# Fracturing in Lower Carboniferous carbonates in the Campine-Brabant Basin (northern Belgium): borehole analyses

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## ABSTRACT

The Lower Carboniferous carbonates in the Campine-Brabant Basin in northern Belgium and the southern Netherlands generally have a low primary porosity. However, existing fractures enhance the permeability of this potential geothermal reservoir. In this study, Lower Carboniferous carbonate sequences of two borehole case studies allowed to investigate the factors controlling fracture properties. Significant relationships were found between variables from core material and geophysical well logs. Image log interpretations provide extra information to test these relationships and their predictability.

## 1. INTRODUCTION

The Lower Carboniferous carbonates in the Campine-Brabant Basin in northern Belgium and the southern Netherlands hold potential as a geothermal reservoir. Geothermal wells have been drilled recently in both Belgium and the Netherlands which provide new information on the Lower Carboniferous reservoir. The reservoir rock consists of fractured and partly karstified limestones and dolostones. Since the matrix porosity of the carbonates is generally very low (circa 1-2% on average), fractures account for a major part of the porosity and permeability of the system. To lower the risks for developing future geothermal projects in this basin, this study aims to better predict the reservoir characteristics, focusing on the distribution and characteristics of fractures.

Multiple wells were drilled into the Lower Carboniferous carbonates in the Campine-Brabant Basin (fig. 1) and core material and/or geophysical well logs are available of different boreholes. This paper summarizes the analyses that were performed on the Heibaart DZH1 borehole and on the MOL-GT-01-S1 and MOL-GT-03-S1 boreholes. The aim of these studies is to gain insight into factors affecting the distribution and characteristics of fractures, which enhance reservoir permeability.

## 2. METHODOLOGY

A workflow for the characterization of carbonate reservoir fracturing from boreholes was proposed by Van der Voet et al. (submitted). In a case study of the Lower Carboniferous carbonates in the Heibaart DZH1 borehole (drilled in 1977) in northern Belgium, different existing datasets were integrated with newly acquired data regarding structural and diagenetic features from cores, such as veins, stylolites and vugs (fig. 2). Most interesting from a reservoir perspective are joints, which are opening mode fractures without cementation. Information on joints cannot be deduced from core material directly, because it is impossible to define the cause of a discontinuity between two successive core samples. This can be due to natural open fractures, drilling activities, transport or previous sampling. However, partially open veins (partially cemented fractures with remaining porosity; fig. 3) are, unlike joints, quantifiable from core material and could contribute to the porosity and permeability of the reservoir. Veins (completely cemented fractures) do not have an effect on permeability but vein properties could provide information on the mechanical behavior of a rock unit. Stylolites mainly act as permeability barriers. Frequencies of such features were quantified, as well as their characteristics, for instance width and inclination. The previously acquired data hold information on lithology, geochemistry and geophysical well logs (fig. 2; Muchez et al., 1987; Muchez, 1988).

After the description and quantification of structural and diagenetic properties from cores, and a check on data quality, representativeness and limitations on all datasets, extensive data exploration and statistical tests were performed. As a first step, variables with restricted values were transformed, in order to eliminate the non-negativity problem or interdependencies for concentration data. The transformed variables were used for the statistical tests. A stepwise approach was used, including Kruskal-Wallis and Wilcoxon tests to compare categorical to numerical variables, and Spearman rank correlation tests and Principal Component Analyses (PCA) to study relationships between numerical variables (Davis, 2002; Van der Voet et al., submitted).

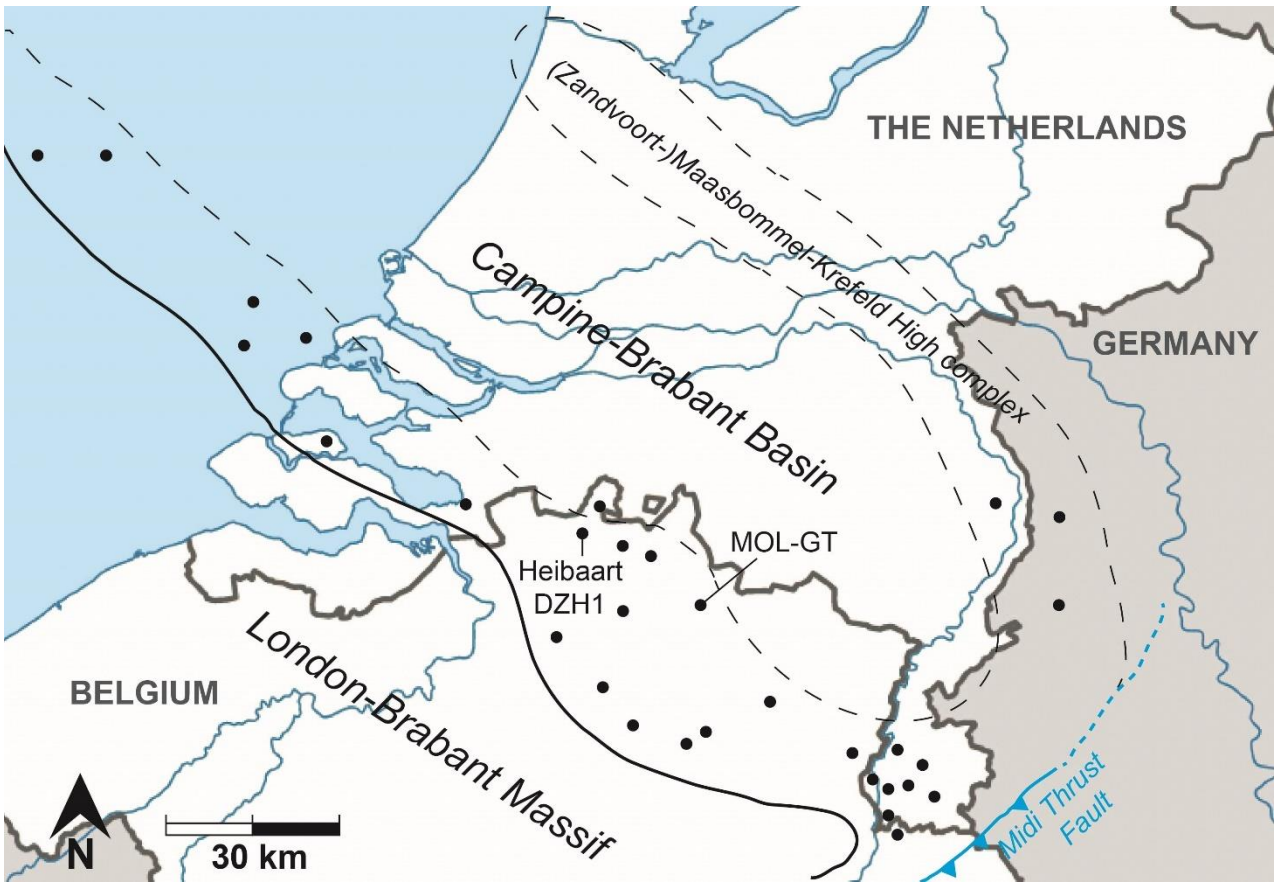


**Figure 1: Map of the Campine-Brabant Basin, modified after: Bless et al. (1983), Muchez & Langenaeker (1993), Geluk et al. (2007), Kombrink et al. (2008) and Van Hulten (2012). The locations of the wells that were drilled into the Lower Carboniferous carbonates are shown by black dots. The possible outlines of the carbonate platforms are indicated by dashed black lines. 'MOL-GT' refers to the geothermal wells drilled in Mol-Donk (Balmatt project).**

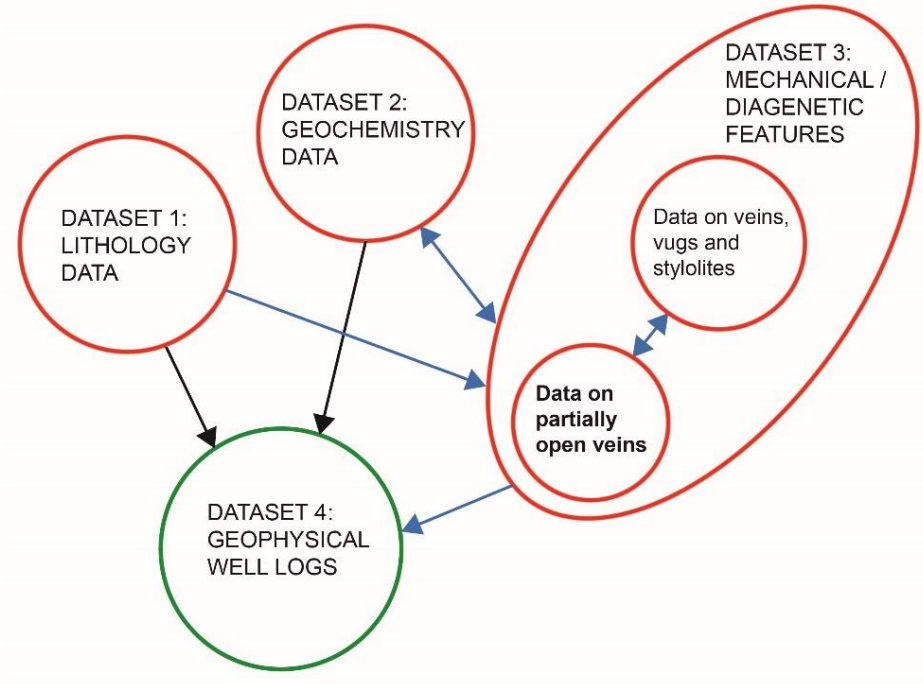


**Figure 2 Overview of the datasets used in the case study of the Heibaart DZH1 borehole (Van der Voet et al., submitted). The arrows show the variables which (possibly) affect other variables. The blue arrows indicate the relationships investigated in this study. The data in red circles were all derived from core material.**

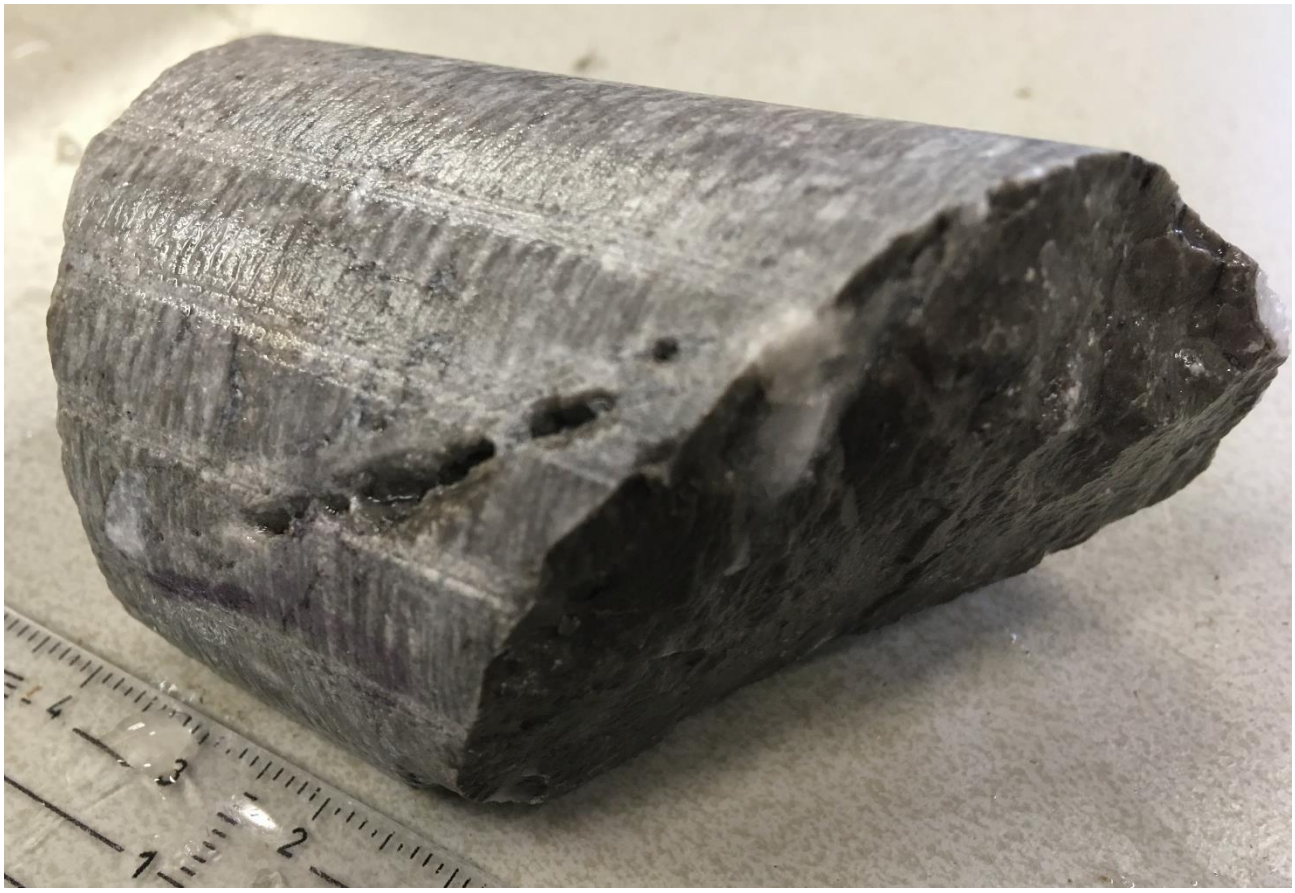

**Figure 3 Example of a partially open vein in a core samples of the Heibaart DZH1 borehole, at a depth of 1178m. This vein is partially cemented by calcite. The numbers on the scale represent cm.**

Where joints in carbonate rocks are hard to quantify from core material, they are generally well visible on image logs. MOL-GT-01-S1 (2016) and MOL-GT-03-S1 (2018) are two of the wells drilled by VITO in Mol, northern Belgium (Broothaers et al., this volume). Formation MicroImager (FMI) logs are available from these boreholes. Based on microresistivity contrasts, conductive fractures, drilling-induced fractures, resistive fractures, bed boundaries and stylolites were interpreted and quantified (fig. 4). Resistive planar features on these logs are interpreted as veins, while the conductive planar features are interpreted to be open and filled with saline water. Also, borehole intersections with faults were interpreted, based on the resistivity contrast and a changing bedding dip around these features, most likely resulting from fault drag.

Regarding the MOL-GT wells, a similar fracture characterization study is being performed as for the Heibaart DZH1 case. The quantified data on fractures and stylolites are being integrated with information on the lithology (from specific geophysical well logs and cuttings), bed thickness, geophysical well logs and fault locations. Furthermore, drilling parameters, such as the Weight On Bit (WOB), Rate Of Penetration (ROP) and hookload, are compared to the quantified fracture data, in order to study the predictive value of these parameters.

## 3. RESULTS AND INTERPRETATIONS

### 3.1 Heibaart DZH1 borehole

The Kruskal-Wallis and Wilcoxon tests show that differences exist between the lithotype units of the Lower Carboniferous sequence. For instance, an interval with cryptalgal boundstones, reflecting a buildup structure (Muchez et al., 1987), contains the highest vein frequencies and relatively high resistivity values compared to the other lithotype units, and relatively low values of organic carbon and potassium (Van der Voet et al., submitted). Also, multiple significant Spearman rank correlations were found between variables. The vein frequency variable is negatively correlated to the potassium variable and positively to the resistivity log variables. The fact that fracturing occurred preferentially in the most ‘pure’ boundstones (high resistivity, low K concentration) and less in the wacke- to grainstones, could be explained by differential compaction (Alzayer, 2018; Van der Voet et al., submitted). The wacke- to grainstones could accommodate a larger amount of strain by mechanical compaction before failure, than the more competent boundstones, which therefore fracture earlier. Also, a significant positive correlation was observed between the open part (%) of partially open veins and the resistivity logs. Van der Voet et al. (submitted) demonstrate more comprehensive descriptions and

interpretations of results from the Heibaart DZH1 borehole.

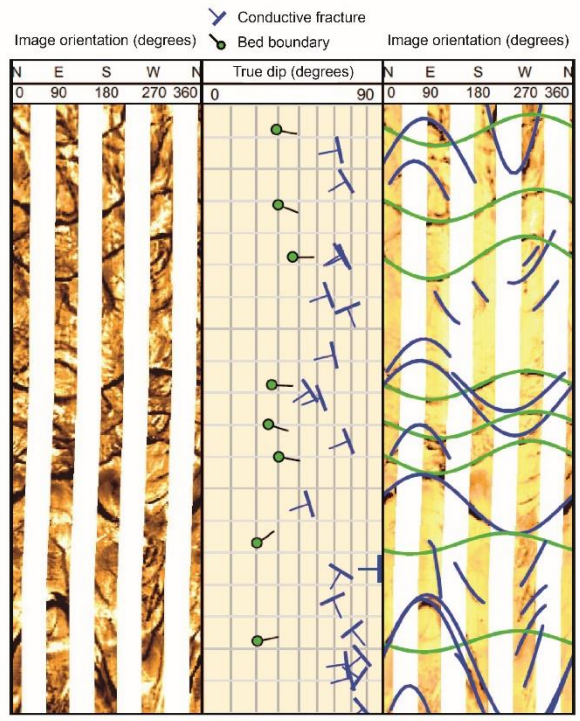


**Figure 4: Formation MicroImager (FMI) data from the MOL-GT-01-S1 borehole, indicating interpretations of bed boundaries and conductive fractures, of which the latter most likely resemble joints filled with saline water. The dip and azimuth of the features are shown.**

### 3.2 MOL-GT wells

An extensive study on fractures in the MOL-GT wells and their controlling factors is carried out at the moment. One of the aims is to test the correlations found in the Heibaart DZH1 borehole, in order to provide insights in the predictability of characteristics by geophysical well logs. Moreover, the FMI log allows to take into account the frequency and characteristics of joints as well as bed boundaries, which were features not detectable from core material. In this way, the thickness of beds can be taken into account as a variable. Also, the relationships between fault intersections and fracture distribution is investigated.

## 4. CONCLUSIONS

By integrating different datasets regarding the Lower Carboniferous carbonates in the Heibaart DZH1 borehole in northern Belgium, a comprehensive study is performed on the fracturing of subsurface carbonate rocks. After the quantification of structural and diagenetic features from core material, such as partially open veins, statistical analyses led to insight into the factors controlling the properties of these features. Differential compaction had an effect on the development of fractures in this case, since veins (both cemented or partially open) are more abundant in the massive reefal buildup boundstones than in the layered wacke- to grainstones. Significant correlations were found between geophysical well logs and properties of (partially open) veins and stylolites. These relationships are now being tested in a similar Lower Carboniferous carbonate sequence in the MOL-GT geothermal wells in Mol, northern Belgium. The available image logs of these recent boreholes were used to quantify frequencies and properties of fractures, stylolites and bed boundaries, which are used in statistical analyses, to further investigate which factors influence or could predict fractures properties.

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