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The physics of non-volcanic tremor: insights from laboratory-scale earthquakes

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Due to his extensive early experience in field structural geology, Luigi Burlini's experimental research was always aimed at using laboratory techniques and simulations to improve our understanding of the physics of natural rock deformation. Here we present an example of collaborative work from the later part of his scientific career in which the main goal was unravelling the physics of non-volcanic tremor in subduction zones. This was achieved by deforming typical source rocks (serpentinites) under conditions (300 MPa and 600oC) that approach those expected in nature (up to 1 GPa and 500oC). The main technical challenge was to capture deformation-induced microseismicity (in the form of acoustic emissions) released under such extreme conditions by means of in-situ transducers designed to work at only modest temperatures (up to 200oC). The main scientific challenges were (1) to link the acoustic emission output to specific physical processes, such as cracking, fluid flow or fluid-crack interactions, by means of waveform and microstructural analysis; and (2) to extrapolate the laboratory acoustic emission signals (kHz to MHz frequency) associated with mm to cm-scale processes, to natural seismicity (0.1-1 Hz frequency) associated with km-scale rock volumes by means of frequency scaling (Aki and Richards, 1980).
Episodic tremor and slip (ETS) has been correlated with rupture phenomena in subducting oceanic lithosphere at 30 to 45 km depth, where high Vp/Vs ratios, suggestive of high-fluid pressure, have also been observed. ETS, by accommodating slip in the down-dip portion of the subduction zone, may trigger megathrust earthquakes up-dip in the locked section. In our experiments we measured the output of acoustic emissions during heating of serpentinite samples to beyond their equilibrium dehydration temperature. Experiments were performed on cores samples 15 mm in diameter by 30 mm long under hydrostatic stresses of 200 or 300 MPa in a Paterson high-pressure/high-temperature, internally-heated gas apparatus. Acoustic emission (AE) output was recorded via two piezoelectric transducers embedded within the sample end caps and a third remote transducer located outside the pressure vessel. Drained and undrained experimental conditions were achieved by placing either permeable or impermeable ceramic discs at the samples ends.
At 200 MPa, serpentinite dehydrates to talc + olivine + water around 5000C. Associated microseismicity, in the form of high-energy AE events, was confined to a narrow temperature interval just above the equilibrium dehydration temperature. This temperature overstep is expected, and is due to the heating rate in our experiments being much higher than for equilibrium studies. The high-energy AE events were characterised by very long durations, which is typical of a cascade of multiple, overlapping, shorter events that cannot be individually discriminated. Under drained conditions, the serpentinite samples showed a clear volume reduction following dehydration and subsequent compaction. By contrast, under undrained conditions, the samples maintained the same dimensions, but lost weight, implying that no compaction occurred during dehydration. Our results therefore demonstrate conclusively that seismicity can be generated by dehydration reactions even in the absence of a deviatoric stress. This observation is consistent with recent finding that tremor activity in nature has a strong tidal periodicity, indicating that tidal forces modulate slip velocity and suggesting near lithostatic fluid pressures at hypocentral depths. Furthermore, we suggest that the cascades of events that follow the onset of dehydration may well be related to the low-amplitude long-duration seismic events (seismic tremor) that characterize the seismic activity in subduction zones and that has been tentatively interpreted as being caused by dehydration of the subducting slab. Our laboratory observations support this hypothesis, since our low-amplitude, long-duration events were correlated with outflow of water from the samples through the porous spacers.