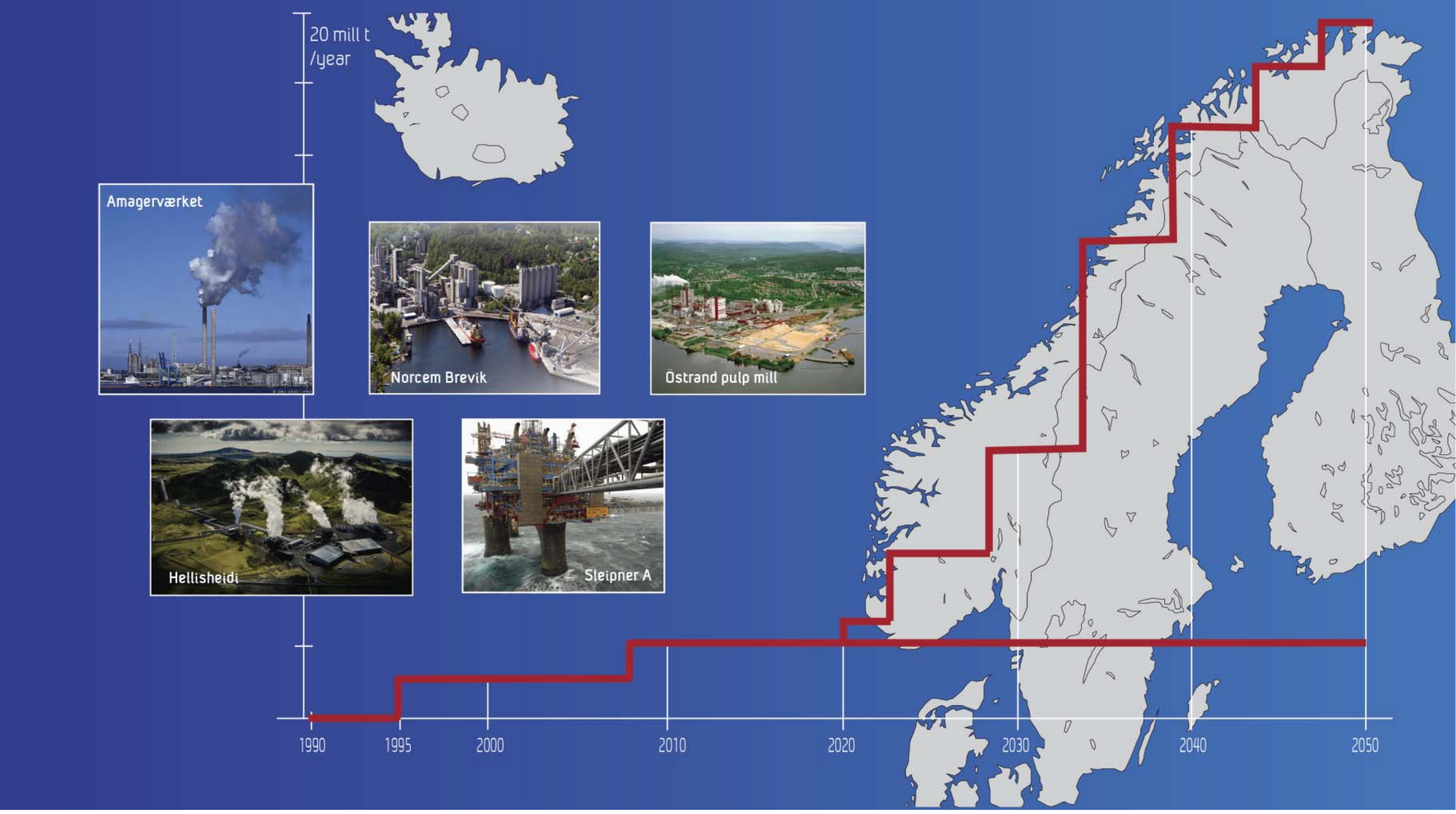

Screening for CO_2 storage sites in Southeast North Sea and Southwest Baltic Sea

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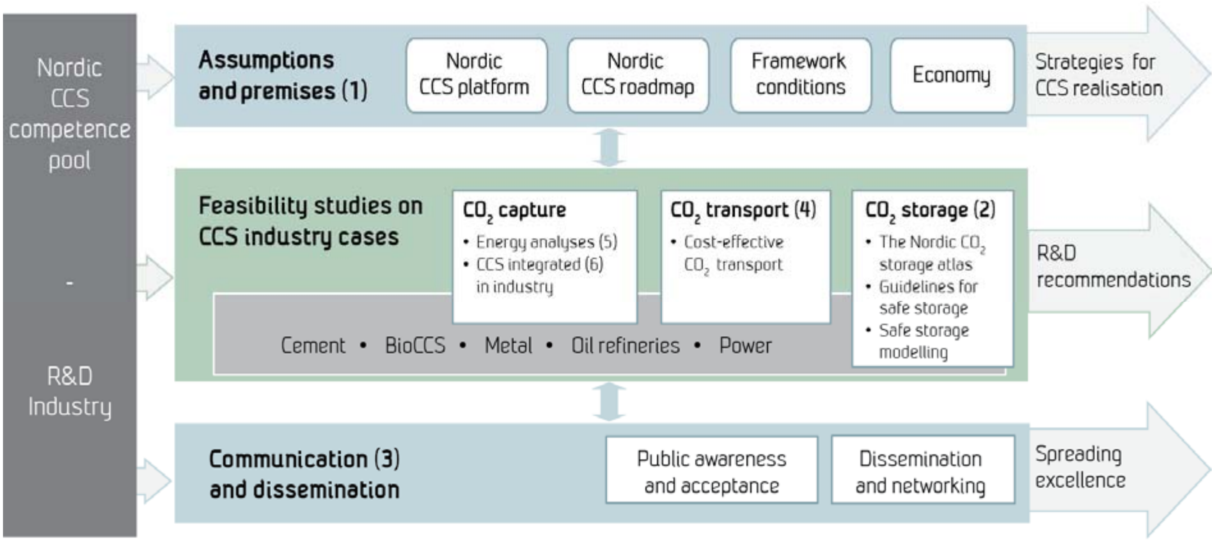

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Summary

As a means to increase the knowledge of potential storage capacities in the offshore areas in the southern parts of Denmark following areas have been screened i) the Danish sector in North Sea south of the Ringkøbing-Fyn High, ii) the Danish part of the West Baltic Sea south of Ringkøbing-Fyn High and iii) eastern German and western Poland shelf areas in the Baltic Sea. The screening work has identified 13 new structures potentially suitable for CO_2 storage, 3 in the Danish North Sea and 10 in the West Baltic Sea.

Keywords Storage capacity, South Denmark, Baltic Sea, North Sea, screening

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Nordic CCS Competence Centre, NORDICCS, is a networking platform for increased CCS deployment in the Nordic countries. NORDICCS has 10 research partners and six industry partners, is led by SINTEF Energy Research, and is supported by Nordic Innovation through the Top-level Research Initiative.

Screening for CO2 storage sites in Southeast North Sea and Southwest Baltic Sea

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Abstract

Storage atlases such as the GeoCapacity database give a good overview of present knowledge about European areas holding potential geological storage resources. These overview maps can however to a certain extent be misleading since they do not always inform the user whether regions not holding such resources have been investigated or not. For example, the GeoCapacity database shows that there are several potential aquifer storage sites in the German sector of the North Sea. According to the database, this area does not extend into the Danish sector, but this is an area that up to now has not been covered by screening efforts. The same situation applies to the waters between Denmark and Germany in the Southeast part of the Baltic Sea (other areas of the Baltic Sea have been screening by the for example the Bastor and the CCSP project).

As a means to increase the knowledge base of potential storage capacities in these regions, Vattenfall has supported R&D that builds on previous work of the EC FP6 project GeoCapacity. The results will be part of the web-based Nordic CO_2 Storage atlas currently under development by the NORDICCS project. This atlas will when finalised compromise potential storage sites in all the Nordic countries.

The specific offshore areas covered are i) south of Ringkøbing-Fyn High in the Danish sector of the North Sea, ii) the German sector of the North Sea, iii) south of Ringkøbing-Fyn High in the Danish Baltic Sea, and iv) eastern German and western Poland shelf areas of the Baltic Sea. The screening is based on data from the South Permian Basin Atlas, and on a joint venture petroleum exploration program (Petrobaltic) of the former Soviet Union, Polish Republic and German Democratic Republic.

The regional site screening work was accomplished in Spring 2013 by GEUS and UGS. As a result, several not previously mapped candidate storage sites have been identified. The extended version of the abstract will present the methodology used (including the applied set of screening criteria), and the findings.

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Screening for CO_2 storage sites in Southeast North Sea and Southwest Baltic Sea

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Abstract

Mapping efforts over the past decade has resulted in fairly good knowledge about the wide range of CO_2 storage options that exists across Europe. Several research groups in Europe are currently maturing this knowledge further with the end-goal to maturing the knowledge about suitable sites to the level where there is significant certainty of storage capacity. This paper present work that contribute to this effort, where regions offshore Denmark and Germany not previously mapped have been investigated for storage capacity. These regions are the i) Danish sector of the southeast part of the North Sea, ii) the Danish sector of the Southwest part of the Baltic Sea, and iii) the German sector of the Southwest part of the Baltic Sea (partly extending into the Polis sector). The results show that there are important near-shore potential storage sites available, though the certainty is limited about their actual storage capacity,

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Keywords: CO_2 storage; screening; CO_2 storage capacity; West Balic Sea; Southern North Sea.

The availability of proven storage capacity is a prerequisite for any investment decision in commercial capture plants and transport infrastructure. A wide range of CO_2 storage options exists across Europe. Several research groups are currently building second-generation databases on storage potential in certain regions for deep saline aquifers and hydrocarbon fields for policymaking purposes, based on national or regional updates of the database developed by the former GeoCapacity project (first generation).

Databases such as the GeoCapacity database give a good overview of present knowledge about European areas with potential geological storage resources. Overview maps based on their storage site data can however to a certain extent be misleading since they do not always inform the user whether regions not holding such resources have been investigated or not. For example, the GeoCapacity GIS (Geographical Information System) database shows that

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there are several potential aquifer storage sites in the German sector of the North Sea, but according to the database, this area does not extend into the Danish sector. The non-existing storage sites in these blank areas are not due to its structural geology, but instead that this area has not been covered by any screening efforts up to date. The same situation applies to the waters between Denmark and Germany in the Southeast part of the Baltic Sea.

As a means to increase the knowledge of potential storage capacities in these regions a screening project was initiated in spring 2013, following a similar approach as has been done earlier for onshore areas in Germany [1] and onshore in Denmark [2]. The specific offshore areas covered are i) the Danish sector in North Sea south of the Ringkøbing-Fyn High, ii) the Danish part of the West Baltic Sea south of Ringkøbing-Fyn High and iii) eastern German and western Poland shelf areas in the Baltic Sea, see Fig.1. The screening is based on data from the Petroleum Geological Atlas of the South Permian Basin Area and on the joint venture petroleum exploration program Petrobaltic (former Soviet Union, Polish Republic and German Democratic Republic) [3,4].

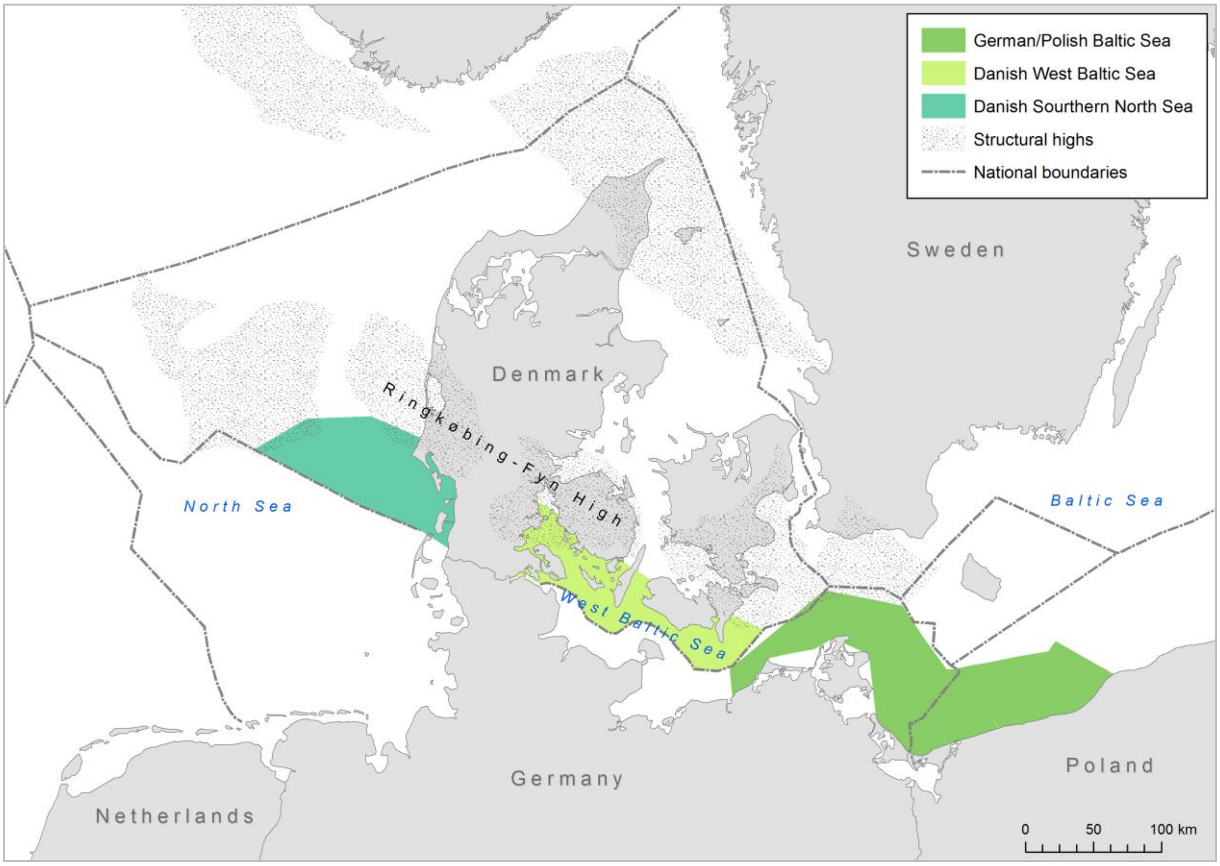

Fig. 1. The newly screened areas that expand the storage site data coverage of the Geocapacity database.

The regional CO_2 site screening work was accomplished by the Geological Survey of Denmark and Greenland (GEUS) and the company Untergrundspeicher- und Geotechnologie-Systeme GmbH (UGS) and supported by Vattenfall AB. As a result, several not previously mapped candidate storage sites have been identified. This paper will present the methodology used in the screening process including the applied set of screening criteria, and the findings. Parts of the findings will go into the Nordic CO_2 Storage atlas database currently under development by the NORDICCS project.

2. Geological setting

The North German Basin started to subside in Early Permian leading to accumulation of up to 2300 meter of Upper Rotliegend sediments. The Ringkøbning-Fyn High separated the North German Basin from the Danish Basin (Fig. 2). The Permian subsidence pattern of North German Basin was generally saucer-shaped and the northern margin was rather straight along the southern slope of the Ringkøbing-Fyn High. During high sea-level stands carbonate and evaporites banks developed along the basin margin and on isolated highs whereas the central part of the basin was starved with sediments. At low sea-level stands the central basin area was filled with thick halite deposits. Cyclic evaporation led to deposition of more than 1500m halite dominated sequences in the central part of North German Basin [5,6]. Post depositional flow of Permian Zechstein salt formed large dome structures and faults with variable offset and extension will generally accompany the salt structures.

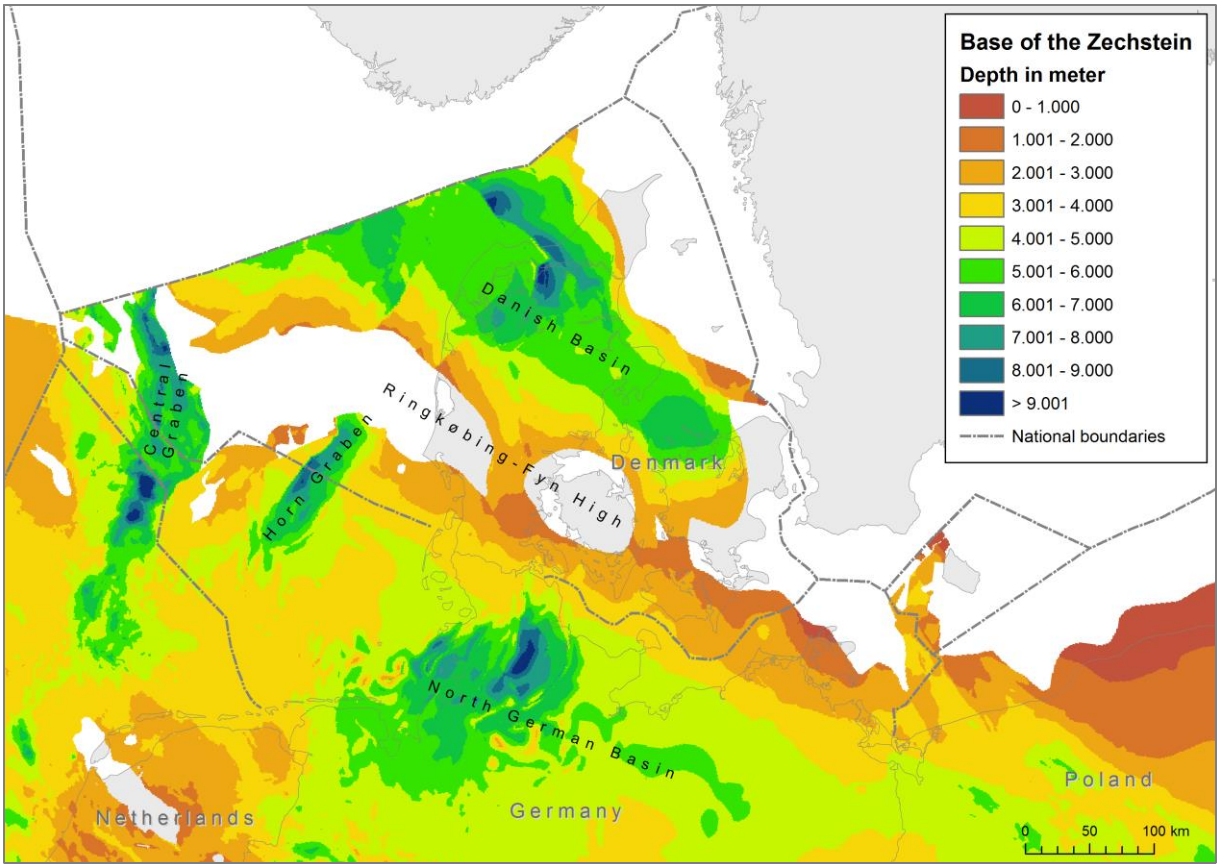

Fig. 2. Depth map of the base Zechstein showing the main outline of the North German Basin and the Danish Basin.

In Early Triassic the saucer-shaped subsidence pattern was interrupted by development of the northerly trending Central Graben and Horn Graben (Fig. 2). The Horn Graben experienced intense rifting and rapid subsidence during the Triassic reflected in the sediment distribution [7,8,9]. During the Triassic the Ringkøbing-Fyn High probably acted as an intra-basinal positive structure between the subsiding North German Basin and the Danish Basin.

At the end of the Triassic a global transgressive event caused marine conditions in early Jurassic time [10,11]. The Early Jurassic marine depositional phase was terminated by a regional erosional event in early Middle Jurassic time, caused by uplift of the central North Sea area, including the Ringkøbing-Fyn High. Shallow marine fluviodeltaic and shoreface sediments were deposited along the Fennoscandian border zone as the Gassum Formation. The Gassum Formation extended into the Danish Basin, across the Ringkøbing-Fyn High and locally into the North German Basin. The shallow marine deposits were succeeded by deposition of offshore marine clay in the Early Jurassic, the Fjerritslev Formation. The Lower Jurassic marine deposits probably only occurred prior to the mid-Jurassic uplift of the high. Subsequent erosion seems to have removed much of the Lower Jurassic deposits, which in the Danish area are only known from wells in the north-eastern part of the North German Basin [10].

The early Cretaceous is recognised by a regional tectonic subsidence and transgression and to the south of the Ringkøbing-Fyn High the Vedsted Formation overlays older Lower Jurassic and Triassic deposits. The Vedsted Formation consists of marine silty claystones of varying thickness due to tectonic activity during deposition. The Vedsted Formation is succeeded by the Rødby Formation, the top unit of the Lower Cretaceous. The Rødby Formation is a transgressive sequence of marlstones, limestones and claystones. The sediments become increasingly calcareous, which together with their uniform thickness reflects the transition to a more regional subsidence pattern and onset of late Cretaceous chalk deposits [12,13]. The Lower Cretaceous is followed by the Upper Cretaceous chalk group that reaches a thickness of 300 – 500 meter in the Danish area south of Ringkøbing-Fyn High.

The Triassic is divided into three lithostratigraphic super groups consisting of Buntsandstein (Lower Triassic), Muschelkalk (Middle Triassic) and Keuper (Upper Triassic) based on outcrops in central Germany. This division of the German Triassic can be correlated across large parts of the North German Basin (Fig. 3). Major facies changes are found towards the basin margins e.g. southern North Sea sector and southern Denmark and consequent changes in boundaries and nomenclature. The German Triassic nomenclature was adopted for the Danish Triassic deposits by Sorgenfrei and Buch [12], redefined by Bertelsen [14] and renewed by Michelsen and Clausen [15].

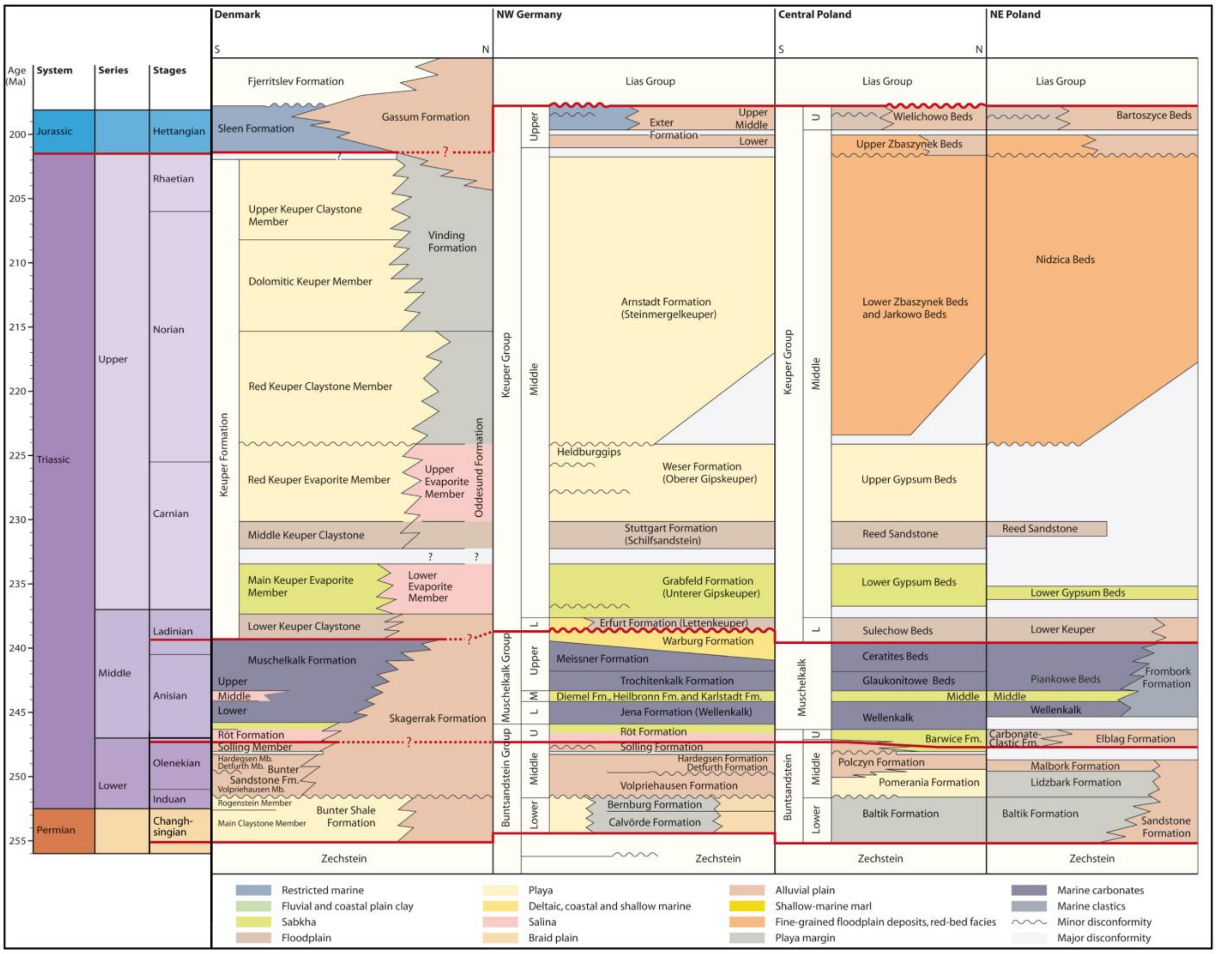

Fig. 3. Stratigraphic scheme. Modified from South Permian Basin Atlas [1].

3. Methodology

3.1 The Danish North Sea Sector and the West Baltic Sea, south of the Ringkøbing-Fyn High

The primary reservoir formation is the Bunter Sandstone Formation and in west Baltic Sea area the presence of the Gassum Formation below 800 meters depth gives an opportunity for an additional storage reservoir. The screening focused on mapping of anticline structures originating from up-doming caused by the buoyancy of the Zechstein salt. Initially the structures were identified on the Top Bunter Sandstone Formation grid from the South Permian Basin Atlas. Verification of the structures were done by checking the seismic lines crossing the structures to avoid mapping none existing structures originating from interpolation errors in the gridding routine. Delineations of the structures were marked on the seismic lines and new structure outlines were drawn on the basis of the seismic data.

The CO_2 storage capacity is calculated using the methodology of GeoCapacity [16]. The approach used in GeoCapacity for storage capacity estimation in deep saline aquifers is a slightly simplified version of the formulas presented in Bachu et al. [17]. The formula used for storage capacity estimation is:

$$M_{CO2} = V \times S/G \times \phi \times \rho_{CO2r} \times S_{eff}$$

M_{CO2}	regional bulk or trap specific storage capacity
V	volume of regional or trap aquifer
S/G	average gross sand (Gross sand thicknesses are calculated using 30% Vshale cut-off) thickness/formation thickness ratio of regional or trap aquifer
ϕ	average reservoir (gross sand) porosity of regional or trap aquifer
ρ_{CO2r}	CO_2 density at reservoir conditions
S_{eff}	storage efficiency factor for bulk volume of regional aquifer or trap specific

Analysis of the reservoir properties was based on log and core data from 10 well in the West Baltic Sea and 1 well in the North Sea. These wells also provided information about properties of the sealing formations.

3.2 Eastern German and western Poland shelf areas in the Baltic Sea

Potential geological storage structures of the stratigraphic series Upper Cretaceous, Jurassic/Upper Keuper (correlating stratigraphically to the above mentioned Gassum Formation), Bunter sandstone, Zechstein and Rotliegend are identified on basis of interpreted seismic depth maps of the exploration project Petrobaltic [4]. The older and deeper lying formations are not of interest due to their depth, the unsufficient petrophysical properties and/or the possibility of oil and gas bearing reservoirs. The screening process includes the application of the criteria depth (800-3500 mbsl) and size of structure (> 10 km²). A second step comprises the evaluation of thickness for the storage horizons and a compilation of porosity and permeability values and based thereupon a calculation of the available pore volume. Additionally, information is collected of structure type and of sealing cap rock formations. The storage properties of the sandstones are deduced from stratigraphical, lithological and petrophysical data of 4 offshore and 60 onshore boreholes.

4. Results of the screening

4.1 The Danish North Sea Sector and West Baltic Sea, south of the Ringkøbing-Fyn High

The screening work has identified 13 structures potentially suitable for CO_2 storage, 3 in the Danish North Sea and 10 in the West Baltic Sea (Fig. 4). The primary reservoir formation in the study area is the Lower Triassic Bunter Sandstone Formation. Based on well data from wells located south of Ringkøbing-Fyn High, the Bunter Sandstone Formation consists of 2 pronounced sandstones layers (unofficially called Upper and Lower Bunter Sand) separated by a shale section. Top of the Bunter Sandstone Formation is found in app. 1100-1600 meters depth except in the area close to the edge of the Horn Graben where top for the reservoir sand is found in approx. 1900-2700 meters depth. Four reservoir sand layers have been identified in the North Sea well, Erik-1 (Fig. 4). The Upper Triassic-Lower Jurassic Gassum Formation only has a limited area of distribution in the West Baltic Sea and the formation cannot be correlated to the North Sea area. In areas where the Gassum Formation is present, the top of the formation will in most cases be above 800 meter.

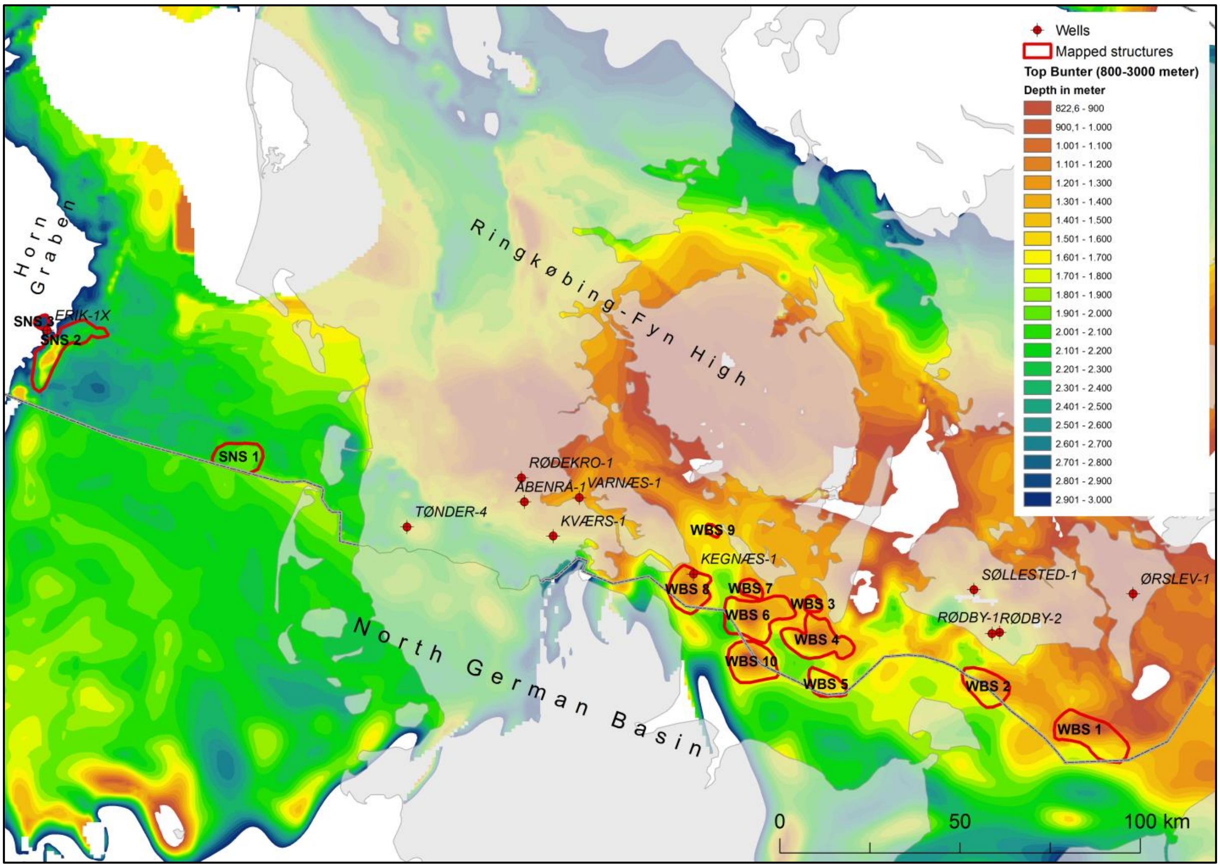

Fig. 4. The identified structures (red contour lines) in the Danish North Sea south of Ringkøbing-Fyn high and in the Danish part of the west Baltic Sea, and location of the wells use in the analysis of reservoir properties.

South of the Ringkøbing-Fyn High the log analysis indicates gross sand thicknesses in the range 35-75 meter and associated porosities between 14 and 19%. The Bunter Sandstone Formation is subdivided into four members but not all units can be distinguished in the Danish wells south of Ringkøbing-Fyn High. The lowest *Volpriehausen* Member is present in all wells south of Ringkøbing-Fyn High and is characterized by a lower sand dominated unit and an upper clay dominated unit interbedded with sandy-silty beds [13]. The uppermost *Solling* Member is the most widespread member of the Bunter Sandstone Formation in the Danish area [13]. The *Detfurth* and *Hardegsen* Members are present in the North Sea as thick sandstones, whereas to the east in the west Baltic Sea they only consist of very thin sand layers [13].

With respect to the Upper Triassic–Lower Jurassic Gassum Formation, gross sand thicknesses of about 100 meter have been encountered in the Ørslev-1 (Fig. 4). It is noteworthy that the gross sand thickness decreases considerably in a westerly direction and only amounts 18 meter in the Kværs-1 well. South of the Ringkøbing-Fyn High the log analysis does not provide any information on the porosity of the Gassum reservoir. The results of the CO_2 storage capacity estimates, using three different storage capacity figures, for the identified structures are summarised in table 1.

Table 1. Storage capacity estimates of the mapped structures in southern Denmark.

Structures	Reservoir/ formation	Volume Bunter Sandstone Fm. (km^3)	Gross sand thickness/ formation thickness	Porosity	Reservoir density of CO^2 (ton/m^3)	Storage Capacity S_{eff} =10% (Mt)	Storage Capacity S_{eff} =20% (Mt)	Storage Capacity S_{eff} =40% (Mt)
WBS 1	Bunter SS	34.38	0.18	0.18	0.550	61.3	122.5	245.0
WBS 2	Bunter SS	31.11	0.23	0.19	0.560	76.1	152.3	304.6
WBS 3	Bunter SS	4.42	0.17	0.14	0.610	6.4	12.8	25.7
WBS 4	Bunter SS	36.02	0.29	0.14	0.560	81.9	163.8	327.5
WBS 5	Bunter SS	14.53	0.30	0.14	0.610	37.2	74.4	148.9
WBS 6	Bunter SS	46.66	0.18	0.14	0.560	65.9	131.7	263.4
WBS 7	Bunter SS	7.53	0.20	0.14	0.610	12.9	25.7	51.4
WBS 8	Bunter SS	30.88	0.18	0.15	0.560	46.7	93.4	186.7
WBS 9	Bunter SS	2.61	0.16	0.14	0.610	3.6	7.1	14.2
WBS 10	Bunter SS	38.80	0.18	0.14	0.550	53.8	107.6	215.1
SNS 1	Bunter SS	17.22	0.21	0.15	0.620	33.6	67.3	134.5
SNS 2	Bunter SS	159.35	0.25	0.15	0.610	364.6	729.0	1458.1
SNS 3	Bunter SS	10.53	0.25	0.15	0.620	24.5	49.0	97.9

Based on the Danish screening the West Baltic Sea has more favorable potential for CO_2 storage in confined structures. In the Danish West Baltic Sea a cluster of structures (WBS 3-WBS 8) would offer the opportunity to exploit several structures and in this way achieve a larger storage capacity for the area. In the southern North Sea area the SNS 2 structure seems to have a large storage capacity, but this structure is bounded by large faults due to its location on the edge of the Horn Graben. The top of the SNS 3 structure is located at a depth close to 3000 meter making it challenging to utilize for CO_2 injection, and the last structure, SNS 1, has a quite limited storage capacity.

A pre-requisite for CO_2 storage is the presence of an appropriate sealing formation overlying the reservoir rock. Marine mudstones, evaporites and clay-stones with sealing properties have been penetrated by all wells within the study area meaning that assessment of the status for abandoned wells would be a focus for future potential storage site developers.

4.2 Eastern German and western Polish shelf areas in the Baltic Sea

In the eastern German and western Polish shelf areas 148 potential storage structures at the investigated stratigraphic horizons Upper Cretaceous, Jurassic/ Upper Keuper, Middle/ Lower Buntsandstein, Zechstein and Rotliegend were identified in the whole working area at depths below 800 meter. Most of them occur at the bases of the Middle/ Lower Bunter (59 structures), Zechstein (50) and Jurassic/ Upper Keuper (33). The horizons Upper Cretaceous (2) and Rotliegend (7) are of minor importance. A great number of these structures are too small for underground storage of CO_2. However, 16 structures of Middle Bunter and Jurassic/ Upper Keuper appear suitable for a more detailed evaluation process, depending on depth range and size of the storage structures as well as frequency of occurrence, thickness of the sandstone horizons and their expected petrophysical properties (Fig. 5). In the German part 10 structures was identified and 6 in the Polish part of the investigation area. There could exist more structures in the eastern Polish part, but this area have not be evaluated due to lack of data.

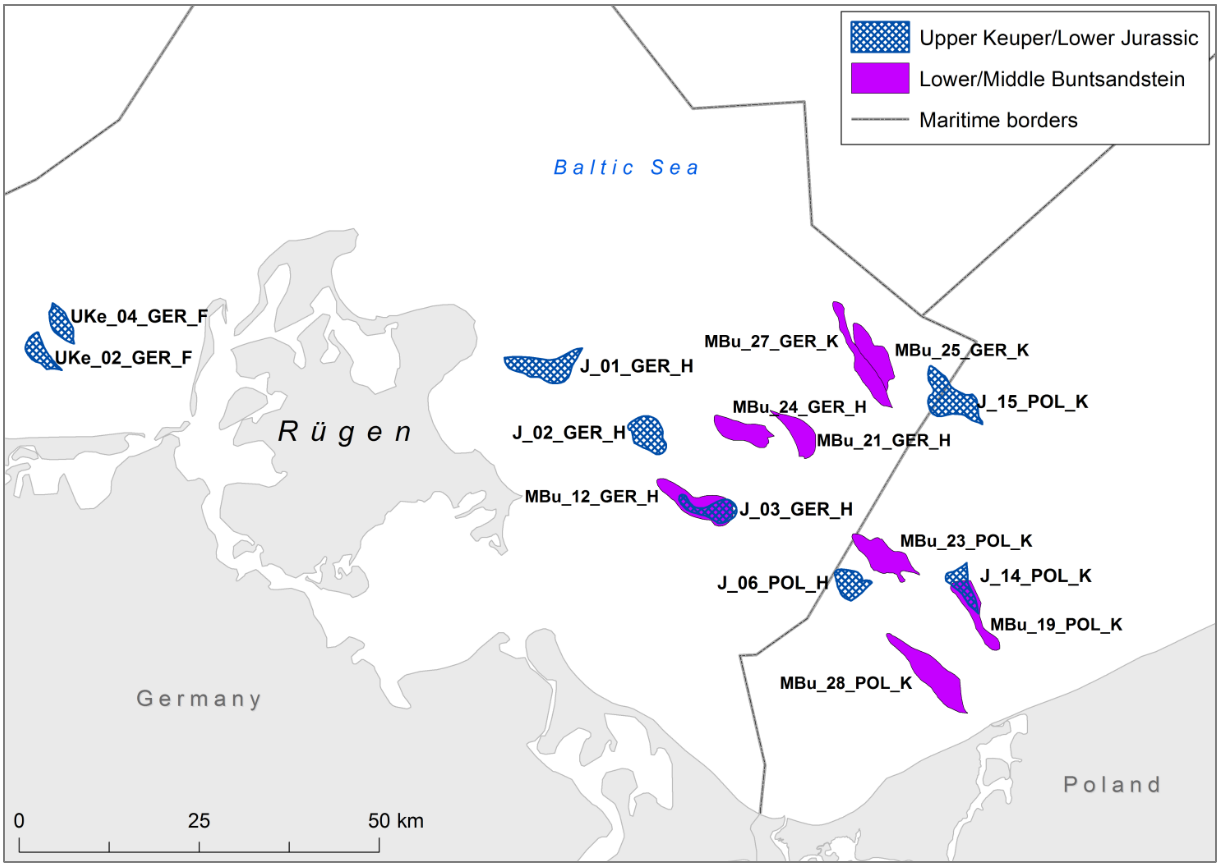

Fig. 5. Location of the identified structures in the eastern German and western Polish areas in the Baltic Sea.

Table 2, shows the determined parameters of the potential storage structures. The storage complex is often formed by several sandstone horizons with a thickness of at least 10 meter. The cumulative thickness varies from 10 to more than 100 m. The maximum sandstone thicknesses occurs east of the Rügen island, but thickness decreases rapidly to the north and to the west. Porosity data could only be gathered from onshore boreholes and they have been extrapolated to the offshore structures. The porosity of the Jurassic and Upper Keuper sandstones vary between minimum values of 20-26% and maximum values of 30-40%, where the highest porosities occur on the islands of Rügen and Usedom and the permeability is documented to be 100 – 1000 mD. The sandstones of the Middle Bunter have a porosity of 15 to 30 % and values above 20 % are typical for the margin of the North German Basin. Porosities of 15 % or less are connected with a high silt and clay content or with a high degree of cementation. The permeability of the Bunter sandstones ranges from less than 1 to more than 2200 mD.

Table 2. Storage structures of the German and Polish shelf areas in the Baltic Sea.

Name	Country	Stratigraphy	Depth Top (m)	Amplitude (m)	Area (km^2)	Thickness (m)	Porosity (%)	Pore volume (km^3)
J_01_GER_H	Germany	Lower Jurassic	800	<50	26	37	20	0.19
J_02_GER_H	Germany	Lower Jurassic	850	<100	19	70	25	0.33
J_03_GER_H	Germany	Lower Jurassic	925	<50	14	100	25	0.36
J_06_POL_H	Poland	Lower Jurassic	825	>100	14	100	25	0.34
J_14_POL_K	Poland	Lower Jurassic	800	<50	11	100	25	0.28
J_15_POL_K	Poland	Lower Jurassic	1000	<50	29	100	25	0.73
UKe_02_GER_F	Germany	Upper Keuper	900	100	11	30	20	0.07
UKe_04_GER_F	Germany	Upper Keuper	850	>150	11	10	20	0.02
MBu_12_GER_H	Germany	Middle Bunter	1825	<50	30	63	20	0.38

MBu_19_POL_K	Poland	Middle Bunter	2100	<100	19	50	20	0.19
MBu_21_GER_H	Germany	Middle Bunter	1800	500	17	50	20	0.17
MBu_23_POL_K	Poland	Middle Bunter	1850	<150	26	50	20	0.26
MBu_24_GER_H	Germany	Middle Bunter	1800	<100	20	50	20	0.20
MBu_25_GER_K	Germany	Middle Bunter	2400	100	21	100	20	0.42
MBu_27_GER_K	Germany	Middle Bunter	2400	100	23	100	20	0.46
MBu_28_POL_K	Poland	Middle Bunter	1600	<150	37	50	20	0.37

The pore volume of the Jurassic and Keuper underground structures vary between 0.02 and 0.7 km³ whereupon the smallest volumes (0.07 and 0.02 km³) are situated in the most western part of the investigation area, due to low sandstone thicknesses and low porosities. The underground structures of the Middle Bunter show pore volumes of 0.17 to 0.46 km³. The pore volume estimations for the structures MBu_25_GER_K and MBu_27_GER_K was calculated with a thickness of 100 meter, despite a nearby situated borehole encountered remarkably thicker sandstones. However, this cautious approach was chosen due to uncertainties about the tectonic situation as well as the composition and petrophysical properties of the sandstones and their applicability on the whole structures. The pore volume would be more than 1 km³ for each structure by use of the whole sandstone thickness.

By using these data, it has to take into account that thickness, porosity and consequentially the calculated pore volume of the storage complexes are deduced and interpolated from onshore and offshore boreholes which are sometimes more than 50 km away and should therefore be used with caution.

5. Conclusions

Several not previously mapped structures have been identified in the Danish southern North Sea sector, the Danish West Baltic Sea and in the eastern German and western Polish shelf areas.

For the two Danish areas the most attractive area for CO_2 injection is the West Baltic Sea where a cluster of structures could be utilized and hereby achieving a larger storage capacity. Results from the Danish areas will be part of the web-based Nordic CO_2 Storage atlas currently under development by the NORDICCS project. When finalized, the atlas will compromise potential storage sites from all the Nordic countries, something that is appealing to many stakeholders of this region. The main part of this atlas will be publicly available.

The investigation of the East German and West Polish Baltic shelf area resulted in identification of 16 underground structures at the bases of the Jurassic/ Upper Keuper and the Middle Bunter. They are selected from about 150 underground structures by the criteria; depth (> 800 m), size (> 10 km²) and thickness of storage complex (> 10 m). Pore volume estimations show capacities of up to 0.7 km³. The estimated pore volume has a low significance with respect to the real storage potential of the structures, but lack of precise data and consequently lack of relevant reservoir parameters prohibited more detailed evaluation of storage capacities. Furthermore, the significance of the results is limited, due to a small number bore-holes included in this study and consequentially a small amount of data. Additionally, the extrapolation of those few data to the whole area has been difficult because of the complex structural geology of the East German Baltic shelf area. Therefore, the suitability of the identified underground structures has to be investigated by a more comprehensive exploration program including the sealing formations on top of the storage complex.

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Screening for CO_2 storage sites in Southeast North Sea and Southwest Baltic Sea

norden
Top-level Research Iniative

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Introduction

The availability of proven storage capacity is a prerequisite for any investment decision in commercial capture plants and transport infrastructure. Databases such as the GeoCapacity database give a good overview of present knowledge about European areas with potential geological storage resources, but some areas have not been covered in previous screening projects, e.g. the waters between Denmark and Germany in the south-eastern part of the Baltic Sea and in the south-western North Sea (Fig. 1).

As a means to increase the knowledge of potential storage capacities in these regions a screening project was initiated in spring 2013. The regional CO_2 site screening work was accomplished by the Geological Survey of Denmark and Greenland (GEUS) and the company Untergrundspeicher- und Geotechnologie-Systeme GmbH (UGS) and supported by Vattenfall AB. As a result, several not previously mapped candidate storage sites have been identified in these regions.

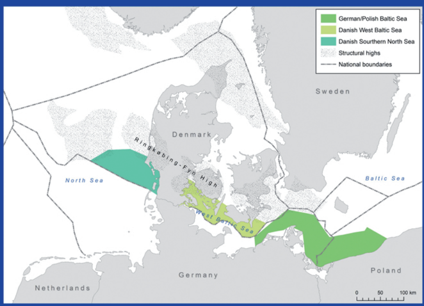

Fig. 1. The newly screened areas that expand the storage site data coverage of the Geocapacity database.

German/Polish screening

Potential geological storage structures on Middle Bunter and Upper Keuper/Jurassic stratigraphic level have been identified on basis of interpreted seismic depth maps from the exploration project Petrobaltic [3]. The screening criteria used in the process were; depth 800-3500 mbsl, size of structure > 10 km² and thickness of storage complex > 10 m. In the German part 10 structures were identified and 6 in the Polish part of the investigation area (Fig. 4). For these 16 structures a more detailed evaluation process were carried out, depending on depth range and size of the storage structures as well as frequency of occurrence, thickness of the sandstone horizons and their expected petrophysical properties.

The storage complex is often formed by several sandstone horizons with a thickness of at least 10 meter. The cumulative thickness varies from 10 to more than 100 m. The maximum sandstone thicknesses occur east of the island Rügen, but thickness decreases rapidly to the north and to the west. Table 2 show the parameters for the potential storage structures. Pore volume estimations show capacities of up to 0.7 km³. The estimated pore volume has a low significance with respect to the real storage potential of the structures, but data are deduced and interpolated from onshore and offshore boreholes which are sometimes more than 50 km away and should therefore be used with caution. Consequently the lack of relevant reservoir parameters prohibited more detailed evaluation of storage capacities.

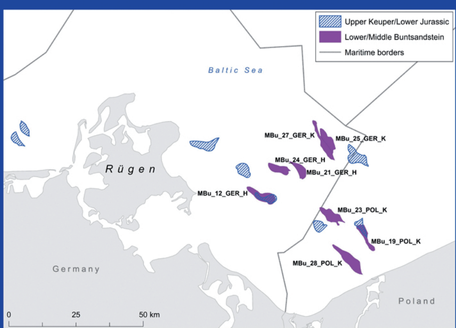

Fig. 4. Location of the identified structures in the eastern German and western Polish areas in the Baltic Sea.

Table 2. Storage structures of the German and Polish shelf areas in the Baltic Sea.

Name	Country	Stratigraphy	Depth Top (m)	Amplitude (m)	Area (km²)	Thickness (m)	Porosity (%)	Pore volume (km³)
J_01_GER_H	Germany	Lower Jurassic	800	<50	26	37	20	0.19
J_02_GER_H	Germany	Lower Jurassic	850	<100	19	70	25	0.33
J_03_GER_H	Germany	Lower Jurassic	925	<50	14	100	25	0.36
J_06_POL_H	Poland	Lower Jurassic	825	>100	14	100	25	0.34
J_14_POL_K	Poland	Lower Jurassic	800	<50	11	100	25	0.28
J_15_POL_K	Poland	Lower Jurassic	1000	<50	29	100	25	0.73
UKe_02_GER_F	Germany	Upper Keuper	900	100	11	30	20	0.07
UKe_04_GER_F	Germany	Upper Keuper	850	>150	11	10	20	0.02
MBu_12_GER_H	Germany	Middle Bunter	1825	<50	30	63	20	0.38
MBu_19_POL_K	Poland	Middle Bunter	2100	<100	19	50	20	0.19
MBu_21_GER_H	Germany	Middle Bunter	1800	500	17	50	20	0.17
MBu_23_POL_K	Poland	Middle Bunter	1850	<150	26	50	20	0.26
MBu_24_GER_H	Germany	Middle Bunter	1800	<100	20	50	20	0.20
MBu_25_GER_K	Germany	Middle Bunter	2400	100	21	100	20	0.42
MBu_27_GER_K	Germany	Middle Bunter	2400	100	23	100	20	0.46
MBu_28_POL_K	Poland	Middle Bunter	1600	<150	37	50	20	0.37

Danish screening

The screening is based on data from the Petroleum Geological Atlas of the South Permian Basin Area and focused on mapping of anticline structures, originating from up-doming caused by the buoyancy of Zechstein salt. The screening work has identified 13 structures potentially suitable for CO_2 storage (Fig. 2). Table 1 summarises the reservoir parameters and storage capacities for the 13 Danish structures.

The primary reservoir formation in the study area is the Lower Triassic Bunter Sandstone Formation (Fig. 3). Based on well data, the Bunter Sandstone Formation consists of 2 pronounced sandstones layers separated by a shale section. Top of the Bunter Sandstone Formation is found in app. 1100-1600 meters depth except in the area close to the edge of the Horn Graben where top for the reservoir sand is found in approx. 1900-2700 meters depth. The secondary reservoir, the Upper Triassic-Lower Jurassic Gassum Formation is only present in a limited area of the West Baltic Sea and the formation cannot be correlated to the North Sea area. In areas where the Gassum Formation is present, the top of the formation will in most cases be above 800 meter.

The results of the Danish screening show that the West Baltic Sea has a more favourable potential for CO_2 storage in confined structures than the southern North Sea area. In the Danish West Baltic Sea a cluster of structures (WBS 3-WBS 8) offers the opportunity to exploit several structures and in this way achieve a larger storage capacity for the area. Only three structures have been mapped in the Danish southern North Sea, and two of the structures located at the edge of the Horn Graben, is either having large faults cutting the structure or the reservoir located at around 3000 meters depth making it challenging to utilise.

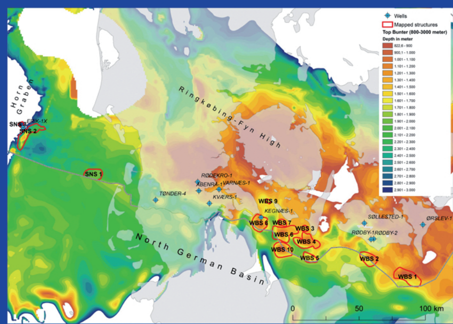

Fig 2. The identified structures (red contour lines) and location of the wells use in the analysis of reservoir properties.

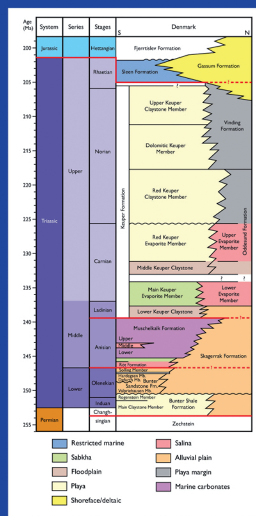

Fig. 3. Stratigraphic chart of the Triassic in Denmark.

Table 1. Storage capacity estimates of the mapped structures in southern Denmark.

Structures	Reservoir/ formation	Volume Bunter Sandstone Fm. (km³)	Gross sand thickness/ formation thickness	Porosity	Reservoir density of CO_2 (ton/m³)	Storage Capacity* S_{eff} =10% (Mt)	Storage Capacity* S_{eff} =20% (Mt)	Storage Capacity* S_{eff} =40% (Mt)
WBS 1	Bunter SS	34.38	0.18	0.18	0.550	61.3	122.5	245.0
WBS 2	Bunter SS	31.11	0.23	0.19	0.560	76.1	152.3	304.6
WBS 3	Bunter SS	4.42	0.17	0.14	0.610	6.4	12.8	25.7
WBS 4	Bunter SS	36.02	0.29	0.14	0.560	81.9	163.8	327.5
WBS 5	Bunter SS	14.53	0.30	0.14	0.610	37.2	74.4	148.9
WBS 6	Bunter SS	46.66	0.18	0.14	0.560	65.9	131.7	263.4
WBS 7	Bunter SS	7.53	0.20	0.14	0.610	12.9	25.7	51.4
WBS 8	Bunter SS	30.88	0.18	0.15	0.560	46.7	93.4	186.7
WBS 9	Bunter SS	2.61	0.16	0.14	0.610	3.6	7.1	14.2
WBS 10	Bunter SS	38.80	0.18	0.14	0.550	53.8	107.6	215.1
SNS 1	Bunter SS	17.22	0.21	0.15	0.620	33.6	67.3	134.5
SNS 2	Bunter SS	159.35	0.25	0.15	0.610	364.6	729.0	1458.1
SNS 3	Bunter SS	10.53	0.25	0.15	0.620	24.5	49.0	97.9

*Storage capacity estimations based on GeoCapacity methodology.

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