

## Fracture cementation in the North Sea

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Fluid migration and distribution are important aspects of the evolution of sedimentary basins.

An essential parameter affecting fluid flow is permeability. Even mm thick fractures have permeabilities many orders of magnitude above surrounding sediments, and thus have the potential of focusing fluid flow. It is a major task to establish the importance of these fractures as fluid conduits.

One aspect is to determine the mechanisms of mass transport and precipitation of the fracture cements. Basically the question is whether the mineral cementing fluids are locally sourced from the wall rock by diffusion or local fluid advection, or have been externally imported and focused into the fractures, or both.

Detailed investigation of vein mineral and wall rock may help in establishing the relative importance of the two major cementing processes. Here, we will focus on the use of petrographical observations. In addition, we use microscale stable isotope analysis of carbonate cemented fractures obtained with the laser ablation method (O and C) in order to establish the direction of material transfer.

**Fracture cements.** Cemented fractures occur in various lithologies of Tertiary to Palaeozoic ages within the North Sea, including sandstones, mudrocks, chalk, limestones and volcanics. The fractures are commonly subvertical and 1-2 mm thick, rarely exceeding 1–2 cm, and they are in many cases reactivated. The fractures are cemented by a variety of minerals. However, the about 150 fracture occurrences recorded in our North Sea fracture database are dominantly cemented by carbonates. Other minerals include kaoline, baryte, pyrite and only occasional quartz. This observation contrasts with the common occurrence of quartz veins in metamorphic rocks. Bitumen is also sometimes seen as a fracture filling material. Cemented fractures may be monomineralic, or they are seen to be filled with more than one mineral type.

**Carbonate cement.** Calcite, dolomite/ankerite and siderite are all observed. The grain size of the fracture carbonates is in most cases notably coarser than the grain size in wall rock cements. The wall

rock cement is generally also carbonate, but chemically distinct from the vein mineral (e.g. siderite versus dolomite or calcite). Multiple generations of carbonate cementation in fractures occur as well, and also precipitation by carbonate preceding a quite different phase as kaoline is occasionally observed.

Carbonate fractures in sandstones which are not cemented by carbonates are recorded in a few cases.

**Pyrite cement.** Pyrite fracture cements are less common, but are observed both within sandstones and altered volcanics. Some fractures have walls lined by early pyrite, and central parts cemented by carbonate, thus documenting the presence of compositionally different fluids at various stages of fracture cementation.

**Kaoline cement.** Fractures cemented by kaoline occur within sandstones and interlayered igneous rocks. The texture is fine grained and appear similar to pore-filling, blocky kaoline cement. Wall rock cements recorded are carbonates or clays.

**Baryte cement.** Baryte cemented fractures are observed within all lithologies. The grains are commonly coarse compared to wall rock, which is cemented by either clays or carbonates. Both equant and elongated grains occur. Dendritic growth is recorded in one case.

**Quartz cement.** Quartz cemented fractures are rarely observed and pure quartz veins are only found within altered igneous rocks. These are probably due to hydrothermal activities. Chert veins are seen within chalk, and carbonate fractures hosted in sandstones occasionally contain a few grains of coarse quartz, which evidence the presence of silicate fluids.

**Isotopes.** The laser ablation method allows for very small-scale recording of variations in isotope composition (C, O) across a carbonate filled fracture. One example of such a carbon isotope profile is given in Fig. 1. The carbon isotopes demonstrate that the carbon source for fracture mineralisation was different from that of the local wall rock. If the fracture fillings has been formed by wall rock dissolution and redistribution, the  $\delta^{13}\text{C}$  value of the precipitating mineral would be close to the average value of the

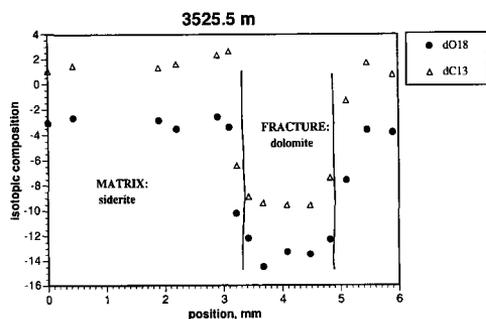


FIG.1. Stable isotope compositions of dolomite in the fracture and siderite in the mudrock matrix.

dissolving wall rock carbonates. The oxygen isotopes show that the cementation of the fracture was affected by a water and/or temperature field distinctly different from the wall rock cementation.

**Textures.** Important information about the precipitation mechanism of cement within a fracture can be inferred from textural observations.

The crystal morphology of carbonates is determined by a variety of fluid and chemical parameters, such as saturation degree, presence of inhibitors, and hydrodynamic state (Gonzales et al. 1992). Although quantitative considerations are difficult to obtain, equant crystals indicate relatively moderate fluid flow velocities at lower supersaturation, while elongated, preferential growth crystals and fibrous habitus are indicative of higher supersaturation and higher fluid velocities (Gonzales et al., 1992; Zaihua et al., 1995). The importance of microenvironment parameters such as substrates for crystal evolution is pointed out by Dickson 1993.

The observations of the fracture cementation in our database from the North Sea show that:

There is commonly a distinct difference in grain size between fracture cement carbonate and wall rock cement, the fracture cement being coarser.

The borders of the veins are generally distinct with little textural evidence of mutual influence between wall rock minerals and fracture cement.

There is commonly a an abrupt difference in chemistry between fracture cement carbonate and wall rock carbonate cement, as visualised in UV light.

There is little textural evidence of closing a fracture by one-direction cement growth from one side of the fracture wall to the other, which would be expected in the case of local diffusion or advection

(Fisher et al., 1995). On the contrary, there is frequent indications of symmetrical growth from both fracture walls towards the centre.

Fractures with more than one cement phase often appear symmetrical, in that that the fracture walls are lined by one phase with a distinctly different second phase in the central parts. A similar observation is made in fractures where bitumen occurs as thin fracture wall linings, with kaoline filling in the central parts. Such bitumen is expected to have a sealing effect which strongly will reduce material transport from wall rock into the fracture. Thus an external import of fluid must be responsible for the the central cement.

It often appears that the mineral growth is initiated by nucleation at sites in the fracture walls, and then has proceeded towards the centre of the fracture until a certain thickness was achieved. Later precipitation of a different phase at scattered nucleation sites in the centre and further growth has closed the fracture.

The fractures are generally closed by cement. Only in a few cases are local open spaces seen, and then restricted to the central parts of the fracture.

Equant fabric dominates. Elongated grains representative of preferred growth directions are less common, while fibrous growth oriented at right angle to the fracture walls are only seen in a few cases.

**Conclusions.** The diagenesis of fractures from the North Sea is dominated by carbonate precipitation. Our petrographic and isotopic data from these fractures strongly indicate a major external sourcing of mineral precipitating fluids, in contrast to locally derived material by local fluid advection or diffusion.

Petrographic observations indicate different precipitating conditions, but dominance of moderate fluid flow velocities and moderate supersaturations are indicated by equant grain fabric.

There are frequent evidences of fracture reactivations recorded by separate events of mineral cementation, which imply pulses of fluids of different compositions.

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