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Hydraulic triggering of earthquakes following the 1976 M=6.5 Friuli (Northern Italy) and 1998 M=6 Bovec (Slovenia) events

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Several examples support the idea that the stress released by an earthquake, or even artificially generated, for example, by reservoir or borehole infilling, can at least in part be transferred, and that other earthquakes at different locations and times may result. Static, dynamic and hydraulic stress transfer are three mechanisms which have been successfully applied to account for a broad range of phenomena, from microseismicity to aftershocks or individual earthquakes which were previously considered as, in some sense, independent. For seismic hazard, it is particularly crucial to identify mechanisms capable of predicting how much strain excess can be released at a given spatial and temporal separation from the triggering event. This paper concentrates on the diffusion of incompressible fluids in a porous medium as a possible mechanism to transfer stress away from a main earthquake. The triggering and triggered earthquakes are assumed to release a strain which is estimated from magnitude using known statistical relations with slip area and scalar seismic moment. We test the hypothesis that each triggered earthquake releases a strain close to the strain induced by the incoming hydraulic head in the porous medium. Given the boundary conditions appropriate for a sudden pore fluid change at the boundary of a semi infinite porous medium, the pore pressure can be computed at each time and distance, provided the diffusion coefficient is known. This simple approach is applied to catalogue earthquakes which followed the M=6.5 compressive event of May 6., 1976 in Friuli, Northern Italy, an area characterized by active indentation into stable Eurasia. A fit of the equivalent strain data released by individual earthquakes to the solution of the diffusion equation constrains the diffusion coefficient roughly to 10 m^2/sec, with an estimated uncertainty of 20 -30 %. The catalogue earthquakes following the main event are then examined in detail,

to identify those which took place at or near the arrival of the hydraulic head triggered by the main event. Of 66 events from magnitude 3.8 to 6.3 in the time window till September 16, 1977, and falling within 50 km from the epicenter of the main event, 26 are found to be spatially, temporally and energetically consistent with the transit of the hydraulic head. The other events tend to concentrate in the time frame immediately following the main event, and may probably be explained in terms of static or dynamic stress transfer. The hypocentral depth of the diffusive events is typically 10 km, and the epicenters appear aligned with the strike of thrust faults in an area characterized by basin deposits, suggesting that the hydraulic head propagated along cracks orthogonal to the dominant direction of thrust. This would explain the somewhat higher value of the diffusion coefficient relative to typical values reported in the laboratory for bulk rocks. Similar results are obtained for the Bovec (1998) earthquake. The data in this case imply a somewhat larger diffusion coefficient. This value is used to infer zones and epochs of seismic risk following the Bovec (2004) event.