THE sP* WAVES FROM A DEEP SHOCK

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A clear precursor to S arrival was observed at the JMA and Nagoya University Telemeter Network stations for a deep shock occurring in the Volcano Islands. The apparent velocity, particle motions and travel times show that this phase is sP*: S converted to P* at the ocean bottom. A remarkable fact is that this converted P* propagated in the oceanic crust more than some hundreds kilometers maintaining such a large amplitude that gave rise to misidentification of S arrival at many JMA stations.

In the course of a study of the S-wave velocity structure in the upper mantle we found an exceptionally strong precursor to S arrival in the seismograms of the Volcano Islands deep-focus earthquake of May 18, 1979 (origin time: 20 hr 18 min 02.6 sec; epicenter: 24.21°N, 142.33°E; depth: 578 km; magnitude: 5.7 by USGS) at seismic stations of the Nagoya University Telemeter Network and the Japan Meteorological Agency (JMA). These stations are particularly suitable for detection of S phases and their converted phases because they have relatively long-period seismographs (the PELS type of Nagoya University and the VI type of JMA) whose intrinsic periods are 10 and 5 sec respectively. In Fig. 1 the P and S arrivals reported in the JMA bulletin are plotted against epicentral distance. The JB arrivals are used as a reference. As compared to the P arrivals the S arrivals are immensely scattered, an unusual observation for large deep shocks. The scatter consists of large negative residuals at twelve stations in a distance range 1,200 to 1,500 km and large positive residuals at almost all the other stations. Large positive residuals are interpreted as due to a later phase strongly refracted at the 650 km discontinuity. Large negative residuals of -4 to -8 sec are interpreted as due to a precursor to S in the form of sP*: S converted to P by the reflection at the ocean bottom which propagated through the oceanic crust and further through the lower continental crust as P*. This paper reports the nature of the sP* phase.

Figure 2 shows the locations of the epicenter and the stations at which a clear precursor to S was observed. Their vertical seismograms are shown in Fig. 3. The precursor is more conspicuous than the first S arrival and sometimes as large as the most predominant S arrival (=the later phase from the 650 km discontinuity). Using the seismograms in a distance range 1,200 to 1,500 km an apparent velocity of 6.8 km/sec was obtained for the precursor. This value is similar to P-

Fig. 1. Residuals of the P and S arrivals reported in the JMA bulletin relative to the JB travel time.

wave velocities of the lower crust in the Japanese Islands (YOSHII and ASANO, 1972; UKAWA and FUKAO, 1981) and those of the layer III of the oceanic crust (MURAUCHI *et al.*, 1968; CHRISTENSEN and SALISBURY, 1975). Figure 4 shows the particle motions of the P and S phases and the precursor to S in a vertical plane along the great circle. This figure clearly indicates that the precursor is a longitudinal wave with an incident angle greater than those of the P and S phases. All these observations suggest that the precursor is a longitudinal wave of P* nature.

For a shock at a depth of 580 km apparent velocities of P and S waves are greater than 10 and 6 km/sec respectively. Only the S waves with apparent velocities around 6.8 km/sec can contribute to the observed P* phase upon their conversion to P. A critical conversion occurs at an epicentral distance of about 700 km, a distance insensitive to the adopted velocity structure. There are two conceivable ways of conversion. One is a reflection at the ocean bottom and the other is a refraction at the Moho. The former includes an ordinary sP wave that suffers a wide angle reflection at the Moho. The latter is a phase that has often been reported as 'Sp' (e.g., BÄTH and STEFÁNSSON, 1966). The 'Sp' phase should be small, however, in the present case because it does not reach Japanese stations in a geometrical ray sense through the crust with 10 km thickness. We consider that the observed sP* waves are largely generated at the ocean bottom by reflection. The travel time curves of the sP* were calculated for the Jeffreys' S mantle structure with

Fig. 2. Epicenter of the earthquake investigated ($\times$), the S to P conversion line (—) and the ranks of detection of the precursor to S. The ranks are expressed as $\bullet$: Clear arrival of sP*, $\blacktriangle$: Precursor with an arrival slightly different from the expected sP* arrival (see Fig. 3), and $\circ$: sP* arrival not observed.

three different crustal P velocities of 6.4, 6.8 and 7.2 km/sec. They are superposed on the reduced seismograms in Fig. 3. The agreement with the observation is quite good for a crustal model with a velocity of 6.8 km/sec, justifying our interpretation for the observed precursor from a view point of travel time.

As can be seen in Fig. 2, a clear sP* phase was observed mainly in the central

Fig. 3. Reduced seismograms of the JMA and Nagoya University Telemeter stations. The latter stations are marked by asterisks. The reduced velocity is 7.0 km/sec. The three travel time curves are explained in the text.

Honshu and in the eastern part of western Japan. In northern Japan and in the most Kyushu and Shikoku regions sP* was not observed or was weak. In northern Japan the theoretical conversion points lie in the Izu-Bonin arc, beneath which the S to P* conversion may be inefficient or the propagation as P* may be ineffective because of a heterogeneous crustal structure. The reason for the weakness of sP* in the Kyushu and Shikoku regions is not obvious. It appears to be difficult to

Fig. 4. (a) Records of INU and TYN which belong to the Nagoya University Telemeter Network and (b) their particle motions for P, sP* and S on a vertical plane along the great circle path. The time windows for P, sP* and S are shown in (a).

explain the weakness in northern Japan and in the Kyushu and Shikoku regions simultaneously by a radiation pattern of S wave. Although the focal mechanism of this earthquake has not yet been determined, the P wave first motions are "up" at all the JMA stations except one and the S waves are clearly recorded at almost all the stations. The most remarkable fact in our observation is that the sP* wave propagated as P* more than some hundreds of kilometers through the Philippine Sea Plate maintaining its large amplitude. Such an effective propagation of P* in the oceanic crust is sometimes reported in oceanic explosion studies (AOKI, 1979).

Our discovery for sP* was fortuitous. Although we examined several other deep shocks, no obvious sP* phase was found partly because time differences of sP*-S or sP*-sP were too small.

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