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Impact of great subduction earthquakes on the long-term forearc morphology, insight from mechanical modelling

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The surge of great subduction earthquakes during the last fifteen years provided numerous observations requiring revisiting our understanding of large seismic events mechanics. For instance, we now have clear evidence that a significant part of the upper plate deformation is permanently acquired. The link between great earthquakes and long-term deformation offers a new perspective for the relief construction understanding. In addition, a better understanding of these relations could provide us with new constraints on earthquake mechanics. It is also of fundamental importance for seismic risk assessment. In this presentation, I will compile recent results obtained from mechanical modelling linking megathrust ruptures with upper-plate permanent deformation and discuss their impact.

We will first show that, in good accordance with lab experiments, aseismic zones are characterized by frictions larger or equal to 0.1 whereas seismic asperities have dynamic frictions lower than 0.05. This difference will control the long-term upper-plate morphology. The larger values along aseismic zones allow the wedge to reach the critical state, and will lead to active thrust systems forming a relief. On the contrary, low dynamic friction along seismic asperities will place the taper in the sub-critical domain impeding any internal deformation. This will lead to the formation of forearc basins inducing negative gravity anomalies. Since aseismic zones have higher friction and larger taper, fully creeping segments will tend to develop peninsulas. On the contrary, fully locked segments with low dynamic friction and very low taper will favor subsiding coasts. The taper variation due to megathrust friction is also expressed through a correlation between coast-to-trench distance and forearc coupling (e.g., Mexican and South-American subduction zones). We will then discuss how variations of frictional properties along the megathrust can induce splay fault activation. For instance, we can reactivate normal faults at the down-dip limit of the seismogenic zone or at an increasing slip transition (e.g., Chile and Japan). Finally, we will show that the fault vergence is controlled by the frictional properties. Sudden and successive decreases of the megathrust effective friction during frontal propagation of earthquakes will lead to the formation of landward-vergent frontal thrusts in the accretionary prism. Therefore, a particular attention needs to be paid to accretionary prisms with normal faults implying large up-dip ruptures (e.g., Alaska and Japan) or with frontal landward-vergent thrust faults, markers of past seafloor coseismic ruptures leading to very large tsunamis (e.g., Cascadia and Sumatra).

If the forearc long-term deformation seems in good accordance with our understanding of earthquake mechanics, recent studies have pointed to a major discrepancy between short- and long-term deformation at the coast (i.e. the Central Andes subduction zone). An analogue discrepancy has been pointed out for the Himalaya after the 2015 Mw 7.8 Gorkha earthquake. Melnick (2016) proposed that the coastal long-term deformation could be related to deep and less frequent earthquakes instead of standard subduction events. It is now of fundamental importance to understand the link between the coastal long-term record and the short-term deformation for seismic risk assessment and relief building processes understanding. It will probably constitute the next challenge for mechanical modelling.