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ScienceDirect
Russian Geology and Geophysics 55 (2014) 649–667
RUSSIAN GEOLOGY AND GEOPHYSICS
www.elsevier.com/locate/rgg

# Formation mechanisms of ultradeep sedimentary basins: the North Barents basin. Petroleum potential implications

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Received 18 February 2013; accepted 26 November 2013

**Abstract**

Consolidated crust in the North Barents basin with sediments 16–18 km thick is attenuated approximately by two times. The normal faults in the basin basement ensure only 10–15% stretching, which caused the deposition of 2–3 km sediments during the early evolution of the basin. The overlying 16 km of sediments have accumulated since the Late Devonian. Judging by the undisturbed reflectors to a depth of 8 s, crustal subsidence was not accompanied by any significant stretching throughout that time. Dramatic subsidence under such conditions required considerable contraction of lithospheric rocks. The contraction was mainly due to high-grade metamorphism in mafic rocks in the lower crust. The metamorphism was favored by increasing pressure and temperature in the lower crust with the accumulation of a thick layer of sediments. According to gravity data, the Moho in the basin is underlain by large masses of high-velocity eclogites, which are denser than mantle peridotites. The same is typical of some other ultradeep basins: North Caspian, South Caspian, North Chukchi, and Gulf of Mexico basins. From Late Devonian to Late Jurassic, several episodes of rapid crustal subsidence took place in the North Barents basin, which is typical of large petroleum basins. The subsidence was due to metamorphism in the lower crust, when it was infiltrated by mantle-source fluids in several episodes. The metamorphic contraction in the lower crust gave rise to deep-water basins with sediments with a high content of unoxidized organic matter. Along with numerous structural and nonstructural traps in the cover of the North Barents basin, this is strong evidence that the North Barents basin is a large hydrocarbon basin.

*Keywords:* ultradeep basins; lithospheric stretching; eclogitization; rapid crustal subsidence; lithospheric weakening; hydrocarbon potential; North Barents basin

## Introduction

The sediments in some ultradeep basins within the continents and on their margins are up to ~ 20 km thick. Examples include the North Caspian, South Caspian, and North Chukchi basins (Glumov et al., 2004; Kostyuchenko et al., 1999; Vinogradov et al., 2005). Structures of the same type include the East Barents megabasin, which consists of two partly isolated basins: South Barents and North Barents (Fig. 1). Most researchers attribute their formation to stretching of Precambrian continental crust (probably, with breakup and spreading in the deepest parts of the basin) (Bogdanov and Khain, 1996; Drachev et al., 2010; Gramberg, 1997; Ivanova et al., 2011; Shipilov and Tarasov, 1998; Verba, 2007; Worsley, 2008; and others). In (Artyushkov, 2005), it was shown on the basis of available seismic-profiling data (which did not reach the basement at that time) to a depth of 6 s that the upper part of the sedimentary cover of the East Barents basin to a depth of ~ 15 km lacks deformations typical of strong stretching. Therefore, it was presumed that the main cause of the subsidence was the well-known mechanism of rock contraction in the lower crust owing to the metamorphic gabbro to eclogite transition (Baird et al., 1995; Hamdani et al., 1994; Haxby et al., 1976; Kennedy, 1959; Mareschal and Lee, 1983; O'Connell and Wasserburg, 1972). Also, this hypothesis is supported by gravity data indicating that a thick layer of rocks denser than mantle peridotites is present in the lithosphere beneath the megabasin (Kaban, 2001; Kaban et al., 2004).

Unfortunately, very schematic profiles (Bogdanov and Khain, 1996) were used in the analysis of the structure of the sedimentary cover in the East Barents basin (Artyushkov,

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http://dx.doi.org/10.1016/j.rgg.2014.05.009

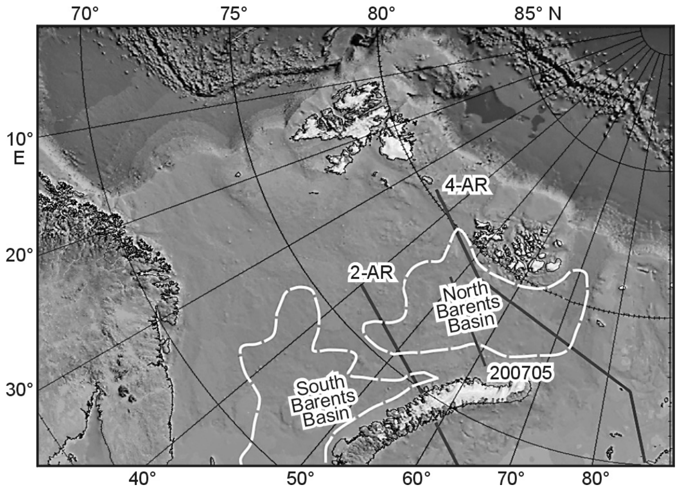


Fig. 1. Ultradeep basins in the eastern Barents Sea. The position of the composite geologic-geophysical profiles 2-AR and 4-AR is shown along with that of the seismic profile running through the upper part of the sedimentary cover.

2005). As the basin depth and the intensity of its basement stretching were unknown at that time, it was impossible to assess the contribution of stretching to the crustal subsidence during the early stage of formation of the basin. The megabasin was later crossed by the profiles 2-AR and 4-AR (Fig. 1), based on integrated data from deep seismic soundings, deep seismic-refraction and -reflection profiling, gravimetric and magnetic measurements, and magnetotelluric soundings (Ivanova et al., 2006, 2011; Roslov et al., 2009). Some authors pointed out that the basin lithosphere, which, according to the gravity data, is at the isostatic equilibrium, is submerged much deeper than it could be expected, judging by the attenuation of the consolidated crust above the Moho (Ebbing et al., 2007; Gac et al., 2012; Ritzmann and Faleide, 2009; Ritzmann et al., 2007; Roslov et al., 2009; Semprich et al., 2010). The conclusion was made that the lithosphere below the Moho contains large masses of eclogites formed from gabbro (basaltoids) in the lower crust (Artemieva and Thybo, 2013; Gac et al., 2012; Semprich et al., 2010) or from the mafic rocks which were supplied to the crust attenuated by stretching as a result of underplating (Roslov et al., 2009). One of simplified models is shown in Fig. 2.

The same situation was previously observed for some other ultradeep basins: South Caspian and North Caspian (Artyushkov, 2007, 2010b), North Chukchi basin (Artyushkov, 2010a), and the Gulf of Mexico (Mooney and Kaban, 2010). To retain anomalous subsidence of the consolidated crust therein, the Moho must be underlain by large masses of dense eclogites. Their formation requires high lithostatic pressures, often unachievable in continental crust ~ 40 km thick (Carswell, 1990; Dobretsov and Polyansky, 2010; Spear, 1993; and others). Therefore, it was hypothesized that the metamorphism-related contraction of predominantly mafic rocks in the lower crust in ultradeep basins develops gradually with subsidence and the accumulation of a thick sedimentary cover (Artyushkov, 2010b). Also, it was presumed for the East Barents basin that the pressure in the lower crust increased

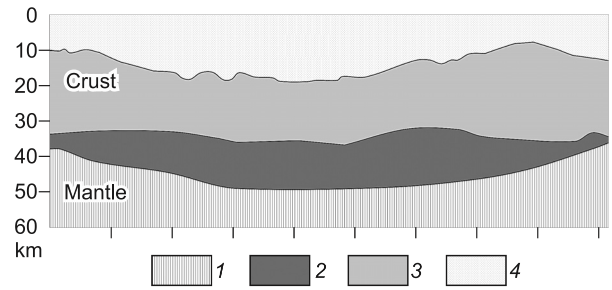


Fig. 2. One of possible models for the localization of a lens of dense high-grade mafic rocks below the Moho in the East Barents basin on the profile 2-AR (modified after (Gac et al., 2012)). *1*, mantle peridotites; *2*, dense high-grade mafic rocks; *3*, the upper crust with 85% felsic rocks and 15% mafic rocks; *4*, sediments.

owing to the accumulation of sediments during lithospheric bending under the action of large forces along this layer (Gac et al., 2012; Semprich et al., 2010).

The northern part of the basin (North Barents basin) has recently been covered with a dense network of seismic-reflection profiles with a total length of 19,000 km (Grigor'eva et al., 2009; Khlebnikov et al., 2009). The profiling was carried out with streamers 6–8 km long. As a result, a high resolution was achieved for the structure of the sedimentary cover to a depth of ~ 16 km and for the basement on the basin slopes. We use these results, together with the profiles 2-AR and 4-AR, to assess the contribution of stretching to the basin subsidence and to reconstruct its evolution. This allows an assessment of the role of different mechanisms in the formation of the basin and its hydrocarbon potential. To determine general regularities in the formation of ultradeep basins, we compare the North Barents basin with some other basins. This makes it possible to define the criterion for distinguishing structures formed mainly by eclogitization of the basaltic layer in a great number of deep sedimentary basins.

## Crustal stretching in the North Barents basin

The formation of deep sedimentary basins by viscous stretching of the lower crust with the splitting of its brittle upper part into faulted blocks was first hypothesized by one of the authors of this paper for the Baikal basin in 1966. After the first publications (Artemjev and Artyushkov, 1971; Artem'ev and Artyushkov, 1968), this mechanism began to be regarded worldwide as the main cause of large crustal subsidence on the continents. Some authors later proposed different models for lithospheric stretching, the most popular of which is "pure shear" (McKenzie, 1978).

During the first stage of the studies, in the absence of seismic data on the structure of the lower part of the sedimentary cover and basement in many deep intraplate basins, lithospheric stretching was only postulated as the cause of their formation. Systems of tilted blocks bounded by large normal faults were revealed in some basins with increasing sounding depth. All the researchers interpret these structures