Rarotonga also showed explosion effects in the ionosphere for both events. However, other ionospheric stations—Adak, San Francisco, Washington, White Sands, Huancayo, Godley Head and Okinawa —did not show any certain explosion effects. Accordingly, it is concluded that direct-explosion effects on the ionosphere and the geomagnetic field occurred over an area in the central Pacific, roughly the region 170° E.–150° W. and 40° N.–22° S. Radio signals from Honolulu (10 and 15 Mc./s.) and from San Francisco (13·75 Mc./s.) received in Japan showed sudden drops[7] after both explosions. These were due to radio absorption in that central Pacific region.

From the present study of these geomagnetic and ionospheric effects, the explosion height is estimated as 70–80 km. on August 1, and about 40 km. on August 12, although the *New York Times* simply reported it as 100 miles on August 1 and lower than that on August 12.

In addition, three other nuclear explosions that occurred in the south Atlantic on August 27, 30 and September 6, 1958, at about the 480-km. level, were considered. No remarkable geomagnetic and ionospheric effects directly associated with these blasts could be detected in the normal magnetograms or ionograms.

Full details of this work will be published in the *Journal of Geophysical Research*. I wish to express my thanks to Dr. W. O. Roberts and Mr. A. H. Shapley for their kind help, and to Mr. D. B. Bucknam for his considerable assistance. I am also grateful to the Boulder Laboratories of the National Bureau of Standards for an appointment as guest worker and for extending to me their facilities. I wish to thank the International Geophysical Year Data Centers *A* for Geomagnetism and the Ionosphere for the use of data. This study was supported by the National Academy of Sciences as part of the International Geophysical Year Programme with assistance from the Ford Foundation.

S. MATSUSHITA

High Altitude Observatory,
University of Colorado,
Boulder, Colorado. June 2.

[1] *New York Times*, Aug. 2 and 13 (1958); Mar. 19, 20 and 26 (1959).
[2] Steiger, W. R., and Krivoy, H. L., *Hawaiian Acad. Sci.* (in the press).
[3] Cullington, A. L., *Nature*, **182**, 1365 (1958).
[4] Fowler, P. H., and Waddington, C. J., *Nature*, **182**, 1728 (1958).
[5] Kellogg, P. J., Ney, E. P., and Winckler, J. R., *Nature*, **183**, 358 (1959).
[6] Elliot, H., and Quenby, J. J., *Nature*, **183**, 810 (1959).
[7] Obayashi, T., Coroniti, S. C., and Pierce, E. T., *Nature*, **183**, 1476 (1959).

Magnetic Effects Resulting from Two High-Altitude Nuclear Explosions

ON August 1 and 12, 1958, two nuclear devices were exploded in the upper atmosphere above Johnston Island in the North Pacific. No exact information is available to us regarding the heights of the explosions; but it is believed that the first explosion was higher than the second. Unusual magnetic effects, mentioned previously by Cullington[1], were recorded after both explosions on magnetographs at Honolulu, Palmyra Island, Fanning Island, Jarvis Island and Apia. Fig. 1 shows the location of these observatories.

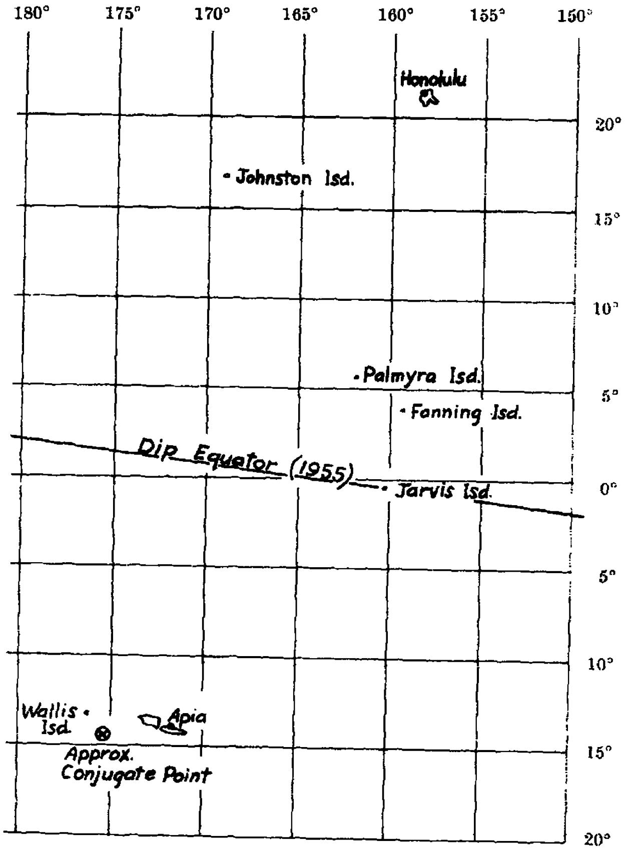

Fig. 1. The region of the Pacific showing islands where unusual magnetic effects were recorded

Vector diagrams of the variations in a horizontal plane are shown in Fig. 2*a* and *b*. Fig. 2*a* refers to the first explosion, and Fig. 2*b* to the second. The effects at Palmyra, Fanning and Jarvis are very similar, and only the Jarvis Island diagram is presented here. Variations in a vertical plane are not illustrated, since the only important effect they reveal is a marked downwards movement in Z at Apia at about 10:55 G.M.T., following the second explosion.

An examination of these diagrams has led us to classify the effects into four phases—initial, second, main and final, as labelled in Fig. 2*a* and *b*.

We suggest the following broad interpretations.

Initial phase. A hydromagnetic impulse affected by dispersion, corresponding to the Alfvén wave postulated by Kellog *et al.*[5].

The front edge travels faster than 10^8 cm./sec. and the time of the maximum corresponds to the speed of a transverse hydromagnetic wave of frequency 1 c./s. travelling parallel to the magnetic field[3]. Across the lines of force, the impulse travels at about the same speed, but suffers greater damping.

Second phase. Produced basically by the transport of individual β-particles[4], photoelectric and Compton electrons, and possibly ions along the line of force from above the point of the explosion to the conjugate point.

As the shock wave and fireball move upwards, more and more individual charged particles can make their escape. Radioactive decay of escaping high-energy neutrons probably broadens the region over which the transport occurs.

As well as those magnetic fields due directly to the travelling particles, dynamo effects are caused by

(*Continued on page* 51)

(*Continued from page* 34)

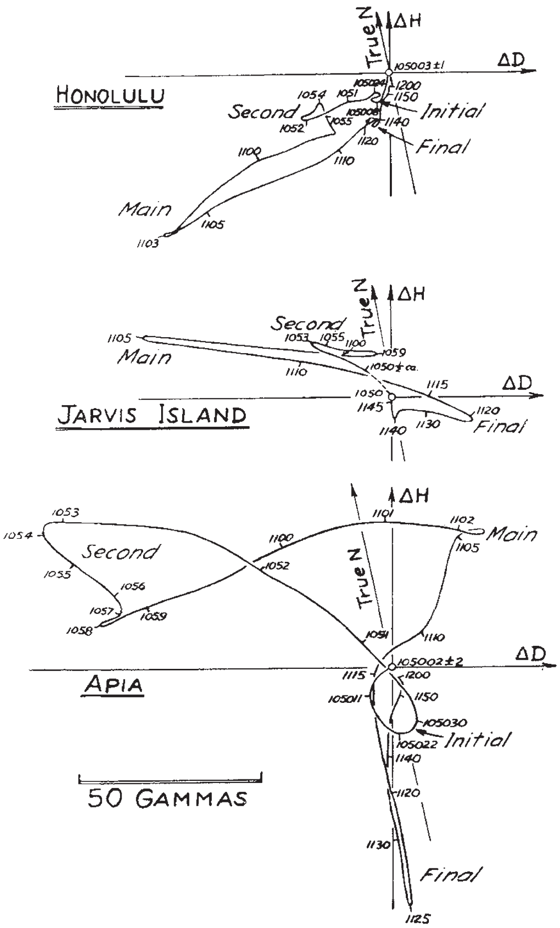

Fig. 2*a*. Vector diagrams showing the horizontal plane magnetic effects of the explosion of August 1. Times are G.M.T.

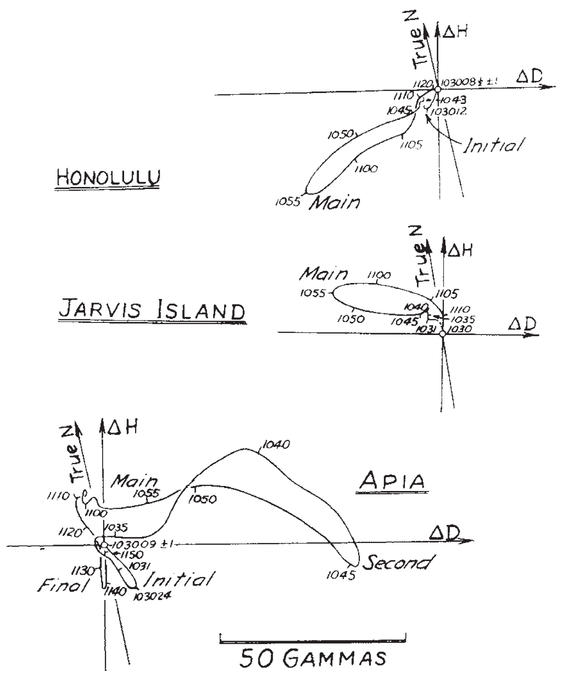

Fig. 2*b*. Vector diagrams showing the horizontal plane magnetic effects of the explosion of August 12. Times are G.M.T.

local *E*- or *F*-region winds in the area of increased ionization produced by these particles, particularly near the conjugate point.

Main phase. Gas motion due to the explosion which, by the time of maximum of this phase, extends to the region of the meridians through Honolulu and Jarvis Islands. G. A. M. King and C. H. Cummack (personal communication) independently propose a shock front spreading from Johnston Island with radially uniform horizontal speed. They associate the arrival of this at each station with the time of maximum of the main phase there, except at Apia, where they associate it with the time of maximum of the final phase.

Adopting the idea of a circular horizontal boundary centred on Johnston Island, applied to an expanding conducting cloud, we suggest a broad qualitative interpretation of the magnetic vectors as follows.

Fig. 3*A* shows the type of distortion produced in the horizontal magnetic field, assuming that the lines of force are to some extent frozen in the gas.

Fig. 3*B* shows a current system which might be produced by the e.m.f. induced in the northern section of the cloud moving against the Earth's vertical magnetic field, with return current moving preferentially along the meridian and linking up in the region of high ionization near the conjugate point.

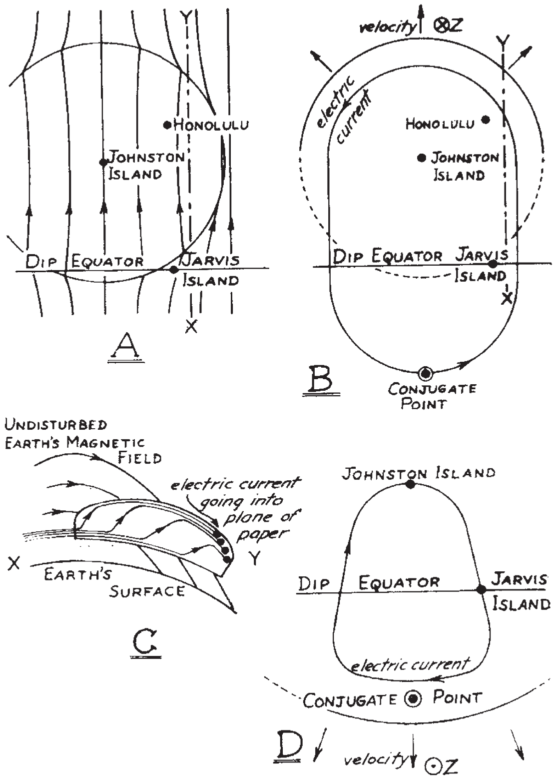

Fig. 3. (*A*) Distortion of Earth's horizontal magnetic field by expanding conducting cloud during the main phase. (*B*) Electric current induced by motion against *Z* of northern section of expanding cloud during main phase. (*C*) Current system in vertical plane across section *X*—*Y* to approximate distortion in (*A*) combined with the current system of (*B*). (*D*) Electric current induced by motion against *Z* of southern section of expanding cloud during final phase

Fig. 3*C* shows a vertical section across *X–Y* of Figs. 3*A* and *B*. In this is pictured a current system which is imagined to combine that of 3*B* with currents to approximate the distortion shown in 3*A*.

Note that the return current across the equator contributes to the required distortion, and we suggest that this as well as anisotropic conductivity control the direction of flow.

Final phase. A later development of the motion producing the main phase, corresponding to the passage of the shock front over Apia as postulated by King and Cummack. In Fig. 3*D* we suggest an interpretation of the magnetic vectors on this idea. This current system would depend on the abnormal ionization still situated in the whole region between Johnston Island and the conjugate point.

The development of all phases after the first explosion is faster, and affects a wider region, consistent with the belief that the first was the highest.

We hope to publish a full account of this work in the *N.Z. Journal of Geology and Geophysics*.

J. A. LAWRIE
V. B. GERARD
P. J. GILL

Magnetic Survey,
Geophysics Division,
Department of Scientific and Industrial Research,
Christchurch, New Zealand.
May 28.

[1] Cullington, A. L., *Nature*, **182**, 1365 (1958).
[2] Kellog, P. J., Ney, E. P., and Winckler, J. R., *Nature*, **183**, 358 (1959).
[3] Akasofu, S., Rep. Ionospheric Res. in Japan, **10**, 4, 231 (1956).
[4] Fowler, P. H., and Waddington, C. J., *Nature*, **182**, 1728 (1958).

Some Geomagnetic Phenomena associated with Nuclear Explosions

THE three International Geophysical Year stations operated in the central Pacific by the Scripps Institution of Oceanography have consistently recorded magnetic disturbances following, and apparently caused by, the various nuclear tests conducted by the British in the vicinity of Christmas Island. This fact is particularly interesting because, unlike the American bomb which was exploded in the ionosphere over Johnston Island on August 1, 1958, producing auroral and magnetic effects over a large area of the Pacific[1], the British tests are believed to have occurred at relatively low altitudes in the lower atmosphere.

Fig. 1 shows magnetograms for the explosion of April 28, 1958, and Fig. 2 the positions of the observing stations relative to the shot point, which was stated to have been within ten miles of 1° 40′ N., 157° 15′ W. The altitude has not been disclosed, but official reports indicate that the device was dropped by a *Valiant* jet bomber, and it may be supposed that the height of detonation was substantially less than the ceiling of about 60,000 ft. for that class of aircraft.

The pronounced anomalies in *Z* and *D*, which reach a maximum at Jarvis and Fanning between 12 and 15 min. after the event and at Palmyra about 10 min. later, are similar in character to those which followed other tests, and we have no doubt that they are directly related to the nuclear explosion. We have examined magnetograms from the nearest magnetic observatories outside the immediate area,

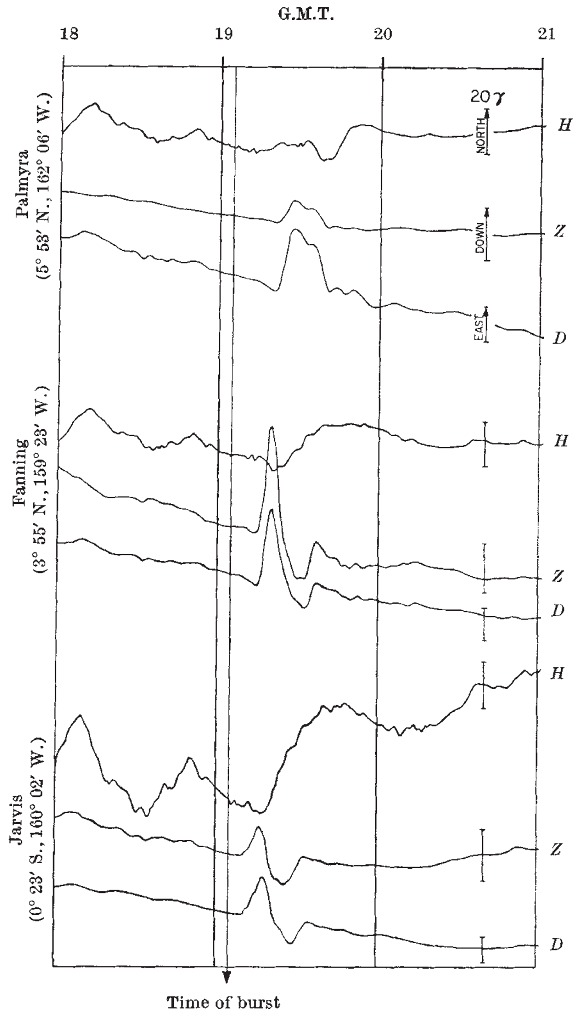

Fig. 1. Magnetograms for the Christmas Island nuclear explosion of April 28, 1958

that is, Apia, Guam and Honolulu, but have not found any magnetic effects that we can positively identify with this or with any other of the British tests. This is surprising, because Apia and Honolulu are only about three times as far as Palmyra from Christmas Island.

The disturbances recorded at our three stations have several features in common. They begin quite suddenly after a delay of several minutes (rather longer at Palmyra than at the other two stations), they move in the same relative phase and they persist for about half an hour, but perhaps the most striking feature of the magnetograms is the absence of any observable disturbance in *H* corresponding to the major disturbance in *Z* and *D* (though an unusual, and probably related, type of local disturbance in *H* at Palmyra commenced about 26 min. after the event and lasted for about 20 min.). The absence of an *H* component would be explained if the phenomenon involved horizontal currents parallel to the magnetic meridian, and in this connexion it may be noted that the Earth's magnetic field is very nearly horizontal throughout the area. More generally, possible mechanisms for producing such disturbances include : (*a*) the motion of charged particles, in certain circumstances controlled by the Earth's magnetic field ; (*b*)