551·596·1(54)

Reflection of sound waves from the Stratosphere over India in Different Seasons of the Year

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(*Received 9th August, 1949*)

1. *Introduction.*

THE India Meteorological Department arranged a series of observations in different seasons of the year to study the phenomenon of propagation of sound in the stratosphere over India from explosions. Full details of these investigations have been given in three separate papers relating to the three trials held from 30th May to 2nd June[1], 16th to 20th October[2], and 29th January to 1st February[3] during the year 1946-47. It is, therefore, not proposed to describe here in detail arrangements made for explosions and the equipment used for the observations.

The general set up for the three trials was more or less the same. Explosions were made from two centres located in reserved forests in the Central provinces. Seven recording stations were established along the line joining the two explosion centres and two along the line almost at right angles to it. During the first trial in summer 1946, one explosion centre was at Ponia (Lat. 23°40.5′N; Long. 80° 23′E) and the other at Pulgaon (Lat. 20° 42′N; Long. 78° 27′E). During the post-monsoon and winter trials the second explosion centre was shifted from Pulgaon to Sindi (Lat. 20°52′N; Long. 78°51′E). The recording stations remained located at the same places during the three trials except that the recording station at Sukhtara (Lat. 21° 56′N; Long. 79°31.5′E) was shifted to Korai (Lat. 21° 47′N; Long 79° 29′E) during the second and the third trials. The locations of the stations mentioned above are shown in Fig. 1.

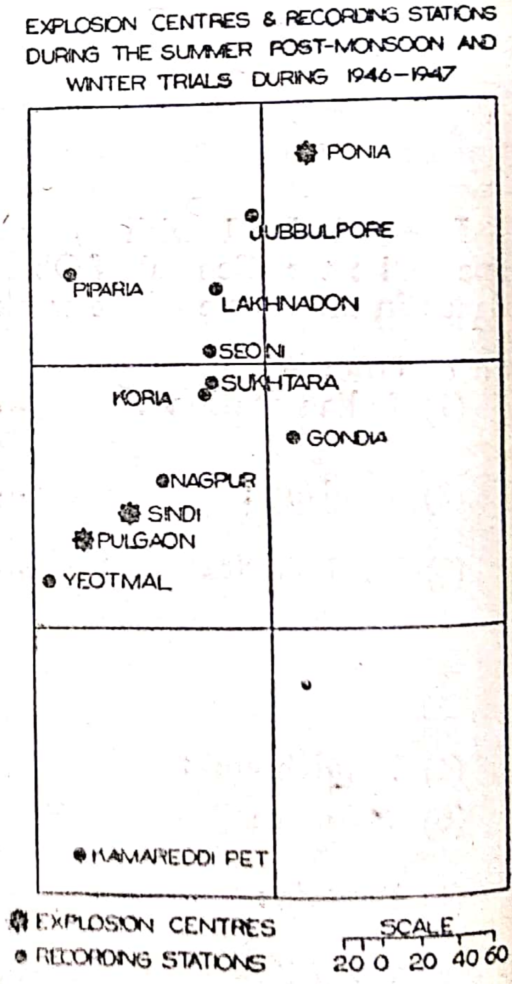


Fig. 1

All the stations given in Fig. 1 were manned by the I. Met. D. personnel except Kamareddi where the army officers of the 1st. Indian Survey Regiment very kindly agreed to take observations on behalf of the India Meteorologica Department. Kamareddi was the most distan recording station from the explosion centre at Ponia, being at a distance of 638 kms. from it.

The apparatus employed for recording the sound waves from these explosions was the army sound ranging recorder S.R. No. 2; MK. 1, usually employed for the location of enemy mortars. The details of the recording apparatus have already been described in the first paper relating to the summer trial.

II. *Records of Sound Waves.*

In the summer of 1946, the explosions from Ponia gave better records at stations to the south whereas Pulgaon explosions were not recorded at most of the stations to the north. A few typical records of the explosions on first June, at 1800 hrs. are given in *Plate I.* This explosion was recorded at Seoni, Sukhtara, Pipariya, Nagpur and Yeotmal.

In the post-monsoon and winter trials the position was reversed and the records of explosion waves from Sindi to the stations north of it were better recorded than the explosion waves from Ponia to the stations south of it. A few typical records of the explosions at Sindi during the post-monsoon and winter trials are given in *plates II and III.* This preferred propagation of sound in a particular direction is attributable to the upper wind system that prevailed during the trial concerned. The extent to which the opposi g wind can obstruct the propagation of sound in a particular direction can be judged from the fact that during the post-monsoon trial even some of the explosions from Ponia were not recorded at Jubbulpore which was at a distance of 68 kms. from the explosion centre located there.

Another interesting feature brought out by these observations is that there is no particular limit to the distance to which ground wave can travel from an explosion centre. In fact the ground wave, in many cases, reached the second zone of audibility where sound is supposed to arrive only after a detour through the upper atmosphere. In other words, the ground wave traversed the so-called "Zone of silence," though with feeble intensity. In the "Zone of silence" sound though not audible was at least recordable. The propagation of ground wave appears to be dependant to a considerable extent on the quantity of the explosives used. During the post-monsoon and winter trials the ground wave reached as far as Jubbulpore and Gondia being 294 kms. and 240 kms. from the explosion centres at Sindi and Ponia respectively. As expected the intensity of the ground wave decreased with increasing distance.

III. *Time—Distance Graphs.*

The average times of arrival of sound waves from the explosion centres to the recording stations during three trials are given in table I.

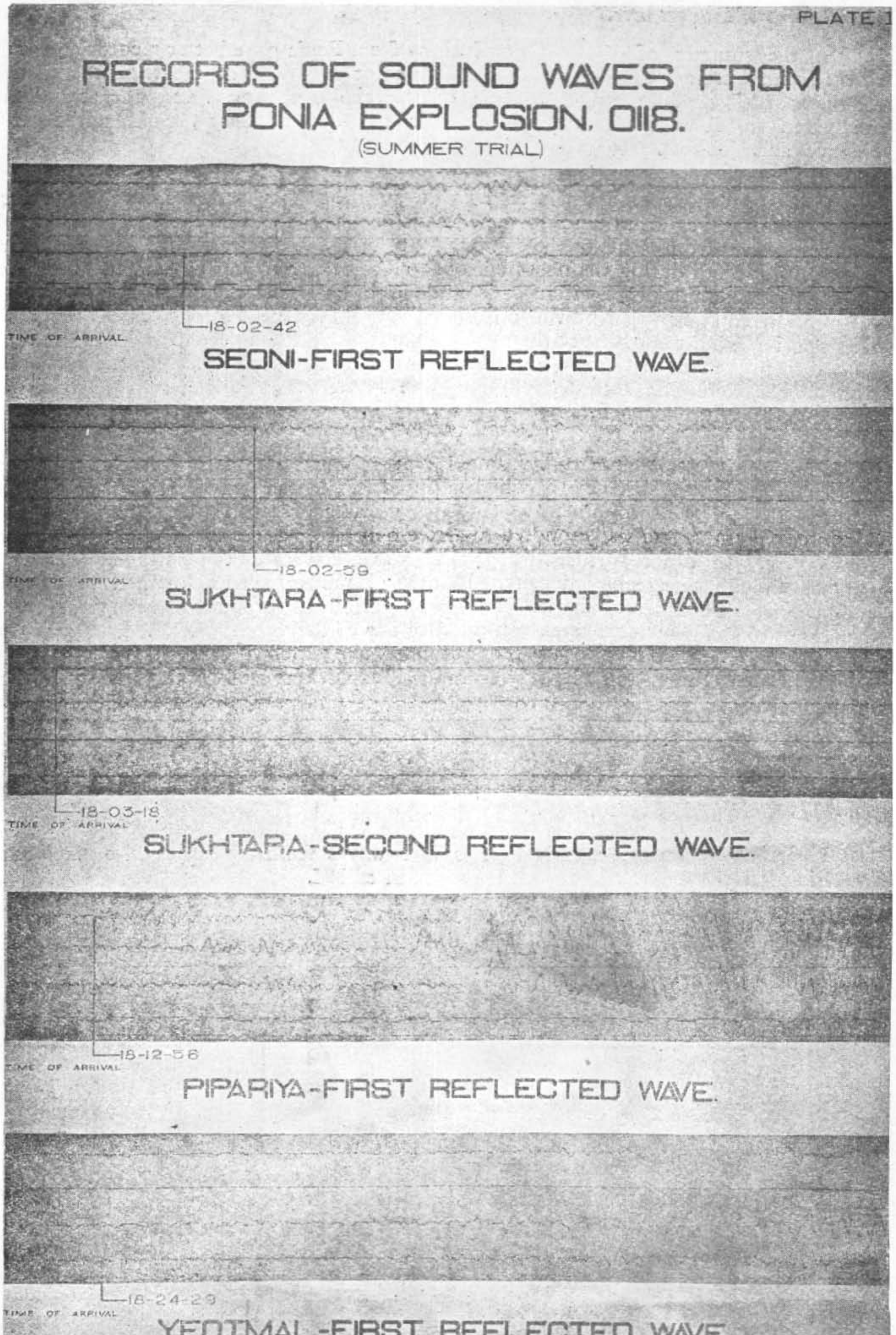
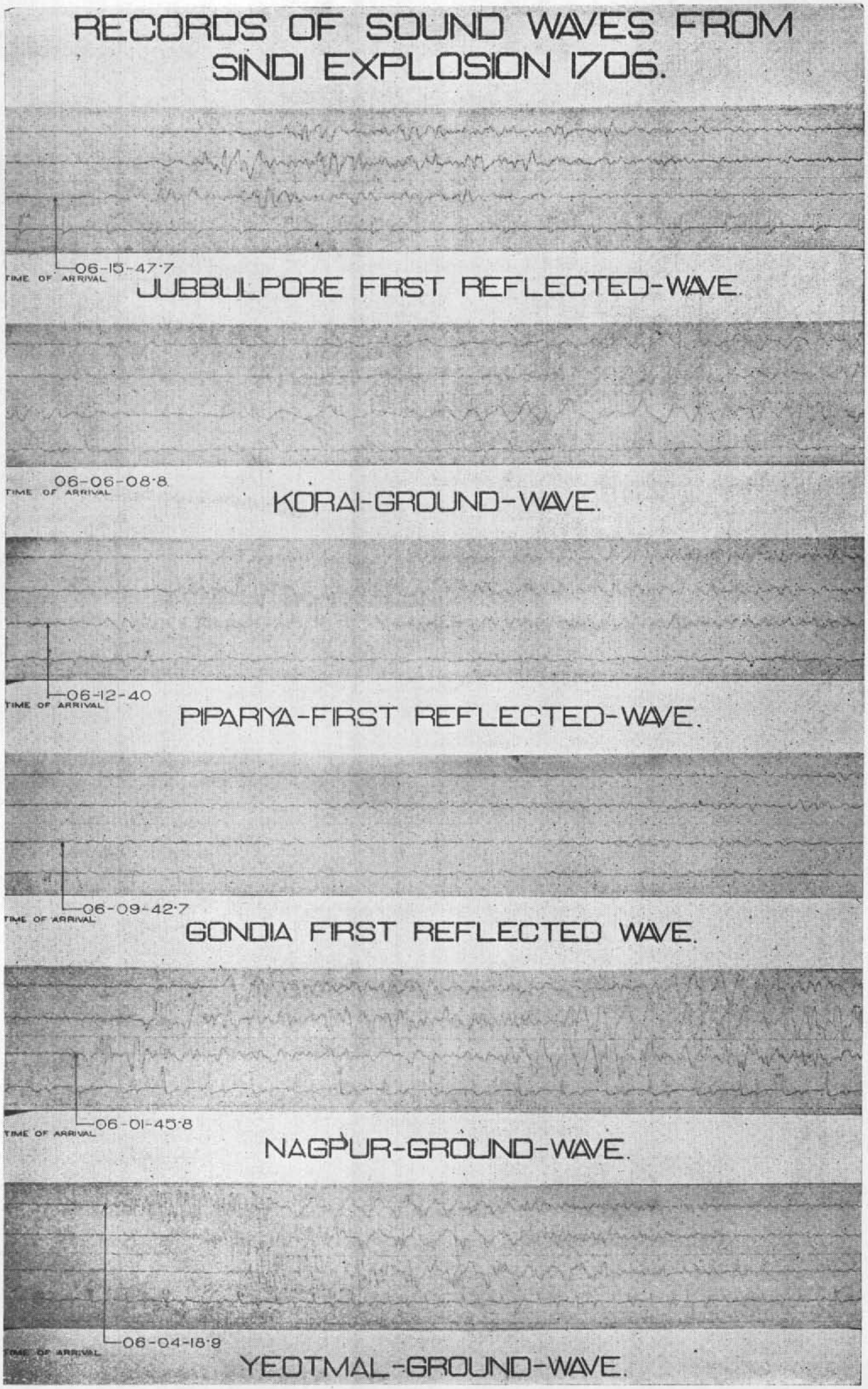


PLATE I
RECORDS OF SOUND WAVES FROM
PONIA EXPLOSION. 0118.
(SUMMER TRIAL)
18-02-42
TIME OF ARRIVAL
SEONI-FIRST REFLECTED WAVE.
18-02-59
TIME OF ARRIVAL
SUKHTARA-FIRST REFLECTED WAVE.
18-03-18
TIME OF ARRIVAL
SUKHTARA-SECOND REFLECTED WAVE.
18-12-56
TIME OF ARRIVAL
PIPARIYA-FIRST REFLECTED WAVE.
18-24-29
TIME OF ARRIVAL
YEOTMAL-FIRST REFLECTED WAVE.

POST-MONSOON TRIAL. PLATE II



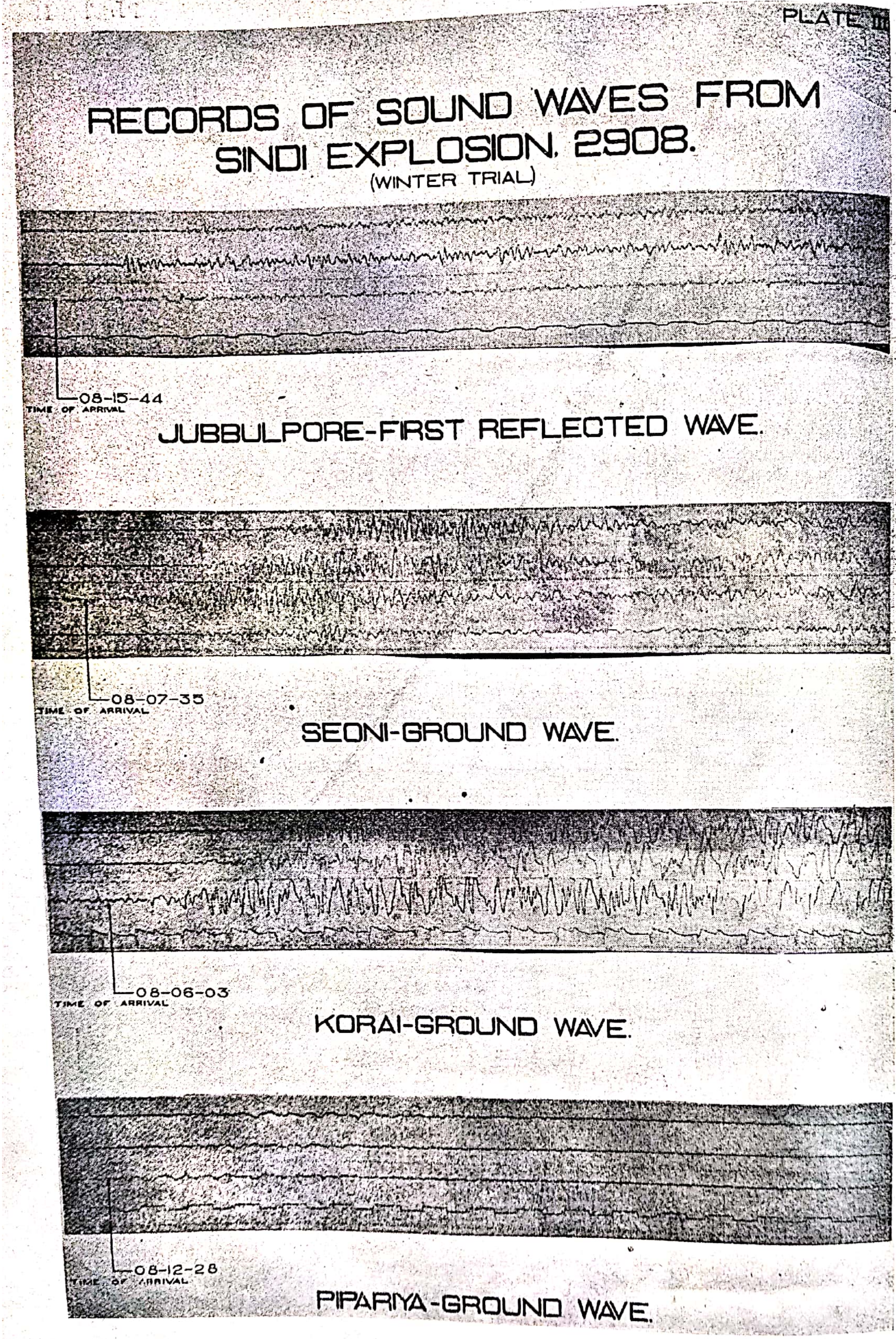


PLATE III
RECORDS OF SOUND WAVES FROM SINDI EXPLOSION, 2908.
(WINTER TRIAL)
08-15-44
TIME OF ARRIVAL
JUBBULPORE-FIRST REFLECTED WAVE.
08-07-35
TIME OF ARRIVAL
SEONI-GROUND WAVE.
08-06-03
TIME OF ARRIVAL
KORAI-GROUND WAVE.
08-12-28
TIME OF ARRIVAL
PIPARIYA-GROUND WAVE.

TABLE I.

Times of Arrival of Sound Waves in Summer, Post-Monsoon and Winter Trials.

S. No.	Station	Distance from Pulgaon in Kms.	Distance from Ponia in Kms.	Distance from Sindi in Kms.	Summer Trial: Ponia	Summer Trial: Pulgaon	Post-monsoon Trial: Ponia	Post-monsoon Trial: Sindi	Winter Trial: Ponia	Winter Trial: Sindi
1.	Jubbulpore	329	68	294	191(6)	Not recorded	189(7)	835(3); 940(12)	194(6)	833(2); 930(2); 952(5); 977(2)
2.	Lakhnadon	245	148	211	405(1)	863(3)	410(1); 481(1): 520(5)	610(6); 723(10)	415(2); 525(6); 564(1)	609(6); 625(3); 714(12); 748(3); 786(1)
3.	Seoni	194	198	156	563(2); 667(3); 690(4); 710(1)	725(1); 740(1)	550(4)	455(7); 562(4)	642(1); 703(1)	453(6); 565(4)
4.	Sukhtara	179	214	..	607(4); 715(4); 724(4); 731(6)	679(1)	..	..	..	..
5.	Korai	..	230	127	..	..	641(4)	371(11); 414(6); 452(3); 483(5)	655(2); 793(2); 814(1)	363(9); 420(3); 458(2); 479(5)
6.	Pipariya	231	236	218	779(9); 793(1)	792(6): 824(1)	671(3)	745(8)	828(1)	749(11)
7.	Gondia	208	240	164	686(1); 803(3); 829(4)	785(3)	665(1)	474(8); 530(12)	682(4); 820(5)	470(11); 555(1); 583(4); 620(5)
8.	Nagpur	81	315	40	1016(5); 1028(1)	225(4)	1104(1); 1142(2); 1185(1)	105(12)	Not recorded	105(12)
9.	Yeotmal	48	437	91	1367(2); 1473(4): 1492(2); 1514(1)	138(11)	Not recorded	259(6)	Not recorded	268(4); 342(2)
10.	Kamareddi	270	638	294	1994(1); 2066(1); 2173(2)	892(2); 907(3); 927(1); 944(1)	Not recorded	Not recorded	Not recorded	Not recorded

These times are averages of a number of observations which have been grouped together as corresponding to certain definite pulses. The number of observations from which each of the average values have been worked out is given by the figures within brackets. The time-distance graphs of the three trials are given in Fig. 2.

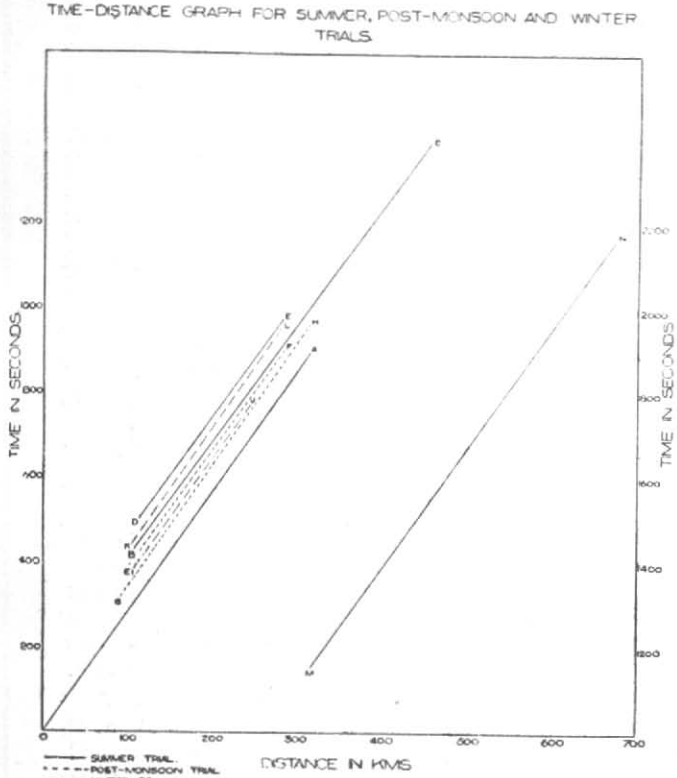


Fig. 2.

The graphs relating to the three trials are shown separately by continuous, broken and dot-dash lines. It will be interesting to mention here that during all the trials the time-distance graphs corresponding to the ground wave remained the same as shown by the continuous line OA in Fig. 2. This line corresponding to the ground wave extends well into the region where the graph corresponding to the reflected wave appears. At good number of stations both the ground and the reflected waves were recorded. For each trial we got more than one graph corresponding to the reflected waves. It is, however, interesting to note that a good number of points in all the three trials fall on one common time-distance graph indicated by the line BC in Fig. 2. This shows that though there were several layers from which the sound got reflected, yet there was one particular layer which formed a predominant stratum in the stratosphere from where sound waves got reflected in all the seasons of the year. The observations during the summer trials appeared to be most successful in as much as sound waves after suffering two reflections between ground and the stratosphere were recorded at Yeotmal and Kamareddi from explosions at Ponia. The time-distance graphs relating to the third zone of audibility are shown by the line MN in Fig. 2.

IV. *Trajectories of sound waves.*

The general method of building up the sound trajectories has already been described in the three papers already mentioned. The combined trajectories for all the three trials for explosions from Ponia are shown in Fig. 3.

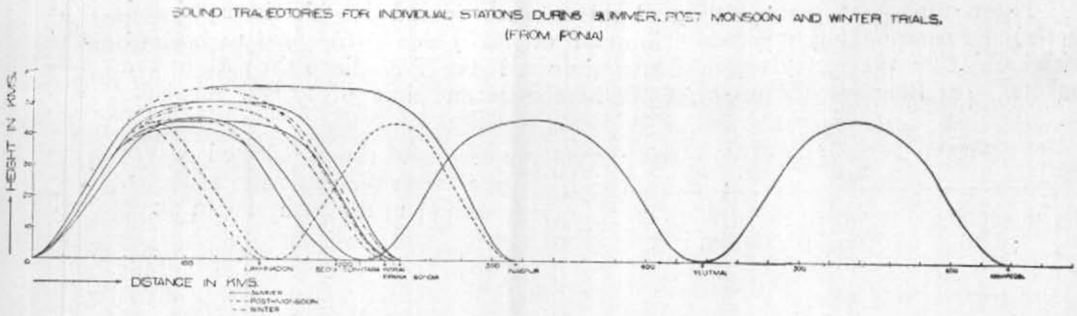


Fig. 3.

All the trajectories of the sound waves for explosions from Sindi are shown in Fig. 4.

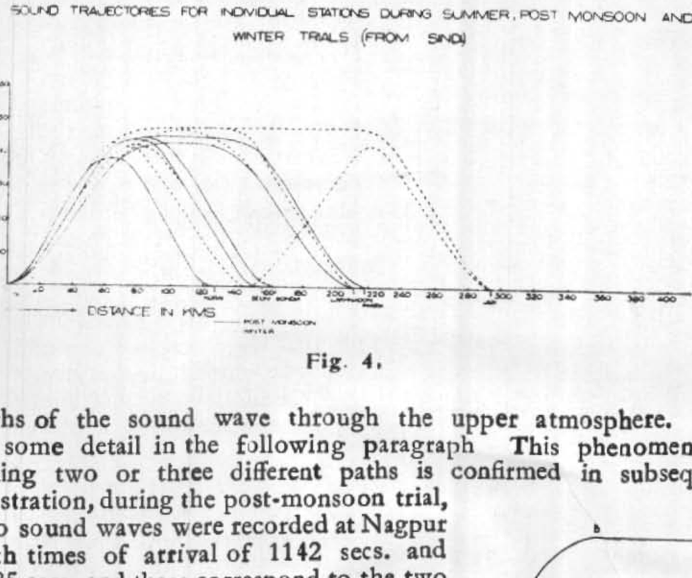
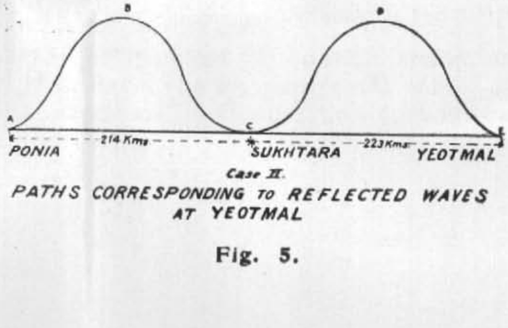


Fig. 4.

It may be pointed out that no reflected wave corresponding to the explosions from Pulgaon during the summer trial, could be recorded at any of the nine recording stations shown in Fig. 1. At Yeotmal and Kamareddi, during the summer trial, more than one reflected wave was recorded and their times of arrival correspond to two or three different paths of the sound wave through the upper atmosphere. The subject is discussed in some detail in the following paragraph This phenomenon of the sound wave taking two or three different paths is confirmed in subsequent tri ls also. As an illustration, during the post-monsoon trial, two sound waves were recorded at Nagpur with times of arrival of 1142 secs. and 1185 secs. and these correspond to the two paths shown in Fig. 3. The first sound wave travelled a long horizontal distance in the stratosphere and then reached the ground and the second one suffered two reflections as shown by broken-line trajectories at Nagpur in Fig. 3. Similarly, during the winter trials, the records at Jubbulpore for explosions from Ponia gave two times of arrival of 930 secs and 977 secs. which correspond to the two paths shown by the broken-line in Fig. 4.

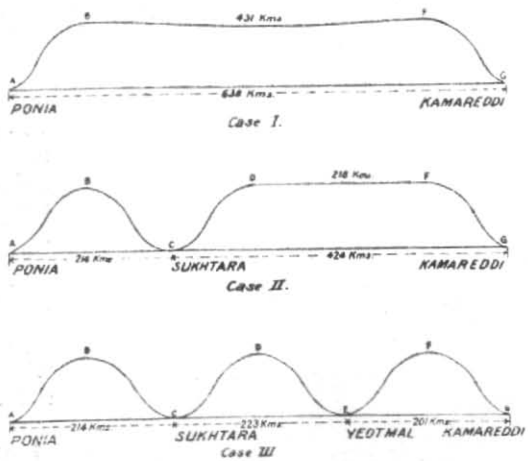


PATHS CORRESPONDING TO REFLECTED WAVES AT YEOTMAL

Fig. 5.

Coming back to the trajectories of sound waves for explosion from Ponia during the summer trials as recorded at Yeotmal and Kamareddi, it may be mentioned that at Yeotmal two sound pulses were recorded with times of arrival of 1,350 and 1,476 secs. The time interval of 1,476 secs. correspond to two successive reflections of the sound wave as shown in case II Fig. 5 in which the path of the sound wave is indicated by the curve ABCDE. The second time of arrival of 1,350 secs. corresponds to the path ABDE shown in case I of Fig. 5.

Similarly, at Kamareddi during the summer trial three reflected waves were recorded at intervals of 1,994; 2,066 and 2,173 secs., after the explosion at Ponia. The first one corresponds to the path shown in case I, second to the path shown in case II and the third to the path shown in case III of Fig. 6.



PATHS CORRESPONDING TO THREE REFLEGTED WAVES AT KAMAREDDI

Fig. 6.

V. *Temperatures in the warm layer.*

The velocity of sound at the top of the trajectory that is the critical veloctiy V° can be found out from the formula $V = V_0$ Sec θ where V is the velocity of the wave and θ the angle of descent. Knowing the critical velocity the corresponding temperature at the highest point on the trajectory is obtainable. From the observations made during the three trials it has been possible to get temperatures at different heights within the warm layer as the angle of descent and the height of the trajectories for individual stations are known. The temperatures of the warm layer and the corresponding heights during the three seasons are given in table II below :—

TABLE II

Maximum Heights of the Sound Trajectories and Corresponding Temperaturcs.

		Sumer Trial		Post-monsooon Trial.				Winter Trial			
		Ponia		Ponia		Sindi		Ponia		Sindi	
S. No.	Station	Max. Ht. of trajectory (Kms.)	Corres-ponding tempera-ture °A	Max. Ht. of trajectory (Kms)	Corres-ponding tempera-ture °A	Max. Ht. of trajectory (Kms.)	Corres-ponding tempera-ture °A	Max. Ht. of trajectory (Kms)	Corres-ponding tempera-ture °A	Max. Ht. of trajectory (Kms.)	Corres-ponding tempera-ture °A
1.	Jubbulpore ..	..	..	..	..	34·1	304 (31°C)	..	..	41·7	309 (36°C)
2.	Lakhnadon ..	..	..	34.1	312 (39°C)	42·0	312 (39°C)	42.0	309 (36°C)	47·0	329 (56°C)
										46 5 47·0	329 (56°C)
3.	Seoni ..	42·0	324 (51°C)	..	..	43·5	322 (49°C)	44.5	311 (38°C)	42·0	316 (43°C)
4.	Sukhtara ..	45·0	316 (43°C)	..	..	..	..	..	..	..	..
5.	Korai ..	..	..	..	..	33·3	..	48.6	309 (36°C)	36·0	..
						38·0	..	54.5	324 (51°C)	38·0	327 (54°C)
6.	Pipariya ..	44·0	327 (54°C)	..	..	44·7	314 (41°C)	..	..	..	..
7.	Gondia ..	51·0	..	..	..	44·0	324 (51°C)	50.0	..	..	..
8.	Nagpur ..	55 0	345 (72°C)	55·0 43·5	327 (54°C) 414 (41°C)	..	..	..	..	..	..
9.	Yeotmal ..	45 0	317 (44°C)	..	..	..	..	..	..	..	..

From this table it has been possible to plot the temperature in the warm layer from 40-60 kms. The lapse rate corresponding to the three seasons in the warm layer is given in Fig. 7.

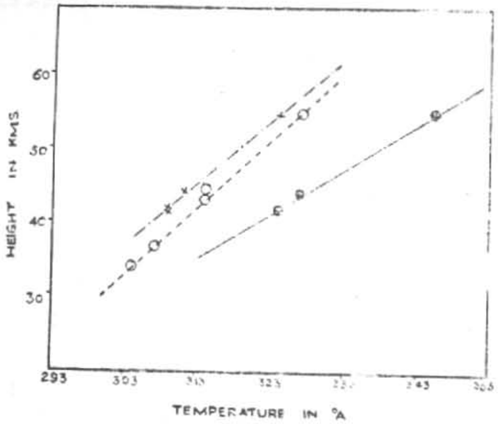


Fig. 7.

It will be observed that the lapse rate during the summer season is very steep which may also mean that the warm layer becomes less deep. The lapse rate for the post-monsoon and winter trials appear more or less to be the same. From these observations it would appear that there is no marked seasonal variation of the height of the temperature inversion layer, although its depth may be assumed to vary in different seasons being the thinnest during the summer.

VI. Acknowledgments.

The author is extremely grateful to Dr. S. K. Banerji, D.Sc., F.N.I., the Director General of Observatories for all the help and guidance he gave in connection with these observations. Thanks are due to Dr. K. R. Ramanathan, the then Officer on Special Duty and Dr. S. C. Roy, Deputy Director General of Observatories, for their active help and interest in the prosecution of the work during the course of the three trials. Thanks are also due to the Army Officers of the General Head Quarters India, who rendered all possible help in connection with the supply of the equipment, transport and explosives. Last, but not the least the author is thankful to Messrs. P. K. Gupta and N. Krishnamurti for the help in the preparation of manuscript and tables.

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