A marine CSEM study for the characterization of methane hydrate and free gas reservoirs at the Nyegga CNE03 pockmark, Norwegian Sea

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1. Background & Objectives
- The motivation to study gas hydrates deposits emerges from three main reasons:
  1. Possible role in climate change
  2. Geohazard to marine infrastructures
  3. Future potential as energy source
- In 2012, a controlled-source electromagnetic (CSEM) survey was conducted along the Nyegga CNE03 pockmark, where high-resolution 3D seismic was previously collected in 2000 as part of the HERMES project (Erut et al. 2016). CSEM data from CNE03 were sampled as part of the 2014 Arctic Landslide Tsunami project.
- The aim of this CSEM study is to detect and quantify the methane hydrate and free gas deposits along the Nyegga region, at the CNE03 chimney pockmark, offshore Norway. Here we present the 2.5D CSEM inversion results that were computed using the data acquired by both the ocean bottom electrostatic field receiver (OBER) and the 3-axis towed receiver (Vulcan).

2. The Nyegga Region & CNE03 Pockmark
- Water depth ranges from 700 - 800 m
- The region was formed as a result of recurring slumping episodes during the Pliocene/Cenozoic.
- Nyegga accommodates about 300 - 600 m of Glacial-Interglacial deposits.
- There are approximately 415 complex chimney pockmarks at Nyegga (Petersen et al. 2012).
- Recent estimations suggest that there is ~710 GSm (10 million cubic meters) of gas hydrate beneath Nyegga (Sauger et al. 2010).
- The CNE03 pockmark is a chimney-like structure, characterized by a hydrothermal vent and deep-seated associated anomalies.

3. The CSEM Survey at CNE03
- The CNE03 pockmark may be a representative geological feature of global importance for methane escape from beneath continental margins.
- The CSEM survey at CNE03 had two sets of systems:
  1. The GEOMAR CSEM system
  2. The University of Southampton (UoS) CSEM system, which included the following instruments:
     - DAS1 - A deep towed electromagnetic source
     - OBER - High ocean bottom electrostatic field receivers
     - Vulcan - 3-axis fixed offset towed receiver
     - The UoS CSEM survey layout
     - Hyperbolic Line 1 & 2

4. An Example of a Starting Model for the 2.5D CSEM Inversions
- The starting models for the 2.5D CSEM inversions were constructed using Mamba2D model builder, from MAREDIM inversion code by Kerr (2011)

5. Vulcan Pmax & OBE Amplitude and Phase 2.5D CSEM Isotropic Inversions Cross-plots

6. Lines 1 & 2: Vulcan Isotropic Pmax Inversions and OBE 2.5D CSEM Isotropic / Anisotropic Inversions

7. Line 1: Seismic section coincident with the 2.5D CSEM Isotropic inversion

8. Estimated Hydrate Saturation using Archie's Law

9. Summary & Conclusions
- Hydrate was found within a core sample from the CNE03 pockmark center.
- OBE 2.5D ampliude & phase CSEM inversions and Vulcan initial Pmax inversions, successfully detected a pipe-like resistivity anomaly structure at the CNE03 pockmark.
- A deeper resistivity structure was detected, possibly corresponding to a free gas layer below the BGHSZ.
- Anisotropy ranges between 2 - 10% along the CNE03 pockmark and the BGHSZ region.
- Vulcan 2.5D Pmax inversion results suggest the presence of additional prominent resistors along CNE03.
- Based on Archie’s equation, there is approximately 33% - 43% of resistive material along CNE03 chimney.
- The results support previous seismic assessments, indicating the presence of both hydrate and free gas at the Nyegga CNE03 pockmark.