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The spatial and temporal distribution of pipe formation, offshore Namibia

J.L. Moss*, J. Cartwright

3D Lab, School of Earth and Ocean Sciences, Cardiff University, Main Building, Park Place, Cardiff CF10 3YE, UK

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ABSTRACT

A group of nearly 400 pipe structures from the continental slope of northern Namibia are analysed for their spatial and temporal distribution. The pipes most likely formed as a result of highly focused fluid venting, and understanding the factors controlling their distribution in space and time is key to their genesis. We analysed their spatio-temporal distribution using an arbitrary chronostratigraphic timescale, from which it is concluded that the pipes did not form at the same time. Pipe formation is shown to be intermittent and persistent, with 2–29 pipes forming in each of the >20 arbitrary time intervals that are considered to span the Neogene period. The spatial distribution of these pipes is clustered to dispersed. Spatial statistics conducted on the distribution of pipe formation timings have shown that two statistically significant groups of pipes exist within the population, (1) in the North and West and (2) in the South, with the former occurring prior to the latter. Locally, pipe formation is sporadic with clusters and outliers occurring during the same time period. A conceptual model is proposed whereby pipe formation in specific locations is the result of localised breaching of the seals for isolated pressure cells which are locally independent yet broadly controlled. An inferred basinal fluid source is thought to determine the broader patterns of pipe formation, and the focus of this fluid source shifts from North to South with time. At a local scale, multiple local factors interact producing a sporadic pipe formation distribution through a prolonged period of highly focused fluid migration. Once formed, the pipes continued to focus fluids intermittently, leading in some cases to later pockmark formation.

1. Introduction

Focused fluid migration is an important process in sedimentary basins, and is manifested in a range of structures such as sand intrusions, mud volcanoes and fluid expulsion pipes (Berndt et al., 2003; Cartwright et al., 2007). Pipes are vertical columnar zones of seismic disturbance, which are interpreted to be the expression of highly focused migration of fluids through low permeability sequences (Fig. 1) (Løseth et al., 2001). Fluid migration is focused into narrow, near-vertical zones where presumed increased permeability permits fluids to bypass the pore network. Pipes propagate from shallow fluid sources (<1 km below the seabed) and terminate at seabed pockmarks, craters or vents. Pipes are considered to form by the catastrophic breaching of top seals to shallow gas reservoirs in a highly dynamic process involving hydraulic fracture under elevated pore fluid pressures, and fluid driven erosion and collapse (Berndt et al., 2003; Cartwright et al., 2007; Hustoft et al., 2007; Judd and Hovland, 2007; Ligtenberg, 2005; Løseth et al., 2001). Pipes have recently become a major research focus because they have implications for basin analysis, modelling overpressure development, seal failure and gas hydrate development.

A large population of nearly 400 pipes from offshore northern Namibia was recently described by Moss and Cartwright (in press) (Fig. 2), who extended the descriptive base for pipe structures. Based on a geometrical-acoustic description, they proposed a genetic model that built on previous studies in favouring a mechanism involving hydraulic fracturing and pressure release from a locally overpressured 'cell.' Moss and Cartwright (in press) considered other pipe genetic models including dissolution of carbonate or evaporite units (Bertoni and Cartwright, 2005), fluid escape by slow seepage (Cartwright et al., 2007) and rapid hydrothermal venting (Davies et al., 2002), but were able to discount these possible alternatives based on the regional geological setting and knowledge of the likely stratigraphy. No evaporites are known in northern Namibia, the seismic stratigraphy does not indicate the presence of thick carbonates and no igneous intrusions have been interpreted within the post-Karoo sedimentary sequence in this part of the Namibian margin (Clemson et al., 1997; Corner et al., 2002), making dissolution and hydrothermal venting unlikely. Moss and Cartwright (in press) considered pipe formation utilising a purely seepage based genetic

* Corresponding author. Tel: +44 (0) 29 208 74830; fax: +44 (0) 29 208 74326.
E-mail address: mossjl@cardiff.ac.uk (J.L. Moss).

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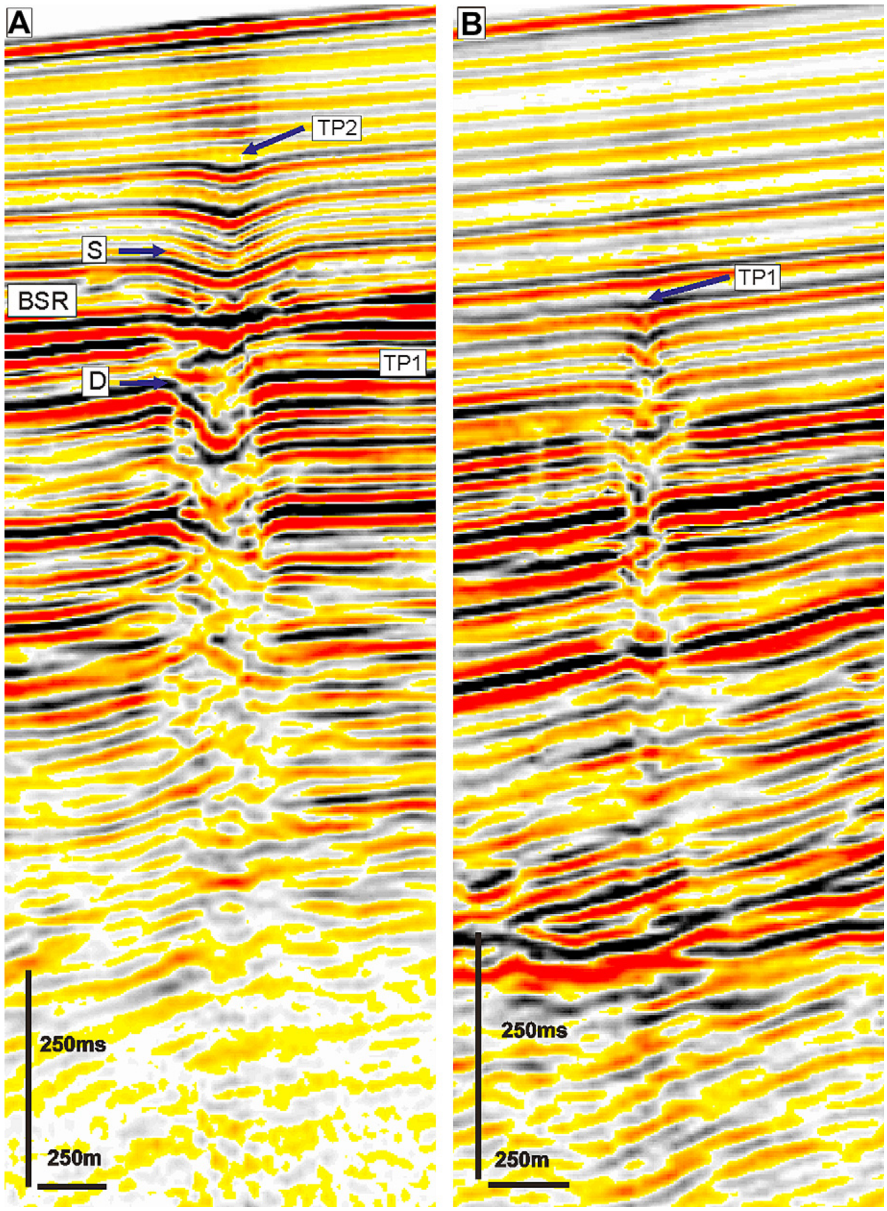

Fig. 1. Pipe examples. These vertical columnar zones of seismic disturbance are interpreted to be the expression of highly focused fluid migration. A) Wide pipe (Pipe P24). Time Point 1 (TP1) is towards the base of the pipe and marked by steeply dipping, truncated reflections (D). Shallow reflections towards the top of the pipe are more gently curving (S). Time Point 2 (TP2) is at the top of the pipe and marked by fill geometry. This example of a wide pipe is transected by the hydrate layer (BSR). B) Narrow pipe (Pipe P116). Time Point 1 and Time Point 2 are marked by the same reflection. This reflection is at the top of the pipe and marked by fill geometry.

model unlikely for the majority of Namibe Basin pipes due to their observations of erosional truncation (e.g. defining the craters) but acknowledged that seepage may be involved.

The timing of pipe formation is generally quite poorly constrained in all previous descriptions of pipes. One approach has been to constrain the maximum period of pipe formation from the accurate identification of pipe fluid sources. This methodology is only feasible where it is possible to determine when overpressure started to develop, and where precise delineation of the pipe base and its interaction with a fluid source can be established (Gay et al., 2003; Duck and Herbert, 2006; Gay and Berndt, 2007; Heggland, 1998; Pinet et al., 2008; Van Rensbergen et al., 2007). This method is limited by commonly occurring seismic artefacts obfuscating the diagnostic identification of the bases of pipes, but even when this interpretation can be made, this approach provides no constraints on the timing of subsequent pipe evolution.

The main aim of this paper is to tackle the outstanding question of the dating of pipe formation and subsequent behaviour as fluid flow conduits. Firstly this paper extends the initial description of Moss and Cartwright (in press) by placing pipe genesis within a more quantitative spatial and temporal framework, permitting the examination of how the distribution of pipes evolved through the basin's history. Secondly, it introduces a more rigorous quantitative approach to the analysis of fluid escape pipes. It is acknowledged that the analysis of timing of pipe formation cannot be separated from the conceptual model for pipe formation. We note the uncertainties in this approach and attempt to overcome these by including alternative approaches to dating pipe activity. Irrespective of which specific approach is taken to dating pipes, the conclusion reached here is that pipe formation is highly irregular through time and space, and this should prompt further evaluation of the current group of genetic models.