
Flexural folding and flexural eigen wavelength splitting in Songliao Super Basin, Northeast China

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A series of nearly 400 km long transects of subsurface seismic imaging data across the Songliao Super Basin in Northeast China reveal a magnificent upper crustal scale flexural folding system initiated in Late Cretaceous. The timing of the compressional deformation feature is consistent with the convergence of the Pacific plate to the Eurasia plate in Northeast Asia (**needs to be verified**). The spacing of the fold axes vary from SE to NW. Towards SE, the folds are tighter while spatially these fold axes are closer to the converging boundary of the Pacific plate with a shorter wavelength of approximately 20 km, and the thickness of the corresponding folded sediment package is thinner. The wavelengths of the folds gradually increase towards the northwest with middle and longer wavelengths of 30 and 50 km respectively while the overall sediment packages are thickened. (**a structure map is necessary to describe the spatial geometry of the folds**). The eigen wavelengths of flexural folding are examined to predict the variation of the observed fold wavelengths. The result suggests (**we need to do more work to get our modeling results**)?

The large scale intraplate flexural folding due to the interplate collision has been well predicted by the governing equation of the flexure deformation of the Earth lithosphere and the eigen wavelength behavior of the flexural folding has been detailed in *Lithosphere Dynamics*¹. However, due to the limitation of efficient large scale data sets archived to manifest the flexural folds spatially and in depths, so far only limited observations directly or indirectly provide the evidences of the existence of these lithosphere scale large folds. Zuber² developed a rheological model to quantify the oceanic Indian intraplate folding with a spatially uniform wavelength of approximately 200 km in Bengal Bay, and the intraplate folding is originated from the northward convergence of the Indian plate to the Eurasia plate. Jin³, et al. demonstrate with observed flexural spectral splitting in the vertical direction that the lithosphere of

the Tibetan plateau is decoupled with a characteristic upper crustal spectral wavelength of 150 km, and an upper mantle lithosphere spectral wavelength of 500 km. The intraplate flexural folding over the plateau is also caused by the collision between the Indian plate and the Eurasia plate. Both above flexural folding are not very intuitively demonstrated and imbed a considerable mathematical derivation. Fortunately, there is a super sedimentary basin in Northeast China, illustrating a large-scale flexural folding within the basin and a systematic flexural wavelength splitting horizontally. The super basin is called Songliao Basin⁴, located in the Northeast Asia and formed within the Eurasia plate (Fig. 1A). The basin is elongated in NE-SW direction with a short axis span of approximately 400 km, and the long axis span of nearly 1,000 km. Due to its rich hydrocarbon resources, the basin has been

imaged intensively so that a significant folding system is revealed via seismic imaging. In this paper, we will present the data observation of the folds, model the

characteristic wavelengths of the flexural folding, and finally discuss its possible root cause due to the converging Pacific plate towards the Eurasia plate.

Flexural folding data observations

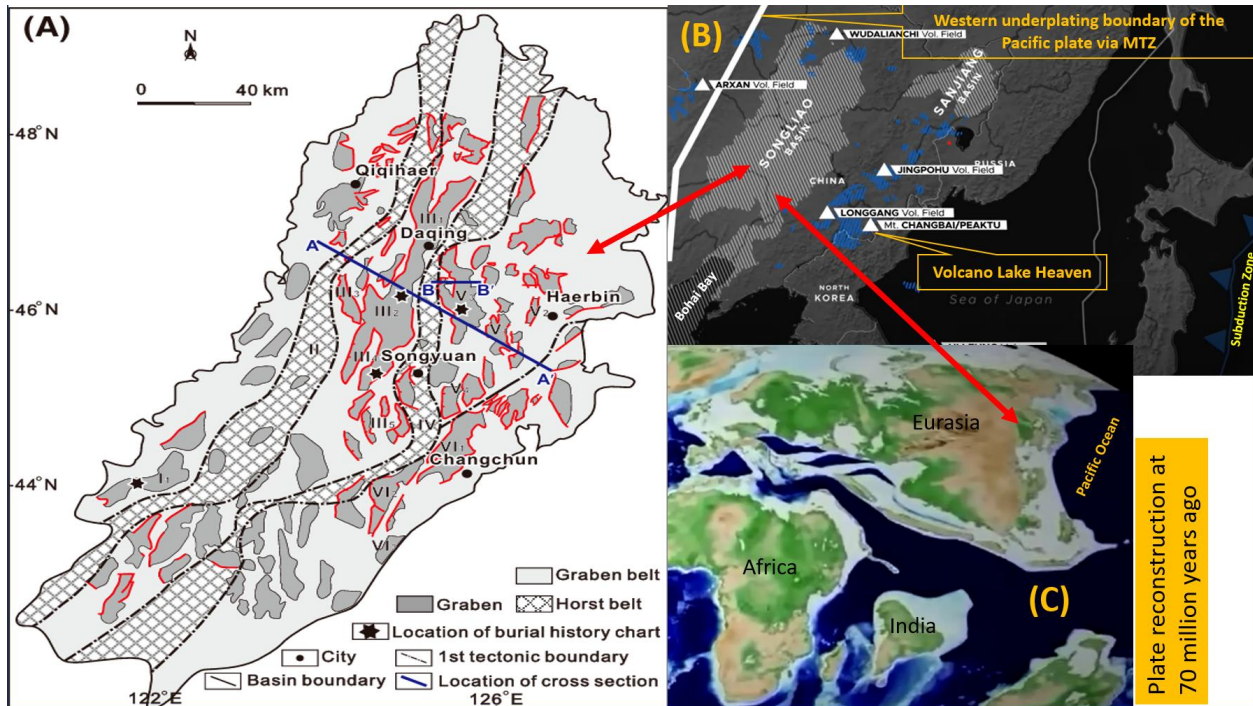


Fig. 1. (A) Structural contour map of Top of Yaojia⁴ Formation in Upper Cretaceous with Reference Lines of A-A', B-B', and C-C' in Fig. 2, and Reference Well ? in Fig. ? The interval of the contour map is ? meters. (B) Present day index map of Songliao Basin. (C) Index map of Songliao Basin at 70 million years ago from Global Plate Reconstruction⁵.

Early Jurassic. What triggered this syn-rift process needs further investigation. However, the mid-ocean ridge that formed the Pacific plate is thought to have originated around 190 Ma, and the west boundary of the Pacific plate adjacent to the Songliao basin on the Eurasia plate (Fig. 1C) has been diving underneath the Eurasia plate⁵ since then. There is a high possibility that the syn-rift was caused by the underplating of the Pacific plate while the subducting slab was rolling back due to its heavy gravity pull⁶ so that a back arc extension process was triggered. As Royden⁶ stated that if the plate convergence rate is faster than the plate subduction rate, then the upper plate stands a shortening process even though many authors have noted that wherever plate convergence rates are exceeded by subduction rates at oceanic subduction boundaries, upper plate extension occurs within the overriding plate normally in a back arc extension⁶, and if the subduction rate is faster, the upper plate is under extension. The issue is what is the cycle process when the same upper plate stands both extension and compression at various time in response to the underplating of the same subduction plate? The tectonic history of the Songliao Basin falls into this cycle process. The syn-rift event stopped around 108 Ma, and then the basin experienced a long stable thermal subsidence (Fig. 2) until roughly 72 Ma while an inversional compression⁴ occurred (Fig. 1A, & Fig. 2). The inversion resulted a significant erosion on the top of the Songliao Basin (Fig. 2), and when the inversion process ended is a question because right adjacent to the Songliao Basin in the south is the Tertiary syn-rift North China Super Basin centered at the Bohai Bay (Fig. 1B). The seismic depth imaging data will be presented in a separate paper due to the

page limitation of *Nature*. The dynamic equilibrium at the advancing plate boundaries may deform its corresponding upper plate or called overriding plate in various ways due to its subduction slab pull⁶ which makes the slab stops advancing, or finally retreating. However, when part of the subducting slab front is dropped in the mantle, the plate advancing may recover again so that the extension regime and the compression regime can be recorded in the sedimentary rocks of the same basin at various time. On the other hand, how far the compressional stress field can be effectively transmitted from the converging boundary to the inland of the upper plate also needs to be investigated. Based on the folding of the Songliao basin (Fig. 2), the folding of the sediments is phased out beyond the NW of the largest fold which crested at (we need the horizontal coordinates of the seismic cross sections) and the distance from the crest to the far SE of the cross sections is about 200 km if the SE end of the sections are closest to the Pacific plate converging boundaries. A more comprehensive 3D big data analysis via the Earth Lithosphere deformation modeling joined with more detailed plate reconstruction in the subduction zone and its adjacent tectonic regimes should be carried out in order to disclose the reality of the cycling process of shortening and extension in time on the same upper plate. Furthermore, the active seismic imaging data in the Songliao basin and the passive earthquake seismic tomographic data beneath Volcano Lake heaven (Fig. 2B) due to the underplating from MTZ (Mantle Transition Zone roughly between 400-600 km in depth) of the subducting Pacific plate⁷ can be integrated to reveal more dynamic mechanism of the tectonic evolution of the Songliao Super basin and its vicinity.

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1. Jin, Y. & Jiang, X. *China Science Publishing House, Lithosphere Dynamics*, 59-79 (2002).
 2. Zuber, M. T. *J. Geophys. Res.* **92**, 4817-4825 (1987).
 3. Jin, Y., McNutt, K. M., & Zhu, Y. *Nature* **371**, 669-674 (1994).
 4. Liu, B., Liu, L., Fu, J., Lin, T., He, J., Liu, X., Liu, Y. & Fu, X. *AAPG Bulletin* **107**, 1257-1297 (2023)
 5. Scotese, C. R., *Paleomap Project*, [online](#).
 6. Royden, L. *Tectonics* **12**, 303-325 (1993).
 7. *Volcano Lake Heaven in China derived from the Mantle Transition Zone of the Pacific Plate Subduction*, [online](#).

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