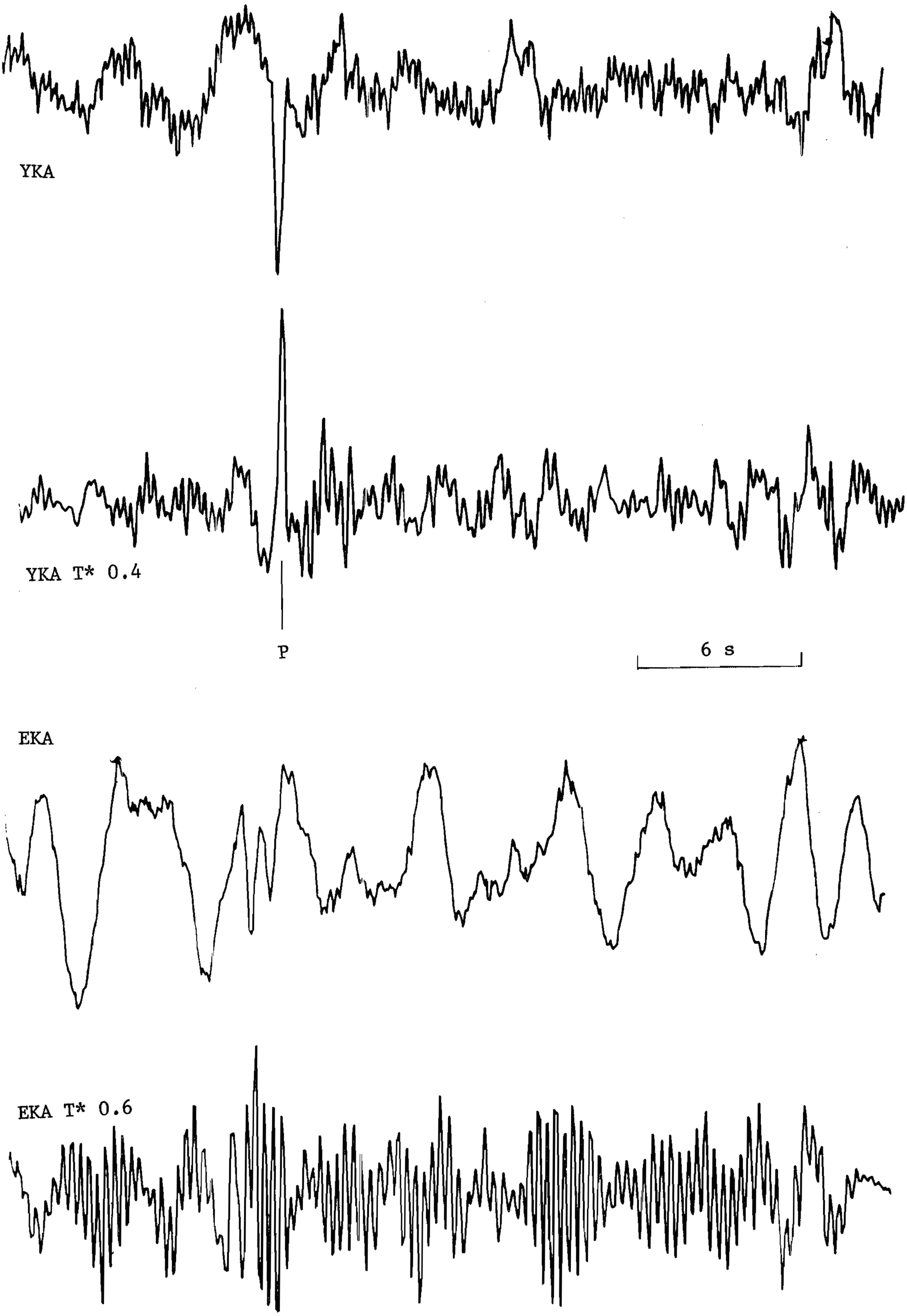

FIGURE 8.1.3. YELLOWKNIFE AND ESKDALEMUIR SUM-ALL UNFILTERED ARRAY AND SPIKE FILTERED SEISMOGRAMS

8.1.4 Explosion 4. 24 November 1972 (1000 GMT)

This explosion occurred in an area of dry unconsolidated sediments so the yield estimate in table 3 could be low by a factor of two or more. The velocity structure is not known but assumptions on Pn velocity are made by extrapolating from the known structure. The magnitude at GBA is much lower than the other array magnitudes and this is believed to be caused by the deep structure associated with the Tibetan mountains - the rays to GBA bottom and spend a significant portion of their travel time in that region. The yield is estimated to be at least 20 kton but this may be an underestimate if the shot medium is very dry.

TABLE 8.1.4

PDE DATA CARD NO. 71-72 EXPLOSION NO. 4

Date: 24 November 1972 Geographical Location: Western Kazakh

Epicentre: 51.843°N 64.152°E

Origin Time: 09 59 57.8

m_b 5.2

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	38.7	302.5	40.8	0.6	10 07 24.2	5.06
YKA	66.0	359.4	67.8	0.6	10 10 46.6	5.61
GBA	39.6	159.5	15.8	0.6	10 07 32.3	4.59
WRA			No records			

Multiple Array Location: 51.84°N 64.15°E

Origin Time: 09 59 57.8 GMT

Average Array m_b: 5.09

Shift Relative to PDE Location: 6.3 km 50.7°E of N

Estimated Yield: 20 kton

Estimated Depth: 670 m

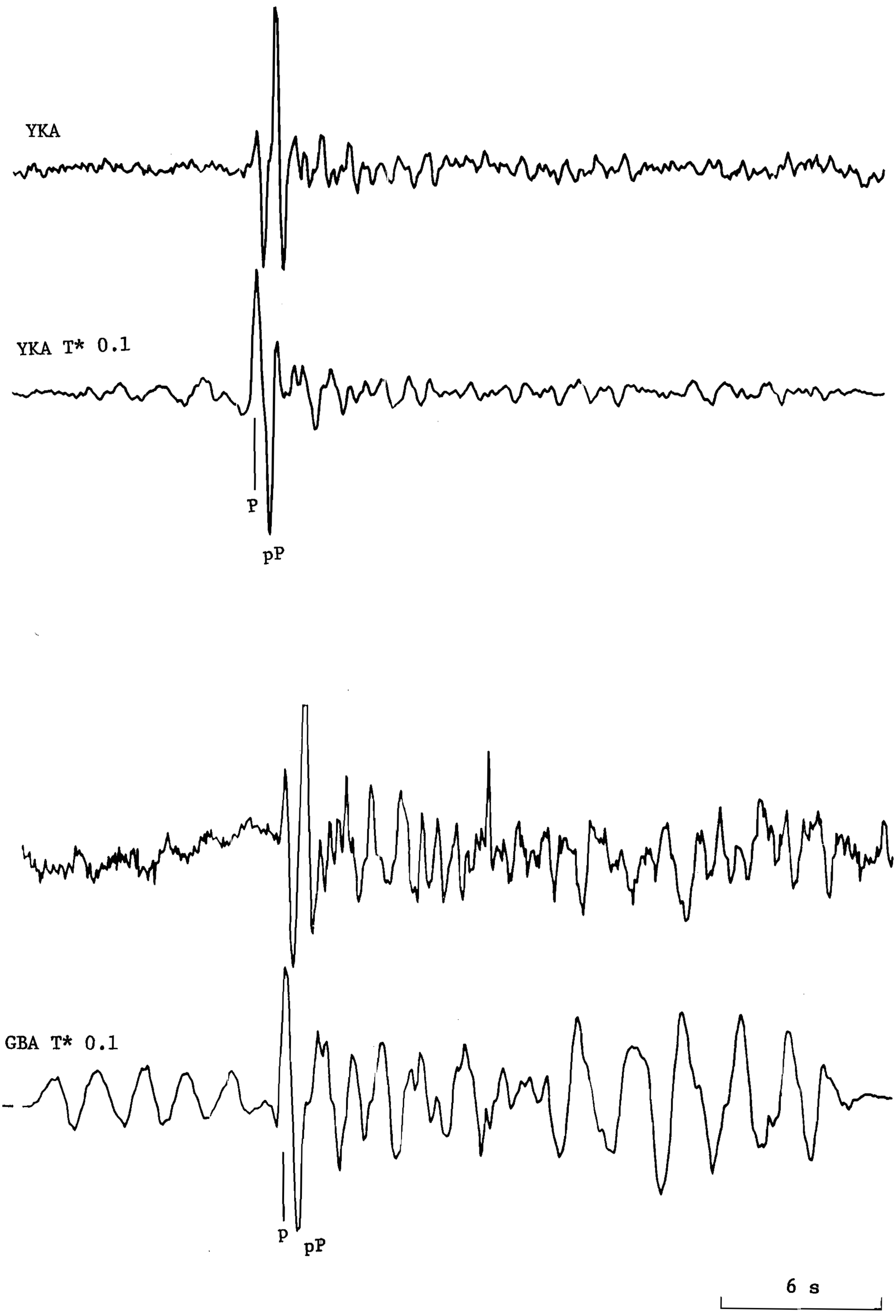

FIGURE 8.1.4(a). YELLOWKNIFE AND GAURIBIDANUR SUM-ALL UNFILTERED AND SPIKE FILTERED RECORDS

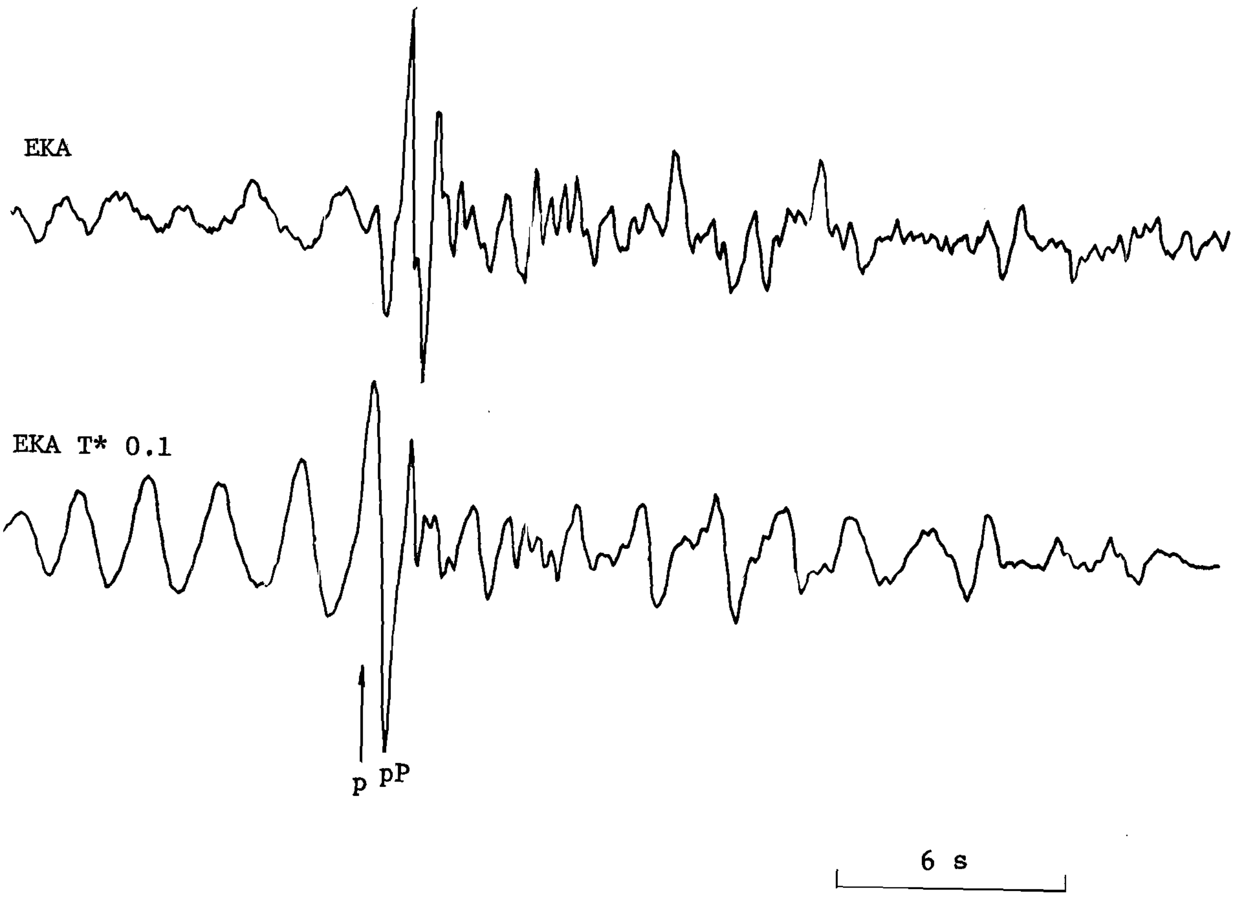

FIGURE 8.1.4(b). ESKDALEMUIR SUM-ALL UNFILTERED AND SPIKE FILTERED RECORDS

8.1.5 Explosion 5. 15 August 1973

North of the Tashkent Basin is a region of dry sediments of the order of 100 m thick but the spike filtered records of the explosion (figures 8.1.5(a) and (b)) indicate an explosion at a depth well below the superficial sediments. Earthquakes of magnitude m_b $6\frac{1}{2}$ have been located near this area and, as seismic areas are commonly associated with areas of high attenuation, this may be what causes the relatively small P wave at GBA. The yield is 25 kton at a depth of 670 m. The complexity shortly after the P wave may be caused by reverberation in the dry, low velocity sediments overlying the shot point.

TABLE 8.1.5

PDE DATA CARD NO. 50-73 EXPLOSION NO. 5

Date: 15 August 1973 Geographical Location: Tadzhik SSR

Epicentre: 42.711°N Origin Time: 01 59 57.8

67.410°E m_b 5.3

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	46.1	311.5	67.8	0.6	02 08 26.7	5.63
YKA	75.2	1.0	67.8	1.0	02 11 42.5	5.64
GBA	30.2	160.4	3.5	0.6	02 06 11.0	4.14
WRA	87.5	120.0	56.2	0.8	02 12 48.6	5.70

Multiple Array Location: 42.65°N
67.83°E

Origin Time: 01 59 57.9 GMT

Average Array m_b: 5.66
(excluding GBA)

Shift Relative to
PDE Location: 35 km 100.2°E of N

Estimated Yield: 25 kton

Estimated Depth: 670 m

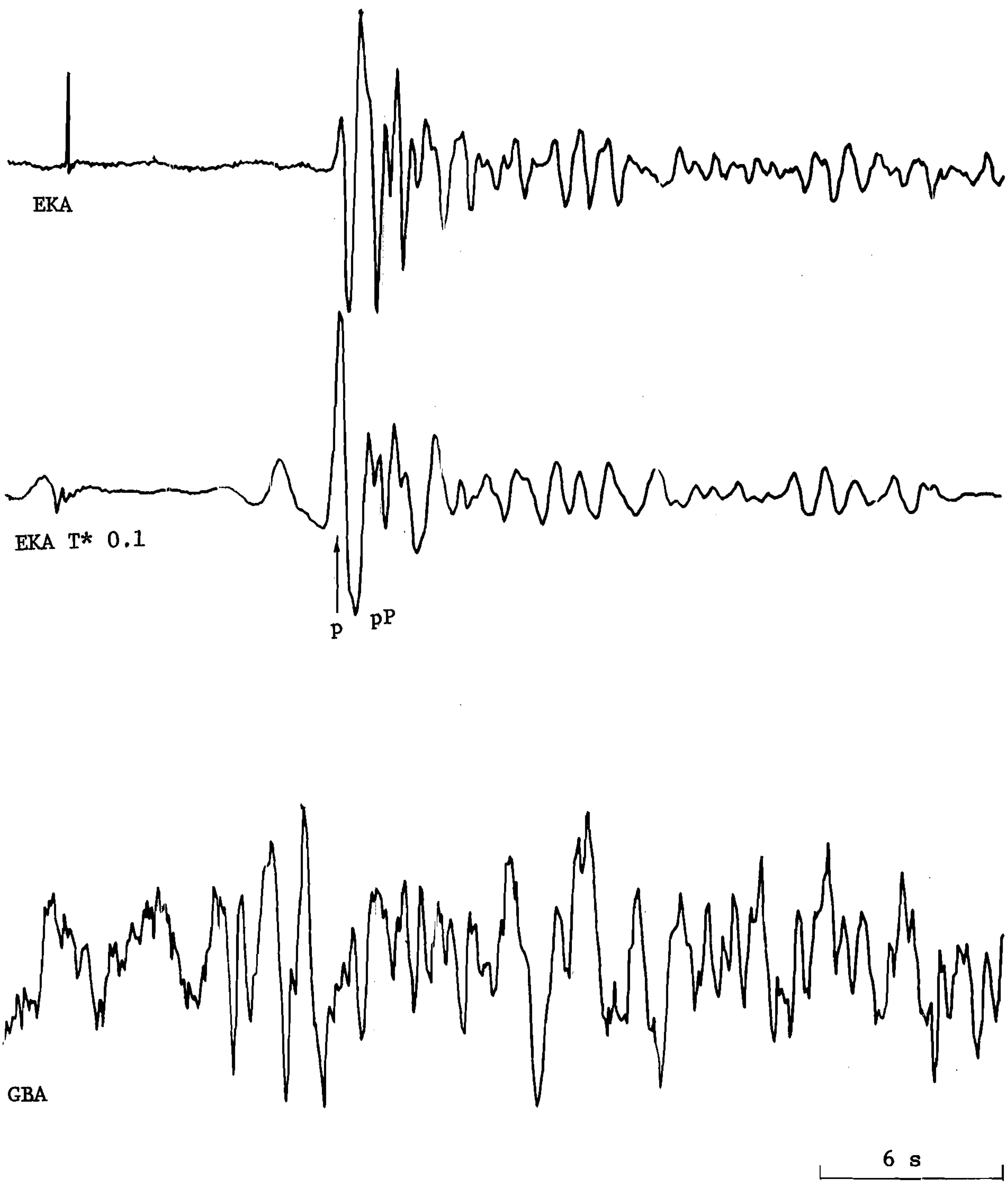

FIGURE 8.1.5(a). THE SUM-ALL UNFILTERED RECORDS AT ESKDALEMUIR AND GAURIBIDANUR. THE SPIKE FILTERED RECORD IS FROM ESKDALEMUIR

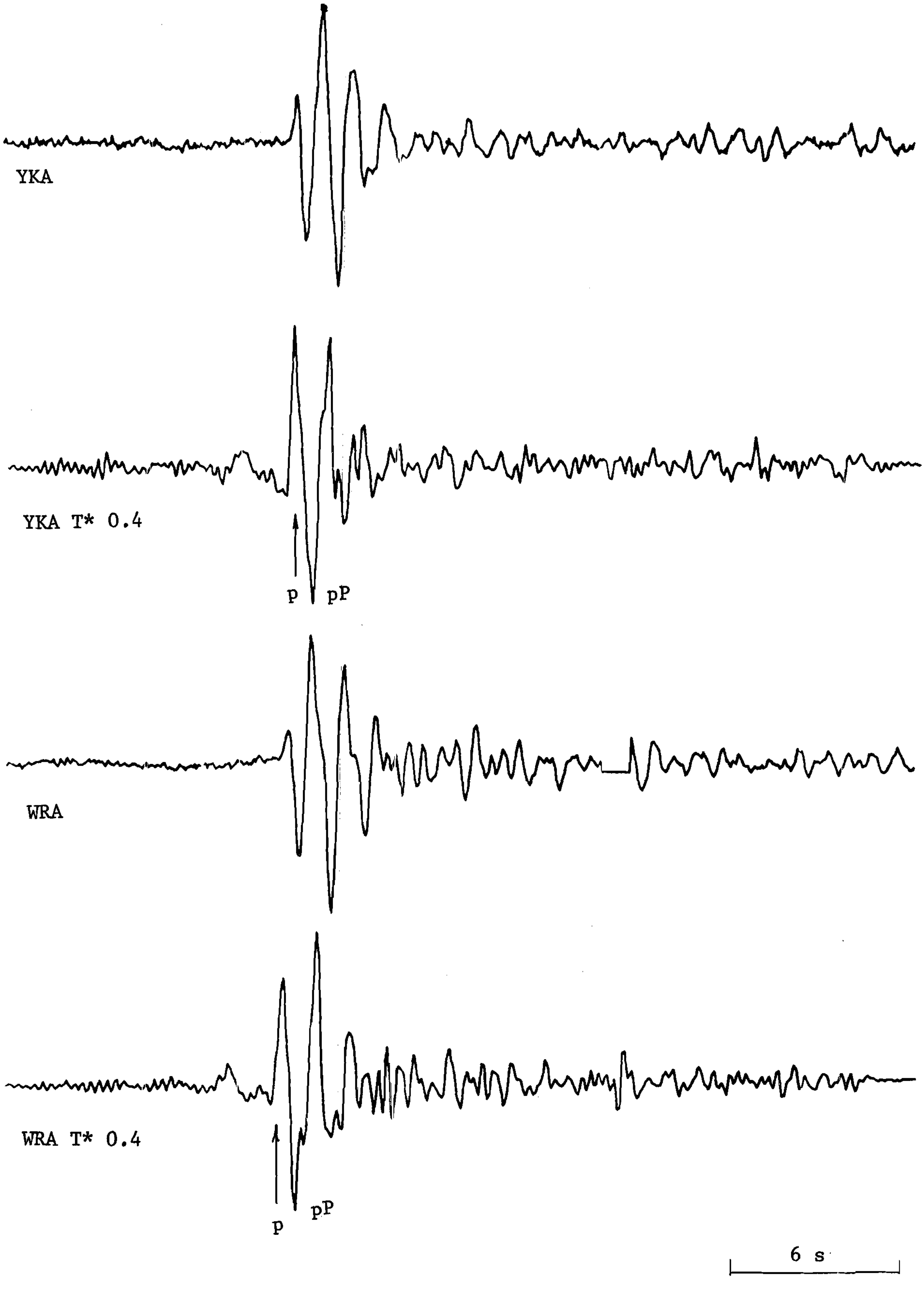

FIGURE 8.1.5(b). THE SUM-ALL UNFILTERED AND SPIKE FILTERED RECORDS FROM YELLOWKNIFE AND WARRAMUNGA

8.1.6 Explosion 6, 19 September 1973

The epicentre is due north of explosion 5 and is further from the seismically active zone. Seismic transmission should be good from this area so the high frequencies observed at the four array stations are not unexpected. The depth is estimated to be about 1200 m which means the coupling should be efficient and on this assumption the yield is estimated to be 20 kton.

TABLE 8.1.6

PDE CARD DATA NO. 56-73

EXPLOSION NO. 6

Date: 19 September 1973

Geographical Location: Central Kazakh

Epicentre: 45.64°N
67.85°E

Origin Time: 02 59 57.2

m_b 5.2

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	44.3	309.4	42.4	0.8	03 08 09.5	5.22
YKA	72.2	1.2	17.7	0.6	03 11 24.6	5.15
GBA	33.0	162.7	20.1	0.4	03 06 35.9	5.00
WRA	88.8	120.4	9.3	0.5	03 12 55.8	5.30

Multiple Array Location: 45.65°N
67.60°E

Origin Time: 02 59 57.3 GMT

Average Array m_b: 5.17

Shift Relative to
PDE Location: 19.7 km 275.9°E of N

Estimated Yield: 20 kton

Estimated Depth: 1200 m

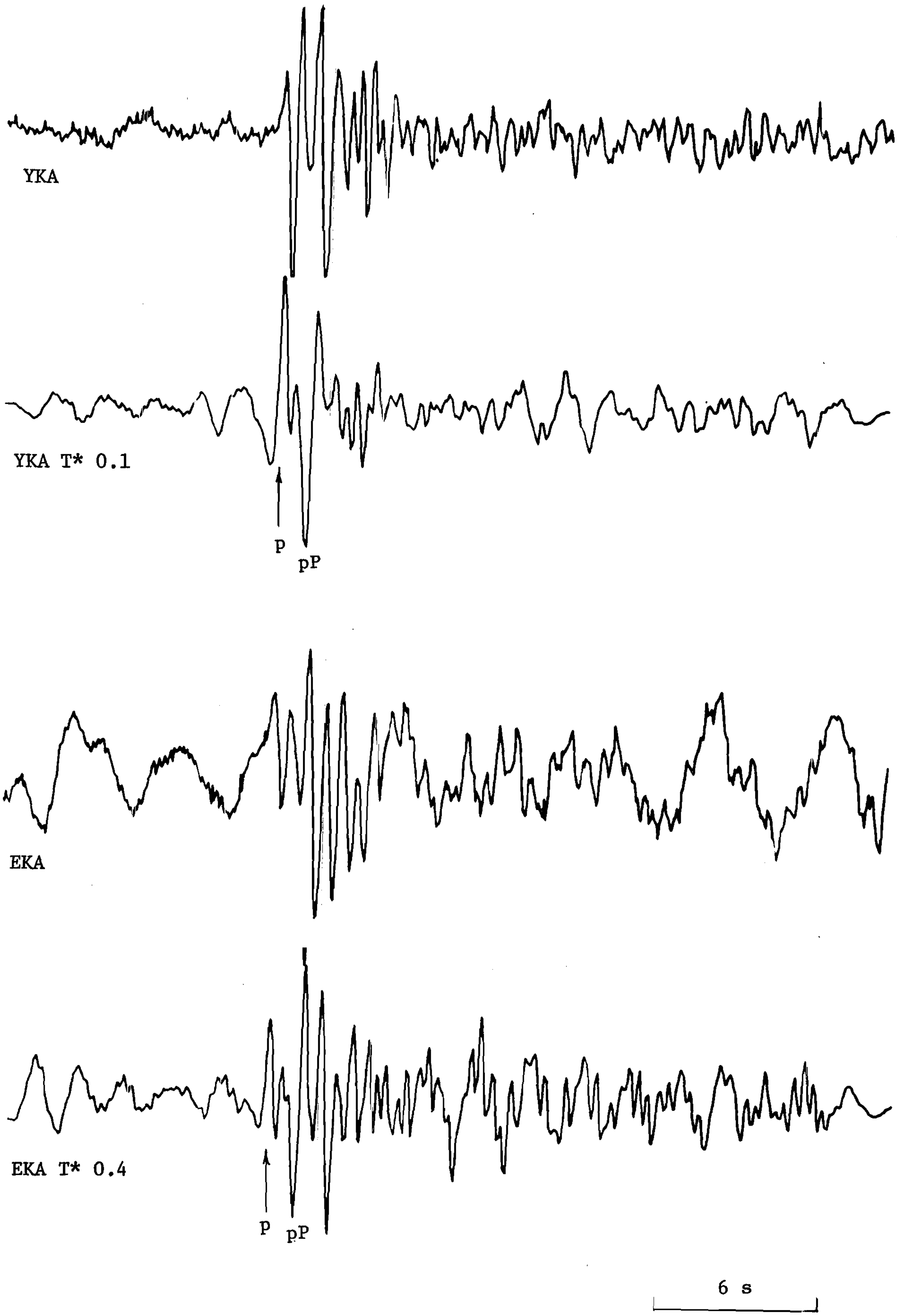

FIGURE 8.1.6(a). SUM-ALL UNFILTERED AND SPIKE FILTERED SEISMOGRAMS FROM YELLOWKNIFE AND ESKDALEMUIR

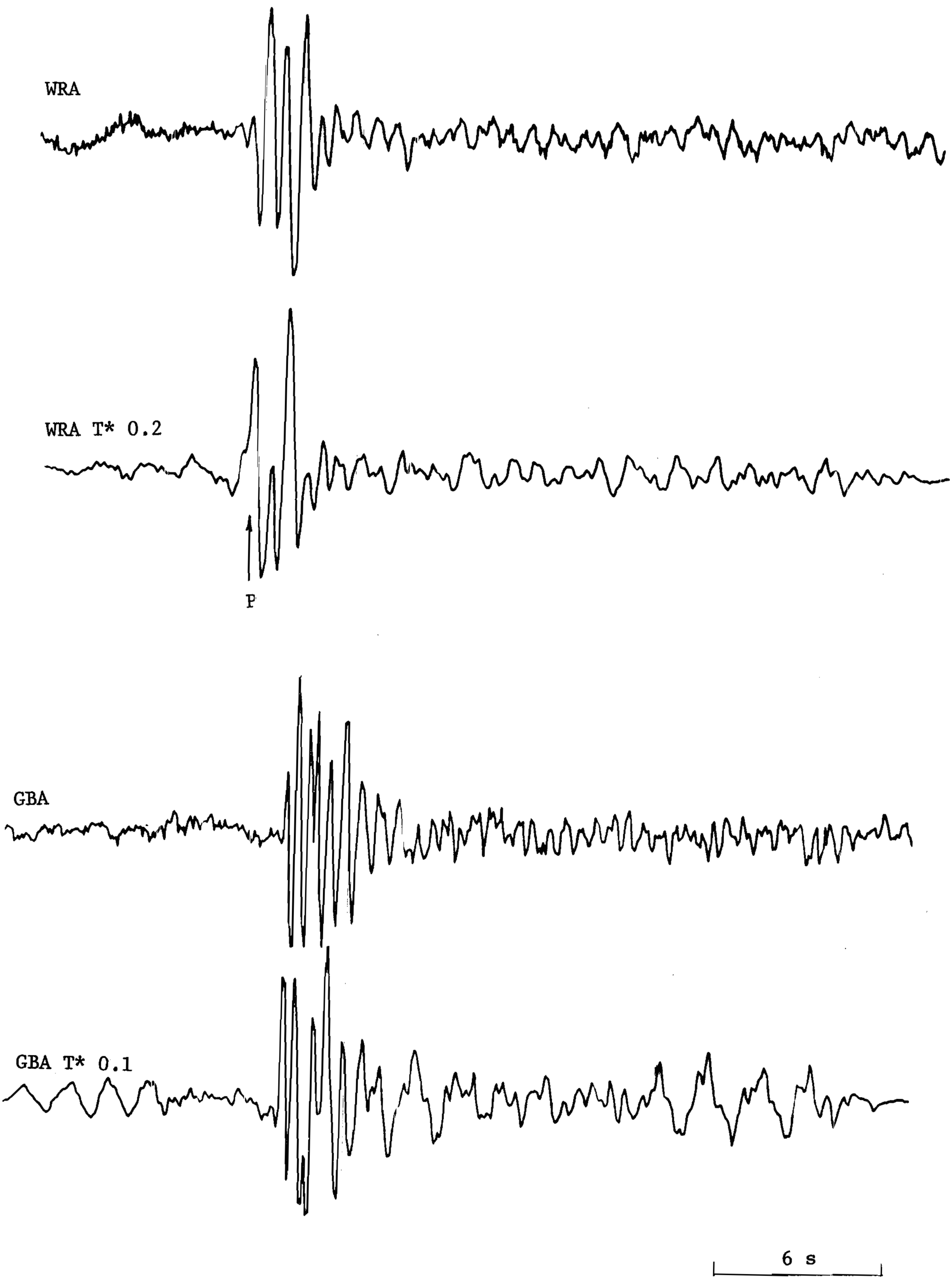

FIGURE 8.1.6(b). SUM-ALL UNFILTERED AND SPIKE FILTERED RECORDS FROM WARRAMUNGA AND GAURIBIDANUR

8.2 The Russian Platform

8.2.1 Explosion 7. 20 August 1972

The explosion occurred within the North Caspian Basin, an area which subsided throughout the Permian and Mesozoic times, receiving 4 to 10 km of sediments in the process. Many dome and other gentle uplift structures of platform type formed at this time. The estimated depth is 840 m, deep enough to be possibly associated with a salt dome feature. However, the frequency looks suspiciously low for salt coupling and it is unlikely that the high frequencies have been removed by the upper mantle structure in the source region because of the high Pn velocity (8.15 km/s). The complexity of the P wave train suggests that there are low velocity superficial sediments in the area and that the shot occurred beneath a particularly thick surface layer. The yield is estimated to be 70 kton.

TABLE 8.2.1

PDE DATA CARD NO. 49-72 EXPLOSION NO. 7

Date: 20 August 1972 Geographical Location: Western Kazakh SSR

Epicentre: 49.462°N 48.179°E Origin Time: 02 59 57.9

m_b 5.7

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	31.3	300.7	242	1.0	03 06 21.0	6.08
YKA	67.6	351.4	82.8	1.2	03 10 56.9	5.92
GBA	43.1	135.9	Detected but processing fault			
WRA						

Average Array m_b: 6.00 Estimated Depth: 840 m

Estimated Yield: 70 kton

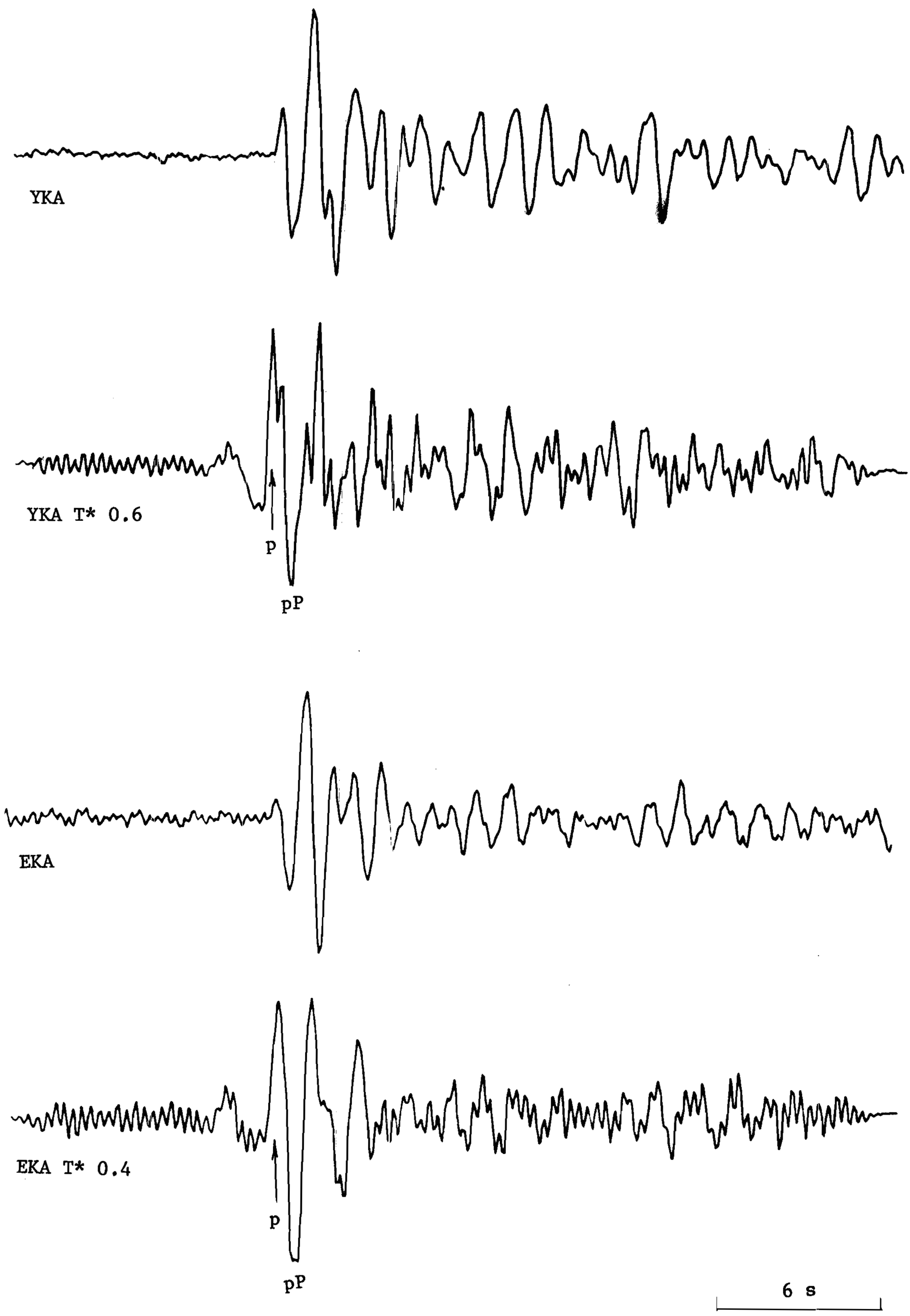

FIGURE 8.2.1. SUM-ALL UNFILTERED AND SPIKE FILTERED SEISMOGRAMS FROM YELLOWKNIFE AND ESKDALEMUIR

8.2.2 Explosion 8. 30 September 1973

Detonated on the boundary between the North Caspian Basin and the South Urals Basin, the velocity-depth structure of this area is typical of platform structure, consisting of a three-layer crust with a mantle Pn velocity of 8.15 km s^{-1}. Propagation away from this region should be efficient with the possible exception of rays which penetrate the upper mantle beneath the Urals. Certainly the ray to YKA appears to have transversed more complex paths than the ray to EKA but the effect, if any, is quite small. It may be that, the epicentre is sufficiently wide of the Ural structure that the downward going P wave is sufficiently deep to avoid the structure. The yield for this explosion is estimated to be 22 kton.

TABLE 8.2.2

PDE DATA CARD NO. 58-73

EXPLOSION NO. 8

Date: 30 September 1973

Geographical Location: Western Kazakh SSR

Epicentre: 51.608°N 54.582°E

Origin Time: 04 59 57.5

m_b 5.2

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	33.5	299.5	42.4	0.8	05 06 41.0	5.33
YKA	66.0	354.5	17.0	0.7	05 10 45.9	5.23
GBA						
WRA						

Multiple Array Location: 51.70°N 54.82°E

Origin Time: 04 59 57.5 GMT

Average Array m_b: 5.28

Shift Relative to PDE Location: 14.5 km 314.2°E of N

Estimated Yield: 22 kton

Estimated Depth: 600 m

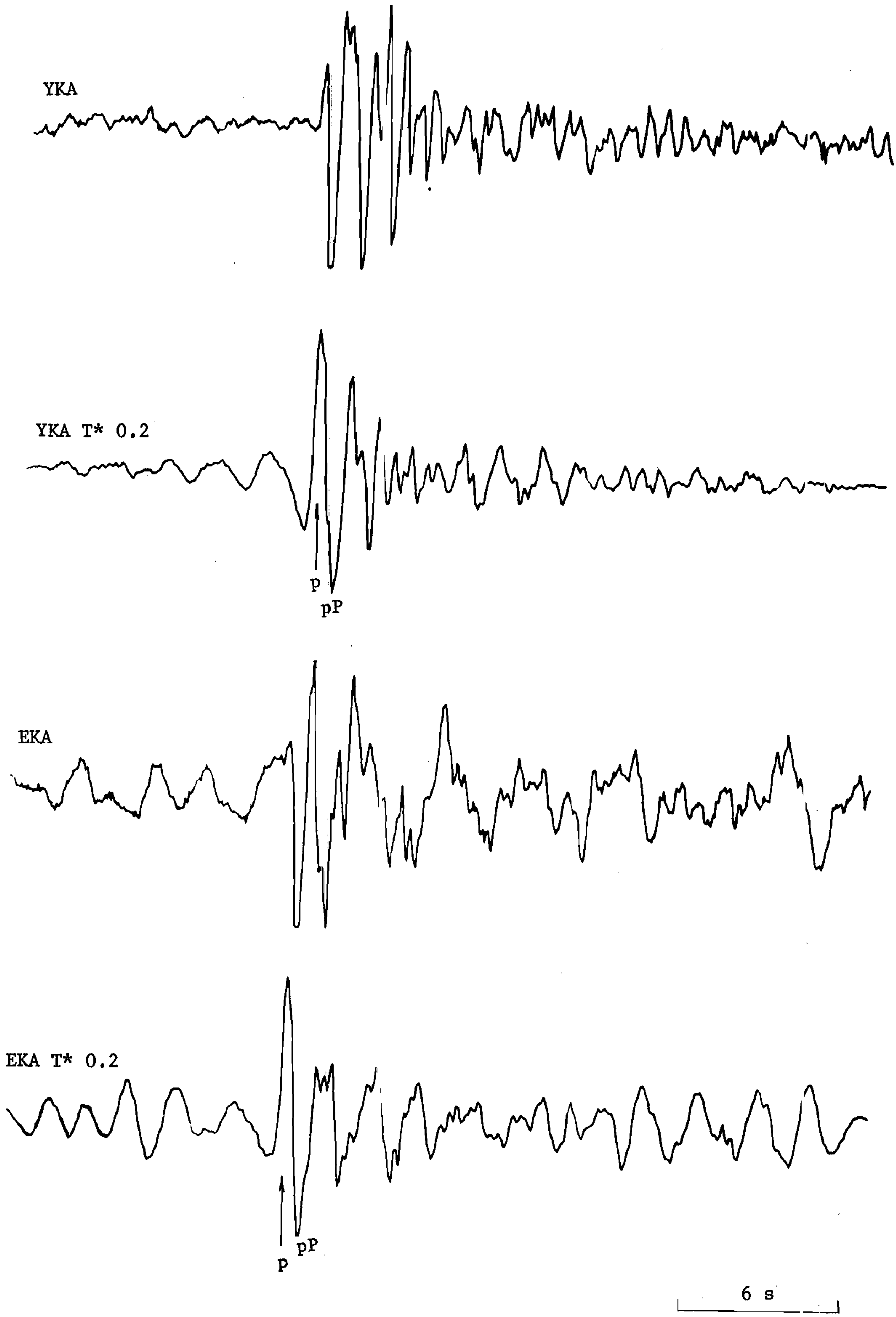

FIGURE 8.2.2. SUM-ALL UNFILTERED AND SPIKE FILTERED SEISMOGRAMS FROM YELLOWKNIFE AND ESKDALEMUIR

8.2.3 Explosion 9. 21 September 1972

8.2.4 Explosion 10. 24 November 1972

The explosions occurred close to each other in the Kuybyshev area of the Volga-Ural Uplift region of the Russian Platform. This aseismic area is known to be rich in gas and oil deposits with many salt dome structures. The crustal thickness is of the order of 35 km and the Pn velocity is 8.15 km s^{-1}. Propagation away from this region should be good unless the P waves are perturbed by the structure underlying the Urals.

The seismograms from these explosions are significantly different from other seismograms generated by PNE explosions in the Soviet Union. They appear to be made up of two pulses with distinctly different amplitudes. In each signal we can see a clear compressional first onset followed by a dilatational pulse, a third compressional pulse is then observed. Given a low velocity superficial layer above the shot point, it is possible, and has been confirmed by model studies, for a reverberation within this layer to give rise to a third compressive pulse. This pulse is, we believe, often confused with or mis-identified as a "slap-down" pulse, although a dry, low velocity unwelded superficial layer presents the ideal circumstances for "slap-down" generation to occur.

An alternative explanation, but not preferred, is that there are two explosions fired about 1.1 s apart similar to the MEDEO explosions in which conventional explosives of 1.7 and 3.6 kton were fired at the same location but separated by 3.6 s [9].

Assuming only a single explosion for each event, we estimate the yield of explosion 9 to be 18 kton at a depth of 480 m and 7 kton and a depth of 550 m for explosion 10.

TABLE 8.2.3

PDE DATA CARD NO. 59-72 EXPLOSION NO. 9

Date: 21 September 1972 Geographical Location: Western Russia

Epicentre: 52.127°N Origin Time: 09 00 01.2

51.994°E m_b 5.1

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	32.1	298.0	14.5	0.6	09 06 26.3	4.56 4.86
YKA	65.2	353.2	8.4 14.1	0.8	09 10 41.3	4.62 5.15
GBA	43.5	142.6	20.8	0.4	09 08 03.9	4.44 4.81
WRA			Core shadow:	not processed		

Multiple Array Location: 52.13°N 51.86°E Origin Time: 08 59 56.7 GMT

Average Array m_b: 4.94 Shift Relative to PDE Location: 9 km 268.9°E of N

Estimated Yield: 18 kton Estimated Depth: 480 m

TABLE 8.2.4

PDE DATA CARD NO. 73-72 EXPLOSION NO. 10

Date: 24 November 1973 Geographical Location: Western Russia

Epicentre: 52.78°N Origin Time: 09 00 08.0

51.07°E m_b 4.7

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	31.3	296.7		Not	recorded	
YKA	64.5	352.7	3.6 14.7	0.6 0.8	09 10 42.6	4.38 5.27
GBA	44.4	107.4	6.1	0.8	09 08 03.9	3.99 4.28
WRA			Core shadow:	not processed		

Average Array m_b: 4.78 Estimated Depth: 550 m

Estimated Yield: 7 kton

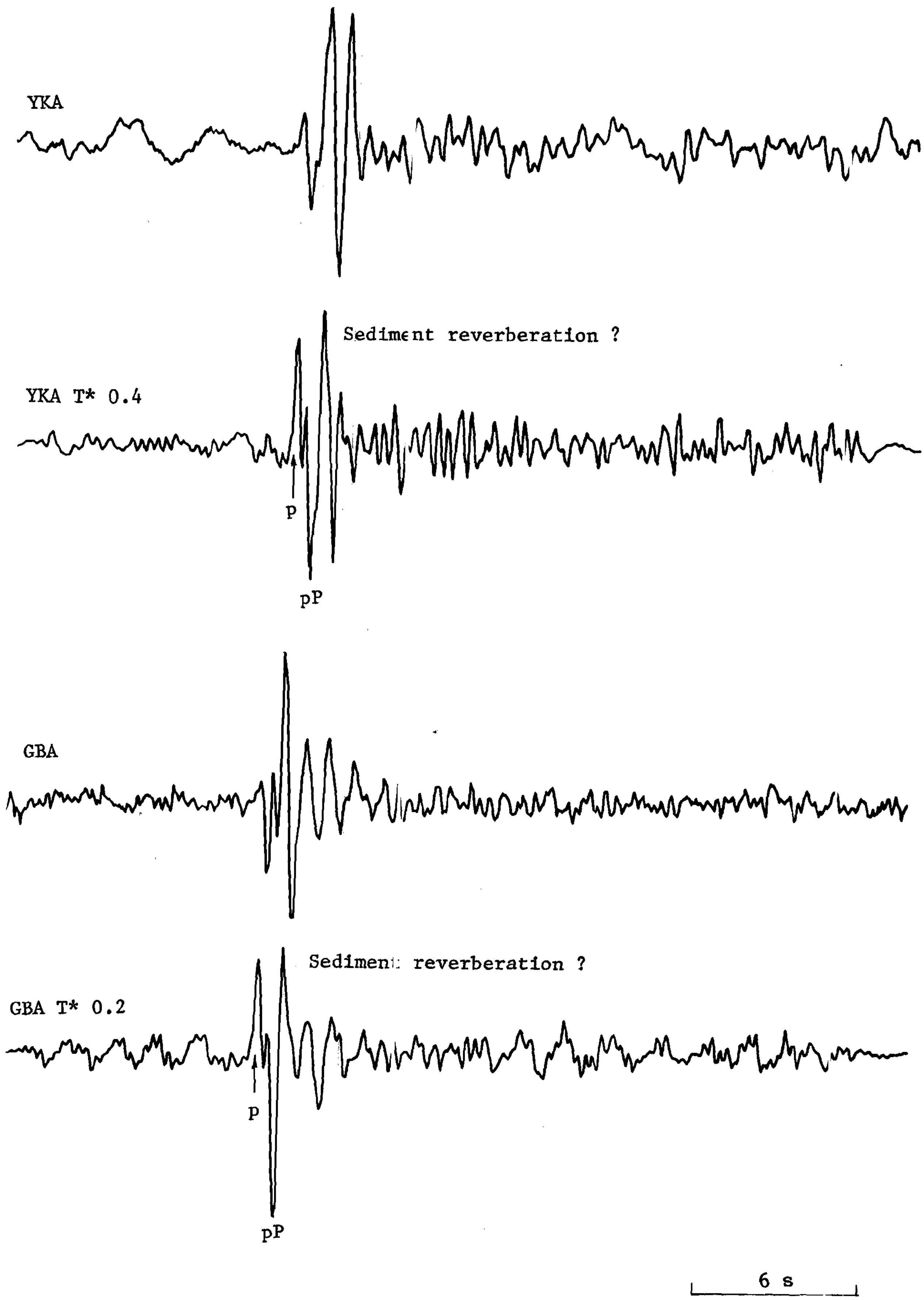

FIGURE 8.2.3(a). SUM-ALL UNFILTERED AND SPIKE FILTERED SEISMOGRAMS FROM YELLOWKNIFE AND GAURIBIDANUR

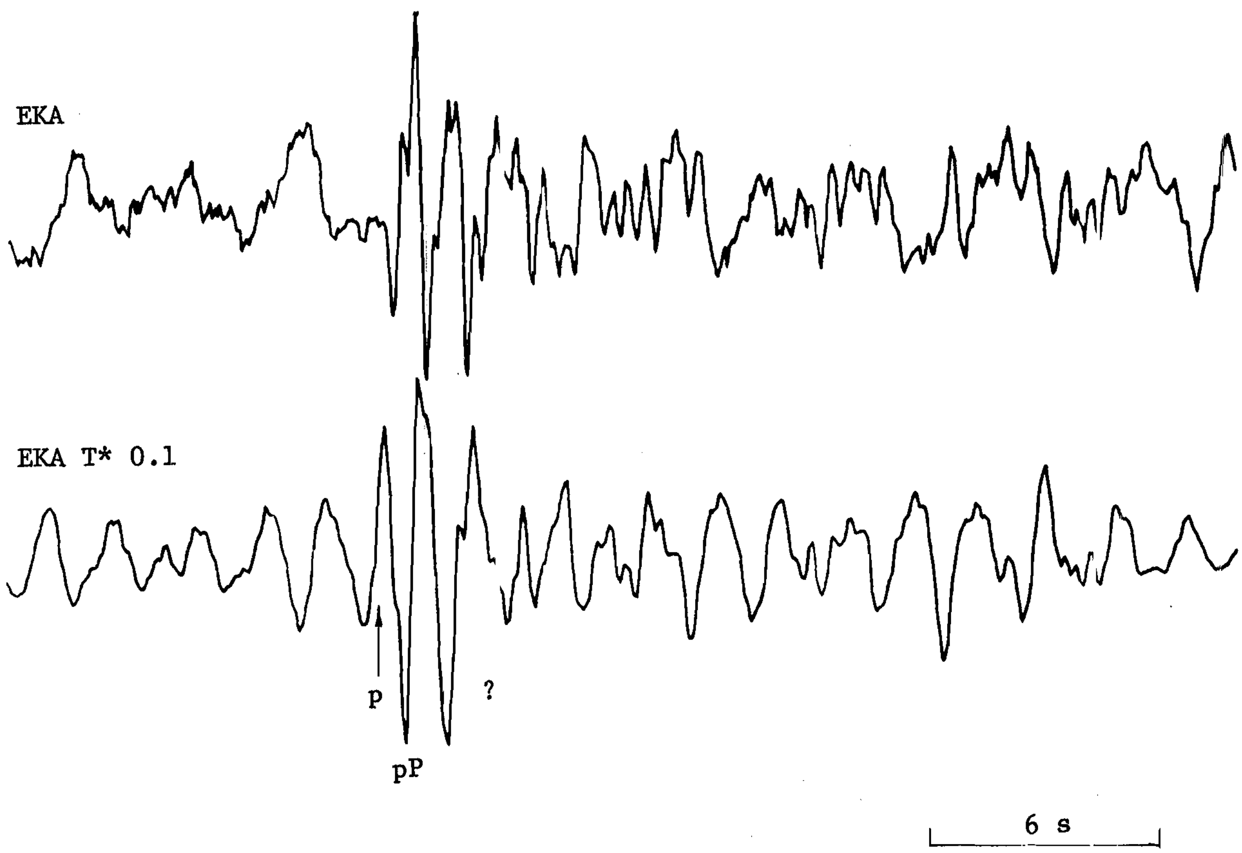

FIGURE 8.2.3(b). SUM-ALL UNFILTERED AND SPIKED SEISMOGRAMS FROM ESKDALEMUIR

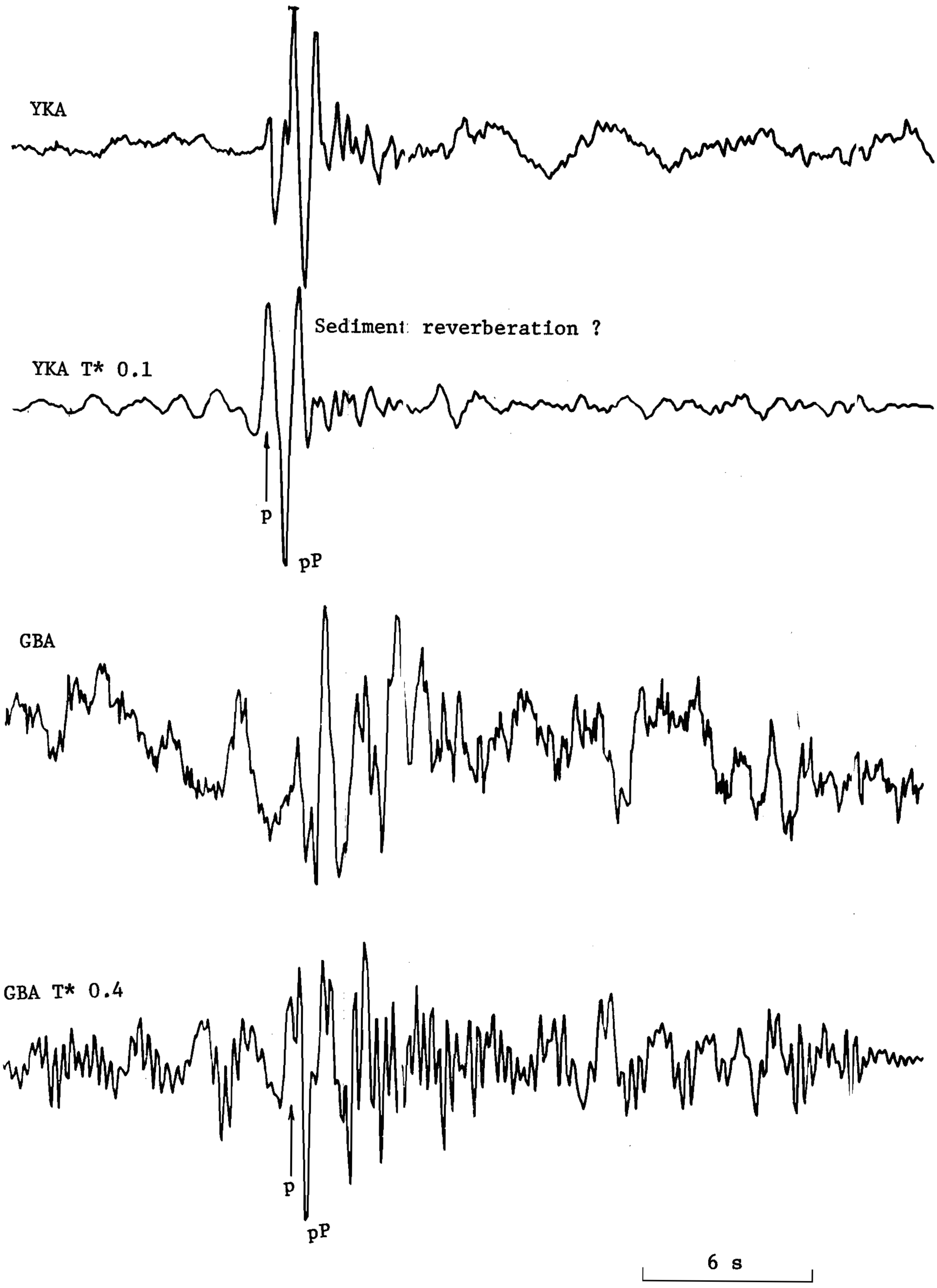

FIGURE 8.2.4. SUM-ALL UNFILTERED AND SPIKED SEISMOGRAM FROM YELLOWKNIFE AND GAURIBIDANUR

8.2.5 Explosion 11. 9 July 1972

Within the Dneiper Trough region of the Russian Platform where this explosion took place, the crustal thickness is of the order of 45 - 50 km. Deep normal faults bounding the Dneiper Trough extend at least into the upper mantle. Numerous deep-seated faults occur at the granite basalt interface. Thick, low velocity sediments lie in the trough and become very thin in the region of the Voronezh Uplift. There are many salt domes in the area as well as large deposits of gas and oil. The upper mantle Pn velocity is 8.1 km s^{-1} which indicates good seismic wave transmission away from the region, but the complicated and faulted structure could produce azimuthally varying signals. The explosion was detonated at 2500 m depth which implies that it may be associated with a stimulation experiment within the oil fields. The yield is estimated to be 16 kton.

TABLE 8.2.5

PDE DATA CARD NO. ISC Data

EXPLOSION NO. 11

Date: 9 July 1972

Geographical Location: Kharkov Region

Epicentre: 49.78°N
35.40°E

Origin Time: 06 59 57.9

m_b 4.8

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	23.9	298	10.0	0.5	07 05 14.8	4.60
YKA	65.6	345	9.6	0.8	Time Code Error	5.01
GBA	49.7	121	4.4	0.6	07 08 53.4	4.60
WRA		Core shadow: not processed				

Average Array m_b: 4.73

Estimated Depth: 2500 m

Estimated Yield: 16 kton

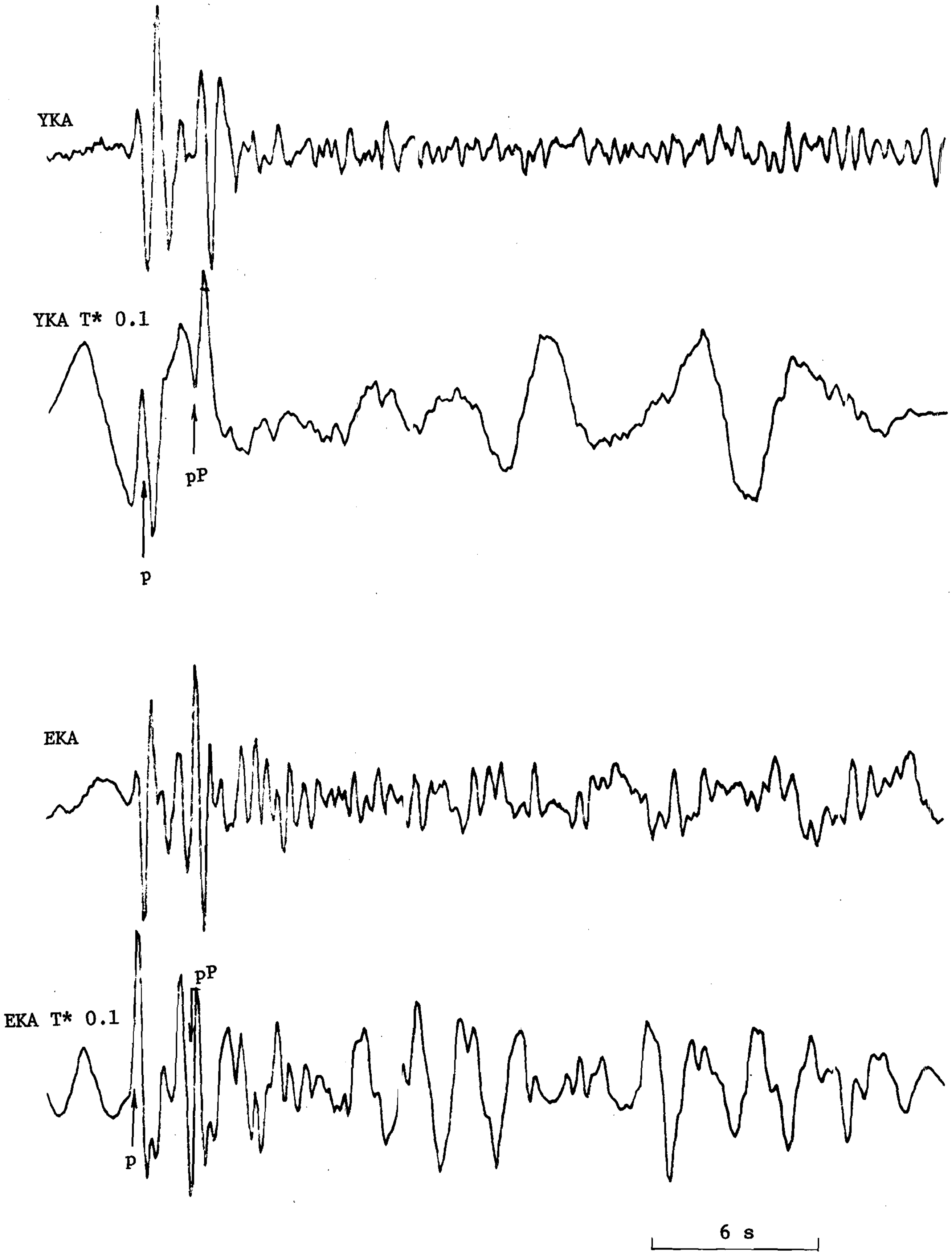

FIGURE 8.2.5(a). SUM-ALL UNFILTERED AND SPIKE FILTERED SEISMOGRAMS FROM YELLOWKNIFE AND ESKDALEMUIR

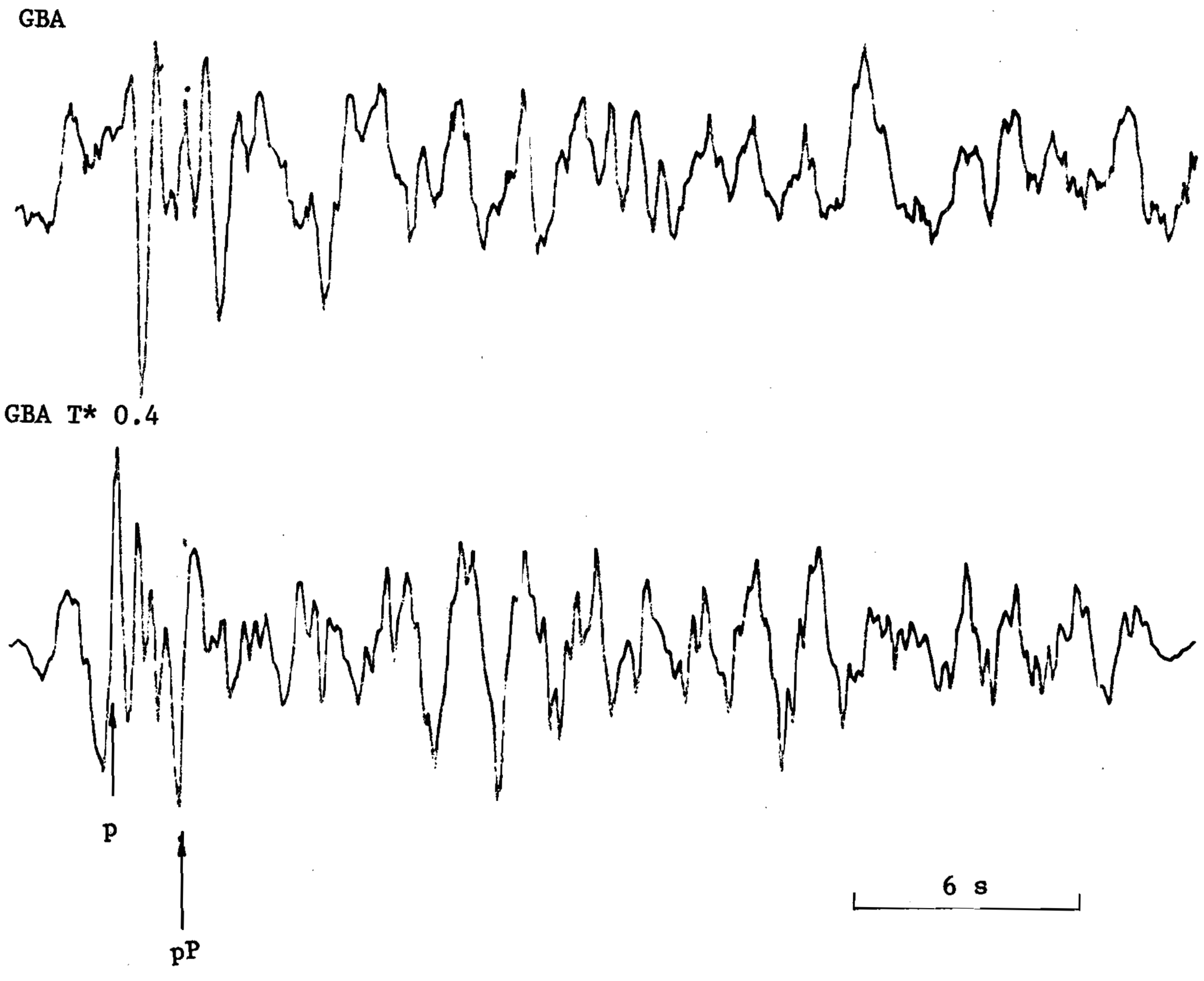

FIGURE 8.2.5(b). SUM-ALL UNFILTERED SEISMOGRAMS AND SPIKE FILTERED SEISMOGRAM FROM GAURIBIDANUR

8.3 The Kazakh Fold System Area

8.3.1 Explosion 12. 28 August 1973

This explosion occurred in the Tengiz Basin within the same tectonic region as the Soviet test site at Semipalatinsk, although the epicentral location is well away from the test site. The crust is around 45 km thick and the Pn velocity may be 8.5 km s^{-1} which is unusually high. Assuming that this is so, the yield is estimated to be 12 kton, but from the seismograms the explosion could have been very shallow with virtually no free surface reflection so the yield estimate may be as high as 25 kton.

TABLE 8.3.1

PDE DATA CARD NO. 54-73 EXPLOSION NO. 12

Date: 28 August 1973

Geographical Location: Central Kazakh

Epicentre: 50.550°N
68.395°E

Origin Time: 02 59 57.6

m_b 5.3

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	41.6	305.3	27.8	0.6	03 07 48.4	4.70
YKA	67.3	1.5	38.0	0.6	03 10 54.5	5.36
GBA	37.5	165.5	4.8	0.5	03 07 15.6	4.48
WRA	91.0	120.8	7.0	1.0	03 13 04.3	4.93

Multiple Array Location: 50.62°N
68.49°E

Origin Time: 02 59 57.3 GMT

Average Array m_b: 4.87

Shift Relative to
PDE Location: 10.7 km 39.3°E of N

Estimated Yield: 10 - 40 kton

Estimated Depth: Very shallow

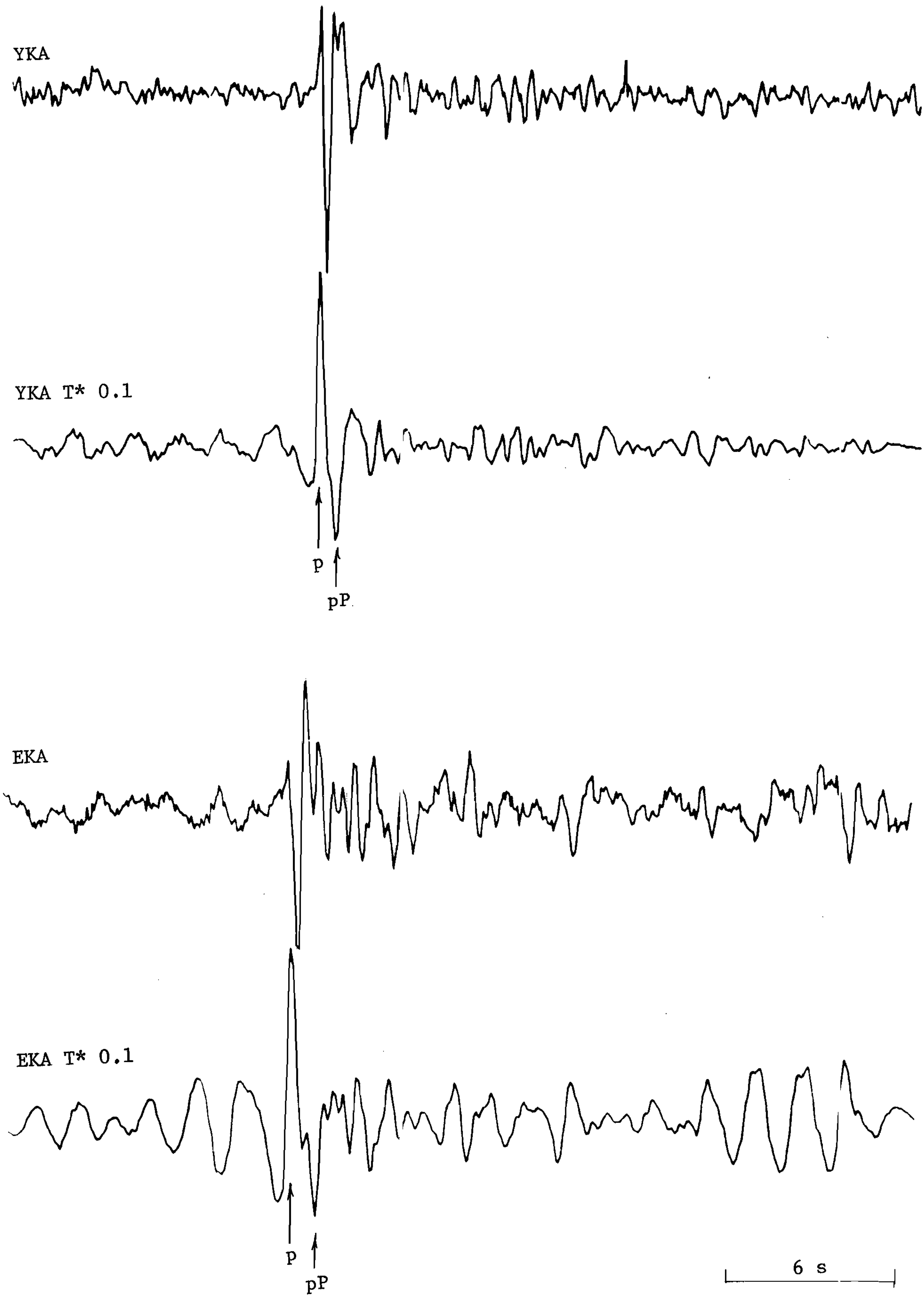

FIGURE 8.3.1(a). SUM-ALL UNFILTERED AND SPIKED SEISMOGRAMS FROM YELLOWKNIFE AND ESKDALEMUIR

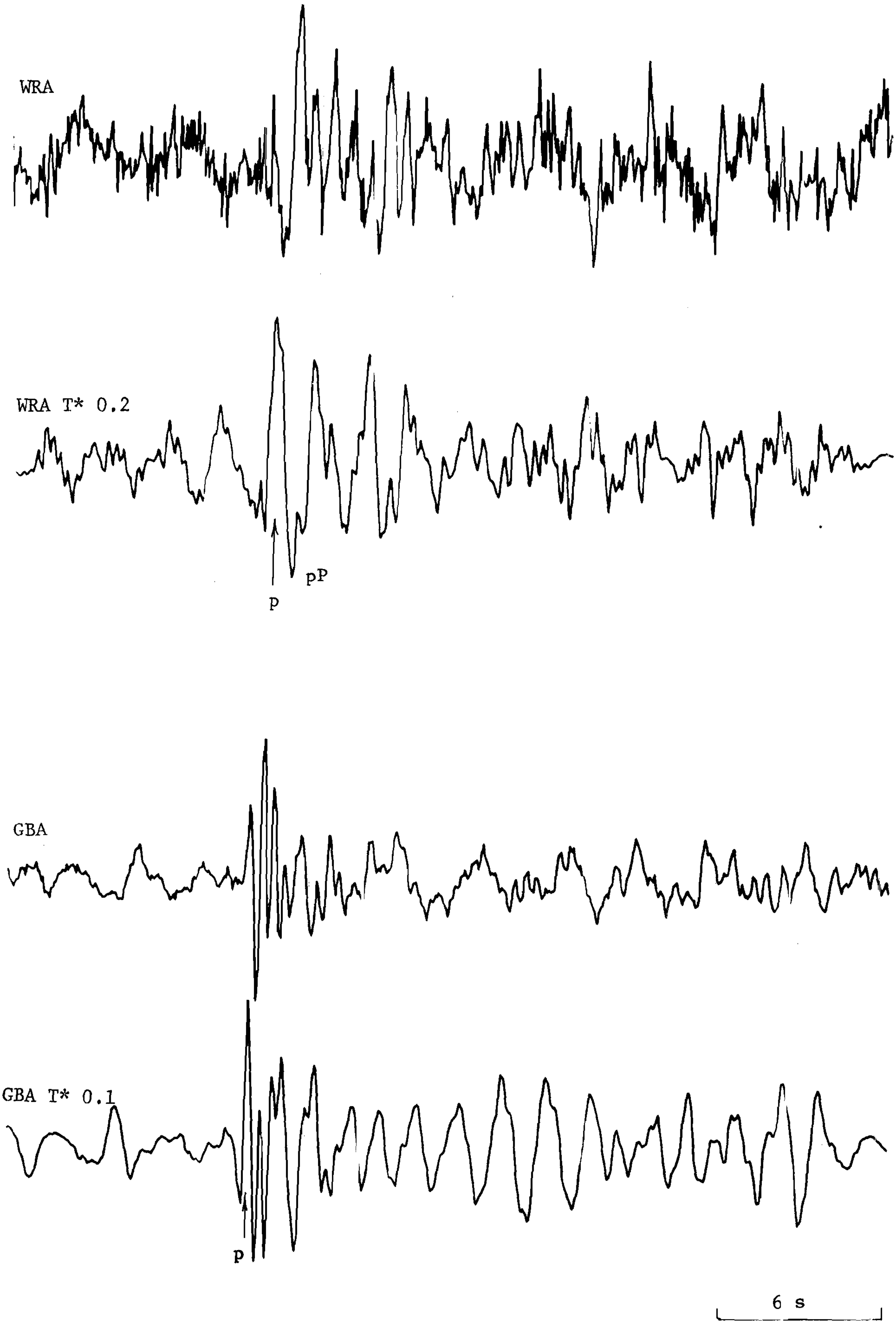

FIGURE 8.3.1(b). SUM-ALL UNFILTERED AND SPIKED SEISMOGRAMS FROM WARRAMUNGA AND GAURIBIDANUR

8.4 Explosion within the Baltic Shield Basin

8.4.1 Explosion 13. 4 September 1973

This is the only large explosion recorded within the Baltic Shield region in an area of apatite mining close to the town Apatity so it may be associated with the mining activity in this area.

The Eskdalemuir record is typical of "second zone" seismograms showing many arrivals after the direct P wave. The magnitude is very low but this is probably caused by the regional variations from the standard Gutenberg and Richter distance correction term used in the magnitude determinations. However, Yellowknife gives a normal teleseismic P wave which, on analysis, indicates a depth of the order of 350 m. The yield is estimated to be in the range 5 - 10 kton depending on whether it was nuclear or chemical.

TABLE 8.4.1

PDE DATA CARD NO. 52-72

EXPLOSION NO. 13

Date: 4 September 1972

Geographical Location: Western Russia

Epicentre: 67.689°N
33.445°E

Origin Time: 07 00 03.6

m_b 4.6

Array Station	Δ°	Source to Station Az°	Amplitude, mμ	T, s	Onset Time	Magnitude
EKA	21.0	252.0	6.5	0.4	07 04 48.3	3.91
YKA	48.1	340.7	7.8	0.6	07 08 43.8	4.79
GBA	61.1		Not recorded			
WRA		Core shadow: not processed				

Average Array m_b: 4.35

Estimated Depth: 0 - 350 m

Estimated Yield: 5 - 10 kton

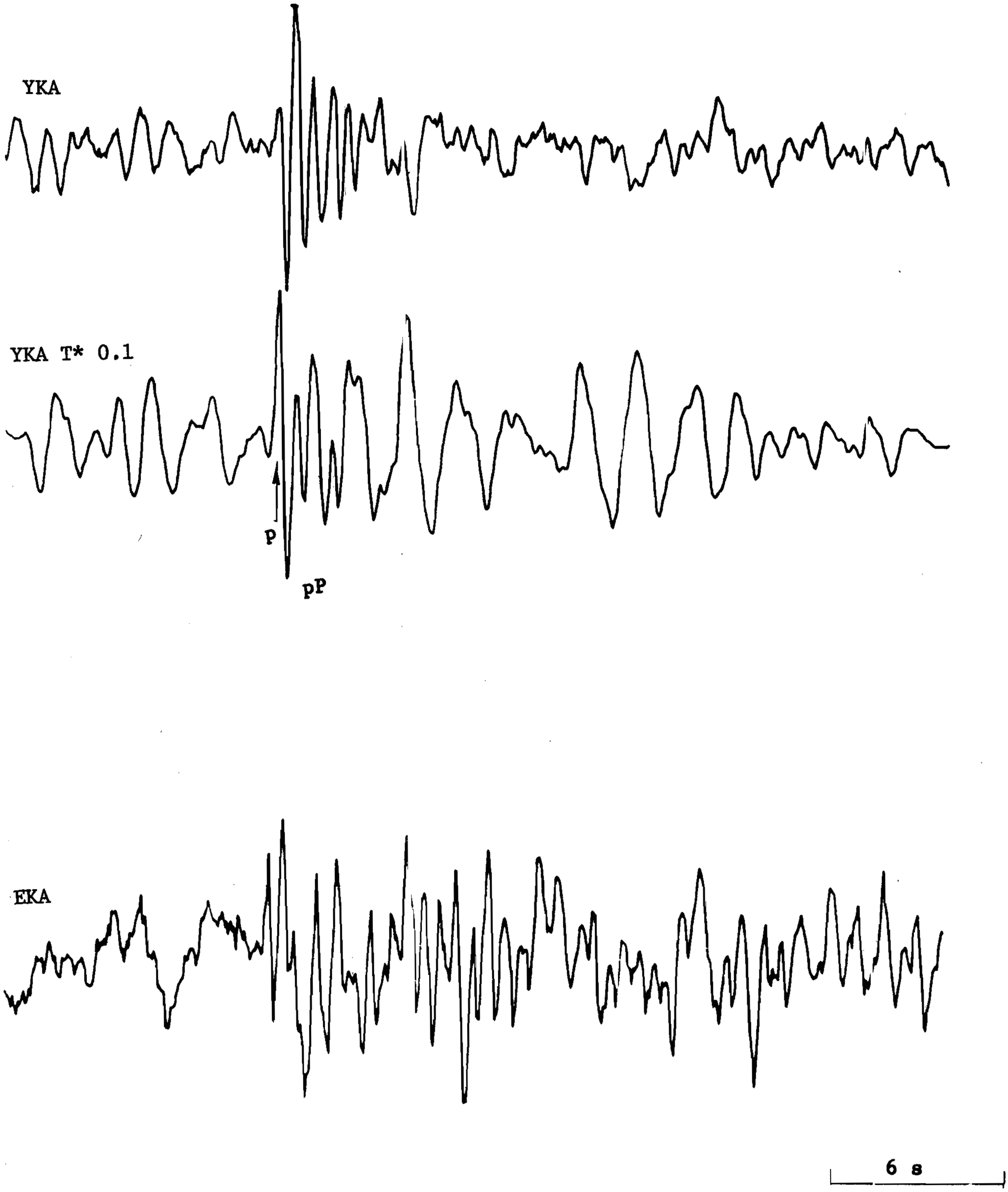

FIGURE 8.4.1. SUM-ALL UNFILTERED SEISMOGRAM FROM ESKDALEMUIR AND YELLOWKNIFE AND SPIKE FILTERED SEISMOGRAM FROM YELLOWKNIFE

9. ACKNOWLEDGMENTS

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Abstract

Short period seismological array data from four medium aperture arrays have been analysed to estimate the location and depth of presumed underground explosions conducted as part of the Soviet programme of Peaceful Nuclear Explosions (PNE) during 1972 and 1973. No evidence is presented to confirm that these are explosions or that they are nuclear. The explosions considered here were detonated at locations which are in general aseismic and well away from the underground explosion test sites in Kazakh and Novaya Zemlya.

Yield estimates for the explosions are made based on the world-wide average m_b values determined from the P waves.