

# A four-phase model for the Sveconorwegian orogeny, SW Scandinavia

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The Sveconorwegian orogenic belt resulted from collision between Fennoscandia and another major plate, possibly Amazonia, at the end of the Mesoproterozoic. The belt divides, from east to west, into a Paleoproterozoic Eastern Segment, and four mainly Mesoproterozoic terranes transported relative to Fennoscandia. These are the Idefjorden, Kongsberg, Bamble and Telemarkia Terranes. The Eastern Segment is lithologically related to the Transcandinavian Igneous Belt (TIB), in the Fennoscandian foreland of the belt. The terranes are possibly endemic to Fennoscandia, though an exotic origin for the Telemarkia Terrane is possible. A review of existing geological and geochronological data supports a four-phase Sveconorwegian assembly of these lithotectonic units. (1) At 1140–1080 Ma, the Arendal phase represents the collision between the Idefjorden and Telemarkia Terranes, which produced the Bamble and Kongsberg tectonic wedges. This phase involved closure of an oceanic basin, possibly marginal to Fennoscandia, accretion of a volcanic arc, high-grade metamorphism and deformation in the Bamble and Kongsberg Terranes peaking in granulite-facies conditions at 1140–1125 Ma, and thrusting of the Bamble Terrane onto the Telemarkia Terrane probably at c. 1090–1080 Ma. (2) At 1050–980 Ma, the Agder phase corresponds to the main Sveconorwegian oblique (?) continent-continent collision. It resulted in underthrusting and burial of the Idefjorden Terrane to high-pressure conditions at 1050 Ma, followed by exhumation. Crustal thickening in the Telemarkia Terrane led to protracted granite magmatism starting at 1050 Ma and to high-grade metamorphism starting at 1035 Ma. Metamorphism peaked in granulite-facies conditions in the Rogaland-Vest Agder Sector. (3) At 980–970 Ma, the Falkenberg phase reflects final convergence in the belt, shortly followed by divergence. Foreland propagation of the orogeny is indicated by underthrusting of the Eastern Segment to eclogites facies conditions at c. 970 Ma. (4) Between 970 and 900 Ma, the Dalane phase corresponds to gravitational collapse of the belt. It is associated with post-collisional magmatism increasing in volume westwards, exhumation of the southern part of the Eastern Segment as a core complex, and exhumation of the Rogaland-Vest Agder sector in the Telemarkia Terrane as a wide gneiss dome. Formation of the gneiss dome peaked at 930–920 Ma with low-pressure high-temperature granulite-facies metamorphism and intrusion of an anorthosite-mangerite-charnockite (AMC) complex.

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## Introduction

The Sveconorwegian orogenic belt is situated at the southwestern margin of Fennoscandia. It is one of the classical, well-exposed Grenvillian orogenic belts (Fig. 1) (Berthelsen 1980). Like most Grenvillian belts, it is deeply eroded and its hinterland rifted away during Neoproterozoic continent dispersal (Torsvik et al. 1996). On the basis of paleomagnetic and geological information, the Sveconorwegian belt is generally restored, in a variety of configurations, to the east of the Grenville belt of Laurentia, facing Amazonia, at the end of the Mesoproterozoic and during the Neoproterozoic (Gower et al. 1990; Hoffman 1991; Torsvik et al. 1996; Karlstrom et al. 2001; Cawood & Pisarevsky 2006; Bogdanova et al. 2008). Geological models for the Grenvillian-Sveconorwegian orogeny, derived from these reconstructions, involve an oblique collision between a common Laurentia-Baltica margin and the Amazonia indenter.

This paper reviews available geochronological data on magmatic and metamorphic events in the Sveconorwegian Belt. New zircon U-Pb data are also reported on a few samples to complete this information. The compila-

tion is used to create synthetic metamorphic and magmatic maps for several important time slices. The paper proposes an improved terrane analysis and a permissive, four-phase geological model for the Sveconorwegian orogeny.

## The Sveconorwegian belt

The continental crust affected by Sveconorwegian reworking and attached to Fennoscandia before the Phanerozoic Caledonian orogeny includes the c. 500 km wide Sveconorwegian belt, sensu stricto, exposed to the southeast of the Caledonian front, and several lithotectonic units exposed in the southern part of the Caledonian belt (Fig. 1; Berthelsen 1980; Gorbatsevich & Bogdanova 1993). These include the Western Gneiss Complex, the large basement window in Western Norway, and nappes attributed to the Middle Allochthon, namely the Lindås, Dalsfjord and Jotun Nappes (Tucker et al. 1990; Bingen et al. 2001b; Corfu & Andersen 2002; Skår & Pedersen 2003; Lundmark et al. 2007; Lundmark & Corfu 2008). Though classical models for Caledonian tectonic transport restore these units somewhere to the northwest of their present

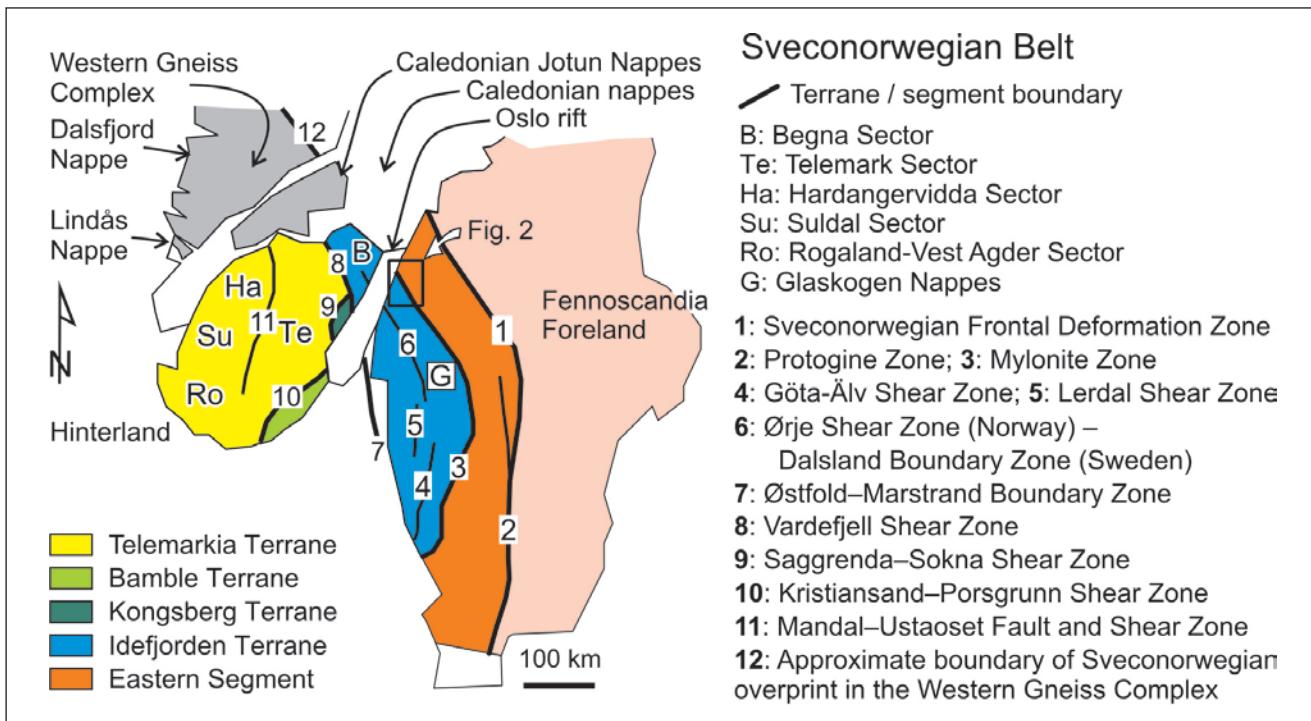


Fig. 1. Situation map of SW Scandinavia showing the main lithotectonic units and shear zones of the Sveconorwegian orogenic belt.

day position, their exact location and linkage to pre-Caledonian Fennoscandia remains speculative.

The Sveconorwegian belt sensu stricto is the focus of this paper. It is divided into five main lithotectonic units separated by crustal scale shear zones (Fig. 1). The easternmost unit, traditionally called the Eastern Segment (Berthelsen 1980), is regarded as a parautochthonous unit directly linked to the Fennoscandia foreland (Wahlgren et al. 1994; Persson et al. 1995; Söderlund et al. 1999). The other lithotectonic units have suffered significant Sveconorwegian transport relative to Fennoscandia and are referred to as terranes. These are the Idefjorden, Kongsberg, Bamble and Telemarkia Terranes (Fig. 1).

## U-Pb geochronological data

### Methods

U-Pb geochronological data are reported on zircon from 4 samples. Standard methods of mineral separation were used, including water-table, magnetic, and heavy liquid separation. Crystals were selected for analysis by hand-picking under alcohol.

Zircon from three samples was analysed by laser ablation - inductively coupled plasma mass spectrometry (LA-ICPMS) at the Geological Survey of Norway (Table 1). The data were collected with a Finnigan Element I single collector sector ICPMS, fed by a Finnigan 266 nm laser microsampler. Analyses were performed following Bingen et al. (2005). The laser beam was rastered over an area of c. 40 x 60  $\mu\text{m}$  at the surface of selected crystals presented

## Sveconorwegian Belt

- Terrane / segment boundary
- B: Begna Sector
- Te: Telemark Sector
- Ha: Hardangervidda Sector
- Su: Suldal Sector
- Ro: Rogaland-Vest Agder Sector
- G: Glaskogen Nappes
- 1: Sveconorwegian Frontal Deformation Zone
- 2: Protogine Zone; 3: Mylonite Zone
- 4: Göta-Älv Shear Zone; 5: Lerdal Shear Zone
- 6: Ørje Shear Zone (Norway) – Dalsland Boundary Zone (Sweden)
- 7: Østfold–Marstrand Boundary Zone
- 8: Vardefjell Shear Zone
- 9: Saggrenda–Sokna Shear Zone
- 10: Kristiansand–Porsgrunn Shear Zone
- 11: Mandal–Ustaoset Fault and Shear Zone
- 12: Approximate boundary of Sveconorwegian overprint in the Western Gneiss Complex

on double-sided tape. Two to three analyses were made at the same position to ensure progressive ablation from the surface to the core of the crystal. Masses were measured for 60 sec. The interference between  $^{204}\text{Pb}$  and  $^{204}\text{Hg}$  contained in the Ar gas was corrected by monitoring  $^{202}\text{Hg}$ . A 60 sec gas blank analysis was performed between each analysis. The measured isotope ratios were corrected for element- and mass-bias effects using the Geostandard 91500 reference zircon. Common Pb detected in the analyses is mainly instrumental. A common Pb correction was thus applied using a modern isotopic composition (Stacey & Kramers 1975) on the basis of the  $^{204}\text{Pb}$  analysis. Ablation related variation in element fractionation of up to several percent is unavoidable with the instrumentation used. Therefore, the weighted average  $^{207}\text{Pb}/^{206}\text{Pb}$  age is regarded as the most reliable age estimate.

Zircon from one sample of the Flå granite pluton was analysed by isotope dilution - thermal ionisation mass spectrometry (ID-TIMS) at Washington University following the procedures outlined in Tucker et al. (1999; Table 2). Ages were derived with the following decay constants:  $\lambda^{238}\text{U} = 1.55125 \cdot 10^{-10} \text{ y}^{-1}$ ;  $\lambda^{235}\text{U} = 9.8485 \cdot 10^{-10} \text{ y}^{-1}$ ;  $\lambda^{232}\text{Th} = 4.9475 \cdot 10^{-11} \text{ y}^{-1}$ ,  $^{238}\text{U}/^{235}\text{U} = 137.88$ . The ISOPLOT program (Ludwig 2001) was used to generate concordia diagrams and average ages.

### Granitoids from the Eastern Segment

Few geochronological data are available in the northernmost Norwegian part of the Eastern Segment, known as the Solør Complex (Heim et al. 1996; Nordgulen 1999; Mansfeld 2000; Alm et al. 2002). Therefore, three samples from distinct units were selected (Fig. 2).

**Table 1. LA-ICPMS U-Pb data on zircon**

	206Pb	207Pb		207Pb		206Pb			206Pb		207Pb		
Id	204Pb	206Pb	1σ	235U	1σ	238U	1σ	Co	238U	1σ	206Pb	1σ	Di
			(%)		(%)		(%)		(Ma)		(Ma)	(%)	
(1)	(2)	(3)		(3)		(3)		(4)	(5)		(5)		(6)
<b>FUN33, rhyolite</b>													
01p,x	1853	0.09586	1.2	2.584	2.4	0.1955	2.1	0.87	1151	22	1545	22	25
10p	1091	0.10396	1.5	2.853	2.7	0.1990	2.3	0.83	1170	24	1696	28	31
20	6803	0.10355	1.1	3.001	2.4	0.2102	2.2	0.88	1230	24	1689	21	27
22	1701	0.10229	1.4	2.969	2.1	0.2105	1.6	0.75	1231	18	1666	26	26
24p	1003	0.10290	1.4	3.122	2.6	0.2201	2.2	0.84	1282	26	1677	26	24
13p	5992	0.10337	0.8	3.303	1.6	0.2317	1.4	0.87	1344	17	1686	14	20
04p,x	2014	0.09961	1.4	3.256	2.5	0.2371	2.1	0.83	1372	26	1617	26	15
07p,x	1376	0.10694	1.3	3.673	2.1	0.2491	1.7	0.79	1434	21	1748	24	18
02	4998	0.10228	1.1	3.580	2.4	0.2539	2.2	0.90	1458	29	1666	20	12
16p	7609	0.10379	1.0	3.676	1.9	0.2568	1.6	0.86	1474	21	1693	18	13
11	6971	0.10265	1.1	3.829	2.3	0.2706	2.0	0.87	1544	28	1673	21	7.7
03	12247	0.10493	1.1	3.926	2.1	0.2714	1.8	0.84	1548	25	1713	21	9.7
23	10545	0.10220	1.0	3.930	1.6	0.2789	1.3	0.78	1586	18	1664	19	4.7
05	26493	0.10598	1.3	4.140	1.9	0.2833	1.3	0.71	1608	19	1731	24	7.1
17	15579	0.10224	1.0	3.995	1.9	0.2834	1.6	0.85	1608	23	1665	18	3.4
12	9093	0.10224	1.0	4.029	1.8	0.2858	1.5	0.83	1621	21	1665	19	2.7
08	16105	0.10464	0.9	4.128	1.7	0.2861	1.4	0.85	1622	21	1708	17	5.0
21	15508	0.10388	1.1	4.124	1.7	0.2879	1.4	0.80	1631	20	1695	19	3.7
09	16229	0.10521	1.1	4.202	1.9	0.2897	1.5	0.81	1640	22	1718	21	4.6
14	50662	0.10429	0.8	4.269	1.5	0.2969	1.3	0.86	1676	19	1702	14	1.5
15	15630	0.10335	0.9	4.231	1.7	0.2969	1.5	0.86	1676	22	1685	16	0.5
18	4993	0.10208	1.3	4.191	2.0	0.2978	1.6	0.78	1680	23	1662	24	-1.1
<b>FUN26, granite</b>													
01p,x	4681	0.09507	1.1	2.197	3.4	0.1676	3.2	0.94	999	30	1529	21	35
15p,x	10359	0.10472	0.9	2.706	2.3	0.1874	2.1	0.92	1107	22	1709	17	35
06p	10227	0.10282	0.8	3.327	2.1	0.2347	2.0	0.92	1359	24	1676	15	19
16	19066	0.10417	1.0	3.863	2.2	0.2690	2.0	0.90	1536	28	1700	18	9.7
08p	2656	0.10593	1.5	3.935	1.9	0.2695	1.2	0.61	1538	16	1730	28	11
11p	3711	0.10380	0.9	3.975	1.7	0.2777	1.4	0.85	1580	20	1693	16	6.7
02	8394	0.10360	1.0	3.988	1.7	0.2792	1.4	0.81	1587	20	1690	19	6.1
03p	6486	0.10433	1.1	4.037	1.7	0.2806	1.3	0.75	1595	18	1703	21	6.3
17p	17162	0.10285	1.0	4.002	1.7	0.2822	1.3	0.80	1602	19	1676	19	4.4
21p	18003	0.10451	0.9	4.068	1.8	0.2823	1.5	0.85	1603	21	1706	17	6.0
19p	2441	0.10289	1.0	4.023	1.7	0.2836	1.4	0.80	1609	19	1677	19	4.0
14	20798	0.10561	1.0	4.148	1.7	0.2849	1.4	0.82	1616	20	1725	18	6.3
23p	5804	0.10305	0.9	4.056	1.9	0.2855	1.6	0.87	1619	23	1680	17	3.6
13p	6746	0.10381	0.8	4.106	1.5	0.2868	1.2	0.82	1626	17	1693	15	4.0
24	15160	0.10370	1.1	4.111	1.9	0.2875	1.5	0.81	1629	22	1691	20	3.7
07	10538	0.10330	0.9	4.105	1.7	0.2882	1.5	0.87	1632	22	1684	16	3.1
09	11072	0.10429	0.8	4.172	1.4	0.2901	1.2	0.83	1642	17	1702	14	3.5
18	15265	0.10308	0.8	4.196	1.5	0.2952	1.2	0.82	1668	18	1680	16	0.8
22	587346	0.10494	0.9	4.284	1.7	0.2960	1.4	0.84	1672	21	1713	17	2.4
10	23958	0.10382	0.7	4.271	1.6	0.2984	1.4	0.89	1683	21	1694	13	0.6
20	1755	0.10510	2.0	4.354	2.4	0.3004	1.4	0.57	1694	20	1716	36	1.3
04	14985	0.10382	0.8	4.304	1.5	0.3006	1.3	0.84	1694	19	1694	16	-0.1
12	6966	0.10269	0.7	4.290	1.4	0.3030	1.2	0.84	1706	18	1673	14	-2.0
05	122367	0.10487	0.9	4.387	1.6	0.3034	1.3	0.84	1708	20	1712	16	0.2
<b>FUN38, granitic gneiss</b>													
01p	11497	0.10346	0.7	3.882	2.0	0.2721	1.9	0.93	1552	26	1687	14	8.0
04p	33572	0.10284	0.9	3.932	1.6	0.2773	1.3	0.84	1578	19	1676	16	5.9
16p	6373	0.10415	1.0	4.020	1.6	0.2799	1.3	0.80	1591	18	1699	18	6.4
23p	5777	0.10236	0.7	3.982	1.2	0.2821	1.0	0.83	1602	14	1667	13	3.9
06p	14472	0.10407	0.8	4.065	1.5	0.2833	1.3	0.85	1608	18	1698	15	5.3
20p	8096	0.10291	0.8	4.029	1.6	0.2839	1.4	0.86	1611	20	1677	15	3.9
12p	5419	0.10385	0.9	4.068	1.6	0.2841	1.3	0.84	1612	19	1694	16	4.8
05	37174	0.10541	0.9	4.171	1.5	0.2870	1.3	0.83	1626	18	1721	16	5.5
17	110354	0.10538	1.0	4.171	1.7	0.2871	1.4	0.81	1627	20	1721	19	5.5
02p	42032	0.10340	0.8	4.098	1.5	0.2874	1.2	0.83	1629	18	1686	16	3.4
09p	55522	0.10439	0.8	4.156	1.5	0.2888	1.3	0.86	1635	19	1704	14	4.0
18p	16215	0.10315	0.8	4.137	1.5	0.2909	1.3	0.86	1646	18	1681	14	2.1
21	19469	0.10490	0.8	4.217	1.6	0.2916	1.4	0.85	1649	20	1713	15	3.7
13	24932	0.10379	0.9	4.176	1.5	0.2918	1.2	0.81	1651	18	1693	16	2.5
08	11581	0.10193	0.8	4.110	1.8	0.2924	1.6	0.88	1654	23	1660	15	0.3
15	39170	0.10422	0.9	4.206	1.7	0.2927	1.4	0.86	1655	21	1701	16	2.7
07	19559	0.10450	0.9	4.228	1.6	0.2934	1.3	0.83	1659	19	1706	16	2.7
10	22466	0.10456	0.8	4.237	1.6	0.2939	1.3	0.84	1661	19	1707	15	2.7
19	49621	0.10375	0.8	4.231	1.7	0.2957	1.4	0.87	1670	21	1692	15	1.3
11	23029	0.10360	0.7	4.236	1.5	0.2965	1.2	0.86	1674	18	1690	14	0.9
22	67947	0.10366	1.0	4.243	2.0	0.2968	1.8	0.88	1676	26	1691	18	0.9
14p	23435	0.10450	0.8	4.292	1.6	0.2979	1.4	0.88	1681	20	1706	14	1.4
24	8110	0.10357	1.0	4.327	1.5	0.3030	1.1	0.74	1706	16	1689	18	-1.0
03	26469	0.10312	0.8	4.318	1.7	0.3037	1.5	0.89	1710	22	1681	14	-1.7

(1) Analysis identifier, p: first surface ablation, x: not used for age calculation (2) Measured ratio (3) Ratio corrected for common Pb

(4) Correlation of errors (5) Age corrected for common Pb (6) Discordance of the analysis:  $100 - (100 \times (206\text{Pb}/238\text{U})\text{age} / (207\text{Pb}/206\text{Pb}))\text{age}$

**Table 2. ID-TIMS zircon U-Pb data on the Flå granite pluton**

Fraction	ID	Nb.	Concentrations			Th/U	Atomic ratios		$\pm\sigma$	$^{207}\text{Pb}$	$\pm\sigma$	$^{206}\text{Pb}$	$\pm\sigma$	Age (Ma)		
			Wt. rad ( $\mu\text{g}$ )	Pb (ppm)	U (ppm)		$^{206}\text{Pb}$	$^{207}\text{Pb}$								
							$^{204}\text{Pb}$	$^{206}\text{Pb}$								
			(1)	(2)	(2)		(3)	(4)								
<b>N9438. granite</b>																
1		3	13	15.8	75	1	1.61	9615	0.06999	6	1.49288	243	0.15470	24	928.0	1.7
2		3	9	18.3	83	5	1.86	1451	0.07007	15	1.49235	388	0.15449	28	930.5	4.4
3		1	5	12.9	62	4	1.70	748	0.06993	33	1.47154	741	0.15261	29	926.4	9.5

(1) Number of crystals analysed

(2) Concentrations are known to  $\pm 30\%$  for sample weights of  $30 \mu\text{g}$  and  $\pm 50\%$  for samples  $< 3 \mu\text{g}$ .(3) Corrected for 0.0215 mole fraction common-Pb in the  $^{205}\text{Pb}$ - $^{235}\text{U}$  spike.(4) Calculated Th/U ratio assuming that all  $^{208}\text{Pb}$  in excess of blank, common-Pb, and spike is radiogenic

(5) Measured, uncorrected ratio

(6) Ratio corrected for fractionation, spike, blank, and initial common-Pb (at the determined age from Stacey and Kramers, 1975). Pb fractionation correction =  $0.094\%/\text{amu}$  ( $\pm 0.025\% 1\sigma$ ); U fractionation correction =  $0.111\%/\text{amu}$  ( $\pm 0.025\% 1\sigma$ ). U blank =  $0.2 \mu\text{g}$ ; Pb blank  $< 10 \mu\text{g}$ . Absolute uncertainties ( $1\sigma$ ) in the Pb/U and  $^{207}\text{Pb}/^{206}\text{Pb}$  ratios calculated following Ludwig (1980)

Table 2. ID-TIMS U-Pb data on zircon, Flå granite pluton

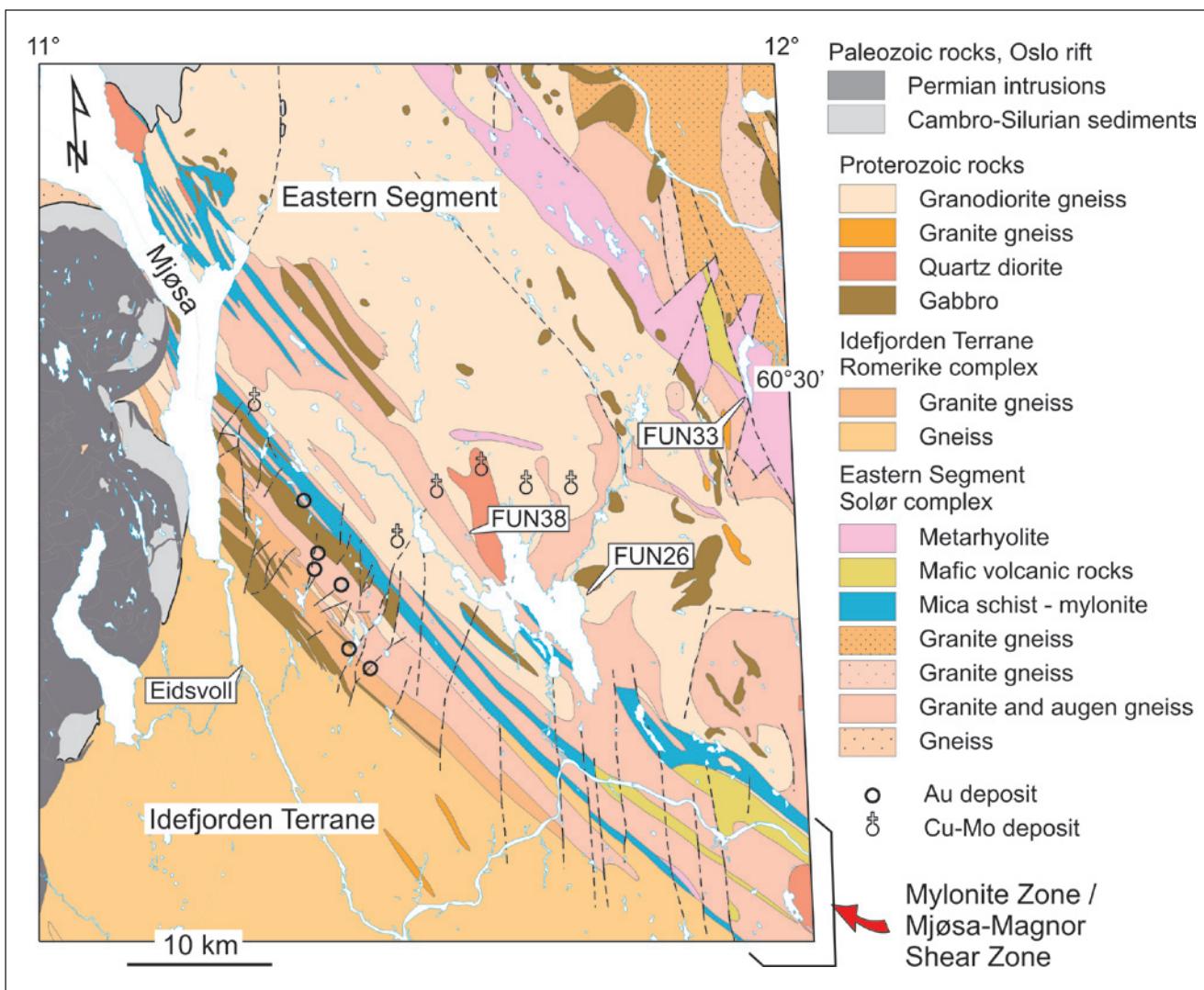


Fig. 2. Simplified geologic map of a portion of the Sveconorwegian belt, east of the Oslo rift, following Nordgulen (1999). The map shows the location of granitoid samples FUN26, 33, and 38.

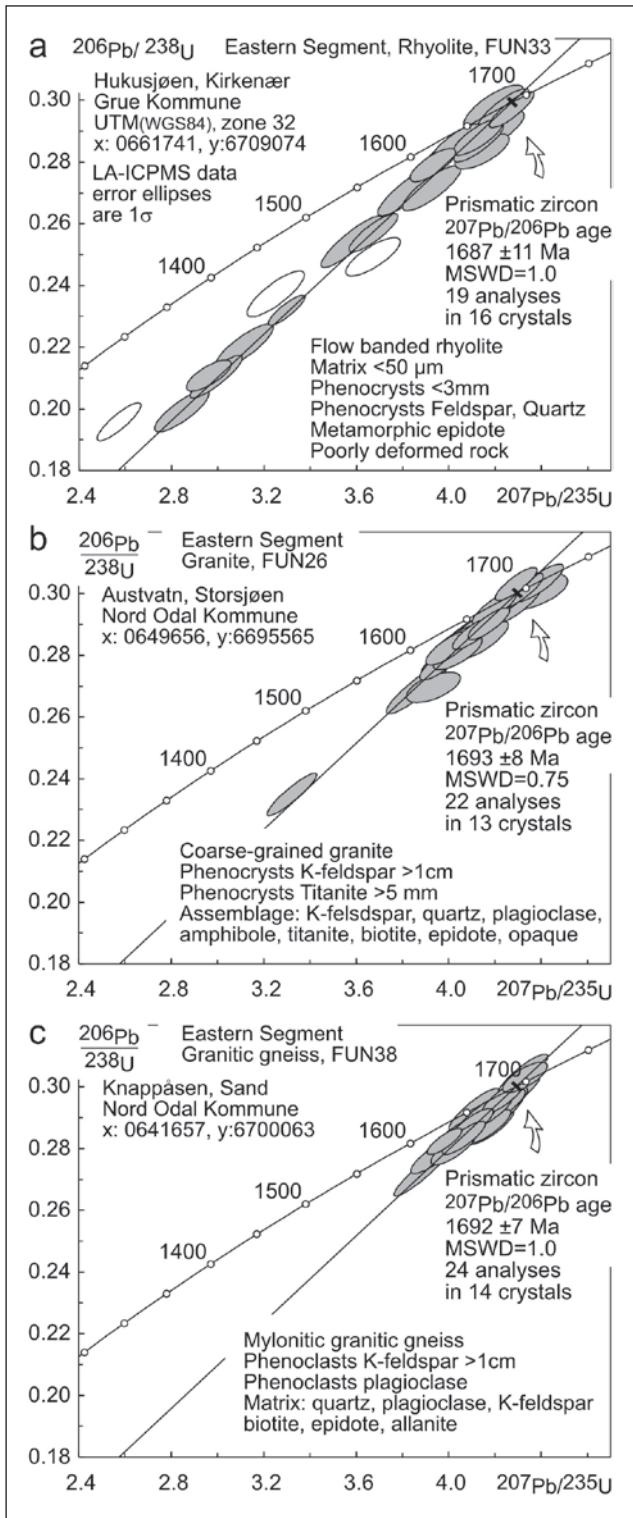


Fig. 3. LA-ICPMS U-Pb data on zircon from three granitoids from the Eastern Segment.

Sample FUN33 is a little deformed rhyolite collected from an elongate metarhyolite body (>50 km long) situated some 25 km east of the Mylonite Zone (Fig. 2). The sample shows small quartz and feldspar phenocrysts (<3 mm) in a fine-grained (<50 µm) volcanic matrix with centimetre-scale flow banding preserved. Nineteen analyses of prismatic zircon spread along a concordia line

with a lower intercept age close to 0 Ma. The weighted average  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1687 \pm 11$  Ma is interpreted as the extrusion age of the rhyolite (Fig. 3). No evidence for Sveconorwegian overprint is observed in the sample or in the zircon data.

Sample FUN26 represents a little deformed granitic gneiss (Fig. 2). The outcrop is made up of coarse-grained granite characterized by centimetre-scale K-feldspar megacrysts and by automorphic megacrysts of titanite larger than 5 mm. Prismatic zircon yields a  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1693 \pm 8$  Ma (Fig. 3), which dates the magmatic crystallization of this massive plutonic rock.

Sample FUN38 is granitic gneiss collected in a quarry situated in the vicinity of the Mylonite Zone (Fig. 2). The quarry exposes variably mylonitic, west dipping, N-S trending granitic to granodioritic gneiss. The sample is protomylonitic. It contains K-feldspar and plagioclase phenocrysts commonly larger than 1 cm separated by shear bands rich in fine-grained quartz and biotite. Metamorphic epidote is present in the matrix of the sample and reflects amphibolite-facies overprint. Zircon is prismatic, with no sign of a metamorphic rim. Twentyfour analyses of zircon yield a  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1692 \pm 7$  Ma, corresponding to the intrusion of the magmatic protolith of this gneiss (Fig. 3).

#### Flå granite pluton

The Iddefjorden Terrane hosts two large post-collisional granite plutons (Fig. 4), the Bohus-Iddefjorden pluton to the east of the Oslo rift (Eliasson & Schöberg 1991; Eliasson et al. 2003) and the Flå pluton to the west of the Oslo rift (Smithson 1963; Nordgulen 1999). The Flå pluton (c. 70 x 20 km in size) consists of a central core (20 x 10 km) of fine-grained, equigranular granite surrounded by a variably megacrystic, mainly medium-grained granite consisting of grey to pink-red microcline, grey quartz, greyish white plagioclase and biotite. The pluton is unfoliated and contacts with the wall rocks are discordant. Undeformed pegmatite dykes probably related to the pluton occur up to several kilometres away in the gneissic wallrock. Inclusions of the wallrock gneisses are common and locally very abundant. The granite is metaluminous to weakly peraluminous with limited variation in composition as shown, for example, by a narrow range in  $\text{SiO}_2$  (69-74 wt%) and  $\text{K}_2\text{O}$  (4.2-5.8 wt%) contents (Nordgulen, unpublished data).

Sample N94-38 is a biotite granite collected in the southern marginal part of the pluton (Tjuvenborg locality, Fig. 4). The sample contains variably sized (c. 0.5-2 cm) sub-hedral megacrysts of microcline. Rounded mafic enclaves of medium- to fine-grained diorite occur some 20-30 m away from the sampling site. Three zircon fractions, collected in a population of prismatic pale-brown zircon, yield concordant analyses with an average  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $928 \pm 3$  Ma (Fig. 5). This age records the intrusion of the Flå granite pluton.

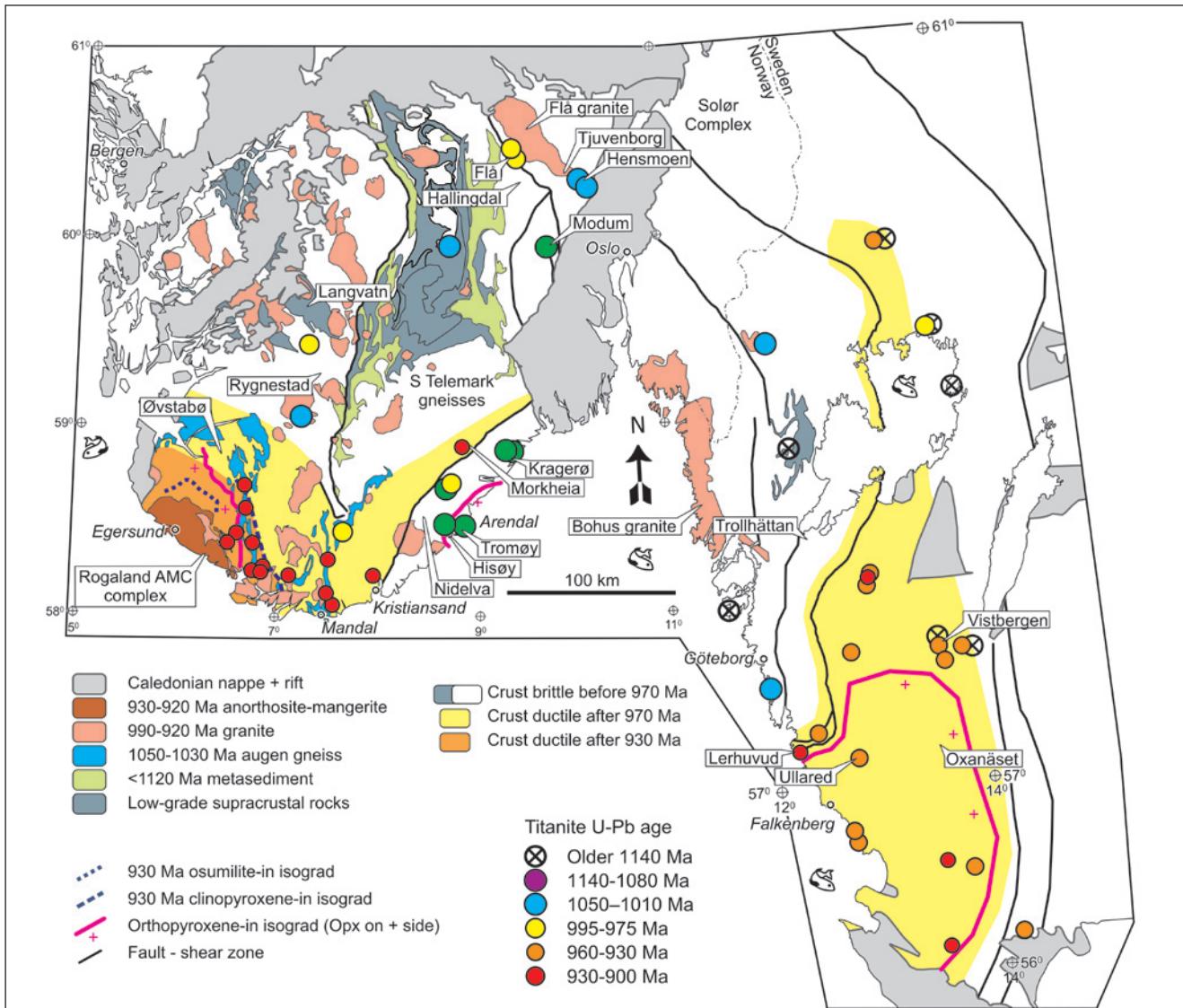


Fig. 4. Sketchmap of the Sveconorwegian belt, showing the distribution of titanite U-Pb data, as well as some of the lithologies, localities, isograds discussed in the text. Map following Bingen et al (2006).

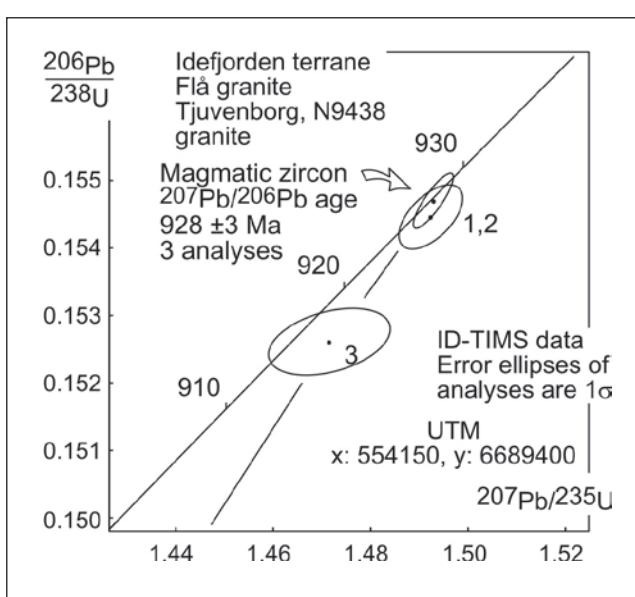


Fig. 5. ID-TIMS U-Pb data on magmatic zircon from the Flå granite pluton.

The age of the Bohus granite pluton is estimated from two concordant monazite and xenotime analyses from a pegmatite. The monazite analysis yields a  $^{206}\text{Pb}/^{238}\text{U}$  age of  $922 \pm 5$  Ma and a  $^{207}\text{Pb}/^{206}\text{Pb}$  age of c. 926 Ma (Eliasson & Schöberg 1991). The age estimates on the Flå and Bohus granites overlap, confirming that these two very similar plutons are coeval.

## Review

Published, mainly U-Pb, geochronological data recording magmatic and metamorphic events in the Sveconorwegian belt are summarized in Tables 3, 4 and 5. Cumulative probability diagrams of magmatic events are presented in Fig. 6. Distribution of titanite data is presented in Fig. 4. Maps showing the distribution of magmatic and metamorphic events between 1220 and 900 Ma are sketched in Figs. 7 and 8.

**Table 3. Compilation of geochronological data on magmatic events in the Sveconorwegian belt**

Location (1)	Lithology, sample	Min (2)	System	Age (Ma)	$\pm 2\sigma$	Reference
<b>Telemarkia Terrane</b>						
Rogaland	Hunnedalen dyke, HD1	Cpx	Sm-Nd	855	$\pm 59$	Walderhaug et al., 1999
Rogaland	Rymteland pegmatite	Urn	U-Pb	914	$\pm 6$	Pasteels et al., 1979
Rogaland	Egersund-Ogna anorthosite, margin 75-32	Bdl	U-Pb	915	$\pm 4$	Schäfer et al., 1996
Telemark	Tørdal granite, 082996-1	Zrn	U-Pb	918	$\pm 7$	Andersen et al., 2007
Rogaland	Tellnes dyke, ilmenite norite, T2	Zrn	U-Pb	920	$\pm 3$	Schäfer et al., 1996
Rogaland	Egersund-Ogna anorthosite, EO1	Zrn	U-Pb	929	$\pm 2$	Schäfer et al., 1996
Rogaland	Farsund charnockite, PA70A	Zrn	U-Pb	930	c.	Pasteels et al., 1979
Rogaland	Tellnes dyke, quartz mangerite, 849	Zrn	U-Pb	931	$\pm 5$	Schäfer et al., 1996
Rogaland	Hidra monzonorite, charnockite dyke	Zrn	U-Pb	931	$\pm 10$	Pasteels et al., 1979
Rogaland	Helleren anorthosite, 75-65	Zrn	U-Pb	932	$\pm 3$	Schäfer et al., 1996
Rogaland	Åna-Sira anorthosite, 92-21	Zrn	U-Pb	932	$\pm 3$	Schäfer et al., 1996
Telemark	Vehuskjerringa granite, 072496-1	Zrn	U-Pb	932	$\pm 4$	Andersen et al., 2007
Telemark	Vrådal granite, 0816961	Mnz	U-Pb	939	$\pm 20$	Andersen et al., 2002
Telemark	Tovdal granite	Zrn	U-Pb	940	$\pm 10$	Andersen et al., 2002
Telemark	Bessefjell granite	Zrn	U-Pb	940	$\pm 19$	Andersen et al., 2002
Rogaland	Lyngdal granodiorite, La68A-Pa69K	Zrn	U-Pb	950	$\pm 5$	Pasteels et al., 1979
Rogaland	Holum granite, 98BN21D	Zrn	U-Pb	957	$\pm 7$	Bingen et al., 2006
Rogaland	Sæbyggjenut granite	Zrn	U-Pb	959	$+50/-32$	Andersen et al., 2002
Telemark	Vrådal granite, granite TA01-7	Zrn	U-Pb	964	$\pm 18$	Andersen et al., 2007
Telemark	Vrådal granite, "hybrid rock" TA01-10	Zrn	U-Pb	970	$\pm 6$	Andersen et al., 2007
Suldal	Byklom granite	Zrn	U-Pb	970	$+14/-18$	Andersen et al., 2002
Telemark	Hørving granite	Zrn	U-Pb	971	$+63/-34$	Andersen et al., 2002
Rogaland	Granulite-facies leucosome, Ørsdalen, 3 samples	Moly	Re-Os	973	$\pm 4$	Bingen & Stein, 2003
Telemark	Torsdalsfjell granite, 080396-1	Zrn	U-Pb	990	$\pm 14$	Andersen et al., 2007
Suldal	Augen gneiss, Suldal, B00144	Zrn	U-Pb	1018	$\pm 33$	Bingen et al., 2005
Telemark	Otternes granite, 072696-2	Zrn	U-Pb	1023	$\pm 24$	Andersen et al., 2007
Telemark	Fennefoss augen gneiss	Zrn	U-Pb	1031	$\pm 2$	Pedersen & Konnerup-Madsen, 2000
Telemark	Mykleås diorite	Zrn	U-Pb	1034	$\pm 2$	Pedersen & Konnerup-Madsen, 2000
Rogaland	Charnockite gneiss, Gyavatnet, NR19A	Zrn	U-Pb	1035	$\pm 6$	Möller et al., 2002
Telemark	Fennefoss granodioritic augen gneiss, B613	Zrn	U-Pb	1035	$\pm 3$	Bingen & van Breemen, 1998
Rogaland	Roskreppefjord granite	Zrn	U-Pb	1036	$+23/-22$	Andersen et al., 2002
Rogaland	Charnockite gneiss, Gyavatnet, NR17C	Zrn	U-Pb	1037	$\pm 16$	Möller et al., 2002
Rogaland	Pegmatite leucosome, Gyavatnet, NR16A	Zrn	U-Pb	1039	$\pm 11$	Möller et al., 2003
Rogaland	Granodiorite augen gneiss, Osen, NR2B	Zrn	U-Pb	1039	$\pm 7$	Möller et al., 2002
Rogaland	Garnet migmatite gneiss, Gyadalen, NR12E	Zrn	U-Pb	1046	$\pm 12$	Möller et al., 2003
Rogaland	Feda granodiorite suite, Mandal augen gneiss, B206	Zrn	U-Pb	1049	$+2/-8$	Bingen & van Breemen, 1998
Rogaland	Feda granodiorite suite, Vegga augen gneiss, B642	Zrn	U-Pb	1051	$+2/-8$	Bingen & van Breemen, 1998
Rogaland	Feda granodiorite suite, Feda augen gneiss, B113	Zrn	U-Pb	1051	$+2/-8$	Bingen & van Breemen, 1998
Rogaland	Feda granodiorite suite, Liland augen gneiss, B195	Zrn	U-Pb	1051	$+2/-4$	Bingen & van Breemen, 1998
Suldal	Garnet granite gneiss, Vanvik, B00147	Zrn	U-Pb	1065	$\pm 74$	Bingen et al., 2005
Telemark	Morkheia monzonite suite, monzonite M37	Zrn	U-Pb	1130	$\pm 2$	Heaman & Smalley, 1994
Telemark	Morkheia monzonite suite, sheared monzonite M12	Zrn	U-Pb	1132	$\pm 3$	Heaman & Smalley, 1994
Telemark	Morkheia monzonite suite, monzonite M220	Zrn	U-Pb	1134	$\pm 2$	Heaman & Smalley, 1994
Telemark	Gunnarstul granite gneiss	Zrn	U-Pb	1134	$\pm 21$	Andersen et al., 2002
Telemark	Heddal Gp, Skogså porphyry, TA992	Zrn	U-Pb	1145	$\pm 4$	Laajoki et al., 2002
Telemark	Eiddal granite gneiss, N95-65	Zrn	U-Pb	1146	$\pm 5$	Bingen et al., 2003
Telemark	Hesjåbuitind gabbro sill	Zrn	U-Pb	1146	$\pm 2$	Dahlgren et al., 1990
Telemark	Høydalsmo Gp, Dalå porphyry, 830KLN	Zrn	U-Pb	1150	$\pm 4$	Laajoki et al., 2002
Telemark	Fjellstadfjell granite, 072696-1	Zrn	U-Pb	1151	$\pm 9$	Andersen et al., 2007
Telemark	Haglebu granite gneiss, N95-113	Zrn	U-Pb	1153	$\pm 2$	Bingen et al., 2003
Telemark	Brunkeberg Fm, porphyry, 903KLN	Zrn	U-Pb	1155	$\pm 2$	Laajoki et al., 2002
Telemark	Oftefjell Gp, Ljosdalsvatnet porphyry, 902KLN	Zrn	U-Pb	1155	$\pm 3$	Laajoki et al., 2002
Telemark	Venås quartz monzonite-granite, 071996-1	Zrn	U-Pb	1157	$\pm 7$	Andersen et al., 2007
Rogaland	Hidderskog charnockite gneiss	Zrn	U-Pb	1159	$\pm 5$	Zhou et al., 1995
Telemark	Sørkjevatn Fm, metarhyolite-microgranite, B9825	Zrn	U-Pb	1159	$\pm 8$	Bingen et al., 2003
Telemark	Vennesla augen gneiss, B603	Zrn	U-Pb	1166	$+61/-21$	Bingen & van Breemen, 1998
Telemark	Åmannsbru rhyolite porphyry dyke, 082896	Zrn	U-Pb	1168	$\pm 27$	Andersen et al., 2007
Telemark	Nore Gp, Rødberg rhyodacite, B9840	Zrn	U-Pb	1169	$\pm 9$	Bingen et al., 2003
Telemark	Flåvatn granite gneiss	Zrn	U-Pb	1184	$+7/-5$	Dahlgren et al., 1990
Telemark	Gjerstad augen gneiss, M5	Zrn	U-Pb	1187	$\pm 2$	Heaman & Smalley, 1994
Telemark	Vråvatn Co, Granitic gneiss, S Vrådal, TA01-13	Zrn	U-Pb	1202	$\pm 9$	Andersen et al., 2007
Telemark	Drivheia granite gneiss, M200	Zrn	U-Pb	1205	$\pm 9$	Heaman & Smalley, 1994
Telemark	Vråvatn Co, Granodioritic gneiss, Kviteseid, TA01-14	Zrn	U-Pb	1205	$\pm 8$	Andersen et al., 2007
Telemark	Vråvatn Co, Granitic gneiss, Kviteseid, TA01-15	Zrn	U-Pb	1208	$\pm 6$	Andersen et al., 2007
Telemark	Vråvatn Co, Granitic gneiss, Fossøy, Vrådal, TA01-3	Zrn	U-Pb	1219	$\pm 8$	Andersen et al., 2007
Rogaland	Knaben I mine, granitic gneiss, B0126	Zrn	U-Pb	1258	$\pm 7$	Bingen unpubl
Suldal	Trossovdal Fm, Nyastøl metarhyolite	Zrn	U-Pb	1259	$\pm 2$	Brewer et al., 2004
Suldal	Trossovdal Fm, Nyastøl metarhyolite, B9817	Zrn	U-Pb	1260	$\pm 8$	Bingen et al., 2002
Suldal	Breive Gp, Hovden metarhyolite, B9824	Zrn	U-Pb	1264	$\pm 4$	Bingen et al., 2002
Suldal	Breive Gp, quartz porphyry, B9818	Zrn	U-Pb	1275	$\pm 8$	Bingen et al., 2002
Telemark	Iveland-Gautestad metagabbro	Zrn	U-Pb	1279	$\pm 3$	Pedersen & Konnerup-Madsen, 2000
Telemark	Vindeggen gp, Sandvik metadiabase, KLN7076	Zrn	U-Pb	1347	$\pm 4$	Corfu and Laajoki, 2008

Location	Lithology, sample	Min	System	Age	$\pm 2\sigma$	Reference
(1)		(2)		(Ma)		
Telemark	Tinn granite, 0831962	Zrn	U-Pb	1476	$\pm 13$	Andersen et al., 2002
Rogaland	Lyngdal granite gneiss, Pa66R	Zrn	U-Pb	1486	c.	Pasteels & Michot, 1975
Suldal	Ullensvang Gp, metarhyolite, S93-338	Zrn	U-Pb	1489	$\pm 1$	Bingen et al., 2005
Suldal	Skånevik supracrustals, metarhyolite, J-482A	Zrn	U-Pb	1491	$\pm 5$	Bingen et al., 2005
Telemark	Granite gneiss, Gol, N95-112	Zrn	U-Pb	1492	$\pm 3$	Bingen et al., 2005
Suldal	Augen gneiss, Roldal, B00127	Zrn	U-Pb	1495	$\pm 13$	Bingen et al., 2005
Telemark	Rjukan Gp, Vermork fm, Skardfoss rhyolite KLN7035	Zrn	U-Pb	1495	$\pm 2$	Laajoki & Corfu, 2007
Suldal	Sauda supracrustals, augen gneiss, B00106	Zrn	U-Pb	1496	$\pm 11$	Bingen et al., 2005
Suldal	Sauda supracrustals, granodiorite gneiss, B00145	Zrn	U-Pb	1497	$\pm 12$	Bingen et al., 2005
Suldal	Botsvatn Co, Bykle, granodiorite gneiss, B02022	Zrn	U-Pb	1498	$\pm 8$	Bingen et al., 2005
Suldal	Granite gneiss, Vanvik, B00149	Zrn	U-Pb	1499	$\pm 11$	Bingen et al., 2005
Suldal	Botsvatn Co, Bykle, granite gneiss, B02027	Zrn	U-Pb	1499	$\pm 12$	Bingen et al., 2005
Suldal	Augen gneiss, Sand, B00-137	Zrn	U-Pb	1501	$\pm 11$	Bingen et al., 2005
Telemark	Rjukan Gp, Myrstul rhyolite dyke	Zrn	U-Pb	1502	$\pm 1$	Dahlgren et al., 1990
Suldal	Granite, Aurdal, R94-66	Zrn	U-Pb	1506	$\pm 2$	Bingen et al., 2005
Suldal	Granodiorite, Sand, B00139	Zrn	U-Pb	1506	$\pm 13$	Bingen et al., 2005
Vardefjell SZ	Flå, granodioritic banded gneiss, B99114	Zrn	U-Pb	1507	$\pm 14$	Bingen et al., 2008
Telemark	Grotte suite, tonalite gneiss	Zrn	U-Pb	1509	$+19/-3$	Ragnhildstveit et al., 1994
Telemark	Rjukan Gp, Runhellehovet metarhyolite	Zrn	U-Pb	1510	c.	Dahlgren et al., 1990
Telemark	Rjukan Gp, metarhyolite, Uvdal, S93-305	Zrn	U-Pb	1512	$+10/-8$	Bingen et al., 2005
Suldal	Augen gneiss, Vanvik, B00112	Zrn	U-Pb	1516	$\pm 11$	Bingen et al., 2005
Suldal	Suldal supracrustals, granodioritic gneiss, B00140	Zrn	U-Pb	1519	$\pm 12$	Bingen et al., 2005
Vardefjell SZ	Flå, tonalitic banded gneiss, B99111	Zrn	U-Pb	1528	$\pm 16$	Bingen et al., 2008
<b>Bamble and Kongsberg Terranes</b>						
Bamble	Herefoss granite	Zrn	U-Pb	920	$+16/-27$	Andersen et al., 2002
Bamble	Herefoss granite, 107	Ttn	U-Pb	926	$\pm 8$	Andersen, 1997
Bamble	Grimstad Granite	Zrn	U-Pb	989	$\pm 9$	Kullerud & Machado, 1991
Bamble	Gloserheia pegmatite	Eux	U-Pb	1060	$+8/-6$	Baadsgaard et al., 1984
Bamble	Gjeving charnockite gneiss	Zrn	U-Pb	1152	$\pm 2$	Kullerud & Machado, 1991
Bamble	Levang granitic gneiss dome, Southern part	Zrn	U-Pb	1167	$\pm 50$	O'Nions & Baadsgaard, 1971
Bamble	Hovdefjell charnockite gneiss	Zrn	U-Pb	1168	$\pm 2$	Råheim unpublished
Bamble	Tromøy gabbro-tonalite complex, Hisøy tonalite, HGG	Zrn	U-Pb	1178	$\pm 9$	Andersen et al., 2004
Bamble	Tromøy gabbro-tonalite complex, 4 samples	Zrn	U-Pb	1198	$\pm 13$	Knudsen & Andersen, 1999
Kongsberg	Morud metagabbro	Cpx	SmNd	1224	$\pm 15$	Munz & Morvik, 1991
Bamble	Nelaug gneiss	Zrn	U-Pb	1460	$\pm 21$	de Haas et al., 2002
Kongsberg	Granodiorite gneiss, Veldstad, N95-66	Zrn	U-Pb	1500	$\pm 5$	Bingen et al., 2005
Bamble	Jomås granodiorite, 8/97 JOM	Zrn	U-Pb	1522	$\pm 14$	Andersen et al., 2004
Kongsberg	Metadacite gneiss, Bingen, 01/19	Zrn	U-Pb	1529	$\pm 7$	Andersen et al., 2004
Kongsberg	Granodiorite, Snarum, HFG	Zrn	U-Pb	1534	$+9/-8$	Andersen et al., 2004
Bamble	Charnockite gneiss, Flosta	Zrn	U-Pb	1542	$\pm 8$	Kullerud & Machado, 1991
Bamble	Justøy tonalite, Justøy, 5/97JUS	Zrn	U-Pb	1557	$\pm 24$	Andersen et al., 2004
Bamble	Justøy tonalite, Homborsund, 9/97HOM	Zrn	U-Pb	1569	$\pm 23$	Andersen et al., 2004
Bamble	Gjerstadvatn tonalite, 10/97NES	Zrn	U-Pb	1572	$\pm 20$	Andersen et al., 2004
<b>Idefjorden Terrane</b>						
	Blomskog granite, pegmatite BM1	Moly	Re-Os	915	$\pm 3$	Bingen et al., 2006
	Hakefjorden norite, contact melt HAS96003	Zrn	U-Pb	916	$\pm 11$	Scherstén et al., 2000
	Bohus granite, pegmatite-aplite, 88102	Mnz	U-Pb	922	$\pm 5$	Eliasson & Schöberg, 1991
Begna	Flå granite, phenocryst granite, N9438	Zrn	U-Pb	928	$\pm 3$	Bingen et al., this work
	Göteborg dolerite, Tuve dyke	Bdl	U-Pb	935	$\pm 3$	Hellström et al., 2004
	Vinga porphyry	Zrn	U-Pb	963	$\pm 17$	Åhäll & Schöberg, 1999
	Skuleboda rare-mineral pegmatite	Clm	U-Pb	984	$\pm 6$	Romer & Smeds, 1996
	Högsbo rare-mineral pegmatite	Clm	U-Pb	1030	$\pm 1$	Romer & Smeds, 1996
	Timmerhult rare-mineral pegmatite	Clm	U-Pb	1039	$\pm 3$	Romer & Smeds, 1996
	Skantorp rare-mineral pegmatite	Clm	U-Pb	1041	$\pm 2$	Romer & Smeds, 1996
	Sandsjön granite gneiss, 78140	Zrn	U-Pb	1210	$+36/-34$	Welin et al., 1981
	Segmon granite, SWS9	Zrn	U-Pb	1249	$+10/-7$	Persson et al., 1983
	Bunketorp granite, 79023	Zrn	U-Pb	1279	$\pm 62$	Welin & Samuelsson, 1987
	Västergötland dolerite, Trollhättan	Bdl	U-Pb	1300	c.	Söderlund et al., 2005
	Göta granite, IML1	Zrn	U-Pb	1304	$\pm 6$	Austin Hegardt et al., 2007
	Kärra granite, DC20009	Zrn	U-Pb	1311	$\pm 8$	Austin Hegardt et al., 2007
	Ursand granite	Zrn	U-Pb	1319	$\pm 6$	Piontek et al., 1998
	Stråvalla augen gneiss	Zrn	U-Pb	1325	$\pm 18$	Andersson, 2001
	Kärra granite, pegmatite, DC200020	Zrn	U-Pb	1325	$\pm 8$	Austin Hegardt et al., 2007
	Chalmers gabbro, felsic facies, DC9723	Zrn	U-Pb	1333	$\pm 8$	Kiel et al., 2003
	Hästefjorden granite	Zrn	U-Pb	1334	$+7/-3$	Piontek et al., 1998
	Askim granite, Lindome, DC9913	Zrn	U-Pb	1336	$\pm 10$	Austin Hegardt et al., 2007
	Askim granite, 78170	Zrn	U-Pb	1362	$\pm 9$	Welin & Samuelsson, 1987
	Orust dyke swarm, Islandsberg dyke	Zrn	U-Pb	1457	$\pm 6$	Åhäll & Connelly, 1998
Begna	Hensmoen, granodioritic gneiss, B99143	Zrn	U-Pb	1495	$\pm 11$	Bingen et al., 2008
	Brevik gabbro	Zrn	U-Pb	1502	$\pm 2$	Åhäll & Connelly, 1998
	Stigfjorden granite	Zrn	U-Pb	1503	$\pm 3$	Åhäll & Connelly, 1998
	Norstrand-Sörmarka granodiorite, TA121	Zrn	U-Pb	1517	$\pm 12$	Andersen et al., 2004
	Hisingen suite, Hällungen granodiorite	Zrn	U-Pb	1530	$\pm 6$	Åhäll & Connelly, 2008
	Hisingen suite, Grann granite	Zrn	U-Pb	1530	$\pm 18$	Åhäll & Connelly, 2008

Location	Lithology, sample	Min (2)	System	Age (Ma)	$\pm 2\sigma$	Reference
(1)	Stenungsund tonalite, Säxeröd sample, Hisingen suite	Zrn	U-Pb	1535	$\pm 13$	Åhall 1991
	Lane granite, 79019	Zrn	U-Pb	1535	$\pm 14$	Welin et al., 1982
	Koster segment, Hisingen suite, Segelskären gabbro	Zrn	U-Pb	1538	$\pm 7$	Åhall & Connally, 2008
	Koster segment, Hisingen suite, Nord-Koster diorite	Zrn	U-Pb	1538	$\pm 7$	Åhall & Connally, 2008
	Hisingen suite, Uddevalla granodiorite	Zrn	U-Pb	1539	$\pm 10$	Åhall & Connally, 2008
	Koster segment, Hisingen suite, Bot granite	Zrn	U-Pb	1541	$\pm 11$	Åhall & Connally, 2008
	Koster segment, Hisingen suite, Måskär granite	Zrn	U-Pb	1545	$\pm 5$	Åhall & Connally, 2008
	Ranrike granodiorite east	Zrn	U-Pb	1546	$\pm 4$	Åhall & Connally, 2008
	Koster segment, Storön tonalite	Zrn	U-Pb	1546	$\pm 7$	Åhall & Connally, 2008
	Hisingen suite, Bifrost granodiorite	Zrn	U-Pb	1547	$\pm 6$	Åhall & Connally, 2008
	Ranrike granodiorite east	Zrn	U-Pb	1550	$+9/-5$	Åhall & Connally, 2008
	Röseskär felsic dyke	Zrn	U-Pb	1553	$\pm 2$	Connally & Åhall, 1996
Begna	Follum diorite, metatonalite, N95-130	Zrn	U-Pb	1555	$\pm 3$	Bingen et al., 2005
	Rivöfjorden layered gabbro	Zrn	U-Pb	1555	$\pm 2$	Åhall et al., 2000
	Burö-Hällsö diorite	Zrn	U-Pb	1555	$\pm 2$	Connally & Åhall, 1996
	Hisingen suite, Landvetter granodiorite	Zrn	U-Pb	1558	$\pm 10$	Åhall & Connally, 2008
	Förö granite dyke	Zrn	U-Pb	1558	$\pm 2$	Åhall et al., 2000
	Biskopsgården granodiorite	Zrn	U-Pb	1559	$\pm 2$	Åhall et al., 2000
	Bäckefors granite	Zrn	U-Pb	1561	$\pm 2$	Åhall et al., 2000
	Gösta granite, SWS7	Zrn	U-Pb	1563	$+32/-21$	Persson et al., 1983
	Hisingen granite, Rya granodiorite	Zrn	U-Pb	1563	$\pm 2$	Åhall et al., 2000
	Hisingen suite, Lane granite	Zrn	U-Pb	1566	$\pm 3$	Åhall & Connally, 2008
	Midtskog tonalite, TA116	Zrn	U-Pb	1567	$\pm 8$	Andersen et al., 2004
	Hisingen suite, Ytterby granodiorite	Zrn	U-Pb	1570	$\pm 7$	Åhall & Connally, 2008
	Feiring quartz diorite, Ø3	Zrn	U-Pb	1574	$\pm 17$	Andersen et al., 2004
	Hisingen suite, Eggsgjö granodiorite	Zrn	U-Pb	1578	$\pm 7$	Åhall & Connally, 2008
	Idala tonalite	Zrn	U-Pb	1584	$\pm 15$	Åhall et al., 1995
	Gabbro, granitic contact melt ASCH9801	Zrn	U-Pb	1585	$\pm 4$	Ahlin et al., 2006
	Björkelangen granodiorite, TA118	Zrn	U-Pb	1585	$\pm 18$	Andersen et al., 2004
	Migmatitic banded orthogneiss, Bua, TK1+TK2	Zrn	U-Pb	1585	$\pm 11$	Andersson et al., 2002
	Rönnäng tonalite	Zrn	U-Pb	1587	$\pm 3$	Connally & Åhall, 1996
	Uddevalla granodiorite, 76267	Zrn	U-Pb	1587	$\pm 36$	Welin et al., 1982
	Stenkyrka granite	Zrn	U-Pb	1588	$\pm 5$	Connally & Åhall, 1996
	Red syeno-granite gneiss, Lake Racken, DC972	Zrn	U-Pb	1590	$\pm 14$	Larson et al., 1999
	Töcksfors granodiorite	Zrn	U-Pb	1594	$\pm 7$	Åhall & Connally, 2008
	Harnäs gneiss, Hn96093	Zrn	U-Pb	1595	$+24/-17$	Alm et al., 2002
	Grey quartz monzodiorite gneiss, Lake Racken, DC9413	Zrn	U-Pb	1596	$\pm 11$	Larson et al., 1999
	Tistedal granodiorite, Ø1	Zrn	U-Pb	1599	$+15/-16$	Andersen et al., 2004
	Göteborg suite, Åmal granodiorite	Zrn	U-Pb	1599	$\pm 6$	Åhall & Connally, 2008
	Göteborg suite, Håle tonalite	Zrn	U-Pb	1602	$\pm 10$	Åhall & Connally, 2008
	Lerum granite, 76263	Zrn	U-Pb	1603	$\pm 40$	Welin & Samuelsson, 1987
	Migmatitic granodiorite, Stora Lundby, mesosome 9701b	Zrn	U-Pb	1605	$\pm 10$	Scherstén et al., 2004
	Göteborg suite, Kallebäck orthogneiss	Zrn	U-Pb	1605	$\pm 9$	Åhall & Connally, 2008
Begna	Granodioritic gneiss, Vindflomyra, N95-95	Zrn	U-Pb	1606	$\pm 2$	Bingen et al., 2005
	Göteborg suite, Kil tonalite	Zrn	U-Pb	1607	$\pm 4$	Åhall & Connally, 2008
	Göteborg batholith, Frykdalshöjden orthogneiss	Zrn	U-Pb	1608	$\pm 4$	Åhall & Connally, 2008
	Höjen tonalite, SWS8	Zrn	U-Pb	1609	$+35/-25$	Persson et al., 1983
	Åmal Fm, Tösse porphyry	Zrn	U-Pb	1614	$\pm 7$	Lundqvist & Skiöld, 1993
	Delsjön augen gneiss, Landvetter Badplats, DC04202	Zrn	U-Pb	1614	$\pm 5$	Ahlin et al., 2006
	Slemmestad metarhyolite, 01/25	Zrn	U-Pb	1615	$\pm 31$	Andersen et al., 2004
	Åmal granodiorite, 77018	Zrn	U-Pb	1616	$\pm 24$	Welin et al., 1982
	Migmatitic Delsjön augen gneiss, Stora Delsjön, EAH0309	Zrn	U-Pb	1618	$\pm 7$	Ahlin et al., 2006
	Åmal Fm, Tösse dacite	Zrn	U-Pb	1619	$\pm 5$	Åhall & Connally, 2008
	Olstorp ultramafic intrusion, contact melt OD16	Zrn	U-Pb	1624	$\pm 6$	Scherstén et al., 2000
	Åmal Fm, Kappebo rhyolite	Zrn	U-Pb	1631	$\pm 3$	Åhall & Connally, 2008
	Göteborg batholith, Kabbosjön granite	Zrn	U-Pb	1634	$+3/-2$	Åhall & Connally, 2008
	Horred Fm, Mjösjö dacite	Zrn	U-Pb	1643	$\pm 29$	Åhall et al., 1995
	Horred Fm, Mjösjö 2 dacite	Zrn	U-Pb	1659	$+8/-6$	Åhall & Connally, 2008

**Eastern Segment, Protogine Zone, and Sveconorwegian Frontal Deformation Zone**

North	Riddaho pegmatite	Clm	U-Pb	942	$\pm 2$	Romer & Smeds, 1996
South	Undeformed granite dyke, Högabjär, HB4	Zrn	U-Pb	945	$\pm 7$	Möller et al., 2007
South	Undeformed granite dyke, Tjärnesjö granite, Sundhult	Zrn	Pb-Pb	947	$\pm 12$	Andersson et al., 1999
South	Undeformed granite dyke, Högabjär, HB6	Zrn	U-Pb	952	$\pm 7$	Möller et al., 2007
South	Undeformed granite dyke, Gällared	Zrn	Pb-Pb	956	$\pm 7$	Möller & Söderlund, 1997
PZ	Görbjörnarp syenite	Zrn	U-Pb	1204	$+14/-8$	Hansen & Lindh, 1991
PZ	Gumlösa-Glimåkra granite, 84083	Zrn	U-Pb	1204	$\pm 3$	Söderlund & Ask, 2006
PZ	Taberg ultramafic intrusion, leucogabbro A1	Ap	U-Pb	1204	$\pm 2$	Larsson & Söderlund, 2005
PZ	Rumperöd dolerite dyke	Bdl	U-Pb	1215	$\pm 5$	Söderlund et al., 2005
PZ	Aplite dyke in Vaggeryd syenite, 19.2	Zrn	U-Pb	1218	$\pm 3$	Söderlund & Ask, 2006
PZ	Vaggeryd syenite, 320	Zrn	U-Pb	1219	$\pm 3$	Söderlund & Ask, 2006
PZ	Vaggeryd syenite, 19.5	Zrn	U-Pb	1220	$\pm 3$	Söderlund & Ask, 2006
PZ	Anorthosite gabbro in Vaggeryd syenite, 209.2	Zrn	U-Pb	1220	$\pm 3$	Söderlund & Ask, 2006
PZ	Pegmatite dyke in Vaggeryd syenite, 19.4	Zrn	U-Pb	1221	$\pm 3$	Söderlund & Ask, 2006
PZ	Bjärejhalla dolerite dyke	Bld	U-Pb	1221	$\pm 16$	Söderlund et al., 2005
South	Vårgårda quartz-monzonite, deformed facies	Zrn	U-Pb	1224	$+9/-8$	Berglund, 1997

Location	Lithology, sample	Min (2)	System	Age (Ma)	$\pm 2\sigma$	Reference
(1)						
South	Migmatitic Torpa granite, TA1	Zrn	U-Pb	1359	$\pm 26$	Andersson et al., 2002
South	Tjärnesjö granite, isotropic facies, Björshult	Zrn	U-Pb	1368	$\pm 4$	Andersson et al., 1999
South	Torpa granite	Zrn	U-Pb	1380	$\pm 6$	Åhäll et al., 1997
South	Tjärnesjö granite, veined facies, TJ25D	Zrn	U-Pb	1394	$\pm 11$	Andersson et al., 1999
South	Folded metagranite dyke, Högabjär, HB3	Zrn	U-Pb	1394	$\pm 12$	Möller et al., 2007
South	Stensjö granite pegmatite dyke, 4	Zrn	U-Pb	1399	$+7/-6$	Christoffel et al., 1999
South	Varberg charnockite-granite association, 8	Zrn	U-Pb	1399	$+12/-8$	Christoffel et al., 1999
South	Glassvik deformed pegmatite dyke	Zrn	Pb-Pb	1409	$\pm 20$	Söderlund, 1996
South	Sårdal granite, pegmatite dyke, 3	Zrn	U-Pb	1426	$+9/-4$	Christoffel et al., 1999
South	Gåsanabbe mafic orthogneiss, paleosome, 5	Zrn	U-Pb	1438	$+12/-8$	Christoffel et al., 1999
PZ	Tåghusa streaky granite, CJA46	Zrn	U-Pb	1442	$\pm 9$	Cecys et al., 2002
South	Deformed granitic dyke, Gällared S	Zrn	U-Pb	1443	$\pm 26$	Söderlund et al., 2002
South	Beden granodiorite, Romleåsen, 85016	Zrn	U-Pb	1449	$+23/-11$	Johansson et al., 1993
South	Charnockite, NW of Örkelljunga, 85019	Zrn	U-Pb	1452	c.	Johansson et al., 1993
South	Aplitic dyke, post-S2 pre-S3, Vråna, 3	Zrn	U-Pb	1457	$\pm 7$	Connelly et al., 1996
PZ	Stenshuvud porphyritic granite, SGU1	Zrn	U-Pb	1458	$\pm 6$	Cecys et al., 2002
North	Östmark dolerite, 77129	Zrn	U-Pb	1465	$\pm 11$	Welin, 1994
PZ	Flackarp granite gneiss, 76314	Zrn	U-Pb	1531	$\pm 8$	Johansson, 1990
South	Hinnyryd adamellite-monzogranite	Zrn	U-Pb	1548	$\pm 10$	Lindh, 1996
PZ	Åker metabasite	Zrn	U-Pb	1562	$\pm 6$	Söderlund et al., 2004
PZ	Åker metabasite, dolerite dyke, 412	Zrn	U-Pb	1567	$\pm 3$	Söderlund and Ask, 2006
Centre	Metadolerite dyke, CHW670-OK450	Bdl	U-Pb	1568	$+30/-8$	Wahlgren et al., 1996
Centre	Ölme metadolerite	Bdl	U-Pb	1569	$\pm 3$	Söderlund et al., 2005
PZ	Metadolerite	Bdl	U-Pb	1574	$\pm 9$	Möller, in Söderlund et al. 2005
PZ	Mullsjö granite, 86054	Zrn	U-Pb	1601	$\pm 13$	Welin, 1994
South	Aplitic dyke, Visbergen, 6	Zrn	U-Pb	1612	$\pm 8$	Connelly et al., 1996
South	Vägasked grey gneiss, 85017	Zrn	U-Pb	1640	$\pm 16$	Johansson et al., 1993
North	Granodiorite Ammesjön 79112	Zrn	U-Pb	1645	$\pm 9$	Welin, 1994
South	Migmatitic granodiorite, Viared, DC03116	Zrn	U-Pb	1647	$\pm 12$	Austin Hegardt et al., 2005
South	Steninge mafic dyke, Steninge, 2	Zrn	U-Pb	1654	$\pm 9$	Christoffel et al., 1999
South	Paleosome in orthogneiss, Visbergen, 4	Zrn	U-Pb	1660	$\pm 5$	Connelly et al., 1996
Centre	Metagranite, Karlstad, W1	Zrn	U-Pb	1661	$\pm 27$	Söderlund et al., 1999
South	Sårdal orthogneiss, paleosome, 1	Zrn	U-Pb	1664	$\pm 7$	Christoffel et al., 1999
South	Migmatite granitic gneiss, Oxanäset, mesosome OX1	Zrn	U-Pb	1668	$\pm 11$	Möller et al., 2007
South	Migmatitic gneiss, locally charnockitic, 3 samples	Zrn	U-Pb	1671	$\pm 4$	Rimsa et al., 2007
PZ	Hagshult granite, 83114	Zrn	U-Pb	1673	$\pm 19$	Jarl, 2002
SFDZ	Trysil "tricolor" granite gneiss, Tr4	Zrn	U-Pb	1673	$\pm 8$	Heim et al., 1996
Centre	Grey granite gneiss, Forshaga, SWS2	Zrn	U-Pb	1674	$+24/-19$	Persson et al., 1995
PZ-SFDZ	Metagranite, Övre Fryken, W2	Zrn	U-Pb	1674	$\pm 7$	Söderlund et al., 1999
Centre	Monzonite, Broby, E1	Zrn	U-Pb	1674	$\pm 7$	Söderlund et al., 1999
South	Borås tonalite, AA9637	Zrn	U-Pb	1674	$\pm 8$	Scherstén et al., 2000
North	Brustad augen gneiss, Br9602	Zrn	U-Pb	1674	$\pm 10$	Alm et al., 2002
South	Stenberget red gneiss, Romleåsen, 85015	Zrn	U-Pb	1675	$\pm 25$	Johansson et al., 1993
South	Veined granitic gneiss, Mårdaklev	Zrn	U-Pb	1676	$\pm 10$	Söderlund et al., 2002
Centre	Filipstad gneissic granite	Zrn	U-Pb	1676	$\pm 7$	Lindh et al., 1994
South	Veined granitic gneiss, Gällared N, old component	Zrn	U-Pb	1679	$\pm 13$	Söderlund et al., 2002
Centre	Hagfors gneissic granite	Zrn	U-Pb	1684	$\pm 13$	Lindh et al., 1994
South	Unveined + veined orthogneiss, Dagsås	Zrn	U-Pb	1686	$\pm 14$	Söderlund et al., 2002
South	Migmatitic banded orthogneiss, Skene gneiss, SE-1	Zrn	U-Pb	1686	$\pm 11$	Andersson et al., 2002
South	Migmatite granitic gneiss, Högabjär, mesosome HB1	Zrn	U-Pb	1686	$\pm 12$	Möller et al., 2007
North	Rhyolite, Hukusjöen, FUN33	Zrn	U-Pb	1687	$\pm 11$	Bingen et al., this work
Centre	Quartz-monzonite gneiss, Zachrisdal, AL84030	Zrn	U-Pb	1688	$\pm 10$	Persson et al., 1995
North	Torsby granite, DC9416	Zrn	U-Pb	1689	$\pm 12$	Larson et al., 1999
PZ	Fryele granite, 88082	Zrn	U-Pb	1690	$\pm 5$	Welin, 1994
South	Granitoid, Hesta suite, Lake Åsunden, 2	Zrn	U-Pb	1692	$\pm 3$	Connelly et al., 1996
PZ	Rymmen gabbro, 2 samples	Zrn	U-Pb	1692	$\pm 7$	Clæson, 1999
North	Granitic gneiss, Knappåsen quarry, FUN38	Zrn	U-Pb	1692	$\pm 7$	Bingen et al., this work
North	Granite, Austvatn, FUN26	Zrn	U-Pb	1693	$\pm 8$	Bingen et al., this work
North	Porphyry, Nyhusen, TL9403	Zrn	U-Pb	1697	$\pm 8$	Lundqvist & Persson, 1999
South	Grey orthogneiss with veinlets, Gällared S	Zrn	U-Pb	1698	$\pm 12$	Söderlund et al., 2002
South	Paleosome in orthogneiss, South Härene, 1	Zrn	U-Pb	1699	$\pm 3$	Connelly et al., 1996
SFDZ	Quartz monzodiorite	Zrn	U-Pb	1699	$\pm 7$	Stephens, in Söderlund et al., 1999
South	Interboudin granite pegmatite, inherited zircon, EAH0207	Zrn	U-Pb	1701	$\pm 10$	Austin Hegardt et al., 2005
SFDZ	Granite, Grå-Larsknipen, TL9406	Zrn	U-Pb	1702	$\pm 11$	Lundqvist & Persson, 1999
PZ	Alvesta granite gneiss, 86011	Zrn	U-Pb	1713	$\pm 3$	Johansson, 1990
North	Tonalite, Mo	Zrn	U-Pb	1731	$\pm 7$	Mansfeld, 2000
Centre	Meta granite	Zrn	U-Pb	1777	$+38/-22$	Welin, in Söderlund et al., 1999
PZ-SFDZ	Filipstad granite, 82051	Zrn	U-Pb	1783	$\pm 10$	Jarl & Johansson, 1988
SFDZ	Järna granite	Zrn	U-Pb	1786	$+14/-12$	Persson, in Söderlund et al., 1999
SFDZ	Venjan porphyry, St. Kullsberget, TL9402	Zrn	U-Pb	1792	$+10/-8$	Lundqvist & Persson, 1999
SFDZ	Quartz-feldspar porphyry, L. Digerliden, TL9401	Zrn	U-Pb	1795	$\pm 4$	Lundqvist & Persson, 1999
SFDZ	Granite locally charnockitic	Zrn	U-Pb	1796	$\pm 7$	Stephens, in Söderlund et al., 1999

(1) Telemarkia Terrane: Vardefjell SZ; Vardefjell Shear Zone, Rogaland: Rogaland Vest Agder Sector

Eastern Segment: North: Solør transect, Centre: Lake Vänern transect, South: South of Vårgårda, PZ: Protogine Zone

SFDZ: Sveconorwegian Frontal Deformation Zone

(2) Ap: apatite, Bdl: baddeleyite, Cpx: clinopyroxene, Mnz: monazite, Moly: molybdenite, Ttn: titanite, Urn: uraninite, Zrn: zircon

Table 3. Compilation of geochronological data on magmatic events in the Sveconorwegian belt.

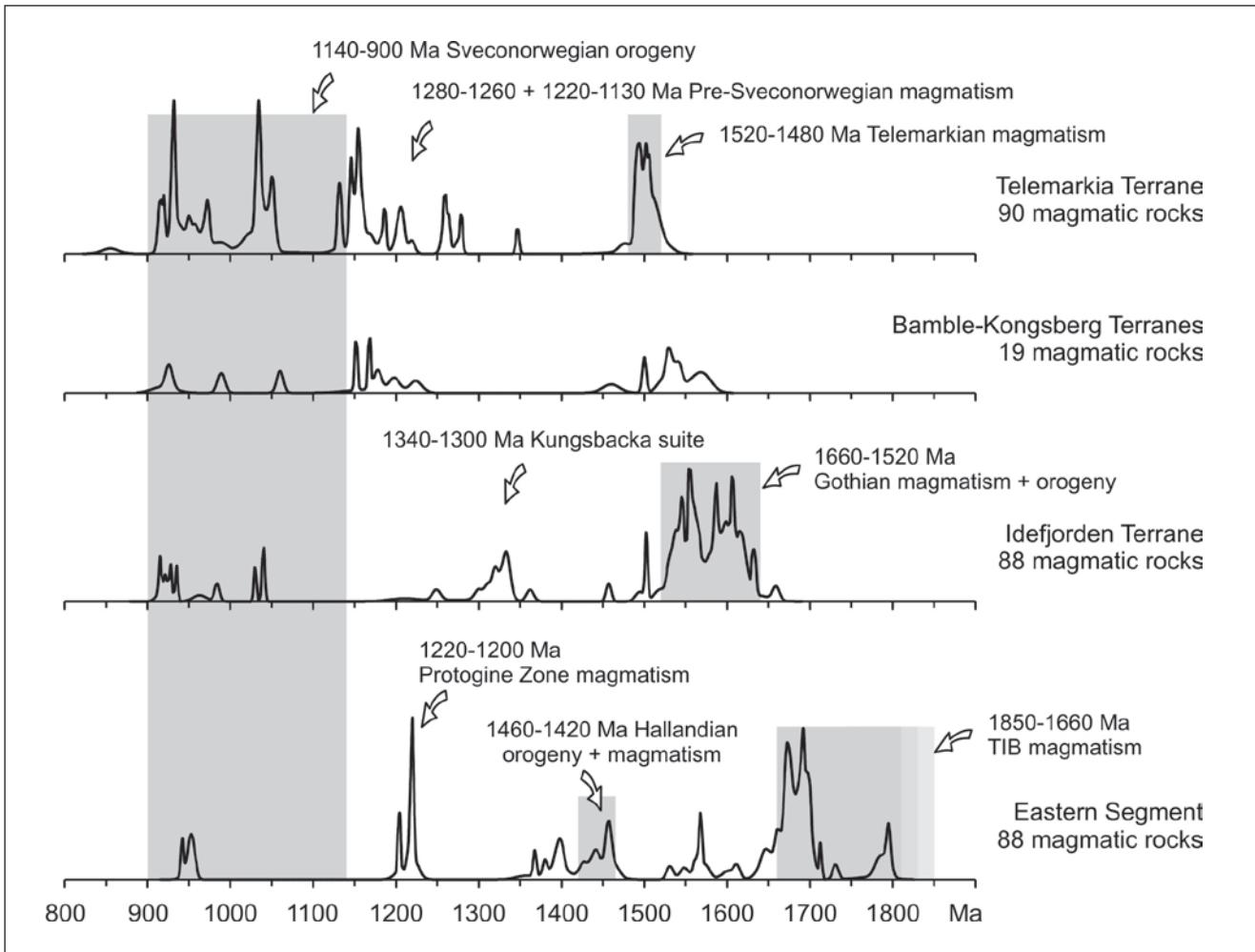


Fig. 6. Cumulative probability curves of geochronological data on magmatic events in the five lithotectonic units of the Sveconorwegian belt. Data from Table 3.

### Fennoscandia foreland

The Fennoscandia foreland of the Sveconorwegian belt (Fig. 1) is made up of Paleoproterozoic crust of the Svecofennian belt and the Transcandinavian Igneous Belt (TIB; Gorbatschev & Bogdanova 1993; Högdahl et al. 2004; Korja et al. 2006). The TIB consists of little deformed granitoids and porphyries formed between 1850 and 1660 Ma, with a general alkali-calcic signature. This Paleoproterozoic continental basement was intruded by several generations of Mesoproterozoic and younger magmatic rocks. These include 1650–1500 Ma rapakivi granite plutons and related rocks (Haapala et al. 2005), the 1460 Ma Tuna dolerites (Söderlund et al. 2005), 1460–1440 Ma granite plutons (Cecys & Benn 2007), the 1270–1250 Ma Central Scandinavian Dolerite Group (Söderlund et al. 2006), and the 978–946 Ma Blekinge-Dalarna dolerites (Söderlund et al. 2005). The rapakivi plutons are unconformably overlain by an undeformed cover of continental sandstone, known as the Jotnian sandstones. The latter are older than 1270 Ma and interlayered with the Jotnian basalts, possibly coeval with the 1460 Ma Tuna dolerites (Söderlund et al. 2005).

### Eastern Segment

The Eastern Segment is mainly made up of 1800–1640 Ma variably gneissic granitoids, compositionally similar to rocks of the TIB (Fig. 6; Table 3; Söderlund et al. 1999; Söderlund et al. 2002; Högdahl et al. 2004; Möller et al. 2007). The new data on the Solør Complex (Figs. 2, 3) demonstrate that the northernmost part of the Eastern Segment conforms to this description. These granitoids are intruded by volumetrically minor magmatic suites. These are mainly 1560 Ma mafic dykes, 1460–1380 Ma granite dykes and plutons and 1250–1200 Ma granite plutons (Fig. 7; Andersson et al. 1999; Söderlund et al. 2004; Larsson & Söderlund 2005; Söderlund & Ask 2006). A pre-Sveconorwegian 1460–1410 Ma amphibolite-facies metamorphic event, known as the Hallandian, is recorded by metamorphic zircon and characterized by migmatitization of orthogneisses (Table 4; Christoffel et al. 1999; Söderlund et al. 2002; Möller et al. 2007).

The intensity of Sveconorwegian reworking and metamorphism increases from north to south and from east to west (Johansson et al. 1991; Söderlund et al. 1999).

**Table 4. Compilation of monazite, zircon and molybdenite geochronological data in the Sveconorwegian belt attributed to high-grade metamorphism**

Terrane	Min (1)	Max (2)	$A_{\text{ge}} \pm 2\sigma$ (Ma)	Facies (3)	Lithology/Sample	Method (4)	n (4)	Reference (5)
<b>Telemarkia Terrane</b>								
Suldal	Zrn	1014±1		Am	Amphibolite, Nore sund, B99130	U-Pb ID-TIMS	3	Bingen et al., 2008
Suldal	Moly	1032±2		Am	Sulfide ore in metagabbro, Langvatn, LG1-LG3	Re-Os ID-NTIMS	3	Stein & Bingen, 2002
Suldal	Moly	1047±2, 1025±2, 1017±2		Am	Metabasalt, Kobbernuten, LG4-LG7	Re-Os ID-NTIMS	6	Stein & Bingen, 2002
Suldal	Mnz	1005±7		Am	Migmatitic metapelitic gneiss, Rynestad, B0234	U-Pb LA-ICPMS	18	Bingen et al., 2008
Rogaland-VA	Mnz	928±3, 927±1, 925±2, 925±2		Am	Augen gneiss, Feda, B120	U-Pb ID-TIMS	4	Bingen & van Breemen, 1998
Rogaland-VA	Mnz	1002±7		Am	Granitic gneiss, Knaben II mine, B0128	U-Pb SIMS	11	Bingen et al., 2008
Rogaland-VA	Mnz	927±5, 924±5		Am	Augen gneiss, Sirdal, B185	Th-Pb ID-TIMS	2	Bingen et al., 2008
Rogaland-VA	Mnz	1006±3, 975±2, 912±3, 907±5		Am	Augen gneiss, Sirdal, B185	U-Pb ID-TIMS	4	Bingen & van Breemen, 1998
Rogaland-VA	Mnz	999±5, 922±5		Am	Augen gneiss, Feda, B135	Th-Pb ID-TIMS	2	Bingen et al., 2008
Rogaland-VA	Mnz	1010±2, 1000±1, 930±1, 928±1		Am	Augen gneiss, Feda, B135	U-Pb ID-TIMS	4	Bingen & van Breemen, 1998
Rogaland-VA	Mnz	914±4, 910±9		Am	Augen gneiss, Feda, B113	Th-Pb ID-TIMS	2	Bingen et al., 2008
Rogaland-VA	Mhz	1012±1, 1008±1, 990±1, 974±2, 904±5		Am	Augen gneiss, Feda, B113	U-Pb ID-TIMS	5	Bingen & van Breemen, 1998
Rogaland-VA	Zrn	1032±5, 1020±7, 1011±7, 1002±7, 980±7		Am	Augen gneiss, Osen, NR2B	U-Pb SIMS	5	Möller et al., 2002
Rogaland-VA	Mnz	904±8		Gr	Augen gneiss, Sira, B198	U-Pb ID-TIMS	1	Bingen & van Breemen, 1998
Rogaland-VA	Mnz	971±2, 951±6		Gr	Augen gneiss, Liland, B195	U-Pb ID-TIMS	2	Bingen & van Breemen, 1998
Rogaland-VA	Mnz	997±1, 986±2, 985±1, 972±1		Gr	Charnockitic gneiss, Vikeså, B650	U-Pb ID-TIMS	4	Bingen & van Breemen, 1998
Rogaland-VA	Zrn	1010±18, 981±3, 963±3, 927±7, 904±4		Gr	Various granulites, samples 10B, 16A, 22H, 22D, FF13	U-Pb SIMS	20	Möller et al., 2002
Rogaland-VA	Mnz	1004±1, 950±1, 943±1, 932±1		Gr	Charnockitic gneiss, Kværnik, B647	U-Pb ID-TIMS	4	Bingen & van Breemen, 1998
Rogaland-VA	Mnz	1007±2, 979±1		Gr	Augen gneiss, Liland, B107	U-Pb ID-TIMS	2	Bingen & van Breemen, 1998
Rogaland-VA	Zrn	1015±11, 964±3, 928±10, 909±13		Gr	Migmatitic aluminous granulite, Grasdalen, 12E	U-Pb SIMS	30	Möller et al., 2002
Rogaland-VA	Zrn	1017±6 to 970±6, 922±14		Gr	Charnockitic gneiss, Grasdalen, 19A+17A	U-Pb SIMS	12	Möller et al., 2002
Rogaland-VA	Mnz	1013±5, 980±5		Gr	Charnockitic gneiss, Grasdalen, B649	Th-Pb ID-TIMS	2	Bingen et al., 2008
Rogaland-VA	Mnz	1019±1, 1005±1, 1004±1, 1001±1		Gr	Charnockitic gneiss, Grasdalen, B649	U-Pb ID-TIMS	4	Bingen & van Breemen, 1998
Rogaland-VA	Mnz	997±5, 947±5		Gr	Augen gneiss, Drængsdalen, B191	Th-Pb ID-TIMS	2	Bingen et al., 2008
Rogaland-VA	Mnz	1032±5, 990±8		Gr	Augen gneiss, Drængsdalen, B191	U-Pb ID-TIMS	5	Bingen & van Breemen, 1998
Rogaland-VA	Zrn	1035±9, 989±11, 955±8		Gr	Felsic granulite, Øystabø, B00158	U-Pb SIMS	13	Bingen et al., 2008
Varddefjell SZ	Zrn	1008±14		Am	Metapelitic gneiss, Byrkjeid, 122B	U-Pb SIMS	30	Tomkins et al., 2005
Varddefjell SZ	Zrn	1012±7		Am	Banded gneiss granodioritic, Flå, B99114	U-Pb SIMS	7	Bingen et al., 2008
Varddefjell SZ	Zrn	1012±7		Am	Banded gneiss tonalitic, mylonitic, Flå, B99111	U-Pb SIMS	15	Bingen et al., 2008
<b>Bamble-Kongsberg Terranes</b>								
Kongsberg	Mnz	1092±1		Am	Nodular gneiss, Snarum, B0030	U-Pb ID-TIMS	2	Bingen et al., 2008
Kongsberg	Mnz	1093±6		Am	Nodular gneiss, Snarum, B0030	U-Pb SIMS	9	Bingen et al., 2008
Kongsberg	Mnz	1095±12		Am	Nodular gneiss, Snarum, B0030	U-Pb LA-ICPMS	10	Bingen et al., 2008
Kongsberg	Zrn	1102±28		Am	Quartzite, Snarum, N95129	U-Pb SIMS	1	Bingen et al., 2001
Kongsberg	Moly	1112±4		Am	Sulfide ore, Skuterud mine, BU9601	Re-Os ID-NTIMS	1	Bingen et al., 2008
Bamble	Mnz	1127±6		Am	Quartzite, Kragerø, B0024	U-Pb SIMS	15	Bingen et al., 2008
Bamble	Mnz	1134±14, 1107±9		Am	Quartzite, Blakstad, B0116	U-Pb SIMS	10	Bingen et al., 2008
Bamble	Zrn	1124±8		Gr	Quartzite, Torungen, 36,93110	U-Pb SIMS	2	Knudsen et al., 1997
Bamble	Zrn	1125±46		Gr	Tonalitic gneiss, Tromøy, 6,95	U-Pb SIMS	1	Knudsen et al., 1999
Bamble	Mnz	1135±6		Gr	Metapelitic gneiss, Hisøy, B0111	U-Pb SIMS	7	Bingen et al., 2008
Bamble	Mnz	1133±6		Gr	Metapelitic gneiss, Hisøy, B0109	U-Pb SIMS	12	Bingen et al., 2008
Bamble	Mnz	1137±7		Gr	Metapelitic gneiss, Hisøy, B0109	U-Pb LA-ICPMS	31	Bingen et al., 2008
Bamble	Mnz	1137±1		Gr	Metapelitic gneiss, Hisøy, B0109	U-Pb ID-TIMS	3	Bingen et al., 2008
Bamble	Mnz	1145±3		Gr	Metapelitic gneiss, Arendal, 92-12c	U-Pb ID-TIMS	1	Cosca et al., 1998

Idefjorden Terrane		Zrn	917±13	Am	Migmatitic granodiorite, Stora Lundby, leucosome 9701a	U-Pb SIMS		12	Scherstén et al., 2004
		Zrn	971±8	Am	Red syenito-granite gneiss, Lake Racken, DC972	U-Pb SIMS		3	Larson et al., 1999
		Zrn	974±22	Am	Migmatitic Delsjön augen gneiss, Stora Delsjön, EAH0309	U-Pb SIMS			Ahlén et al., 2006
		Zrn	980±13	Am	Migmatitic banded gneiss, Bua, TK1+TK2	U-Pb SIMS		8	Andersson et al., 2002
		Zrn	1024±52	Am	Metagreywacke, Skagerrak Fm, DC9417	U-Pb SIMS		2	Ahäll et al., 1998
		Zrn	1043±11	Am	Kärra granite, pegmatite, DC2000020	U-Pb SIMS		8	Austin Hegardt et al., 2007
		Zrn	1026±5	Gr	Metadolerite dyke, Trollhättan, Haregårdsten	U-Pb ID-TIMS		3	Söderlund et al., 2008
		Zrn	1046 ±6	Gr	Metadolerite dyke, Trollhättan, Lundén	U-Pb ID-TIMS		3	Söderlund et al., 2008
Begna		Zrn	1091±18	Am	Granodioritic gneiss, Hensmoen, B99143	U-Pb SIMS		3	Bingen et al., 2008
Begna		Minz	1538±8, 1052±4, 1025±9	Am	Metapelitic gneiss, Hensmoen, B99137	U-Pb SIMS		13	Bingen et al., 2008
		Zrn	1540±7	Am	Burholmen migmatite	U-Pb SIMS		3	Ahäll et al., 2008
		Zrn	1540±32	Am	Nord-Koster metapsamite	U-Pb SIMS		1	Ahäll et al., 2008
Eastern Segment									
South		Zrn	949±4	Am	Interboudin pegmatite, Vistbergen, 7	U-Pb ID-TIMS		10	Connelly et al. 1996
South		Zrn	954±21	Am	Interboudin pegmatite, Tjärnesjö granite, DC9719	U-Pb SIMS		9	Andersson et al., 1999
South		Moly	957±4, 949±4	Am	Felsic vein cutting eclogite boudin, Viared VR3	Re-Os ID-NTIMS		2	Austin Hegardt et al., 2005
South		Zrn	961±13	Am	Late-kinematic "pinch-and-swell" pegmatite, Gällared N	U-Pb SIMS		8	Söderlund et al., 2002
South		Zrn	963±22	Ecl	Deformed granite dyke in eclogite boudin, Ullared, N049	U-Pb SIMS		4	Johansson et al., 2001
South		Zrn	968±13	Am	Migmatitic Torpa granite, TA1	U-Pb SIMS		10	Andersson et al., 2002
South		Zrn	969±13	Am	Migmatitic banded orthogneiss, Skene gneiss, SE-1	U-Pb SIMS		14	Andersson et al., 2002
South		Zrn	969±27	Am	Glassvik deformed pegmatite dyke	Pb-Pb TIMS		4	Söderlund, 1996
South		Zrn	972±14	Ecl	Zircon in garnet, eclogite boudin, Lilla Hammås, Ullared	U-Pb SIMS		4	Johansson et al., 2001
South		Moly	974±3	Ecl	Felsic vein along eclogite boudin, Viared, VR1	Re-Os ID-NTIMS		1	Austin Hegardt et al., 2005
South		Zrn	974±25	Am	Garnet amphibolite, Ljungby, 8705	U-Pb ID-TIMS		5	Wang et al., 1998
South		Zrn	975±17	Am	Garnet amphibolite, Knäred, 9015	U-Pb ID-TIMS		3	Wang et al., 1998
South		Zrn	976±7	Am	Syn-tectonic leucosome, Oxanäset, QX3	U-Pb SIMS		11	Möller et al., 2007
South		Zrn	982±15	Am	Deformed granitic dyke, Gällared S	Pb-Pb TIMS		4	Söderlund et al., 2002
South		Zrn	992±24	Am	Veined gneiss facies, Tjärnesjö granite, TJ25D	U-Pb SIMS		6	Andersson et al., 1999
South		Minz	1410±9, 948±4	Am	Deformed granite dyke, Särdal, 3	U-Pb ID-TIMS		5	Christoffel et al., 1999
South		Zrn	1415±15	Am	Migmatitic granodiorite, Viared, DC03116	U-Pb SIMS		8	Austin Hegardt et al., 2005
South		Zrn	1419±12	Am	Reddish veined orthogneiss, Dagsås	U-Pb SIMS		4	Söderlund et al., 2002
South		Zrn	1425±7	Am	Migmatitic granitic gneiss, Högbär, leucosome HB2	U-Pb SIMS		18	Möller et al., 2007
South		Zrn	1426±8	Am	Interbouding granite pegmatite, Viared, EAH0207	U-Pb SIMS		9	Austin Hegardt et al., 2005
South		Zrn	1428±9	Am	Grey unveined orthogneiss, Dagsås	U-Pb SIMS		6	Söderlund et al., 2002
PZ		Zrn	1437±21	Am	Åker metabasite	U-Pb SIMS		4	Söderlund et al., 2004
South		Zrn	1449±11	Am	Veined granitic gneiss, Gällared N	U-Pb SIMS		15	Söderlund et al., 2002
South		Zrn	1464±8	Am	Grey orthogneiss with veinlets, Gällared S	U-Pb SIMS		3	Söderlund et al., 2002

- (1) Telemarkia Terrane; Yardefjell; SZ: Yardefjell Shear Zone, Rogaland Vest Agder Sector  
 Eastern Segment: North: Solør transect, Centre: Lake Vanern transect, South: South of Vårgårda, PZ: Protogine Zone  
 SFdz: Sveconorwegian Frontal Deformation Zone  
 (2) Mnz: monazite, Moly: molybdenite, Zrn: zircon  
 (3) Metanorphic facies: Am: amphibolite-facies, Gr: granulite-facies, Ecl: decompressed eclogite boudin  
 (4) For Th- Pb-ID-TIMS, the listed age is 208Pb/232Th age, equivalent to both 207Pb/235U and 206Pb/238U ages  
 (5) n: number of analysed fractions

Table 4. Compilation of monazite, zircon and molybdenite geochronological data in the Sveconorwegian belt attributed to high-grade metamorphism.

**Table 5. Compilation of titanite U-Pb data in the Sveconorwegian belt**

Location (1)	Lithology, sample, fraction	Facies (2)	Type (3)	n (4)	Date (Ma)	$\pm 2\sigma$	Reference
<b>Telemarkia Terrane</b>							
Telemark	Vennesla augen gneiss, B603, TB	Am	207Pb/206Pb	1	901	$\pm 7$	Bingen & van Breemen, 1998
Telemark	Drivheia granite gneiss, M200, Tb	Am	Low. intercept	4	907	$\pm 14$	Heaman & Smalley, 1994
Telemark	Drivheia granite gneiss, M200, Tb	Am	207Pb/206Pb	1	913	c.	Heaman & Smalley, 1994
Telemark	Fennefoss granodioritic augen gneiss, B613, TB	Am	207Pb/206Pb	2	978	$\pm 23$	Bingen, unpublished
Rogaland-VA	Augen gneiss, Feda, B135, TB	Am	207Pb/206Pb	2	915.4	$\pm 2.2$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Feda, B113, TC	Am	207Pb/206Pb	3	915.6	$\pm 1.8$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Feda, B120, TA	Am	207Pb/206Pb	1	916.9	$\pm 1.9$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Veggia, B642, TB	Am	207Pb/206Pb	1	917	$\pm 14$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Feda, B114, TC	Am	207Pb/206Pb	1	917.5	$\pm 1.8$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Sirdal, B179, TA	Am	207Pb/206Pb	1	918.6	$\pm 2.4$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Mandal, B204, TB	Am	207Pb/206Pb	2	918.7	$\pm 3.9$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Mandal, B630, TC	Am	207Pb/206Pb	2	918.9	$\pm 4.4$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Sirdal, B185, TB	Am	207Pb/206Pb	2	925	$\pm 13$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Mandal, B206, TA	Am	207Pb/206Pb	2	927	$\pm 9$	Bingen & van Breemen, 1998
Rogaland-VA	Byklom granite	Am	Min. isochron	6	983	$\pm 68$	Andersen et al., 2002
Rogaland-VA	Roskrekpfjord granite	Am	Min. isochron	4	1009	$\pm 10$	Andersen et al., 2002
Rogaland-VA	Tinn granite, 2 samples (071996-2 + 083196-2)	Am	Min. isochron	7	1031	$\pm 32$	Andersen et al., 2002
Vardefjell SZ	Tonalitic banded gneiss, Flå, B99111	Am	207Pb/206Pb	2	985	$\pm 16$	Bingen et al., 2008
Vardefjell SZ	Granodioritic banded gneiss, Flå, B99114	Am	207Pb/206Pb	3	985	$\pm 5$	Bingen et al., 2008
Rogaland-VA	Augen gneiss, Liland, B107, TA	Gr	207Pb/206Pb	1	919	$\pm 6$	Bingen & van Breemen, 1998
Rogaland-VA	Augen gneiss, Sira, B198, TA	Gr	207Pb/206Pb	2	919.8	$\pm 4.2$	Bingen & van Breemen, 1998
<b>Bamble and Kongsberg Terranes</b>							
Bamble	Nelaug granitic gneiss, t beige	Am	207Pb/206Pb	1	994	$\pm 30$	de Haas et al., 2002
Bamble	Nelaug granitic gneiss, t orange-red	Am	207Pb/206Pb	1	1090.9	$\pm 1.9$	de Haas et al., 2002
Bamble	Calc-silicate gneiss, Kragerø, 92-1, Sph921	Am	207Pb/206Pb	1	1105	$\pm 2$	Cosca et al., 1998
Bamble	Pegmatite, Kragerø, 92-2, Sph922a2	Am	207Pb/206Pb	3	1106	$\pm 2$	Cosca et al., 1998
Kongsberg	Albitite margin Øverbykollen metagabbro, G-10	Am	207Pb/206Pb	4	1079.6	$\pm 2.5$	Munz et al., 1994
Bamble	Marble, Arendal, 92-15, Sph9215b	Gr	207Pb/206Pb	1	1103	$\pm 2$	Cosca et al., 1998
Bamble	Marble, Tromøy, 92-10, Sph9210a	Gr	207Pb/206Pb	1	1137	$\pm 2$	Cosca et al., 1998
<b>Idefjorden Terrane</b>							
	Veddige augen gneiss, Mylonite Zone	Am	207Pb/206Pb	5	953	$\pm 6$	Andersson, 2001
	Migmatitic granitoid, Følsbyn, SWS-38	Am	207Pb/206Pb	1	1023	c.	Connelly & Åhäll, 1996
Begna	Migmatitic augen gneiss, Hensmoen, B99140	Am	207Pb/206Pb	2	1024	$\pm 9$	Bingen et al., 2008
Begna	Migmatitic augen gneiss, Hensmoen, B99140	Am	207Pb/206Pb	1	1040	$\pm 14$	Bingen et al., 2008
	Kungsbacka, W of Göta Älv Shear Zone	Am	207Pb/206Pb	1	1040	c.	Johansson, 1993
Begna	Hensmoen, granodioritic gneiss, B99143	Am	207Pb/206Pb	3	1043	$\pm 8$	Bingen et al., 2008
	Bäckefors granite		207Pb/206Pb	2	1554	$\pm 2$	Åhäll et al., 2008
	Rönnäng tonalite, T2light		207Pb/206Pb	1	1565	c.	Connelly & Åhäll, 1996
	Rönnäng tonalite, T1dark		207Pb/206Pb	1	1573	c.	Connelly & Åhäll, 1996
<b>Eastern Segment, Protogine Zone, and Sveconorwegian Frontal Deformation Zone</b>							
Centre	Metagranite, Övre Fryken, W2, TD-TF	Am	207Pb/206Pb	3	956	$\pm 6$	Söderlund et al., 1999
Centre	Metagranite foliated, Karlstad, W1, TE-TG	Am	207Pb/206Pb	3	976	$\pm 4$	Söderlund et al., 1999
Centre	Quartz monzonite, sheared, Lilla Edsvatnet, E2, TA	Am	207Pb/206Pb	1	1638	c.	Söderlund et al., 1999
Centre	Metagranite, Övre Fryken, W2, TB	Am	207Pb/206Pb	1	1674	c.	Söderlund et al., 1999
South	Mafic boudin in Mylonite Zone, Lerhuvud	Am	207Pb/206Pb	1	917	$\pm 14$	Johansson & Johansson, 1993
South	Paleosome in orthogneiss, South Härene, 1, T2	Am	207Pb/206Pb	1	923	c.	Connelly et al., 1996
South	Garnet amphibolite, 9015	Am	206Pb/238U	3	923	$\pm 3$	Wang et al., 1998
South	Vägasked grey gneiss, 85017	Am	207Pb/206Pb	2	929	$\pm 22$	Johansson et al., 1993
South	Paleosome in orthogneiss, South Härene, 1	Am	Low. intercept	5	932	$\pm 10$	Connelly et al., 1996
South	Särdal orthogneiss, paleosome, 1, T2	Am	207Pb/206Pb	2	934	c.	Christoffel et al., 1999
South	Gåsanabbe mafic orthogneiss, paleosome, 5	Am	207Pb/206Pb	2	935	$\pm 5$	Christoffel et al., 1999
South	Garnet amphibolite, 9007	Am	206Pb/238U	3	945	$\pm 2$	Wang et al., 1998
South	Titanite in garnet, eclogite boudin, Lilla Hammås, Ullared	Ecl	206Pb/238U	5	945	$\pm 4$	Johansson et al., 2001
South	Migmatitic orthogneiss, Vistbergen, 4 samples	Am	Low. intercept	17	949	$\pm 4$	Connelly et al., 1996
South	Aplitic dyke, Vråna, 3	Am	Low. intercept	7	950	$\pm 10$	Connelly et al., 1996
South	Vårgårda quartz-monzonite, deformed facies, T1-T3	Am	207Pb/206Pb	3	950	$\pm 5$	Berglund, 1997
South	Granitoid, Hesta suite, Lake Åsunden, 2	Am	Low. intercept	8	956	$\pm 4$	Connelly et al., 1996
South	Interboudin granite pegmatite, EAH0207	Am	207Pb/206Pb	8	961	$\pm 26$	Austin Hegardt et al., 2005
South	Aplitic dyke, Vråna, 3	Am	Up. intercept	7	1457	$\pm 7$	Connelly et al., 1996
South	Migmatitic orthogneiss, Vistbergen, 4 samples	Am	Up. intercept	17	1470	$\pm 25$	Connelly et al., 1996
PZ	Gumlösa-Glimåkra gneissic granite, Vanås Gods, 86010	Am	207Pb/206Pb	3	942	c.	Johansson, 1990
PZ-SFDZ	Monzonite, Broby, E1, TA		207Pb/206Pb	1	1657	c.	Söderlund et al., 1999
PZ-SFDZ	Metagranite, Åserud, W3, TA	Am	207Pb/206Pb	1	1676	c.	Söderlund et al., 1999

(1) Eastern Segment: North: Solør transect, Centre: Lake Vänern transect, South: South of Vårgårda, PZ: Protogine Zone  
SFDZ: Sveconorwegian Frontal Deformation Zone

(2) Metamorphic facies: Am: amphibolite-facie, Gr: granulite-facies, Ecl: decompressed eclogite boudin

(3) selected date

(4) n: number of analysed fractions

*Table 5. Compilation of titanite U-Pb data in the Sveconorwegian belt.*

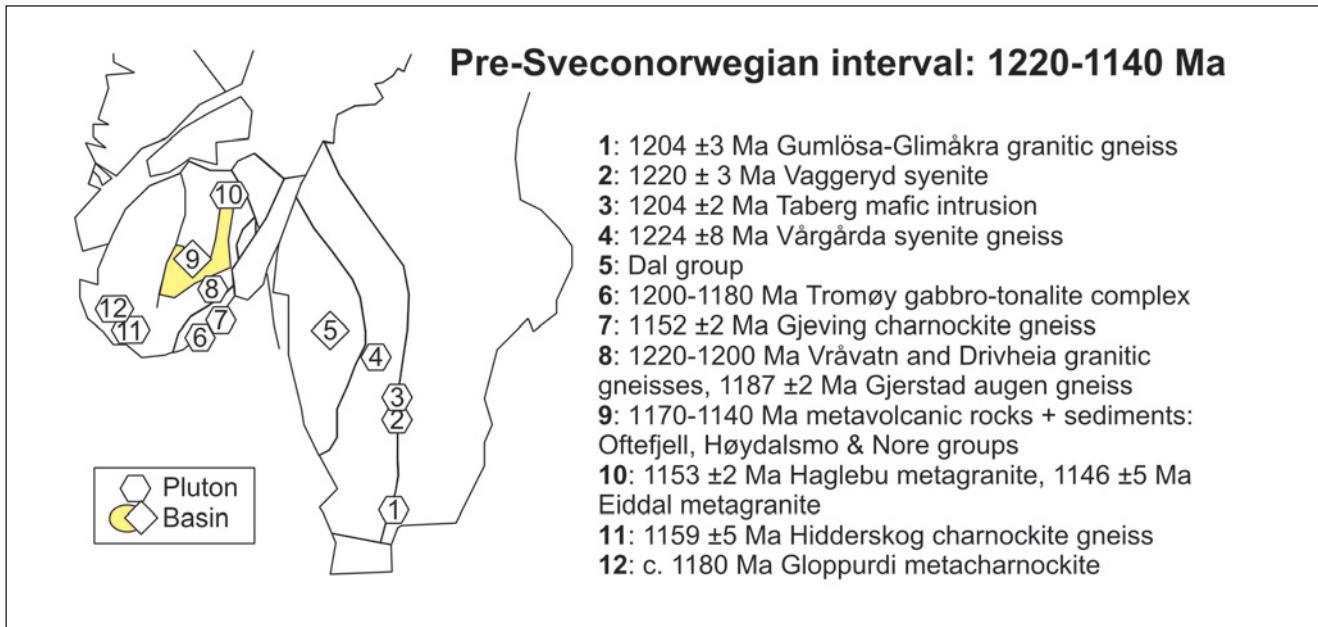


Fig. 7. Sketchmap showing the distribution of magmatic rocks and sedimentary basins between 1220 and 1140 Ma shortly before the Sveconorwegian orogeny.

In the northernmost part of the Eastern Segment (Solør Complex), no significant Sveconorwegian metamorphism has been detected except in the vicinity of the Mylonite Zone and other local shear zones (Figs. 2, 3). In the centre of the segment, around lake Vänern, penetrative amphibolite-facies metamorphism is recorded east of the Mylonite Zone, and fading away to the east. Secondary titanite at  $976 \pm 4$  to  $956 \pm 6$  Ma dates this deformation (Table 5; Söderlund et al. 1999).

The Eastern Segment south of lake Vänern shows penetrative amphibolite-facies metamorphism. Mafic boudins display high-pressure granulite-facies and locally decompressed eclogite-facies assemblages (Johansson et al. 1991; Möller 1998; Möller 1999; Austin Hegardt et al. 2005). These boudins show evidence of a clockwise pressure-temperature path, with peak conditions exceeding 1.5 GPa and decompression through 0.96-1.2 GPa and 705-795 °C (Fig. 8d; Möller 1998; Möller 1999). Metamorphic zircon from several samples brackets Sveconorwegian high-grade metamorphism and migmatitization between  $992 \pm 24$  and  $961 \pm 13$  Ma (Table 4; Andersson et al. 1999; 2002a; Söderlund et al. 2002; Möller et al. 2007). Zircon inclusions in eclogite-facies garnet provide a maximum age of  $972 \pm 14$  Ma for the eclogite-facies overprint (Ullared locality; Fig. 8d; Johansson et al. 2001). Titanite U-Pb data range from  $956 \pm 4$  to  $923 \pm 3$  Ma (Fig. 4, Table 5; Connelly et al. 1996; Söderlund et al. 1999; Johansson et al. 2001). The main group of hornblende  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau ages between  $934 \pm 6$  and  $931 \pm 6$  Ma, from the southern part of the segment, is interpreted by Page et al. (1996a; 1996b) as the timing of cooling through c. 550-500 °C.

Around and south of lake Vänern, the Eastern Segment is characterized by large E-W to WNW-ESE trending

fold structures prominent on aeromagnetic maps, and by high-strain zones parallel to these folds (Berglund et al. 1997; Möller et al. 2007). WNW-ESE high-strain zones locally host eclogite boudins and thus formed after peak eclogite-facies metamorphism. Zircon in a synkinematic amphibolite-facies leucosome dates one of the WNW-ESE trending folds at  $976 \pm 7$  Ma (Oxanäset locality; Fig. 4; Möller et al. 2007), i.e. this fold is coeval, within error, with the age of eclogite-facies metamorphism. Cross-cutting granitic dykes place the end of ductile deformation at  $956 \pm 7$  Ma in one of the high-strain zones (Möller & Söderlund 1997), while an interboudin pegmatite attests to extensional deformation at  $949 \pm 4$  Ma at the Vistbergen locality (Fig. 4; Connelly et al. 1996).

The Eastern Segment is bounded in the east by two orogen-parallel lineaments, the Protogine Zone and the Sveconorwegian Frontal Deformation Zone (SFDZ; Fig. 1; Andréasson & Rodhe 1990; Wahlgren et al. 1994). The Protogine Zone is made up of generally extensional shear zones defining the eastern limit of penetrative Sveconorwegian reworking. Further to the east, the Sveconorwegian Frontal Deformation Zone marks the easternmost limit of Sveconorwegian deformation along discrete shear zones. South of lake Vättern, these two lineaments merge into a broad zone (20-30 km wide) of steep, ductile to brittle, N-S trending and anastomosing, normal faults and shear zones (Andréasson & Rodhe 1990; Söderlund et al. 2004). Around lake Vänern, they define a fan-like structure with predominant normal movement (top down to-the-east) along the Protogine Zone and later reverse movement to the east along the Sveconorwegian Frontal Deformation Zone (Wahlgren et al. 1994; Juhlin et al. 2000). Muscovite  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau ages from ductile shear zones range from  $964 \pm 1$  to  $905 \pm 5$  Ma (Andréasson & Dallmeyer 1995; Page et al. 1996b). In the

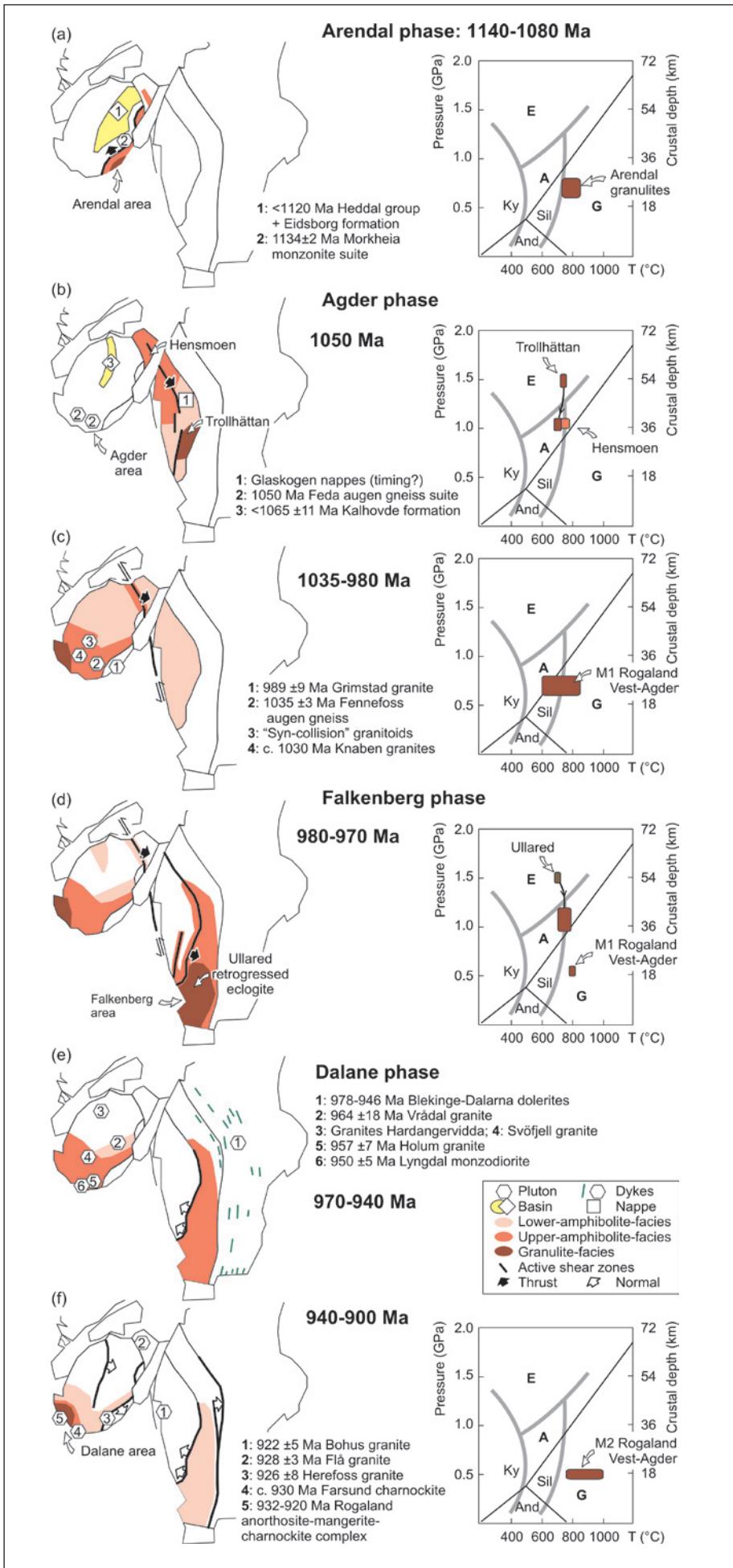


Fig. 8. Sketchmaps showing the distribution of metamorphism, magmatic rocks and sedimentary basins during the Sveconorwegian orogeny. For each time slice, metamorphism is illustrated in the pressure-temperature space.

(a) Arendal phase: 1140-1080 Ma.

(b, c) Agder phase: 1050-980 Ma.

(d) Falkenberg phase: 980-970 Ma.

(e, f): Dalane phase: 970-900 Ma.

References quoted in text and in Tables 3, 4, 5.

northernmost part of the Eastern Segment (Solør Complex), the Protogine Zone and the Sveconorwegian Frontal Deformation Zone are poorly documented, as little Sveconorwegian deformation has been identified. Along the Protogine Zone south of lake Vänern, two pulses of Pre-Sveconorwegian bimodal continental magmatism are recorded between 1220 and 1200 Ma (Larsson & Söderlund 2005; Söderlund & Ask 2006). The spatial link between this magmatism and the Protogine Zone, suggests that the eastern limit of the Sveconorwegian belt was a zone of protracted lithospheric weakness during the Mesoproterozoic (Söderlund & Ask 2006). Lithological continuity between the Eastern Segment and the Sveconorwegian foreland is apparent on geological maps. This suggests that major displacement along the Protogine Zone and Sveconorwegian Frontal Deformation Zone is lacking (Andréasson & Rodhe 1990).

#### *Idefjorden Terrane*

The Idefjorden Terrane (Fig. 1) is made up of 1660–1520 Ma mainly calc-alkaline and tholeiitic plutonic and volcanic rocks, associated with greywacke-bearing metasedimentary sequences (Fig. 6; Table 3; Brewer et al. 1998; Åhäll & Larson 2000; Bingen et al. 2001a; Andersen et al. 2004a; Åhäll & Connolly 2008). Lithologies show an average younging towards the west. From east to west, these are the 1660–1640 Ma Horred metavolcanic rocks, the 1630–1590 Ma Åmål Formation and coeval Göteborg granite suite, and the 1590–1520 Ma Stora Le-Marstrand Formation and coeval Hisingen plutonic suite. These lithologies were assembled during the Gothian accretionary event (Andersen et al. 2004a; Åhäll & Connolly 2008; Bingen et al. 2008a). The timing of Gothian amphibolite-facies metamorphism is estimated at 1540 Ma (Table 4; Åhäll & Connolly 2008; Bingen et al. 2008b). The 1660–1520 Ma lithologies are overlain by the poorly dated supracrustal Dal Group (Fig. 2; Brewer et al. 2002). They are intruded by the 1340–1250 Ma bimodal plutonic Kungsbacka suite (Austin Hegardt et al. 2007), and 960–920 Ma post-collisional norite-granite plutons, including the Flå and Bohus plutons (Fig. 5; Eliasson & Schöberg 1991; Scherstén et al. 2000; Årebäck & Stigh 2000; Hellström et al. 2004; Bingen et al. 2006).

The Idefjorden Terrane displays a general N–S to NW–SE Sveconorwegian structural grain. It contains several amphibolite-facies orogen-parallel shear zones, including the Ørje Shear Zone (Norway) or Dalsland Boundary Zone (Sweden) and the Göta Älv Shear Zone (Park et al. 1991), as well as a nappe complex, the Glaskogen Nappes (Fig. 1; Lindh et al. 1998). The grade of Sveconorwegian metamorphism is variable and ranges from greenschist-facies to amphibolite-facies and locally granulite-facies. High-pressure mafic granulite boudins are reported in the eastern part of the Idefjorden Terrane, east of the Göta Älv Shear Zone (Trollhättan locality; Fig. 8b; Söderlund et al. 2008). They yield pressure-temperature estimates ranging from c. 1.5 GPa–740 °C to c. 1.0 GPa–700 °C. This metamorphism lies between 1046 ± 6 and 1026

± 5 Ma according to zircon U–Pb data and Sm–Nd and Lu–Hf mineral isochrons (Table 4; Söderlund et al. 2008). Amphibolite-facies metamorphism, west of the Göta Älv Shear Zone and Dalsland Boundary Zone lies between 1043 ± 11 Ma and c. 1023 Ma according to zircon and titanite data (Hansen et al. 1989; Austin Hegardt et al. 2007). West of the Oslo rift, high-pressure amphibolite-facies conditions (1.0–1.2 GPa, 690–780 °C) are recorded (Hensmoen locality; Fig. 8b; Bingen et al. 2008b). U–Pb data define three age clusters for high-grade metamorphism at 1091 ± 18 Ma (zircon rim), 1052 ± 4 to 1040 ± 14 Ma (monazite and titanite) and 1025 ± 9 to 1024 ± 9 Ma (monazite and titanite, Table 5; Bingen et al. 2008b). High-pressure conditions are dated at 1052 ± 4 Ma in a kyanite-bearing metapelite.

Orogen-parallel shear zones in the Idefjorden Terrane are interpreted as transpressive thrust zones (Park et al. 1991). One zircon rim U–Pb date at 974 ± 22 Ma in the vicinity of the Göta Älv Shear Zone (Ahlin et al. 2006) suggests that this zone was active at c. 970 Ma. The Mylonite Zone, bounding the Idefjorden Terrane in the east (Fig. 1), is an arcuate, generally west-dipping shear zone. It is interpreted as a sinistral transpressional thrust zone with an overall top-to-the-southeast transport direction (Park et al. 1991; Stephens et al. 1996). It is reworked as a normal extensional shear zone (Berglund 1997). The age of thrusting is not directly established, but zircon U–Pb data in the Idefjorden hanging wall and Eastern Segment foot wall record amphibolite-facies metamorphism, migmatitization and associated ductile deformation between 980 ± 13 and 971 ± 8 Ma (Larson et al. 1999; Andersson et al. 2002a). This interval is equivalent, within error, to the age of amphibolite-, granulite- and eclogite-facies metamorphism in the Eastern Segment foot wall. Indirect estimates for extensional tectonics along the Mylonite Zone are provided by hornblende <sup>40</sup>Ar/<sup>39</sup>Ar plateau ages between 918 ± 6 and 910 ± 6 Ma, a titanite age at 917 ± 14 Ma and a zircon age in a stromatic migmatite at 917 ± 13 Ma (Johansson & Johansson 1993; Page et al. 1996a; Scherstén et al. 2004).

#### *Bamble and Kongsberg Terranes*

The Bamble and Kongsberg Terranes (Fig. 1) are made up of 1570–1460 Ma, mainly calc-alkaline, plutonic suites associated with quartzite or greywacke-dominated metasediment complexes (Figs. 2, 6; Table 3; Starmer 1985; Starmer 1991; Nijland et al. 1993; Knudsen et al. 1997a; de Haas et al. 1999; Andersen et al. 2004a). The quartzite-rich complexes have a characteristic assemblage of quartzite, mica gneiss, sillimanite-rich gneiss and minor orthoamphibole-cordierite rocks. The Kongsberg Terrane hosts a suite of c. 1200 Ma mafic plutons (Munz et al. 1994). The Bamble Terrane hosts the 1200–1180 Ma gabbro-tonalite Tromøy complex, 1170–1150 Ma granite-charnockite metaplutons (Fig. 7), 1060 Ma pegmatites and 990–920 Ma post-collisional granite plutons (Baadsgaard et al. 1984; Kullerud & Dahlgren 1993; Andersen et al. 2002a; Knudsen & Andersen 1999; Andersen et al. 2004a).

Geophysical data suggest that the Bamble and Kongsberg Terranes form two tectonic wedges overlying the Telemarkia Terrane (Andersson et al. 1996; Ebbing et al. 2005). The Kongsberg Terrane shows a steep, N-S trending Sveconorwegian structural grain (Starmer 1985; Andersen & Munz 1995). Peak amphibolite-facies conditions are in the sillimanite stability field (Munz 1990). The Bamble Terrane has a pronounced NE–SW trending structural grain defined by a strong planar fabric, isoclinal folds and lithological banding (Starmer 1985; Starmer 1991; Kullerud & Dahlgren 1993). Several isograds show that the regional metamorphic grade increases across strike to the southeast and reaches intermediate-pressure granulite-facies conditions in the Arendal area (Touret 1971; Smalley et al. 1983; Nijland & Maijer 1993). Peak pressure-temperature conditions are estimated to be  $0.70 \pm 0.11$  GPa and  $793 \pm 58$  °C in the core of the granulite-facies domain (Fig. 8a; Harlov 2000).

Geochronological data give evidence for two metamorphic phases (Tables 4, 5). The first phase at 1140–1125 Ma is limited to the Bamble Terrane. It is recorded in amphibolite-facies and granulite-facies rocks by zircon at  $1125 \pm 46$  and  $1124 \pm 8$  Ma (Knudsen et al. 1997b; Knudsen & Andersen 1999), by monazite ranging from  $1145 \pm 3$  to  $1127 \pm 6$  Ma (Cosca et al. 1998; Bingen et al. 2008b) and by titanite in marble at  $1137 \pm 2$  Ma (Fig. 4; Cosca et al. 1998). A monazite at  $1137 \pm 1$  Ma in a sillimanite-bearing granulite probably dates peak granulite-facies conditions (Hisøy locality; Bingen et al. 2008b).

The second metamorphic phase covers both the Bamble and Kongsberg Terranes. In the Bamble Terrane, data include a monazite age at  $1107 \pm 9$  Ma and titanite ages between  $1106 \pm 2$  and  $1091 \pm 2$  Ma (Fig. 4; Cosca et al. 1998; de Haas et al. 2002; Bingen et al. 2008b). These data overlap with the main cluster of amphibole  $^{40}\text{Ar}/^{39}\text{Ar}$  cooling ages, ranging from  $1099 \pm 3$  to  $1079 \pm 5$  Ma, in samples distributed in the amphibolite- and granulite-facies domains (Cosca & O’Nions 1994; Cosca et al. 1998). In the Kongsberg Terrane, data from the quartzite-rich Modum Complex include a zircon U-Pb age at  $1102 \pm 28$  Ma, a molybdenite Re-Os age at  $1112 \pm 4$  Ma in a cobalt ore, a monazite U-Pb age at  $1092 \pm 1$  Ma, and a titanite age at  $1080 \pm 3$  Ma recording hydrothermal activity in an albite (Fig. 4; Munz et al. 1994; Bingen et al. 2001a; Bingen et al. 2008b). Available data support the view that the event at 1110–1080 Ma includes the peak of amphibolite-facies metamorphism in the Kongsberg Terrane, as opposed to a phase of regional cooling and unroofing in the Bamble Terrane. Importantly, both events at 1140–1125 and 1110–1080 Ma are recorded in one sample from the amphibolite-facies domain in Bamble (Bingen et al. 2008b), indicating that the two events cannot be attributed to two separate tectonic units.

The Kristiansand-Porsgrunn Shear Zone forms the boundary between the Bamble and Telemarkia Terranes (Fig. 1). It dips to the southeast and is interpreted as a Sveconorwegian thrust zone reworked as an extensional

detachment (Starmer 1991; Henderson & Ihlen 2004; Mulch et al. 2005). Thrusting is associated with north-west-verging folds developed under amphibolite-facies conditions and the intrusion of pegmatite bodies (Henderson & Ihlen 2004). The time of thrusting is not directly dated: it is nevertheless younger than  $1132 \pm 3$  Ma, the age of the Morkheia Monzonite Suite deformed along the shear zone (Fig. 2; Heaman & Smalley 1994). Thrusting probably post-dates the peak of the most widespread event of amphibolite-facies metamorphism recorded in the Bamble and Kongsberg Terranes at c. 1110 Ma and may overlap with amphibole  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau ages and titanite U-Pb ages recording regional cooling at c. 1090–1080 Ma. Secondary titanite at  $994 \pm 30$  Ma in the hanging wall of the shear zone may relate to reactivation of the shear zone or reheating in relation to metamorphism in the Telemarkia footwall (Fig. 4; de Haas et al. 2002). UV-laser  $^{40}\text{Ar}/^{39}\text{Ar}$  data on muscovite porphyroblasts constrain a phase of extensional deformation along the shear zone between  $891 \pm 3$  and  $880 \pm 3$  Ma (Mulch et al. 2005). This estimate is consistent with two titanite ages at  $913 \pm 5$  and  $901 \pm 7$  Ma and three amphibole  $^{40}\text{Ar}/^{39}\text{Ar}$  age spectra ranging from  $893 \pm 14$  to  $861 \pm 36$  Ma, giving evidence for late-Sveconorwegian cooling between 910 and 860 Ma in the Telemarkia foot wall of the shear zone (Heaman & Smalley 1994; Bingen et al. 1998).

#### *Telemarkia Terrane*

The Telemarkia Terrane (Fig. 1) is characterized by a voluminous 1520–1480 Ma magmatic event (Fig. 6; Table 3; Bingen et al. 2005), referred to as the Telemarkian event by Bingen et al. (2008a). No older magmatic rocks are positively identified. The 1520–1480 Ma volcanic and plutonic suites have a poorly defined geochemical signature. They are interlayered with and overlain by quartzite-bearing metasedimentary sequences older than c. 1350 Ma (Fig. 4; Dons 1960; Bingen et al. 2001a; Laajoki et al. 2002; Andersen & Laajoki 2003; Corfu & Laajoki 2008). These rocks were intruded and unconformably overlain by several magmatic suites and sediments between 1280 and 1130 Ma (Heaman & Smalley 1994; Laajoki et al. 2002; Brewer et al. 2002; Bingen et al. 2002; Andersen et al. 2004b; Brewer et al. 2004; Andersen et al. 2007b). The Telemarkia Terrane is the location of voluminous Sveconorwegian plutonism, including 1050–1035 Ma granodiorite to granite suites, 1030–1000 Ma syn-collisional granitoids, 970–930 Ma post-collisional monzodiorite to granite plutons, and the 930–920 Ma Rogaland anorthosite-mangerite-charnockite (AMC) complex (Duchesne et al. 1985; Demaiffe et al. 1986; Schärer et al. 1996; Bingen & van Breemen 1998a; Schiellerup et al. 2000; Andersen et al. 2001; Bogaerts et al. 2003; Bolle et al. 2003a; Vander Auwera et al. 2003; Andersen et al. 2007b). Undeformed c. 850 Ma mafic dykes post-date regional cooling (Walderhaug et al. 1999).

For descriptive purposes, the Telemarkia Terrane is divided into four “sectors”. These are the Telemark, Hardangervidda, Suldal and Rogaland-Vest Agder Sectors

(Fig. 1; Bingen et al. 2005). The boundaries between them are generally transitional, except along the N-S trending Mandal-Ustaoset Fault and Shear Zone (Fig. 1; Sigmond 1985). The four sectors of the Telemarkia Terrane expose rocks of variable paleo-crustal levels, with metamorphism ranging from low-grade to granulite-facies.

The Hardangervidda Sector consists of amphibolite-facies gneisses with a general E-W structural grain (Sigmond 1998). The Suldal Sector is characterized by greenschist- to epidote-amphibolite-facies supracrustal sequences, associated with plutonic rocks. The timing of metamorphism in these two sectors has commonly been assumed to be pre-Sveconorwegian. Nevertheless, in low-grade c. 1260 Ma supracrustal rocks of the Suldal Sector (Langvatn locality in Sæsvatn-Valdal sequence), a molybdenite Re-Os age of  $1032 \pm 2$  Ma defines Sveconorwegian epidote-amphibolite-facies deformation in metabasalt (Stein & Bingen 2002), while in the underlying basement a monazite age at  $1005 \pm 7$  Ma dates amphibolite-facies migmatitization (Ryghestad locality; Fig. 4; Table 4; Bingen et al. 2008b).

The central part of the Telemark sector is made up of low-grade supracrustal rocks (Fig. 4). In these rocks, original stratigraphic relationships and textures are extensively preserved (Dons 1960). Four main stratiform sequences, separated by unconformities, are defined (Dons 1960; de Haas et al. 1999; Laajoki et al. 2002; Bingen et al. 2003; Andersen & Laajoki 2003; Andersen et al. 2004b; Laajoki & Corfu 2007). The lower sequence is made up of the 1510–1500 Ma bimodal volcanic rocks of the Rjukan Group. It is overlain by the quartzite-dominated Vindegen Group. The overlying unconformable sequence is made up of 1170–1140 Ma bimodal volcanic rocks interlayered with metasediments. The uppermost sequence, younger than 1120 Ma, is made up of immature clastic sediments (Eidsborg Formation, Heddal Group and the Kalhovd Formation; Fig. 8a). The timing of low-grade metamorphism in the central part of the Telemark Sector is poorly known. A  $1031 \pm 32$  Ma mineral Pb-Pb isochron reflects isotopic homogenisation during this event (Andersen et al. 2002c). Towards the northeast of the Telemark sector, metamorphic grade increases to amphibolite-facies in rocks of mainly metasedimentary parentage (Hallingdal Complex; Fig. 4). Metamorphism is dated at  $1014 \pm 1$  Ma by means of zircon in an amphibolite boudin (Bingen et al. 2008b). This is consistent with the observation that the Heddal Group ( $<1121 \pm 15$  Ma) is overprinted by this metamorphism. Towards the south, supracrustal rocks abut a NE-SW trending amphibolite-facies gneiss complex, referred to as the South Telemark Gneisses by Andersen et al. (2007b; Fig. 4). Titanite ages at c.  $913$  to  $901 \pm 7$  Ma in this gneiss complex attest to late-Sveconorwegian high-grade metamorphism (Fig. 4; Table 5; Heaman & Smalley 1994; Bingen et al. 1998).

The Rogaland-Vest Agder sector is characterized by amphibolite- to granulite-facies metamorphism. Four isograds reflect an increase of metamorphic grade

towards the Rogaland anorthosite-mangerite-charnockite (AMC) complex (Fig. 4; Tobi et al. 1985). These are, from northeast to southwest, clinopyroxene-in in granodioritic gneiss, orthopyroxene-in in granitic gneiss, osumilite-in in paragneiss, and pigeonite-in in granitic gneiss. The osumilite and pigeonite isograds are parallel to the contact of the Rogaland AMC complex (Tobi et al. 1985). Osumilite assemblages indicate dry (water-poor), high-temperature, low-pressure granulite-facies conditions (Holland et al. 1996), and pigeonite requires peak temperatures exceeding  $865$  °C. Westphal et al. (2003) estimate that peak temperature increased towards the intrusive contact of the AMC complex, from c.  $760$  °C at 13 km, to  $900$  °C at 5 km, to more than  $1000$  °C near the contact, for a pressure of 0.5 GPa (Fig. 8f). Petrological evidence suggests that superposition of three metamorphic phases took place. High-temperature granulite-facies assemblages (M2) commonly include relicts of older, high-grade medium-pressure assemblages (M1, 0.6–0.8 GPa), and they are themselves commonly surrounded by post-peak corona textures (M3). Granulite-facies orthopyroxene-bearing assemblages are reported for both M1 and M2 phases (Tobi et al. 1985; Jansen et al. 1985; Vander Auwera 1993; Westphal et al. 2003). Metamorphic zircon from a variety of samples ranges from  $1068 \pm 28$  to  $901 \pm 18$  Ma, with two principal modes, one at  $1030$ – $990$  Ma attributed to M1 and the second at  $930$ – $920$  Ma attributed to M2–M3 (Table 4; Möller et al. 2002; Möller et al. 2003; Tomkins et al. 2005). Monazite U-Pb and Th-Pb data define overlapping age ranges, from  $1032 \pm 5$  to  $970 \pm 5$  Ma for M1, and from  $930 \pm 2$  to  $922 \pm 5$  Ma for M2 (Bingen & van Breemen 1998b; Bingen et al. 2008b). Molybdenite associated with generally deformed quartz veins, pegmatites or leucosomes from several localities yields Re-Os crystallization ages ranging from  $982 \pm 3$  to  $917 \pm 3$  Ma (Bingen & Stein 2003; Bingen et al. 2006). Titanite U-Pb data define a regional scale cluster at  $918 \pm 2$  Ma, best regarded as a cooling age (Fig. 4, Table 5; Bingen & van Breemen 1998b). Amphibole  $^{40}\text{Ar}/^{39}\text{Ar}$  apparent ages range from  $1059 \pm 8$  to  $853 \pm 3$  Ma (Bingen et al. 1998). The main cluster at  $871 \pm 10$  Ma overlaps with biotite Rb-Sr ages (Verschure et al. 1980) and is interpreted as a cooling age. Available geochronological data carry several important implications for the regional metamorphic evolution. (1) Monazite data from a felsic granulite, situated outside the area affected by M2 (Øvstabø locality), demonstrate granulite-facies metamorphism during M1 at  $1032 \pm 5$  or  $990 \pm 8$  Ma (Fig. 8c; Bingen et al. 2008b). (2) Molybdenite in orthopyroxene-bearing leucosomes in the Ørsdalen district demonstrates granulite-facies conditions at  $973 \pm 4$  Ma, probably related to decompression biotite dehydration-melting following M1 metamorphism (0.55 GPa– $800$  °C; Bingen & Stein 2003). (3) Zircon included in cordierite coronas around garnet dates regional decompression at  $955 \pm 8$  Ma following M1 metamorphism (Tomkins et al. 2005). (4) Zircon dated at  $927 \pm 7$  Ma in apparent equilibrium with M2 high-temperature granulite-facies assemblages (Möller et al. 2003) links the osumilite and pigeonite isograds with intrusion of the Rogaland AMC complex (932

$\pm 3$  to  $920 \pm 3$  Ma; Fig. 8f; Schärer et al. 1996). (5) Monazite in clinopyroxene-rich samples ranging from  $930 \pm 2$  to  $925 \pm 2$  Ma indicates that the clinopyroxene isograd relates to M2 metamorphism (Bingen & van Breemen 1998b; Bingen et al. 2008b). (6) Molybdenite Re-Os data, collected from deformed rocks, constrain the last increment of regional ductile deformation to be younger than  $947 \pm 3$  Ma on a regional scale, and younger than  $931 \pm 3$  Ma to the west of the clinopyroxene isograd (Bingen et al. 2006). A deformation event younger than  $917 \pm 3$  Ma is recorded in direct contact to the anorthosite plutons. These data imply that intrusion of the post-collisional granite plutons and anorthosite plutons was associated with ductile deformation, in accordance with structural data on the plutons (Bolle et al. 2000; Bolle et al. 2003b).

The N-S trending Mandal-Ustaoset Fault and Shear Zone limit the Telemark Sector to the west (Fig. 1). In its northern part, it forms a ductile shear zone and a brittle normal fault system recording downthrow of the Telemark Sector relative to the Hardangervidda Sector (Sigmond 1985). The fault system displaces rocks of the Kalhovd Formation, deposited after  $1065 \pm 11$  Ma (Bingen et al. 2003). Southwards, the Mandal-Ustaoset Zone merges into the N-S trending structures characteristic of the Rogaland-Vest Agder Sector and South Telemark Gneisses (Bingen & van Breemen 1998a).

The Vardefjell Shear Zone between the Telemarkia and Idefjorden Terranes (Fig. 1) dips to the southwest. It is characterized by amphibolite-facies banded gneiss rich in amphibolite-layers and amphibolite boudins. The timing of amphibolite-facies metamorphism in banded gneiss is estimated at  $1012 \pm 7$  to  $1008 \pm 14$  Ma according to zircon data (Table 4; Bingen et al. 2008b). Amphibolite-facies deformation along the Vardefjell Shear Zone is coeval or younger than peak metamorphism at c. 1010 Ma. Post-peak mylonitization is younger. Fabric-parallel titanite may record continued deformation at  $985 \pm 5$  Ma (Fig. 4; Table 5; Bingen et al. 2008b). Titanite data suggest that the Vardefjell Shear Zone did not accommodate late orogenic extensional deformation after c. 985 Ma.

## Exotic vs. indigenous models

The three largest lithotectonic units in the Sveconorwegian belt, the Eastern Segment, the Idefjorden Terrane and the Telemarkia Terrane are characterized by distinct events of continental growth (in the sense of the oldest event of widespread magmatism; Fig. 6; Table 3; Bingen et al. 2005; Bingen et al. 2008a). In the Eastern Segment, continental growth took place between 1800 and 1640 Ma overlapping with magmatism in the TIB. In the Idefjorden Terrane, it took place between c. 1660 and 1520 Ma during the Gothian accretionary event. In the Telemarkia Terrane, it took place at 1520–1480 Ma. These three main lithotectonic units have thus independent ancestries. The Bamble and Kongsberg Terranes share their Mesopro-

terozoic magmatic evolution, starting at 1570 Ma, with the Idefjorden and Telemarkia Terranes (Fig. 6). They can thus result from interaction between these two terranes. Cornell and Austin Hegardt (2004) observed that all magmatic suites and metamorphic events older than c. 980 Ma in the Idefjorden Terrane are distinct from those in the Eastern Segment. Consequently, they propose that both the Idefjorden and Telemarkia Terranes were exotic to Fennoscandia before the Sveconorwegian orogeny and accreted along a suture zone represented by the Mylonite Zone at around 980 Ma. This model provides an elegant explanation for  $972 \pm 14$  Ma eclogite-facies metamorphism in the Eastern Segment, but lacks independent lithological evidence.

The Sveconorwegian belt lacks known exposure of Sveconorwegian ultramafic rocks that could represent ophiolite sequences and mark a suture zone resulting from closure of an oceanic basin between the three main lithotectonic units. As of today, it is not known whether the belt hosts a suture zone, and consequently if the belt includes exotic lithotectonic units.

### Exotic Telemarkia

Two main lines of evidence from the pre-Sveconorwegian 1220–1130 Ma history (Fig. 7) can be used to suggest an exotic ancestry for the Telemarkia Terrane (Bingen et al. 2005; Corfu & Laajoki 2008; Fig. 9). (1) In the Bamble Terrane, the 1200–1180 Ma Tromøy gabbro-tonalite complex (Fig. 4; Fig. 7) has a low-K calc-alkaline to tholeiitic signature and is interpreted as the remnant of an immature island arc (Smalley et al. 1983; Knudsen & Andersen 1999; Andersen et al. 2002b; Andersen et al. 2004a). This suggests that a subduction setting prevailed at the margin or outboard of Fennoscandia. The Tromøy complex represents the only significant evidence, available today, for the presence of an oceanic basin at the onset of the Sveconorwegian orogeny. Location of the Tromøy complex in the small Bamble Terrane is compatible with closure of the basin between the Idefjorden and Telemarkia Terranes (Fig. 7; Fig. 9). (2) In the Telemarkia and Bamble Terranes, widespread continental bimodal magmatism is recorded between 1220 and 1130 Ma (Fig. 7, Table 3; Heaman & Smalley 1994; Brewer et al. 2002; Laajoki et al. 2002; Bingen et al. 2003; Andersen et al. 2007b). It includes, a juvenile granite batholith formed between 1220 and 1190 Ma and possibly with associated mafic underplates, 1190–1140 Ma A-type granite-charnockite plutonism, and the alkaline  $1134 \pm 2$  Ma Morkheia monzonite suite. It also includes, as part of the Telemark supracrustal rocks, 1170–1140 Ma bimodal volcanic rocks interlayered with immature clastic metasediments. These rocks form several groups and formations of comparatively limited lateral extent. Local unconformities attest to active erosion and tectonic activity between 1170 and 1140 Ma (Laajoki & Lamminen 2006). Geotectonic interpretation of the 1220–1130 Ma magmatism proves controversial. Part of the early 1200 Ma magmatism has been interpreted as evidence for active continental margin

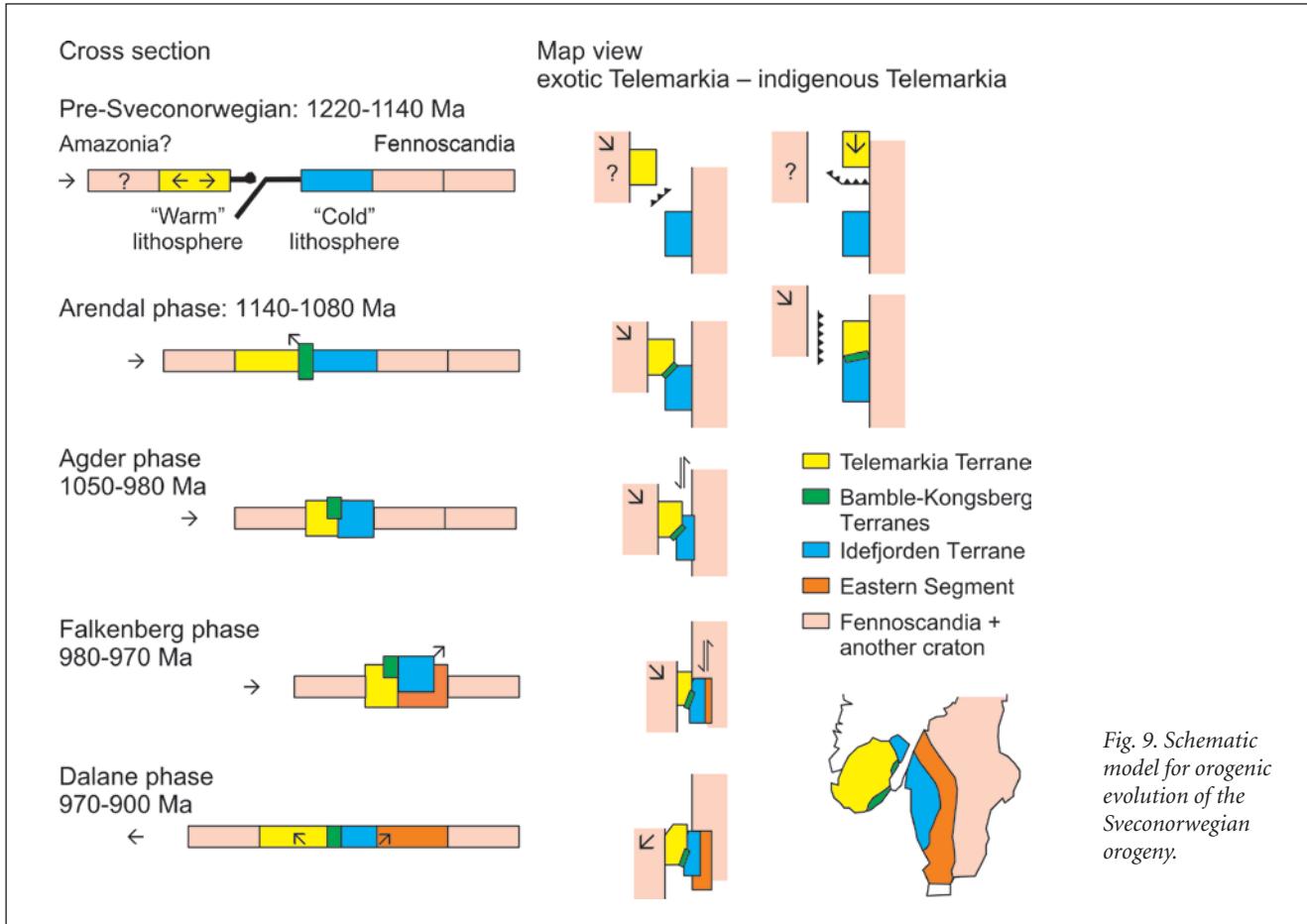


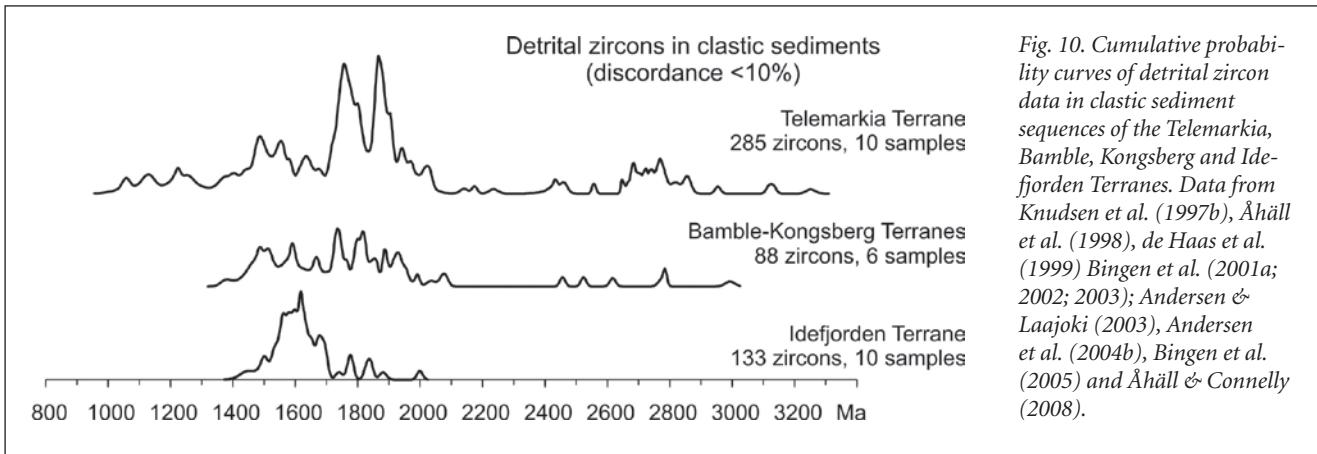
Fig. 9. Schematic model for orogenic evolution of the Sveconorwegian orogeny.

setting (Drivheia gneiss; Heaman & Smalley 1994). The younger 1170-1140 Ma bimodal magmatism and associated sediment basins, and the 1130 Ma alkaline magmatism suggest an extensional or transtensional tectonic regime. This rock assemblage has been variably interpreted in a context of continental rifting (Laajoki et al. 2002; Andersen et al. 2007b), continental back-arc setting (Brewer et al. 2002; Andersen et al. 2007b) or a Basin and Range setting (Bingen et al. 2003). The 1220-1130 Ma magmatism is widespread in the Telemarkia Terrane but totally absent in the Idefjorden Terrane. This difference is compatible with a separation of the two terranes at the onset of the Sveconorwegian orogeny. It also underscores the contrast between the fertile “warm” nature of the Telemarkia lithosphere and the sterile “cold” nature of the Idefjorden lithosphere.

#### Indigenous Telemarkia

Most available geologic models picture the Sveconorwegian terranes as indigenous to Fennoscandia, either as peripheral or as part of the margin of this craton during the Mesoproterozoic (Fig. 9; Berthelsen 1980; Åhäll et al. 1998; de Haas et al. 1999; Åhäll & Larson 2000; Bingen et al. 2001a; Andersen et al. 2002b). For example, Berthelsen (1980) proposed closure of a marginal oceanic basin between the Telemarkia Terrane and the rest of the belt. Indigenous models are supported, but not demonstrated, by various arguments based on geochronology and iso-

tope geochemistry. (1) Three magmatic suites, characteristic of the Telemarkia Terrane, have time equivalents in cratonic Fennoscandia, supporting a linkage. The voluminous 1520-1480 Ma magmatism, including bimodal volcanic rocks of the Rjukan Group (Bingen et al. 2005; Laajoki & Corfu 2007), is coeval with the volumetrically minor 1530-1500 Ma Ragunda rapakivi granite suite in western Fennoscandia (Persson 1999; Åhäll et al. 2000; Andersson et al. 2002b). The 1280-1260 Ma continental bimodal magmatic suite associated with clastic sediments in the Suldaal Sector (Bingen et al. 2002; Brewer et al. 2004) is coeval with the 1271-1247 Ma Central Scandinavian Dolerite Group which occurs over large parts of Fennoscandia (Söderlund et al. 2006). The 1220-1190 Ma granite plutonism in the Telemark Sector (Heaman & Smalley 1994; Andersen et al. 2007b) is coeval with the 1220-1200 Ma, mainly granitic plutonism along the Protogine Zone (Larsson & Söderlund 2005; Söderlund & Ask 2006). (2) Isotopic compositions (Pb, Sr, Nd, Hf) of magmatic and sedimentary rocks exposed in the Idefjorden and Telemarkia Terranes can be derived by various combinations of crustal reservoirs exposed in the western part of Fennoscandia and of mantle reservoirs (Andersen et al. 2001; Andersen et al. 2002b; Andersen & Laajoki 2003). (3) Quartzite dominated clastic sediment sequences in the Telemarkia Terrane are characterized by broad, multimodal detrital zircon age distributions ranging from Archaean to Mesoproterozoic (de Haas et al.



1999; Bingen et al. 2001a; 2002; 2003; Andersen & Laajoki 2003). All detrital zircon populations can be accounted for by felsic source rocks exposed on Fennoscandia.

Independently of any model, the presence of Palaeoproterozoic and Archaean zircon populations in all clastic sediment sequences deposited between c. 1500 and 1060 Ma in the Telemarkia, Bamble and Kongsberg Terranes implies that these terranes were situated at the margin of an evolved craton during the Mesoproterozoic (Fig. 10).

## A four phase model

### *Arendal phase, 1140-1080 Ma*

The oldest Sveconorwegian high-grade metamorphism at c. 1140 Ma has been detected in the Bamble Terrane in the Arendal area. The orogenic phase associated with this metamorphism is thus referred to as the Arendal phase (Fig. 8a). This phase is best interpreted as an early-Sveconorwegian 1140-1080 Ma collision between the Telemarkia and Idefjorden Terranes (Figs. 8a, 9). This collision resulted in the formation of the Bamble and Kongsberg tectonic wedges (Andersson et al. 1996; Ebbing et al. 2005), containing lithologies characteristic of both the Telemarkia and Idefjorden Terranes (Fig. 6).

The succession of pre- to early-Sveconorwegian events in the Sveconorwegian belt can be integrated in a tentative geotectonic scenario (Figs. 8a, 9), compatible with both an exotic or indigenous origin for the Telemarkia Terrane. At 1220 Ma, northwest-directed subduction (under the Telemarkia Terrane) of an oceanic basin (marginal to Fennoscandia, or not) produced the 1200-1180 Ma Tromøy volcanic arc offboard Telemarkia (now in the Bamble Terrane) and possibly a granite batholith in the southern part of the Telemarkia Terrane (1200 Ma Drivheia gneiss and other gneisses). At 1190 Ma, an extensional regime, possibly due to subduction of a mid-oceanic ridge or initiation of transcurrent movements, resulted in 1190-1130 Ma continental bimodal magmatism and associated sediment basins in the Telemarkia

Terrane. At 1140 Ma, collision between the Telemarkia and Idefjorden Terranes produced an orogenic wedge consisting of the Bamble and Kongsberg Terranes. This process resulted in crustal thickening with metamorphism peaking in intermediate-pressure granulite-facies conditions, southwest-directed shortening, and the formation of granulites (1140-1125 Ma Arendal granulites). At 1110 Ma, continued convergence resulted in the propagation of high-grade metamorphism over the whole of the Bamble and Kongsberg Terranes and locally into the Idefjorden Terrane (1110-1080 Ma metamorphism), and finally in thrusting of the Bamble Terrane onto the Telemarkia ramp (Kristiansand-Porsgrunn Shear Zone). Thrusting was followed by regional cooling at 1080 Ma. The unconformable cover of immature clastic sediments deposited after 1120 Ma in the Telemark Sector (Heddal Group, Eidsborg Formation, Kalhovd Formation; Fig. 8a; de Haas et al. 1999; Bingen et al. 2003) possibly represents a foreland or intramontane basin related to mountain building and tectonic denudation of the Bamble and Kongsberg wedges. The 1080-1050 Ma time span following unroofing of the Bamble and Kongsberg Terranes was a period of apparent tectonic quiescence in the Sveconorwegian belt.

### *Agder phase, 1050-980 Ma*

The main Sveconorwegian orogenic event, here called the Agder phase, took place between 1050 and 980 Ma (Figs. 8 b, c). It probably resulted from an oblique (?) continent-continent collision between Fennoscandia and another large continent, possibly Amazonia (Fig. 9). This phase corresponds to tectonic imbrication and crustal thickening in the central part of the orogen, including deformation, metamorphism and magmatism in the Idefjorden and Telemarkia Terranes.

At 1050 Ma (Fig. 8b), the Idefjorden Terrane was underthrust and buried to a depth of at least 35 km and possibly more than 50 km, resulting in high-pressure amphibolite- to granulite-facies metamorphism (1.0-1.5 GPa; Bingen et al. 2008b; Söderlund et al. 2008). Emplacement of the Glaskogen nappe complex and oblique (sinis-

tral) eastwards thrusting along some of the major shear zones in this terrane are possibly coeval with this event (though these events are not directly dated). High-pressure metamorphism in the Idefjorden Terrane is coeval to the intrusion of 1050–1030 Ma high-K calc-alkaline granodiorite plutons in the Telemarkia Terrane (Feda and Fennefoss augen gneiss suites; Table 3; Bingen et al. 1993; Bingen & van Breemen 1998a). Geotectonic interpretation of these “orogenic” granodiorite suites remains ambiguous. They can reflect either the final stage of an active continental margin setting in the belt, or melting of a protolith with active margin signature as a result of crustal thickening.

At 1035 Ma, the Telemarkia Terrane entered a period of crustal thickening. Available data demonstrate that the different sectors of the Telemarkia Terrane, though of variable metamorphic grade, share a common metamorphic event starting at around 1035 Ma (Fig. 8c, Table 4). The oldest metamorphic dates at 1035–1030 Ma are recorded in the low-grade lithologies of the Telemark and Suldal Sectors. These were cooled shortly after 1030 Ma (Stein & Bingen 2002). Several lines of evidence from zircon, monazite and molybdenite geochronology demonstrate that the high-grade lithologies of the Rogaland-Vest Agder Sector resided in high-grade conditions for more than 100 million years between 1035 and 900 Ma. Metamorphism peaked in granulite-facies conditions first during the Agder phase between 1035 and 980 Ma (M1 medium pressure metamorphism). This metamorphism was associated with widespread syn-collisional granitic plutonism (Table 3).

While the Telemarkia Terrane underwent crustal thickening at 1035 Ma, monazite and titanite data indicate unroofing in the Idefjorden Terrane at 1025 Ma. This suggests that exhumation of high-pressure metamorphic rocks in the Idefjorden Terrane took place in a convergent setting. Mechanisms for such exhumation have been explored, for example, by Hynes and Eaton (1999). The Vardefjell Shear Zone accommodated deformation between these two terranes between 1010 Ma (amphibolite-facies metamorphism) and 985 Ma (fabric-parallel titanite; Bingen et al. 2008b). This timing is coeval with high-grade metamorphism in the Telemarkia hanging wall of the shear zone (1014 Ma), but post-dates exhumation of high-pressure rocks in the foot wall (1025 Ma). The geometry along the Vardefjell Shear Zone is consistent with a component of northeastwards thrusting at or after 1010 Ma. A significant strike-slip component is probable, in accordance with sinistral strike-slip relations recorded in the Østfold-Marstrand Boundary zone, east of the Oslo rift (Fig. 1; Hageskov 1985).

The high-pressure signature of metamorphism in the Idefjorden Terrane (1.0–1.5 GPa) contrasts with the medium-pressure signature of metamorphism in the Telemarkia Terrane (0.6–0.8 GPa; Fig. 8b, c). Together with the westwards increase in volume of syn-collisional

magmatism, this contrast reflects the warmer thermal nature of the crust in the Telemarkia Terrane relative to the Idefjorden Terrane.

#### *Falkenberg phase, 980–970 Ma*

At 980–970 Ma (Fig. 8d), high-grade metamorphism is recorded in the Eastern Segment, implying that crustal thickening propagated eastwards, one step deeper into the foreland of the orogen (Fig. 9). This is referred to as the Falkenberg phase. Eclogite relics in the Eastern Segment, dated at  $972 \pm 14$  Ma, attest to burial of Fennoscandia crust to a depth of at least 50 km. They represent the last undisputable evidence for convergence in the Sveconorwegian belt, and their formation was shortly followed by exhumation to a middle crustal level (Möller et al. 2007). Amphibolite-facies metamorphism, migmatitization and related deformation along the Mylonite Zone and the Göta-Älv Shear Zone at 980–970 Ma (Andersson et al. 2002a; Ahlin et al. 2006) are possibly related to SE-directed oblique thrusting of the Idefjorden Terrane onto the Eastern Segment (Park et al. 1991; Stephens et al. 1996).

In the hinterland of the orogen, in the Rogaland-Vest Agder Sector, the Falkenberg phase is also interpreted as the transition between convergence and divergence. Molybdenite Re-Os geochronology records granulite-facies melting at 970 Ma, interpreted as evidence for regional decompression following regional M1 medium pressure metamorphism (Bingen & Stein 2003).

#### *Dalane phase, 970–900 Ma*

At and after 970 Ma (Figs. 8e, f), the Sveconorwegian belt entered a period of relaxation or gravitational collapse (Fig. 9), as discussed by Bingen et al. (2006) and Möller et al. (2007). The lack of preserved late-orogenic Sveconorwegian foreland basins on Fennoscandia suggests that thinning of the orogen was driven more by extension than erosion. Two high-grade domains, the southern part of the Eastern Segment and the Rogaland-Vest Agder sector in the Telemarkia Terrane, were exhumed to upper crustal levels after 970 Ma (Fig. 4), producing large-scale gneiss dome or core complex-like structures.

The southern part of the Eastern Segment is interpreted as a large asymmetric metamorphic core complex exhumed in the footwall of the Mylonite Zone. Möller et al. (2007) and Berglund et al. (1997) interpret the E-W to WNW-ESE trending fold structures and high-strain zones in the Eastern Segment as evidence for combined N-S directed shortening and E-W extension (constrictional deformation), and suggest that they formed during crustal flow, associated with exhumation of high-pressure rocks to a middle-crustal level in the foot wall of the Mylonite Zone. Initially rapid exhumation of high-pressure lithologies at 970 Ma was followed by comparatively slower exhumation and regional cooling between 960 and 920 Ma. Exhumation of the Eastern Segment

overlaps with the formation between 960 and 900 Ma of N-S trending, steep, normal shear zones at the front of the orogen (Protogine Zone; Andréasson & Rodhe 1994; Wahlgren et al. 1994; Söderlund et al. 2004), and intrusion of the orogen-parallel (N-S trending) Blekinge-Dalarna dolerites, mainly between 950 and 940 Ma, in the foreland of the Sveconorwegian belt (Söderlund et al. 2005).

In the Telemarkia Terrane, the amphibolite- to granulite-facies domain of Rogaland-Vest Agder can be interpreted as a large-scale gneiss dome (Corti et al. 2003), progressively exhumed after 970 Ma (Bingen et al. 2006). The extent of this gneiss dome is not well defined, but it may include high-grade gneisses in the southern part of the Telemark sector (South Telemark Gneisses). Two stages of doming can be inferred. (1) A first stage, between 970 and 940 Ma (Fig. 8e), was associated with production of voluminous post-collisional monzodiorite-granite plutonism, local-scale decompression melting and a regional-scale drop in pressure (Vander Auwera et al. 2003; Tomkins et al. 2005; Bogaerts et al. 2006). The regional N-S trending structural pattern and NE-SW trending lineation in a c. 960 Ma granite (Bolle et al. 2003b) suggest a N-S to NE-SW directed (orogen-parallel) extension. (2) a second stage at 930-910 Ma, was restricted to the area southwest of the clinopyroxene isograd (Dalane area), and was associated with intrusion of the 930-920 Ma Rogaland AMC suite (Schärer et al. 1996), and low-pressure high-temperature M2 metamorphism (Fig. 8f) (Bingen & van Breemen 1998b; Möller et al. 2002; Möller et al. 2003). The second stage of doming was followed by regional cooling between 920 and 900 Ma, as evident from titanite U-Pb data (Fig. 4; Table 5; Bingen & van Breemen 1998b; Heaman & Smalley 1994).

In most of the exposed central and northern part of the orogen, in the Telemarkia and Idefjorden Terrane, there was comparatively little unroofing after 970 Ma. Shallow plutons and discordant veins attest to generally brittle upper crustal conditions and extensional setting between 970 and 910 Ma (Åhäll & Schöberg 1999; Scherstén et al. 2000; Stein et al. 2000; Årebäck & Andersson 2002; Eliasson et al. 2003; Hellström et al. 2004). Extensional reactivation of major Sveconorwegian shear zones occurred between 970 and 880 Ma (Johansson & Johansson 1993; Mulch et al. 2005; Page et al. 1996a; Page et al. 1996b; Scherstén et al. 2004).

The volume of post-collisional magmatism increases dramatically westwards towards the hinterland of the Sveconorwegian belt and peaked at 930-920 Ma with intrusion of the Rogaland AMC Complex (Schärer et al. 1996) and the large Bohus and Flå plutons (Figs. 5, 6). The surge of magmatism and associated high-temperature metamorphism (M2 in Rogaland-Vest Agder) may be related to upwelling of hot lithospheric mantle close to the base of the crust at the end of the Sveconorwegian orogenic cycle (Bingen et al. 2006).

## Conclusions

The Sveconorwegian orogeny is bracketed between 1140 and 900 Ma. Division of the Sveconorwegian orogeny into four genetic orogenic phases is a step towards improved correlation of the Sveconorwegian belt with other Grenvillian belts, and improved paleogeographic reconstructions for the Mesoproterozoic and Neoproterozoic.

The most reasonable location for a suture zone in the Sveconorwegian belt, if any, is between the Telemarkia and Idefjorden Terranes. This interpretation implies that the Telemarkia Terrane was possibly exotic to Fennoscandia, and accreted during the Sveconorwegian orogeny, by closure of an oceanic basin (Figs. 7, 9).

The four Sveconorwegian orogenic phases have distinct tectonometamorphic significance (Figs. 8, 9). (1) At 1140-1080 Ma, the early-Sveconorwegian Arendal phase is interpreted as an early collision of comparatively restricted extent. Collision between the Idefjorden and Telemarkia Terranes generated the Bamble and Kongsgberg orogenic wedges, possibly as a result of accretion of the Telemarkia Terrane. (2) At 1050-980 Ma, the Agder phase corresponds to crustal thickening and imbrication in the central part of the orogen, probably as a result of the main event of oblique continent-continent collision. The high-pressure metamorphism at 1050 Ma towards the foreland of the belt (Idefjorden Terrane) contrasts with the protracted medium-pressure metamorphism between 1035 and 970 Ma towards the hinterland (Telemarkia Terrane). (3) At 980-970 Ma, the Falkenberg phase represents the last step of foreland propagation of orogeny, characterized by eclogite-facies overprint in the parautochthonous Eastern Segment. It was shortly followed by divergence. (4) Between 970 and 900 Ma, the Dalane phase is one of gravitational collapse of the belt, characterized by voluminous post-collisional magmatism, gneiss dome and core complex formation and low pressure, high temperature metamorphism.

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