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Correlation between tectonic stress regimes and methane seepage on the west-Svalbard margin

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Abstract. Methane seepage occurs across the west-Svalbard margin at water depths ranging from the upper shelf at < 300 m to gas hydrate systems in the deep sea at > 1000 m. The Vestnesa sedimentary ridge, located on oceanic crust between 1000-1700 m water depth, hosts a perennially stable gas hydrate system with evidence of both past and present-day seepage. On the ridge, an eastward transition from a zone with clear morphological evidence of past seepage to a zone of active present-day seepage coincides with a change in the faulting pattern of near-surface strata. We modelled the tectonic stress regime due to oblique spreading along the Molloy and Knipovich spreading ridges to investigate whether spatial and temporal variations in the regional stress field may explain patterns of seepage distribution. The model reveals a zone of tensile stress that extends northward from the Knipovich Ridge and encompasses a zone of active seepage and extensional faulting. A zone of past seepage is presently located in a strike-slip regime. Our modelling results suggest that seepage is promoted by opening of faults and fractures in a tensile regime. We develop a conceptual model to describe how seepage may be controlled by an interplay between tectonic stresses and pore fluid pressure within shallow gas reservoirs across the passive margin off west-Svalbard. Glacio-isostatic flexural stresses may have influenced fluid dynamics along the Vestnesa Ridge in the past, explaining the presence of dormant pockmarks outside the ridge segment that is under a tensile regime at present and reconciling formerly suggested models of seepage periodicity linked to glacial cycles.

1. INTRODUCTION

Seafloor seepage is a wide-spread phenomenon which consists in the release of natural gases into the oceans. Hundreds of gigatonnes of carbon are stored as gas hydrates and shallow gas reservoirs in continental margins (e.g., Hunter et al., 2013). The release of these carbons over geological time is an important component of the global carbon cycle. Understanding and quantifying seepage has important implications for ocean acidification, deep-sea ecology and global climate. Periods of massive methane release from gas hydrate systems (e.g., Dickens, 2011) or from large volcanic basins like that in the mid-Norwegian Margin (e.g., Svensen et al., 2004) have been linked to global warming events such as the Palaeocene-Eocene thermal maximum. We know that methane seepage has been occurring for millions of years, but we have a poor understanding of what forces it.

Present day seepage is identified as acoustic flares in the water column commonly originating at seafloor depressions, while authigenic carbonate mounds are used as indicators of longer-term seepage activity (e.g., Judd and Hovland, 2009). Seepage at the theoretical upstream termination of the gas hydrate stability zone (GHSZ) (i.e., coinciding with the shelf edge) on different continental margins, has been explained by temperature driven gas-hydrate dissociation (e.g., Skarke et al., 2014; Westbrook et al., 2009). On formerly glaciated margins, active seepage is believed to be associated with pressure changes resulting from the retreat of the ice-sheet (e.g.,

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Andreassen et al., 2017; Portnov et al., 2016). The effect of post-glaciation uplift on gas hydrate stability has been recently suggested as an alternative explanation for seepage localized at the shelf break offshore west-Svalbard (Wallmann et al., 2018)

Across the formerly glaciated west-Svalbard margin, active seepage extends beyond the shelf break and the region formerly covered by ice. As a matter of fact, active seepage sites have been identified from inside Isfjorden (Roy et al., 2014) to water depths of ~1200 m (Smith et al., 2014) where the Vestnesa Ridge hosts a perennially stable gas hydrate system beyond the ice-sheet grounding line. Seafloor pockmarks along the Vestnesa Ridge, first documented by Vogt (1994), exist along the entire ridge. However, acoustic flares have been observed to originate exclusively at large pockmarks located on the eastern part of the sedimentary ridge (Fig. 1,2). The presence of inactive pockmarks adjacent to a zone of active seepage along the Vestnesa Ridge, raises the question what stopped previously active seepage sites?

Plaza-Faverola et al., (2015) documented seismic differences in the orientation and type of faulting along the ridge and showed a link between the distribution of gas chimneys and faults. They suggested that tectonic stress variations may have a long-term effect on the spatial distribution of fault-related gas migration and seepage evolution. Here, we modelled the tectonic stress regime due to mid-ocean ridge spreading at Molloy and Knipovich ridges in Fram Strait, to test how spreading at these ridges influences the tectonic field along the Vestnesa Ridge. The tectonic model contributes with additional evidence of a correlation between regional stress regime and seepage patterns along the Vestnesa Ridge initially postulated based on seismic interpretation (Plaza-Faverola et al., 2015). Our study is in line with observations of earthquake-induced seafloor seepage (e.g., Geersen et al., 2016) and stress field variations (e.g., Plaza-Faverola et al., 2014) at accretionary margins suggesting that the effect of regional stresses on fluid dynamics in the near-surface has implications for seepage systems globally.

1. GEOLOGICAL SETTING OF THE VESTNESA RIDGE SEEPAGE SYSTEM

In Fram Strait, sedimentary basins are within tens of kilometres from ultra-slow spreading Arctic mid-ocean ridges (Fig. 1). The opening of the Fram Strait was initiated 33 Ma ago and evolved as a result of slow spreading of the Molloy and Knipovich Ridges (Engen et al., 2008). The circulation of deep water masses through Fram Strait started during the Miocene, ca. 17-10 Ma ago (Ehlers and Jokat, 2009; Jakobsson et al., 2007), establishing the environmental conditions for the evolution of bottom current-driven sedimentary drifts (Eiken and Hinz, 1993; Johnson et al., 2015). The NW-SE oriented Vestnesa sediment depocenter, extends for ca. 100 km off the west-Svalbard passive margin (Fig. 1b) and developed in the tectonically complex transition zone from oceanic to continental crust (Eiken and Hinz, 1993). In addition, the effect of ice-sheet dynamics on the west-Svalbard margin (Knies et al., 2009; Patton et al., 2016) has influenced the stratigraphy, and most likely the morphology, of the Vestnesa Ridge and adjacent sedimentary basins. The sedimentary succession along the Vestnesa Ridge is > 5 km thick in places and has been divided in three main stratigraphic units (Eiken and Hinz, 1993; Hustoft, 2009): the deepest sequence, YP1, consists of synrift and post-rift sediments deposited directly on oceanic crust; YP2 consists of contourites; and YP3, corresponding to the onset of Pleistocene glaciations (ca. 2.7 Ma ago) (Mattingsdal et al., 2014), is a mix of glaciomarine contourites and turbidites.

The gas hydrate system dynamics along the Vestnesa Ridge seems to be highly influenced by spatial variations in the geothermal gradient and the gas composition (Plaza-Faverola et al., 2017). Thermogenic gas is accumulating at the base of the GHSZ (Fig. 2) and part of this gas sustains present day seepage activity (Bünz et al., 2012; Plaza-Faverola et al., 2017). Seepage has been occurring at least since the onset of the Pleistocene glaciations c. 2.7 Ma ago (Plaza-Faverola et al., 2015). Many transient seepage events are suspected and one was dated to ca. 17.000 years based on the presence of a ~1000 years old methane-dependent bivalve community possibly sustained by a gas pulse through a fault (Ambrose et al., 2015).

2. SEISMIC DATA

The description of faults and fluid flow related features along the Vestnesa Ridge is documented in Plaza-Faverola et al., 2015. The description is based on two-3D high resolution seismic data sets acquired on the western and the eastern Vestnesa Ridge segments respectively, and one 2D seismic line acquired along the entire Vestnesa Ridge extent (Fig. 2 this paper). These data have been previously used for the investigation of BSR dynamics (Plaza-Faverola et al., 2017) and documentation of gas chimneys and faults in the region (Petersen et al., 2010; Plaza-Faverola et al., 2015). The data were acquired on board R/V Helmer Hanssen using the 3D P-Cable system (Planke et al., 2009). Final lateral resolution of the 3D data sets is given by a bin size of 6.25x6.25 m^2 and the vertical resolution is > 3 m with a dominant frequency of 130 Hz. Details about acquisition and processing can be found in Petersen et al., 2010 and Plaza-Faverola et al., 2015. For the 2D survey the dominant frequency was ~80 Hz resulting in a vertical resolution > 4.5 m (assumed as $\lambda/4$ with an acoustic velocity in water of 1469 m/s given by CTD data; Plaza-Faverola et al., 2017).

3. THE MODELING APPROACH

Tectonic processes at plate margins have a major influence on regional stress patterns (Heidbach et al., 2010). Given the proximity to the Molloy and Knipovich Ridges, it is likely that ridge push has a major control on the regional, tectonic stress field on Vestnesa Ridge. Other stress sources of importance in the region are gravitational stresses due to bathymetry/topography and subsurface density contrasts and flexural stresses due to sediment erosion and deposition. During the Quaternary, the west-Svalbard margin was furthermore affected by glacially induced flexural stresses due to the glaciations. Here, we focus on the tectonic stress due to ridge push. We use the approach by Keiding et al. (2009) based on the analytical solutions derived by Okada (1985), to model the plate motion and tectonic stress field due to spreading along the Molloy and Knipovich Ridges. Because the model only incorporates plate spreading, it is likely that the actual stress field on the west-Svalbard margin differs to some extent from the stress field predicted by our model. However, by excluding all other sources of stress, we are able to investigate the influence of tectonic stress exclusively.

The Okada model and our derivation of the stress field from it is described in more detail in appendix A. The Molloy and Knipovich Ridges are modelled as rectangular planes with opening and transform motion in a flat earth model with elastic, homogeneous, isotropic rheology. Each rectangular plane is defined by ten model parameters used to approximate the location, geometry and deformation of the spreading ridges (Okada, 1985; see supplement Table 1). The locations of the two spreading ridges were constrained from bathymetry maps (Fig. 3). The two spreading ridges are assumed to have continuous deformation below the brittle-ductile transition, with a half spreading rate of 7 mm/yr and a spreading direction of N125°E, according to recent plate motion models

(DeMets et al., 2010). Because the spreading direction is not perpendicular to the trends of the spreading ridges, this results in both opening and right-lateral motion; that is, oblique spreading on the Molloy and Knipovich Ridges. The Molloy Transform Fault, which connects the two spreading ridges, trends N133°E, thus a spreading direction of N125°E implies extension across the transform zone. We use a depth of 10 km for the brittle-ductile transition and 900 km for the lower boundary of the deforming planes, to avoid boundary effects. For the elastic rheology, we assume typical crustal values of Poisson's ratio = 0.25 and shear modulus = 30 GPa (Turcotte and Schubert, 2002).

We focus on the stress field in the upper part of the crust (where the GHSZ is) and characterise the stress regime based on the relative magnitudes of the horizontal and vertical stresses. We refer to the stresses as σ_v (vertical stress), σ_H (maximum horizontal stress) and σ_h (minimum horizontal stress), where compressive stress is positive (Zoback and Zoback, 2002). A tensile stress regime ($\sigma_v > \sigma_H > \sigma_h$) favours the opening of steep faults that can provide pathways for fluids. Compressive ($\sigma_H > \sigma_h > \sigma_v$) and strike-slip ($\sigma_H > \sigma_v > \sigma_h$) regimes do not favour such opening (e.g., Grauls and Baleix, 1994).

The model predicts zones of tensile stress near the spreading ridges, and strike-slip at larger distance from the ridges. Despite the simplicity of the model assumptions, the agreement between predicted stress regime and observed earthquake focal mechanisms is reassuring, with normal faulting mechanisms along the ridges and strike-slip mechanisms dominating everywhere else, particularly along the Spitsbergen and Molloy Transform Faults (Fig. 3).

An unexpected pattern arises near the Vestnesa Ridge due to the interference of the stress from the two spreading ridges. A zone of tensile stress extends northward from the Knipovich Ridge, encompassing the eastern part of the Vestnesa Ridge. The western Vestnesa Ridge, on the other hand, lies entirely in a zone of strike-slip stress (Fig. 3). Sensitivity tests for realistic variations in 1) mid-oceanic spreading, 2) depth of the brittle-ductile transition, and 3) elastic moduli, show that the tensile stress zone covering the eastern Vestnesa Ridge is a robust feature of the model, that is, variations in the parameters result in a change of the extent and shape of the tensile zone but the zone remains in place (Supplementary material).

4. CORRELATION BETWEEN MODELLED TECTONIC STRESS REGIME, FAULTING AND SEEPAGE

The zone of tensile stress on the eastern Vestnesa Ridge coincides with a zone of faulting and restricted seepage at the crest of the Vestnesa Ridge (Fig. 2, 3). The match between the extend of the modelled tensile zone and the active pockmarks is not exact; active pockmarks exist a few kilometres westward from the termination of the tensile zone (Fig. 3). However, the agreement is striking from a regional point of view, considering the uncertainty of the model as illustrated by the sensitivity tests (Supplementary material). In the predicted tensile zone towards the east of the Vestnesa Ridge, the sub-seabed faults are NW-SE oriented, near vertical and have a gentle normal throw (< 10 m). They are spatially linked to gas chimneys and active seepage (Bünz et al., 2012; Plaza-Faverola et al., 2015). Some of the faults show thicker sediment thicknesses at the hanging wall, allowing identification of discrete periods of faulting (Plaza-Faverola et al., 2015). The character of the faults changes towards the western

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Vestnesa Ridge and the predicted strike-slip regime. The density of faulting and seismic definition decreases westward (Fig. 2, 4). In this part of the ridge gas chimneys are narrower, stacked more vertically than active chimneys towards the east and it is possible to recognise more faults reaching the present-day seafloor (Plaza-Faverola et al., 2015).

A cluster of larger scale N-S to NNW-SSE trending extensional faults outcrop at the southern slope of the Vestnesa Ridge, also within the zone of predicted tensile stress (Fig. 1, 3). In agreement with our models, these extensional faults have been suggested to indicate the northward propagation of the Knipovich Ridge rift system (Crane et al., 2001; Vanneste et al., 2005). However, it is likely that faulting along this steep slope of the Vestnesa Ridge (Fig. 1) was partially induced by gravitational stress.

The striking correlation between predicted tectonic stress regime, faulting structures and current seepage does, in fact, suggest that tectonic stress has potentially a major influence on the near-surface sedimentary deformation. Hereafter, we discuss the implications of the interaction between tectonic stresses and pore-fluid pressure for the evolution of gas seepage along the Vestnesa Ridge.

5. SEEPAGE COUPLED TO STRESS CYCLING

Based on the correlation between tectonic stress regimes and seepage patterns, we postulate that current seepage at the eastern Vestnesa Ridge segment is favoured by the opening of pre-existing faults in a tensile stress regime (Fig. 2b). Depending on the tectonic regime, permeability through faults and fractures may be enhanced or inhibited (e.g., Hillis, 2001; Sibson, 1994). Thus, spatial and temporal variations in the tectonic stress regime may control the transient release of gas from the seafloor over geological time as documented for example for CO_2 analogues in the Colorado Plateau (e.g., Jung et al., 2014). We conjecture that seepage along the Vestnesa Ridge has been driven by cycles of increased secondary permeability via the formation of tension fractures near faults or brecciation of fault zones. Formation of tension fractures is facilitated if the minimum horizontal stress is smaller than the pore-fluid pressure (p_f), that is, the minimum effective stress is negative ($\sigma_h' = \sigma_h - p_f < 0$) (e.g., Grauls and Baleix, 1994). A negative minimum effective stress and subsequent increase in secondary permeability in a tensile stress regime can be achieved particularly easy in the near-surface. Continued flow through opened faults and fractures may lead to brecciation and development of seismic chimneys (Fig. 2b) (Sibson, 1994).

The steep NW-SE oriented faults mapped along the Vestnesa Ridge may have formed in a strike-slip regime but become permeable for gas accumulated beneath the GHSZ in periods of tensile stress. We suggest that the eastern Vestnesa Ridge segment is currently in a phase of stress relaxation where σ_h is close to zero and σ_h' is negative, due to high pore-fluid pressure at the base of the GHSZ (i.e., the shallowest reservoir holding gas from escaping to the seafloor). A high pressure at the base of the GHSZ in this part of the ridge is explained by a constant input of thermogenic gas from an Eocene reservoir since at least ca. 2 Ma ago (Knies et al., in press). Along the western Vestnesa Ridge, on the other hand, the fluid pressure at the base of the GHSZ would not be high enough to overcome the minimum horizontal stress and seepage is thus not promoted at present (Fig. 2a).

While the tectonic stress is constant over short geological time spans, the chimney development and seafloor seepage has been a transient process because of slight variations in pore-fluid pressure or the influence of other stress generating mechanisms that bring the system out of equilibrium. Geophysical and paleontological data indicate that there was once seepage and chimney development on the western Vestnesa Ridge segment (e.g., Consolaro et al., 2015; Plaza-Faverola et al., 2015). Past seepage through faults may have been repeatedly incited by glacially induced horizontal stresses during Quaternary glaciations (Fig. 4). During glacial periods, the load of the ice forces the lithosphere down and creates an isostatic forebulge along the periphery of the ice, generating considerable flexural stresses in the upper part of the lithosphere (Lund and Schmidt, 2011). The lateral expansion of grounded ice in the western Barents Sea region is limited by the continental shelf break, and the Vestnesa Ridge was likely affected by tensional flexural stresses in the forebulge around the time of glacial maximums (Patton et al., 2016). We consider it likely that the repeated waxing and waning of the ice sheet caused a cyclic modulation of the stress field and influenced the dynamics of gas accumulations along the Vestnesa Ridge in the past; thus explaining the correlation between past seepage and glaciation events observed in other continental margins e.g., for chimneys off the mid-Norwegian margin (Plaza-Faverola et al., 2011), the Gulf of Lion (Riboulot et al., 2014), but also along the Vestnesa Ridge (Plaza-Faverola et al., 2015).

A long-term variation in tectonic stress on the Vestnesa Ridge is caused by its location on a constantly growing plate. As the oceanic plate grows, Vestnesa Ridge moves eastward with respect to the Molloy and Knipovich Ridges, causing a westward shift in the regional stress field on Vestnesa Ridge (Fig. 5). In the future, the eastern Vestnesa Ridge may temporarily move out of the tensile zone, while the western Vestnesa Ridge moves into it (Fig. 5). This suggests that active seepage may reappear at pockmarks to the west of the currently active seepage zone.

6- CONCLUSIONS

The results of modelling the stress regime generated exclusively by mid-ocean ridge spreading in Fram Strait support seismic evidence of the correlation between faulting and seepage distribution along the Vestensa sedimentary ridge, offshore the west Svalbard margin. Tectonic stresses due to oblique spreading along the Molloy and the Knipovich ridges influences the present day stress field across the west-Svalbard passive margin. A correlation between a tensile stress regimes and seepage activity suggests that episodic seepage through gas chimneys has been controlled by an interplay between varying minimum horizontal stresses and pore fluid pressure at the free gas zone beneath the hydrate reservoir. Present-day seepage is facilitated by opening of faults and fractures in a tensile stress regime, where pore fluid pressure overcome the minimum horizontal stress. Pockmarks that are inactive at present under a strike-slip regime, but were active multiple times in the past, may have been activated by additional tensile stresses (e.g., from glacial related lithospheric adjustments). Future reactivation of currently dormant pockmarks is likely following the gradual westward propagation of the tensile stress zone on the Vestnesa Ridge.

Figures

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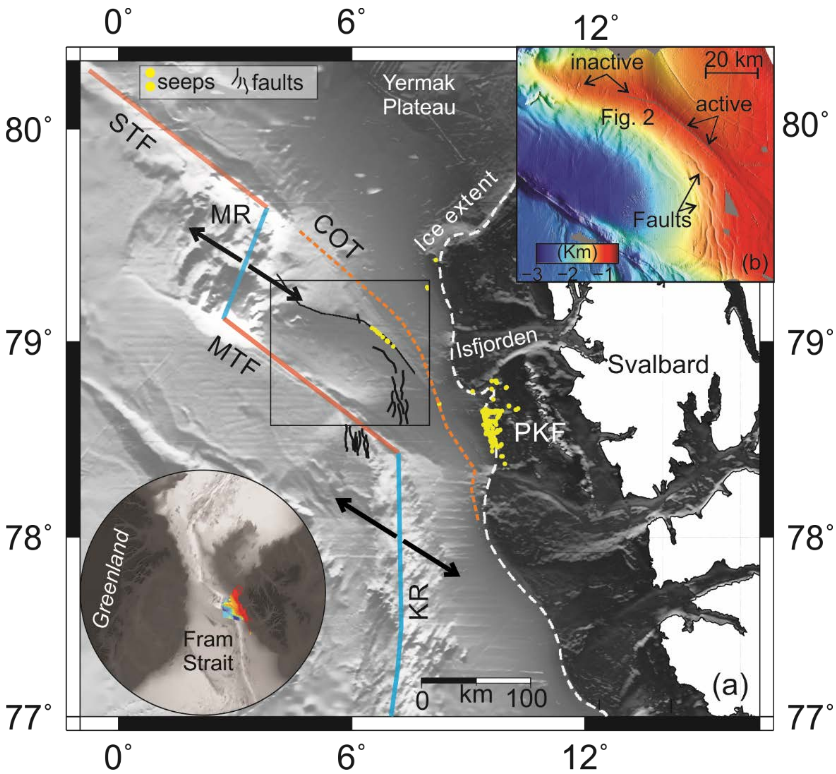

Figure 1: (a) International Bathymetry Chart of the Arctic Ocean (IBCAO) showing the geometry of mid-ocean ridges offshore the west-Svalbard margin; (b) High resolution bathymetry along the Vestnesa Ridge (UiT, R/V HH multi-beam system). Seafloor pockmarks are observed along the entire ridge but active seep sites are restricted to its eastern segment; PKF=Prins Karl Foreland; STF=Spitsbergen Transform Fault; MR=Molloy Ridge; MTF=Molloy Transform Fault; KR=Knipovich Ridge; COT=Continental-Oceanic Transition (Engen et al., 2008); Ice-Sheet Extent (Patton et al., 2016).

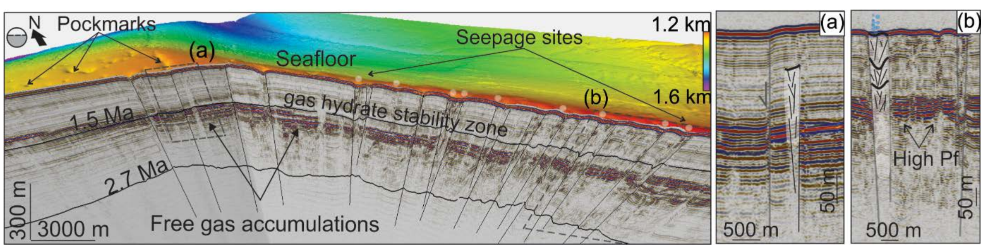

Figure 2: Integrated seismic and bathymetry image of the gas hydrate system along the Vestnesa Ridge. (a) Outcropping fault located at the transition from the active to the currently inactive pockmark region; (b) Gas chimneys with active seepage and inferred high pore-fluid pressure (Pf) zone.

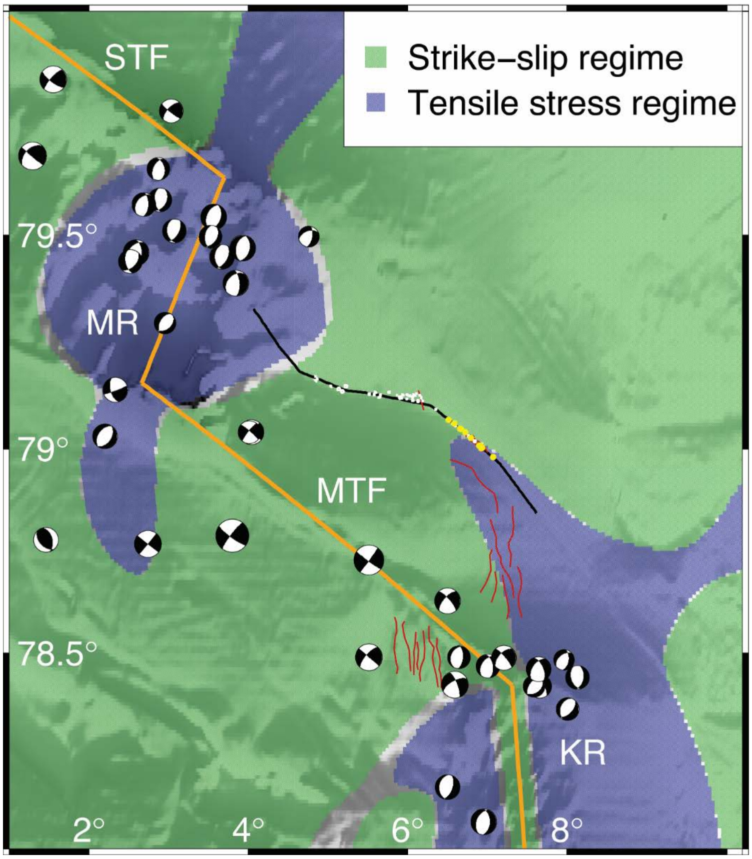

Figure 3: Modelled upper crustal tectonic stress field (blue – tensile and green - strike-slip regime), due to oblique spreading at Molloy Ridge (MR) and Knipovich Ridge (KR). The seismic line is projected as reference for the crest of the Vestnesa Ridge. Red lines are faults, yellow dots seeps and white circles inactive pockmarks. The focal mechanisms are from the ISC Online Bulletin (http://www.isc.ac.uk).

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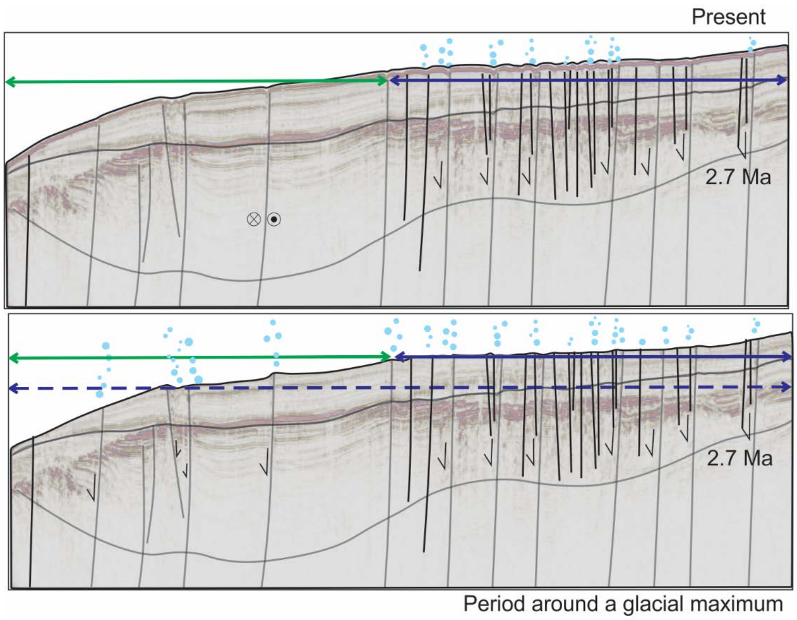

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259 **Figure 4**: Conceptual model of the evolution of seepage coupled to faulting and spatial variations in the stress
260 regime (tensile=blue; strike-slip=green) along the Vestensa Ridge, offshore the west-Svalbard margin. At present
261 day, tensile stress from mid-ocean ridge spreading (blue solid line) favours seepage exclusively on the eastern
262 segment of the Vestnesa Ridge. Seepage on the western Vestnesa Ridge and other regions may have been induced
263 repeatedly since the onset of glaciations 2.7 Ma ago (Mattingsdal et al., 2014), due to tensional flexural stresses in
264 the isostatic forebulge around the time of glacial maximums.

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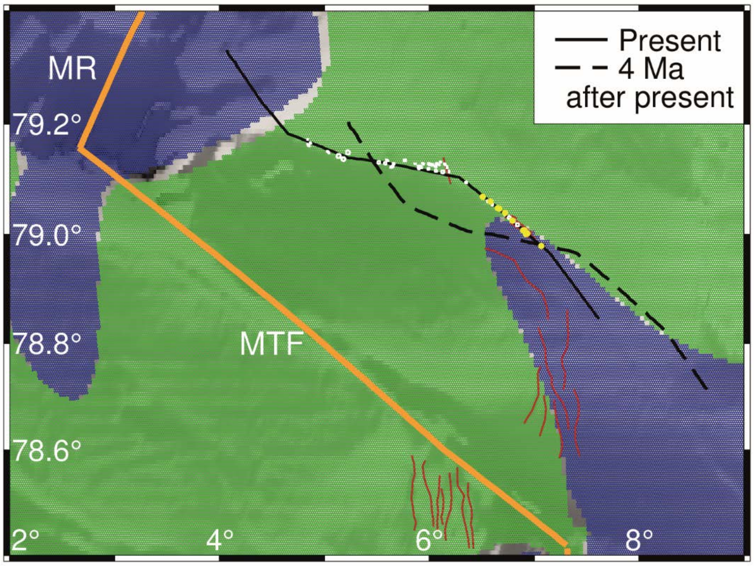

Figure 5: Stress field in figure 3 showing the location of the Vestnesa Ridge at present and 4 Ma after present time, assuming a constant spreading velocity of 7 mm/yr in the direction N125°E. The black polygon corresponds to the seismic line in Plaza-Faverola et al., 2017 and partly shown in figure 2. It is presented as reference for the crest of the eastern and western Vestnesa Ridge segments

Appendix A

Model description

We use the analytical formulations of Okada (1985) for a finite rectangular dislocation source in elastic homogeneous isotropic half-space (Fig. A.1). The dislocation source can be used to approximate deformation along planar surfaces, such as volcanic dykes (e.g. Wright et al., 2006), sills (e.g. Pedersen and Sigmundsson, 2004), faults (e.g. Massonet et al, 1993) and spreading ridges (e.g. Keiding et al., 2009). More than one dislocations can be combined to obtain more complex geometry of the source or varying deformation along a planar source. The deformation of the source can be defined as either lateral shear (strike-slip for faults), vertical shear (dip-slip at faults) or tensile opening.

The Okada model assumes flat Earth without inhomogeneities. While the flat-earth assumption is usually adequate for regional studies (e.g. Wolf, 1984), the lateral inhomogeneities can sometimes cause considerable effect on the deformation field (e.g. Okada, 1985). However, the dislocation model is useful as a first approximation to the problem.

At mid-ocean ridges, deformation is driven by the continuous spreading caused primarily by gravitational stress due to the elevation of the ridges, but also basal drag and possibly slab pull. Deformation occurs continuously in the ductile part of the crust. Meanwhile, elastic strain builds in the upper, brittle part of the crust. To model this

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setting, the upper boundary of the dislocation source must be located at the depth of the brittle-ductile transition zone. The lower boundary of the source is set to some arbitrary large depth to avoid boundary effects.

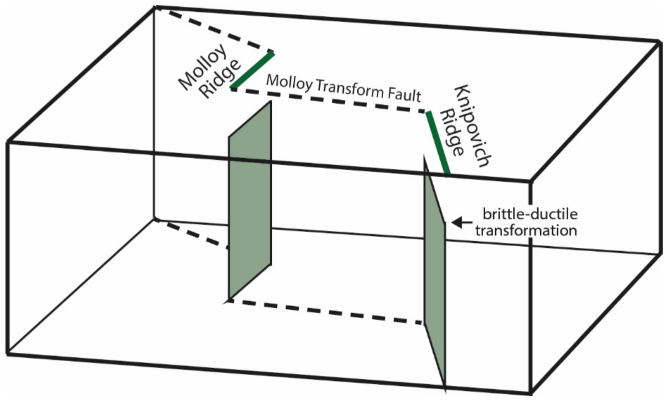

Fig A.1 Extract of model showing the location of the dislocation sources (light green) for Molloy and Knipovich ridges. Note that the model is an infinite half-space, i.e. it has no lateral or lower boundary.

The Okada model provides the displacements u_x, u_y, u_z (or velocities if deformation is time-dependent) at defined grid points at the surface and subsurface. It also provides strain (or strain rates) defined as:

$$\varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$$

The stress field can then be calculated from the predicted strain rates. In homogeneous isotropic media, stress is related to strain as:

$$\sigma_{ij} = \lambda\delta_{ij}\varepsilon_{kk} + 2\mu\varepsilon_{ij}$$

where δ_{ij} if the Kronecker delta, λ is Lamé's first parameter, and μ is the shear modulus. Lamé's first parameter does not have a physical meaning but is related to the shear modulus and Poisson's ratio (ν) as $\lambda = \frac{2\mu\nu}{1-2\nu}$.

The absolute values of stress are in general difficult to model (e.g. Hergert and Heidbach, 2011), and not possible with our analytical model. However, the model provides us with the orientations and relative magnitude of the stresses. That is, we know the relative magnitudes of the vertical stress (σ_v), maximum horizontal stress (σ_H) and minimum horizontal stress (σ_h). From this, the stress regime can be defined as either tensile ($\sigma_v > \sigma_H > \sigma_h$), strike-slip ($\sigma_H > \sigma_v > \sigma_h$) or compressive ($\sigma_H > \sigma_h > \sigma_v$).

Author contribution

Andreia Plaza-Faverola conceived the paper idea. She is responsible for seismic data processing and interpretation. Marie Keiding did the tectonic modelling. The paper is the result of integrated work between both.

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Centre for Arctic Gas Hydrate, Environment and Climate, Tromsø, Norway and can be made available by contacting APF. Modelled stresses can be made available by contacting MK.

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