Gas hydrate-related sedimentary pore pressure changes offshore Angola

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ABSTRACT

The thickness of the free gas column below the base of the gas hydrate stability zone is a proxy for the pore pressure in the free gas bearing sediments underneath. In the study area the pore over-pressrues derived under this assumption range between 0 and 1430 kPa ± 30% which appear to be the typical maximum over-pressure that the gas hydrate sediments can withstand before hydro-fracturing occurs. A number of gas chimneys rise from the gas cloud to the seabed. Over-pressures of about 1000 kPa are found under these gas chimneys. We interpret the fact that over-pressures under chimneys are significantly below the maximum over-pressures as an indication of draining of the gas reservoirs by gas blow-out events. The upslope prolongation of gas clouds at the base of the gas hydrate stability zone away from known gas sources suggests that gas hydrate formation changes the permeability of the host sediments and steers fluid migration pathways. Both the calculated over-pressure distribution and the calculated free gas distribution indicate that gas hydrates significantly reduce permeability of marine sediments on a basin-wide scale.

INTRODUCTION

Continental margins are dynamic environments. Fluids are migrating through the sediments because of sediment compaction, in situ production of biogenic gases, and by thermogenic break-down of organic carbon during burial and by heating of sediments due to volcanic intrusions (Berndt, 2005). When rising gas-rich fluids enter the gas hydrate stability zone they form gas hydrates if temperatures are low and pressures are high (Sloan Jr., 1998).

The way in which gas hydrate formation influences the fluid flow systems in continental margins is still poorly understood. In particular, it is debated whether gas hydrates can significantly change the permeability of sediments which would allow pore pressure build-up.

It is important to understand the effects of gas hydrates on fluid flow systems, because the presence of gas hydrates has important consequences for their role in slope stability in a time of deep-water exploration, for their mobility in response to climate change and for the risks associated with their exploration as an energy resource after all 500 to 2500 Gt of carbon are stored in marine gas hydrates and the free gas reservoirs associated with them (Archer and Buffett, 2005; Milkov, 2004). This is up to half of all the carbon in the Earth's carbon cycle.

In this paper we evaluate a large, high-resolution 3D seismic data set from the Angolan Margin mapping the thickness of the free gas cloud beneath the bottom simulating reflector (BSR) as a proxy

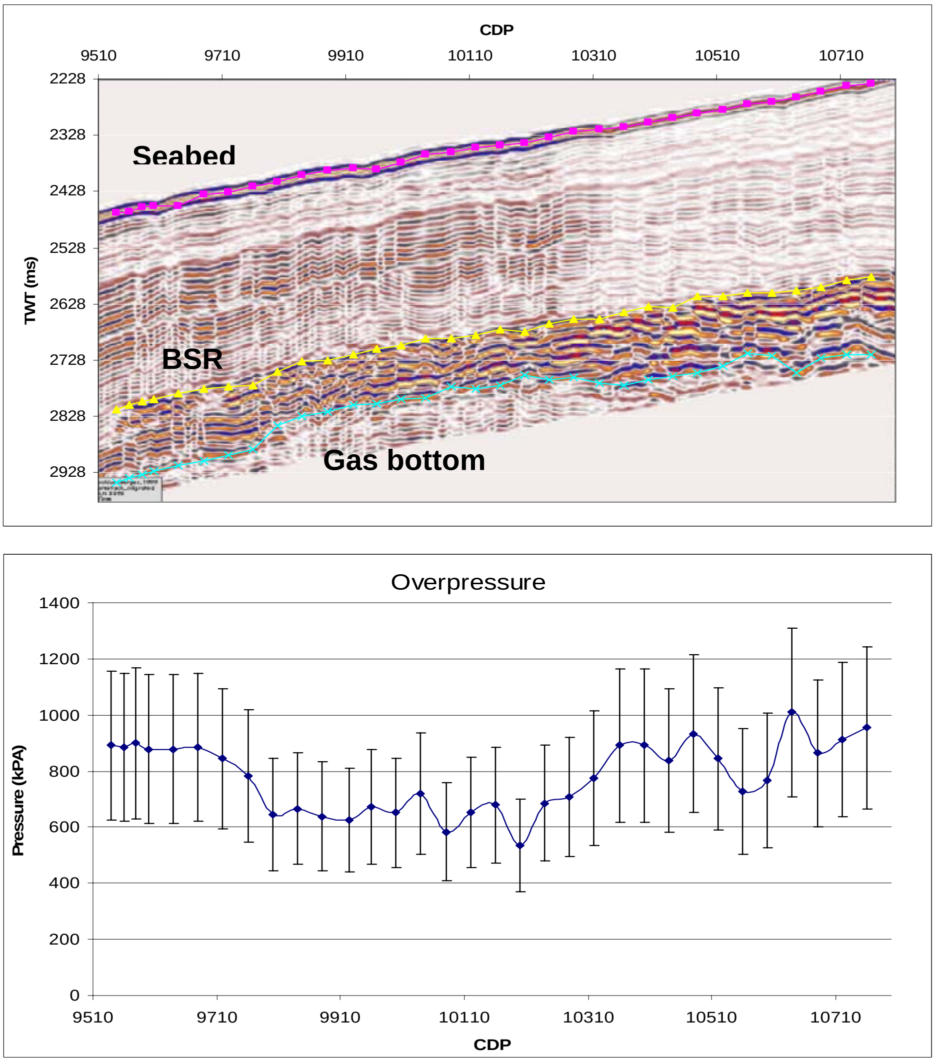

Fig. 1: Picking of seabed, BSR and gas bottom in the seismic profiles (top). The pressures shown in the bottom diagram are excess pore pressures above hydrostatic pressure. The errors are based on picking accuracy and uncertainties in velocities and density.

for over-pressure. This method has limitations but provides first order calculations of sediment pore pressure over large areas (Hornbach et al., 2004). The objective of the paper is to (a) constrain the effect of gas hydrate formation on sediment permeability and (b) test the hypothesis that gas chimneys develop in the areas of highest over-pressure as a result of hydro-fracturing (Berndt et al., 2003).

DATA BASE

The study is based on high-resolution 3D seismic data acquired by BP Exploration from Block 31 in 1999 for exploration purposes. The 3D dataset has an inline and crossline spacing of 12.5 m. The 3D dataset was processed by BP Exploration including poststack time migration. The frequency content of the dataset is 90 Hz in the shallow subsurface which corresponds to vertical resolution of 10 to 12 m.

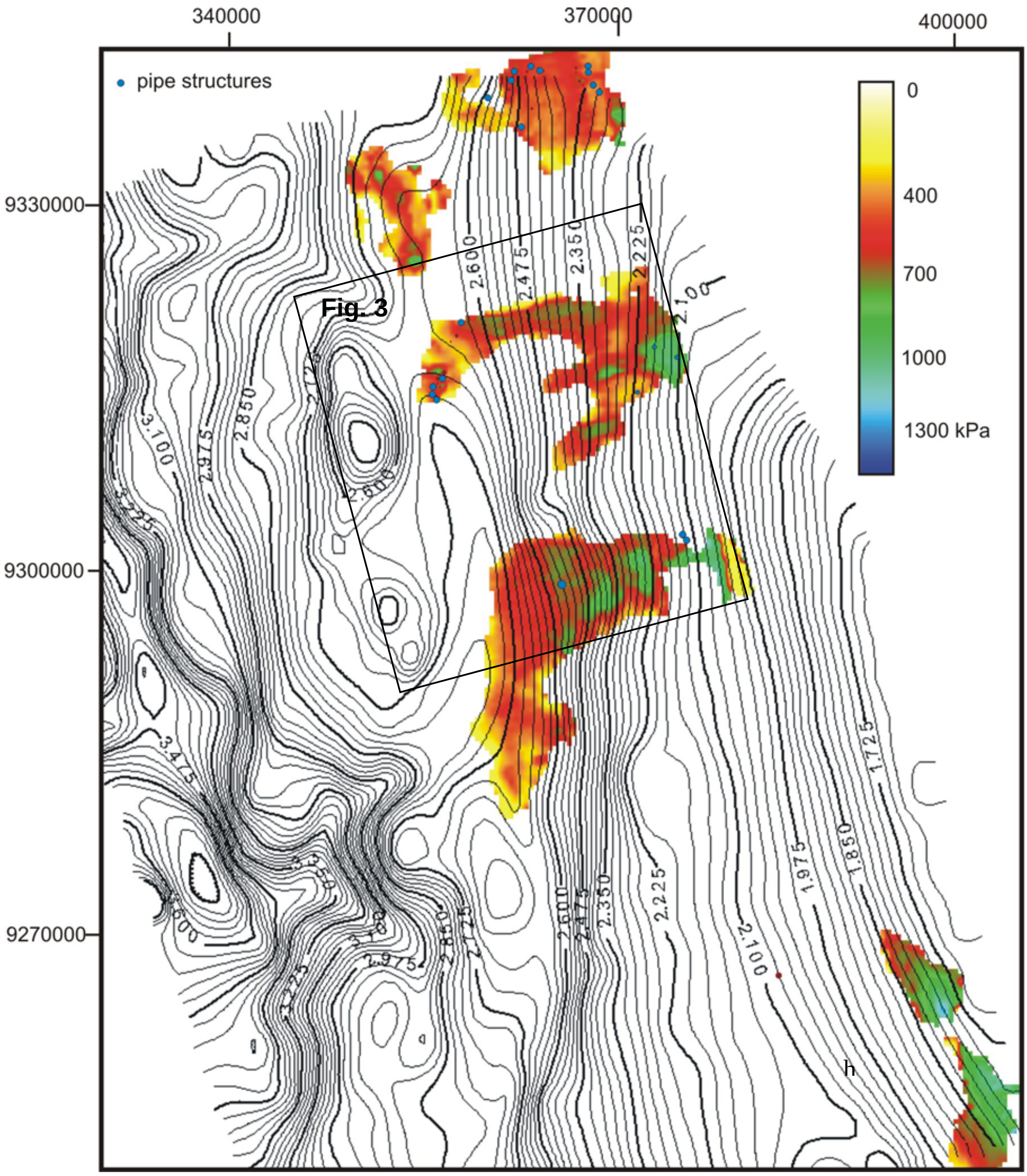

Fig. 2: Overpressure map of the study area offshore Angola showing the magnitude of overpressure under the BSR as derived from the free gas distribution under the Gas hydrate stability zone. Contours show seabed depth in seconds TWT.

OVER-PRESSURES

The over-pressures determined from gas cloud heights (Fig. 1) in the study area vary between 0 and 1430 kPa ± 30% (Fig. 2). There is a general trend of increasing over-pressure from the north to the south with typical over-pressures rising from 400 to 1000 kPa in the north to 800-1200 kPa in the south. Within individual gas clouds the over-pressure is commonly increasing upslope which may be

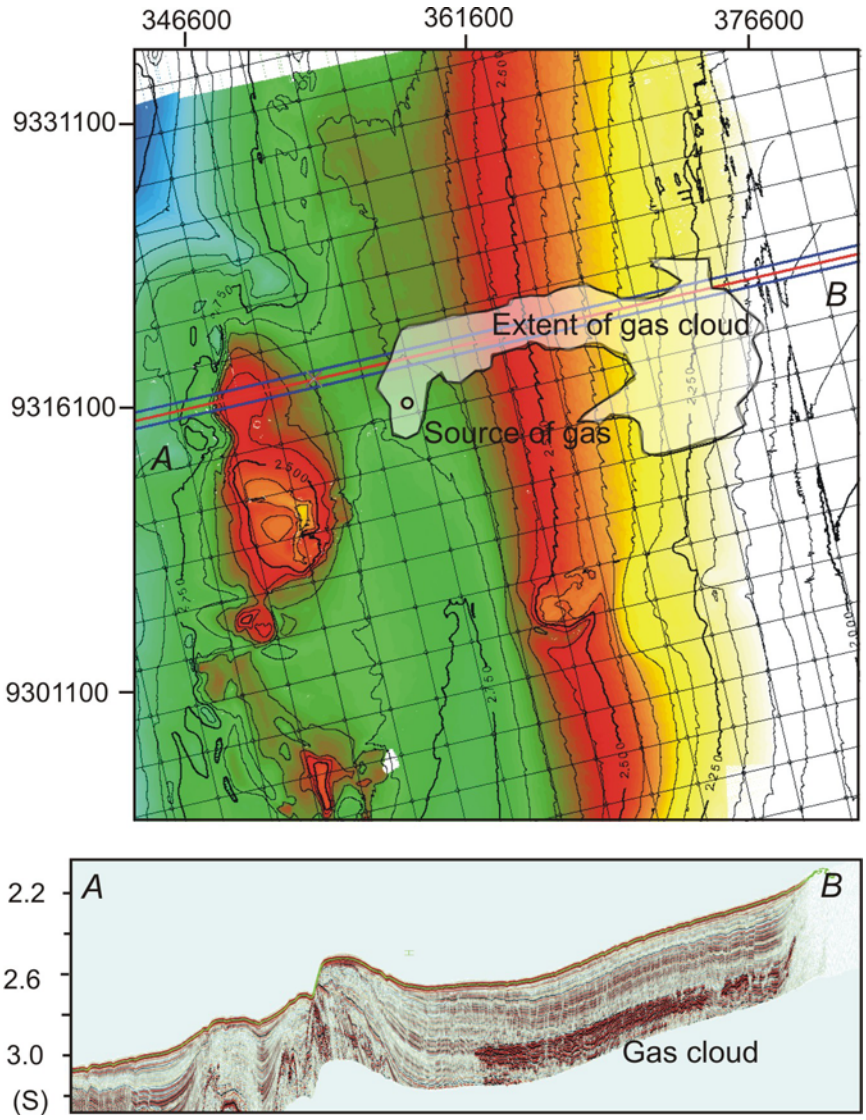

Fig. 3: Distribution of free gas above one of the known gas reservoirs (circle). Note, that the gas cloud is extending consistently extending upslope from the source and maintains its width of approximately 5 km. Bottom: Corresponding seismic line.

caused by gas migration and accumulation in the shallowest part of the gas clouds. The maximum overpressures of 1200 to 1400 kPa likely indicate the maximum strength of the sediments above which they fail by hydro-fracturing.

Seismic pipe structures, i.e. vertical columns of high seismic amplitudes from the top of the gas cloud to the seabed, are abundant within the data set. These have been interpreted as the result of sudden gas blow-outs by hydro-fracturing (Berndt et al., 2003; Bouriak et al., 2000). Although the pipes occur in areas of high overpressure of typically 1000 kPa, they are most often not associated with the highest over-pressures. We explain this observation by venting of the gas and decrease of over-pressure once the pipes develop.

GAS CLOUD DISTRIBUTION

Gas hydrate-related BSR occur mainly in the northern part of the study area. There is no spatial relationship with the presence or absence of salt diapirs. As gas hydrate stability is dependent on the salinity of pore water (Sloan Jr., 1998) this indicates that salt induced pore water salinity variations are a fairly local phenomena.

Fig. 3 shows a detailed map of one of the gas clouds for which a known gas source could be identified (circle in the western part of the gas cloud). There is a striking correlation of this gas cloud with the local dip of the seabed. The gas cloud follows the seabed upslope from the source, first in a northeasterly and then in a easterly direction. The 3D seismic data clearly show that this distribution of the gas cloud is not controlled by lithological changes, i.e. the top of the gas cloud cross-cuts the strata.

From the close spatial correlation of the gas cloud extent and the seabed we conclude that gas hydrates in this area reduce the permeability of sediments. As the gas rises from the gas reservoir and reaches the gas hydrate stability zone it forms hydrate which clogs the pore space and prevents deeper gas from ascending further. The following gas then migrates upslope along the base of the hydrate stability zone forming new hydrate. In the example shown in Fig. 3 this process continues for some 50 km. The continuous width of the gas cloud is a measure for continuous permeability and steady state gas supply and migration.

CONCLUSIONS

The distribution of free gas at the base of the gas hydrate stability zone on the Angolan Margin is a proxy for pore pressure variations. Gas hydrates reduce the permeability of the sediments varying the basin's fluid flow system, and causing over-pressure by gas trapping. In cases where the over-pressure exceeds the strength of the sediments, they fail by hydro-fracturing leading to blow-out of gas to the seabed.

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