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Compelling evidence of an aseismic slab beneath central Taiwan from a dense linear seismic array

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Abstract

From a dense linear seismic array consisting of 15 short-period seismic stations deployed across the suture zone, an aseismic slab subducted beneath central Taiwan was clearly detected. In addition to the direct P-waves, the identification of the mantle refracted phases generated by an intermediate-depth earthquake (M_L=5.8) in southeastern Taiwan and recorded by the linear array as well as some seismic stations (CWBSN) along the Eastern Central Range shows that a subducted crust with a low velocity exists down at the depth of at least 89 km. This strongly suggests that the subduction of the Eurasian plate in southern Taiwan most likely extends to central Taiwan, where there has been an absence of mantle earthquakes in the Wadati–Benioff zone. What the subduction slab without mantle earthquakes could very well be attributed to is the subducted continental crust, where the rock strength is totally different from that of the oceanic crust.

Keywords: Aseismic slab; Continental subduction; Central Taiwan; Linear seismic array

1. Introduction

The island of Taiwan is located at one part of the convergence zones between the Eurasian Plate (EUP) and the Philippine Sea Plate (PSP) (Tsai et al., 1977). To the northeast of Taiwan, the PSP subducts beneath the EUP. To the south the EUP underthrusts the PSP (Fig. 1). The subducted slab in northeastern as well as that in southern Taiwan have both been unambiguously characterized by the occurrence of a large number of earthquakes in the Wadati–Benioff zone. It cannot be ignored, however, that the strong convergence behavior between the two plates in central Taiwan, albeit of compelling interest, has long remained unclear in that there is no Wadati–Benioff zone between the latitudes of 23°N and 24°N (Fig. 1b). Thus, various tectonic models based on diverse assumptions, such as the critical wedge (Suppe, 1981; Dalhen and Barr, 1989), lithospheric collision (Wu et al., 1997), crustal subduction and exhumation (Lin and Roecker, 1998; Lin, 2000; 2002) among others, have been proposed to explain the mechanisms and evolution processes of the Taiwan Orogeny.

Although there have been no deep mantle earthquakes beneath central Taiwan, some studies (such as those by Chemenda et al., 1997; Lin et al., 1998; Teng et al., 2000; Lallemand et al., 2001; and Lin, 2002) have suggested that the eastward subduction of the EUP beneath the PSP not only occurs in southern Taiwan, but also extends to central Taiwan. Such a feature has gained, at least to a certain extent, some support on the weight of evidence from two recent studies. One is the analysis of both the travel-time residuals and the differences in the amplitudes of the tele-seismograms recorded at broadband stations in Taiwan (Chen et al., 2004). The other is the identification of the Moho-reflections from a dense linear array in the central Taiwan area (Lin, 2005). However, neither the exact plate boundaries nor the geometry of the subducted slab has been clearly defined from the limited seismic stations that were in place at the time of those earlier studies.

In this study, a dense linear seismic array was deployed across the plate boundary between the EUP and PSP to examine the major deep structures beneath central Taiwan.

This paper focuses on the analyses of the later phases recorded by this linear array that were generated by an intermediate-depth earthquake located in the Wadati–Benioff zone in southeastern Taiwan. In addition to the direct P-waves, the identification of

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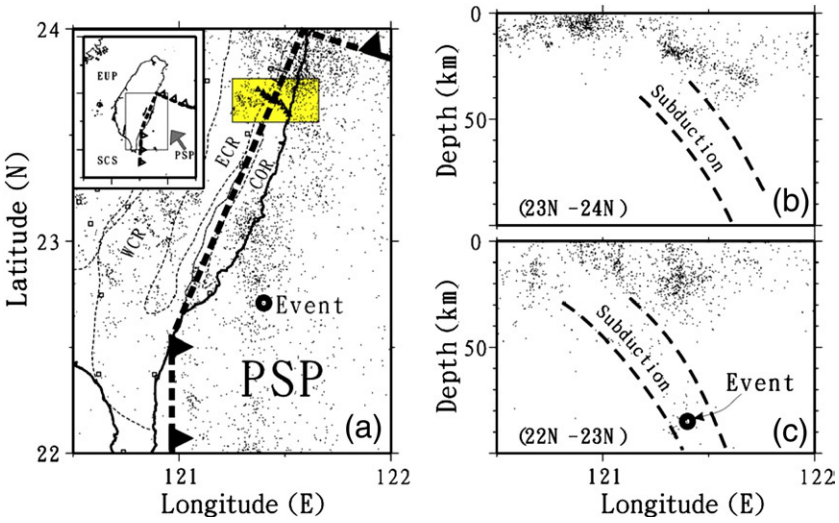

Fig. 1. (a) Seismicity (small dots) and the CWBSN seismic stations (squares) in southeastern Taiwan. The dense linear array with 15 temporary seismic stations (triangles) in eastern Taiwan is also shown. The geological provinces are marked WCR (Western Central Range), ECR (Eastern Central Range), LV (Longitudinal Valley) and COR (Coastal Range). The inset map shows the simplified tectonics of the Taiwan area. The convergent direction between the Eurasian plate (EUP) and Philippine Sea plate (PSP) is shown by the large arrow in the inset map. The hypocentral projections of earthquakes within (b) 23°N–24°N and (c) 22°N–23°N in the E–W cross-sections are shown. The subducted crust is marked by the dashed lines.

other phases along different paths in the upper mantle has provided some constraints from which the geometry of the subducted slab beneath central Taiwan can be inferred. The results here are further used to evaluate a variety of tectonic models that have been proposed earlier to explain the Taiwan Orogeny.

2. Seismic array and data

Consisting of 15 seismic stations (KF01–KF15), the dense linear seismic array (Fig. 2) which enabled this research was deployed to study the deep crust and mantle structures across the suture zone in the period between August and October, 2003. By design, this seismic array, roughly striking in the NW–SE direction, crossed the major geological structures in the eastern part of central Taiwan (Ho, 1988) which are the Eastern Central Range (ECR), the Longitudinal Valley (LV) and the Coastal Range (COR). The fifteen seismic stations, i.e., KF01–KF06, KF07–KF10 and KF11–KF15, were respectively located in the COR, LV and ECR. To examine the high-frequency later phases recorded by the linear array, the station spacing averaged about 1–2 km, thus making for a total length of some 20 km. Each seismic station was equipped with a three-component short-period sensor (LE3D, with a dominant frequency of 1 Hz), and continuous seismic data were sampled at the rate of 100 points per second, with the timing system at each station automatically synchronized by satellite signals from the Global Position System.

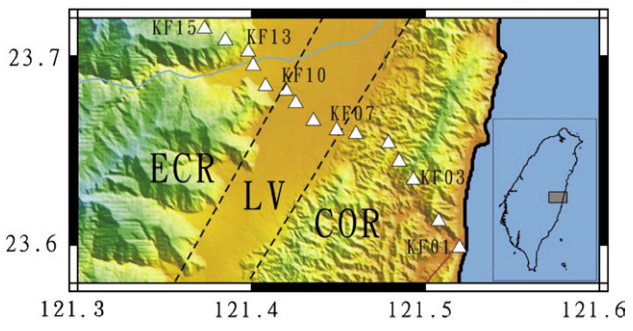

Fig. 2. Seismic stations (triangles) of a densely linear array and topographic relief in the eastern Taiwan area marked by a grey box.

Although numerous local earthquakes were recorded by the seismic array during the 3-month seismic deployment in 2003, in this study only larger and deeper events (M_L>4.0 and focal depth>60 km) have been examined for investigating the subduction structures. In total, there were 5 deep earthquakes with local magnitudes from 4.0 to 5.8 that occurred in the southeastern Taiwan area during the deployed period (Table 1). Some multiple P-waves were clearly found from the seismograms generated by three larger events (Fig. 3 and Appendix A—Fig. 1), while seismic signals for two smaller events ($M_L \leqq 4.3$) were strongly contaminated by background noises (Appendix A—Fig. 2).

To improve the understanding of the structure implications from the anomalous multiple P-waves, in this study the detailed analysis has been focused on the larger earthquake with a local magnitude of 5.8 because a clear and interesting pattern of multiple phases were consistently recorded by the seismic array. According to the Central Weather Bureau Seismic Network (CWBSN) earthquake catalog, that particular earthquake was located at the latitude of 22.73°N and the longitude of 121.37°E at

Table 1
Five deep earthquakes beneath southeastern Taiwan reported by the CWB from September to December, 2003

Time (year/months/day/h/min)	Latitude (deg/min)	Longitude (deg/min)	Depth (km)	Magnitude (M_L)
2003/09/02/23/09	21/10.44	122/08.75	150.60	4.0
2003/09/07/13/57	21/07.53	122/00.09	177.05	4.2
2003/09/10/22/55	22/42.54	121/23.96	85.36	5.8
2003/11/24/21/29	22/02.83	122/38.76	60.54	4.4
2003/12/06/03/47	21/58.23	121/46.51	141.26	4.7