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Seismic investigation of Arctic seafloor seepage systems aided by tectonic modelling

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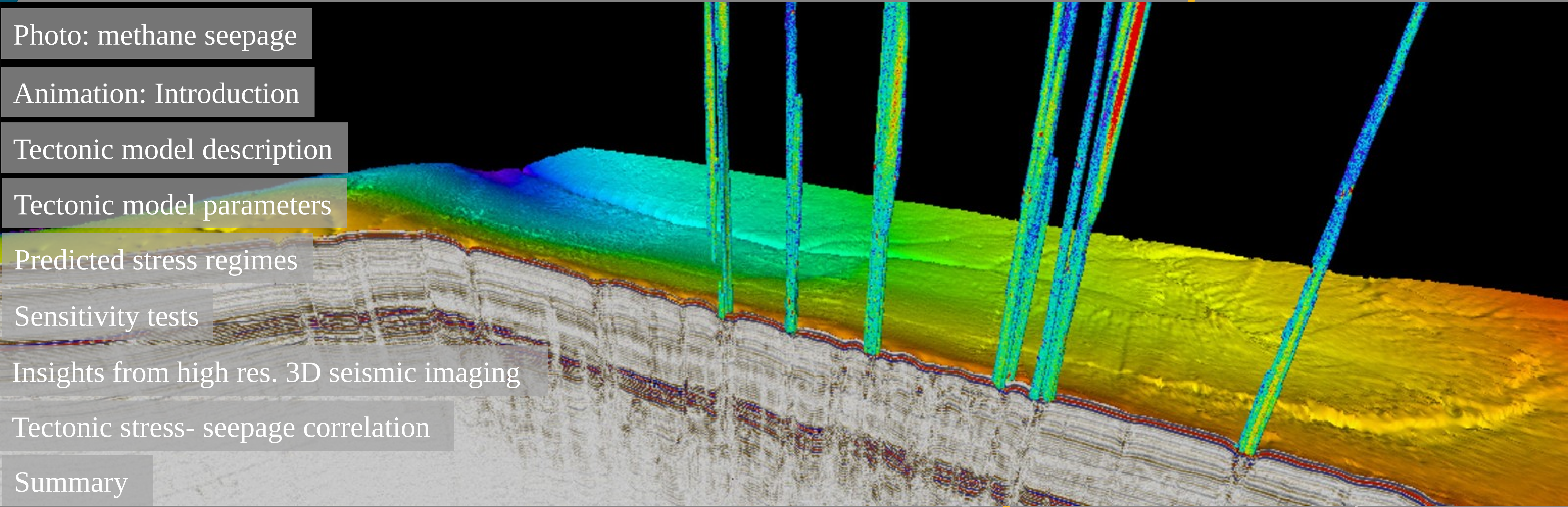
Environment and Climate



- Photo: methane seepage
- Animation: Introduction
- Tectonic model description
- Tectonic model parameters
- Predicted stress regimes
- Sensitivity tests
- Insights from high res. 3D seismic imaging
- Tectonic stress- seepage correlation
- Summary

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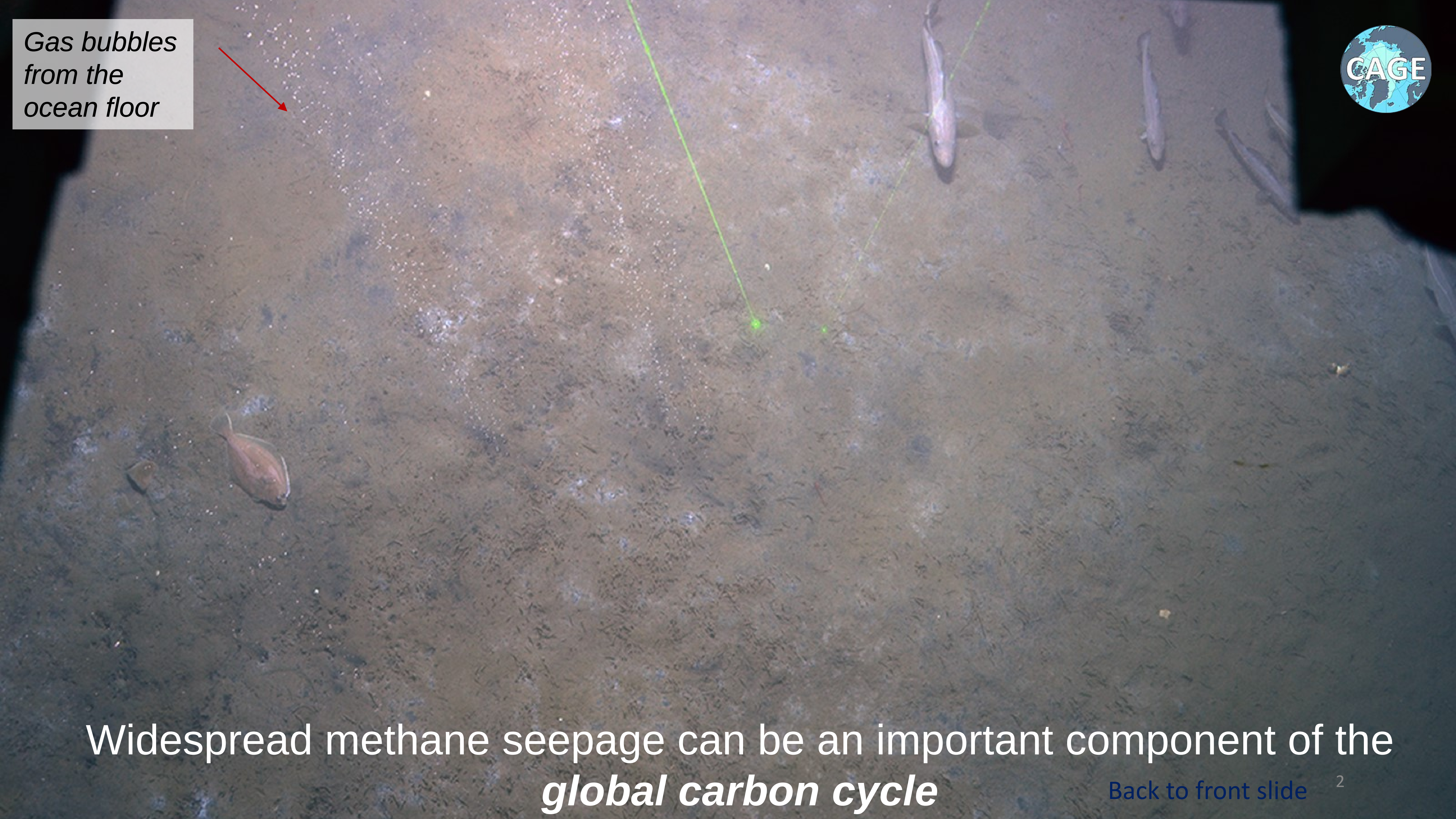

Widespread methane seepage can be an important component of the ***global carbon cycle***

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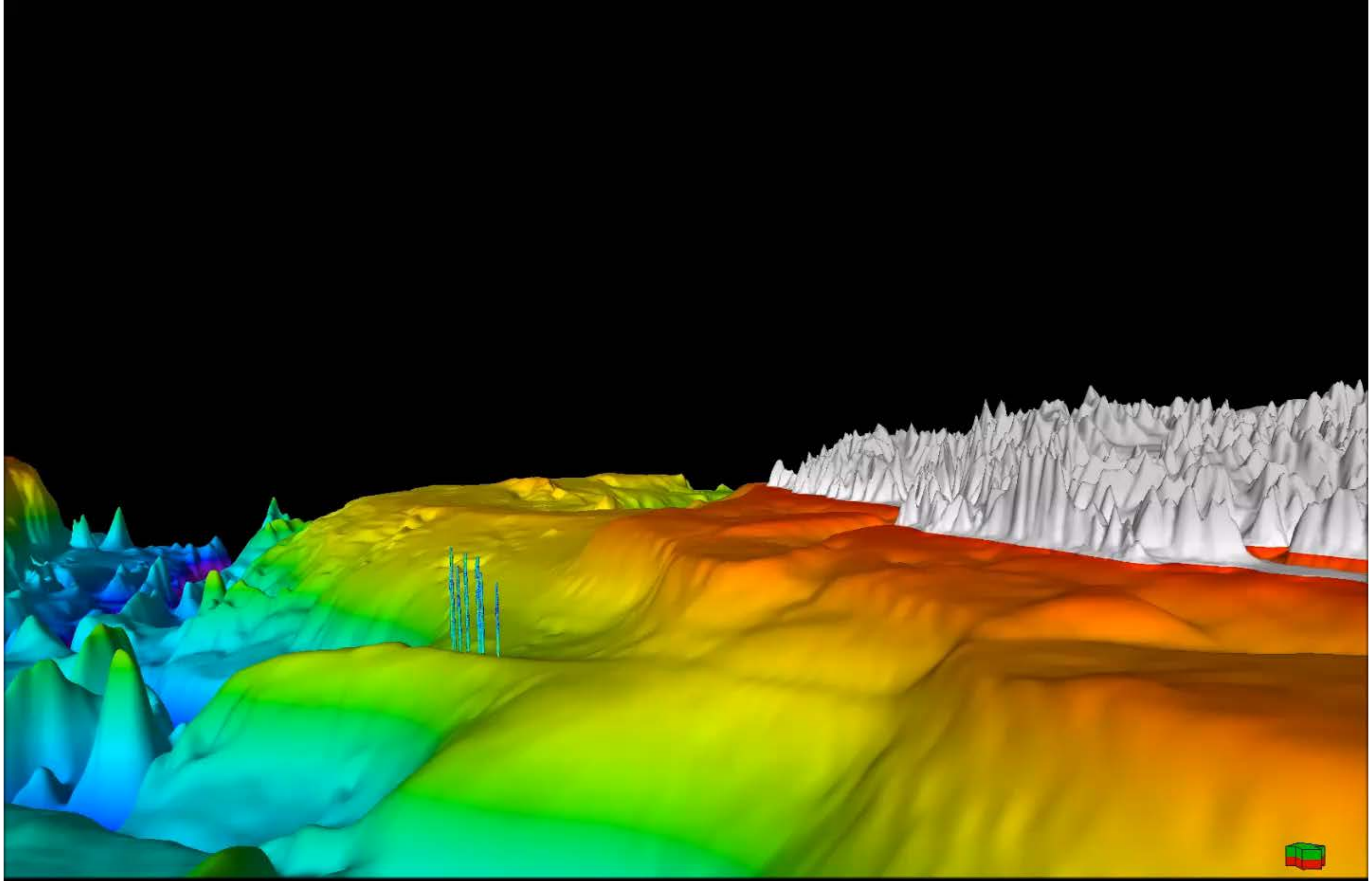

Strike-slip

Tensile

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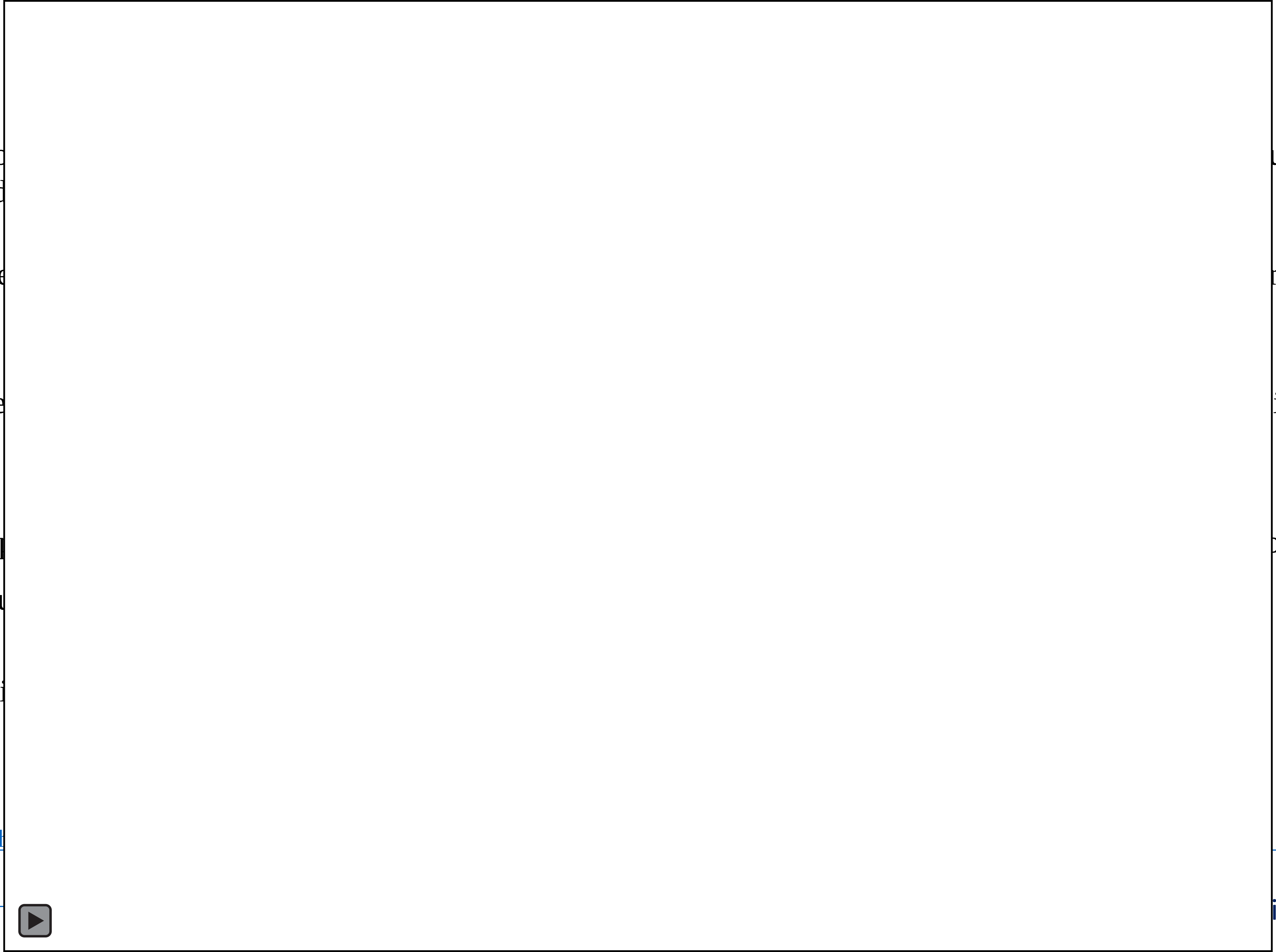
1- We mo uence of NW-SE d

2- We use mogeneous isotropic

3- The de ip-slip at faults)

4- The up on zone. The lower bou

5- Stress i



where δ_{ij} if th meaning but is related to the

Fig 1: Bathymetry map with schematic representation of the oblique spreading projected.

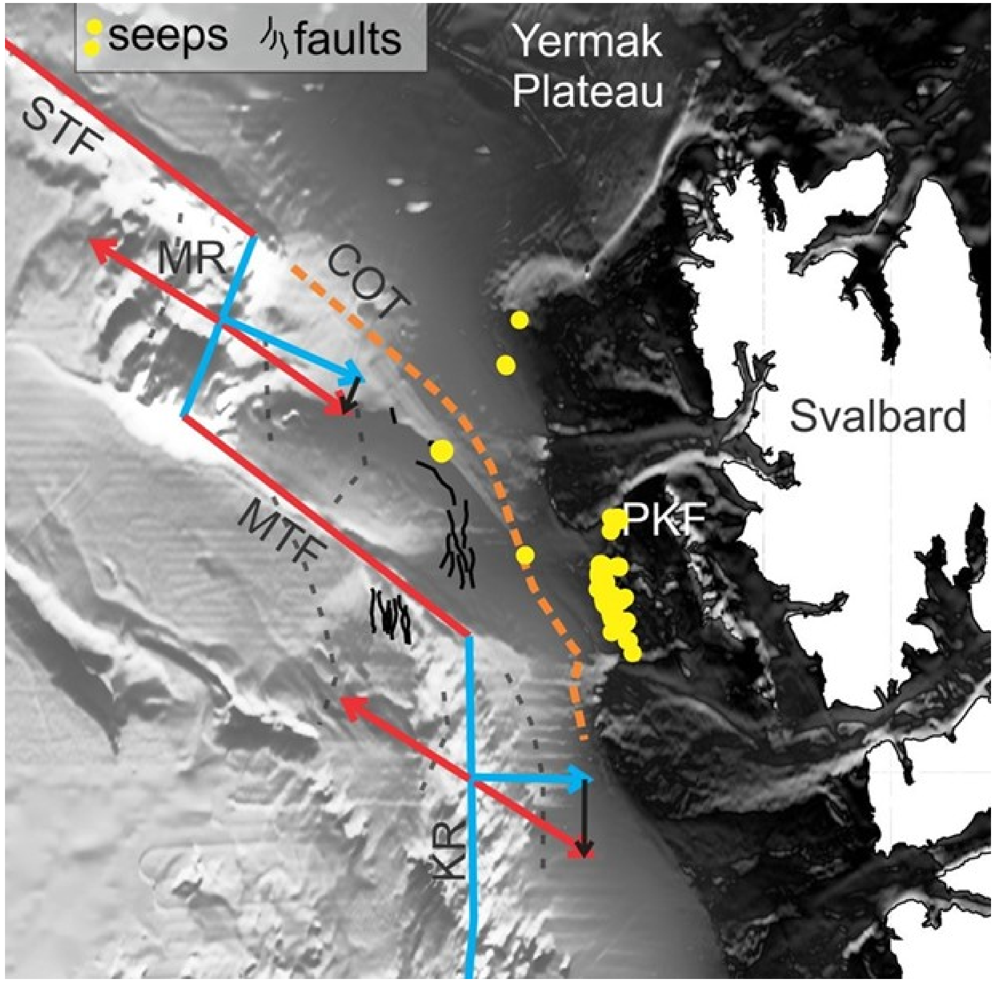
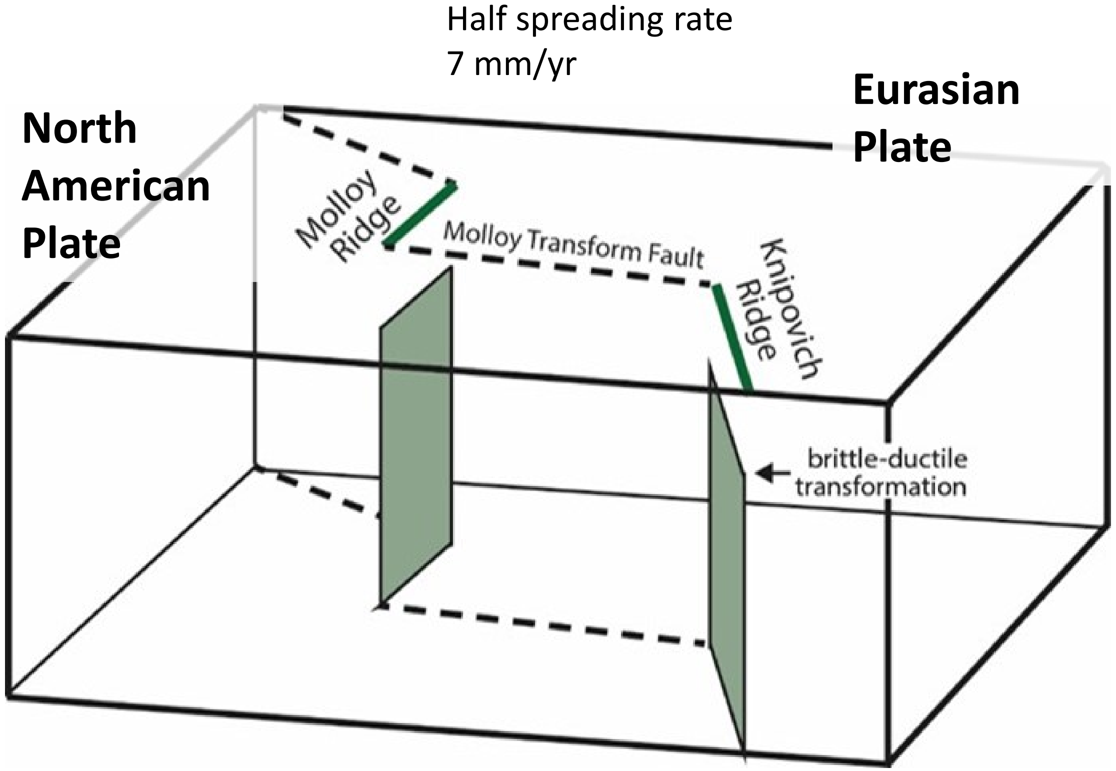


Fig 2: Extract of model showing the location of the dislocation sources (light green) for Molloy and Knipovich ridges. Note that the model is an infinite half-space, i.e. it has no lateral or lower boundary.



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Model parameters

Table 1. Model parameters for the two rectangular planes (Okada, 1985) used to approximate the deformation due to oblique spreading along Molloy Ridge (MR) and Knipovich Ridge (KR)

Ridge	Length (km)	Depth to lower boundary (km)	Depth upper boundary (km)	Dip (°)	Strike (°)	East midpoint (UTM, m)	North midpoint (UTM, m)	Right-lateral motion* (mm/yr)	Vertical motion (mm/yr)	Opening* (mm/yr)
MR	57	900	10	-90	28	380.000	8820.000	1.8	0	13.9
KR	180	900	10	-90	-3	467.000	8616.000	8.6	0	11.1

* Calculated by assuming a half spreading rate of 7 mm/yr in the direction of N125°E on both the MR and KR.

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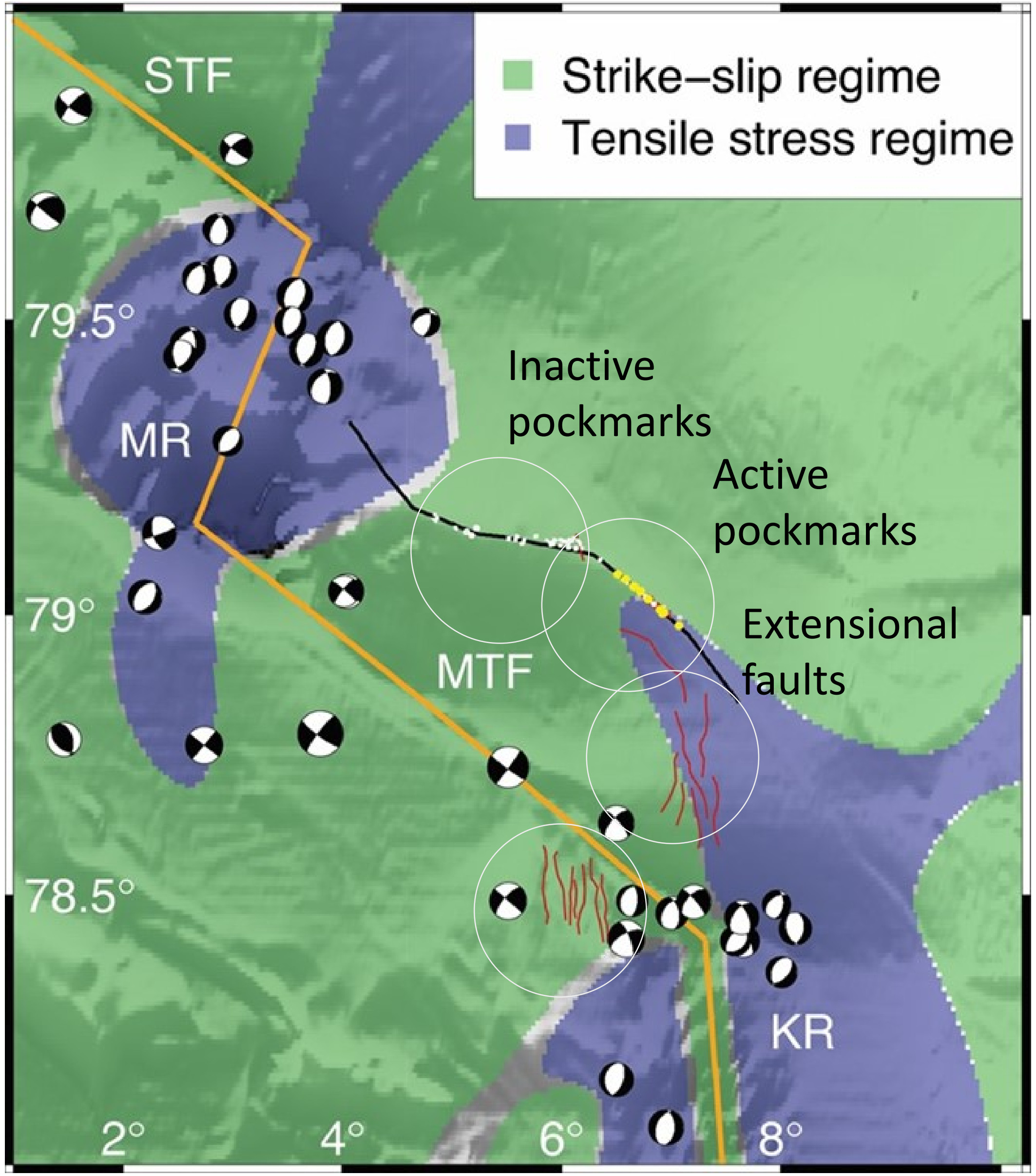
The tectonic model predicts a change in stress regime from strike slip at non-seeping sites to tensile at the active seepage zone

Earthquakes focal mechanisms match well the predictions



Pockmarks and faults south of the Molloy Transform Fault (MTF) are also inactive and under a strike-slip regime at present (Waghorn et al., in review)

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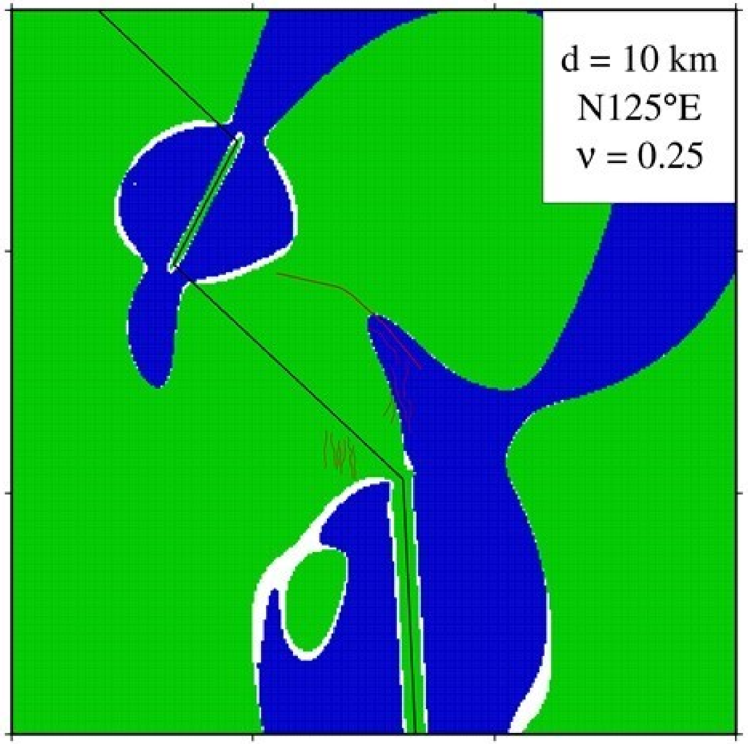
Sensitivity tests suggest that the tensile stress zone covering the eastern VR is a robust feature of the model

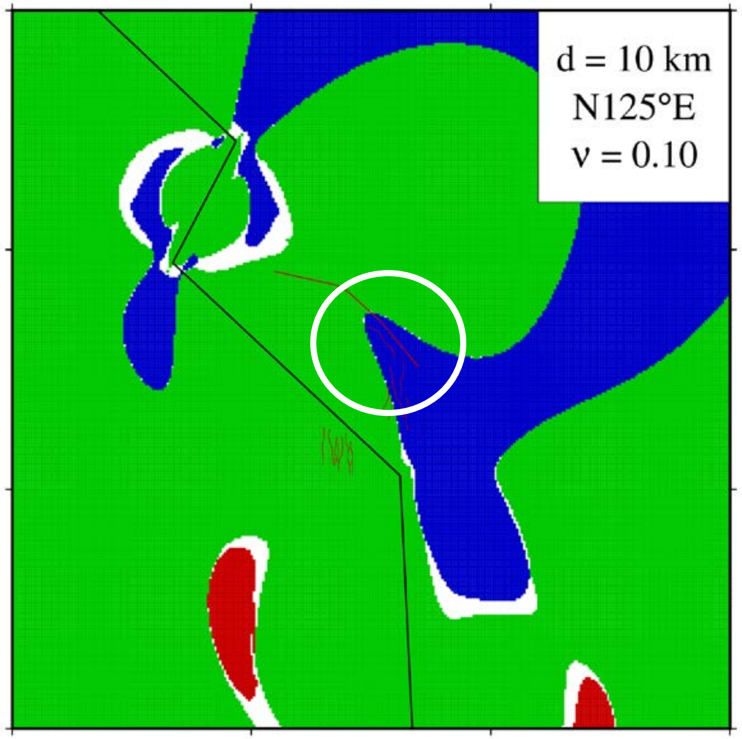
Variation of the spreading direction by > 10°

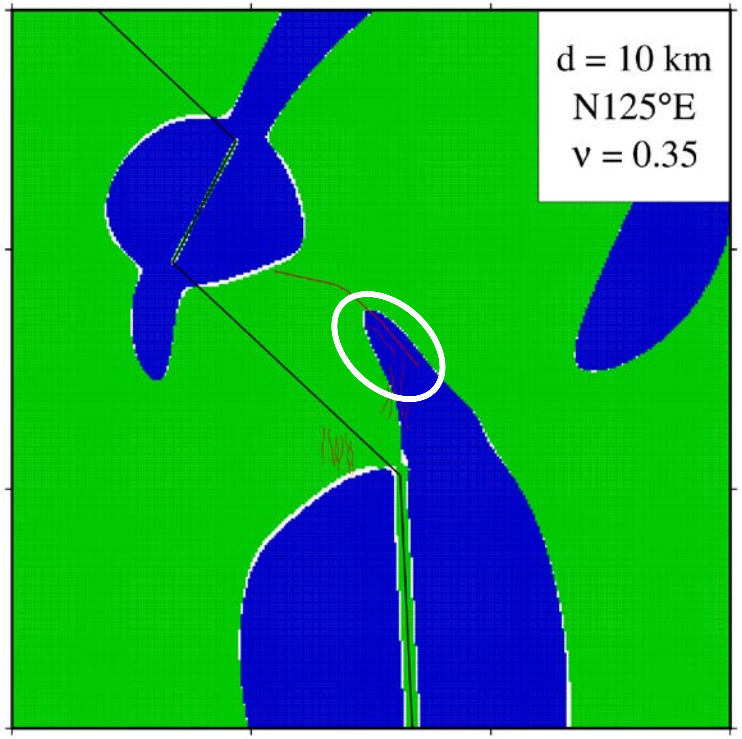
Preferred model

Decrease of depth to upper boundary by up to 5 km

Variation of the Poisson’s ratio by ca. -/+ 0.1







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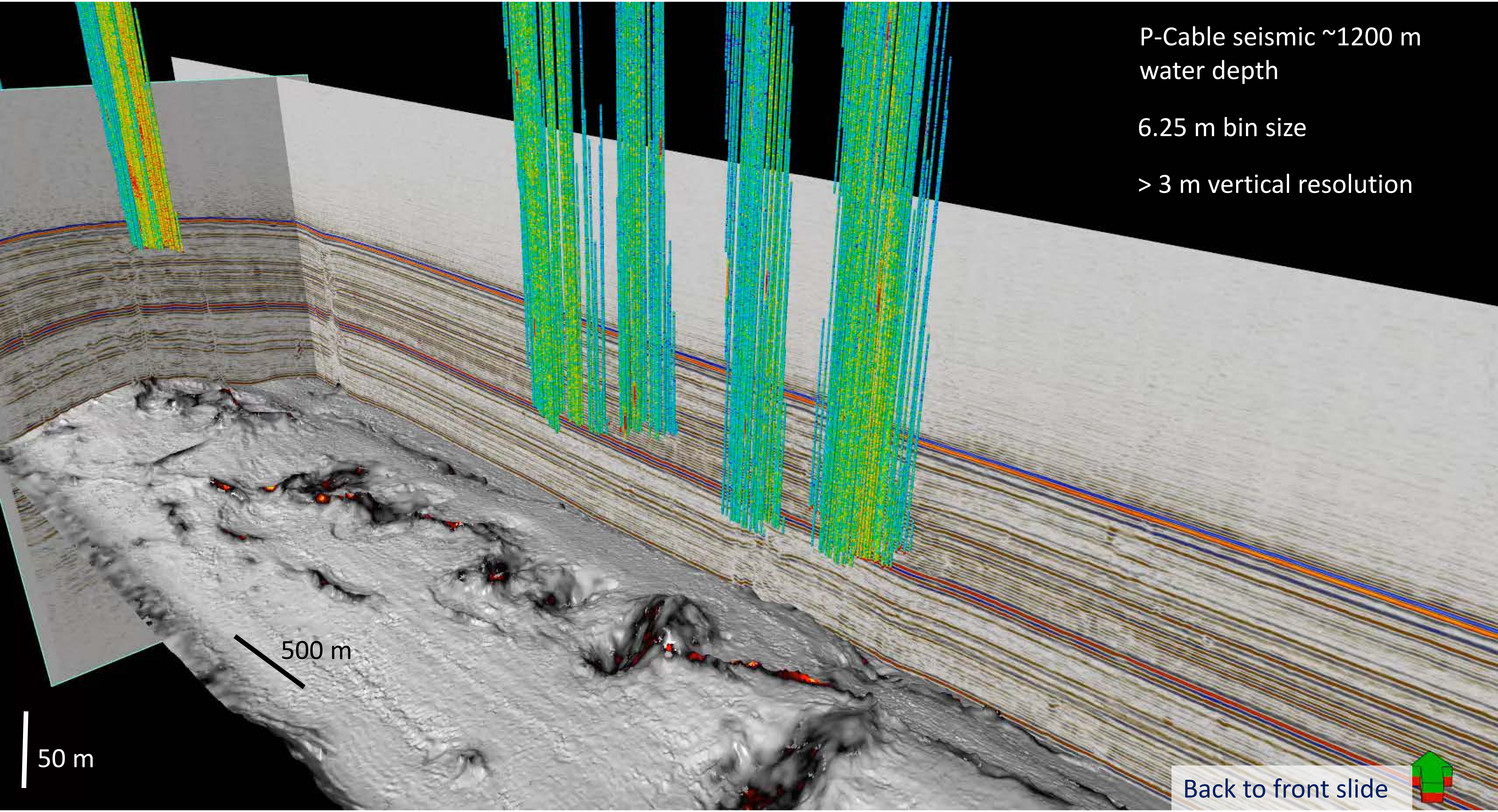

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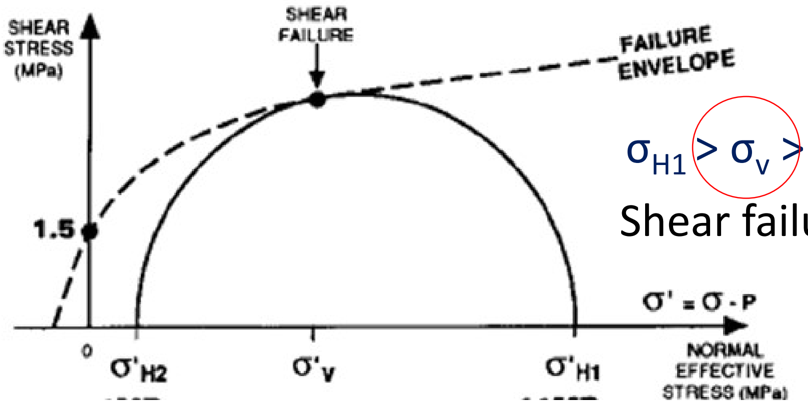
Seepage occurs in periods of stress relaxation where the opening of new or existing tensile fractures is favored

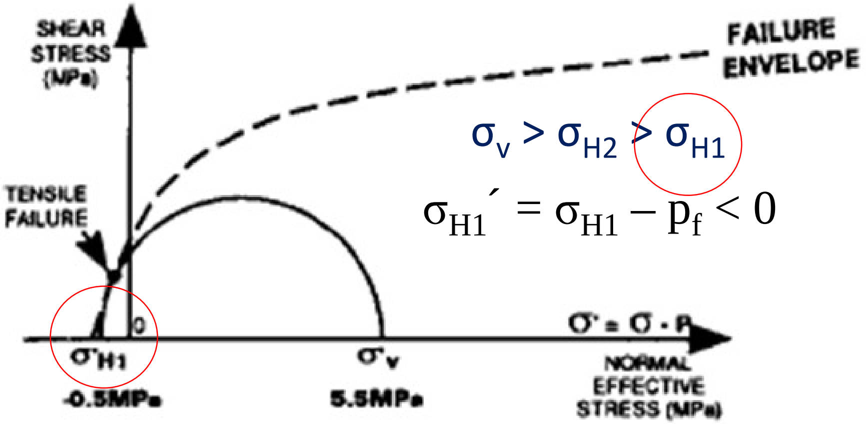
Period of «compression»



$\sigma_{H1} > \sigma_v > \sigma_{H2}$

Shear failure

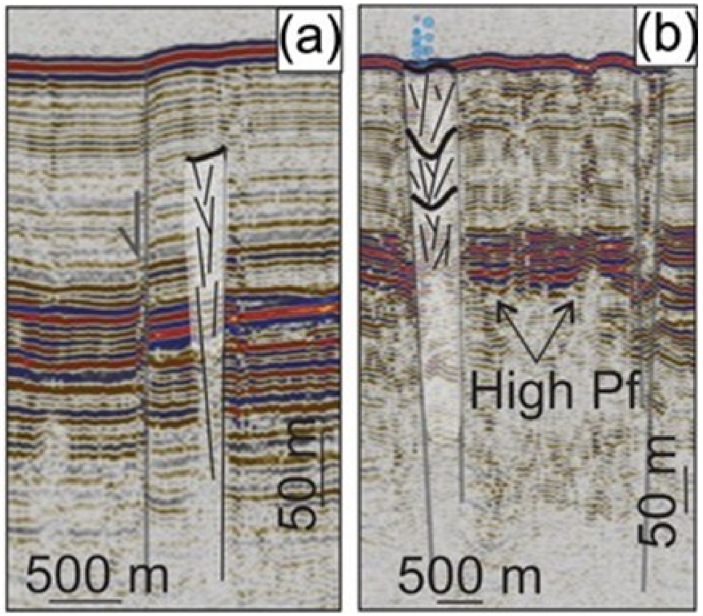
Period of stress relaxation



$\sigma_v > \sigma_{H2} > \sigma_{H1}$

$\sigma_{H1}' = \sigma_{H1} - p_f < 0$

(modified from Grauls and Baleix, 1994)



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Summary

1- Despite seismic evidences for shallow methane along the entire Vestnesa Ridge and morphological expressions for past seepage, seepage is restricted to a zone of near-vertical faults on the eastern ridge segment.

2- We hypothesize that spatial and temporal variations in the stress filed controls seepage activity.

3- A simple analytical model of the stress regime due to oblique spreading at Knipovich and Molloy ridges supports our working hypothesis.

4- The model predicts a zone of tensile stress that extends northward from the Knipovich ridge and comprises the active seepage zone at Vestnesa ridge while the non-seepage zone is under a strike-slip regime.

5- Seepage is promoted in the tensile stress regime where pore-fluid pressure wins over horizontal stresses.

6- Next step: go numerical to calculate actual principal stresses and include glacial related stresses.

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Relationships between elastic moduli

	LAME MODULUS λ	SHEAR MODULUS μ	YOUNG'S MODULUS E	POISSON'S RATIO ν	BULK MODULUS K
λ, μ			$\frac{\mu(3\lambda+2\mu)}{\lambda+\mu}$	$\frac{\lambda}{2(\lambda+\mu)}$	$\frac{3\lambda+2\mu}{3}$
λ, E		Irrational		Irrational	Irrational
λ, ν		$\frac{\lambda(1-2\nu)}{2\nu}$	$\frac{\lambda(1+\nu)(1-2\nu)}{\nu}$		$\frac{\lambda(1+\nu)}{3\nu}$
λ, K		$\frac{3(K-\lambda)}{2}$	$\frac{9K(K-\lambda)}{3K-\lambda}$	$\frac{\lambda}{3K-\lambda}$	
μ, E	$\frac{\mu(2\mu-E)}{E-3\mu}$			$\frac{E-2\mu}{2\mu}$	$\frac{\mu E}{3(3\mu-E)}$
μ, ν	$\frac{2\mu\nu}{1-2\nu}$		$2\mu(1+\nu)$		$\frac{2\mu(1+\nu)}{3(1-2\nu)}$
μ, K	$\frac{3K-2\mu}{3}$		$\frac{9K\mu}{3K+\mu}$	$\frac{3K-2\mu}{2(3K+\mu)}$	
E, ν	$\frac{\nu E}{(1+\nu)(1-2\nu)}$	$\frac{E}{2(1+\nu)}$			$\frac{E}{3(1-2\nu)}$
E, K	$\frac{3K(3K-E)}{9K-E}$	$\frac{3EK}{9K-E}$		$\frac{3K-E}{6K}$	
ν, K	$\frac{3K\nu}{(1+\nu)}$	$\frac{3K(1-2\nu)}{2(1+\nu)}$	$3K(1-2\nu)$		

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http://solidmechanics.org/text/Chapter3_2/Chapter3_2.htm

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