SEISMOLOGICAL AND RELATED ASPECTS OF THE 1954 HYDROGEN BOMB EXPLOSIONS

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Summary

Seismic data, recorded in the regular way, from four American hydrogen bomb explosions of 1954, indicate that the origin-times of the explosions were, in G.M.T.: (i) Feb. 28 days 18 hr 45 min 0 sec, (ii) Mar. 26 days 18 hr 30 min 0 sec, (iii) Apr. 25 days 18 hr 10 min 0 sec, (iv) May 4 days 18 hr 10 min 0 sec. If these surmised times are correct, and if the assumed source-point is correct, the results show that the seismic travel-times from Bikini in all azimuths need reductions of the order of 1–2 sec (possibly more) from the standard travel-times.

The analysis focuses attention on the great value atomic explosions can have in advancing knowledge of the Earth's interior when precise details of origin-times and source-points are released.

The analysis is also applied to observations by Yamamoto of air waves from the explosions. It is shown that there is no seasonal effect on the mean air velocities as suggested by Yamamoto. Also discrepancies which appeared in Yamamoto's work between the velocities for these shocks on the one hand, and the Krakatoa eruption of 1883 and the fall of the Siberian meteor of 1908 on the other hand, are removed.

I. INTRODUCTION

About the middle of March 1954 news of the explosion of a hydrogen bomb was made public. Press reports indicated that the explosion occurred near Bikini, and, according to Japanese fishermen, shortly before dawn on March 1.

The first author (T.N.B.-G.) noted on Riverview seismograms an isolated impulse at a time which would agree with the arrival of waves from the bomb. A similar isolated impulse was then found to be reported in the Brisbane seismological bulletin. As bulletins from seismological stations in other countries came in, routine entries were examined for reports of readings at the appropriate times. It soon became evident that seismic waves from the bomb were recorded at a number of widely spread stations, the readings fitting together in quite good agreement.

During March, April, and May 1954 news was released of the occurrence of three further hydrogen bomb explosions, and sets of readings of these explosions were gathered in a similar way. It may be remarked that none of the bulletins associated the readings in question with an atomic explosion.

It soon became evident that the readings were seismologically valuable and the first author carried out a provisional analysis of them.

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At a meeting in Paris in April 1956 of the Council of the International Union of Geodesy and Geophysics, the second author (K.E.B.) raised the question of the new ethical situation created as to whether scientists, who in the regular course of their work have made observations of results connected with atom or hydrogen bomb explosions carried out by a nation other than their own, should publish an analysis of such observations. Dr. J. W. Joyce of the United States, who was present at the meeting, kindly undertook to raise the question in Washington on his return, so far as it affected explosions carried out by the United States. Subsequently, when one of us was passing through Canada, Dr. Joyce kindly telephoned to say that the United States had no objections, ethical or otherwise, to the publication of work based on observations made in the course of regular scientific work. Following this advice, the authors proceeded further with the analysis, which is given below, the readings having in the meantime been slightly supplemented from further regular sources.

II. Analysis of Seismogram Readings

Table 1 shows the times and nature (impetus or emersio) of the onsets at stations which appear to have recorded the hydrogen bombs of (i) February 28, 1954, (ii) March 26, 1954, (iii) April 25, 1954, (iv) May 4, 1954. The times given in the table are in minutes and seconds after 18 hr (G.M.T.) on each of the four occasions.

A striking feature of the table is the broad agreement, at each individual station, of the entries under the seconds columns for the various shocks. This agreement is specially noticeable in the impetus readings at those stations—Brisbane, Riverview, Victoria, Pasadena, Fayetteville, and Quetta—which have recorded two or more impetus onsets; in no case is there a difference of more than a second from shock to shock. This suggests that the intervals between the explosion times of all four bombs were very close to integral numbers of minutes.

This suggestion is strengthened on examining the readings at stations which have recorded all four shocks. The mean values of the seconds readings at these stations (replacing 58 sec by −2 sec at Baguio for shock (iii)) are: (i) 29·1 sec; (ii) 30·1 sec; (iii) 29·0 sec; (iv) 28·9 sec. If the readings at Kimberley are omitted (the reading for shock (ii) at Kimberley is very discordant with the other readings), the mean values are: (i) 30·3 sec; (ii) 29·8 sec; (iii) 29·7 sec; (iv) 30·3 sec. The mean of these four times is 30·0 sec and indicates that all four explosions occurred within 0·3 sec of the same number of seconds after a whole number of minutes (G.M.T.). Moreover, the observations at stations recording just two or three of the shocks—Noumea, Quetta, Fayetteville, Tananarive, and Pretoria—are in agreement with this conclusion. (Matushiro is not here included since the reading of shock (i) could only be S, not P—see Table 2.)

The readings likewise imply that the source-position was approximately the same in all four shocks.

It is known that the shocks took place in the vicinity of the Bikini atoll. For the shock of July 24, 1946, which also occurred in this vicinity, details of the position have been released, and are given by Gutenberg and Richter (1946) as 11° 35′ N., 165° 30′ E. Taking the latitude to be geographic, the corresponding geocentric direction-cosines are $-0\cdot9486$, $+0\cdot2454$, $+0\cdot1995$. The distances Δ from this position to the stations—Brisbane, Baguio, Riverview, Victoria, Pasadena, Fayetteville, and Quetta—which have recorded an impetus P onset from shock (i) are as shown in Table 2. The corresponding theoretical travel-times, as given by the Jeffreys-Bullen tables and corrected for ellipticity are 7 min 43·9 sec, 8 min 9·5 sec, 8 min 36·3 sec, 11 min 9·1 sec, 11 min 30·2 sec, 13 min 9·8 sec, 13 min 10·2 sec respectively. These times and the data in Table 1 imply origin-times for shock (i) which differ from 1954 February

TABLE 1

TIMES AND NATURE OF ONSETS OF HYDROGEN BOMB EXPLOSIONS

Station	(i) 28.ii.1954			(ii) 26.iii.1954			(iii) 25.iv.1954			(iv) 4.v.1954		
	min	sec		min	sec		min	sec		min	sec	
Noumea	51	45	(e)							16	45	(e)
Matsushiro	57	29	(e)	36	53	(e)						
Brisbane	52	43	(i)	37	43	(i)	17	43	(i)	17	43	(i)
Baguio	53	5	(i)	38	2	(e)	17	58	(e)	18	2	(e)
Riverview	53	35	(i)	38	36	(i)	18	35	(i)	18	36	(i)
Kaimata										19	28	(e)
Victoria	56	5	(i)	41	5	(i)				21	7	(e)
Pasadena	56	29	(i)	41	29	(i)	21	29	(i)	21	28	(i)
Fayetteville	58	8	(i)	43	9	(i)						
Quetta	58	6	(i)				23	8	(e)	23	7	(i)
Kiruna										23	30	(e)
Uppsala										24	12	(e)
Ksara				49	42	(e)						
Stuttgart	63	44	(e)	48	45	(e)	28	45	(e)	28	45	(e)
Tananarive				48	54	(e)				28	54	(i)
Pretoria	64	16	(i)	49	16	(e)				29	15	(e)
Kimberley	64	22	(e)	49	32	(e)	29	25	(e)	29	20	(e)
Tamanrasset	64	26	(e)	49	24	(e)	29	28	(traces)	29	28	(e)

28 days 18 hr 45 min 0·0 sec by $-0\cdot9$, $-4\cdot5$, $-1\cdot3$, $-4\cdot1$, $-1\cdot2$, $-1\cdot8$, and $-4\cdot2$ sec respectively. The observations of the 1946 atomic explosion showed that the P waves reached American stations $1\cdot8\pm0\cdot8$ sec earlier than the J.-B. tables would imply (Bullen 1948); this discrepancy is probably connected with the crustal thickness at the source, but may partly arise from corrections needed to the travel-time table (Jeffreys 1954). If this correction of 1·8 sec be applied uniformly to the present readings, the implied origin-times become $+0\cdot9$, $-2\cdot7$, $+0\cdot5$, $-2\cdot3$, $+0\cdot6$, $0\cdot0$, and $-2\cdot4$ sec, which give a mean value of $-0\cdot8\pm1\cdot5$ sec.

There is thus a strong suggestion that the four detonations took place at times extremely close to integral numbers of minutes in G.M.T., a suggestion which is supported by the fact that the origin-time of the 1946 explosion is given as within 0·2 sec of precisely 35 min 0 sec past the hour. If this suggestion is adopted, and the data for the shocks (ii), (iii), and (iv) are treated as in the last paragraph, then the origin-times are close to : (i) Feb. 28 days 18 hr 45 min 0 sec, (ii) Mar. 26 days 18 hr 30 min 0 sec, (iii) Apr. 25 days 18 hr 10 min 0 sec, (iv) May 4 days 18 hr 10 min 0 sec. It will be noticed that the times are all integral multiples of 5 min past the hour, which lends further support to the pattern here suggested.

TABLE 2

P AND *PKP* RESIDUALS

Station	Δ	Az.	(i) 28.ii.1954 (sec)	(ii) 26.iii.1954 (sec)	(iii) 25.iv.1954 (sec)	(iv) 4.v.1954 (sec)	Mean Residual (sec)
Noumea	33°·70	180°	— 0·2			— 0·2	— 0·2
Matsushiro ..	34°·96	320°	+ 0·7 (*S*)	— 3·0			— 3·0
Brisbane	40°·68	195°	— 0·9	— 0·9	— 0·9	— 0·9	— 0·9
Baguio	43°·78	280°	— 4·5	— 7·5	—11·5	— 7·5	— 7·7
Riverview ..	47°·17	195°	— 1·3	— 0·3	— 0·3	— 1·3	— 0·8
Kaimata	54°·03	175°				— 0·5	— 0·5
Victoria	68°·94	40°	— 4·1	— 4·1		— 2·1	— 3·4
Pasadena ..	72°·39	55°	— 1·2	— 1·2	— 1·2	— 2·2	— 1·4
Fayetteville ..	91°·43	55°	— 1·8	— 0·8			— 1·3
Quetta	91°·50	300°	— 4·2		— 2·2	— 3·2	— 3·2
Kiruna	96°·91	345°				— 4·0	— 4·0
Uppsala	104°·24	345°				+ 4·9	+ 4·9
Ksara	114°·18	315°		0 (*PP*)*			
Stuttgart ..	116°·36	340°	— 1·8	— 0·8	— 0·8	— 0·8	— 1·0
Tananarive ..	119°·93	255°		+ 0·3		+ 0·3	+ 0·3
Pretoria	137°·37	245°	—10·7	—10·7		—11·7	—11·0
Kimberley ..	139°·58	240°	— 8·5	+ 1·5	— 5·5	—10·5	— 5·7
Tamanrasset ..	140°·60	300°	— 6·6	— 8·6	— 4·6	— 4·6	— 6·1

* If the reading at Ksara were taken as 48 min 42 sec instead of 49 min 42 sec, the reading would agree with *PKP* with a residual of —0·1 sec.

In Table 2, the above origin-times are assumed, and the residuals computed against the J.-B. tables corrected for ellipticity. The residuals are taken against the *P* tables for $\Delta < 105°$ and *PKP* for $\Delta > 105°$, except for two cases where *S* and *PP* phases appear to have been recorded. Table 2 also gives the approximate azimuths of the stations from the assumed source-point, and the mean residuals in cases where two or more *P* or *PKP* phases have been recorded.

An outstanding feature of Table 2 is that practically all the residuals are negative for all azimuths. (In the case of the Uppsala reading, the *P* wave has grazed the core, and Dr. Båth informs us that the real onset, which is of emersio type, could be up to 7 sec earlier than the time recorded.) As already pointed out, the 1946 explosion showed that for paths from Bikini to the United States the travel-times are about 2 sec less than those given by the J.-B. tables, The present data show that, if the origin-times have been correctly surmised. then the travel-times for paths in all directions from Bikini are less than those given by the J.-B. tables. This is in keeping with the evidence that the crustal thickness in the Pacific region is significantly less than that in continental regions.

The observations of Brisbane, Riverview, Pasadena, and Fayetteville, where only impetus readings have been recorded, are of particular interest. The mean residuals at Brisbane and Riverview, which have approximately the same azimuth, are in practically full agreement; and the same applies to Pasadena and Fayetteville. These two sets of means differ by only 0·5 sec and so suggest that the *P* travel-times from Bikini to Australia and to the United States differ, if at all, by not much more than a half-second. This would be a firm conclusion if the assumed origin-times and source-position are closely accurate.

It will be noticed from Table 2 that the three Pretoria readings while very self-consistent are apparently 11 sec early, and indeed markedly early compared with the readings at nearly all other stations. For this reason we wrote to Dr. A. L. Hales who kindly re-examined the records for us. He gives these results for Pretoria. Shock (i): start at 64 min 15·0 sec; phase at 64 min 23·5 sec; large impulse at 64 min 26·3 sec. Shock (ii): start not well defined, onset probably at 49 min 15·8 sec, but not later than 49 min 17·5 sec; large impulse at 49 min 28 sec. Shock (iii); not readable. Shock (iv): short, small but clear, at 29 min 16·1 sec; large impulse at 29 min 28·1 sec. Dr. Hales comments on the remarkable similarity of the records for shocks (i), (ii), and (iv). He states that " it is perhaps possible that there is an error of as much as 3 sec in the records of (ii) " but doubts " whether any one could change the readings of (iv) by more than 1 sec ". The Pretoria residuals corresponding to Dr. Hales's readings are: (i) −11·7 sec, −3·2 sec, −0·4 sec; (ii) −10·9 sec, +1·3 sec; (iv) −10·6 sec, +1·4 sec. The existence of small readings of the order of 10 to 11 seconds earlier than expected therefore appears to be well confirmed.

Dr. Hales also kindly re-examined the Kimberley records, which he finds to be remarkably similar in general appearance to the Pretoria ones. The residuals become: (i) −8·0 sec, −1·6 sec, +1·1 sec; (ii) −8·0 sec, +1·0 sec; (iii) −6·1 sec; (iv) −10·7 sec, +1·8 sec. The Kimberley residuals, while not quite as self-consistent as the Pretoria residuals, also exhibit early residuals. Should source data on the four shocks become available it may be possible to draw some interesting inferences from these features. The implications are also being considered from other aspects.

If there were no dependence of the *P* and *PKP* travel-times on azimuth, the distribution of the residuals in Table 2 would suggest that the source-points of the explosions were on the average slightly to the north-west of the assumed point. To shift the source-point and origin-times on this evidence would, however, be to treat the shocks as natural earthquakes, and because of the relatively small number of readings no useful inferences could be made on travel-times.

Should, however, precise details of the origin-times and source-points of the explosions come to be released, the data of the present paper can be used as important checks on the travel-time table and as important evidence on the question of the variation of travel-time with azimuth.

It may be remarked that the reading at Matushiro, if a genuine reading of waves from the hydrogen bomb (i), appears to be the first occasion on which an *S* reading has been recorded from an atomic explosion.

What the present discussion does is to focus sharply the potential value of atomic explosions for the advancement of seismological knowledge. The precision of the inferences which can be made from the 1954 explosions depends overwhelmingly on the release of the source data. If the surmises made in the present paper are correct, then some of the suggestions made will become firm inferences. If, on the other hand, the surmised origin-times and source-points have to be corrected, then a simply made adjustment of the computations made in the present paper will still lead to valuable results.

III. Application to Microbarographic Readings

A study of waves through the air from the 1954 hydrogen bomb explosions has been made by Yamamoto (1955). Yamamoto uses microbarograph recordings at a number of Japanese stations to estimate mean velocities of the air waves between the source and the station at Shionomisaki (33° 27′ N., 135° 46′ E.). A table in his paper gives the velocities corresponding to the arrival-times of the first troughs as : (i) 284 m/sec, (ii) 287 m/sec, (iii) 304 m/sec, (iv) 310 m/sec. He infers that there is " a tendency for the velocity to increase with the progress of the season from cold to warm ", but is at pains to point out that " some inaccuracy must arise from the smallness of the triangle we are forced to employ ". He also compares his results with figures for the air waves from the Krakatoa eruption of August 27, 1883 and the fall of the Siberian Meteor of June 30, 1908. Whipple (1930) states that the velocities in these cases corresponding to the arrival of the first trough are 314 and 318 m/sec respectively. Whipple gives 323 m/sec as the velocity corresponding to the first onset in the case of the Siberian Meteor.

It is possible to use the seismic discussion of the present paper to test Yamamoto's inferences, and to improve sharply the precision of the results.

The hours and minutes (G.M.T.) of the arrival-times of the first troughs at Shionomisaki on the relevant days are given by Yamamoto as : (i) 22 hr 17 min, (ii) 22 hr 1 min, (iii) 21 hr 40 min, (iv) 21 hr 41 min. Using the estimated origin-times in the present paper, the corresponding travel-times are : (i) 3 hr 32 min, (ii) 3 hr 31 min, (iii) 3 hr 30 min, (iv) 3 hr 31 min, which yield a mean of 3 hr $31 \cdot 3 \pm 0 \cdot 8$ min. The four travel-times are in good agreement with one another and do not show any seasonal trend as suggested by Yamamoto. Presumably there were large errors in the origin-times computed by Yamamoto from his limited group of stations.

Copies of the actual records at Shionomisaki are shown in Yamamoto's paper, and these indicate that the first onsets arrived about 4 min before the first troughs. Thus the mean travel-time for the first onsets is indicated as approximately 3 hr 27 min. If the source-point be taken to be that assumed in the present paper, the distance to Shionomisaki is 35° 52′ or 3986 km. The mean velocity of the air waves given by using these figures is 321 m/sec.

Uncertainty in identifying the time of onset on the microbarograph record contributes an uncertainty of about 2 m/sec to this last result. Any alteration required in the position of the assumed source point could alter the velocity further by up to 3 m/sec. Any allowable change in the seismic origin-times used would, on the other hand, have negligible effect on the present calculations.

The result of the present calculations is therefore to bring Yamamoto's observations into line with the results for the Krakatoa eruption and the Siberian Meteor.

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