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Extreme Dynamic Metamorphism and Earthquakes

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For 50+ years after the discovery of deep earthquakes in the 1920s, their causal mechanism was one of the major unsolved problems of geophysics. It was clear that the physics that explains shallow earthquakes could not apply to deep ones because the pressure is too high at ≥~50km to allow a fault to move, even if you could initiate one. The answer for the deepest earthquakes (350–680km) turned out to involve the olivine-spinel phase transformation that should occur quietly in subduction zones but most of them are so cold that olivine is carried out of its stability field into the Mantle Transition Zone and when it warms up to a temperature at which the reaction can begin, an instability occurs that produces earthquakes. We made that discovery in my laboratory 25 years ago this year but it has been only during the last 10 years that seismology has been able to identify the presence of metastable olivine existing where the deepest earthquakes occur, thereby confirming this mechanism. Ten years ago we discovered how dehydration embritttlementcan explain intermediate-depth earthquakes (50–350 km) even though dehydration reactions have a negative volume change at high pressures. Finally, during the last 10 years, there has been a blossoming of high-speed friction experiments that for the first time allow probing of the sliding mechanism of shallow earthquakes. These experiments confirm that the vast majority of crustal earthquakes initiate by overcoming friction on pre-existing faults but the new experiments have shown that at earthquake sliding speeds (~1meter/second) extreme shear heating occurs, triggering mineral reactions that enable sliding at very low stresses. The high-pressure and medium-pressure faulting and high-speed friction experiments all have a common element: When the sliding surface (gouge) is examined shortly after it is created, it is found to be made up of a fully-dense nanocrystalline solid. In the high-pressure experiments, phase transformation yields a nanocrystalllinematerial which initiates the instability whereas in the high-speed experiments, the shear-heating-driven mineral reactions generate the nanocrystalline material. Thus, in faulting experiments simulating depths greater than ~50km, phase transformation under stress is the cause of failure whereas it is aconsequence of failure in high-speed experiments. But both lead to lubrication by a nanocrystalline sliding surface.

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