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Nano-grains form carbonate "fault mirrors"

Shalev Siman-Tov (1), Einat Aharonov (1), Amir Sagy (2), and Simon Emmanuel (1)

(1) Hebrew University at Jerusalem, Institute for Earth Sciences, Jerusalem, Israel (einatah@cc.huji.ac.il), (2) Geological Survey of Israel, Jerusalem, Israel

Many faults are characterized by naturally polished glossy surfaces, termed fault mirrors (FMs), which form during slip. Recent experiments also find that FMs form during rapid (but not slow) sliding between rock surfaces, and that FM formation coincides with pronounced friction reduction. The structure of FMs and the mechanism of their formation are thus important for understanding the mechanics of frictional sliding in general, and during earthquakes in particular. Here we characterize the small-scale structure of natural carbonate FMs from 3 different faults along a tectonically active region of the Dead Sea Transform. Atomic force microscopy measurements indicate that the FMs possess extremely smooth surface topography, accounting for their mirror-like appearance. Electron microscope characterization tools revealed a thin (< 1 μm) layer, composed of tightly packed nano-scaled grains, coating a rougher layer composed of micron-size calcite crystals. The crystals contain closely-spaced, plastically-formed, mechanical twins, which define new sub-grain boundaries. The narrow sub-grains are observed to break into sub-micron pieces near the sheared surface. This observation suggests a new brittle-ductile mechanism for nano-grain formation.

Our observations further suggest that FMs require two main ingredients: (i) Nano grains and (ii) a hard and very smooth surface, probably formed by nano-grain sintering, a plastic process requiring high temperatures that arise only during rapid enough sliding. Both nano-grains and nano-scale-smooth surfaces were previously suggested to induce frictional weakening. We discuss possible physical processes that may control the observed connection between FM formation and frictional weakening.