Fracture Evolution on Fold Limbs: Interplay between Bed-parallel Extension and Shear

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Many procedures for the prediction of fractures on folds place much emphasis on the fold hinges and the curvature approach. However, planar fold limbs can also display strong fracture development. Fractures develop progressively through the folding history, as the limb dips increase from sub-horizontal to their final orientation. The focus of the present study is on a suite of second-order structures, and associated fractures, that are most commonly observed on limbs that have moderate to steep dips.

In many folds that we have examined in various Cretaceous sandstone units within the Foothills region of central Alberta, we have observed slickensides on bedding surfaces or small faults that indicate either flexural slip or bed-parallel extension within the fold limbs. In some instances the two deformational processes appear to be unconnected, but in many situations there is a clear linkage between the shearing and extension of the beds.

Bed-parallel shearing is the classic expression of flexural slip. It is facilitated by the presence of shaley or coaly beds intercalated with the sandstone beds. Flexural slip can accommodate much strain within the fold limbs and, thereby, stunt the development of fractures within the bounding beds. The flexural slip surfaces are sometimes observed to depart from bedding surfaces and cut through the adjacent beds at low angles, creating small-displacement faults or shear zones (resulting in either bedding parallel contraction or extension).

Bed-parallel extension features are expected to increase in number or offset as the fold limbs become progressively steeper. With increasing dip, the beds within the limbs become steeply inclined to the regional compressive stress direction, and the potential extension direction becomes sub-parallel to bedding. Type II fractures are the common expression of extension in the down-dip direction, and type I fractures can accommodate bed-parallel extension parallel to the fold axis. Room problems that may develop in the core of the fold as it tightens can also contribute to bed-parallel extension in the limbs.

The features of specific interest here are extensional shear zones that are formed at low-angles to bedding on the fold limbs, often creating bounding zones of strong fracturing to brecciation. These shear zones are commonly located within the shaley or coaly beds for part of their existence, but then cut across the sandstone beds at low to moderate angles to bedding. Displacements on the zones that we have observed on the fold limbs are typically several tens of cms and occasionally a few metres.

Because these extensional shear zones are inclined at low angles to bedding, they produce minor overall thinning of the beds, and they may be difficult to separate from bedding features on image logs. The shear surfaces themselves have strong, down-dip striations, but little occurrence of significant aperture, open or mineral-filled. The fractures developed marginal to the shear zones, though, can be very dilatant but very short (<10 cm). These fractures commonly have a type II orientation, but the orientation patterns can become dispersed as the deformation increases. This damage zone adjacent to the main slip surface may be only a few cms to tens of cms thick, but it could produce high-rate flow zones if the apertures are not occluded with mineral cements. In many exposures the shear surface, and its associated damage zone, appears to penetrate only a few tens of cms into the sandstone unit from the shale/sandstone or coal sandstone interface, but elsewhere the low-angle shear zone can cut across, or develop within, a sandstone unit several metres thick.

Both contractional and extensional shear zones can develop within folds at different or overlapping periods in the fold development. It appears that the extensional shear zones have more strongly developed zones of associated fracturing. Both the contractional and extensional shear zones are vastly subordinate in number to the fractures that are formed at high-angles to bedding, but they may still have strong impacts on the reservoir flow behaviour where encountered by the wellbore.