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The deep lateral growth process of the plateau is a hot topic in earth science. As the growth boundary zone of the northeastern Tibetan Plateau, southern Ningxia geomorphic zone is controlled by four major arcuate fault zones (Fig. 1), namely Haizhou fault (HYF), Xiangshan–Tianjingshan fault (XTSF), Yantongshan fault (YTSF), Niushoushan–Luoshan fault (NLSF). For a long time, it is unknown the deep deformation process of the southern Ningxia geomorphic belt between the northeastern Tibetan Plateau and the Ordos Basin (Fig. 1), especially, how do the dip Angle of the contact surface, block strength, lithospheric thickness, and the viscosity of the lower crust and lithospheric mantle affect the subduction process between the blocks. Based on a large amount of geological and geophysical data, and using the geodynamic simulation software Underworld 2 (Moresi et al., 2019; Mansour et al., 2020) or UW geodynamics (Beucher et al., 2019), this paper establishes the two-dimensional particle-in-cell finite difference numerical model of the transverse section across the northeastern Tibetan Plateau and Ordos block (Fig. 2). Considering the complex crust-mantle structure (Sun et al., 2021; Moresi et al., 2007), parameters and boundary conditions in the study area, and no pre-existing faults, we reconstruct the NE-directed subduction process of the northeastern Tibetan Plateau beneath the Ordos block by using different dip angles of block boundary, slab strength and viscosity of lower crust and lithospheric mantle, and propose the lateral growth mechanism of the northeastern margin of the Tibetan Plateau.

The numerical simulation results show that:

(1) The upright block boundary increases the difficulty of subduction. The subduction of the northeastern Tibetan Plateau is still in progress; however, the subduction action is not significant, and there is no evident deformation in Ordos (Fig. 3; Model-1). If the contact boundary is typical of a certain dip angle, the subduction is beginning earlier, and the margin of Ordos block deforms intensively (Fig. 3; Model-2). However, whether the contact boundary of the block is vertical, or at any angle, core slab (lower crust) with low viscosity (0.1 times of asthenosphere) will be thinning, but the thinning ratio is less than that of the underlying lithospheric mantle. The strain is concentrated at the front edge of the plate, and decreases quasi-linearly with the distance from the contact boundary. Thus, it shows the buried depth of the Moho in the southern Ningxia geomorphic belt becomes gradually shallow from southwest to northeast, as evidenced by geophysical data (Pan and Niu, 2011; Guo and Chen, 2017; Li et al., 2017).

(2) The boundary of the Ordos block and northeastern Tibetan plateau is upright (Fig. 3; Model-3). If the strength of the block in the northeastern Tibetan Plateau is increased, the Ordos block can be intensively deformed, and stress concentrated in the boundary. The upper crust is subsiding, and the lower crust is thinning far away from the boundary, and the lithospheric mantle "falls" near the boundary. However, there is no significant subduction in the northeastern Tibetan Plateau, and the thickness of the core slab (lower crust) with low viscosity (the same as the asthenosphere) does not deform significantly. The strain concentration mainly occurred at the leading edge and the trailing edge of the block, that is, the long-wavelength subsidence occurred at the trailing edge, while the short-wavelength shear softening occurred at the leading edge. The simulated lithospheric deformation is in good agreement with the swath profile (Sun and Liu, 2018) of the northeastern Tibetan Plateau and the Ordos block.

(3) Under the condition of strong lithospheric mantle (500 times of asthenosphere), subduction is still difficult to occur in the northeastern Tibetan Plateau under the premise of no preexisting fault (fragile zone). This means that subduction is only more difficult even if several conditions are met: presence of lower crustal flow; a weaker lithosphere; preexisting structures (Mesozoic–Cenozoic fault zones).

Key words: northeastern Tibetan Plateau, Ordos block, southern Ningxia geomorphic belt, deep lateral growth processes, numerical modeling

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Fig. 2. Initial model and parameter setting. Model-2 is compared with Model-1 to study the effect of the angle of the contact of the block boundary on the difficulty of subduction and the deformation characteristics of the two blocks. Model-3 is compared with Model-1 and Model-2 to study the effect of plate strength on the difficulty of subduction and the deformation characteristics of two blocks by changing the thickness of the lithosphere and the viscosity of the lithosphere mantle.
The result of Model-1 shows that the vertical contact boundary increases the difficulty of subduction, but subduction can still occur; Ordos block has no significant deformation; no significant subduction occurred in the northeastern Tibetan Plateau, but the thickness of the low viscosity Core_slab (lower crust: viscosity is 0.1 of asthenosphere) was reduced, but the thickness ratio was not as high as that of the underlying lithospheric mantle; the strain concentrates on the leading edge of the plate (NE Tibet) and the thickness decreases quasi-linearly with distance from the contact boundary. The result of Model-2 shows that if the contact boundary is set as dip angle, subduction behavior appears earlier; Ordos block has no significant deformation; no significant subduction occurred in the northeastern Tibetan Plateau, but the thickness of the low viscosity Core_slab (lower crust: viscosity is 0.1 of asthenosphere) was reduced, but the thickness ratio was not as high as that of the underlying lithospheric mantle; the strain concentrates on the leading edge of the plate and the thickness decreases quasi-linearly with distance from the contact boundary. The result of Model-3 shows that by strengthening the northeastern margin of the Tibetan Plateau, the Ordos block can undergo significant deformation and stress concentration, and the upper crust will settle and the lower crust will thin away from the boundary, while the lithospheric mantle will "fall" near the boundary; at this time, the contact boundary is set as upright and subduction phenomenon can still appear earlier; no significant subduction occurred in the northeastern Tibetan Plateau, but the thickness of the low-viscosity Core_slab (lower crust: viscosity is equivalent to asthenosphere) did not change significantly; the strain concentration mainly occurs in the leading edge and trailing edge of the plate, that is, the trailing edge has long wavelength subsidence, and the leading edge has short wavelength shear softening.

**Fig. 3. Simulation results.**

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**References**


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