Fault kinematics in the Thuringian Basin and the Flechtingen-Calvörde Block, Germany

The role of Jurassic extension tectonics in regional deformation patterns

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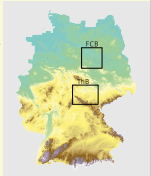
Introduction



Fault systems in the *Thuringian Basin* (ThB) and the *Flechtingen-Calvörde Block* (FCB) of the central German platform show similarities in terms of fault orientation and kinematic mechanisms that are mostly the result of thrust faulting during Late Cretaceous-Early Cenozoic basin inversion. Though fault and fracture patterns and their corresponding structural evolution during inversion have been subject to several scientific investigations, little is known with regard to the role of extension dynamics during Jurassic rifting. In this study, we present a comprehensive approach to identifying analogue deformation structures and related fault kinematics in both study areas. Outcrops in sedimentary strata in the *Thuringian Basin* and in igneous rocks of the *Flechtingen-Calvörde Block*, as well as in reoriented core samples from the *Altmark-Brandenburg Basin* have been studied for comparison in terms of fault orientation, fracture populations and respective kinematic mechanisms.

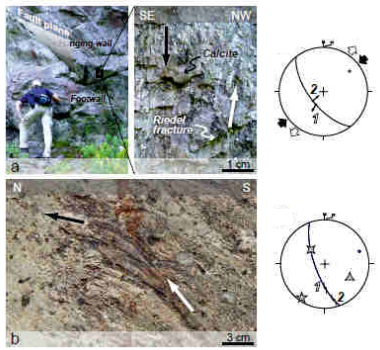


Fig. A-1: (a) Reverse reactivation of a normal fault evidenced by calcite slickenfibers crystallized on incongruous steps of Riedel shear fractures. White and black arrows respectively refer to the 1st and 2nd chronology of slip of the footwall, as the picture is taken from underside of the hanging-wall. (b) Twisted striae on a sub-vertical fault plane suggest successive increments of dextral strike-slip motion and fault block rotation under the same contraction.

A) Thuringian Basin

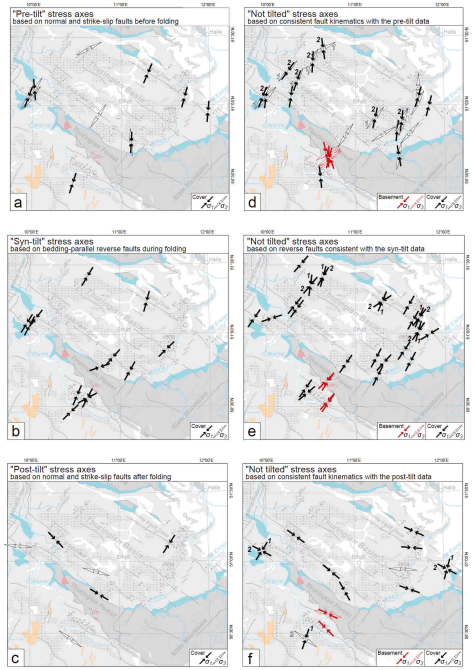


Fig. A-2: Paleostress maps for the study area. Horizontal maximum and minimum principal stress axes, σ1 and σ3 respectively, are given based on right dihedra method of [1]. The data for which a relative tilt geometry could be reconstructed are categorized as pre-, syn- and post-tilt geometries (a, b and c). The data obtained from horizontal strata, as well as the basement granite, are categorized into consistent kinematics with and presented in parallel to the relative tilt geometries as "not tilted" stress axes (d,e and f). Numbers next to the stress axes indicate relative binary chronology based on successive striae of the corresponding fault-slip data. See [2] for detailed explanation.

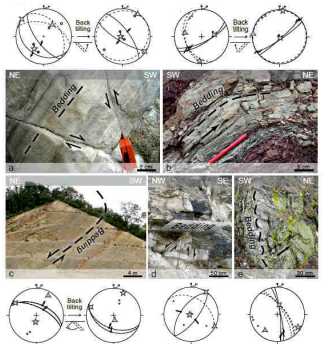


Fig. A-3: Tilt correction for the fault-slip data of cover rocks. (a) Tilted conjugate-like normal faults on a flank of folded strata. (b) Tilted strike-slip fault plane, characterized by striae parallel to the bedding plane. (c) Overturned limb of a local anticline, with marked bedding-parallel flexural slip. (d) Conjugate-like normal faults cutting through previously tilted strata. (e) Subvertical strike-slip fault plane cutting through steeply tilted, folded strata.

B) Flechtingen-Calvörde Block

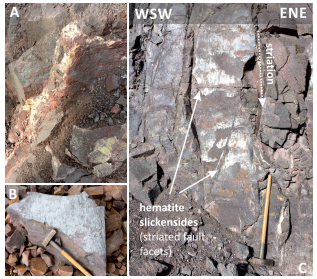


Fig. B-1: A) Mineralized extension fracture (025/89), paragenetic squence: hematite - red, iron-rich calcite-white calcite (*Dönstedt-Eiche* quarry). B) Hematite slickenside with striation on porphyry rock fragment (*Bodendorf* quarry). C) Hematite slickensides on steep normal fault (111/73) in the *Dönstedt-Eiche* quarry.

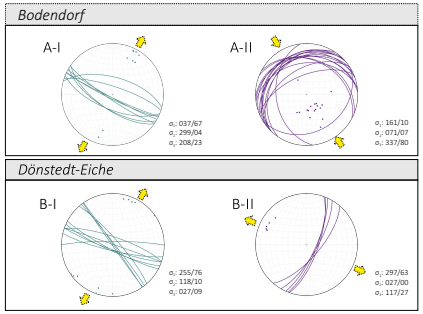


Fig. B-2: Stereoplots illustrating fault kinematics in igneous rocks of the *Flechtingen-Calvörde Block*. A-I) Hematite-calcite mineralization in normal faults probably related to Late Jurassic extension. A-II) Fault planes likely representing inversion-related compression. B-I) Hematite-calcite paragenesis in normal faults related to NW-SE directional rifting. B-II) Hematite slickensides that most likely formed after basin inversion and correspond to a Cenozoic- present day stress field (compare [2]). Calculated **(U-Th)/He** ages of hematite mineralization within fracture set B-I suggest tectonic extension at 136 ± 12 mya.

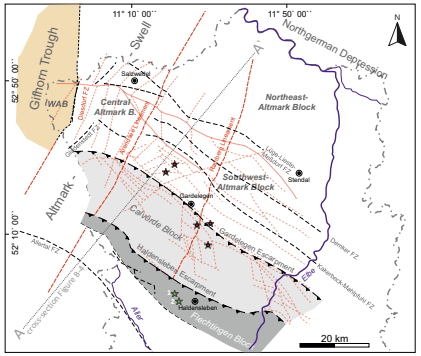


Fig. B-3: Structural map of the *Flechtingen-Calvörde Block* and the adjacent *Altmark-Brandenburg Basin* showing major tectonic lineaments of Paleozoic (red) and Mesozoic (black) age, a light brown shade marks the Triassic N-S striking *Gifhorn Trough*. Sampled wells are indicated by red stars, numbered green stars mark quarries (1: *Bodendorf*, 2: *Dönstedt-Eiche*); (dark/light) grey background represents basement units below (thick/thin) Mesozoic and Cenozoic cover.

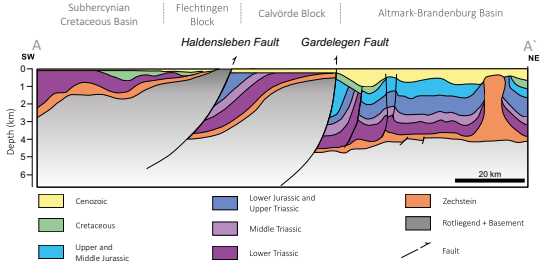


Fig. B-4: Schematic geological cross section through the *Flechtingen-Calvörde Block* and the *Altmark-Brandenburg Basin* showing major SW dipping reverse faults, which delineate important thrust zones that formed during Late Cretaceous - Early Cenozoic convergence. The origin of NW-SE striking fault systems in the study area dates back to pre-Mesozoic times, however, their kinematic nature during Triassic and Jurassic times - prior to basin inversion - was most likely transtensional (modified from [4]).

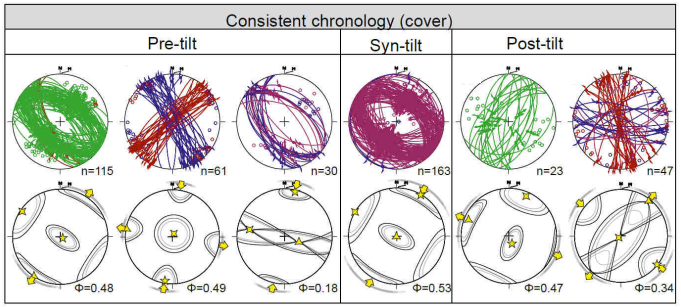


Fig. A-4: Stereoplots of the fault-slip data of the cover rocks from the *Thuringian Basin* separated based on consistent chronology and kinematics. Stress tensors are computed based on direct inversion method of [3] and given as the orientation of σ1, σ2 and σ3 axes, with 60, 75 and 90% confidence ellipses, azimuthal confidences in gray curves and the ratio of stress magnitude differences ϕ.

C) Altmark-Brandenburg Basin

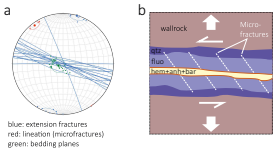


Fig. C-1: a) Stereoplot of a quartz-fluorite (+hematite-anhydrite-barite) fracture mineralization in Upper Rotliegend sandstone *(depth: 3810.0 m - 3843.0 m)*. b) Schematic sketch of the respective mineralization illustrating vein opening and simultaneous ore mineral precipitation + subsequent microfracturing. Cemented fractures clearly postdate syn-tectonic deformation bands of Upper Rotliegend age, and thereore are most likely the result of Mesozoic rifting.

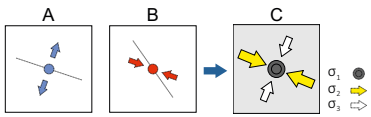


Fig. C-2: Opening mode of a fracture set (A) and orientation of a set of microfractures within fluorite mineralization (B) derived from a re-oriented core from the adjacent Altmark-Brandenburg Basin

A: WNW-ESE trending extension fractures → NNE-SSW extension
B: NW-SE trending lineation → WNW-ESE directional shearing (probably simultaneous to A or later → affecting qtz+fluo only)
C: principal stress directions → NNE-SSW directional extensional

Conclusions

- Structural analysis in the *Thuringian Basin* and the *Flechtingen-Calvörde Block* proved similarities in both study areas with respect to pre-, syn-, and post-inversion tectonism. Predominant WNW-ESE striking faults were locally active during both, Late Jurassic- Early Cretaceous extension and Late Cretaceous- Early Cenozoic compression.
- Fault patterns in the *Flechtingen-Calvörde Block* clearly associated with Jurassic extension tectonics are rare, as they were mostly overprinted during basin inversion (see [5]). However, investigated fault and fracture sets mostly coincide with normal faults known from the *Thuringian Basin* and the *Altmark-Brandenburg Basin* that clearly predate basin inversion.
- Moreover, (U-Th)/He age dating of hematite mineralization related to normal faults in the *Flechtingen-Calvörde Block* revealed tectonic stretching in that area taking place during Late Jurassic- Early Cretaceous rifting (ca. 140 mya).

References

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Acknowledgments

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