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A combined method to determine the full state of stress from wellbore measurements: examples of application highlight the specific behaviour of shales in a geological sequence.

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Determination of the full stress tensor as a function of depth is a notoriously difficult problem. In this paper, we present an integrated method to determine the full state of stress in geological layers from wellbore measurements. After describing the two techniques it is based on, we present a few application examples, which outline the role of the rheology of geological formations on the sate of stress.

The first technique relies on interpreting images of the formation along the wellbore wall, especially in deviated wells [1]. The position of failure events associated to the drilling process, typically breakouts or drilling induced fractures, provides information on the full stress tensor, such as its orientation and the ratio between the principal stresses. Note that this method does not provide by itself a unique determination of the stress tensor.

The second technique relies on measuring the stress normal to a hydraulic fracture initiated with either hydraulic or sleeve (packer) fracturing [2], [3]. Different kind of information can be obtained, from just the intensity of the minimum stress to the determination of the three principal stresses, particularly when a combination of hydraulic and packer fracturing is used in wells drilled parallel to the minimum stress.

Integrating the two methods is a powerful tool to access the complete stress field through wellbore measurements and can be used to construct a vertical profile of the stress tensor.

As an illustration, we shall first present an example where the combination of methods was used to determine the three principal stresses and their orientation in a single layer, by combining hydraulic fracturing with the interpretation of drilling induced fractures in a deviated well in the North Sea.

An example of stress profiling in a limestone/shale sequence on the Eastern border of the Parisian basin where researches are carried out by the French gouvernement on nuclear waste repositories in deep geological formation will then be presented. The geological structure is horizontal, such that most of the variations in stresses can be attributed to variations in the rheology of the formations [3], [4]. It is observed that the limestone formations bear a large differential stress, whereas the state of stress in the shales is close to lithostatic. Furthermore, the orientation of the minimum horizontal stress is roughly constant throughout the sequence, but in the vicinity of the contact between the upper limestone and the shale layer, indicating a specific behaviour of that boundary.

Another example of a strong contrast of behaviour between shales and sandstones will be presented from two wells in Algeria. In that example, high deviatoric stresses also seem to be locked in place in the sandstone layers, whereas a low deviatoric stress is present in the shales.

These examples will illustrate the advantage of this integrated method, namely providing access to a vertical profile of the full stress tensor from wellbore measurements. They also suggest that the role of the rheology of geological formations on the state of stress in a geological sequence is mostly visible on the intensity of the stresses: variations in rheology, e.g. the long term plastic behaviour of shales, are correlated with large variations in the intensity of the stresses, whereas the orientation of the stress ellipsoid remains unaffected by variations in formation rheology.

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