Structural outline, depositional setting and assessment of Mesozoic low enthalpy geothermal reservoirs in the marginal eastern parts, of the Danish Basin

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ABSTRACT

The subsurface geology in the transnational Øresund area between Sweden and Denmark is composed of a 2 000–3 500 m thick sequence of Phanerozoic strata. The Øresund region, centred on the cities of Copenhagen and Malmö is the most densely populated area in Scandinavia. In the range of 3.8 million people work and live in the region. In spite of the fact that there are suitable geological as well as socio-economic prerequisites geothermal energy has not been utilized to any greater extent. Today geothermal energy is extracted from a two well system at the Margretheholm site and distributed to the district heating system in Copenhagen. Heat is extracted from warm water flowing through absorption heat pumps (225 m^3/h and 73°). The producing reservoir (11.8 Dm) is the lower Triassic sandstone interval at 2 550 m depth (midpoint). The geothermal plant has been in full operation since 2006 and generates on a yearly basis approximately 300 TJ heat corresponding to the consumption of 4 000–5 000 households. A similar feasibility project in the city of Malmö proved a geothermal potential in the Rhaetian, Lower Jurassic and Lower Cretaceous reservoirs between 1 600–1 820 m depth. A production temperature of 51.5° and 14.0 Dm was verified by tests in two investigation wells. Rejuvenated interest in developing geothermal resources in Denmark and the Øresund region have stressed the need for comprehensive geological descriptions, models and definition of the structural framework controlling the distribution and characteristics of the potential geothermal reservoirs.

1. INTRODUCTION

The Øresund region, centred on the cities of Copenhagen and Malmö is the most densely populated area in Scandinavia, with approximately 3.8 million people working and living in the region. The region is today linked in numerous joint projects which aim to facilitate everyday life of the inhabitants, including cross country Interreg III projects funded by the EU community. Large scale infrastructure projects, including the Øresund Bridge, the Metro in Copenhagen and the Citytunnel in Malmö are examples where knowledge about the cross country geology has played an important role. Joint activities and projects related to energy issues with the aim to create innovative solutions for the future have also been performed. In the beginning of this century E.ON (former Sydkraft AB), together with DONG (Dansk Olie and Naturgas A/S) and HGS (Hovedstadens Geotermiske Samarbejde) launched exploration for geothermal utilization of deep lying Mesozoic reservoirs beneath the cities of Malmö and Copenhagen. The exploration included seismic surveys and drilling of deep low enthalpy geothermal wells at two new locations, i.e. the FFC site in Malmö and the Margretheholm site in Copenhagen. The wells and the seismic surveys provided new, important and complementary information on the subsurface geology concerning the characteristics of the potential geothermal reservoirs in the Mesozoic sequence. Today geothermal energy is extracted from a two well system at the Margretheholm site and distributed to the district heating system in Copenhagen. The geothermal plant has been in full operation since 2006 and generates on a yearly basis 300 TJ heat corresponding to the consumption of 4 000–5 000 households. The producing reservoir is the Lower Triassic sandstone interval at 2 550 m depth (mid point). Heat is extracted from warm water flowing through absorption heat pumps (225 m^3/h and 73°). The cooled formation water (17°) is re-injected in a deviated injector well and the same target sandstone beds at a distance of approximately 1 500 m from the producing well. A corresponding project in the city of Malmö was not put into operation due to an excess of heat available to the district heating system, mainly supplied from a waste incineration plant in Malmö. Tests proved a geothermal potential in the Rhaetian, Lower Jurassic and Lower Cretaceous reservoirs between 1 670–1 828 m depth. A production temperature of 51.5° and of 14.0 Dm was verified.

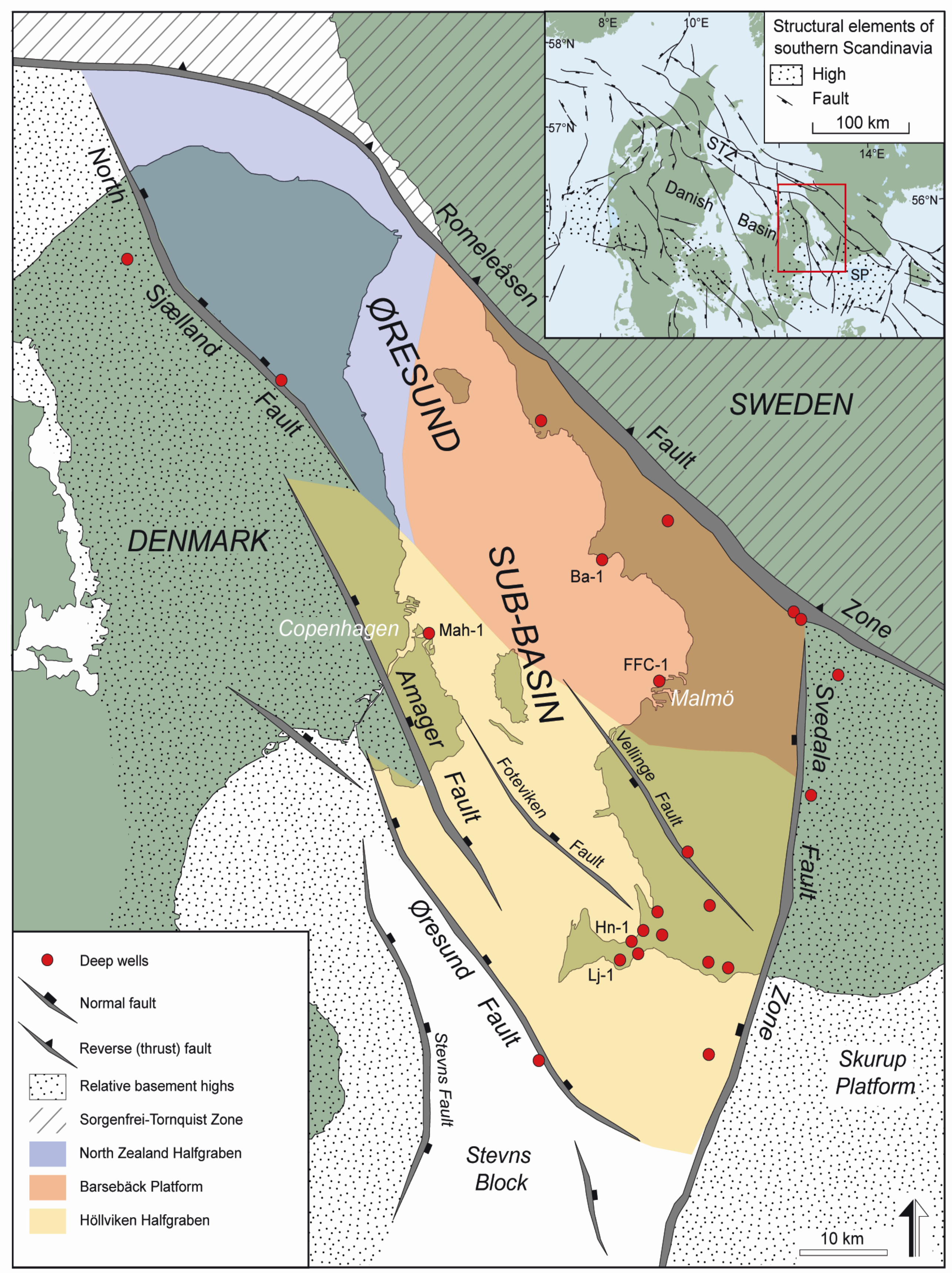

Figure 1: Map of the Øresund region with main structural elements and deep wells (Ba-1:Barsebäck-1, Hn-1: Höllviksnäs-1, Lj-1: Ljunghusen-1, FFC-1 and Mah-1: Margretheholm-1).

Geological feasibility studies regarding the potentiality for finding low enthalpy geothermal reservoirs in the Øresund region as well as in southwest Scania started already in the late 1970-ties. Bjelm et al. (1977, 1979) compiled a review of the subsurface geology in Scania, regarding the geothermal potential. In their study they concluded that there were several potential Mesozoic sandstone reservoirs between c. 400 and 2 500 meters depth in southwest Scania. A similar assessment of potential geothermal reservoirs in Denmark was presented by Michelsen et al. (1981), however, mainly leaving out the Øresund area due to lack of subsurface geological data on the easternmost part of Zealand. Except for a pilot project on northern Jutland (Mahler and Magtengaard 2010) and a project in Lund (Bjelm and Alm 1995) it was not until the late 1990-ties there were a rejuvenated interest in assessing the geothermal potential as an important sustainable energy resource in the Øresund area. The Geological Survey of Denmark and Greenland (GEUS) (Sørensen et al. 1998) presented a conceptual geological model and assessment of the potential of finding deep geothermal reservoirs in the greater Copenhagen area. This first model was primarily based on data from southwest Scania and information from the deep wells on the Falsterbo Peninsula, i.e. Ljunghusen-1 and Höllviksnäs-1 drilled by the Geological Survey of Sweden in 1954–55 (SGU) and by the Swedish Oil Prospecting CO (OPAB) in 1971. This study was followed by other GEUS reports, which focused on predicted subsurface models and reservoir characteristics (Nielsen et al. 2004, Mathiesen et al. 2009). A country update report for the geothermal resources in Denmark was in addition presented by Mahler and Magtengaard (2010).

The rejuvenated interest in developing geothermal resources in Denmark and the Øresund region have stressed the need for a comprehensive geological description of the subsurface geology. A first and essential part of this is a description and definition of the structural framework controlling the distribution and characteristics of the potential geothermal reservoirs. This has been performed by joining geological data from the Swedish and Danish geological surveys which has allowed the construction of a structural and stratigraphic framework for the assessment of potential geothermal reservoirs, regarding distribution, composition and physical properties in the Øresund region.

2. GEOLOGICAL SETTING AND GEOTHERMAL RESERVOIRS

The Øresund area is part of the transition zone between the Danish Basin to the west and southwest and the Baltic Shield to the northeast. The Danish Basin formed as a result of rifting during Late Carboniferous–Early Permian times (Vejbæk 1997). The basin received large amounts of sediments during the Triassic and Jurassic as a consequence of thermally controlled subsidence during a post-rift phase (Liboriussen et al. 1987, Vejbæk 1989, Erlström et al. 1997). The basin is limited to the southwest by the Ringkøbing-Fyn High. The north-eastern margin follows the NW–SE oriented Sorgenfrei-Tornquist Zone (STZ), which is characterized by extensive block-faulting along the southwest margins of the Baltic Shield (Sorgenfrei and Buch 1964, Liboriussen et al. 1987). The STZ has been repeatedly active since Late Palaeozoic times with the main events occurring during the Mesozoic Era. Several Triassic–Jurassic extensional episodes are recognised (Norling and Bergström 1987), but these and older Palaeozoic events are often obscured by the Late Cretaceous–Palaeogene inversion tectonics (Norling and Bergström 1987, Michelsen and Nielsen 1991, Mogensen 1994, Michelsen 1997, Erlström et al. 1997). The tectonic movements actively controlled deposition and erosion, resulting in a heterogeneous representation of strata in the Danish Basin.

The Øresund Sub-basin, centred on the Øresund region, constitutes a marginal sub-basin to the Danish Basin (Fig. 1). Localized subsidence in combination with rifting has resulted in deposition and preservation of a 2 000–3 500 m thick Mesozoic succession, including several potential low enthalpy geothermal reservoirs. The succession is dominated by Upper Cretaceous carbonates, however, below 1 000–1 500 meters depth there is, in the deepest parts of the Øresund Sub-basin a 500–1 500 m thick Lower Cretaceous, Lower Jurassic and Triassic sequence with several sandstone dominated lithofacies.

The Øresund Sub-basin is divided into the Höllviken Halfgraben, the Barsebäck Platform and the North Zealand Halfgraben (Fig. 1) with somewhat different representation and thickness of the potential geothermal reservoirs. The geothermally interesting successions, especially the Triassic deposits, increase significantly in thickness towards the bounding faults in the west (Fig. 2). The structural outline of the Øresund Sub-basin is controlled by a set of right-stepping normal extension faults to the west and to the east by a reverse fault which constitutes the boundary fault to the Sorgenfrei-Tornquist Zone.

The normal faults to the west were initiated during Permo–Carboniferous rifting and reactivated during Triassic E–W tension (Erlström et al. 1997, Sivhed et al. 1999). Extension and subsidence in the Early and Middle Triassic resulted in localized accommodation space and thickening of the corresponding strata towards the delimiting faults, especially the Øresund, Amager and North Sjœlland faults. The vertical throw of the faults varies laterally as the faults have a shear character and the fault dies out along the strike. This is especially seen along the Øresund Fault which dies out to the NE and the North Sjœlland Fault to the SE. This has created gently dipping transfer zones or relay ramps with less thick deposits. The Barsebäck Platform constitutes a transfer zone between the North Zealand Halfgraben and the Höllviken Halfgraben. The formation of localized fault controlled depocentra has resulted in that Lower and Middle Triassic

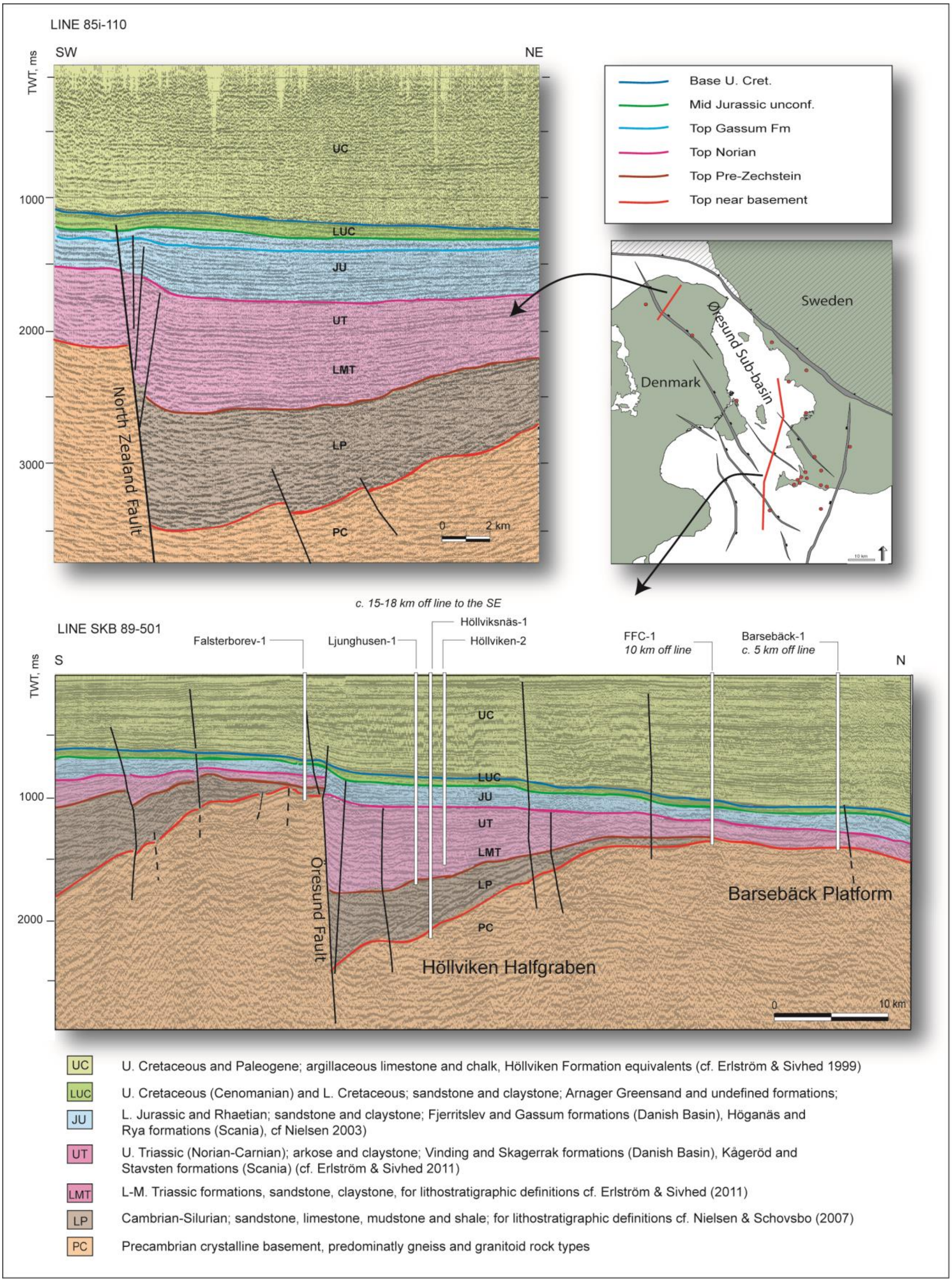

Figure 2: Two interpreted geosections illustrating the subsurface geology of the North Zealand Halfgraben (above) and Höllviken Halfgraben (below).

Geothermal reservoirs are primarily found in the Höllviken Halfgraben and in a similar thickening succession towards the North Sjœlland Fault (Fig. 2). On the Barsebäck Platform the Triassic succession primarily consists of the Upper Triassic Kågeröd Formation, at least in the east, as verified by data from the Barsebäck-1 well.

The main geothermal reservoirs in the Triassic are the sandstone layers in the Ljunghusen Sandstone, Hammar and Flommen formations corresponding to the Bunter Sandstone Formation in the North German Basin (Erlström and Sivhed 2012). The Keuper sandstone beds are in addition also potential geothermal reservoirs. However, hydraulic test in the FFC-1 well in Malmö give a lower production capacity of 5.8 Dm in comparison to 11.8 Dm for the Bunter reservoirs (Flommen and Hammar formations) in the Margretheholm-1 well.

By the end of the Triassic, i.e. Rhaetian, the subsidence was more homogeneous in the Danish Basin and a laterally continuous 100–300 m thick Rhaetian–Lower Jurassic succession of strata formed. The deposits are referred to as the Gassum Formation in the Danish Basin and the Höganäs and basal most Rya formations in Scania (Michelsen et al. 2003, Ahlberg et al. 2003). In the Øresund region the succession includes in the numerous shore face sandstone layers, which are considered to be the main geothermal reservoir. The main part of the sandstone intervals are composed of fine-grained, well sorted quartz arenite. This is reflected by porosity vales in the range of 25–30% but the permeability is commonly below 100 mD. Medium-grained beds, although subordinate in the succession, contribute, thus considerably to the productivity as they have a permeability in the range of several darcys. Medium-grained intervals are in the Höllviksnäs-1 well primarily found in the Rhaetian and the Sinemurian intervals.

Uplift of the southern margins of the Danish Basin, including the Ringkøbing-Fyn High, during early Middle Jurassic times resulted in a deeper erosive truncation of Jurassic strata towards the southwest (Nielsen 2003). The deposition resumed in the Øresund region again in the Early Cretaceous, represented by a 5–20 m thick Lower Cretaceous sandstone unit overlying Pliensbachian to Aalenian strata (Lindström and Erlström 2011). This sandstone is followed by variegated mudstone layers with interbeds of sandstone and an up to 60 m thick glauconitic sandstone, i.e. Arnager Greensand, which constitutes the top of Lower Cretaceous mixed marginal marine facies setting.

The sandstone beds are referred to as the Lower Cretaceous reservoirs, which are considered the fifth potential geothermal interval in the Øresund Subbasin. In total the Lower Cretaceous is in the range of 100 m thick. The Arnager Greensand is found to have the best reservoir properties to the south. In Höllviksnäs-1 the sand is 52 m thick and primarily composed of medium-grained porous and permeable sandstone. Analysis of the permeability on cores from wells in SW Scania give values in the range of 600

Table 1 Compilation of general characteristics of the main potential geothermal reservoirs in the Øresund Subbasin. The information comes primarily from deep wells in the Höllviken Halfgraben (cf. Fig. 2).

	Ljunghusen	Flommen and Hammar	Keuper	Rhaetian-Lower Jurassic	Lower Cretaceous
Reservoir lithology	Medium-grained, moderately sorted sub-arkose	Medium- and coarse-grained sub-arkose	Coarse-grained arkose and conglomerates	Fine- and medium-grained quartz arenite	Fine- and medium-grained glauconitic quartz arenite
Depositional setting	Arid, terrestrial, eolian	Arid-semi arid, ephemeral flood-plain and playa-like	Arid red beds, alluvial fans	Deltaic-marginal marine	Marine
Age	Buntsandstein (Scynthian)	Buntsandstein (Scynthian)	Ladinian–Norian	Rhaetian–Pliensbachian	Cenomanian–Berriasian
Net sand,	20–60 m1[1]	80–120 m	20–50 m	60–100 m	20–50 m
Depth, m sl	2 007–2 050 m[1] 2 640–2 660 m[2] 2 088–2 150 m[3]	1 890–2 007 m[1] 2 470–2 660 m[2] 1 940–2 088 m[3]	1 498–1 678 m[1] 2 016–2 230 m[2] 1 860–2 075 m[3]	1 288–1 142 m[1] 1 638–1 965 m[2] 1 672–1 820 m[3]	1 190–1 288 m[1] 1 591–1 638 m[2] 1 605–1 672 m[3]
Permeability	(High?)	1 000 mD[2] 443 mD[3]	0–50 mD[4] 0–100 mD[3]	10–4 000 mD[1,,3]	
Porosity	20–28% (logs)[1]		2–16%[4]	18–34[1,3]	
Temperature	56–57°[1] 77°[2]	53–55°[1] 73°[2]	46–47°[1]	36–38°[1] 42–44°[3]	36–38°[1] 44–45°[3]
Salinity	?	12–19%[1,3]			
kh	?	11.8 Dm, 73°[2]	5.8 Dm, 62°[1]	14 Dm 51.5°[1]	

[1] Höllviksnäs-1, [2] Margretheholm-1, [3]FFC-1, [4] Höllviken-2

to 1 500 mD (Erlström and Sivhed 1997) while data from analysis on corresponding fine-grained sandstone and siltstone beds in FCC-1 give values which are <55 mD. Geophysical log data also indicate decreasing reservoir properties to the north. The sandstone interval found on top of the mid Jurassic unconformity is judged to be extremely good reservoir. This is based on regional continuity from logs, core analysis and hydraulic test data from FFC-1. Here a permeability of several darcys has been monitored.

In the Late Cretaceous, the fault-controlled subsidence within the Sorgenfrei-Tornquist Zone came to an end. The Jurassic–Lower Cretaceous depocentra became inverted during which resulted from a change in the regional stress orientations to a predominantly compressive regime, associated with Alpine deformation in northern Europe and the opening of the North Atlantic. During this time the Romeleåsen Fault Zone evolved as an uplifted high and delimited the Danish Basin to the north and northeast. Extensive erosion synchronous with the peak inversion during Campanian times resulted in the formation of several hundred meters thick sandstone layers along the fault zone in the marginal parts of the basin in Scania (Erlström 1990). The Campanian Lund Sandstone is utilized in Lund for low enthalpy heat production since 1985 (Bjelm and Alm 1995). Minor inversion of the Øresund, Amager and North Sjælland faults also occured at this time.

2.1 Geothermal reservoirs in the Höllviken Halfgraben

In Höllviksnäs-1 there are between c. 1 200 to 2 060 m depth (Fig. 3) five main reservoirs of geothermal interest in the Lower Cretaceous, Lower Jurassic–Rhaetian and the Triassic. The Triassic reservoirs are found in the Ljunghusen Sandstone, in the Flommen and Hammar formations, the Keuper formations. The other reservoirs are in the Rhaetian–Lower Jurassic and the Lower Cretaceous succession (cf. Table 1, Fig. 3). The geothermal gradient ranges between 25 and 28°/1000 and the formation temperature lies at c 1 500 m depth is 40–45°.

Ljunghusen, Flommen and Hammar reservoirs

The Lower Triassic reservoirs are only verified in the deepest parts of the Øresund Sub-basin (cf. Fig. 3). Results from permeability and porosity measurements (Springer 1997) show that the reservoir properties vary greatly within the Triassic. The variability in permeability and porosity is related to frequent variations in degree of cementation and matrix content. The formation fluid has a density of 1.12 g/cm^3 as a result of a high amount of dissolved sodium chloride. In general the salinity of the Triassic formation fluids varies between 12 and 19% between 1 500 and 2 100 m depth in south-west Scania. Beside fluids a small amount of solute gases, 86 cm^3/l, almost exclusively consist of nitrogen with small admixtures of hydrocarbons (<2%) and carbon dioxide (0.52%). A relatively high amount of helium (5.7%) is striking.

The Ljunghusen Sandstone is found only in the deepest parts of the Höllviken Halfgraben and has been drilled through in the wells Ljunghusen-1, Höllviksnäs-1 and in the two wells at the Margretheholm site in Copenhagen. It is composed of relatively well-sorted, poorly consolidated, medium-grained quartz sandstone with low matrix content. The reservoir has not been hydraulically tested but the geophysical wire-line logs indicate permeable, porous and c 50 m thick homogeneous sandstone beds at the base of the Triassic sequence. The Ljunghusen Sandstone is most likely synchronous with the Volpriehausen Sandstone in northern Germany. Between c. 2 500 and 2 600 m depths in the MAH-1 and MAH-2 wells and at 1 940–2 030 m depth in the Ljunghusen-1 core, the Hammar Formation is dominated by coarse- and medium-grained subarcosic sandstone beds interbedded with variably coloured red-green-brown and purple claystone and mudstone beds. The sandstone beds are in parts poorly consolidated and highly permeable. In the geothermal wells MAH-1 and MAH-2, this interval was chosen as the most suitable Triassic reservoir for geothermal energy production. The hydraulic test of the perforated well over this interval in MAH-1 gives permeability >1 000 mD. The 73 °C warm formation water at 2 500 m depth has a Cl^- content of c. 130 g/l. Most of the Hammar Formation was likely formed in a landscape with low relief. Playa systems (mudflats) interfingering with fluvial systems (braided river) with an ephemeral character dominated the depositional environment. These conditions prevailed in much of the North German Basin (Lepper and Röhling 1998) during the deposition of the middle Buntsandstein, e.g. the Detfurth and Hardegsen Formations. A similar depositional pattern occurred most likely also in the Höllviken Halfgraben but with a more pronounced influx of coarse clastic sediments from the Fennoscandian high to the north-east. Several unconformities are verified in Germany (Lepper and Röhling 1998) as a result of the rift-related tectonic realm and the shift in erosional base level. The Solling Formation is marked by a widely distributed erosional base which cuts into underlying formations (Hardegesen etc.) marking one of the most prominent Triassic unconformities in the North German Basin. This has resulted in the formation of a proximal thick sandstone unit. A similar situation is interpreted in the Höllviken Halfgraben where the Hammar Formation is considered to correlate to the Solling Formation.

The Keuper reservoirs

The Vellinge Formation (Fig. 3) marks a change from the relatively humid climate, as witnessed by the character of the underlying Falsterbo Formation into a more arid, continental climate with proximal deposition of variably sorted sandstones interbedded with numerous conglomerate beds. Parts of the sequence are composed of laminated fluvial sandstone beds with a greyish overprint which indicate that there were still periods of a more humid climate. Analyses for some of the sandstone layers give a permeability in

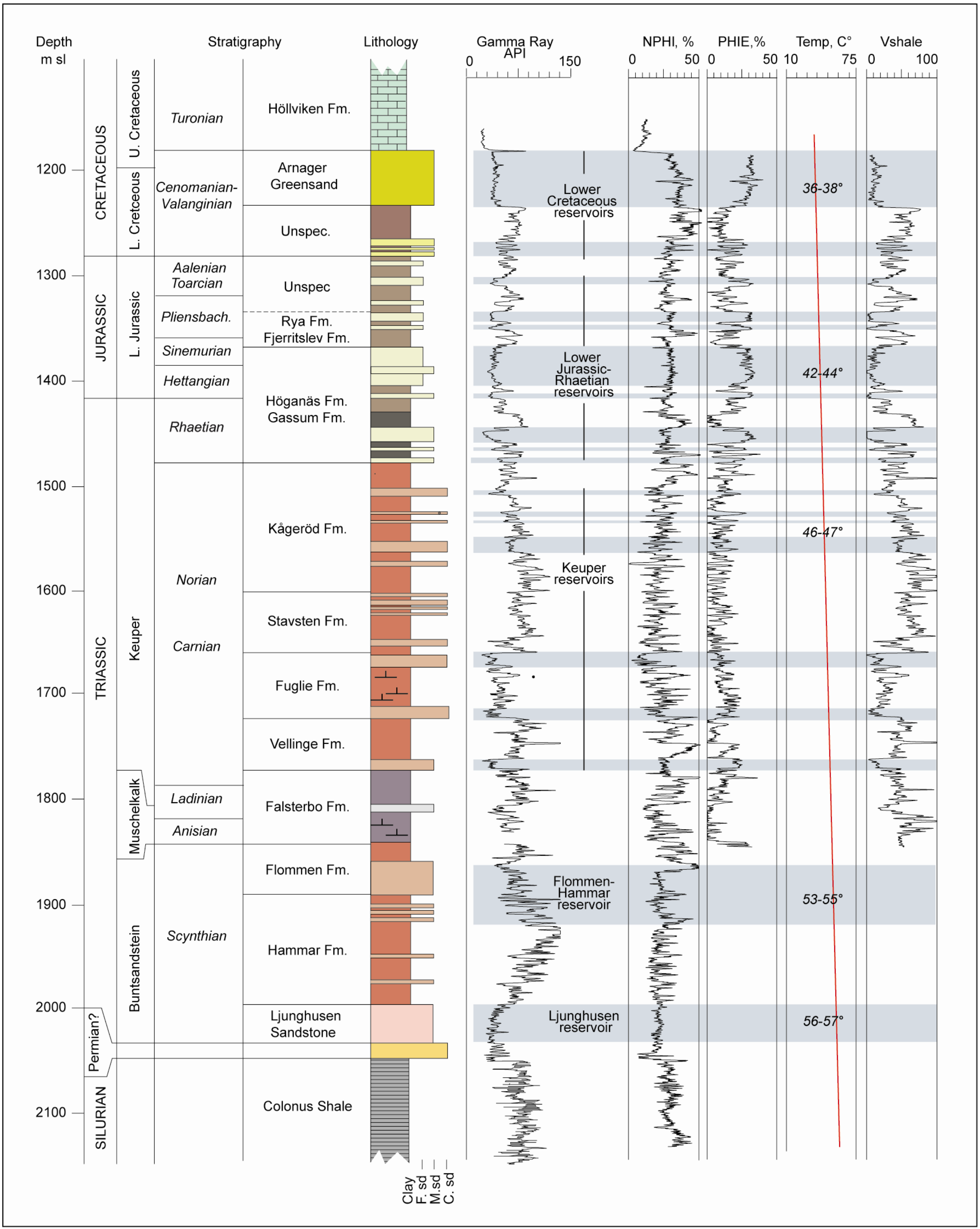

Figure 3: Composite log of the Lower Cretaceous–Triassic succession in the type well Höllviksnäs-1 well for the Höllviken Halfgraben. The potential geothermal reservoirs are shaded light blue.

the range of 1 000 mD. However, most samples have a permeability <50 mD. The cementing agent is mainly meniscus silica and quartz overgrowth. Calcite occurs in subordinate amounts in the investigated sandstone intervals. However, calcite is very common as pore-filling cement in the conglomerates.

The best reservoir interval of the Vellinge Formation seems, based on geophysical logging data and analyses on cores, to be a 15–20 m thick sandstone unit immediately overlying the greyish, micaceous, fine clastic beds of the Falsterbo Formation. This interval can be correlated between several wells in the Höllviken Halfgraben, e.g. Ljunghusen-1, MAH-1 and Höllviksnäs-1. The base of the sandstone was likely developed in a regressive system tract resulting in the deposition of more proximal sediments in the Höllviken Halfgraben, as indicated by the high frequency of conglomerate beds in the deposits of the Vellinge Formation.

Another good reservoir interval occurs in the middle of the Vellinge Formation, where laminated, relatively well-sorted sandstone beds occur. The Vellinge sandstone reservoirs are difficult to correlate outside the Höllviken Halfgraben. They could possibly be correlated with the Hauptsandstein of the Erfurt Formation in the North German Basin.

The permeable sandstone beds in the Stavsten Formation and the basal part of the Kågeröd Formation are generally extremely poorly sorted and variably cemented by pore-filling sparitic and poikilotopic calcite. Pedogenic related features (nodules, dendritic calcite, rhizoliths and calcrete) and conglomerate beds occur frequently in the sequence. Loose permeable sandstone beds occur, but the overall reservoir is of poor quality. In the upper part of the Kågeröd Formation (1 880–1 920 m) in the FFC-1 well, there are permeable beds of light grey sandstone alternating with dense conglomerate beds which have quite good reservoir properties. It cannot be excluded that parts of the Stavsten–Kågeröd reservoir acts as a fractured reservoir instead of as a pore reservoir due to the more or less complete calcite cementation. Analyses on core samples give in general very poor results on permeability and porosity for the Stavsten and Kågeröd formations. The lateral variability of the lithological composition (grain size, sorting, cementation etc.) is estimated to be high, which is also verified by the heterogeneous character of the log signals in this interval.

Rhaetian–Lower Jurassic reservoirs

Most of the Rhaetian–L. Jurassic sequence is dominated by the 100–300 m thick Rhaetian to Hettangian Gassum Formation, corresponding to the Höganäs Formation in Scania. The succession is characterized by a sequence of fine-grained shallow marine and shore face sands deposited in deltaic and tidal environments alternating with heterolites and clays. Six major lithofacies have been recognized in the succession, i.e. fine-grained quartz arenite, medium-grained arenite, silt and clay dominated heterolites, sand-dominated heterolites, claystone and coal (Bou Daher 2012). The relative amount of sandstone layers is high, between 40 and 60%. However, a major amount of the sandstones beds consist of fine-grained micaceous quartz arenites with poor hydraulic properties. Analyses on cores (Erlström and Sivhed 1997) show a permeability ranging from 50 mD for the fine-grained sands to 1 500 mD for medium-grained varieties. The individual sandstone beds are highly variable in lateral distribution. There are a few sequence boundaries which can be traces between wells in the Höllviken Halfgraben (Bou Daher 2012). The assessment of the hydraulic properties for individual sandstone beds is thus highly uncertain as there might be significant hydraulic boundaries linked to the sedimentary facies and occurrence of local lens shaped sand bodies. There are in addition no reliable hydraulic tests data from this interval.

Figure 4: The geothermal plant and well head at the Margretheholm site in Copenhagen.

Lower Cretaceous reservoirs

In FFC-1 a c. 10 m thick sandstone sequence overlying the mid-Jurassic unconformity has proven to have excellent reservoir properties. The unit is in FFC-1 composed of medium-grained quartz arenite with permeability in the range of several darcys. Extensive hydraulic tests in FFC-1 have verified a regionally extensive reservoir with a transmissivity of 7.9 x 10^{-4} m^2/s. Subsurface mapping have also identified a regionally distributed unit, at least in the Höllviken Halfgraben, with thicknesses ranging between a few metres to a few tens of metres. Production test and flow meter logging of a perforated section in FFC-1, including both the Rhaetian–Lower Jurassic and the Lower Cretaceous reservoirs between 1 600–1 820 metres depth, showed that up to 80% of the production derived from the 10 m thick Lower Cretaceous sandstone unit.

Reservoirs in the North Zealand Halfgraben

The subsurface geology in the North Zealand Halfgraben is in contrast to the southern parts of the

Øresund Sub-basin poorly known. There is today a sparse net of older seismic lines, but the quality is in generally poor and absence of key wells makes it difficult to tie and define the sedimentary succession. The seismic marker corresponding to the base of the Upper Cretaceous and the top Triassic marker can be traced throughout the Øresund Sub-basin and thus enables a reliable prediction on the presence of the geothermal reservoirs in this interval. It is more uncertain if the Lower Triassic reservoirs are present. The seismic data indicate that the Triassic is significantly increasing in thickness towards the Sjælland Fault which implies the presence of Lower Triassic reservoirs in the deepest parts of the halfgraben.

The conceptual model of the subsurface geology includes, thus, more or less the same type of reservoirs that occur in the Höllviken Halfgraben. The thickness of the Triassic and Jurassic deposits could even be somewhat thicker than in the Höllviken Halfgraben. A significant thickening of the sequence towards the North Sjœlland Fault is clearly seen in the seismic data (Fig. 2). The Rhaetian–Lower Jurassic reservoirs are relatively well known from the adjacent Helsingborg area in the east margin of the halfgraben (Norling et al 1993, Ahlberg et al. 2003, Bou Daher 2012). Here successions of sandstone reservoirs, similar to the ones in the Höllviken Halfgraben, are found.

3 CONCLUSIONS

The study presents for the first time a comprehensive description of the structural framework and geological setting of the easternmost parts of the Danish Basin. The established model includes the definition of the Øresund Sub-basin, with up to 3 500 meters of Mesozoic strata, and assessment of the main geothermal reservoirs. Several low enthalpy geothermal reservoirs occur between c. 1 200 and 3 000 meters depth. These have so far only to a limited extent been utilized for geothermal purposes. The formation temperature ranges between approximately 40° and 70° for the reservoirs in the Lower Cretaceous to Lower Triassic succession. In general the temperature gradient is 25–28°/1 000 m. Production test from two geothermal projects in Malmö and Copenhagen give a kh capacity between 5 and 14 Dm for the different reservoir intervals.

The knowledge and experience from the Copenhagen geothermal plant (Fig. 4) at Margretheholm as well as the results from the joint geological assessment of the potential reservoirs presented here are important constituents in evaluating the possibility for an extended utilization of low enthalpy geoenergy in the urban Øresund region.

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