FOCAL MECHANISM OF THE 22 NOVEMBER 1969 KAMCHATKA EARTHQUAKE FROM TELESEISMIC WAVEFORM ANALYSIS

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Introduction

On November 22, 1969 an earthquake with a magnitude of approximately M_s=7.5 occurred off of the eastern coast of the Kamchatka peninsula, USSR. (Figure 1). This large earthquake is located in an extremely complex tectonic setting where the active plate boundary geometry is poorly understood. Thus an understanding of the mechanism of this event is important to the understanding of the plate tectonics of the region.

Tectonic Setting

The Kamchatka peninsula is a remnant island arc system. During the late Cretaceous, the Kula plate was being subducted under the Eurasian plate forming the Iruneiskaya arc (Savostin *et al.*, 1983). The subduction continued until the Eocene when the Kula-Pacific ridge was subducted under the Aleutian trench (Savostin *et al.*, 1983). At this time, the modern tectonic setting began to form.

Today, the tectonic setting is much more complicated than 150 million years ago. The Pacific plate is being subducted under the southern half of the peninsula in the Kurile trench. Subduction under the peninsula probably ends at the junction of the Kurile and Aleutian trenches near the Kamchatka Cape (Stauder and Maulchin, 1976). The boundary between the Sea of Okhotsk microplate and the North American plate runs northeast from this junction to Karaginskiy Island where it turns northwest, across the peninsula, through the Sea of Okhotsk, and onto the Soviet mainland. The dominant motion along this boundary has been strike-slip (Savostin *et al.*, 1983). The Eurasian plate bounds the Sea of Okhotsk plate microplate on the west. None of these plate boundaries have been accurately defined. This may be due to the relatively young age of the Sea of Okhotsk microplate, probably Holocene (Savostin *et al.*, 1983). This may not have been enough time for surface expressions to form. The 22 November 1969 earthquake was located in the area where the boundary between the North American plate and the Sea of Okhotsk microplate changes from a northeasterly trend to a northwesterly trend.

Previous Studies

None of the previous studies of this event have involved the use of body waveform analysis. In 1976, Stauder and Maulchin examined this earthquake using first motion analysis and S wave polarization angles. They gave the magnitude of the event as m_b=6.3 and gave a depth of 33 km. This depth was based on a location inversion and represents a standard default depth for the method. Their methods were not designed to determine depth or to estimate the rupture time of the earthquake.

The ISC Bulletin gives a depth of 51.1 km for this event. ISC depths are generally considered to be unreliable for earthquakes of less than 100 km depth. The ISC reports a magnitude of 6.3. A more recent study by Seno and Eguchi (1983) report a depth of 38 km and a body wave magnitude of m_b=7.0. They estimate that the moment-magnitude, M_w may be as large as 7.8.

Analysis

A first motion mechanism was determined from picks made on 24 WWSSN long period seismograms. This mechanism is shown in Figure 2. The fault plane is probably the shallow, northwest dipping nodal plane. The strike and dip of this plane, N50°-80°E, 5°-10° NW are approximately coincident with the paleo-subduction zone. The cluster of compressions surrounding the center of the focal sphere clearly indicates a thrust mechanism.

It was clear from the examination of the P wave arrivals that this event was significantly larger than the magnitude 6.3 reported by some of the previous studies. Many of the P records were off scale, and only those records from

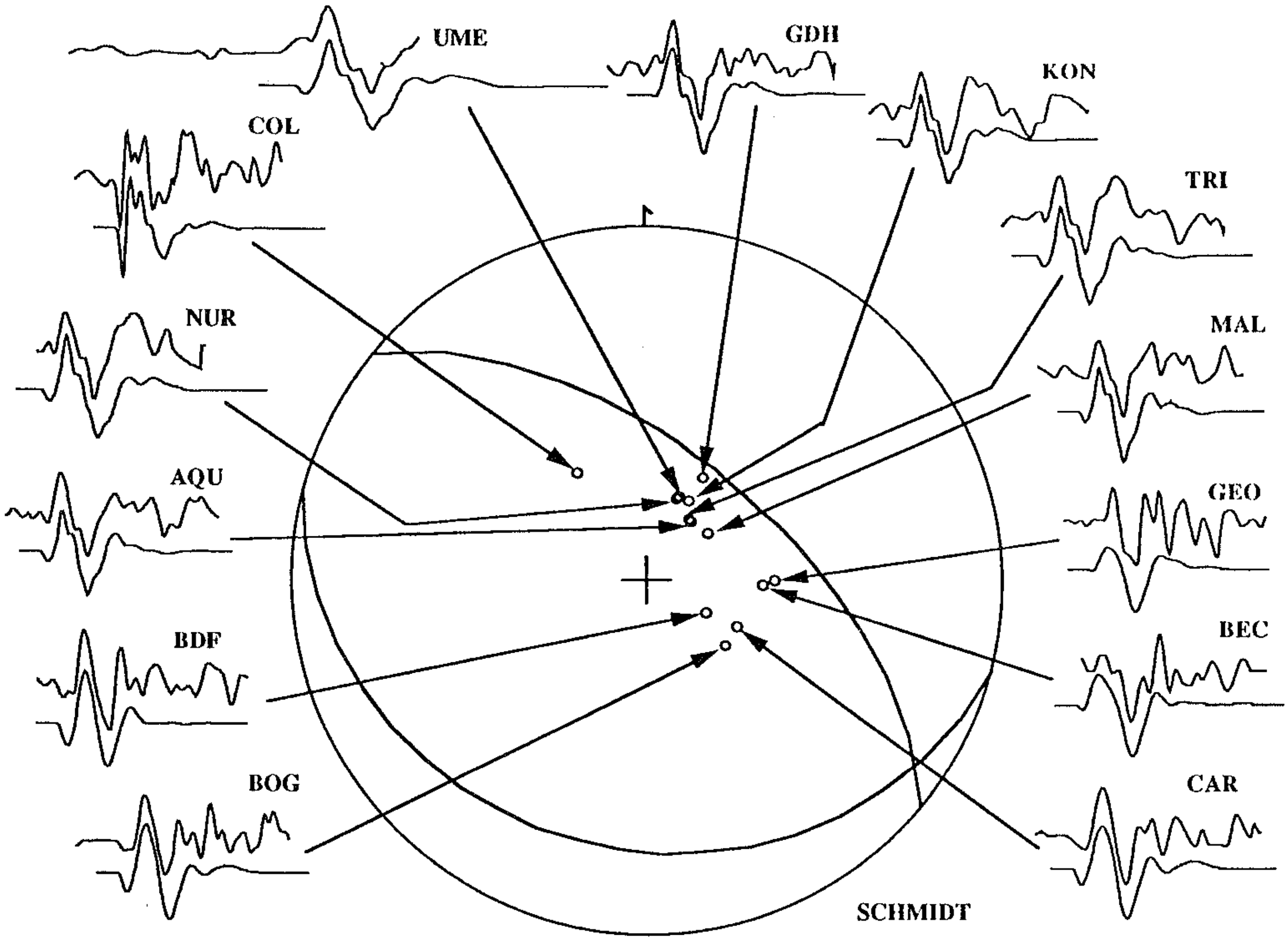

Figure 2: Composite figure representing the best fit of the synthetics to the observed achieved with this study. The circles represent dilatations. The epicenter of the main shock is the center of the stereonet. Observed seismograms are represented with the top line and the synthetics are represent with the bottom line. The source-time function varied with azimuth and the following were held constant: Strike = 320°, Dip = 60°, Slip Angle = 285°, Depth = 2.5 km

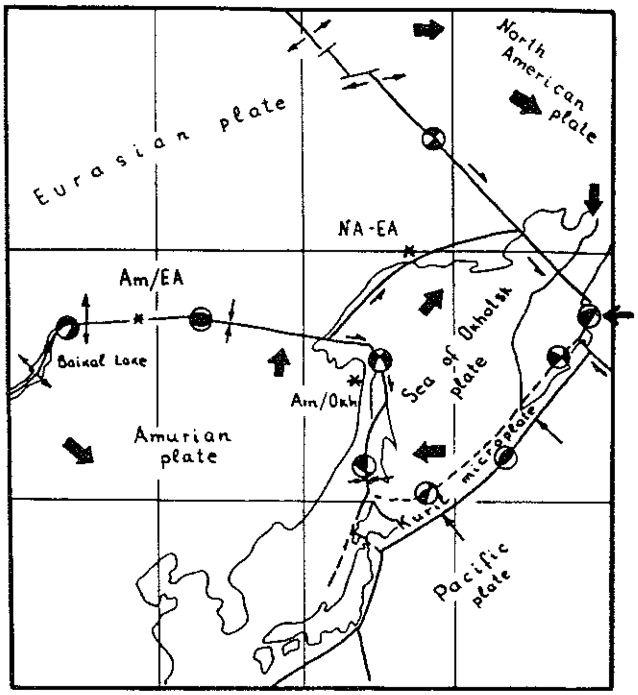

Figure 1. Plate tectonic setting of the Kamchatka peninsula. The 22 November 1969 earthquake is indicated with an arrow. The focal mechanism shown is the one determined in this study. Other typical focal mechanisms are shown on plate boundaries.

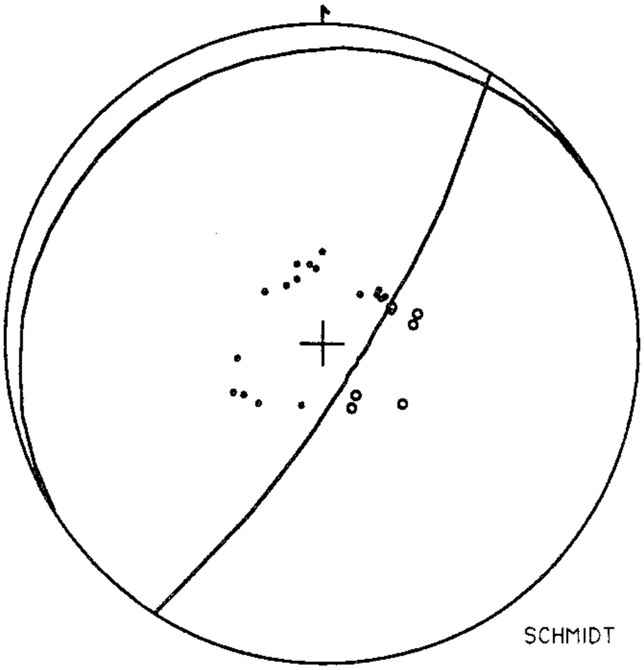

Figure 2. First motion focal mechanism obtained in this study. The steeper nodal plane has strike= 32°, dip= 80° and a slip angle=80°. Since this is a thrust mechanism, the shallower plane is most likely the actual fault plane.

low magnification stations were suitable for digitizing and modeling. A total of 18 records were digitized. Many of the records showed a characteristic double peak at the onset of the P waveform. This was suggestive of a shallow source with the second peak an expression of the free surface reflections pP and sP.

The P waveforms that could be digitized were modeled using first motion synthetic seismograms. The seismograms were computed using an assumed crustal model that included a 1 km water layer and a sediment layer. The strike and dip were held at the values obtained in the first motion mechanism while the depth and source time function were varied to achieve the best possible fit at all available stations. In the course of this modeling, it was determined that shallow depths, 5-18 km would not yield good fits. Moreover it was clear that the double peak was due to complexity of the rupture that would have to be modeled as a complex source time function. To limit the number of degrees of freedom, a double pulse source time function was assumed.

A set of best fit seismograms is shown in Figure 3. The mechanism parameters are strike=32°, dip=80°, slip angle=80°. The strike and dip are for the steeper of the two nodal planes. The best fit depth is between 20 and 25 km inclusive of the 1 km water layer.

All stations require a pair of trapezoidal source time function separated by 5.5 seconds. The first pulse has a duration of 4 seconds. The three dilatational stations require a significantly longer second pulse than the compressional stations. For the compressions, the best fit second pulse has a duration of 6 seconds while the dilatations require a second pulse with a duration of 17 seconds. This suggests a strong directionality to the rupture. The moment of the second pulse is approximately four times the moment of the first pulse. The complexity of the waveforms, as well as the observed directionality strongly suggest that the rupture is more complicated than this simple two pulse model. This complexity supports the larger estimates of this earthquake's magnitude

Conclusions

The 22 November 1969 Kamchatka earthquake was a predominately thrust event with a moment magnitude in excess of 7.5. The focal depth was between 20 and 25 km. The presumed fault plane dips at between 5° and 10° to the northwest similar to the paleo-subduction zone in this area. The earthquake has a complex rupture process with several pulses, strong directionality, and an overall duration in excess of 12 seconds. This thrust event is located along a poorly defined plate boundary that is dominated by strike slip events. This suggests that this earthquake involves reactivation of faults associated with the paleo-subduction zone.

References

Stauder, W. and L. Maulchin, 1976, Fault motion in the larger earthquakes of the Kurile-Kamchatka arc and of the Kurile-Hokkaido corner, *Journal of Geophysical Research*, **81**, p. 297-308.

Seno, T. and T. Eguchi, 1983, Seismotectonics of the western Pacific rim, in *Geodynamics of the Western Pacific-Indonesian Region*, Geodynamics Series Volume 11, AGU and GSA.

Savostin, L., L. Zonenshain and B. Baranov, 1983, Geology and plate tectonics of the Sea of Okhotsk, in *Geodynamics of the Western Pacific-Indonesian Region*, Geodynamics Series Volume 11, AGU and GSA.

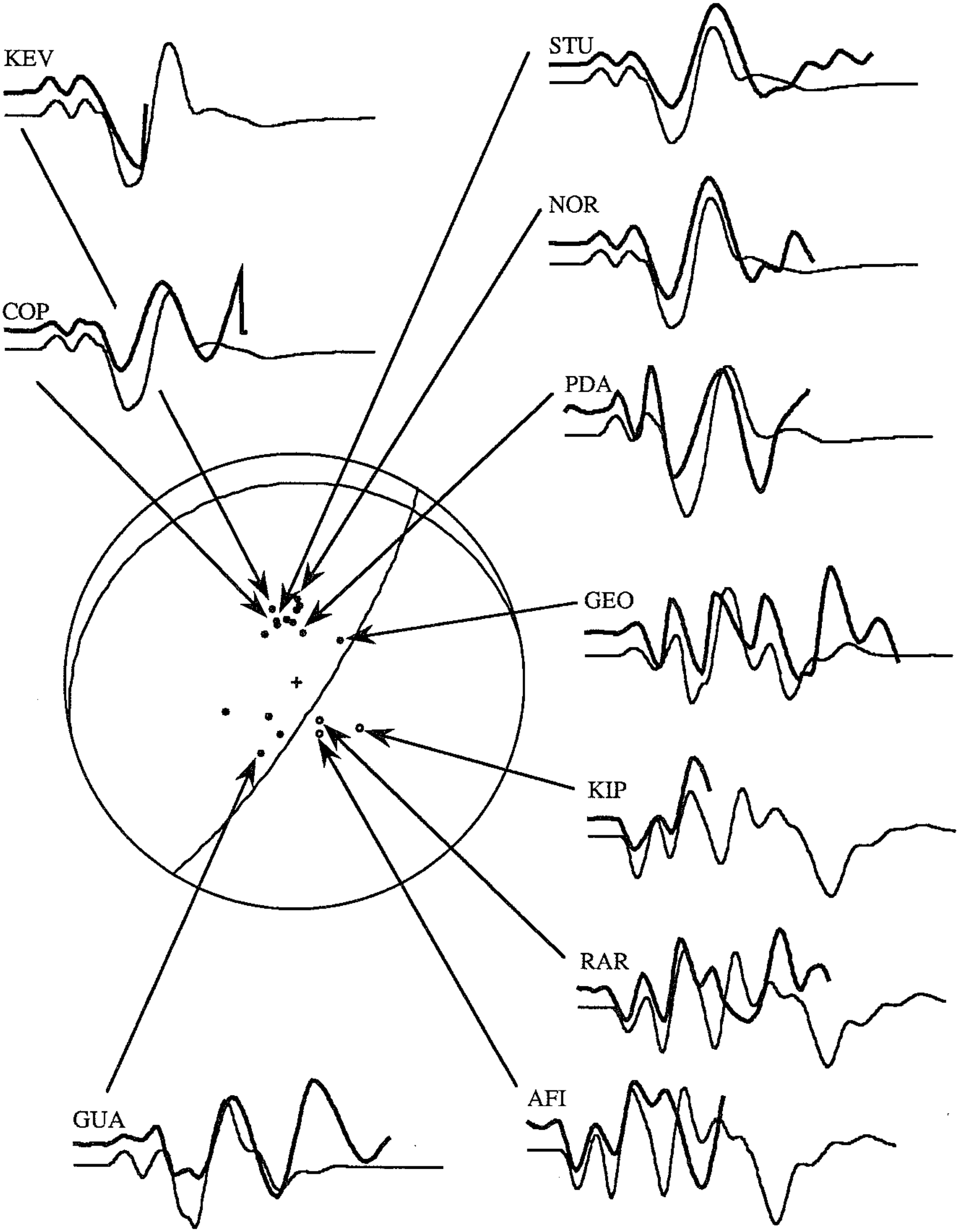

Figure 3. Best fit P wave synthetic seismograms from the 22 November 1969 earthquake. The heavy trace is the observed seismogram as digitized.

ANALYSIS OF AFTERSHOCKS OF THE JUNE 10, 1975 NEMURO-OKI EARTHQUAKE

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INTRODUCTION:

Tsunami earthquakes are a small group of earthquakes known to have produced anomalously large tsunamis relative to their seismic magnitudes. The June 10, 1975 Nemuro-Oki earthquake, which occurred in the subduction zone of the Kurile Island Trench northeast of Japan ($M_s = 7.0$, $T_o = 13:47:12.5$, 42:97°N, 147.17°E) is one such tsunami earthquake. Previous studies of this mainshock have shown it to have an unusually long rupture time of approximately 40 seconds (Kroeger et al., 1987; Fukao, 1979). One explanation for both the long rupture process and the large tsunami generation may be rupture in the low rigidity sediments of the accretionary wedge. However, it is difficult to determine the depth of the mainshock due to its complex rupture. Analysis of its aftershocks with their shorter, simpler time functions may be helpful in determining the fault mechanism of the main earthquake.

The purpose of this study was to model the first motion P- and SH-wave seismograms of the aftershocks to determine their depths in order to better understand the fault geometry of the mainshock. We wanted to see if the aftershocks occurred at depths in the oceanic crust or in the accretionary wedge. We expected to find aftershocks with a short source time function of less than 5 seconds, which is normal for earthquakes of their magnitudes. The aftershocks we modeled were the June 13 ($M_s = 6.4$, $T_o = 18:08:11.7$, 43.5°N, 147.7°E), June 14 ($M_s = 6.1$, $T_o = 18:38:10$, 43.5°N, 147.9°E), and June 22, 1975 ($M_s = 6.1$, $T_o = 22:44:10$, 43.2°N, 147.1°E) aftershocks.

METHODS:

We gathered WWSSN seismogram microfiche records from stations with distances between 30° and 102° away from the source. Two short sections of the first motions of the P- and SH-wave seismograms were printed and digitized for use in the modeling. From these records, we were able to determine the first motion of the P-waves which enabled us to locate the nodal planes giving a well controlled strike and an estimate of the dip of the fault. We synthetically modeled P- and SH-waves from the stations using synthesizer software written for the Macintosh by Glenn C. Kroeger at Trinity University.

Waveforms are the result of a series of rays which include the sum of all direct rays as well as wave phases which reflect off of geologic boundaries near the source, such as the ocean floor, the ocean surface, and the Moho boundary. The depth of the earthquake controls relative arrival time of these rays, and the fault geometry controls the relative pulse amplitudes. Waveforms are also controlled by their source time function which models the duration of the earthquake rupture process.

A layered model of the crustal structure, having layer boundaries with velocity changes at 5, 9, 11, and 17 km, was constructed based on assumed geometry of the accretionary wedge, the Kurile Island Trench, and refraction profiles of the area off the east coast of Hokkaido near the epicenter (Asano et al., 1980). Figure 1 is a cross section of the trench showing our layered model and the velocity structure from the refraction survey. By entering different strike, dip, depth, and time function variables, the computer mathematically synthesized seismic waves which we compared with our digitized seismogram data. Altering the combination of these variables enabled us to come up with a best fit waveform for as many seismic stations as possible.

RESULTS:

After analyzing our P-wave data, we found that all modeled depths were shallow (Table I). A few stations located close to the nodal plane, such as col, bks, and pmg, were key in determining the depth. The best fit modeled P-wave forms for recorded stations are illustrated in Figures 2, 3, and 4. Modeling SH-waves confirmed the fault parameters and time functions of the P-waves, but they suggested a slightly greater depth of 8-9 km, which were still located well within the accretionary wedge.