Estimation of seismic and elastic properties of the crust and upper mantle beneath the Korean Peninsula

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Abstract

It is important to perform the quantitative interpretation of the continental margin lithosphere for a more accurate and comprehensive understanding of its tectonic behavior. In this study, we derived the seismic and elastic properties from the 2D seismic data recorded by the Korea Meteorological Administration (KMA) in 2014. In general, most of the previous researches have been based on travel time tomography or Full Waveform Inversion (FWI) methods. However, these methods are not robust to directly apply to the seismic ambient noise data due to its low signal-to-noise ratio (SNR). Therefore, we conducted L2-norm model-based impedance inversion to not only delineate the local geological structures but also suppress the meaningless footprints in the observed data. Moreover, we used FWEA18 models (Tao et al., 2018) as initial velocity and density models to create the inversion result more stable and accurate. Then, we interpreted the lithosphere and asthenosphere from the inverted P-impedance model, which is more obvious than the interpretation of the pre-existing data. The average depths of Moho and Lithosphere-Asthenosphere-Boundary (LAB) are 30 km and 80km, respectively. Furthermore, we estimated the change of bulk density as well as P- and S-wave velocities of the crust, lithospheric mantle, and asthenospheric mantle. Also, we predicted four elastic properties of each layer from the inverted seismic properties, such as bulk modulus, shear modulus, Young's modulus, and Poisson's ratio. These model results can help to understand the physical state and elastic behavior variations of the lithospheric and asthenospheric mantle as well as local lithospheric structures beneath the peninsula.

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Hanyang University RISE — Reservoir Imaging with Seismic & EM technology

Abstract

It is important to perform the quantitative interpretation of the continental margin lithosphere for a more accurate and comprehensive understanding of its tectonic behavior. In this study, we derived the seismic and elastic properties from the 2D seismic data recorded by the Korea Meteorological Administration (KMA) in 2014. In general, most of the previous researches have been based on travel time tomography or Full Waveform Inversion (FWI) methods. However, these methods are not robust to directly apply to the seismic ambient noise data due to its low signal-to-noise ratio (SNR). Therefore, we conducted L2-norm model- based impedance inversion to not only delineate the local geological structures but also suppress the meaningless footprints in the observed data. Moreover, we used FWEA18 models (Tao et al., 2018) as initial velocity and density models to create the inversion result more stable and accurate. Then, we interpreted the lithosphere and asthenosphere from the inverted P-impedance model, which is more obvious than the interpretation of the pre-existing data. The average depths of Moho and Lithosphere-Asthenosphere- Boundary (LAB) are 30 km and 80km, respectively. Furthermore, we estimated the change of bulk density as well as P- and S-wave velocities of the crust, lithospheric mantle, and asthenospheric mantle. Also, we predicted four elastic properties of each layer from the inverted seismic properties, such as bulk modulus, shear modulus, Young's modulus, and Poisson's ratio. These model results can help to understand the physical state and elastic behavior variations of the lithospheric and asthenospheric mantle as well as local lithospheric structures beneath the peninsula.

Introduction

- As the Korean Peninsula (KP) became seismically active, we need to focus on potential earthquake damage due to several moderate-sized earthquakes (Mw > 3.5), such as the 2016 Gyeongju earthquake (5.8) and the 2017 Pohang earthquake (5.4).
- Therefore, accurate seismic and elastic property models are required because they affect seismic wave propagation and help to estimate the earthquake source location and corresponding moment tensor solution.
- The seismic images are generated by the ambient noise recorded from 115 seismic stations of the Korea Meteorological Administration Network in 2014 (Song et al., 2018).

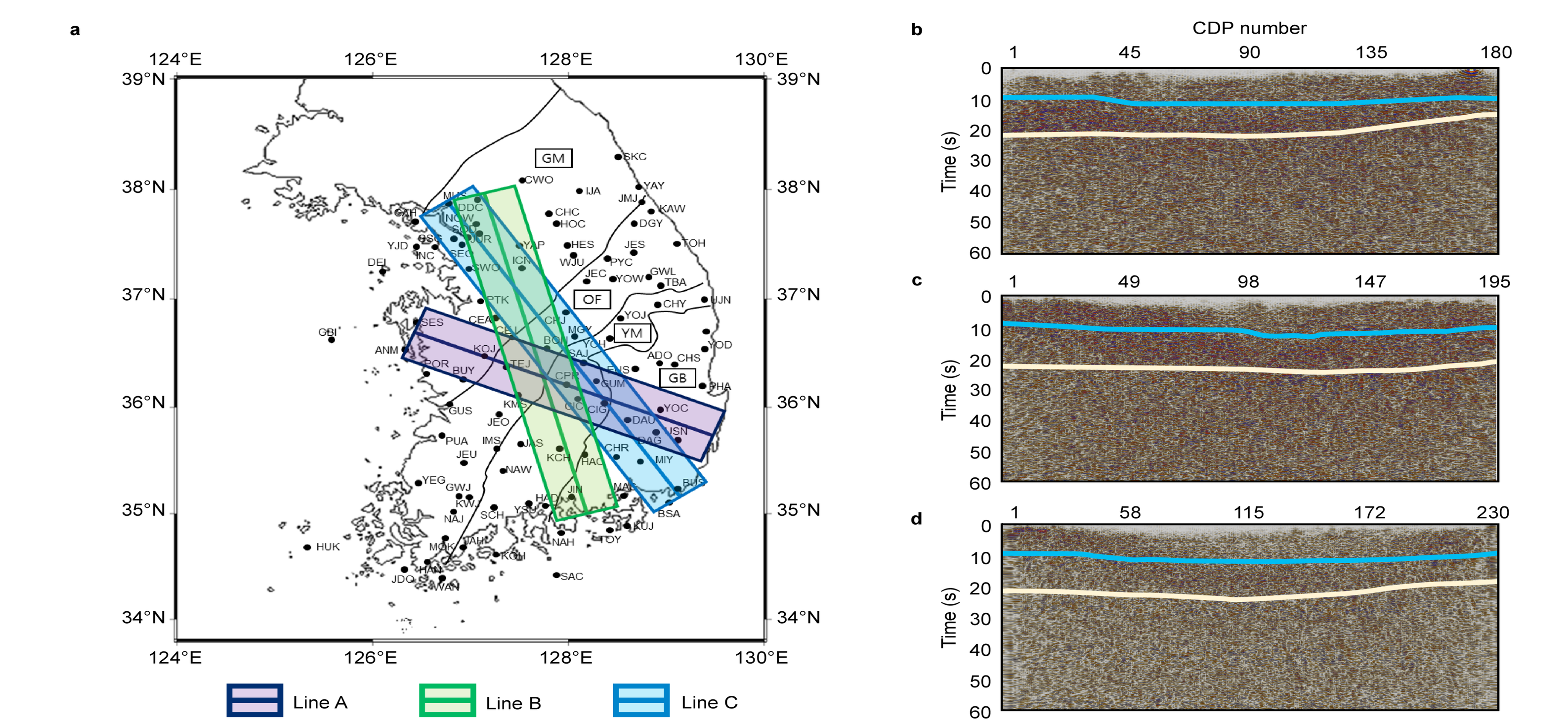

Fig. 1. Map showing the study area of the Korean peninsula (a) and seismic reflection images of the three profile lines (b-d; (b) Line A, (c) Line B, and (d) Line C). Note that the light-blue line and beige line indicate the Moho (at 9-12 s) and LAB horizons (at 17-23 s), respectively.

Data Processing, Interpretation, and Inversion

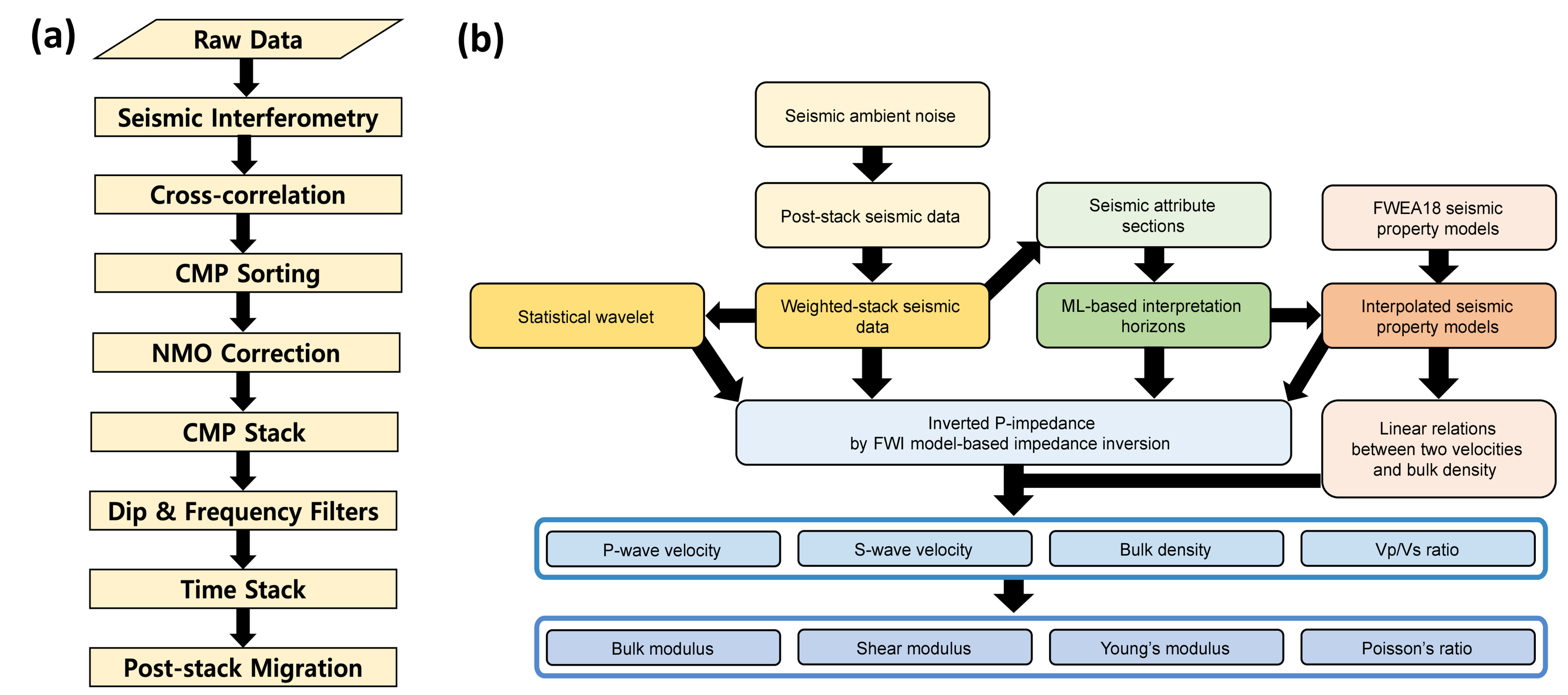

Fig. 2. The workflow of seismic data processing (a), and seismic inversion strategy (b) by using the seismic data and seismic models from the FWEA18 datasets.

Machine Learning-based Interpretation

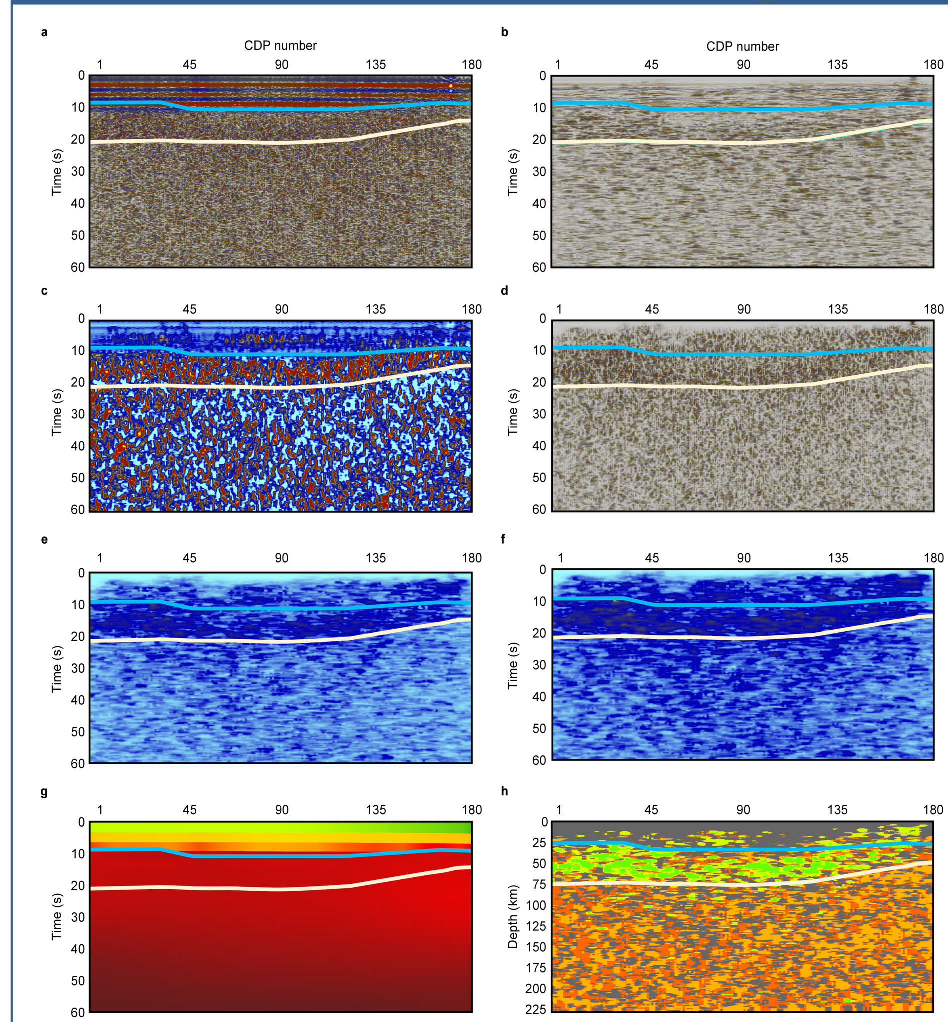

Fig. 3. (a) Original seismic reflection image beneath line A developed by seismic interferometry image and synthetic data from FWEA 18. (b-f), Five attribute images used for clustering that emphasize the boundaries using the first derivative (b), iso-frequency component (c), convolution-based spectral decomposition (d), RMS amplitude (e), and envelope (f). (g), the P-wave velocity model from the FWEA18 datasets (Tao et al., 2018). (h), Resultant image of the K-means clustering derived from the attribute images. Note that the depth of the Moho horizon exist at approximately 27-35 km. All lines representing the depth of the LAB exist at about 70-92 km (Song et al., 2019).

Conclusions

- In this study, we apply advanced quantitative seismic inversion and interpretation with machine learning techniques to interpret geologically meaningful boundaries using seismic ambient noise data and invert the seismic and elastic properties of the upper mantle beneath the peninsula.
- These results show more detailed geological structures and physical property changes in the upper mantle. The results can also help to understand the rheological and tectonic evolution of the lithosphere and the asthenosphere underneath the KP.

Inversion of Seismic and Elastic Properties

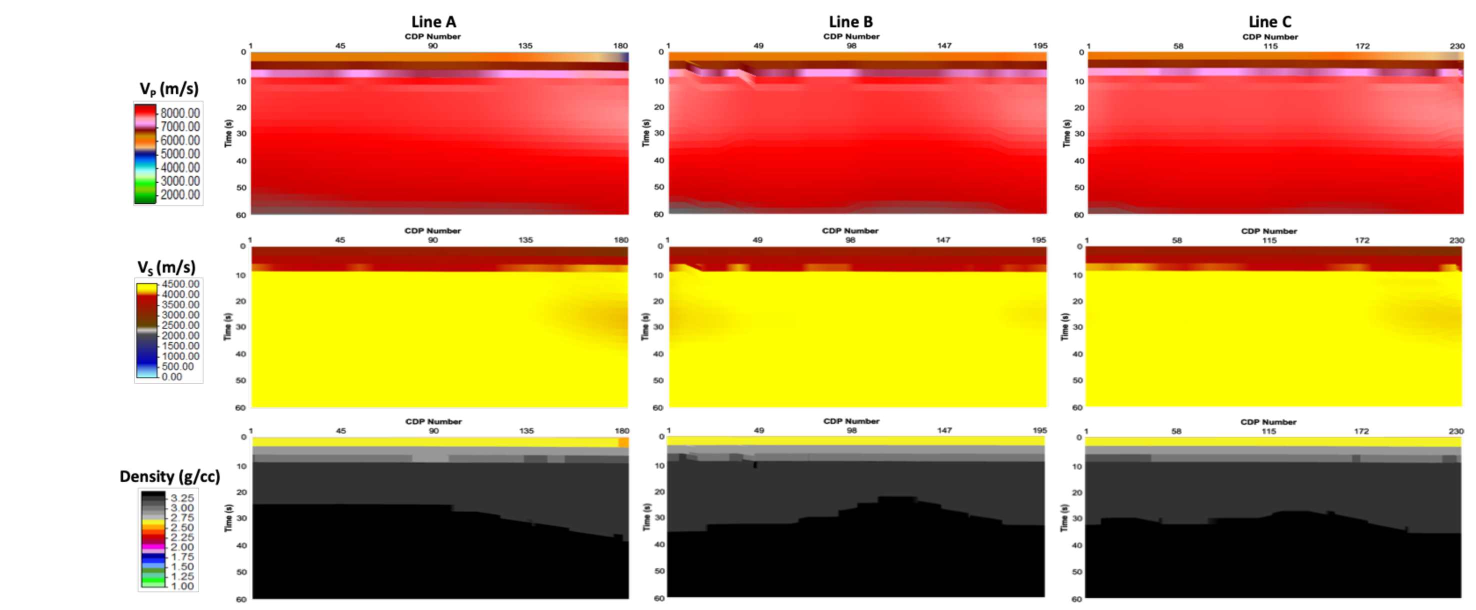

Fig. 4. Initial seismic velocity and density models for the background models of the model-based impedance inversion. Note that these are developed by interpolation of the original sparse FWEA18 model based on the seismic data acquisition geometry.

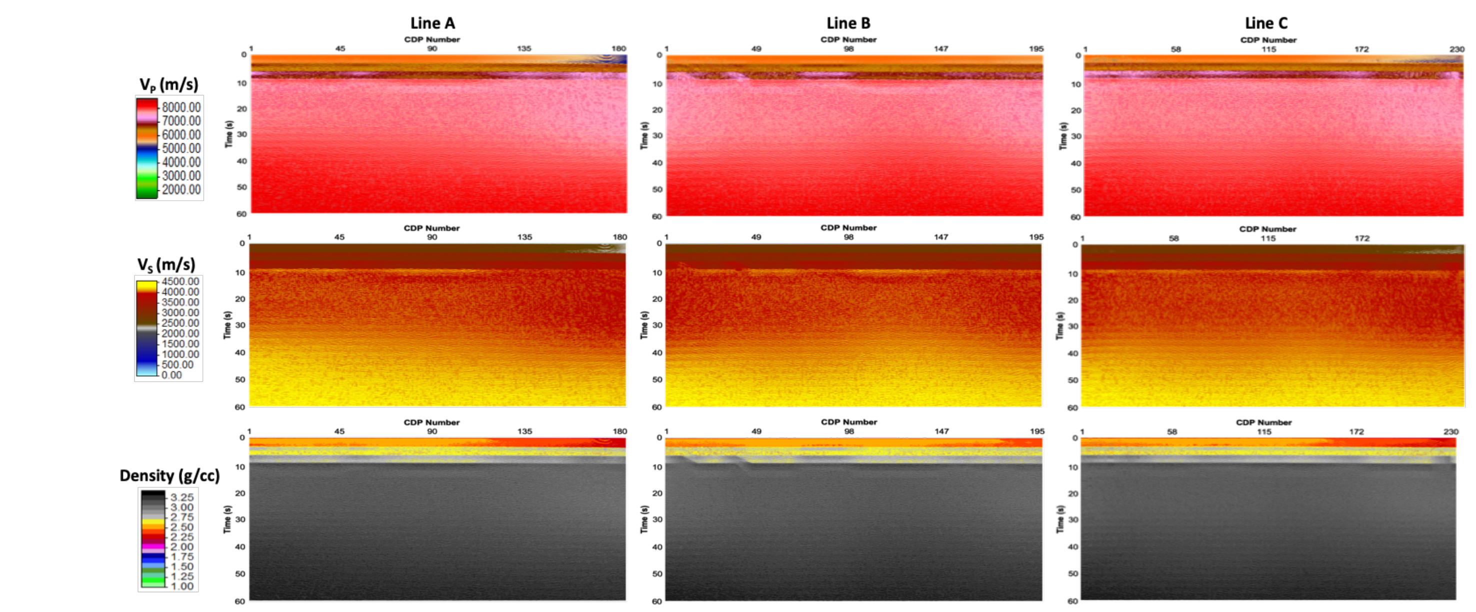

Fig. 5. Inverted seismic velocity and density models from the initial models (Fig. 4.) and the post-stack seismic data. Through the linear relationships of Vp-Vs-density in the FWEA18 research, we can estimate the Vp, Vs, and density variations from the inverted impedance model.

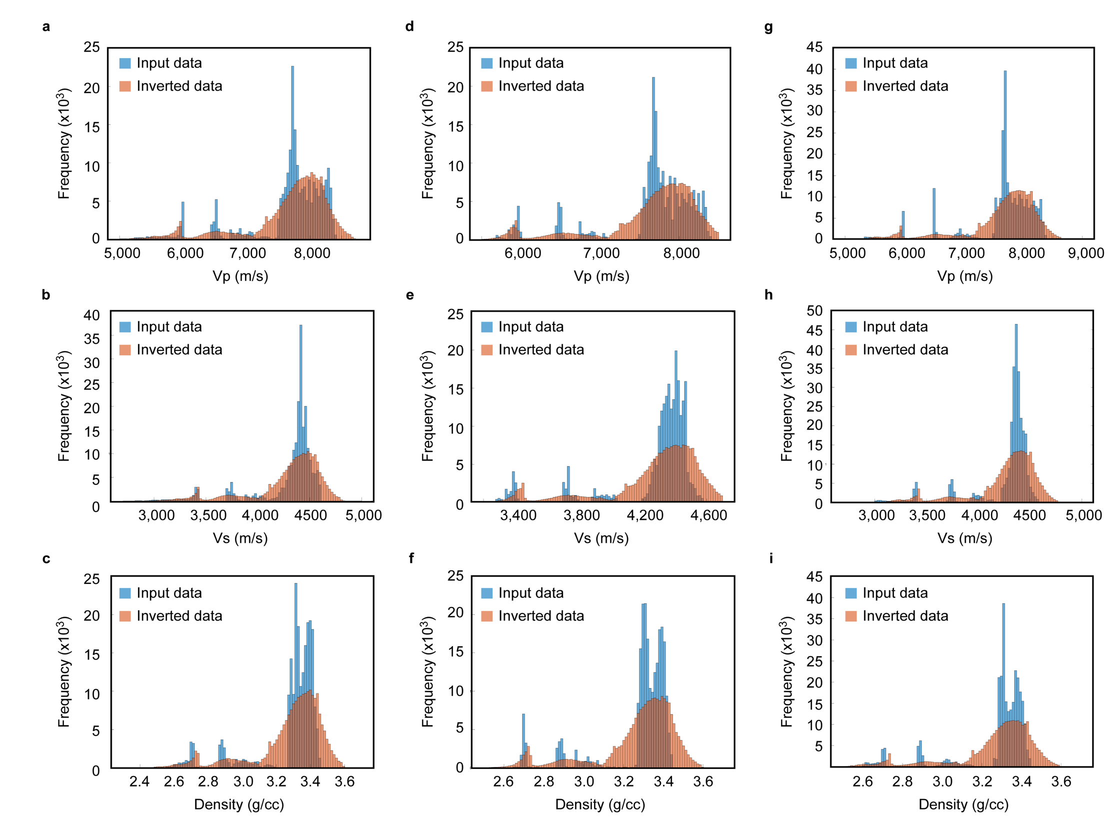

Fig. 6. Comparisons between the seismic property distribution of the input FWEA 18 model (blue) and that of the inverted model (red) beneath line A (a-c), line B (d-f), and line C (g-i).

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