Technology Development on *In Sit*u Stress Measurement during IODP Phase2

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Abstract

In the IODP Phase2, reliable methods to measure in situ tensor stress have to be developed. The methods need to be reliable in measuring tensor stress, and work under deep borehole and at the very depth intervals of the science target. We propose a new method, based on the evaluation of the current technologies.

1. Scientific and engineering needs

In the Geohazard Workshop report (Morgan et al., 2009), it is clearly stated that more reliable is situ stress should be obtained, and unfortunately horizontal stress has never been measured within DSDP/ODP/IODP. *In situ* stress is important not only for scientific interests (such as to know failure conditions and faulting regime) but also for engineering purposes (such as borehole stability analysis).

Stress distribution along the fault is one of the key parameters to construct earthquake model.

2. Current and existing technologies

2-1 XLOT (Extended leak-off test)

XLOT has been widely used in oil industry and scientific drilling to estimate stress, especially for the purpose of borehole stability study. Although there are several attempts to apply XLOT for scientific purposes, there are several problems:

1) Injected fluid volume

Usually they inject a large volume of fluid. This causes a lot of problems for precise stress estimation and borehole condition.

2) Compliance

Usually they apply fluid from the surface/ship. This causes improper compliance for precise stress estimate.

3) Fracture detection

Without confirming that a vertical hydraulic fracture was created (which is very difficult to do at sea, since impression packers are impractical and image logs are usually too low resolution) we cannot confirm that we are measuring the minimum horizontal principle stress unless it is significantly lower in magnitude that the vertical stress (i.e., we are in a normal or strike-slip faulting environment). Rather, it is safest to say we are measuring the minimum principle stress, which in a reverse faulting environment is likely to be vertical.

2-2 Borehole breakouts

Borehole breakout analysis is widely used to estimate stress direction, and stress ratio. However, it is necessary to know rock strength to estimate stress values. The rock strength is one of the most difficult parameters to measure and evaluate. There are still debates about the reliability of core strength measurements, such as strain rate of the measurements, the effect of uni-axial or tri-axial measurements and the effect of intermediate stress on the results.

2-3 Core stress measurements

ASR (Anelastic Strain Recovery) method has been proposed for stress estimate from recovered core samples. Because ASR test must be conducted immediately after the core retrieval, we need to carefully decide whether ASR is really necessary for on board measurements.

However, ASR suffers from poor theoretical background on why ASR results show tectonic stress. So it is necessary to confirm the validity of ASR stress data by comparing with reliable stress estimates.

2-4 Hydraulic Fracturing

Hydraulic fracturing (HF) method is suitable in principle for in-situ stress measurements, and the standard method is already established (Haimson and Cornet, 2003). However, there are limited cases in which HF method of in-situ stress measurement is applied to offshore wellbores prepared for ODP/IODP nor oil & natural gas development.

The reason for limited application of HF method to offshore wellbore can be drawn as follows;

1) During the in-situ test, the HF tool is fixed tightly by inflating packers to contact with the borehole wall. After the test, the packers should retract to their original shape and then the tool can move. However, there is considerable possibility that the packers fail to retract successfully and the tool gets stuck in the borehole.
2) The tool can be conveyed by drill string instead of wireline, and the use of drill string may reduce the risk of getting stuck in the borehole. However, the use of drill string makes it hard to arrange the wires connecting the downhole transducers and the surface data acquisition system, and furthermore, the use of drill string increases considerably the time for the tool running in the borehole.
3) For wireline logging in a riserless hole, the drill string is used to be a corridor between deck and wellhead, in which a logging tool is conveyed. However, it is not the case for the HF tool, because the tool is too big to run in the drill string.
4) Borehole image logging such as FMI has to be carried out twice separately. The first logging is carried out before the HF test in order to look for test sections which are free from pre-existing fractures, and the second one is carried out after the HF test in order to detect the fractures which have been induced or activated by the HF tests.

3. Experiences MDT during IODP Exp319

As the first expedition of the NanTroSEIZE Stage 2, IODP Expedition 319 was carried out this year, and a new wellbore was drilled to 1603.7 mbsf from seafloor at 2054 m water depth of Site C0009. In this expedition, the HF method was applied to measure state of in-situ stress at two test sections (Ito et al., 2009). However, due to a risk of the HF tool getting stuck in the borehole, the time for the HF test was restricted so short, i.e. one hour, that the test could not be carried out completely following the standard which defines the test procedure (Haimson and Cornet, 2003). Due to lack of time, no borehole image was taken after the tests. Therefore, we do not know the orientation of fractures which were induced or activated by hydraulic fracturing, and we can not estimate the direction of SHmax.

4. Developments of new methods for IODP Phase2

It is not possible to estimate the maximum horizontal stress by conventional hydraulic fracturing, mainly because of too large compliance of the hydraulic fracturing system.

A new strategy of HF for deep stress measurements (Ito et al., 2007, 2008), has been proposed recently to overcome the disadvantages of the conventional HF method as pointed out above. Furthermore, Ito et al. (2007, 2008) has proposed specifically a new tool of Deep Rock Stress Tester, DRST, to realize the new strategy. The DRST allows us to solve the essential problem for determining SHmax, which is involved in current testing system. As a result, the DRST will make easier to apply the HF method to offshore wellbores.

Judging from both operational and theoretical difficulties, we need to carefully pursue the possibility of developing new technologies and applying the new and existing methods with considering science targets and borehole conditions.

We also have to understand that DRST is based on several assumptions and will work in limited borehole conditions, for example for ultra deep conditions.

HTPF is also proposed to be used in IODP. The advantage of the HTPF is to re-open existing fractures to measure shut-in pressure and then calculate stress tensor. It will work if there is independent, favorably oriented fracture system (at least six) within the depth interval of science target. We are afraid that this is not always true that we can encounter this situation. Another problem is that we need six independent tests to determine stress tensor. As described in 3. Experiences MDT during IODP Exp319, we frequently encounter the situation that enough time for the experiments will not be guaranteed mainly for safety reasons due to borehole conditions.

For deep wells, such as deeper than 3 km, borehole walls tend to be damaged due to compressive stress concentration. When the pressure of the mud-water mixture used for drilling fulfills fracture conditions, tensile fractures can be formed at the point of minimum stress concentration [Stock et al., 1985; Brudy and Zoback, 1993]. Fractures in response to high compressive stress are known as borehole breakout (BBO) [e.g., Zoback et al., 1985;

Barton et al., 1988], and the tensile fractures are known as drilling induced tensile fractures (DIF). In the damaged borehole due to BBO, we have no technique for direct measurement of *in situ* stress. In combining with compressive strength, the stress state has been estimated for such conditions. However, as has been seen in Brudy et al. [1997], ambiguity in the estimation of the maximum horizontal stress is very large. The DIF is formed under high tensile stress concentration. As the thermal stress due to rapid cooling is one of the sources for tensile stress, the DIF does not propagate far from borehole wall. Besides, the fractures tend to close when the circulation of mud water stops. If we have any technology for detection of re-opening of such closed tensile fractures with increasing pressure, we can measure stress directly with certain accuracy. Measurement technologies for pressure and temperature are also necessary but it should be easier than the technology for detection of fracture re-opening.

New technology developments need to have a stage of conceptional design, testing and sea trial. Collaboration of IOs, EDP and science community is highly necessary to achieve this kind of IODP engineering development, and infrastructure of the platform, such as data communication and power supply through platform's cable system, and significant improvement of heave problem will help scientist to develop this kind of new technologies.

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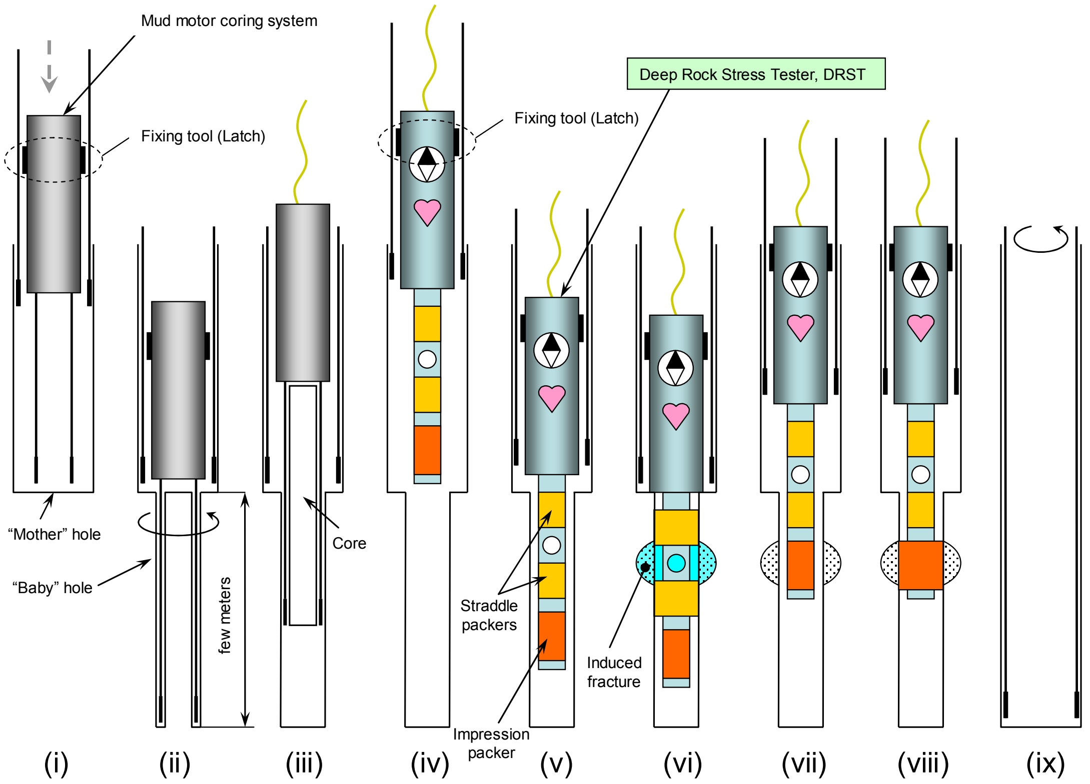

Schematic of the DRST and operation procedure.