Linking orogenesis across a supercontinent; the Grenvillian and Sveconorwegian margins on Rodinia

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Abstract

The Sveconorwegian orogeny in SW Baltica comprised a series of geographically and tectonically discrete events between 1140 and 920 Ma. Thrusting and high-grade metamorphism at 1140–1080 Ma in central parts of the orogen were followed by arc magmatism and ultra-high-temperature metamorphism at 1060–920 Ma in the westernmost part of the orogen. In the eastern part of the orogen, crustal thickening and high-pressure metamorphism took place at 1050 in one terrane and at 980 Ma in another. These discrete tectonothermal events are incompatible with an evolution resulting from collision with another major, continental landmass, and better explained as accretion and re-amalgamation of fragmented and attenuated crustal blocks of the SW Baltica margin behind an evolving continental-margin arc. In contrast, the coeval, along-strike Grenvillian orogeny is typically ascribed to long-lived collision with Amazonia. Here we argue that coeval, but tectonically different events in the Sveconorwegian and Grenville orogens may be linked through the behavior of the Amazonia plate. Subduction of Amazonian oceanic crust, and consequent slab pull, beneath the Sveconorwegian may have driven long-lived collision in the Grenville. Conversely, the development of a major orogenic plateau in the Grenville may have slowed convergence, thereby affecting the rate of oceanic subduction and thus orogenic evolution in the Sveconorwegian. Convergence ceased in the Grenville at ca. 980 Ma, in contrast to the Sveconorwegian where convergence continued until ca. 920 Ma, and must have been accommodated elsewhere along the Grenville–Amazonia segment of the margin, for example in the Goiás Magmatic Arc which had been established along the eastern Amazonian margin by 930 Ma. Our model shows how contrasting but coeval orogenic behavior can be linked through geodynamic coupling along and across tectonic plates.

Keywords: Sveconorwegian; Grenville; Rodinia; supercontinent; orogeny; accretion

1. Introduction

The Late Mesoproterozoic Grenville–Sveconorwegian orogenic belt forms the backbone in most reconstructions of the Late Mesoproterozoic supercontinent Rodinia, and is typically envisaged as a linear orogenic belt resulting from collision between Laurentia (Grenville) and Baltica (Sveconorwegian) with Amazonia (Sunsas) (e.g., Li et al., 2008). Correlation between the Grenville and Sveconorwegian orogens has been based on paleomagnetic data (e.g., Evans, 2013) and recognition of coeval tectonic events and a similarities in orogenic architecture (e.g., Bingen et al., 2008a; Gower et al., 1990; Möller et al., 2015). These interpretations do, however, leave several major questions unanswered. For example: 1) how did the Grenville orogen sustain ca. 70 Myr of convergence following the onset of continent-continent collision? 2) how could tectonically similar events take place at roughly the same time over distances of several thousand kilometers? More importantly, new interpretations of magmatic and metamorphic evidence from the western part of Sveconorwegian Province (Fig. 1) are incompatible with processes related to continent-continent collision (Blereau et al., 2016; Bybee et al., 2014; Coint et al., 2015; Slagstad et al., 2013a) and require that the SW Baltica margin remained active throughout Sveconorwegian orogenesis (see also discussion in Möller et al., 2013; Slagstad et al., 2013b).

Here, we present a new synthesis of the Sveconorwegian orogenic evolution that includes the entire orogen, and discuss how the currently available evidence suggest an evolution characterized by diachronous accretion of previously fragmented crustal blocks along an active continental margin. These new interpretations argue against a direct continuation of, and correlation with, the collisional Grenville Province, and this new framework allows us to propose a model involving geodynamic feedback along tectonically different segments of the Baltica–Laurentia margin.

2. Late Mesoproterozoic Baltica–Laurentia–Amazonia configuration

Paleomagnetic data from Baltica, Laurentia, and Amazonia are inconclusive with respect to these continents' configuration in the Rodinia supercontinent (cf., Evans, 2009; Hartz and Torsvik, 2002; Li et al., 2008). The relative configuration of Baltica and Laurentia, with Baltica located adjacent to Greenland in a nearly present-day orientation, seems the least controversial (Li et al., 2008). However, available paleomagnetic data for pre- and Grenvillian time (ca. 1140–1020 Ma), come mainly from Laurentia, particularly from rocks of the North American Mesoproterozoic Mid-Continent Rift system. Younger paleomagnetic poles are rather sparse. The paleomagnetic record for Baltica contains a very limited number of poles (e.g., Li et al., 2008 for a review). Approximately 1260 Ma paleomagnetic poles for Laurentia and Baltica (Buchan et al., 2000) suggest that the two continental blocks were adjacent by that time. The ca. 1100–1040 Ma (younger age limit is more likely) paleomagnetic pole for the Bamble sector (Fig. 1) (Meert and Torsvik, 2003; Torsvik and Eide, 1998) permits the reconstruction of Laurentia and Baltica as a unity almost to the Late Mesoproterozoic. This pole is virtually the same as a pole from the 1045 ± 50 Laanila dolerite intrusion (Mertanen et al., 1996). In contrast, a more recent paleomagnetic study in the Bamble and Telemark areas (Piper, 2009) reports different pole positions, although these poles were assigned somewhat younger ages of ca. 950–900 Ma. These poles, if an alternative polarity of the geomagnetic field is chosen, fall close to an even younger, 850 Ma paleomagnetic pole for Baltica (Walderhaug et al., 1999). This scarcity in available paleomagnetic data for Baltica introduces large uncertainties in paleogeographic reconstructions. Although the amount and quality of paleomagnetic poles for Baltica is far from perfect, the Grenville and Sveconorwegian apparent polar wander paths (APWP) have similarities and fit reasonably well after ca. 60° clockwise rotation of Baltica (Pisarevsky et al., 2003), and in the majority of paleogeographic reconstructions, Baltica is positioned in an approximately present-day orientation adjacent to NE Laurentia (e.g., Dalziel, 1992; Li et al., 2008; Pisarevsky et al., 2003).

The paleomagnetic record for Amazonia is also rather scant. On the basis of a single paleomagnetic pole for the ca. 1200 Ma Nova Floresta gabbro (Tohver et al., 2002), Amazonia was interpreted as initially colliding with the southern segment of Grenville province at the Llano uplift. In more recent papers (Tohver et al., 2004; Tohver et al., 2006), the authors proposed a scenario of strike-slip translation of Amazonia along the Laurentian eastern margin towards Baltica. Elming et al. (2009) further developed this model, which, in addition to ca. 3000 km of sinistral strike-slip translation along the eastern margin of Laurentia, includes almost 180° rotation of the Amazonia Craton, but with Baltica much farther north and the Sveconorwegian Province adjacent to NE Greenland. However, as pointed out by Evans (2013), if the alternative polarity for the 1200 Ma Nova Floresta pole is chosen, a much simpler scenario can be drawn up, in which Amazonia eventually collided with eastern Laurentia. It is worth noting that due to the absence of a continuous paleomagnetic record, the polarity of the 1200 Ma Nova Floresta paleomagnetic pole is unconstrained and can be chosen freely. Here, we adopt the dynamically simpler model of Evans (2013), that generally adopts the Amazonia–Laurentia relative position of previous Rodinia models (e.g., Li et al., 2008; Pisarevsky et al., 2003) We note, however, that our model only hinges on Baltica being proximal to Laurentia, together forming one tectonic plate, with Amazonia colliding with Laurentia to form the Grenville orogen.

For simplicity, the plate configuration is kept unchanged throughout the discussed period (1140–920 Ma), although some rotation might have taken place in this period. However, as stated above, the exact orientation of Baltica with respect to Laurentia is not critical to our model.

3. The pre-orogenic (>1140 Ma) Baltica and Laurentian margins

The Baltica–Laurentia margin is typically interpreted to have been active for several hundred millions of years prior to Sveconorwegian–Grenvillian orogenesis (Culshaw et al., 2013; McNutt and Dickin, 2011; Rivers and Corrigan, 2000; Roberts and Slagstad, 2015). The various components of this active margin are relatively well understood in the Grenville Province, reflected in the large-scale subdivisions of the orogen which are variably based on where the units were derived from (e.g., Carr et al., 2000) or their metamorphic evolution (Rivers et al., 1989). Collision with the Amazonian continent is generally believed to have terminated this active margin (Hynes and Rivers, 2010; Rivers and Corrigan, 2000), resulting in widespread metamorphism under a large, orogenic plateau and northwestward thrusting of marginal and outboard units onto the Laurentian margin (Jamieson et al., 2010).

The nature of the pre-Sveconorwegian (>1140 Ma) SW Baltica margin is relatively poorly known. In contrast to the Grenville orogen, the Sveconorwegian margin cannot be subdivided into units that formed the pre-orogenic margin of Baltica, overthrust by more outboard-derived units. Rather, the Sveconorwegian orogen appears to consist only of rocks that belonged to the pre-orogenic margin of Baltica, mainly formed between 1.8 and 1.5 Ga (Bingen et al., 2005; Möller et al., 2015; Roberts et al., 2013). The period between ca. 1.28 and 1.14 Ga was characterized by widespread emplacement of mafic dikes, bimodal volcanism, and sedimentation, suggesting widespread, long-lived continental extension interpreted to have taken place in a continental back-arc setting (e.g., Brewer et al., 2002; Roberts et al., 2011; Söderlund et al., 2006). Although the actual arc has so far escaped identification or has been removed by subduction erosion or other, later geologic processes, this interpretation is consistent with an active Baltica–Laurentia margin. Based on the relatively well-documented extensional history of SW Baltica between 1.28 and 1.14 Ga (Roberts and Slagstad, 2015), we assume that this part of Baltica comprised variably thinned continental ribbons and intervening basins, similar to those forming eastern Australasia today.

Schematic cross-sections of the Sveconorwegian Province at different times are shown in Figure 2. The corresponding activity along the Baltica–Laurentia margin is shown in Figure 3 in which the pre-Sveconorwegian SW Baltica margin is schematically presented by a series of color-coded (ref. Fig. 1) ovals that represent parts of the extended and thinned SW Baltica margin that are preserved in the Sveconorwegian orogen.

4. 1090–1020 Ma: Grenvillian continent-continent collision and Sveconorwegian accretion

In the Grenville orogen, the period between 1090 and 1020 Ma was characterized by orogen-wide, high-grade metamorphism and deformation, interpreted to reflect Grenvillian continent-continent collision with Amazonia (Ottawan phase, Hynes & Rivers 2010; Rivers 2012). This long-lived convergence resulted in NW-directed stacking of tectonic units representing the margin of Laurentia, outboard terranes, and exotic, Amazonia-derived units (see Rivers, 2015 for a recent review), in a large hot orogen (LHO), akin to the Himalaya–Tibetan Orogen (Jamieson et al., 2010; Rivers, 2012). In the easternmost Grenville Province, the general picture of NW-directed thrusting gives way to a dextral, strike-slip lateral-ramp regime (Fig. 3B; Gower et al., 2008). Gower et al. (2008) speculate that one major consequence of this change in tectonic style is that the Grenville Province did not continue as a major orogenic belt eastwards into Baltica, and "*that models involving Laurentia–Baltica links during Grenvillian orogenesis require rethinking*".

High-grade metamorphism in the Bamble sector (Fig. 1) between ca. 1140 and 1080 Ma is the earliest Sveconorwegian tectonic event (Bingen et al., 2008b), followed by emplacement of a major granitic batholith, the Sirdal Magmatic Belt (SMB) in the Rogaland–Hardangervidda sector, that was well underway by 1060 Ma (Coint et al., 2015), associated with coeval mafic magmatism (Høy, 2016) and inferred voluminous mafic underplating (Bybee et al., 2014). Magmatism in the SMB is interpreted to reflect establishment of a continental arc on the SW Baltica margin that appears to have ceased at 1020 Ma (Coint et al., 2015; Slagstad et al., 2013a), coincident with cessation of Ottawan convergence in the

Grenville Province. Approximately coeval with emplacement of the SMB, the Idefjorden terrane, farther east, underwent high-pressure metamorphism at 1045 Ma, followed by upper amphibolite-facies metamorphism at 1025 Ma (Söderlund et al., 2008). The tectonic significance of the early-Sveconorwegian metamorphic events in the Bamble sector and Idefjorden terrane is not clear, but they may reflect accretionary events related to long-lived convergence, accretion and amalgamation along the SW Baltic margin (Söderlund et al., 2008). The timing of juxtaposition of these units is unknown, but thrusting of the Rogaland–Hardangervidda sector over the Idefjorden terrane may have taken place as late as 1010 Ma (Bingen et al., 2008b).

5. 1020–980 Ma: End of convergence in the Grenville Province, crustal imbrication and onset of orogen-wide extension in the Sveconorwegian Province

Most workers assume that plate convergence related to the Grenvillian Ottawan phase lasted until ca. 1020 Ma, followed by a tectonically quiescent period. Although late-orogenic extension has been documented in several parts of the Grenville Province, the timing and duration of extension is unclear. Culshaw et al. (1997) argued for focused extension on the Shawanaga shear zone at ca. 1020 Ma, whereas Rivers (2012) and Rivers and Schwerdtner (2015) argued for much longer-lived extension. At present, the magnitude, duration, and possible along-strike variation of orogenic extension in the Grenville Province is unsettled (Culshaw et al., 2016), but it appears clear that significant extension was taking place by 1020 Ma. Following this extensional period, renewed contractional deformation during the Rigolet phase, between 1005 and 980 Ma (Hynes & Rivers 2010; Rivers 2012), most likely reflects a second, distinct stage of convergence and propagation of the orogen into its foreland (Carr et al., 2000).

Changes in geodynamic setting are also evident in the Sveconorwegian Province at this time. Magmatism in the SMB ceased at ca. 1020 Ma, and eclogite-facies metamorphism is recorded in the Eastern Segment at 980 Ma (Möller, 1998; Möller et al., 2015). This high-pressure (HP) event has been correlated with the roughly coeval Rigolet phase in the Grenville Province because both events represent foreland-directed thrusting and HP metamorphism close to the orogenic foreland (Möller et al., 2015). Large-scale extension has been documented along the Mylonite Zone (Viola et al., 2011), separating the eclogite-bearing Eastern Segment from the overlying Idefjorden terrane, and preserved prograde mineral zoning in the eclogites bears evidence of relatively rapid burial and exhumation, suggesting that the observed extension may play a role in their exhumation (Möller, 1998).

6. 990–920 Ma: Tectonic quiesence in the Grenville Province, widespread extension and magmatism in the Sveconorwegian Province

The cessation of convergence in the Grenville Province after ca. 980 Ma, and evidence for late-Rigolet free-boundary extension, suggest a major reorganization of plate boundaries at that time, possibly with initiation of subduction systems elsewhere at ca. 980 Ma (Hynes and Rivers, 2010; see also Murphy and Nance, 1991). Widespread, late- to post-orogenic magmatism in the eastern Grenville Province includes alkalic mafic dykes at 985–975 Ma, followed by monzonitic, syenitic, and granitic magmatism at 975–955 Ma (Gower and Krogh, 2002; Wasteneys et al., 1997).

Starting at 990 Ma or slightly earlier, voluminous ferroan granites (HBG suite, hornblende-biotite granite), minor gabbros, mafic dykes and anorthosite (RIC, Rogaland Igneous Complex) intruded various parts of the Sveconorwegian orogen and its foreland (e.g., Høy, 2016; Jensen and Corfu, 2016; Slagstad et al., 2013a; Vander Auwera et al., 2011). This magmatism appears to have been more or less continuous throughout the Sveconorwegian orogen until ca. 915 Ma (Söderlund et al., 2005; Vander Auwera et al., 2011). The ferroan compositions of these rocks has led to suggestions that they are extension related (Vander Auwera et al., 2011), matching structural/geochronological evidence of long-lived extensional reactivation of the Mylonite Zone at least until 920 Ma (Viola et al., 2011). Traditionally, this extension has been ascribed to orogenic collapse and delamination of thickened lithosphere; however, both the duration of extension and time gap between crustal thickening and magmatism (e.g., >100 Myr in the Bamble sector, where thrusting and high-grade metamorphism took place before 1080 Ma) pose problems for this interpretation (Slagstad et al., 2013b). An alternative that is favored here is that this prolonged extension took place in a continental back-arc setting (Coint et al., 2015; Slagstad et al., 2013a), similar to that proposed for the bimodal, ferroan granite-rhyolite provinces in the US (e.g., Bickford et al., 2015; Slagstad et al., 2009).

No metamorphism is recorded in the Bamble–Kongsberg sector after 1080 Ma and in the Idefjorden terrane after 1025 Ma (Bingen et al., 2008b). In contrast, the Rogaland sector in the western part of the Sveconorwegian orogen appears to have undergone high-grade regional metamorphism between 1035 and 970 Ma, or even longer, including ultra-high temperature (UHT) metamorphism at 1000 Ma (Drüppel et al., 2013). However, as discussed by Slagstad et al. (2013b) and Coint et al. (2015) this is unlikely to reflect the establishment of a long-lived orogenic plateau. The argument for prolonged high-grade metamorphism stems largely from geochronological evidence (Bingen et al., 2008b) from the SW part of the Rogaland sector. This region is characterized by voluminous, younger (ca. 990–920 Ma) intrusions, and recent work by Høy (2016) and Blereau et al. (2016) suggests that the <1030 Ma zircon and monazite ages must be reinterpreted to reflect the thermal- and/or fluid effects of voluminous, long-lived accretionary processes. This interpretation of metamorphic evolution is radically different from that proposed for the Grenville Province, where crustal thickening preceded, and resulted in, high-grade metamorphism (Jamieson et al., 2010).

7. A geodynamically linked but tectonically distinct Laurentia–Baltica margin

Interpretations that directly link processes and events in the Sveconorwegian and Grenville provinces (e.g., Bingen et al., 2008a) require that tectonically identical events happened coevally over distances of several thousand kilometers. Not only is such a linkage tectonically unlikely, it is also unwarranted given the evidence of very different orogenic styles, summarized above.

Convergence in the Grenville orogen appears to have been sustained for more than 60 Myr after initial collision (Jamieson et al., 2010), even longer than the Himalayan–Tibetan system (ca. 50 Myr, but still ongoing). The driving force behind long-lived and ongoing convergence between India and Asia is debated. Tectonic removal of the upper, low-density part of the Indian continental lithosphere may yield sufficient negative buoyancy to drive subduction and continued convergence (Capitanio et al., 2010; Tate et al., 2015), in addition to push from the Indian Ocean ridge and pull from subducting Indian oceanic crust east (e.g., Sunda arc) and west (Makran) of the Himalayas (Copley et al., 2010). The relative importance of these potential driving forces is unknown. Copley et al. (2010) demonstrated a strong relationship between a plate's absolute velocity and the proportion of its margins that is subducting. The significance of subduction for driving plate motion was further emphasized by Faccenna et al. (2012), who showed that development of subduction zones at different times has greatly affected the direction of movement of the Pacific plate the last 70 Myr.

Conversely, the collision between India and Asia and the development of the Tibetan Plateau appears to have slowed the movement of the Indian plate by a factor of almost four (Copley et al., 2010), which in turn will affect subduction-zone processes, e.g., in the form of increased slab rollback and trench retreat. Different geodynamic processes taking place at different sections along an extensive plate margin may, therefore, have predictable effects elsewhere along the same margin.

The basic premises of the Sveconorwegian–Grenville tectonic model presented below and in Figure 3 are (i) that Laurentia and Baltica were adjacent during Grenvillian–Sveconorwegian orogenesis, as argued by paleomagnetic evidence, and (ii) that there was only one converging plate, referred to as the Amazonian plate, consisting of both continental (Amazonia) and oceanic lithosphere.

The exact timing of full-fledged continent-continent collision in the Grenville Province is uncertain, and most likely diachronous. Ottawan high-grade metamorphism staring at 1090 Ma (Rivers, 2012) provides a minimum age for collision in parts of the orogen. Thus, collision was well underway at the onset of voluminous arc-related magmatism along the SW margin of Baltica at ca. 1060 Ma (Figs. 2B, 3B; Coint et al., 2015). By analogy with the India–Asia collision, development of an orogenic plateau in the Grenville would have slowed the Amazonian plate, resulting in increased rollback and trench retreat of the oceanic portions of the plate. Periods of vigorous arc magmatism in the Indonesian arc have been correlated with periods of increased slab rollback and trench retreat (Hall and Smyth, 2008), and we speculate that the SMB may represent the effects of plate slowdown and increased slab roll back. Conversely, pull from the subducting Amazonian oceanic lithosphere in the Sveconorwegian may have been a factor driving long-lived Ottawan convergence in the Grenville Province.

Cessation of SMB arc magmatism at 1020 Ma and convergence and thrusting in the Sveconorwegian orogen, coincided with the end of Ottawan convergence. It is possible that this part of the orogenic evolution reflects a shallowing subduction angle in the

Sveconorwegian resulting in increased compression here (Fig. 2C). This change would have slowed plate motions, reduced slab pull, and removed a potential driving force in the Grenville segment of the plate boundary (Fig. 3C). Alternative models are the accretion of an oceanic plateau, subduction of a ridge, or increased trenchward migration of the upper, Baltican plate; so far there is no clear evidence discriminating these processes.

Bimodal, ferroan magmatism and large-scale crustal extension in the Sveconorwegian Province had started by 990 Ma, heralding the onset of a continental extensional regime that was operative until at least 920 Ma (Slagstad et al., 2013a). A likely geodynamic setting for such a long-lived extensional event is a continental back-arc or extensional-arc setting (cf., Slagstad et al., 2009), reflecting steepening subduction and slab roll back (Fig. 3D). The consequent increased slab pull may once again have triggered contraction in the Grenville during the 1005–980 Ma Rigolet phase. Hynes and Rivers (2010) suggested that cessation of late convergence in the Grenville Province was due to a major reorganization of plate boundaries. In fact, shortly after termination of tectonic activity in the Sunsas Belt, the opposite, eastern margin of the Amazonian Craton was fragmented, forming a series of Neoproterozoic marginal basins parallel to the margins of the Amazonian Craton (see Cordani et al., 2009 and references therein). This fragmentation was followed by the development of a long-lived magmatic arc, the Goiás Magmatic Arc, which was active between ca. 930 and 550 Ma (Cordani et al., 2009; Pimentel et al., 2011). It is possible that these events reflect the establishment of a new plate margin capable of accommodating continued northward movement of the Amazonian plate, as indicated by events in the Sveconorwegian Province. This coupling across large continental masses, whereby subduction is initiated on the outskirts of a continental mass after collision on its interior, has been previously described by Murphy and Nance (1991) and Cawood and Buchan (2007). The model presented here for the Sveconorwegian orogeny bears resemblance to the tectonic-switching model of Collins (2002), and in addition argues that the effects of such switching may geodynamically impact other parts of the plate's boundary.

8. Conclusions

We argue that the tectonic evolutionary histories of the Grenville and Sveconorwegian orogens are best understood in terms of tectonically distinct events along an extensive, convergent margin. Potential feedback effects, suggested by studies of present-day geodynamic processes, provide a plausible framework for roughly coeval, but tectonically discrete events in the two orogens. In particular, long-lived subduction of oceanic crust, and consequent slab pull, beneath the Sveconorwegian orogen, may have been a major driving force for prolonged Grenvillian continent-continent collision. Conversely, establishment of an orogenic plateau in the Grenville orogen may have slowed down convergence, resulting in vigorous arc magmatism in the Sveconorwegian orogen. This geodynamic linkage removes the argument for one-to-one correlations of tectonic events over distances of several thousand kilometers, which appear unreasonable considering the tectonic diversity observed along modern plate margins.

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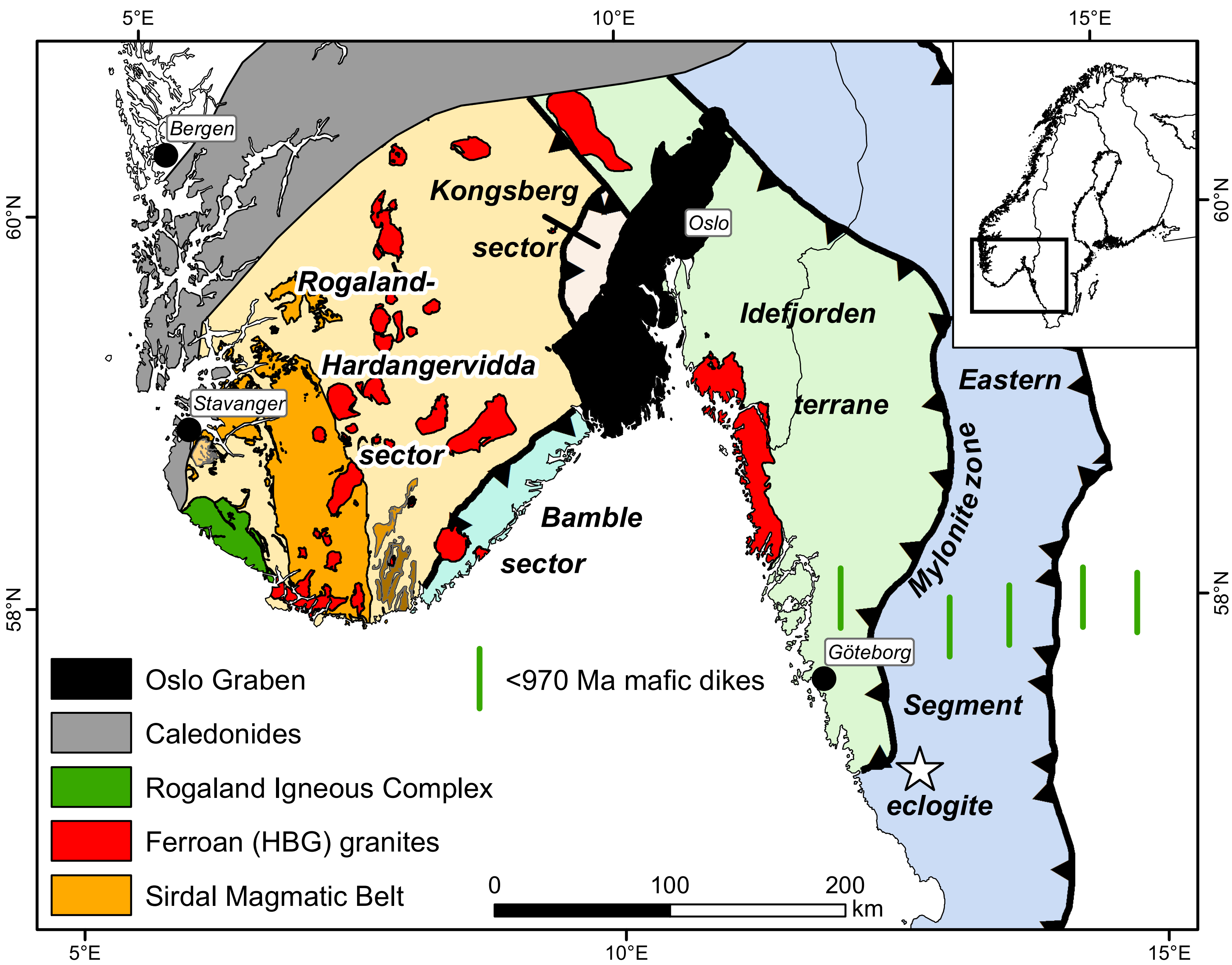
Captions

Figure 1. Simplified geological map of the Sveconorwegian Province, outlining the major tectonic units.

Figure 2. Cartoon showing the evolution of the Sveconorwegian orogeny, indicating the main events outlined in the text. TIB: Trans-Scandinavian Igneous Belt, SMB: Sirdal Magmatic Belt, HBG: hornblende-biotite granite suite (ferroan), RIC: Rogaland Igneous Complex.

Figure 3.Schematic paleogeographic reconstruction of Laurentia, Amazonia, and Baltica showing how events in the Sveconorwegian orogen may have influenced the Grenville orogen, and vice versa.



5°E
10°E
15°E
60°N
58°N
Bergen
Kongsberg
sector
Oslo
Rogaland-
Hardangervidda
sector
Stavanger
Idefjorden
terrane
Eastern
Mylonite zone
Bamble
sector
Göteborg
Segment
eclogite
Oslo Graben
Caledonides
Rogaland Igneous Complex
Ferroan (HBG) granites
Sirdal Magmatic Belt
<970 Ma mafic dikes
0
100
200
km

Fig. 1

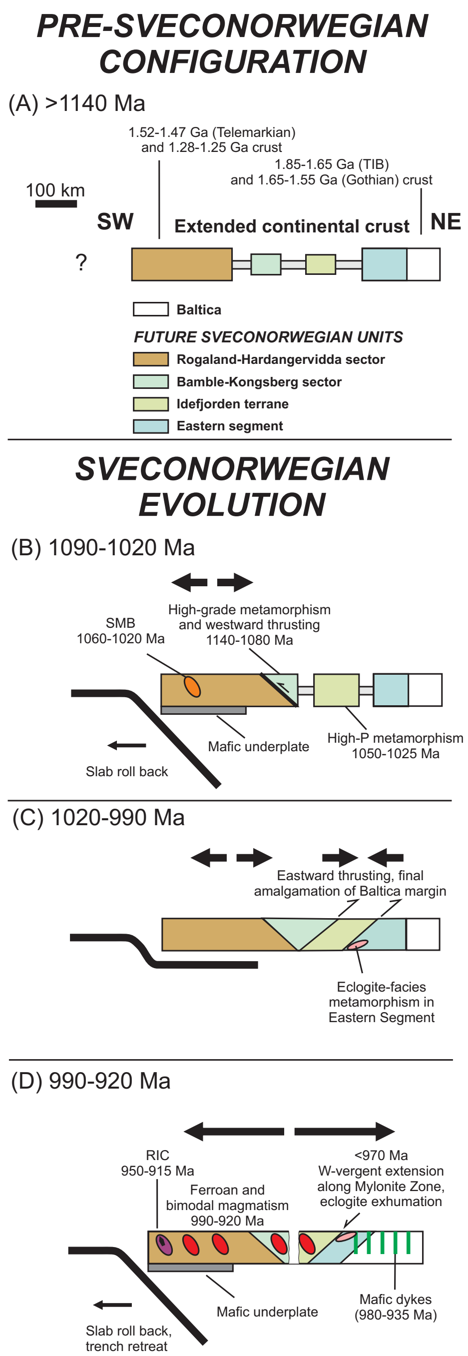

PRE-SVECONORWEGIAN CONFIGURATION
(A) >1140 Ma
1.52-1.47 Ga (Telemarkian) and 1.28-1.25 Ga crust
1.85-1.65 Ga (TIB) and 1.65-1.55 Ga (Gothian) crust
100 km
SW
Extended continental crust
NE
?
Baltica
FUTURE SVECONORWEGIAN UNITS
Rogaland-Hardangervidda sector
Bamble-Kongsberg sector
Idefjorden terrane
Eastern segment
SVECONORWEGIAN EVOLUTION
(B) 1090-1020 Ma
SMB 1060-1020 Ma
High-grade metamorphism and westward thrusting 1140-1080 Ma
Mafic underplate
High-P metamorphism 1050-1025 Ma
Slab roll back
(C) 1020-990 Ma
Eastward thrusting, final amalgamation of Baltica margin
Eclogite-facies metamorphism in Eastern Segment
(D) 990-920 Ma
RIC 950-915 Ma
Ferroan and bimodal magmatism 990-920 Ma
<970 Ma W-vergent extension along Mylonite Zone, eclogite exhumation
Mafic underplate
Mafic dykes (980-935 Ma)
Slab roll back, trench retreat

Fig. 2

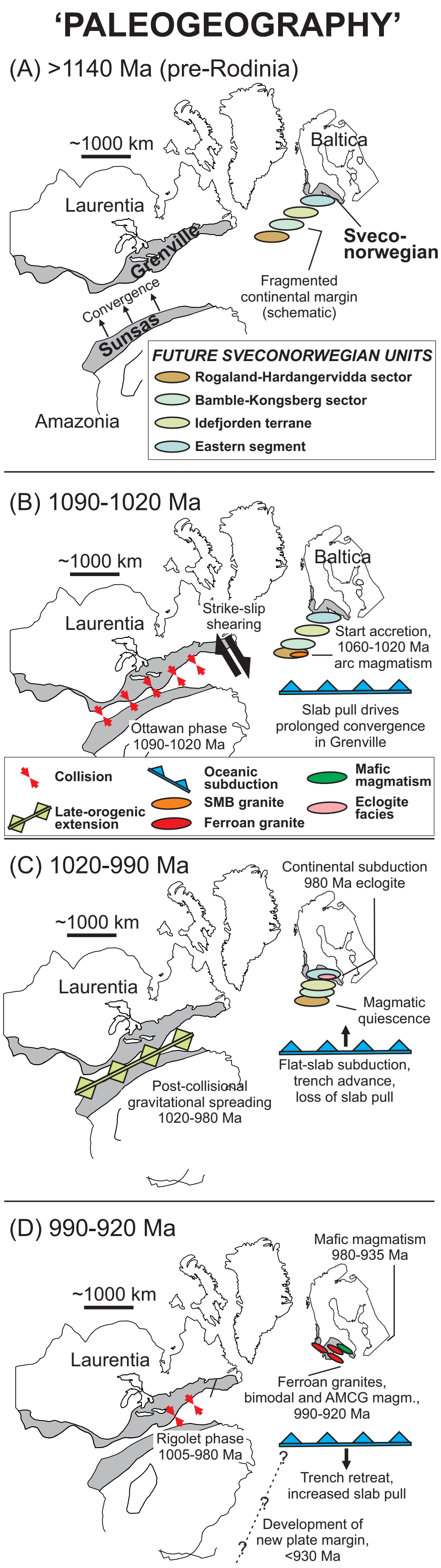

'PALEOGEOGRAPHY'
(A) >1140 Ma (pre-Rodinia)
~1000 km
Baltica
Laurentia
Grenville
Sveco-
norwegian
Convergence
Fragmented
continental margin
(schematic)
Sunsas
Amazonia
FUTURE SVECONORWEGIAN UNITS
Rogaland-Hardangervidda sector
Bamble-Kongsberg sector
Idefjorden terrane
Eastern segment
(B) 1090-1020 Ma
~1000 km
Baltica
Strike-slip
shearing
Laurentia
Start accretion,
1060-1020 Ma
arc magmatism
Slab pull drives
prolonged convergence
in Grenville
Ottawan phase
1090-1020 Ma
Collision
Oceanic
subduction
Mafic
magmatism
SMB granite
Eclogite
facies
Late-orogenic
extension
Ferroan granite
(C) 1020-990 Ma
Continental subduction
980 Ma eclogite
~1000 km
Laurentia
Magmatic
quiescence
Flat-slab subduction,
trench advance,
loss of slab pull
Post-collisional
gravitational spreading
1020-980 Ma
(D) 990-920 Ma
Mafic magmatism
980-935 Ma
~1000 km
Laurentia
Ferroan granites,
bimodal and AMCG magm.,
990-920 Ma
Rigolet phase
1005-980 Ma
Trench retreat,
increased slab pull
Development of
new plate margin,
<930 Ma

Fig. 3