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# Are sills really elastic hydraulic fractures?

Juán B. Spacapan (1), Olivier Galland (2), Héctor A. Leanza (3), and Sverre Planke (4)

(1) Museo de Historia Naturales, Universidad de la Plata, La Plata, Argentina (juanbspacapan@hotmail.com), (2) University of Oslo, Physics of Geological Processes (PGP), Oslo, Norway (olivier.galland@fys.uio.no), (3) CONICET, Buenos AIres, Argentina (hectorleanza@gmail.com), (4) CEED, University of Oslo and VBPR, Oslo, Norway (planke@vbpr.no)

Seismic reflection data and field observations have over the past few decades revealed the presence of voluminous igneous sill complexes in sedimentary basins worldwide. The implications of sill emplacement in sedimentary basins are numerous: they trigger maturation of organic-rich formations, they produce large quantities of greenhouse gases that trigger dramatic climate change and mass extinctions, and they produce small- and large-scale structures that affect fluid flow. Therefore, a proper understanding of their emplacement mechanism is essential. Most models of sill and laccolith emplacement account for purely elastic host rock, and their propagation mechanism is dominantly assumed to be according to the Linear Elastic Fracture Mechanics (LEFM) theory. Recent field and seismic observations, however, demonstrated that part, if not all, sill- and laccolith-induced deformation is accommodated by inelastic deformation, strongly questioning the relevance of the LEFM theory applied for igneous intrusions.

In this contribution, we present detailed structural observations from spectacularly well-exposed sills in the northern Neuquén Basin, Argentina. We studied a 50-m outcrop that exhibits very clearly three sills of different sizes, the shapes of their tips, and the associated structures in their sedimentary host rock, i.e. the calcareous pelites of the organic-rich Vaca Muerta Fm. This formation is adequate to map the structures at the outcrop scale, as it consists in fine layers of mudstone inter-bedded with weak shale, such that it is possible to map each layer along the entire outcrop. Detailed structural mapping evidence that the sedimentary layers have not been opened, i.e. pushed away by the emplacement of the sills, as expected from the LEFM theory. Indeed, some of the sedimentary layers are not present at the location of the sills, but they appear duplicated several times ahead of the tips of the three observed sills; the relative movements between the duplicated segments are clearly associated with shortening. Therefore, our field observations show that the host rock is pushed and shortened ahead of the sill tips, in total contradiction with the extensional features predicted by the LEFM theory. The structures described above strongly suggest instead that these sills were emplaced according to the viscous indenter model, in good agreement with recent laboratory models (Abdelmalak et al., 2012). These detailed observations strongly question the geological relevance of the LEFM theory applied to igneous sheet intrusions, and call for more field observations to better constrain the dynamics of sill and dyke emplacement mechanisms.

Abdelmalak, M.M., Mourgues, R., Galland, O., Bureau, D., 2012. Fracture mode analysis and related surface deformation during dyke intrusion: Results from 2D experimental modelling. Earth Planet. Sci. Lett. 359-360, 93-105.