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Structure and kinematics of an outcrop-scale triangle zone

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Triangle zones are widespread structural elements that link fold-and-thrust belts with their foreland basins. The expression 'triangle zone' has been used to describe different types of structures with a triangular shape in cross-section. In most cases, it is used to describe an antiformal feature on the leading edge of a fold-and-thrust belt that is internally characterized by a duplex zone with vertically-stacked horses. The triangle zone is bounded by two detachments: A lower hinterland-dipping detachment and a foreland-dipping upper detachment. The point where the detachments meet defines the tip of the triangle zone. The lower detachment has a flat-ramp-flat geometry and forms the base of the local duplex stack, whereas the upper one is dominated by back thrusting and separates the antiformal stack from the foreland syncline.

We present here a structural analysis of an outcrop-scaled (ca. 12 m wide) triangle zone, which developed during the Variscan Orogeny, and is exposed in the siliclastic, Upper Carboniferous strata of the Harz Mountains in northern Germany. The geometry of the triangle zone can be compared with larger outcrop and seismic-scale structures. The exposure allows a detailed insight into the structure of the complete triangle zone and the factors controlling the deformation. A kinematic analysis was carried out to describe the evolution from the undeformed to the deformed stage. The external form of the triangle zone is the same as proposed for larger ones, with two bounding detachments that dip in opposite directions. However, in general, triangle zones are internally characterized by a duplex zone of vertically-stacked horses. In contrast, this triangle zone shows a core of very tight folds. It can be therefore classified as a semi-ductile structure. The folds verge in the transport direction of the thrust faults. The triangle zone initially evolved from a fault-bend fold. The detachment flats followed bedding contacts and a ramp connected two detachment levels. A foreland shift of the hanging-wall ramp caused a sticking point for successive accretion of material in the triangle zone, mainly by folding. During the final stage, a roof thrust developed in the hanging-wall.

The main controlling factor during the evolution of the triangle zone was the mechanical stratigraphy. Flat and laterally-continuous depositional units favoured the development of two thrusts parallel to the bedding planes. In addition, rheological contrasts between the individual beds in the siltstone succession might have support the formation of the detachment surfaces. Strain localization caused the concentration of deformation in the triangle zone.

Our analysis offers an alternative, folding interpretation for a structure that is commonly modelled as a thrust stack.