Identifying the Amount and Timing of Layer Parallel Shortening in Compressive Regions using Thin-Sections and Analog Models*

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Abstract

Layer parallel shortening (LPS) is known to be a process occurring during deformation of a region under an applied compressive stress. LPS is thought to occur before the development of major structures such as folds or faults and is generally taken up by volume change within the beds, resulting in structures such as pressure-solution cleavage, reduction of porosity and potential stylolite development on the bed scale, or pressure solution and deformation of grain boundaries on the grain scale. Since much of the deformation related to LPS is taken up on the grain scale, the actual amount of LPS is difficult to quantify in the field or from map data. Thus, in constructing a balanced and restored cross-section, an element of the deformation is unaccounted for. As a result, any restored cross-section and the deformation amounts, timing and hydrocarbon in place estimates calculated from this section may be fundamentally flawed.

Various authors have placed the amount of LPS within the range of 5-20% initial shortening, indicating that the cross-sections created may have up to 20% error within them. This study presents an analysis of structures indicating LPS, based on thin sections and polished slabs from samples collected from the Teton Anticline, Sawtooth Range, Montana. Stylolites within oriented limestone samples from the lower member of the Mississippian Madison Formation (Figure 1) which cross-cut the recrystallized limestone grains indicate that LPS is occurring in later stages of deformation than the recrystallization of the sample.

Additional evidence for LPS around and across the Teton Anticline structures comes from the fabric of the Jurassic Swift Sandstone which caps the fold structure. The sandstone is a calcite-cementer, quartz sandstone, and oriented samples show evidence of pressure solution and grain-boundary deformation around the fold structure (Figure 2). The presence of sedimentary structures indicates that the deformation of these units has not been sufficient to destroy primary structure, and thus that the grain boundary deformation potentially results from LPS rather than high temperature plastic deformation. Extinction patterns in the quartz grains and irregular nature of these margins indicate that these structures may be early LPS that has been preserved, or later-stage LPS, as in the limestone sample described above.

In addition, initial analog modeling results by the PI indicate that LPS also varies with depth in the deforming system, such that LPS is greatest near the base of a deforming sediment system. At this point in the study, we conclude that LPS varies with position on the structure, with depth in the sediment sequence, and that although most LPS occurs in early deformation stages, LPS continues to occur throughout the deformation sequence.

These flaws and the flawed interpretations based on inaccurate cross-sections are likely to propagate through an entire research or exploration sequence. Given an interpretation based on a flawed model (lacking quantified LPS) the errors may propagate through the entire exploration sequence, resulting in poor drilling decisions and lower than optimum recovery rates for a given field. If these flaws can be removed, following this and further research to calibrate and quantify the amount of LPS, then improved interpretations of sub-surface structures are expected, leading to scientifically sound drilling decisions and improved recovery rates.

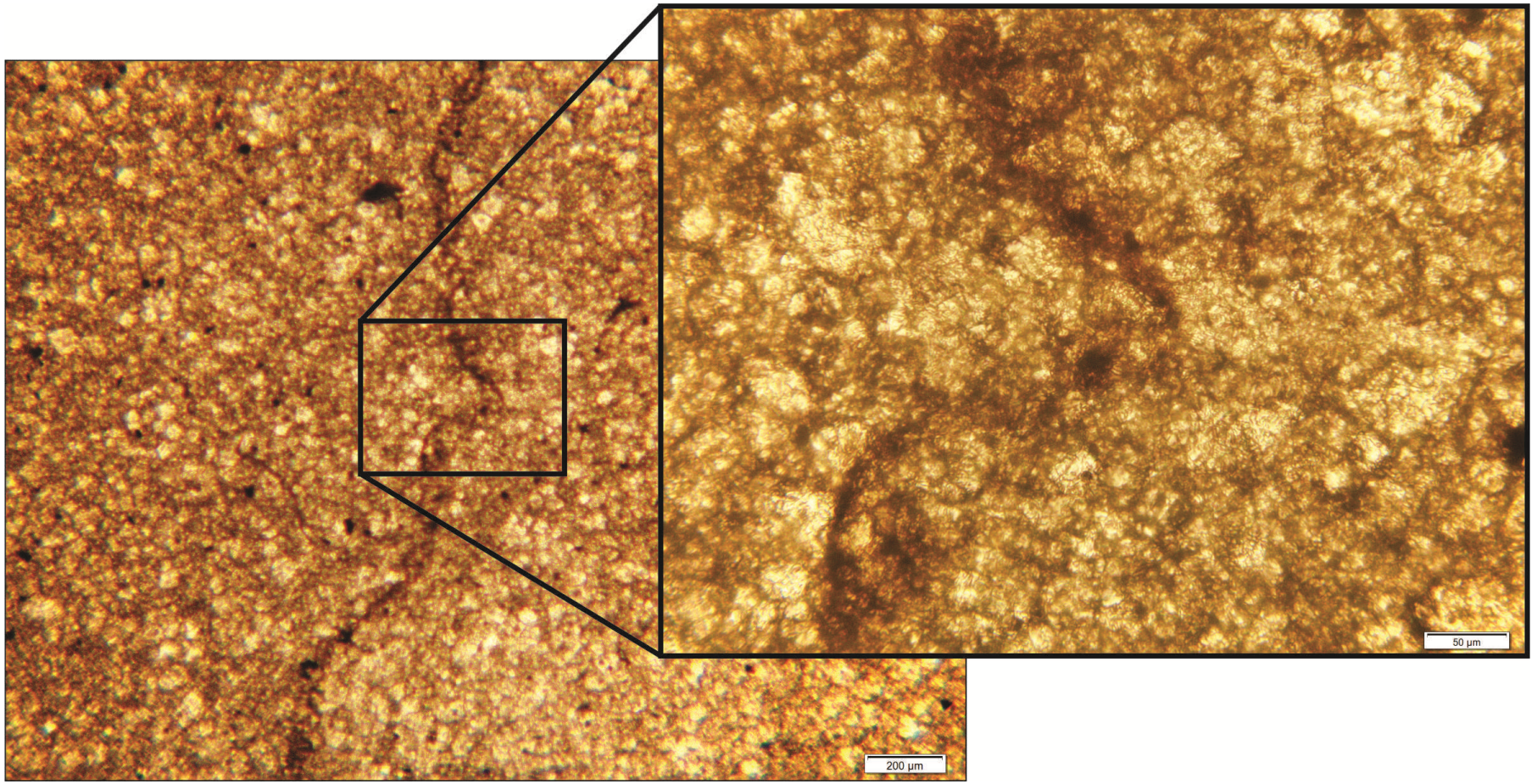

Figure 1. Stylolite cross-cutting the recrystallized limestone fabric in an oriented sample of Mississippian Madison Limestone from the Teton Anticline, Montana. The sample is oriented perpendicular to strike, such that LPS has occurred L-R across the image, perpendicular to the stylolite being generated. This implies that LPS-related structures are still forming later in the deformation sequence than the recrystallization. Image taken in PPL.

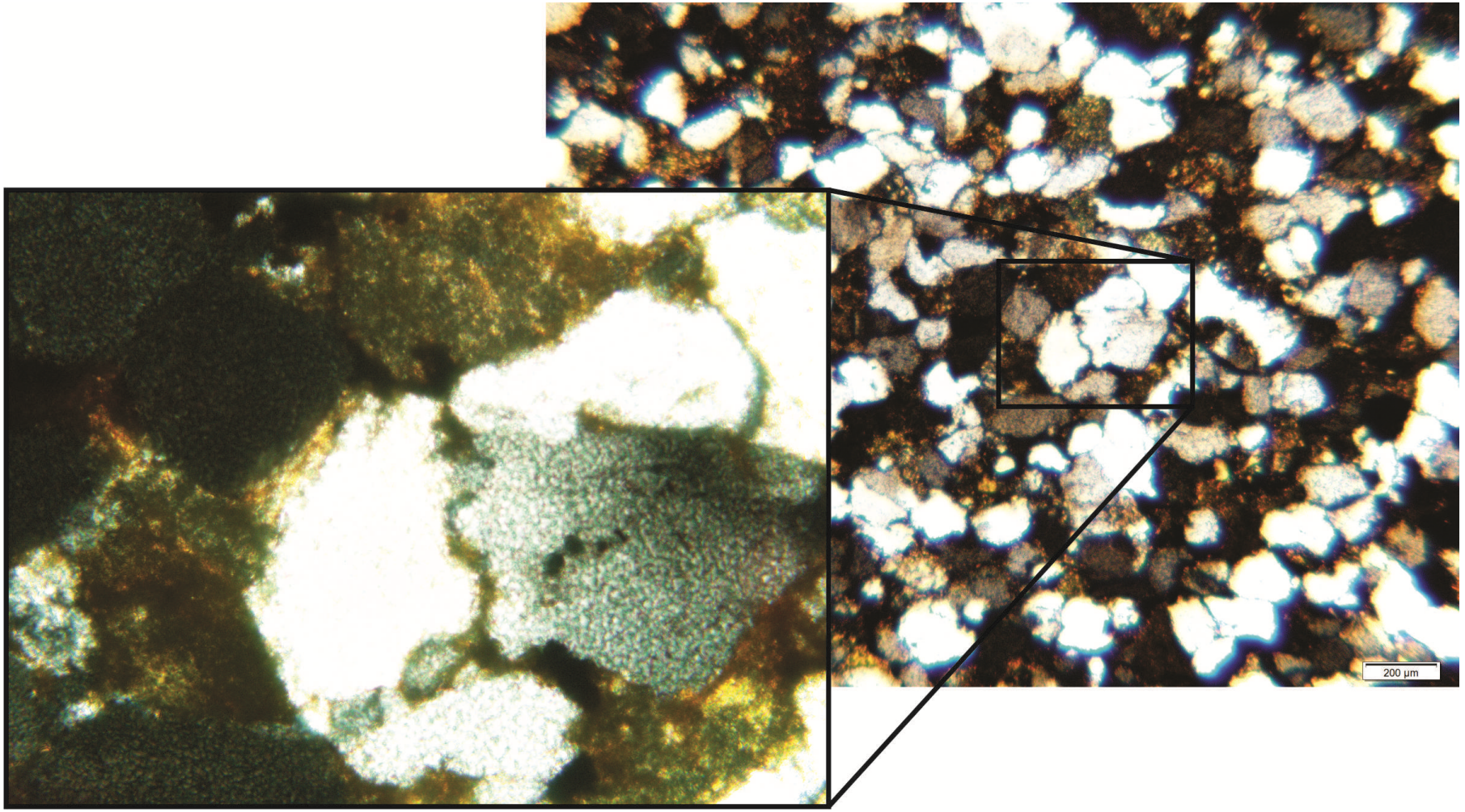

Figure 2. Deformed grain boundaries on quartz grains within an oriented sample of the Jurassic Swift Sandstone, Teton Anticline, Montana. The sample is oriented perpendicular to strike, such that LPS has occurred L-R across the image, perpendicular to the deformed grain boundary. This implies that LPS-related structures are either being preserved through the deformation or are still forming later in the deformation sequence. Image taken in XPL.