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The East European Craton (Baltica) before and during the assembly of Rodinia

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Abstract

Prior to participating in Rodinia, the East European Craton (Baltica) had undergone a complex process of development. Many of the structures, which were important during the amalgamation of Rodinia, were formed between ca. 1.7 and 1.4 Ga. From ca. 1.6 Ga onwards, the evolution of the western and eastern parts of this Craton followed very different path. While accretion of juvenile continental crust, and eventually, continental collision took place in the west, rifting and extension consistently dominated in the east.

Between 1.14 and 0.90 Ga, the Sveconorwegian orogeny marked the incorporation of the East European Craton (Baltica) into Rodinia. This process involved four distinct phases related to Baltica's movements. During the 1.14–1.10 Ga Arendal phase there was accretion and early collision, during the 1.05–0.98 Ga Agder phase continent–continent collision took place, while the 0.98–0.96 Ga Falkenberg phase and the 0.96–0.90 Ga Dalane phase involved final convergence and post-collisional relaxation, respectively.

The differences of tectonic regime in the East European Craton during the late Mesoproterozoic were determined by the movement and rotation of this megaterrane concomitantly with the Rodinia assembly. This led to collisional tectonics in the present west while break-up and the formation of passive margins occurred in the east.

Keywords: Rodinia; East European Craton; Baltica; Mesoproterozoic; Sveconorwegian orogeny; Rifting

1. Introduction

The present paper targets the East European Craton (EEC) before and during its incorporation into Rodinia at ca. 1.2–0.9 Ga. A major aim was to assess how and to what extent its characteristics were formed before the assembly of Rodinia, independently of that process.

The EEC is the coherent mass of Precambrian continental crust that occupies almost the entire northeastern half of the European continent (Fig. 1). It was assembled at ca. 1.8–1.7 Ga, roughly concomitantly with the formation of the Palaeo- to Mesoproterozoic, still somewhat hypothetical Columbia/Nuna supercontinent, which appears to have persisted until ca. 1.4 Ga (Hoffman, 1989, 1997; Gower et al., 1990; Condie, 2002; Rogers and Santosh, 2002; Zhao et al., 2004).

After its formation, the EEC has never been dismembered completely, but signs of accretion of new crust and, in particular, rifting along its margins as well as truncated tectonic trends indicate that its size and shape have changed repeatedly (Bogdanova et al., 2005a; Gee and Stephenson, 2006). However, we know little about the nature and timing of these events, and the present whereabouts of the continental crust that was rifted away.

Prior to its incorporation in Rodinia and after the fragmentation of this supercontinent, the EEC repeatedly formed the core of separate continents or belonged to megacontinental assemblages like, for instance the Paleoproterozoic Nuna (Hoffman, 1997) or the Paleo-Mesoproterozoic NENA of Gower et al. (1990). To these continental units as well as to terranes within supercontinents the terms "Baltica" and "Protobaltica" have been applied in different manner (Cocks and Torsvik, 2005).

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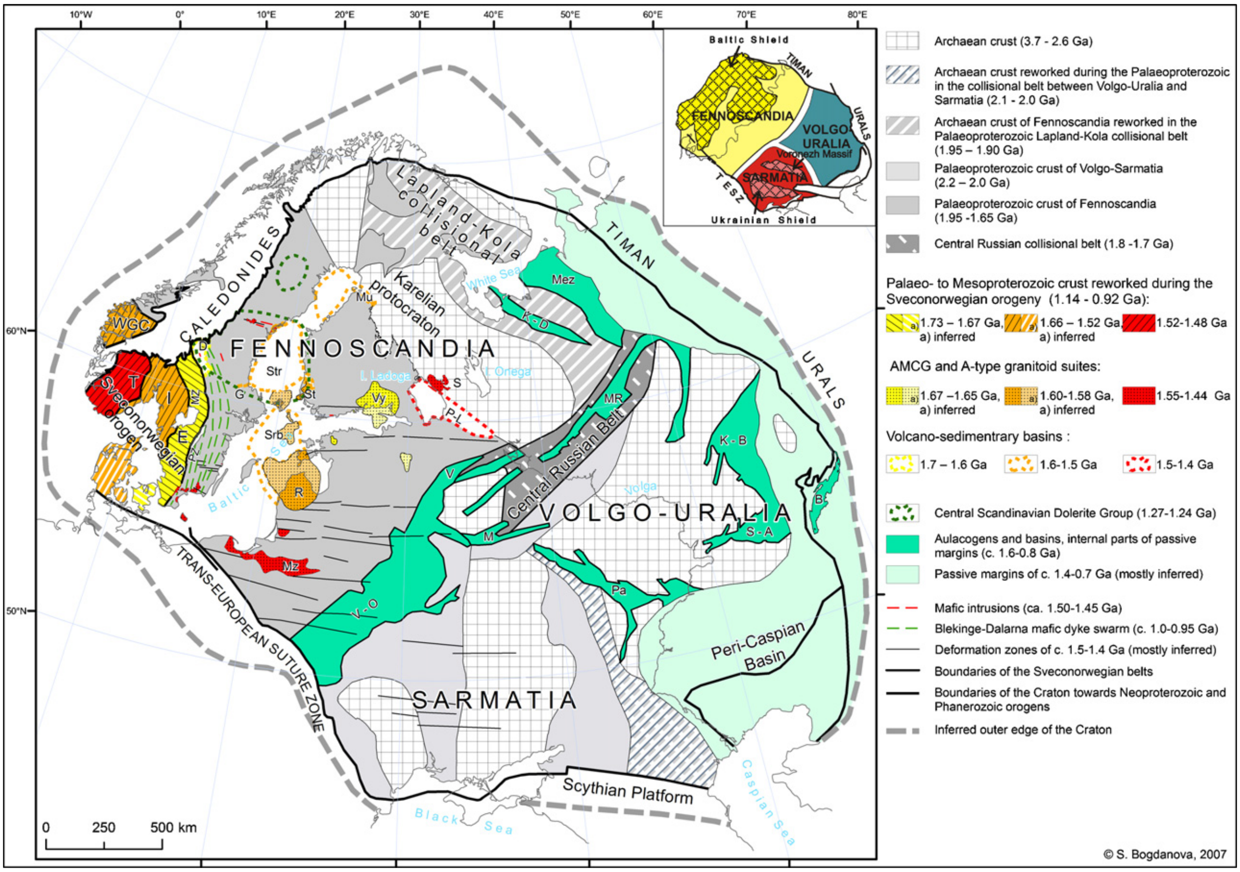

Fig. 1. Late Palaeoproterozoic to Early Neoproterozoic tectonic complexes in the East European Craton (Baltica) © S. Bogdanova. Letters mark: B, Bashkirian uplift (S. Urals); D, Dala basin; E, Eastern Segment; G, Gävle graben; I, Idefjorden terrane; K-B, Kama-Belsk aulacogen; K-D, Kandalaksha-Dvina graben; M, Moscow graben; Mez, Mezen rifts; MR, Mid-Russian aulacogen; Mu, Muhos graben; MZ, Mylonite Zone; Mz, Mazury igneous complex; Pa, Pachelma aulacogen; P-L, Pasha-Ladoga graben; PZ, Protogine; Zone R, Riga pluton; T, Telemarkia; S, Salmi pluton; S-A, Sernovodsk-Abdulino aulacogen; St, Satakunta graben; Srb, Strombus basin; Str, Strömmingsbådan basin; V, Valday graben; V-O, Volyn-Orsha aulacogen; Vy, Vyborg pluton; WGC, Western Gneiss Complex.

In current geological terminology, "Baltica" is thus a paleocontinent (and plate) that was formed by the break-up of Rodinia in the Neoproterozoic and existed until the formation of Laurussia during the Caledonian Orogeny in the mid-Palaeozoic (Gee, 2005).

Particularly in paleomagnetic reconstructions, however, the term "Baltica" is being employed extensively to describe a major terrane that comprised and still comprises the East European Craton as its core. In this sense, "Baltica" is commonly used independently of time and independently of whether the terrane formed separate palaeocontinents, belonged to groups of continents together with, e.g. Laurentia and Amazonia, or constituted part of a supercontinental assembly. In the literature, reference is thus made to "Baltica today" and Paleoproterozoic Baltica, while Cocks and Torsvik (2005) differentiate between "Baltica" after the break-up of Rodinia and "Protobaltica" as part of the Rodinian collage ca. 1 billion years ago.

Although the configurations of the East European Craton and Baltica were not the same as in Late Neoproterozoic–Early Palaeozoic (Dalziel, 1997; Cocks and Torsvik, 2005; Cawood and Pisarevsky, 2006; Li et al., this volume), we use in the present paper the term "Baltica" in a wide terrane sense. This is in order to avoid disagreement with the terminology traditionally used in the Rodinia contexts and maps. Among the Rodinia terranes, Baltica is one of the few for which paleomagnetic data provide good paleogeographic positions. For this reason, it plays a key role in pre-Rodinian and Rodinian reconstructions (Buchan et al., 2001; Pesonen et al., 2003; Pisarevsky et al., 2003).

A major problem in previous Precambrian studies of the EEC has been its Neoproterozoic–Phanerozoic sedimentary cover that hides the crystalline crust in large areas (Fig. 1, inset). It is only exposed in the Baltic Shield in the northwest and the Ukrainian Shield, in the south. During the latest decades, however, numerous deep drillings and good geophysical coverage of the Russian Platform have become available, which provides ample information about the composition and structure of the entire craton. There are also many new TIMS and SIMS zircon ages and new data on the Sm–Nd and other isotopic systems even from the covered platform areas. Lately, new seismic profiling data have been obtained particularly with regard to the formation and architecture of Mesoproterozoic rifts and aulacogens.

2. The crustal segments of the East European Craton

The East European Craton (EEC) was formed between ca. 2.0 and 1.7 Ga by the successive collision of three once autonomous crustal segments/megablocks (Bogdanova, 1993; Gorbatschev and Bogdanova, 1993; Bogdanova et al., 2005a). These are

Fennoscandia, Sarmatia and Volgo-Uralia (Fig. 1). Each of them comprises Archean as well as Proterozoic crust and each still retains a measure of individuality. Fennoscandia includes the Baltic Shield, Sarmatia features exposed ancient crust both in the Ukrainian Shield and partly in the Voronezh Massif (Fig. 1, inset), while the Precambrian basement of Volgo-Uralia is hidden entirely beneath later cover deposits. Paleomagnetic data confirm that the three constituent crustal segments of the EEC had different geographical positions in the early Paleoproterozoic and belonged to different lithospheric plates (e.g. Pesonen et al., 2003).

The assembly of the EEC began at 2.0 Ga when Sarmatia and Volgo-Uralia joined each other to form the Volgo-Sarmatian protocraton. The suture zone comprises a ca. 2.10–2.05 Ga belt of juvenile crust at the edge of Sarmatia in the present west, which is in tectonic contact with remnants of a passive margin of Volgo-Uralia. All the rocks within the suture zone underwent metamorphism, migmatization, S-type granitic magmatism and deformation between 2.05 and 2.02 Ga (Shchipansky and Bogdanova, 1996; Shchipansky et al., 2007). The Volgo-Sarmatian protocraton existed as a separate unit until ca. 1.8–1.7 Ga when it docked with Fennoscandia and a unified craton was created.

In the Meso- and Neoproterozoic, the Paleoproterozoic collisional sutures between the three original crustal segments of the EEC were reactivated by rifting, the resultant Pachelma, Mid-Russian and Volyn-Orsha aulacogens still marking the sites of the one-time segment boundaries (Bogdanova et al., 1996; Kostyuchenko et al., 1999; Suleymanov et al., 2007).

In short outline, the pre-collisional histories of the three crustal segments were as follows.

2.1. Fennoscandia

The Archean evolution of Fennoscandia can be traced back to ca. 3.5–3.2 Ga, when a continental core was created in its present southeastern part (Slabunov et al., 2006). In addition, other minor ancient blocks are found in various places in Finland (Kröner and Compston, 1990; Huhma et al., 2004; Sorjonen-Ward and Luukkonen, 2005). Between 3.1 and 2.7 Ga, several events of accretion formed the larger Fenno-Karelian granite–gneiss–greenstone protocontinent, while minor continental blocks of that age occur farther northeast. From 2.5 to 2.0 Ga, however, the Archean craton was rifted and disrupted. Small oceans were opened, some crust drifted away altogether, and eventually a wide passive margin was developed along what is now the southwestern and southern edges of the former craton (e.g. Mints et al., 1996; Nironen, 1997; Lahtinen et al., 2005).

The formation of continental crust in present southwestern Fennoscandia took place during several episodes of accretion, which are referred to the Svecofennian complex of orogenic events between ca. 1.95 and 1.85 Ga (Gaál and Gorbatschev, 1987; Gorbatschev and Bogdanova, 1993; Nironen, 1997; Lahtinen et al., 2005). After 1.85 Ga, Paleoproterozoic growth of crust continued semi-simultaneously with the collision between Fennoscandia and Volgo-Sarmatia (Bogdanova et al., 2006). In southeastern Sweden, three episodes of accretion toward the present south–southwest at 1.83–1.82, 1.81–1.78 and 1.77–1.75 Ga have been distinguished (Andersson et al., 2004; Mansfeld et al., 2005; Johansson et al., 2006), which led to the formation of E–W to NW–SE trending belts of juvenile crust and continental magmatic arcs.

Concomitantly with the early stages of the Svecofennian orogeny, several Archean crustal blocks collided in the present north, where the Lapland-Kola Orogen (Fig. 1) was developed (Daly et al., 2006; Tuisku and Huhma, 2006).

2.2. Sarmatia

In Sarmatia, the outlines of the structural pattern are determined by several separate Archean microcontinents with the ages of the crust of 3.7–2.8, 3.6–2.8, 3.2–3.0 and 2.7–2.6 Ga, which are intervened by belts of 2.2–2.1 Ga Paleoproterozoic crust (Shchipansky and Bogdanova, 1996; Shcherbak et al., 2005; Claesson et al., 2006; Shchipansky et al., 2007). In the Paleoproterozoic belts and in zones of reworking within the Archean domains, the tectonic grain of Sarmatia mostly trends N–S. However, it changes abruptly to NE–SW along the northwestern margin of this crustal segment, where a continental-margin igneous belt was formed at 2.0–1.95 Ga (Bogdanova et al., 2006). For some distance, this belt also continues along the northwestern margin of Volgo-Uralia, which indicates that Sarmatia and Volgo-Uralia had joined each other by that time (Bogdanova et al., 2004a).

2.3. Volgo-Uralia

Volgo-Uralia is located in the eastern part of the EEC, and is still a somewhat enigmatic crustal segment hidden by an extensive younger platform cover. Its Precambrian crust is mostly Archean, with large belts of 3.0–2.7 Ga meta-sedimentary and meta-igneous granulites, and subordinate komatiite-bearing greenstone sequences. Granitoid gneisses with ages above 3.3 Ga have recently been discovered (Bogdanova et al., 2005b).

Superimposed on the Archean patterns are large Paleoproterozoic dome-like structures, which were formed either by diapirism (Bogdanova, 1986) or by large-scale fold interference. These contrast distinctly with the Paleoproterozoic tectonic styles in Fennoscandia and Sarmatia. Paleoproterozoic metasupracrustal formations with numerous granitoid intrusions occur both in the interior parts of the "domes" and in extensive areas along some of the margins of Volgo-Uralia where they are dominated by turbiditic pelites and greywackes with some carbonaceous rocks. Metamorphism and anatectic remelting of these deposits took place at ca. 2.05–2.02 Ga (U–Pb zircon, TIMS and SHRIMP ages), which is also the time when Volgo-Uralia and Sarmatia collided (Shchipansky and Bogdanova, 1996; Kremenetsky et al., 2007; Shchipansky et al., 2007).

3. 1.8–1.7 Ga: amalgamation of the East European Craton

The period between 1.8 and 1.7 Ga was the time when Fennoscandia and Volgo-Sarmatia approached each other and

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eventually docked along a suture subsequently outlined by the Volyn-Orsha and Mid-Russian aulacogens (Fig. 1). This process may have involved rotation of Volgo-Sarmatia relative to Fennoscandia (Pesonen et al., 2003) with associated transcurrent movements (Bogdanova et al., 1996). An indication of the time of docking may be the development of numerous transpressional, mostly dextral, shear zones in Fennoscandia at 1.82 Ga (Högdahl and Sjöström, 2001; Väisänen and Skyttä, 2007), but similar processes also occurred much later, at about 1.7 Ga (Bergman et al., 2006).

Oblique collision between Fennoscandia and Volgo-Sarmatia in a NNW direction at 1.84–1.80 Ga (the "Svecobaltic Orogeny") has been invoked by Lahtinen et al. (2005) to explain the formation in southern Finland of a granite–migmatite belt associated with shearing and thickening of the crust. However, the events in southern Finland may also have been related to the early stages of the semi-simultaneous, ca. 1.83–1.75 Ga, multiphase accretionary growth of continental crust in southeastern Sweden (Mansfeld et al., 2005; Johansson et al., 2006), and western Lithuania and Latvia (Claesson et al., 2001; Mansfeld, 2001; Bogdanova et al., 2006), which was directed toward the present south–southwest (cf. Section 2).

Other processes possibly related to the collision between Volgo-Sarmatia and Fennoscandia may have been the 1.80–1.78 Ga post-collisional granitoid magmatism around the Gulf of Finland (Ehlers et al., 1993; Eklund et al., 1998; Korsman et al., 1999) and NNW–SSE compression along the "Finlandia Shear System" of Kärki and Laajoki (1995). The latter comprised several stages of thrusting as well as dextral and sinistral shearing of the Archean crust. In consequence, some Archean crustal blocks were displaced relative to each other, while Paleoproterozoic complexes were thrust atop the Archean basement. Voluminous granitoid and mafic magmatism along extensional fault zones in the Archean and Paleoproterozoic crust took place at ca. 1.80–1.75 Ga both in northern Finland (Nironen, 2005 and references therein), the Kola region and southern Karelia (Svetov, 1979; Vetrin et al., 2002).

In Sarmatia, the collision of Volgo-Sarmatia with Fennoscandia caused extensive re-arrangement of the Archean and Paleoproterozoic upper lithosphere, and major AMCG (=anorthosite–mangerite–charnockite–granite) magmatism between 1.80 and 1.74 Ga (Bogdanova et al., 2004b, 2006).

The structural evolution in the Central Russian collisional belt between Fennoscandia and Volgo-Sarmatia (Fig. 1) is still known poorly. This belt contains a number of displaced crustal blocks, some derived from Fennoscandia, others from Volgo-Uralia (Bogdanova et al., 1996). In its northwestern part, a titanite age of ca. 1.75 Ga from a strongly sheared ca. 2.5 Ga monzonite (U–Pb zircon TIMS) suggests that tectonic reworking took place during that time (Samsonov et al., 2005). The Meso- to Neoproterozoic grabens within the Central Russian Belt define a pattern, which may have been inherited from late Paleoproterozoic collisional structures. New seismic reflection and refraction profiling across the Central Russian belt has clearly demonstrated the presence of thick crustal roots, and wedges of Fennoscandian upper lithosphere that dip beneath the edge of Volgo-Sarmatia (Suleymanov et al., 2007). Similarly, numerous deformation zones dipping to SE make up the Volgo-Uralian crust (Trofimov, 2006), which can have been related to the 1.85–1.80 Ga reworking of the Archean and Paleoproterozoic rocks (Bogdanova, 1986; Bogdanova et al., 2005b).

4. The East European Craton between 1.7 and 1.4 Ga: diversity of tectonic regimes within a supercontinent

During most of the time between ca. 1.7 and 1.4 Ga, the EEC appears to have been part of Palaeo- to Mesoproterozoic Columbia supercontinent (Karlstrom et al., 2001; Rogers and Santosh, 2002; Zhao et al., 2004) and the Mid-Proterozoic Laurentia–Baltica NENA megacontinent (Gower et al., 1990), with its present western marginal parts facing zones of subduction (Rogers and Santosh, 2002). Thus, they were sites of convergent orogenic tectonics, whereas basin formation and intracratonic magmatism took place farther inland. In the central and eastern parts of the EEC, platform cover was deposited simultaneously with incipient rifting.

In the following text, these different tectonic settings and regimes are reviewed.

4.1. Accretion in the southwest

After the formation of the youngest EW-trending crustal belts in present southeastern Sweden around 1.75 Ga (cf. Section 2), accretionary growth of new crust in the southwestern part of the EEC was soon resumed, but now that growth was directed toward the west rather than the south–southwest (modern coordinates).

Between ca. 1.73 and 1.48 Ga, a succession of roughly NS-trending crustal belts was formed (Fig. 1). These are arranged in a consistently westwards younging order, but a subject of current discussion is whether their formation was due to semi-continuous albeit episodic accretionary growth of the crust at the margin of Fennoscandia (the Gothian complex of orogenic events between ca. 1.75 and 1.55 Ga, Gaál and Gorbatschev, 1987; Åhäll and Gower, 1997), or whether collision between the EEC and exotic, entirely foreign, terranes had been involved (J. Andersson et al., 2002; Cornell and Austin Hegardt, 2004).

From east to west, the following rock belts can be distinguished:

(1) Farthest east is the terrain between the so-called Protogine Zone and Mylonite Zone (Figs. 1 and 9), where continental crust was formed between ca. 1.73 and 1.67 Ga. This is Berthelsen's (1980) Eastern Segment of the Sveconorwegian Orogen, which has also been described as a combination of the Ätran terrane in the south and the Klarälven terrane in the north (Åhäll and Gower, 1997).
(2) To the west of the Mylonite Zone, three different rock belts occur in the Idefjorden terrane (Åhäll and Gower, 1997). Amongst these, the supracrustal Horred Formation in the extreme southeast has an age of 1.66 Ga, while the Åmål belt in the east and the Østfold-Marstrand belt in the west (Åhäll et al., 1998) were formed at ca. 1.64–1.59 and 1.59–1.55 Ga, respectively. Both feature supracrustal and differentiated plutonic lithologies, the TTG suite of plutonic rocks in the

Østfold-Marstrand complex also intruding the Horred and Åmål belts.

(3) Still farther west, the relatively small Bamble and Kongsberg terranes form a strongly tectonized belt separating the Idefjorden terrane from the 1.52 to 1.48 Ga Telemarkia terrane (Bingen et al., 2005) in southern Norway (T, in Fig. 1).

A notable feature of the Eastern Segment (the Ätran and Klarälven terrains) are large, ca. 1.73–1.67 Ga, commonly alkali-calcic A- and I-type granitic intrusions, which belong to the younger part of the Transscandinavian Igneous Belt (TIB, Högdahl et al., 2004). These are concentrated predominantly to the boundary between southeastern and southwestern Sweden along the Protogine Zone but also occur deep inside these domains.

In the part of Norway west of the Caledonide belt there are numerous Precambrian rocks in the Western Gneiss Region and the Vestranden terrane (WGG in Fig. 1). They resemble the lithologies in the Idefjorden terrane and Eastern Segment, but the ages are mostly between ca. 1.69 and 1.64 Ga (Tucker et al., 1990; Austrheim et al., 2003; Skår and Pedersen, 2003), which fits neither of these two terrains precisely.

A common characteristic of the majority of these rock groups is that they were formed in igneous belts along active continental margins, an exception being the ca. 1.59–1.55 Ga metavolcanics in the Østfold-Marstrand belt, which originated in either oceanic island arc (Åhäll et al., 1998) or back-arc (Cornell et al., 2000) settings. A particular case is the 1.51–1.50 Ga Rjukan volcanics in the Telemarkia terrane, which shows a continental-rift chemical signature (Brewer et al., 1998), but can still have been formed in an active continental margin. Along the boundary between the Telemarkia and Idefjorden terranes, in consequence, collisional tectonics have been proposed both for the ca. 1.55–1.50 Ga period (Åhäll et al., 2000) and the Sveconorwegian orogeny (Berthelsen, 1980; Bingen et al., 2005).

With regard to the role of the Mylonite Zone, the tectonic belt between the 1.73–1.67 Ga Eastern Segment and the 1.66–1.52 Ga Idefjorden terrane (MZ in Fig. 1), interpretations have differed. While it has mostly been seen as a boundary between two successively formed crustal belts in Fennoscandia, that was reactivated during the Sveconorwegian orogeny (e.g. Gorbatschev and Bogdanova, 1993; Åhäll and Gower, 1997; Bingen et al., 2005, 2006), other authors have emphasized the different ages of the adjoining terranes and the intensity of deformation along the Mylonite Zone (e.g. J. Andersson et al., 2002). On the basis of their interpretation of age and P-T data, Cornell and Austin Hegardt (2004) recently suggested that the adjoining terranes had nothing in common until late in the Sveconorwegian orogeny, when the whole Eastern Segment was involved in a subduction–exhumation cycle. The principal objections against this interpretation emphasize the consistent, virtually uninterrupted, westward younging of the adjoining rock belts and the good correlation of the orogenic episodes at the western edge of the EEC with events of deformation and intracratonic magmatism farther inside the Craton (Åhäll et al., 2000 and cf. below). In addition, no active-margin or oceanic Sveconorwegian lithologies whatsoever are known from the eastern foreland of the Mylonite Zone.

Subsequent to their formation, almost all the Precambrian rock complexes and structures in southwestern Sweden and southernmost Norway were reworked during the ca. 1.14–0.95 Ga Sveconorwegian orogeny (Figs. 1 and 9), which affected the entire territory to the west of the "Protogine Zone" (PZ in Fig. 1), one of the most important lithospheric boundaries in southern Fennoscandia (Andréasson and Rodhe, 1990; Claeson, 2003; Gorbatschev and Bogdanova, 2004).

While the PZ has been described as a "Sveconorwegian Front" (Wahlgren et al., 1994; Stephens et al., 1996), it is rather a product of recurrent deformation between ca. 1.7 and 0.7 Ga. Originally, it separated ca. 1.7 Ga accreted crust from an older foreland in the east but was thereafter deformed around ca. 1.45 Ga, outlined by ca. 1.57–1.56 Ga gabbro and 1.22–1.20 Ga syenite and dolerite intrusions, and reactivated also by extensive rifting at ca. 0.8–0.7 Ga (Andréasson and Rodhe, 1990; Connelly et al., 1996; Claeson, 1999; Söderlund et al., 2004; Söderlund and Ask, 2006).

4.2. *Fennoscandian interiors: 1.65–1.50 Ga AMCG magmatism and basin formation*

Simultaneously with the accretion of new continental crust in westernmost Fennoscandia, substantial structural reworking and igneous activity affected the rest of that crustal segment. Åhäll et al. (2000) were the first to point out the coincidence in time of the accretionary orogenic events with the rapakivi-granitic igneous activity in the interior parts of Fennoscandia that took place particularly at ca. 1.65–1.62, 1.59–1.56, 1.55–1.53 and 1.53–1.50 Ga (Fig. 1). The easternmost of these intrusions are nearly 1000 km from the belts of juvenile crust in the west and were previously considered "anorogenic".

The rapakivi-granitic A-type magmatism was part of a more extensive AMCG igneous activity, which formed large plutons as well as minor diapiric bodies. Within the upper levels of the AMCG plutons, the most widespread rocks are granites, while gabbro-anorthosites tend to underlie them in the middle and lower crust (Korja et al., 2001). Dolerite dykes often accompany the plutons, either occurring in their immediate surroundings or forming extensive swarms between the granite intrusions (Haapala and Rämö, 1992; Rämö et al., 1996; U.B. Andersson et al., 2002; Rämö and Haapala, 2005).

Characteristically, the AMCG intrusions associate with large fault-bounded, in part semi-circular basins, which are exposed at Earth's surface or have been recorded by geophysical surveys (Korja et al., 1993; All et al., 2006). These depressions are filled with conglomerates, arkosic to subarkosic fluviatile and aeolian sandstones, and subordinate shales, all interbedded with mafic and felsic igneous rocks (Kohonen and Rämö, 2005). The greatest thicknesses of the basin and graben sequences are ca. 2 km on land and up to 4 km seismically (BABEL, 1993; Korja et al., 2001). Good instances of such structures are the Satakunta, Gävle and Pasha-Ladoga basins. They represent a long volcano-sedimentary evolution, which lasted during the emplacement of the gabbro-anorthosite-rapakivi intrusions between ca. 1.65

and 1.50 Ga (e.g. U.B. Andersson et al., 2002; Rämö and Haapala, 2005). The earliest igneous activity is recorded by ca. 1.65 Ga dolerite dykes around the Vyborg rapakivi pluton and in swarms trending parallel to the long axis of the Satakunta basin (Kohonen et al., 1993; Kohonen and Rämö, 2005). The sedimentation occurred at least at ca. 1.5 Ga, as indicated by the ca. 1499 ± 30 Ma Sm–Nd mineral-isochron age of a basalt in the Pasha-Ladoga graben (Bogdanov et al., 2003) and the 1457 ± 2 Ma U–Pb baddelyite age of a dolerite sill in that structure (Rämö et al., 2005). It cannot be excluded, however, that these basins were depocentra also much later, e.g. during the ca. 1.27–1.24 Ga dolerite magmatism in almost the same areas (Fig. 1, cf. Section 5).

In the Gulf of Finland, a volcano-sedimentary succession occurs on the island of Suursaari/Hogland (Puura et al., 1983). That sequence has an exposed thickness of ca. 200 m. It rests atop Paleoproterozoic gneisses and features basal quartzites and quartzite conglomerates overlain by agglomerates and flows of labradorite porphyrites. Quartz porphyries follow discordantly higher up. These rocks are chemical equivalents of the Vyborg rapakivi granite; a quartz-porphyry in the lower part of the sequence having an age of ca. 1.64 Ga (U–Pb zircon, TIMS, Bogdanov et al., 1999).

The Satakunta basin is part of the large South Bothnian depression (Korja et al., 2001) with many on-shore and island exposures on both sides of the Gulf of Bothnia (Fig. 1). The more than 1.5 km thick Satakunta Formation (St in Fig. 1) consists of various red-bed sandstones, conglomerates, and thin mudstone layers. On the western side of the Gulf of Bothnia, the rift-compressed Gävle basin (G in Fig. 1) contains conglomerates, gravelstones, arkoses, subarkoses, siltstones and minor shales as well as an extensive sheet of dolerite. The total thickness of these rocks has been estimated to between 800 and 1000 m (Gorbatschev, 1967). Detritus derived from porphyries with ages of either 1.70 or 1.57 Ga and a cross-cutting 1.26-Ga dolerite neck (Söderlund et al., 2006) constrain the age of the Gävle Formation to the same range as that in Satakunta.

In the Pasha-Ladoga graben (PL in Fig. 1), the almost 300 m thick Salmi Formation is a sequence of red-bed arkoses, siltstones, conglomerates, tuffs and cross-bedded tuffitic sandstones. Similarly to the other pre-1.5-Ga sedimentary sequences mentioned above, this formation was deposited in a basin related to the AMCG magmatism, in this case the ca. 1.55–1.53 Ga Salmi intrusion (Amelin et al., 1997).

Most probably, the large offshore Strombus and Strömmingsbådan basins, and the depositional basin of the Muhos Formation (Fig. 1) were all developed in the same way as the Satakunta and Gävle basins. Strombus is associated with the ca. 1.58 Ga Riga AMCG pluton and the 1.60–1.59 Ga Breven-Hällefors dolerite dykes (All et al., 2006), while the Strömmingsbådan basin is close to the ca. 1.58 Ga Nordingrå and the 1.52–1.50 Ga Ragunda and Rödön rapakivi, syenite and gabbro suites (Persson, 1999; U.B. Andersson et al., 2002). Characteristically, their lowermost deposits were all formed in similar continental, land-locked basins vicinal to areas of high relief and coeval AMCG igneous activity.

At ca. 1.54–1.50 Ga, the large AMCG Mazury complex was intruded into the Paleoproterozoic crust of northeastern Poland and Lithuania (Dörr et al., 2002; Wiszniewska et al., 2002; Skridlaite et al., 2003). Some sedimentary basins in central Poland may also be related to that event (Kubicki and Ryka, 1982).

The western part of the EEC thus appears to have been a fairly hilly territory between 1.7 and 1.5 Ga, possibly uplifted by AMCG intrusions separated by intervening depositional basins (Fig. 1). As estimated by Puura and Floden (1999), the presently exposed depth levels of these intrusions were originally 3–4 km below Earth's surface. This explains why the volcanic cover of the plutons is almost solely found in relatively large basins.

4.3. 1.5–1.4 Ga: collision, deformation and magmatism during the Danopolonian Orogeny

During the period between 1.5 and 1.4 Ga, substantial regions in the western part of the East European Craton were affected by igneous activity, metamorphism and deformation suggesting a sequence of major orogenic events for which the name "Danopolonian Orogeny" has been proposed (Bogdanova, 2001).

Intracratonic granitoid magmatism and associated metamorphism and migmatization of older rocks were particularly intense at 1.47–1.42 Ga in southern Sweden, and also occurred in Lithuania, northern Poland and on the Danish island of Bornholm (Kornfält and Vaasjoki, 1999; Čečys et al., 2002; Söderlund et al., 2002; Čečys, 2004; Cymerman, 2004; Johansson et al., 2004; Obst et al., 2004; Čečys and Benn, 2006; Johansson et al., 2006; Motuza et al., 2006; Skridlaite et al., 2007). In this large region, the $^{40}Ar/^{39}Ar$ ages of amphiboles from various rocks range between ca. 1.50 and 1.45 Ga (Beunk and Page, 2001; Bogdanova et al., 2001).

A characteristic Danopolonian feature in southern Fennoscandia and the adjoining part of Sarmatia is extensive faulting along large, nearly EW-trending, zones of shearing, which cut the Paleoproterozoic regional tectonic grain at high angles (Fig. 1). Some of these are reactivated late Paleoproterozoic shear zones. These zones and linked NW-striking shears accommodated a number of granitoid intrusions, which were emplaced syntectonically (Fig. 2) into the upper and middle crust at ca. 1.47–1.42 Ga, during generally NE–SW compression (Čečys et al., 2002; Cymerman, 2004; Čečys and Benn, 2006; Motuza et al., 2006).

In the Eastern Segment of the Sveconorwegian Orogen, which represents a deeper erosion level than the terrains farther east beyond the Protogine Zone (PZ in Fig. 1), migmatite formation was widespread at ca. 1.46–1.42 Ga (Larson et al., 1986; Christoffel et al., 1999; Söderlund et al., 2002; Appelquist et al., 2006; Möller et al., 2006). Metamorphic charnockitization and mafic–charnockitic–granitic magmatism (the "Hallandian event" of Hubbard, 1975) occurred ca. 1.40 Ga (Christoffel et al., 1999; Rimša et al., in press), while the latest associated granites were formed at 1.38 Ga (Ahäll et al., 1997; Andersson et al., 1999). In any case, the Hallandian event can either have

Fig. 2. The Danopolonian Orogeny. The syntectonic coarse "A"-type granitoids of ca. 1.45 Ga age on the Danish island of Bornholm. Both magmatic and solid-state foliations are EW-trending and gently N-dipping. Top-to-the south lineation is dipping similarly. Photograph by S. Bogdanova.

been post-collisional in relation to the Danopolonian Orogeny or forebode later crustal extension in the entire EEC. Roughly simultaneously there also appears to have been N–S to NE–SW compression and folding in the Eastern Segment. However, this deformation has also been referred to the Sveconorwegian orogeny (Bingen et al., 2006).

Altogether, the structural, geochronological and geological data suggest that the Danopolonian orogeny was related to collision between the Mesoproterozoic EEC (Baltica) and another continent, presumably Amazonia or some of other South-American terranes (Bogdanova, 2001). These two continental blocks had much in common during the early Mesoproterozoic (Geraldes et al., 2001; Tohver et al., 2005; Teixeira et al., 2006; Fuck et al., this volume). However, paleomagnetic studies in Amazonia to define its position at 1.5–1.4 Ga are still lacking.

Simultaneously with the Danopolonian Orogeny, rifting and the formation of continental basalts and mafic dykes occurred in various parts of the western EEC. The Salmi Formation in the NW-striking Pasha-Ladoga graben is a good example of such magmatism (cf. above; P-L in Fig. 1). Its ca. 1.50–1.46 Ga continental andesitic and porphyritic basalts, and volcanoclastic materials compose several flows, while a swarm of coeval mafic dykes marks the northeastern flank of the graben (Svetov, 1979; Amantov et al., 1996; Bogdanov et al., 2003). A ca. 1.46 Ga thick sill of olivine dolerite, a feeder stock of the Salmi volcanics, intruded into the Salmi deposits (Rämö et al., 2005). Swarms of ca. 1.46 Ga dolerite dykes are present also in southern Finland (Luttinen and Kosunen, 2006) and in central Sweden (Söderlund et al., 2005), where they are associated with ca. 1.47 Ga quartz porphyries and a rapakivi-type granite intrusion (Claesson and Kresten, 1997). It is notable that all these rocks appear to occur in NW-trending extension-related structures, which are paired to the approximately NE–SW-directed Danopolonian convergence and may have been its "back-arc" effect.

4.4. Deep interiors of the craton: stability followed by rifting

While accretionary orogeny characterized the marginal parts of the EEC in the present west at 1.7–1.5 Ga and collisional orogeny affected the southwest between 1.5 and 1.4 Ga, very different tectonic regimes prevailed in the central, southern and eastern parts of the craton.

During the earlier part of that period, cover sediments were deposited atop the now stable crystalline basement, but from ca. 1.5 Ga onwards, successively more intense rifting followed concomitantly with the early stages of the Danopolonian Orogeny. Close to the eastern margin of the craton, initially abortive attempts at break-up began even earlier, at 1.6–1.5 Ga as described below.

4.4.1. The inferred oldest craton cover

Deep drillings in the Pachelma aulacogen, the Moscow graben and some of the grabens in the Mid-Russian and Volyn-Orsha aulacogens (Figs. 1 and 3) have disclosed finely interbedded quartzitic sandstones and gravelstones as well as kaolinite–sericite phyllites in the basal parts of these structures. In the various grabens, the cumulative thicknesses of the deposits vary between ca. 400 and 1200 m. The predominant, nearly monomictic, orthoquartzitic compositions of these sandstones and their high degree of sorting indicate deposition of well-weathered materials in shallow-water marine, lacustrine and deltaic environments (Kheraskova et al., 2002). In seismic profiles, such deposits are easily distinguished by their characteristically cross-cutting, wavy reflection patterns, which are also found in the unrifted parts of the platform. Thus it can be inferred that the mature, well-sorted, quartzitic–phyllitic deposits once covered rather large platform areas, their present seemingly predominant occurrence in the grabens only reflecting better protection against erosion and better disclosure by deep drillings.

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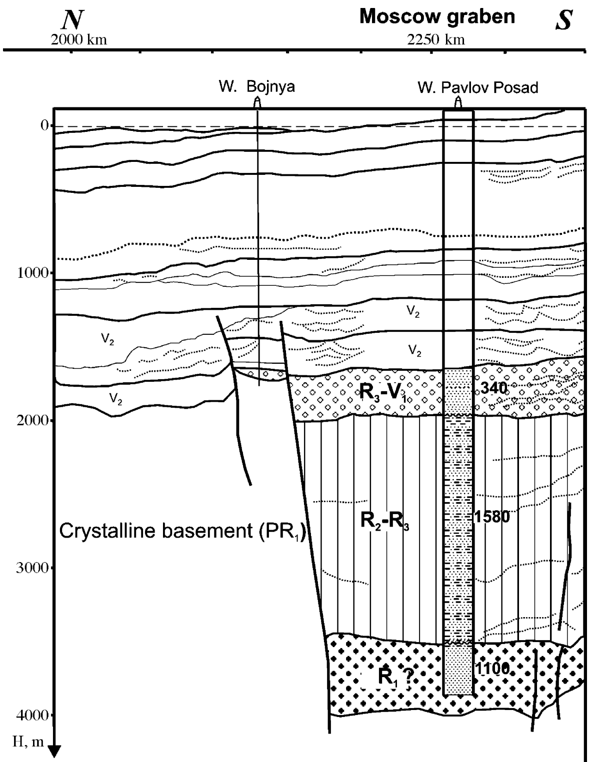

Fig. 3. A fragment of Geotransect Ev-1 (Lodeynoye Pole-Voronezh) showing the position of the Mesoproterozoic deposits in the Moscow graben (modified after Kheraskova et al., 2006). In the Pavlov Posad drilling well, the deposits are: quartz sandstones of the Calymmian (R_1?), subarkosic sandstones and siltstones of the 1.4–1.0 Ga Ectasian and Stenian (R_2–R_3), and arkosic sandstones of the 1.0–0.85 Ga Tonian and Cryogenian (R_3–V_1). V_2 denotes Ediacaran (<0.63 Ga) deposits. The upper sequences are Paleozoic and Mesozoic. The numbers along the well log indicate the thicknesses of the deposits. Thin dashed lines mark seismic reflectors.

As rifting progressed, some of the oldest sediments in the rift grabens were disrupted, tilted and folded. This is seen well in the Kandalaksha-Dvina graben (K-D in Figs. 1 and 5), in the northeastern part of the craton. The ages for these repeatedly recycled sediments are circumstantial and not determined precisely. These deposits could therefore also be equivalents of the oldest known quartzites around Lake Onega in the Baltic Shield, which are cut by gabbro-dolerites of 1770 ± 12 Ma age (U–Pb zircon TIMS; Bibikova et al., 1990). Seismically (Figs. 5 and 8), they occur below the syn-rift deposits related to the major rifting in the EEC at ca. 1.4–1.2 Ga. The latter, in turn, underlie paleontolologically and isotopically dated Tonian (1.00–0.85 Ga) deposits (cf. below).

4.4.2. *Rifting in the east: attempts at break-up from 1.6 Ga onwards*

Farthest in the east, along and within the southern Urals (Fig. 1), there are exposed up to 6 km thick sedimentary cover successions, which contain flows, lava breccias and tuffites of mostly trachybasaltic compositions (Alekseev, 1984; Kozlov et al., 1989; Maslov, 2004; Ernst et al., 2006). From these strata, Calymmian ages of 1.6–1.4 Ga have been obtained by isotopic dating and paleontological analysis (Maslov, 2004; Semikhatov et al., 2006). Very commonly, the rocks are diverse and rather poorly sorted. In the Burzyan Group, for instance, the lower parts contain sedimentary breccias, conglomerates, poorly sorted arkosic and lithic sandstones, and some siltstones and black shales (Fig. 6). Close to the base of the sequence, a dacitic porphyry has yielded a U–Pb TIMS zircon age of 1615 ± 45 Ma (Krasnobayev, 1986).

With time, the Calymmian sedimentation changed from immature continental to shallow marine, and thick massive and bedded limestones and dolostones were deposited, many of these stromatolitic (Fig. 6). From two limestones, Pb–Pb ages of 1550 ± 50 and 1430 ± 30 Ma have been reported, which fits well with the stratigraphical positions of the dated samples (Semikhatov et al., 2006). Black shales and siltstones characterize the uppermost Calymmian in this sequence. A discordantly overlying succession of ca. 1.4–1.0 Ga sedimentary rocks with associated bimodal igneous intrusions defines the upper boundary of that sequence (cf. Section 5).

Farther west, in the Kama-Belsk and Sernovodsk-Abdulino aulacogens (K-B and S-A in Fig. 1), terrigeneous and carbonate deposits dominate the sedimentary piles, which reach thicknesses of up to 9 km (Figs. 6 and 7). The settings of this sedimentation have been described as alluvial, deltaic, and shallow- to deep-shelf marine (Maslov, 2004). Mesoproterozoic (Calymmian) ages have mostly been deduced from stromatolites and from K–Ar datings of 1.49–1.43 Ga glauconite and Rb–Sr datings of argillites, which yielded 1.48–1.41 Ga (e.g. Maslov, 2004 and references therein). Cross-cutting mafic dykes have K–Ar ages of 1.38–1.37 Ga (Fig. 6).

The modes of sedimentation, the substantial thicknesses of the deposits and the presence of bimodal mafic to felsic magmatic rocks all suggest attempts at rifting in the early Mesoproterozoic. In this context, it is interesting to note the low $^{87}Sr/^{86}Sr$ initial ratios (0.70460–0.70480) of the carbonates in the Calymmian section of the southern Urals. These indicate that the depocentra of that time must have been connected to the world ocean (Semikhatov et al., 2002, 2006), and rifting can thus have been associated with the development of a passive margin.

5. 1.4–1.2 Ga: rifting and igneous activity

From ca. 1.4 Ga onwards, the tectonic regimes in the EEC changed radically. The 1.5–1.4 Ga Danopolonian Orogeny in the southwest was over and in many places mafic and within-plate bimodal magmatism signalled extension and rifting (e.g. Åhäll and Connely, 1998).

In westernmost Fennoscandia, deposition of thick quartzite-dominated sandstones took place atop the Telemarkia terrane (Bingen et al., 2002; Laajoki et al., 2002), while the Idefjorden terrane features similar but still undated sandstones with ca. 1.3 Ga dolerites (Söderlund et al., 2005), and a semi-continuous belt of 1.34–1.31 Ga granite intrusions derived from partial melting of the crust at various depth levels (Holme, 2001). This belt extends ca. 400 km along the entire exposed length of the terrane.

Farther inland, mafic dyking and bimodal magmatism between ca. 1.4 and 1.2 Ga affected various parts of western Fennoscandia (Åhäll and Connely, 1998; Christoffel et al., 1999; Brewer et al., 2004; Cornell and Austin Hegardt, 2004). Red-bed sandstone deposition continued within and in the vicinity of the ca. 1.6–1.5 Ga AMCG related depocentra.

Between ca. 1.27 and 1.24 Ga large areas around the northern Baltic Sea in Sweden and Finland were involved in episodic mafic igneous activity (Gorbatschev et al., 1987; Suominen, 1991; Elming and Mattson, 2001; Kohonen and Rämö, 2005; Söderlund et al., 2005, 2006), which created a province of numerous large dolerite sheet intrusions (Fig. 1) but apparently only a few dykes (the Central Scandinavian Dolerite Group). This magmatism has played a role in the discussion of pre-Rodinian geodynamic settings, where it has been referred to a mantle plume assumedly responsible for the continent break-up at ca. 1.25 Ga that separated the EEC (Baltica) from Laurentia (e.g. Buchan et al., 2000). By re-examining the different interpretations, Söderlund et al. (2006), however, concluded that the 1.27–1.24 Ga mafic magmatism can be explained better by prolonged hot-spot activity or alternating extension–compression along a continuous Baltica–Laurentia margin. The latter model re-substantiates the original interpretation of Gorbatschev et al. (1987).

In southern Sweden somewhat later, the bimodal Protogine-Zone magmatism at ca. 1.22–1.20 Ga marked another major event of extension manifested by several bodies of syenite and monzogranite as well as large swarms of NS-trending dolerite dykes, all aligned with the PZ (Fig. 1), but with the dolerites also occurring scores of kilometres farther to the west (Connelly et al., 1996; Söderlund et al., 2005; Söderlund and Ask, 2006).

In the central and eastern EEC, extension between 1.4 and 1.2 Ga created large aulacogens and presumable passive continental margins (Fig. 1). Particularly intense tectonic activity occurred in zones trending roughly NW to NNW, in the first place the marginal zone of the craton facing the much later Timanide (ca. 0.6 Ga) and Uralide (ca. 0.3 Ga) orogenic belts, but also the neighbouring Mezen' and the more distant Pachelma zones of rifting. The Mezen' zone follows the Lapland-Kola Paleoproterozoic collisional belt, while the Pachelma aulacogen (Pa in Fig. 1) runs parallel with but somewhat to the north of the collisional zone between Volgo-Uralia and Sarmatia.

The Pachelma aulacogen extends from the vicinity of Moscow to the Peri-Caspian basin, possibly representing one arm of a Proterozoic triple-point system where the other two arms trend nearly parallel to the northern and northwestern margins of that basin (Bush and Kazmin, 2007). It is a ca. 800 km long chain of distinct, *en-echelon*, NW-striking grabens separated by horsts and saddles. The formation of the Pachelma aulacogen took place mostly in the Ectasian, but in part also continued in the Devonian (Kheraskova, 2005). The arrangement of the grabens and horsts suggests sinistral relative displacement of the adjoining crustal blocks (Bogdanova et al., 1996). Deep drillings in this aulacogen have penetrated a 700 m thick succession of variegated, poorly sorted, coarse- and medium-grained arkosic sandstones, gravelstones, siltstones and mudstones resting unconformably atop basal quartz-rich sandstones. The new reflection profiling across the Pachelma aulacogen indicates this upper succession at least locally is more than 4 km thick (Kheraskova, 2005).

In the adjacent Moscow graben (Figs. 1, M and 3), similar continental red-beds dominate a 500 m thick sequence made up of alternating gravelly arkoses, "cherry"-brownish mudstones, and siltstones. At the top are brown claystones with lenses of siltstones and gritstones, as well as limestones. Mafic volcanic rocks have not been yet found in the drill-cores, but their presence is suggested by the gravity and magnetic data (Bogdanova et al., 1996).

In the Volyn-Orsha aulacogen, ca. 300 m thick red Ectasian and possibly lower Stenian talus and proluvial rocks with mafic sills yielding still imprecise K–Ar and Rb–Sr ages between ca. 1.3 and 1.1 Ga (Aksenov, 1998 and references therein) fill the Valday/Krestsy graben (V in Fig. 1). Farther southwest in this wide aulacogen, similar red arkosic gravelstones, sandstones, and siltstones occur in several separate shallow grabens, where sediment thicknesses reach 900 m. Similar terrigeneous red-bed sediments also characterize the deepest known parts of the graben sequences in the Mid-Russian aulacogen (MR in Fig. 1), where they reach thicknesses of ca. 1500 m (Kheraskova et al., 2002).

Close to the northeastern and eastern margins of the EEC, however, the Ectasian sequences are much different from those in the interior parts of the Craton.

In the Mezen' rift province, recent reflection- and refraction-seismic profiling (Kostyuchenko et al., 1999, 2006; Kheraskova et al., 2006) has demonstrated the presence of numerous grabens, half-grabens and horsts (Figs. 1 and 4). Atop all the graben fills is an up to 2 km thick succession of Late Ediacaran deposits, whereas within the grabens there are three principal rock sequences delimited by sub-horizontal, continuous reflectors (Figs. 5 and 8). These reflectors are considered to represent stratigraphic disconformities separating strata of different seismic characters (Kheraskova et al., 2006). The lowermost of the three seismically distinguished sequences has been found only in the Kandalaksha-Dvina graben. While it has not been drilled through, it is seismically similar to basal cover complexes elsewhere in the eastern EEC. Because of that, it appears to be Calymmian or even latest Paleoproterozoic in age.

The next higher seismically distinguished rock sequence is up to 4 km thick and to judge from its microfossils probably Ectasian (Veis et al., 2004). It is widespread in all the Mezen' grabens locally also resting directly on the crystalline basement. Because of its varying wavy seismic patterns, which appear to lean against the bounding faults, this sequence has been attributed to deposition simultaneous with the rifting (Kheraskova et al., 2006). Its uppermost levels have been reached by drillings disclosing a rhythmic succession of sandstones, siltstones and gritstones, and also some black shales of both terrestrial and marine origins (Figs. 4 and 8). At the boundary toward the uppermost sequence in the Mezen' rifts, Ectasian microfossils give way to Tonian types (Veis et al., 2004), the lithologies gradually acquiring deep-water characteristics.

In the southern Urals region, the Ectasian succession commences with an up to 3.5 km thick volcano-sedimentary rock pile, which comprises numerous lava flows and layered sill intrusions of both mafic and felsic compositions (Alekseev, 1984). The cumulative thickness of these chemically bimodal igneous

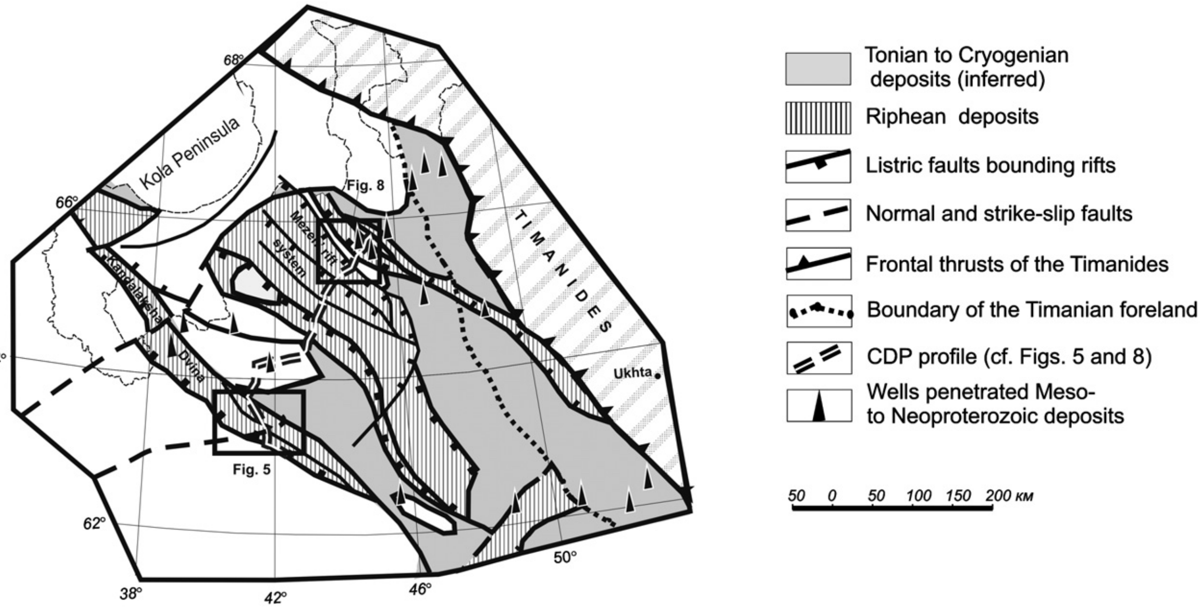

Fig. 4. Rifts in the north-easternmost part of the East European Craton (modified after Kheraskova et al., 2006).

rocks ranges from 450 to 1400 m, while their U–Pb zircon TIMS and SHRIMP ages as well as the Sm–Nd ages of the volcanics, dykes, sills and other intrusions are ca. 1.39–1.38 Ga (Ernst et al., 2006; Ronkin et al., 2006). The associated sedimentary rocks are arkosic sandstones and siltstones, quartz sandstones and quartzites, conglomerates, and some black shales. The amounts of carbonate rocks and black shales increase upwards in the stratigraphy, whereas the coarse-grained terrigeneous rocks become fewer (Fig. 6).

In the Kama-Belsk aulacogen (Figs. 1, 6 and 7), the Urals-type volcano-sedimentary sequences thin out, and the overall thickness of the cover deposits is less than 1600 m. Here, the lithologies are much more terrigeneous, even though some dolostones and marls intercalated with silt- and claystones may be present. The K–Ar ages of glauconite and sericite from some of the sandstone members vary between 1297 and 1232 Ma, while those of the cross-cutting dolerites range between 1338 and 1120 Ma (Maslov, 2004 and references therein).

In summary, the paleogeography of the East European Craton between 1.4 and 1.2 Ga was defined principally by the rifting of the crust. In the east, the formation of most NW-trending aulacogens preceded the development of passive margins along

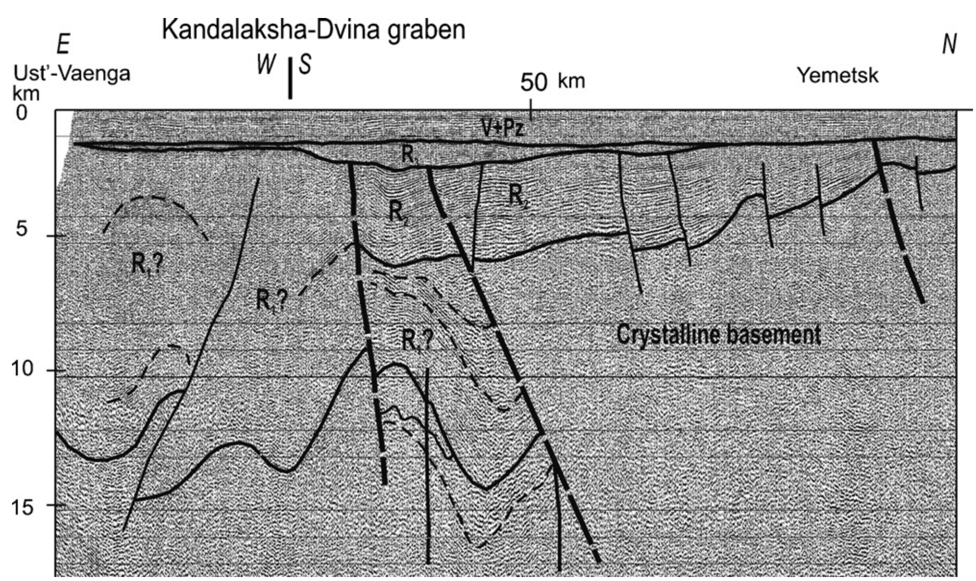

Fig. 5. Structure of the Kandalaksha-Dvina graben according to the reflection seismic profile I—I (modified after Kheraskova et al., 2006). The position of the profile is shown in Fig. 4. The letters indicate: R_1?, Statherian-to-Calymmian deposits; R_2, Ectasian deposits; R_3, Tonian deposits; V + PZ, Ediacaran and Paleozoic deposits.

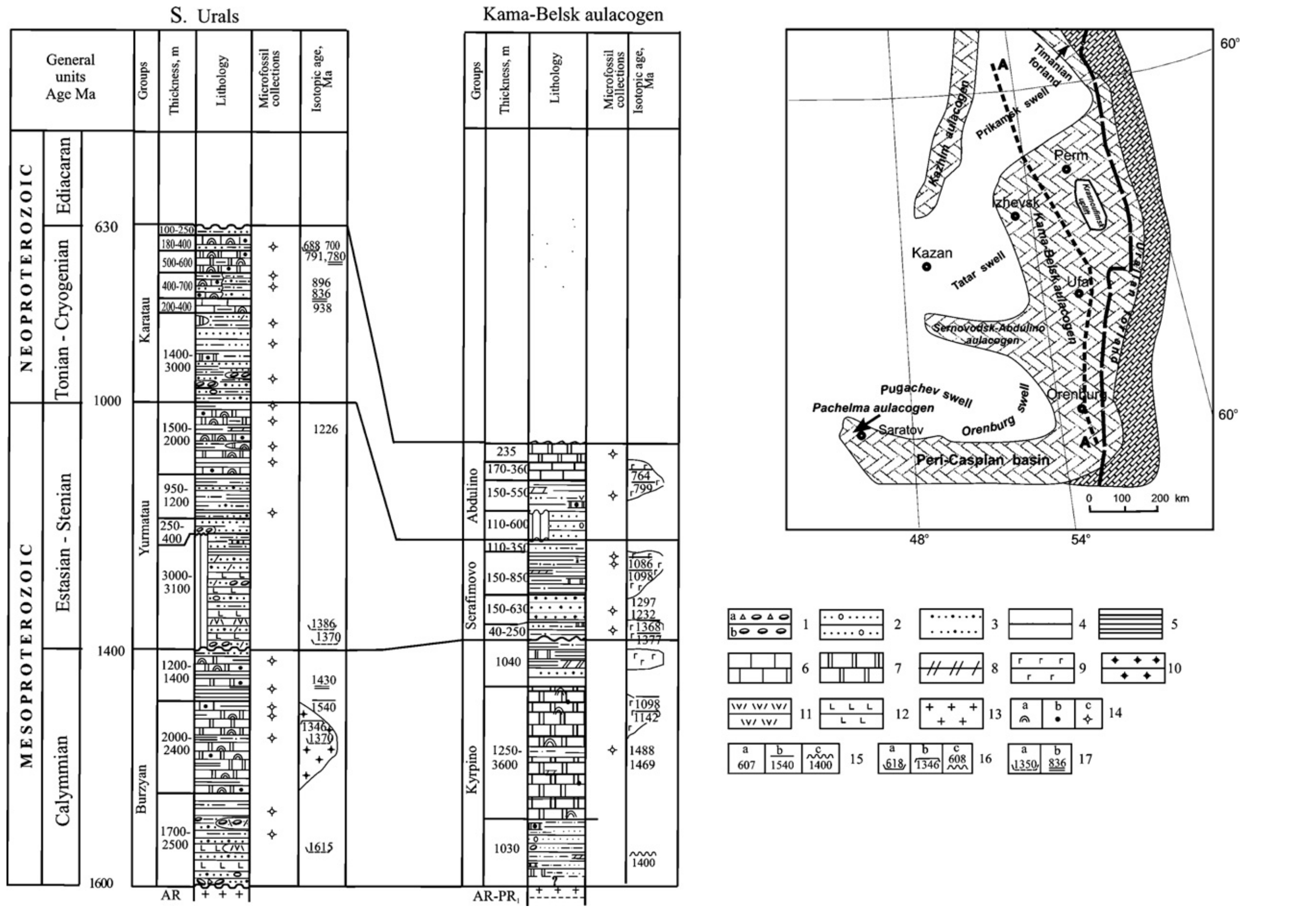

Fig. 6. Stratigraphic correlation of the Meso-to-Neoproterozoic deposits in the South Urals (the Bashkirian Anticlinorium, B in Fig. 1) and the Kama-Belsk aulacogen (K-B in Fig. 1; compiled after Kozlov et al., 1989; Ernst et al., 2006; Ronkin et al., 2006). Note that Ediacaran deposits are not shown in this chart. The inset indicates major structures of the sedimentary cover between the Urals and the Volgo-Uralian oil-and-gas province. 1: conglomerate-breccia (a) and conglomerates (b); 2: gravelstones; 3: quartzitic, arkosic and polymictic sandstones; 4: siltstones; 5: argillites; 6: limestones; 7: dolostones; 8: marls; 9: gabbro-dolerites; 10: granites; 11: rhyolites and dacites; 12: basalts; 13: crystalline basement; 14: fossils—(a) stromatolites, (b) microphytolites, (c) microfossils; 15–17, isotopic age (mln. years)—15: by the K–Ar method on (a) glauconite, (b) whole rock, (c) illite; 16: by Rb–Sr method on (a) glauconite, (b) whole rock, (c) illite; 17: by the U–Pb zircon method (a) and the Pb–Pb method (b) on carbonates.

the northeastern, eastern and southeastern edges of the craton. In the west, episodic extension of the crust was related to semi-continuous subduction along the still persisting common margin of Laurentia, Greenland and Baltica (Gower et al., 1990; Gorbatschev and Bogdanova, 1993; Åhäll and Gower, 1997; Karlstrom et al., 2001; Condie, 2002; Rogers and Santosh, 2002).

6. The Sveconorwegian orogeny: the East European Craton (Baltica) becomes part of Rodinia

The western margin of the EEC was affected by the Sveconorwegian orogeny at the end of the Mesoproterozoic (Berthelsen, 1980; Gorbatschev and Bogdanova, 1993). A ca. 500 km wide orogenic belt is preserved today to the west of the Protogine Zone in southwesternmost Scandinavia and its extension through the Western Gneiss Complex, the main basement window in the Caledonides of Western Norway (Figs. 1 and 9). The mere width of this belt suggests that Baltica collided with another major plate. Models involving oblique continent–continent collision (i.e. with significant strike-slip motion) between a coherent Baltica–Laurentia margin and Amazonia are deeply entrenched in the literature (Hoffman, 1991; Karlstrom et al., 2001; Tohver et al., 2002, 2005).

Prior to the major collisional stage, the Sveconorwegian orogeny shortly followed upon an event of continental magmatism and basin formation in the Telemarkia and Bamble terranes (Figs. 9 and 10a). It included deposition of 1.17–1.14 Ga bimodal volcanics interlayered with clastic sediments and intrusion of 1.22–1.14 Ga A-type granite–charnockite as well as local 1.13 Ga alkaline plutons (Fig. 10a; cf. Heaman and Smalley, 1994; Zhou et al., 1995; Brewer et al., 2002; Laajoki et al., 2002; Bingen et al., 2003; Andersen et al., 2007). This event suggests extensional or transtensional tectonic regime at the onset of the Sveconorwegian Orogeny in the Telemarkia and Bamble terranes, possibly in a back-arc tectonic setting (Brewer et al., 2002). In addition, the 1.20–1.18 Ga gabbro-to-tonalite Tromøy complex in the Bamble terrane is interpreted as the remnant of an island arc formed outboard of Baltica (Knudsen and Andersen, 1999; Andersen et al., 2004). It represents direct evi-

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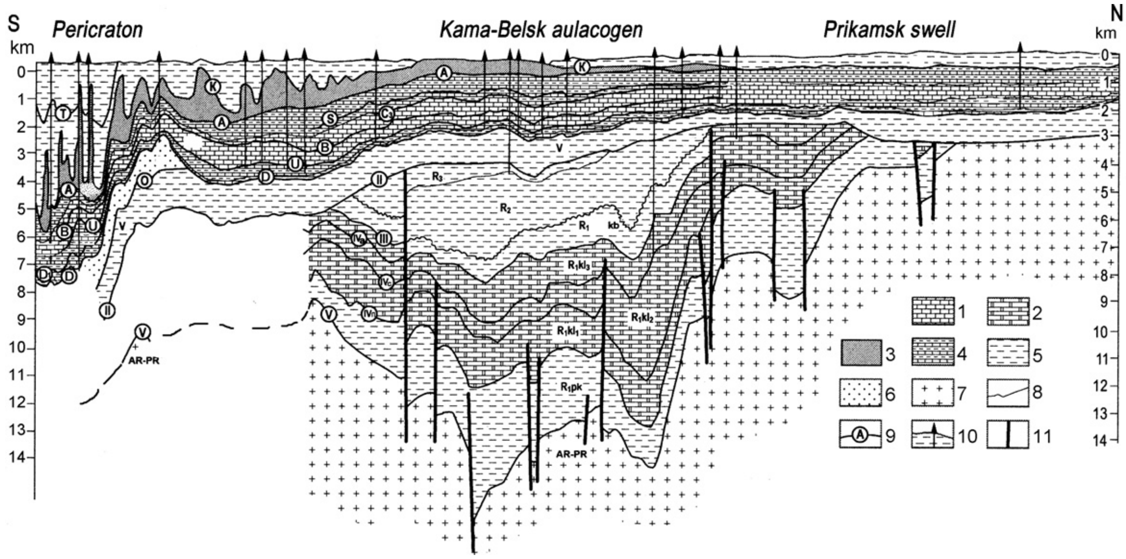

Fig. 7. Seismostratigraphic section of the Kama-Belsk aulacogen in Volgo-Uralia as based on reflection seismic profiles (the location of the cross-section is shown in the inset of Fig. 6, A-A). Compiled by V. Puchkov. 1: limestones; 2: dolomites and dolomitized limestones; 3: salt and sulphates; 4: alternating terrigenous and carbonate rocks; 5: terrigenous rocks; 6: same, mostly sandstones; 7: crystalline basement; 8: boundaries of the stratigraphic subdivisions; 9: seismic horizons; 10: wells; 11: faults. The stratigraphic subdivisions (only indicated for the Precambrian) are: AR-PR_1: Archean-Paleoproterozoic rocks of the crystalline basement. Mesoproterozoic and the lower part of the Neoproterozoic—R_1: Calymmian, R_1pk: Prikamsk subseries undifferentiated; R_1kl: Kaltasa formation with subformations; R_1kl_1: Sauzovo; R_1kl_2: Arlan; R_1kl_3: Ashit; R_1kb: Kabakovo formation. R_2 are Ectasian, R_3 Stenian and Tonian; V-Cryogenian and Ediacaran strata. The seismic reflectors are indicated by encircled letters—V: top of the crystalline basement; IVп: base of the Kaltasa formation; Ivc–IVа: base and top of the Arlan subformation; III: top of the Kaltasa formation; II: base of the (Ediacaran); O: base of the Ordovician; D: base of Devonian deposits; D1: top of the Lower Devonian deposits; U: base of the coal-bearing formation (C_1h); B: base of the Bashkirian stage; C_3: top of the Carboniferous; S: top of the Sakmarian stage; A: top of the Artinskian stage; К: top of the Kungurian stage; T: base of Triassic deposits.

dence of a subduction-related setting in the time interval before the Sveconorwegian orogeny.

High-grade metamorphism and deformation directly related to the Sveconorwegian orogeny lasted from 1.14 to 0.90 Ga (Bingen and van Breemen, 1998a; Cosca et al., 1998; Söderlund et al., 2002), defining the total duration of this orogeny. The nature and location of metamorphism and associated tectonic activity changed through time in the Sveconorwegian orogen, in such a way that four main and distinct orogenic phases can be defined. These are named here after regions where they are well recorded, namely the 1.14–1.08 Ga *Arendal phase*, the 1.05–0.98 Ga *Agder phase*, the 0.98–0.96 Ga *Falkenberg phase*, and the 0.96–0.90 Ga *Dalane phase* (Fig. 10).

6.1. Arendal phase, 1.14–1.08 Ga: accretion and local early collision

The oldest amphibolite- to granulite-facies Sveconorwegian metamorphism is recorded in the Bamble and Kongsberg terranes (Harlov, 2000) between 1.14 and 1.10 Ga (Fig. 10a; Cosca et al., 1998). A cluster of amphibole Ar–Ar spectra records regional cooling below ca. 550 °C at 1.10–1.08 Ga (Cosca et al., 1998). Unroofing was followed by a period of apparent quiescence. The Bamble terrane displays strong NE–SW trending Sveconorwegian structural grain, largely related to NW-directed shortening and thrusting of the Bamble terrane onto the Telemarkia terrane (Henderson and Ihlen, 2004), in accordance

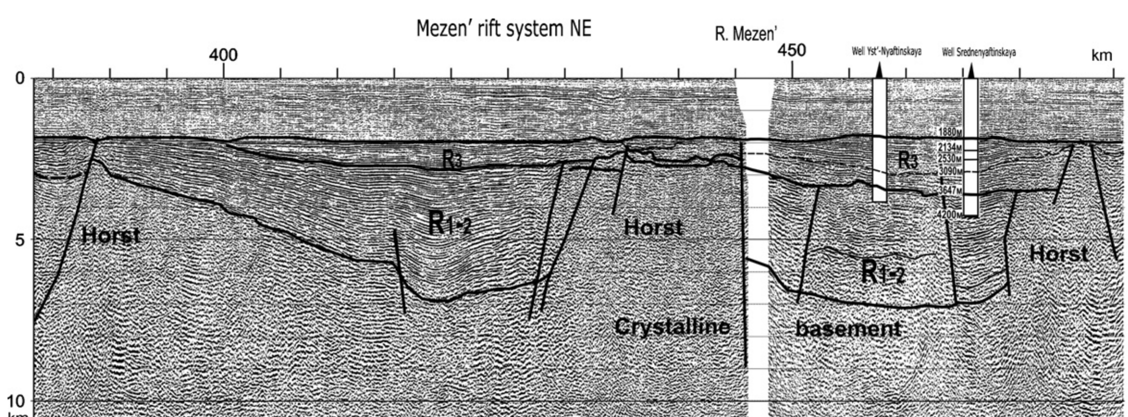

Fig. 8. Structure of the upper crust in the Mezen' rift province along the seismic reflection profile I—I (modified after Kheraskova et al., 2006). The position of the profile is shown in Fig. 4.

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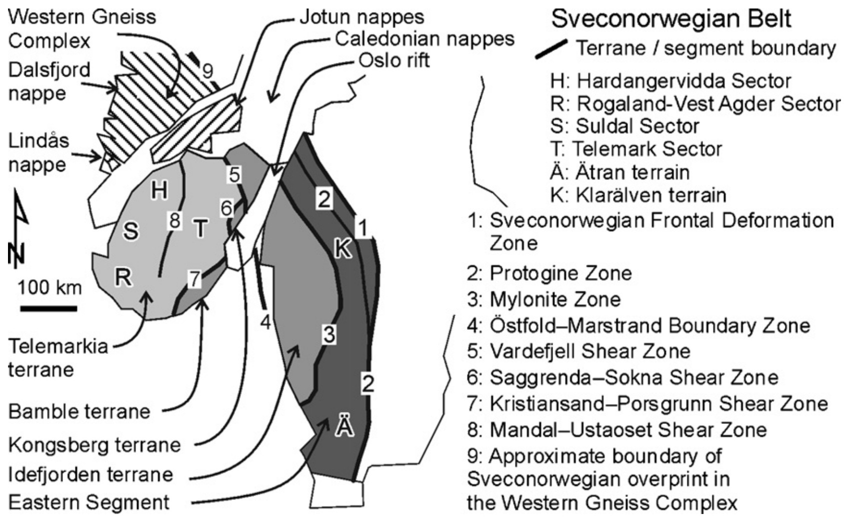

Fig. 9. Major structural elements of the Sveconorwegian orogen (modified after Bingen et al., 2005).

with geophysical evidence (Andersson et al., 1996). The unconformable cover of immature clastic sediments deposited after 1.12 Ga in the central Telemark area (Bingen et al., 2003) possibly represents a foreland- or intermontane basin related to mountain building at 1.14–1.10 Ga. The 1.14–1.10 Ga metamorphism is interpreted as the remnant of an early-Sveconorwegian collision, probably involving accretion of the 1.20–1.18 Ga island arc preserved in Trømoy (Andersen et al., 2004) (Fig. 10b). If the Telemarkia terrane was not attached to Baltica before the Sveconorwegian orogeny, the thrusting of the Bamble and Kongsberg terranes onto Telemarkia at 1.10 Ga sets a minimum age for the docking of Telemarkia to Baltica (Fig. 10b).

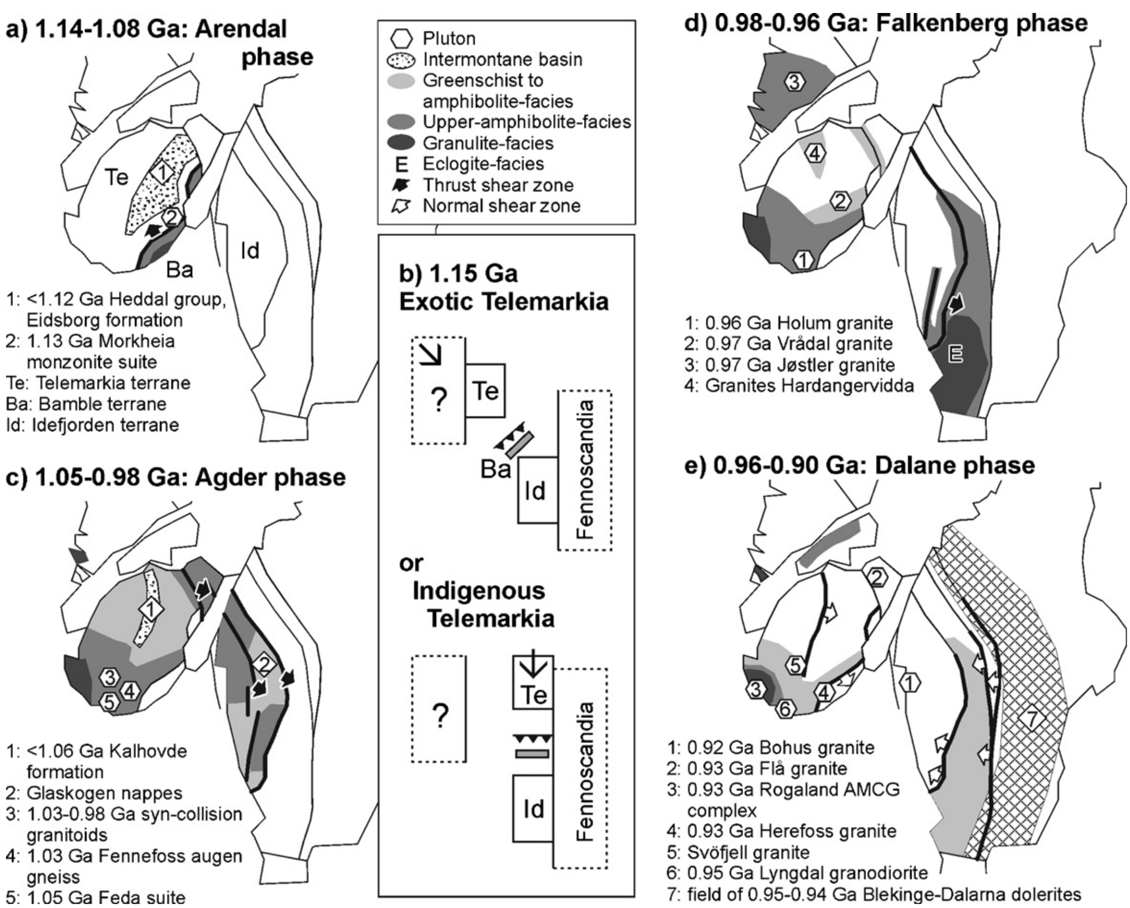

Fig. 10. Main phases of the Sveconorwegian orogeny in map view, with the locations of selected magmatic rocks and sedimentary basins. References are cited in the text. Abbreviations—Te: Telemarkia terrane; Id: Idefjorden terrane; Ba: Bamble terrane.

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6.2. Agder phase, 1.05–0.98 Ga: continent–continent collision

At 1.05 Ga, the zone affected by Sveconorwegian metamorphism widened towards the hinterland and foreland of the orogen to include the Telemarkia and Idefjorden terranes (Fig. 10c). This metamorphism reflects crustal thickening in the central part of the orogen. In the Idefjorden terrane, high-pressure (kyanite-grade) amphibolite-facies metamorphism and locally high-pressure granulite-facies metamorphism are recorded between 1.05 and 1.02 Ga. This metamorphism is not penetrative in the Idefjorden terrane (Åhäll et al., 1998). It was probably associated with development of generally N–S to NW–SE trending shear zones, interpreted as due to transpression (Park et al., 1991), and formation of a nappe complex (Lindh et al., 1998). In the Telemarkia terrane, regional Sveconorwegian metamorphism ranges from greenschist-facies, in supracrustal rocks exposed in the Telemark and Suldal sectors, to granulite-facies, in the southwesternmost part in the Rogaland-Vest Agder sector (Tobi et al., 1985). Available U–Pb and Re–Os data show that the different complexes or sectors of the Telemarkia terrane share a common, generally penetrative, regional metamorphism between 1.03 and 0.98 Ga, reaching granulite-facies conditions (Bingen and van Breemen, 1998a; Stein and Bingen, 2002; Möller et al., 2003).

In the Telemarkia terrane, intrusion of 1.05–1.03 Ga high-K calc-alkaline granitoids (Bingen and van Breemen, 1998b) was followed by widespread syn-collisional 1.03–0.98 Ga granitic plutonism. The westwards increase in volume of plutonism reflects a warmer thermal structure of the crust in the hinterland of the orogen. The Agder phase is related to the main Sveconorwegian continent–continent collision, involving crustal thickening in the central part of the orogen and thrusting towards the foreland. The geochemical signature of 1.05–1.03 Ga calc-alkaline granitoids in the west of the orogen may be interpreted as evidence for a continental active-margin setting at the start of this phase.

6.3. Falkenberg phase, 0.98–0.96 Ga: final Sveconorwegian convergence

At 0.98–0.96 Ga, the Sveconorwegian orogeny propagated eastwards into the foreland, deforming the Eastern Segment (Ätran and Klarälven terrains; Fig. 10d). This event probably corresponds to the last increment of convergence in the Sveconorwegian orogen. It is associated with major deformation along the Mylonite Zone, and resulted in protracted metamorphism and crustal melting in the hinterland of the orogen (Telemarkia terrane).

In the Eastern Segment, intensity of Sveconorwegian deformation and metamorphism decreases eastwards towards the Protogine Zone (Wahlgren et al., 1994) and increases from N to S, to reach high-pressure granulite-facies in the southern part of the segment. Relics of eclogite boudins are locally observed, mainly hosted in shear zones (Möller, 1998, 1999; Austin Hegardt et al., 2005). The eclogites record pressure of ca. 15 kbar along a "clockwise" pressure–temperature path, followed by steep decompression (Möller, 1999). Available geochronological data provide overlapping estimates of 0.97 Ga for the eclogite-facies metamorphism, and 0.98–0.96 Ga for the amphibolite- to granulite-facies metamorphism (Connelly et al., 1996; Wang et al., 1998; Andersson et al., 1999; Johansson et al., 2001; Söderlund et al., 2002; Austin Hegardt et al., 2005). The eclogites provide evidence for deep burial of Fennoscandia crust during the final Sveconorwegian convergence in the eastern part of the orogen.

Sveconorwegian deformation along the Mylonite Zone seems to include a component of SE-directed oblique thrusting (Park et al., 1991; Stephens et al., 1996), followed by a component of extension (Berglund, 1997). U–Pb data in the vicinity of the Mylonite Zone record metamorphism at 0.98–0.97 Ga, probably related to the thrusting component (J. Andersson et al., 2002). Recent U–Pb data also suggest that some shear zones in the Idefjorden terrane may have been formed or reactivated at 0.98–0.97 Ga (Ahlin et al., 2006).

In the Western Gneiss Complex, amphibolite- to granulite-facies metamorphism is dated at 0.99–0.97 Ga (Tucker et al., 1990; Skår and Pedersen, 2003; Røhr et al., 2004), while in the Rogaland-Vest Agder sector of the Telemarkia terrane, protracted granulite-facies metamorphism, possibly related to regional decompression, is detected at 0.97 Ga (Bingen and Stein, 2003; Tomkins et al., 2005).

6.4. Dalane phase, 0.96–0.90 Ga: post-collisional relaxation

After 0.97 Ga, the Sveconorwegian orogen entered a period of relaxation or gravitational collapse. Two high-grade domains, one centered in the Eastern Segment and another in the Rogaland-Vest Agder sector of the Telemarkia terrane, underwent major exhumation after 0.97 Ga (Möller, 1999; Bingen et al., 2006). However, there was comparatively little unroofing after that time in most of the exposed central and northern part of the orogen (Fig. 10e). Post-collisional magmatism increases dramatically westwards toward the hinterland of the orogen (Eliasson and Schöberg, 1991; Andersen et al., 2001; Bogaerts et al., 2003; Skår and Pedersen, 2003; Vander Auwera et al., 2003).

In the Eastern Segment, prominent large-scale E–W to SE–NW trending folds and shear zones have been interpreted as evidence for E–W extension coeval with N–S shortening (Berglund, 1997). These structures largely account for exhumation of high-pressure metamorphic rocks in the footwall of the Mylonite Zone (Möller, 1999). Geochronological data bracket initially rapid exhumation and regional cooling between 0.96 and 0.92 Ga (Connelly et al., 1996; Wang et al., 1998; Christoffel et al., 1999; Johansson et al., 2001; Söderlund et al., 2002; Austin Hegardt et al., 2005). In the Idefjorden terrane, shallow plutons and veins attest to brittle upper crustal conditions and extensional setting between 0.97 and 0.93 Ga (Stein and Bingen, 2002; Hellstrom et al., 2004). Close to the front of the orogen and along the Protogine Zone, steep ductile to brittle, N–S trending, normal shear zones formed between 0.97 and 0.94 Ga (Wahlgren et al., 1994; Andréasson and Dallmeyer, 1995; Söderlund et al., 2004).

In the foreland of the orogen, to the east of the Protogine Zone, the N–S trending Blekinge-Dalarna dolerites (Figs. 1 and 10e) intruded mainly between 0.95 and 0.94 Ga, possibly as a consequence of relaxation in the Sveconorwegian Orogen (Söderlund et al., 2005).

In the Telemarkia terrane, the amphibolite- to granulite-facies domain of Rogaland-Vest Agder was progressively exhumed, probably as a large-scale gneiss dome, after 0.96 Ga (Tomkins et al., 2005; Bingen et al., 2006), together with production of voluminous post-collisional granodiorite-granite plutonism (Andersen et al., 2001, 2007; Bogaerts et al., 2003; Vander Auwera et al., 2003).

At 0.93–0.92 Ga, a voluminous pulse of plutonism occurred in the western half of the Sveconorwegian orogen. This pulse included AMCG magmatism associated with ultra-high temperature metamorphism dated at 0.93–0.92 Ga (Fig. 10e; Duchesne et al., 1985; Tobi et al., 1985; Schärer et al., 1996; Bingen and van Breemen, 1998b; Möller et al., 2003).

Extensional reactivation of major Sveconorwegian shear zones occurred between 0.98 and 0.92 Ga (Page et al., 1996; Scherstén et al., 2004; Mulch et al., 2005). In the Rogaland-Vest Agder sector of the Telemarkia terrane, titanite U–Pb data define regional cooling below ca. 600 °C at 0.92–0.91 Ga (Heaman and Smalley, 1994; Bingen and van Breemen, 1998b).

7. Rodinian sedimentary cover and passive margins

The syn-Rodinian sedimentary basins in the Sveconorwegian orogen are small and have poor lateral continuity. They mainly reflect intermontane sedimentation in a tectonically active environment (Bingen et al., 2003). In the central and eastern parts of the EEC, however, a widespread cover succession was deposited between ca. 1.1 and 0.7 Ga, i.e. during the lifetime of Rodinia (Kheraskova et al., 2002). This Stenian- to Cryogenian cover can be traced as a distinct seismostratigraphic layer in virtually all the aulacogens and also in the intervening areas. It overlies with sharp disconformity both the subjacent Mesoproterozoic deposits and the crystalline basement (Figs. 1, 5 and 8; cf. also Pease et al., this volume).

As different from the older cover formations rich in red-bed lithologies, this cover is dominated by grey, carbonaceous, marine sediments, black claystones, variegated siltstones and sandstones. The latter occur particularly in the lower parts of the succession. Intercalations of andesitic–dacitic and rhyolitic tuffs are present. Within this general framework, however, there is substantial variation of strata thickness, lithologies, and the tectonic settings of deposition. These range from stagnant interior basins to shallow inner and deeper outer shelves, and eventually to passive continental margins (Puchkov, 2000; Maslov, 2004; Kheraskova, 2005).

The strata in the interior of the EEC thus feature both carbonate-free and calcareous lithologies, the former characterizing relatively uplifted terrains in Volgo-Uralia, whereas the latter occur in the upper deposits of the Moscow graben and the western parts of the Pachelma aulacogen, where they record maxima of Tonian and later marine transgressions related to the Peri-Caspian Basin (Fig. 1).

Carbonate rocks similarly indicating transgression are a regular component also of the shelf deposits in present eastern Volgo-Uralia. A well-studied case is the Tonian-to-Cryogenian Karatau Group in the Bashkirian Anticlinorium (B in Fig. 1). In this case, the lower ca. 1.4–3 km thick formation consists of arkoses of various kinds, siltstones and claystones with thin beds and lenses of conglomerates, gravelstones, and sandy dolostones. Shallow-marine siliciclastics and carbonate deposits of ca. 850 Ma Pb–Pb ages (Ovchinnikova et al., 1998) are present higher up (Kozlov, 2002). In the uppermost Karatau formations, which reach more than 2 km in thickness, the role of carbonaceous, particularly stromatolitic and microphytolitic rocks is still greater. K–Ar datings of glauconite from these stratigraphic levels have yielded ages between ca. 940 and 700 Ma, while a highest-age constraint of the deposition is provided by the ca. 1100 Ma ages of the youngest detrital zircons (U–Pb, TIMS, Krasnobayev, 1986).

Farther inland in Volgo-Uralia, the coeval but thinner cover sequences of the Kama-Belsk and Sernovodsk-Abdulino aulacogens (Figs. 1, 6 and 7) feature dominant marly and other dolostones intercalated with clay- and siltstones. Altogether, sedimentation in these shelf depressions was marked by frequent changes of sea level and numerous attendant disconformities and breaks.

Along the present eastern margin of the craton, the considered shelf deposits form a semi-continuous, approximately 1500 km long belt extending from the Polar- to the South Urals (Maslov, 2004) and obviously outlining an incipient Tonian- to Cryogenian ocean. Most cover rocks of that continental margin were subsequently hidden or destroyed by the Paleozoic Uralian orogeny, sizable relics only remaining farthest northeast, along the boundary between northeastern Baltica and the Timanides (Fig. 1). In that region, the Tonian-Cryogenian cover changes from near-shore and shallow-marine deposits in the Mezen’ rift area to continental-margin sediments including up to 10 km thick turbidites in the adjacent Timan-Pechora region (Olovyanishnikov, 1998).

It can thus be concluded that already during the time when Sveconorwegian, Rodinia-related collisional tectonics affected the southwestern EEC, passive continental margins heralding incipient break-up began to form along its northeastern, eastern and southeastern peripheries. Subsequently, from the Cryogenian onwards, rifting of the EEC continued in conjunction with the general dispersal of Rodinia (cf. Pease et al., this volume).

8. The East European Craton (Baltica) in the Rodinia assembly: intercontinental correlations and palaeogeography

Most models of the position of the East European Craton (the Baltica megaterrane) within the Rodinia configuration place it in the southeastern part of the supercontinent, adjacent to southeastern Laurentia, Greenland, and Amazonia (Dalziel, 1991, 1997; Hoffman, 1991; Park, 1992; Gorbatschev and Bogdanova, 1993; Weil et al., 1998; Pisarevsky et al., 2003). Such a position is supported well by paleomagnetic and geological data, the differences between the various models being chiefly due to the

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continuous upgrading of these databases. Over the latter years, the indicated position of Baltica has thus been shifted somewhat more to the south in relation to Laurentia and Greenland and closer to Amazonia (Pisarevsky et al., 2003; Cawood and Pisarevsky, 2006; Li et al., this volume).

Within the Rodinia framework, a number of microcontinental terranes were associated with the larger continental masses. Some of them, like Oaxaquia and Rockall, were situated between the major continental blocks and may have been displaced fragments of these units, while the "Proto-Avalonian" group (the northern British Isles, Svalbard, and others) can have been formed along the southern and eastern margins of Rodinia (Murphy et al., 2000; Keppie et al., 2003; Cawood, 2005; Cawood and Pisarevsky, 2006; Kirkland et al., 2006). A problem with regard to the latter group is that these small terranes had subsequently been involved in the Timanian/Cadomian and Caledonian Orogenies, which makes it difficult to decipher their Grenvillian/Sveconorwegian relationships.

Regarding the chronologies and nature of the major events of crust formation and development, Baltica rather closely resembles the adjacent Rodinian continents (Fig. 11). Similarly to the Grenvillian belt of Laurentia, its present western part underwent a long orogenic evolution marked by a variety of tectonic regimes (Rivers, 1997; Davidson, 1998; Gower and Krogh, 2002) and interaction with a "third" continent, which was most likely Amazonia. The recent reconstruction by Tohver et al. (2002, 2005) of the NE-directed movements of Amazonia along the Grenvillian margin of Laurentia between ca. 1.2 and 1.05 Ga suggests that this continent played an important role in the kinematic evolution of both Laurentia and Baltica. Such interaction with a "third" continent has also been inferred in several previous models (e.g. Park, 1992; Gorbatschev and Bogdanova, 1993).

For the time between ca. 1100 and 900 Ma, however, a clockwise ca. 60° rotation of Baltica in relation to Laurentia is required to satisfy the apparent polar wandering paths (APWPs) for Laurentia and Baltica (Pisarevsky et al., 2003; Pisarevsky and Bylund, 2006). In this context, it is important that the final rotation coincided in time with the high-pressure Falkenberg stage of the Sveconorwegian orogeny in the Eastern Segment in Sweden at ca. 0.98–0.95 Ga, which has no precise age equivalent either in the other parts of the Sveconorwegian belt or Rodinian blocks and terranes (Fig. 11). This rotation could explain the interaction between the Eastern segment and the Idefjorden terrane across the Mylonite Zone at that time (cf. above) and presumably also the formation of the large Blekinge-Dalarna dolerite (BDD) swarm of dykes along the eastern margin of the Sveconorwegian Orogen between ca. 0.98 and 0.94 Ga (Söderlund et al., 2005).

Thus at a time when the eastern Grenvillian Orogen in Laurentia was already in a state of post-collisional extension (Gower and Krogh, 2002; Davidson, this volume), convergence must have acted still in the Sveconorwegian Orogen. In addition to its possible effects on the eastern Sveconorwegian terranes, the rotation between 1.10 and 0.90 Ga and the attendant oblique collision also appear to have caused interaction with a different continental unit, most probably the Oaxaquian microcontinent in present Mexico, which experienced high-grade metamorphism (Weber and Hecht, 2003) simultaneously with the Falkenberg-stage granulitic to eclogitic metamorphism in southwestern Sweden. Oaxaquia is an exotic terrane which had been rifted off Amazonia (Keppie et al., 2003; Weber and

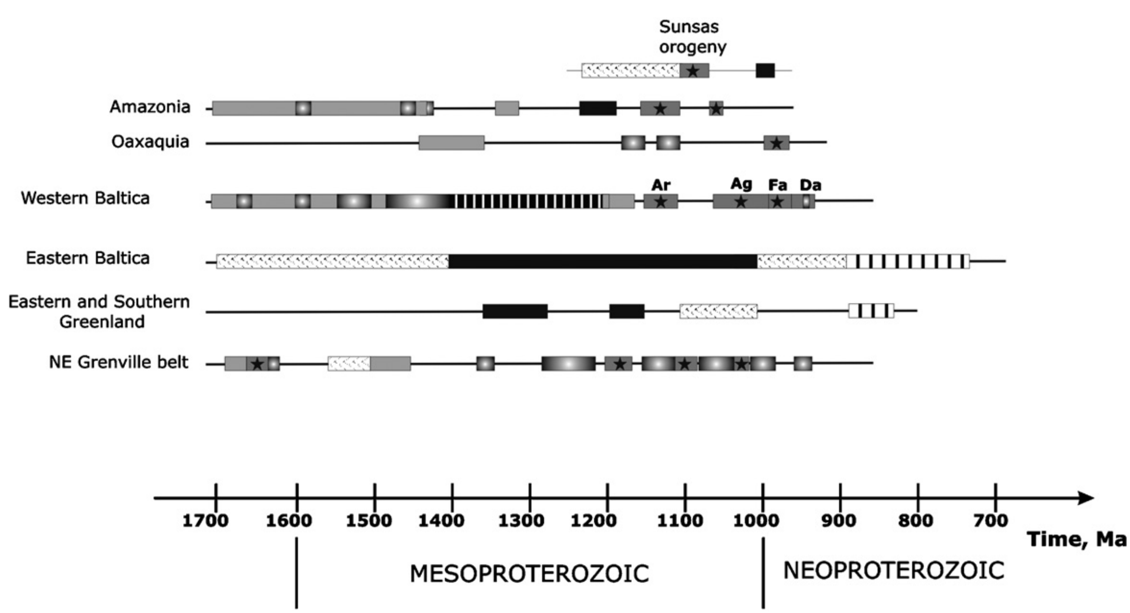

Fig. 11. Timing of the major tectonic and magmatic events in the East European Craton (Baltica) as compared with the other continental blocks of eastern Rodinia. The tectonic settings are—grey: island arcs and active continental margins; stars: collisional orogens; gradient grey: intracratonic AMCG and A-type granitoid magmatism; black: rifting; striped black: spread rifting; dashed: intracontinental basins; white striped: passive margins. The letter symbols are—Ar: Arendal; Ag: Agder; Fa: Falkenberg; Da: Dalane. These indicate various phases of the Sveconorwegian orogeny (cf. Fig. 10). The age data are from: Davidson, this volume (NE Grenville belt), Kalsbeek et al., 2000 and Upton et al., 2003 (Greenland), Geraldes et al., 2001 and Tohver et al., 2002, 2005 (Amazonia), Keppie et al., 2003 (Oaxaquia).

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Hecht, 2003) and probably squeezed in between Amazonia and Baltica (Pisarevsky et al., 2003; Li et al., this volume) at ca. 0.95 Ga (Ballard et al., 1989). This was the time when Baltica rotated to occupy its final position within Rodinia.

9. Synopsis: the East European Craton from the Paleo- to the Neoproterozoic

A fundamental trait in the evolution of the East European Craton (EEC) after its assembly at ca. 1.8–1.7 Ga was the profound difference of tectonic regimes in its present western and eastern parts (Figs. 1 and 11 and Table 1).

In the west, active-margin processes and simultaneous AMCG-type and other igneous activity farther inland dominated except during the Ectasian (1.4–1.2 Ga). In the central and eastern parts of the EEC, in contrast, recurrent rifting alternating with the deposition of mature platform-type sediments was the prevalent process from the late Paleoproterozoic to the Neoproterozoic. The first major orogenic processes that formed the continental crust along the eastern margins of the Craton occurred only at ca. 620 Ma in the shape of the Timanian Orogeny (cf. Pease et al., this volume).

In the west, accretionary growth of the crust after the EEC assembly appears to have gone on semi-continuously from ca. 1.7 to 1.5 Ga. After that followed two periods of reorganization of the previous plate configurations during the collisional Danopolonian and Sveconorwegian Orogenies at ca. 1.5–1.4 and 1.1–0.9 Ga, respectively. These involved the docking of the EEC/Baltica with other major terranes, presumably Amazonia in both cases. However, additional paleomagnetic work must be carried out to constrain these relationships.

The remarkable similarity of the Paleoproterozoic and Mesoproterozoic evolution of the western EEC to that in southern Laurentia and southern Amazonia has been considered as evidence of a long-lived conjugate margin (Gower et al., 1990; Gorbatschev and Bogdanova, 1993; Åhäll and Gower, 1997; Karlstrom et al., 2001; Rogers and Santosh, 2002; Zhao et al., 2004). Although the paleomagnetic data are still ambiguous,

Table 1
Essentials of the pre-Rodinian and Rodinian evolution of the East European Craton

Age, Ga	Tectonic regimes and settings		
	Western part		Eastern part
ca. 1.8	Collision of the Fennoscandian and Volgo-Sarmatian megablocks, assembly of the East European Craton as an entity		
1.73-1.55	Gothian Orogeny: westward accretionary growth of the crust in Fennoscandia		Deposition of platform cover
	1.73-1.67 Ga: Formation of the "Eastern Segment" 1.66-1.55 Ga: Formation of the Idefjorden terrane	Interiors: From ca. 1.65 Ga: recurrent AMCG* and mafic magmatism; development of associated "red bed" sedimentary-volcanic basins	Incipient rifting largely along the Paleoproterozoic collisional zones between the different crustal segments of the EEC; deposition of thick sedimentary sequences, sub-alkaline bimodal within-plate magmatism
1.52-1.48	Formation of the Telemarkia terrane in the westernmost Fennoscandia	Interiors: ca.1.52-1.50 Ga AMCG magmatism	
1.50-1.40	Danopolonian orogeny: compressional deformation, syntectonic "A"-type granitoid magmatism; metamorphism and migmatization of older crust	Interiors: Mafic and bimodal magmatism. Continued development of "red bed" sedimentary-volcanic basins	
1.40-1.20	Rifting of the crust and bimodal magmatism. Formation of large continental flood basalt provinces. Continued red-bed sedimentation. Incipient stage of the formation of the Volyn-Orsha aulacogen.		Major rifting event, intense mafic magmatism and deposition of thick sedimentary sequences. Development of the Mezen' and South Urals' rifts, Pachelma and Mid-Russian aulacogens. Incipient stage of passive margin?
1.20-1.14	Development of a W-facing active continental margin		
1.14-0.90	Sveconorwegian Orogeny: 1.14-1.05 Ga: Accretion and local early collision 1.05-0.98 Ga: Continent-continent (Baltica-Amazonia) collision 0.98-0.96 Ga: Final convergence 0.96-0.90 Ga: Post-collisional relaxation		From ca. 1.1 Ga onwards development of a new coherent sedimentary cover over large areas in the EEC.
0.85-0.60	Rifting and dispersal associated with the break-up of Rodinia. In the east, formation of passive continental margin. Eventually, formation of a separate Baltica continent.		

*AMCG: Anorthosite-Mangerite-Charnockite-Granite (rapakivi).

this suggests that the EEC was part of a supercontinental/megacontinental collages during much of the Meso- and Neoproterozoic. It acted as a separate continent or the core of a continent only around ca. 1.2–1.1 Ga, and again between ca. 0.6 and the Caledonian Orogeny (cf. Li et al., this volume).

In the central and eastern parts of the EEC, mature sediments were deposited during two distinct periods. One is a still poorly age constrained period before ca. 1.4 Ga, the other has been dated to ca. 1.1–0.7 Ga. Both thus coincide with the times when the supercontinents Columbia/Nuna and Rodinia were in existence.

In the eastern EEC abortive rifting interpreted as a failed attempt at continent break-up and accompanied by mafic magmatism took place already at ca. 1.6 Ga, but the large transcratonic aulacogens were created only from ca. 1.4 Ga onwards. This rifting was simultaneous with the Ectasian period of extension and bimodal magmatism in the Fennoscandian crustal segment in the west. Concerning the various maxima of rifting in the EEC, coincidence in time with the rotation of continental blocks and their assemblages is indicated by paleomagnetic data (Buchan et al., 2000; Meert, 2002; Pesonen et al., 2003; Pisarevsky et al., 2003; Li et al., this volume).

Farthest northeast in the EEC, the cover formation between 1.1 and 0.7 Ga passed into a stage of first shallow and later deep-shelf sedimentation, and eventually the deposition of thick succession of turbidites, subsequently involved into the Timanian Orogeny. This late Neoproterozoic period was obviously related to Rodinia break-up.

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References

Åhäll, K.-I., Connely, J., 1998. Intermittent 1.53–1.13 Ga magmatism in western Baltica; age constraints and correlations within a postulated supercontinent. Precambrian Res. 92, 1–20.

Åhäll, K.-I., Connely, J.N., Brewer, T.S., 2000. Episodic rapakivi magmatism due to distal orogenesis? Correlation of 1.69–1.50 Ga orogenic and inboard, "anorogenic" events in the Baltic Shield. Geology 28 (9), 823–826.

Åhäll, K.-I., Cornell, D.H., Armstrong, R., 1998. Ion probe zircon dating of metasedimentary units across Skaggerak: new constraints for early Mesoproterozoic growth of the Baltic Shield. Precambrian Res. 87, 117–134.

Åhäll, K.-I., Gower, C.F., 1997. The Gothian and Labradorian orogens: variations in accretionary tectonism along a late Paleoproterozoic Laurentia–Baltica margin. GFF 119, 181–191.

Ahäll, K.-I., Samuelsson, L., Persson, P.-O., 1997. Geochronology and structural setting of the 1.38 Ga Torpa granite; implications for charnockite formation in SW Sweden. GFF 119, 37–43.

Ahlin, S., Austin Hegardt, E., Cornell, D., 2006. Nature and stratigraphic position of the 1614 Ma Delsjön augen granite-gneiss in the Median Segment of south-west Sweden. GFF 128 (1), 21–32.

Aksenov, E.M., 1998. The Geological Evolution of the East European Craton in the Late Proterozoic. Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia, Summary of Doctor Sciences' thesis, 106 pp. (in Russian).

Alekseev, A.A., 1984. Riphean-Vendian Magmatism of the Western Slope of the Urals. Nauka, Moscow, 136 pp. (in Russian).

All, T., Flodén, T., Puura, V., 2006. A complex model of Mesoproterozoic sedimentary and igneous suites in a graben setting north of Gotland, Baltic Sea. GFF 128 (1), 53–63.

Amantov, A., Laitakari, I., Poroshin, Y., 1996. Jotnian and Postjotnian: Sandstones and Diabases in the Surroundings of the Gulf of Finland. Geological Survey of Finland, special paper 21, pp. 99–113.

Amelin, Y.V., Larin, A.M., Tucker, R.D., 1997. Chronology of multiphase emplacement of the Salmi rapakivi granite-anorthosite complex, Baltic Shield: implications for magmatic evolution. Contrib. Mineral. Petrol. 127 (4), 353–368.

Andersen, T., Andresen, A., Sylvester, A.G., 2001. Nature and distribution of deep crustal reservoirs in the southwestern part of the Baltic Shield: evidence from Nd, Sr and Pb isotope data on late Sveconorwegian granites. J. Geol. Soc. (Lond.) 158, 253–267.

Andersen, T., Griffin, W.L., Jackson, S.E., Knudsen, T.-L., Pearson, N.J., 2004. Mid-Proterozoic magmatic arc evolution at southwest margin of the Baltic Shield. Lithos 73, 289–318.

Andersen, T., Griffin, W.L., Sylvester, A.G., 2007. Sveconorwegian crustal underplating in southwestern Fennoscandia: LAM-ICPMS U–Pb and Lu–Hf isotope evidence from granites and gneisses in Telemark, southern Norway. Lithos. 93 (3–4), 273–287.

Andersson, J., Moller, C., Johansson, L., 2002. Zircon geochronology of migmatite gneisses along the Mylonite Zone (S Sweden): a major Sveconorwegian terrane boundary in the Baltic Shield. Precambrian Res. 114 (1–2), 121–147.

Andersson, J., Soderlund, U., Cornell, D., Johansson, L., Moller, C., 1999. Sveconorwegian (-Grenvillian) deformation, metamorphism and leucosome formation in SW Sweden, SW Baltic Shield: constraints from a Mesoproterozoic granite intrusion. Precambrian Res. 98 (1), 151.

Andersson, M., Lie, J.E., Husebye, E.S., 1996. Tectonic setting of post-orogenic granites within SW Fennoscandia based on deep seismic and gravity data. Terra Nova 8, 558–566.

Andersson, U.B., Neymark, L.A., Billström, K., 2002. Petrogenesis of Mesoproterozoic (Subjotnian) rapakivi complexes of central Sweden: implications from U–Pb zircon ages, Nd, Sr and Pb isotopes. Trans. Roy. Soc. Edinburgh: Earth Sci. 92 (3–4), 201–228.

Andersson, U.B., Sjöström, H., Högdahl, K., Eklund, O., 2004. The Transscandinavian Igneous Belt, evolutionary models. In: Högdahl, K., Andersson, U.B., Eklund (Eds.), The Transcandinavian Igneous Belt (TIB) in Sweden: A Review of its Character and Evolution. Geological Survey of Finland, pp. 104–112.

Andréasson, P.-G., Dallmeyer, R.D., 1995. Tectonothermal evolution of high-alumina rocks within the Protogine Zone, southern Sweden. J. Metamorph. Geol. 13, 461–474.

Andréasson, P.-G., Rodhe, A., 1990. Geology of the Protogine Zone south of Lake Vättern, southern Sweden: a reinterpretation. Geologiska Föreningens i Stockholm Förhandlingar 112 (2), 107–125.

Appelquist, K., Brander, L., Larson, S.Å., Stigh, J., 2006. 1.45 Ga metamorphic imprint on zircons from the Transscandinavian Igneous Belt and the Eastern Segment. Bull. Geol. Surv. Finland (Special Issue 1), 10.

Austin Hegardt, E., et al., 2005. Eclogites in the central part of the Sveconorwegian Eastern Segment of the Baltic Shield: support for an extensive eclogite terrane. GFF 127, 221–232.

Austrheim, H., Corfu, F., Bryhni, I., Andersen, T.B., 2003. The Proterozoic Hustad igneous complex: a low strain enclave with a key to the history of the Western Gneiss Region of Norway. Precambrian Res. 120 (1–2), 149–175.

BABEL Working Group, 1993. Deep seismic reflection/refraction interpretation of crustal structure along BABEL profiles A and B in the southern Baltic Sea. Geophys. J. Int. 112, 325–343.

Ballard, M.M., Van der Voo, R., Urrutia-Fucugauchi, J., 1989. Paleomagnetic results from Grenvillian-aged rocks from Oaxaca, Mexico: evidence for a displaced terrane. Precambrian Res. 42 (3–4), 343–352.

Berglund, J., 1997. Mid-Proterozoic evolution in south-western Sweden. Ph.D. Thesis. Publication A15, Department of Geology, Earth Science Centre, Göteborg University, Göteborg.

Bergman, S., Sjöström, H., Högdahl, K., 2006. Transpressive shear related to arc magmatism: the Paleoproterozoic Storsjön-Edsbyn Deformation Zone, central Sweden. Tectonics 25, TC1004, doi:10.1029/2005TC001815.

Berthelsen, A., 1980. Towards a palinspastic tectonic analysis of the Baltic Shield. In: Cogne, J., Slansky, M. (Eds.), Geology of Europe, from Precambrian to the post-Hercyninan Sedimentary Basins. Mémoires. Mémoires du B.R.G.M, Paris, pp. 5–21.

Beunk, F.F., Page, L.M., 2001. The structural evolution of the accretional continental margin in the Palaeoproterosoic Svecofennian orogen in southern Sweden. Tectonophysics 339 (1–2), 67–92.

Bibikova, E.V., Kirnozova, T.I., Lazarev, Y.I., 1990. U–Pb isotope age of the Vepsian in Karelia. Doklady (Trans.) USSR Acad. Sci. 310 (1), 189–191 (in Russian and English).

Bingen, B., Mansfeld, J., Sigmond, E.M.O., Stein, H.J., 2002. Baltica–Laurentia link during the Mesoproterozoic: 1.27 Ga development of continental basins in the Sveconorwegian Orogen, southern Norway. Can. J. Earth Sci. 39, 1425–1440.

Bingen, B., et al., 2003. Relations between 1.19–1.13 Ga continental magmatism, sedimentation and metamorphism, Sveconorwegian province, S Norway. Precambrian Res. 124 (2–4), 215–241.

Bingen, B., et al., 2005. Timing of continental building in the Sveconorwegian orogen, SW Scandinavia. Norwegian J. Geol. 85, 87–116.

Bingen, B., Stein, H.J., 2003. Molybdenite Re–Os dating of biotite dehydration melting in the Rogaland high-temperature granulites, S Norway. Earth Planet. Sci. Lett. 208 (3–4), 181–195.

Bingen, B., Stein, H.J., Bogaerts, M., Bolle, O., Mansfeld, J., 2006. Molybdenite Re–Os dating constrains gravitational collapse of the Sveconorwegian orogen, SW Scandinavia. Lithos 87 (3–4), 328.

Bingen, B., van Breemen, O., 1998a. Tectonic regimes and terrane boundaries in the high-grade Sveconorwegian belt of SW Norway, inferred from U–Pb zircon geochronology and geochemical signature of augen gneiss suites. J. Geol. Soc. (Lond.) 155, 143–154.

Bingen, B., van Breemen, O., 1998b. U–Pb monazite ages in amphibolite- to granulite-facies orthogneisses reflect hydrous mineral breakdown reactions: Sveconorwegian Province of SW Norway. Contrib. Mineral. Petrol. 132, 336–353.

Bogaerts, M., Scaillet, B., Liégeois, J.-P., Vander Auwera, J., 2003. Petrology and geochemistry of the Lyngdal granodiorite (Southern Norway) and the role of fractional crystallization in the genesis of Proterozoic ferro-potassic A-type granites. Precambrian Res. 124, 149–184.

Bogdanov, Y.B., Levchenkov, O.A., Komarov, A.N., Yakovleva, S.Z., Makeev, A.F., 1999. A new sequence of the early Riphean in the Baltic Shield. Doklady (Trans.) Russ. Acad. Sci. 366 (1), 76–78 (in Russian).

Bogdanov, Y.B., Savatenkov, V.V., Ivannikov, V.V., Frank-Kamenetsky, D.A., 2003. Isotope geochronology of the Riphean volcanic rocks of the Salmi formation. In: Proceedings of the Second Russian Conference on Isotope Geochronology, St. Petersburg, pp. 71–72 (in Russian).

Bogdanova, S., De Waele, B., Bibikova, E., Postnikov, A., Popova, L., 2005b. Volgo-Uralia: SHRIMP evidence of strong Paleoproterozoic reworking of the Archean crust. In: Wingate, M.T.D., Pisarevsky, S.A. (Eds.), Supercontinents and Earth Evolution Symposium 2005 Geological Society of Australia Inc. Abstracts 81. Fremantle, Western Australia, p. 118.

Bogdanova, S., et al., 2006. EUROBRIDGE: new insight into the geodynamic evolution of the East European Craton. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere Dynamics. Geological Society, London, Memoirs 32, pp. 599–628.

Bogdanova, S.V., 1986. The Earth's Crust of the Russian Platform in the Early Precambrian (as Exemplified by the Volgo-Uralian Segment). Nauka, Moscow, 224 pp. (in Russian).

Bogdanova, S.V., 1993. Segments of the East European Craton. In: Gee, D.G., Beckholmen, M. (Eds.), EUROPROBE in Jablonna 1991. European Science Foundation, Polish Academy of Sciences, pp. 33–38.

Bogdanova, S.V., 2001. Tectonic settings of 1.65–1.4 Ga AMCG magmatism in the western East European Craton (western Baltica). J. Conf. Abstr. 6 (1), 769.

Bogdanova, S.V., Bibikova, E.V., Postnikov, A.V., Taran, L.N., 2004a. A Paleoproterozoic magmatic belt near Moscow. Doklady (Trans.) Russ. Acad. Sci. 395 (3), 376–380 (in Russian and English).

Bogdanova, S.V., et al., 2004b. The 1.80–1. 74 Ga gabbro-anorthosite-rapakivi Korosten Pluton in the NW Ukrainian Shield: a 3-D geophysical reconstruction of deep structure. Tectonophysics 381, 5–27.

Bogdanova, S.V., Gorbatschev, R., Garetsky, R.G., 2005a. The East European Craton. In: Selley, R.C., Cocks, L.R., Plimer, I.R. (Eds.), Encyclopedia of Geology. Elsevier, pp. 34–49.

Bogdanova, S.V., Page, L.M., Skridlaite, G., Taran, L.N., 2001. Proterozoic tectonothermal history in the western part of the East European Craton: $^{40}Ar/^{39}Ar$ geochronological constraints. Tectonophysics 339 (1–2), 39–66.

Bogdanova, S.V., Pashkevich, I.K., Gorbatschev, R., Orlyuk, M., 1996. Riphean rifting and major Paleoproterozoic boundaries in the East European Craton: geology and geophysics. Tectonophysics 268, 1–22.

Brewer, T.S., Åhäll, K.-I., Darbyshire, D.P.F., Menuge, J.F., 2002. Geochemistry of late Mesoproterozoic volcanism in southwestern Scandinavia: implications for Sveconorwegian/Grenvillian plate tectonic models. J. Geol. Soc. (Lond.) 159, 129–144.

Brewer, T.S., Ahall, K.I., Menuge, J.F., Storey, C.D., Parrish, R.R., 2004. Mesoproterozoic bimodal volcanism in SW Norway, evidence for recurring pre-Sveconorwegian continental margin tectonism. Precambrian Res. 134 (3–4), 249–273.

Brewer, T.S., Daly, J.S., Ahall, K.-I., 1998. Contrasting magmatic arcs in the Paleoproterozoic of the south-western Baltic Shield. Precambrian Res. 92 (3), 297–315.

Buchan, K.L., et al., 2001. Rodinia: the evidence from integrated palaeomagnetism and U–Pb geochronology. Precambrian Res. 110, 9–32.

Buchan, K.L., et al., 2000. Comparing the drift of Laurentia and Baltica in the Proterozoic: the importance of key Paleomagnetic poles. Tectonophysics 319 (3), 167.

Bush, V.A., Kazmin, V.G., 2007. The Riphean stage of the development of the intracontinental "non-granitic" Peri-Caspian basin. In: Karyakin, Y.V. (Ed.), Fundamental Problems of Geotectonics. GEOS, Moscow, Russia, pp. 119–123.

Cawood, P.A., 2005. Terra Australis Orogen: Rodinia breakup and development of the Pacific and Iapetus margins of Gondwana during the Neoproterozoic and Paleozoic. Earth Sci. Rev. 69 (3–4), 249–279.

Cawood, P.A., Pisarevsky, S.A., 2006. Was Baltica right-way-up or upside-down in the Neoproterozoic? J. Geol. Soc. (Lond.) 163, 1–7.

Čečys, A., 2004. Tectonic implications of the ca. 1.45 Ga granitoid magmatism at the southwestern margin of the East European Craton. Doctoral Thesis. Lund University, Lund, 25 pp.

Čečys, A., Benn, K., 2006. Emplacement and deformation of the ca. 1.45 Ga Karlshamn granitoid pluton, southeastern Sweden, during ENE–WSW Danopolonian shortening. Int. J. Earth Sci. (Geologische Rundschau) 95, doi:10.1007/s00531-006-0114-6.

Čečys, A., Bogdanova, S., Jansson, C., Bibikova, E., Kornfält, K.-A., 2002. The Stenshuvud and Tåghusa granitoids: new representatives of Mesoproterozoic magmatism in southern Sweden. GFF 124, 149–162.

Christoffel, C.A., Connelly, J.N., Åhäll, K.I., 1999. Timing and characterization of recurrent pre-Sveconorwegian metamorphism and deformation in the Varberg-Halmstad region of SW Sweden. Precambrian Res. 98 (3–4), 173–195.

Claeson, D.T., 1999. Geochronology of the Rymmen gabbro, southern Sweden; implications for primary versus inherited zircon in mafic rocks and rheomorphic dykes. GFF 121 (1), 25–31.

Claeson, D.T., 2003. The timing of the Protogine zone deformation. GFF 125 (1), 47.

Claesson, S., Bibikova, E., Bogdanova, S., Skobelev, V., 2006. Archean terranes, Paleoproterozoic reworking and accretion in the Ukrainian Shield, East-European Craton. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere Dynamics. Geological Society, London, Memoir 32, pp. 645–654.

Claesson, S., Bogdanova, S.V., Bibikova, E.V., Gorbatschev, R., 2001. Isotopic evidence of Paleoproterozoic accretion in the basement of the East European Craton. Tectonophysics 339 (1–2), 1–18.

Claesson, S., Kresten, P., 1997. The anorogenic Noran granite—a Mesoproterozoic rapakivi intrusion in south-central Sweden. GFF 119, 115–122.

Cocks, L.R., Torsvik, T.H., 2005. Baltica from the late Precambrian to mid-Palaeozoic times: the gain and loss of a terrane's identity. Earth Sci. Rev. 72 (1–2), 39–66.

Condie, K.C., 2002. Breakup of a Paleoproterozoic supercontinent. Gondwana Res. 5 (1), 41–43.

Connelly, J.N., Berglund, J., Larson, S.Å., 1996. Thermotectonic evolution of the Eastern Segment of southwestern Sweden: tectonic constraints from U–Pb geochronology. In: Brewer, T.S. (Ed.), Precambrian Crustal Evolution in the North Atlantic Region. Geological Society, London, pp. 297–313, special publication 112.

Cornell, D., Årebäck, H., Scherstén, A., 2000. Ion microprobe discovery of Archean and Early Proterozoic zircon xenocrysts in southwest Sweden. GFF 122 (4), 377–383.

Cornell, D., Austin Hegardt, E., 2004. When, where and how did the Sveconorwegian Terranes of Sweden meet? In: Proceedings of the 26th Nordic Geological Winter Meeting, GFF, Uppsala, Sweden, p. 20.

Cosca, M.A., Mezger, K., Essene, E.J., 1998. The Baltica–Laurentia connection: Sveconorwegian (Grenvillian) metamorphism, cooling, and unroofing in the Bamble Sector, Norway. J. Geol. 106, 539–552.

Cymerman, Z., 2004. Precambrian structures of Bornholm and their relationships to the Kaszuby region (N Poland). Przegląd Geologiczny 52 (7), 593–602 (Polish with English abstract).

Daly, J.S., Balagansky, V.V., Timmerman, M.J., Whitehouse, M.J., 2006. The Lapland-Kola orogen: Paleoproterozoic collision and accretion of the northern Fennoscandian lithosphere. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere Dynamics. Geological Society, London, Memoirs 32, pp. 579–598.

Dalziel, I.W.D., 1991. Pacific margins of Laurentia and East Antarctica–Australia as a conjugate rift pair: evidence and implications for an Eocambrian supercontinent. Geology 19, 598–601.

Dalziel, I.W.D., 1997. Neoproterozoic–Paleozoic geography and tectonics: review, hypothesis, environmental speculation. Geol. Soc. Am. Bull. 109, 16–42.

Davidson, A., 1998. An overview of Grenville Province geology. In: Lucas, S.B., St-Onge, M.R. (Eds.), Geology of the Precambrian Superior and Grenville Provinces and Precambrian Fossils in North America. Geological Society of America, pp. 205–270, The Geology of North America C-1.

Davidson, A., this volume. Late Paleoproterozoic to mid-Neoproterozoic history of northern Laurentia: an overview of central Rodinia. Precambrian Res.

Dörr, W., et al., 2002. U–Pb and Ar–Ar geochronology of anorogenic granite magmatism of the Mazury complex, NE Poland. Precambrian Res. 119, 101–120.

Duchesne, J.-C., Maquil, R., Demaiffe, D., 1985. The Rogaland anorthosites: facts and speculations. In: Tobi, A.C., Touret, J.L. (Eds.), The Deep Proterozoic Crust in the North Atlantic Provinces. NATO ASI Series. Reidel, Dordrecht, pp. 449–476.

Ehlers, C., Lindroos, A., Selonen, O., 1993. The late Svecofennian granite–migmatite zone of southern Finland—a belt of transpressive deformation and granite emplacement. Precambrian Res. 64, 295–309.

Eklund, O., Konopelko, D., Rutanen, H., Fröjdö, S., Shebanov, A.D., 1998. 1.8 Ga Svecofennian post-collisional shoshonitic magmatism in the Fennoscandian shield. Lithos 45, 87–108.

Eliasson, T., Schöberg, H., 1991. U–Pb dating of the post-kinematic Sveconorwegian (Grenvillian) Bohus granite, SW Sweden: evidence of restitic zircon. Precambrian Res. 51, 337–350.

Elming, S.-Å., Mattson, H., 2001. Post Jotnian basic intrusions in the Fennoscandian Shield, and the break up of Baltica from Laurentia: a Paleomagnetic and AMS study. Precambrian Res. 108, 216–236.

Ernst, R.E., et al., 2006. Geochemical characterization of Precambrian magmatic suites of the southeastern margin of the East European Craton, Southern Urals, Russia. Geologichesky Sbornik (Geological Proceedings) 5, 119–161.

Fuck, R.A., Brito Neves, B.B., Schobbenhaus, C., this volume. Rodinia Descendants in South America. Precambrian Res.

Gaál, G., Gorbatschev, R., 1987. An outline of the Precambrian evolution of the Baltic Shield. Precambrian Res. 35, 15–52.

Gee, D.G., 2005. Timanides of Northern Russia. In: Selley, R.C., Cocks, L.R., Plimer, I.R. (Eds.), Encyclopedia of Geology. Elsevier, pp. 49–56.

Gee, D.G., Stephenson, R.A., 2006. The European lithosphere: an introduction. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere Dynamics. Geological Society, London, Memoirs 32, pp. 1–9.

Geraldes, M.C., et al., 2001. Proterozoic geological evolution of the SW part of the Amazonian Craton in Mato Grosso state, Brazil. Precambrian Res. 111, 91–128.

Gorbatschev, R., 1967. Petrology of Jotnian rocks in the Gävle Area. East Central Sweden. Sveriges Geologiska Undersökning, ser. C 621, Stockholm, pp. 1–50.

Gorbatschev, R., Bogdanova, S., 1993. Frontiers in the Baltic Shield. Precambrian Res. 64, 3–22.

Gorbatschev, R., Bogdanova, S., 2004. The Protogine Zone south of Lake Vättern: a major lithospheric boundary in the Baltic Shield. GFF 126 (1), 22–23.

Gorbatschev, R., et al., 1987. Mafic dyke swarms of the Baltic Shield. In: Halls, H.C., Fahrig, W.F. (Eds.), Mafic Dyke Swarms. Geological Association of Canada, pp. 361–372, special paper 34.

Gower, C.F., Krogh, T., 2002. A U–Pb geochronological review of the Proterozoic history of the eastern Grenville Province. Can. J. Earth Sci. 39, 795–829.

Gower, C.F., Ryan, A.F., Rivers, T., 1990. Mid-Proterozoic Laurentia–Baltica: an overview of its geological evolution and a summary of the contributions made by this volume. In: Gower, C.F., Rivers, T., Ryan, B. (Eds.), Mid-Proterozoic Laurentia–Baltica. Geological Association of Canada, St. John's Newfounland, pp. 23–40.

Haapala, I., Rämö, T., 1992. Tectonic setting and origin of the Proterozoic rapakivi granites of Southeastern Fennoscandia. Trans. Roy. Soc. Edinburgh Earth Sci. (83), 165–171.

Harlov, D.E., 2000. Pressure–temperature estimation in orthopyroxene-garnet bearing granulite facies rocks, Bamble Sector, Norway. Mineral. Petrol. 69, 11–33.

Heaman, L.M., Smalley, P.C., 1994. A U–Pb study of the Morkheia Complex and associated gneisses, south Norway: implications for disturbed Rb–Sr systems and for the temporal evolution of Mesoproterozoic magmatism in Laurentia. Geochim. Cosmochim. Acta 58, 1899–1911.

Hellstrom, F.A., Johansson, A., Larson, S.A., 2004. Age and emplacement of late Sveconorwegian monzogabbroic dykes, SW Sweden. Precambrian Res. 128 (1–2), 39–55.

Henderson, I.H.C., Ihlen, P.M., 2004. Emplacement of polygeneration pegmatites in relation to Sveconorwegian contractional tectonics: examples from southern Norway. Precambrian Res. 133, 207–222.

Hoffman, P.F., 1989. Speculations on Laurentia's first gigayear (2.0 to 1.0 Ga). Geology 17, 135–138.

Hoffman, P.F., 1991. Did the breakout of Laurentia turn Gondwanaland inside-out? Science 252, 1409–1412.

Hoffman, P.F., 1997. Tectonic genealogy of North America. In: van der Pluijm, B.A., Marshak, S. (Eds.), Earth Structure: An Introduction to Structural Geology and Tectonics. W. W. Norton & Company, New York, London, pp. 459–464.

Högdahl, K., Andersson, U.B., Eklund, O. (Eds.), 2004. The Transscandinavian Igneous Belt (TIB) in Sweden: a review of its character and evolution. Geological Survey of Finland Special Paper 37, Espoo, 123 pp.

Högdahl, K., Sjöström, H., 2001. Evidence for 1.82 Ga transpressive shearing in a 1.85 Ga granitoid in central Sweden: implications for the regional evolution. Precambrian Res. 105 (1), 37–56.

Holme, K., 2001. Geochemical Development of Proterozoic Granites in the SW Baltic Shield. Lund University, Sweden, 19 pp.

Hubbard, F.N., 1975. The Precambrian crystalline complex of south-western Sweden. The geology petrogenetic development of the Varberg Region. Geol. Fören Stockholm Förh (97), 223–236.

Huhma, H., Mutanen, T., Whitehouse, M., 2004. Oldest rocks of the Fennoscandian Shield: the 3.5 Ga Siurua trondhjemite gneis in the Archean Pudasjärvi granulite belt, Finland. GFF 126, 10.

Johansson, Å., Bogdanova, S., Čecys, A., 2006. A revised geochronology for the Blekinge Province, southern Sweden. GFF 128 (4).

Johansson, Å., Bogdanova, S., Claesson, S., Taran, L., 2004. Gneisses and granitoids of Bornholm. GFF 126 (1), 24.

Johansson, L., Möller, C., Soderlund, U., 2001. Geochronology of eclogite facies metamorphism in the Sveconorwegian Province of SW Sweden. Precambrian Res. 106 (3–4), 261–275.

Kalsbeek, F., Thrane, K., Nutman, A.P., Jepsen, H.F., 2000. Late Mesoproterozoic to early Neoproterozoic history of the East Greenland Caledonides: evidence for Grenvillian orogenesis? J. Geol. Soc. (Lond.) 157, 1215–1225.

Kärki, A., Laajoki, K., 1995. An interlinked system of folds and ductile shear zones—late stage Svecokarelian deformation in the central Fennoscandian Shield, Finland. J. Struct. Geol. 17 (9), 1233–1247.

Karlstrom, K.E., et al., 2001. Long lived (1.8–1.0 Ga) convergent orogen in southern Laurentia, its extensions to Australia and Baltica, and implications for refining Rodinia. Precambrian Res. 111, 5–30.

Keppie, J.D., Dostal, J., Cameron, K.L., 2003. Geochronology and geochemistry of Grenvillian igneous suites in the northern Oaxacan Complex, southern Mexico: tectonic implications. Precambrian Res. 120 (3–4), 365–389.

Kheraskova, T.N., 2005. The significance of N.S. Shatsky's works on the tectonics of ancient platforms and their petroleum resources from a modern viewpoint. Geotectonics (Geotektonika) 39 (4), 253–271 (in Russian and English).

Kheraskova, T.N., Sapozhnikov, R.B., Volozh, Y.A., Antipov, M.P., 2006. Geodynamics and evolution of the Northern East European platform in the Late Precambrian as inferred from regional seismic profiling. Geotectonics (Geotektonika) 40 (6), 434–449 (in Russian and English).

Kheraskova, T.N., Volozh, Y.A., Vorontsov, A.K., Pevzner, L.A., Sychkin, N.I., 2002. Sedimentation conditions at the Central East European platform in the Riphean and Early Vendian. Lithol. Miner. Resour. 37 (1), 68–81.

Kirkland, C.L., Daly, J.S., Whitehouse, M.J., 2006. Granitic magmatism of Grenvillian and late Neoproterozoic age in Finnmark, Arctic Norway-Constraining pre-Scandian deformation in the Kalak Nappe Complex. Precambrian Res. 145 (1–2), 24–52.

Knudsen, T.-L., Andersen, T., 1999. Petrology and geochemistry of the Tromoy gneiss complex, south Norway, an alleged example of Proterozoic depleted lower continental crust. J. Petrol. 40, 909–933.

Kohonen, J., Pihlaja, P., Kujala, H., Marmo, J., 1993. Sedimentation of the Jotnian Satakunta sandstone. Bull. Geol. Surv. Finland 369, 1–35.

Kohonen, J., Rämö, T., 2005. Sedimentary rocks, diabases, and late cratonic evolution. In: Lehtinen, M., Nurmi, P.A., Rämö, O.T. (Eds.), Precambrian Geology of Finland—Key to the Evolution of the Fennoscandian Shield. Elsevier, Amsterdam, pp. 563–603.

Korja, A., Heikkinen, P., Aaro, S., 2001. Crustal structure of the northern Baltic Sea palaeorift. Tectonophysics 331 (4), 341–358.

Korja, A., Korja, T., Luosto, U., Heikkinen, P., 1993. Seismic and geoelectric evidence for collisional and extensional events in the Fennoscandian Schield—implications for Precambrian crustal evolution. Tectonophysics 219, 129–152.

Kornfält, K.-A., Vaasjoki, M., 1999. U–Pb zircon dating of Småland and Karlshamn granites from the southeasternmost Sweden. In: Bergman, S. (Ed.), Radiometric Dating Results. 4. SGU C831. Swedish Geological Survey, Uppsala, Sweden, pp. 33–41.

Korsman, K., Korja, T., Pajunen, M., Virransalo, P., GGT/SVEKA W.G., 1999. The GGT/SVEKA transect: structure and evolution of the continental crust in the Paleoproterozoic Svecofennian Orogen in Finland. Int. Geol. Rev. 41, 287–333.

Kostyuchenko, S., et al., 2006. Crustal structure and tectonic model of northeastern Baltica, based on deep seismic and potential field data. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere Dynamics. Geological Society, London, Memoirs 32, pp. 521–539.

Kostyuchenko, S.L., Egorkin, A.V., Solodilov, L.N., 1999. Structure and genetic mechanisms of the Precambrian rifts of the East European Platform in Russia by integrated study of seismic, gravity and magnetic data. Tectonophysics 313, 9–28.

Kozlov, V.I., Krasnobayev, A.A., Larionov, N.N., 1989. The Early Riphean of the Southern Urals. Nauka, Moscow, 208 pp. (in Russian).

Kozlov, V.I.e.a. (Editor), 2002. Explanatory Notes for the Geological Map of the Russian Federation and Adjacent Territories of Republic of Kazakhston, Scale 1 to 1000 000 (Sheets N-40 and 41). Ufa, Russia, Institute of Geology, Ufa Science Centre, 356 pp. (in Russian).

Krasnobayev, A.A., 1986. Zircon as an Indicator of Geological Processes. Nauka, Moscow, 145 pp. (in Russian).

Kremenetsky, A.A., et al., 2007. The Voronezh parametric well: new data for the geodynamic model of the formation of the Voronezh crystalline massif. In: Karyakin, Y.V. (Ed.), Fundamental Problems of Geotectonics. GEOS, Moscow, Russia, pp. 360–363 (in Russian).

Kröner, A., Compston, W., 1990. Archean tonalitic gneiss of Finnish Lapland revised: zircon ion-microprobe ages. Contrib. Mineral. Petrol. 104 (3), 348–352.

Kubicki, S., Ryka, W. (Eds.), 1982. Geological Atlas of Crystalline Basement in Polish Part of the East European Platform. Wydawnistwa Geologiczne, Warsaw, 24 tables pp.

Laajoki, K., Corfu, F., Andersen, T., 2002. Lithostratigraphy and U–Pb geochronology of the Telemark supracrustals in the Bandak-Sauland area, Telemark, South Norway. Norwegian J. Geol. 82, 119–138.

Lahtinen, R., Korja, A., Nironen, M., 2005. Paleoproterozoic tectonic evolution. In: Lehtinen, M., Nurmi, P.A., Rämö, O.T. (Eds.), Precambrian Geology of Finland—Key to the Evolution of the Fennoscandian Shield. Elsevier, Amsterdam, pp. 481–532.

Larson, S.Å., Stigh, J., Tullborg, E.-L., 1986. The deformation history of the eastern part of the Soutwest Swedish gneiss belt. Precambrian Res. 31, 237–257.

Li, Z.X., et al., this volume. Assembly, configuration, and break-up history of Rodinia: a synthesis. Precambrian Res.

Lindh, A., Gorbatschev, R., Lundegårdh, P.H., 1998. Beskrivning till berggrundskartan över Värmland Län; Västra Värmlands Berggrund. Sveriges Geologiska Undersökning, Ser. Ba 45 (2), 1–405.

Luttinen, A.V., Kosunen, P.J., 2006. The Kopparnäs dyke swarm in Inkoo, southern Finland: new evidence for Jotnian magmatism in the SE Fennoscandian Shield. In: Hanski, E., Mertanen, S., Rämö, T., Vuollo, J. (Eds.), Dyke Swarms—Time Markers of Crustal Evolution. Balkema, London, pp. 85–97.

Mansfeld, J., 2001. Age and eNd constraints on the Paleoproterozoic tectonic evolution in Latvia and Lithuania. Tectonophysics 339, 135–152.

Mansfeld, J., Beunk, F.F., Barling, J., 2005. 1.83–1.82 Ga formation of a juvenile volcanic arc—implications from U–Pb and Sm–Nd analyses of the Oskarshamn-Jönköping Belt, southeastern Sweden. GFF 127, 149–157.

Maslov, A.V., 2004. Riphean and Vendian sedimentary sequences of the Timanides and Uralides, the eastern periphery of the East European Craton. In: Gee, D.G., Pease, V. (Eds.), The Neoproterozoic Timanide Orogen of Eastern Baltica. Geological Society, London, Memoirs 32, pp. 19–35.

Meert, J., 2002. Paleomagnetic evidence for a Paleo-Mesoproterozoic supercontinent Columbia. Gondwana Res. 5 (1), 207–215.

Mints, M.V., et al., 1996. The Early Precambrian of the Northeastern Baltic Shield: Paleogeodynamics, Crustal Structure and Evolution. Nauchny Mir Publishing, Moscow, 287 pp. (in Russian).

Möller, A., O'Brien, P.J., Kennedy, A., Kröner, A., 2003. Linking growth episodes of zircon and metamorphic textures to zircon chemistry: an example from the ultrahigh-temperature granulites of Rogaland (SW Norway). In: Vance, D., Müller, W., Villa, I.M. (Eds.), Geochronology: Linking the Isotopic Record with Petrology and Textures. Geological Society, London, pp. 65–81, special publications.

Möller, C., 1998. Decompressed eclogites in the Sveconorwegian (-Grenvillian) orogen of SW Sweden: petrology and tectonic implications. J. Metamorph. Geol. 16, 641–656.

Möller, C., 1999. Sapphirine in SW Sweden: a record of Sveconorwegian (-Grenvillian) late-orogenic tectonic exhumation. J. Metamorph. Geol. 17, 127–141.

Möller, C., Andersson, J., Eliasson, T., Hellström, F., Lundqvist, L., 2006. Ion probe zircon dating of polimetamorphic gneisses, southeast Sveconorwegian Province—defining 1.44 Ga migmatization, 1.40 Ga granitic dyke, and post-1.40 Ga folding. Bull. Geol. Soc. Finland (Special Issue 1), 107.

Motuza, G., Čečys, A., Kotov, A.B., Salnikova, E.B., 2006. The Zemaičiu Naumiestis granitoids: new evidences for Mesoproterozoic magmatism in western Lithuania. GFF 128 (3), 209–272.

Mulch, A., Cosca, M.A., Andresen, A., Fiebig, J., 2005. Time scales of deformation and exhumation in extensional detachment systems determined by high-spatial resolution in situ UV-laser $^{40}Ar/^{39}Ar$ dating. Earth Planet. Sci. Lett. 233, 375–390.

Murphy, B.J., Strachan, R.A., Nance, R.D., Parker, K.D., Fowler, M.B., 2000. Proto-Avalonia: a 1.2–1.0 Ga tectonothermal event and constraints for the evolution of Rodinia. Geology 28 (12), 1071–1074.

Nironen, M., 1997. The Svecofennian Orogen: a tectonic model. Precambrian Res. 86, 21–44.

Nironen, M., 2005. Proterozoic orogenic granitoid rocks. In: Lehtinen, M., Nurmi, P.A., Rämö, O.T. (Eds.), Precambrian Geology of Finland—Key to the Evolution of the Fennoscandian Shield. Elsevier, Amsterdam, pp. 443–480.

Obst, K., Hammer, J., Katzung, G., Korich, D., 2004. The Mesoproterozoic basement in the southern Baltic Sea: insights from the G 14-1 off-shore borehole. Int. J. Earth Sci. (Geologische Rundschau) 93 (1), 1–12.

Olovyanishnikov, V.G., 1998. Late Precambrian of Timan and Kanin Peninsula. The Uralian Branch of the Russian Academy of Sciences, Ekaterinburg, 162 pp. (in Russian).

Ovchinnikova, G.V., Vasilieva, I.M., Semikhatov, M.A., 1998. U–Pb systematics of Proterozoic carbonate rocks: the Inser Group of the stratotype of the Late Riphean (Southern Urals). Stratigr. Geol. Correl. 6 (4), 20–31.

Page, L.M., Stephens, M.B., Wahlgren, C.-H., 1996. $^{40}Ar/^{39}Ar$ geochronological constraints on the tectonothermal evolution of the Eastern Segment of the Sveconorwegian Orogen, south-central Sweden. In: Brewer, T.S. (Ed.), Precambrian Crustal Evolution in the North Atlantic Region. Geological Society, London, Special Publication No. 112, pp. 315–330.

Park, J.K.R.G., 1992. Plate kinematic history of Baltica during the Middle to Late Proterozoic: a model. Geology 20, 725–728.

Park, R.G., Åhäll, K.-I., Boland, M.P., 1991. The Sveconorwegian shear-zone network of SW Sweden in relation to mid-Proterozoic plate movements. Precambrian Res. 49, 245–260.

Pease, V., et al., this volume. Baltica in the Cryogenian, 850–630 Ma. Precambrian Res.

Persson, A.I., 1999. Absolute (U–Pb) and relative age determinations of intrusive rocks in the Ragunda rapakivi complex, central Sweden. Precambrian Res. 95 (1–2), 109–127.

Pesonen, L.J., et al., 2003. Paleomagnetic configuration of continents during the Proterozoic. Tectonophysics 375, 289–324.

Pisarevsky, S., Wingate, M.T.D., Powell, C.M., Johnson, S., Evans, D.A.D., 2003. Models of Rodinia assembly and fragmentation. In: Yoshida, M., Windley, B.F., Dasgupta, S. (Eds.), Proterozoic East Gondwana: Supercontinent Assembly and Breakup. Geological Society, London, pp. 35–55, special publications.

Pisarevsky, S.A., Bylund, G., 2006. Palaeomagnetism of 935 Ma mafic dyles in southern Sweden and implications for the Sveconorwegian Loop. Geophys. J. Int. 166, 1095–1104.

Puchkov, V.N., 2000. Palaeodynamics in Southern and Central Urals. Dauria, Ufa, 146 pp. (in Russian).

Puura, V., et al., 1983. The Crystalline Basement of Estonian Territory. Nauka, Moscow, 208 pp. (in Russian).

Puura, V., Floden, T., 1999. Rapakivi-granite-anorthosite magmatism - a way of thinning and stabilisation of the Svecofennian crust. Baltic Sea Basin. Tectonophysics 305 (1–3), 75–92.

Rämö, O.T., Haapala, I., 2005. Rapakivi granites. In: Lehtinen, M., Nurmi, P.A., Rämö, O.T. (Eds.), Precambrian Geology of Finland—Key to the Evolution of the Fennoscandian Shield. Elsevier, Amsterdam, pp. 533–562.

Rämö, O.T., Huhma, H., Kirs, J., 1996. Radiogenic isotopes of the Estonian and Latvian rapakivi granite suites: new data from the concealed Precambrian of the East European Craton. Precambrian Res. 79, 209–226.

Rämö, O.T., et al., 2005. Mesoproterozoic CFB magmatism in the Lake Ladoga basin, RussianKarelia. In: Vuollo, J., Mertanen, S. (Eds.), Proceedings of the Fifth International Dyke Conference, Abstracts and Programme. Rovaniemi, Finland, July 31–August 3, pp. 41–42.

Rimša, A., Johansson, L., Whitehouse, M.J., in press. Constraints on incipient charnockite formation from zircon geochronology and rare earth element characteristics. Contrib. Mineral. Petrol.

Rivers, T., 1997. Lithotectonic elements of the Grenville Province: review and tectonic implications. Precambrian Res. 86, 117–154.

Rogers, J.J.W., Santosh, M., 2002. Configuration of Columbia, a Mesoproterozoic supercontinent. Gondwana Res. 5 (1), 5–22.

Røhr, T.S., Corfu, F., Austrheim, H., Andersen, T.B., 2004. Sveconorwegian U–Pb zircon and monazite ages of granulite-facies rocks, Hisarøya, Gulen, Western Gneiss Region, Norway. Norwegian J. Geol. 84, 251–256.

Ronkin, Y.L., et al., 2006. The boundary between the Early and Middle Riphean (S. Urals): 1350 +10 Ma or older? In: Proceedings of the III Russian Conference on Isotope Geochronology, GEOS, Moscow, pp. 183–188 (in Russian).

Samsonov, A.V., Bibikova, E.V., Petrova, A.Y., Gerasimov, V.Y., 2005. Tectonic stages of the development of the Central Russian fold belt, the central part of the crystalline basement of the East European platform: geochemistry, geochronology and petrotectonics. In: Karyakin, Y.V. (Ed.), Tectonics of the Earth' Crust and Mantle. Tectonic Implications for Ore Deposit Distribution. GEOS, Moscow, pp. 169–171 (in Russian).

Schärer, U., Wilmart, E., Duchesne, J.-C., 1996. The short duration and anorogenic character of anorthosite magmatism: U–Pb dating of the Rogaland complex, Norway. Earth Planet. Sci. Lett. 139, 335–350.

Scherstén, A., Larson, S.Å., Stigh, D.H., Cornell, J., 2004. Ion probe dating of a migmatite in SW Sweden, the fate of zircon in crustal processes. Precambrian Res. 130, 251–266.

Semikhatov, M.A., et al., 2002. Low $^{87}Sr/^{86}Sr$ ratios in seawater of the Grenville and post-Grenville time: determining factors. Stratigr. Geol. Corr. 10 (1), 1–41 (MAIK, Russia).

Semikhatov, M.A., et al., 2006. Isotopic age, Sr- and C-isotopic characteristics of the deposits of the Early Riphean key-section (the Burzyan Formation in the Southern Urals). In: Proceedings of the III Russian Conference on Isotope Geochronology, GEOS, Moscow, pp. 249–254 (in Russian).

Shcherbak, N.P., Artemenko, G.V., Lesnaya, I.M., Ponomarenko, A.N., 2005. Geochronology of the Early Precambrian of the Ukrainian Shield. The Archean. Naukova Dumka, Kiev, 243 pp. (in Russian).

Shchipansky, A.A., Bogdanova, S.V., 1996. The Sarmatian crustal segment: precambrian correlation between the Voronezh Massif and the Ukrainian Shield across the Dniepr-Donets Aulacogen. Tectonophysics 268 (1–4), 109–125.

Shchipansky, A.A., Samsonov, A.V., Petrova, A.Y., Larionova, Y.O., 2007. Geodynamics of the Eastern Margin of Sarmatia in the Paleoproterozoic. Geotectonics (Geotektonika) 41 (1), 38–62 (in Russian and English).

Skår, Ø., Pedersen, R.B., 2003. Relations between granitoid magmatism and migmatization: U–Pb geochronological evidences from the Western Gneiss Complex, Norway. J. Geol. Soc. (Lond.) 160, 935–946.

Skridlaite, G., Wiszniewska, J., Duchesne, J.-C., 2003. Ferro-potassic A-type granites and related rocks in NE Poland and S Lithuania: west of the East European Craton. Precambrian Res. 124 (2–4), 305–326.

Skridlaite, G., Whitehouse, M.J., Rimša, A., 2007. Evidence for a pulse of 1.45 Ga anorthosite-mangerite-charnockite-granite (AMCG) plutonism in Lithuania: implications for the Mesoproterozoic evolution of the East European Craton. Terra Nova 19 (4), 294–301.

Slabunov, A.I., et al., 2006. The Archean nucleus of the Fennoscandian (Baltic) Shield. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere Dynamics. Geological Society, London, Memoirs 32, pp. 627–644.

Söderlund, P., Söderlund, U., Möller, C., Gorbatschev, R., Rodhe, A., 2004. Petrology and ion microprobe U–Pb chronology applied to a metabasic intrusion in southern Sweden: a study on zircon formation during metamorphism and deformation. Tectonics 23, TC5005, doi:10.1029/2003TC001498.

Söderlund, U., Ask, R., 2006. Mesoproterozoic bimodal magmatism along the Protogine Zone, S Sweden: three magmatic pulses at 1.56, 1.22 and 1.205 Ga, and regional implications. GFF 128 (4), 303–310.

Söderlund, U., Elming, S.A., Ernst, R.E., Schissel, D., 2006. The Central Scandinavian Dolerite Group—protracted hotspot activity or back-arc magmatism? Constraints from U–Pb baddeleyite geochronology and Hf isotopic data. Precambrian Res. 150 (3–4), 136–152.

Söderlund, U., et al., 2005. U–Pb baddeleyite ages and Hf, Nd isotope chemistry constraining repeated mafic magmatism in the Fennoscandian Shield from 1.6 to 0.9 Ga. Contrib. Mineral. Petrol. 150 (2), 174–194.

Söderlund, U., Möller, C., Andersson, J., Johansson, L., Whitehouse, M., 2002. Zircon geochronology in polymetamorphic gneisses in the Sveconorwegian orogen, SW Sweden: ion microprobe evidence for 1.46–1.42 and 0.98–0.96 Ga reworking. Precambrian Res. 113 (3–4), 193.

Sorjonen-Ward, P., Luukkonen, E.J., 2005. Archean rocks. In: Lehtinen, M., Nurmi, P.A., Rämö, O.T. (Eds.), Precambrian Geology of Finland—Key to the Evolution of the Fennoscandian Shield. Elsevier, Amsterdam, pp. 19–99.

Stein, H.J., Bingen, B., 2002. 1.05–1.01 Ga Sveconorwegian metamorphism and deformation of the supracrustal sequence at Sæsvatn, South Norway: Re–Os dating of Cu–Mo mineral occurrences. In: Blundell, D., Neubauer, F., von Quadt, A. (Eds.), The Timing and Location of Major Ore Deposits in an Evolving Orogen. Geological Society, London, pp. 319–335, special publications.

Stephens, M.B., Wahlgren, C.H., Weijermars, R., Cruden, A.R., 1996. Left lateral transpressive deformation and its tectonic implications, Sveconorwegian Orogen, Baltic Shield, Southwestern Sweden. Precambrian Res. 79, 261–279.

Suleymanov, A.K., Zamozhnyaja, N.G., Pavlenkova, N.I., 2007. Integrated seismic reflection and refraction methods for Geotransect 1-EV (the Petrozavodsk-Moscow part). In: Karyakin, Y.V. (Ed.), Fundamental Problems of Geotectonics. GEOS, Moscow, Russia, pp. 241–243 (in Russian).

Suominen, V., 1991. The chronostratigraphy of SW Finland with special reference to the Postjotnian and Subjotnian diabases. Bull. Geol. Surv. Finland 356, 1–100.

Svetov, A.P., 1979. The Platformal Basaltic Magmatism in the Karelides of Karelia. Nauka, Leningrad, Russia, 208 pp. (in Russian).

Teixeira, W., Bettencourt, J.S., Girardi, V.A.V., Onoe, A., Sato, K., 2006. Mesoproteozoic mantle heterogeneity in the SW Amazonian Craton: $^{40}Ar/^{39}Ar$ and Nd–Sr isotopic evidence from mafic-felsic rocks. In: Hanski, E., Mertanen, S., Rämö, T., Vuollo, J. (Eds.), Dyke Swarms—Time Markers of Crustal Evolution. Balkema, London, pp. 113–129.

Tobi, A.C., Hermans, G.A., Maijer, C., Jansen, J.B.H., 1985. Metamorphic zoning in the high-grade Proterozoic of Rogaland—Vest Agder, SW Norway. In: Tobi, A.C., Touret, J.L. (Eds.), The Deep Proterozoic Crust in the North Atlantic Provinces. NATO ASI Series. Reidel, Dordrecht, pp. 477–497.

Tohver, E., van der Pluijm, B.A., Mezger, K., Scandolara, J.E., Essene, E.J., 2005. Two stage tectonic history of the SW Amazon craton in the late Mesoproterozoic: identifying a cryptic suture zone. Precambrian Res. 137 (1–2), 35–59.

Tohver, E., van der Pluijm, B.A., Van der Voo, R., Rizzotto, G., Scandolara, J.E., 2002. Paleogeography of the Amazon craton at 1.2 Ga: early Grenvillian collision with the Llano segment of Laurentia. Earth Planet. Sci. Lett. 199, 185–200.

Tomkins, H.S., Williams, I.S., Ellis, D.J., 2005. In situ U–Pb dating of zircon formed from retrograde garnet breakdown during decompression in Rogaland, SW Norway. J. Metamorph. Geol. 23, 201–215.

Trofimov, V.A., 2006. Deep CMP seismic surveying along the Tatseis-2003 Geotraverse across the Volga-Ural Petroliferous Province. Geotectonics (Geotektonika) 40 (4), 249–262 (in Russian and English).

Tucker, R.D., Krogh, T.E., Råheim, A., 1990. Proterozoic evolution and age—province boundaries in the central part of the Western Gneiss Region, Norway: results of U–Pb dating of accessory minerals from Trondheimsfjord to Geiranger. In: Gower, C.F., Rivers, T., Ryan, B. (Eds.), Mid-Proterozoic Laurentia–Baltica. Geological Association of Canada, pp. 149–173, special paper 38.

Tuisku, P., Huhma, H., 2006. Evolution of Migmatitic Granulite complexes: implications from Lapland Granulite Belt. Part II. Isotopic dating. Bull. Geol. Soc. Finland 78 (II), 143–175.

Upton, B.G.J., Emeleus, C.H., Heaman, L.M., 2003. Magmatism of the mid-Proterozoic Gardar Province, South Greenland: chronology, petrogenesis and geological setting. Lithos 68 (1–2), 43–65.

Väisänen, M., Skyttä, P., 2007. Late Svecofennian shear zones in southwestern Finland. GFF 129 (1), 55–64.

Vander Auwera, J., et al., 2003. Derivation of the 1.0–0.9 Ga ferro-potassic A-type granitoids of southern Norway by extreme differentiation from basic magmas. Precambrian Res. 124, 107–148.

Veis, A.F., Fedorov, D.L., Kuzmenko, Y.T., Vorobéva, N.G., Golubkova, E.Y., 2004. Microfossils and Riphean Stratigraphy in the North European Platform (Mezen' Syneclise). Stratigr. Geol. Corr. 12 (6), 553–571.

Vetrin, V.R., Bayanova, T.B., Kamenetskii, I.L., Ikorskii, S.V., 2002. U–Pb ages and helium isotope chemistry of rocks and minerals from the Litsk-Aragub diorite-granite complex (Kola Peninsula). Doklady (Trans.) Russ. Acad. Sci. 387 (1), 85–89.

Wahlgren, C.-H., Cruden, A.R., Stephens, M.B., 1994. Kinematics of a major fan-like structure in the eastern part of the Sveconorwegian orogen, Baltic Shield, south-central Sweden. Precambrian Res. 70, 67–91.

Wang, X.-D., Söderlund, U., Lindh, A., Johansson, L., 1998. U–Pb and Sm–Nd dating of high-pressure granulite- and upper amphibolite facies rocks from SW Sweden. Precambrian Res. 92, 319–339.

Weber, B., Hecht, L., 2003. Petrology and geochemistry of metaigneous rocks from a Grenvillian basement fragment in the Maya block: the Guichicovi complex, Oaxaca, southern Mexico. Precambrian Res. 124 (1), 41–67.

Weil, A.B., Van der Voo, R., Mac Niocaill, C., Meert, J.G., 1998. The Proterozoic supercontinent Rodinia: paleomagnetically derived reconstructions for 1100 to 800 Ma. Earth Planet. Sci. Lett. 154, 13–24.

Wiszniewska, J., Claesson, S., Stein, H., Vander Auwera, J., Duchesne, J.-C., 2002. The north-eastern Polish anorthosite massifs: petrological, geochemical and isotopic evidence for a crustal derivation. Terra Nova 14, 451–460.

Zhao, G., Sun, M., Wilde, S.A., Li, S., 2004. A Paleo-Mesoproterozoic supercontinent: assembly, growth and breakup. Earth Sci. Rev. 67, 91–123.

Zhou, X.Q., et al., 1995. The 1160 Ma old Hidderskog meta-charnockite: implications of this A-type pluton for the Sveconorwegian belt in Vest Agder (SW Norway). Lithos 36, 51–66.