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RECONNAISSANCE SURVEY OF CENTRAL ASIAN P TIMES

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SUMMARY

Three hundred and forty seven observations from four suitable deep focus (0.026 R) earthquakes of Central Asian region have been studied as a first step towards constructing regional travel-time tables for Central Asia.

Times calculated for the earthquakes of this region have been compared with European Times and Jeffreys–Bullen times. Residuals with respect to European times show both negative and positive trend whereas with respect to Jeffreys and Bullen times they are negative for most of the distances. Calculated times show closer agreement with European times than with Jeffreys-Bullen times for most of the ranges of distances.

INTRODUCTION

For the last 75 years nearly seismology has been an important tool to give us information about the interior of the earth. The maximum information is being given by the travel times of the seismic waves because, these waves, which reach at the surface, come with complete history of the properties of the material they have passed through. Jeffreys and Bullen (1940) calculated the times of these seismic waves by using the statistical methods. The elegance of this method is evident from the fact that they stood to the test of times for over 37 years. In the second part, seismologists rightly started thinking about the regional travel times to know about the detailed information of the interior of the Earth since they are of the opinion that not much can be had by improving the J.B. times as Jeffreys (1939) remark "The present *P*, *S*, *PKP* and *SKS* tables all rest now on observational material through their entire course, it would be impossible to alter any of them to give better agreement with one old or new set of observations without making agreement worse with another. Though we have apparently reached the stage where further improvement is impossible for all earthquakes, since small departures from independence of the errors are beginning to reveal themselves, further development is unlikely to lead to the substitution of any single set of tables for the present ones. It is more likely to lead to the introduction of minor corrections, not always of the same sign, that can be applied to the present tables in specified circumstances".

Arnold (1965) calculated the regional travel times for *P* and *S* waves for the Japanese region. Lapwood and Gogna (1969) calculated the travel times for *P* and *PKP* phases for the Pacific region. Agrawal (1975) studied the travel times of all the principal phases for the events of Indian region.

In this paper travel times for the Central Asian region have been calculated for the depth of 0.026 R since it was to have 4 suitable earthquakes for this depth range to give us a reconnaissance survey for this region.

SELECTION OF DATA

Four earthquakes occurring in Central Asia and having focal depths nearly equal to 0.026 R (varying between 0.0261 R and 0.0265 R) and having good number of obser-

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vations were taken from the bulletins of International Seismological Summary (I. S. S.). These earthquakes are listed in Table 1.

TABLE-I

SELECTED EARTHQUAKES

No.	Date	Timee h	m	s	Latitude	Longitude	Focal Depth
1	11.6.1957	04	57	26	36.56°N	70.58°E	0.0270R
2	7.3.1958	06	55	32	36.55°N	70.68°E	0.0270R
3	8.8.1958	12	52	09	36.64°N	71.04°E	0.0270R
4	12.9.1959	21	20	01	36.51°N	70.99°E	0.0260R

REVISION OF PARAMETERS

The parameters of the earthquakes viz. origin time, epicentre and focal depth were calculated by I.S.S. using J.B. times. Jeffreys (1954) demonstrated using normal earthquakes that European times [Jeffreys (1939)] were closer representative of Central Asian region. Therefore the parameters of the selected earthquakes were revised using European times.

Parameters given by I.S.S. were taken as trial ones and the observations of P arrival times were used in revising the parameters in the following manner:

First the equations of condition are formed in the following manner: Let T be the correction needed to the trial time of origin, x and y be the displacements needed to the trial epicentre (I.S.S.) to the south and to the east respectively measured as angles seen from the centre of the Earth and h' be the correction needed to the trial focal depth (I.S.S). A typical equation of condition is then

$$T+(x\cos\Phi-y\sin\Phi)\frac{dt}{d\Delta}+h'\frac{dt}{dh}=t_0-t_1;$$

where t_0 is the observed value of the time of transmission and t_1 is the calculated value. Φ is the azimuth of the station from the trial epicentre and is measured from north through east. Δ is the distance of the station from the epicentre. $\frac{dt}{d\Delta}$ and $\frac{dt}{dh}$ are taken from travel-time tables.

For each earthquake, the number of equations of condition will be same as the number of observing stations. These equations were solved with the aid of an electronic computer, adjustment for ellipticity being made. The revised parameters thus obtained

are listed in Table 2. Arnold (1965) suspected systematic error in the times at large distances due to faulty allowances for depth. For this reason it was thought necessary to fix the depth at the estimate given by including all observations, then solve for a new estimate of epicentre using observations upto 15°. These newly computed epicentres listed in Table 3, and other parameters (listed in Table 2) are adapted as final parameters of the earthquakes.

TABLE-2

RELOCATED PARAMETERS (OF EARTHQUAKE HYPOCENTRES) USING ALL OBSERVATIONS

No	Latitude	Longitude	Focal Depth
1	36.54°N ±0.04N	70.60° ±0.04E	0.026276 ±0.000585R
2	36.48° ±0.03N	70.66° ±0.03E	0.026344 ±0.000460R
3	36.54° ±0.03N	71.03° ±0.03E	0.026536 ±0.000458R
4	36.54° ±0.03N	70.96° ±0.03E	0.026093 ±0.000476R

TABLE-3

EARTHQUAKE PARAMETERS (OF HYPOCENTRES) RELOCATED USING OBSERVATIONS FOR $\Delta < 15°$ AND FREEZING THE DEPTH

No.	Latitude	Longitude
1	36.49°±0.03N	70.56°±0.03E
2	36.41°±0.03N	70.60°±0.03E
3	36.50°±0.02N	70.98°±0.03E
4	36.52°±0.03N	71.02°±0.05E

TABLE-4

SUMMARIES OF FREQUENCIES OF P RESIDUALS, X_i, AT 5° INTERVAL FOR $0° \leqslant \Delta \leqslant 105°$

Range (deg)	X_i	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9	10
0–5										2	8	27	17	6								
5–10		1					1		1	4	12	21	1	6		1						
10–15							1				2	7	2	1	1							
15–20								2	1	2	5	5	2	1	1	1						
20–25							1			2	7	2	4	4					1	1		
25–30										2	7	6	1	2	1							
30–35											4	1	1	1								
35–40								1		3	9	12	4					1				
40–45			1	1					1	1	9	15	9	8	2	2	1					
45–50			1			1			1	1	1	8	3	3								
50–55											4	6	6			1		1				
55–60								1			3	3	1						1			
60–65												2	2									
65–70											1	2	1									
70–75												4										
75–80											1	1	1									
80–85												1										
85–90																						
90–95											1	4	1	2								
95–100												3						1				
100–105												1					1					

UNSMOOTHED TIMES

The new epicentral distances of the stations observing *P* phase, the azimuths and the residuals (with respect to European *P* times) are calculated. Summaries of the frequencies of the *P* residuals are given in Table 4. These are combined together after subtracting the assumed means of 0.0, 0.0, −1.0, 3.0, 2.0, 1.0, 1.0, 1.0, 0.0, 0.0, −1.0, −1.0, −1.0, −1.0, 0.0, 1.0, 0.0, −1.0, 0.0 and 0.0s from the respective ranges. Summary of these residuals is given in Table 5. It is clear from the distribution of residuals in Table 5 that the mode of distribution is approximately at our zero. The standard deviation σ of the distribution can be calculated by Jeffreys's method (Jeffreys, 1935) by making an estimate of h, the precision constant.

TABLE-5

SUMMARY OF OBSERVED AND CALCULATED FREQUENCIES OF P RESIDUALS, X_i, FOR $0° \leqslant \Delta \leqslant 105°$

	X_i	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1
Observed		1	2	1	0	1	3	4	4	17	74
Calculated	1	0	0	0	0	0	0	1	9	39	97
(0–C)		1	2	1	0	1	3	3	−5	−22	−23
Calculated	2	0	0	0	0	0	1	2	2	15	72

	X_i	0	1	2	3	4	5	6	7	8	9	10
Observed		131	56	35	5	5	2	3	2	1	0	0
Calculated	1	131	97	39	9	1	0	0	0	0	0	0
(0–C)		0	−42	−4	−4	4	2	3	2	1	0	0
Calculated	2	129	54	33	3	3	0	1	0	0	0	0

There are 347 observations in all, of which 261 or 0.752 of the total lie between −1.5s and +1.5s. From a table of error function, we get

$$\text{erf } 0.82 = 0.75$$

Therefore,

$$1.5h = 0.82$$

or

$$h = 0.55$$

Using this value of h and the frequency at the mode, which is 131, the quantity 131 $\exp(-x_i^2 h^2)$ gives a frequency distribution called calculated (1) in Table 5. The difference $(O-C)$ suggests that the required reduction of frequencies should average 2. Subtracting this from the observed frequencies, the frequeney distribution called calculated (2) in Table 5 is obtained. Computing mean and standard deviation we get

$$\text{mean} = +0.08\text{s}, \ \sigma = 1.26\text{s}, \ h = 0.56$$

This repeats the previous the estimate of h sufficiently closely. Thus the value of the Jeffreys's parameter, μ, which is the ratio of the estimated reduction to the maximum exponential term, is given by

$$\mu = 2/129 = 0.0155$$

This value of μ is used in calculating the weights by the formula (Gogna, 1968),

$$W_i = (1 + \mu (x_i) \exp (h^2 x_i^2))^{-1};$$

These are given below:

Residuals+	Weights
0.0	0.98
±1.0	0.98
±2.0	0.95
±3.0	0.79
±4.0	0.30
±5.0	0.02

+ These are deviations of residuals from assumed mean residual of the range.

Adopting these weights, the mean for each range was calculated. The new means were applied as corrections to the Jeffreys's European times to obtain the unsmoothed travel-times, which are given in Table 6.

SMOOTHING

It is well known that near 20° epicentral distance there is a sharp discontinuity in the P wave travel-times. Gogna (1967) found this discontinuity at about 18°.6 for the Pacific region. It was therefore decided to study the observations upto 20° epicentral distance separately. These observations were grouped at one degree interval and weighted means were calculated.

The graph of the unsmoothed times (t) against distances (Δ) shows that there is a point of infexion at about 6° epicentral distance.

Thus

$$t = a + b(\Delta') + c(\Delta')^3; \qquad \ldots(1)$$

where

$$5\Delta' = \Delta - 10^\circ.5$$

TABLE–6

MEAN AND UNSMOOTHED TRAVEL TIMES FOR P-WAVE

Mean distance (deg)	Weight	Mean residuals (seconds)	Unsmoothed travel-times m	s
2.5	58.56	0.34 ±0.12	0	34.48
7.5	43.93	-0.26 ±0.17	1	46.16
12.5	12.54	−0.67 ±0.28	2	50.50
17.5	18.04	2.88 ±0.41	3	53.86
22.5	18.46	2.13 ±0.29	4	43.85
27.5	18.31	0.79 ±0.30	5	29.45
32.5	6.83	0.86 ±0.44	6	13.99
37.5	27.65	0.52 ±0.16	6	56.23
42.5	43.83	0.42 ±0.19	7	36.84
47.5	16.35	0.23 ±0.32	8	16.58
52.5	15.98	0.83 ±0.29	8	55.12
57.5	7.16	−1.29 ±0.39	9	29.08
62.5	3.92	−0.625±0.36	10	03.72
67.5	3.92	−1.05 ±0.53	10	35.00
72.5	3.92	−0.250±0.16	11	05.72
77.5	2.94	1.1 ±0.55	11	34.93
82.5	0.98	−0.1	12	00.30
87.5++	—	—	—	—
92.5	7.78	−0.56 ±0.39	12	48.82
97.5	2.94	−0.2 ±0.10	13	12.20
102.5	1.00	−0.1 ±0.67	13	30.26

++ There are no observations in the range $85° < \Delta < 90°$.

$$a = (144.78 \pm 0.27)s$$

$$b = (65.87 \pm 0.29)s$$

$$c = (-1.25 \pm 0.12)s$$

was fitted to the unsmoothed times by the method of least squares. χ^2 is 5.536 on 13 degrees of freedom which is satisfactory. Smoothed times upto 20° epicentral distances were obtained with the help of equation (1).

TIMES FOR 20° $\leqslant\Delta\leqslant$ 105°

A quadratic equation

$$t=a+b(\Delta')+c(\Delta')^2; \qquad \ldots(2)$$

where

$$\Delta'=\frac{\Delta-62.5}{5}$$

$$a=(602.93\pm0.15)s;$$

$$b=(32.96\pm0.02)s$$

and

$$c=(-0.87\pm0.004)s$$

was fitted to the unsmoothed times in the range $20°\leqslant\Delta\leqslant105°$. χ^2 was 4.12 on 13 degrees of freedom, which is satisfactory. The smoothed times in this range were therefore computed using equation (2).

The travel time at 20° epicentral distance given by the equation (1) is $4m$, $21.36s$ and that given by the equation (2) is $4m$, $19.91s$. The difference may be attributed to the discontinuity at about 20° epicentral distance. It was, therefore, decided to take the times given by the equation (1) upto 17° epicentral distance only and those given by the equation (2) from 22° epicentral distance onwards. The times for the epicentral distances 18°, 19°, 20° and 21° were interpolated using Lagrange's method. The resulting interpolated values are given below.

Epicentral distance (Δ)	Travel times (t)		$dt/d\Delta$
	m	s	(s/deg)
18°	3	59.08	11.42
19°	4	9.76	10.68
20°	4	19.80	10.04
21°	4	29.44	9.64

It was noticed that if we take times from the quadratic equation (2) then the travel times at 105° epicentral distance became much less than expected value. The reason may be that the observed phases after about 95° are not very good and very many. It was therefore decided that the travel times upto 94° epicentral distance should be calculated by equation (2) and for $95°\leqslant\Delta\leqslant105°$, the travel times were obtained by keeping the constant value of $dT/d\Delta$ i.e. 4.44 s/deg, the value at $\Delta=94°$. Thus finally obtained travel times upto 105° epicentral distances are given in Table 7 and exhibited in Figure 1.

CONCLUSIONS

Travel times of P from the earthquakes occurring in Central Asian region at depths of about 0·026 R have been computed. On comparison with European times it

TABBE–7

P TRAVEL-TIMES FOR THE CENTRAL ASIAN REGION EARTHQUAKES (FOR DEPTH 0.026R)

Distance	Smooth Times		dt/dΔ	Smoothed-European Times	Smoothed-J.B. Times
deg	m	s	s/deg	s	s
1	0	28.20		−1.05	−1.50
			10.74		
2		38.94		+0.77	+0.18
			11.25		
3		50.19		+0.84	+0.05
			11.70		
4	1	1.89		+0.41	−0.55
			12.09		
5		13.98		−0.08	−1.14
			12.43		
6		26.41		−0.45	−1.61
			12.69		
7		39.10		−0.67	−1.96
			12.90		
8		52.00		−0.72	−2.12
			13.05		
9	2	5.05		−0.63	−2.09
			13.14		
10		18.19		−0.40	−1.87
			13.17		
11		31.36		−0.04	−1.62
			13.14		
12		44.50		+0.43	−1.24
			13.06		
13		57.56		+0.97	−0.84
			12.90		
14	3	10.46		+1.54	−0.46
			12.69		
15		23.15		+2.09	−0.19
			12.42		
16		35.57		+2.59	+0.01
			12.09		
17		47.66		+3.07	+0.25
			11.42		
18		59.08		+3.27	+0.74
			10.68		
19	4	09.76		+3.24	+1.08
			10.04		
20		19.80		+2.99	+0.90
			9.64		
21		29.44		+0.56	+0.60
			9.43		

Distance deg	Smooth Times m	s	dt/dΔ s/deg	Smoothed-European Times s	Smoothed-J.B. Times s
22		38.87		+2.07	+0.29
			9.38		
23		48.25		+1.62	−0.03
			9.31		
24		57.56		+1.31	−1.20
			9.23		
25	5	6.79		+1.11	−0.31
			9.17		
26		15.96		+1.00	−0.38
			9.10		
27		25.06		+0.94	−0.38
			9.03		
28		34.09		+0.89	−0.39
			8.95		
29		43.04		+0.85	−0 34
			8.89		
30		51.93		+0.81	−0.29
			8.82		
31	6	00.75		+0.77	−0.21
			8.75		
32		9.50		+0.72	−0.16
			8.68		
33		18.18		+0.69	−0.08
			8.61		
34		26.79		+0.68	+0.03
			8.54		
35		35.33		+0.69	+0.07
			8.47		
36		43.80		+0.69	+0 14
			8.41		
37		52.21		+0.68	+0.15
			8.33		
38	7	0.54		+0.65	+0.14
			8.26		
39		8.80		+0.60	+0 10
			8.19		
40		16.99		+0.53	+0.09
			8.13		
41		25.12		+0.45	+0.02
			8.05		
42		33.17		+0.36	−0.07
			7.98		
43		41.15		+0.27	−0.19
			7.92		
44		49.07		+0.19	−0.27
			7.84		
45		56.91		+0.10	−0.37
			7.78		

Distance	Smoothed Times		dt/dΔ	Smoothed-European Times	Smoothed-J.B Times
deg	m	s	s/deg	s	s
46	8	4.69		+0.01	−0.49
			7.70		
47		12.39		−4.09	−0.53
			7.64		
48		20.03		−0.19	−0.69
			7.57		
49		27.60		−0.30	−0.76
			7.49		
50		35.09		−0.44	−0.87
			7.43		
51		42.52		−0.58	−0.98
			7.36		
52		49.88		−0.71	−1.06
			7.29		
53		57.17		−0.83	−1.17
			7.21		
54	9	4.38		−0.95	−1.26
			7.15		
55		11.53		−1.06	−1.35
			7.08		
56		18.61		−1.16	−1.41
			7.01		
57		25.62		−1.25	−1.46
			6.94		
58		32.56		−1.32	−1.52
			6.87		
59		39.43		−1.37	−1.59
			6.80		
60		46.23		−1.41	−1.59
			6.73		
61		52.96		−1.43	−1.60
			6.67		
62		59.63		−1.42	−1.63
			6.59		
63	10	6.22		=1.41	−1.58
			6.52		
64		12.74		−1.36	−1.62
			6.45		
65		19.19		−1.27	−1.61
			6.39		
66		25.58		−1.15	−1.62
			6.31		
67		31.89		−1.05	−1.61
			6.24		
68		38.13		−0.93	−1.57
			6.18		
69		44.31		−0.81	−1.49
			6.10		

Distance deg	Smoothed Times m	Smoothed Times s	dt/dΔ s/deg	Smoothed-European Times s	Smoothed-J.B Times s
70		50.41		−0.69	−1.49
			6.10		
71		56.45		−0.56	−1.45
			5.96		
72	11	2.41		−0.44	−1.45
			5.90		
73		8.31		−0.32	−1.45
			5.83		
74		14.14		−0.20	−1.42
			5.75		
75		19.89		−0.10	−1.37
			5.69		
76		25.58		+0.01	−1.28
			5.62		
77		31.20		+0.10	−1.20
			5.55		
78		36.75		+0.19	−1.15
			5.47		
79		42.22		+0.25	−1.08
			5.41		
80		47.63		+0.32	−1.01
			5.34		
81		52.97		+0.37	−0.97
			5.27		
82		58.24		+0.42	−0.84
			5.20		
83	12	3.44		+0.45	−0.80
			5.13		
84		8.57		+0.49	−0.67
			5.06		
85		13.63		+0.52	−0.61
			4.99		
86		18.62		+0.56	−0.52
			4.93		
87		23.55		+0.57	−0.39
			4.85		
88		28.40		+0.54	−0.28
			4.78		
89		33.18		+0.47	−0.20
			4.71		
90		37.89		+0.37	−0.19
			4.71		
91		42.54		+0.25	−0.18
			4.57		
92		47.11		+ 0.08	−0.27
			4.50		
93		51.61		−0.12	−0.37
			4.44		

Distance	Smoothed Times		dt/d△	Smoothed-European Times	Smoothed-J.B Times
deg	m	s	s/deg	s	s
94		56.05		−0.34	−0.43
			4.44		
95	13	0.49		−0.52	−0.59
			4.44		
96		4.93		−0.66	−0.65
			4.44		
97		9.37		−0.77	−0.81
			4.44		
98		13.81		−0.86	−0.87
			4.44		
99		18.25		−0.92	−1.03
			4.44		
100		22.69		−0.97	−1.09
			4.44		
101		27.13		−1.01	−1.15
			4.44		
102		31.57		−1.02	−1.11
			4.44		
103		36.01		−1.02	−1.07
			4.44		
104		40.45		−1.00	−1.03
			4.44		
105		44.89		−0.91	—
			4.44		

is found that the trend of residuals is both negative and positive ranging between $-1.42s$ at 62° epicentral distance and $+3.27s$ at 18° epicentral distance. The residual with respect to J.B. times are negative for most of the distances ranging between $-2.12s$ at 8° epicentral distance and $+1.08s$ at 19° epicentral distance. These residuals have been exhibited in figure 1(b).

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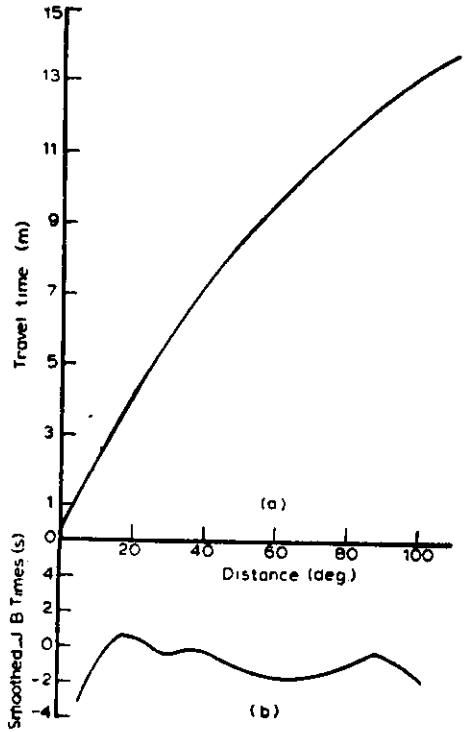

Fig. 1(a) Final P Travel-Time Curve Calculated for Distances to 105°
(b) Deviation of Final Travel-Time Curve (a) From J.B. Times in Seconds

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