A P-velocity Crustal Model of the China-North Korean Border Region

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1. Introduction

The large yield nuclear test conducted by Democratic People's Republic of Korea (DPRK) (North Korea) on September 3, 2017 registered high-quality seismic waveforms at nearby seismic stations (Figure 2). The source time function and radiation pattern of nuclear explosions are much simpler than natural earthquakes, thus providing us a good opportunity to study the crustal structure. The crustal model of China-North Korea border region can provide an initial model for a three-dimensional model and can be of importance for the source analysis of North Korea nuclear tests.

In this study, we present a crustal P-velocity model of China-DPRK border region and discuss two different P-velocity uppermost mantle models (one-layered and two-layered) to explain different Pn (diffracted P wave at Moho) observations.

2. Characters of regional waveforms

We study the crustal P-velocity model using waveform modeling and travel time analysis based on mainly three features of the waveforms:

- Clear regional phases, Pg (direct P wave), Pn are observed
- Moho reflections PmP are indiscernible
- High amplitude of Pg
- Relative large amplitude of Pn and PnPn (Pn free-surface reflection) waves are observed for some stations

The waveforms can be divided into two categories, that is, those with relative low amplitude of Pn (blue traces in Figure 2) and those with relative large amplitude of Pn (red traces in Figure 2). The relative low amplitude of Pn waveforms can be explained using a two-layered crustal model and a one-layered uppermost mantle model with a constant velocity. However, a double-layered uppermost mantle may exist in some regions since high amplitude of Pn waves are observed in some stations.

We will discuss the waveform modeling result of the blue traces with low amplitude of Pn in the third section and the waveform modeling result of red traces in the fourth part.

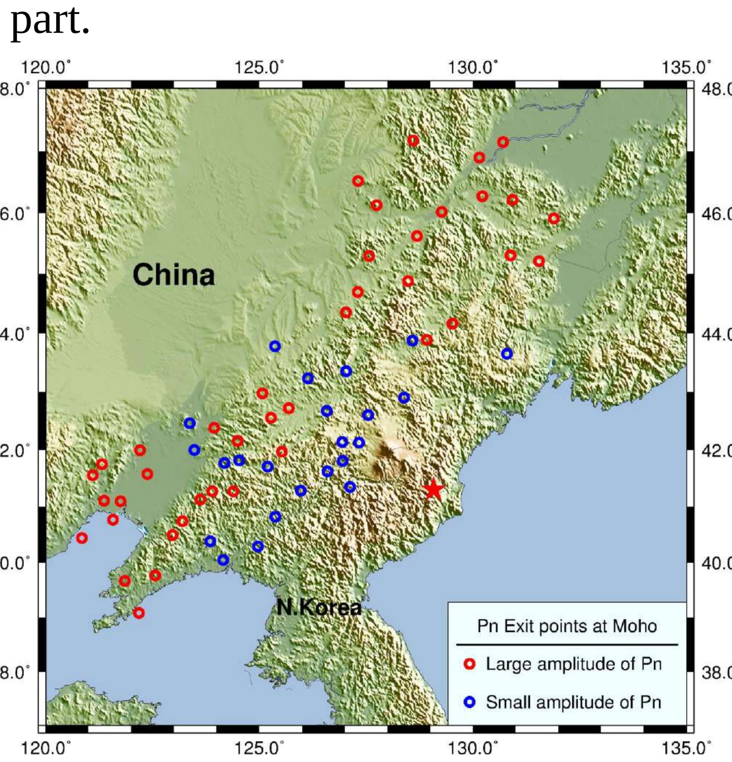


Figure 1. Topographic map of studied area plotted with locations of the nuclear test site (red star) and the geographic exit points at Moho of large amplitude of Pn and high amplitude of Pn wave. Only those with epicentral distance greater than 200 km are plotted since Pn tend to be the onset when the epicentral distance is greater that 200 km.

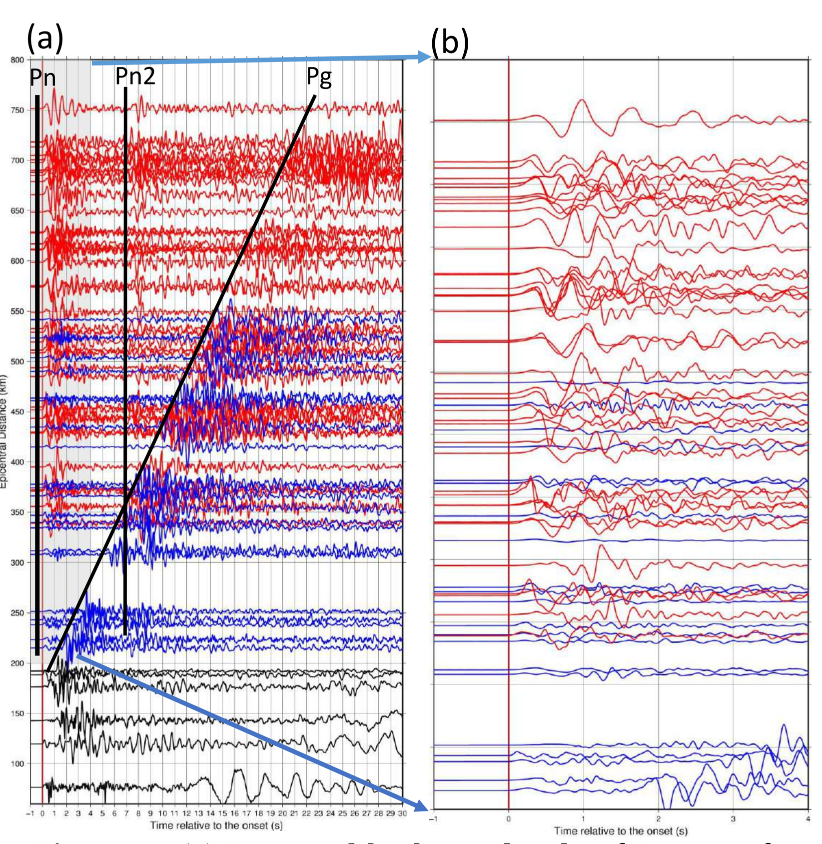


Figure 2. (a) Regional high amplitude of Pn waveforms (red traces), low amplitude of Pn waveforms (blue traces) and waveforms with epicentral distance smaller than 200 km (black traces). Some clear regional phases (Pn, Pg, PnPn) are labeled. All the traces are arranged according to the arrival time of the onsets. (b) Comparison of Pn waveforms of red traces and blue traces from enlarged Pn waveforms of gray area in (a).

3. Waveform modeling of relative low amplitude of Pn observations

The P wave velocity of the upper crust is estimated to be 6.1 km/s by fitting the absolute travel times of the Pg phases. The P wave velocity of the uppermost mantle is 8.019 km/s based on the absolute Pn arrival times (Figure 3).

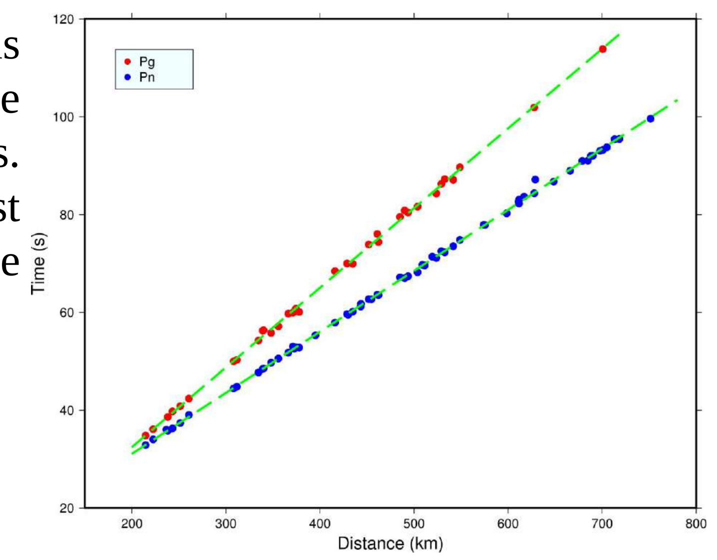
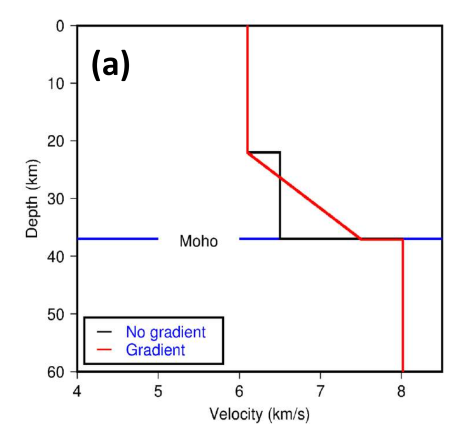
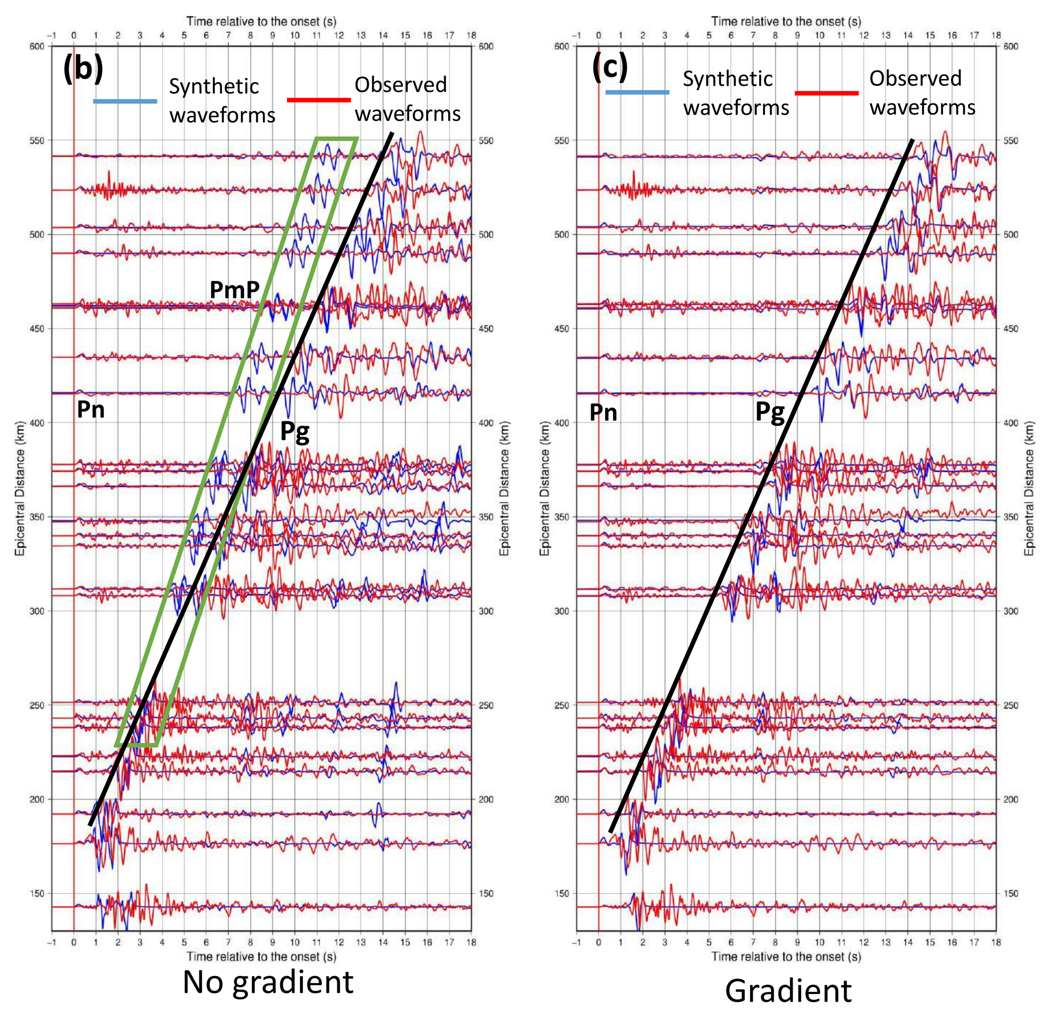


Figure 3. Travel time-distance relationship of Pg and Pn phases. The arrival times are fitted using a green line derived from least squares fitting. The velocity of Pg and Pn are estimated by the slopes of the fitting lines.





The velocity gradient in the lower crust is inferred based on the indiscernible Moho reflections PmP in the seismic data (Figure 4).

Figure 4. Seismic models and waveform modeling result for waveforms with relative low amplitude of Pn. (a) Compressional velocity profiles of the best fitting crustal model (red line) with a gradient lower crust and the crustal model without gradient layer (black line). (b) Comparisons of observed regional waveforms (red traces) in a frequency of 0.01 – 7 Hz and synthetic waveforms (blue traces) calculated using the crustal model without gradient velocity in lower crust (black line in (a)). Some regional phases (Pg, Pn, PmP) are labeled. The observed and synthetic waveforms are both arranged according to the arrival time of the onsets. (c) The same with (b) but the synthetic waveforms are calculated using the model with gradient velocity in lower crust (red line in (a)).

5. Conclusions

1. The crustal structure in China-North Korean border region can be represented by a two-layered model with a constant velocity 6.1 km/s in the upper crust and a gradient velocity in the lower crust. The velocity of uppermost mantle is estimated as 8.019 km/s.
2. An additional discontinuity may exist below the Moho in some regions of the uppermost mantle, to account for the large amplitude of Pn waves observed in some stations.

4. Waveform modeling of relative high amplitude of Pn observations

An additional discontinuity may exist below the Moho in some regions of the uppermost mantle, to account for the large amplitude of Pn waves observed in some stations. That is, actually, the Pn phases are superimposed with the waves that are reflected off at the additional mantle discontinuity.

The waveforms of the onsets are effected by the thickness and the velocity change of the mantle layer. We conduct the waveform modeling test using synthetic waveforms calculated using double-layered mantle models with different thicknesses and velocity changes.

We find that the waveforms can be divided into two classes (Class 1 and Class 2). The waveforms in Class 1 can be fitted using a relative thick mantle layer with thickness of 18 and 21 km (Figure 5(b)), while the waveforms in Class 2 can be explained using a relative thin mantle layer with thickness of 11 km (Figure 5(c)). The waveforms in Class 2 can also be divided into four classes according to their different velocity changes in this additional discontinuity.

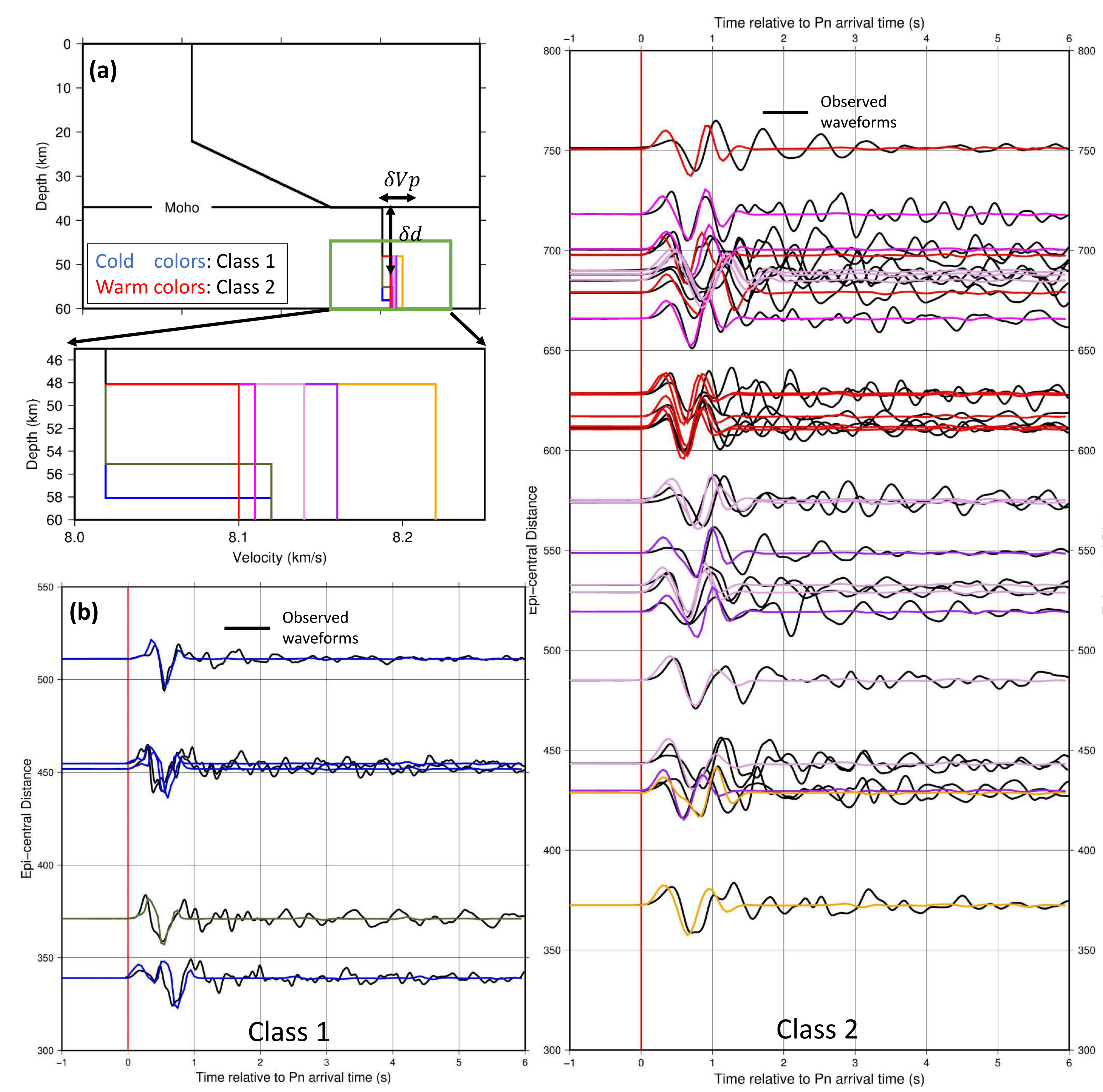


Figure 5. Seismic models and waveform modeling result for Pn waveforms. (a) Compressional velocity profile of the best fitting crustal model (black line) and uppermost mantle model with different thicknesses and velocity changes in an additional discontinuity (lines with cold colors for Class 1, lines with warm colors for Class 2). $\delta Vp, \delta d$ denote the velocity change at this additional discontinuity and the thickness of the uppermost mantle layer respectively. (b) Comparisons of observed Pn waveforms (black traces) of Class 1 in a frequency of 0.01 – 7 Hz and synthetic waveforms (traces with cold colors) of the best fitting P-velocity crustal model and uppermost mantle model. The observed and synthetic waveforms are both arranged according to the arrival time of the onsets. (c) The same with (b) but for Class 2 and this waveforms are in a frequency of 0.01 – 2 Hz.