DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2004/48

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Provenance of Upper Jurassic sandstone in the wells Cleo-1 and 3/7-6: Evidence from geochemical analysis of cuttings

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Summary

A total of 118 samples of washed and dried cuttings from the wells Cleo-1 and 3/7-6 (Norwegian sector) have been analysed for 10 major-, 33 trace- elements and loss on ignition at GEUS. The sample density is approximately one sample per 5 m.

The samples represent Jurassic sand-dominated intervals and the primary objective is to conduct a provenance study to improve the establishment of a depositional model for Late Jurassic sandstone's in the Søgne Basin.

The main finding is that the sandstones in the 3/7-6 well has a very high content of K-feldspar indicating that the source is exposed basement. The sandstone is very immature, indicating that it was deposited very close to the source. Further, the composition of the sandstone in the 3/7-6 well has a very distinct composition different from other Upper Jurassic sands analysed in this study.

The sediment in the Cleo-1 well is generally finer grained than the 3/7-6 sand. It has a lower contents of K-feldspar, but has elevated contents of K-feldspar relative to e.g. Amalie-1. The sediment in Cleo-1 is more mature than the sandstone in the 3/7-6 well, indicating that the sediment was derived from older sedimentary rocks in contrast to the sediment in the 3/7-6 well. Several levels in the Cleo-1 well have high carbonate contents, probably in the form of diagenetic cement.

It was found that the cuttings contain significant amounts of drillmud with variable contents of baryte (highest in the 3/7-6 well, locally more than 50 % baryte). The primary effect of this is that the absolute concentrations of the elements analysed in the cuttings do not directly reflect the geology in the wells. Accordingly, the main method has been to crossplot the geochemical data and use element/element ratios. Apart from the influence from the mud, the analytical results are influenced by steel from the drilling procedure. Crossplots of the various elements revealed that the elements Ba, Sr, Na, Fe, Mn, Cr, Ni and V have been introduced in the drilling procedure, and can not be regarded in the evaluation of the analysis of the geology in the wells.

To improve the possibilities for evaluating the geological information in the analytical data, the results have been corrected attempting to remove the effects from artefacts such as drillmud, steel and hydrocarbons.

Contents

Introduction

The present study has been conducted by GEUS for DONG in the period October to December 2003

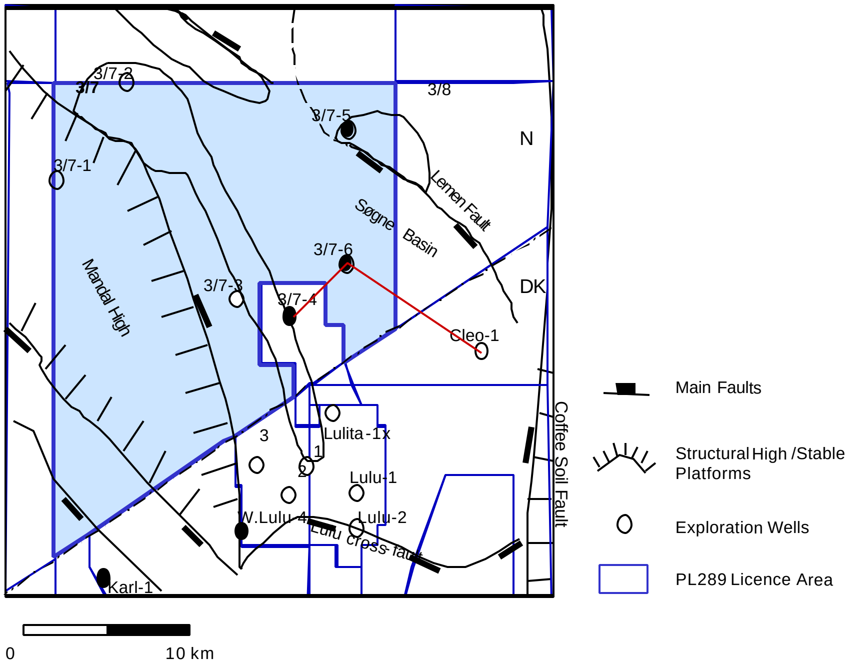

Figure 1 Location map

Objectives

The primary objective is to conduct a provenance study to support the establishment of a depositional model for Kimmeridgian sandstone's in the Søgne Basin. This is carried out through geochemical considerations based on cuttings from the wells 3/7-6 and Cleo-1 and comparison to analyses from Amalie-1 and Iris-1 located in the Tail End Graben farther to the south.

The Upper Jurassic part of the Cleo-1 well belonging to the J62 sequence (c.f. Partington et al. 1993) consists mainly of silty to sandy mudstone with minor sandy intervals. The analysed intervals in the 3/7-6 well belong to the J62 and J63 sequences (see Figure 2). Both wells are located in the Søgne Basin with Cleo-1 sitting just west of the Coffee Soil Fault and 3/7-6 located between Mandal High to the west and the Coffee Soil Fault to the east (Figure 1). It was assumed that sand in the Cleo-1 well was sourced directly from the Ringkøbing-Fyn High and deposited locally in a fan in the hangingwall of the Coffee Soil Fault. In contrast it was assumed that sand in the 3/7-6 well was derived from sandy shelf or coastal areas located further to the north or Northeast, and deposited in a turbidite system within the north-south trending axis of the Søgne Basin, and probably extending southwards into the Tail End Graben.

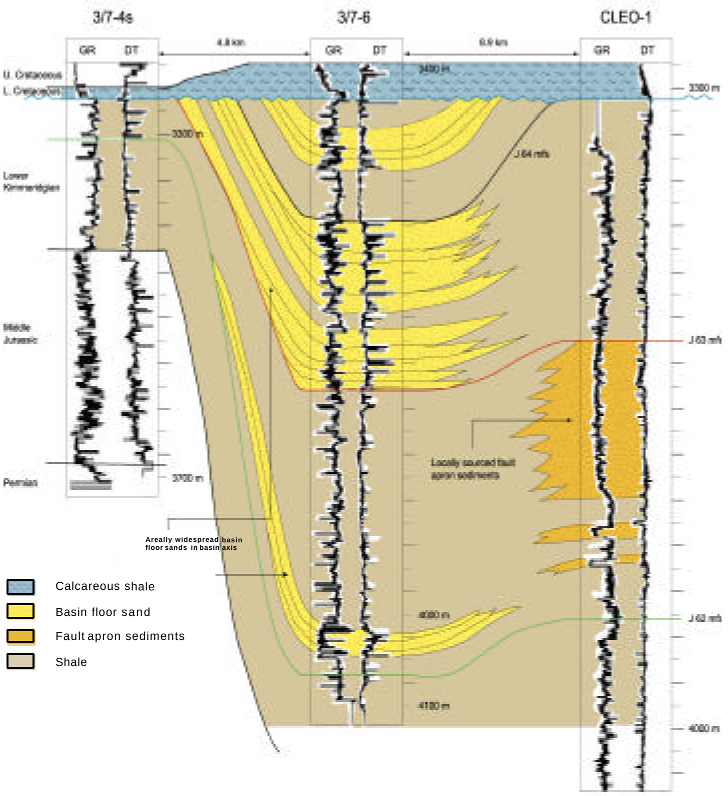

Figure 2 Well log correlation (position of wells shown on Figure 1)

Samples

The samples are dried cuttings. All sample material is stored for possible supplementary investigations.

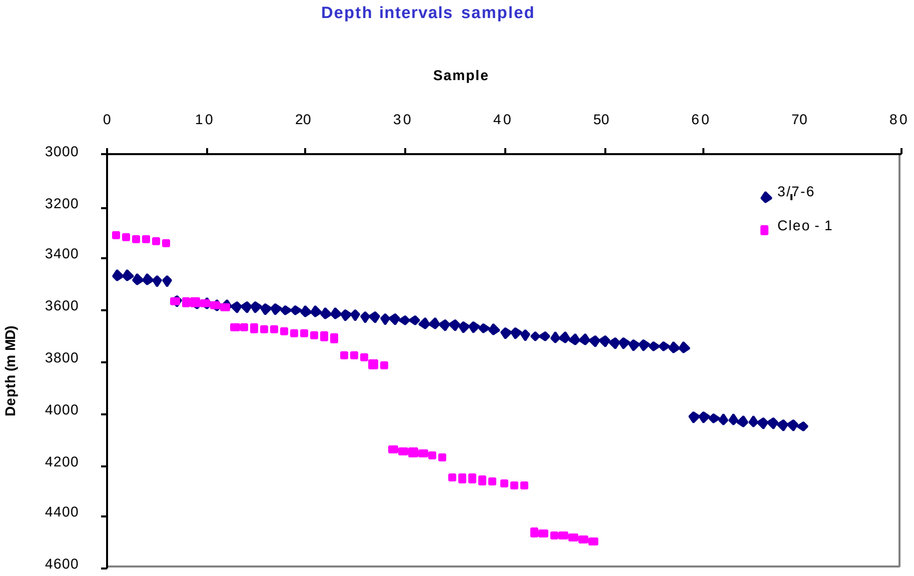

Figure 3 Sampled intervals

Analytical methods

The samples are analysed using two methods namely Fusion X-Ray Flourescence (**XRF**) Inductively Coupled Plasma – Mass Spectrometry (**ICP-MS**) to yield the best chemical basis for the geochemical provenance analysis. Further, the two methods supplement each other.

Two gram of each sample were ground and 1 gram subsequently analysed.

XRF

1 gram of the powder is fused together with a borate flux to a glass disc. This is analysed with GEUS Phillips XRF spectrometer. Na is determined using Atomic Absorption Spectrometry. Content of organic material and volatiles was analysed by ignition of the samples (Kystol & Larsen, 1999).

The XRF method is well suited for major and minor element analysis (Si, Ti, Al, Fe, Mn, Mg, Ca, K, Na and P). Ba and Sr occur as major elements in some samples and the XRF results are chosen for these two elements as well. It is found that interference from Ba affects the XRF results on trace elements, and accordingly the ICP-MS results for all the other elements than Ba and Sr are considered superior to the XRF results.

ICP-MS

A piece of the glass disc described above was dissolved, and the solution introduced into GEUS Perkin Elmer quadrupole ICP-MS. The glass disc method is chosen to ensure that refractive minerals such as zircon and chromite are brought into solution, and this method saves material. Elements analysed are: Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Hf, Ta, Pb, Th and U.

It is found that the ICP-MS results are consistent, and only the Eu analysis seems to be obscured by interference from Ba. This is due to BaO generated in the ICP-MS instrument, which has a mass equivalent to the main Eu isotope analysed (153).

Results

As the cuttings were ground without any further treatment, both contributions from the drilling mud and from other artificial components such as steel chips from the drilling equipment will influence in the results. Accordingly, the elements affected by such artificial signals must be identified.

The drilling mud

Analysis of samples from 3/7-6 (Figure 4) indicates that in this well a drilling mud mainly composed of baryte was used.

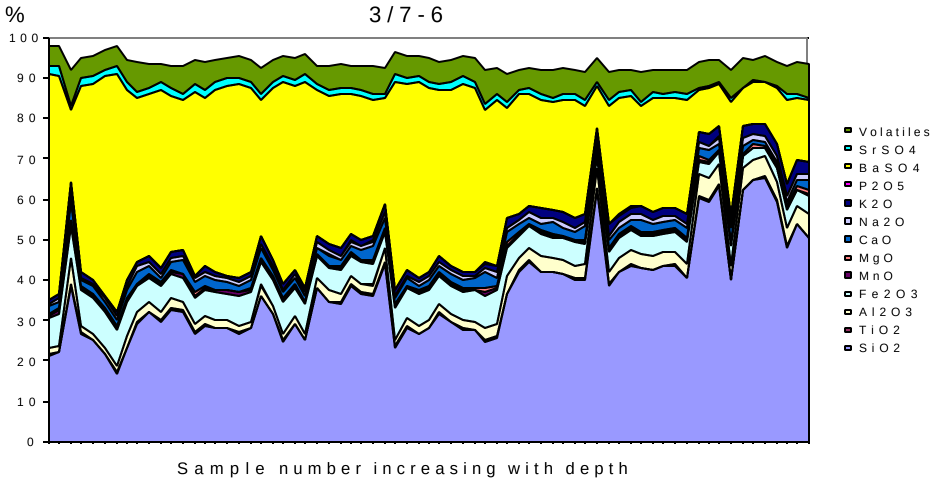

Figure 4 Raw analytical results from the 3/7-6 well. Increasing depth to the right.

In Cleo-1 (Figure 5), the content of Ba is low compared to the 3/7-6 well, whereas the content of volatiles is locally high indicating that organic components (possibly in mud) are present in the analysed samples.

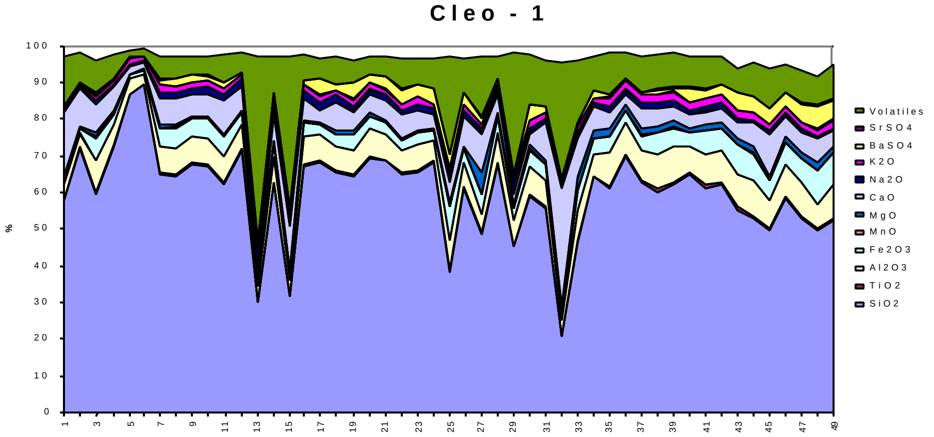

Figure 5 Raw analytical results from the Cleo-1 well. Increasing depth to the right.

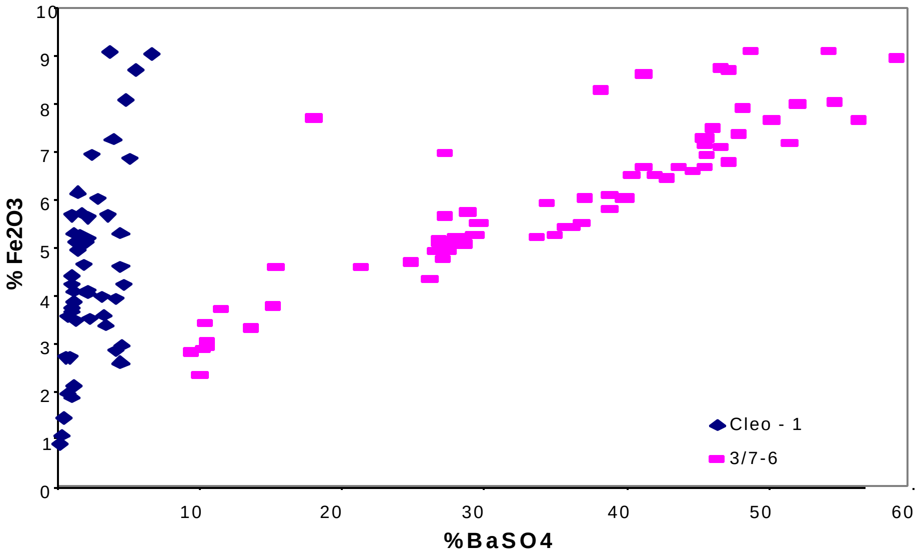

Figure 6 Fe2O3 versus BaSO4

The relationship between Fe and Ba in the 3/7-6 samples (Figure 6) indicates that there is a high iron content in the drillmud in this sample. The iron contents in the Cleo-1 samples are within the same range, but not tied to the Ba content, indicating that the variation may be geological and not tied to the drillmud.

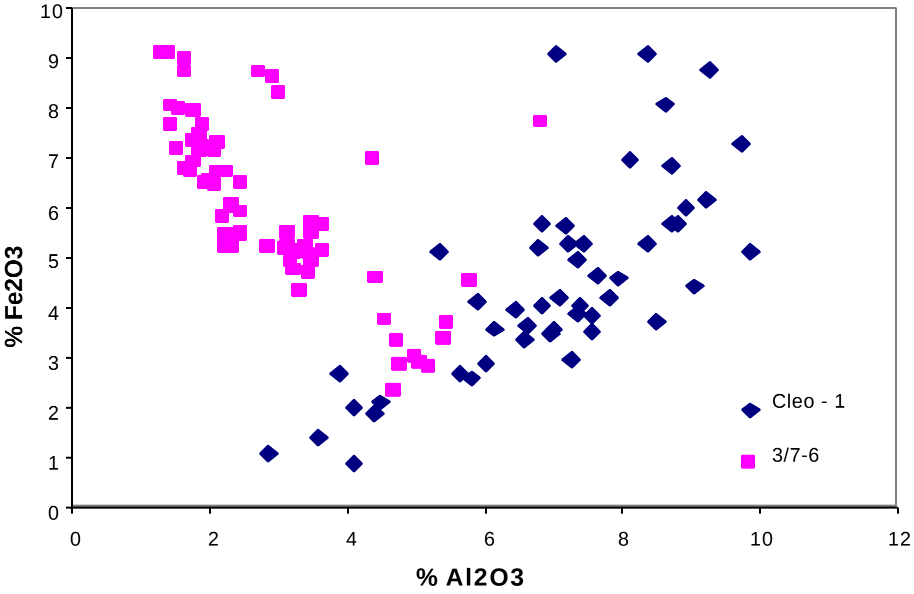

Figure 7 Fe2O3 versus Al2O3

The positive relationship between Fe and Al in the Cleo-1 samples seen on Figure 7 indicate that the Fe is tied to clay. The negative relationship seen in 3/7-6 is interpreted as dilution effect from the drillmud – the more iron (and Ba) rich mud the less Al.

Other artificial effects

Considerable contamination with steel from the drilling process is to be expected.

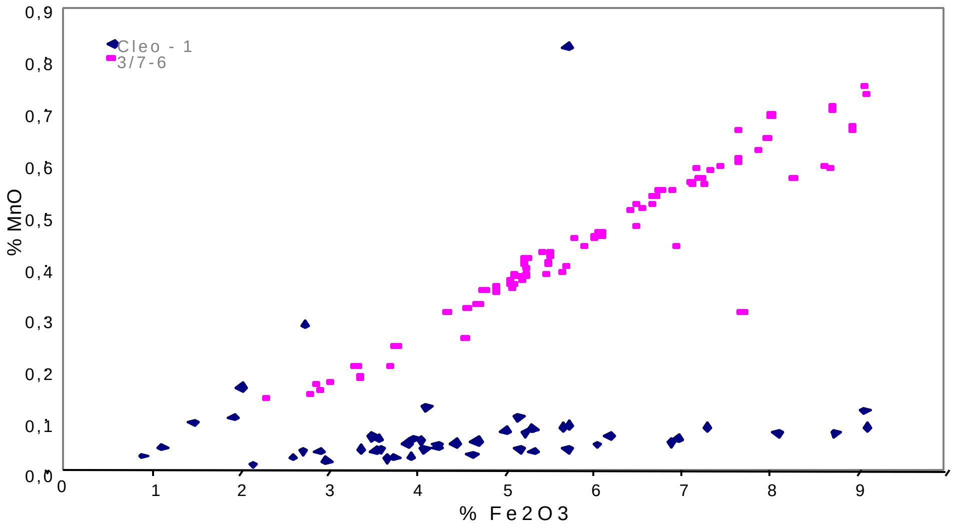

Figure 8 % MnO versus % Fe2O3

In Figure 8, it is seen that there is a good relationship between Mn and Fe in 3/7-6. As noted above the majority of the Fe is tied to clay in Cleo, but in a few samples fall on a nice trend slightly steeper than the 3/7-6 samples, indicating that these contain steel with slightly higher Mn content compared to Cleo. Mn and Fe will accordingly not be used in the present analysis.

When evaluating the dataset, it was found that some other elements were effected by contamination from the equipment.

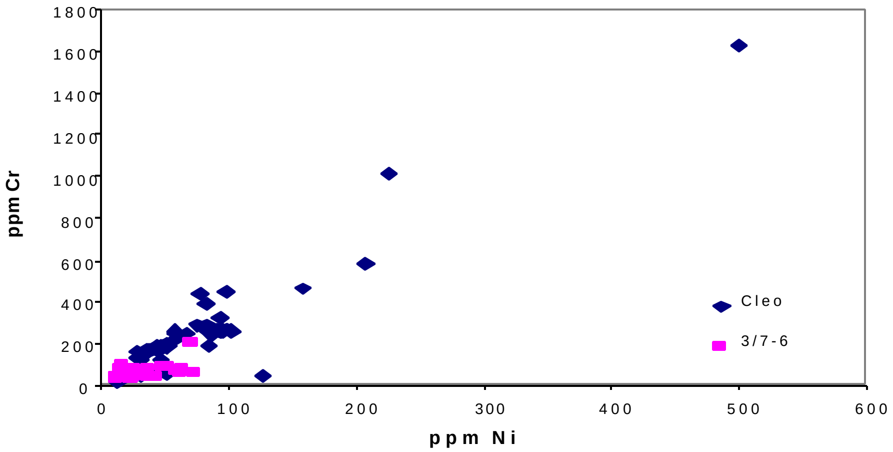

Figure 9 ppm Cr versus ppm Ni

The relationship between Cr and Ni in the Cleo-1 samples In Figure 9 indicates that stainless steel contaminated some samples from this well.

No other major influences from the drilling procedure have been found.

Major- and trace-elements

In mudstone and shale, Aluminium is usually an indicator of the content of clay and mica, and the K/Al ratio show the composition of the clay and mica. However, when high K/Al ratios are found it may exceed what is typical for these minerals, indicating that K-feldspar is common. On Figure 10 it is seen that the 3/7-6 well is characterised by very high K/Al ratios indicating a high content of K-feldspar. Accordingly the rock must be immature and probably can be classified as an arkose. The samples from the Cleo-1 well are also characterised by higher K/Al-ratios, indicating an elevated content of K-feldspar.

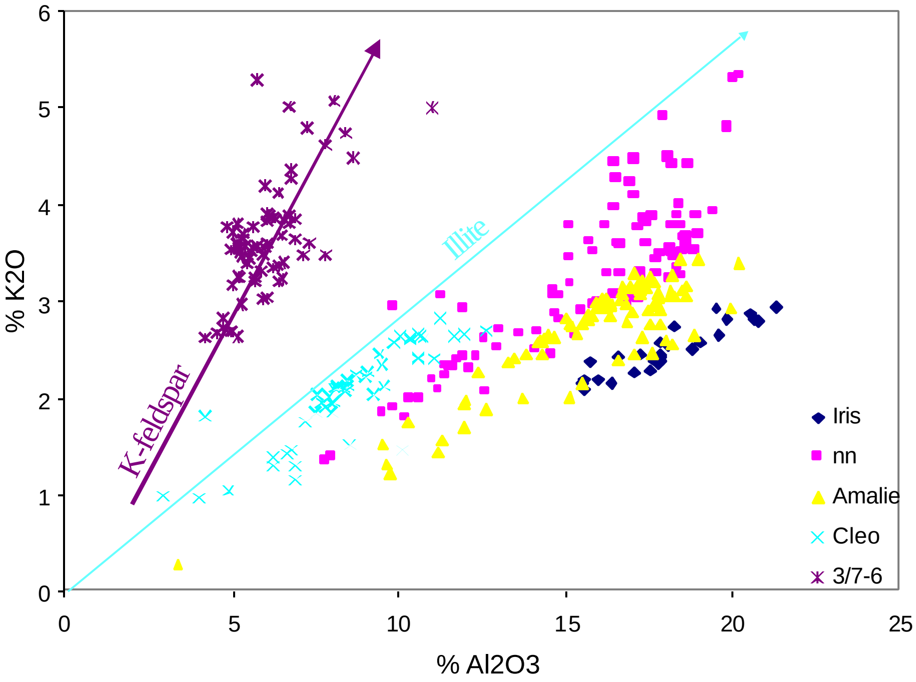

Figure 10 % K2O versus % Al2O3

This high content of K-feldspar in 3/7-6 suggests that the sand was derived from exposed basement and not from redeposition of a sandy source. In this respect the sand in the 3/7-6 well is easy to distinguish from the other sandy deposits analysed (Figure 10).

Another implication of this very high K content is that this is likely to show on a gamma log, as the main signal on a gamma log is from the radioactive K isotope. Successions with high gamma readings may thus be misinterpreted to represent claystone, whereas it is sandstone with a very high content of K-feldspar.

The content of SiO2 can be taken as an indicator of the sand/quartz content, and in Figure 11 it is seen that the 3/7-6 samples generally are SiO2 and hence sand-rich but with high K, indicating high contents of K-feldspar, supporting the observation above. In Amalie-1 there is a trend towards 0 % K and 100 % SiO2 (pure quartzite). This can be taken as a sign of maturity of the sediment. Such a trend is not seen in 3/7-6, which also can be interpreted as the sediments in 3/7-6 being much less mature.

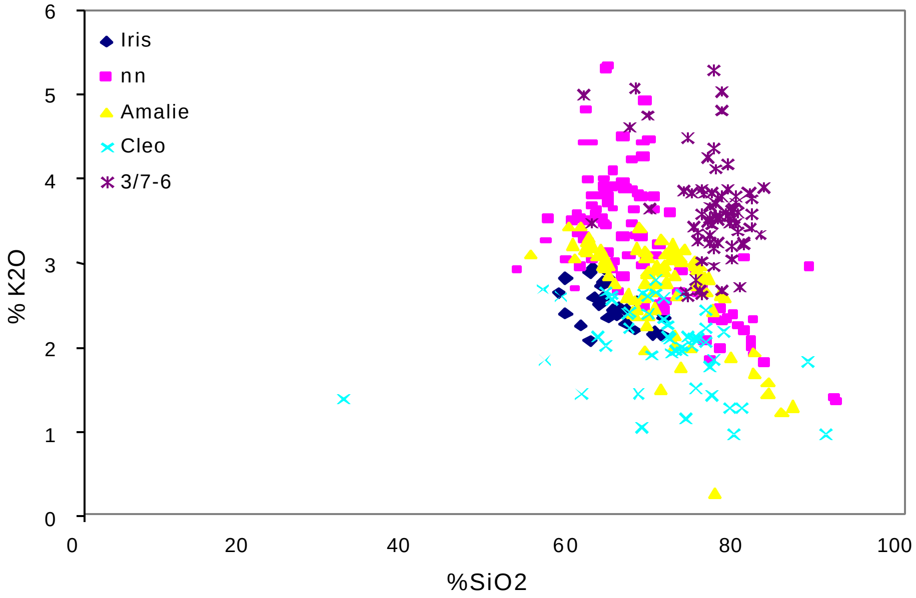

Figure 11 %K2O versus % SiO2 (corrected for influence of baryte, artificial iron and volatiles).

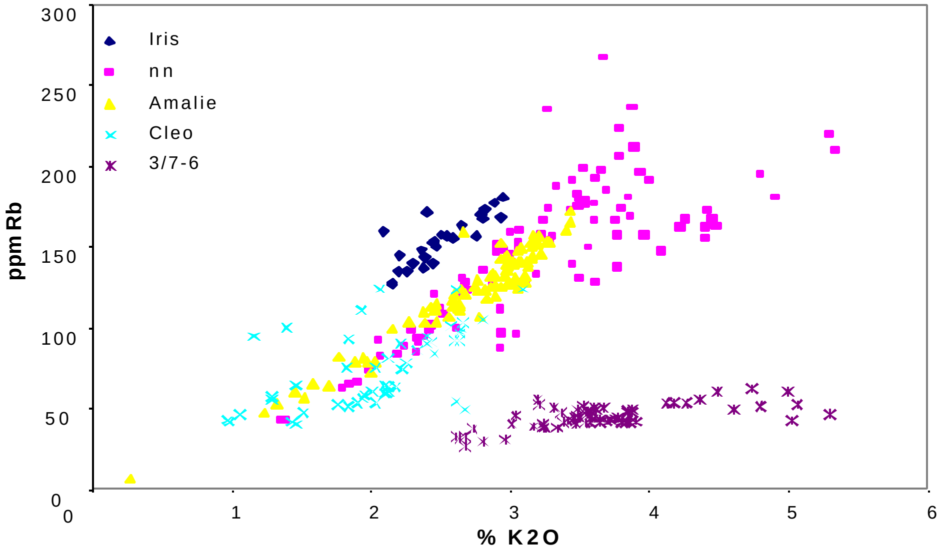

Figure 12 ppm Rb versus % K2O (corrected as Figure 11).

There are significant differences in the Rb content in the K-bearing minerals in the different wells, with low contents of Rb in the feldspars in 3/7-6 well. As can be seen on Figure 12, the sediments in the 3/7-6 well are easy to distinguish from the other sediments analysed.

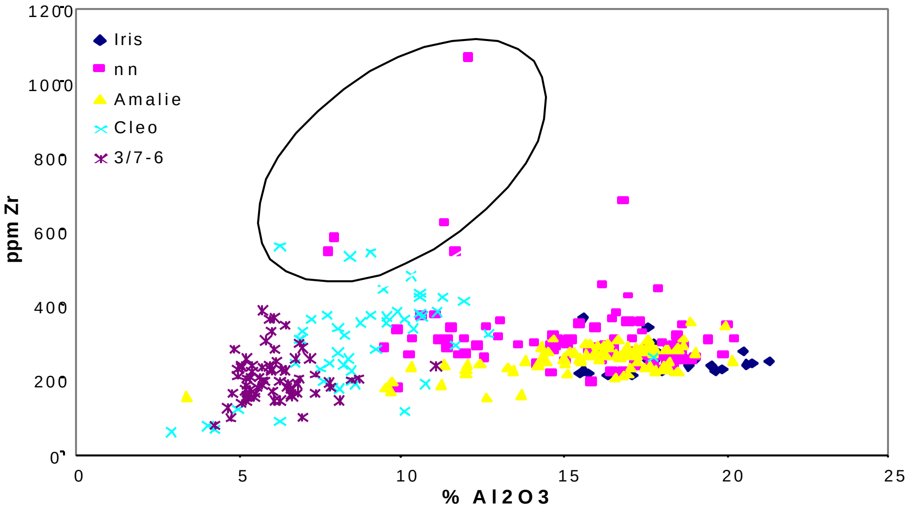

Figure 13 ppm Zr versus % Al2O3.

In Figure 13 it is seen that some of the samples from the Cleo-1 well show distinct Zr enrichment which suggests that these samples have relatively high contents of detrital zircon. As can be seen on Figure 14, the samples with elevated Zr are located in the lower and fine-grained sandstones (low Si/Al ratio) in both the Cleo-1 and the 3/7-6 wells. A similar feature with high detrital zircon in coarse silt ot fine sand is seen in the Miocene Arnum Formation in western Jylland, where zircon-rich heavy mineral deposits are tied to deposits of coarse silt and fine sands accumulated on the outer shoreface (Knudsen, 1998).

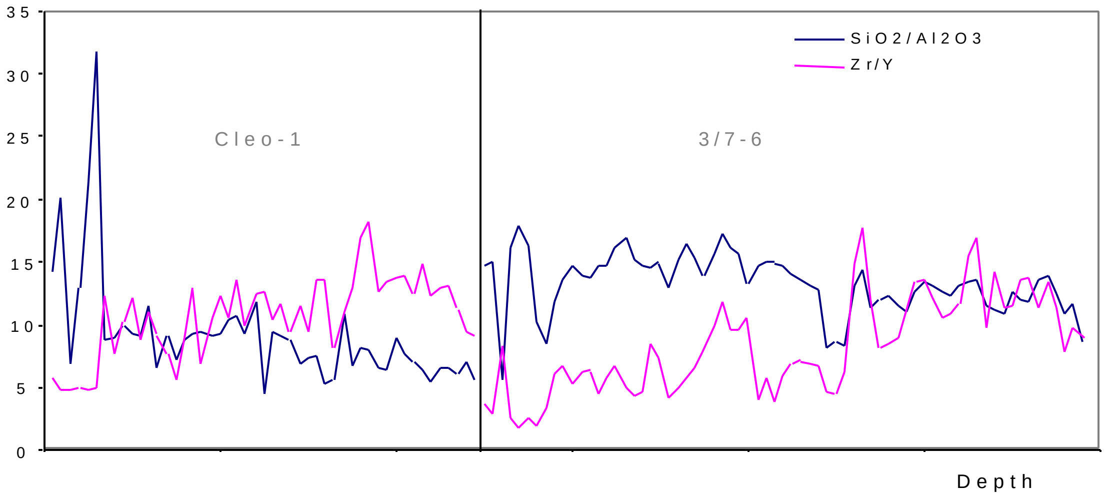

Figure 14 SiO2/Al2O3 and Zr/Y ratios versus depth. As the samples are from fairly narrow intervals in the wells, the samples are just shown in order of increasing depth and not against real depth. For reference see Figure 3.

In Figure 14 a somewhat similar feature in the 3/7-6 well is seen. The deeper parts of the well are generally slightly more fine-grained (lower Si/Al ratio), and higher levels of Zr are seen. This may be due to the lower grain-size or to a different source.

As can be seen on Figure 14, the 3/7-6 well is generally coarser grained compared to the Cleo-1 well (higher SiO2/Al2O3). The only exception is in the uppermost part of the Cleo-1 well which has a high Si/Al ratio indicating high contents of quartz.

Carbonates

One of the features that characterise a sedimentary rock is the content of organic material. This is in the analysis reflected in the loss on ignition. However, such a loss is also seen when a rock contains carbonates and hydrous minerals. The carbonate is calcined when heated and the content of CO2 is seen as loss on ignition. In Figure 15 it is seen that the sediments from the Cleo-1 and 3/7-6 wells have significant differences in what is lost.

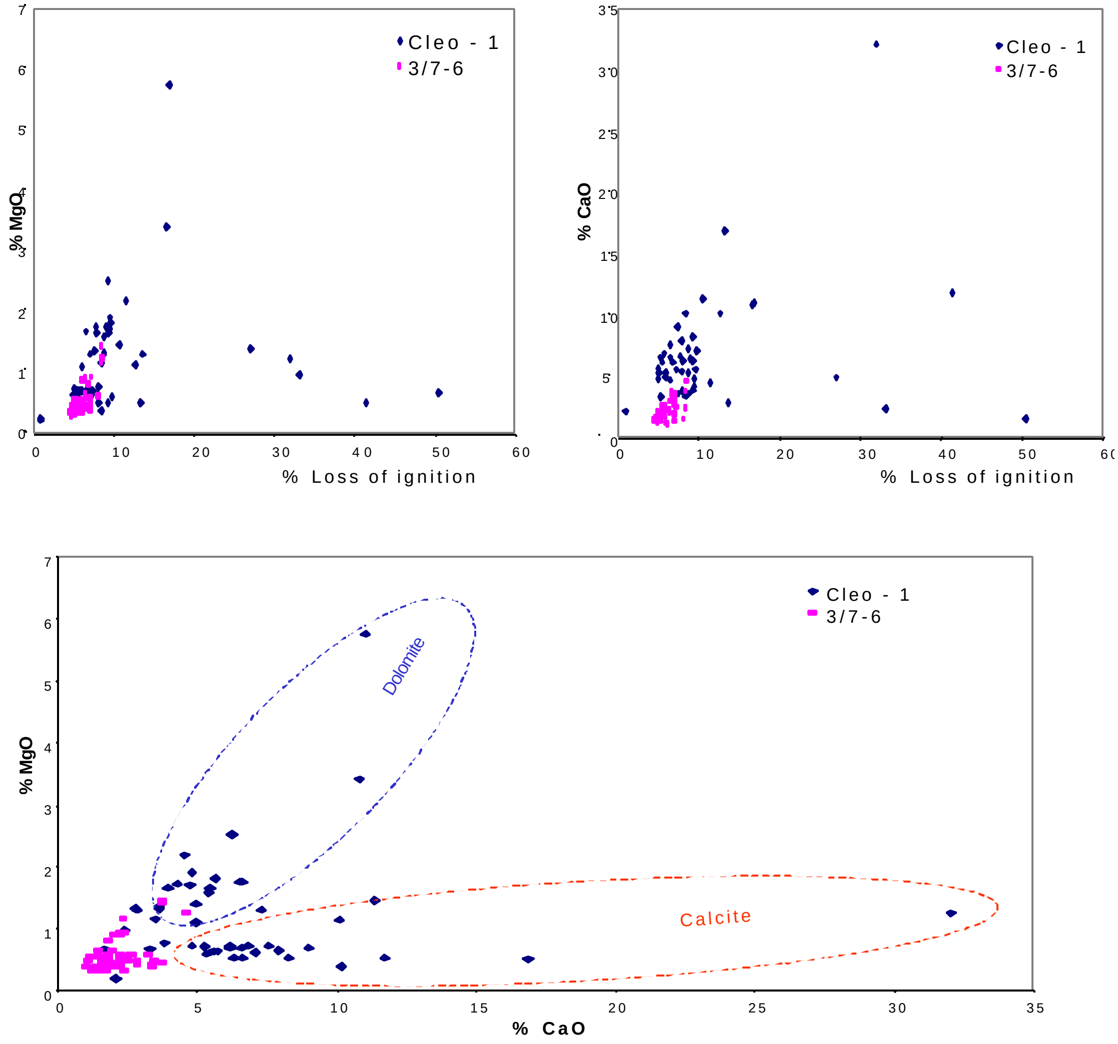

Figure 15 MgO and CaO versus loss of ignition (upper) and MgO versus CaO.

In Figure 15 it is seen that in Cleo-1 there are some samples with high loss of ignition (> 30 %) without any increase in MgO and CaO. This is probably caused by high contents of organic material (oilbased mud?). However, in Cleo-1 there are also samples exhibiting a relationship between loss on ignition and MgO and CaO. This is likely to be caused by dolomite and calcite cement respectively (Figure 15c).

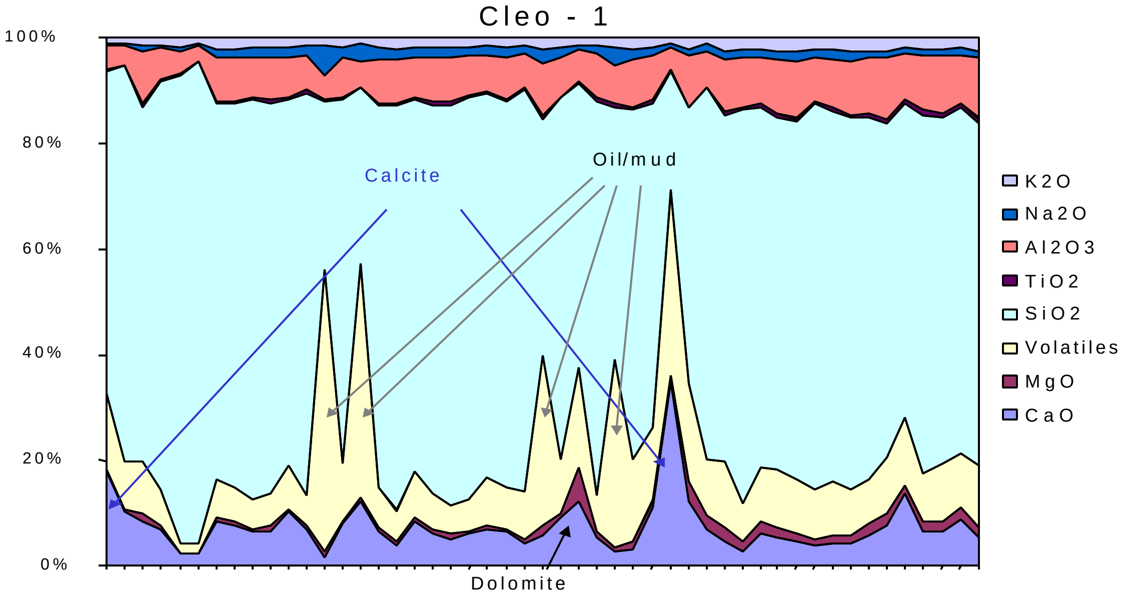

Figure 16 Composition of the Cleo-1 samples normalised to 100 %.

In Figure 16 the location of the calcite and dolomite containing levels can be seen.

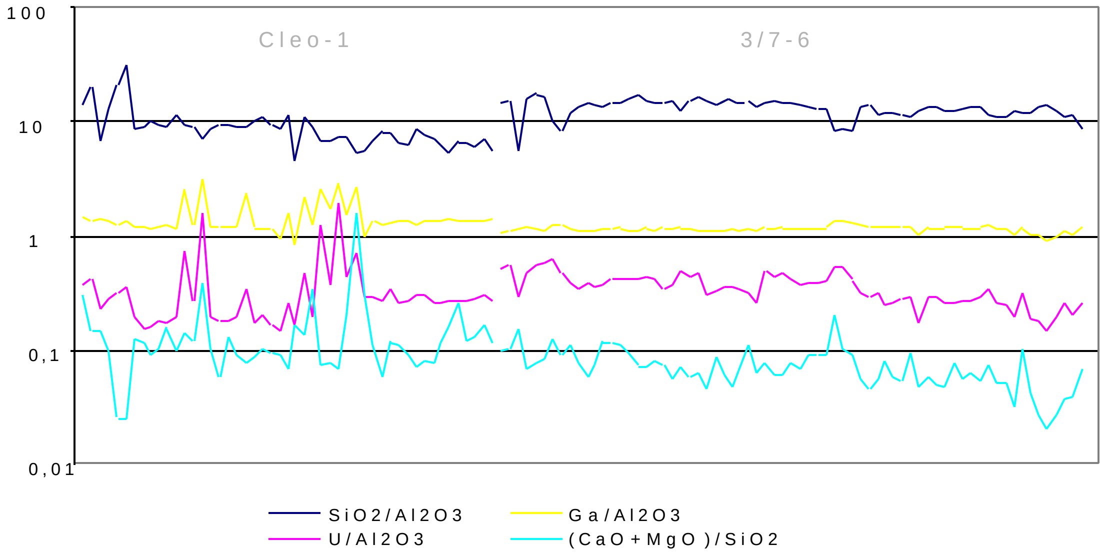

Figure 17 Ratios versus depth in the two wells.

The (CaO+MgO)/SiO2 ratio is indicative of the carbonate content, as also seen on Figure 17. The U/Al2O3 ratio is indicative of the U content in the fine-grained fraction. High U content is indicative of reducing conditions, and it is further seen that the carbonates are precipitated at or adjacent to levels which suffered fluctuating and reducing conditions.

Conclusions and recommendations

The main finding is that the sandstones in the 3/7-6 well has a very high content of K-feldspar indicating that the source is exposed basement. The sandstone is very immature, indicating that it was deposited very close to the source. Further, the composition of the sandstone in the 3/7-6 well has a very distinct composition different from other Upper Jurassic sands analysed in this study.

The sediment in the Cleo-1 well is generally finer grained than the 3/7-6 sand. It has a lower contents of K-feldspar, but has elevated contents of K-feldspar relative to e.g. Amalie-1. The sediment in Cleo-1 is more mature than the sandstone in the 3/7-6 well, indicating that the sediment may have been derived by redeposition of older sedimentary rocks in contrast to the sediment in the 3/7-6 well.

Several levels in the Cleo-1 well have high carbonate contents, probably in the form of diagenetic cement. Both calcite and dolomite cement are present.

If there is a need to confirm the prescence of K-feldspar in the 3/7-6 well, samples of the core can be inspected using petrographic microsope, XRD or SEM.

If there is a need for further insight in the provenance of the sediments in the area, fingerprinting using eg. dating of detrital zircons in the sandstones comparing to zircons in basebasement samples from the area, if such samples are available.

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