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Seismic Recording at Delhi of the Russian Nuclear Explosions on 23 and 30 October 1961

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According to reports which appeared in the newspapers, the U.S.S.R. exploded two Nuclear (Hydrogen) bombs on 23 and 30 October 1961 in their testing ground above the arctic ice cap east of Novaya Zemlya Island. Both the explosions are said to have been exploded in the atmosphere at a height of about 50 to 60 km. The first explosion, *i.e.*, on 23 October, has been estimated to be of the order of 30 megatons and the second on 30 October, has been estimated to be more than 50 megatons.

The explosion on 23 October was recorded by the Seismological Observatory at Upsala (Sweden) at $08^h\ 35^m\ 51^s$ GMT. The French detection services recorded blast wave at $08^h\ 52^m$ GMT from the Novaya Zemlya region in the Arctic. The explosion was also reported to have been recorded by the Royal Netherland Meteorological Service. In Tokyo (Japan) the shock waves started arriving at about $13^h\ 16^m$ GMT.

The explosion on 30 October, was detected by various services in Europe and Japan. All the available reports in newspapers sugested that the explosion was 2 to 4 times more powerful than that of 23 October. At Upsala the explosion was first recorded at $08^h\ 37^m$ GMT.

The purpose of the present note is to present records of these explosions obtained at the Delhi Seismological Observatory by the Long period Press-Ewing Seismographs, consisting of one North-South component, one East-West component and one vertical component. All of them have a seismometer period of 15 seconds and a galvanometer period of about 85 seconds. The magnification available for long period waves is very high.

It is well known that large nuclear explosions carried out under water or ground generate seismic waves which can be detected by sensitive seismographs located thousands of miles away. Smaller explosion in the kiloton range, however do not possess enough energy to be recorded at distances of more than a few hundred miles. A large amount of data on the travel times of seismic body waves generated by nuclear explosions during the American tests near the Marshall Island has been made available and used for travel times studies of seismic waves (Carder and Baily 1958, Kogan 1960). A number of these explosions were recorded in India by sensitive vertical seismographs (Tandon 1958) operating at Shillong, Chatra and Poona. In all these cases, only the P-wave had been recorded, since the instruments were short period vertical seismographs. At many other stations in the world, however, the S-phase as well as the other reflected and refracted phases have also been recorded. Surface waves appear to have been recorded only at a few stations where long period seismographs have been in operation. The records thus obtained have provided the seismologists with new data for the study of the internal constitution of the earth. Results

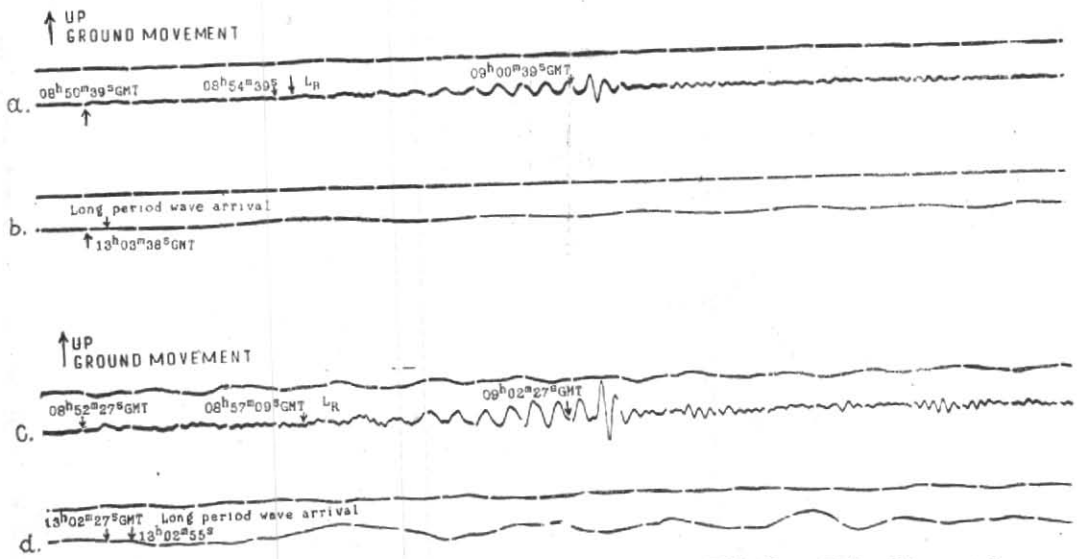

Fig. 1. Seismic records of Russian Nuclear Explosions taken at Delhi by Press–Ewing Seismographs
(To = 15 sec, Tg=90 sec)

(a) 23 October 1961, Raleigh waves

(b) 23 October 1961, Long period air coupled ground waves

(c) 30 October 1961, Raleigh waves

(d) 30 October 1961, Long period air coupled ground waves

of travel times of the P-wave generated in the nuclear explosions carried out by the Americans in the Marshall Islands have shown that in the range $\triangle > 35°$ its arrival time is about 2 seconds earlier than that given in Jeffreys and Bullen's Tables, presumably due to the absence of the granitic layer in the Pacific.

So far, on Indian seismograms seismic waves had been detected only in those cases when the explosions were carried on under ground or in deep water. No records could be traced for explosions carried in the atmosphere. In the case of the two recent explosions by the USSR which are said to have been carried out at a height of 50 to 60 km in the atmosphere, enough energy appears to have entered into the earth to cause seismic disturbance at large distances. The records obtained by the vertical component of the Press-Ewing long period seismograph for these two explosions are given in Fig. 1. It will be seen that the two records are almost identical. Every wave and group of waves which appeared on the record of 23 October appears identically with enhanced amplitude on the record of 30 October. This shows that the nature of origin and the wave paths in the two cases were the same. The waves seem to follow the normal dispersion of Raleigh waves for continental paths. This fact will be studied in detail in another communication. It was noticed in the records of all the three components of 23 October 1961 that the recorded waves were followed about 4 hrs 10 min later by a train of very long period waves having periods of the order of three to four minutes. The records obtained on 30 October also clearly showed the presence of these long period waves after an interval of nearly 4 hrs 5 min with increased amplitudes. These waves also show normal dispersion. It is clear, therefore, that these long period waves have also been recorded as a result of the nuclear explosion. The records will now be discussed in detail for these two cases.

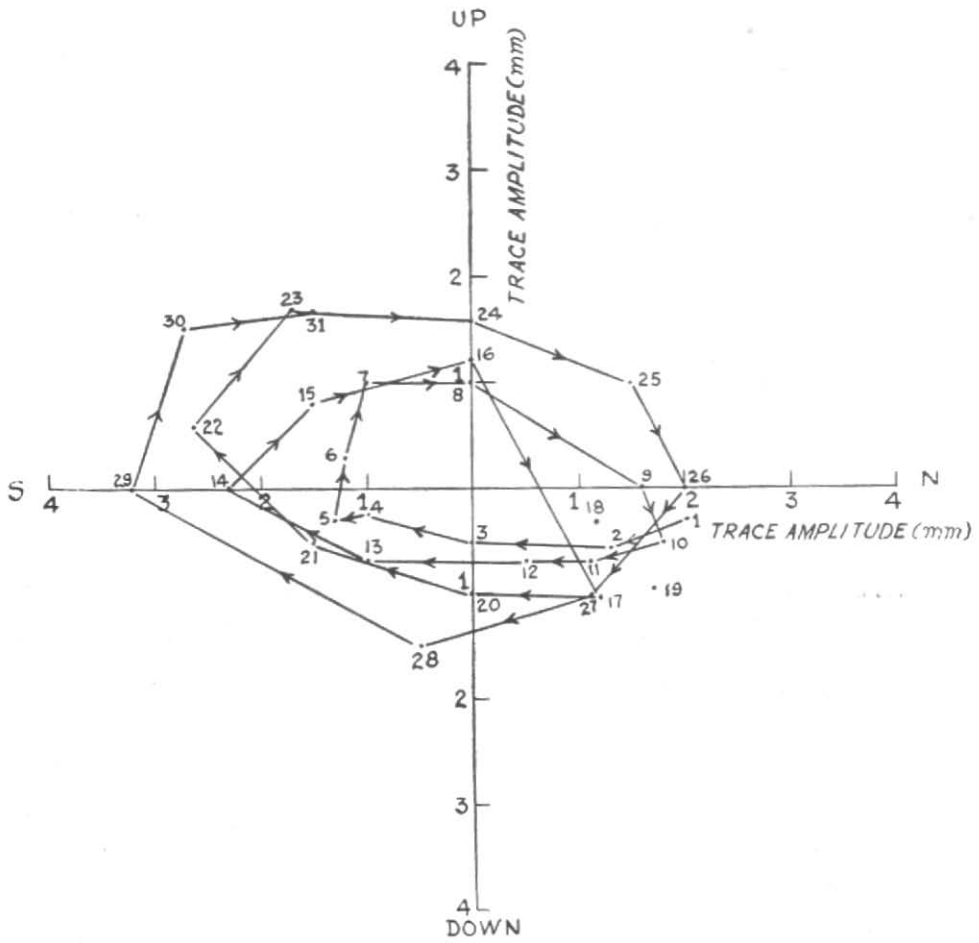

Fig. 2. Observed particle movement for record of 23 October 1961, showing retrograde motion

Discussion

(1) *23 October*

The records indicate arrival of some disturbance soon after 08h 50m GMT but regular waves sinusoidal in appearance began arriving on the vertical component at 08h 55m GMT. Since the azimuth of the source of disturbance (east of Novaya Zemlya Island) is almost due north of Delhi it was easy to undertake a study of the particle motion with the help of the N—S component and the vertical. The position of the particle plotted at an interval of 4 seconds within the time interval 08h 57m 39s to 08h 59m 39s GMT is given in Fig. 2. The motion clearly indicates the predominance of Raleigh waves although it appears that they are mixed up with Love waves, the amplitude of which is much smaller, as evidenced by the low amplitudes on the E—W component.

Assuming that the explosion took place in the neighbourhood of Lat. 77°N and Long. 70°E, the distance of the origin from Upsala (Sweden) would be about $\triangle=24°$ corresponding to a P-travel time of 5 min 17 sec. Since the first wave (P) arrived at Upsala

at 08h 35m 51s GMT, the origin time of the explosion works out to be 08h 30m 34s GMT. The distance of this assumed origin from Delhi works out to be about $\triangle=49°$. The first Raleigh wave maximum having period of 50 seconds arrived at Delhi at 08h 55m 15s GMT. Assuming the value of 3·6 km/sec for the group velocity for this period we get a travel time of 25 min 10 sec for $\triangle=49°$ and the origin time would, therefore, be 08h 30m 05s GMT in close agreement with that obtained from Upsala data. The explosion was also recorded by the French detection services at about 08h 52m GMT which appears to be in general agreement with the expected time of short period Raleigh waves at Paris.

Another item of information available through newspaper reports is that the first shock waves began arriving at Tokyo at 13h 16m GMT. The distance of Tokyo to the assumed point of origin is $\triangle=51°$ and the travel time of shock wave would be 4 hrs 45 min, thus giving a speed of 330 m/sec, a value identical with the speed of sound in air. In Delhi the first long period wave recorded by the seismographs arrived at 13h 04m GMT giving a travel time of 4 min 34 sec. Since the distance of Delhi is 49°, *i.e.*, 5440 km, the speed of these waves comes out to be 330m/sec in agreement with the speed of shock waves recorded at Tokyo. The long period waves were, therefore, transmitted with the velocity of sound. It was first thought that the long period waves might be Mantle Raleigh waves which have gone round the earth, but in that case the waves should have appeared on the seismogram about an hour earlier.

Since the long period waves were recorded by all the components (horizontal and vertical), the recording was due to genuine ground motion and not due only to the pressure fluctuations in the atmosphere. The presence of these waves, on seismic records, which originated as a result of explosion in the atmosphere, and travelled with the speed of sound in air shows the effectiveness of ground to air coupling and supports the theory advanced by Press and Ewing (1951) and Jardetzky and Press (1952).

(2) *30 October*

According to newspapers this explosion was recorded by the Upsala Observatory at 08h 37m GMT. Presuming that the explosion was conducted at the same place as that of 23 October (*i.e.*, near Lat. 77°N and Long 70°E) the distance of the origin from Upsala $\triangle=24°$ and the travel time for P-wave 5 min 17 sec give an origin time of 08h 32m GMT. The first group of Raleigh waves (T=52 sec) at New Delhi was recorded at 08h 57m 09s GMT at a distance of $\triangle=49°$ with a group velocity of 3·6 km/sec, the travel time would be 25 min 10 sec as in the earlier case of 23 October, and the origin time comes out to be 08h 32m in good agreement with Upsala data. The first long period waves ($T\sim280$ sec) arrived at Delhi at 13h 02m 55s GMT after a travel time of 4 hrs 31 min, giving an average speed of 333 m/sec, in agreement with that observed for the explosion of the 23rd. The shock waves for this shock were recorded first at the Kew Observatory, England at 1200 GMT after a travel time of 3 hrs 28 min. Since Kew is located at $\triangle=35°$, the speed of the shock waves works out to be about 320 m/sec, in general agreement with the values arrived at earlier from other stations.

Energy of the explosions

The largest earth movement on the 23rd as well as on 30 October corresponded to a wave of period of nearly 16 seconds. The ground motion due to this was found to be 2·6 microns on the 23rd and 6 microns on the 30th. At a distance of $\triangle=49°$ these ground movements would correspond to earthquake magnitude in the Richter Gutenburg Scale of 5·6 and 5·9 respectively. The seismic energy radiated from the source

(*i.e.*, communicated to the ground) in the two cases would be of the order of $6 \cdot 3 \times 10^{19}$ ergs and $1 \cdot 8 \times 10^{20}$ ergs respectively according to the formula

$$\text{Log}\, E = 11 \cdot 4 + 1 \cdot 5 M.$$

This shows that the energy communicated to the earth in the case of the explosion on the 30th was about 3 times larger than that of the 23rd.

The energy corresponding to a Kiloton Atomic bomb is of the order of 4×10^{19} ergs and that of a 50 Megaton bomb would, therefore, be 2×10^{24} ergs which is of the same order as obtained in the case of the largest earthquakes. Even when the bomb is exploded at a height of 50—60 kilometres about 1/10,000 of the total energy appears to enter the earth in the form of seismic waves.

Conclusion

From the seismic records obtained at Delhi and the data available from newspaper reports, it seems that the Russians exploded the Nuclear Bombs on 23 and 30 October near Lat. 77°N and Long. 70°E. Surface waves in which the Raleigh waves predominate have been recorded identically for the two cases. In addition to these, long period waves having period of the order of three to four minutes were recorded by the seismographs about 4 hrs and 10 min after the arrival of Raleigh waves. These waves, which seem to have a normal dispersion, travel with the velocity of sound in air. Their presence on seismograms demonstrates the effectiveness of ground to air coupling and supports the theory advanced by Press and Ewing (1951).

It seems that an energy of about $1 \cdot 8 \times 10^{20}$ ergs was transmitted to the ground in the explosion of 30 October which was about three times more powerful than that of 23 October. About 1/10,000 of the total energy in the case of these explosions in the air appears to have been transmitted into the earth.

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