Interactions between pre-existing fabrics and fault patterns during oblique rifting revealed by enhanced-gravity analog modeling

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Yaoyao Zou[1], Daniele Maestrelli[2], Giacomo Corti[3], Chiara Del Ventisette[2,3], Liang Wang[4,1], Xiaofan Wan[1], Yanjie Gao[1], and Chuanbo Shen[1]

(1)Key Laboratory of Tectonics and Petroleum Resources, Ministry of Education, China University of Geosciences, Wuhan, China; (2)Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Florence, Italy; (3)Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse, Florence, Italy; (4)Geophysical Exploration Center, China Earthquake Administration, Zhengzhou, China

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1 INTRODUCTION

Multiple fault populations with different orientations and complex fault patterns can be observed during oblique rifting, conditions which result from a complex rift kinematics which combines dip-slip and strike-slip motion. Although analysis of different natural cases and analog or numerical modeling have shed light on the relations between rift obliquity and the related fault architecture, many aspects of the process remain poorly understood. One of these aspects is related to the existence of pre-existing fabrics in the upper crust, which may further complicate the fault pattern by forcing the development of faults with atypical geometries and orientation.

Here, we performed enhanced-gravity analog models of oblique narrow rifting to characterize the evolution and architecture of rift-related faults developing in a brittle upper crust characterized by inherited fabrics. The models reproduce a rift obliquity of 30° (angle between the rift trend and the orthogonal to the direction of extension), kept constant in all the experiments, and pre-existing vertical fabrics with variable orientation (from 0°, i.e. orthogonal to extension, to 90°, i.e. extension-parallel).

2 MODEL SETUP AND SCALING

- The analog experiment series was performed in an artificial gravity field of 18g using the large capacity centrifuge available at the TOOLab (Tectonic Modelling Laboratory) of CNR-IGG and UNIFI-DST.
- We built a three-layer modeling structure , corresponding to the brittle upper crust, ductile lower crust, and lithosphere. The upper brittle sand layer was cut by a knife to simulate the fabrics in the upper crust. We define a parameter α to represent the angle between the rift axis and the trend of cuttings.
- The geometric scale ratio of models is ca.10^{-6}, which means that 1mm in the experiments corresponded to 1km in nature. The velocity of lateral extension in the models scaled to the natural values of ~7.9 mm yr^{-1}, which is consistent with the natural examples.

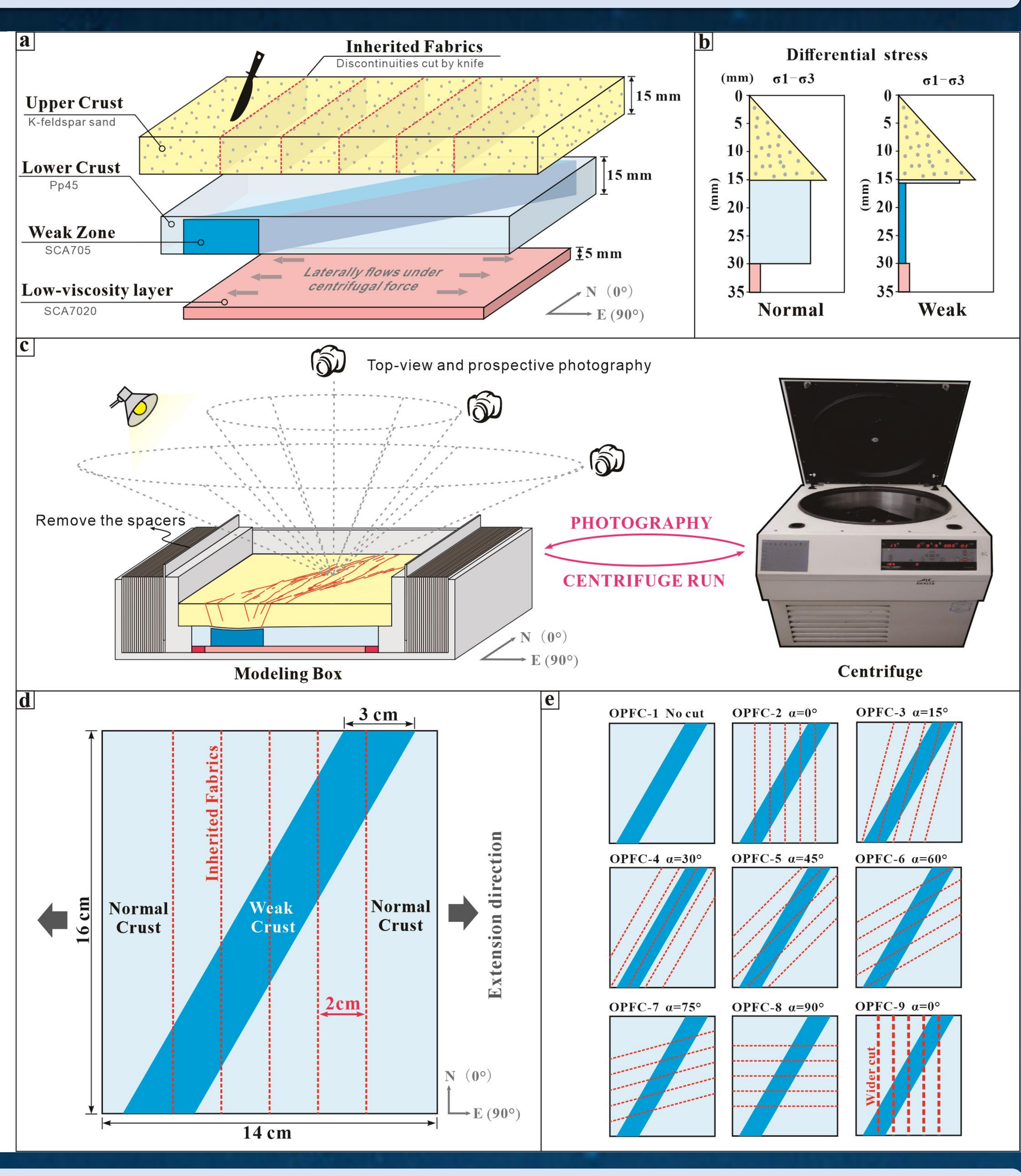
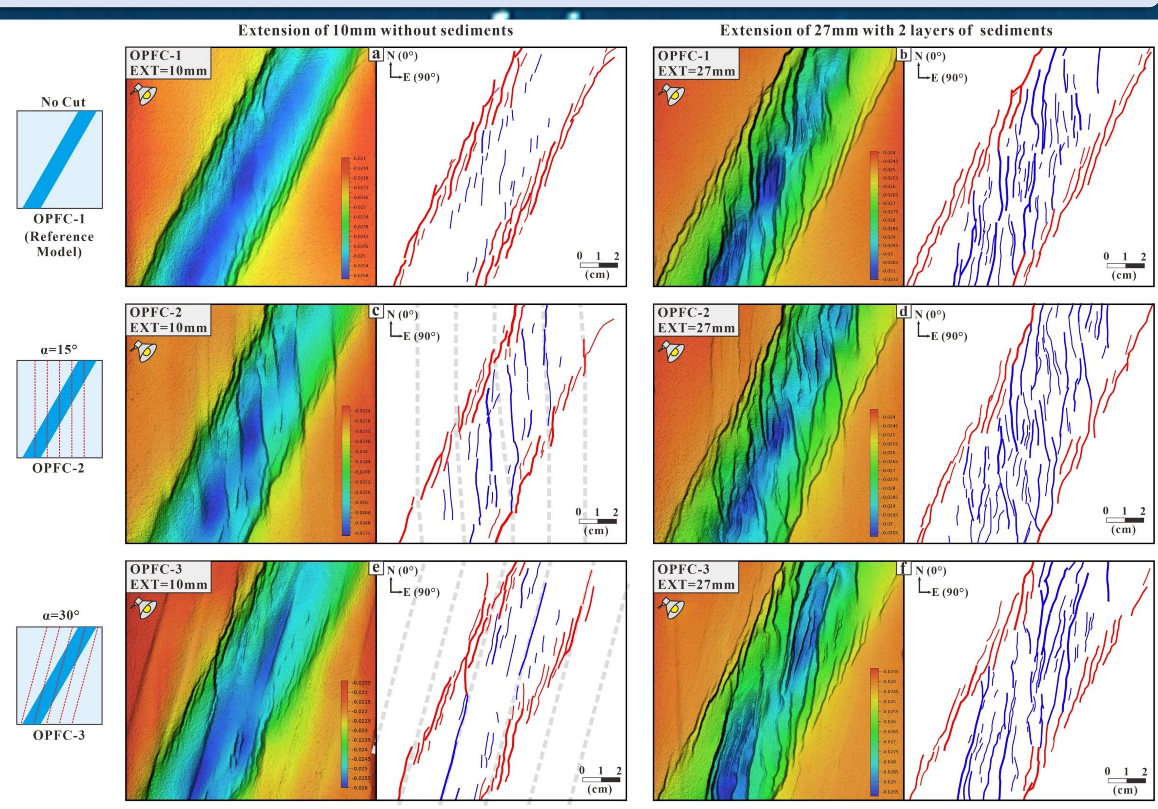
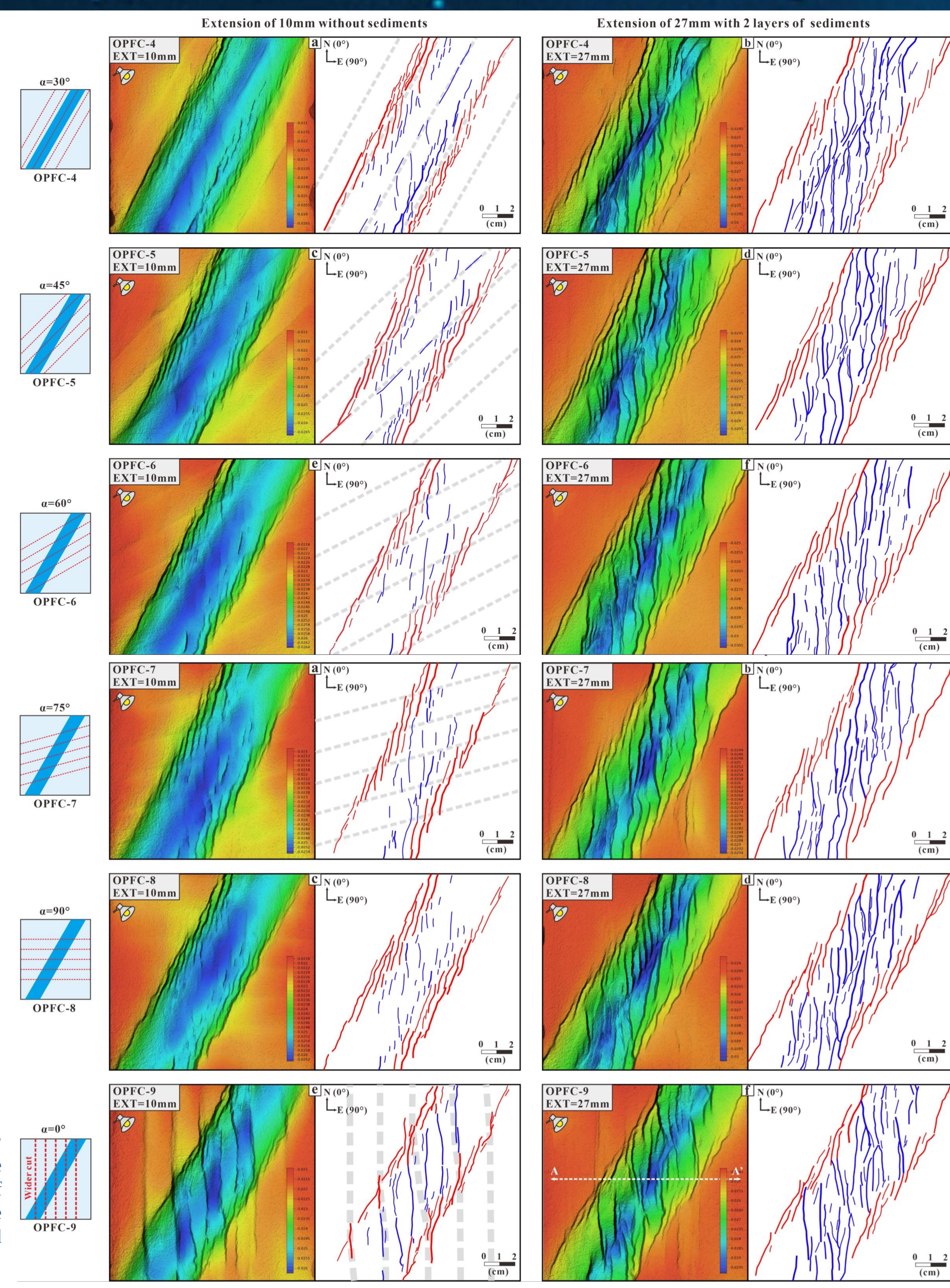


Figure 1. (a) The three-dimensional sketch shows a brittle-ductile multilayer lithosphere structure rebuilt in this model series, and the inherited fabrics are reproduced by cutting of knife. (b)The representative strength profiles correspond to the normal and weak sections of models, respectively. (c)Standard procedure of model running and monitoring. (d) Top-view geometry of the lower crust and inherited fabrics, as well as boundary conditions. (e) Graphical summary of the inherited fabric structures for all models discussed in this study.

3 RESULTS

- The result of 9 models are presented here. The DEMs (Digital Elevation Models) of model surface topography were generated with the Agisoft PhotoScan by 3D perspective photos. The DEM and the fault interpretation of each model after 10mm and 27mm (with 2-layers syn-rift sediments) of extension are shown, in order to demonstrate the influence of brittle fabrics on the initial rifting basins (Figure 2).





- **Low to moderate obliquity (α<= 45°)**

When the extension is 10mm, the preexisting cuts obviously affect and change the en echelon geometry of the boundary faults and cause some J-shape or S-shape faults. Also, the preexisting cuts promote the development of a large number of faults in the rift, and led to obvious fault groups along the preexisting cuts. These atypical faults strongly control the position and pattern of depocenter within the rift.

When the extension is 27mm after 2-layers sediments putting, the preexisting cuts still influence the orientation of faults, and seem to control the continuity or segmentation of depocenter.

- **High obliquity (angle >= 60°)**

The geometry of rift-related faults is closer to the OPFC-1, the no-fabrics model, indicating that the influence of the inherited fabrics is diminishing.

Figure 2. Digital Elevation Models (DEM) of the model surface and line-drawing of structures of OPFC-1 to OPFC-9 at the 10mm and 27mm. The grey dashed lines show the location of inherited fabrics. EXT: extension.

4 DISCUSSIONS

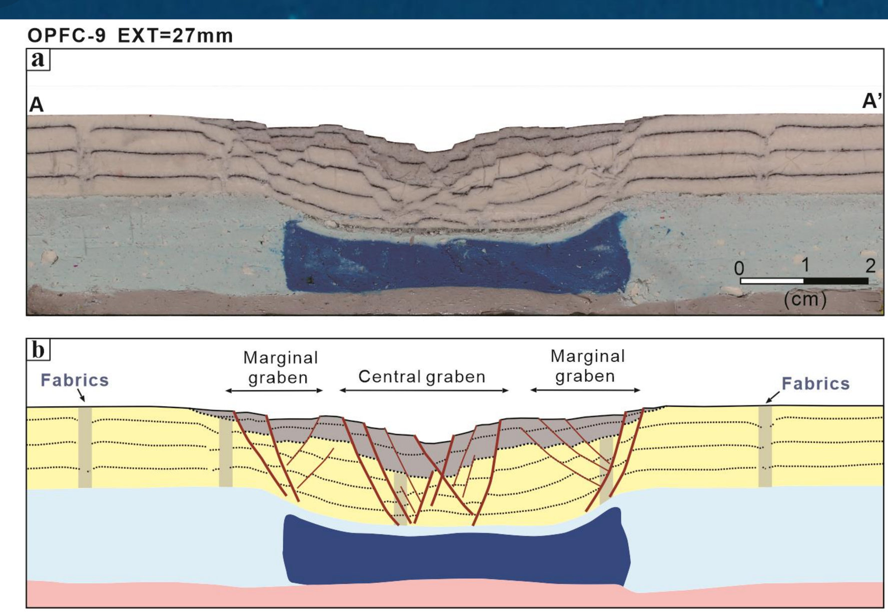


Figure 3. Pre-existing fabric may induce the development of more faults. (a) The picture and (b) interpretation of the cross-section (See Figure 2 for location) of Model OPFC-9 with the extension of 27mm. The grey layer is the sediments, and the yellow layer is the upper crust. The red solid lines are normal faults, the black dashed lines are the mark layers.

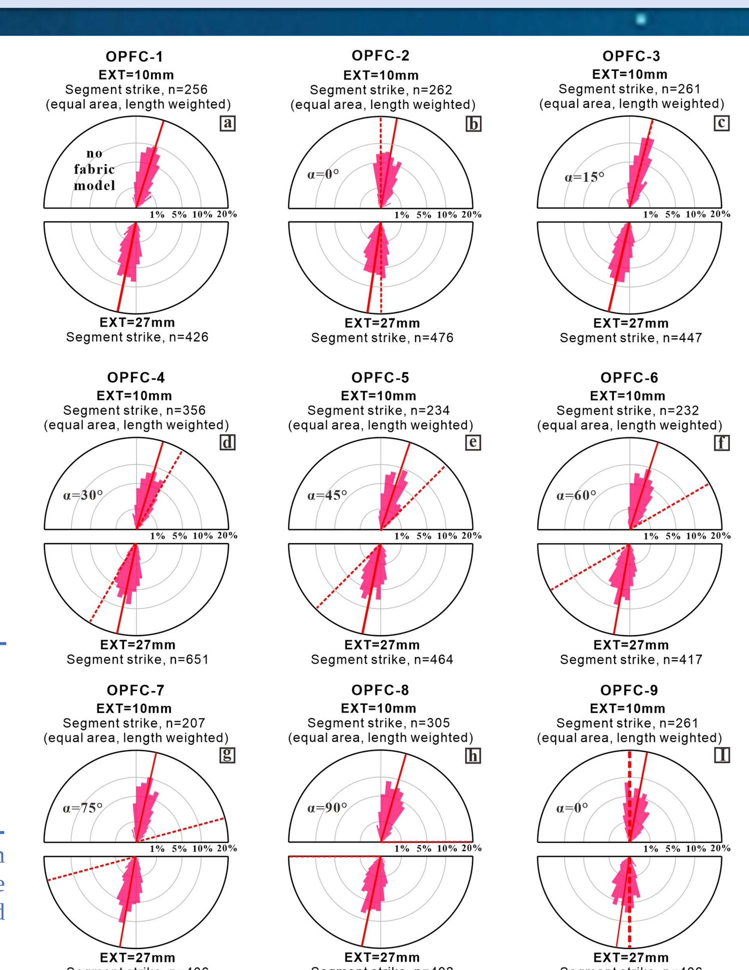


Figure 4. Rose diagrams of fault orientation with 10mm extension (top) and 27mm extension (bottom) in the different models (see text details). The red solid lines in the rose diagrams denote the length-weighted mean value of fault distribution, and the red dashed lines in the rose diagrams show the orientation of the pre-existing fabrics.

- The section of the model OPFC-9 indicates that the reactivation of preexisting fabrics may contribute to the development of faults and depocenter within rifts (Figure 3).
- Fault rose diagrams (Figure 4) show that preexisting cuts of low to moderate obliquity have a significant effect on the fault strike of the oblique rift, resulting in more concentrated fault strikes (when consistent with the fault strike) or more discrete fault strikes (when inconsistent with the fault strike).
- We summarize the influence of preexisting structures on oblique rift fault patterns and depocenters (Figure 5).

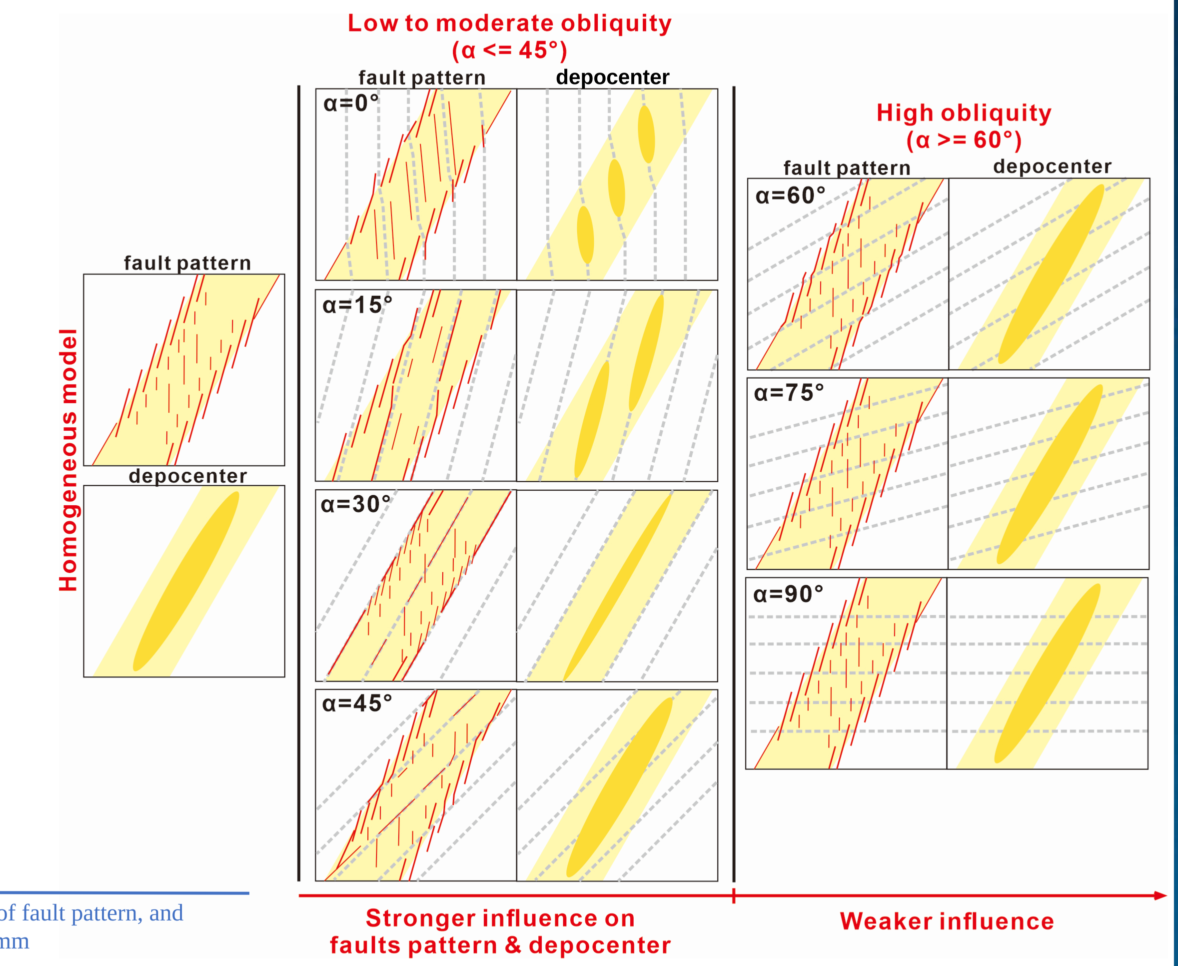


Figure 5. Summary of experimental results in terms of fault pattern, and depocenter with the extension of 10mm

5 COMPARING WITH NATURE EXAMPLE

- Wonji-Asela area is located at central sector of Main Ethiopian Rift (MER), East African Rift System (EARS), which was thought to be the most typical example to illustrate the influence of pre-existing structure on oblique rift.
- The model OPFC-9 demonstrates high similarity with the Wonji-Asela area, including the obliquity of rift (~30°) and pre-existing structures (α=~45°) . Our model suggests that preexisting structures may be a important factor in the bending or strike rotation of rift-related faults

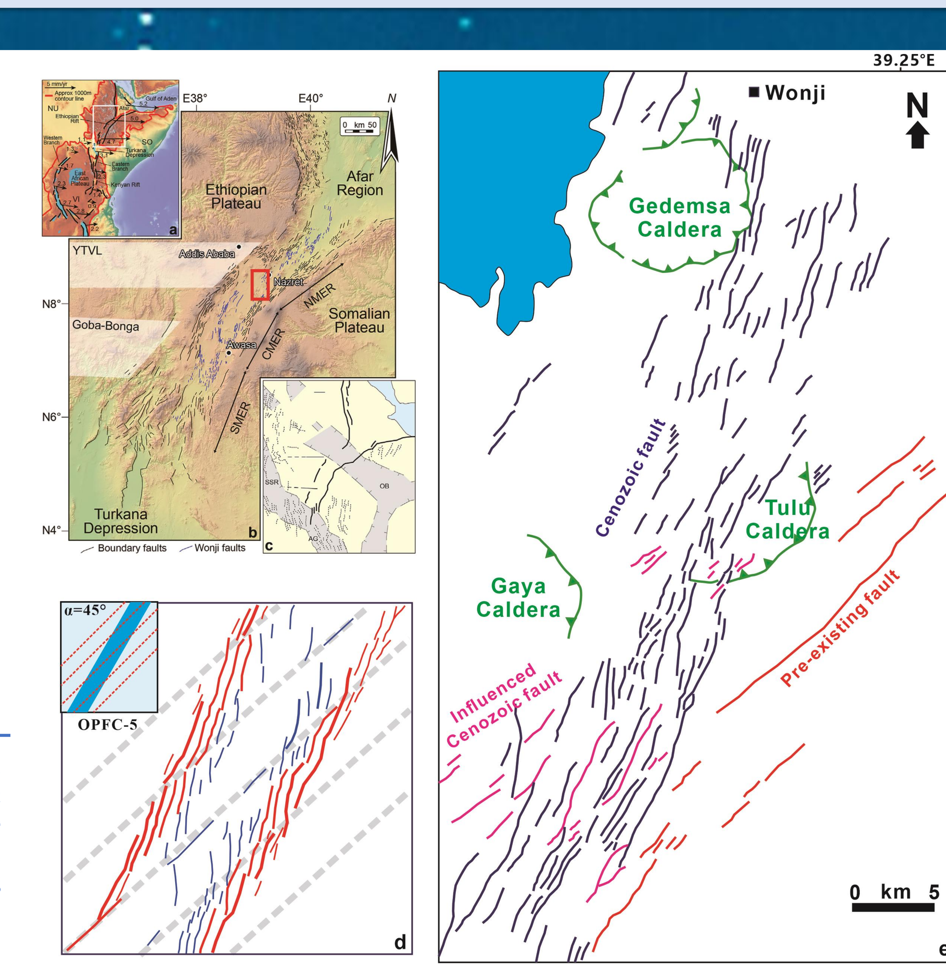


Figure 6. (a-c) Tectonic setting of the Main Ethiopian Rift (MER). (d) and line-drawing of structures of model OPFC-5. (e) Tectonic map of Wonji-Asela area, central sector of MER. The red lines are the pre-existing faults, the bule lines are the border faults of MER, and the pink lines are the atypical faults influenced by pre-existing structures.

6 CONCLUSIONS

- Pre-existing brittle fabrics have significant impact on the related structures of oblique rift. The interaction is particularly obvious when the obliquity of fabric orientations are less than or equal to 45° , and become weak when more than 60°。
- Our model shows that the reactivation of pre-existing brittle fabrics can lead to complex fault patterns. These effects occur on both boundary faults and intra-rift faults at the initial stage of oblique rifting, which in turn lead to the location and segmentation of depositional centers. This effect may persist until late stage of oblique rifting.
- The results of our models have a good similarity with the faults pattern in Wonji-Asela area, Main Ethiopian Rift (MER), which illustrate the important role of pre-existing fabrics on the fault patterns and depocenters during oblique rifting.

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Author contact: yaoyaozou@cug.edu.cn (Yaoyao Zou, PhD candidate)

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