Marine and Petroleum Geology 58 (2014) 187–198

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Potential impact of gas hydrate and its dissociation on the strength of host sediment in the Krishna–Godavari Basin

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ARTICLE INFO

Article history:
Received 8 November 2013
Received in revised form
13 May 2014
Accepted 15 May 2014
Available online 24 May 2014

Keywords:
Gas hydrate
Pressure coring
Dissociation
Soil classification
Undrained shear strength
NGHP-1

ABSTRACT

During the Indian National Gas Hydrate Program (NGHP) Expedition 01, conducted between April–August 2006, a number of pressure cores containing gas hydrate-bearing sediments were recovered under *in-situ* pressures. Two of these cores (NGHP-01-10B-08Y and NGHP-01-21C-02E), after initial characterization, were sub-sectioned. They were then rapidly depressurized and frozen in liquid nitrogen. A number of sub-sections were delivered to the University of Southampton for further analysis. High-resolution 3-D X-ray computer tomography carried out in the first instance revealed that the structure and form of the hydrate within the host sediment had been preserved. However, the exsolution of free gas from the pore water during depressurization, and before the subsequent freezing, had caused the formation of significant voids within each sub-sections, precluding detailed testing of intact cores.

Following this initial appraisal detailed soil characterization, such as particle size analysis, water content and salinity, were carried out on sub-samples from the core sections following thawing and dissociation of the hydrate. In addition, specific gravity and strength tests, including liquid and plastic limit and undrained triaxial compression tests, were carried out on the combined sediment from all the core sections. The results of these tests showed the sediment to be a high plasticity clay. The remoulded combined sediment had a relatively high water content, and low shear strength, considering the vertical effective stress to which the *in-situ* sediment had been subjected, therefore creating significant under-consolidation of the *in-situ* sediment.

In this paper a number of hypotheses are presented in an attempt to explain this under-consolidation, including factors, such as the change in moisture content due to hydrate dissociation, over-pressure, the influence of salinity on sediment strength, as well as the effect of hydrate veins. It is considered likely that hydrate veins, enhancing sediment strength, were the main contributing factor to the apparent under-consolidation. Hydrate dissociation induced by production of gas hydrates within this under-consolidated sediment may potentially lead to seafloor instability and further research is required to assess this likelihood.

1. Introduction

In recent years considerable interest has arisen in the potential of methane gas hydrate as a significant source of methane gas for our future energy needs. Gas hydrate, a clathrate compound where water molecules encase gas modules to form an ice-like compound under certain conditions of temperature and pressure, are ubiquitous within the continental margins of the world's oceans and below permafrost in Arctic margins (Kvenvolden, 1993). Recent advances in estimating the volume of methane gas sequestered within hydrate suggest values between 1.7×10^{15} m^3 (Archer et al., 2009) and 4×10^{16} m^3 (Wood and Jung, 2008). Although these values may differ by an order of magnitude, even at the low estimate, they still represent a volume greater than current estimates (3.4×10^{14} m^3) of known reserves, or potential undiscovered resources, of conventional natural gas (Ahlbrandt et al., 2005). This large and as-yet untapped resource has led to a growing number of national governments, some without conventional fossil fuel reserves, sponsoring exploratory offshore drilling expeditions of their

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http://dx.doi.org/10.1016/j.marpetgeo.2014.05.008
0264-8172/

continental margins, such as Canada, China, India, Japan, South Korea, USA as well as in the Arctic (Canada, Japan, USA) to investigate this potential resource.

One such research expedition was the Indian National Gas Hydrate Program Expedition 01 (NGHP-01), which was conducted between April–August 2006. The goal of this multi-disciplinary expedition, including drilling, coring and logging operations, was to characterize the occurrence, distribution and extent of gas hydrate along the Indian continental margins, and in particular the geological and geochemical controls associated with the hydrate, to enable an assessment of the potential energy resource from gas hydrate. During the NGHP-01 expedition a total of 21 site locations were investigated (Fig. 1A) with 39 boreholes drilled at the various sites. Of the 39 boreholes, 12 were logged with logging-while-drilling (LWD) tools, 13 were wireline logged and 21 were used to recover sediment cores. The most extensively investigated area during the expedition was the Krishna–Godavari Basin located in the central eastern passive continental margin of the Indian Peninsula; 15 of the 21 sites investigated were located in this area (Fig. 1B). The Krishna–Godavari Basin was formed through a number of depositional cycles ranging from the Late Carboniferous to the Holocene, with resulting sedimentary thickness of several kilometers (Rao, 2001) that are predominantly clay/claystone with minor sand and siltstone bands. The richest marine gas hydrate accumulations in the area was discovered at Site NGHP-01-10, which was located at the top of a tightly folded, NE-SW trending ridge structure, characterized by numerous horst and graben features showing extensive faulting (Ramana et al., 2009). Logging data, and inferred infra-red data from conventional cores recovered at the site, suggested that hydrate existed as solid nodules and as veins in high angle, and cross-cutting horizontal, fractures in fine grained sediment over a depth interval of ~25–160 m below seafloor (mbsf). Estimates of hydrate saturations in the pore space were initially reported to be around 80% for this interval, although these have subsequently been revised to ~40% when taking account of the anisotropy of the hydrate veins in the sediment (Cook et al., 2010; Ghosh et al., 2010). Due to the abundance of hydrate at this site, additional sites were chosen (NGHP-01-12, 13, 21) in close proximity to NGHP-01-10 to better delineate the occurrence of gas hydrates in this region. All sites were located in the same seismically distributed section, and showed the same sediment, and hydrate, morphology (Collett et al., 2008).

Due to the thermobaric nature of gas hydrate, changes in pressure conditions during conventional core recovery lead to

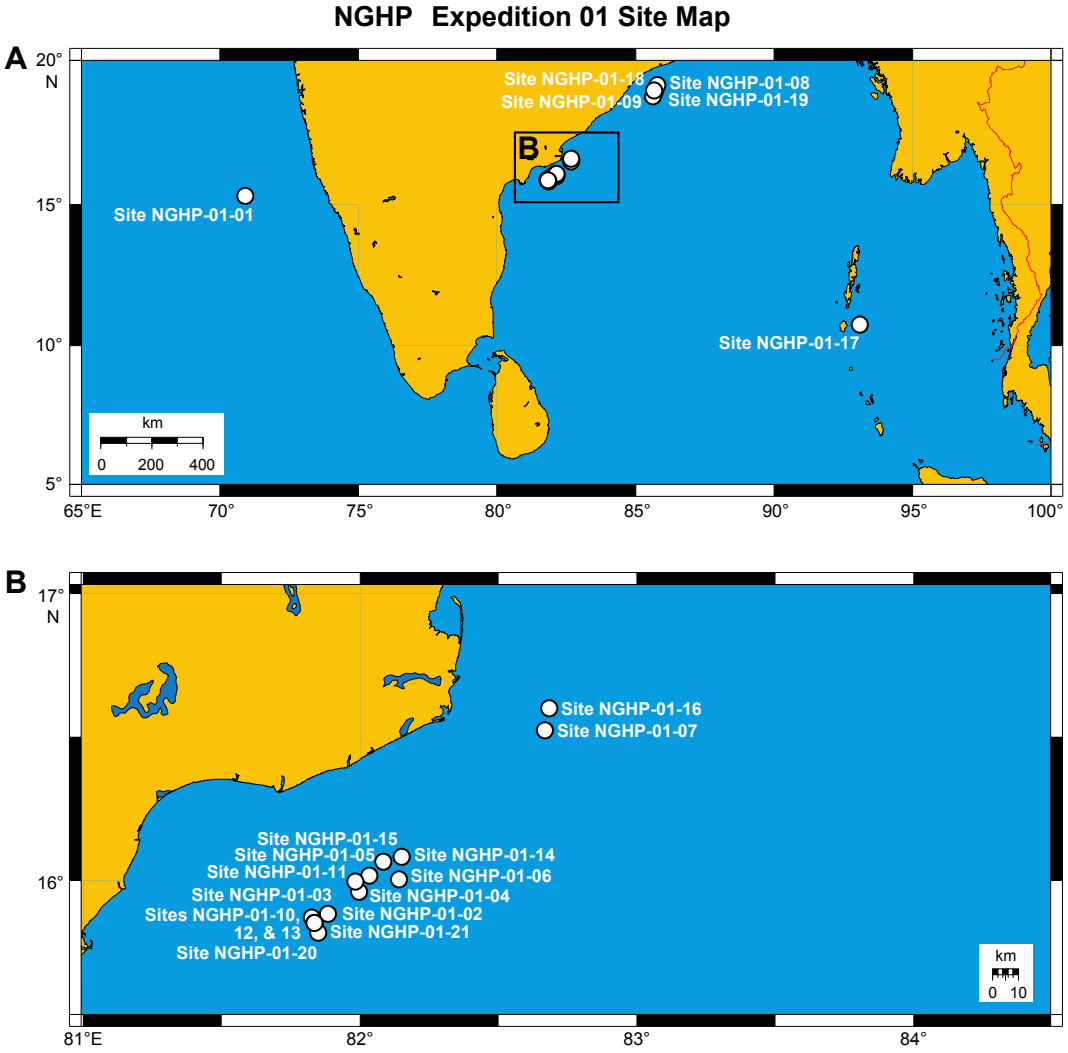

Figure 1. A) Site location map highlighting the location of the 21 drill sites on the Indian continental margin drilled during NGHP-01 expedition. B) Inset map showing the drill sites within the Krishna–Godavari Basin.