Reservoir compaction: What role does petrographic heterogeneity play in the Groningen gas field?

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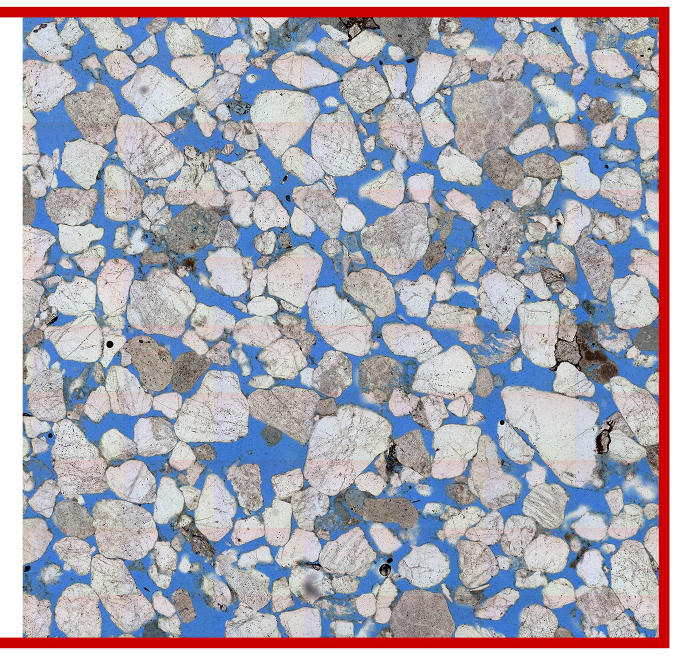
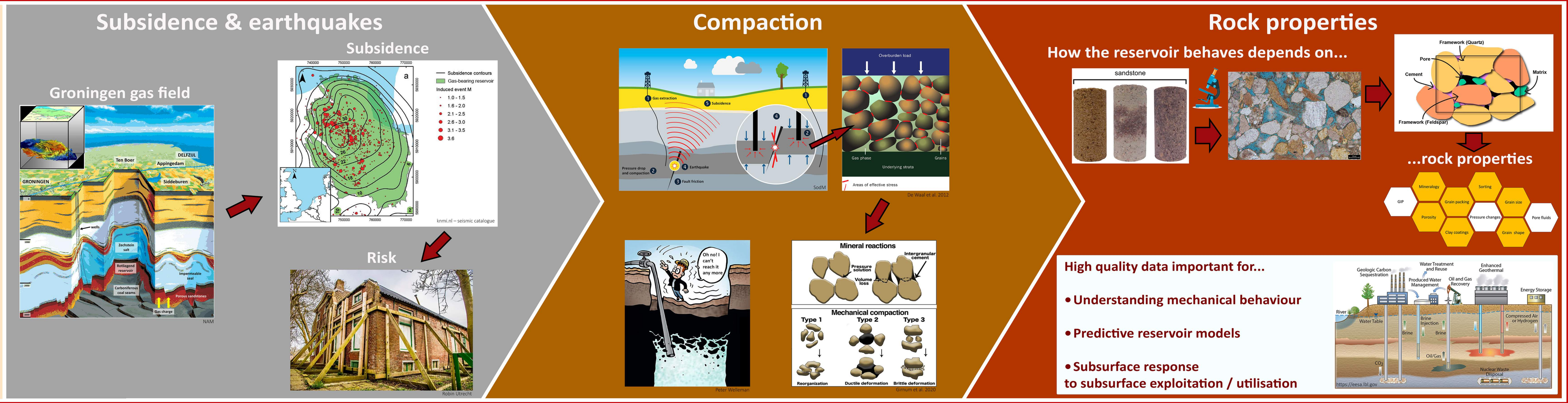


Introduction

The ongoing gas depletion in the Groningen gas field led to a pressure drop within the sandstone reservoir, which resulted in reservoir compaction and associated surface subsidence and seismicity. It has been decided to minimize gas production in 2022, although further compaction of the reservoir can still occur for many years with as result more earthquakes. Compaction of sandstone reservoirs, such as the Groningen gas field, is likely related to the rock properties (petrography), which can also impact the fluid flow within, and the geochemical and geomechanical properties of the reservoir. To predict how a reservoir responds to fluid extraction, it is thus crucial to have a clear understanding of the reservoir petrography and the factors controlling its lateral variability. Previous research shows that compaction of authigenic clays within the sandstones can account for a signicant part of the inelastic strain. Therefore, more knowledge about the rock properties contributes to a better prediction of the subsidence in and around gas fields. The research focusses on constraining the petrographic heterogeneity of the gas field by studying core plugs from wells within the gas field, which can be implemented into a predictive petrographic model that improves our knowledge of subsurface response to subsurface utilisation.



Aims

The main purpose of this study is to provide a petrographic model of the Groningen gas field and surrounding aquifers in order to predict reservoir compaction and surface subsidence. The approach is threefold: **(1) to quantify spatial petrographic trends** within the Rotliegend reservoir rock respective to detrital composition and diagenetic components, **(2) to identify petrographic controls** that might have an impact on the geomechanical behaviour, such as authigenic cement and clays, and **(3) to apply image segmentation on thin section images** to determine the importance of semi-automated identification of key petrographic parameters on large petrographic datasets. The data will be used to provide a petrographic framework that can be implemented as a standard dataset in future reservoir studies.

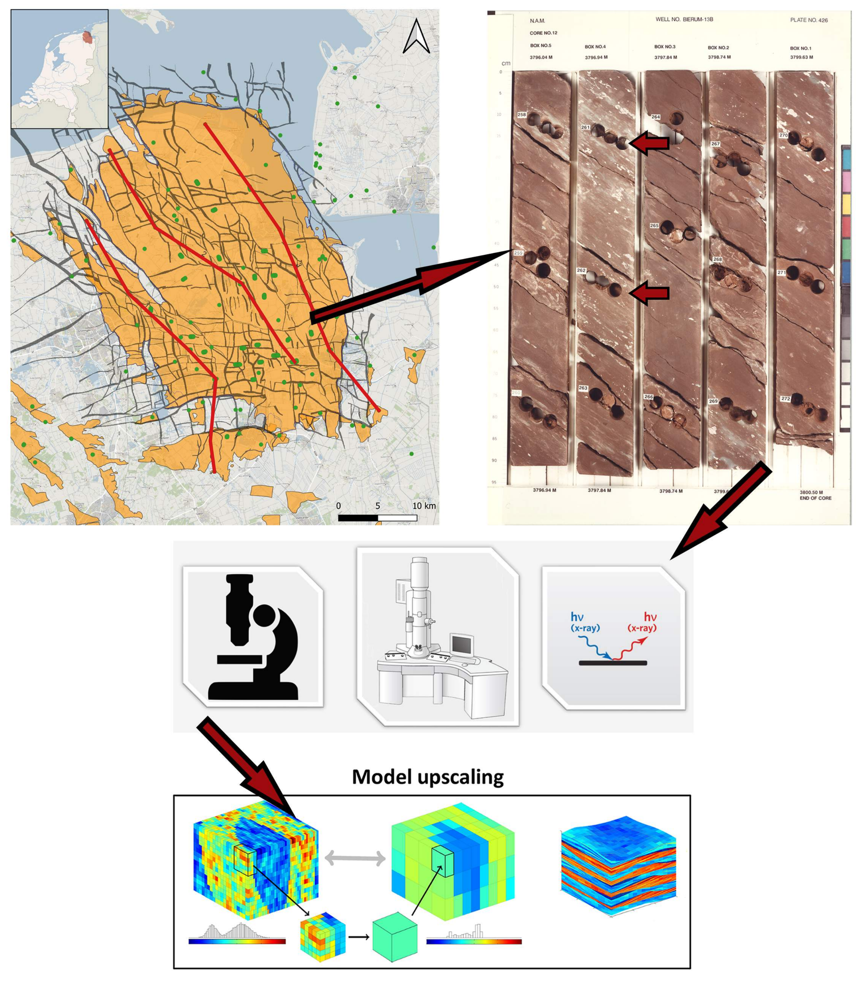


Figure 1: General workflow for this project going from well selection to sample selection from cores, subsequent analysis by optical microscopy, electron microscopy (SEM) and X-Ray Diffraction (XRD), and eventually model upscaling. The map represents the Groningen gas field with wells (green dots), profiles with selected wells (red lines) and faults (black lines).

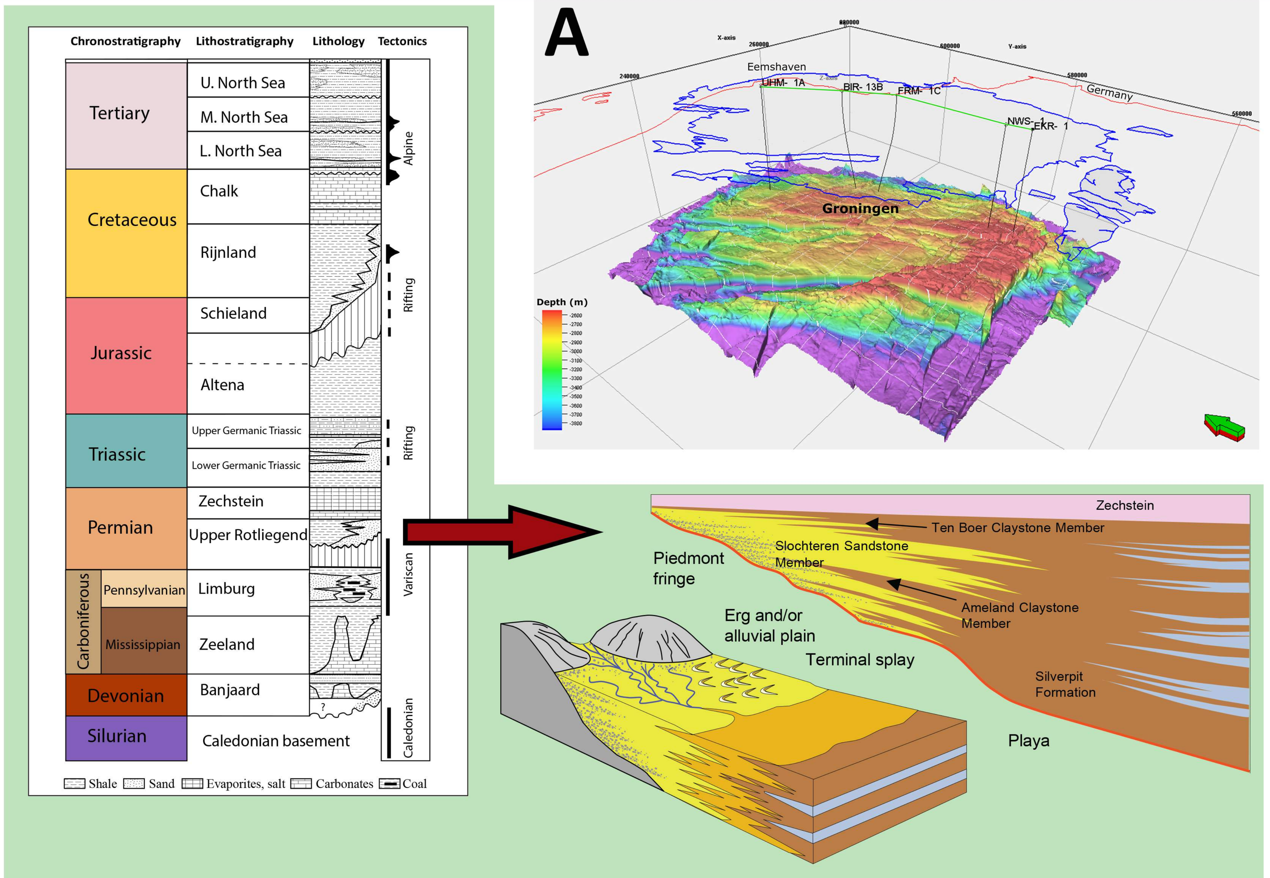
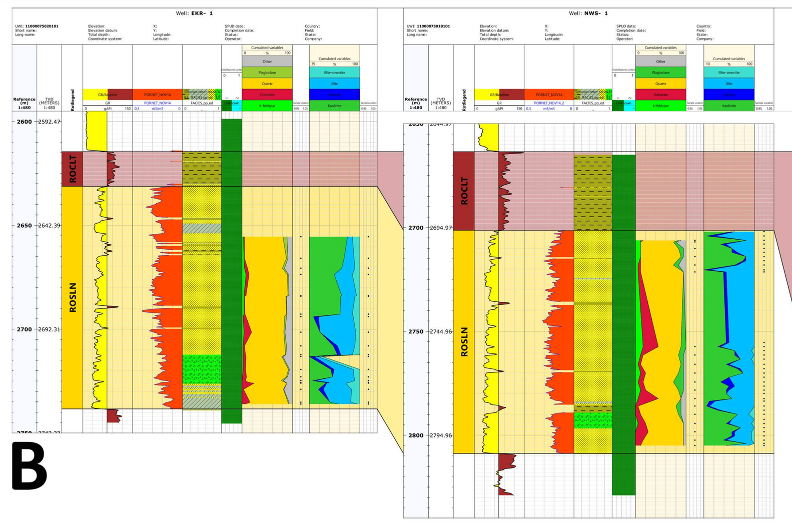


Figure 2: A) Stratigraphic overview of The Netherlands showing the main lithological units with the Slochteren Formation and lithofacies pointed out with the arrow. Modified after Mckie (2011) [1] and Van Hulten et al. (2012)[2]. The Rotliegend in The Netherlands consist of the Slochteren sandstone intertwined by the Ameland and the Ten Boer claystone Members from the Silverpit Formation and is the main petroleum target within the Netherlands.



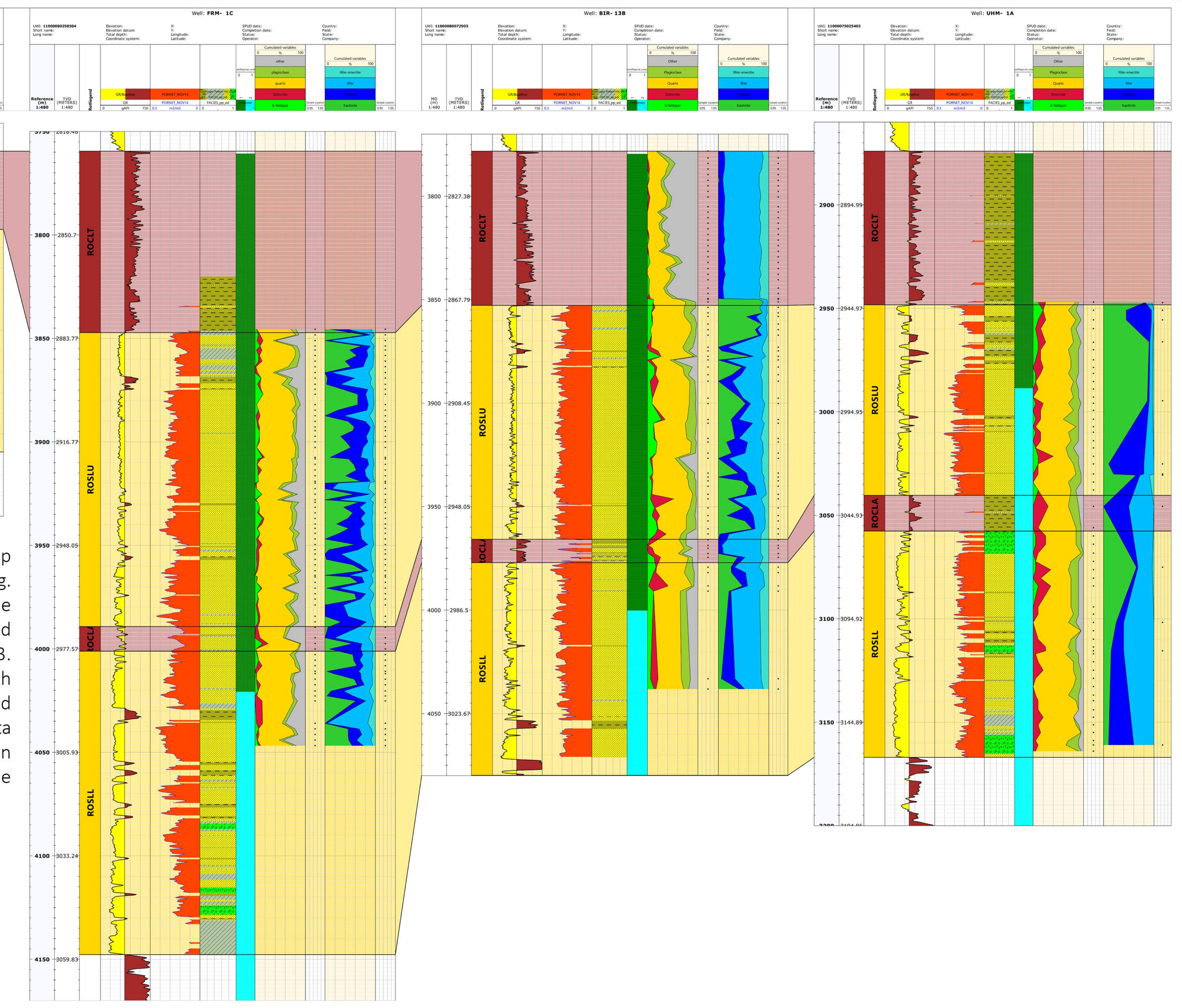


Figure 3: A) 3D map of the Groningen gas field based on availabe data including a 2D map op the gas field (blue transparant plane). profile line (green) and wells from the cross section in Fig. 3B, and a depth map of the Rotliegend sandstone reservoir. Red line is the outline of the Netherlands. Modified after NAM, 2020 [3]. **B)** South-to-north cross section ot the Rotliegend reservoir in Groningen (see profile in Fig. 3A) that has been made with the Techlog 2015.3. Whole rock and clay XRD data (courtesy of NAM) has been plotted over depth together with sample locations from the cores. Gamma-Ray (GR), porosity and lithofacies data is exported from the Petrel model [3]. True Vertical Depth (TVD) has been calculated from NLOG data (https://www.nlog.nl/boringen). The field consists of four major units: Lower Slochteren sandstone (ROSLL), Ameland claystone (ROCLA), Upper Slochteren sandstone (ROSLU) and the Ten Boer claystone (ROCLT).

1 Petrographic heterogeneity

The petrography is being determined from core samples, which includes detrital and authigenic mineralogy, depositional environment, grain properties and porosity (Fig 3). The sandstones mainly consist of quartz, feldspar and a variety of lithics. Authigenic minerals are mainly consist of dolomite cement and varying forms of clay such as kaolinite, illite and chlorite. On reservoir scale, some **petrographic relations** between certain minerals can be observed such as **decreasing feldspar with depth**, a **linear relationship between kaolinite and amount of feldspar**, and an **increase of chlorite** in core material **towards the north**. In the coming months, more samples will be analyzed under the microscope to upscale the dataset. The next question is how these **rock properties control compactional processes.** Additional analysis will be performed by SEM and XRD.

2 Authigenic clay

The clays surround grains and occupy pore space, which locally inhibits cementation of pore-filling quartz, feldspar or dolomite (Fig 4.). Illite is often present as two layers in the form of **tangential illite** or mixed-layer clay that formed the inner layer, stressing the importance of inherited clay rims on the formation of authigenic clay. **Radial illite** and even **meshwork illite** is observed on tangential illite rims where cementation gives space for these clays to grow. Furthermore, **dissolution of quartz** (Fig. 5) might have occured where illite coatings are present between grain contacts and the clay coatings inhibit significant fracturing of the grains, which can have an impact on the structural integrity of the sandstones.

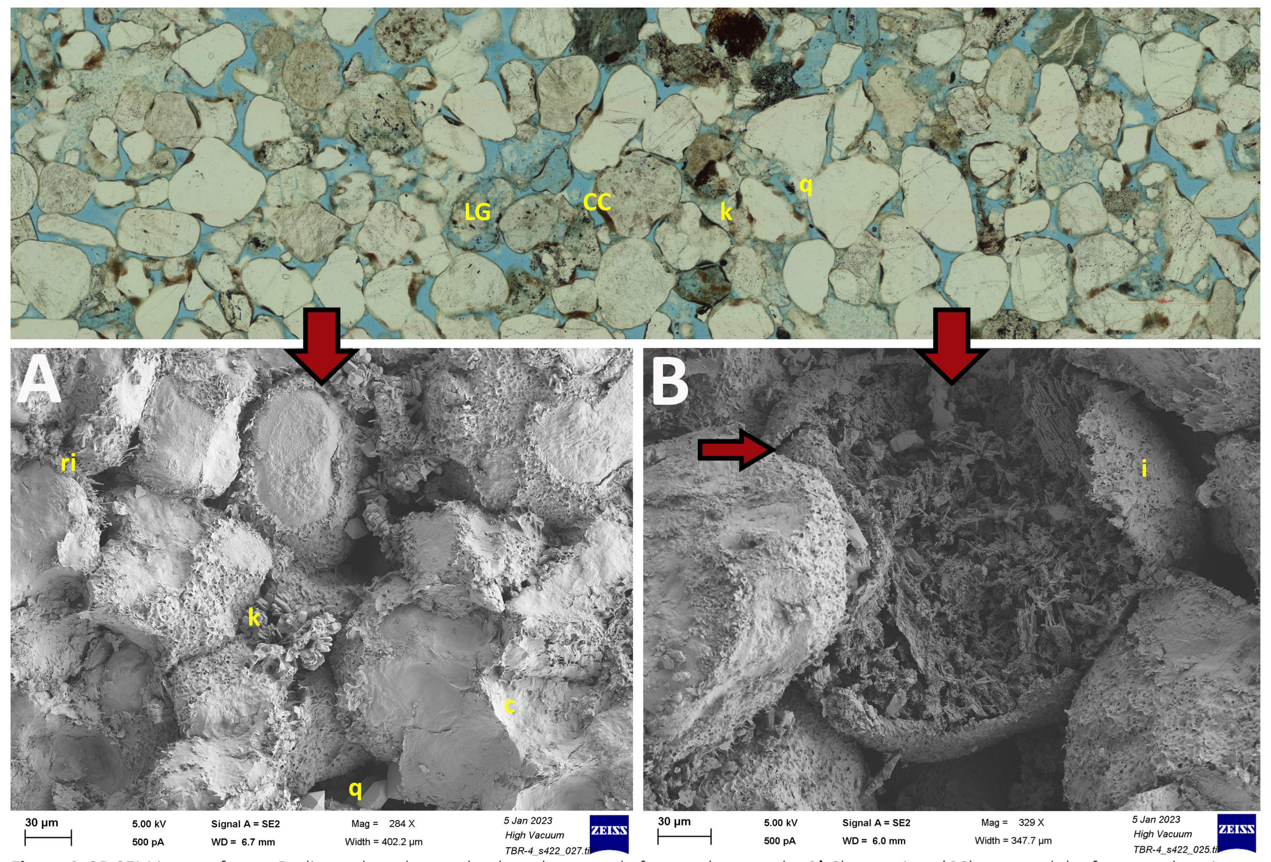


Figure 4: 3D SEM images from a Rotliegend sandstone that have been made from a plug sample. **A)** Clay coatings (CC) surround the framework grains on which the initial formation of radial illite (ri) can be observed. Vermicular kaolinite (k) 'booklets' are present in the pore space between the illite. At the bottorm of the image euhedral authigenic quartz (q) and carbonate cement (c) can be observed. **B)** A partial leached feldspar grain (LG) with replacive illite and dolomite in the intragranular pore space. These types of fragile 'framework grains' can affect the structural integrity of the rock. Note the indented illite rim (arrow), which indicates that compaction continued until after the illitization of the clay rims.

3 Image segmentation

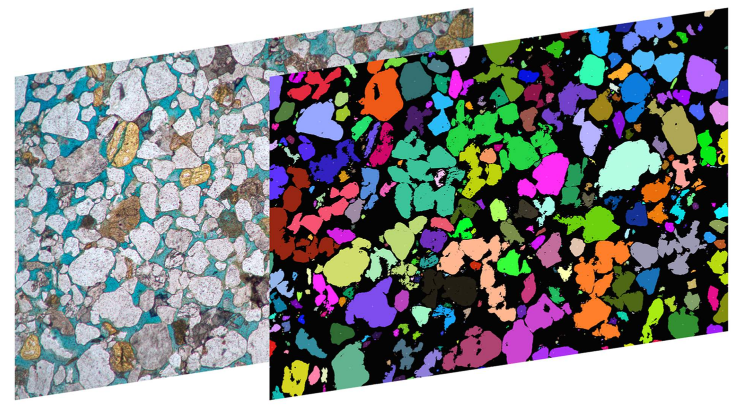


Image segmentation is applied on SEM images and elemental maps to differentiate between grains and surrounding clays in order to observe authigenic **clay distribution** and **clay morphology** to improve our understanding of **diagenetic and deformation processes**. Different methods have been applied such as **combining elemental maps** to highlight illite and kaolinite and traditional image segmentation based on intensity. The amount of scans and image resolution are important factors for the accuracy of the segmentation.

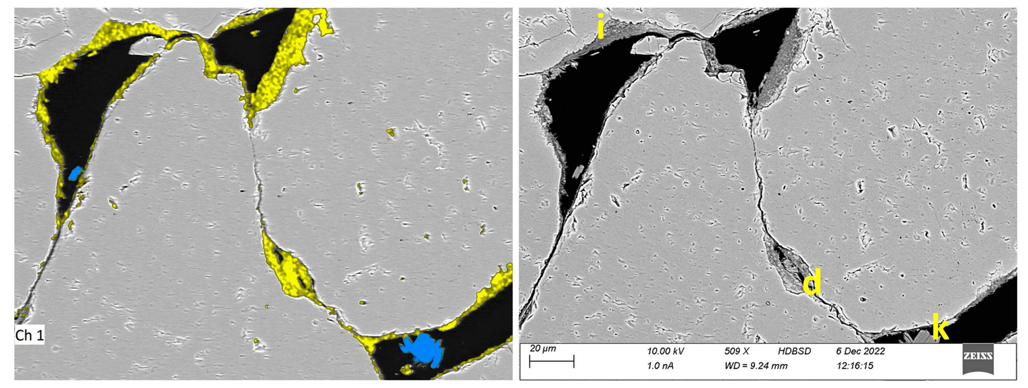


Figure 5: Segmented and normal BSD image of quartz grains with tangential illite (i) in yellow and kaolinite (k) in blue. Elemental maps of Al and K are combined to highlight te distribution of illite. Only the Al map shows the presence of kaolinite. Resolution and amount of scans play a significant role in the accuracy of these images. In the normal BSD image different layering of illite can be observed together with possible quartz dissolution (d) between the grain contacts.

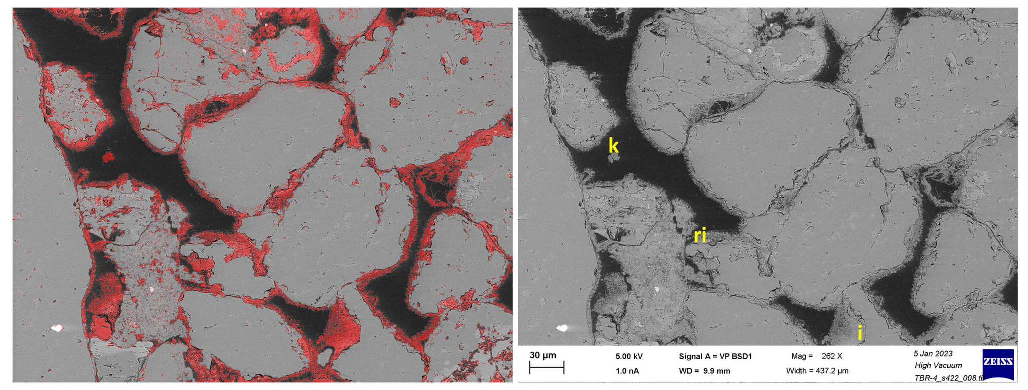


Figure 6: Highlighted illite clays in a high quality (FESEM) image. Segmentation of clays is based on gray value intensity after which the grains are removed and the segmented mask is placed on the original image. It is a quick method to illustrate clay distribution and grain alteration, although, the accuracy of the segmentation is limited to some extent. Tangential (i) and radial illite (ri) with locally some kaolinite (k) crystals can be observed in the SEM image.

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References

[1] Mckie, T. (2011). A comparison of modern dryland depositional systems with the Rotliegend Group in the Netherlands. The Permian Rotliegend of the Netherlands. SEPM (Society for Sedimentary Geology), Oklahoma, USA, 89-103.

[2] Van Hulten, F. F. N. (2012). Devono-carboniferous carbonate platform systems of the Netherlands. Geologica Belgica.

[3] NAM (2020). Petrel geological model of the Groningen gas field, the Netherlands.