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Determination of the maximum horizontal principal stress magnitude in a stratified formation

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During year 2000, a stress measurement campaign was conducted by hydraulic fracturing (HF) in the Callovo-Oxfordian formation of the eastern Parisian basin, at depth ranging from 375 m to 499m. Claystone (argillite) are encountered from 499 to 419 m while limestone is encountered from 419 to 375 m. The site will become an underground laboratory for investigating in situ the possibility of developing a nuclear waste repository in the claystone formation, a 130m thick layer that lies between two carbonate units. The campaign provided a first vertical profile of the minimum in-situ stress orientation and magnitude. But classical interpretation of pressure records suggested a maximum horizontal stress magnitude significantly larger within the claystone than within the limestone, a feature not compatible with the rheological properties of these materials. In years 2003-2004, a new stress determination program was undertaken so as to ascertain the vertical variation of the stress field above, within, and below the future laboratory site with particular attention to the maximum horizontal principal stress determination. This was achieved through hydraulic tests in vertical and inclined wells together with the analysis of borehole breakouts when they occurred.

Two kinds of hydraulic tests have been conducted : classical straddle packer tests on intact zones and on preexisting fractures (HTPF tests), and sleeve fracturing tests in which the fluid is injected within a deformable packer so that a pressure is applied to the borehole wall without any fluid penetration when fracture initiates. Classical HF tests have confirmed previous results on the minimum horizontal principal stress magnitude and orientation. HTPF tests have provided data for constraining the vertical stress magnitude that has been found to be slightly smaller than the weight of overburden, for the tests performed in inclined boreholes. Further, sleeve fracturing has generated en echelon fractures in an inclined borehole drilled in the lower limestone.

Analysis of the orientation of these en echelon fractures constrains very efficiently the maximum stress magnitude. In a horizontal borehole drilled parallel to the minimum principal stress direction, sleeve fracturing in the claystone generated horizontal longitudinal fractures. Hydraulic reopening of these fractures followed by further sleeve reopening provided satisfactory constraints on the maximum principal stress magnitude together with a measurement of the vertical stress component in the claystone. These results are consistent with borehole breakouts that have been observed in the same horizontal borehole, within the callovo-Oxfordian claystone formation.

The maximum horizontal principal stress is found to be oriented N $150 \pm 10^{\circ}$E within the whole tested formation, with small local rotation close to material interfaces. The magnitude of the minimum horizontal principal stress exhibits the same value (8 MPa) within the limestones that are encountered above and below the claystone, but is equal to the vertical component within the claystone (around 12.5 MPa). Within the claystone the maximum horizontal principal stress magnitude ($13 \leq S_H \leq 15$ MPa) is only slightly larger than the minimum horizontal principal stress magnitude, consistent with a low yield strength for this material.

These results show that on this site the vertical stress profile depends on the local rheological material properties rather than on friction equilibrium on pre-existing faults.