DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/84

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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# Preface

This report has been prepared as part of the evaluation of the geothermal potential in the Rødding area that GEUS has performed for Skive Geotermi.

The results of the study of cuttings and sidewall core samples are integrated with petrophysical log interpretations and are discussed in the GEUS Notat 08-EN-12-13: ”Evaluation and comparison of the Gassum Formation sandstone reservoir in the wells Rødding-1 and Oddesund-1. Based on well log data, cuttings and sidewall samples” by Kristensen, L., Therkelsen, J & Nielsen, L.H.

# Contents

# 1. General aspects for use of cuttings and sidewall core samples

Conventional full cores are the most reliable source of information on reservoir properties. However, cores were not taken from the Gassum Formation in Oddesund-1, Rødding-1 and Kvols-1 wells. Therefore this investigation has been performed on cuttings and sidewall core samples.

Information from cuttings samples compared to core samples is subject to several possible errors. When cuttings samples are the only available samples it has to be emphasized that they may not reveal all the required or necessary information for the assessment of reservoir quality. It should be noted that, especially for cuttings samples, intensely cemented sandstone samples have a higher survival potential than less cemented sandstone fragments. This has the effect that there is a risk of a higher representation from the cemented horizons in the cuttings samples.

The use of sidewall cores gives the advantage that the sample is taken from a precisely known level in the well and a whole sandstone sample is recovered. A disadvantage can be that the sidewall of the wells in sandstone intervals may be infiltrated by drilling mud. By examination it can be difficult to distinguish between detrital mud and infiltrated drilling mud in the pores of the sandstone and the infiltrated drilling mud may obliterate and disguise potential authigenic mineral phases.

# 2. Examined samples

The petrographic analysis of sandstones from the Gassum Formation in the Rødding-1 and Oddesund-1 wells has been carried out on 9 sandstone samples, whereas 5 were sidewall core samples and 4 cuttings samples. The samples are represented by depth and sample type in this manner:

Rødding-1:
1995 m b. kb. (sidewall core)
2006 m b. kb. (cuttings)
2010 m b. kb. (sidewall core)
2021 m b. kb. (cuttings)

Oddesund-1:
1956,5 m b. kb. (sidewall core)
1962,0 m b. kb. (sidewall core)
1966,2 m b. kb. (sidewall core)
1969 m b. kb. (cuttings)
1975 m b. kb. (cuttings)

The petrography of the cuttings and sidewall core samples from respectively the Rødding-1 and Oddesund-1 wells are described in detail below.

# 3. Rødding -1

## 3.1 1995 m b. kb. (sidewall core)

The specimen is a sandstone, which appears light grey, and with a fine – coarse grain size. The sandstone is weakly cemented and therefore relatively friable.

Figure 1 shows an overview from the Scanning electron microscopy (SEM) analysis of the fine – coarse-grained sandstones, where pore spaces clearly are affected by a clayey matrix, which can be drilling mud. Detrital grains are represented by a majority of quartz and feldspars. One glauconitic pellet has been observed. Authigenic chlorite forms coatings on detrital quartz grains (Fig. 2). The chlorite is often enclosed in authigenic quartz, whereas smectitic clay (drilling mud?) partly covers quartz overgrowths. Furthermore, feldspars are often partially dissolved. The presence of authigenic chlorite and quartz contributes to a reduction of the original porosity and permeability, whereas dissolution of feldspar may enhance porosity and permeability.

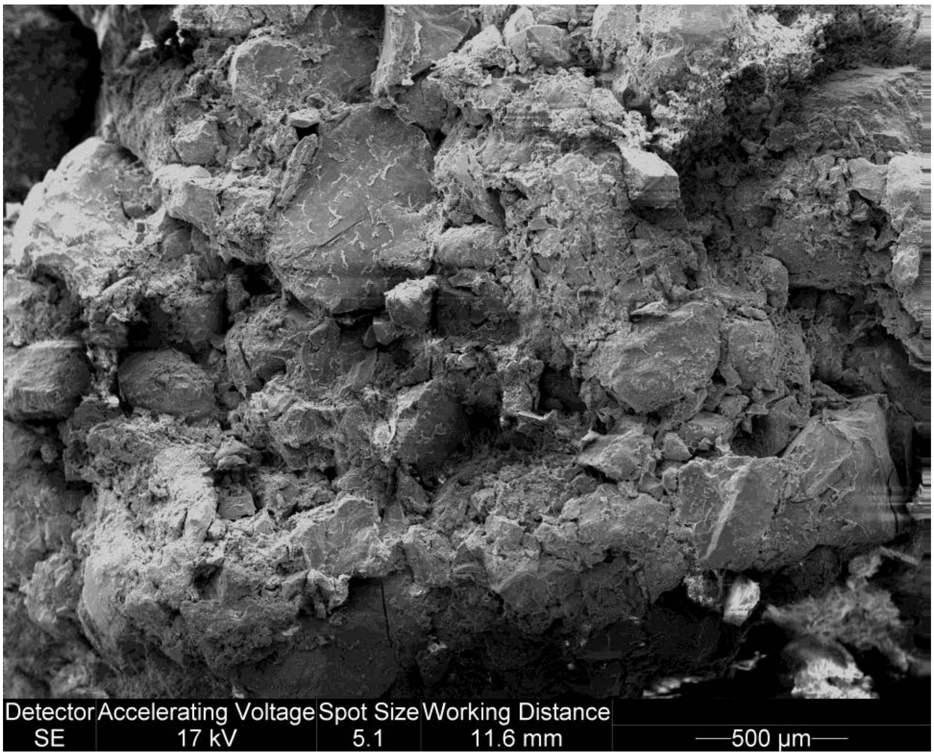


Fig. 1. Abundant pore filling clay between detrital grains in fine to coarse grained sandstone. The clay can be a mixture of authigenic and detrital origin or be drilling mud.

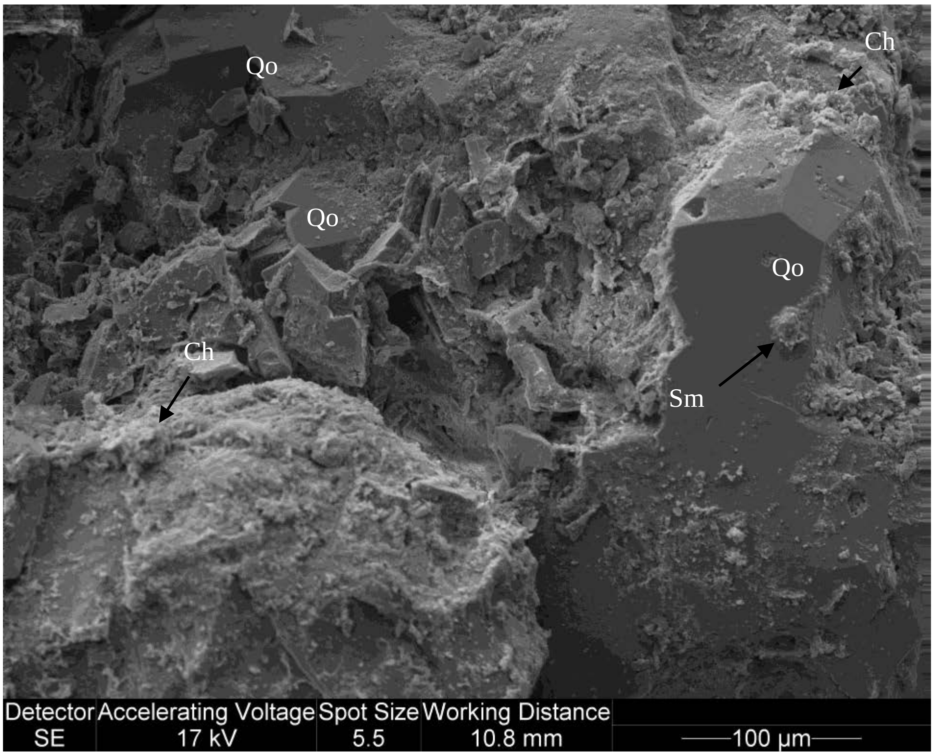


Fig. 2. Quartz overgrowths (Qo) and chlorite (Ch) on detrital quartz sand grain. Smectitic clay (Sm) is coating quartz overgrowth, which can be originating from infiltrated drilling mud.

## 3.2 2006 m b. kb. (cuttings)

The cuttings sample from this depth is dominated by medium – very coarse-grained sand grains and to a lesser degree greyish very fine – fine-grained sandstone fragments. A very coarse sand grain and a fine-grained sandstone fragment have been chosen for further investigation by Scanning Electron Microscopy (SEM).

The Scanning Electron Microscopy (SEM) reveals that the very coarse quartz grain occurs with some, but incipient quartz overgrowths (Fig 3). The origin of the coarse sand grains is probably from a highly porous layer. Authigenic chlorite occurs as a thin coating on the quartz grain, which are enclosed in authigenic quartz (Fig. 4).

The fine-grained sandstone fragment often occurs with quartz overgrowths and some pore-filling authigenic chloritic clay (Fig. 5 and 6). The chlorite is overgrown by quartz. A common observation is feldspar dissolution in varying degree, which contributes to enhanced porosity. Further, sporadic authigenic Ti-oxide (Anatase?) is observed.

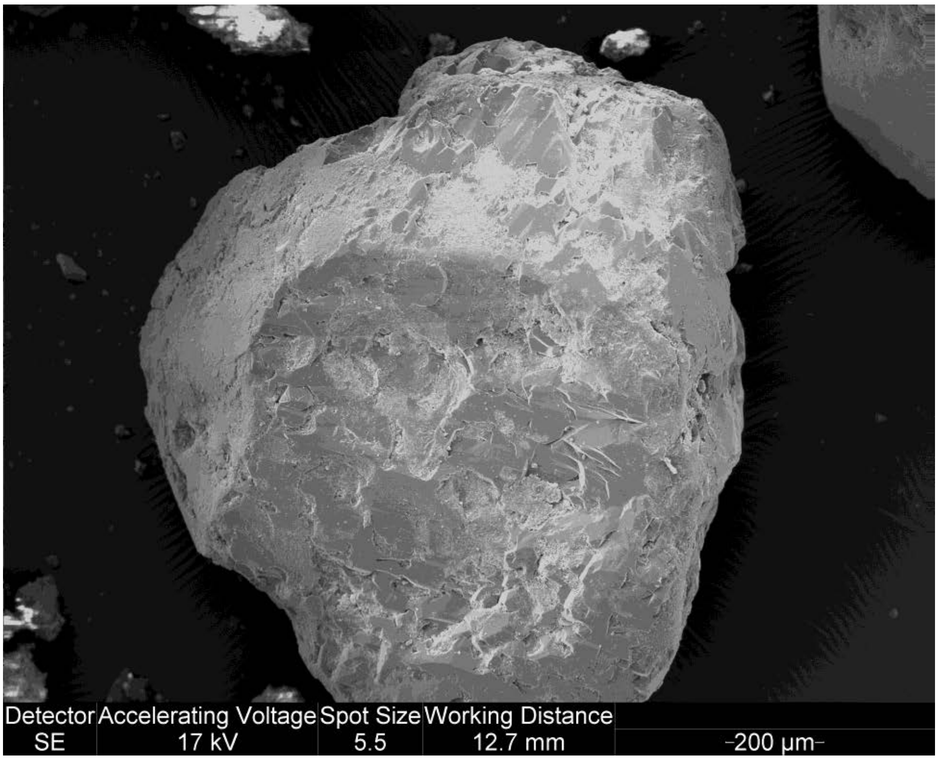


Fig. 3. Scattered incipient authigenic quartz on detrital quartz sand grain.

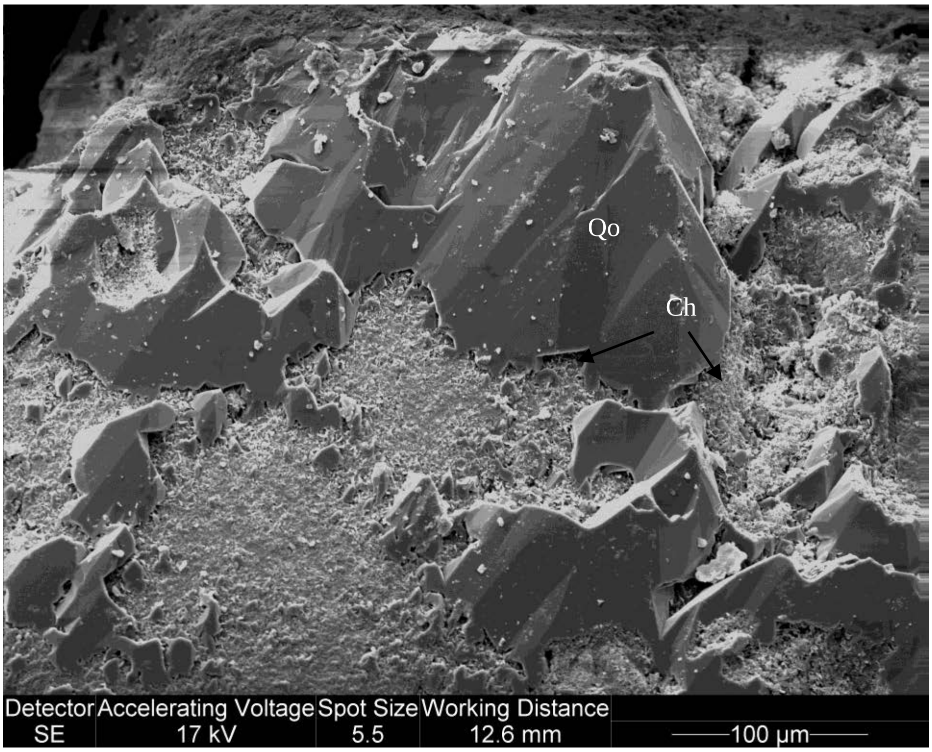


Fig. 4. Close up of authigenic quartz on detrital quartz sand grain. Note the thin coating of chlorite on the sand grain surface.

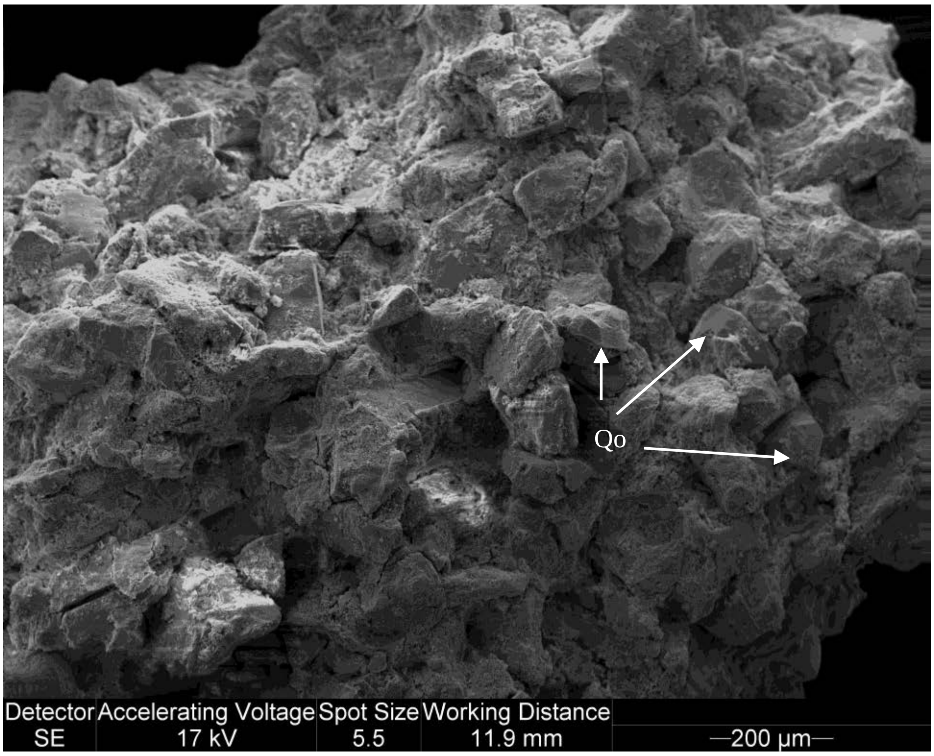


Fig. 5. Apparent authigenic quartz on detrital quartz sand grains. Chlorite occurs scattered in pore spaces.

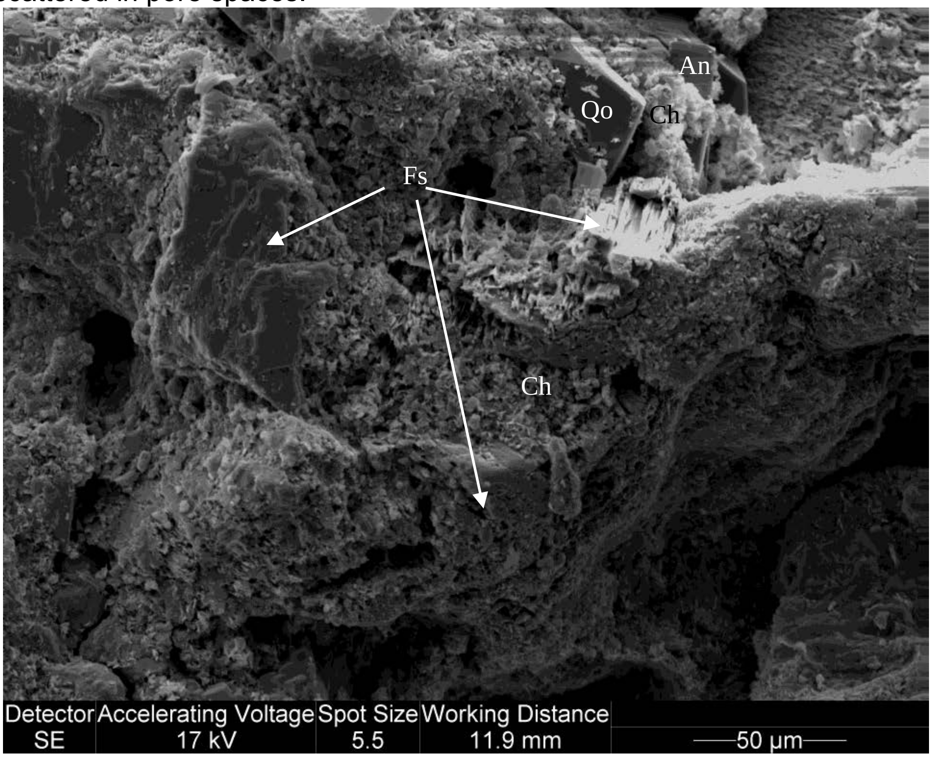


Fig. 6. Euhedral quartz overgrowth (Qo), partially dissolved feldspars (Fs) and chlorite (Ch) in pore spaces. Further, euhedral Ti-Oxide (Anatase?) has developed.

## 3.3 2010 m b. kb. (sidewall core)

The specimen is a fine-grained – coarse-grained sandstone, which appears brownish-grey. The sandstone is weakly cemented and therefore relatively friable.

The sandstone was analysed by use of Scanning Electron Microscopy (SEM), which reveals that pore spaces often are filled by an unidentified but presumably smectitic/chloritic clayey matrix, which also coats detrital grains (Fig 7 and 8). The clay may be infiltrated drilling mud.
The quartz grains in the sandstone generally occur with no or incipient quartz overgrowths and chlorite is seen coating quartz grains. Sporadic kaolinite is observed in pore spaces; probably of authigenic origin.

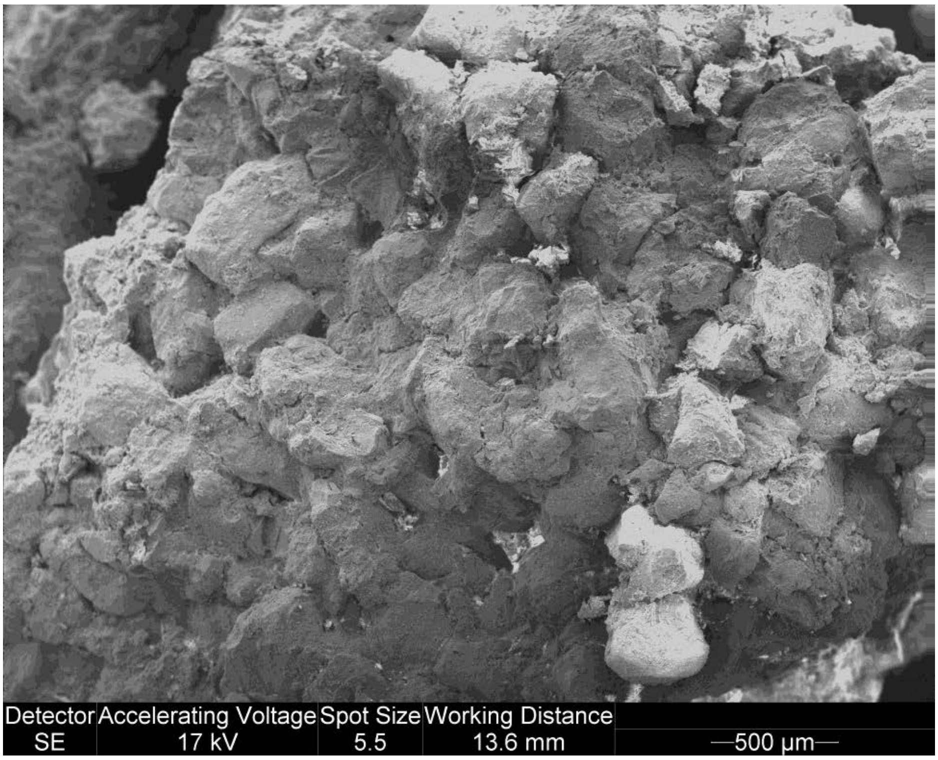


Fig. 7. Pore spaces filled by smectitic/chloritic clay. No authigenic quartz on detrital quartz sand grain.

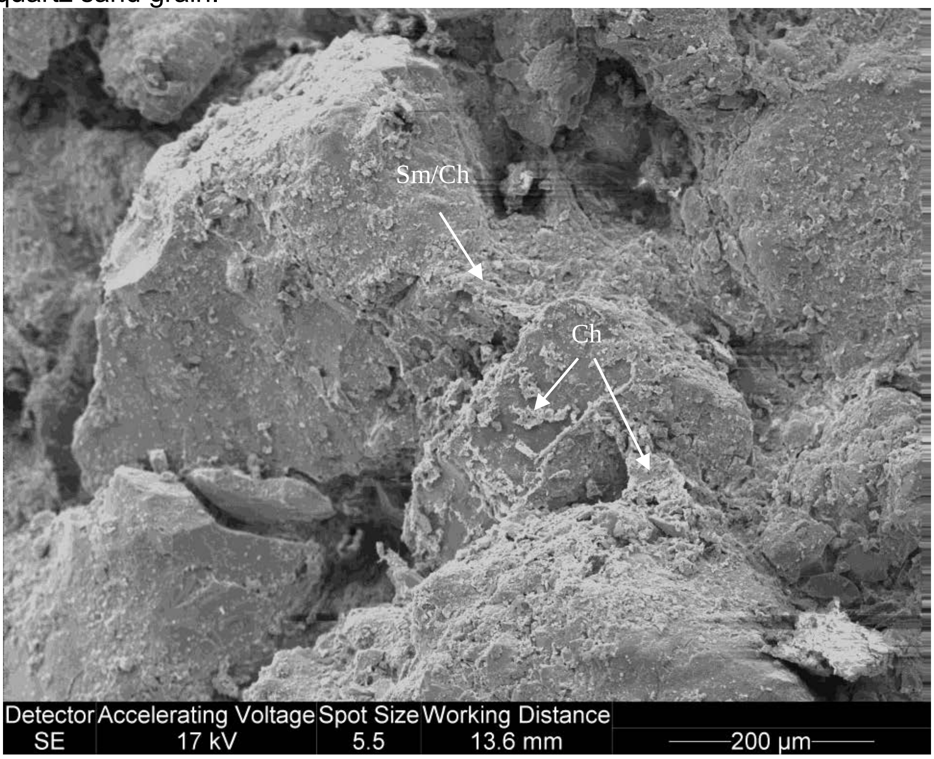


Fig. 8. Authigenic chlorite (Ch) on detrital quartz sand grain. Smectitc/chloritic clay (Sm/Ch) infilling pore space.

## 3.4 2021 m b. kb. (cuttings)

The cuttings sample from this depth is dominated by dark grey mudstones, which is probably cavings (downfall). Scattered between the mudstone fragments are medium to very coarse sand-grains and greyish fine-grained sandstone fragments. A very coarse sand grain and a very fine – fine-grained sandstone fragment have been chosen for further investigation by Scanning Electron Microscopy (SEM).

The Scanning Electron Microscopy (SEM) reveals that the very coarse detrital quartz grain occurs with incipient quartz overgrowths (Fig. 9 and 10). There seems not to be authigenic clay growth on the grain surface.
The origin of the coarse sand grain may probably be from highly porous sediments.

The very fine-grained – fine-grained sandstone fragment occurs with abundant quartz overgrowths (Fig. 11 and 12) and authigenic chlorite and kaolinite. The chlorite and kaolinite is overgrown by quartz (Fig. 12). Dissolution of feldspars, which contributes to enhanced porosity, is common.

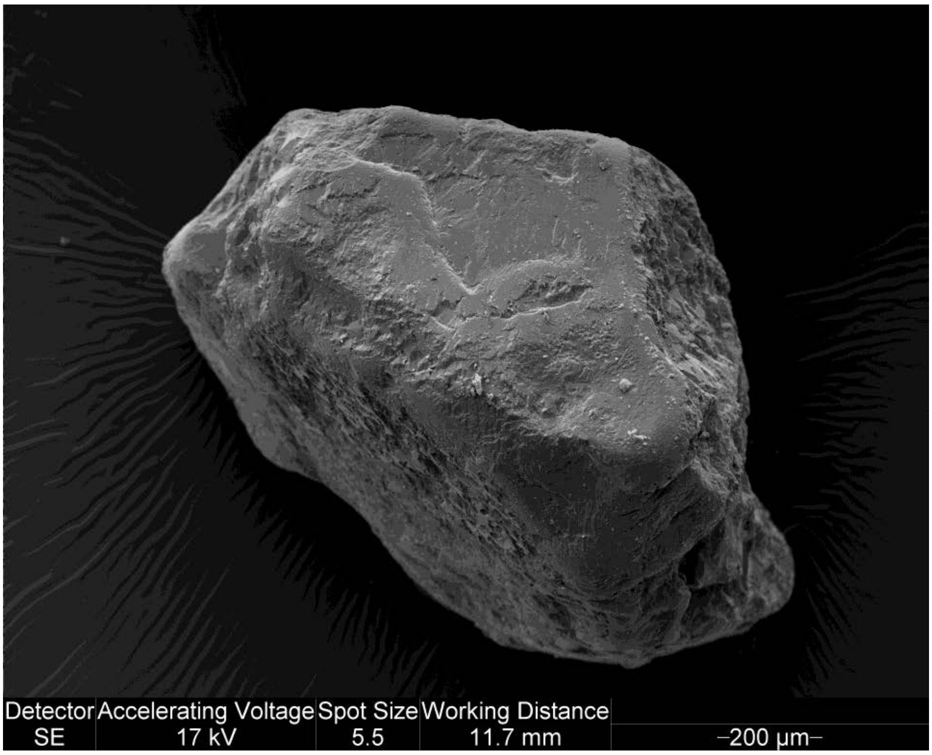

Fig. 9. Scattered incipient authigenic quartz on coarse detrital quartz sand grain.

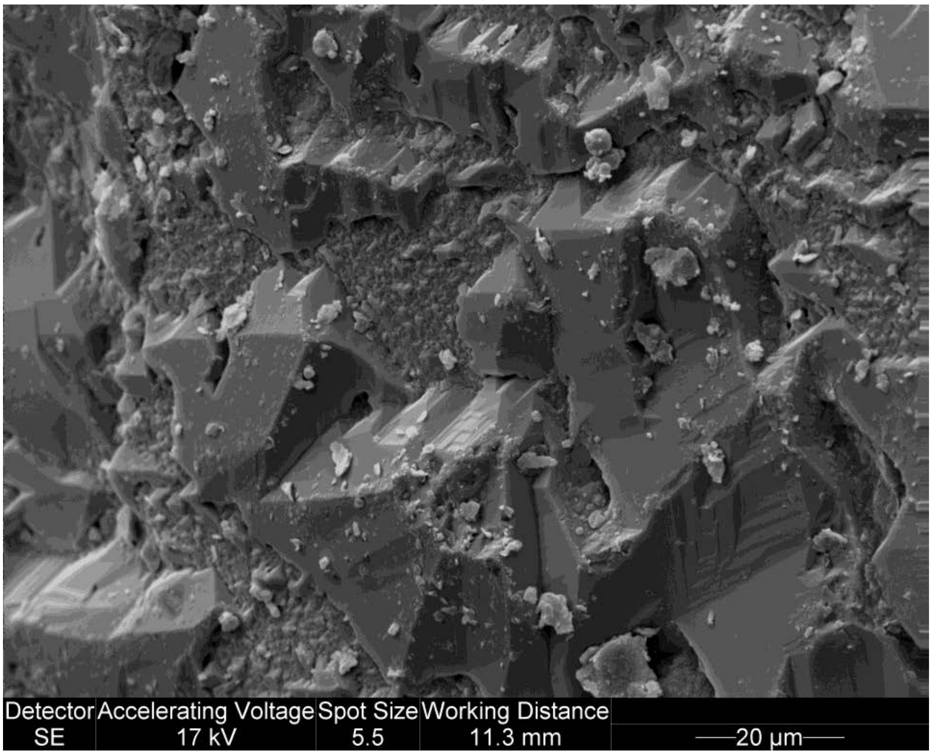

Fig. 10. Close up on minor incipient authigenic quartz on detrital quartz sand grain.

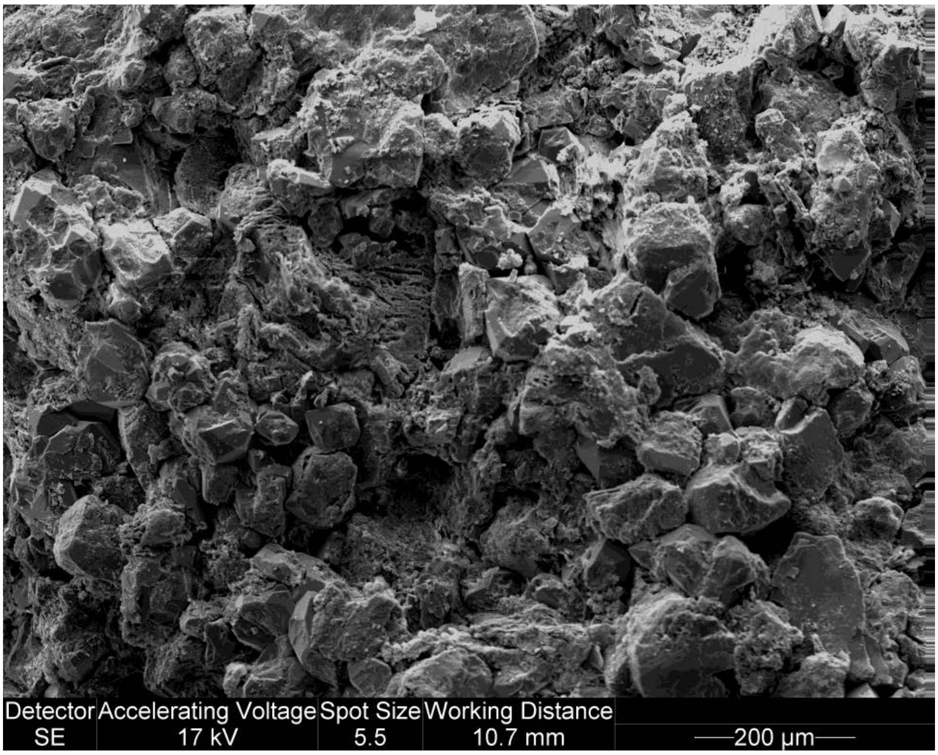


Fig. 11. Abundant authigenic quartz growing on detrital quartz sand grains.

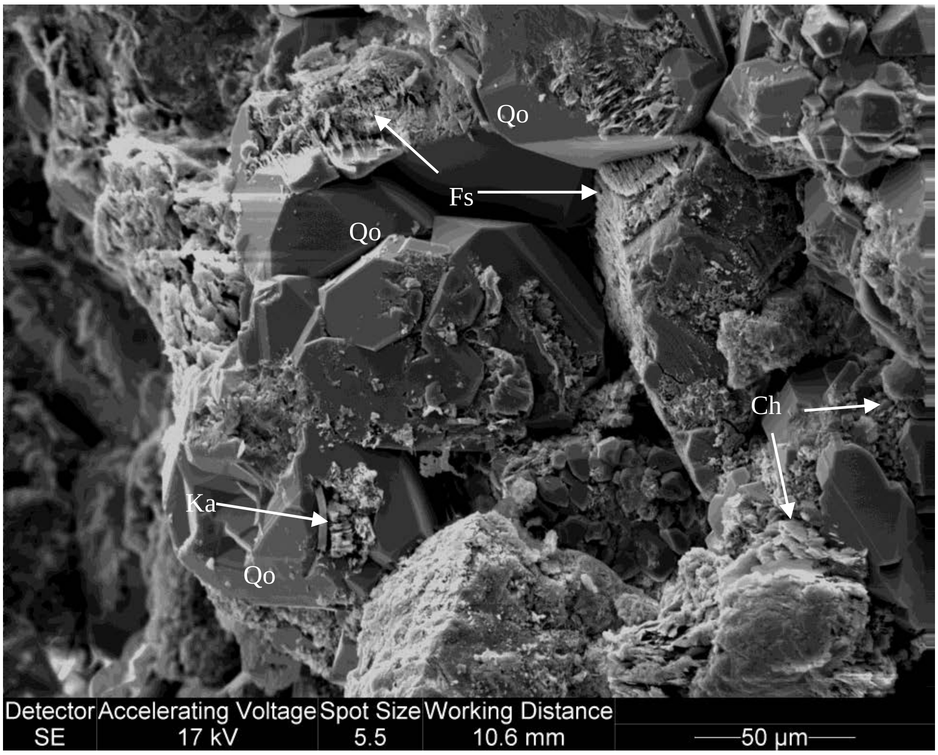


Fig. 12. Euhedral authigenic quartz (Qo) overgrowing chlorite (Ch), kaolinite (Ka) and partially dissolved feldspar (Fs).

# 4. Oddesund -1

## 4.1 1956,5 m b. kb. (sidewall core)

The specimen is a medium – coarse-grained sandstone, which appears whitish. The sandstone is weakly cemented and therefore relatively friable. Sporadic pyrite and glauconite is observed.

Figure 13 shows an overview of the medium – coarse-grained sandstone, where pore spaces are occluded by a smectitic clayey matrix, which may be drilling mud. Detrital grains are represented by a majority of quartz and feldspars. Authigenic chlorite and kaolinite are seen to form on detrital quartz grains (Fig. 14). The chlorite and kaolinite are often enclosed in authigenic quartz. Sporadic pyrite framboids are observed. Feldspars often occur partially dissolved. The presence of authigenic chlorite and quartz contributes to a reduction in porosity and permeability, whereas dissolution of feldspar may enhance porosity and permeability.

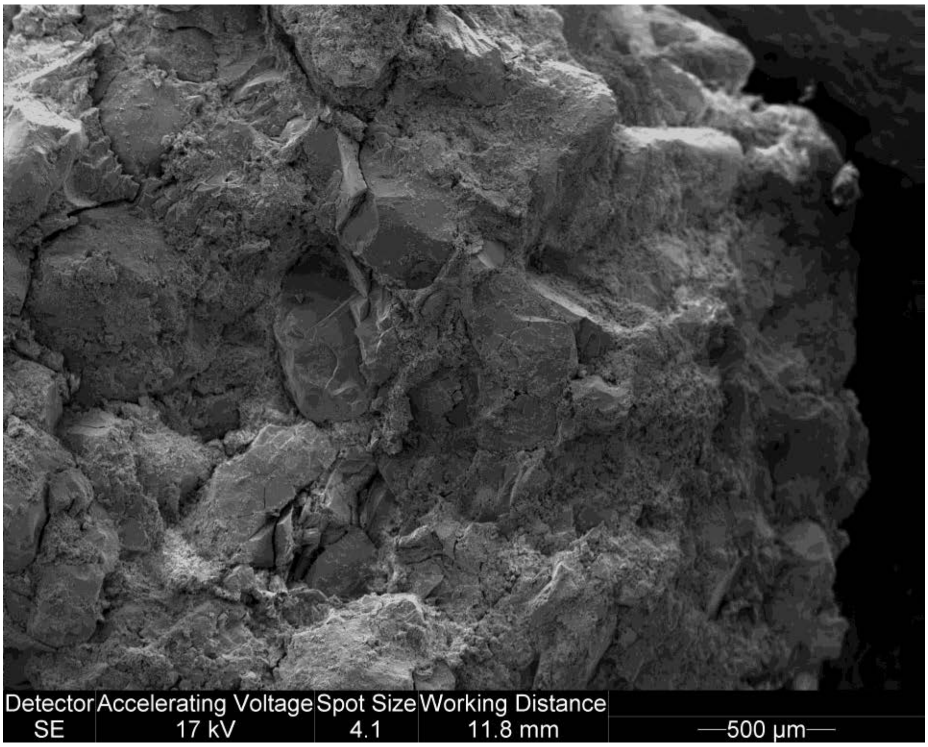


Fig. 13. Abundant unidentified pore-filling clay between detrital grains in medium to coarse grained sandstone. The clay can be a mixture of authigenic and detrital origin or be drilling mud.


Fig. 14. Incipient quartz overgrowths (Qo) on detrital quartz sand grain. The overgrowths often partly engulf authigenic kaolinite (Ka) and chlorite (Ch).

## 4.2 1962 m b. kb. (sidewall core)

The specimen is a fine – medium-grained sandstone, which appears whitish-grey. The sandstone is weakly cemented and therefore relatively friable. Sporadic pyrite and mica is observed.

The Scanning Electron Microscopy (SEM) reveals that the sandstones pore spaces occur occluded by a smectitic/chloritic clayey matrix, which probably is drilling mud (Fig. 15). Detrital grains are represented by quartz and feldspars. Only minor incipient quartz overgrowths (Fig. 16) have been observed and it has not been possible to determine whether some of the chloritic clay is of authigenic origin or whether it is infiltrated drilling mud.

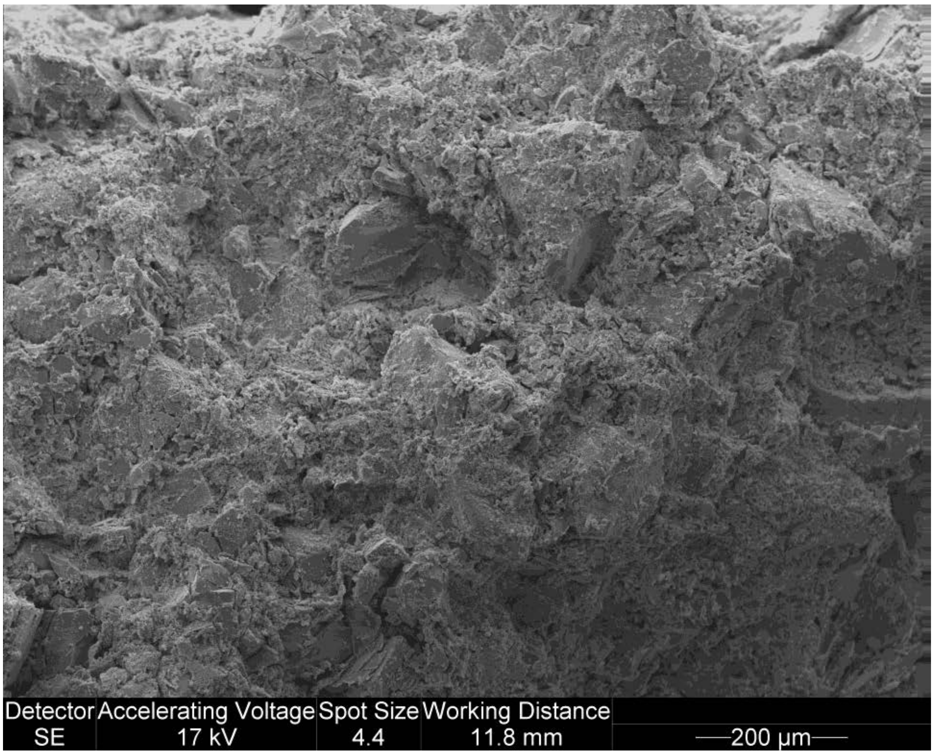

Fig. 15. Overview showing pore occluding clayey matrix between detrital quartz and feldspar.

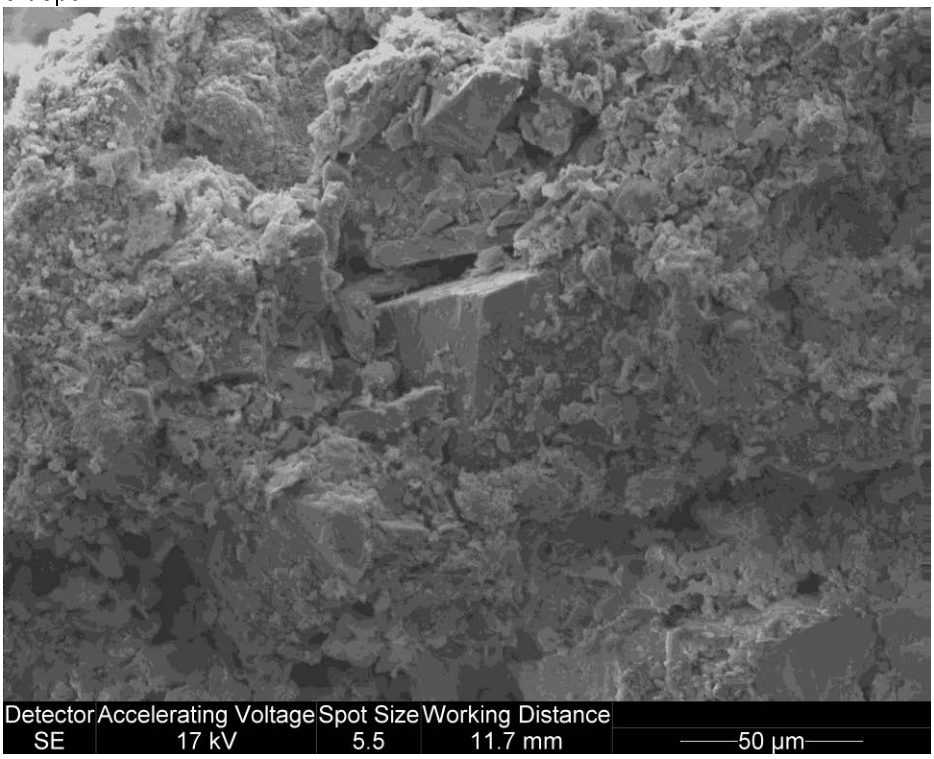

Fig. 16. Minor incipient authigenic quartz overgrowths; smectitic/chloritic matrix.

## 4.3 1966,2 m b. kb. (sidewall core)

The specimen is a fine – medium-grained sandstone, which appears light grey. The sandstone is weakly cemented and therefore relatively friable. Sporadic pyrite and mica occur.

The analyse by use of Scanning Electron Microscopy (SEM) reveals that pore spaces are filled by an unidentified but presumably smectitic/chloritic clayey matrix, which also coats detrital grains (Fig 17). The clay matrix may be infiltrated drilling mud. Detrital grains are represented by a majority of quartz and feldspars. Quartz cement is sporadic. Feldspars often occurs partially dissolved (Fig 18). Sporadic discrete authigenic pyrite and kaolinite occur. Chlorite may be of authigenic origin but may also originate from infiltrated drilling mud.

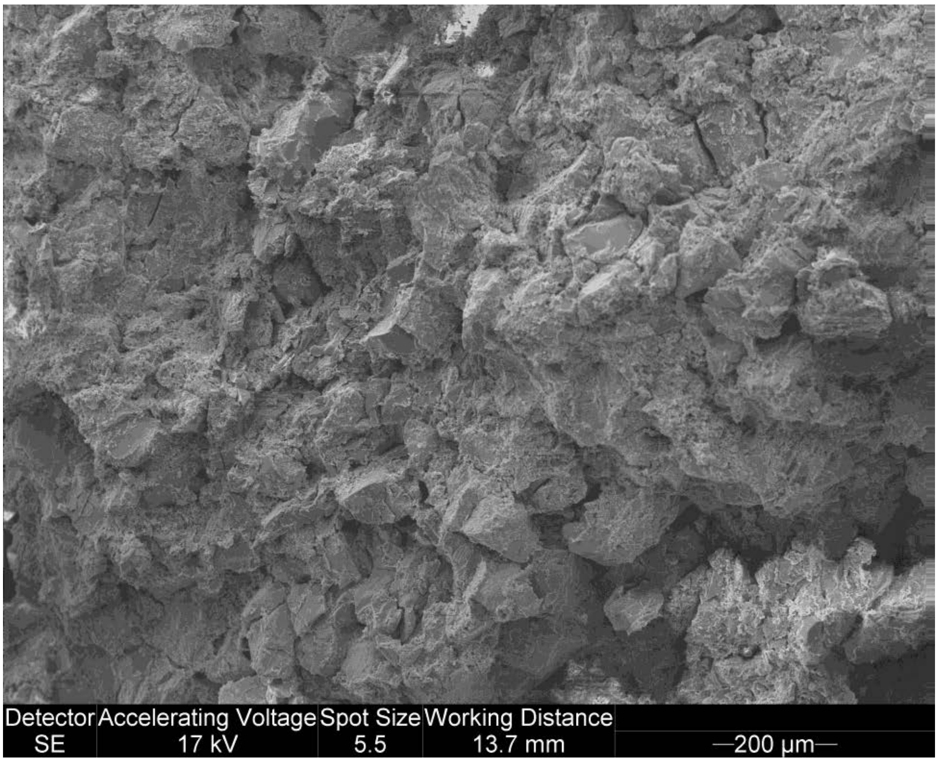

Fig. 17. Abundant pore-filling clayey matrix between detrital quartz and feldspar.

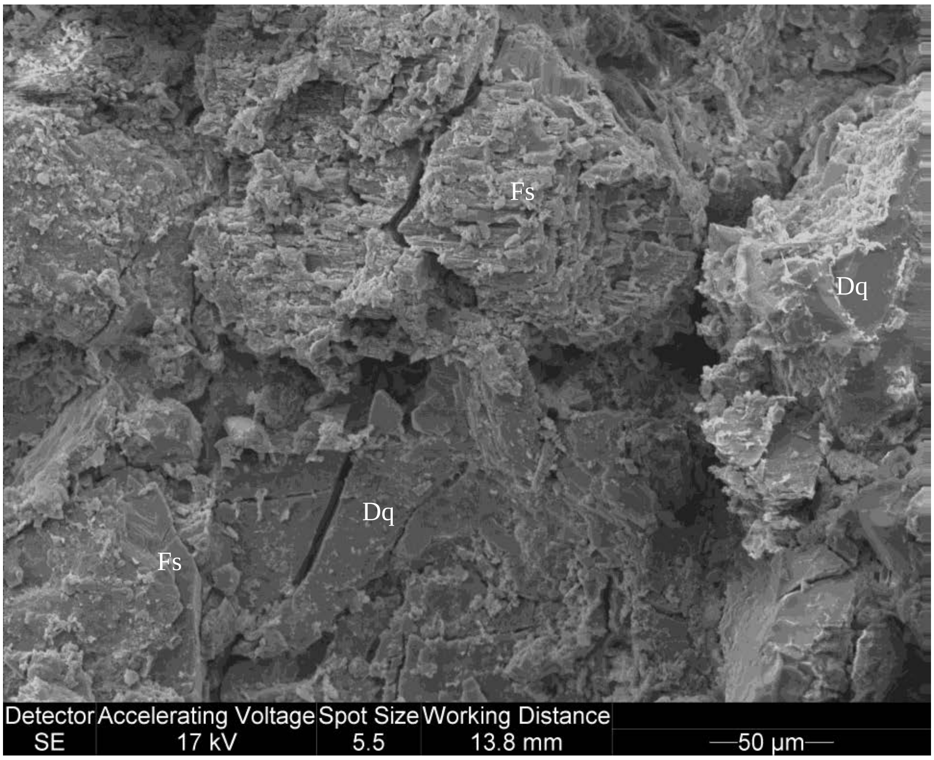

Fig. 18. Scattered clay, detrital quartz (Dq) and partially dissolved feldspar (Fs).

## 4.4 1969 m b. kb. (cuttings)

The cuttings sample from this depth is dominated by dark grey mudstone, which probably is cavings (downfall). Scattered in the mudstone fragments are found coarse sand to very fine gravel grains and light grey fine – medium-grained sandstone fragments. A very fine gravel grain and a fine – medium-grained sandstone fragment have been chosen for further investigation by Scanning Electron Microscopy (SEM).

The Scanning Electron Microscopy (SEM) reveals that the detrital very fine gravel quartz grain occurs with incipient quartz overgrowths preferably in former grain contact points (Fig. 19). A minor amount of carbonate cement (ankerite) and authigenic chlorite grow on the grain surface (Fig. 20).

The origin of the very fine gravel-grain may probably be from highly porous sediments.

The fine – medium-grained sandstone fragment occurs with abundant quartz overgrowths (Fig. 21) and authigenic chlorite and kaolinite. The chlorite (Fig. 22) and kaolinite is overgrown by quartz. Dissolution of feldspars, which may contribute to enhance porosity, is common.

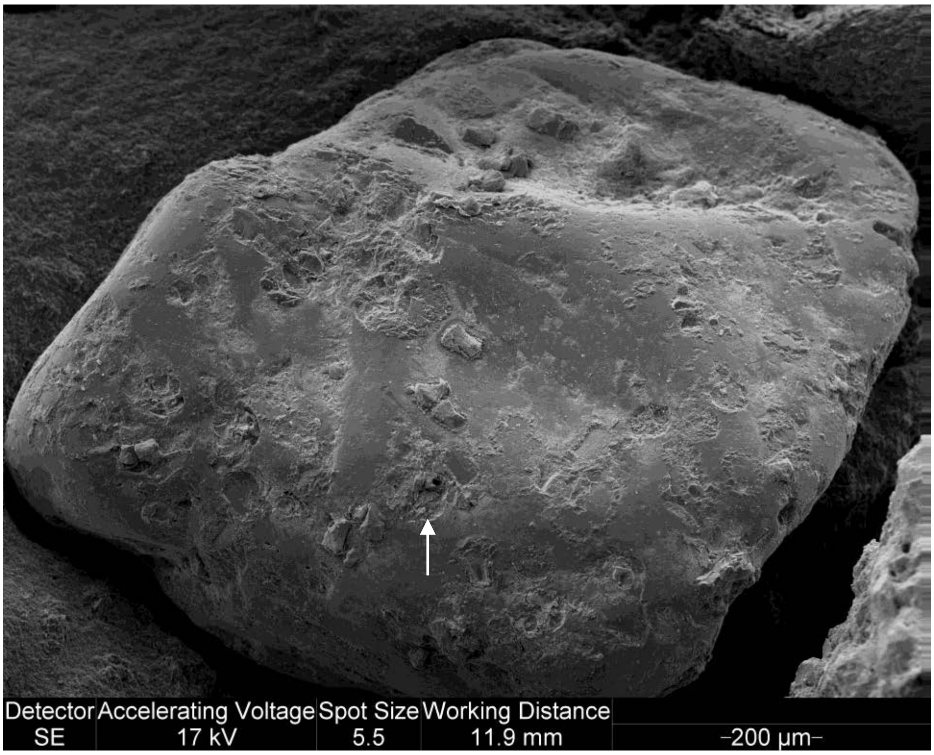

Fig. 19. No authigenic quartz on detrital quartz granule grain. Note former grain contact points (arrowed).

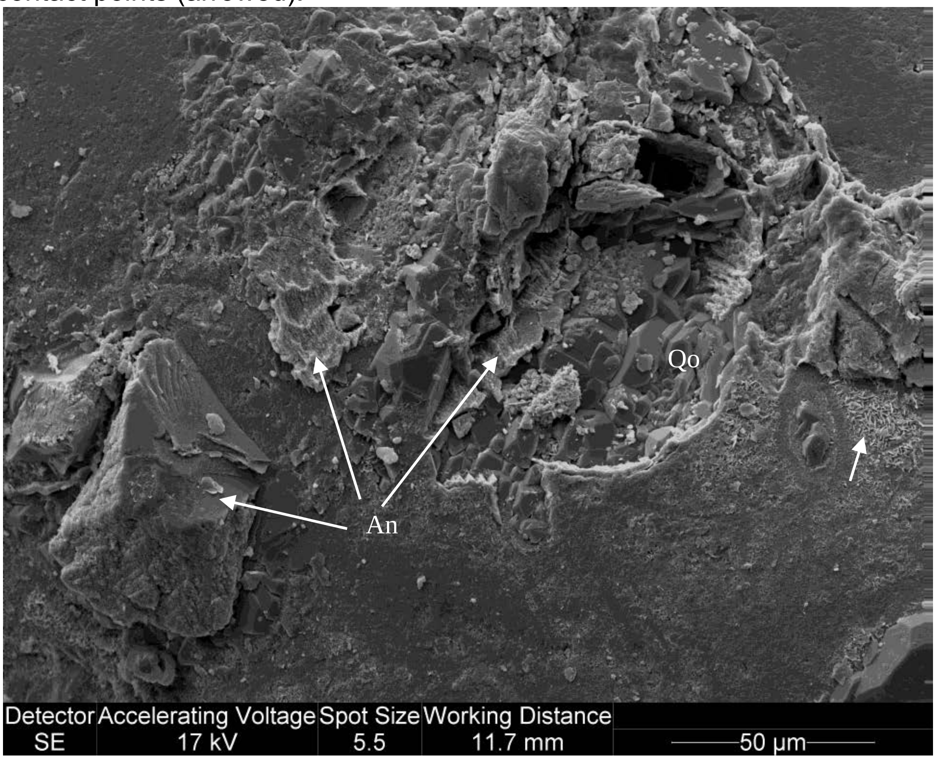

Fig. 20. Incipient authigenic quartz (Qo) in former grain contact point on detrital quartz gravel grain; minor reminiscences of carbonate cement (Ankerit) and authigenic honeycomb structure from chlorite (arrowed).

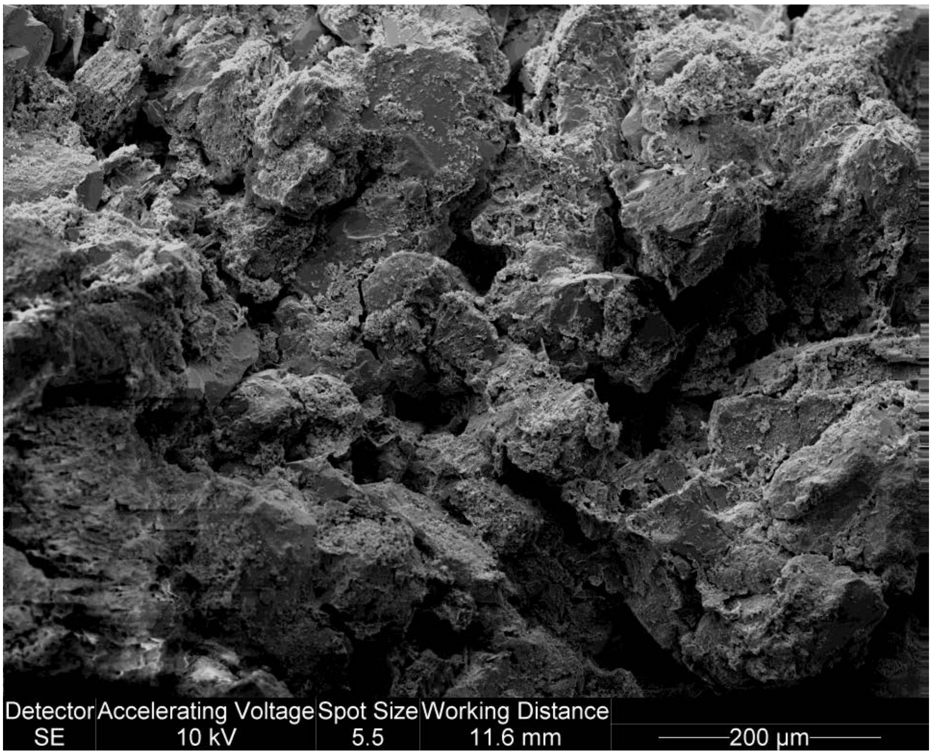

Fig. 21. Common authigenic quartz and partially dissolved feldspars in fine to medium grained sandstone.

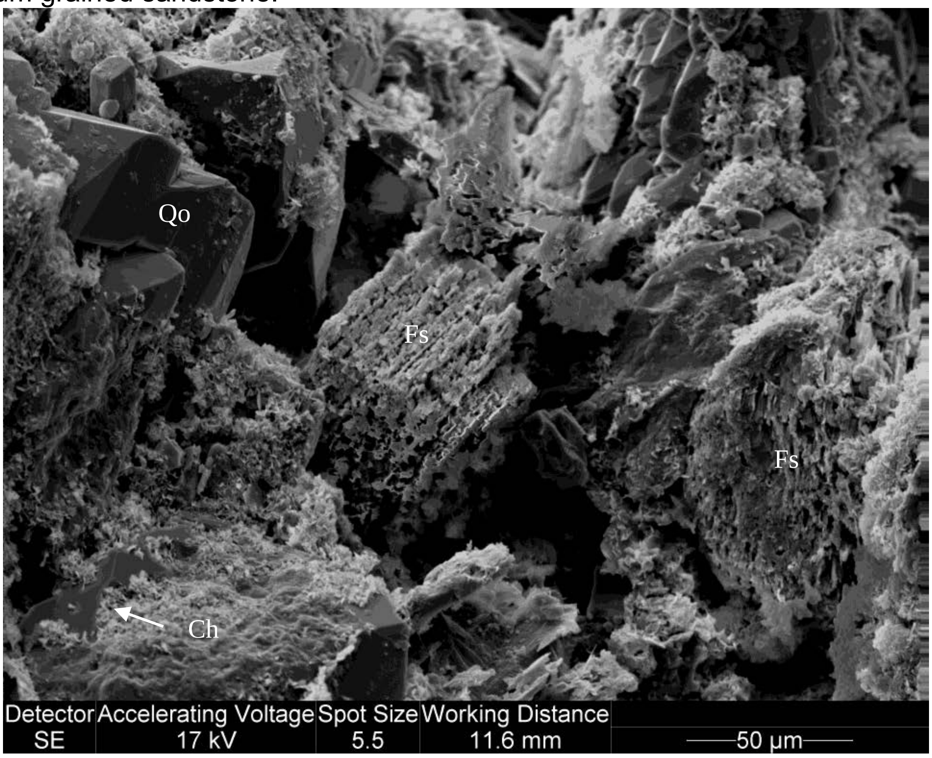

Fig. 22. Close up of euhedral quartz (Qo) overgrowths and partially dissolved feldspar (Fs). Authigenic chlorite partially enclosed by quartz overgrowth (Ch).

## 4.5 1975 m b. kb. (cuttings)

The cuttings sample from this depth is dominated by dark grey mudstone, which is probably cavings (downfall). Scattered in the mudstone fragments are coarse sand to very fine gravel-grains and light greyish very fine – medium-grained sandstone fragments. A fine – medium-grained sandstone fragment have been chosen for further investigation by Scanning Electron Microscopy (SEM).

The use of Scanning Electron Microscopy (SEM) reveals that the fine – medium-grained sandstone fragment occurs with quartz overgrowths and dissolution of feldspars (Fig. 23 and 24), the latter may contribute to enhance porosity, is a common feature. The sandstone is also cemented by calcite (Fig. 24) and by smectitic-chloritic-illitic clays

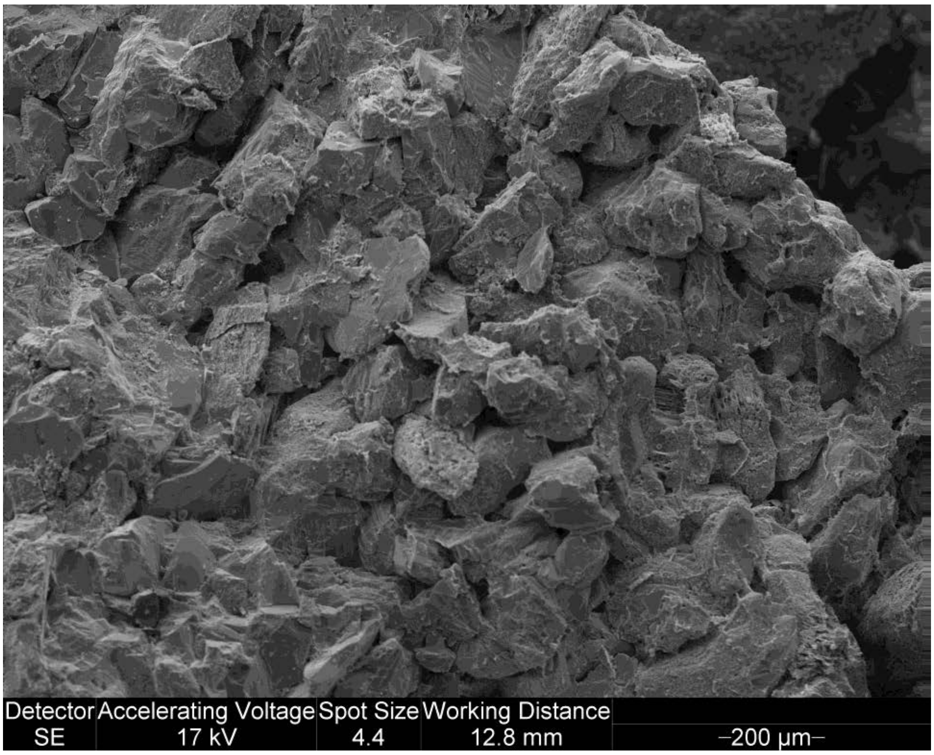

Fig. 23. Scattered authigenic quartz and partially dissolved feldspars in fine to medium grained sandstone.

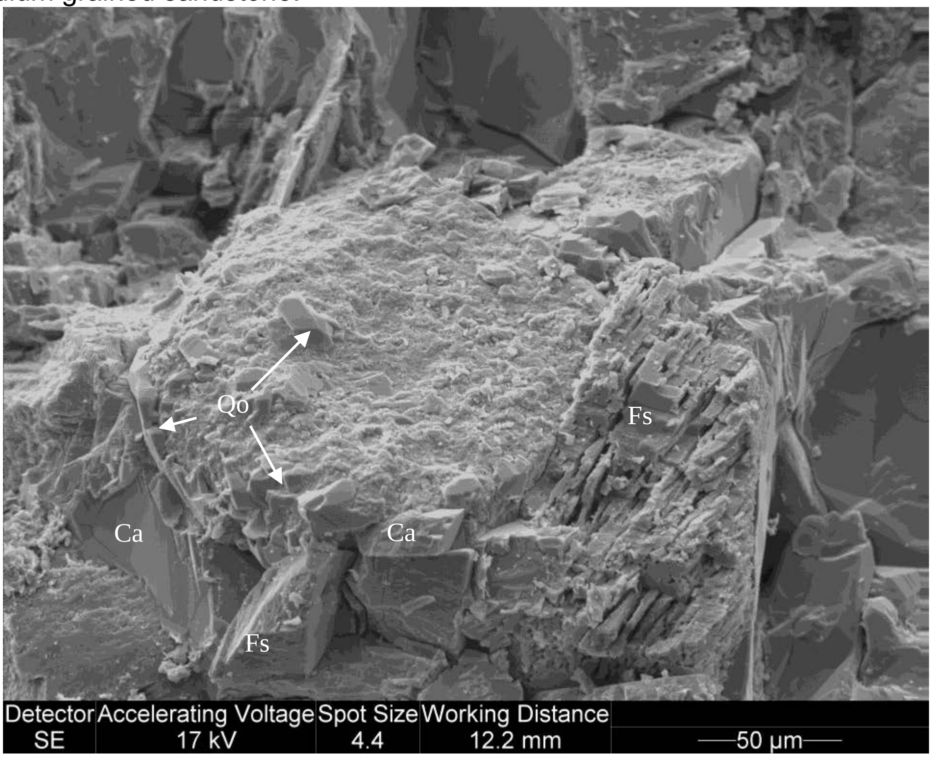

Fig. 24. Incipient authigenic quartz on detrital quartz sand grain and calcite cement. Note also partially dissolved feldspar (Fs).

# 5. Petrographic correlation

When correlating samples from the Oddesund-1 and Rødding-1 wells it is necessary to divide the samples into single grains and sandstone fragments from cuttings samples and sidewall cores.

In both wells the single grains are typically coarse sand grains, which show restricted cementation of any kind and therefore are assumed to originate from sandstone intervals with good reservoir properties.

The sandstone fragments from the cuttings samples are in the interval of very fine to medium in grain size. The two sandstone fragments from Rødding-1 are very fine- to fine-grained sand, whereas the two from Oddesund-1 are fine- to medium-grained sand. They are all characterised by quartz and chlorite cements, which are dominating and to a lesser degree kaolinite and calcite. All samples show dissolution of feldspars.

All sidewall cores from the two wells are friable in hand sample. They all contain pore occluding clayey matrix, which may be a result of infiltrating drilling mud. Similar to the sandstone fragments from cuttings samples, the sidewall core samples all more or less are dominated by quartz and chlorite cements and to a lesser degree kaolinite. Dissolution of feldspars is also common.

On the basis of the descriptions above, it is likely that the Gassum Formation in the Rødding-1 and Oddesund-1 wells are relatively similar in petrographic composition. As the Gassum Formation occurs at almost similar burial depth it is likely that their reservoir properties are similar.