Dominant Control of 3D Fault Geometry on the Seismogenic Environment of the Longmenshan Fault: Insights from Viscoelastic Finite Element Modeling in Eastern Tibet

Yixuan Yang[1,2], Wei Tao[1,2*], Junxiang Qiao[1,3], Haoyue Sun[1,3], Xuhang Yang[1,2], Renqi Lu[1,2], Wei Wang[1], Fang Xu[1] , Xiao Sun[1] , Xin Wang[1,3]

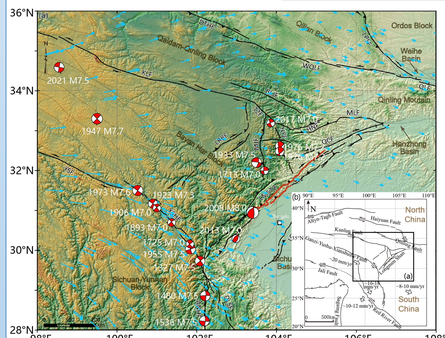
1. State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration, Beijing 100029
2. Sichuan-Chongqing Earthquake Science Research Center, Sichuan 646000, China
3.Shanxi Taiyuan Continental Rift Dynamics Observation and Research Station, Beijing 100029, China.

EGU26-9011

Abstract

In this study, we constructed a 3D inhomogeneous viscoelastic finite element model of the eastern margin of the Tibetan Plateau, which is constrained by multi-source data and 3D fault geometries. This model enables a quantitative analysis of the seismogenic mechanisms and controlling factors of the Longmenshan Fault Zone (LMSFZ). The results indicate that: (1)The kinematics of the LMSFZ govered by the fault geometry. The seismogenic environment of deep shear driving and shallow high-energy locking is formed by deep low-angle shearing and shallow high-angle locking. (2) The southwestern segment of the LMSFZ (Dachuan area) is identified as a high-risk zone, exhibiting strong locking-high energy accumulation. The northeastern segment (north of Beichuan), despite lower energy density, exhibits high instability potential and long-term risk. (3) The 3D fault geometry is the primary driver of strain energy distribution. Inter-fault stress transfer modulated by tectonic source distance is secondary; and crustal rheology is a tertiary background factor with minimal perturbation on stress patterns.

Geological Setting



- The Longmenshan Fault Zone, over 550 km long, lies at the eastern margin of the Tibetan Plateau and features complex 3D geometry and segmented activity.
- It marks a key zone where eastward extrusion of plateau material is resisted by the Sichuan Basin, resulting in strong NE–SW compression.
- Nearby faults include the subparallel Longriba Fault and the obliquely intersecting Minjiang and Huya Faults.

Data

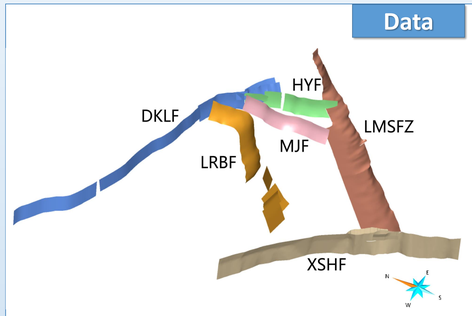
Material Parameters

	Qaidam-Qinling Block			Bayan Har Block		
	Upper Crust	Middle & Lower Crust	Upper Mantle	Upper Crust	Middle & Lower Crust	Upper Mantle
d / km	20	30 / 63	100	20	30 / 63	100
Vp / km·s^{-1}	5.9	6.5	8.3	5.2	5.8	8.3
Vs / km·s^{-1}	3.4	3.8	4.4	3	3.3	4.4
ρ / ×10^3 kg·m^{-3}	2.7	2.7	3.3	2.69	2.84	3.3
E / Pa	7.8×10^{10}	9.6×10^{10}	1.8×10^{11}	6×10^{10}	7.7×10^{10}	1.8×10^{11}
ν	0.25	0.24	0.3	0.25	0.26	0.3
η / Pa·s	1.0×10^{21}	1.0×10^{20}	1.0×10^{20}	1.0×10^{21}	5.0×10^{18}	1.0×10^{20}

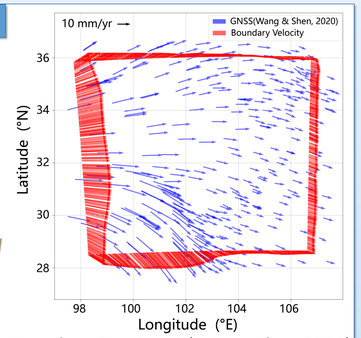
	Sichuan Basin			Sichuan-Yunnan Block		
	Upper Crust	Middle & Lower Crust	Upper Mantle	Upper Crust	Middle & Lower Crust	Upper Mantle
d / km	20	30 / 45	100	20	30 / 63	100
Vp / km·s^{-1}	5.1	6.4	8.3	5.8	6.2	8.3
Vs / km·s^{-1}	3.1	3.8	4.4	3.4	3.6	4.4
ρ / ×10^3 kg·m^{-3}	2.6	2.86	3.3	2.79	2.86	3.3
E / Pa	6×10^{10}	1×10^{11}	1.8×10^{11}	7.9×10^{10}	9.2×10^{10}	1.8×10^{11}
ν	0.2	0.23	0.3	0.24	0.25	0.3
η / Pa·s	1.0×10^{21}	1.0×10^{20}	1.0×10^{20}	1.0×10^{21}	1.0×10^{19}	1.0×10^{20}

Faults are set as finite-thickness weak zones with medium parameters assigned as one-tenth (0.1×) the arithmetic mean of the adjacent blocks.

Data



3D Fault Geometry Model (Lu et al.,2025)



Boundary Constraint (Wang&Shen,2020)

Methods

Work Flow

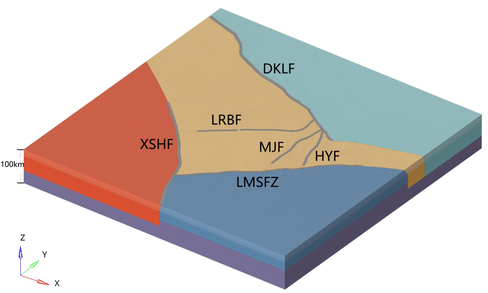
Step 1 *Geometric-Topological Partitioning*
Block Boundary & Lithospheric Structure

Step 2 *Refined Hexahedral Meshing*
Multi-scale Gradient Mesh Refinement

Step 3 *3D Finite Element Numerical Simulation*
Inhomogeneous Medium & Exceeding 100kyr

Step 4 *Python-based Automated Processing*
Automated Extraction & Visualization of Data

3D Finite Element Model



The Eastern Tibetan Depth: 100 km
Nodes: 1, 631, 964
Elements: 1, 294, 290

98°E–107°E , 28°N–36°

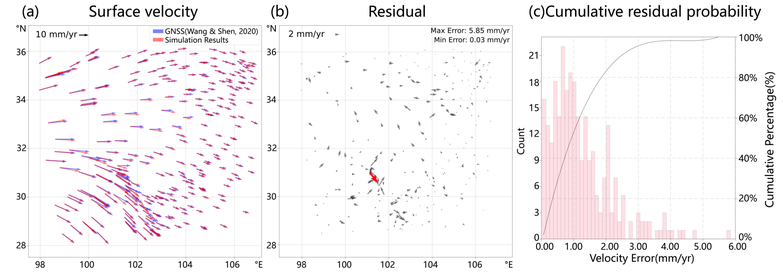
Maxwell Viscoelastic Constitutive Equation:

$$\dot{\varepsilon}=\frac{1}{2G}\dot{S}+\frac{S}{2\eta}+\frac{1}{3K}\dot{p}I$$

$\dot{\varepsilon}$ —— Strain Rate
G —— Shear Modulus
S —— Deviatoric Stress
η —— Viscosity Coefficient
K —— Bulk Modulus
$\dot{p}$ —— Mean Stress
I —— Identity Tensor

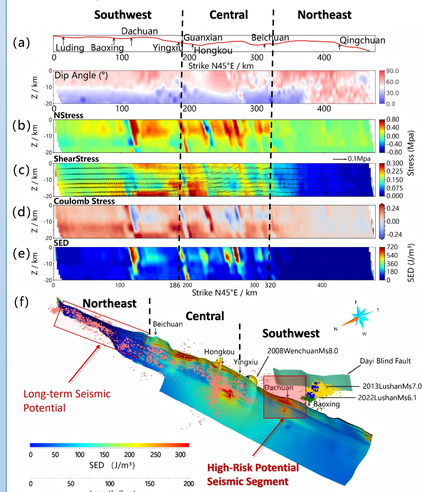
Results & Discussions

Model Validation



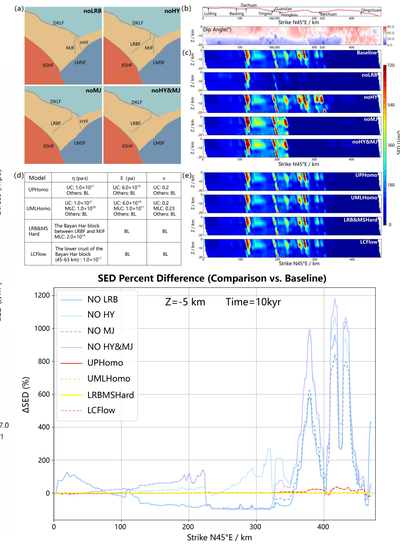
Stress-Strain Evolution & Seismicity of the Longmenshan Fault

- **Southwest Segment (Dachuan Area):** Strong Inter-Seismic Locking & High Energy Accumulation & Seismic Gap
- **Northeast Segment:** Low Energy Accumulation & High Instability



Quantifying Hierarchical Influences via Comparative Simulations

3D Fault Geometry > Near Faults > Crustal Medium



Reference

- Lu, R. Q., et al. (2025). 3D community fault model v1.0 for major active fault zones in the Sichuan-Yunnan region. National Earthquake Data Center. https://doi.org/10.12080/nedc.zt_dzkxyjxm.ds00001.2025
- Wang, M., & Shen, Z. K. (2020). Present-day crustal deformation of continental China derived from GPS and its tectonic implications. Journal of Geophysical Research: Solid Earth, 125(2), e2019JB018774. https://doi.org/10.1029/2019JB018774

Email: yyx9068@gmail.com ; taowei@ies.ac.cn