CLEEN
Cluster for Energy and Environment

Research Report nr D518
Helsinki 2014

Nicklas Nordbäck & Joonas Virtasalo

Report on the prospective areas for CO2 storage in Western Russia

ccsp
Carbon Capture and Storage Program

CLEEN LTD
ETELÄRANTA 10
P.O. BOX 10
FI-00130 HELSINKI
FINLAND
www.cleen.fi

ISBN XXX-XX-XXXX-X
ISSN XXXX-XXXX

Cleen Ltd.
Research Report nr D518

Nicklas Nordbäck & Joonas Virtasalo

Report on the prospective areas for CO2 storage in Western Russia

ccsp
Carbon Capture and Storage Program

Cleen Ltd
Helsinki 2010

Report Title: Report on the prospective areas for CO2 storage in Western Russia

Key words: CO2 storage, Western Russia

Abstract

The aim of this report is to, on a large scale; identify the stratigraphical sequences with potential for geological CO2 storage in NW Russia. Generally, to store CO2 a porous, permeable formation with a caprock usually at a depth below 800 m is needed. Porosity is required for the space to store, permeability for the ability to inject large quantities of CO2, caprock to ensure that the CO2 stays inside the formation and sufficient depth to maximise the quantities stored.

A large part of NW Russia is covered by a several km thick succession of sedimentary rocks, ranging from Proterozoic to Quaternary in age. The underlying Archean to Proterozoic basement has undergone intensive rifting at different stages that created sedimentary basins of different types. The Mezen, Moscow and Volga-Ural basins are examples of basins formed at Proterozoic time while Timan-Pechora and Barents Sea basins are younger basins that evolved during the Paleozoic.

Mezen and Moscow basins have not been drilled and explored as much as the more potential hydrocarbon areas of Russia. However, some prospective Vendian layers seem to exist in both regions and especially the Devonian sequence of Moscow basin looks promising from a CO2 storage perspective.

In Volga-Ural and Timan Pechora basins potential for geological CO2 storage exist, both in aquifers and in depleted oil and gas fields. The Paleozoic strata has a high potential for CO2 storage in both regions and in Timan Pechora a high storage potential also in the overlying Mesozoic sequence. These regions have for a long time both been active in oil and gas production and exploration and have therefore reached a high level of maturity regarding the availability of data.

The arctic offshore location of the East Barent Sea basin makes it a challenging area for exploration. Although not very well studied, there is a huge hydrocarbon potential in this region and CO2 storage has already been demonstrated in sediments of Mesozoic age on the Norwegian part of Barents Sea. In addition to the Mesozoic sequence, some parts of the Paleozoic might also offer possibilities for CO2 storage in the East Barents Sea basin.

Table of contents

1 Introduction

The aim of this report is to, on a basin scale; identify the potential stratigraphical sequences for geological CO2 storage in the Russian part of the East European Craton (EEC) and Russian part of Barents Sea region.

Geological storage of CO_2 can be undertaken in a variety of geological settings in sedimentary basins (sedimentary basins are depressions or areas of subsidence with infillings of sediments either offshore or onshore). These include depleted oil and gas reservoirs, use of CO_2 in enhanced oil recovery (EOR), deep saline aquifers, deep unmineable coal seams and use of CO_2 in enhanced coal bed methane recovery. Deep, porous rock formations with trapped natural fluids such as oil, natural gas or highly salty and unusable water are common throughout the world.

The potential for storage in Russia has not yet been systematically studied and many regions are still quite unknown, also from a hydrocarbon perspective. The Russian Federation is however extremely rich in oil and gas deposits, accounting for 13% of the world oil reserves and more than 30 % of world gas reserves. The north-central European part of Russia includes hydrocarbon fields in the Volga-Ural and Timan-Pechora oil-gas provinces, Kaliningrad Region and offshore regions including the Barents Sea and Baltic Sea. The north-western region has 10% of all Russian oil and gas reserves. Many hydrocarbon fields of NW Russia have already been depleted and could in the future be of interest for enhanced oil and gas recovery (EOR and EGR) (Shogenova et al. 2011).

Areas with commercial hydrocarbon findings are usually highly potential for CO2 storage and have also been studied in more detail compared to areas without oil and gas findings, these areas are therefore more mature for CO2 storage. CO2 storage potential might however also exist in other sedimentary formations with otherwise suitable reservoir properties but where a source rock and/or suitable conditions for hydrocarbon generation have been lacking.

2 CO2 storage criteria

To store CO_2 a porous, permeable formation with a caprock usually at a depth below 800 m is needed. Porosity is required for the space to store, permeability for the ability to inject large quantities of CO_2, caprock to ensure that the CO_2 stays inside the formation and sufficient depth to maximise the quantities stored. Critical parameters that are considered for geological storage are gathered in Table 1-1 (IPCC 2005).

Table 1-1. Requirements on CO_2 geological storage (based on Chadwick et al. 2008)

Parameter	Requirement	Comments
Capacity	**> 100 Mt CO_2**	Equivalent production of about 2 Mt of carbon dioxide per year from a source under 50 years. Storage capacity should generally be much larger than what the nearby source produces during its lifetime.
Depth	**800-2500 m**	At around 800 m depth CO_2 enters supercritical state. Below 2500 m depth the rock (aquifer) is generally too dense. Shallower aquifers may be interesting if the carbon dioxide can be injected under positive pressure and still be in supercritical state.
Thickness of formation	**20-50 m**	Net thickness. Can thus be divided into one or more sandstone levels separated by dense rocks.
Porosity	**>10%**	Preferably above 15%.
Temperature	**>31.1°C**	For the CO_2 to enter supercritical state.
Salinity	**>30g/l**	Preferably above 100g/l
Pressure	**>73.9 bars**	For the CO_2 to enter supercritical state.
Permeability	**>200 mD**	Different numbers reported.
Caprock	**Site specific**	Layers of low permeability rock that overlay the storage formation, ensuring that buoyant dense or vapour-phase CO_2 does not leak into overlying strata.

3 Geology of western Russia

The East European Craton (ECC) is the coherent mass of Precambrian continental crust that occupies almost the entire northeastern half of the European continent (Fig. 3-1).The EEC comprises lithospheric provinces ranging in age from Archean to late Proterozoic; most of the Russian, or East European, platform is early Proterozoic.

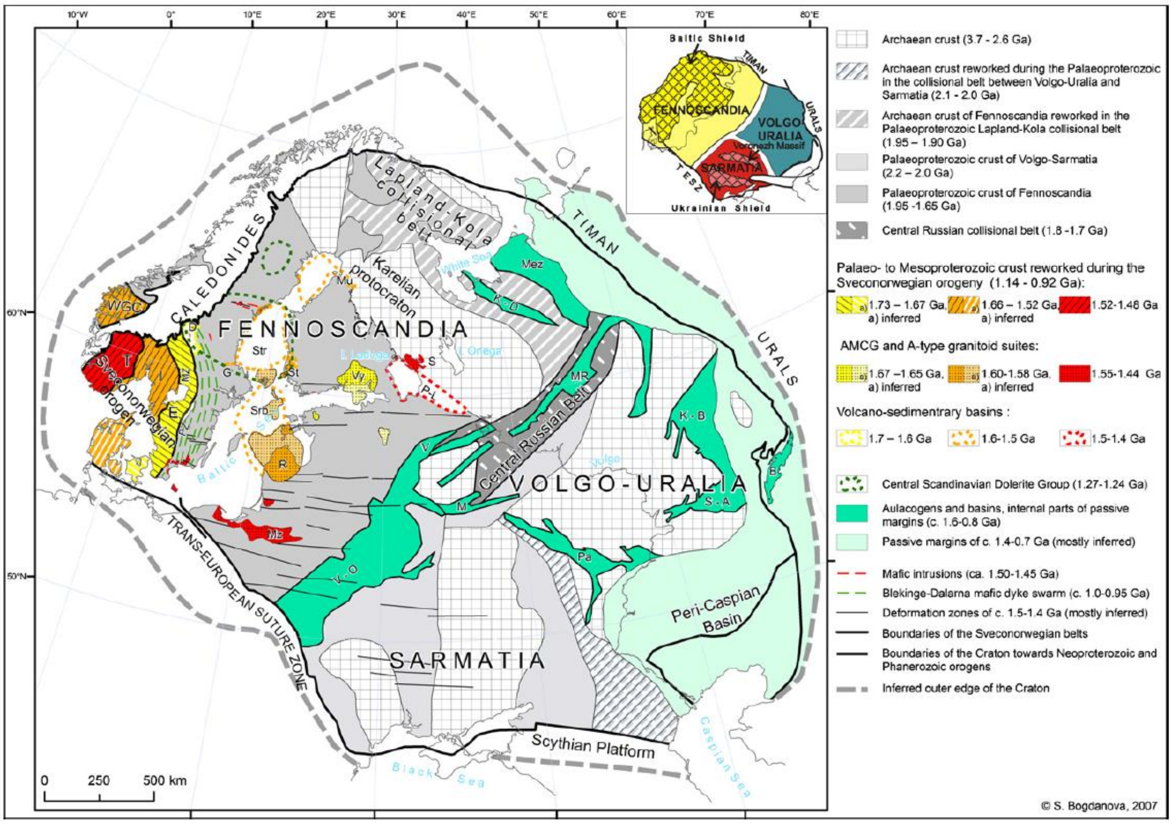

Figure 3-1. Late Palaeoproterozoic to Early Neoproterozoic tectonic complexes in the East European Craton (Bogdanova et al. 2007).

A large part of the EEC has undergone intensive rifting in late Proterozoic and Paleozoic time. Mezen, Moscow and Volga-Ural basins are all intracratonic basins formed at Proterozoic time (Fig. 3-2).

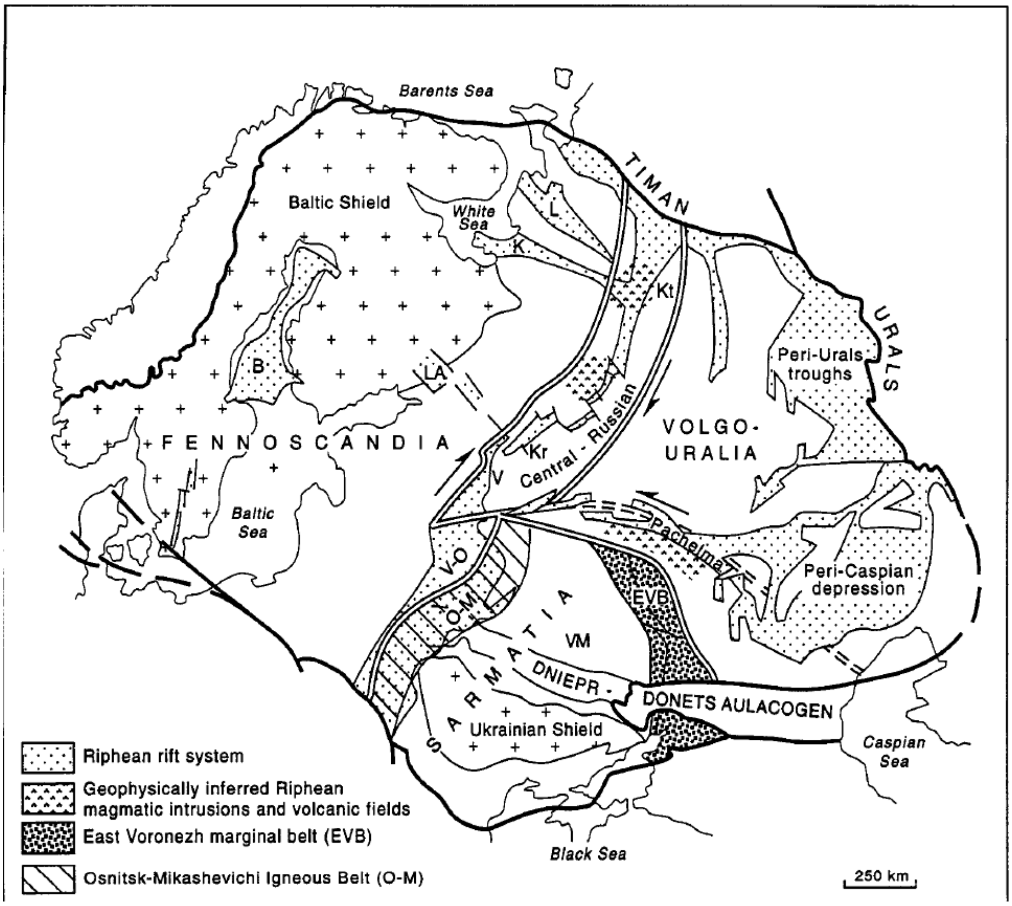

Figure 3-2. Riphean rift system in the EEC (Bogdanova et al. 1996).

Main rift cycles are dynamically related to the separation of continental terranes from the margins of the EEC and the opening of Atlantic-type palaeo-oceans and/or back-arc basins. The origin and evolution of sedimentary basins on the EEC was governed by repeatedly changing regional stress fields. Periods of stress field changes coincide with changes in the drift direction, velocity and rotation of the East European plate and its interaction with adjacent plates (Nikishin et al. 1996). Almost all sedimentary basin types described by modern plate-tectonics have been recognized within the territory of the Former Soviet Union (FSU) and Eastern Europe.

During the middle and late Proterozoic, thick sequences of sediment were deposited in basins throughout Russia. This period is in Russian stratigraphy divided into the Riphean (1.65 billion to 800 million years ago) and Vendian sequences (650 million to 545 million years ago) (Fig. 3-3). As a result of scientific isolation of the former USSR geological community, the stratigraphic terminology and meaning of many important units and formations is still at odds with western terms.

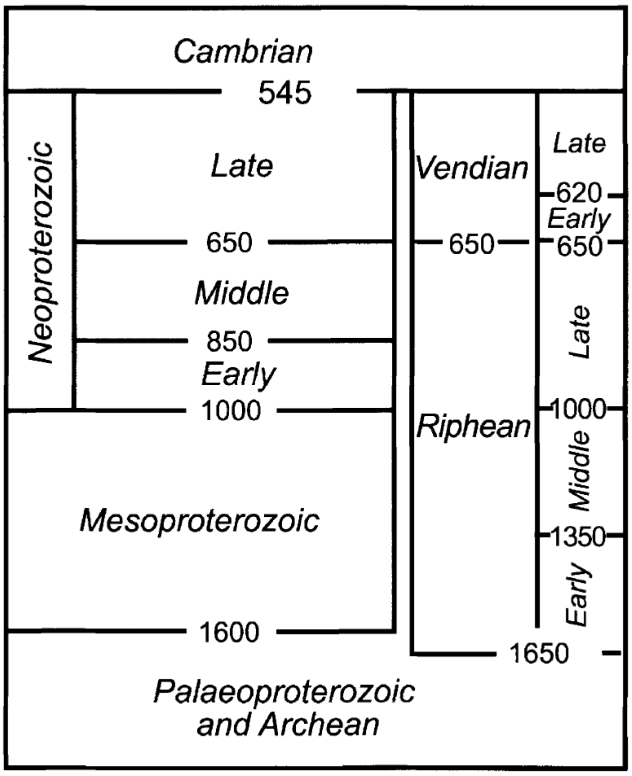

Figure 3-3. Comparison of the Riphean-Vendian and Proterozoic subdivisions of the Precambrian timescale.

During the Paleozoic (541-252 million years ago) the sedimentary basins of EEC experienced their maximal subsidence and also some regional uplifting. The Paleozoic was also a time of widespread rifting on the East European Craton (EEC) and especially at its margins (Stephenson et al.2006). Timan Pechora and East Barents Sea are examples of basins evolving at this time. Paleozoic thick sediments were later deposited on top of the Vendian sequence and can be found also in many other sedimentary basins in Russia. The Russian platform area is now covered by a thick sedimentary cover, which is in sharp contrast to the exposed basement of the Baltic Shield (Fig 3-4).

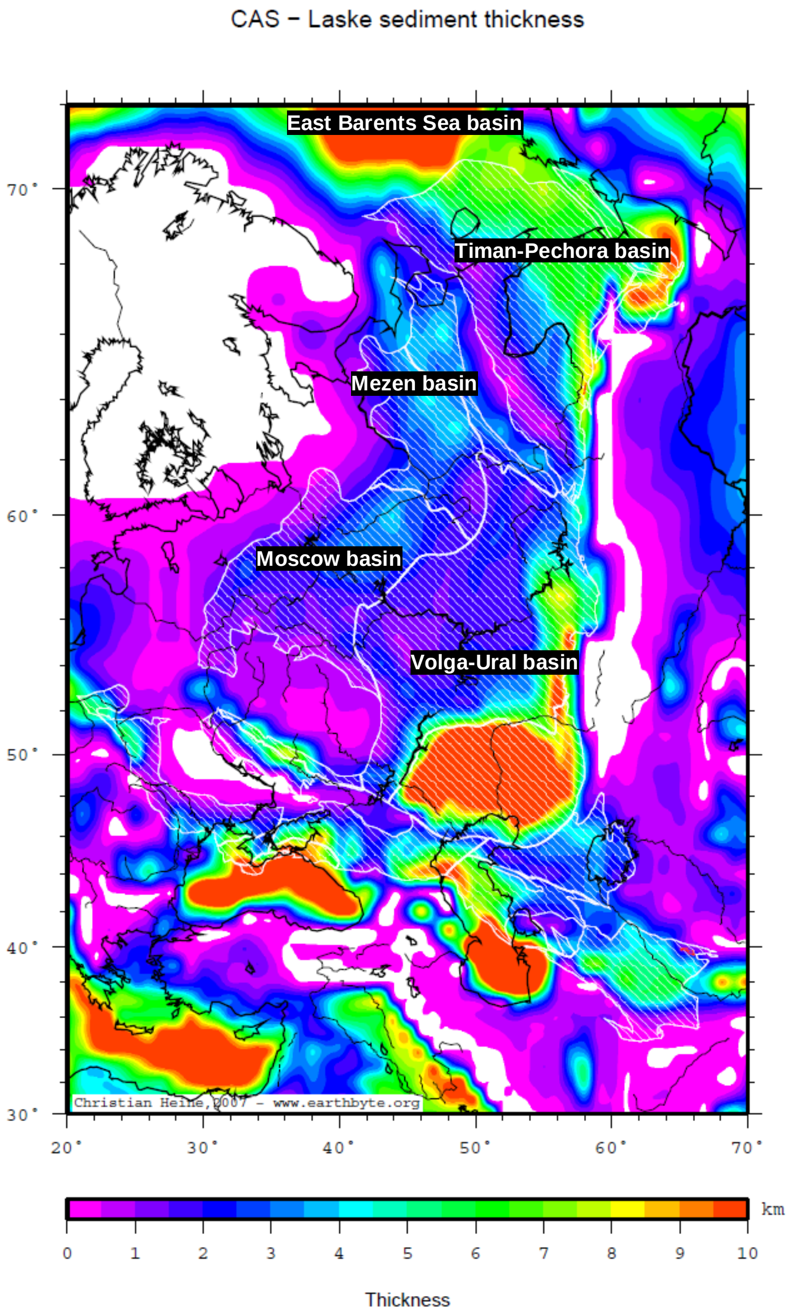

Figure 3-4. Laske sediment thickness map with sedimentary basins of western Russia outlined.

4 Sedimentary basins of Western Russia and their CO2 storage potential

4.1 Mezen basin (Mezen syneclise)

The Mezen basin is a vast depression located in the northern Russian Plate. It is bounded by the Baltic Shield in the west and the Kanin–Timan Foldbelt in the east. The basin merges with the Moscow basin via the Middle Russian aulacogen in the south (Fig. 4-1).

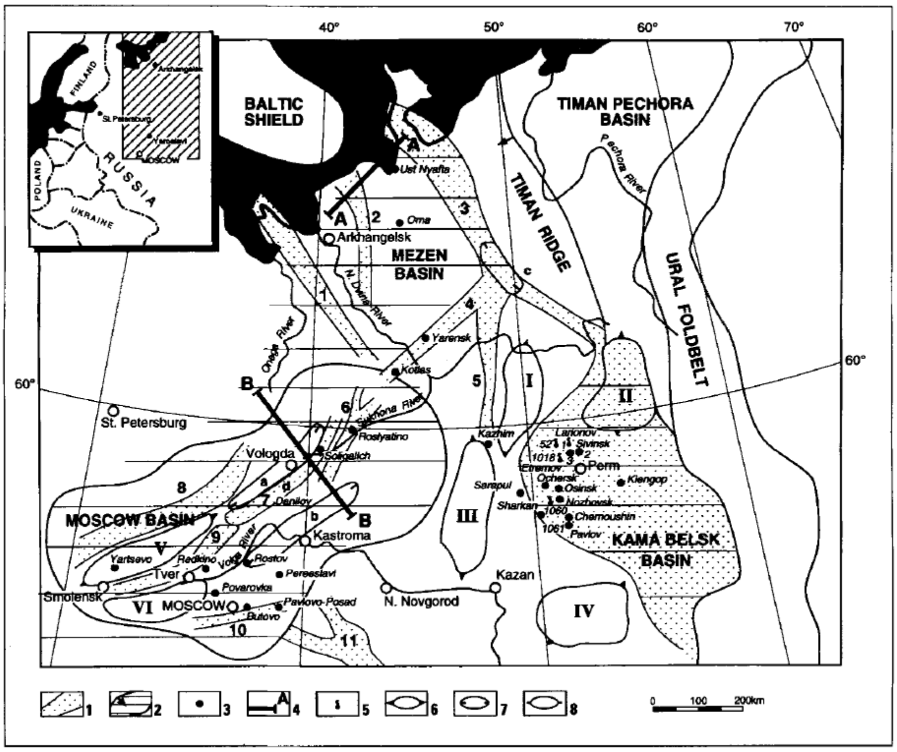

Figure 4-1. Distribution of Proterozoic sedimentary rocks on the Russian Platform and related tectonic structures (Fedorov, 1997).

The formation of the Mezen basin is closely related to processes of the Riphean rifting at the northeastern margin of the Russian Plate and its subsidence in the Late Vendian above the system of Riphean paleorifts. Therefore, the basement is broken into blocks expressed in the topography as Riphean depressions and horsts. These structures mostly extend in the northwestern direction and make up a branched network of rift grabens (Malov, 2002). The sedimentary cover is up to over 4 km thick with a median thickness of around 2 km. The sedimentary cover of Mezen basin includes mainly Middle–Upper Riphean, Upper Vendian, and Paleozoic rocks (Fig. 4-2). Seismic data suggest that depths to the basement may be far greater (6-8 km) in the Timan Foredeep (Fedorov, 1997).

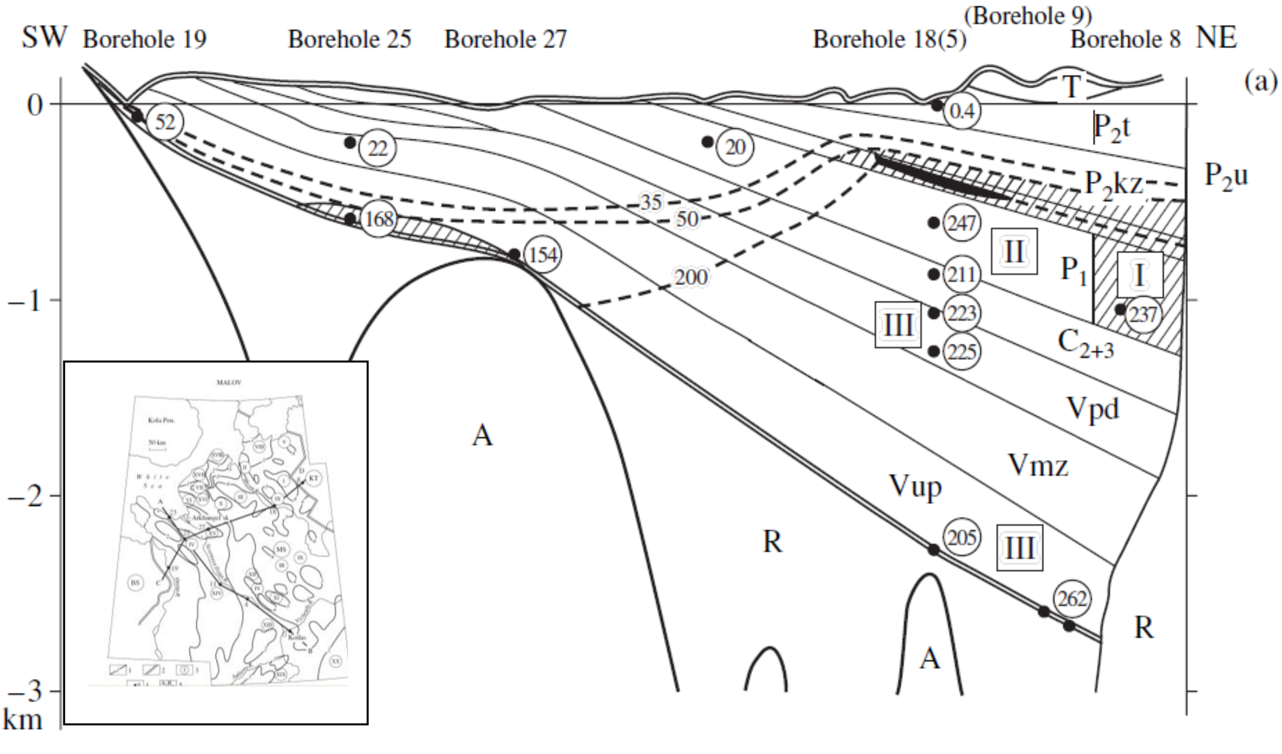

Figure 4-2. SW-NE trending stratigraphic profile across the the strike of the major paleorifts, northern part of Mezen basin (Malov, 2002).

Riphean rocks make up the base of the sedimentary cover of Mezen and are developed over the entire territory with the most complete sections observed in the rift depressions. On basement highs, the Riphean rock sequence is sharply reduced up to the point of their complete pinchout. Their occurrence depth varies from tens of meters near the White Sea coast to 2–2.5 km in the eastern part of the basin. On the whole, the complete Riphean sequence, about 2 km thick, includes two (Middle and Upper Riphean) cycles. The lower cycle is mainly composed of mudstones with interlayers of marls, dolomites, and sandstones. The upper cycle is dominated by sand. The mudstones contain fine-dispersed organic matter. The Riphean sequence also includes volcanic rocks (basalts and dolerite basalts) and volcaniclastic breccias (Malov, 2002).

The Riphean sequence is probably not prospective from a CO2 storage viewpoint due to the compactness of the rocks; porosity values range from 1.27 to 9.5 % and permeability from 0.01 to 16.0 mD (Shibina et al., 1998).

Vendian rocks with angular unconformity overlie the Riphean sequence. Their total thickness (674–1388 m) has been recovered in the eastern part of the basin at a depth of 700–1500 m. The base of the Vendian sequence lies at a depth of 1840–2530 m. In the Pesha Depression however, the Vendian sequence is encountered at a depth of 1790–3252 m and here its base may be located at a depth of 3–4.5 km. In the western part of the basin, the Vendian rocks are observed at depths ranging from 0 to 300 m (Malov, 2002). These rocks are universally spread in the Mezen basin and represented by the Ust-Pinega (Redkino Horizon), Mezen, and Padun (Kotlin Horizon) formations.

CO2 storage parameters are generally better in the Vendian compared to the Riphean but the lower parts (Ust-Pinega, Mezen) contains mostly mudrocks and poorly sorted dense rocks, probably not suitable for CO2 storage. Shibina et al. 1998 reports porosity values of 3.5-5.3 % and permeability of 0.0005-1.16 mD for Ust-Pinega and porosity values of 13-17 % and permeability mostly between 3.1-25.5 mD (max value 98.5 mD) for Mezen formation. The 160 m thick Padun formation overlying Mezen consists of sandstones and siltstones separated by mudstone interlayers. Porosity ranges between 7-22 % and permeability runs as high as 1372.2 mD. Values for the Vendian sediments reported by Malov 2002 are similar to those of Shibina et al. 1998 and also indicate that the highest porosity and permeability values are registered where each of the three Vendian formations are closest to the surface.

In the Mezen basin the upper part of the Vendian is interesting from a CO2 storage perspective. Thickness, porosity and permeability are sufficient in the Padun formation which should be present at an adequate depth (> 800 m), from the central parts of Mezen basin and eastwards. A potential caprock is still uncertain but layers with low permeability could be present in the overlying strata.

Mezen is not well studied and there is a low amount of data compared to some other areas with higher oil potential. In this region there is presently only around 10-20 deep drill holes (discussions with VNIGRI, 2014).

4.2 Moscow basin (syneclise)

The Moscow basin is located in the central portion of the Russian Platform, and covers the Tver, Moscow, Yaroslavl and Kostroma administrative regions (Fig. 4-1). The basin is an intra-cratonic structure probably formed through thinning of the crust that produced a number of extensional rifts which gave rise to widespread depressions within the overlying sedimentary cover. At the base of the Moscow Basin is a system of generally NE-SW striking grabens filled with Riphean deposits. The deepest well drilled in the central part of the basin near the village of Roslyatino, to a depth of 4,552 m, did not penetrate the basement. The Pavlovo-Posad-I Well in the Podmoskovny graben reached greater depths (4,779 m). It passed through over 3,000 m of Riphean strata, but likewise did not reach the basement. Within the uplifted blocks separating the grabens, the basement has been reached at 1,000-2,500 m (Fedorov, 1997).

The stratigraphic column in the basin is up to 5-km thick. The Proterozoic and Palaeozoic intervals are of approximately equal thickness, while the overlying Mesozoic is relatively thin. Within the Proterozoic succession as a whole, the Riphean interval is the thickest, while Vendian strata are the most widespread and is unconformably overlying the Riphean succession, or resting directly on the uplifted basement blocks. Within the Palaeozoic, sedimentary rocks of Devonian age (419-359 million years ago) are dominant (Fig 4-3) (Fedorov, 1997).

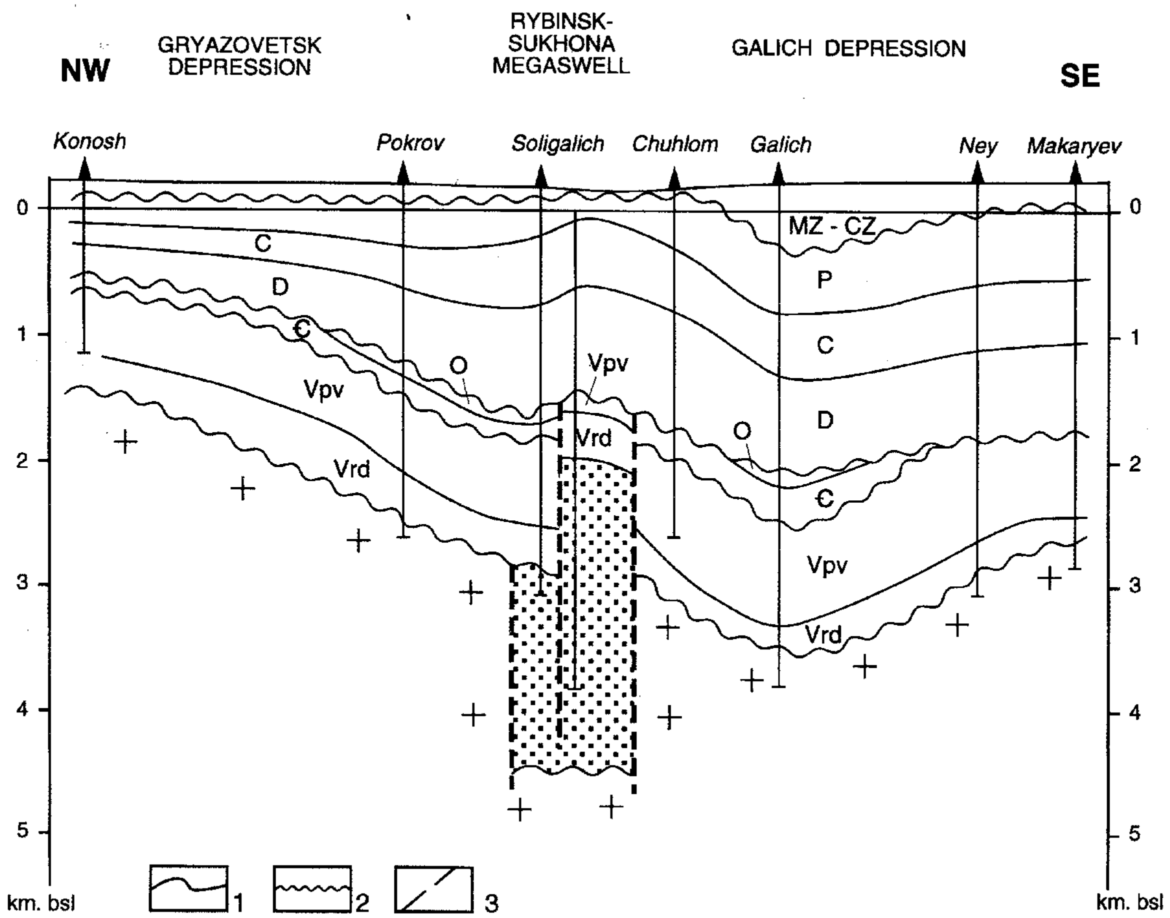

Figure 4-3. NW-SE cross-section across the Moscow Basin (line of section is B-B in Fig. 4-1) between the Konosh and Makaryev wells.

According to Fedorov 1997 wells to the west of the Moscow Basin have penetrated Early Riphean red-coloured siliciclastics, up to several tens of metres thick, of presumably continental origin. During the Middle Riphean, marine conditions spread from the eastern margins of the Russian Platform over the central areas. The Middle Riphean sediments are composed of well-sorted, shallow-marine sandstones alternating with organic-rich claystones and thinly-bedded, grey siliciclastic sedimentary rocks. Upper Riphean sediments are thinner because of pre-Vendian erosion and are mostly composed of poorly-sorted sandstones with interbedded siltstones and mudstones, up to several hundred metres thick. From a CO2 storage perspective, large portions of the Riphean sequence of the Moscow basin are probably located too deep to be favourable for storage, many reservoir properties still remain uncertain but are presumably similar to the corresponding sequence from Mezen where the potential for CO2 storage can be regarded as low due to inadequate porosity and permeability.

The Vendian of Moscow basin can be divided into upper and lower sub-systems and is generally composed of siliciclastic rocks that are less deformed than the Riphean. Lower Vendian sub-system in the Moscow basin has only been delineated in the south of the Moscow Basin; its lower boundary is placed at the base of a tillite unit which has been dated to about 650 Ma. These glacial deposits can also be referred to as the Laplandian Horizon. This horizon also includes red-coloured volcaniclastics and has a maximum thickness of 135 m.

The Upper Vendian Sub-system in the Moscow Basin has been divided into three series. The Redkino series is characterised by a cyclic arrangement of strata. Its lower boundary is located at the base of coarse-grained sandstone, above which dark-grey and brown siltstones and mudstones become dominant. Interbedded marls and pellicles of dark organic matter are common, cycles can be traced laterally. Minor oil shows in the Danilov area have been reported from the lower part of the series. The Povarov Series is a 500-m thick unit consisting of greenish-grey and red-coloured sandstones and claystones, which lie unconformable above the Redkino Series. It is as thick in the Moscow Basin as the Redkino series, and the most complete sections have been mapped in the axial part of the basin. The lower boundary of the series is located at the base of a sandstone unit. The Rovno Series, 25- to 100-m thick, is at the top of the Vendian succession, and probably corresponds to middle Cambrian age. This unit unconformably overlies the Povarov Series in the north and the west of the basin. Its lower boundary is located at the base of a grey-green or pale-grey, quartz-rich glauconitic sandstone unit. The Series includes three intervals with a cyclic structure. Sandstones are present at the base of each cycle, and pass up into siltstones or alternating siltstones and mudstones.

The Redkino and Povarov Series are often combined as a single unit, the Valday complex. This unit can also be identified in the Mezen Basin corresponding to Ust-Pinega and Mezen formations. The Rovno series also seems to have many similarities to the Padun formation in Mezen. In Shogenova et al. 2011 the Cambrian Tiskre formation of the Baltic area is mentioned as a potential unit for CO2 storage in Moscow basin. The Tiskre formation is correlated in Grazhdankin & Krayushkin 2007 to the Padun formation of Mezen basin. This indicates that Tiskre, Rovno and Padun formations might all be of similar middle Cambrian age (~515 Ma).

The Vendian of Moscow basin is situated at a suitable depth for CO2 storage and according to Fedorov 1997 it contains several possible reservoirs in different sandstone units of different thicknesses (5-80 m). The porosity of these sandstones varies between 5-32 % and permeabilities of 500-677 md are reported. Among the most persistent cap rocks in the Moscow Basin are the claystones of the Redkino Series, which are 50- 150 m thick. Salt-bearing strata of Devonian age have been identified and these may also constitute impermeable seals, capping upper Vendian reservoir rocks. Based on this the Vendian of Moscow basin can be regarded as prospective for CO2 storage.

The following geological description over the Devonian (419-359 Ma) of the Moscow basin is from Alekseev et al. 1996. Figure 4-4 shows a Devonian sub-longitudinal lithostratigraphic diagram across the Moscow basin. During the early Devonian, the Moscow basin corresponded to an area of erosion. Only in the northern part the lagoonal alluvial Pirogovo formation is present. During the late Emsian (~400 Ma), terrestrial and lagoonal terrigenous sedimentation is documented by well data (Ryazhsk Formation) in the southern and central parts of the Moscow basin. To the east, the sediments of the Ryazhsk Formation became more marine. During the second half of the early Eifelian (~390 Ma), the relatively narrow depression on the southern margin of the Moscow basin was filled with an evaporitic halite unit. The late Eifelian (~388 Ma) was a time of a regional marine transgression giving rise to the accumulation of shallow-water carbonates. The high amplitude Eifelian/Givetian (~387 Ma) regression caused erosion of the latest Eifelian sediments and transformation of the basin into a floodplain characterized by Givetian terrigenous sediments. During the Givetian (387-383 Ma), marine environments existed only in the area that is now occupied by the top of the Voronezh anticline which at that time subsided relative to the Moscow basin. One of the most important Palaeozoic transgressions took place during the mid-Frasnian (~377 Ma), as indicated by the deposition of shallow-marine carbonates throughout the Moscow basin. The Frasnian/Famennian (~372 Ma) boundary is characterized by a very sharp sea-level drop. A shallow- marine normal salinity basin was reestablished in later early Famennian times. The late Famennian (~362-359 Ma) is characterized by regressive conditions, giving rise to the deposition of evaporitic sediments in the entire Moscow basin (Fig. 4-4).

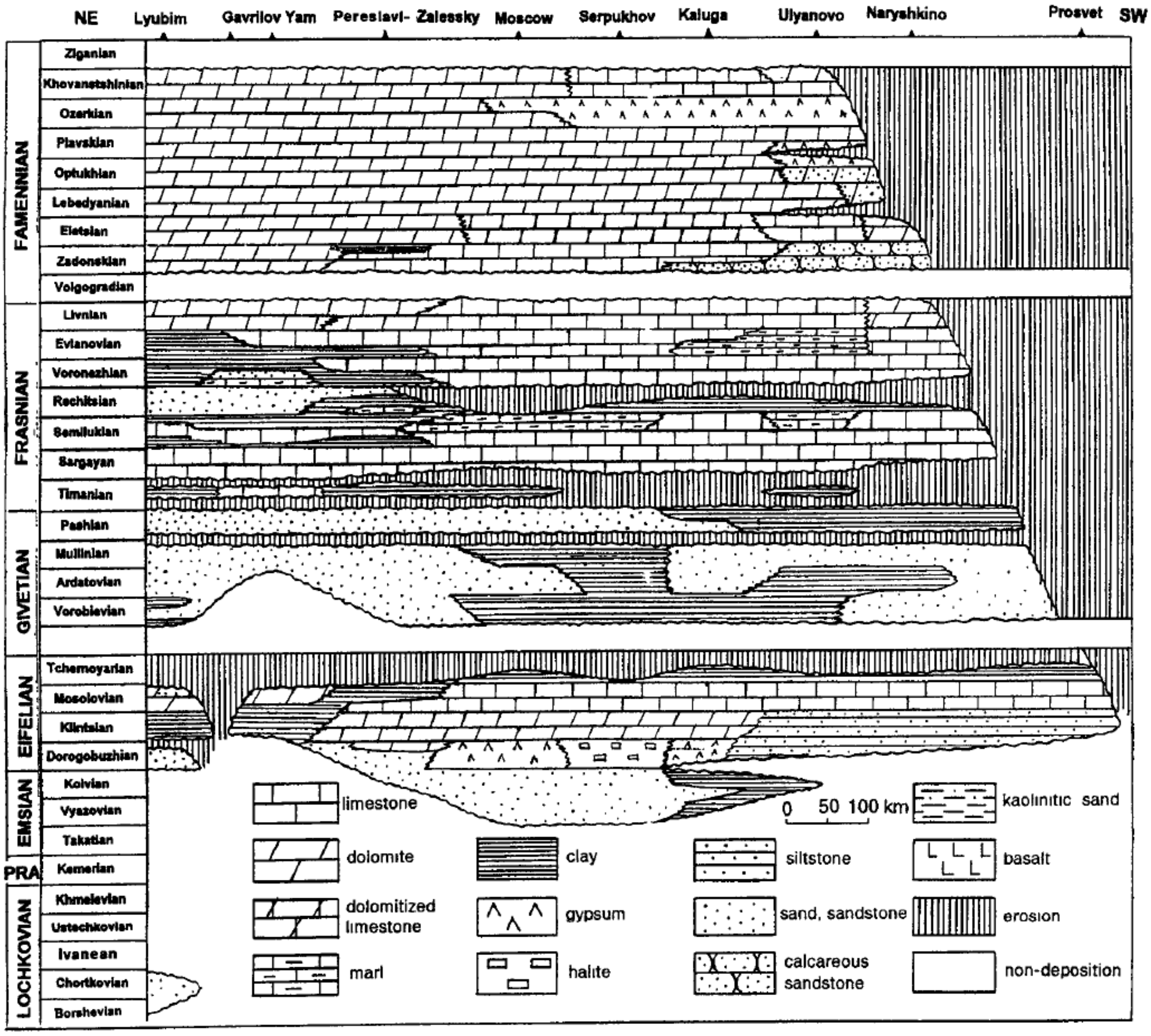

Figure 4-4. Devonian sub-longitudinal lithostratigraphic diagram across the Moscow basin and Voronezh Anteclise, along the Lyubim-Prosvet line (Alekseev et al. 1996).

The depth of the Devonian sequence in Moscow basin is ideal for CO2 storage and capping layers also seem to exist in the form of clay and halite layers in the middle and lower parts. Porosity values have not yet been found in the literature from these layers but the middle and lower Devonian should contain potential reservoirs. In Bogulavsky et al 2003 the Moscow basin is evaluated from a geothermal energy perspective and the middle Devonian at a depth from 800 up to 1700 m is found to have permeability as high as 1.5-3 darcy. In Guschina et al 2008 the Devonian deep saline aquifers of Moscow Basin are also described as prospective for CO2 storage but any precise data is not presented. Consequently, the Devonian of Moscow basin can be regarded as highly prospective for CO2 storage.

4.3 Volga-Ural (Kama-Belsk) basin

Volga-Ural basin is located in the southeast margin of the Russian Platform (Fig. 3-4) and extends over the Perm region and parts of the Tatar, Bashkir and Udmurt Republics. It is bounded by the Komi-Perm basement massif to the north; by the Sisolsk and Kotelnich Massifs to the NW and west respectively; by the Tatar Massif to the south; and by the Ural fold-belt to the east (Fedorov 1997).

Studies show that the basin has underwent a complete "Wilson Circle" from continent rift to continent collision, and is regarded as a typical giant foreland basin where subsidence has continued from the Riphean until Quaternary (2.59 Ma) (Fig. 4-5). The tectonic evolution of the basin can be divided into four stages including: 1) clastic rock in intracontinental rift; 2) carbonate tableland in passive margin; 3) foreland basin of orogenic belt; 4) clastic rock in foreland basin. Good assemblages of source rock, reservoir and seal exist in the marine facies carbonate rocks of the middle and upper Paleozoic, resulting in a giant petroliferous region which has great potential for petroleum exploration (Bin & Xiaomin 2011).

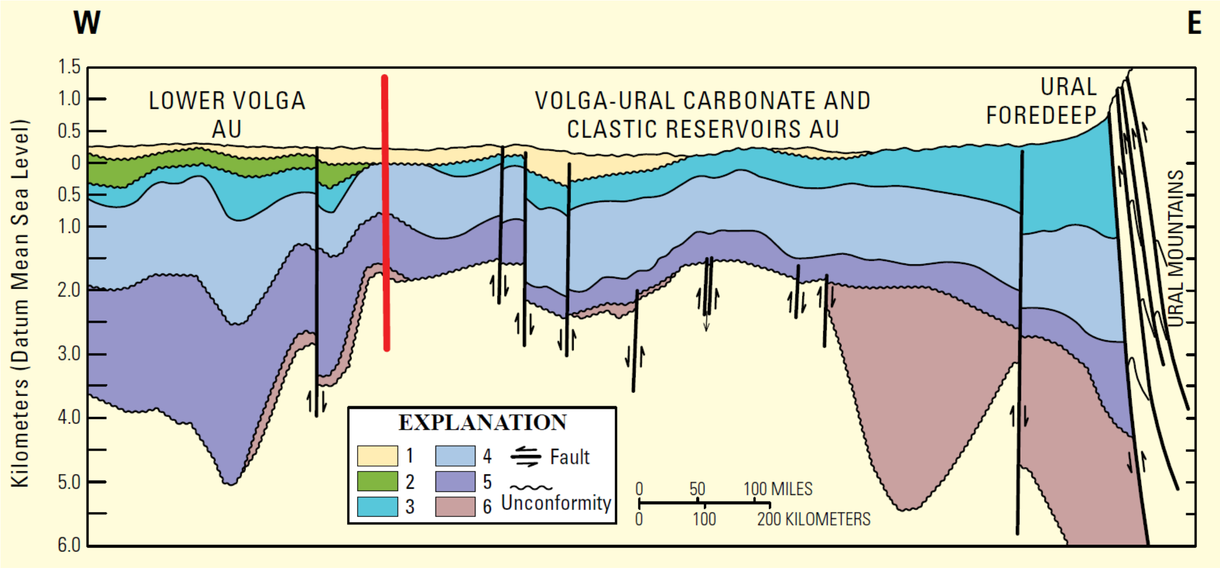

Figure 4-5. Schematic geologic SW-NE cross section of the Volga-Ural basin. Rock units: 1, Pliocene, mostly continental clastic rocks; 2, Mesozoic, mostly continental clastic rocks; 3, Permian, continental clastic rocks and marine carbonate rocks; 4, Carboniferous, mostly marine carbonate rocks; 5, Devonian, marine clastic and carbonate rocks; 6, Proterozoic, marine clastic and carbonate rocks (Peterson & Clarke 1983).

The sedimentary succession in Volga-Ural overlies an Archean (> 2.5 Ga) crystalline basement and consists according to Peterson & Clarke 1983 of seven main sedimentation cycles as follows: 1) Riphean continental sandstone, shale, and conglomerate beds from 500 to 5,000 m thick deposited in aulacogens. 2) Vendian continental and marine shale and sandstone up to 3,000 m thick. 3) Middle Devonian-Tournaisian transgressive deposits, which are sandstone, siltstone, and shale in the lower part and carbonates with abundant reefs in the upper; thickness is 300-1,000 m. In the upper carbonate part is the Kamsko-Kinel trough system, which consists of narrow interconnected deep-water troughs. 4) The Visean-Bashkirian (347-315 Ma) cycle, which began with deposition of Visean elastics that draped over reefs of the previous cycle and filled in an erosional relief that had formed in some places on the sediments of the previous cycle. The Visean elastics are overlain by marine carbonates. Thickness of the cycle is 50-800 m. 5) Early Moscovian-Early Permian (315-290 Ma) terrigenous clastic deposits and marine carbonate beds 1,000-3,000 m thick. 6) The late Early Permian-Late Permian cycle (280-270 Ma), which reflects maximum growth of the Ural Mountains and associated Ural foredeep. Evaporites were first deposited, then marine limestones and dolomites, which intertongue eastward with clastic sediments from the Ural Mountains. 7) Continental redbeds of Triassic (252-201 Ma) age and mixed continental and marine clastic beds of Jurassic (201-145 Ma) and Cretaceous (145-66 Ma) age, which were deposited on the southern, southwestern, and northern margins of the Russian platform.

The Volga-Ural basin contains the greatest thickness of Proterozoic strata (up to over 10 km) (Fedorov 1997). Although the middle-upper part of the Proterozoic (Riphean-Vendian) seems to have otherwise favourable reservoir parameters it is not interesting from a CO2 storage perspective, due to excessive depths (mostly over 3000 m) of these sediments.

Hundreds of oil and gas fields have been found in the Volga-Ural province of which almost all are present in the Paleozoic strata. These include the following sequences: Devonian clastics, upper Devonian and lowermost Carboniferous carbonates, lower Carboniferous clastics, lower and middle Carboniferous carbonates, middle Carboniferous clastics, middle and upper Carboniferous carbonates, lower Permian carbonate-evaporites and upper Permian clastic-carbonates.

The Paleozoic interval of the Volga-Ural basin is highly prospective for CO2 storage except for the Permian (299-252 Ma) part that probably is too shallow.

4.4 Timan-Pechora basin

The Timan–Pechora Basin is a triangular-shaped area of 379 000 km^2 that represents the northeastern-most cratonic block of Eastern European Russia (Fig. 3-4). The basin is bounded to the west and SW by the Timan Ridge. The SE boundary is marked by the Ural Mountains, the NE boundary is the Pay-Khoy Ridge and Novaya Zemlya, and the northwestern boundary is the southern Barents Sea Province. The Timan-Pechora Basin Province has a long history of oil and gas exploration and production. The first field was discovered in 1930 and, after years of exploration, more than 230 fields have been discovered and more than 5,400 wells have been drilled. This has resulted in the discovery of more than 16 billion barrels of oil and 40 trillion cubic feet of gas (Lindquist 1999).

The stratigraphy of the Timan–Pechora Basin reflects the tectonic and sedimentation history of the east margin of the eastern European craton (Fig. 4-6). Continental rifting in the Ordovician (485-443 Ma) and Silurian (443-419 Ma) resulted in deep rift basins that eventually filled with synrift facies. The overall development of a passive margin from the Ordovician to Early Devonian is characterized by widespread carbonate platforms and deep-basin environments where organic-rich shales were deposited. The Middle Devonian is characterized by siliciclastic deposits, which gradually changed to carbonate platform and basin sediments in the Upper Devonian and Carboniferous. The Early Permian began with carbonate deposition that changed to siliciclastics in the adjacent foreland basin to the west of the Uralian fold and thrust belt. Siliciclastic sedimentation continued into the Triassic and Jurassic.

Prospective rocks for geological CO2 storage in the Timan–Pechora Basin include; Lower Ordovician siliclastics, Lower Silurian carbonates to Lower Devonian platform carbonates, Middle Devonian siliciclastics, Upper Devonian reef carbonates, Carboniferous to Lower Permian platform and reef carbonates, and Upper Permian to Triassic siliciclastics (Table 4-1; Prischepa et al. 2011).

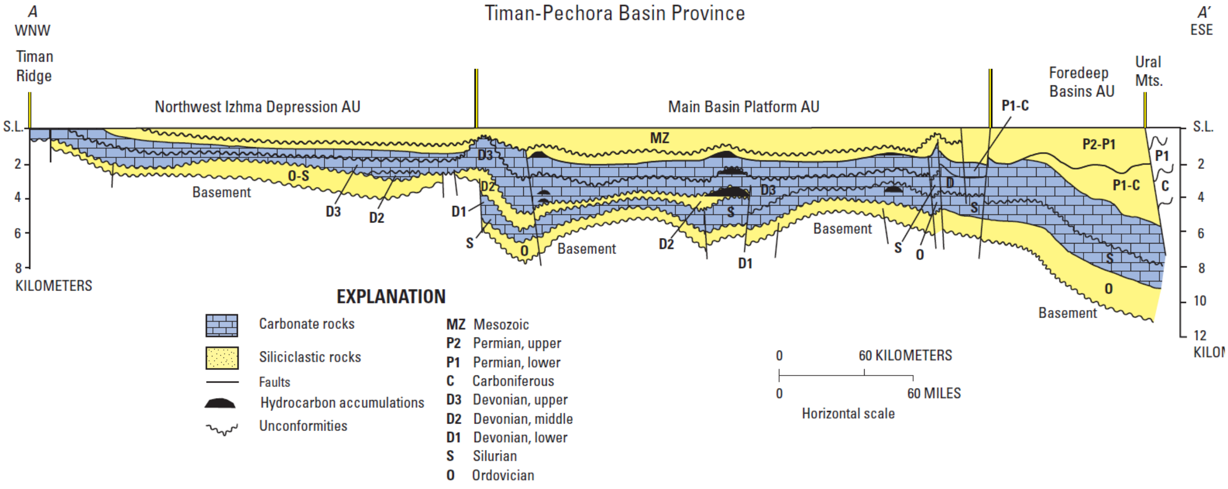

Figure 4-6. Regional cross section of the Timan-Pechora Basin (from Lindquist 1999).

Nearly all known hydrocarbon reservoirs in the Timan–Pechora Basin are within structural traps (Fig. 4-6). However, the regional seal properties of the stratigraphic traps are virtually untested, and might be future exploration targets for CO2 storage. The Lower–Middle Frasnian regionally extensive terrigenous carbonates (Timan mudstones) provide possible regional seals for the underlying sandstones (Lower Ordovician, Lower Silurian–Lower Devonian, Middle Devonian–Lower Frasnian).

Table 4-1. Prospective CO2 geological storage rock formations in the Timan–Pechora Basin (Prischepa et al. 2011).

Age	**Facies**	**Porosity**
Lower Ordovician	Terrigenous clastic and effusive rocks, representing alluvial or delta plain and rift facies	Porosity in sandstones decreases southward from 22 to 6%
Lower Silurian–Lower Devonian	Carbonate sandstones and shales	Up to 15–20%
Middle Devonian–Lower Frasnian	Terrigenous, laterally extensive siliclastic sandstones	9–22%
Upper Devonian (Domanik/Semiluki–Tournaisian)	Regionally extensive reservoir-quality carbonate facies include primarily barrier reef and barrier island biogenic complexes, isolated buildups, drapes and sandstone clinoforms.	12–22%
Carboniferous–Lower Permian	Platform and reef carbonates	15–20%
Upper Permian	Terrigeneous red-bed polymictic sandstones	12–15%
Triassic	Terrigenous alluvial, deltaic and lacustrine sandstones and mudstones. Laterally extensive.	12–20%

4.5 East Barents Sea basin

The East Barents Sea basin stretches eastward from the North Atlantic to Novaya Zemlya (Fig. 3-4). It is represented by a system of mini-basins, grabens and troughs separated by inverted swells and uplifts (Stoupakova et al. 2011). Only the Mesozoic (252-66 Ma) sedimentary complex, overlying the Permian carbonates, is reliably established (Fig. 4-7). Palaeozoic rocks can be traced by deep seismic profiling. Structurally, the East Barents Sea basin is dominated by ENE–WSW and NE–SW trends with local influence of WNW–ESE striking elements. The trends were probably formed due to crustal rifting during the Devonian–Early Carboniferous when two platform blocks (East Europe and Svalbard) separated from each other. Compensated sedimentation and inversion occurred in the Late Carboniferous–Early Permian. The rifting was repeated in the Permian–Triassic, with inversion in the Cretaceous–Cenozoic (145 Ma – present).

The Paleozoic sediments are not well established but likely too deeply seated to be of interest for CO2 storage. Some potential upper Devonian, Carboniferous and lower Permian carbonate reservoirs similar to those in the Timan–Pechora Basin might however be present at a shallower depth on Novaya Zemlya and along the western margin of the East Barents Sea basin.

Lower and Middle Triassic fluvial, deltaic, paralic, and marine sandstones are hydrocarbon reservoirs in the East Barents Sea basin, but the sandstones are thin, compartmentalized, and have poor reservoir quality (Klett & Pitman 2011). The Lower to Middle Triassic rocks are covered by local Triassic mudstone formations. In the Norwegian part of Sea commercial CO2 injection has been conducted in the late Triasic early Jurassic Tubåen formation.

The 400–600-m-thick succession of Middle Jurassic sandstone (Fig. 4-7) is the major hydrocarbon reservoir in the East Barents Sea basin (Klett & Pitman 2011), with a high potential also for CO2 geological storage. The sandstones are sealed by Upper Jurassic to Lower Cretaceous mudstones. Middle Jurassic seals are also present and include mudstone of Bathonian to Callovian and Aalenian to early Bathonian in age. Deltaic and marine sandstones of Callovian, Bajocian and Aalenian ages are the major hydrocarbon reservoirs, with potential for the CO2 storage. The Middle Jurassic rocks in the East Barents Basins are thicker in the northern and central depressions, and thinner or completely eroded on major uplifts. Porosity in Ledovoye, Ludlovskoya, and Shtokmanovskoya hydrocarbon fields in these deposits range from 15 to 25% and permeability varies from hundreds of millidarcies to more than one darcy.

Lower Cretaceous rocks, mainly mudstone-rich clinoforms and possibly submarine channel and fan sandstones are also potential reservoirs. They are locally sealed by Lower Cretaceous mudstones.

The Mesozoic sedimentary complex of East Barents Sea is highly prospective for CO2 storage as a whole but not well studied. There is a huge hydrocarbon potential and CO2 storage has already been demonstrated in sediments of this age on the Norwegian part of Barents Sea.

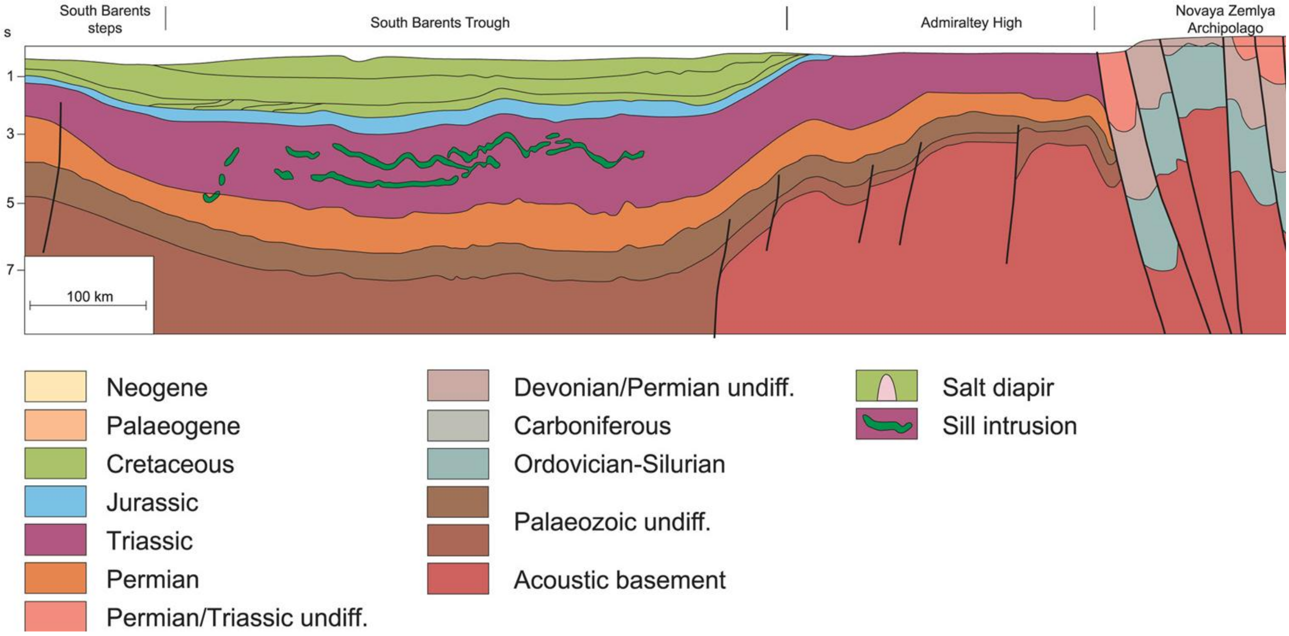

Figure 4-7. Regional cross section of the East Barents Sea basin (from Stoupakova et al. 1999).

5 Summary and discussion

The studied area is situated in the northwestern part of Russia, including the Russian part of the East European Craton (ECC) and the East Barents Sea area. A large part of this area is covered by a several km thick succession of sedimentary rocks, ranging from Proterozoic to Quaternary in age. The underlying Archean to Proterozoic basement has undergone intensive rifting at different stages that created sedimentary basins of different types. The Mezen, Moscow and Volga-Ural basins are examples of basins formed at Proterozoic time while Timan-Pechora and Barents Sea basins are younger basins that evolved during the Paleozoic. Details on potentially suitable sedimentary sequences for CO2 storage are gathered in Table 5-1.

Mezen and Moscow basins have not been drilled and explored as much as the more potential hydrocarbon areas of Russia. However, some prospective Vendian layers seem to exist in both regions and especially the Devonian sequence in Moscow basin looks promising from a CO2 storage perspective.

The Mezen basin has a sedimentary cover of up to 4 km thickness. The parts that are situated at an adequate depth for CO2 storage are Riphean to Vendian in age. The Riphean rocks seem to be excessively dense and therefore not suitable for CO2 storage. The porosity in Mezen increases with decreasing depth, and reservoir parameters for CO2 storage appear adequate in the Padun formation of the upper Vendian sequence. The Padun formation should be present below 800 m, eastwards from the centermost parts of Mezen. A cap rock remains uncertain but could still be present in the overlying strata. The Moscow basin has a stratigraphic column of up to 5 km thickness, with Vendian and Devonian sediments situated at an adequate depth for CO2 storage. The Vendian contains several possible reservoirs in different sandstone units of different thicknesses. Claystones in the lower parts of the Vendian sequence and salt-bearing strata of Devonian age may constitute impermeable seals for Vendian reservoir rocks. In Moscow basin the depth of the Devonian sequence is ideal for CO2 storage and capping layers also seem to exist in the form of clay and halite layers in the middle and lower parts. Porosity values remain unclear but the middle and lower Devonian should contain very good reservoirs.

Volga-Ural and Timan Pechora seem to have a very high capacity for CO2 storage both in aquifers and depleted oil and gas fields. These regions have for a long time both been active in oil and gas production and exploration and have therefore reached a high level of maturity regarding the availability of data. Challenges in these areas could include uncertainties regarding old production and exploration wells, conflicts of interest with oil production and from a Finnish perspective the large distance (1500-2000 km) from Finnish CO2 sources. Timan-Pechora is situated partly in permafrost region which could create additional challenges for CO2 storage operations. Timan-Pechora and especially Volga-Ural could be of interest for EOR due to the high degree of depletion and low degree of extraction in some of the fields. Possible storage sites in Volga-Ural are situated close to Russian CO2 point sources.

The several km thick Proterozoic succession of Volga-Ural basin is located too deep to be suitable for CO2 storage. However, in the Paleozoic strata that lie at suitable depth, hundreds of oil and gas fields have been found. Potential reservoir rocks for CO2 storage are present in the following sequences: Devonian clastics, upper Devonian and lowermost Carboniferous carbonates, lower Carboniferous clastics, lower and middle Carboniferous carbonates, middle Carboniferous clastics, middle and upper Carboniferous carbonates, lower Permian carbonate-evaporites and upper Permian clastic-carbonates. Prospective CO2 geological storage rocks in the Timan–Pechora Basin include: Lower Ordovician siliclastics, Lower Silurian carbonates to Lower Devonian platform carbonates, Middle Devonian siliciclastics, Upper Devonian reef carbonates, Carboniferous to Lower Permian platform and reef carbonates, and Upper Permian to Triassic siliciclastics. Nearly all known hydrocarbon reservoirs in the Timan–Pechora Basin are within structural traps. However, potential stratigraphic traps are virtually untested, and might be future exploration targets. The Lower–Middle Frasnian regionally extensive terrigenous carbonates (Timan mudstones) provide possible regional seals for the underlying sandstones (Lower Ordovician, Lower Silurian–Lower Devonian, Middle Devonian–Lower Frasnian).

The arctic offshore location of the East Barent Sea basin makes it a challenging area for exploration and under the current Russian energy policy, only state-owned giants Gazprom and Rosneft have been granted offshore exploration licences. Although not very well studied, there is a huge hydrocarbon potential in this region and CO2 storage has already been demonstrated in sediments of Mesozoic age on the Norwegian part of Barents Sea (Snöhvit project by Statoil).

Paleozoic sediments similar to those in Timan Pechora are also present in East Barents Sea basin but these are not as well established. The Paleozoic is likely too deeply seated in most parts of this basin to be of interest for CO2 storage. Some upper Devonian, Carboniferous and lower Permian carbonate reservoirs might however be present at a shallower depth on Novaya Zemlya and along the western margin of the East Barents Sea basin. The Mesozoic sedimentary complex of East Barents Sea is highly prospective for CO2 storage. Potential storage reservoir sequences include Lower and Middle Triassic sandstone, Middle Jurassic sandstone and Lower Cretaceous rocks.

Table 5-1. Prospective sedimentary sequences for CO2 storage in NW Russia.

Sequence	Depth (m)	Thickness (m)	Porosity (%)	Permeability (mD)	Cap rock	Setting	Maturity	Distance (km)	Storage Potential
Mezen basin – Vendian	800 - 1500	160	7-22	Up to 1372.2	Uncertain	Onshore	Low	1000	Prospective
Moscow basin - Vendian	800 – 2500	5 – 80	5-32	500-677	Probable	Onshore	Low	800	Prospective
Moscow basin - Devonian	800 - 2000	-	-	Up to 3000	Probable	Onshore	Low	800	Highly Prospective
Volga-Ural basin – Paleozoic	800 - 2500	-	-	-	Proven	Onshore	High	1800	High
Timan Pechora basin – Paleozoic-Mesozoic	800 - 2500	-	9-22	-	Proven	Onshore/Arctic	High	1500	High
East Barents Sea basin – (Paleozoic)-Mesozoic	800 - 2500	-	15-25	100-1000	Proven	Offshore/Arctic	Low	1000	High

6 References

Bin, L., Xiaomin, Z. 2011. Petroleum geology and exploration potential of Volga-Ural Basin：one typical foreland[J]. PETROLEUM GEOLOGY & EXPERIMENT, 2012, 34(1): 47-52.

Bogdanova. S.V., et al., 1996. Riphean rifting and major Palaeoproterozoic crustal boundaries in the basement of the East European Craton: geology and geophysics. Tectonophysics 268, 1-21.

Bogdanova,S.V.,etal.,2007. The East European Craton (Baltica) before and during the assembly of Rodinia. Precambrian Res.160, 23–45.

Boguslavsky E.I., Vainblat A.B., Pevzner L.A., Smislov A.A., Khakhaev B.N., Boguslavskaja L.I. 2003. Geothermal resources of Russia.

Chadwick, A., Arts, R., Bernstone, C., May, F., Thibeau, S. & Zweigel, P.r. 2008. Best practice for the storage of CO2 in saline aquifers – observations and guidelines from the SACS and CO2STORE projects. British Geological Survey Occasional Publication 14, 267 p.

Fedorov, D. L. 1997. The stratigraphy and hydrocarbon potential of the Riphean-Vendian (Middle-Late Proterozoic) succession on the Russian platform. Journal of Petroleum Geology, vol 20(2), April 1997, pp205-222.

IPCC 2005. Carbon Dioxide Capture and Storage. IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by the Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge (USA).

Klett, T.R. & Pitman, J.K. 2011. Geology and petroleum potential of the East Barents Sea Basins and Admiralty Arch. In: Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A.V. & Sørensen, K. (eds) Arctic Petroleum Geology. Geological Society, London, Memoirs 35, 295–310.

Lindquist, S. J. 1999. The Timan–Pechora Basin Province of northwest Arctic Russia. Domanik–Paleozoic total petroleum system. US Geological Survey Open–File Report 99-50-G, 1–40.

Malov, A.I., 2002. Water–Rock Interaction in Vendian Sandy–Clayey Rocks of the Mezen Syneclise. Lithology and Mineral Resources, Vol. 39, No. 4, 2004, pp. 345–356. Translated from Litologiya i Poleznye Iskopaemye, No. 4, 2004, pp. 401–413.

Peterson, J.A., & Clarke, J.W., 1983. Petroleum geology and resources of the Volga-Ural Province, U.S.S.R.: U.S. Geological Survey Circular 885, 27 p.

Prischepa, O.M., Bazhenova, T.K. & Bogatskii, V.I. 2011. Petroleum systems of the Timan–Pechora sedimentary basin (including the offshore Pechora Sea). Russian Geology and Geophysics 52, 888–905.

Schenk, C.J. 2011. Geology and petroleum potential of the Timan–Pechora Basin Province, Russia. In: Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A.V. & Sørensen, K. (eds) Arctic Petroleum Geology. Geological Society, London, Memoirs 35, 283–294.

R. A. Stephenson, T. Yegorova, M.-F. Brunet, S. Stovba, M. Wilson, V. Starostenko, A. Saintot and N. Kusznir. 2006. Late Palaeozoic intra- and pericratonic basins on the East European Craton and its margins. Geological Society, London, Memoirs 2006, v.32; p463-479.

Shibina, T. D., Bazhenova, T.K. & Jarkov, A.M. 1998. Oil and Gas Potential of Riphean-Vendian Deposits in Mezensk Syneclise, Russian Plate. 60 th EAGE Conference & Exhibition, extended abstract.

Shogenova, A., Shogenov, K., Vaher, R., Ivask, J., Sliaupa, S., Vangkilde-Pedersen, T., Uibu, M & Kuusik, R. 2011. CO2 geological storage capacity analysis in Estonia and neighbouring regions. Energy Procedia 4 (2011), p. 2785-2792.

Stoupakova, A.V., Henriksen, E., Burlin, Yu.K., Larsen, G.B., Milne, J.K., Kiryukhina, T.A., Glolynchik, P.O., Bordunov, S.I., Ogarkova, M.P. & Suslova, A.A. 2011. The geological evolution and hydrocarbon potential of the Barents and Kara shelves. In: Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A.V. & Sørensen, K. (eds) Arctic Petroleum Geology. Geological Society, London, Memoirs 35, 325–344.

Grazhdankin D. V. & Krayushkin A. V. 2007. Trace Fossils and the Upper Vendian Boundary in the Southeastern White Sea Region. Doklady Earth Sciences, 2007, Vol. 416, No. 7, pp. 1027–1031.