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Control of sub-horizontal faults on normal fault growth and architecture

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The Callovian-Oxfordian clay formation is currently studied by Andra in Eastern Paris basin (France) for hosting a deep geological disposal of radioactive waste. This 500 m-deep clay formation is surrounded by two limestone formations. In such a “multilayer system”, faults within limestones might propagate to clay layers. Such a situation could decrease the containment ability of the clay formation by creating preferential pathways for radioactive solute towards limestones.

IRSN is conducting studies in support of the regulatory review of this disposal project. In order to improve our understanding of fault development in such alternations of more or less competent rocks, well-exposed meso-scale faults cutting clay-limestone alternations have been investigated in the South-Eastern basin, France. Based on a selected data set among the observed normal faults with centimetre to decimetre offsets, we illustrate here the important role of sub-horizontal faults located in clays on both the propagation and the architecture of the normal faults.

In the three selected sites, showing normal faults crossing decimetre to metre-thick clay-limestone alternations, sub-horizontal faults are observed within some of the clay layers, both close to and at a distance from the normal faults. They are referred below as CHF (clay horizontal faults). Careful examinations of the CHF planes reveal that, in each site, the slip vector has a direction similar to that of the calculated minimum principal stress responsible for the normal faults, and thus confirms a genetic link between the CHF and the meso-scale normal faults.

Faults restricted by CHF were observed in two sites. Their maximum displacement varies between 1 and 12 cm in the first one and between 4 and 43 cm in the second one. The restriction by CHF induces changes in the displacement profiles, a typical flat-topped pattern with a low gradient zone near the nucleation point and large but various gradients at tips. Such changes in the displacement profiles are similar to those observed along faults restricted by lithological interfaces. The fault architecture is also strongly modified as the displacement accumulates on the restricted faults: the number of fault segments increases with the maximum displacement, causing the fault thickness to expand close to the restrictor, especially within limestones, and up to 2m. Although no fault crossing the CHF has been observed in these two sites, we speculate that restriction occurs till a maximum displacement threshold as it does for faults restricted by lithological interfaces.

In the third site, we observe normal fault zones passing through CHF. These faults consist of one or more sub-vertical segments in limestones. In the clay layers affected by CHF, fault segments may propagate across CHF or may connect to it. We first show that the thickness of the fault zones depends on the presence of CHF in surrounding clays and could become very large relatively to the fault displacement, up to about 2 m for a fault with $\sim$ 20 cm maximum displacement. Secondly, where fault segments, located in the two limestone units surrounding a clay layer, abut again the CHF in the clay, they may define a connected overstep zone of compressive type with a very large width, which seems to increase with the thickness of the clay unit. This pattern implies an increase of the fault length in clays. Thirdly, study of the displacement profiles show that the displacement gradients are constant in clay layers whenever CHF are present or not, with a mean value greater than in limestones. Thus, even if CHF guides the fault path, the important fault length in clays contributes to discourage the vertical propagation of the normal fault.