

TAICRUST and Deep Seismic Imaging of Western End of the Ryukyu Arc-Trench System

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Abstract

The TAICRUST project is a comprehensive seismic program carried out by scientists from Taiwan, the U. S. and France to investigate the deep structure of the Taiwan arc-continent collision zone. Deep seismic reflection profile data were collected by the R/V Maurice Ewing in the area off eastern and southern Taiwan in August and September of 1995. Wide-angle reflection and refraction data have also been collected by using both ocean bottom seismometers (OBS) and onland seismic recording instruments. Data collected during the TAICRUST survey are being processed and analyzed at various participating institution in Taiwan and in the U. S. Here we present some deep seismic reflection results at the western end of the Ryukyu subduction system.

Two deep seismic reflection profile which run perpendicular to the Ryukyu arc-trench system and parallel to the arc in the center of the forearc basin, respectively, reveal the sedimentary and crustal structures of the western end of the Ryukyu arc-trench system. The oceanic basement of the subducting Philippine Sea plate in the Huatung Basin can be traced to extend below the toe of the Yaeyama Ridge. A deep reflection has been observed at about 1.5s below the basement reflection. Near 3 sec of sediments are observed in the Ryukyu Trench. Thick forearc basin strata are little deformed. The arc

basement can be clearly imaged beneath the forearc basin strata and the arc-side of the accretionary wedge. Three forearc basin have been identified in the study area. An elevated basement, which is caused by the subduction of the Gagua Ridge, separates the East Nanao Basin from the Nanao Basin. Active normal faults cut the upper portion of this basement high and the thick Nanao Basin strata on top of it. However, the western half of the Nanao basin strata are almost undisturbed. Further west, elevated arc basement and deformed old arc strata form basement of the Hopping Basin. The depths of the East Nanao Basin, the Nanao Basin and the Hopping Basin are 4500m, 3600m, respectively, illustrating the step-wise elevated forearc basin structures as the Ryukyu arc extends toward the Taiwan collision zone. The Taiwan collision has affected the western end of the Ryukyu forearc region west of 122° 20'E.

Introduction

Taiwan is situated at the juncture between Ryukyu and the Luzon arc systems. The collision of the Luzon volcanic arc with the passive Chinese continental margin that started about 5 million years ago has produced the present Taiwan mountain belt (Biq, 1972; Ho, 1986; Teng, 1990) and may also be responsible for the recent phase of the back-arc extension and opening of the southern Okinawa trough (Letouzey and Kimura, 1986). While the collision is

presently active in the southern Taiwan (Yu and Chen, 1994) and offshore southeastern Taiwan (Lundberg et al., 1992; Lundberg et al., 1997), the mountain building process may have ceased in the northern Taiwan (Yu et al., 1995), and the northeastern part of Taiwan may have transformed into the extensional Ryukyu back-arc system (Teng, 1996). The TAICRUST deep seismic imaging is a collaborative research project conducted jointly by the scientists from Taiwan, the United States and France. Two main objectives of this program are, firstly, to provide critical deep structural information of the Taiwan mountain belt and the incipient collision zone south of Taiwan for the purpose of understanding the mountain building processes generated by arc-continent collision; and secondly, to image the structures of the Ryukyu trench-arc-and-backarc-basin system and to investigate the effect of the Taiwan arc-continent collision to the termination of the Ryukyu subduction system and the development of the Okinawa backarc extension system.

Deep Seismic Data Acquisition

The major data acquisition efforts of the TAICRUST project was carried out during the EW9509 cruise of R/V Maurice Ewing from August 23 to September 24, 1995. R/V Ocean Researcher I was used during that period of time for deployment and retrieving OBSs along designated profiles. Marine seismic reflection profiling data, wide-angle reflection and refraction data (recorded by both OBSs and onland seismometers), underway 3.5kHz profiles, marine gravity and magnetic data as well as Hydrosweep swath bathymetry data have all been collected. The distribution of the deep seismic reflection profiles and locations of the OBSs and onland seismometers for the TAICRUST survey is shown in Figure 1.

The R/V Maurice Ewing's 20-airgun array

with a total volume of 8420 in³ provided excellent seismic source signatures. For marine reflection profiling, 16 sec of seismic reflection data were recorded at 2 ms sampling rate for each shot using a 160-channel digital streamer of 4-km in length. Over 4800 km of deep seismic reflection profile data have been collected in this survey. OBSs were deployed along six of the MCS profiles to record wide-angle reflection and refraction signals during the survey (Fig. 1).

There were three types of onland seismic recording instruments used to record the shots fired by Ewing's 8420 in³ airgun array. 35 IRIS-type portable seismometers were deployed to form linear arrays across the central part and southern part of Taiwan, respectively, for two onland-offshore seismic profiles. Five portable seismometers have also been deployed across the Hengchun peninsula for a third offshore-onland profile (Fig.1). Three PANDA/PANDA II telemetric local seismic networks were deployed over eastern and southern half of the Taiwan island for a broad regional recording of deep seismic signals. Over 70 permanent seismic stations of the Central Weather Bureau Seismic Network (CWBSN) were also set to record the shots from Ewing.

MCS/OBS profiles running N-S across the Ryukyu trench-arc-back arc basin and running E-W along the Ryukyu forearc basin were designed to observe the deep structure of the Ryukyu subduction system and the effect of the Taiwan arc-continent collision on its termination. Transects across the Taiwan mountain belt (onland-offshore profiles) and the Luzon subduction-collision zone (MCS/OBS profiles) are expected to reveal the structural variation at different stages of the on-going subduction-collision system. Observations on progressive deformation of the Luzon forearc basin and its closure during accretion of the intra oceanic Luzon volcanic arc (MCS profiles south of Taiwan) would

provide us an opportunity to understand the dynamic processes operating in an active arc-continent collision.

Different types of deep seismic imaging data are being processed and analyzed at various Institutions. In this sort paper, we present only some preliminary results from our analyses of two of the TAICRUST deep seismic reflection profiles in the area east of Taiwan (Fig. 2).

Crustal Structure of the Ryukyu Arc-Trench System

A N-S trending seismic reflection profile (EW9509-1) which crosses the Ryukyu trench-arc-backarc system along 122°30'E (Fig. 2) reveals a typical convergent margin structure if trench, accretionary wedge, forearc basin, arc and backarc basin (Fig. 3).

The subducting Philippine Sea oceanic crust is covered by 0.5 to 1 sec thick sediments in the Huatung Basin. A sub-basement reflection can be observed about 1.5 sec below the oceanic basement reflection. Velocity structure derived from OBS data suggests that this sub-basement reflection corresponds to the top of a high velocity (>8 km/sec) layer (Wang et al., 1996), thus may represent Moho reflection.

The thickness of the sediments increases rapidly north of the Taitung submarine canyon toward the trench. Thick trench fill has been accreted to the Yaeyama ridge. The top reflection of the subducting oceanic crust can be traced up to about 30 km underneath the accretionary wedge. The Yaeyama ridge separates the forearc basin from the Ryukyu trench and Huatung basin. Its general morphology as well as the chaotic and diffractive seismic characteristics suggest that this ridge represents an accretionary wedge that was built from the imbrication of sedimentary units off-scraped from the Ryukyu trench. Several northward dipping reflections may represent the imbricated

thrusts.

The Nanao basin is located at mid-slope between the Ryukyu arc slope and the Yaeyama ridge. Its maximum width is about 25 km and elongates parallel to the strike of the trench (Fig. 2). Seismic profile EW9509-1 shows that the thickness of the forearc basin sediments reaches over 2.5 sec (or about 3 km). Seismic reflections of the forearc basin strata are strong and continuous. The forearc basin strata onlap the strong arc slope reflection to the north and the Yaeyama ridge to the south. Seismic reflection characteristics of the forearc basin sediments indicate that they mainly consist of turbidite sequences derived from the Taiwan mountain belt.

The southern portion of the Ryukyu arc here presents a gentle slope dipping southward. The arc slope can be traced down to 8 sec beneath the forearm basin strata. Due the presence of strong multiple reflections, the internal structure of the Ryukyu arc is not revealed on this profile. However, tilted blocks and horst-and-graben structures are observed in the northern half of the arc.

Normal faults are the most prominent structural features in the Okinawa trough. In the central portion of the trough, volcanic intrusions are observed in a zone of about 10 km wide. These volcanic intrusions interrupt strong continuous reflection signals of the trough sediments, and emerge to the sea floor to form submarine volcanoes.

Structural Variations of the Ryukyu Forearc Basin

Seismic profile EW9609-14 which runs through the center of the forearc basin from east to west (Fig. 2) clearly reveals the structures of the East Nanao, the Nanao and the Hopping forearc basins (Fig. 4). The forearc basin strata lie on top of an undulating Ryukyu arc basement. Two basement highs separates the East Nanao basin from the

Nanao basin and the Nanao basin from the Hoping basin, respectively. The depths of the forearc basins becomes shallower westward as the Ryukyu arc approaches the Taiwan collision zone.

The Nanao basin as observed on profile EW9609-14 is about 75 km long and has a maximum sediment thickness of 4 sec in its eastern part. The sediments in the western half of the Nanao basin is almost underformed with continuous parallel reflections lying flatly and on-lapping the forearc basement. Symmetrical normal faults are observed around the depocenter of the basin. East of the depocenter, the Nanao basin strata are cut by numerous west-dipping normal faults and show divergent depositional pattern with reflections dip westward. This suggest that the basement high lies underneath the eastern portion of the Nanao basin has been raised steadily during the in-filling of the Nanao basin sediments. Since morphologically this basement high aligns very well with the Gagua ridge to the south, we suggest that the uplifting of this forearc basement is caused by the subduction of the Gagua ridge.

West of about $122^{\circ}20'E$, the forearc basin appears to be highly deformed. The basement high which separates the Nanao basin and the Hoping basin consists of a thick (over 2 sec in two-way traveltime) titled sedimentary layer lying on top of the arc basement. This tilted thick sedimentary layer has been mapped over the western end of the Ryukyu arc slope, and is interpreted to be deposited in this region before the Taiwan arc-continent collision (Lallemand et al., 1997). The tilting of this sedimentary layer was caused by the rapid subsidence of the Hoping basin basement. The present Hoping basin sediment which consists mostly of turbidites from the Taiwan mountain belt lying unconformably over this tilted layer. Part of the accretionary wedge material has

also been deformed here and incorporated into the forearc basin. A highly folded and thrust structure which separates the titled sedimentary layer and the Yacyama ridge should be the results of the Taiwan collision.

Conclusions

Deep seismic reflection profiles across the Ryukyu trench-arc system perpendicularly and across the central portion of the Ryukyu forearc basins parallel to the strike of the Ryukyu arc provide structural control for the western end of the Ryukyu trench-arc system. Major observations revealed by these two profile are:

1. Sub-basement reflection are observed in the Huatung basin which may represent the Moho of the subducting philippine Sca plate.
2. Typical convergent margin structures are observed along profile EW9509-1. Due to the large amount of incoming sediments derived from the Taiwan mountain belt, trench fills are thick and the accretionary wedge is well developed.
3. Thick (near 4 sec) and very little deformed basin strata lie on top of the Ryukyu arc basement. The sediment cover on top of the Ryukyu arc slope and arc basement is quite thin to the east of $122^{\circ}20'E$, but a thick (almost 3 sec) tilted sedimentary strata has been observed on top of the Ryukyu arc slope west of $122^{\circ}20'E$.
4. The northern Ryukyu arc is characterized by the horst-and-graben structures which may be formed to opening of the Okinawa trough, North-dipping normal faults prevail the northern flank of the Ryukyu arc which underlies the southern half of the Okinawa trough. Volcanic intrusion distributed within a 10-km wide zone in the central portion of the Okinawa trough.
5. The forearc basin structures of the western Ryukyu trench-arc system are affected by the subducting Gagua Ridge at about $123^{\circ}E$, and by the Taiwan collision zone of about

122°20'E.

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Figure 1. Map showing locations of the TAICRUST deep seismic reflection profiles (dark lines), ocean bottom seismometers (triangles) and land seismometers (squares). Bathymetric contours are in 200 meters.

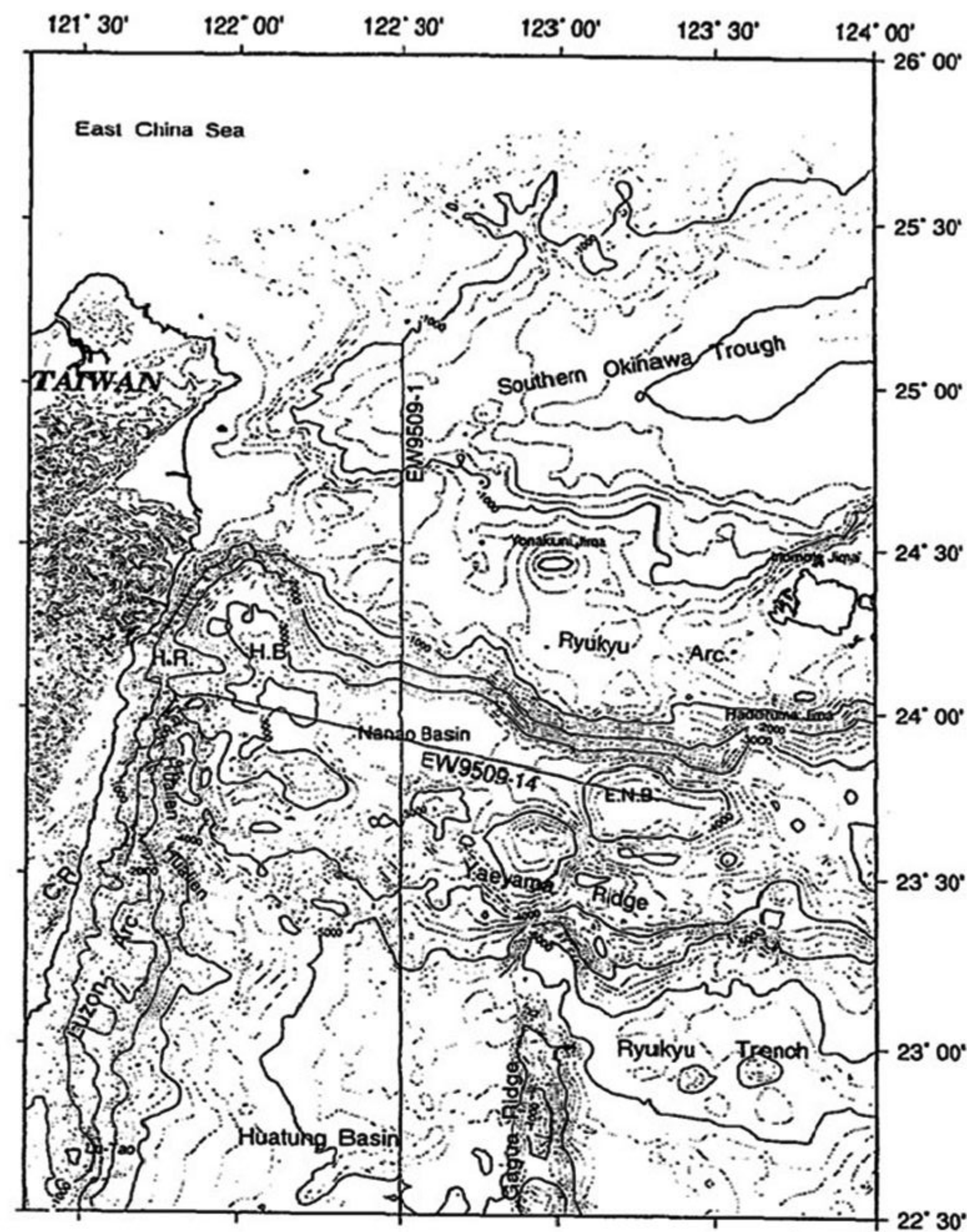


Figure 2. Bathymetry of the western end of the Ryukyu arc-trench system and Southern Okinawa Trough. Locations of the two seismic reflection profiles EW9509-1 and EW9509-14 are also shown. C.R.: Coastal Range, E.N.B.: East Nanao Basin, H.B.: Hoping Basin, H.R.: Hsincheng Ridge.

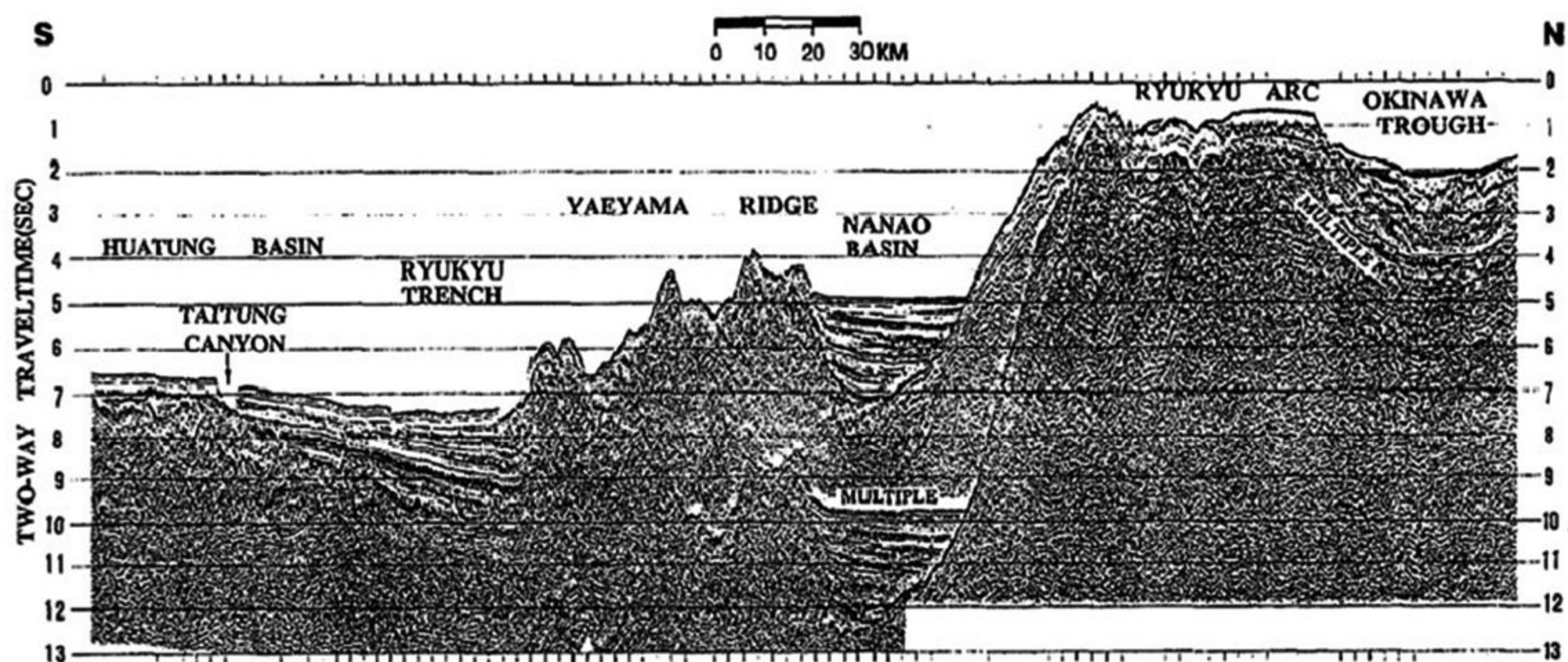


Figure 3. Post-stack time migrated seismic profile of EW9509-1. This profile runs N-S across the Ryukyu arc-trench and backarc system.

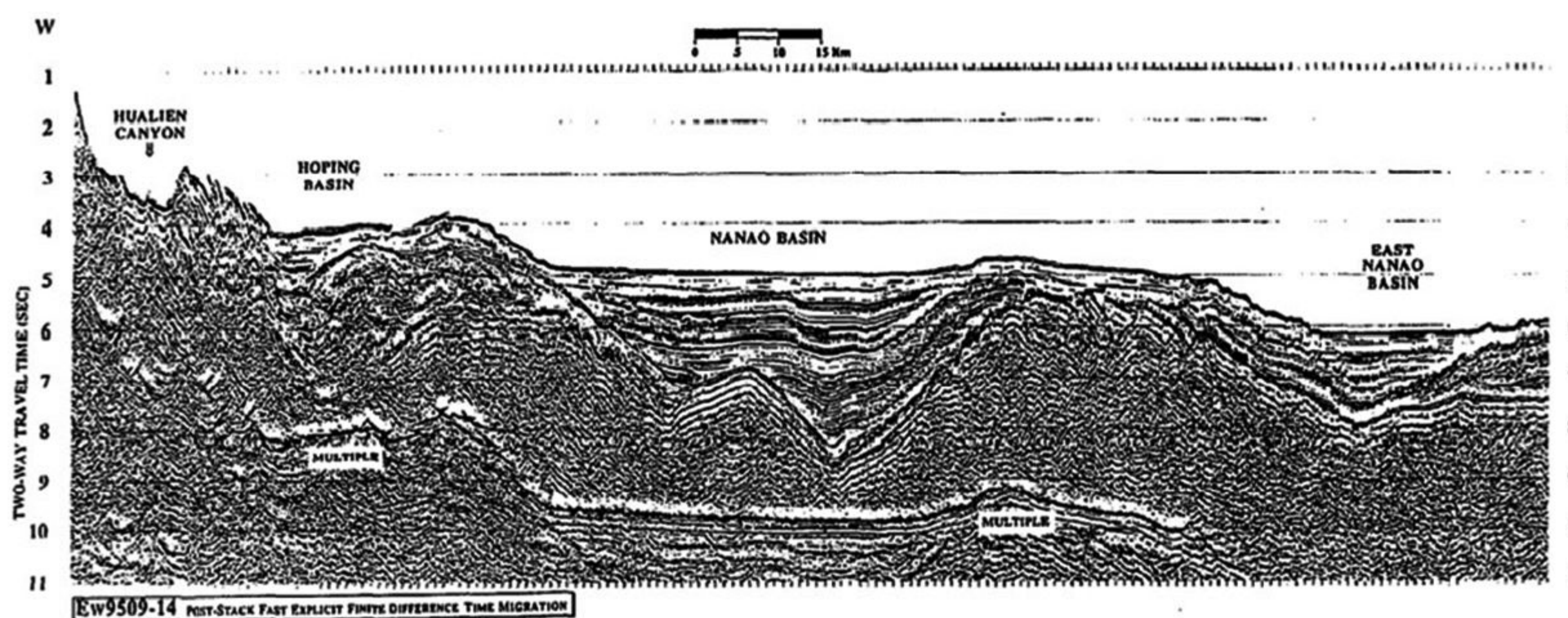


Figure 4. Post-stack time migrated seismic profile of EW9509-14. This profile runs E-W along the axis of the forearc basins.