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Pressure significance of gas chimneys

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ABSTRACT

Analysis was carried out of part of the northern North Sea to test what the presence and style of gas chimneys indicate about fluid pressure (P_f) within hydrocarbon reservoirs. Previous results suggest that broad chimneys above a trap and thin chimneys on the flanks indicate the presence of hydrocarbons, whilst thin chimneys in the crest suggest the hydrocarbons have escaped. Each type of gas chimney is usually associated with overpressure within Mesozoic reservoirs, but the water leg is hydrostatically-pressured in most Cenozoic reservoirs. This indicates: (a) gas leaking from a trap does not necessarily cause P_f to become hydrostatic; (b) overpressure may not be necessary for the expulsion of gasses through seal units to create the chimneys; (c) although gas chimneys indicate the existence of an active hydrocarbon system, their presence does not appear to indicate anything significant about present-day P_f.

1. Introduction

Gas chimneys are vertical, columnar features in which the normal sequence of seismic reflections has been disturbed, and this is assumed to be caused by the upward migration of gas (e.g. Judd and Hovland, 1992). The presence of gas in chimneys has been confirmed by well data, with wells drilled through gas chimneys presenting higher saturations of gas recorded in the mud gas readings, along with decreased sonic well logged velocities in the cap rock (e.g. Arntsen et al., 2007). Disturbances of the seismic reflections are usually characterised by low amplitudes and low trace-to-trace similarity (Meldahl et al., 2001). Upward fluid migration has been interpreted as hydrocarbon leakage pathways in the seal (Meldahl et al., 2001).

Heggland (2005) proposes a gas chimney classification that enables predictions to be made about the presence of hydrocarbons in a trap, and therefore helps risking hydrocarbon prospects. This classification was defined using drilled traps from the Norwegian sector of the North Sea. In type I chimneys (Fig. 1a–f), a fault has served as hydrocarbon migration pathway, with the gas chimney visible as a narrow feather-like feature on seismic data. They can be subdivided in type IA, where the chimney is on top of a structural closure, leaving little or no trapped hydrocarbons (Fig. 1a–c); and type IB, where the chimney is on the flank, leaving a hydrocarbon column up-dip (Fig. 1d–f). Type II chimneys are wide features that cover a large area at the top of the structure and do not seem to be associated with faults of seismic resolution (Fig. 1g–i). Heggland (2005) suggests that Type II chimneys are related to gas that either has come out of solution from upward-moving water that has become trapped in shales (zero flux rate), or gas migrating with a relatively slow flux rate through sub-seismic fractures. Type II chimneys are not regarded as a risk to hydrocarbon presence within the trap, indicating hydrocarbons in the underlying structure (Heggland, 2005).

A predrill understanding of P_f is important for successful drilling. P_f can be measured directly or estimated using various parameters recorded during drilling or logging as proxies. Direct measurements include different wireline formation testing tools such as the Modular Formation Dynamics Tester tool (MDT), the Repeat Formation Tester tool (RFT) and Drill Stem Tests (DST). These types of measurements are considered of high reliability (Moss et al., 2003). Indirect measurements rely on empirical approaches or observation of drilling parameters. These measurements provide a static image of present day P_f.

Overpressure is where P_F exceeds the value that would be expected for that depth in a water column, i.e. it is above hydrostatic pressure (e.g. Fertl and Chilingarian, 1989; Swarbrick and Schneider, 1999; Bjørlykke et al., 2010). While Karstens and

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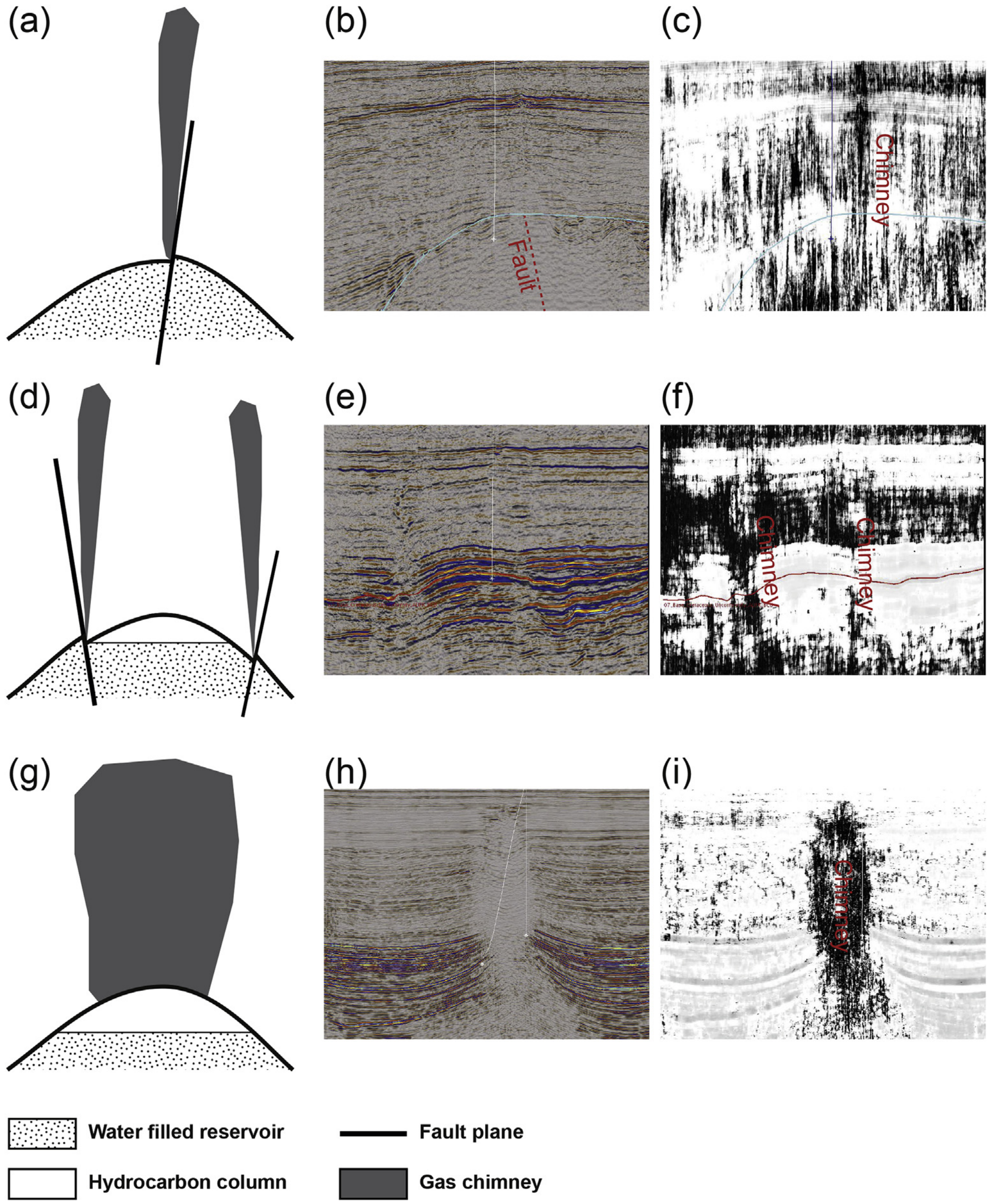

Fig. 1. Gas chimney classification (Heggland, 2005) and their expression on seismic data. (a) Type IA chimney on top of a structural closure. The chimney is associated with a fault, which involves a risk that hydrocarbons (HC) have left the trap. (b) Seismic example. Blue line = top reservoir. (c) Chimney cube expression of a type IA chimney. (d) Type IB chimney on the flank of a structural closure, in which hydrocarbons may be preserved. (e) Seismic example. (f) Chimney cube expression of a type IB chimney. Red line = top reservoir. (g) Type II chimney covers a large area on top of a structural closure, indicating hydrocarbons are present in the underlying structure. (h) Seismic example. (i) Chimney cube expression of a type II chimney. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Berndt (2015) describe the relationships between gas chimney types and inferred P_f evolution in the Southern Viking Graben, they present no P_f data and do not discuss the potential of using gas chimneys to predict P_f.

We hypothesise that gas chimneys form because high P_f causes migration of gasses to areas of lower P_f. The aim of this work is therefore to test whether there is a relationship between P_f and gas chimneys.

2. Geological setting of the study area

Data from the Viking Graben and the surrounding structures in the northern North Sea (Fig. 2) are used. The Viking Graben is a NNE-trending rift system in the northernmost part of the North Sea Graben (Gautier, 2005), created by Late Jurassic extension (Ziegler, 1992; Færseth, 1996), which was followed by thermal cooling and subsidence during the Cretaceous and Cenozoic. The following events control the hydrocarbon prospectivity of the region (Pegrum and Spencer, 1990):

- Rifting during the Upper Jurassic allowed deposition of the organic-rich sediments of the Viking Group.
- Rapid sediment accumulation during the Cenozoic accounts for much of the maturity of the Viking Group (e.g. Cornford, 1986, 1998).
- Once migration started during the Cenozoic (Pegrum and Spencer, 1990), hydrocarbons accumulated in reservoirs from a wide range of ages.

Reservoirs can be grouped into pre-Jurassic pre-rift