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STRUCTURE OF THE CRUST ACROSS THE RED RIVER SHEAR ZONE IN NORTHERN VIETNAM FROM LINEAR ARRAY OBSERVATION

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ABSTRACT

The Red River fault is the first order tectonic structure running from the southeastern margin of the Tibet plateau to the Vietnam East Sea that separates the South China block to the north and the Indochina block to the south. Hence, understanding the Red River fault structure is critical for evaluating the hypotheses of the tectonic evolution of Southeast Asia and the extrusion mechanism along the Red River fault caused by the continent-to-continent collision between the Indian and Eurasian plates.

Using a 250 km long profile of 25 broadband seismic stations across the Red River fault in northern Vietnam has provided a high-resolution P receiver function section which interpreted in term of crustal architecture and composition. Results reveal distinct features of crustal structures across Red River shear zone. The Moho depth is ranging from 28 to 32 km, with an average of about 30 km. The Vp/Vs ratio is lower and stable values in the north of Red River fault but highly variable in the south, suggesting that the crust in the south of Red River fault might be effected by the interaction of micro blocks in Northern Vietnam which separated by the major faults (Ma River fault, Da River fault, Son La fault, Red River fault). The shear wave velocity profile pointed out a sharp variation of the lower crust and uppermost mantle beneath the Red River shear zone, suggesting that the Red River shear zone is a lithospheric structure.

Key words: Receiver Function, Migration, Red River Shear Zone, Seismic Linear Array.

1. INTRODUCTION

The Red River shear zone (RRSZ), a major continental strike slip faults in Southeast Asia, is the most profound geological structure that separates the South China block and Indochina block. This zone is extending approximately 1000km between southeastern Himalayas and East Sea block. In northern Vietnam, this shear zone is comprised by the Lo River fault, Chay River fault, and Red River fault (Fig. 1). The seismicity recorded along the RRSZ showed that the earthquake activity in the north of RRSZ is still active, but it is low activity in the south (Allen et al., 1984; Leloup et al., 2001). Knowledge of the deformation of the RRSZ is important not only for understanding tectonic evolution in southeast Asian, but also for evaluating the hypotheses of the mechanism of deformation along the RRSZ caused by the continent-continent collision between the Indian and Eurasian plates.

The cooperation between Institute of Earth Sciences, Academia Sinica and Institute of Geophysics, Vietnam Academy of Science and Technology is to conduct a dense seismic array (comprising 25 locations, about 250km) crossing linearly the RRSZ in northern Vietnam from 2013 up to now. The high quality data from this array allow examining the crustal and mantle structures across the RRSZ. In this project, we use the P-to-S converted phases from the distant earthquake events to image the detailed crustal structure underneath the southern tip of RRSZ. The results are expected to provide the evident images of structure across the RRSZ and to understand the tectonic development of the RRSZ and surrounding areas in northern Vietnam.

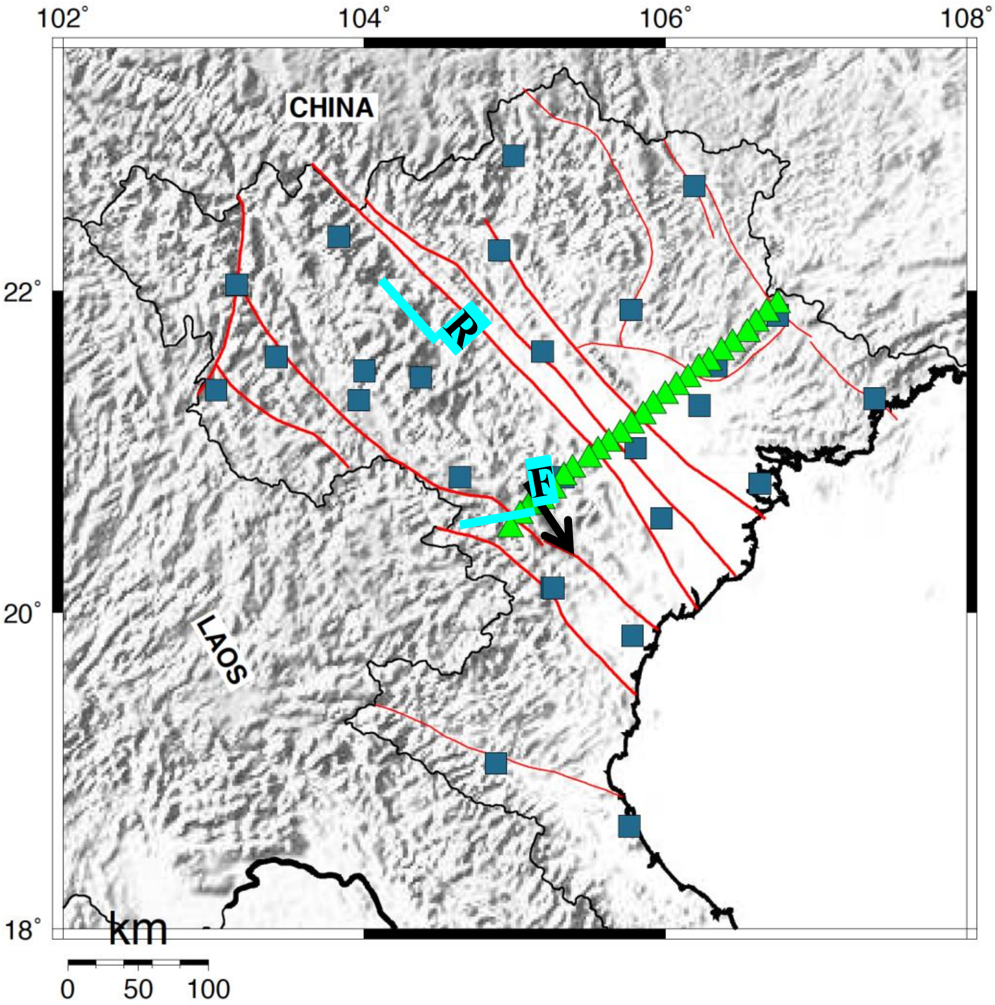

Figure. 1 Map showing 50 stations of the portable broadband seismic array deployed in northern Vietnam. The dark-blue symbols indicate the seismic stations deployed from 2006~2012. The green symbols indicate the linear seismic station deployed since 2013 up to now. The red lines show the locations of the main faults in northern Vietnam.

2. Data and Method

2.1. Teleseismic Data

During the network operation, we selected more than 500 teleseismic events within an epicentral distance range of 30^0 and 90^0, with magnitude $M_W \geq 6.0$ to perform the receiver function analysis. The number of recorded events included in the final analysis varies from 20 to 400 for a specific station. Most of the selected events were derived from the northwestern and southwestern Pacific Ocean, as well as along the Indonesian islands (Fig. 2).

The quality of data depends on the ambient noise, site condition, and the quality of instrumentation. We selected the events that have a high signal-to-noise ratio for analyzing steps (Fig. 3)

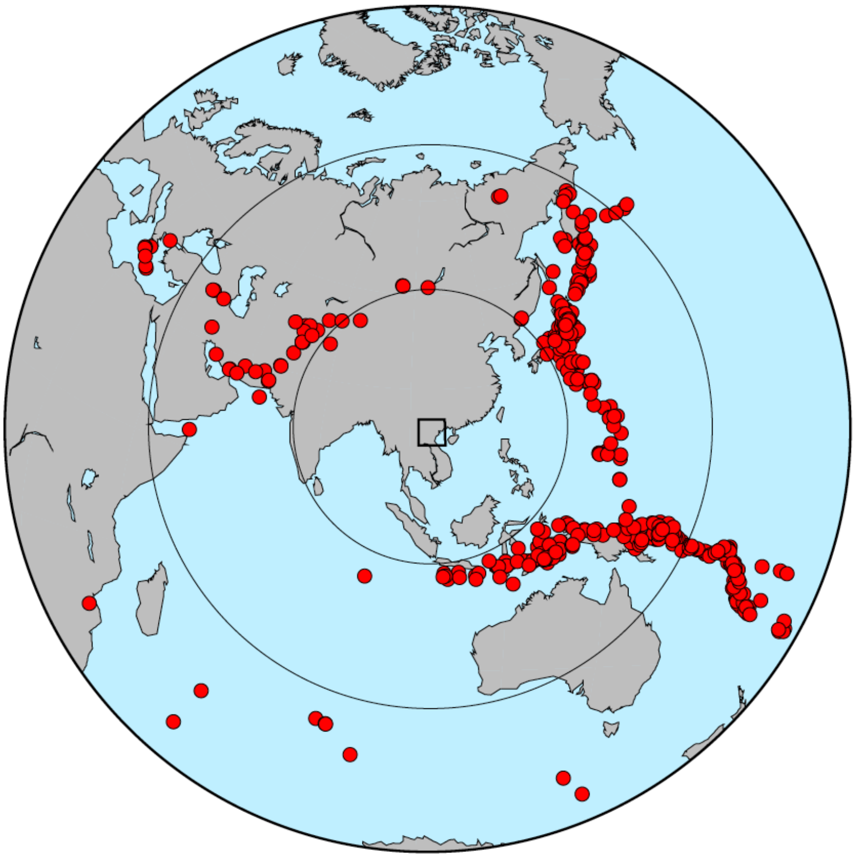

Figure 2. Azimuthal projections of epicenters of more than 500 earthquakes analyzed in this project, with projection center in northern Vietnam (black rectangle). The epicentral distances range from 30^0 to 90^0 for earthquakes magnitude of Mw≥6.0.

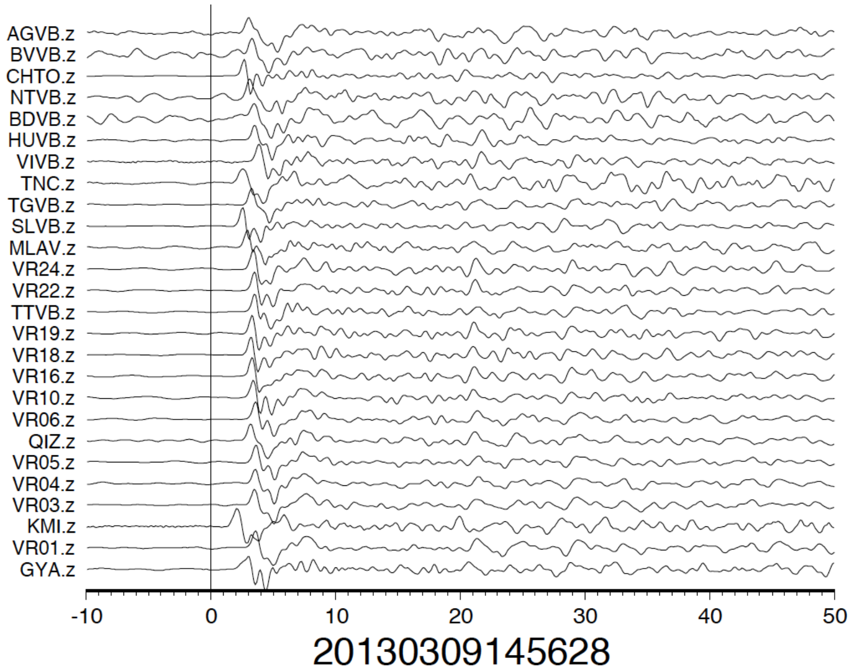

Figure 3. The P-wave coda of vertical component recorded at the linear array and surrounding stations from the earthquake occurred on 09 March 2013 with magnitude of 5.9 located at 157.22E and 50.89N. The waveforms were shifted to the original time of the earthquake.

2.2. Receiver Function Methods

Receiver function analysis is a direct method of extracting constraints on crust and upper mantle structures from teleseismic waveforms recorded at 3-components seismic stations. The basis aspect of this method is that part of the P-wave energy from a distant earthquake impinging to a discontinuity in the upper mantle and crust underneath the station site is converted to S-waves (Ps). The S-wave basically travel slower than P-waves, and therefore, a direct measure of the depth of this discontinuity is calculated using the difference of the direct P and conversion Ps phases, if the velocity model is known (Fig. 4). The receiver functions now can generate increasingly detailed one or two-dimensional images of fundamental structures, such as the Moho and upper mantle transition zone discontinuities near 410 km and 670 km depth (Zhu and Kanamori, 2000).

A velocity structure imaging technique for receiver function is used to construct the crustal velocity structure beneath each seismic station. We confirm the velocity structure at each station based on the optimal match between a synthetic and observational receiver functions. The velocity models are inferred by a waveform inversion of stacked receiver functions for each station (Zheng et al., 2015).

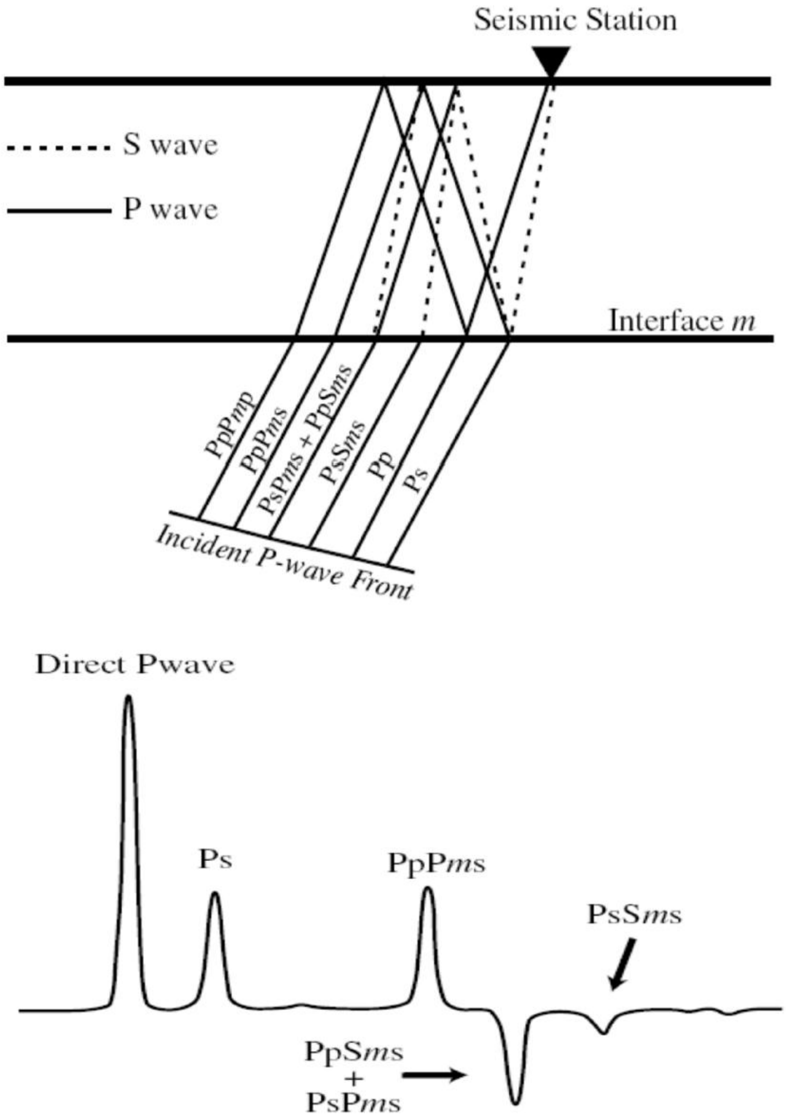

Figure 4. The ray paths of cobversion-phase Ps and multiple phases, PpPms, PpSms+PsPms, traveling within a simple single-layer crust, and synthetic receiver function of the simple crust (after Ammon 1991).

3. PRELIMINARY RESULTS

3.1. Calculation of P-wave Receiver Functions

Receiver functions at each station were computed according to the following procedures. First, we manually checked each event by performing auto- and cross-correlation to ensure that the event had a clear first P-phase, and that the recording was of high quality regarding the signal-to-noise ratio (SNR). Noisy recordings were discarded. Second, the selected seismograms were cut from 50s before, to 150 s after the first P-wave arrivals. The horizontal components were then rotated to the radial and tangential directions, and deconvolved with the vertical component in the time domain to estimate the receiver function (Fig. 5).

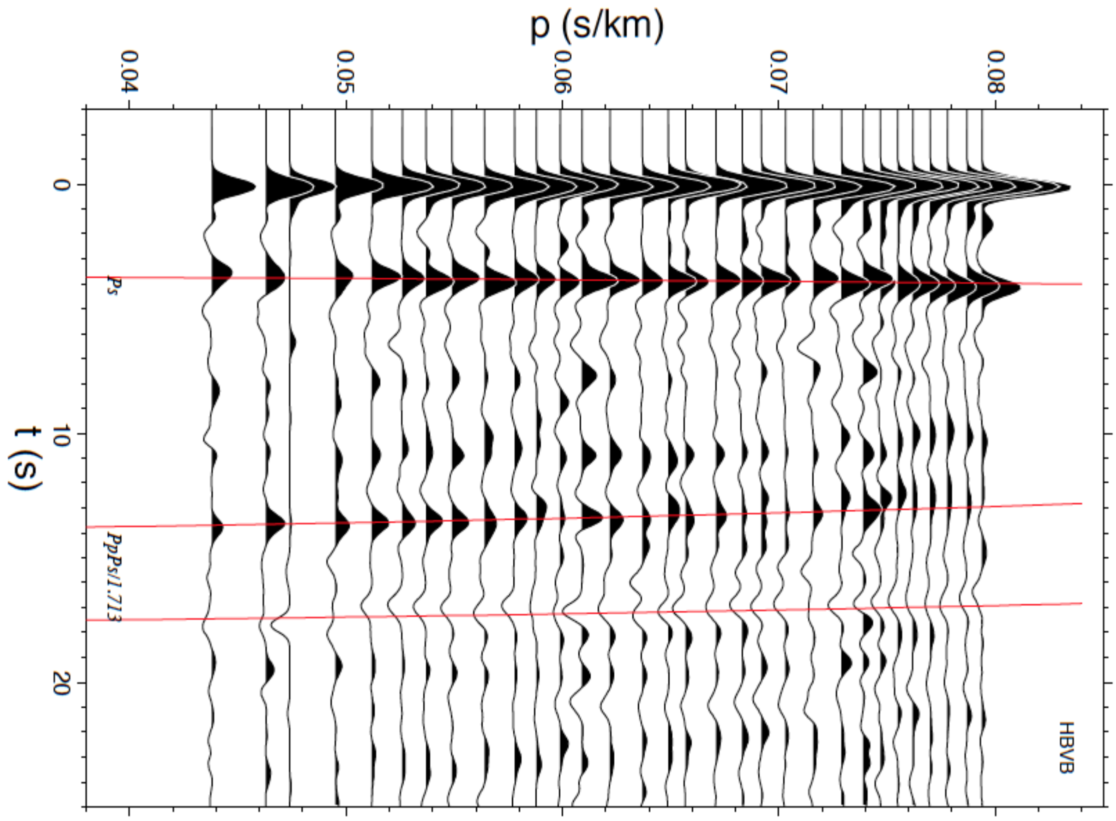

Figure 5. Radial receiver functions from HBVB station (location in Fig. 1) were arranged as a function of the ray parameter (p) with predicted travel times of Ps, PpPs, and PpSs+PsPs (red line from the top to bottom, respectively).

3.2. Receiver Function Imaging of the Crustal Structure of RRSZ

The radial receiver functions (RF) at each station were stacked to enhance the coherence signals and to eliminate the random noises. Since then, the RF is now possible to generate increasingly detailed two-dimensional image of the crust across the RRSZ by back-projecting the recorded signal along the theoretical raypath and stacking the amplitude information into lateral and vertical bins (Zhu and Kanamori, 2000). A cross-section is then migrated by taking the mean sample value in each bin and transforming the data into offset and depth space (Fig. 6).

The migrated image shows that the Moho discontinuity is relatively thin and flat in the right of the RRSZ where is belonging to the south China block. However, the Ps phase amplitudes in the RRSZ are more complex and discontinuously, perhaps indicative of lower crust layering and/or gradational Moho (Figs. 6, 7).

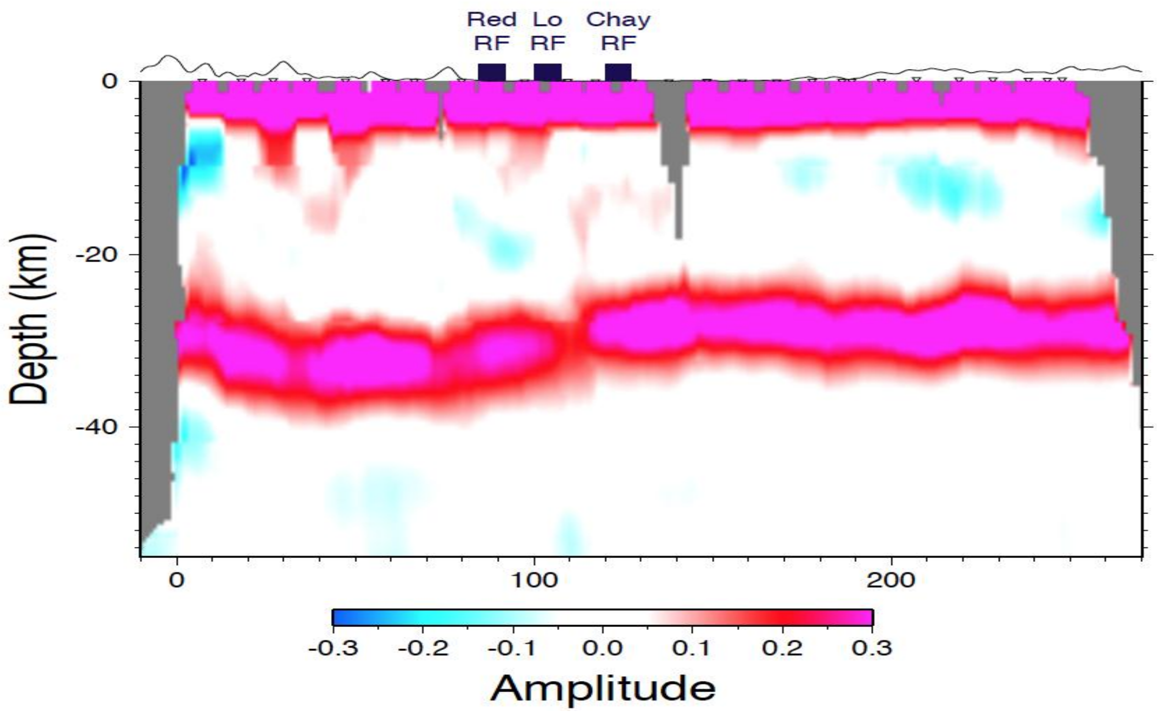

Figure 6. Migrated crustal section crossing the Red River shear zone. Reverberations from the Moho discontinuity as the maximum CCP amplitude.

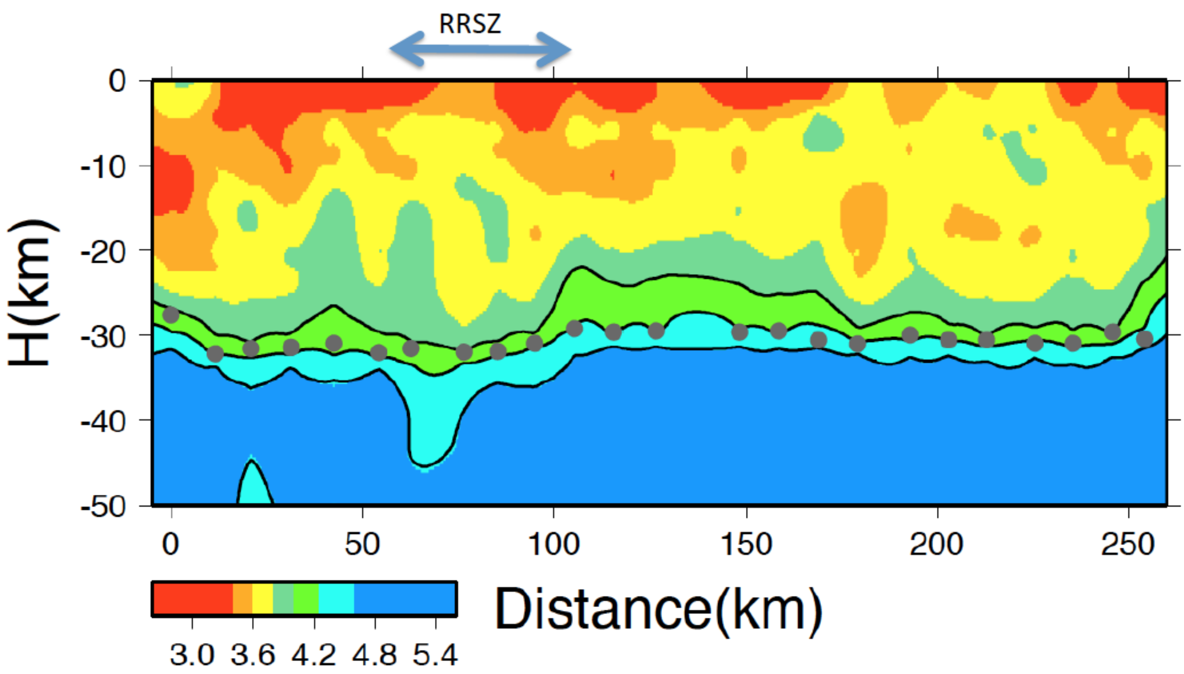

Figure 7. Shear wave velocity structure of crust and uppermost mantle compiled from the individual model at each station. The dark gray circles are the crustal thickness beneath each station derived from H-κ method.

3.3. 2D Shear Wave Velocity Structure

The stacked radial receiver functions were inverted to obtain the average shear wave velocity model for each station of the linear array by using the linearized inversion method (Ammon, 1991).

The final velocity image beneath the linear array is shown in Figure 7, which is compiled from the best fitting shear wave velocity models for the individual stations. A thin upper crust with a shear wave velocity of 3.4-3.6 km/s is cover by a sedimentary sequence with a shear wave velocity of 2.0-3.0 km/s. The middle crust is characterized by a shear wave velocity of 3.6-3.8 km/s, which covers the lower crust with a shear wave velocity of 4.0-4.4 km/s. The Moho discontinuity might have the shear wave velocity of 4.2 km/s, it is well correlated with the crustal thickness derived from the H-κ method (Fig. 7). In the RRSZ, the lower crust has a gradational transition zone, it suggests that the RRSZ is a lithospheric structure.

4. CONCLUSION

The crustal thickness across RRF is shallow, ranging from 28 to 32 km, with an average of about 30 km.

The Vp/Vs ratio is lower and stable values in the north of Red River fault but highly variable in the south, suggesting that the crust in the south of Red River fault might be effected by the interaction of micro blocks in Northern Vietnam which separated by the major.

The shear wave velocity profile pointed out a sharp variation of the lower crust and uppermost mantle beneath the Red River shear zone, suggesting that the Red River shear zone is a lithospheric structure.

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