Fluids Involved in the Occurrence of the 1975 Ms 7.3 Haicheng Earthquake Evidenced From Seismic Velocity Anomalies

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1. Why Haicheng?

The Liaodong Peninsula lies on the eastern margin of the North China Craton, where inherited deep faults, Mesozoic-Cenozoic tectonic reworking, and persistent seismic activity make the region a key area for studying strong intraplate earthquakes.

- The 1975 Haicheng earthquake remains the only major earthquake for which an official short-term prediction was successfully issued before rupture.
- It provides an especially important case for examining how fault zone structure and fluid-related processes may interact during the preparation and rupture of strong continental earthquakes.

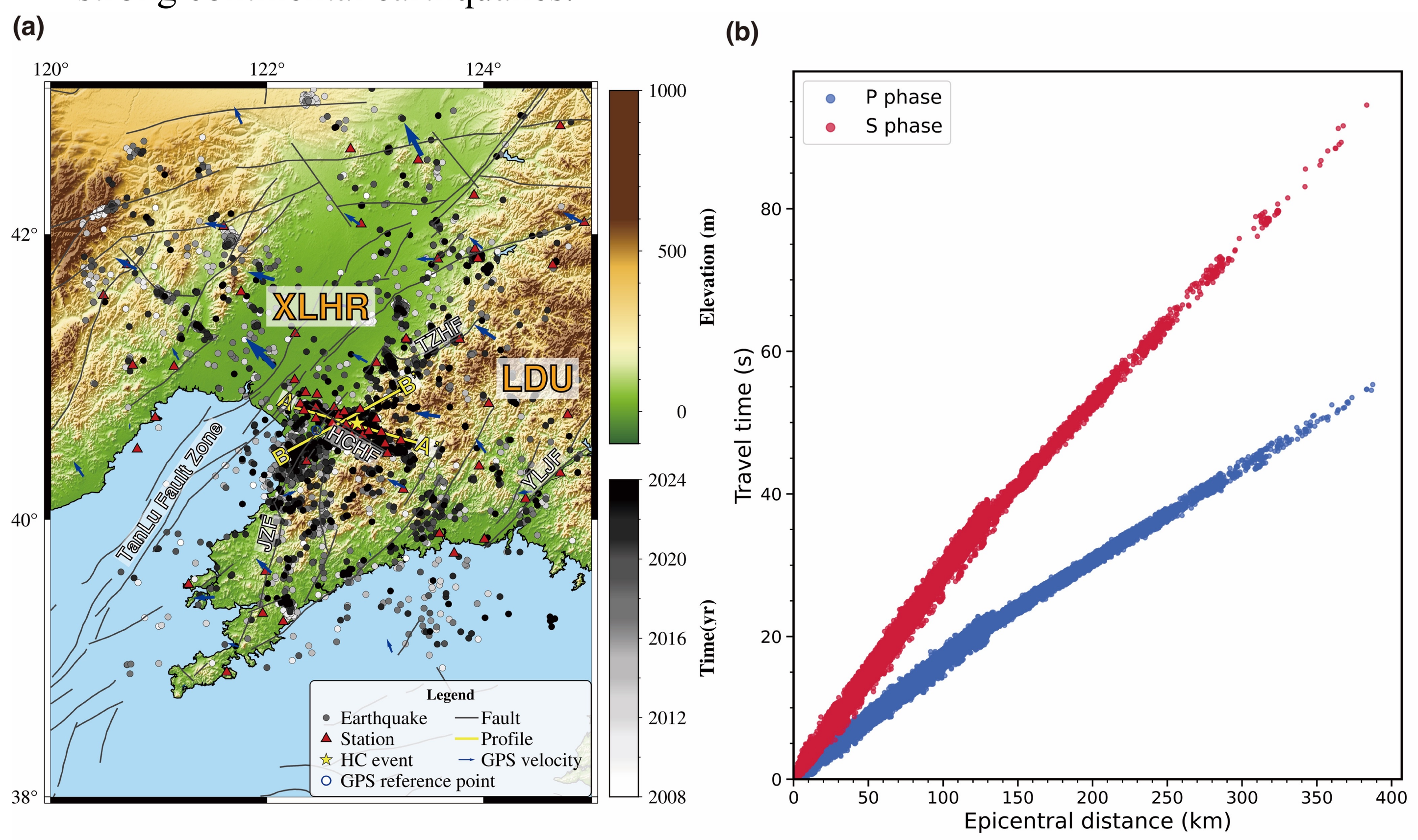

Fig.1. Tectonic settings, seismicity and station distribution, and traveltime-distance curves for P and S arrivals. XLHR: Xialiaohe Rift; LDU: Liaodong Uplift.

2. Seismic Dataset

Permanent-network observations and temporary-station records were integrated to construct a dense body-wave travel-time dataset for the Haicheng source region.

35,677 EARTHQUAKES

67 SEISMIC STATIONS

340k P ARRIVALS

300k S ARRIVALS

270k S-P DIFFERENTIAL TIMES

5 km LOCAL-GRID LATERAL SPACING

Table1 Comparison of Residuals.

	P & S wave arrival times RMS	S-P times RMS	VI
Initial residuals	0.281	0.245	-
No Constraint	0.057	0. 096	3.07
VI Constraint	0.058	0.094	2.84

The comparison shows that both inversions achieve similar levels of data fitting, whereas the VI value decreases after applying the information-variation constraint, implying a significant enhancement in consistency among different velocity models.

3. Variation-of-information constrained tomography

1 Direct inversion for Vp/Vs

S-wave travel times are directly used to solve for Vp and Vp/Vs (κ) through a chain rule.

$$d^{T_s} = G_H^{T_s}\Delta H + G_{U_s}^{T_s}\Delta U_s = G_H^{T_s}\Delta H + G_{U_s}^{T_s}\frac{V_p}{V_s}\Delta U_p + G_{U_s}^{T_s}\frac{1}{V_p}\Delta\kappa$$

2 Use of S-P differential times

S-P travel time is used to directly solve for Vp/Vs by removing the effect of origin time.

$$d^{T_{s-p}} = G_H^{T_{s-p}}\Delta H + G_{U_p}^{T_p}\frac{1}{V_p}\Delta\kappa$$

3 Variation-of-information (VI) constraint

VI constraints are imposed between Vp and Vp/Vs to preserve petrophysical consistency while allowing local structural heterogeneity to emerge during inversion.

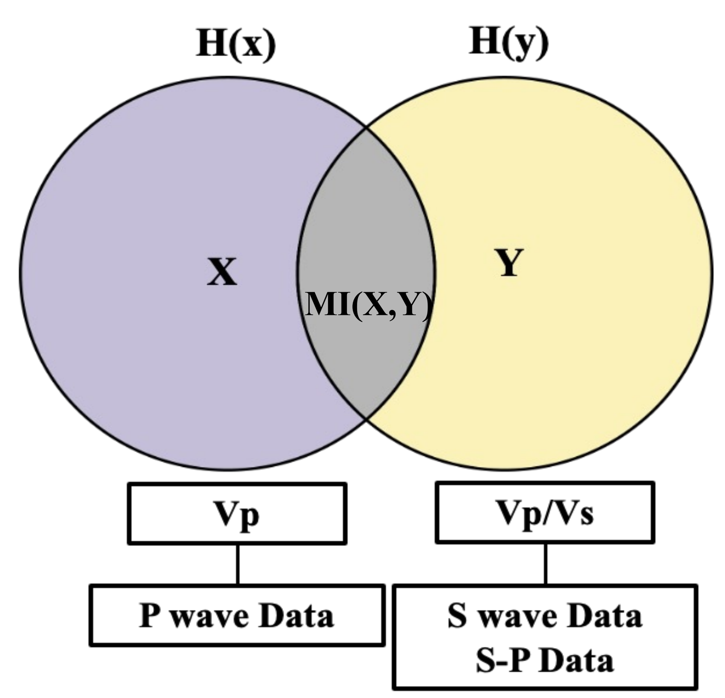

Fig.2. Schematic diagram of mutual information

- X represents the Vp model inverted from P travel times;
- Y represents the Vp/Vs model directly inverted from both the S-P time data and S-wave data based on the chain rule;
- H(X) and H(Y) represent the information entropy of the two models, respectively.

$$MI(x,y) = H(x) + H(y) - H(x,y)$$

Minimizing an objective function

$$VI(X,Y) = H(X,Y) - MI(X,Y) = 2H(X,Y) - H(X) - H(Y)$$

4 L-BFGS for the nonlinear inverse problem

The chain-rule parameterization introduces nonlinear coupling among model parameters; L-BFGS is used to maintain computational efficiency and stable convergence.

4. Resolution and Validation

Checkerboard Resolution Test

- Alternating **±5%** perturbations are imposed on Vp and Vs with opposite signs.
- This results in a corresponding Vp/Vs perturbation of approximately **10%**

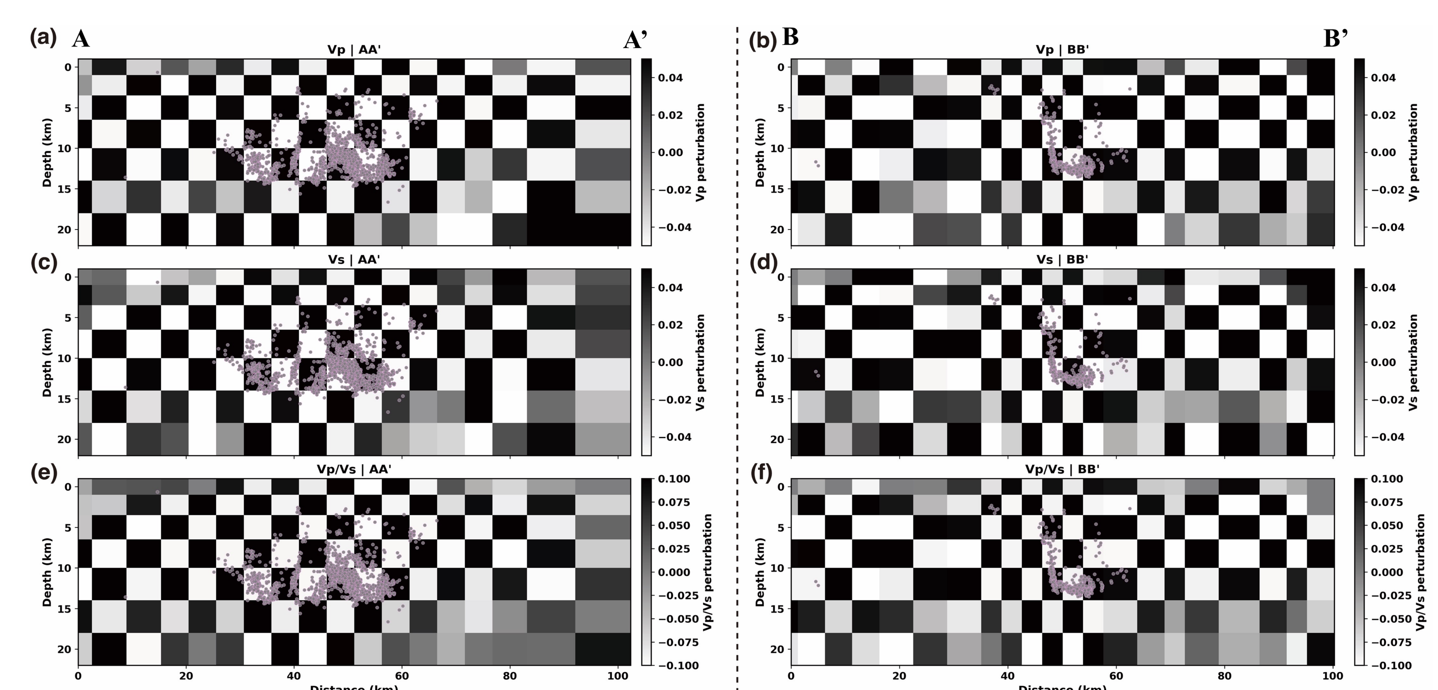

Fig.3 Vertical checkerboard test results of Vp, Vs, and Vp/Vs along profiles AA' and BB'.

5. Velocity Results and Clustering Analysis

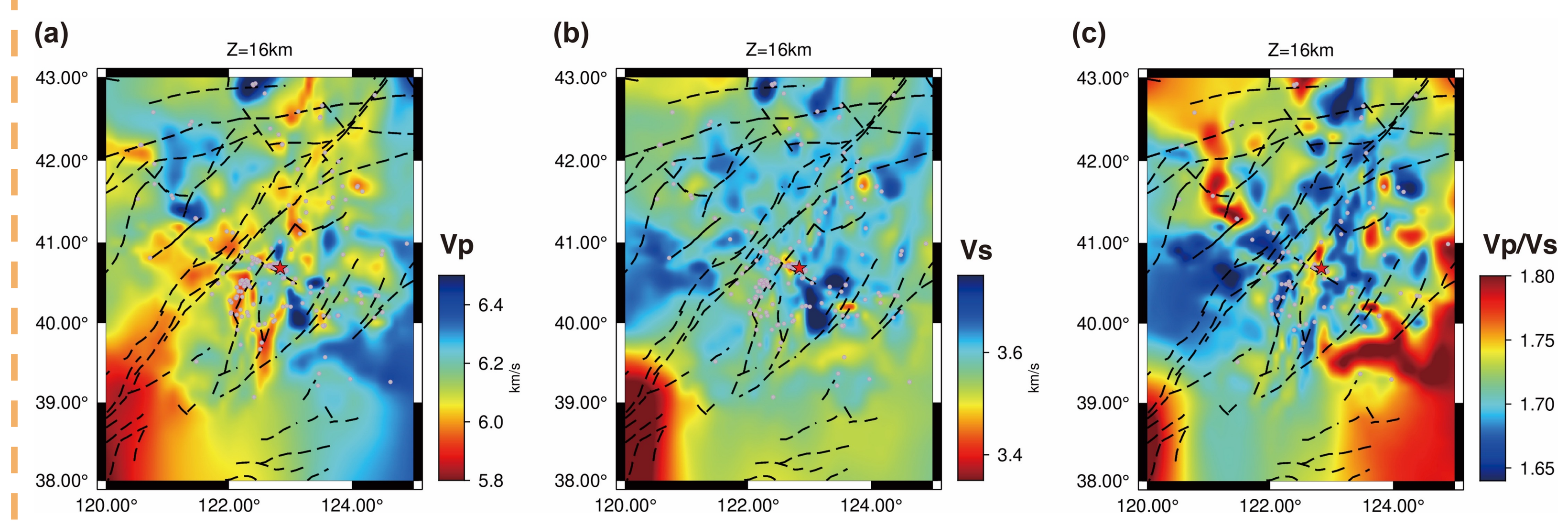

Fig.4. The horizontal slices at 16km of the Vp, Vs, and Vp/Vs models.

- Relocated earthquakes cluster preferentially above, or along the margins of velocity anomalies.
- Along the fault plane, Haicheng earthquake is initiated at the edge of low Vp/Vs zone (asperity), with high Vp/Vs zones adjacent to it, indicating fluids are involved in the earthquake generation process.

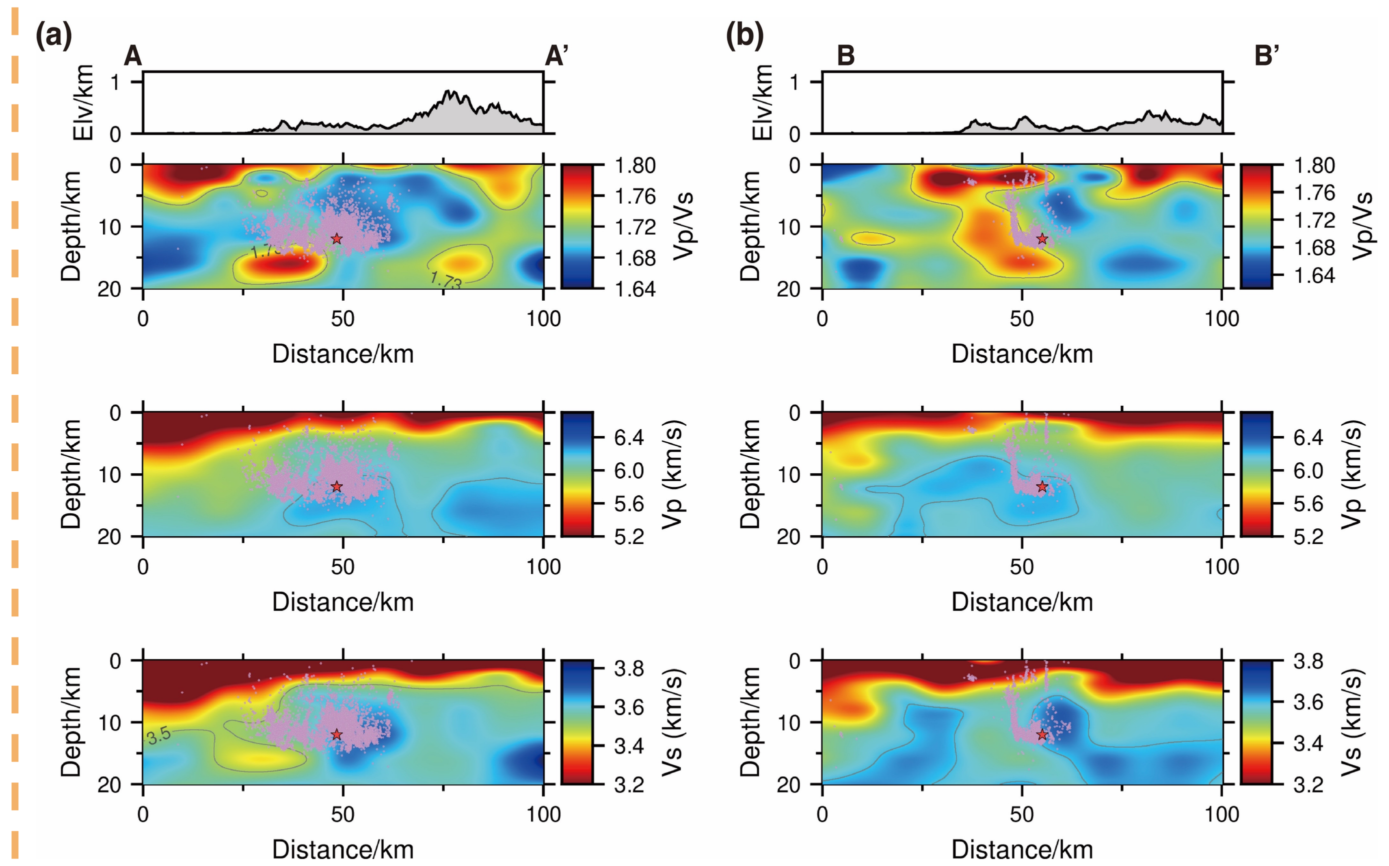

Fig.5. The vertical results of Vp, Vs, and Vp/Vs along profiles AA' and BB'.

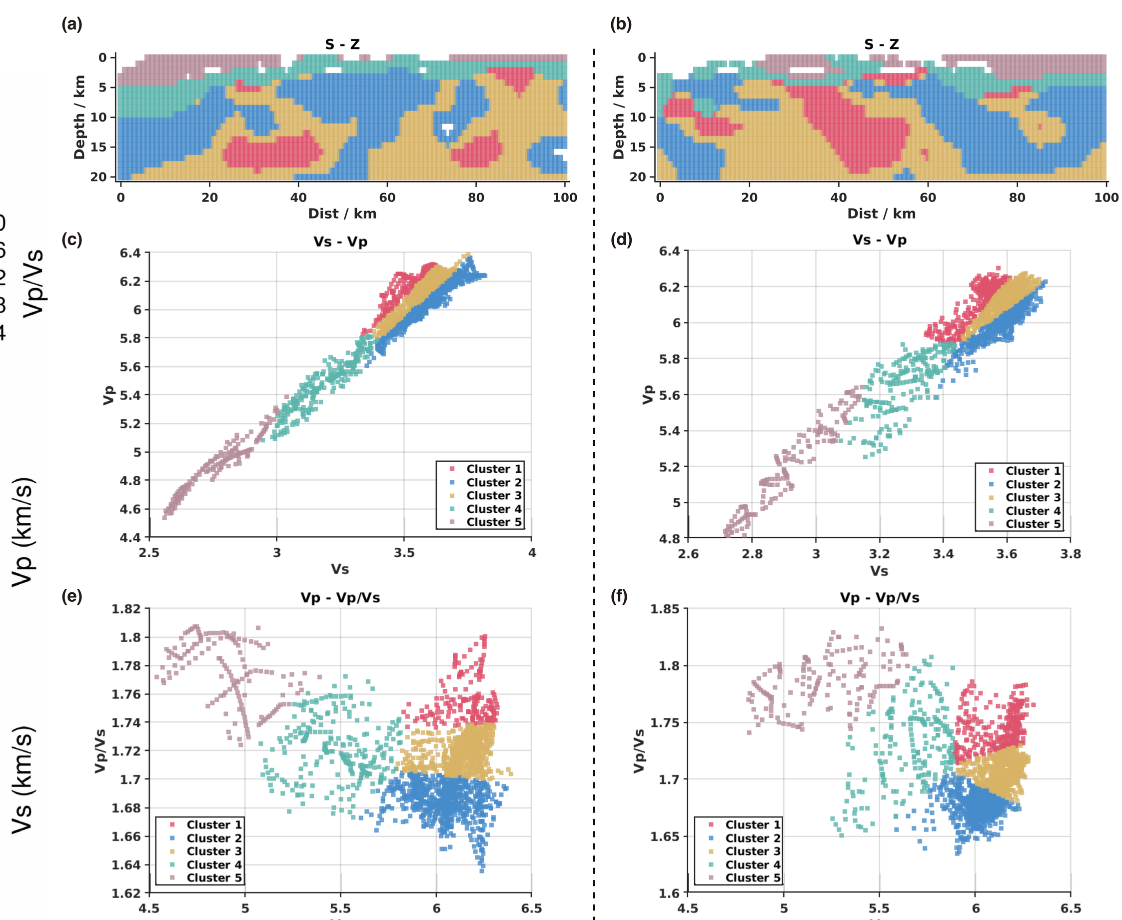

Fig.6. Clustering results along two fault-crossing profiles (AA' and BB').

6. Take-Home Messages

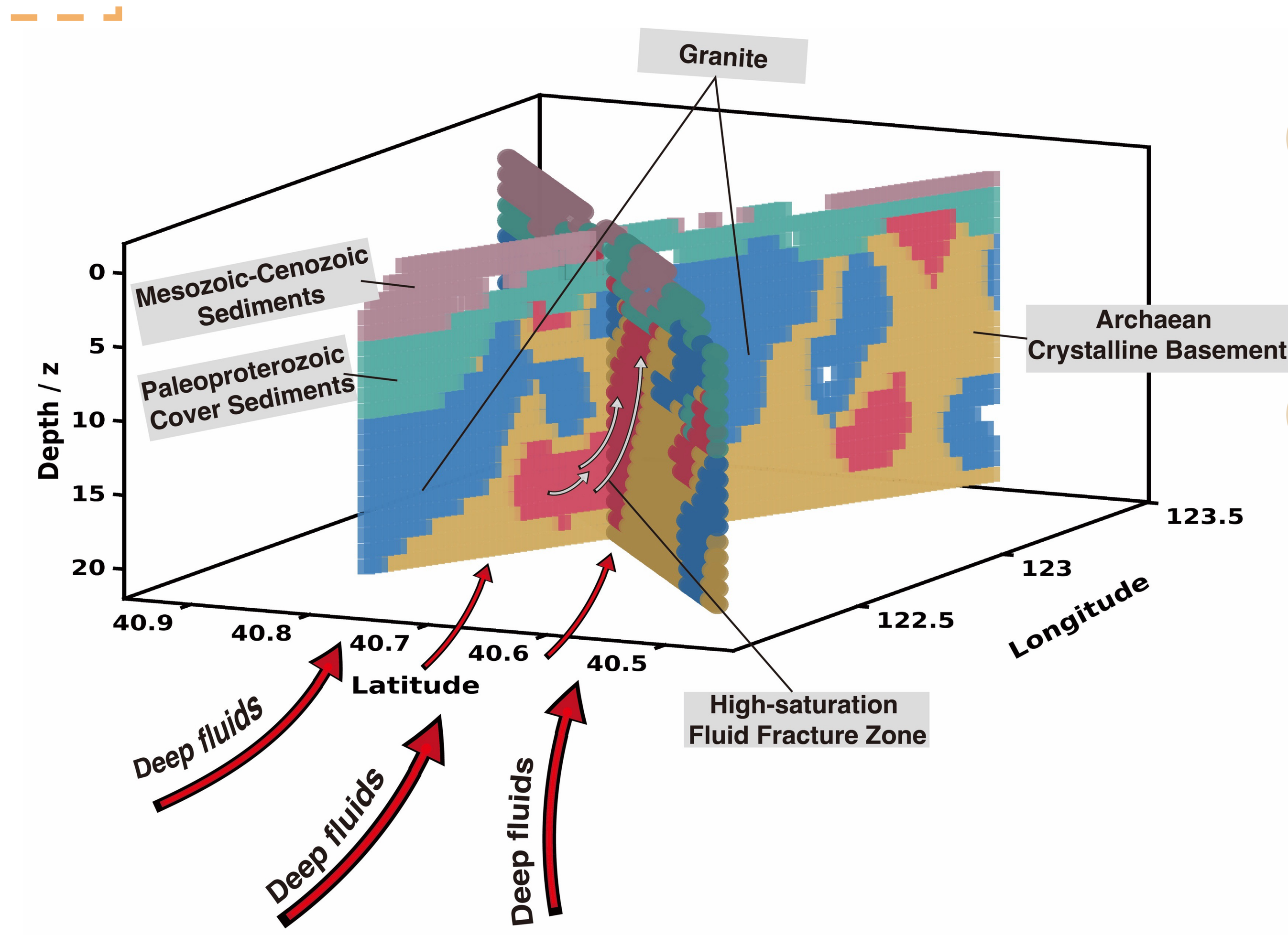

Fig.9. A conceptual model of the Haicheng earthquake.

1. The VI-constrained joint inversion framework improves the stability, consistency, and interpretability of Vp, Vs, and Vp/Vs models in the Haicheng source region.
2. Clustering analysis identifies five internally coherent units. Within the seismogenic depth range, two clusters representing dense granitoids and high-saturation fluid-rich fractured zones are identified.
3. The preferred interpretation links deep thermal-fluid input, conjugate fault geometry, and competent granitoids (acting as asperities) to the occurrence of the 1975 Haicheng earthquake.