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SEISMIC CHARACTERISTIC OF FOCUSED FLUID FLOWS IN THE NORWEGIAN SEA

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Abstract: This study uses 3D seismic data, covering an area of c. 25000 km^2 in Moring basin, offshore Norway. The study focused on the interval of 2500 ms below the seafloor. Five key surfaces have been mapped including seafloor marked from Ks2 to Ks5. Pockmarks are intensively developed in the study area, approximately 50 single pockmarks (from 150 - 300 m in diameter and 12 m in deep). They have a higher density in the shallow sequences and are populated mainly in the high topography area. Some pockmarks are associated with the vertical pipes which are characterized as distorted seismic signals. The pipe is characterized as vertical zones of acoustic wipe-outs pull-up reflections, rooting from the deeper sequence with the length of c. 800 ms. The pipes are possibly formed by the overpressed reservoir in the deep section and the faults also play a significant role. The occurrence of focused fluid flows and pockmarks indicate an active petroleum system and hydrocarbon-filled traps may be leaking to some extent.

Keywords: 3D seismic; Focused fluid flows; Pockmarks; Norwegian sea; Moring basin.

1. INTRODUCTION

Focused fluid migration as hydrocarbon leakage phenomenon in marine sediments is getting the attention of many geoscientists in the context of environment discussions (Berndt et al., 2005). However, it is still not well understood. The technological developments during the past two decades have led to the discovery of a range of focused fluid flow systems, including pipes that are pathways for hydrothermal pore fluids and brines, and gas chimneys that primarily conduct free gas. Many different processes cause fluids to migrate in the sedimentary basins and reach the surface (Berndt, 2005). A hydromechanical model proposed for the formation of shallow pockmarks indicates that the sedimentation rate cannot generate the overpressure required for pockmark formation on the seafloor. Thus, it is suggested that hydrocarbon migration from the deeper overpressured reservoir. It is well proposed that pore-pressure increase within porous sands can cause their overburden seals to be ruptured and then lead to sand fluidization and centimeter to meterscale soft-sediment deformation (Davies, 2003). In addition, focused fluid flow systems have also been quoted as release mechanisms for submarine landslides and related tsunamis (Bugge et al., 1987). They reach the seabed where they are evidenced as different kinds of pockmarks, craters or mud mounds (Hovland and Judd, 1988).

Direct observations of hydrocarbon leakages are difficult for the obvious reason that they take place below the Earth's surface. Evidence of the active leakage of oil or gas and associated formation water is, therefore, most commonly found on the surface, on the seafloor, or in seawater while remnants of subsurface palaeo-leakage anomalies may be found in the outcrops (Cobbold and Castro, 1999; Parnell and Kelly, 2003). Active subsurface leakage is commonly imaged indirectly by seismic or by other remote subsurface imaging tools or observation in well cores or wireline logs. Among those, seismic images provide the most extensive available indications of leakage (Cartwright et al., 2007; Løseth et al., 2009). The objectives of this paper are to investigate the occurrence and also the controls of the pockmarks and focused fluid flows in the Moring basin offshore Noway, using 3D seismic data.

2. GEOLOGICAL SETTING

The study area is located in the Moring basin, on the More marginal High. The evolution of sedimentary environments in the Norwegian continental margin since the Early Carboniferous is directly linked with the evolution of the tectonic framework of the broader region of the northern North Atlantic. The area has been tectonically active from Carboniferous to late Pliocene time with the main tectonic phases in Late Paleozoic, late Mid-Jurassic-Early Cretaceous, and Late Cretaceous-Early Tertiary time. However, the More Basin was generally tectonically quiet throughout the Cretaceous and Tertiary periods, experiencing mainly continuous subsidence (Brekke, 2000; Evans et al., 2002; Ichaso et al., 2016). This study focused on the interval of Neogen sequence in the shallow marine environment.

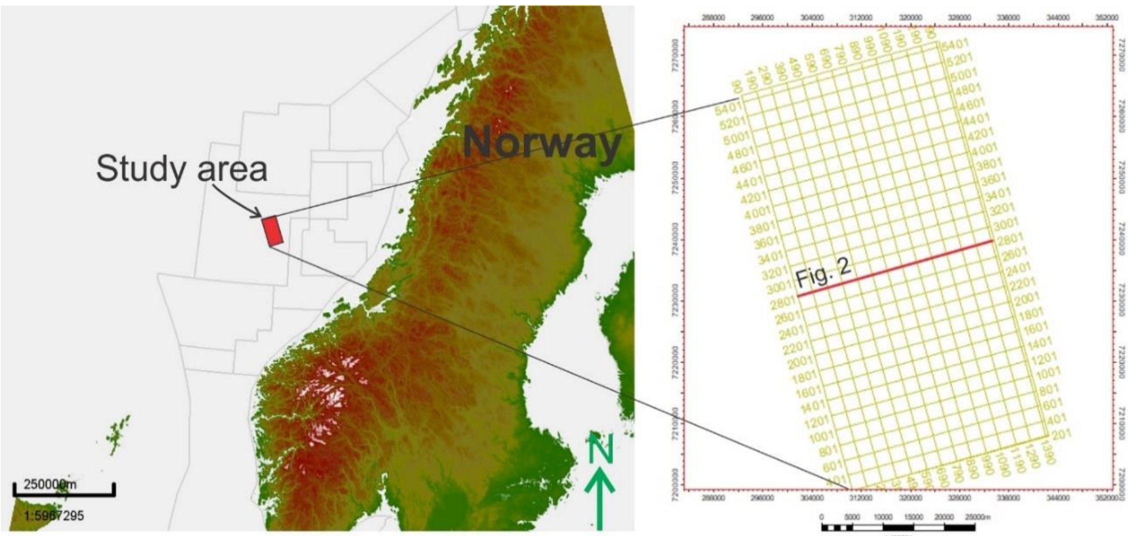

Figure 1. Study area is located in offshore Norway, covering an area of 25000 km^2.

3. DATASET AND METHODOLOGY

This study used open access high-resolution 3D seismic reflection dataset from offshore Norway to investigate the occurrence of the pockmarks and focused fluid. It covers an area of 25000 km^2. The water depth range from 600 m and 1000 m. The 3D seismic data include 1300 inlines and 2600 crosslines. The investigated interval is about 2s below the seafloor corresponding to Eocene - Pleistocene sequences. Standard seismic processing was applied to produce zero-phase seismic data. The positive and negative impedance contrast is displayed as red and blue colors on seismic displays, respectively. The vertical seismic resolution is c. 20 m.

Interpretation has been carried out using Petrel software with fine grid interpretation of 50 x 50 m; auto-tracking was then used on all the surfaces and resulted in good quality surfaces. Dip maps and attribute maps were generated of all five surfaces to assist detailed geomorphological analysis. The morphology of the pockmarks, their distribution, and orientation are revealed by a dip map of the seafloor and key surfaces based on the 3D seismic dataset.

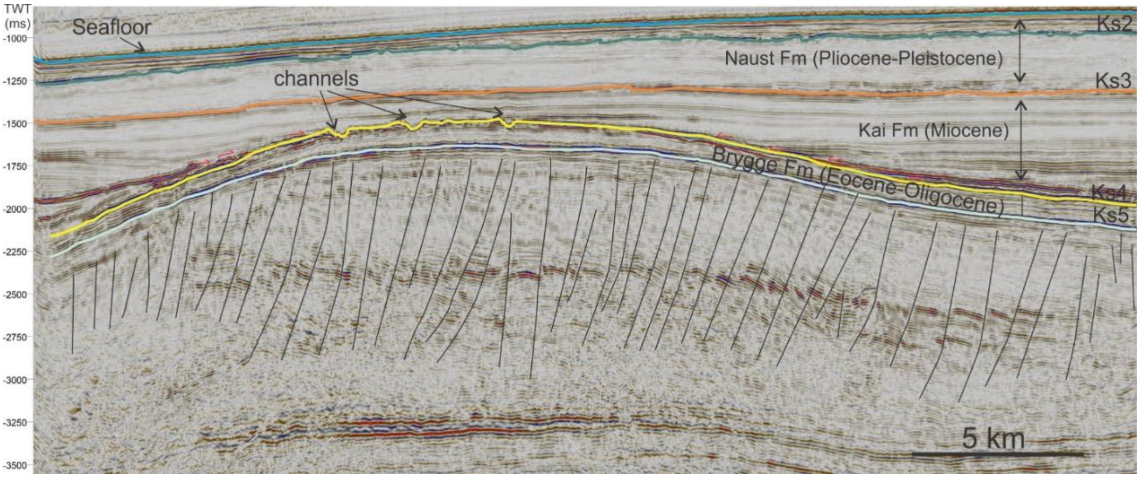

Figure 2. A seismic section illustrating the geological structure of the study area. Five horizons have been mapped and marked as seafloor, Ks2, Ks3, Ks4, and Ks5 corresponding to the Eocene - Pleistocene sequences.

4. RESULTS AND DISCUSSION

In the study area, based on 3D seismic data, pockmarks and pipes have been investigated. Five key surfaces have been mapped (Figure 2). The Naust formation is corresponding to the Pliocene-Pleistocene sequences and is bound to the based by the Key surface 2 (Ks2). The Miocene sequence is bound to the top and base by the unconformity Ks2 and Ks3, respectively. Uplift in late Eocene-Oligocene results in the major unconformity Ks3 which is a highly erosional truncated surface (Figure 2). Beyond these sequences is the Eocene-Oligocene sequence which is bounded to the base by the Ks4. The Ks4 shows the abrupt change in seismic facies from highly faulted, discontinuous, low amplitude reflection below to continuous, sub-parallel, low to high amplitude reflections.

4.1. Pockmark distribution

There are many pockmarks has been observed on the major unconformity (Figure 3). Pockmakrs have cone-shaped circular or elliptical depressions ranging from 150 m to 300 m in diameter and up to 12 m in depth (Figure 4). Pockmarks generally concentrate in the high topography but there are some pockmarks also observed in the central of the study area. They often appear like isolated patches named single pockmarks. On the Ks5, there are two single pockmarks observed in the southern part. On the Ks4, there are c. 30 single pockmarks which populated mainly in the northern part. They are identified along the curve lines correlated adjacent to the channel patterns. Pockmarks on the Ks3 reduce the number compared with those on the Ks2. They are populated mainly in the southeast area with c. 23 single pockmarks. On the Ks2, up to 50 pockmarks have been observed, covering the entire study area (Figure 3). They appeared along straight or curved lines.

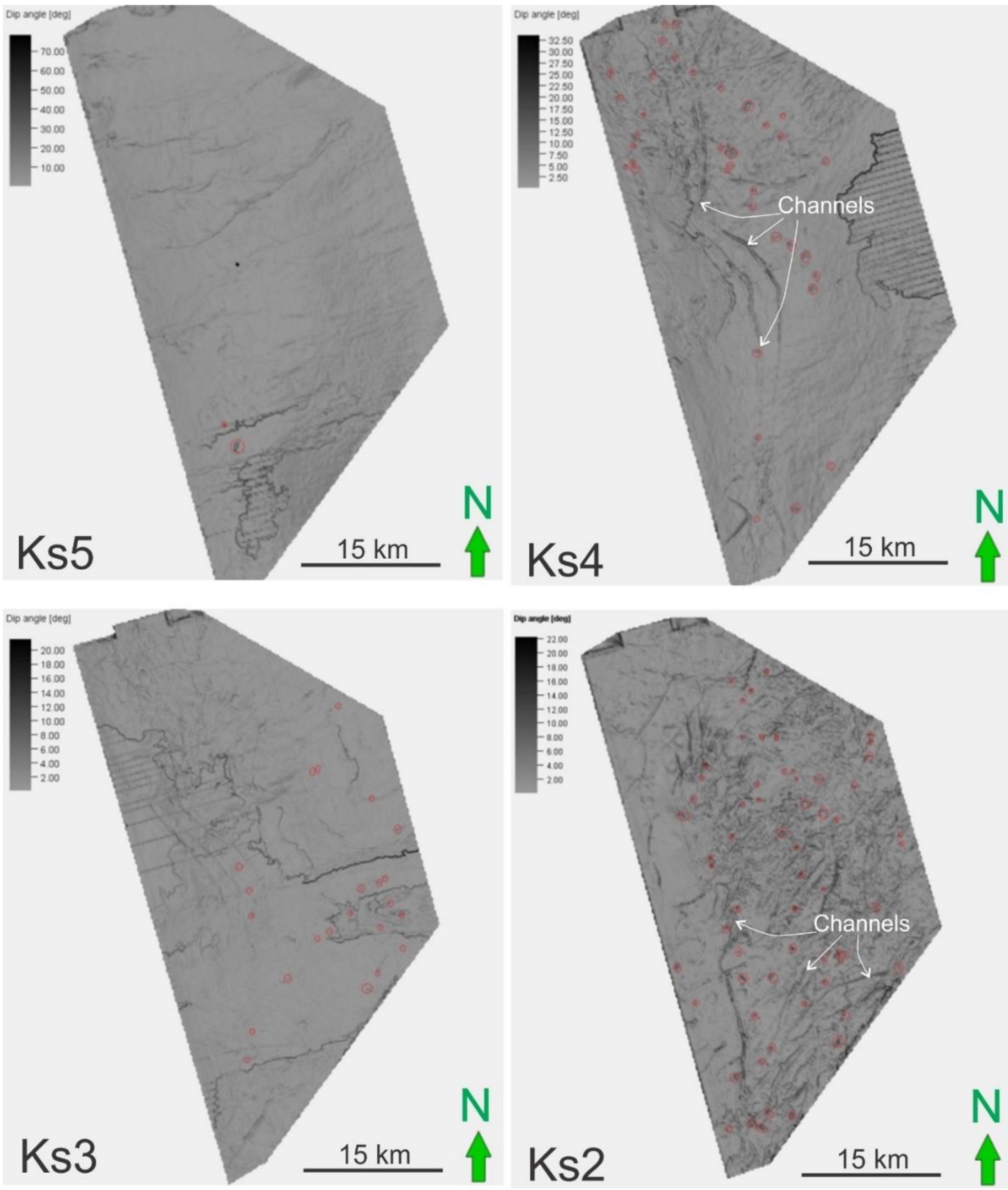

Figure 3. Pockmarks and their distribution on the different key surfaces from Ks2 to Ks5 are revealed on dip maps. Pockmarks are mostly developed on the Ks2 and Ks4.

4.2. Seismic expression of Focused fluid flows (pipes) and their distribution

Some pockmarks are associated with pipes (focused fluid flows). On the Ks3, there are 5/23 pockmarks associated with the focused fluid flows. On the Ks4, there are 18/30 pockmarks associated with the focused fluid flows. The two pockmarks on the Ks5 are overlying pipes. Most pipes in the study area are located in the half eastern part.

The pipe is oval with depressed high-amplitude reflectors. The pipes rise to 800 ms from the highly faulted interval to the Ks4 where they terminate in craters with collapse structures (Figure 4). The seismic character of pipes is described as pull-up reflections (Figure 5). The flanks of pipes correspond to the lateral termination of up-bending of strata. On the flank of pipes, there have small-scale truncations of seismic reflections against the flanks or fronts of some particular pipes. The acoustic anomalies are interpreted as seismic chimneys or pipes and suggestive of fluid flows migration from deeper levels (Hovland and Judd, 1988; Tingdahl et al., 2001).

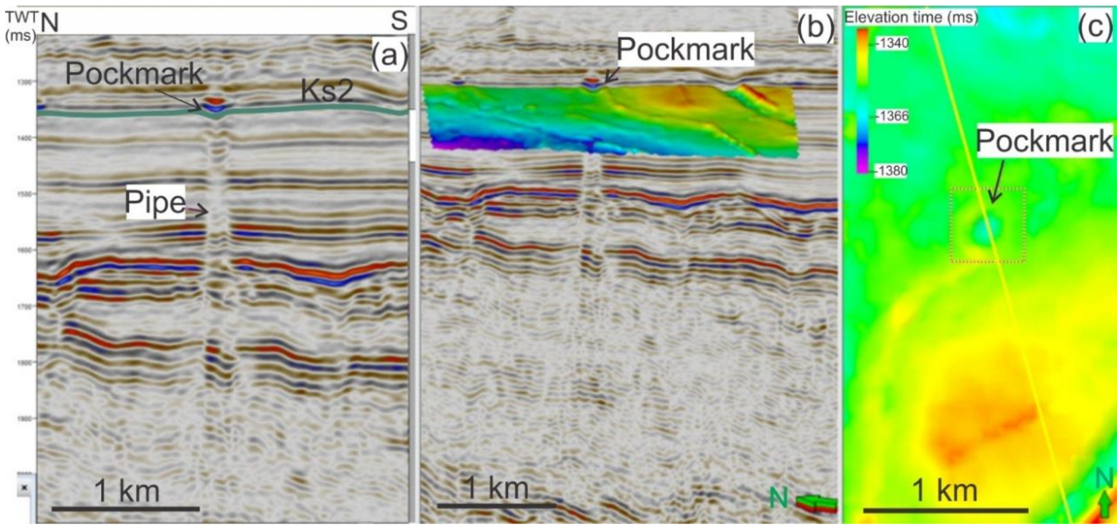

Figure 4. (a) Seismic expression of pockmark associated with pipe that expulsed on the Ks2. (b) 3D view of seismic cross-section (a) and TWT map of Ks2. (c) Two-way-time map of Ks2 showing the pockmark on the map view.

4.3. Driving mechanisms for fluid movement

Different mechanisms have been proposed for the driving forces that control the movement of fluids and the migration pathways that lead to the occurrence of pipes and pockmarks (Gay et al., 2007). In this case study, there can be two causes for fluids to rise from deeper levels and terminate on the Ks4 surface. The first reason may be hydro-fractures above highly overpressured reservoirs leading to violent fluid expulsion. Another reason is that the presence of a widespread normal fault system may provide vertical fluid escape pathways. The occurrence of the number of faults below the Bryggent formation may create the migration pathways for fluid o migrate from the deep section to the shallower.

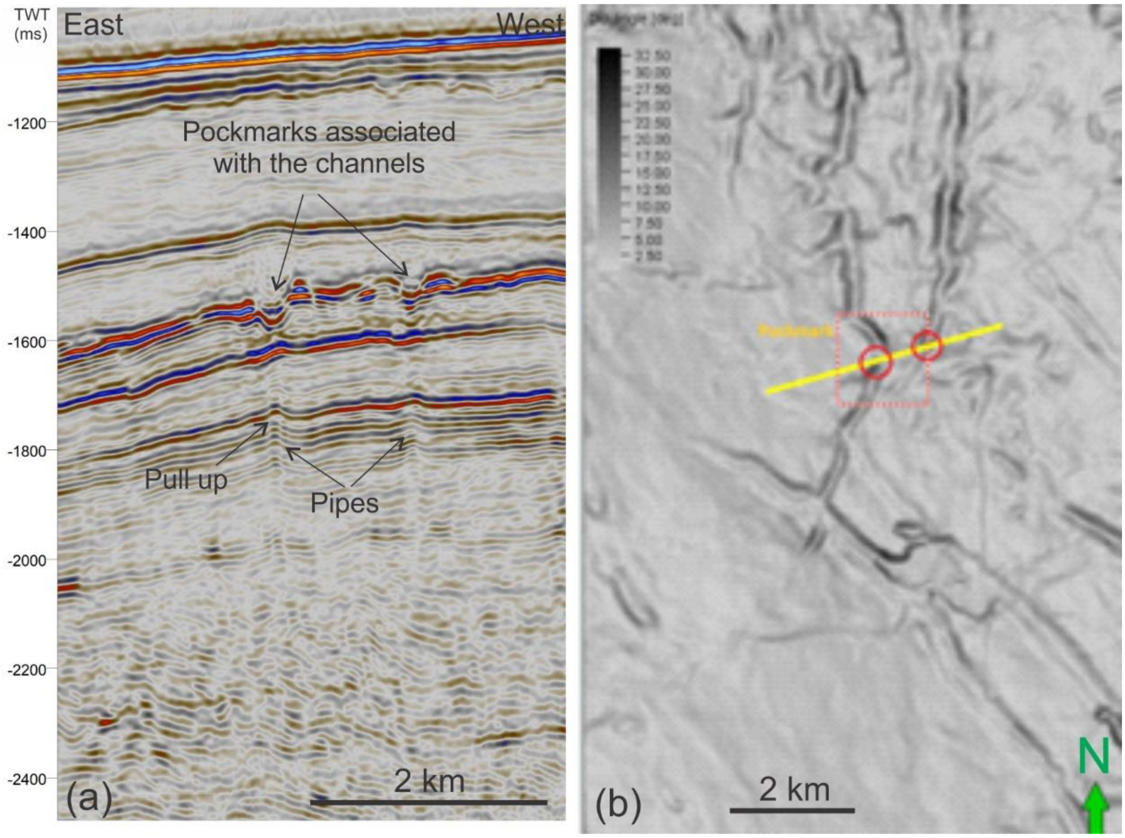

Figure 5. (a) Seismic expression of pockmarks associated with pipes on the cross-section and (b) dip map of the Ks4 showing the pockmarks on the map view.

For the first cause, in some cases, reservoirs can release fluids very fast (Berndt, 2005). The proposed generation model for these pipes involves an increase in pore pressure within the petroleum reservoir until the pore pressure exceeds the competence of the seal and gas blows out to the surface in a short-lived event generating a diatreme. The pipes get blocked after a blow-out and that later blow-outs may not use previously active pipes (Berndt, 2005). This type of pipe has been reported from offshore Nigeria, up to 1300 m high of pipe are rise from the gas reservoir (Løseth et al., 2009).

The existence of high-density faults below the Bryggen formation may also act as the conduit for fluid migration from deep levels to the shallower (Figure 2). Most of the pipes observed are associated with this faulting zone and terminated in the sequence above it. There is no direct pipe rooting from the reservoir observed. Thus, most of the role of faulting in this area possibly plays a key control on the fluid migration and also the formation of pipes and pockmarks.

The study of focused fluid flow is one of the most important fields in marine geology in the future. In terms of the petroleum system, the occurrence of such fluid flow systems can help in predicting the distribution of hydrocarbons in the subsurface. The observation of pipes and pockmarks in this area indicates an active petroleum system and also the possible risk of trap integrity.

5. CONCLUSIONS

This study has focused primarily on describing distributions of focused fluid flows and pockmarks, investigating the seismic characteristic of pipes in Moring basin, offshore Norway. Pockmarks are widely distributed on key surfaces 2 and 4. Some pockmarks are associated with pipe which is terminated on the Ks4. Pockmarks generally concentrate in the high topography, have cone-shaped circular or elliptical depressions ranging from 150 m to 300 m in diameter and up to 12 m in depth. Some pockmarks are associated with focused fluid flows which penetrate through the highly faulted interval and terminate on the Ks4 surface. These acoustic anomalies are seismically characterized as pull-up reflections with a length of 800 ms. The occurrence of pipe is interpreted to be caused by hydrocarbon leakage from the reservoir in the deeper sequence and the range of normal faults may also play an important role as a migration pathway for the fluid escapement from the reservoir and expulsion on the unconformity 4. This indicates an active petroleum system and hydrocarbon-filled traps may be leaking to some extent.

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