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Faults displacement profiles in clay-limestone multilayer systems

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The Callovo-Oxfordian indurated clay formation, located at 500 m depth in Eastern Paris Basin (France), between two limestone formations, is currently studied by ANDRA for hosting a radioactive waste disposal. In this multilayer system, a hypothetical propagation of tectonic faults from limestone to clay layer, which might affect the favourable containment properties of the clay formation, was investigated using various survey methods such as 3D seismic-reflexion, drilling and in situ observations in an underground research laboratory. Because this may not allow fully assessing the absence of tectonic structures in the entire layer, especially faults with small displacement, complementary researches were conducted by IRSN in outcropping analogous clay/limestone multilayer systems providing fault data collection. Their purpose is to establish a well documented model of fault growth and architecture in clay/limestone systems. Faults in various clay/limestone systems have thus been investigated and selected results are presented here, with emphasis on distribution of the displacement along the faults which enables to document restriction and propagation processes and then to propose a growth fault model. We studied, in cross section, normal faults affecting 5 multilayer systems of various age, mineralogy and pattern of layering, in the South-Eastern France basin. Among the studied faults, 8 ones are restricted by clay-limestone interfaces and 13 by sub-horizontal faults within the clay units. 34 non-restricted faults propagated more or less deeply into surrounding clays and 14 others cross-cut several layers. Offsets of sedimentary or tectonic markers were measured to construct the fault displacement profiles and to infer the local displacement gradients. The sampling mesh allowed to document how the local displacement gradients vary along the faults, and this in different sequences. In one site, faults with various lengths offer an almost continuous record of the evolution during the fault growth of displacement, as well as maximum displacement (Dmax) vs. length (L).

Most studied faults have Dmax located in limestone layers indicating that faults nucleated in limestones as already observed in literature. Along non-restricted faults, displacement gradients are almost constant in clay layers with specific value in each system. In the investigated rocks, this gradient ranges from 0.06 to 0.2. Where internal bedding allows accurate determination of displacement gradients in limestones, this parameter is also specific of the lithology and averages 0.08, close to that currently reported in homogeneous systems. In the other outcrops, displacement gradients are too low and could not be defined precisely. Whatever the hosting rock, clay gradients are always more important than those in the surrounding limestones, which indicate that clay formations discourage the vertical propagation of faults. Arrest in the fault propagation by a geological restrictor (layer interface or sub-horizontal fault) results in a modification of the displacement profile and the local gradients are then not anymore characteristic of the lithology. Displacement profiles along these restricted faults systematically exhibit a flat-topped pattern with a low gradient zone near the nucleation point and large but various gradients at tips. This shape results from a progressive increase of near-tip gradient as slip accumulated along the fault, and a linear relation links the tip gradient to Dmax.

Based on these results, an evolution model of the displacement profiles during a fault growth from nucleation in limestones to propagation across several clay and limestone layers is proposed. According to this model, local displacement gradients control the shape of displacement profiles and thus the fault growth and displacement gradients are expected to significantly vary during the fault history, especially when geological restrictors delayed the fault propagation. This model also supports a non-linear Dmax-L relation since faults developed through various lithologies; the greatest discrepancies are associated with fault restriction.