In-situ stress measurement using borehole data: a part of comprehensive evaluation

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1. Introduction

Since the development of new oil fields goes to severe condition areas, drilling troubles caused by tectonic stress often happen. New technologies of well stimulation and Enhanced Oil Recovery (EOR) change a dynamic condition of the underground space. In those circumstances, information of the dynamic earth become more important for the petroleum industry, and a new science field, Petroleum Geomechanics, has been established. For those purposes, techniques for the earth stress evaluation are necessary.

Qualitatively, the stresses can be estimated through geologic features and tectnostratigraphic information. However, quantitative data of the each location and depth should be measured for the engineering purpose. Techniques using drilled core are methods of such quantitative evaluation. However, those methods have limitation of applicability due to high cost of coring and their own natures.

On the other hand, some well logging tools and bottom hole well testing techniques for geologic and petrophysics data acquisition are used also for the stress evaluation. Using such techniques, a lot of valuable information have been taken in a routine operation.

2. In-situ downhole stress evaluation techniques

1) Wellbore failure information

During drilling, the unbalance between earth stress and drilling fluid pressure can cause failure at a part of wellbore wall through compressional or tensile failure processes. Then the wellbore failure conditions observed by a caliper log or a resistivity borehole imager tool can give the direction of principal stress axes and stress magnitudes. Also the imager tools can give the information of fault and natural fractures that give the paleo-stress information.

2) S-wave splitting and phase velocity anisotropy

Some elastic wave logging tools can induce the S-wave with coherent polarization. Using such tools, phase velocity anisotropy can be detected. The reasons of such anisotropy are the stress anisotropy as well as anisotropy of the formation structure such as the aligned natural fractures and wellbore failure during drilling. The cause of the anisotropy can be known by the analysis of phase velocity dispersion.

3) Hydraulic fracturing for the stress measurement

The hydraulic fracturing stress measurement is performed in various depth in different industry and science fields as the direct measurement of the minimum principal stress. The standard method is the pressurization of a short openhole interval using a dual packer system. However, this time consuming and troublesome method is not performed so often in the industrial drilling.

Instead, small scale fracturing using pressure logging tool and Extended Leak-Off Test (ELOT) at the bottom of newly cased and cemented zone are used. Also, pressure history of well stimulation and EOR operations, fluid loss during drilling, and unintended fracturing monitored by PWD (Pressure While drilling) occasionally give the stress information.

3. Agenda of the in-situ stress evaluation

For the correct evaluation of the stress state using the in-situ measurement techniques mentioned above, some nature of them should considered as follows:

1) The methods except for the hydraulic fracturing are indirect methods with some interpretation of data based on empirical knowledge and assumptions of the formation conditions such as uniformity and isotropy.

2) The results are affected by the stress axes, and hole inclination and orientation.

3) To use the wellbore failure information, the poroelastic effect should be taken into account. By this mechanism, the failure is time dependent.

Another important fact is that no single method can give the comprehensive information of the stress state (axes and magnitude of the three principal stresses). Therefore, integrated studies using tectnostratigraphy and core techniques with in-situ measurements are necessary. (See the attached table)

手法	測定可能 項目	特徴	当所における実施内容
震源メカニズム	主応力方位、応力タイプ*	地震活動の活発な地域に限られる	基礎試錐、ケーススタディ対象地域の文献調査
構造地質史、地質構造	主応力方位、応力タイプ*	過去の応力履歴	基礎試錐、ケーススタディ対象地域の調査
GPS 観測による地表面変位	主応力方位	短期的な応力の変化の状況。地表面での値である。地震等の影響を受ける。	基礎試錐掘削地域の調査
水圧破砕法（エクステンディドリークオフテスト他）	最小主応力の大きさ・方位	原位置の正確な値が計測可能、生成されたき裂の向きがわかれば応力方位を決定可能	基礎試錐「チカップ」、「新津」、「東海沖～熊野灘」、その他内外油田で実施・分析
坑井破壊の情報による方法（DTF、ブレイクアウト）	主応力方位、最大・最小主応力の取り得る範囲	検層ログ（イメージツール、キャリパー）によるので、深度ごとの情報が取得可能. 岩石強度の情報が必要.	基礎試錐「富倉」「チカップ」「東海沖～熊野灘」他内外油田で実施
S 波位相速度異方性の分析	最大主応力方位、異方性の程度	検層ログ（弾性波検層ツール）によるので、深度ごとの情報が取得可能. 位相速度分散の分析が必要.	基礎試錐「東海沖～熊野灘」他内外油田で実施
コア法・DSCA	主応力各成分の大きさの比	定方位コアであれば方位の測定が可能、高圧容器が必要	基礎試錐「新津」において実施（実施：帝国石油，産総研）
コア法・ASR	主応力各成分の大きさの比	定方位コアであれば方位の測定が可能、コア取得直後に坑井元で実施	基礎試錐「新津」において実施（実施：帝国石油，ダイヤコンサルタント）

*応力タイプ：正断層型，横ずれ断層型，逆断層型の区別