Polygonal fault systems in Gjallar Ridge, offshore Norway : implications for early processes of deformation, faulting and fluid flow

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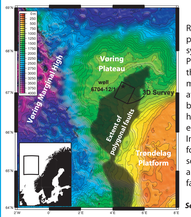
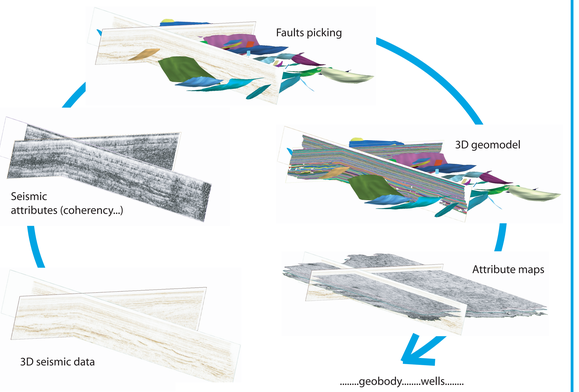
Introduction



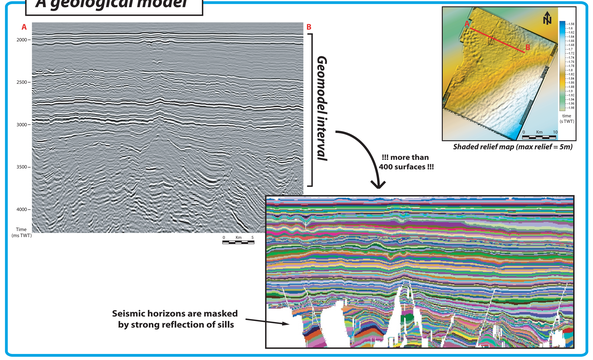
Interpretation of a 3D seismic survey reveals a closely-spaced polygonal fault system in the Gjallar Ridge (Vøring Basin, offshore Norway) affecting mud-dominated Tertiary sequences and displaying a polygonal pattern in plane view. Some of these faults reach the seafloor, thus representing an active system at present.
Polygonal fault systems are identified in many sedimentary basins in the world and it is now accepted that these faults are linked to fluid flow as they form preferential pathways for upwards-fluid migration from deeper level (Gay et al., 2004). However, it is still unknown how they form, spread and affect seabed environment. Characterizing the vertical/horizontal distribution and the mechanical behavior of polygonal faults is essential for predicting sealing capacity over reservoirs for hydrocarbon exploration (reservoir leakage), seabed stability and, finally, the impact on benthic ecosystem and carbon cycle.
In this study, we propose a geometrical model for polygonal fault formation and interaction with focused fluid flow, using a new seismic interpretation software Paleoscan, developed by Eliis. This software allows us to build a geological model of the highly faulted interval from the 3D seismic block and to produce an important horizon stack with different attributes (coherency, envelope, amplitude, fault throw...).

Seabed map with extent of polygonal fault systems in Vøring Basin (after Hustoft et al., 2007).

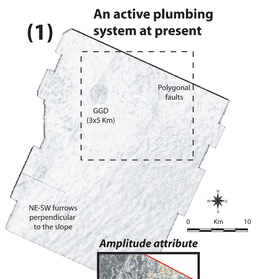
A seismic interpretation with Paleoscan



A geological model

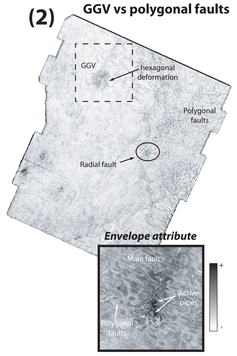


(1) An active plumbing system at present



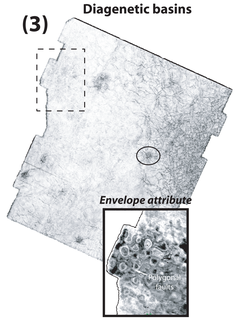
High amplitude for GGD and edges of polygons
= **preferential pathways for fluids**.

(2) GGV vs polygonal faults



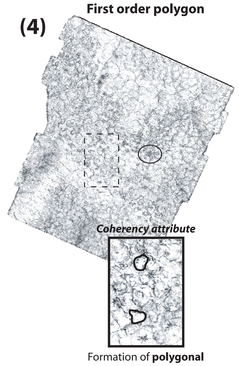
Polygonal faults connect to the GGV and also modify its shape.

(3) Diagenetic basins



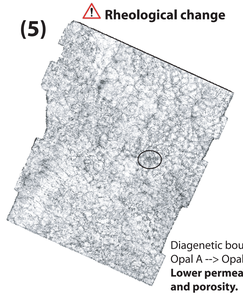
Circular shapes bounded by crests (polygonal faults) and characterized by lower amplitudes than sediments within the depression
= **differential compaction by variation in the proportions of Opal A and Opal CT (Ireland et al., 2010)**.

(4) First order polygon



Formation of **polygonal faults** (width = 1 Km) vertically correlated with seafloor furrows.

(5) Rheological change



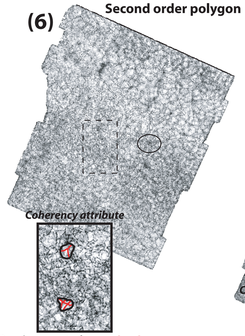
Diagenetic boundary : Opal A --> Opal CT
Lower permeability and porosity.

0 m

Increase of compaction intensity with depth

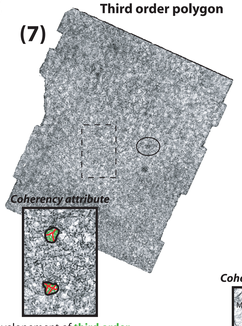
3000 m

(6) Second order polygon



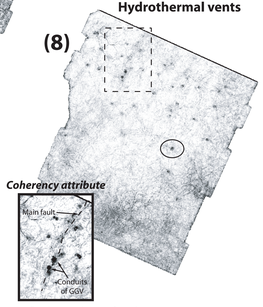
Developement of **second order polygonal faults** (width = 500 m) within first order polygon (orhogonal intersections).

(7) Third order polygon



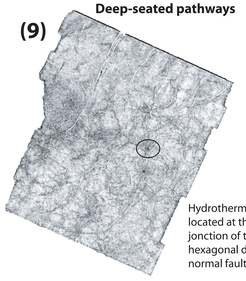
Developement of **third order polygon faults** (width = 300 m).

(8) Hydrothermal vents

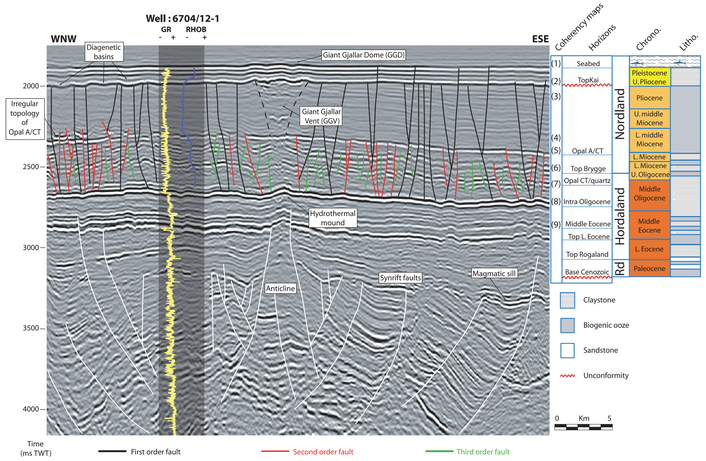


Thermogenic fluids expulsion after the thermal cracking of organic matter, subsequent to emplacement of Paleocene magmatic sills.

(9) Deep-seated pathways

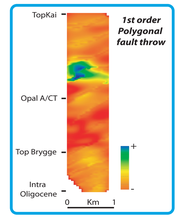


Hydrothermal vents located at the triple jonction of three hexagonal deep normal faults.

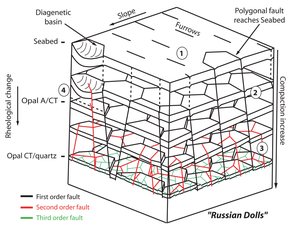


Two vertical individual tiers :
- Middle Miocene / Pliocene interval characterized by faults with an average spacing of 700 m (1st order fault). Some of them reaches the seafloor.
- Middle Oligocene / Lower Miocene sequence showing a fault spacing of 200 m (2nd and 3rd order fault).

First order faults are affecting both intervals and present a change in dip at the border of the two tiers. The throw increases from the top of upper tier to this border and then decreases, correlated with the formation of 2nd and 3rd order faults. As shown in the well 6704/12-1, this change of behaviour is consistent with a lithologic variation corresponding to the Opal A/CT conversion. This diagenetic boundary has an irregular topology and formed depressions by differential compaction just above (diagenetic basins).

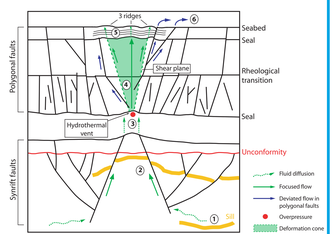


Conclusions



3D evolution of polygonal fault

1/ Volumetric contraction at the sediment/water interface, parallel to the slope, forming furrows on the seabed.
2/ During burial, permeability decreases, contraction of sediment becomes radial and faulting can propagate, creating first order polygonal faults.
3/ While compaction continues, the throw of fault increases. At deeper burial depth, other families of faults, second and third order, have to be generated in order to accommodate fluid expulsion, helped by rheological change (Opal A/CT conversion).
4/ Fluids from Opal CT/quartz conversion, which migrate upward by polygonal faults, favor Opal A/CT conversion at shallow levels and induce differential compaction (diagenetic basin).



Interaction with focused fluid flow

1/ Intrusion of magmatic sills induces thermogenic fluids by organic matter thermal cracking.
2/ Upward migration of deep fluids by diffusion and synrift faults : formation of hydrothermal vents.
3/ Deposition of a thick seal above vents : fluids accumulation and overpressure.
4/ Formation of a "deformation cone", borded by shear planes, in the sediment above overpressure : focused fluid flow inside "cone" and deviation outside by surrounding polygonal faults.
5/ Diffusion of fluids in shallow level : formation of three ridges at the seabed.
6/ **Fluid expulsion from polygonal faults at the modern seafloor.**