Three-dimensional shallow velocity structure beneath the urban agglomerations revealed by methane source and dense array

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1. Active Source Experiment beneath the Guangdong-Hong Kong-Macao Greater Bay Area, China

The three-dimensional (3D) velocity structure beneath urban agglomerations is an important data for urban construction planning and earthquake hazard risk assessment. Combining a short-period dense array with the active source can enable us to conduct high-resolution imaging of shallow structures, with a short observation time. To obtain the high-resolution structure beneath the Guangdong-Hong Kong-Macao Greater Bay Area, we deployed a dense array consisting of 6,172 short-period stations, and carried out 63 active source excitations using new methane green sources in 2020 (Figure 1).

The stations are composed of three types of short-period seismometers: SmartSolo 16HR 3C (5s to 150Hz), Zland 3C (5s to 150Hz), and EPS-2-M6Q (5s to 150Hz). The stations are spaced approximately 0.75 km apart and are covered in three separate sessions from south to north. The observation duration is approximately 5 to 25 days. The excitation spacing for methane sources is approximately 7 km.

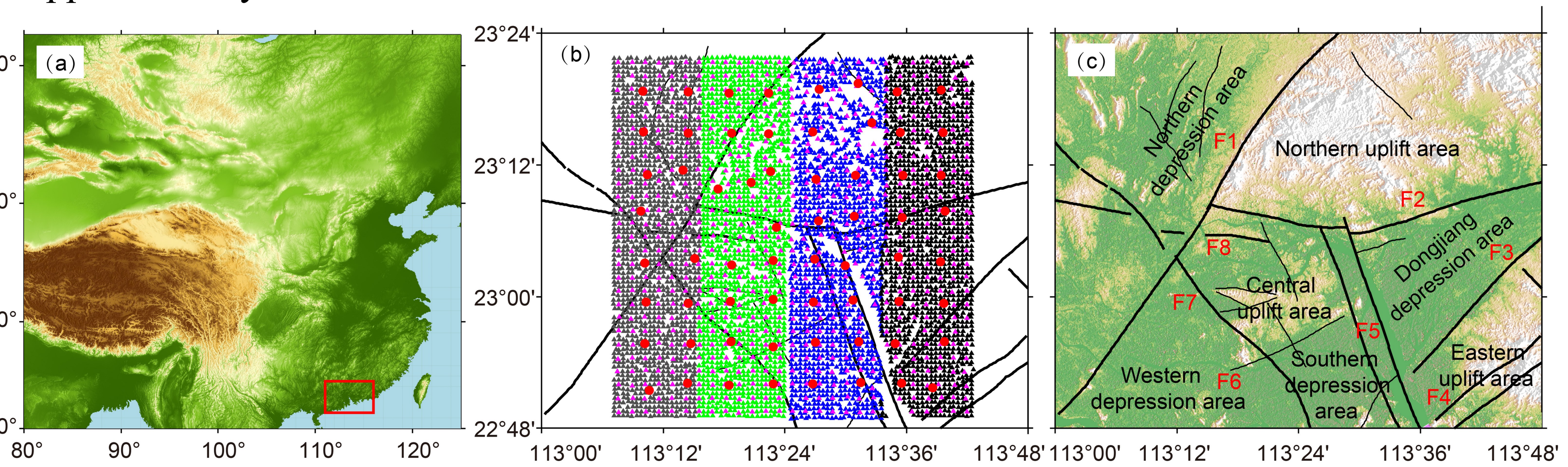

Figure 1 Distribution of dense array and methane sources in the study area.

Triangles in (b) represent portable short seismic array, the different colors represent stations deployed by different institutions. Red dots represent the methane sources and black lines indicate geologic faults. F1, Guangcong fault; F2, Shougouling fault; F3, Shilong-Houjie fault; F4, Zijin-Boluo fault; F5, Zhujiangkou fault; F6, Xinhui-Shiqiao fault; F7, Baini-Shawan fault; F8, Guangsan fault.

2. Schematic diagram of methane source excitation and phase picking

With the increasing limitations on the usage of explosives, we have developed a new type of active source, the methane source, which has been proven to be environmentally friendly, efficient, safe, and economical. It produces seismic waves by rapidly releasing high-pressure air in borehole by igniting oxygen and methane with the reaction products of carbon dioxide and water (Figure 2), and can be applied to various complex terrains to detect small-scale subsurface structures, particularly in cities and fault zones.

In this experiment, the excitation device is the WB-120-1000 type seismic source, with an outer diameter of 120 mm, a length of 1000 mm, and a volume of approximately 10.8 L. During excitation, the source is placed in a 140 mm diameter excitation well with a depth of 8 to 15 meters. The volume ratio of methane to oxygen during gas injection is 1:2, and the injection pressure is 7.5 MPa.

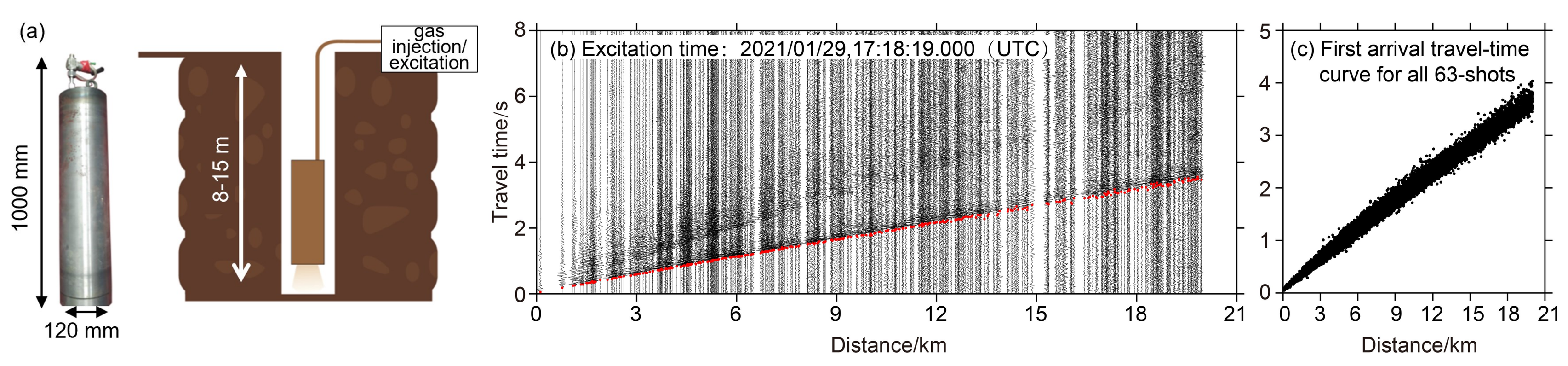

Figure 2 Excitation schematic diagram, waveform and first arrival travel-time curve of methane source. The red dots represent the manually picked first arrival P-wave phases.

3. Result of 3D body-wave tomography

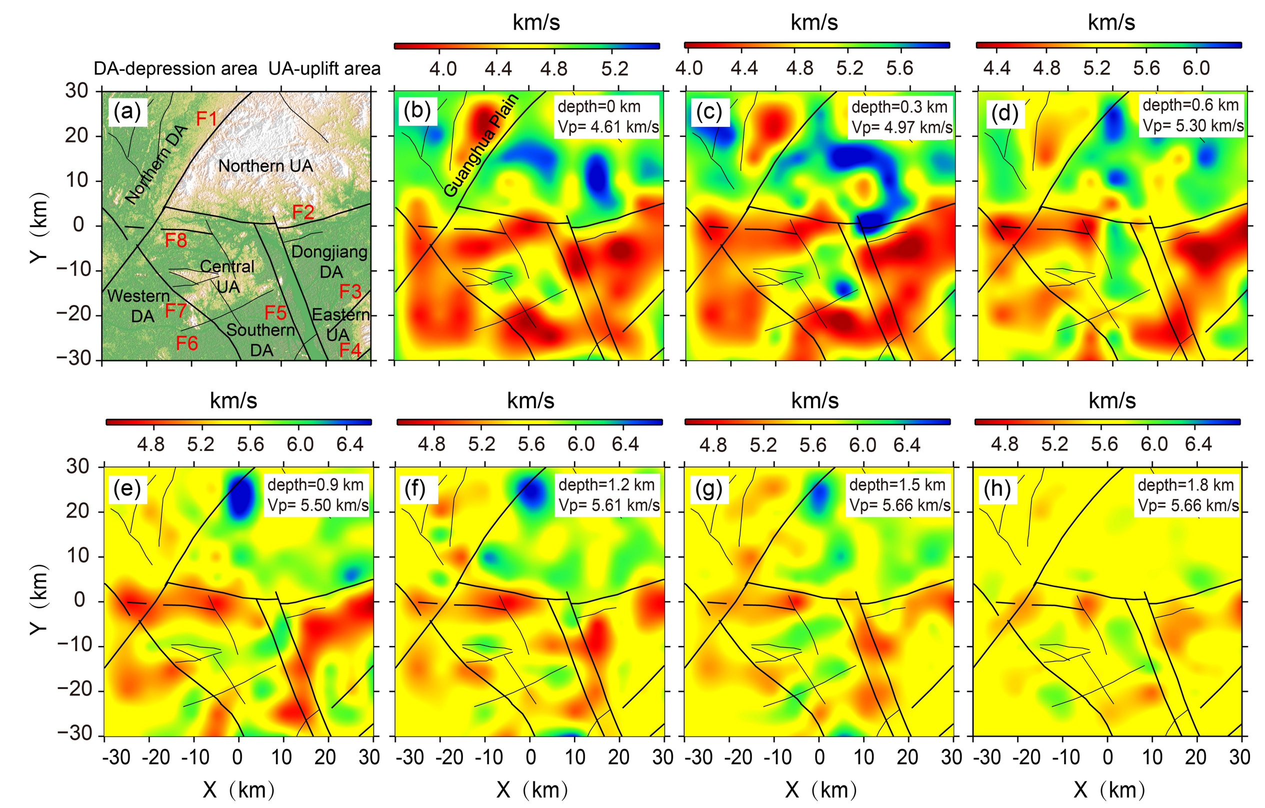

Figure 3 P-wave velocity images at different depths after the inversion.

Firstly, 1D P-wave velocity model of the shallow crust was inverted using the VELEST program. Then, the high-resolution 3D P-wave velocity structure of the shallow crust (above a depth of 1.5 km) in the central urban area of the Guangdong-Hong Kong-Macao Greater Bay Area was obtained using the simul2000 travel-time inversion program (Evans et al., 1994) (Figure 3).

4. Imaging profiles across different faults

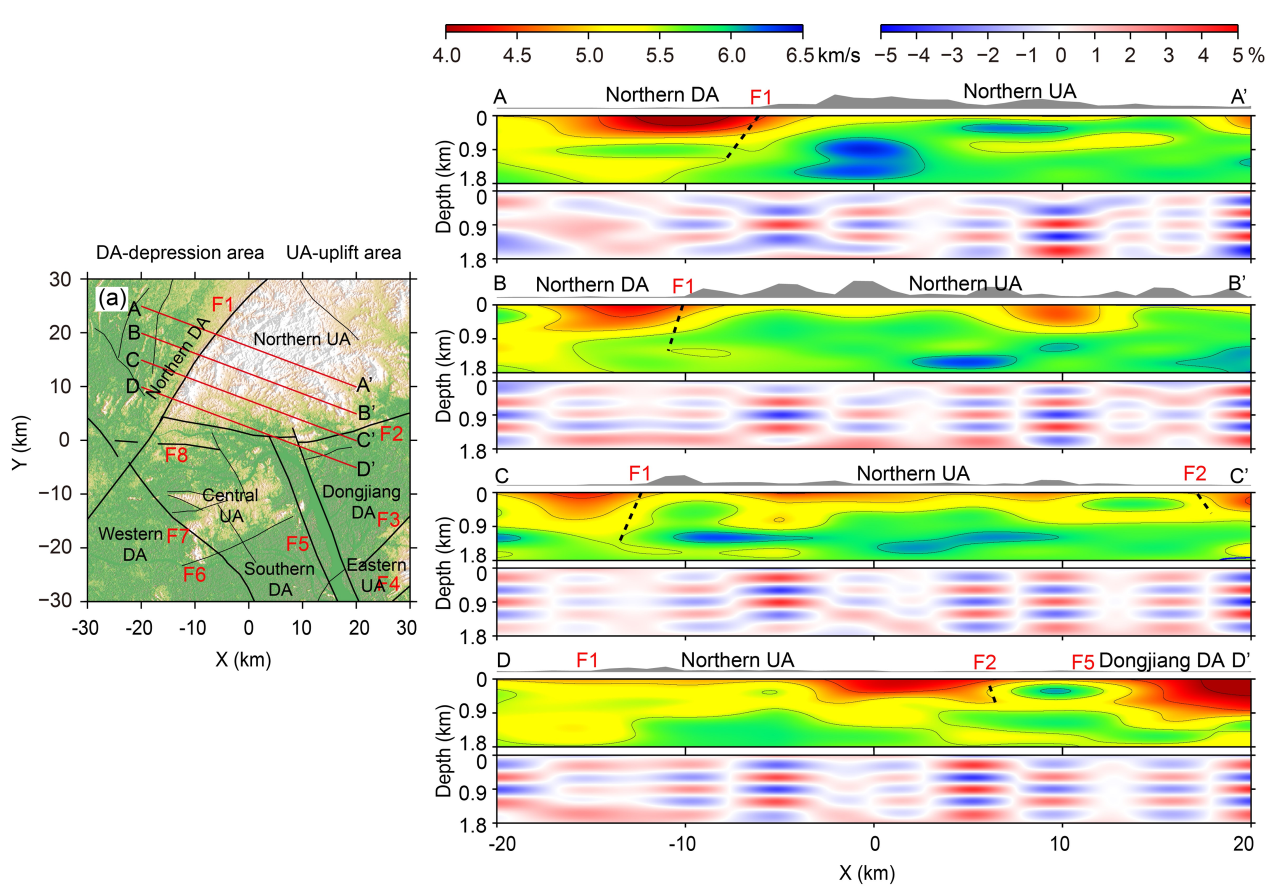

Figure 4 Vertical depth profile of the P-wave velocity images and checkerboard resolution test across the Guangcong fault (F1).

The northern DA has deposited sedimentary formations of the Upper Paleozoic era, exhibiting low-velocity anomalies. Meanwhile, the northern UA is an ancient uplift that dates back to the Proterozoic era, exhibiting generally high-velocity distributions.

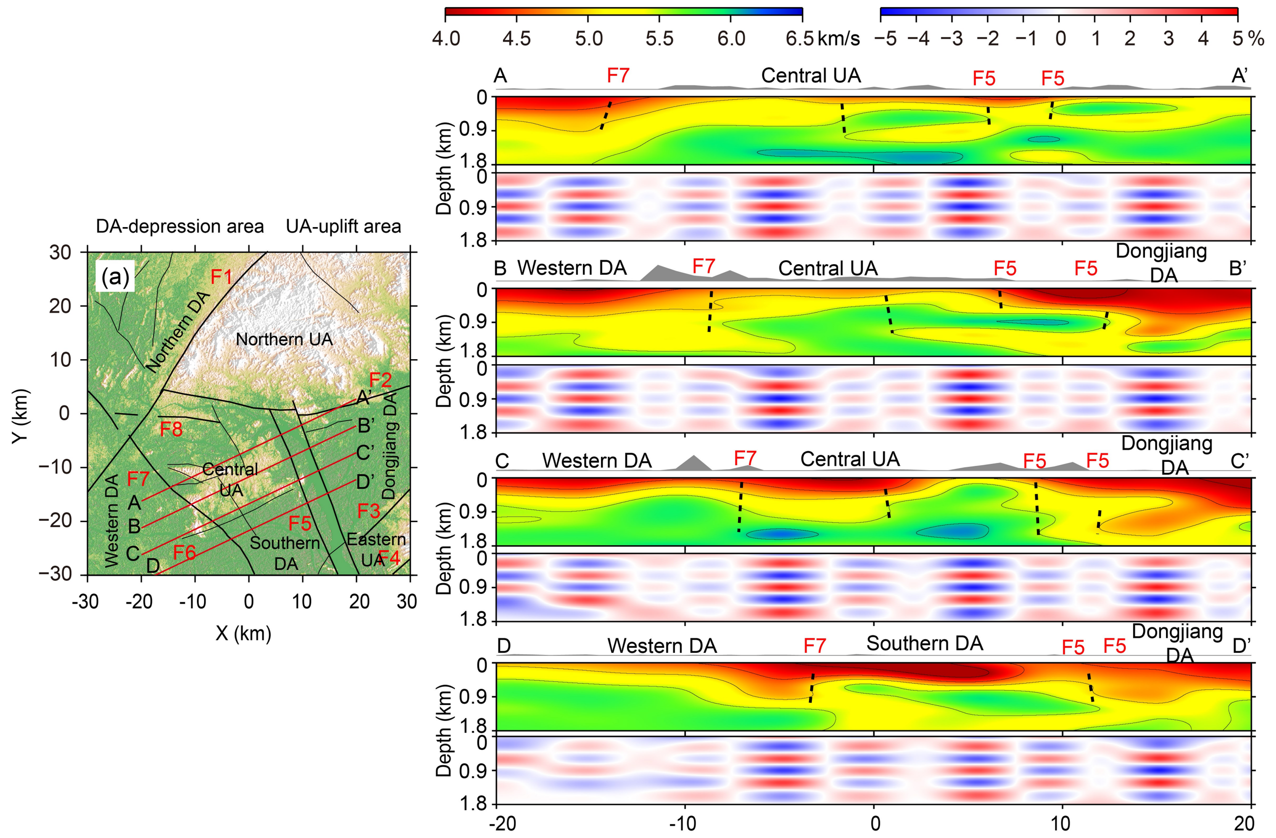

Figure 5 Vertical depth profile of the P-wave velocity images and checkerboard resolution test across the Zhujiangkou (F5) and Baini-Shawan (F7) faults.

The western branch of F5 trends towards the northeast, while the eastern branch trends towards the southwest. The western DA exhibits low velocity, while the central UA shows high velocity, tilting steeply towards the southwest.

4. Imaging profiles across different faults

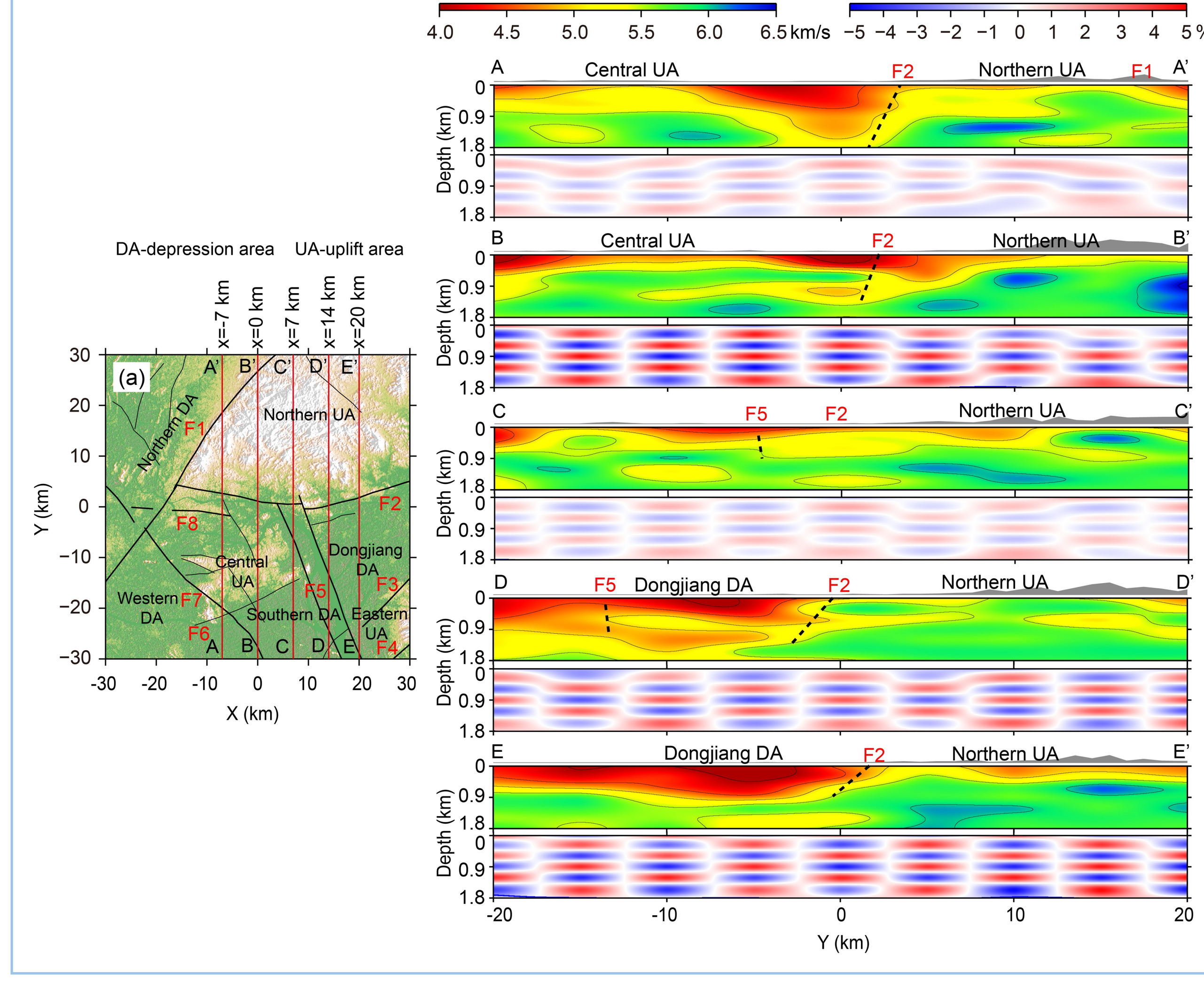

Figure 6 Vertical depth profile of the P-wave velocity images and checkerboard resolution test across the Shougouling fault (F2). The northern UA and central UA exhibit high-velocity anomalies, while the Dongjiang DA shows low-velocity distribution. The F2 tilts towards the south, steeper in the west than in the east, and extends to depths below 1.8 km in some areas.

5. Conclusions

1.The velocity images have a good correspondence with the regional topography and shallow lithology distribution. The depression area presents a low Vp distribution, while the uplift area with high Vp anomalies, which corresponds to clastic sedimentary rocks, granites, and metamorphic rocks, respectively.

2.The velocities have a strong anomaly on both sides of the Guangcong fault, Shougouling fault, Zhujiangkou fault, and Baini-Shawan fault. Among them, the Shougouling fault has the strongest controlling effect, making the velocity images show obvious differences between the north and south side along the fault at different depths.

3.The cross-fault velocity profiles show that regional faults control the distribution and burial depth of sedimentary layers.

4.Our study shows that combination using of new green methane source and dense short-period array is an effective method to detect the shallow velocity structure and fault system under urban agglomerations.

References and Acknowledgements

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2. Evans J, Eberhart-Phillips D, and Thurber C H. 1994. User's manual for SIMULPS12 for imaging Vp and Vp/Vs: A derivative of the "Thurber" tomographic inversion SIMUL3 for local earthquakes and explosions, U.S. Geol. Surv. Open-File Rept, 94–431.

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Supplementary materials

Million-scale seismic phase dataset: A reference dataset for machine learning seismology from ChinArray in Southwest China (CREDIT-X1local).

DNN seismic tools
github.com/cangyeone