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How cementations affect the reservoir properties of the Bunter Sandstone Formation onshore Denmark

Mette Olivarius[1,2], Rikke Weibel[1], Lars Kristensen[1], Morten Leth Hjuler[1], Anders Mathiesen[1], Lars Henrik Nielsen[1], Claus Kjøller[1]

[1] Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350 Copenhagen, Denmark

[2] Department of Geoscience, Aarhus University, Høegh-Guldbergs Gade 2, DK-8000 Aarhus, Denmark

Email: mol@geus.dk

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ABSTRACT

The reservoir quality of the Early Triassic Bunter Sandstone Formation in southern Denmark is generally good, but locally variations in mineralogy and diagenesis may lower the porosity and permeability drastically.

The reservoir properties are influenced by both the composition of the originally deposited sediment (the detrital mineralogy) and by the subsequent dissolution-precipitation processes resulting in various types of cementations (the authigenic mineralogy).

Iron oxide/hydroxide coatings are commonly present, and they help preserve the primary porosity. Anhydrite, carbonate and halite cements, as well as clay clasts and intra-granular clay, reduce the reservoir quality in different degrees.

There is an overall trend of positive correlation between grain size, porosity and permeability.

1. INTRODUCTION

The Bunter Sandstone Formation onshore Denmark is interesting from a geothermal exploitation perspective as it occurs at burial depths where warm water can be expected without having the reservoir properties destroyed by intensive diagenesis. Porosity and permeability measurements have been compared to facies associations and mineralogy in order to explain variations in reservoir quality.

The Bunter Sandstone Formation was deposited in the northern part of the North German Basin in the Early Triassic during arid to semi-arid conditions (Fig. 1), and the depositional settings include aeolian, fluvial and lacustrine environments (Bertelsen 1980, Clemmensen 1985, Olsen 1987, Pedersen 1998).

The formation is found in the southern part of Denmark at burial depths of 1.1-2.1 km (Nielsen and Japsen 1991). It is uncertain how far the formation extends north of the Ringkøbing-Fyn High into the Norwegian-Danish Basin, where it passes into the lower part of the Skagerrak Formation (Bertelsen 1980).

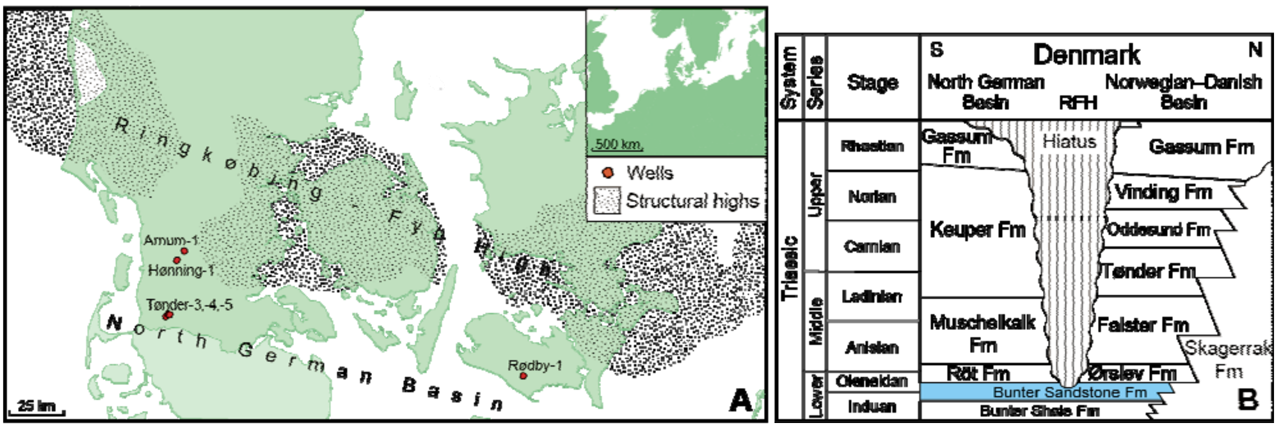

Figure 1: A. Map of the southern part of Denmark where the Bunter Sandstone Formation has been sampled in the indicated wells in the North German Basin. B. Stratigraphic scheme of the Triassic deposits onshore Denmark simplified after Clausen and Pedersen (1999) and Michelsen and Clausen (2002).

2. RESERVOIR PROPERTIES

The reservoir properties are a result of the depositional environment and the associated grain size, the initial detrital mineralogy and the authigenic minerals formed shortly after deposition and during burial. The porosity of the sandstones is generally high, and correlation with the permeability can explain 63% of the variability (Fig. 2).

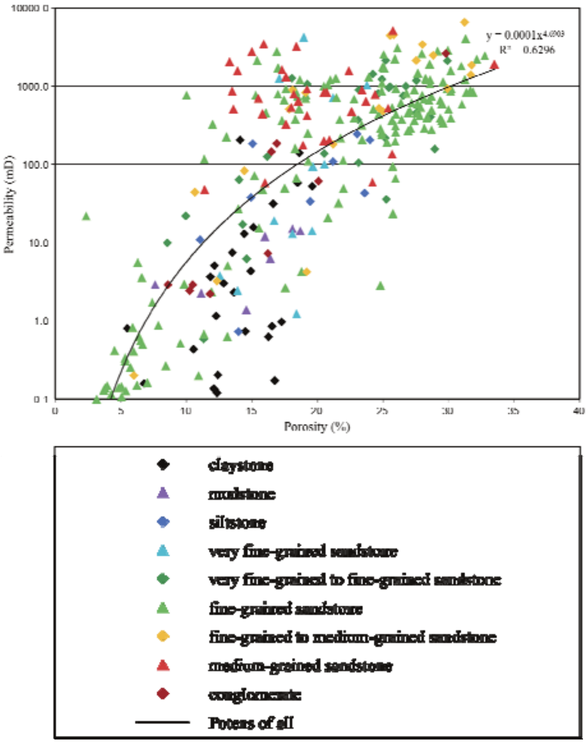

Figure 2: Porosity-permeability trend of the Bunter Sandstone Formation separated into nine grain size categories.

The sandstones have good reservoir quality in many intervals in spite of their primarily fine-grained nature. The high porosity in proportion to permeability in the claystones might be an error in the porosity measurement caused by micro fractures in which the helium gas can enter whereas the mercury liquid cannot, so the grain volume is correct whereas the bulk volume, and hence also the porosity, is overestimated. However, high porosities in claystones at these depths are very common (Mondol et al. 2007)

2.1 Detrital mineralogy

The detrital mineralogy is dominated by quartz, K-feldspar and plagioclase, and comprises also some mica, rock fragments, ooids, heavy minerals, inter-granular clay and clay clasts. The aeolian sandstones have the highest porosity and permeability values and they are characterized by high content of ooids and low content of mica. Furthermore, the grains are more rounded than in the other facies.

The inter-granular clay deposited together with the sand grains in some of the fluvial and lacustrine sediments may constitute a continuous obstacle to motion flow thus causing a large decrease in porosity and especially permeability (Fig. 3A), whereas the delimited clay clasts have less effect on the porosity and permeability because the pore fluids can move around the clasts (Fig. 3B).

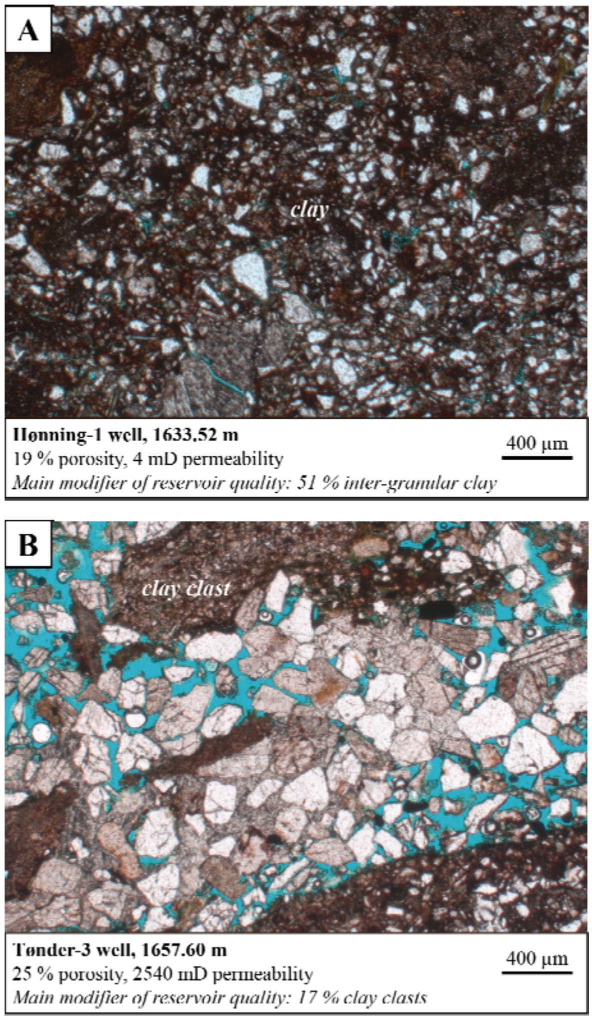

Figure 3: Examples of the effect on reservoir properties of detrital inter-granular clay versus clay clasts. Thin section images with direct light and blue pore space.

2.2 Authigenic mineralogy

Only four authigenic phases have notable impact on reservoir quality, and they comprise anhydrite, carbonate, iron oxide/hydroxide and halite. Iron oxides/hydroxides have precipitated in the sediments as red coatings. They have a positive effect on reservoir quality as the grain coatings generally inhibit or retard subsequent porosity reducing overgrowths by quartz etc.

Precipitations of anhydrite, carbonate minerals and halite cause a decrease in reservoir quality, especially when they form pore-filling cements. Most of the anhydrite probably precipitated as gypsum shortly after deposition, and was subsequently converted into anhydrite during burial. The effect of anhydrite on reservoir quality is not significant even though it occasionally precipitated in large amounts (Fig. 4A).

Carbonate minerals, on the other hand, are critical for the reservoir properties where they have precipitated as poikilotopic cements, but that have only occurred in rare caliche horizons. The reservoir properties are much less reduced when the carbonate has precipitated as rhombs (Fig. 4B).

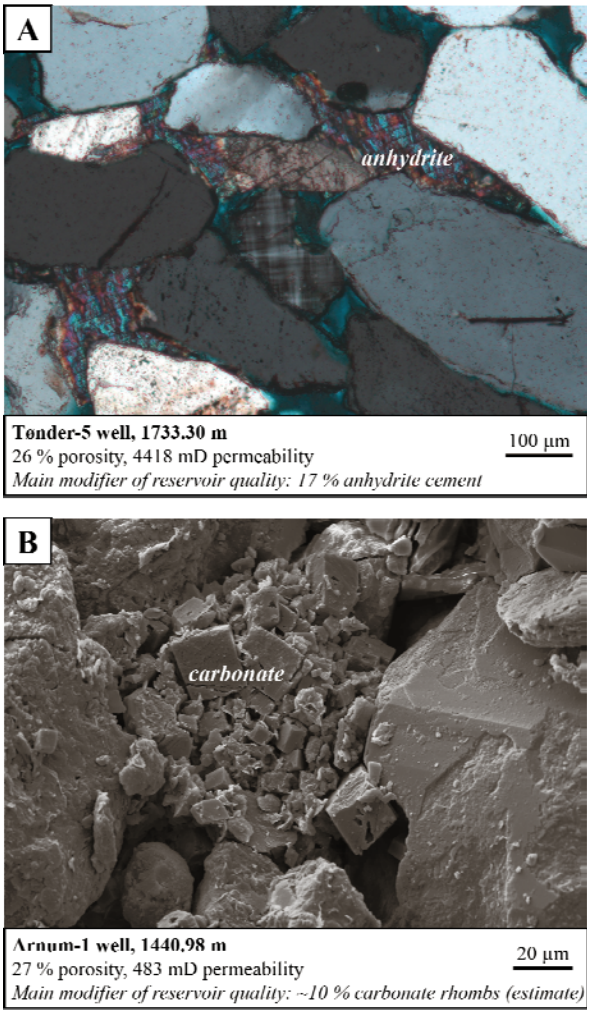

Figure 4: Examples of anhydrite and carbonate cementations and their influence on reservoir properties. A. Thin section image with crossed nicols. B. SEM (secondary electron) image.

Halite is found in varying amounts and it is difficult to quantify how much is authigenic and artificial, respectively, as the salty pore fluids precipitate halite when they dry out (Laier and Nielsen 1989). Secondary porosity constitutes only a minor proportion of the overall porosity, and it is primarily caused by scattered dissolution of feldspars.

3. CONCLUSIONS

The reservoir properties of the Bunter Sandstone Formation can be predicted, to some extent, when the depositional environment is known. The grain size has an effect on reservoir quality, and variations from this trend can be explained by detrital clay content and post-depositional cementations.

Anhydrite and carbonate cements are capable of reducing the reservoir quality significantly, but in most cases they do not have a major influence on porosity and permeability, whereas it is uncertain how large effect halite precipitations have.

REFERENCES

Bertelsen, F.: Lithostratigraphy and depositional history of the Danish Triassic. *Geological Survey of Denmark, Series B*, **4**, (1980), 1-59.

Clausen, O. R. and Pedersen, P. K.: Late Triassic structural evolution of the southern margin of the Ringkøbing-Fyn High, Denmark. *Marine and Petroleum Geology*, **16**, (1999), 653-665.

Clemmensen, L.B.: Desert sand plain and sabkha deposits from the Bunter Sandstone Formation (L. Triassic) at the northern margin of the German Basin. *Geologische Rundschau*, **74**, (1985), 519-536.

Laier, T. and Nielsen, B.L.: Cementing halite in Triassic Bunter Sandstone (Tønder, southwest Denmark) as a result of hyperfiltration of brines. *Chemical Geology*, **76**, (1989), 353-363.

Michelsen, O. and Clausen, O. R.: Detailed stratigraphic subdivision and regional correlation of the southern Triassic succession. *Marine and Petroleum Geology*, **19**, (2002), 563-587.

Mondol, N.H., Bjørlykke, K., Jahren, J. and Høeg, K.: Experimental mechanical compaction of clay mineral aggregates—Changes in physical properties. *Marine and Petroleum Geology*, **24**, (2007), 289-311.

Olsen, H.: Ancient ephemeral stream deposits: a local terminal fan model from the Bunter Sandstone Formation (L. Triassic) in the Tønder-3, -4 and -5 wells, Denmark. *Geological Society Special Publication*, **35**, (1987), 69-86.

Nielsen, L.H. and Japsen, P.: Deep wells in Denmark 1935–1990, lithostratigraphic subdivision. *Geological Survey of Denmark, Series A*, **31**, (1991), 179 pp.

Pedersen, P.K.: Sequence stratigraphic analysis of the non-marine to marginal marine Danish Triassic, supplemented by a field study of the alluvial architecture of the Ericson Sandstone (USA). *Unpublished PhD Thesis, Aarhus University*, (1998).