P524 11000 M LONG GAS BLOW-OUT PIPES

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Summary

A cluster of approximately 100 relative large craters (from 100 m to 500 m in diameter) exists at seabed over a 65 km^2 area offshore Nigeria. Cone structures, interpreted as diatrems, and underlying vertical pipes are observed on seismic data below the craters. The pipes can be traced continuously from seabed and 1000 to 1300 m down to interpreted sandy reservoir zones. These structures are interpreted as vertical fracture pipes similar to outcrop analogues observed in Rhodes, Greece. Seismic modelling proves that such structures should be visible on seismic data. High pressure gas is interpreted to have formed the pipe structures.

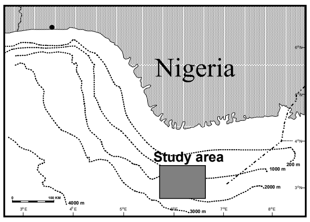

Figure 1. Location of study area in deep water Nigeria.

Introduction

A cluster of circular depressions with underlying pipe-like structures has been observed on the seabed above a mapped structural 4-way closure located on the southern Niger Delta slope (Figure 1). The structure is a compressional dome located just south of a southward moving thrust plane. A N-S striking transtensional fault is subdividing the dome structure. The fault is still active and the seabed is offset. The aim of this paper is to describe the craters and associated pipe structures and to suggest a formation model.

Seismic observations of vertical pipes

The craters at seabed (Figure 2) are clustered above a structural closure located approximately 1000 m below seabed (Figure 3). The craters are circular to semi-circular and vary from below seismic resolution

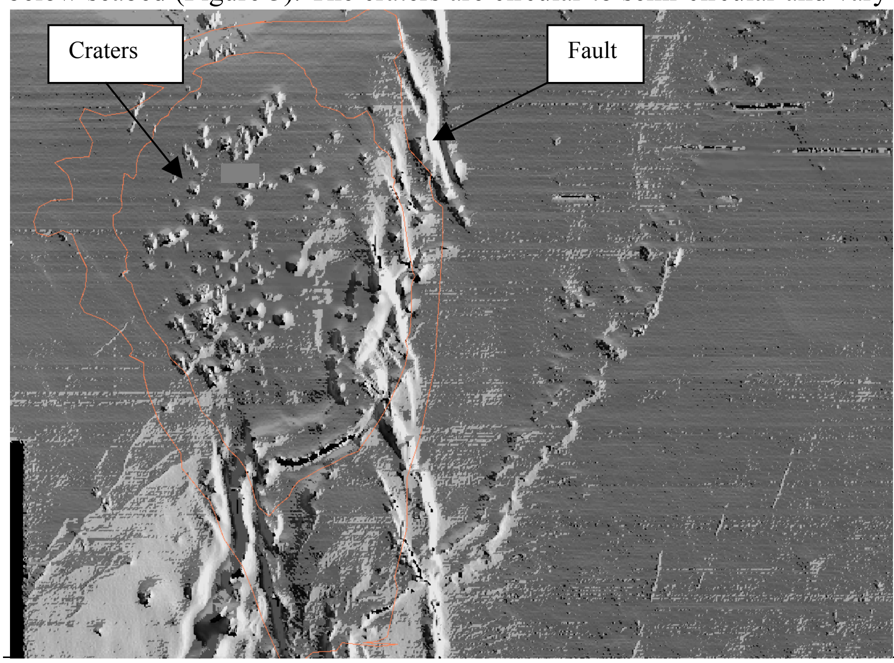

Figure 2. Seabed dip-azimuth map. A cluster of circular to semi-circular craters at seabed, which are covering an area of approx. 65 km2, is well expressed. The craters are clustered above a four way structural closure at approx. 1000 m below seabed. Note that seabed is offset along the N-S fault suggesting that the fault has been recently active.

to 500 m in diameter. Most of the larger craters are between 200 to 400 m in diameter. About 100 large craters have been identified within the cluster (Figure 2). The depth of the individual craters can be up to 30 m, but most craters are around 15 to 25 m deep.

Just below seabed cone shaped zones have been observed below many of the larger craters on seismic (Figure 3). Below a typical crater of 300 m in diameter, the cone is approx. 60 m deep. Further downwards, the beds are bent up into a local anticline with a vertical central zone with distorted seismic signals (Figure 3). Various seismic patterns have been observed within and close to the distorted zone. Common expressions are short distance shifts in polarity. Vertically stacked shifts in polarity define vertical distorted zones that can vary from infinite small to more than 100 m wide. The distorted zones are circular on time slices and thus describe pipe-like structures in 3D. The transition to the distorted zone is more blurred in the deeper parts. It has been possible to trace some of the pipe-like dimmed zones down to interpreted reservoir sands at 2700 ms and 3000 ms, respectively (Figure 4). The pipes can thus be up to 1000 to 1300 m long.

The reservoir sands are channelised and subdivided into segments by faults. The fault planes, which strike NNW-SSE at this level, are dipping between 45° and 60° while the pipes are almost vertical. In a few places the near vertical pipes appear to cut through fault planes and shallower reservoir zones.

A 3D-visualisation program and an internally developed algorithm were used to illustrate the 3D shape of the vertical noise pipes. The process of extracting the pipes is based on a coherency like attribute in a regular cube (Figure 4).

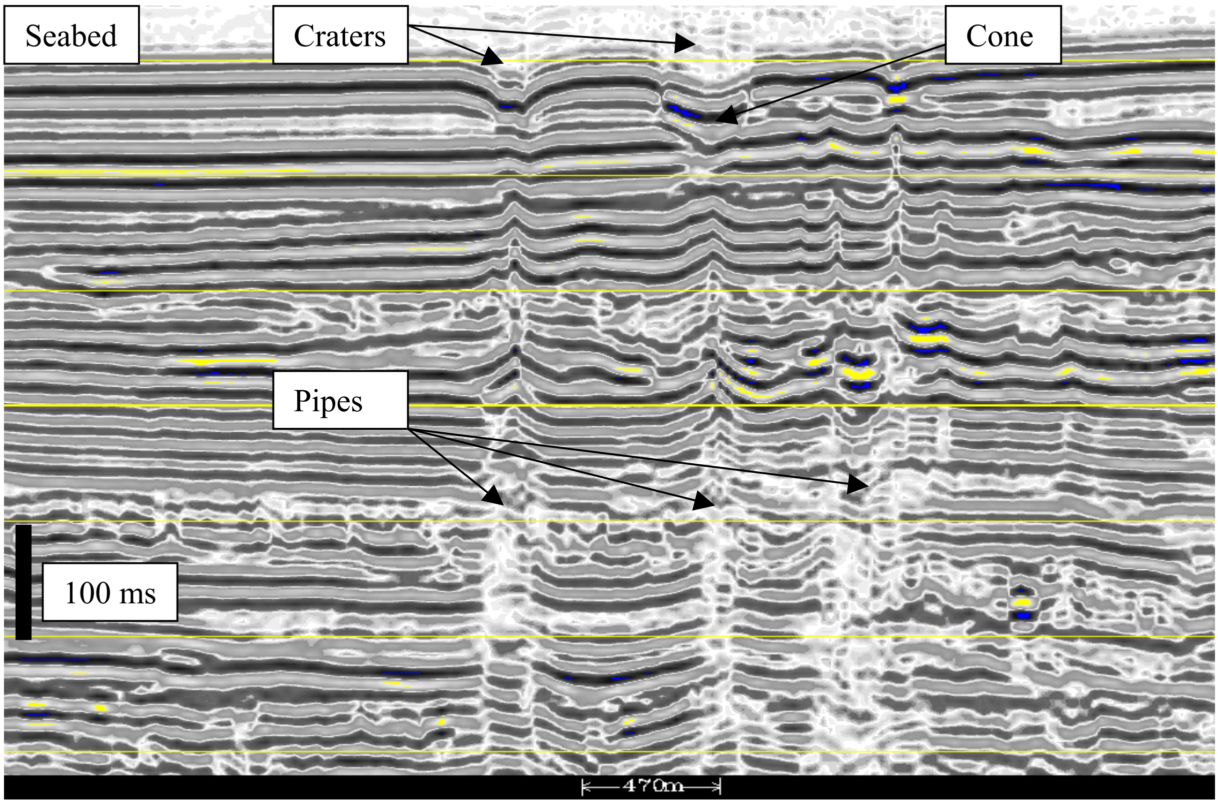

Figure 3. Detailed seismic section showing the seabed craters and a vertical section of the underlying associated pipe structures.

Outcrop analogues from Rhodes, Greece

Several vertical, circular to elliptical pipe-like structures have been observed within Plio-Pleistocene clay at Cape Vagia on the Greek island of Rhodes (Hanken et al., 1996; Hanken et al., in prep). These pipe-like structures are believed to represent good outcrop analogues to the seismic observations offshore Nigeria and are therefore discussed in some more details below.
The vertical pipes was most likely formed by explosive gas eruptions (diatremes) from the Kolymbia limestone (reservoir) through the overlaying Lindos Bay clay (cap rock). The Kolymbia limestone reservoir consists of highly porous and permeable calcareous grainstones. The pipe exposures within this reservoir form circular structures (1 m in diameter) that are linked by 3-4 m high and up to 0.2 m wide vertically oriented fractures. Both fractures and circular structures are filled in by a clay-rich slurry with angular clay clasts (breccia) from the overlaying cap rock units. The transition between the infill and the surrounding grainstone host rock is sharp.

Pipes are exposured in the lowermost part of the Lindos Bay clay. They have a wide, sub-concentric (up to 10 m radius) deformation zone around a central core. The cores of the pipes are almost circular and have a diameter of about 2-2.5 m.

Two exposures of blow-out pipes have been identified further up in the Lindos Bay clay cap rock, approx. 15 m above the top of the reservoir. The structure comprise a 70 cm inner brecciated central core which is rimmed by a 20 cm wide heavily fractured country rock and an outer approx. 4 m gradually less fractured zone. A distinct, concentric deformation zone consisting of steeply dipping and closely spaced fractures surrounds the inner core.

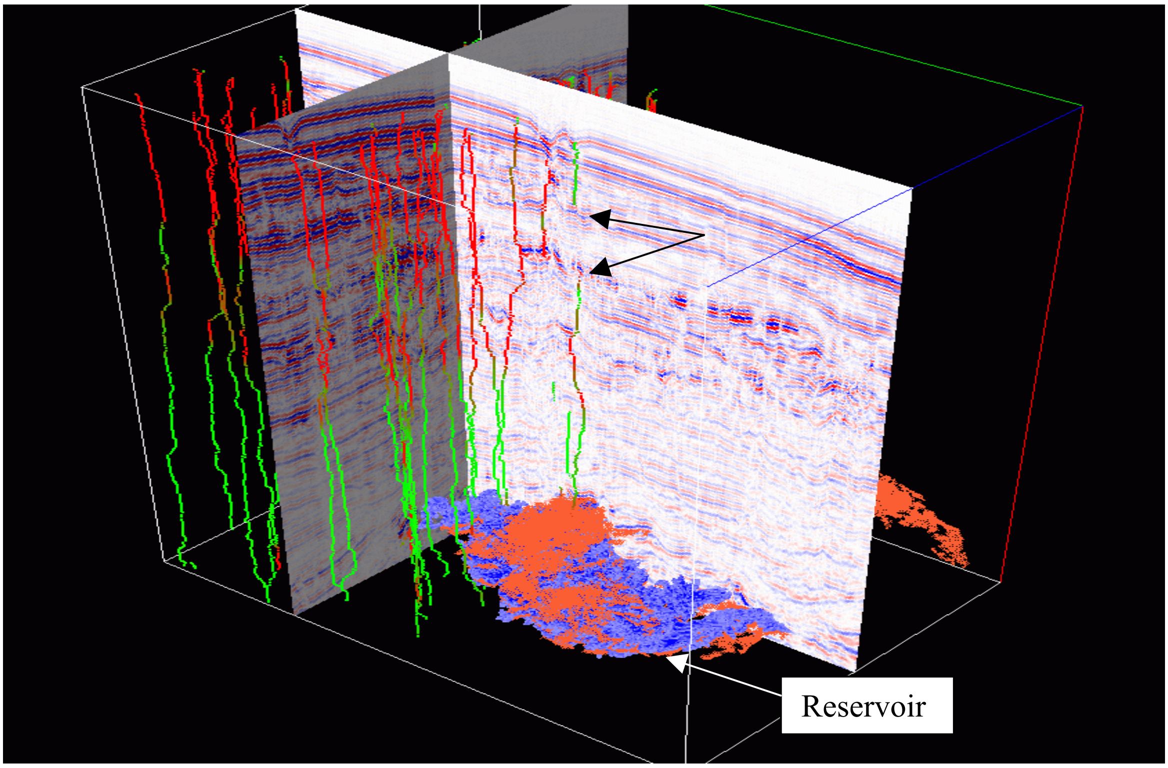

Figure 4. 3D visualisation of assumed reservoir units at the base and vertical pipes that is connecting the reservoir unit with the craters at seabed. Note that the pipes go in and out of vertical seismic sections (arrows).

The observations of the structures found in Rhodes are important because they prove the existence of vertically fractured pipes in poorly consolidated (can-be-cut-by-knife) argillaceous cap rocks. The pipes also demonstrate that natural processes do create vertical permeable zones in cap rocks and that they can be formed in relatively loosely consolidated cohesive claystones. Even though the outcrop structures are significantly smaller than those observed on seismic data they are still considered to be good analogues.

Seismic modelling

A synthetic model of a horizontally layered rock sequence that was cut by a 5 m thick vertical pipe with 20% lower velocities was seismically modelled. The modelling showed that stacked imperfectly collapsed reflection hyperbolas from the edge of the layers indirectly describes the vertical pipe. Thus, it is likely that seismic data will be able to express even thin pipes in the upper part of the seismic record where the frequency is high.

Model

The pipes are believed developed as follows:

1. A pressure increase, approaching the fracture gradient of the cap rock, takes place in the reservoir at approximately 1000 m below seabed.
2. The pressure fractures the caprock, the fracture centres in a circular structure that progrades upward in the clay cap rock. Gas is the pressure carrier and the pressure at the head of the fracture is high due to the expanding gas and the pressure support from the reservoir.
3. When the fractures reach the seafloor, gas starts to blow and a crater develops at seabed.
4. Gas continues to blow through the pipe for a relatively short time, most likely minutes or days. The gas flow in the reservoir may be so strong that cavities develop due to sand production.
5. The pressure drops and the flow rates decrease when a sufficient amount of gas is produced. The sand, rock fragments and slurry in the lower part of the pipe falls back and into the hole in the reservoir that becomes plugged. The field observations suggest that when the pressure again increases a new pipe will form instead of reactivating the previously formed pipes.

References

Hanken, N.-M.; Rønholt, G.; Hovland, M.; Løseth, H.; & Wensaas, L. (in prep): Late Pleistocene blow-out pipes from Rhodes, Greece.

Hanken, N.M., Bromley, R.G. and Miller, J. 1996. Plio-Pleistocene sediments in coastal grabens, north-east Rhodes, Greece. Geological Journal 31, 271-298.