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Extension discrepancy distribution of the hyper-thinned continental crust in the Baiyun Rift, northern margin of the South China Sea

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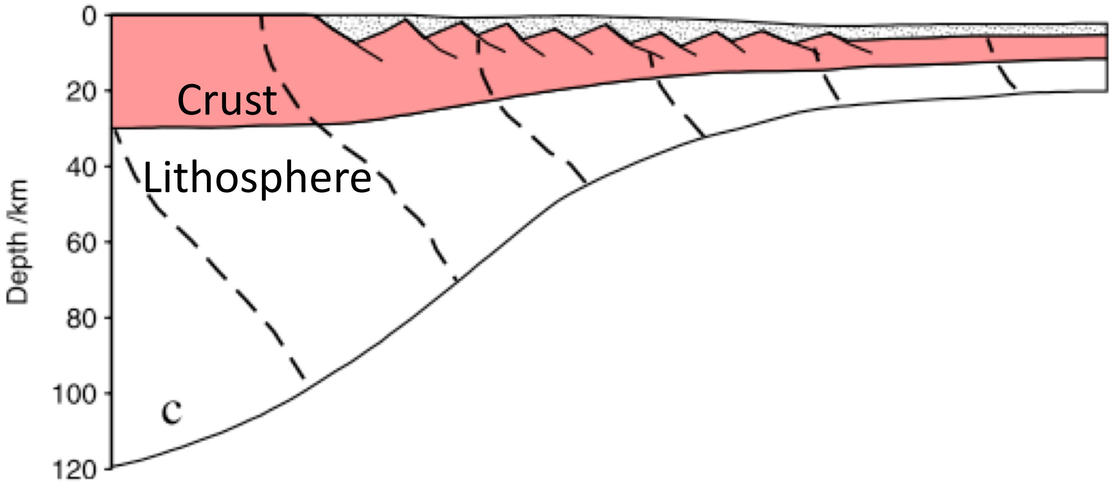
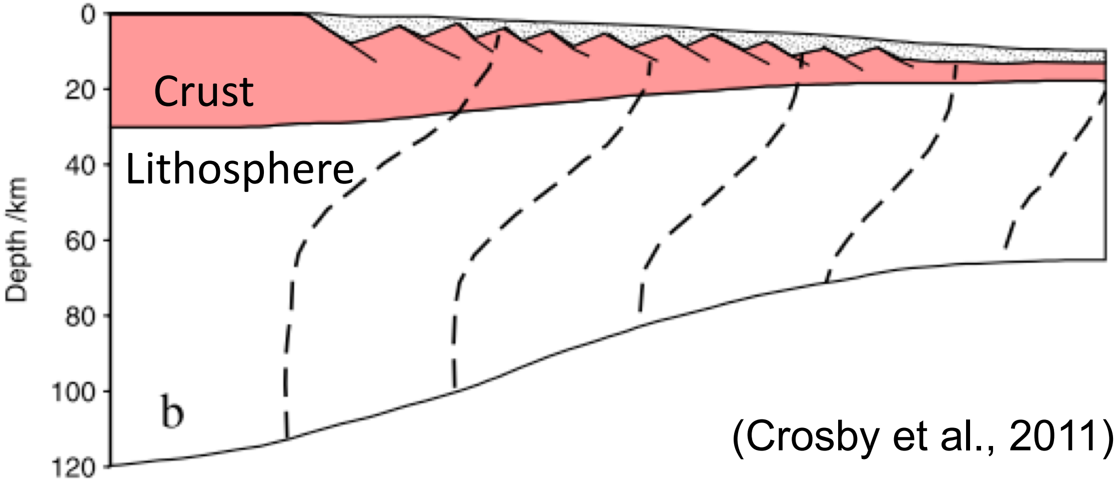
Scenario A Lithospheric mantle is thinned more than crust



Scenario B Crust is thinned more than lithospheric mantle



(Crosby et al., 2011)

Extension discrepancy, upper crust thinned far less than whole crust or lithosphere.

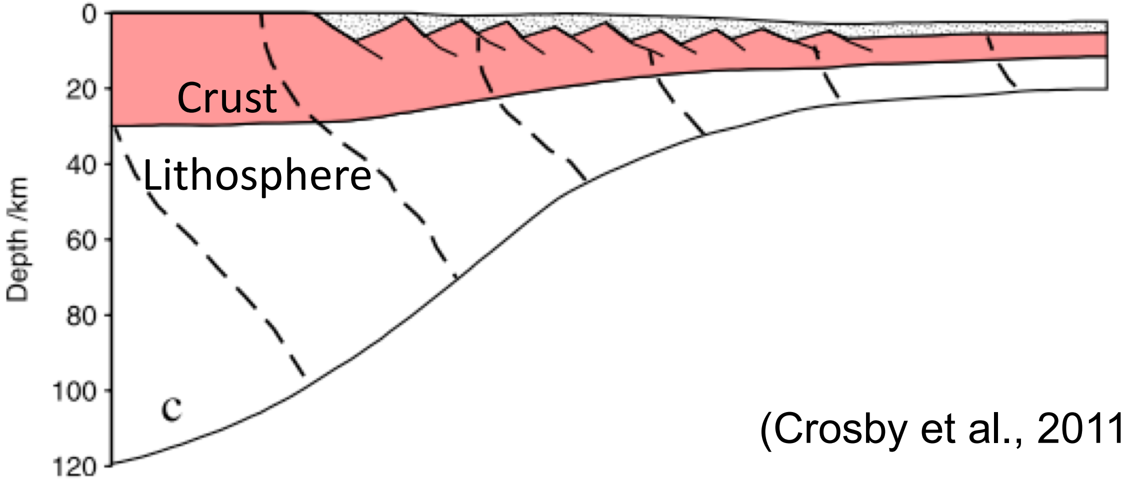
- North Sea (Ziegler, 1983; White 1990)
- Norwegian rifted margin (Kusznir et al., 2005)
- Brazil-Angolan margins (Moulin et al., 2005)

Inverse extension discrepancy, in the hyper-extended domain of rifted margins, the upper crustal extension could exceed the whole crust.

- Brazil-Angolan margin (Crosby et al., 2011)
- Galicia margin (McDermott & Reston, 2015).

Background

Scenario A Lithospheric mantle is thinned more than crust

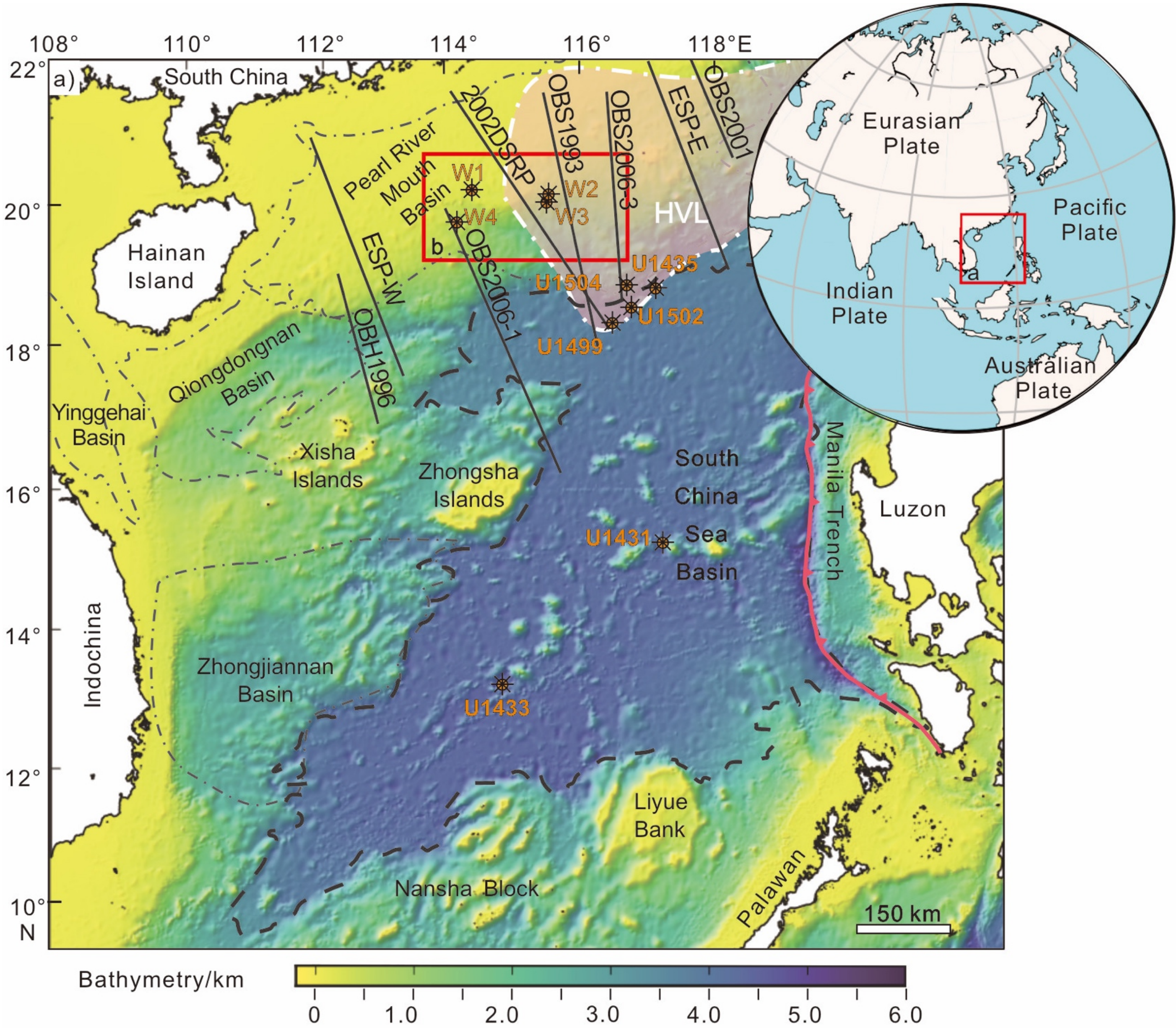


(Crosby et al., 2011)

In the South China Sea margins, most studies reported

extension discrepancy

- Pearl River Mouth basin (Bai et al., 2019; Clift et al., 2002; Hsu et al., 2004)
- Qiongdongnan basin (Tong et al., 2009; Zhao Z. et al., 2018)
- Northwest Palawan margin (Franke et al., 2011)
- Offshore Vietnam (Savva et al., 2014)



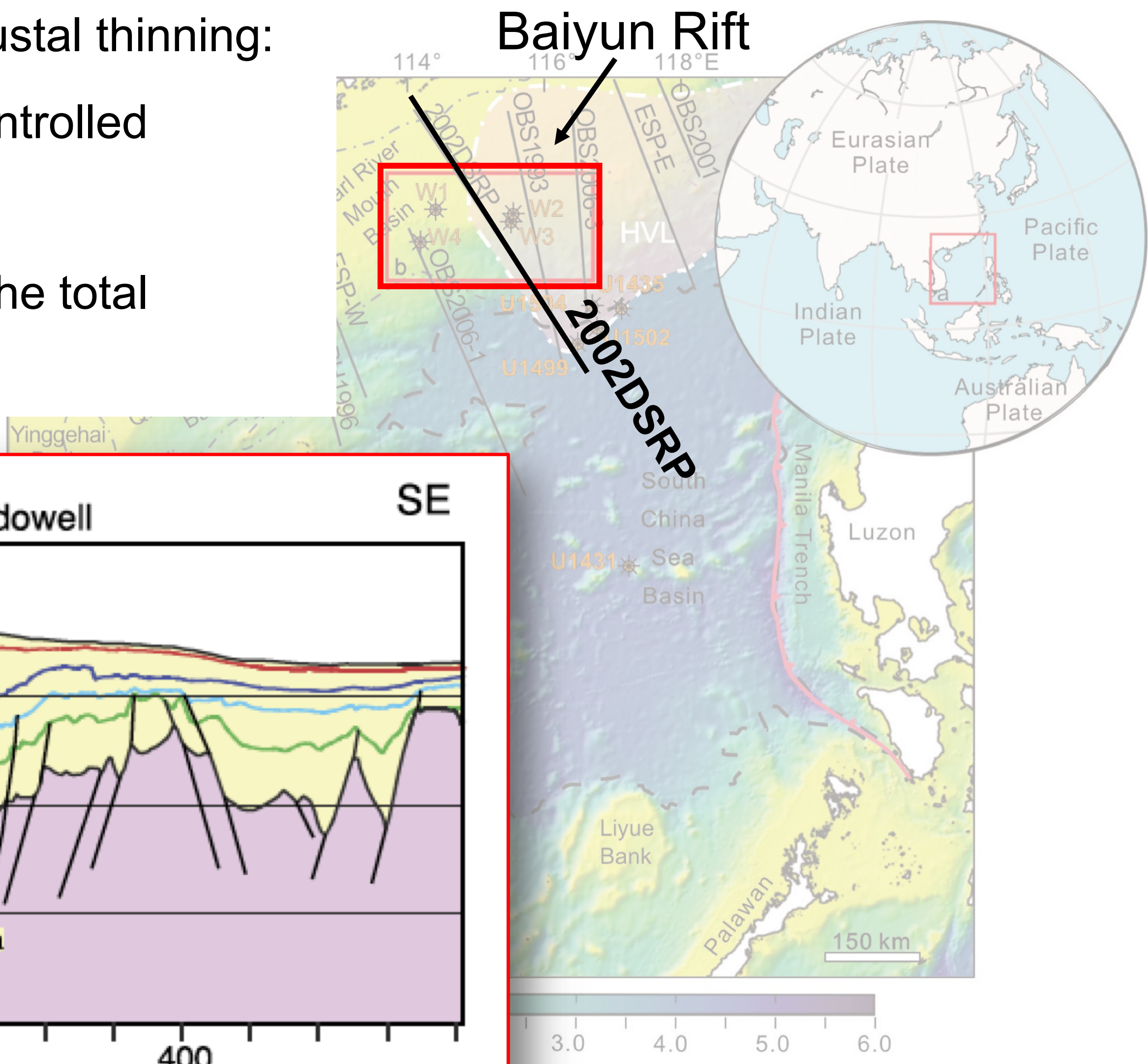
HVL: high-velocity layer in the lower crust

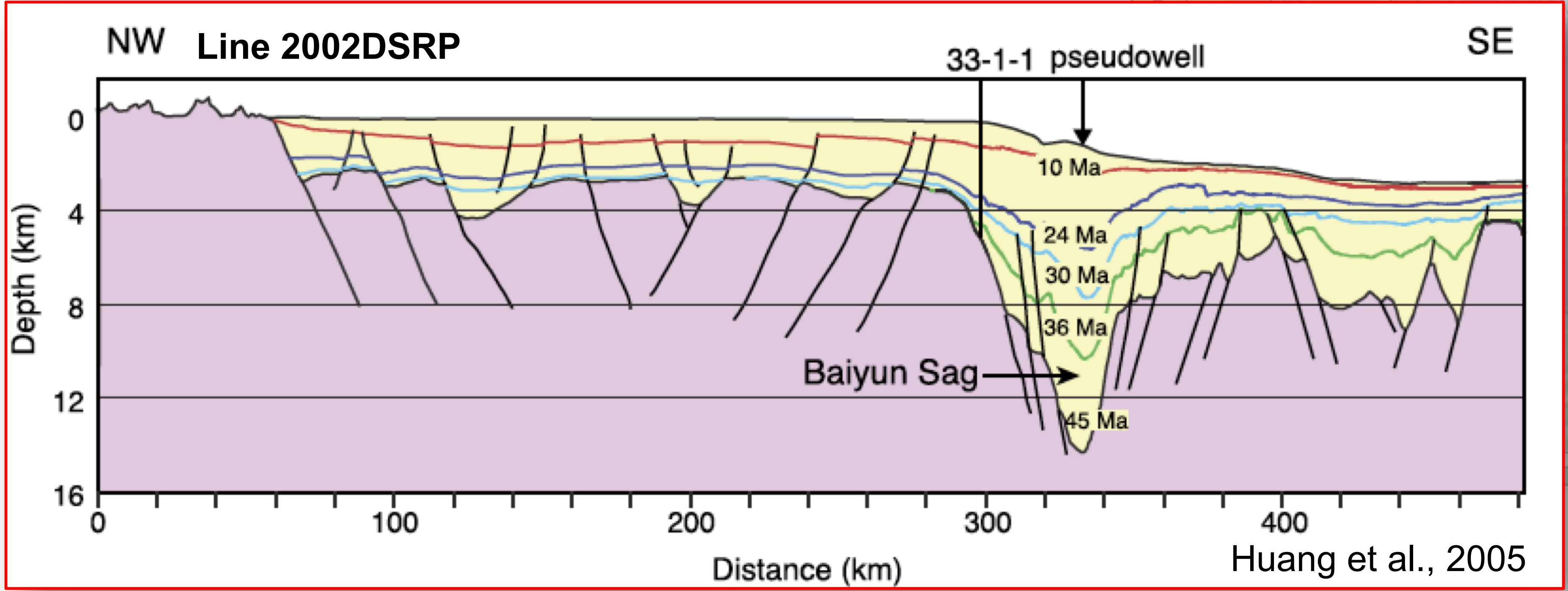
(Zhao Y. et al, 2020, under review)

Background

However, previous studies may have underestimated upper crustal thinning:

1) based on a classic rifted basin model that the rifting was controlled continuously by high-angle normal faulting,
2) under an assumption that the observed faulting is close to the total amount of brittle extension.

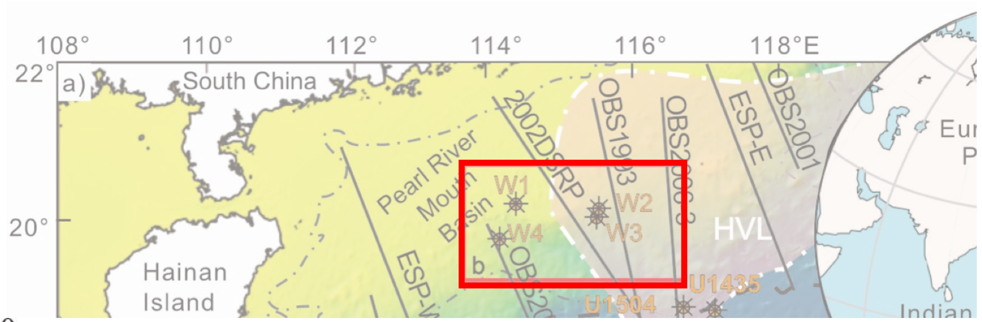


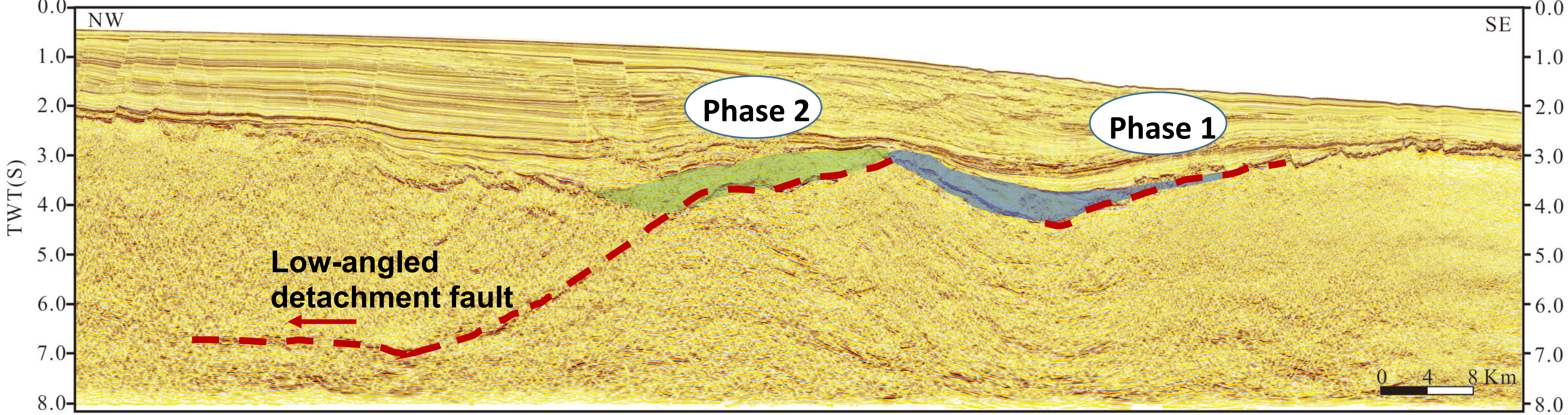


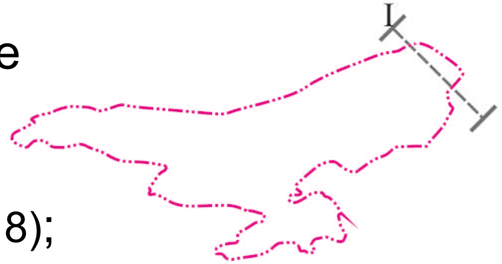
Huang et al., 2005

Background

Baiyun Rift





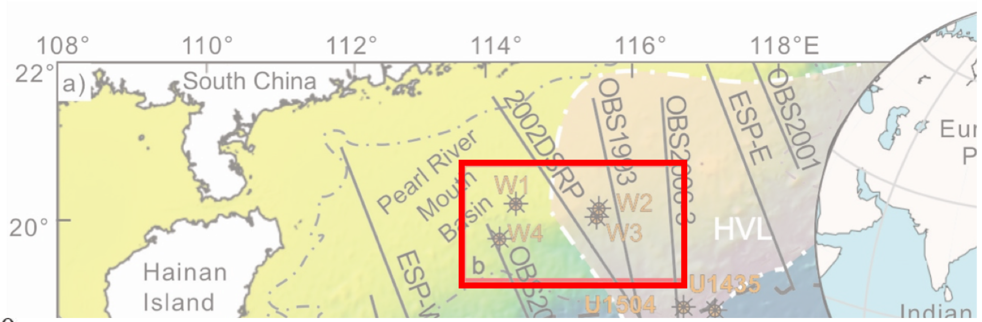


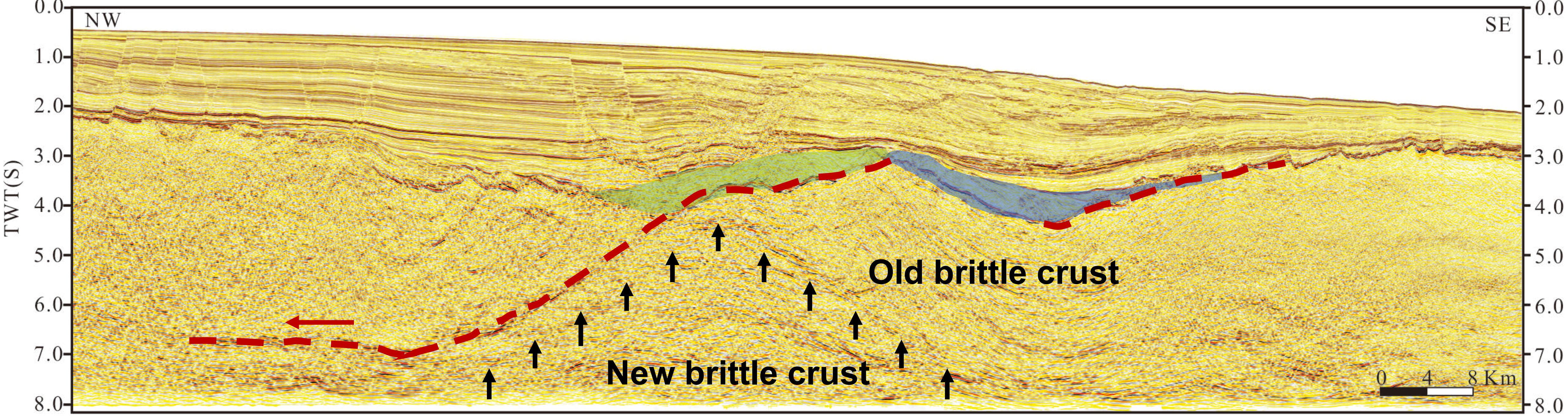
Newly acquired high-resolution multi-channel seismic data indicate that the faults in the hyper-extended domain of the Northern South China Sea show:

1) Low-angled detachment fault dominated the rifted basin evolution (Zhao Y. et al., 2018);
2) Polyphase faulting was failed to restored in previous studies;

Background

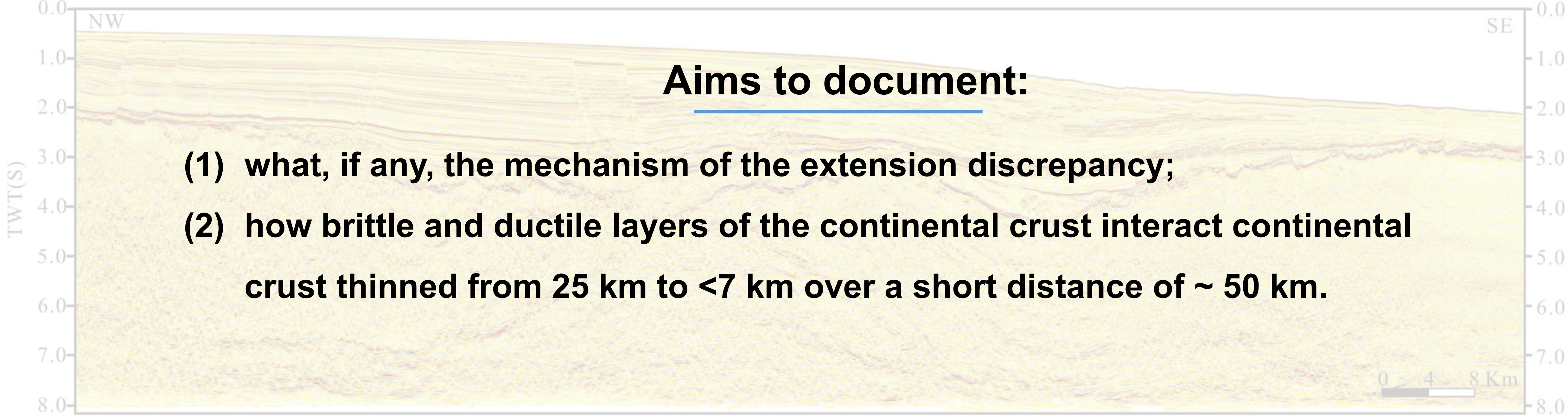
Baiyun Rift





Newly acquired high-resolution multi-channel seismic data indicate that the faults in the hyper-extended domain of the Northern South China Sea show:

3) Lower crustal exhumation formed a new brittle crust during the detachment faulting, which may result in uncertainties of crustal stretching factor.



Aims to document:

(1) what, if any, the mechanism of the extension discrepancy;

(2) how brittle and ductile layers of the continental crust interact continental crust thinned from 25 km to <7 km over a short distance of ~ 50 km.

Methods

1. Seismic interpretation

- Using basin-covered 3D seismic data
- Sedimentary basin structure
- Crustal structure

2. Time-depth conversion

- Stratigraphic velocity after 41 drilling wells
- Crustal velocity after seismic modeling of OBS profiles

3. Rift structure restoration

- Software Move (Midland Valley)
- Following areal balancing principle

4. Crustal extension quantification

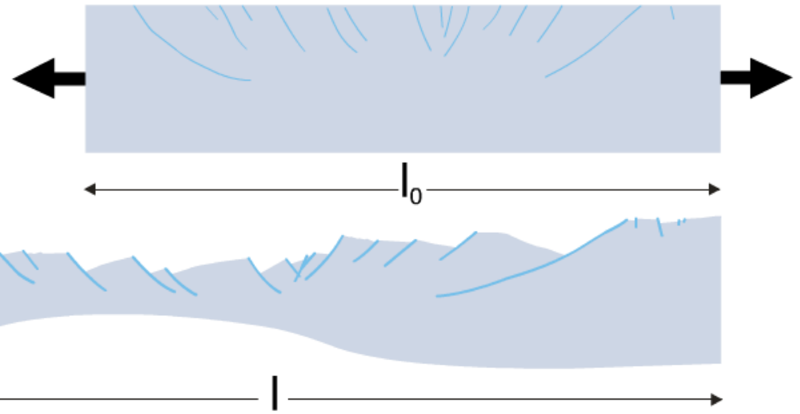
- Crustal thinning factor
- Fault-derived stretching factor
- Sub-resolution faulting examination

Two methods to quantify crustal stretching/thinning amount:

#1, stretching factor, γ_f

$$\beta_f = (1 + \beta_0 cos^2[\frac{\pi(x-x_0)}{W}])$$

To represent graphically, $\gamma_f = 1-1/\beta_f$



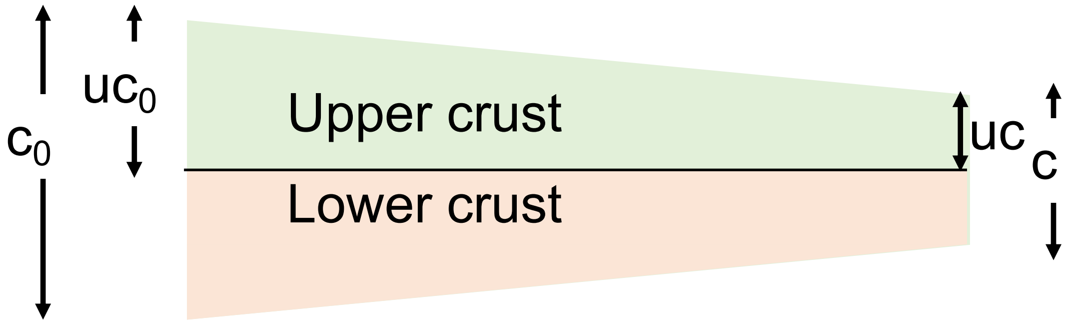
#2, Crustal thinning factor, γ_{uc} and γ_c

$\beta_{uc}=Z_{uc0}/Z_{uc}$ (theoretically = β_f)

$\beta_c=Z_{c0}/Z_c$

To represent graphically, $\gamma_{uc} = 1-1/\beta_{uc}$

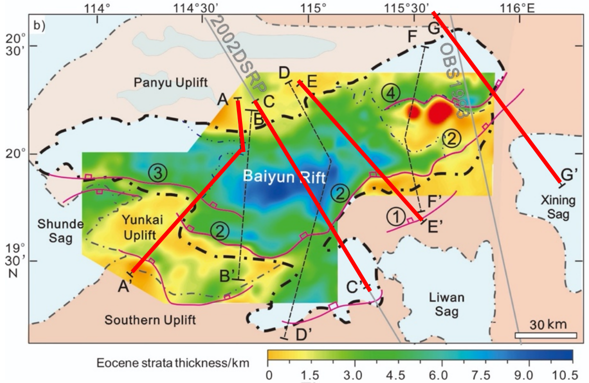
$\gamma_c = 1-1/\beta_c$

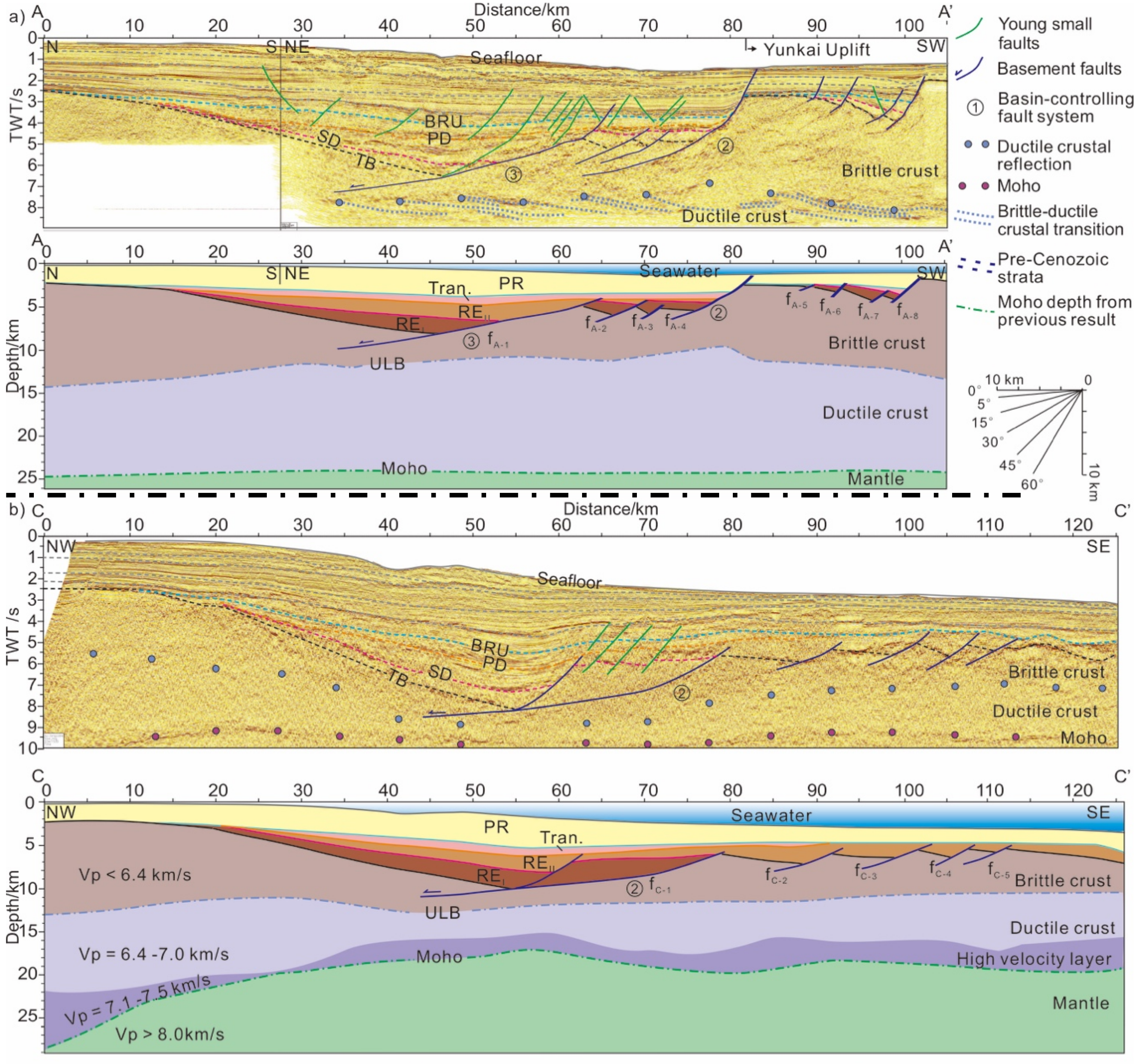


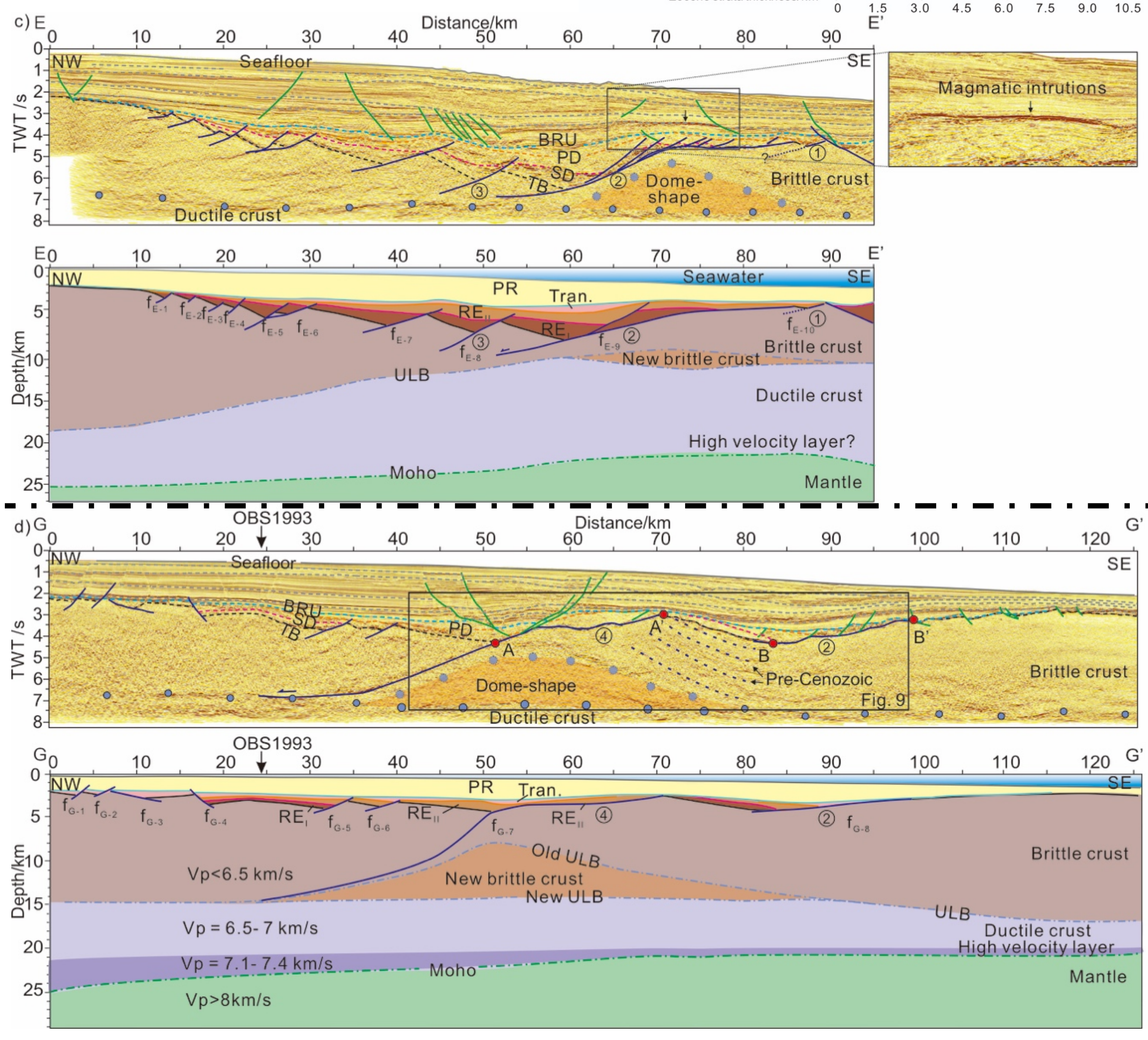
Results

— Interpretations of seismic sections in time and depth domains

See notes at end of presentation.



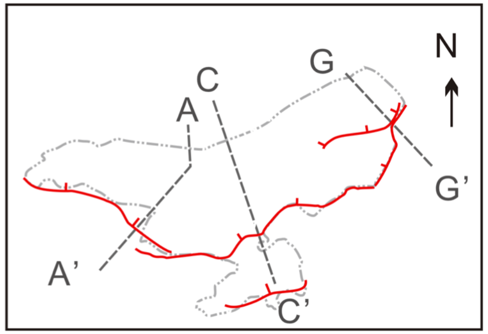




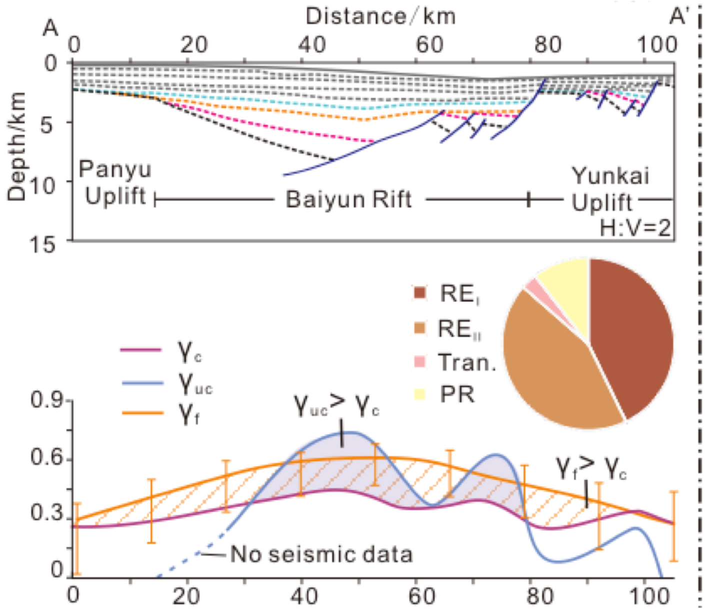
Results

— Selected depth sections and the comparisons between whole crustal thinning factor (γ_c), upper crustal thinning factor (γ_{uc}), and stretching factor (γ_f).

See notes at end of presentation.

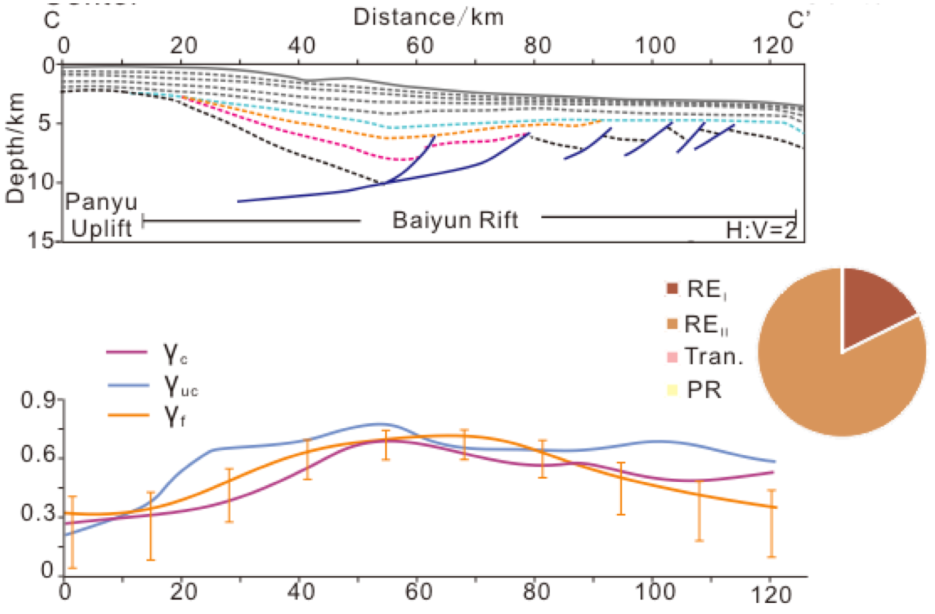


Western Baiyun Rift



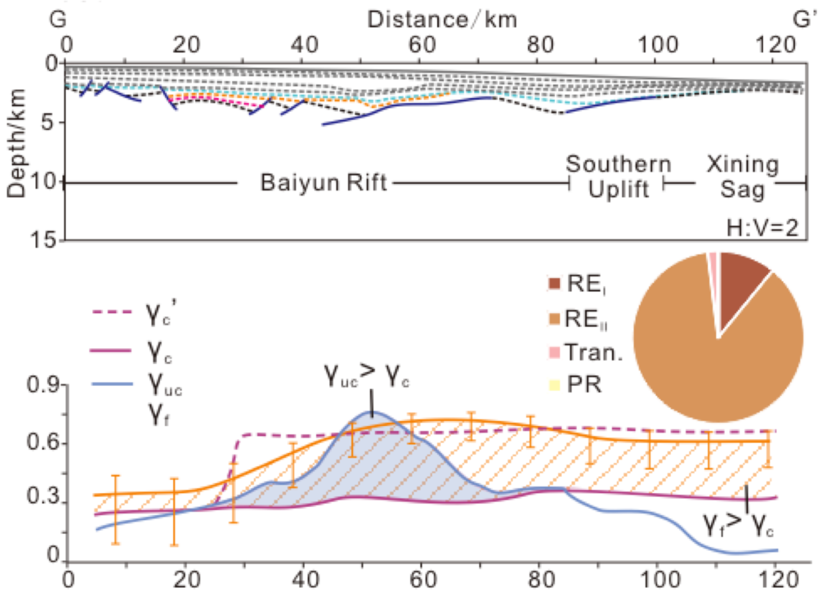
Inverse discrepancy

Central Baiyun Rift



No extension discrepancy

Eastern Baiyun Rift

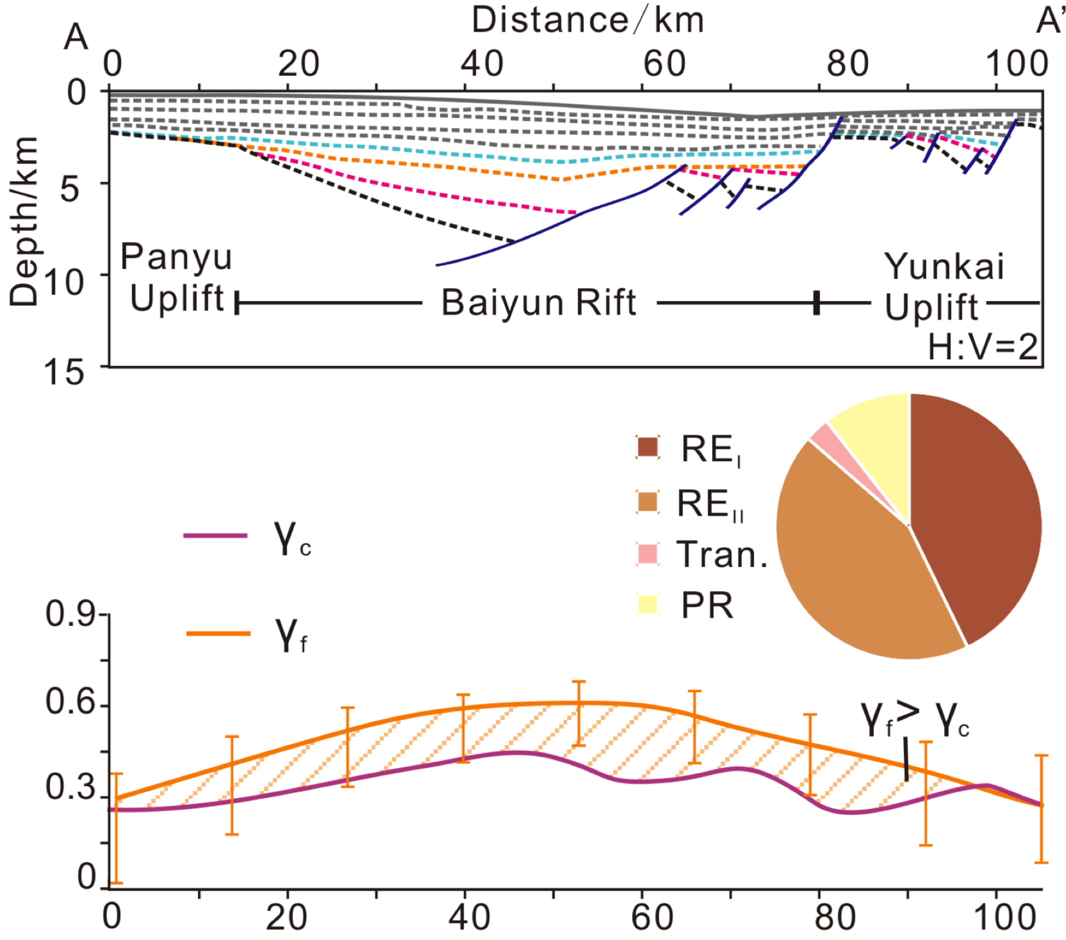


Inverse discrepancy

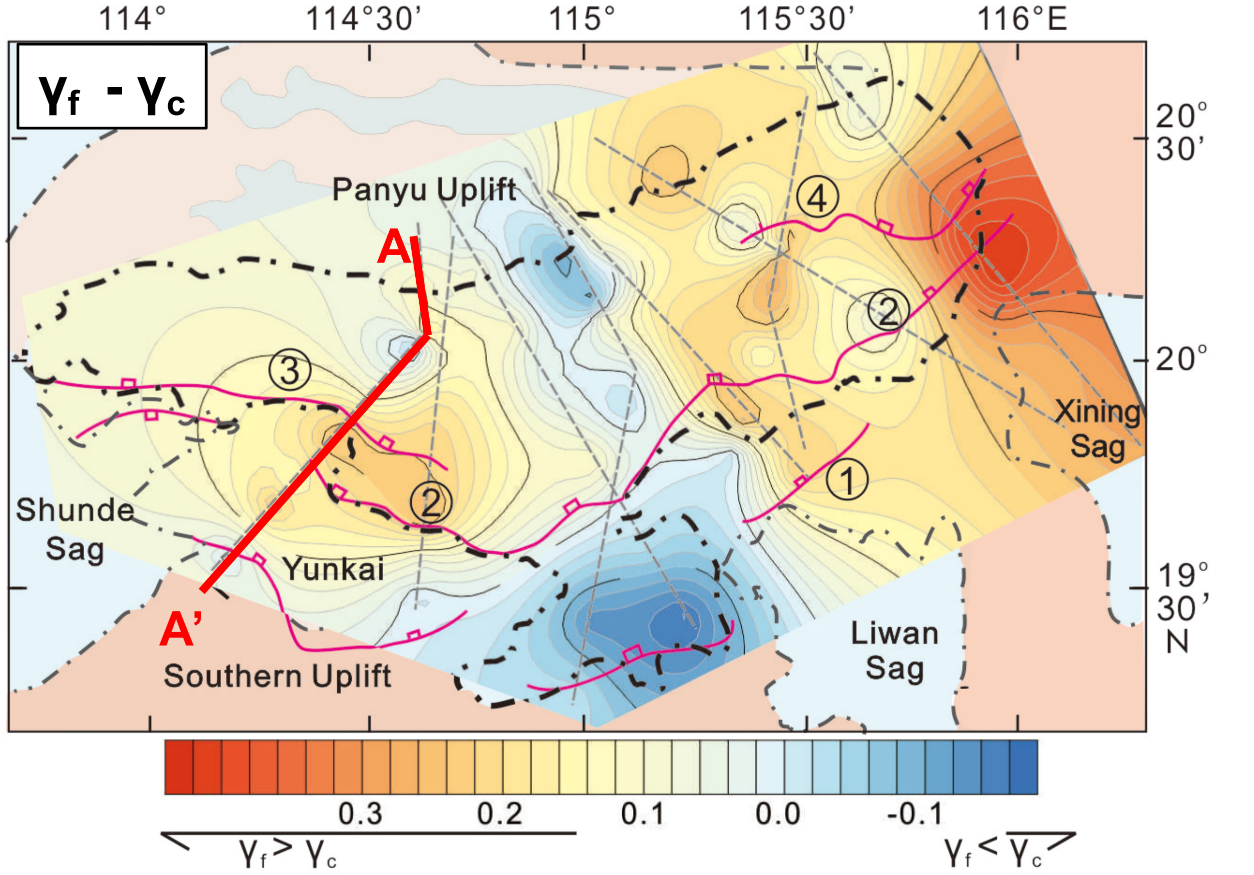
Western Baiyun Rift

Inverse discrepancy

Stretching factor (γ_f) > Whole crustal thinning factor (γ_c)



γ_f > γ_c across section A-A'

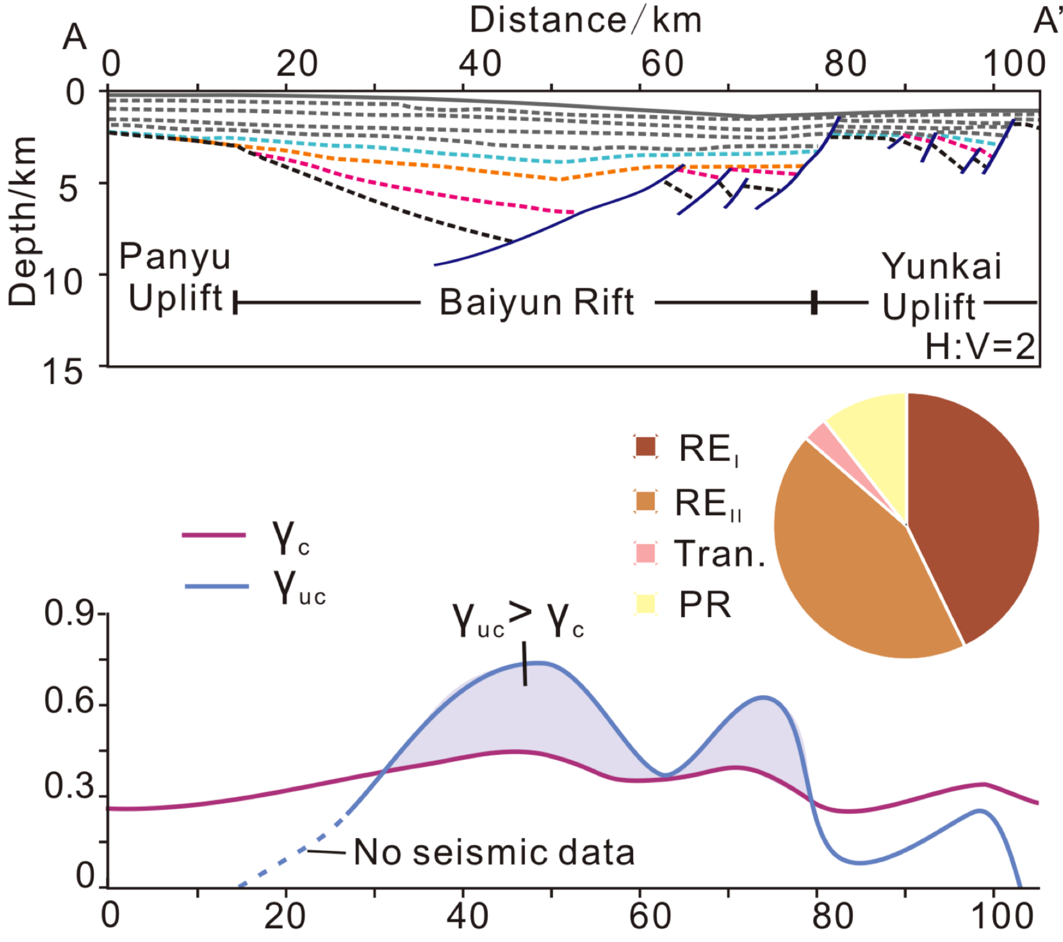


Map compares the difference between γ_f and γ_c

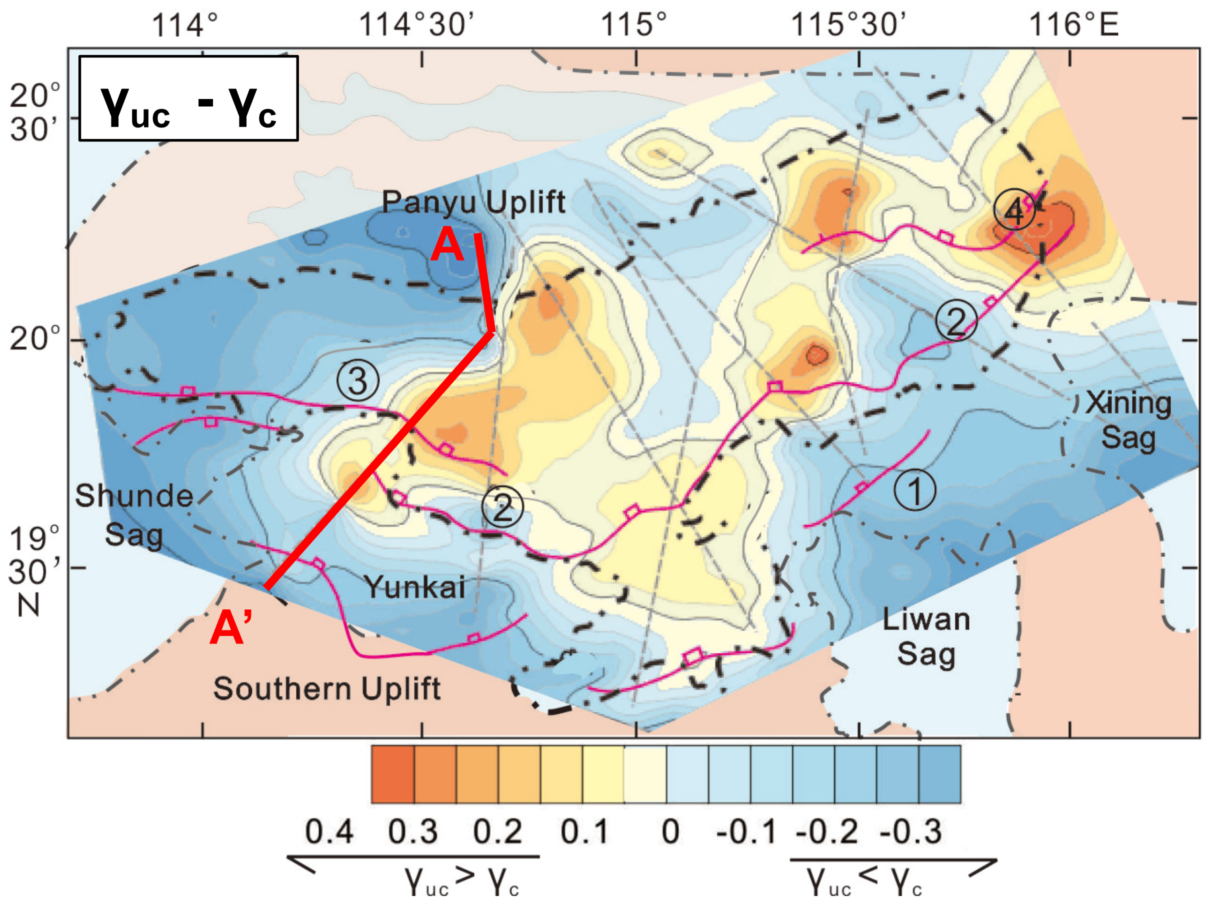
Western Baiyun Rift

Inverse discrepancy

Upper crustal thinning factor (γ_{uc}) > Whole crustal thinning factor (γ_c)



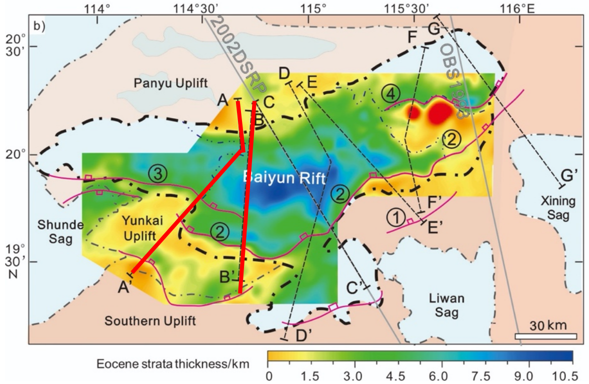
$\gamma_{uc} > \gamma_c$ in the depocenter of section A-A'



Map compares the difference between γ_{uc} and γ_c

Western Baiyun Rift

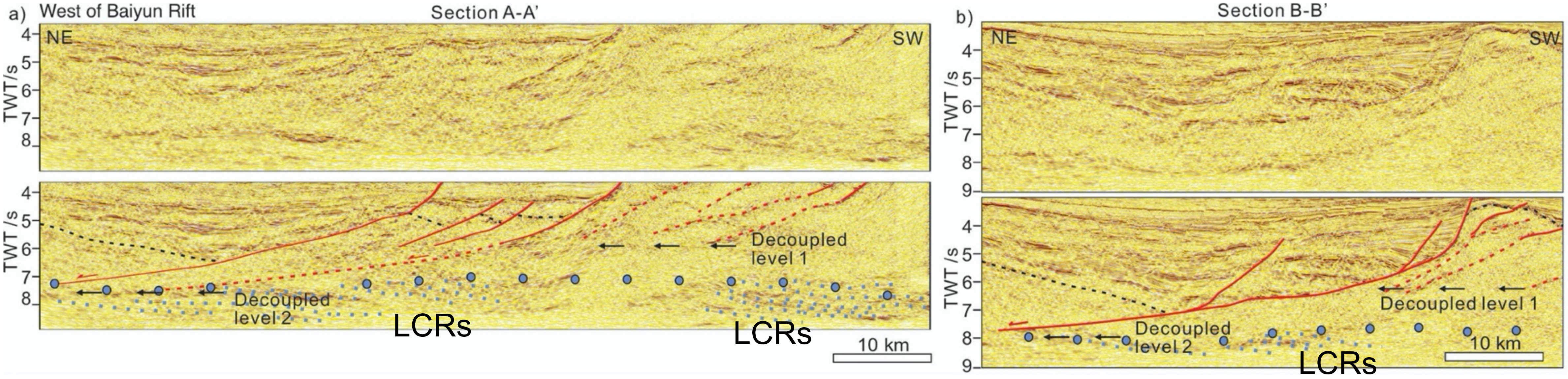
Possible cause: ductile shearing deformation



Evidence In the western Baiyun Rift, lower crustal reflections (LCRs) are identified near the brittle-ductile transition. These LCRs are symmetric to the continentward-dipping faults and notably abundant beneath the low-angled normal faults (LANFs)

reflections, which indicates a deformation dominated by a simple shear towards the continent.

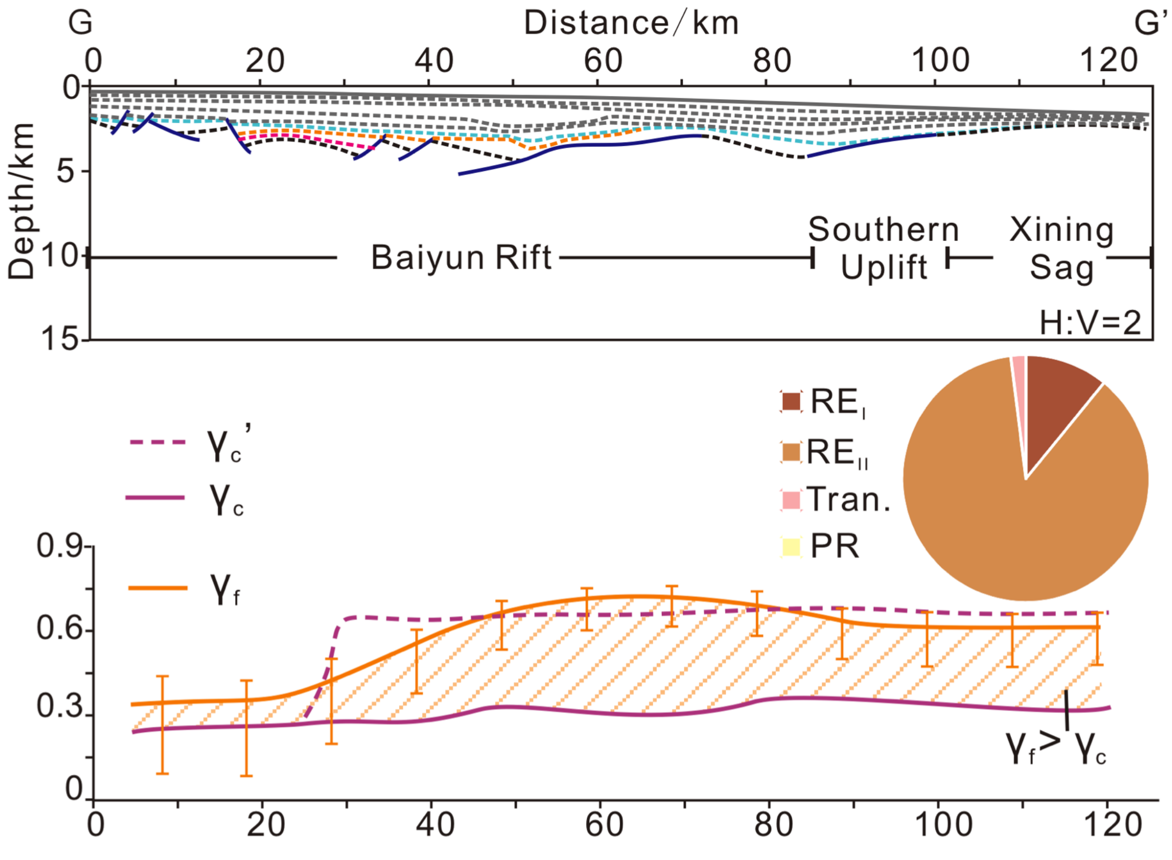
Hence, inverse discrepancy in the western Baiyun Rift is achieved by an intense tectonic faulting in the upper crust and a relatively weak ductile shearing in the lower crust.



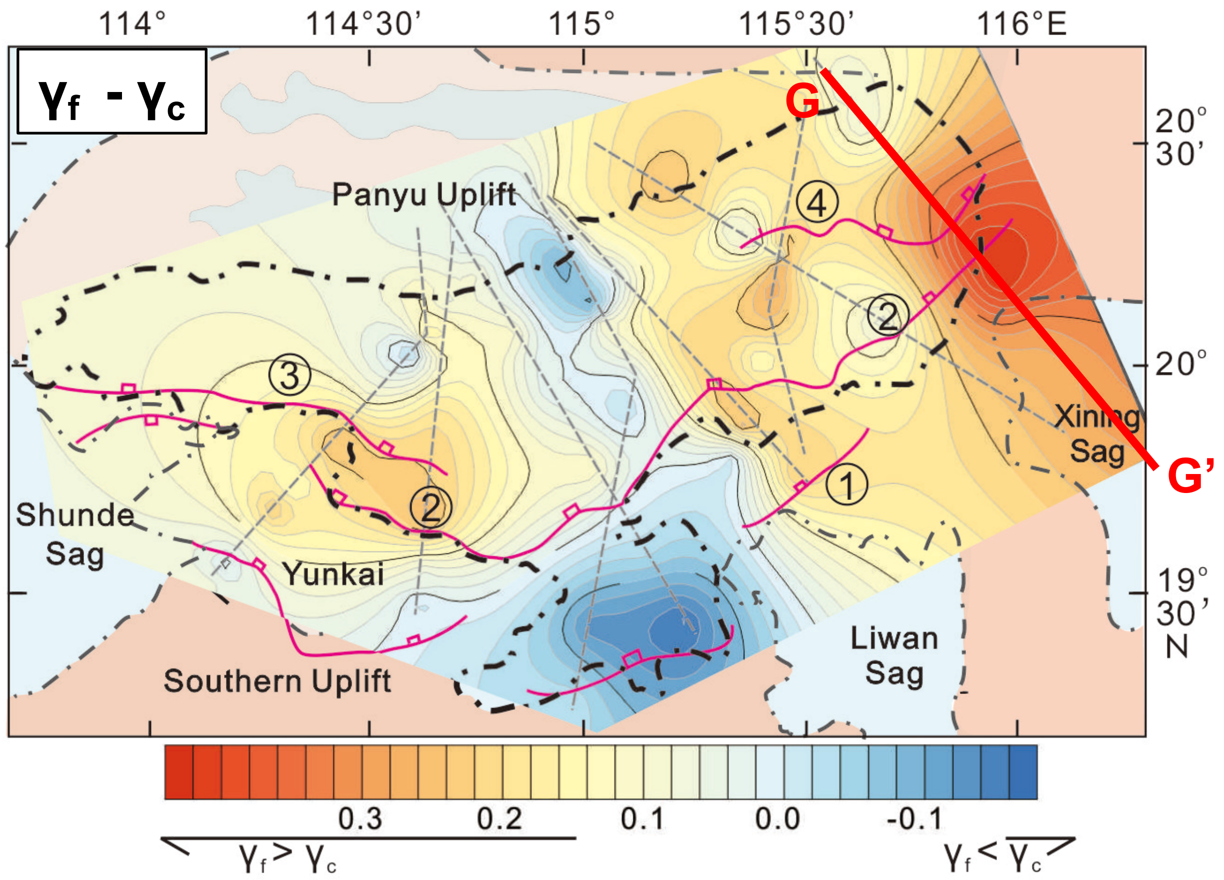
Eastern Baiyun Rift

Inverse discrepancy

Stretching factor (γ_f) > Whole crustal thinning factor (γ_c)



γ_f > γ_c across section G-G'

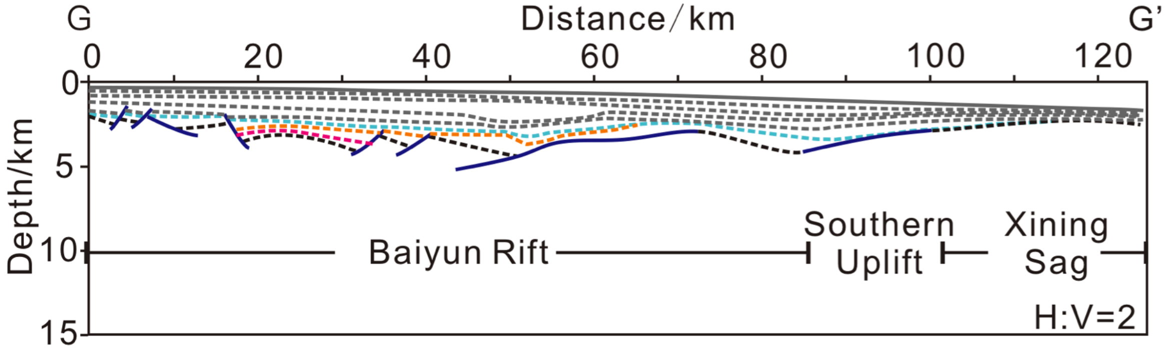


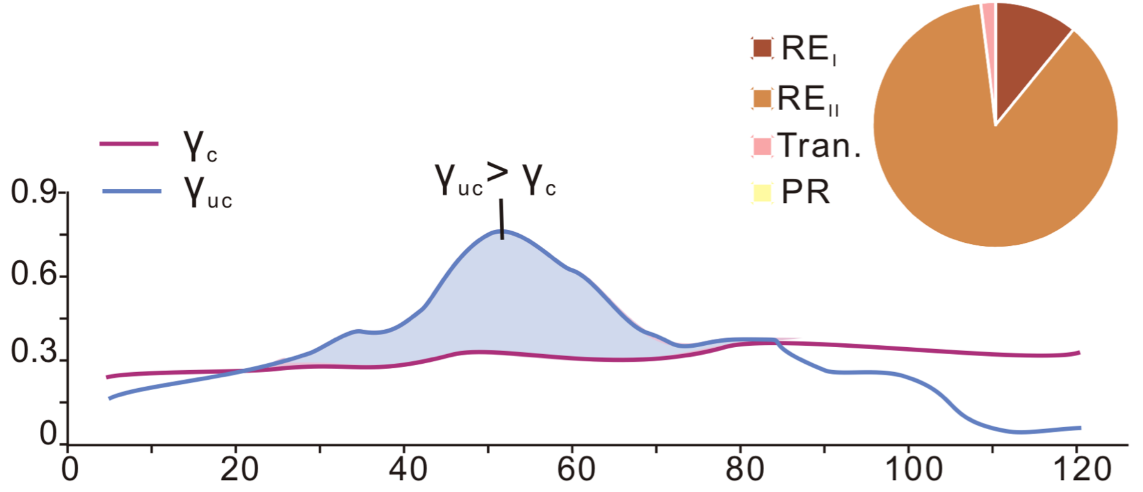
Map compares the difference between γ_f and γ_c

Eastern Baiyun Rift

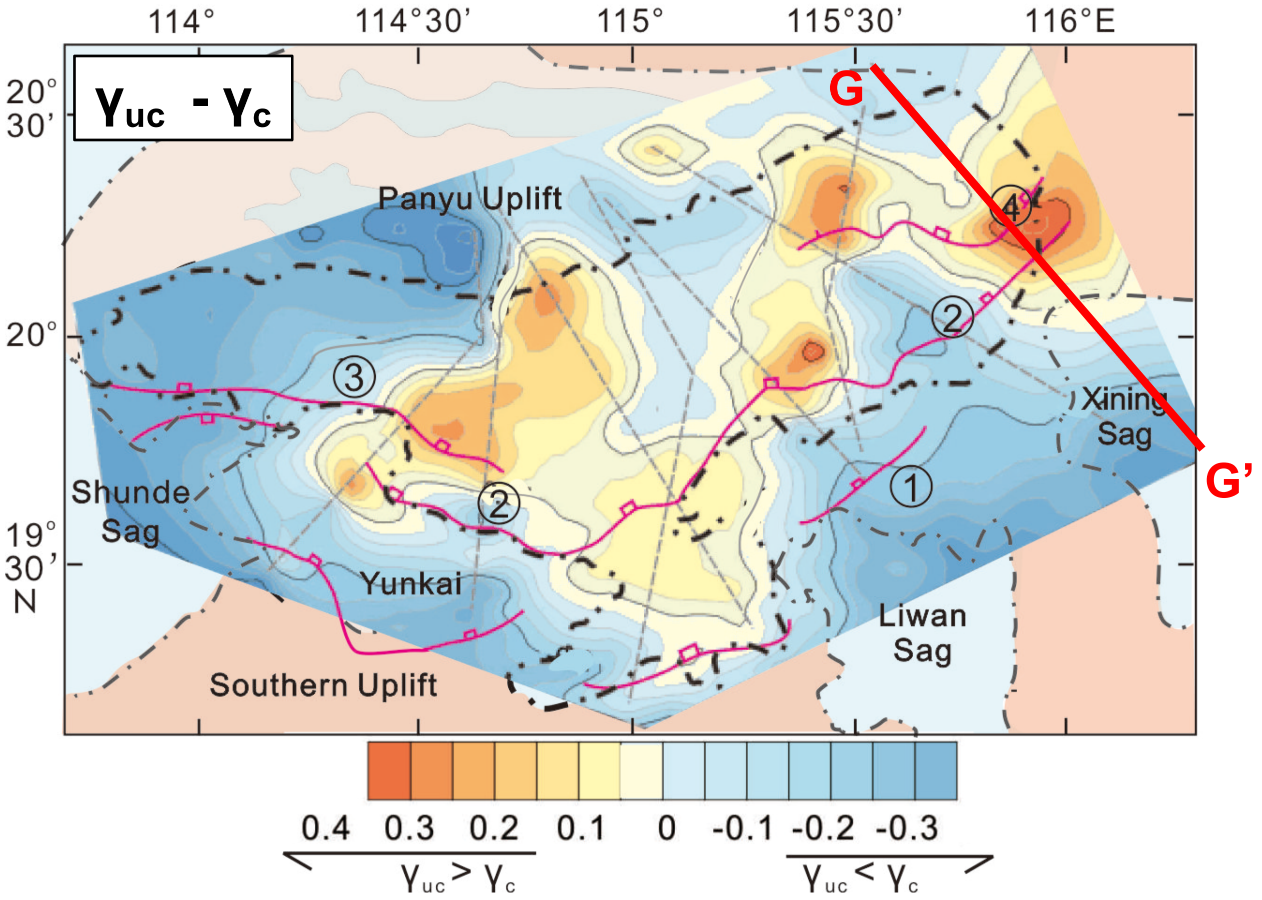
Inverse discrepancy

Upper crustal thinning factor (γ_{uc}) > Whole crustal thinning factor (γ_c)





$\gamma_{uc} > \gamma_c$ in the depocenter of section G-G'

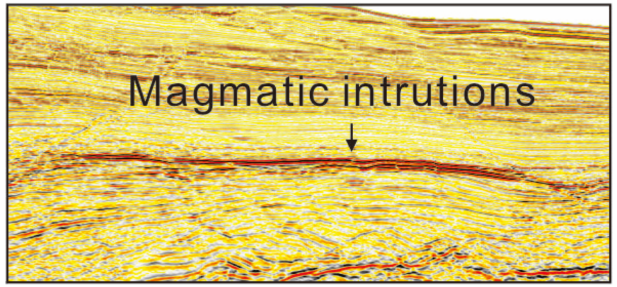


Map compares the difference between γ_{uc} and γ_c

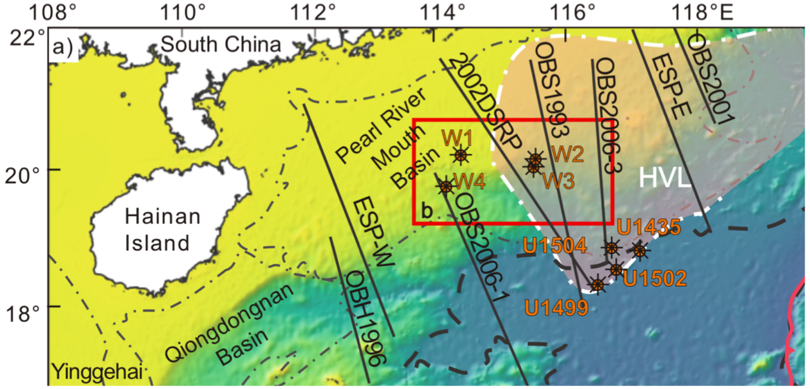
Eastern Baiyun Rift

Possible cause: Lower crustal exhumation

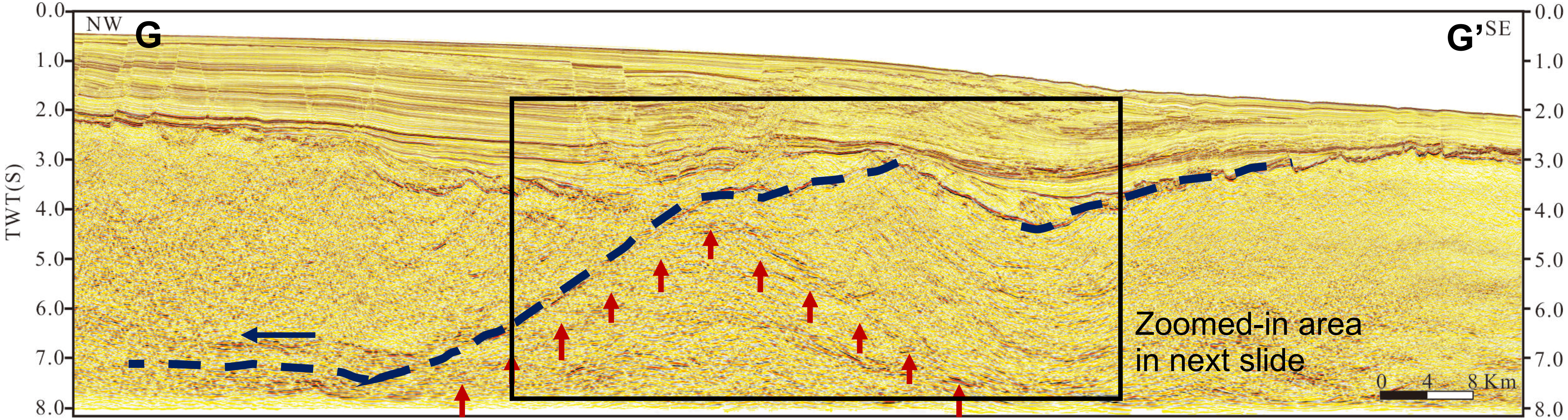
Evidence 1 More intense magmatism in the eastern Baiyun Rift (Zhao F. et al., 2016)



Evidence 2 High-velocity layer in the lower crust extending to the northeast along the NSCS (Yan et al., 2001; Wei et al., 2011)

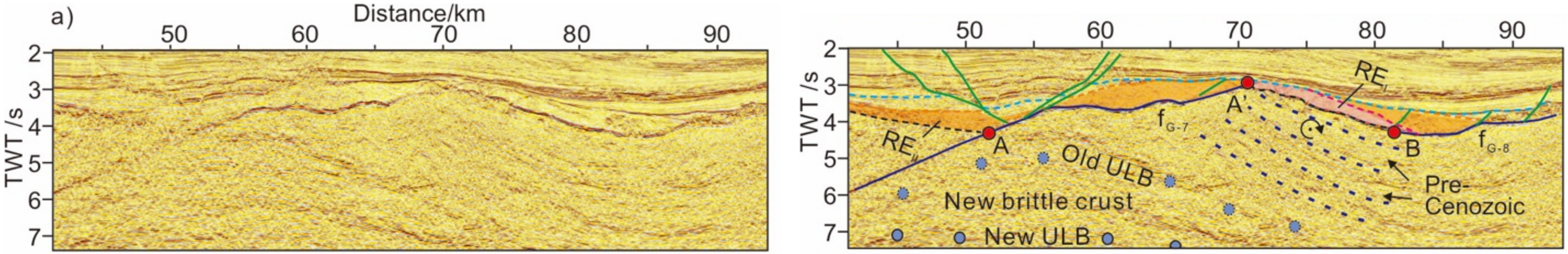


Evidence 3 A dome-shaped structure with chaotic internal reflections is in the footwall of the main LANFs

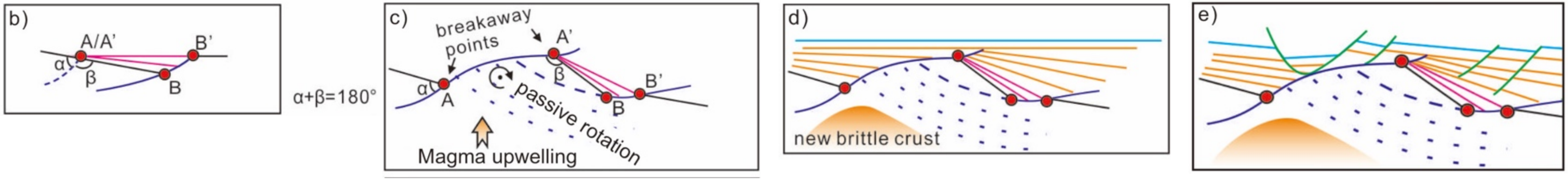


Eastern Baiyun Rift

Polyphase detachment faulting caused the exhumation of the lower crust. Due to isostasy, the magma passively upwelled and thickened the crust and thus results in an underestimation of the whole crustal extension.



a) At least two phases of faulting with two couples of breakaway points, A/A' and B/B', are identified.



b) Sequential development of f_{G-7} and f_{G-8} hyper-stretched brittle crust.

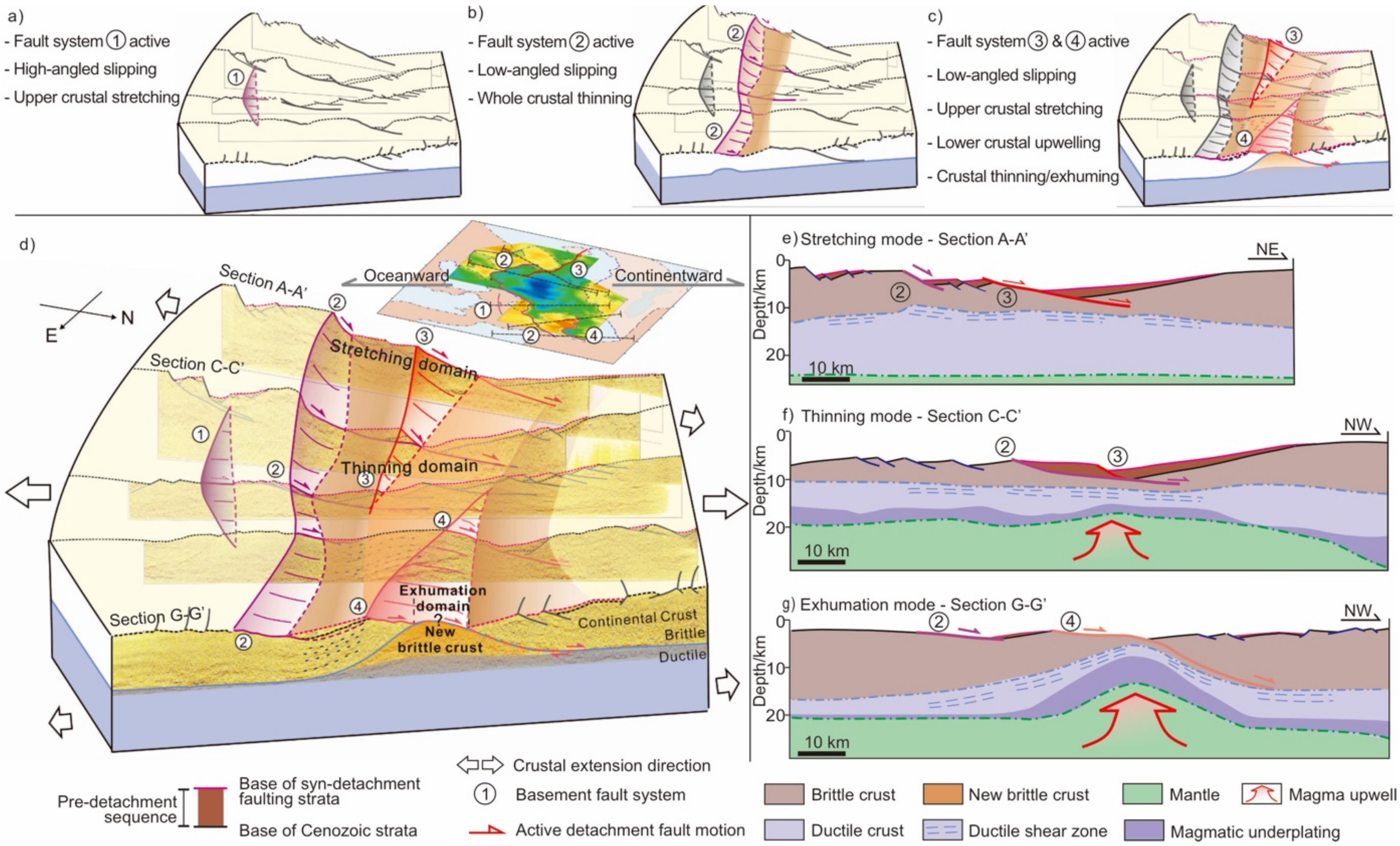
c) Due to isostasy, magmas migrated upward from the mantle, forming the dome-shaped structure at the footwall of the f_{G-7}.

d) With the cooling of magmas, the ductile materials become brittle. New brittle crust and new ULB formed.

e) During post-rifting stage, faults re-activated while have not changed rift geometry.

Summary

- Models of polyphase faulting leading to a later detachment faulting associated with a lower crustal exhumation in the eastern Baiyun Rift. *See notes at end of presentation.*



Notes

Slide # 10

Interpretations of sections A-A’, C-C’, E-E’, and G-G’ in time and depth domains. The pattern of the basement faults changes from a stair-step combination in the west, to a deformed singular fault with large displacements in the east. Shallow dipping basement faults sole out at a depth of 7s-8s TWT, where high-amplitude and continuous reflections developed. We interpret a brittle-ductile transition is at this depth. Moho depth is extracted from the previous result (Li et al., 2019). P-wave velocity is after Yan et al., (2001). RE_{I}, rift episode I; RE_{II}, rift episode II; Tran., transition stage; PR, post-rift stage.

In the west, basement faults are rooting at different depths, suggesting multiple decollement zones. ULB truncates SW-dipping reflections in the lower crust. In the east, a dome-shaped structure with chaotic internal reflections is in the footwall of the main LANFs. Parallel contacting relationship of the dome flank, pre-Cenozoic reflection and the hanging wall of the LANF suggests a synchronic deformation of these structures.

Slide # 11

Error bars of γ_f indicate a range of 0-60% of extension which could be underestimated due to a sub-resolution faulting (Clift & Sun, 2006). Blue and orange shaded regions represent $\gamma_{uc} > \gamma_c$ and $\gamma_f > \gamma_c$, indicating inverse discrepancy. Pie graphs demonstrate the proportion of the extension in each structural evolution episode. The light brown category in the pie graph has the largest proportion shows the most intense extension happened in the RE_{II} when low-angled faults were active. γ_c’ is the thinning factor of the whole crust under an assumption that 50% of the basement is pre-Cenozoic remnants. The actual thinning factor of the crust ranges from γ_c to γ_c’.

Slide #19

(a-d) Block diagrams display a perspective view from the NE of the 3D volume, without sediments to expose the top of the acoustic basement. Four sets of the basement fault systems in the Baiyun Rift have been identified. These fault systems were initiated earlier in the central south and migrated to the NE and NW progressively.

(e-g) Models for temporal and spatial evolution of the hyper-thinning process based on observations from seismic sections in the Baiyun Rift. (e) Stretching mode is characterized by listric faulting, a differential subsidence of half-grabens, and a major ductile shear zone exemplified by section A-A’, western Baiyun Rift. (f) Thinning mode is characterized by the maximum thinning of the crust and the presence of magmatic underplating in the lowest crust. (g) The exhumation mode is well documented by section G-G’, eastern Baiyun Rift. This phase is distinguished by the exhumation and embrittlement of the lower crust from less than 5 km depth along a downward-concave fault ④.

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THANK YOU

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