The Development of the Jura fold-and-Thrust Belt: pre-existing Basement Structures and the Formation of Ramps

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Pre-existing faults in the pre-Mesozoic basement are believed to play an important role in controlling deformation of the thin-skinned Jura Mountains fold-and-thrust belt (JFTB), which constitutes the northernmost extension of the Western and Central European Alps. The JFTB was detached in Triassic evaporites during Middle Miocene and Pliocene compression, exerted by the Alps. Prior to this, the Northern Alpine Foreland (NAF) was intensely pre-structured by faults, partially inherited from Palaeozoic times, that were active during the Mesozoic and Cenozoic structural evolution of continental Europe.

In order to understand the connection between the thin-skinned JFTB formation and pre-existing basement structures, different datasets were compiled: this study provides an up-to-date homogenised structural map of the whole JFTB, a unified deep-borehole database, thickness models across the JFTB and surroundings of 9 lithostratigraphic units (comprising Mesozoic and Tertiary sediments), geological cross-sections across the External Jura, an elevation model of the top of the pre-Mesozoic basement, new U-Pb calcite ages of a slickenfibre and a vein in the External Jura, a brittle-viscous analogue modelling study testing basement controlled oblique-ramps and a kinematic forward model of a section in the External Jura that integrates pre-JFTB extensional phases.

The décollement of the JFTB is predominantly in salt-bearing units of the Middle and Upper Triassic evaporites (or evaporites of the Muschelkalk Group and Keuper Group, respectively). The main décollement level in the Eastern Jura concentrates within the Middle Triassic evaporite layers, whereas in the Central and Southern Jura, the main décollement is in Upper Triassic evaporites (Philippe et al. 1996, Deville 2021). This correlates with thickness centres on isopach maps. Furthermore, isopach maps suggest that the Middle Jurassic Group (Dogger Group) predominantly hosts upper detachments in the Eastern Jura, whereas upper detachments in the Central and Southern Jura are rather in the Lower Jurassic Group (Lias Group).

In the Mesozoic cover of the External Jura, normal fault systems are documented, which are mainly connected to the formation of the European Cenozoic Rift System (ECRIS), which has an Eo-Oligocene age (Illies 1972, Ziegler 1992a). Extensional structures in the Mesozoic cover, which are linked to the formation of the Cenozoic rift system, are mostly identified within faisceaux of the Central Jura and are transported north-westwards above the basal décollement in Triassic evaporites, away from their origin in the basement. The pre-Mesozoic basement underneath the External Jura shows sudden regional offsets (basement faults) with vertical throws of up to 450 m to 600 m. These offsets in the External Jura are mainly attributed to the formation of the ECRIS and to Oligo-Miocene flexural faulting during the migration of the Alpine foredeep. Therefore, basement faults in the External Jura are suggested to pre-date the Mio-Pliocene formation of the JFTB. Basement offsets due to the formation of the ECRIS can form both, upward basement steps and downward basement steps in the direction of transport of the JFTB. Basement faults in connection with the formation of the flexural Alpine foreland basin rather provide upward basement steps. Analogue models testing oblique cover structures controlled by basement faults and comparison to natural structures in the Internal Jura suggest that pre-existing basement steps of several hundred metres also exist beneath the Internal Jura and the Molasse Basin. Basement steps in these domains are rather proposed to originate from flexural faulting in Oligocene times. Basement faults active during Cenozoic times are proposed to have predominantly followed inherited structural seeds of the Variscan orogeny.

The front of the JFTB is essentially pre-determined by the formation of the ECRIS. Underneath the western front of the JFTB (Faisceau lédonien, Revermont), the NNE–SSW striking Bresse Graben border fault zone shows cumulative vertical offsets of up to ~2.8 km. This was an exceedingly high downward step in the direction of tectonic transport of the JFTB and blocked a further propagation of the front of the JFTB. Downward steps that localised the front of the JFTB are also detected underneath the northern front of the JFTB, connected to the Rhine–Bresse Transfer Zone (RBTZ, underneath the Faisceau des Avant-Monts) and the Upper Rhine Graben (URG, underneath the Ferrette Zone). In addition, uplift of ECRIS rift shoulders (up to ~930 m) that started in Eocene times led to several hundred metres erosion of Mesozoic sediments towards the front of the future Jura. Uplift in connection with the Alpine forebulge caused decidedly less erosion than uplift in connection with ECRIS rift shoulders, because flexural uplift did not exceed about 350 m and the forebulge did not remain stationary. The topography of the pre-Mesozoic basement suggests that the present-day forebulge crest lies to the north of the JFTB in the RBTZ. Accordingly, the northern portion of the central External Jura lies in the present day forebulge depo-zone whereas the rest of the JFTB (Southern Jura, southern Central Jura, Internal Jura, Eastern Jura) is in the present-day foredeep. The pre-Mesozoic basement underneath the External Jura shows moderate inclinations that are commonly 1.5° or smaller. Underneath the Internal Jura, basement inclinations are mostly between 2° and 3°. The low basement inclination of the External Jura seemed to have fostered the formation of kilometric plateaus.

In summary, this study confirms an important influence of the basement on the structural development of the JFTB and different structural domains of the JFTB can be partially connected to local basement configurations. New faults in the pre-Mesozoic basement of the Jura Mountains (and Molasse Basin) are proposed. Orientations and throws of basement faults are characterised and lithospheric processes that led to their formation are evaluated. The concepts of this study may be applied to other thin-skinned fold-and-thrust belts worldwide that formed above pre-existing basement structures.

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