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Horizontal stress contrast in the shallow marine sediments of the Gulf of Mexico sites Walker Ridge 313 and Atwater Valley 13 and 14 – Geological observations, effects on wellbore stability, and implications for drilling

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A B S T R A C T

Significant horizontal stress anisotropy was encountered in three blocks in the Gulf of Mexico drilled by the Gulf of Mexico gas hydrates Joint Industry Project, namely, Atwater Valley 13, Atwater Valley 14, and Walker Ridge 313. The geological factors responsible for this state of stress and the implications for wellbore stability and drilling operations are explored. In Atwater Valley 13 and 14, stresses at the well sites were perturbed by the underlying salt. In Walker Ridge 313, a combination of thrusting by adjacent salt and material anisotropy associated with the regional minibasin structure caused the maximum horizontal stress to rotate with depth. Horizontal stress anisotropy combined with a lack of heavy mud caused breakouts to form in the well Walker Ridge 313-G (WR313-G). A simple formula to predict the depth at which wells drilled with seawater are prone to breakouts is derived. Evidence is presented that the breakouts in WR313-G produced heavy cavings which were mainly responsible for the tight hole conditions encountered while drilling this well. However, it is shown that bottom hole assembly (BHA) design and drilling practices such as backreaming may have exacerbated these problems. Modifications to drilling practices based on the experience gained from drilling WR313-G helped to improve the quality of the neighboring borehole WR313-H.

1. Introduction

A frequently made assumption when modeling shallow marine sediments in the Gulf of Mexico is that the horizontal principal stresses are equal or close to equal (Ozkale, 2006; Wojtanowicz et al., 2000). This paper discusses recent evidence of strong horizontal stress contrast from two drilling expeditions of the Gulf of Mexico Gas Hydrate Joint Industry Project (JIP).

During the Leg I campaign in April and May of 2005, the JIP drilled and cored a series of riserless vertical wells at potential gas hydrate sites located at Atwater Valley and Keathley Canyon in the Gulf of Mexico. In Atwater Valley, two wells were drilled with conventional rotary bits (AT13 #1 and AT14 #1) and three were drilled with corers (AT13 #2, ATM #1, ATM #2). In Keathley Canyon, one well was drilled with a conventional rotary bit (KC151 #2) and one was cored (KC151 #3). The expedition was focused on drilling, logging, and coring operations for evaluation of gas hydrate related hazards associated with drilling through clay-dominated sediments that are typical of the shallow sub-seafloor in the deepwater Gulf of Mexico (Ruppel et al., 2008). In 2009 the Leg II expedition of the JIP aimed at evaluating gas-hydrate occurrences in coarser-grained sediments. The JIP conducted logging-while-drilling operations that included drilling and logging seven wells in three blocks: Green Canyon 955, Walker Ridge 313, and Alaminos Canyon 21 (Boswell et al., 2012; Collett et al., 2011; Shedd et al., 2012). The locations of these blocks are shown in Figure 1.

A constant challenge during the drilling campaign was to get optimal data quality by maintaining borehole stability in shallow unconsolidated sediments. According to Collett et al. (2009) many of the encountered drilling hazards were not gas hydrate-related. Issues such as borehole instability, drill cuttings removal, influxes of free gas and an apparent shallow water flow were among the problems faced during the two expeditions. In spite of these problems, most wells successfully reached their targets. Insights into optimizing drilling strategies for marine riserless drilling programs were gained.

In this paper we analyze and review the stress field and stress directions as determined from features indicative of mechanical failure of the wellbore wall observed in logging-while-drilling images and caliper data from the Atwater Valley 13 and 14 sites

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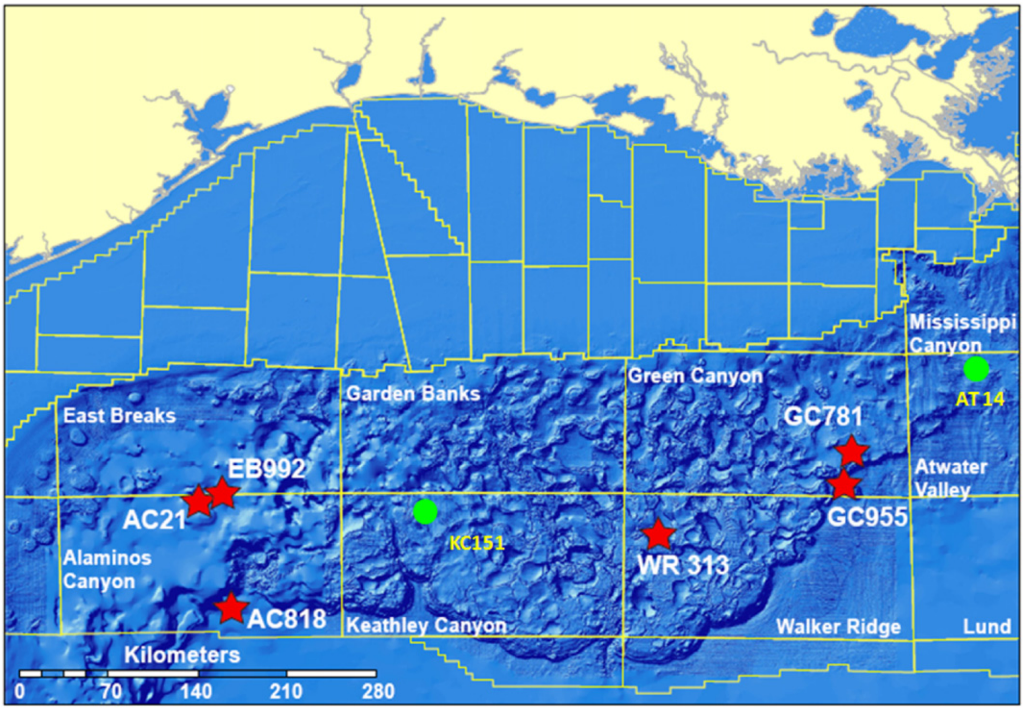

Figure 1. Location map of the northern Gulf of Mexico showing the different JIP sites. JIP Leg I sites are displayed by green dots. The red stars indicate locations drilled during Leg II. Note: The site in AC818 was not drilled since it revealed evidence of overpressures (figure modified from Boswell et al., 2009). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Leg I) and the Walker Ridge 313 site (Leg II). Two types of failure modes are most commonly observed in wellbores, namely "breakouts", a form of compressive failure and "drilling-induced fractures", a form of tensile failure. Both types of failures can provide information about stress orientations. Drilling-induced compressive rock failure leading to breakouts occurs where the maximum hoop stress is higher than the rock strength (Zoback, 2007). In a well drilled parallel to the vertical principal stress Sv, borehole breakouts tend to be aligned with the azimuth of the minimum horizontal stress. On the other hand, drilling-induced tensile fractures develop along the azimuth where the hoop stress is most likely to go into tension. These fractures tend to be aligned with the azimuth of the maximum horizontal stress. Both breakouts and fractures can be identified from resistivity images. Tensile fractures look like cracks along the wellbore wall, while breakouts usually cover a bigger area of the wellbore and the edges are not so well defined. In vertical wells, both features tend to be aligned with the well axis and occur as conjugate pairs separated by 180°. Hence they can be distinguished from natural fractures or failure of the borehole wall caused by hydraulic erosion or mechanical wear. Since tensile fractures observable on wellbore images occur when the wellbore pressure exceeds the fracture gradient, this mode of failure can frequently be correlated with the existence of high wellbore pressure or ECD.[1]

Zoback and Zoback (1980) used breakout information as well as earthquake focal mechanisms to build regional stress maps. Borehole breakouts as stress indicators are also described by Bell and Gough (1979), Plumb and Cox (1987), Plumb and Hickman (1985), Yassir and Zerwer (1997), and others. Examples of drilling-induced tensile fractures as stress indicators are shown in Castillo et al. (2000), Wiprut and Zoback (2000), and Zoback (2007).

The Gulf of Mexico is considered to be a passive margin basin in a plate tectonic context with an extensional stress regime (Stein et al., 1989), but it is actively deforming because of the interplay of salt tectonics and sedimentary loading (Peel et al., 1995). The magnitude of the horizontal stresses in the Gulf of Mexico is not expected to be larger than that of the vertical stress. Rapid deposition at the shelf edge causes slumping, which results in some stress anisotropy. However, horizontal stresses near the seabed are sometimes assumed to be equal to the vertical stress due to their plastic nature (Wojtanowicz et al., 2000). In such circumstances, drilling-induced fractures and breakouts should not exhibit a preferred orientation. However in this paper, evidence of consistently oriented wellbore damage features in sediments located less than 300 feet below the sea floor is presented for sites in Atwater Valley 13, Atwater Valley 14, and Walker Ridge 313.

In the next section, the geological settings of the wells in Atwater Valley and Walker Ridge are described. In Section 3, image logs showing evidence of significant horizontal stress contrast at both sites are presented. In Section 4, possible geological factors that could explain the observed horizontal stress anisotropy are considered. In Section 5, the implications of high horizontal stress contrast for wellbore stability and drilling operations are explored for the Walker Ridge sites.

2. Geologic framework

The present-day Gulf of Mexico is characterized by a complex interaction of salt tectonics and sedimentary loading. The rifting during the Middle Jurassic created deep graben and elevated horst structures whose topography very probably influenced the post-rift deposition of the Upper Jurassic Louann Salt (Peel et al., 1995). Due to deposition of a high volume of Cretaceous–Cenozoic clastic sediments, the shelf margin prograded several hundred kilometers

[1] ECD stands for "Equivalent Circulating Density". It is the density of a static column of drilling fluid required to generate the pressure at a given location in the borehole during mud circulation. The pressure developed during mud circulation is higher than the pressure exerted by a static mud column of the same density due to frictional effects.