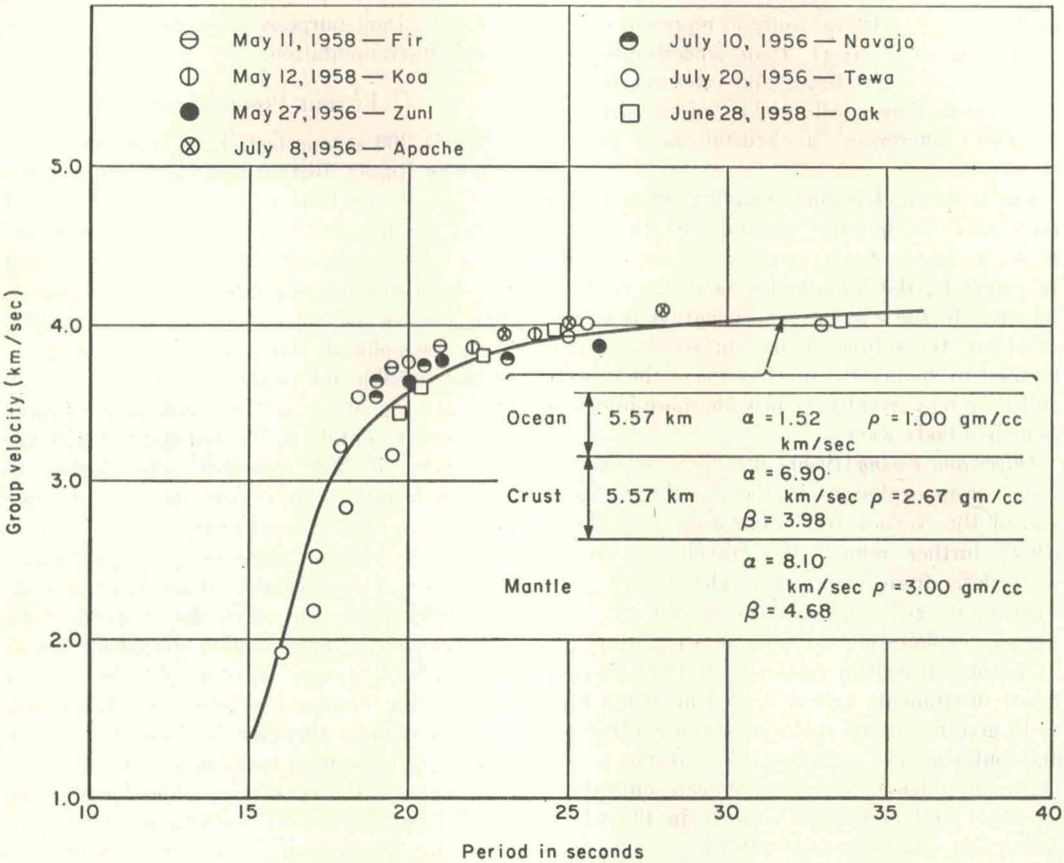

Fig. 1. Surface wave dispersion from Pacific shots recorded at Pasadena.

Kimberly, and Tamanrasset, at distances of 137° to 142°, all showed precursors about 11 sec ahead of the scheduled *P*-wave arrival times and 3 sec ahead of *PKIKP*. These were shown to be *PKP* waves diffracted from the outer core. It had been suggested that the waves thought to be propagated through the inner core (*PKIKP*) might be diffracted *PKP* waves. Hence the identification of these two separated sets of waves added the 'final link in the chain of evidence for the existence of the earth's inner core' [*Burke-Gaffney and Bullen*, [1958].

As the Atomic Energy Commission began declassifying the times and locations of test explosions in the Pacific and Nevada proving grounds, seismological articles began to appear based on records obtained in the routine earthquake watch. *Oliver and Ewing* [1958*a*] observed surface waves at Palisades, New York, from the Wigwam underwater explosion off the coast of California. This source excited two types of surface waves which had not previously been found to propagate along oceanic paths—the short-period branch of the Rayleigh wave and the first shear mode. This knowledge aids in the interpretation of the dispersion of earthquakes and in the use of the dispersion method to determine properties of the crust and mantle.

To illustrate the possibilities of nuclear explosions, we present in Figure 1 the Rayleigh mode dispersion for the oceanic paths between the test sites and Pasadena for six events. The theoretical dispersion curve for the case shown below the curve represents a very good fit to the data. These results place on a firm basis the corresponding results from earthquakes and make possible a precision heretofore not available. Small deviations for different regions must (in the case of artificial sources) represent effects of propagation rather than uncertainties in epicenter or origin time. The interpretation of these deviations will yield information on regional differences in crustal and mantle structure.

Furthermore, the corresponding seismograms represent the impulse response of the wave guide, in this case the oceanic crust and mantle. In principle, the impulse response can be used to separate the effects of propagation from the effects of the source. Thus, surface waves can be used to deduce the mechanism of the source, and they may eventually provide more information than body waves.

Oliver and Ewing [1958*b*] also discussed surface waves from explosions in the Marshall Islands and at the Nevada test site. *Carder and Bailey* [1958] further refined the travel-time curves with data from explosions. The British and Australian governments cooperated in the seismic exploitation of four atomic tests at Maralinga in central Australia in 1956. Appropriate instruments were deployed in such a way as to give maximum information on continental and outer-mantle structure. The result is the first really reliable knowledge of deep continental structure and of mantle velocity in the whole Australian continent [*Doyle*, 1957].

Bullen [1958] summarized the importance of this as follows: 'In Australia, we are, by world standards, very free from earthquakes, and we are also, as yet, short of having an adequate network of observatories. . . . Thus the 1956 explosions provide one instance in which atom bomb explosions have been turned to great advantage, even though the results relate only to near-surface structures.'

With the announcement of the Rainier underground explosion and the Hardtack II series at the Nevada test site, many seismological studies were undertaken, and they have been or will be reported in the literature. Outstanding among these is the work reported by *Romney* [1959].

Romney's account of travel-time and amplitude determination across the United States from the Hardtack II shots will stand as a classic in seismology. Never before have such extensive and accurate records been obtained on a continental scale. Even so, they leave much to be desired, and very much more could be accomplished with a program of atomic explosions for seismic purposes, supported by adequate seismic instrumentation.

Future Possibilities

Nearly 300 atomic tests have been conducted so far by Russia, Britain, and the United States. In Table 1 169 tests performed by the United States are listed.[2] The time and location are given for each, together with some yields and all Pasadena seismic amplitude data. We believe that, because of the secrecy surrounding these tests, seismologists have not sought to glean all the possible information from their records of these tests. We hope that publication of these data, which contain much that has not hitherto been released, will stimulate seismologists to look back into their records to extract more information from these old shots.

Table 1 contains shots of all kinds—high-, medium-, and low-altitude, surface, underground, and underwater—and gives the available yield and Pasadena ground-motion amplitude for *P* and Rayleigh waves. These amplitudes are not those of the Fourier component for the period shown and must therefore be considered rough indications to be used for comparison only.

In Table 2 the seismic coupling for shots of one yield under various conditions are roughly compared. Application of the earthquake magnitude scale to explosions is highly questionable. One approach is to stipulate that the magnitude must correspond to that of a normal earthquake at the same distance which has excited *P* waves of the same amplitude and period. In the future it will be better to work directly with energy. The partition of energy between *P*, *S*, and surface waves will be different for earthquakes and explosions. It should be remarked here that all the underground shots have been in dry desert alluvium or in porous volcanic tuff. The energy coupled to seismic waves from these shots may not be typical of explosions in other types of rock. The Gnome experiment in a compact salt bed would provide more information on this point. For this and other reasons, Table 2 should be viewed as a crude comparison of explosions under varying source conditions.

In terms of distant *P*-wave amplitudes, a

[2] This table is based on shot information compiled by G. W. Johnson for presentation to the International Union of Geodesy and Geophysics at Helsinki, 1960.