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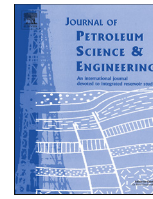

The effect of drilling mud properties on shallow lateral resistivity logging of gas hydrate bearing sediments

Jiaxin Sun [a], Fulong Ning [a,*], Nengyou Wu [b], Shi Li [c], Ke Zhang [c], Ling Zhang [a], Guosheng Jiang [a], V.F. Chikhotkin [a]

[a] Faculty of Engineering, China University of Geosciences, Wuhan 430074, China
[b] Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China
[c] State Key Laboratory of Enhanced Oil Recovery, Beijing 100083, China

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ABSTRACT

Resistivity logging is one of the most important ways of identifying and estimating the saturation level of gas hydrates in permafrost and ocean regions. In practical drilling operations, resistivity loggings, especially shallow lateral resistivity logging in gas hydrate bearing sediments (GHBS), are likely to be affected by drilling mud invasions. Here, we use available data from site measurements to construct a two-dimensional model for hydrate reservoirs around the borehole SH2, a hole that was drilled during the first expedition in Shenhu area of South China Sea to examine and drill into gas hydrates. We then use this model to investigate the characteristics of drilling mud invasions and the effect of drilling mud properties (e.g., temperature, density, and salinity) on resistivity logging using a numerical simulation. This simulation and associated calculations indicate that shallow lateral resistivity logging is significantly affected by variations in drilling mud temperature, which leads to hydrate dissociation and the formation of secondary hydrates. Increasing drilling mud salinity accelerates hydrate dissociation, and has a greater effect on shallow lateral resistivity logging than the free gas produced during drilling and any potential mud density influence, which is generally dependent on the depth at which the drilling mud invasion occurred. This means that future drilling operations should focus on ensuring that the temperature, salinity, and density of drilling muds remain within a reasonable range in order to minimize the effect of mud invasions on resistivity logging data.

1. Introduction

Gas hydrates are non-stoichiometric inclusion compounds formed when hydrophobic gas molecules (usually methane and carbon dioxide) come into contact with water (host molecules) under low-temperature and high-pressure conditions (Sloan, 2003). Gas hydrates are widely distributed in areas of permafrost and in marine sediments at depths of >300 m below the seafloor. The exhaustion of traditional oil and gas resources, combined with a continuous increase in consumption, means that unconventional energy sources, such as natural gas hydrates, are considered to be the most promising future sources of energy. Klauda and Sandler (2005) state that 74,000 Gt of CH_4 is trapped in gas hydrates within marine zones, three orders of magnitude larger than current worldwide conventional natural gas reserves. Consequently, the exploration and exploitation of marine gas hydrates have become a hot topic for current and future energy research.

The main methods of exploration of marine gas hydrates are geology, geophysics, geochemistry, and core drilling based investigations. Although geophysical approaches including seismic detection (Riedel et al., 2002), well logging (Collett, 2001), and the latest marine electromagnetic technology (Schwalenberg et al., 2010) are the most widely used method of gas hydrate exploration (Song et al., 2002), core drilling is the most direct way to identify and evaluate marine gas hydrate reservoirs. A significant amount of marine gas hydrate drilling and corresponding well logging has been undertaken in a number of oceanic zones worldwide. Although a number of advances have been made, there are still three unfavorable factors (i.e., poorly characterized reservoirs, unreliable production technology, and high risks) that have hindered current gas hydrate exploration and exploitation (Ning et al., 2012). The risk factor refers to issues including drilling safety (such as wellbore instability), geological disasters, environment impacts of gas hydrate release, and formation deformation in the production processes. This indicates that ensuring safe drilling

* Corresponding author. Tel.: +86 18963963512; fax: +86 2767883507.
E-mail address: nflzx@cug.edu.cn (F. Ning).

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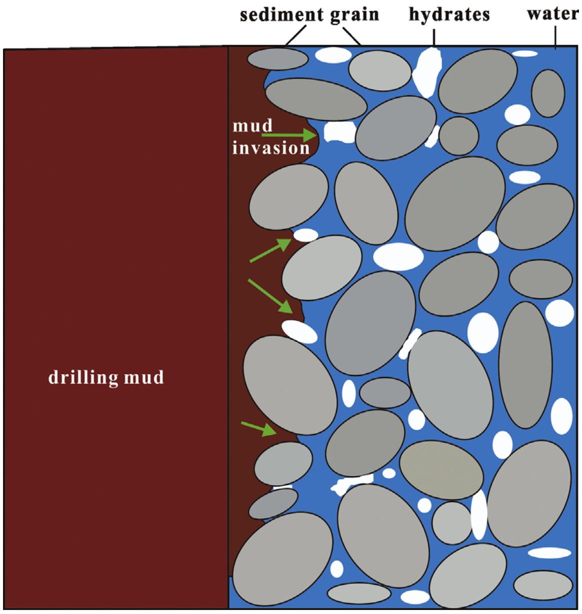

Fig. 1. Schematic diagram of mud invasion into a GHBS (Ning et al.. 2013b).

is a key issue in potential gas hydrate extraction. Previous research has indicated that overbalanced drilling, involving pressures no higher than fracture pressure, is the preferred option for marine gas hydrate drilling (Ning et al., 2008; Collett et al., 2009; Birchwood and Noeth, 2012). This approach uses water-based drilling mud that displaces primary pore fluids (air, water) around the borehole and invades the gas hydrate bearing sediments (GHBS) as a result of hydraulic pressure gradients. It differs from the mud invasions encountered during drilling into conventional oil and gas formations, as drilling into GHBS may also be accompanied by the formation and dissociation of hydrate as a result of the frictional heat generated by the drilling tool and the relatively high temperature of the drilling mud (Ning et al., 2012, 2013a; Fig. 1). The fact that dissociated GHBS-derived methane and reformed hydrates are thought to act as insulating mediums, and that GHBS salinities are also reduced by hydrate dissociation, means that drilling mud invasions have significant effects on resistivity logging undertaken during drilling, especially on shallow lateral resistivity logging, potentially inducing errors in logging interpretation and identification (Ning et al., 2012, 2013a). Therefore, use of overbalanced drilling when investigating marine gas hydrate deposits means that mud invasions into GHBS and the possibly associated dissociation and reformation of gas hydrates are most commonly observed during marine hydrate exploration and exploitation drilling. Previous research undertaken during the GMGS-1 gas hydrate drilling project in the South China Sea focused on the use of TOUGH+HYDRATE software (Moridis et al., 2008) to simulate the one-dimensional invasion of drilling muds with different properties into GHBS, using gas hydrate reservoirs within the SH7 borehole as a case study. We also studied the processes involved in mud invasions and discussed the general influence of these invasions on resistivity logging and well stability (Ning et al., 2013a). Here, we focus on another borehole, SH2, establish a two-dimensional analytical model for this borehole, and further analyze the characteristics of drilling mud invasions and the effects of these invasions on well logging identification and hydrate formation assessment. The results of this study will contribute to improve the theoretical interpretation of well logging inversion data and enable more accurate correction of mud invasion-induced well logging distortions.

2. Research methods

2.1. Background

The study area is located in the southeast of the Shenhu Underwater Sandy Bench area of the central part of the north slope of the South China Sea, between the Xisha Trough and the Dongsha Archipelago. The first Chinese expedition to drill gas hydrates, GMGS-1, was undertaken in this area during April and June 2007 on behalf of the Guangzhou Marine Geological Survey (GMGS) and the Ministry of Land and Resources of the PR China (Fig. 2; Zhang et al., 2007). A total of eight sites were drilled and well logged during this project, with cores recovered at five of these sites, including three sites with recovered gas hydrate samples (SH2, SH3, and SH7; Wu et al., 2007, 2008; Zhang et al., 2007). Core sample analysis indicates the presence of gas hydrates at depths of 153–229 m beneath the seafloor, with thicknesses of 10–43 m and porosities of 33–48%, in areas with water depths of 1108–1245 m. These type I methane hydrates with 26–48% saturation are disseminated throughout the sediment, and the gas produced from these hydrates was originally derived from microorganisms and consists of 96.1–99.82% methane. *In situ* measurements indicate a bottom-water temperature of 3.3–3.7 °C, with a geothermal gradient of 43–67.7 °C km^{-1}, corresponding to a sea-bottom heat flow of 74.0–78.0 mW m^{-2} (average of 76.2 mW m^{-2}).

Riserless drilling is undertaken on a vessel during the GMGS-1 project on the vessel. The used drilling assembly at Site SH2 is shown in Table 1. The rotation rate of drill pipes is between 70-80 r min^{-1}. Seawater is used as a drilling mud with a displacement of

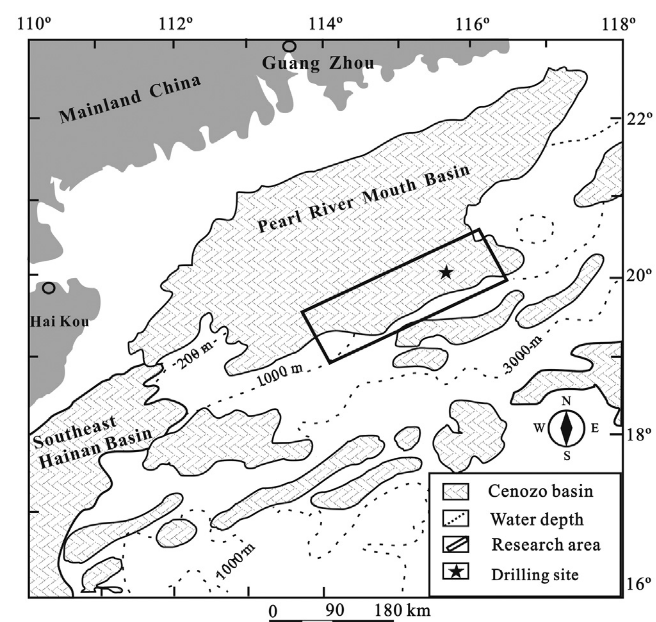

Fig. 2. Location of the Shenhu GMGS-1 project within the South China Sea (Wu et al., 2009).

Table 1
The bottom hole assembly used at Site SH2 in the Shenhu area (Hu et al., 2009).

Main bottom hole assembly	Diameter (mm)	Number	Attached Equipment
Blade core bit	228.6	1	Long-sealing pup joint
Drill collar	177.8	8	Short-sealing pup joint
Drilling pipe	127	22	Landing nipple
Aluminum drilling pipe	175	100	Shut-off nipple
Drilling pipe	127	1	Floating valve nipple