Constraints on the timing and physical conditions of shale detachment faulting using natural examples

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Abstract

A detachment can be defined as a horizon or zone, centimetres to kilometres in thickness, which mechanically decouples deforming rocks or sediments from underlying, non-deforming sequences. Detachment zones accommodate thin-skinned deformation in fold and thrust belts across a variety of tectonic settings. Fold-thrust belts exhibit considerable variation in structural styles and vergence direction depending on the type (salt, overpressured shale, low-angle faults) and characteristics (thickness, strength, dip and dip direction) of the detachment horizon(s). Shale detachments have been previously described as largely ductile in their mechanism of deformation, however, increasing resolution of seismic imaging and understanding of these zones suggest brittle deformation may have a significant role in their internal behaviour and the deformation of overlying fold and thrust belts. Despite the critical influence on the structural style of fold and thrust belts, the precise nature by which detachments control deformation in FTBs is poorly constrained. Dependence on seismic imaging and other indirect or low-resolution study methods has resulted from the lack of outcropping shale detachment zones for detailed study. This study presents an investigation of the structural style and deformational mechanisms of a newly described shale detachment zone in the Khao Khwang Fold and Thrust Belt in Central Thailand, which is an exceptionally well-exposed shale detachment in the Sap Bon Formation shales. This is integrated with new data and structural interpretation from the Chrystalls Beach Complex (accretionary wedge) in southern Otago, New Zealand, and the Osen Røa thrust sheet (collisional) in the Norwegian Caledonides for comparison with results from the larger study in the Khao Khwang FTB.

Detailed field mapping and construction of cross-sections through the detachment zone reveals the deformational style and brittle nature of deformation. In the Sap Bon Formation detachment zone, cross-sections were sub-divided into structural domains based on the style and complexity of deformation. In particular, the 'proximal domain' located directly above the Eagle Thrust exhibited the most heavily deformed shales, and is interpreted to be acting as a detachment zone. The proximal domain is deformed in a continuous vs. discontinuous deformational style where the distribution of contrasting competency domains has governed the distribution of deformational mechanisms. Weak phases (incompetent domains composed of fine-grained shales) have localised strain and host shear-zone like faults which form an anastomosing network through the detachment zone. These shear zones characterise a three-dimensionally complex fault system in the proximal domain, surrounding three-dimensional lenses of competent rock. Extreme structural heterogeneity occurs both in-section and laterally through the proximal domain.

Analysis of the geochemistry of the Sap Bon Formation detachment zone through use of illite crystallinity, carbon and oxygen stable isotopes, vitrinite reflectance, and total organic carbon content analyses reveals a peak deformational temperature of between 160-220 °C. Higher illite crystallinity is observed in the continuously deformed incompetent domains, and is found to be directly linked to the finite strain. Finite strain throughout the Sap Bon Formation detachment zone (and the two comparison field areas) is shown to exhibit a strong correlation to $KI_{(CIS)}$ values, suggesting strain rate may play have a key influence in the development of illite crystallinity, as well as the prograde transformation of clay minerals.

Carbon and oxygen stable isotope mapping across the structural cross sections reveals fluid flow pathways through the evolution of the complex fault zone which constitutes the Sap Bon Formation detachment zone. Results indicate the basal Eagle Thrust, as well as other large faults constituted the primary source of permeability during orogenesis, once rock-matrix permeability had been lost. Oxygen stable isotope values from calcite mineralisation along these major structures are frequently as negative as -16.00 $\delta^{18}O$, indicating relatively hotter precipitating fluid temperatures that the background value of calcite mineralisation in the Sap Bon Formation (~10-12 $\delta^{18}O$). Burial > diagenetic > pre thrust deformation > orogenic association of carbon and oxygen stable isotope results and clay mineralogy provide a conceptual model for the development of the Sap Bon Formation through burial and into the formation of the detachment zone. The timing of this evolution is constrained by K-Ar illite age determinations, with burial occurring no later than 262±5.4 Ma, while faulting related to the onset of orogenesis began by 230±4.6 Ma, with deformation continuing as late as 208±4.1 Ma.

Declaration

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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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