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1.80-1.75 Ga granite suites in the West Troms Basement Complex, northern Norway: Palaeoproterozoic magma emplacement during advancing accretionary orogeny, from field observations

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Abstract

The Ersfjord Granite is part of a suite of c. 1.80-1.75 Ga syeno-granites in the West Troms Basement Complex, northern Norway, presumed to belong to the Transscandinavian Igneous Belt (TIB-1) in the Fennoscandian Shield. Previous data suggest the granite formed post-collisional and ascended as a batholite pluton from a source of sub-continental mantle and/or mafic-intermediate lower crust. We argue that the Ersfjord Granite was emplaced initially (c. 1.80 Ga) as multiple tabular sills in a back-arc extensional setting, then as successive melt injections (c. 1.78-1.75 Ga) in an evolving Andean/Cordilleran type accretionary orogen at the waning stages of the Svecofennian orogen. Field observations indicate melt ascent initiated as successive sills (EG-I) into well-foliated Meso/Neoproterozoic TTG gneisses. Some sills preserved a magmatic layering, others injected and assimilated the host rock gneisses leaving pendants of mafic gneiss/migmatite residuum in between the granite sills. The first tectonic patches of melts (EG-II) ascended into the middle/upper crust along regional shear zones and injected into ductile imbricate thrust stacks (D1 event) during NE-SW directed crustal shortening and medium grade P-T conditions, using the sills and ancestor migmatite pendants as melt pathways. Then the tabular EG-I and II granite sheets and adjacent gneisses were coaxially folded by upright macro-folds (D2 event) and steep, granitic pegmatite dyke swarms (EG-III) intruded parallel to the fold axial surface and in related D2 thrusts, at low grade metamorphic conditions. The final melt emplacement (D3 event) included granite pegmatite dykes and sills (EG-IV) along subvertical D3 fold limbs and steep strike-slip shear zones. Our provisional back-arc and successive accretionary orogenic emplacement model for the Ersfjord Granite may explain ascent of many other TIB-1 magmas in the Fennoscandian Shield.

Keywords

1.80-1.75 Ga TIB-1 related granites, sill intrusions, syn-tectonic thrust emplacement (D1), axial-planar dykes (D2), transpressive dykes (D3), back-arc extension, advancing accretionary orogen.

Commenté [LA1]: Batholith ?

32 1. Introduction

33 Granites are widespread in the middle and upper continental crust from throughout the geological
34 record, both as intrusive batholites, tabular sheets/sills, and discordant dykes in the host rocks
35 (Vigneresse, 1995). One major site where juvenile continental crust grows and thickens is along
36 convergent plate margins in advancing accretionary orogens associated with arc subduction (e.g.,
37 Condie, 2007; Cawood et al., 2009). Such orogens form when the overriding plate advances towards
38 the downgoing plate causing repeated amalgamation of crustal fragments like magmatic arcs,
39 rift/oceanic basins, volcano-sedimentary wedges, high- and low-pressure metamorphic rocks, and
40 juvenile granitoid magmas, requiring strong mechanical coupling, localized strain in shear zones, and
41 thermal rejuvenation (Cawood et al. 2009). Most petrological studies indicate that the primary source
42 of granitoid melts in such orogens is from melting of mafic upper mantle rocks in magmatic arcs
43 and/or back-arcs, and residual para- and ortho-gneisses and granulite/migmatites of the lower
44 continental crust, and most likely melting occurred in a syn- to post-orogenic setting (Brown and
45 Solar, 1998a; Sawyer et al., 2011). The processes however, by which continental margin crust is
46 enriched in juvenile felsic magmas, i.e., the nature of segregation, extraction, and ascent of melt
47 triggered by accretionary tectonism, are still uncertain (Brown and Rushmer, 2006; Brown, 2013).

48 The present paper addresses emplacement mechanisms of a major c.1.80-1.75 Ga, TIB-1 related
49 syeno-granitoid magmatic suite in the Meso/Neoproterozoic Palaeoproterozoic West TROMS Basement
50 Complex (WTBC), northern Norway (Figs. 1, 2; Bergh et al., 2010; Laurent et al., 2019). The WTBC
51 accreted along the northwestern margin of the Fennoscandian Shield during the latest stages of the
52 Svecofennian orogeny (Bergh et al., 2010, 2015), northeast of the high-pressure subduction-related
53 juvenile magmatic arc in the Lofoten-Vesterålen area (Fig. 1; Griffin et al., 1978; Corfu, 2004, 2007).
54 Previous workers consider the 1.80-1.75 Ga TIB-1 magmatism in WTBC as post-collisional and
55 caused by lithospheric reworking (Laurent et al., 2019). We resolve how the widespread and repeated
56 pulses of granitic magmas rather intruded as sills and partly assimilated the host rocks first in an area
57 of extension with elevated heat flow, probably a back-arc setting, and then, in succession during
58 convergent (D1-D3) ductile deformation in a small-scale advancing Andean or North American

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59 Cordillera type accretionary orogen (cf. Cawood et al., 2009). We argue based on field observations,
60 for syn-tectonic ascent and emplacement mechanisms of the granites, in a tectonic setting
61 characterized by compressional shear zone strain typical of accretionary orogens (cf. Brown and Solar,
62 1998a, b; Vernon and Paterson, 2001; Weinberg and Mark, 2008).

63 2. Geological setting and previous work

64 2.1 The Fennoscandian Shield

65 The northern Fennoscandian Shield (Fig. 1) evolved through multiple Archaean orogenic and
66 magmatic events (2.72-2.62 Ga) followed by Palaeoproterozoic rifting (2.5-2.0 Ga), and lastly by
67 complex convergent, arc-accretion and collisional orogenic events at ca. 2.0-1.5 Ga including the
68 Lapland-Kola, Svecofennian, Nordic, and Gothian orogenies (Hölttä et al., 2008; Lahtinen et al., 2005,
69 2008). These events resulted in crustal growth by amalgamation of an Archaean nuclei in the northeast
70 and widespread Palaeoproterozoic accretionary growth towards the southwest (Kärki et al., 1993;
71 Nironen, 1997; Åhäll and Connelly, 2008).

72 Archaean crust is present in the northeast of the Fennoscandian Shield overlain by a widespread
73 Paleoproterozoic volcano-sedimentary basin cover formed during a period of major crustal extension
74 at 2.5-2.0 Ga (Lahtinen et al., 2008; Bingen et al., 2015; Lahtinen and Köykkä, 2020). At c. 2.10 Ga
75 the Archaean continent broke up and resulted in smaller terranes, e.g., the Karelian and Norrbotten
76 provinces (Fig. 1). In the late Palaeoproterozoic interval most known Precambrian juvenile crust
77 crystallized by arc-related magmatism (Daly et al., 2006; Condie, 2007; Cawood et al., 2009) during
78 the Lapland-Kola (1.94-1.86 Ga), Svecofennian (1.92-1.79 Ga), and Nordic (1.78-1.75 Ga) orogens
79 (Gorbatshev and Bogdanova, 1993; Lahtinen et al., 2008, 2009). In addition, the Transscandinavian
80 Igneous Belt (1.87 Ga TIB-0 and 1.80-1.75 Ga TIB-1) formed during a major arc-magmatic episode
81 that took place across the entire Fennoscandian shield (Larson and Berglund, 1992; Gorbatshev,
82 2004; Högdahl et al., 2004), and was followed by the Gothian orogeny (1.7-1.5 Ga) farther south in
83 Scandinavia (Fig. 1; Gaál and Gorbatshev, 1987; Åhäll and Connelly, 2008). The Transscandinavian
84 Igneous belt is trending NNW-SSE and intruded along the southwestern boundary of the Bothnian
85 Basin of the Svecofennian domain, stretching 2000 km across the entire southern part of Sweden

86 northward to Lofoten-Vesterålen and WTBC areas in northern Norway (Fig. 1; Corfu, 2004; Högdahl
87 et al., 2004).

88 Similar Archaean-Palaeoproterozoic basement provinces exist northwest of and within tectonic
89 windows of the much younger Caledonian orogen in northern Norway (Fig. 1). There, small volumes
90 of 1.87-1.86 Ga (TIB-0) intrusions exist in the Lofoten and Vesterålen areas (Fig. 1), in addition to
91 much more voluminous phases of TIB-1 related (c.1.80 Ga) granitoid magmas that belong to the
92 anorthosite-mangerite-charnockite-granite (AMCG) plutonic suite (Griffin et al., 1978; Corfu, 2004,
93 2007). Similar aged granites with a range of ages between 1.87 Ga, 1.80-1.75, and >1.63 Ga are
94 present on the islands of Senja and Kvaløya in western Troms, including the 1792 ± 5 Ma Ersfjord
95 Granite (Fig. 2; Andresen, 1979). The age of the Ersfjord Granite corresponds to the youngest, TIB-1
96 plutons (Högdahl et al., 2004) which formed coeval with late stages of the Svecofennian orogeny.
97 Other TIB-1 related c. 1.80 Ga monzo- and syenogranites crop out in the Rombak and Tysfjord
98 tectonic windows in the Caledonides south of Lofoten (Fig. 1; Andresen and Tull, 1986; Korneliussen
99 and Sawyer, 1989; Angvik et al., 2014). Additionally, several granitic suites dated at c.1.80 Ga are
100 present east of the Caledonian nappe front along strike with the WTBC (Slagstad et al., 2015). These
101 suites merge with A-type monzonitic, modern Andes type intrusive rocks in the Norrbotten province
102 of Sweden (Fig. 1; Bergmann, 2018), formed in a Cordillera type back arc setting by eastward
103 accretion/subduction associated with TIB-1 plutonic rocks farther west (e.g., Bergman et al., 2001;
104 Martinsson et al., 2018).

105 2.2. The West Troms Basement Complex

106 The WTBC is a Meso-/Neoarchaean to Palaeoproterozoic province (Bergh et al., 2010) located west of
107 the Scandinavian Caledonides (Fig. 2; Roberts, 2003; Augland et al., 2014) and considered an
108 autochthonous part of the Fennoscandian Shield farther east (Fig. 1; Henkel, 1991; Olesen et al., 1997;
109 Bergh et al., 2012, 2014; Nasuti et al., 2015). The WTBC comprises TTG gneisses (2.92-2.6 Ga;
110 Myhre et al., 2013) present in three terranes or litho-tectonic segments; a northeastern segment with
111 juvenile (2.96-2.83 Ga) TTG granitoid rocks in Vanna and Ringvassøya, a southwestern segment of
112 sanukitoid type granitoids (2.71-2.69 Ga) in Senja, and an intervening segment on Kvaløya, with

113 remnants of 2.96 Ga, possible reworked TTGs (Fig. 2; Laurent et al. 2019). These crustal segments are
114 separated by regional scale ductile shear zones like the Senja shear belt on Senja (Zwaan, 1995) and
115 the Kvalsund shear zone on Ringvassøya (Fig. 2; Bergh et al., 2010). The host rock TTGs to the
116 Ersfjord Granite on Kvaløya (Fig. 3) belong to the Gråtind Migmatite, Kattfjord Complex, Kvalsund
117 Gneiss, and Bakkejord Diorite aged between 2.96 and 2.61 Ga (Zwaan, 1992; Corfu et al., 2003;
118 Myhre et al., 2013). Main lithologies are tonalites, tonalitic gneisses, and migmatitic felsic and mafic
119 gneisses (Zwaan, 1992; Armitage and Bergh, 2005; Bergh et al., 2010).

120 The Meso/Neoproterozoic rocks in WTBC are assembled with several meta-supracrustal rift-related
121 volcano-sedimentary sequences aged at 2.40-1.97 Ga (Myhre et al., 2011), mafic dyke swarms (2.4
122 and 2.2 Ga; Kullerød et al., 2006; Bergh et al., 2007; Paulsen et al., 2021), and granitoid and mafic
123 igneous rocks in complex c. 1.80-1.75 Ga fold-thrust belt systems (Paulsen et al., 2021). The first
124 juvenile magmatic pulse occurred at 1.87 Ga in Lofoten-Vesterålen (TIB-0) and was followed by 1.80-
125 1.75 Ga TIB-1 related granites and diorites injected during multiple arc- and accretionary tectono-
126 magmatic phases (D1-D3) in the WTBC (Andresen, 1979; Bergh et al., 2010; Laurent et al., 2019).
127 Thus, magmatism linked to the Lapland-Kola orogen (1.94-1.88 Ga) and/or the early Svecofennian
128 orogenic events (1.92-1.88 Ga) (cf. Daly et al., 2006; Lahtinen et al., 2008) are totally lacking in
129 WTBC. The reason may be that the WTBC was separated and/or escaped deformation along the active
130 Andes type Fennoscandian margin until TIB-related, 1.87 and 1.80-1.75 granites intruded due to
131 westward progression of the orogenic deformation (1.78-1.75 Ga) toward the shield margin (Corfu et
132 al., 2003; Bergh et al., 2015; Paulsen et al., 2021).

133 2.3 The Ersfjord Granite

134 The Ersfjord Granite (Andresen, 1979) belongs to the voluminous 1.80-1.75 Ga TIB-1 suite of monzo-
135 /syeno-granite intrusions in the WTBC (Laurent et al., 2019), on the islands of Kvaløya and Senja
136 (Fig. 2). Previous workers considered these granites to be post-collisional batholithic plutons (Laurent
137 et al., 2019). In their model, the granites were largely undeformed and generated by post-tectonic
138 delamination (e.g., Korja et al., 1993) of a deep-seated crustal root which formed earlier in the
139 Svecofennian orogeny at c. 1.92-1.85 Ga (Laurent et al., 2019). Similar lithospheric reworking models

140 have been proposed for 1.80-1.75 Ga TIB-1 granitoids (Åhäll and Larson, 2000; Høgdahl et al., 2004;
141 Gray and Pysklywec, 2012), but these models are not necessarily valid for the WTBC (this work),
142 which account for a younger tectono-magmatic event with larger input of contaminated/ partially
143 melted Archaean-Palaeoproterozoic crust (Laurent et al., 2019).

144 The present work shows that the Ersfjord Granite is not a single plutonic batholite, but rather intruded
145 as sills and dykes in several tectonic pulses/events from c. 1.80 to 1.56 Ga, and termed EG-I to EG-V
146 (see Table 1). These Ersfjord granite intrusions are all mostly massive, coarse-/medium-grained and
147 porphyric, but locally also well foliated, with K-feldspar, plagioclase, quartz, primary biotite/
148 amphibole, epidote/-allanite, occasional muscovite, titanite, epidote, and Fe-Ti oxides/ magnetite, and
149 accessory apatite and zircon (Laurent et al., 2019). Crystallization of the massive EG-I sills is
150 previously dated at 1792 ± 5 Ma, with metamorphic overprints at 1769 ± 3 Ma and 1756 ± 3 Ma
151 (Andresen, 1979; Corfu et al., 2003), whereas similar massive, sill-like granites in Senja yielded ages
152 between 1798 and 1784 Ma (Laurent et al., 2019), the latter thus marking the termination of the most
153 voluminous of the TIB-1 granites in WTBC. Then, successive granite sills and dykes injected into the
154 WTBC in Kvaløya synchronous with orogenic compression (c. 1.78-1.75 Ga), including W-E
155 thrusting (D1), coaxial macro-folding (D2), orogen-parallel thrusting and lateral (transpressive)
156 shearing (D3), and during post-orogenic reworking at 1.63-1.56 Ga (Bergh et al. 2015) (Table 1). In
157 the foreland on Vanna Island, Paulsen et al. (2021) applied D1-D2 events, which correspond to D2-D3
158 in WTBC elsewhere.

159 3. Methods and data

160 Data used in this study (see Table 1) are from recent field and structural analyses by the authors and a
161 master study (Haaland, 2018). Detailed structural analyses were made in Ersfjord Granite sills (EG-I),
162 conformable granite-internal migmatite zones, and related melts in D1 ductile shear zones/thrusts (EG-
163 II), and as melts in the foliation of adjacent TTG gneisses. Fully exposed contacts of the EG-I granite
164 sills with TTGs were studied at Kjølén in the east and Tverrfjellet in the west (Fig. 3). Then we
165 mapped and analyzed relative to host rock deformation, a D2 granite dyke swarm (EG-III) which
166 intruded along axial-planar shear zones of upright D2 macro-folds at Otervika, c.10 km south of the

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167 main Ersfjord Granite body, and finally, resolved melt emplacement into subvertical D3 folds and
168 strike-slip shear zones. The structural analysis involved determining the geometry of orogenic
169 structures and kinematic characters of D1-D3 ductile shear zones that formed synchronous with EG-II
170 to IV melt emplacement, and their relation to shortening strain and deformation patterns in the
171 surrounding TTGs.

172 4. Results

173 The Ersfjord Granite in Kvaløya defines two large and several smaller, oblate- to lens-shaped, N-S to
174 NW-SE trending geometric bodies arranged as several hundred granite sheets, or sills (Fig. 4a) parallel
175 with the main foliation of surrounding TTG gneisses and metasedimentary rocks (Fig. 3). The contacts
176 with the host rocks are intrusive as in sills, except when they are reworked by D1 and D2 ductile
177 thrusts (see below). Internally, these sills (EG-I) vary in thickness from ≤ 2 to c. 100 m, and typically
178 are separated conformably by narrow mafic migmatite zones and superimposed ductile shear zones.
179 Numerous smaller, and mineral-texturally similar granite sheets/sills, foliation-parallel lenses, and
180 dyke swarms exist in the adjacent TTGs, e.g., in the Senja shear belt, in Kvalsund Gneiss east of
181 Kaldfjord, in Kattfjord Complex gneisses at Otervika in southwestern Kvaløya, and in the Kvalsund
182 shear zone on Ringvassøya (Figs. 2, 3).

183 4.1 Pre-tectonic sills (EG-I) and migmatite zones

184 The EG-I sills have an internally weak, but rhythmic, pervasive planar fabric composed of alternating
185 coarse- and medium-grained granite with variable amount of aligned biotite and amphibole (Fig. 4b-
186 c). This fabric dips gently both NE, NW, and north, but is mostly subparallel to sill contacts and
187 foliation in the surrounding TTG gneisses and superposed D1-ductile shear zones (Fig. 3). The coarse-
188 and medium-grained layers contain igneous textures with rectangular-shaped phenocrysts of perthitic
189 feldspar and twinned plagioclase, with sharp grain contacts (Fig. 4d). Locally, aligned plagioclase
190 phenocrysts yield a mineral lineation (Fig. 4e) which is plunging variably but mostly c. W-E. The
191 layered fabric is often truncated and partly reorganized internally by felsic dykes with irregular
192 contacts but similar texture and grain sizes as in the host EG-I sills (Fig. 4e).

193 Clusters and lenses of slightly aligned amphibolite pods exist as dismembered layers parallel to and
194 inside thick EG-I sills, and the mafic and felsic components in combination, define a pseudo-layering
195 (Fig. 5a-c). Locally, more fine-grained granites are seen as rim clusters around larger mafic pods (Fig.
196 5d). In addition to the mafic intercalations, extensive and prevalent, conformable mafic migmatite
197 fabrics separate the EG-I sills and their distributed magmatic fabric. Such mafic migmatite zones are
198 visible from a distance as regular depressions in between benches/ledges of the massive EG-I sills
199 (Figs. 4a). The migmatite zones vary in thickness from <1m to 20 meters (Fig. 6a, b) and contain
200 internally, fabric-parallel lenses and wedges of weakly layered EG-I sills with sharp to variously
201 diffuse edges, and locally they are surrounded/cut by smaller, layer-oblique EG-I veins (Fig. 6c, d).

202 Distinct K-feldspar rich, red-colored granites that are petrographically and texturally similar to most
203 EG-I sills (cf. Laurent et al., 2019) are also widely present in the surrounding Meso/Neoproterozoic TTG
204 gneisses farther west (Fig. 3) and in the Senja shear belt and Kvalsund shear zone (Fig. 2). In outcrops,
205 such sills display sharp (intrusive) contacts and define rhythmic, massive and/or weakly layered
206 granites in between tonalitic and mafic gneisses, whereas others have irregular and truncating, wedge-
207 like contacts (Fig. 7b-d). Some sills are connected by discordant granite veins/clusters bifurcating into
208 the mafic TTG gneiss foliation (Fig. 7b, c), others have irregular and locally boudinage contacts with
209 the foliation of surrounding TTGs (Fig. 7e).

210 **4.2 Syn-tectonic injections (D1-D3)**

211 **4.2.1. Granites injected in D1 ductile thrusts (EG-II)**

212 Several generations of tectonic-related Ersfjord granitic melts (Table 1b-d) post-date the EG-I sill
213 intrusions (cf. Bergh et al., 2010, 2015). We observed and defined the oldest tectonic melts (EG-II) as
214 those that injected into migmatite zones in between EG-I sills and became themselves internally
215 tightly folded, thrust, and sigmoidal sheared (Figs. 8, 9, 10), thus defining ductile D1 shear zones.

216 The large-scale architecture of D1 shear zones is expressed as irregular, anastomosing EG-I sills and
217 migmatite zones at Hollendaren (Fig. 3), where internal truncations define lenses, duplexes, and
218 imbricate stack-like structures (Fig. 8a). Despite these irregularities, most D1 shear zones in the
219 Ersfjord Granite overall are conformable with EG-I sills, migmatite zones, and foliation in the

220 surrounding TTGs (Fig. 3). Along the eastern contact between EG-I sills and Kvalsund Gneiss TTGs
221 at Kjølén, sigmoidal-shaped granite (EG-II) define slices in a thrust-related duplex with top-to-the
222 west displacement (Fig. 8b). Similar west directed D1 thrusts are mapped inside the main Ersfjord
223 Granite body at Hatten and Store Blåmann (Fig. 3), comprising isoclinal D1 folds (Fig. 8c) with
224 variably oriented fold axes that spread along an average shear zone girdle with strike mostly
225 perpendicular to the main westerly shearing direction (Fig. 11a). Stretching lineations are few,
226 probably due to static metamorphic overgrowth on foliation surfaces, but reveal similar shear direction
227 (Fig. 11a). The southwestern contact of the Ersfjord Granite with TTGs at Tverrfjellet (Fig. 3) is also a
228 major thrust zone with top-to-the west sense of shear (Fig. 11a). This shear zone is up to 100 m thick
229 and contains repeated, well-foliated granite lenses and aligned mafic pods in migmatite zones mostly
230 conformable with the underlying TTG foliation.

231 In outcrops, EG-II sills in D1 shear zones are distinguished from EG-I sills in being overprinted by a
232 ductile metamorphic foliation (Fig. 9a, b) which is distinguished from the magmatic fabric by presence
233 of new-grown, syn-kinematic amphibole, flaky biotite, and locally garnet in a recrystallized quartz-
234 feldspar matrix (Fig. 9c-f), suggesting mineral growth during shearing and amphibolite facies
235 metamorphic conditions (see Table 1b). Strong foliation-internal elongation, boudinage, and lateral
236 pinch-out of the EG-II sills and mafic pods can be seen along this foliation (Figs. 9b). The foliation
237 wrapping around mafic pods are cut by both felsic EG-II vein-networks (Fig. 9a), and veins that are
238 transposed and dismembered and often tightly folded by asymmetric, isoclinal and recumbent folds
239 (Fig. 10a, b). Injected EG-II veins are present both along the axial-surfaces and limbs of such internal
240 tight folds (Fig. 10c, d). All these observations of EG-II sills injected into D1 shear zones are
241 summarized in Fig. 10e (see discussion).

242 Presumed D1 deformed EG-II sills are also widely observed along foliation of the surrounding TTG
243 gneisses. Possible EG-II injections in TTGs include those granite sills that are internally displaced,
244 thickened, transposed, and partly folded into the foliation, and tight to isoclinal folded and repeated
245 granite veins in between thicker granite sills (Fig. 10f).

Commenté [LA5]: It is not clear in fig 10e what are the EGII layers with respect to EGI symbols. May be change the size or density of cross symbols for EGII...

246 **4.3.2. Granites related to upright D2 macro-folds (EG-III)**

247 A regional scale N-S to NW-SE trending D2 antiform exists between Ersfjord and Kattfjord (Armitage
248 and Bergh, 2005) which folded all the TTGs and two metasedimentary belts, and the Ersfjord Granite
249 itself in Kvaløya (Figs. 3, 11b). Other major D2 folds are an antiform at Tverrfjellet (Figs. 3, 12),
250 synformal folding of EG-I and -II sills between Hatten and Middagstind (Fig. 3), folds north and east
251 of Kaldfjord, and a synform in the west at Otervika (Fig. 3). Notably illustrative is the D2 antiformal
252 folding of the Tverrfjellet (D1) shear zone (Fig. 12a, b), shown by a change in dip direction on each
253 fold limbs but consistent WSW-directed internal shear sense, thus demonstrating post-D1 folding. At
254 small-scale, D2 folds are asymmetric, and west-verging and they cut D1 foliation and EG-II sills at a
255 high angle, and new EG-III sills are injected into these shear zones, and as separate dykes (Fig. 12c).

256 In the west at Otervika (Fig. 3) the TTGs and enclosed EG-I sills several tens of meters thick are
257 folded by an open synformal D2 fold and cut by a widespread, axial planar granite pegmatite dyke
258 swarm (EG-III) dipping moderately to the SW (Fig. 13a, b). One such pegmatite dyke which
259 petrographically resembles coarse-grained varieties of EG-I sills, is previously dated at 1774 ± 5 Ma
260 (Corfu et al., 2003). In outcrop the EG-III pegmatite dykes vary from planar to irregular, displaying
261 abundant interconnected veins and straight contacts with the adjacent TTGs (Fig. 13b). The dyke
262 contacts are mostly sharp and crosscut the D1 gneiss foliation and EG-I sills at high angle, but we
263 observe injection of EG-III veins into the foliation of the mafic host gneisses as well as indentation of
264 mafic gneiss layers into the EG-III pegmatites.

265 Similar D2 pegmatite dykes are present in TTGs of the Senja Shear Belt, and as irregular, transposed
266 EG-III injections along several D2 axial-planer ductile thrusts in Kattfjord Complex gneisses north of
267 Kaldfjord (Fig. 13c), adjacent to where the main Ersfjord Granite contact itself is a D2-related thrust
268 (Fig. 3). A major, moderately east-dipping D2 shear zone is mapped at Buren (Figs. 3, 4a), which cuts
269 EG-I and -II sills and differs from D1-thrusts in comprising massive EG-III sills transposed and
270 altered to ortho-/ultramylonitic fabrics, but with same top-to-the west thrust sense (Fig. 13d). The
271 mylonites consist of recrystallized, sigmoidal-shaped feldspar and quartz porphyroclasts, often
272 surrounded by a matrix of S-C shaped flaky muscovite and biotite fishes (Fig. 13e). Additional growth

273 of aligned epidote, chlorite, and albite in mafic lenses of the shear zone at Buren addresses lower
274 metamorphic conditions during the D2 event (i.e., greenschist facies) than for the D1 thrusting.

275 **4.3.3. Granites injected in steeply plunging D3 folds and strike-slip zones (EG-IV)**

276 A third group of structures into which Ersfjord granites injected are steeply NNE- to NW-plunging D3
277 macro- and meso-folds accompanied by subvertical NNE-SSW sinistral and NW-SE dextral strike-slip
278 shear zones. The strike-slip shear zones are centimeter- to meter-thick, typically mylonitic, and
279 oriented parallel to limbs and axial surfaces of steeply plunging D3 folds (Fig. 14a-c). Shear-sense
280 estimates appear from drag-folding and ductile offset of D2 dykes (Fig. 14c, d), and by local
281 subhorizontal stretching lineations. Macro-scale D3 folds reveal the same geometry and are inferred
282 from refolding of D2 macro-folds at Tverrfjellet and east of Kaldfjord (Fig. 11b).

283 The D3 shear zones also comprise syn-kinematic injected granite pegmatite dykes and veins (EG-IV)
284 texturally like D2 dykes, but more quartz- and K-feldspar rich (Table 1). An argument in support of
285 D3 age for these dykes is that older EG-III dykes present in the adjacent TTG gneisses have been
286 folded by similar, steeply NNE-plunging folds, and replaced by sheared granite veins (EG-IV) parallel
287 to their axial surfaces (Fig. 14d).

288 Thin section studies of D3 shear zones show a typical mylonitic foliation consisting of sigmoidal
289 lenses of saussuritized plagioclase clasts (albite), in a fine-grained matrix with syn-kinematic
290 aggregates of recrystallized amphibole (now epidote + chlorite), biotite, and iron oxides (Fig. 14e),
291 accounting for greenschist facies metamorphic conditions during D3.

292 **4.3.4. Post-tectonic granite injections (EG-V)**

293 The youngest felsic intrusions in the WTBC belong to a suite of post-D3 granite pegmatite dykes
294 spanning ages between 1633 and 1562 Ma in the Astridal metasupracrustal belt in Senja (Bergh et al.,
295 2015). Such pegmatites have patchy and jagged contacts with TTGs and are also found in Kvaløya
296 where they crosscut all EG-I to -IV intrusions and are associated with quartz + biotite + muscovite +
297 epidote mineral assemblages, as in Senja (Bergh et al., 2015).

298 5. Discussion

299 5.1 Pre-tectonic sill intrusion and emplacement (EG-I)

300 The Ersfjord Granite body is not a single batholithic pluton as previously assumed (Andresen, 1979;
301 Bergh et al., 2010), but rather a set of regionally extensive tabular granite sills (EG-I). The thickest
302 EG-I sills comprise a pervasive elongated fabric which we interpret as magmatic based on intergrowth
303 of crystalline, rectangular feldspar phenocrysts, rhythmic banding/layering, and aligned texture of
304 flaky biotite and hornblende (Figs. 4, 5). These textures may have developed by sheet/sill-internal
305 flowage and/or in-situ local fractionation allowing magmatic layers to form in between already
306 emplaced and newly injected sills (Table 1a). The granites possibly mixed with felsic components of
307 the TTG crust, leaving trails of the mafic migmatite neosomes as rafts or pendant zones in
308 conformable pseudo-layers (Fig. 5). This theory is verified by granite sills merging into and
309 embedding mafic bodies (Figs. 5, 6), suggesting direct magma injection into the foliated host rocks
310 (cf. Pawley et al., 2013). Such a mechanism would indicate upward transfer of voluminous granite
311 melts as high-permeability magma sills into still viscous host rock TTGs (Fig. 7), and where the
312 granite sills became separated from still solid leuco- and melanosome residuum layers (cf., Brown,
313 2010a, 2013).

314 Melting and emplacement of the huge amount of EG-I sills may have been triggered by high heat
315 flow, for example in an extensional back-arc setting of the presumed evolving WTBC accretionary
316 system. In this setting the vertical transfer of magma was large enough to segregate multiple, repeated
317 and voluminous batches of melts that migrated into the upper crust along rheological weak fabrics (cf.
318 Hyndman et al., 2005; Magee et al., 2018), such as Kvalsund shear zone and Senja shear belt. Then,
319 several sheet-like pulses of magma ascended as extensive sills into the TTGs through the coalescence
320 of either channelized magma segments, fingers, or lobes (Pollard et al., 1975; Schofield et al., 2010;
321 Magee et al., 2016, 2018). Relatively small volumes of magma, however, formed compared to
322 volumes in classic plutons attached to e.g., migmatite gneiss domes (e.g., Whitney et al., 2004).

323 **5.2 Syn-tectonic D1 emplacement of sills during ductile thrusting (EG-II)**

324 The onset of major NE-SW compression in the WTBC may have started after intrusion of EG-I granite
325 sills at c. 1784-1774 Ma (Bergh et al., 2015; Laurent et al., 2019) in a presumed, closing back-arc
326 system (cf. Silver et al., 1985). The tectonic-induced EG-II melts were channelized into D1 ductile
327 thrusts subparallel with TTG gneiss foliation and ductile detachment faults (Table 1b) that controlled
328 progressive supply of sill-like magmas (Magee et al., 2018). Crustal thickening by imbricate D1
329 thrusting then allowed new, smaller batches of EG-II magma to flow and reactivate the channels,
330 while adjacent portions of the intrusion partly crystallized (cf. Holness and Humphreys, 2003; Carrier
331 and Marsh, 2015) and became folded and transposed in the D1 thrusts (Fig. 10). These thrust-parallel
332 veins and clusters of granite formed synchronously as interstitial melts that partly obliterated the relic
333 mafic pendant fabric and re-melted the Neoproterozoic TTG gneiss foliation. Magma injection and local
334 re-melting of the TTGs synchronous with ductile deformation is supported by internal felsic net-veins
335 (Fig. 9a) and may explain why renewed melt migration pathways remained operational over a large
336 time frame (cf. Magee et al., 2016). Furthermore, preliminary age dating shows that the Neoproterozoic
337 TTG foliation in areas near main Ersfjord Granite bodies is late-Svecofennian (1.80-1.77 Ga) in age,
338 and thus became fully overprinted and reworked by the regionally widespread D1-foliation (cf. Bergh
339 et al. 2010, 2015; Myhre et al. 2013).

340 The ductile D1 event in WTBC triggered transfer of repeated EG-II granitic melts at amphibolite
341 facies conditions synchronous with compressional, thrust-type deformation (Bergh et al. 2010). Our
342 field data suggest that successive EG-II melts were formed and first used the relict migmatite pendant
343 zones, then the D1 ductile thrusts and reworked TTG foliation as pathways for upward transfer of
344 melts. A two-stage mechanism is favored, suggesting percolative flow of injected granite sills in the
345 magmatic stage (Fig. 5), followed by viscous flow of melts channelized in the migmatite pendants
346 which acted as ductile thrusts (Fig. 10) (cf. Brown and Solar, 1998b; Marchildon and Brown, 2003). A
347 provisional ascent model is that new EG-II magmas were extracted by tectonic reworking and
348 transferred upwards until they reached the near-solid state, foliation-parallel D1 thrusts at higher level
349 in the crust. The granite melts then migrated into the ductile thrusts along hinges and axial surfaces of

350 recumbent isoclinal folds, causing transposition and layer disaggregation (Fig. 10). Thus, the driving
351 force for ascent of new EG-II granite melts was likely strong and successive D1 ductile thrusting/
352 shearing and syn-tectonic flattening (cf. Vernon and Paterson, 2001; Weinberg and Mark, 2008). This
353 occurred in a favorable NE-SW to E-W directed maximum D1 shortening field (Fig. 11a; Bergh et al.,
354 2010), based on elongated and sheared mafic pods and boudins, sigmoidal lenses, tight isoclinal fold
355 axes, and stretching lineations in D1 thrusts both inside reworked migmatite zones of the Ersfjord
356 Granite and in adjacent TTG-gneisses (Fig. 10). The spread in D1 fold axes orientation (Fig. 11a) is
357 likely due to strain-dependent reorientation within different D1 shear zones, controlled by their
358 location relative to sill boundaries, thin versus thick sills, and/or internal pendant migmatite zones.

359 **5.3. Late-tectonic D2 regional folding and dyke injection (EG-III)**

360 The previous obtained age of 1774 ± 5 Ma for the granite pegmatite dykes at Otervika (Corfu et al.
361 2003) constrains the absolute timing of the D2 macro-folding (Table 1c). During this event, both the
362 EG-I and II sills and surrounding TTG foliation were D2 folded and then EG-III injected as granite
363 pegmatite dykes along the axial surfaces and in corresponding D2 thrusts (Figs. 12c, 13a, b). The D2
364 structures also developed by NE-SW to W-E directed maximum principal shortening (Fig. 11b), thus
365 indicating that the D2 macro-folds, corresponding dyke swarm, and D2 thrusts resulted from coaxial
366 crustal shortening relative to D1 (Bergh et al., 2010). The metamorphic conditions during D2,
367 however, were slightly lower (upper greenschist facies), but still high enough to transport volatile
368 granitic melts. The difference in metamorphic grade, and c. 10 Ma age span between EG-I and EG-III
369 melts at Otervika (Table 1a, c) favor melt injection during two separate magmatic events, rather than
370 one progressive D1-D2 shortening. Further, the volume of dyke magma injected during the D2 folding
371 was much less, which may indicate waning granitic magmatism (melting) after c. 1784 Ma. This is
372 supported by a lower frequency of EG-III dykes in TTGs compared to the number of EG-I and II sills.

373 The EG-III pegmatite dykes at Otervika classify as a composite, discordant body of regularly spaced
374 dyke (swarm) with a high aspect ratio (Brown, 2013). Since the pegmatites injected both as dykes and
375 thrusts parallel to the axial-surfaces of D2 folds (Fig. 12c), this suggest ascent of melts in
376 compressional dykes (e.g., Brown, 2004, 2005, 2013), i.e., perpendicular to the regional shortening

377 direction (Fig. 11b). Similar strain-related ascent conduits are recorded in many convergent settings
378 (Wickham, 1987; Lucas and St. Onge, 1995; Brown and Solar, 1998a; Vernon and Paterson, 2001;
379 Weinberg et al., 2013). For example, where tabular granites that link deeper migmatite zones to
380 shallower plutons are transported in dykes oriented at a high angle to the maximum shortening
381 direction (Reichhardt and Weinberg, 2012; Brown, 2013). The EG-III melts were most likely
382 emplaced along semi-ductile, crack-like deformation bands in D2 thrusts (Fig. 12c) (cf. Brown, 2004,
383 2005, 2010b) caused by external applied D2 shortening strain rather than by simple melt-internal
384 (magmatic) over-pressure (Bons et al., 2001, 2004) or dilation in the crust.

385 The source of EG-III pegmatites is unknown, but an option is local re-melting of EG-I sills and
386 subsequent ascent as melt portions into D2 dykes and thrusts. Arguments in support of re-melting is
387 that isolated EG-III dykes merge out from EG-I sills in the TTGs (Fig. 7b-d). Therefore, and since just
388 a small degree of partial melting is required to generate felsic pegmatites in convergent orogens, local
389 re-melting is more likely than keeping the EG-I sills partial molten for >10 m.y.r.

390 **5. 4. Late/post-tectonic D3 transpression and dyke injections (EG-IV and V)**

391 The last deformation event (D3) in the WTBC records a strain history of transpression, with sub-
392 vertical folding and orogen-parallel (NW-SE directed) strike-slip ductile shearing (Table 1d; Bergh et
393 al., 2010; 2015). New-formed granite pegmatite veins, sills, and dykes (EG-IV) were injected as sills
394 and dykes along steep TTG foliation, axial surfaces and limbs of subvertical D3 folds (Fig. 14a-d), and
395 into steep ductile, left- and right slip D3 shear zones that offset D2-dykes (Fig. 14d). These shear
396 zones suffered high strain, internal mylonitization and lateral displacement synchronous with
397 emplacement of the EG-IV melts, still in the ductile regime, but at a slightly higher crustal level
398 (lower greenschist facies conditions) than for the D1 and D2 events. Continued crustal uplift/
399 exhumation and injection of e.g., Rapakivi-like granites (Rämö and Haapala, 1995; Ernst et al., 2008)
400 may explain the last granites (EG-V) injected in the WTBC, in the time span 1633-1562 Ma, likely
401 due to post-orogenic, crustal reworking and rejuvenation (cf. Bergh et al., 2015).

402 **5. 5. Regional implications and geotectonic model**

403 The southwestern margin of the Fennoscandian Shield grew by accretion of juvenile arc-magmatic
404 granitoids during the late-Svecofennian (c. 1.80 Ga), Nordic (c. 1.78-1.75 Ga) and Gothian (1.64–1.52
405 Ga) orogenies (Gaál and Gorbatshev, 1987; Lahtinen et al., 2008; Bingen et al., 2008). Farther
406 northwest, the Ersfjord Granite in WTBC is coeval in age with the youngest granitoids of the
407 Transscandinavian Igneous Belt (TIB-1), formed at c. 1.80-1.75 Ga during waning stages of a
408 voluminous, late-Svecofennian arc-magmatic collisional event (Åhäll and Larson, 2000; Nironen,
409 1997; Ahl et al., 2001; Andersen et al., 2009; Andersson et al., 2004; Corfu, 2004; Gorbatshev, 2004;
410 Högdahl et al., 2004). These TIB-1 granitoids are monzonitic and display I- to A-type geochemical
411 affinities, attesting for melting of mafic to intermediate arc-like crust (Andersen et al., 2009;
412 Andersson et al., 2004; Rutanen and Andersson, 2009) and/or mantle-derived crystalline melts (Skår,
413 2002). Since the same geochemical signatures were obtained for similar aged syeno-granitoids in the
414 WTBC, a comparable source as for the TIB-1 granitoids was proposed (Laurent et al., 2019). The
415 spatial link of the many other c. 1.80-1.75 Ga TIB-1 related granitoid magmatic suites in northern
416 Norway (Griffin et al. 1978; Andresen and Tull, 1986; Korneliussen and Sawyer, 1989; Corfu 2004),
417 and granitoids in the Norrbotten Province of Sweden farther east of the TIB belt (Fig. 1), suggests they
418 may all be co-magmatic and back arc related (e.g., Bergman et al., 2001; Bergmann, 2018; Martinsson
419 et al., 2018).

420 The Lofoten-Vesterålen AMCG suite intrusions, however, were emplaced mostly as massive plutons
421 in a non-compressive (extensional) environment without large pendants of the host rocks (Griffin et
422 al., 1979; Corfu, 2004, 2007; Coint et al., 2020), and presumably post-tectonic relative to the main
423 Svecofennian Orogeny (cf. Laurent et al., 2019). Early arc delamination following NE-ward
424 subduction at c. 1.80 Ga is proposed to have started in Lofoten slightly before or synchronous with
425 crustal accretion and re-assembly of Neoproterozoic crustal segments farther northeast, i.e., in the WTBC
426 (Fig. 15a; Laurent et al., 2019). In this scenario, the 1.80 Ga Ersfjord Granite sills (EG-I), and granites
427 in Senja intruded into TTGs in a back-arc extensional environment within the central TTG crustal
428 segment on Kvaløya and bounding Neoproterozoic shear zones (Senja shear belt, Kvalsund shear zone).

429 (Fig. 15a), i.e., pre-collisional relative to D1-D3 compressional events (Fig. 15b). A back-arc setting is
430 the only region that can provide enough heat flow for long-term melting and ascent of the large
431 granitoid EG-I sills in a setting adjacent to continental crust affected by compression (e.g., Hyndman
432 et al., 2005; Currie and Hyndman, 2006; Currie et al., 2008).

433 The presence in WTBC of multiple crustal (TTG) segments, rift-related volcano-sedimentary
434 sequences, fold-thrust belts, and intervening ductile shear zones into which juvenile mafic and
435 felsic/granitoids (EG-II to IV) intruded (Bergh et al., 2010, 2015; Paulsen et al., 2021), account for
436 continued shortening (D1-D3), amalgamation and melting in an advancing Andean or Cordilleran type
437 accretionary orogenic setting (Fig. 15b). Such orogens are characterized by strong mechanical
438 coupling and upper plate compression and transpression due to oblique assembly, crustal uplift, and
439 thermal rejuvenation (cf. Cawood and Buchan, 2007; Cawood et al., 2009; Lallemand et al., 2005,
440 2008). Similar advancing accretionary events occurred in the WTBC (Fig. 15b, c), northeast of the
441 Lofoten-Vesterålen magmatic arc, during the late- to post-Svecofennian collisional stages, and/or the
442 Nordic and Gothian orogenies (cf. Lahtinen et al., 2008; Dallmeyer, 1992; Bergh et al., 2015). The
443 bounding Senja shear belt and Kvalsund shear zone may have provided the sites of thermal and
444 rheological weakening (cf. Sandiford et al., 2001), and thus were favorable pathways for the renewed
445 ascending Ersfjord and Senja EG-II to IV granitoid melts (Fig. 15b, c).

446 Our proposed advancing accretionary orogenic setting for emplacement of the Ersfjord Granite melts
447 is supported by known melt ascent in both modern and ancient orogens (e.g., Brown, 1994; Petford et
448 al., 2000). Modern examples include the North and South American Cordillera along the eastern
449 Pacific, characterized by accretion and strike-slip motion of earlier rifted arcs and micro-continents,
450 and formation of fold-thrust belts in retro-arcs (e.g., Johnston, 2001; Bergh, 2002; Lee et al., 2007;
451 Cawood et al., 2009). Ancient examples are the Neoproterozoic to Palaeozoic Central Asian Orogenic
452 Belt (Kröner et al., 2007; Windley et al., 2007), the juvenile Palaeoproterozoic Yavapai and Mazatzal
453 provinces (Bergh and Karlstrom, 1992; Karlstrom et al., 2001), and Palaeoproterozoic orogens on the
454 Australian craton (White et al., 2004; Collins and Sawyer, 1996). In all these accretionary orogens,
455 granitic melts migrated through continental crust by compression, upward via structurally controlled

456 pathways like foliation and ductile, crustal shear zones (e.g., Brown, 2007, 2010a; Brown and Solar,
457 1998a, b, 1999), with ancestor melanosomes (White et al., 2004), and by granite melts associated with
458 folds, boudins, and linear features (Collins and Sawyer, 1996).

459 **5.6. Perspectives for future studies**

460 Since Ersfjord Granite melts injected as sills (and dykes) both during pre-collisional extension and
461 synchronous with convergent D1-D3 tectonic events, a direct spatial and temporal comparison of
462 granitic magmas and ductile fabrics can be made. Our field-based approach provides an excellent basis
463 for further geochronological and petrological-metamorphic studies (work in progress). Specific tasks
464 would be: (1) U-Pb zircon dating of the EG-I through -IV generations of granitic sills and pegmatite
465 dykes, and similar intrusions in the surrounding TTG gneisses, which is critical to genetically link the
466 various melts. (2) Resolving the source of magma from geochemical signatures, e.g., mantle- or lower
467 crust-generated (Laurent et al., 2019), and/or by partial melting of host rock gneisses. (3) Testing
468 fluid-induced *in situ* melting/anataxis from a local source in the adjacent TTGs. (4) Isotopic studies of
469 felsic and mafic melts in the migmatite pendant zones to be compared with leucosome and neosomes
470 of migmatitic TTGs, to test if they are new Palaeoproterozoic melts, or remains of Neoproterozoic
471 migmatites. (5) Resolving the source and genesis of D2 and D3 granitic dykes, by re-melting of the
472 pre-tectonic granite sills or from a fluid-enriched migmatite (TTG gneiss) source. (6) Establish the
473 metamorphic history, P-T conditions and evolution of metamorphic minerals grown during the D1-D3
474 events. Such studies are valid to further test our local field-based granite emplacement model, and in
475 evaluating magma sources and ascent of other TIB-1 granitoid intrusions both in the WTBC and
476 comparable Fennoscandian Shield.

477 **6. Conclusions**

478 1) The Ersfjord Granite in the WTBC is not a single batholite body, but a system of tabular granite
479 sills (EG-I) injected into Neoproterozoic crustal segments (c. 1.80-1.78 Ga) triggered by pre-existing
480 ductile shear zones and TTG fabrics in a back-arc extensional setting. The EG-I sills have an internal,
481 distributed magmatic layering and rhythmic remains of Neoproterozoic mafic migmatite pendant zones.
482 The magmatic fabric of the sills developed during the melt/sill flowage and assimilation with the

483 surrounding, foliated TTGs, leaving irregular mafic migmatite pendants in conformable layers
484 between the sills. These pendant zones acted as favorable conduits/pathways for later segregation and
485 tectonic ascent of granitic melts.

486 2) New but smaller granite melts (EG-II) then formed and ascended syn-tectonically in a west-directed
487 imbricate thrust nappes/stack (D1 event; 1.78-1.77 Ga) due to upper plate compression in an
488 advancing Andean-type accretionary orogen. Thrust-parallel EG-II veins and clusters of granite
489 channelized synchronously as interstitial melts that became sheared and partly obliterated the relic
490 mafic pendant fabrics, at medium grade conditions.

491 3) Later, during a separate low grade tectono-magmatic event (D2; 1.774 Ga) granite pegmatite melts
492 (EG-III) intruded as dyke swarms along the axial-surface of upright D2 macro-folds and in steep D2
493 thrusts, coaxial to D1 but higher in the accreted and thickened crust. Discordant EG-III dykes formed
494 by compression at a high angle to the maximum D2 strain (NE-SW shortening), and not from melt
495 overpressure. Still younger granite pegmatite melts (EG-IV) intruded along steep strike-slip shear
496 zones and axial-surfaces of subvertical folds, in an orogen-parallel NW-SE shortening strain field (D3
497 event; c. 1.75 Ga).

498 4) The 1.80-1.75 Ga Ersfjord Granite suite in WTBC demonstrates granitoid magmatism and melt
499 emplacement during pre-collisional back-arc extension, then continent closure and accretion(D1),
500 coaxial shortening and crustal uplift (D2), transpressive reworking by oblique convergence (D3), and
501 thermal rejuvenation (post-D3), in accord with an evolution history of a small-scale, advancing
502 Andean and/or North American Cordillera type accretionary orogen.

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825 Figure captions

826 Figure 1. Overview geological map of the Fennoscandian Shield showing the Archaean Kola, Karelian
 827 and Norrbotten cratons, timing of major Palaeo- and Mesoproterozoic tectonic events (Lapland-Kola,
 828 Svecofennian and Gothian orogens), plutonic rocks of the Transscandinavian Igneous belt, and
 829 regional ductile shear zones (from Koistinen et al., 2001 and Bergh et al., 2015). Note location of the
 830 West Troms Basement Complex and Lofoten-Vesterålen areas to the northwest of the Paleozoic
 831 Caledonian Orogen. Abbreviations: BSSZ=Bothnian-Senja shear zone, MOL=Malangen-Onega
 832 lineament, R=Rombaken, RLZ=Raahe-Ladoga shear zone, Tys=Tysfjord, TIB=Transscandinavian
 833 Igneous Belt, WTBC=West Troms Basement Complex.

834 Figure 2. Geological and structural overview map with cross-section of the West Troms Basement
 835 Complex, after Bergh et al. (2010) and Paulsen et al., (2021). The Ersfjord Granite bodies are in the
 836 middle part of the complex, on the island of Kvaløya.

837 Figure 3. Geological and structural map of the Ersfjord Granite suite and the surrounding host rock
 838 TTG gneisses and metasupracrustal belts in Kvaløya, with interpreted cross-section. Mapped
 839 structures include foliation in the TTG gneisses, and traces of migmatite pendant zones and D1 ductile
 840 shear zones inside the Ersfjord Granite. Note also the Tverrfjellet shear zone (TSZ), D1 and D2 shear
 841 zones at Buren, and upright macro-folds (D2). Map is modified from Zwaan et al. (1998), Bergh et al.
 842 (2010), and Haaland (2018). Abbreviations: Msb=Mjelde-Skorelvvatn belt, Stb=Steinskardtind belt.

843 Figure 4. a) Panorama view of the main Ersfjord Granite body between Buren and Store Blåmann (see
 844 location in figure 3) showing internal tabular fabric dipping gently NW and defining light-colored
 845 sheets/sills (EG-I). b) Close-up view of EG-I granite sill with thin-laminated layers and uniform
 846 rhythmic banded, dark biotite-hornblende rich granite. Locality, Hatten. c) Magmatic layers of coarse-
 847 grained K-feldspar and biotite-hornblende-rich EG-I granite in irregular lens-shaped arrangement
 848 within the distributed magmatic fabric. Locality, Store Blåmann. d) Sharp contact between coarse- and

849 fine-grained EG-I granite layers. Note weak aligned fabric in fine-grained part, whereas the coarse-
850 grained layer has a uniform texture of phenocryst feldspar and quartz. Locality, Store Blåmann. e)
851 Coarse-grained EG-I granite with a distributed magmatic fabric of aligned, porphyric K-feldspar
852 grains defining a mineral lineation in a matrix of biotite, hornblende, and plagioclase. Note discordant
853 EG-I dyke truncating the aligned magmatic fabric with irregular character and similar texture and
854 grain size as in the aligned mineral fabric. Locality, Store Blåmann.

855 **Figure 5.** Field examples of EG-I granite sills with mafic intercalations. a-b) Road-cut section with
856 sketch interpretation showing coarse-grained EG-I sills. Note irregular lenses and clusters of
857 mafic/amphibolitic pods (dark grey shade) embedded in the granite sills. Locality; south of Grøtffjord.
858 c) Lenses and intercalations of aligned mafic pods within EG-I sill, defining pseudo-layers. Locality,
859 Hatten. d) Massive EG-I granite sill with isolated mafic lenses and pods (dark grey) that are slightly
860 elongated. Note light-colored granite rims around individual mafic pods. Locality; Buren.

861 **Figure 6.** a) Outcrop photograph of repeated mafic migmatite zones conformable with massive EG-I
862 sills in the mountain Hatten. b) Section through a migmatite zone at Hatten, with textural details
863 including (c, d) decimeter to meter-thick wedge-shaped, biotite-rich EG-I sills and inter-layered, partly
864 dismembered mafic migmatite gneisses and pods. Hammer for scale is circled yellow.

865 **Figure 7.** Photos of presumed EG-I granites injected as sills into the surrounding TTG gneisses. a)
866 Foliation-parallel K-feldspar rich granite layer/sill in mafic TTGs. Locality, Senja shear belt south of
867 Astridal belt (see location in figure 2). Note aligned hornblende defining planar fabric in the granite. b)
868 Series of TTG gneisses intruded by conformable, massive coarse-grained granite sills. Note sharp sill
869 contacts and discordant linkage of small granite vein (dyke) between the two granite layers. Locality:
870 Kvalsund shear zone on Ringvassøya. c) Coarse-grained granite cluster which bifurcates into the
871 foliation of mafic TTGs, in Kvalsund shear zone. d) Massive and coarse-grained granite arranged as
872 wedge-shaped sills around well-foliated mafic gneisses. Locality; Kvalsund shear zone. e) Series of
873 TTG gneisses with foliation-parallel granite layers/sills, one which comprises boudinage (center of
874 photo) and cut by a younger granite dyke (D2) (upper right in photo).

875 **Figure 8.** a) Photo of mountainside below Hollendaren (see location in figure 3), showing EG-I granite
876 sills with an irregular attitude and variable dips, defining internal imbricates and duplex-like
877 structures. Sense-of shear is to the west (left) as apparent from duplex geometries (in center of photo).
878 b) Contact zone between the main Ersfjord Granite body and Kvalsund Gneiss at the mountain Kjølén.
879 Sigmoidal lenses of granite (EG-II) and intercalated amphibolite gneisses are mixed in a ductile thrust
880 system with top-to-the-west shear sense. Geographic location: 69°44'43''N, 18°46'11''E. c) Close-up
881 view of injected EG-II granite slice and TTG gneiss along thrust surface in figure 9b. Note isoclinal
882 fold and transposed EG-II lenses in mica-rich ductile shear fabric.

883 **Figure 9.** a) Details from a mafic migmatite zone in between EG-I sills, which is injected by irregular
884 EG-II granite sills (lower part of photo) with internal vein-networks (in center of photo) parallel to a
885 weak ductile foliation (D1). Locality; Buren. b) Mafic migmatite zone with aligned, variously
886 dismembered EG-II sheets/sills of granite injected parallel to a foliation (D1), some surrounding mafic
887 pods. Locality; Store Blåmann. c, d) Thin-section image of foliated biotite-rich EG-II granite sill (as in
888 9b) showing granoblastic microcline, albite, and quartz in a well-defined lepidoblastic biotite D1
889 oliation (D1). e, f) Thin section image of foliated mica-rich granite gneiss with garnet porphyroblast in
890 mica-rich D1 foliation. Locality; Tverrfjellet shear zone. Images are shown in cross-polarized light (c,
891 e) and plane-polarized light (d, f).

892 **Figure 10.** Outcrop photographs of syn-tectonic EG-II sills and veins within migmatite zones reworked
893 as D1 ductile shear zones. a) Coarse-grained EG-II veins injected along D1 foliation and isoclinally
894 folded. Locality: Hatten, 69°40'44''N, 18°32'52''E. b) Multiple coarse-grained EG-II granite sills that
895 are internally folded by isoclinal folds and transposed, dismembered, and embedded axial-planar into

896 the main D1 foliation (D1). Locality; Hatten. c) Asymmetric fold in D1 shear zone that folds light-
897 colored EG-I layers and is cut by EG-II granite along the axial-surface (black arrow). Locality; west of
898 Buren, 69°42'59''N, 18°36'01E. d) Outcrop from same shear zone as 10c, showing asymmetric folded,
899 sheared, and imbricated mafic gneiss lenses cut by EG-II sills along axial surfaces of the folds and
900 along imbricate D1 shear foliation surfaces. e) Sketch summary of observations in figure 10c, d from
901 Hatten. f) Presumed EG-I or II granite sills defining layers parallel to foliation in mafic TTGs, and
902 which are themselves internally folded and truncated by new granite veins along fold axial surfaces.
903 Locality; Senja shear belt.

904 Figure 11. Lower-hemisphere stereo-nets showing structural orientation data for the main D1 and D2
905 event features in key areas within and outside the main Ersfjord Granite bodies. a) D1 ductile shear
906 zone foliation outlined as single great circles, average orientation, and poles. Separate D1 stereo-plots
907 below are from key localities at Tverrfjellet, Hatten, and Buren. Great circles display an average D1
908 shear zone orientation for each locality, with enclosed D1 fold axis orientations, and stretching
909 lineations. Note the large spread in trend of measured fold axes along average D1 shear zones,
910 whereas stretching lineations vary less, between WNW and WSW. b) Orientation data for D2 macro-
911 folded D1 foliation (great circles and poles) in Tverrfjellet shear zone, TTGs at Tverrfjellet and
912 between Mjelde-Skorelvvatn and Steinskardtind supracrustal belts, and from D1 and D2 shear zones at
913 Buren. Local D2 fold axis orientations are obtained from constructed β -axes. Note that variations in
914 D2 fold axial surfaces infer refolding by large-scale D3 folds.

915 Figure 12. Panorama view (a) and interpretation (b) of the D2 folded Tverrfjellet shear zone and
916 overlying EG-II Ersfjord Granite sills at the contact with Gråtind Migmatite TTGs southwest of
917 Middagstind (see figure 3 for location). Note intrafolial D1 folds and sigmoidal mafic pods and EG-II
918 lenses in Tverrfjellet shear zone with consistent top-SW shear sense, and the slightly discordant
919 contact to TTGs below. Above the Tverrfjellet shear zone, multiple and conformable D1 shear zones
920 alternate with massive EG-I sills. c) Sketch summarizing features related to D2 macro-folds in TTGs
921 at Otervika. Note axial-planar D2 thrust with injected EG-III veins and associated thrust-related folds
922 (at Buren), and injected EG-III dykes (see details in figure 13).

923 Figure 13. a) Macro-scale D2 synform that folds EG-I sills and the surrounding Kattfjord Complex
924 TTGs at Otervika (see location in figure 3) and showing granitic pegmatite dykes (EG-III) intruded
925 along the axial surface of the fold. Note regular dip of the dykes to the SW (right). b) Outcrop
926 photograph of EG-III granite pegmatite dykes that crosscut foliated TTGs along road-cut in 13a. Note
927 regular orientation of some dykes, complex splay geometries of subsidiary dykes, and locally irregular
928 and bifurcating contacts indicating shearing along dyke contacts. The foliation of TTGs dips left (NE)
929 and comprise internal EG-II veins. c) EG-III granite dykes injected at high angle with D1 foliation in
930 Kattfjord Complex gneisses and along the axial surface of asymmetric D2 meso-folds. Note irregular
931 and transposed EG-III veins caused by injection during thrusting. Locality: 1 km north of Kaldfjord
932 (see location in figure 3). d) Details from a mylonitic D2 shear zone with EG-III granite at Buren,
933 displaying internal feldspar clasts with sigmoidal-shape and top-to-the left (west) sense-of-shear.
934 Location: 69°43'13N, 18°37'2E. e) Thin-section image of the mylonitic texture in EG-III granite at
935 Buren (figure 13d). Sigmoidal and recrystallized quartz lenses are enclosed within a matrix of white
936 mica and biotite, and mica-fishes oblique to the shear zone define S-C structure. Image is oriented W-
937 E and in cross-polarized light.

938 Figure 14. a) Steep D3 ductile shear zone with internal, red-colored EG-IV granite pegmatite,
939 arranged as a sheet truncating subhorizontal (presumed EG-I) sills. Locality; Senja shear belt.
940 69°27'35''N, 18°11'21''E b) Close-up horizontal view of the shear zone in 14a, showing EG-IV
941 granite with ductile foliation, lens-shaped K-feldspar clasts, and a mica-rich matrix. c) Steep D3 shear
942 zone inside Ersfjord Granite sills at Hatten. 69°40'48''N, 18°33'12''E. Note EG-I sills drag-folded
943 sinistrally into the shear zone boundaries. View is to the north. d) Horizontal view of a discordant EG-
944 III pegmatite granite dyke in foliated TTGs. The dyke is D3 folded and transposed into a steep D3

945 shear zone. Locality; Kvalsund shear zone. e) Thin-section image of EG-IV granite in D3 mylonitic
946 shear zone in Ersfjord Granite at Hatten. Note epidote and albite grains defining asymmetric lenses
947 oriented in an S-C texture, enclosed by a biotite-rich matrix, in cross-polarized light.

948 Fig. 15. Schematic geotectonic evolution and emplacement model for the 1.80-1.75 Ga Ersfjord
949 Granite suite and the Senja granitoids in the WTBC, and their relation to the Lofoten-Vesterålen TIB-1
950 Magmatic Suite in a SW-NE diagrammatic transect (modified after Bergh et al., 2010, 2015). a) Pre-
951 collisional stage (1.80-1.784 Ga) with subduction southwest of Lofoten, then delamination of the
952 mafic lower crust and intrusion of voluminous TIB-1 magmas in Lofoten AMCG-suite (Laurent et al.,
953 2029). Farther northeast 2.4-2.0 Ga rift-basins started to close in between Neoproterozoic crustal
954 fragments in WTBC. Extension in back-arcs on Senja and Kvaløya generated large volumes of
955 Ersfjord Granite melts, intruded as EG-1 sills, using Senja shear belt and Kvalsund shear zone as melt
956 pathways. b) Syn-orogenic SW-NE crustal shortening (1.78-1.774 Ga), imbricate nappe thrusting/
957 stacking, and recumbent folding of arc-related crustal blocks (D1-event) in an evolving accretionary
958 setting. Renewed EG-II Ersfjord Granite melts intruded using EG-1 sills and migmatite pendants as
959 melt pathways. c) Late-tectonic (1.774-1.745 Ga) accretion and coaxial, regional macro-folding (D2-
960 event) followed by orogen-parallel shortening and transpression (D3 event) (Bergh et al., 2010), when
961 the crust uplifted, and terranes fully amalgamated. EG-III and EG-IV granite pegmatite dykes and sills
962 intruded as axial-planar dykes and thrusts in D2 folds, and along subvertical D3 fold limbs and steep
963 D3 strike-slip shear zones, in the vicinity of Senja shear belt and Kvalsund shear zone. Abbreviations:
964 Ab=Astridal belt, KSZ=Kvalsund shear zone, MSB=Mjelde-Skorelvvatn supracrustal belt, RGb=
965 Ringvassøya greenstone belt, SvB= Svanfjellet supracrustal belt, Ssb=Senja shear belt, Tb=Torsnes
966 supracrustal belt, Vg=Vanna Group.

967 Table 1. Summary characteristics of injected Ersfjord Granite magmas in WTBC, termed EG-I to V,
968 and including previous age dating results (from Corfu et al., 2003; Armitage and Bergh, 2005; Bergh
969 et al., 2010, 2015; Myhre et al., 2013; Laurent et al., 2019), structural characteristics, metamorphism,
970 tectonic setting, and tectonic-induced melt emplacement (this work).

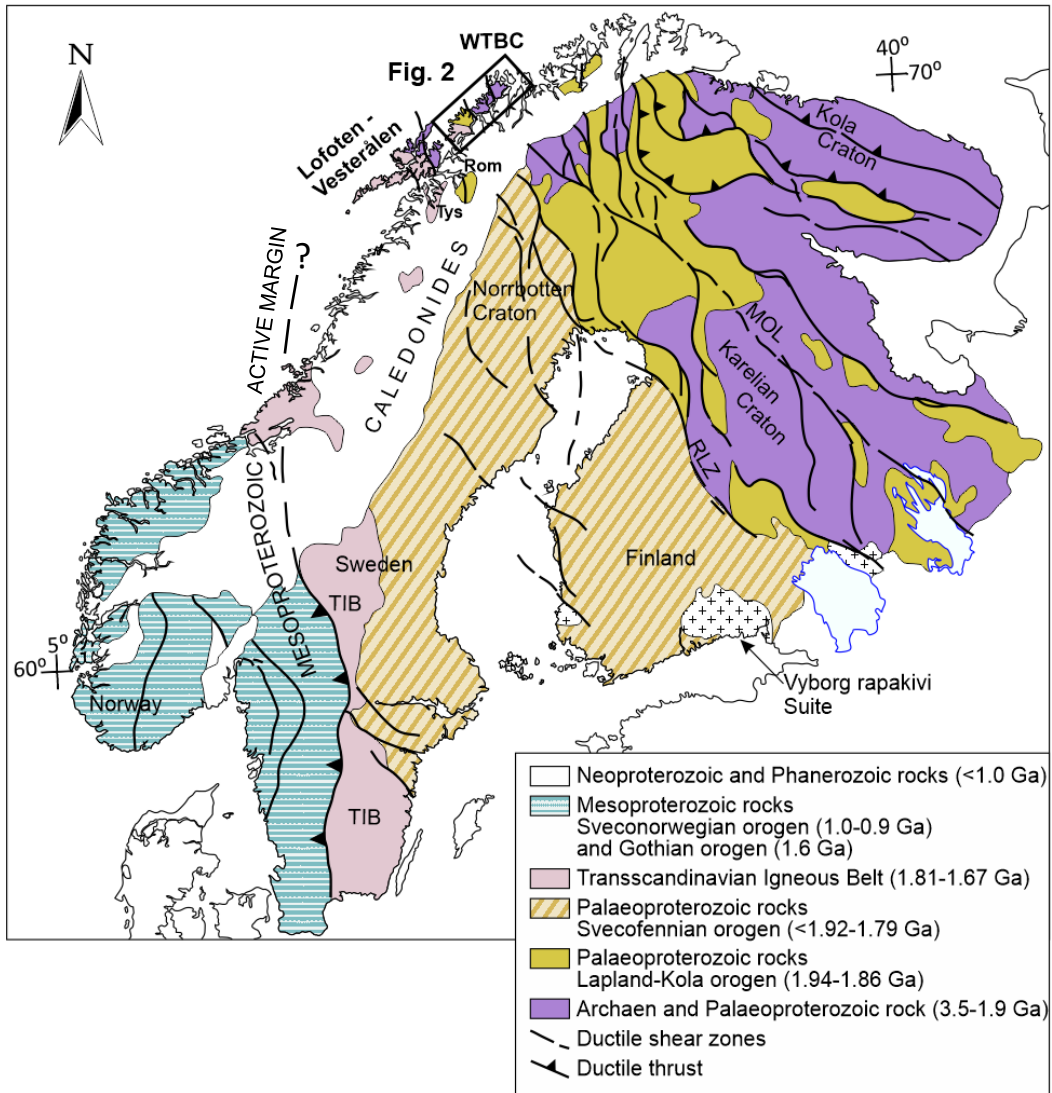


Figure 1.

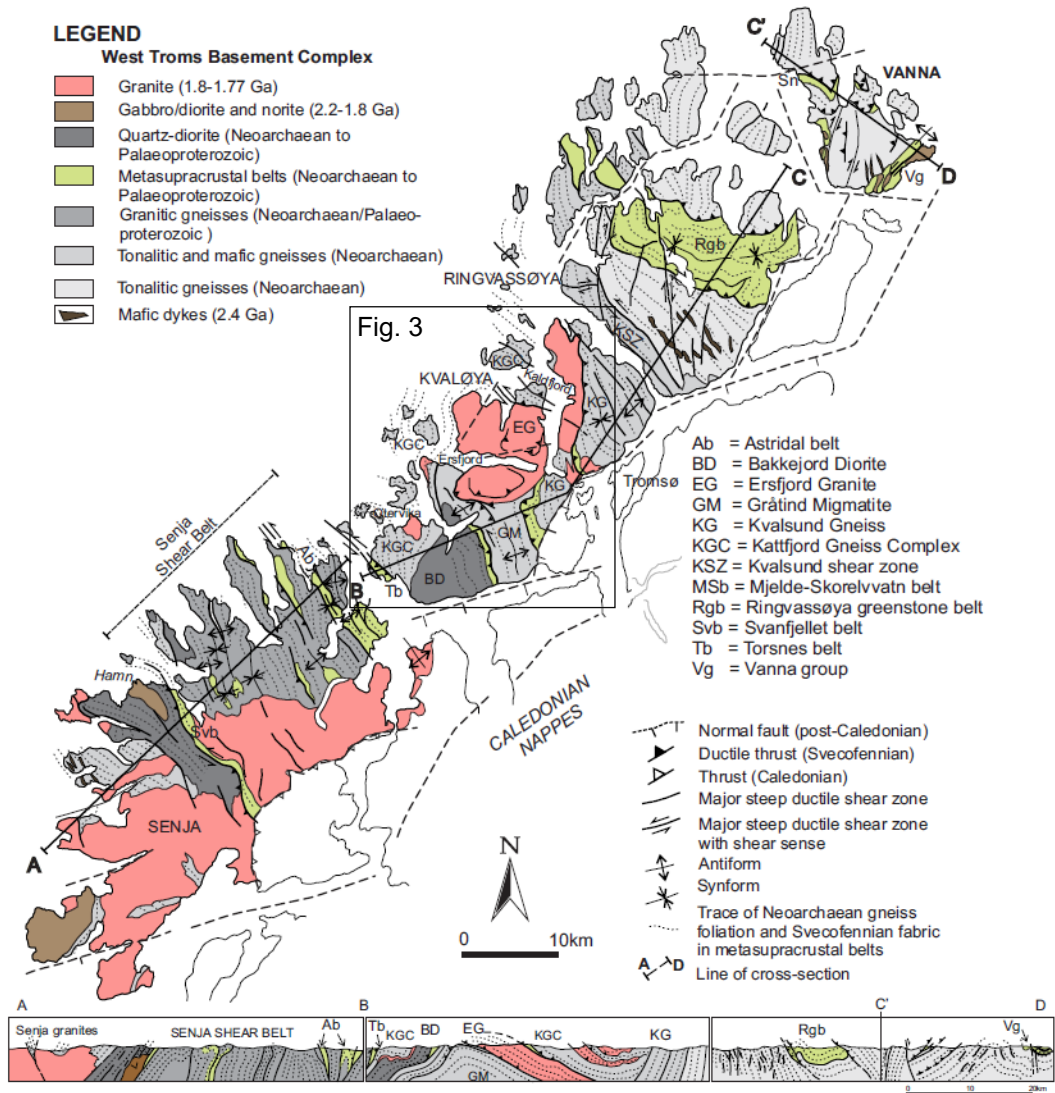


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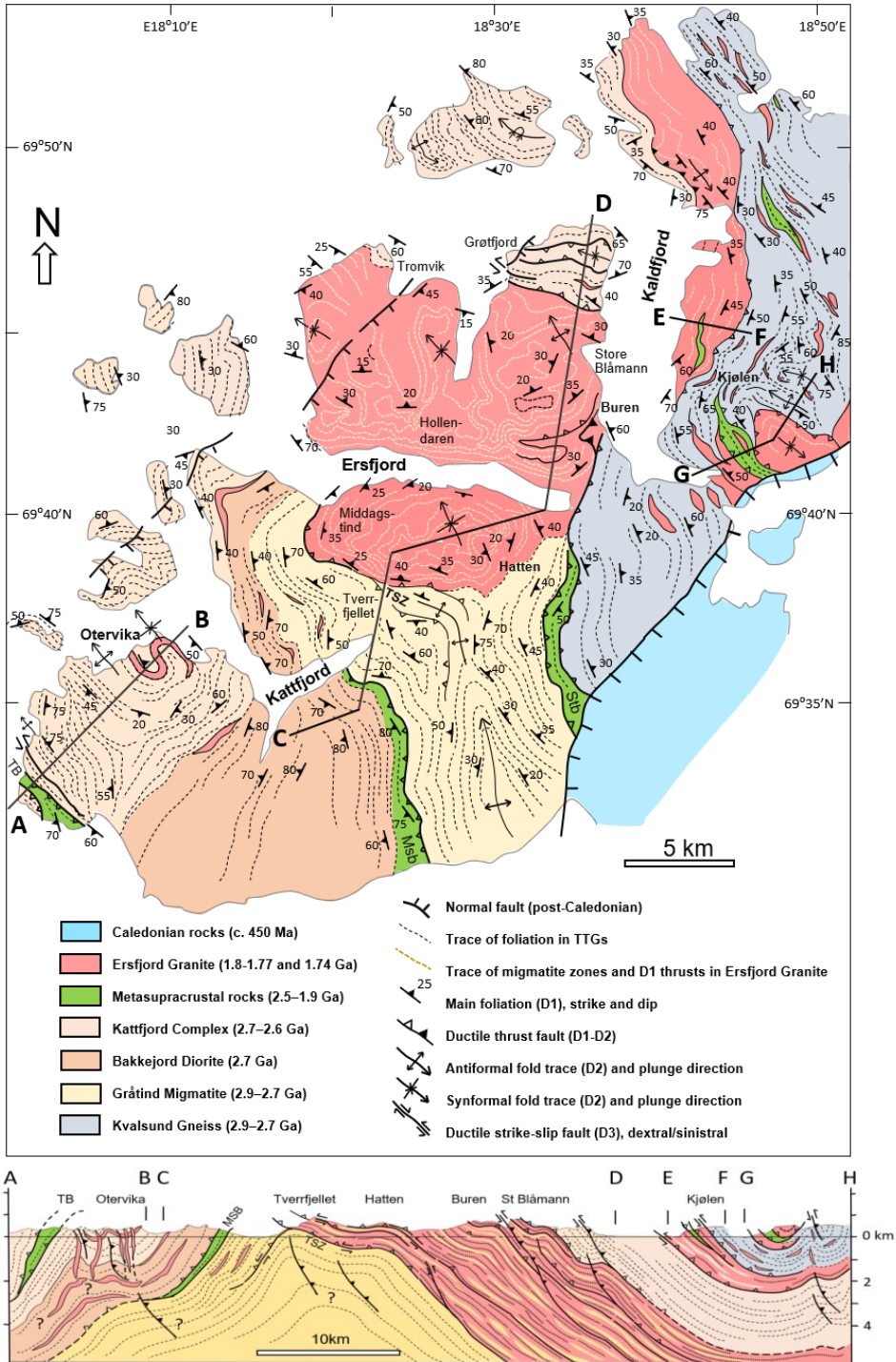


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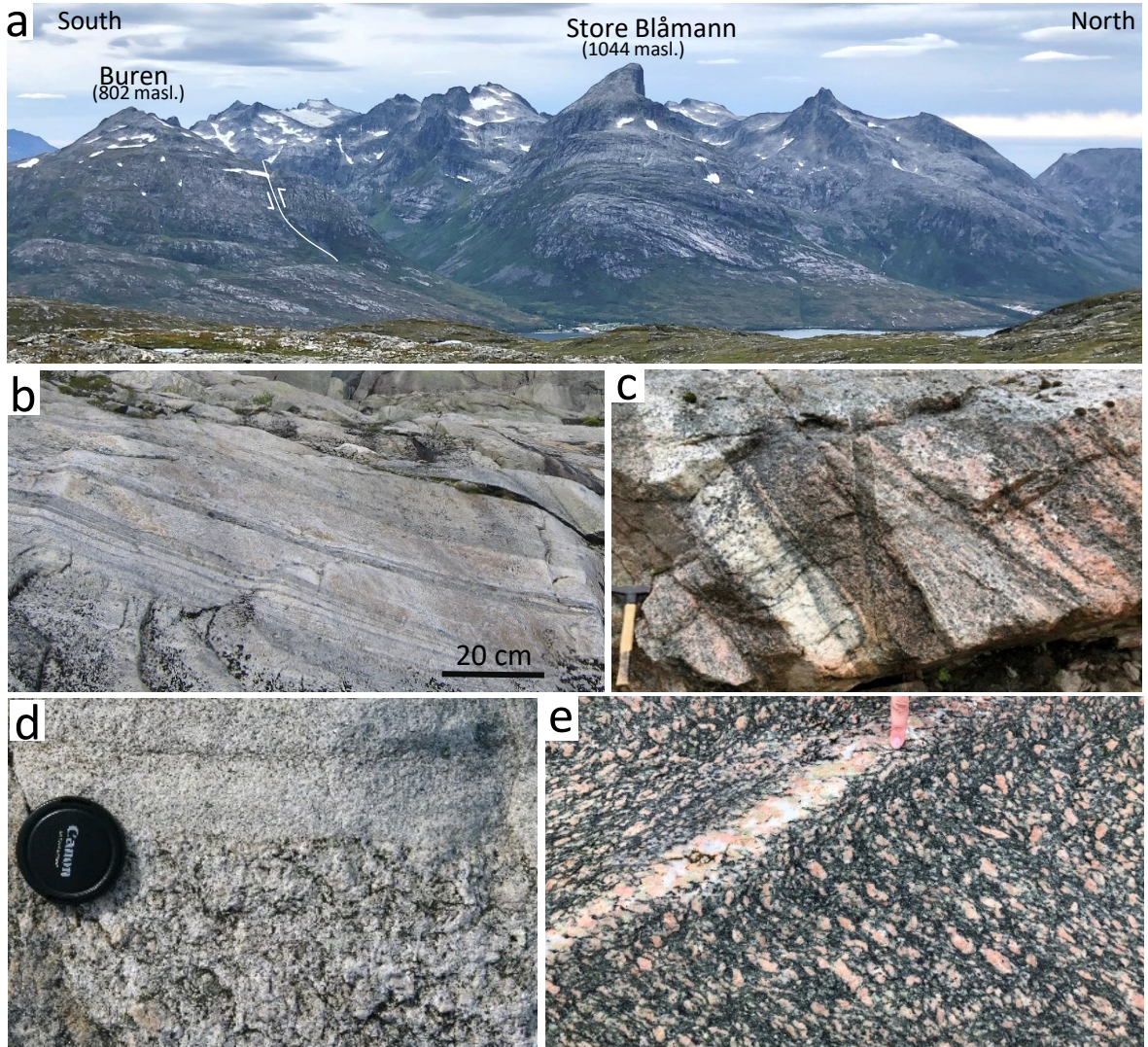


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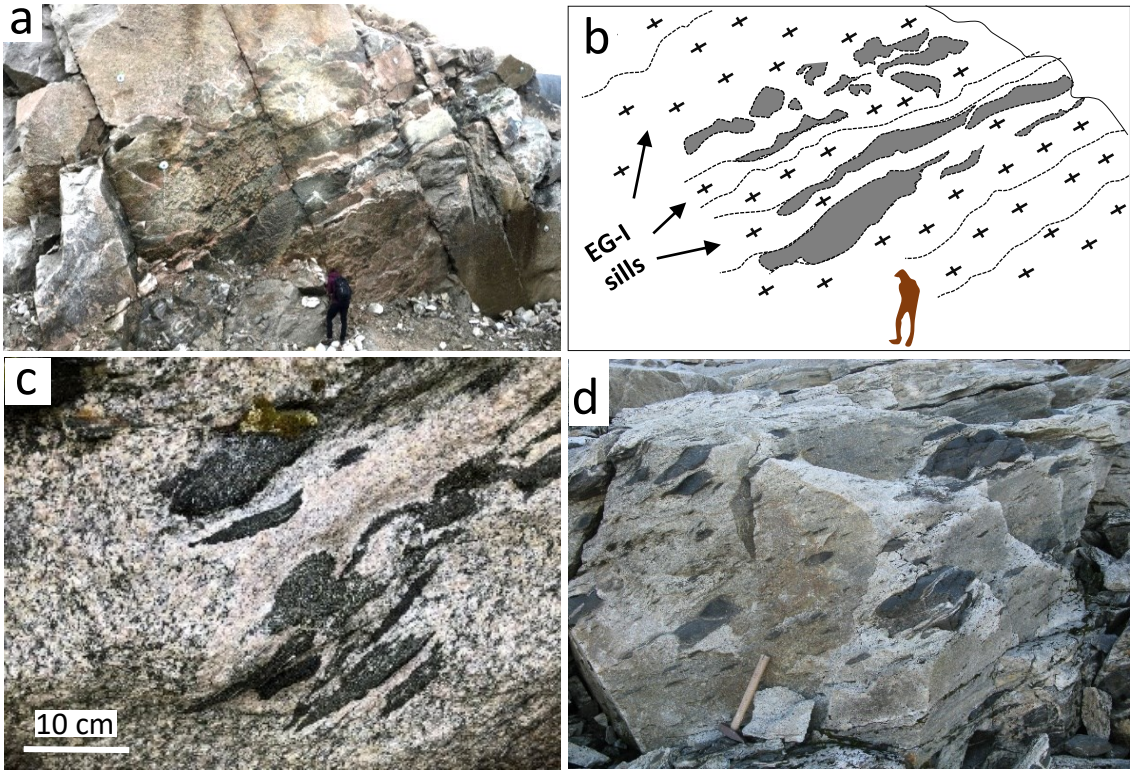


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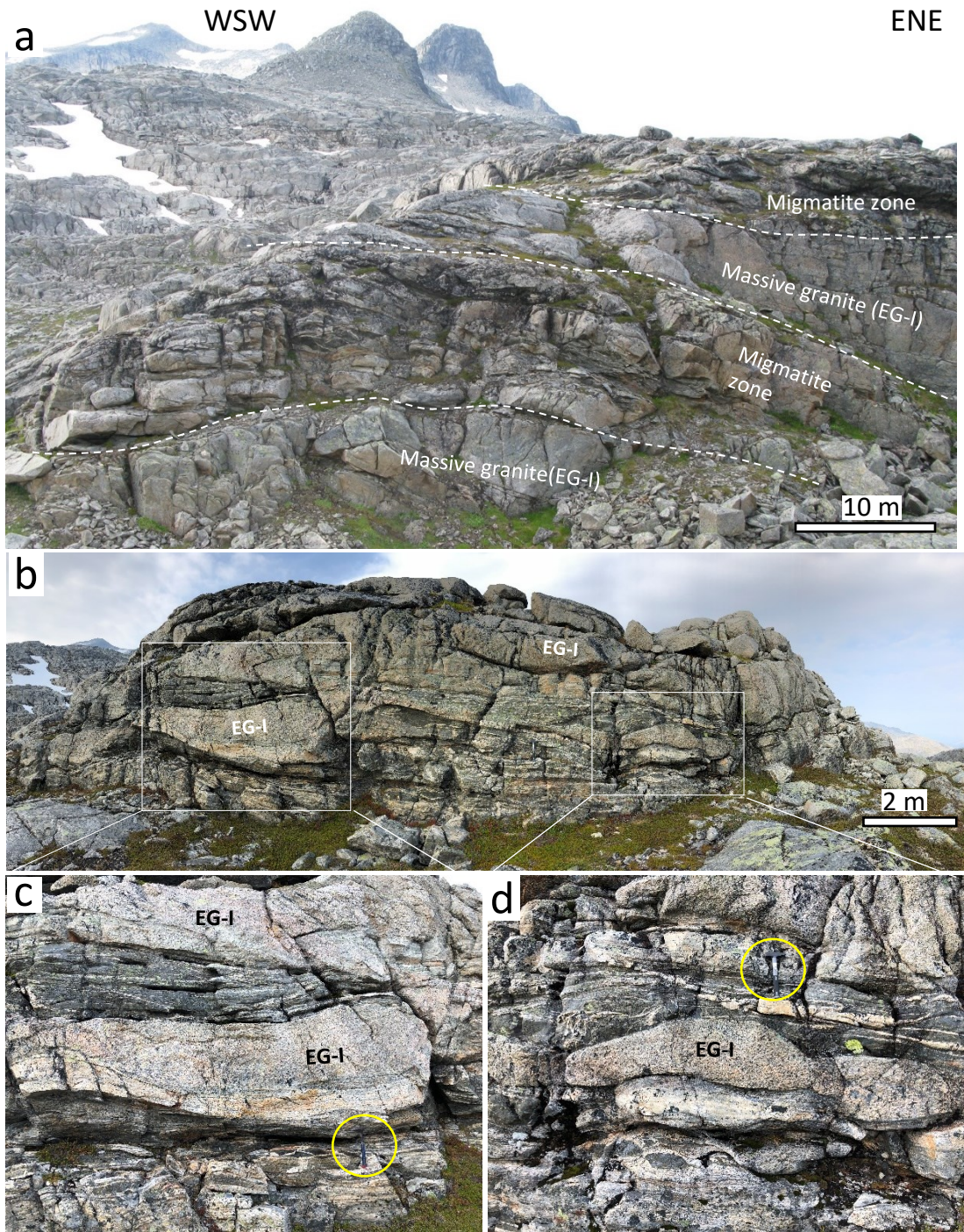


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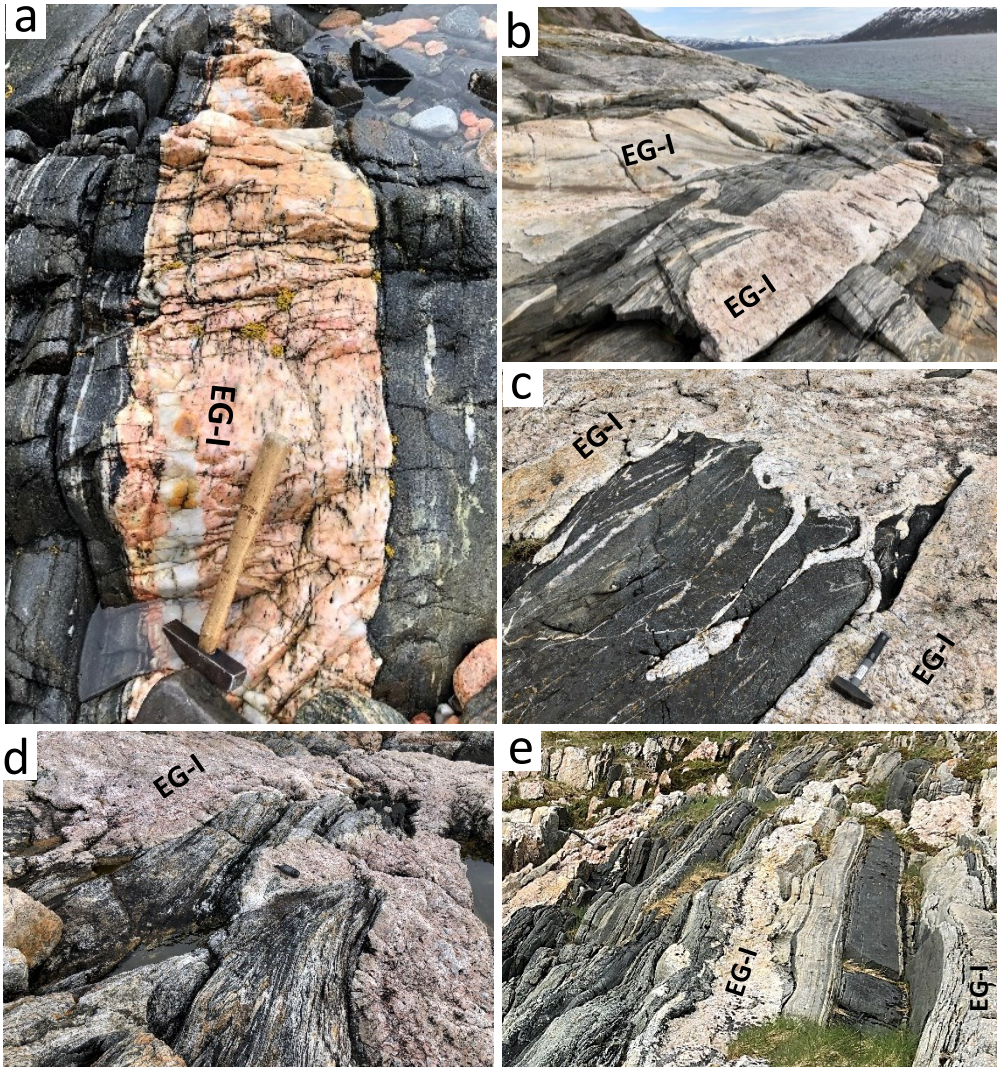


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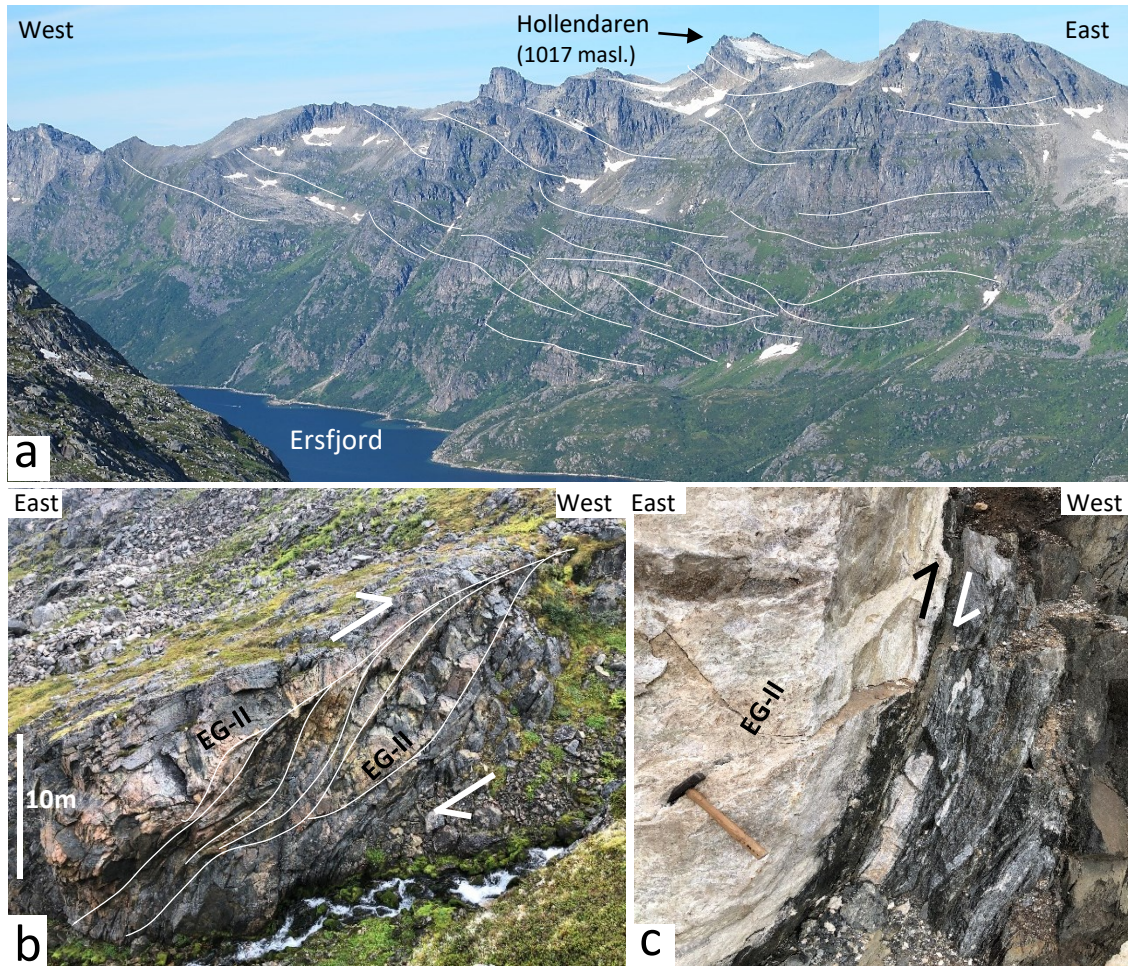


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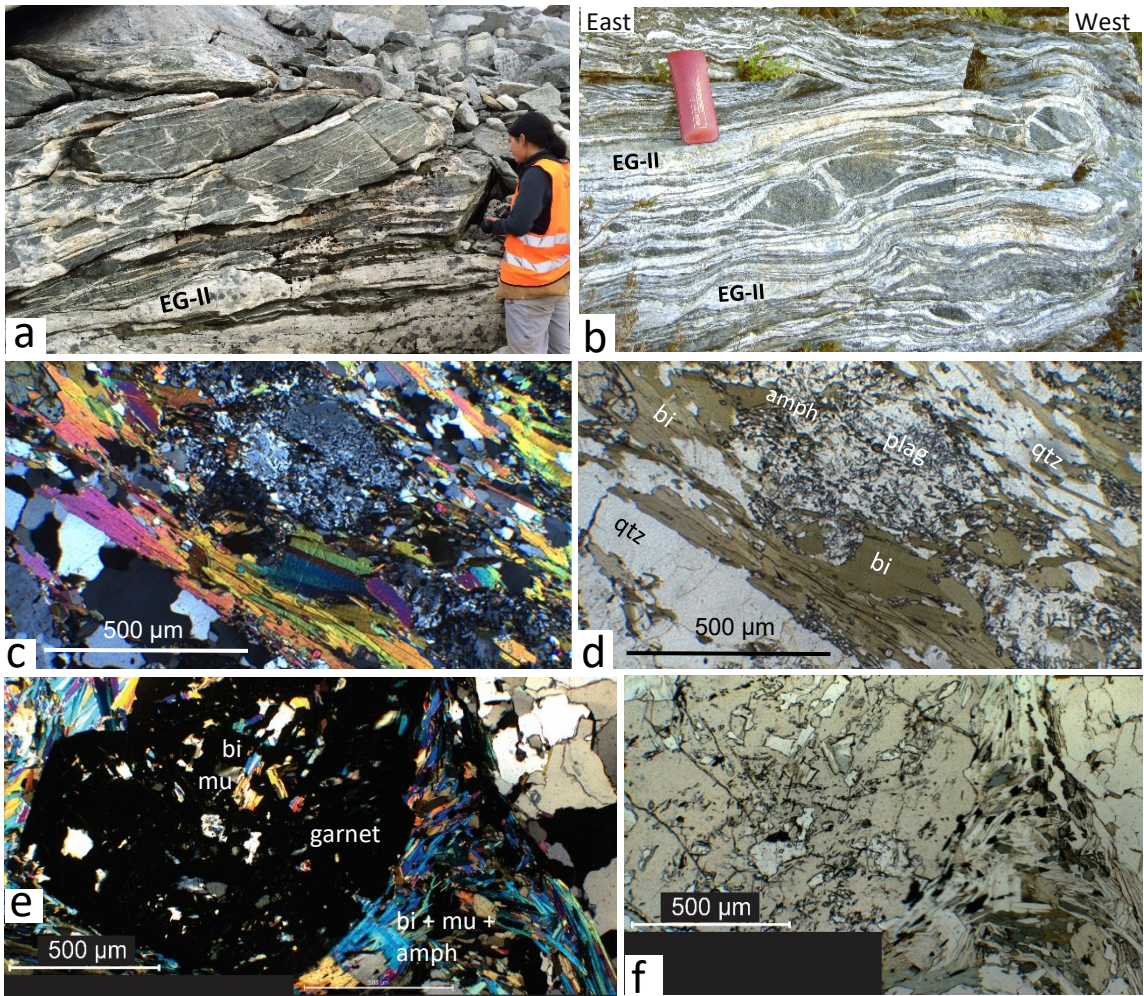


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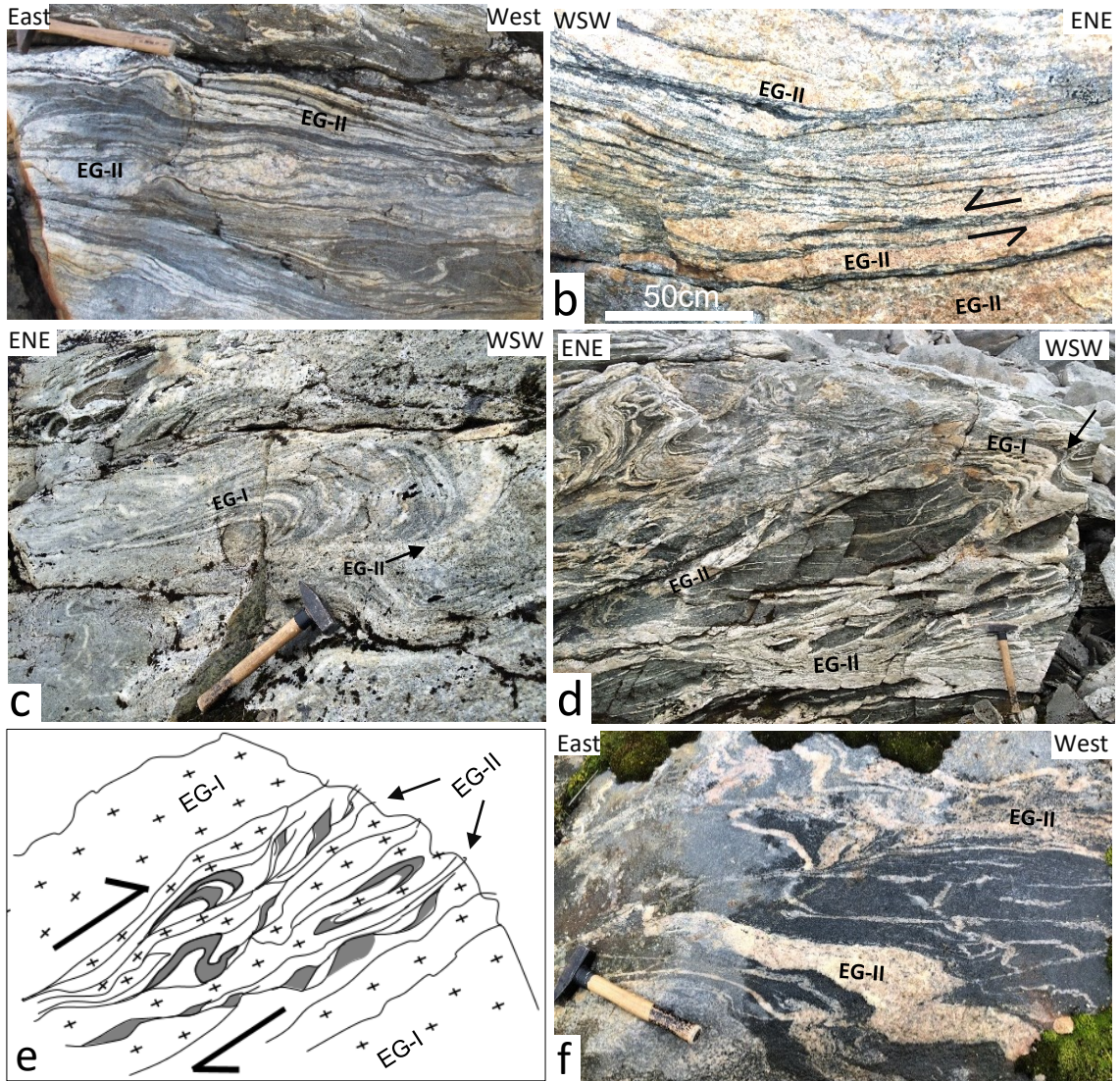


Figure 10.

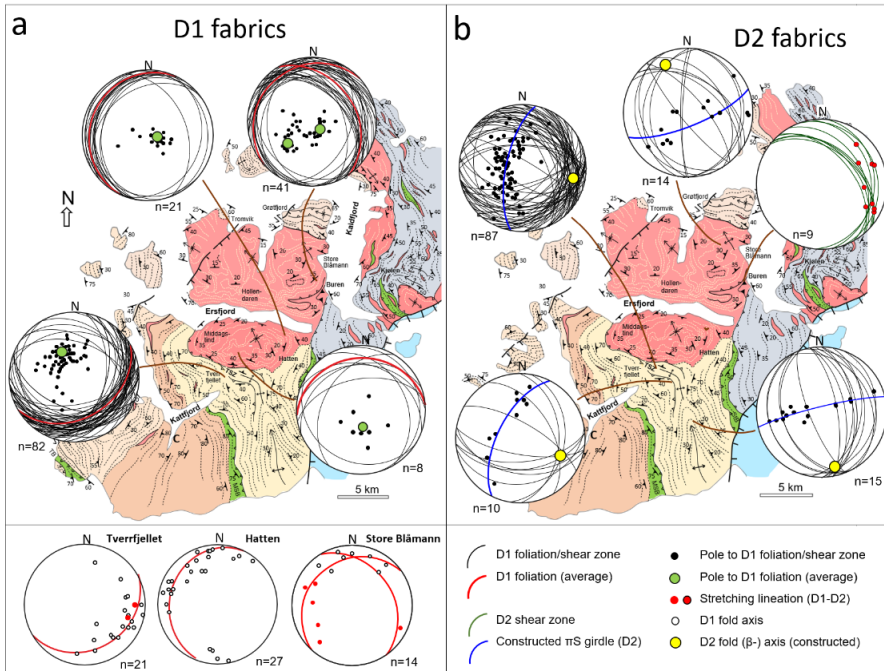


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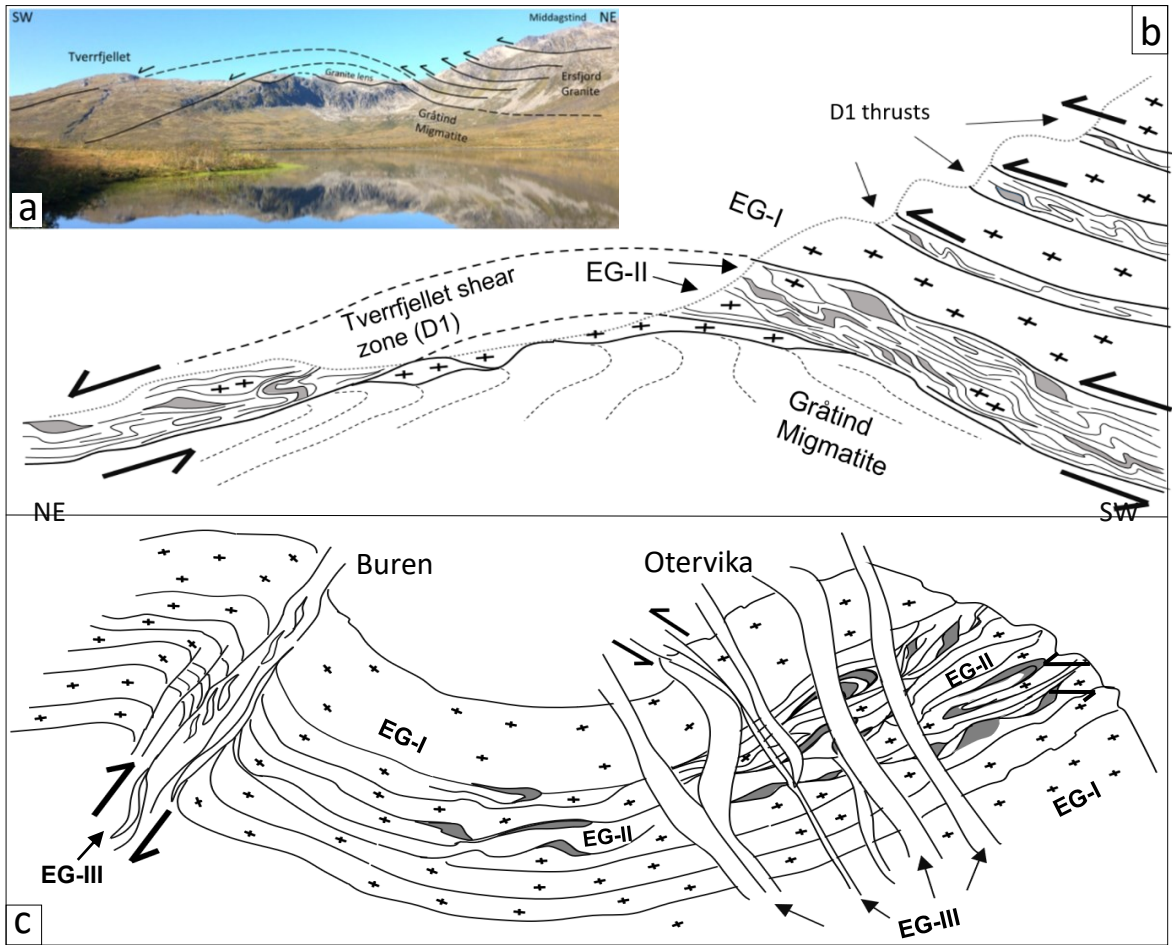


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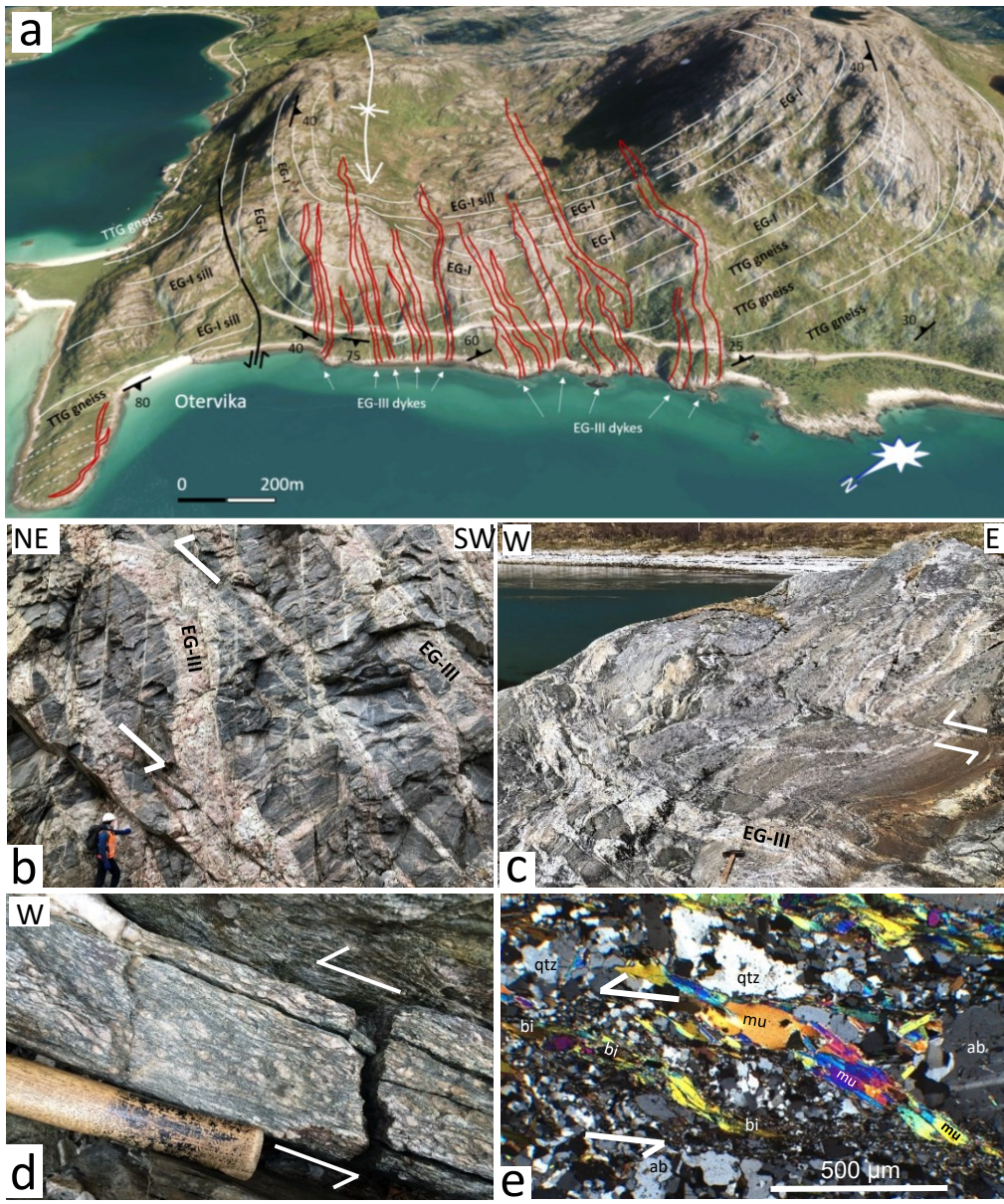


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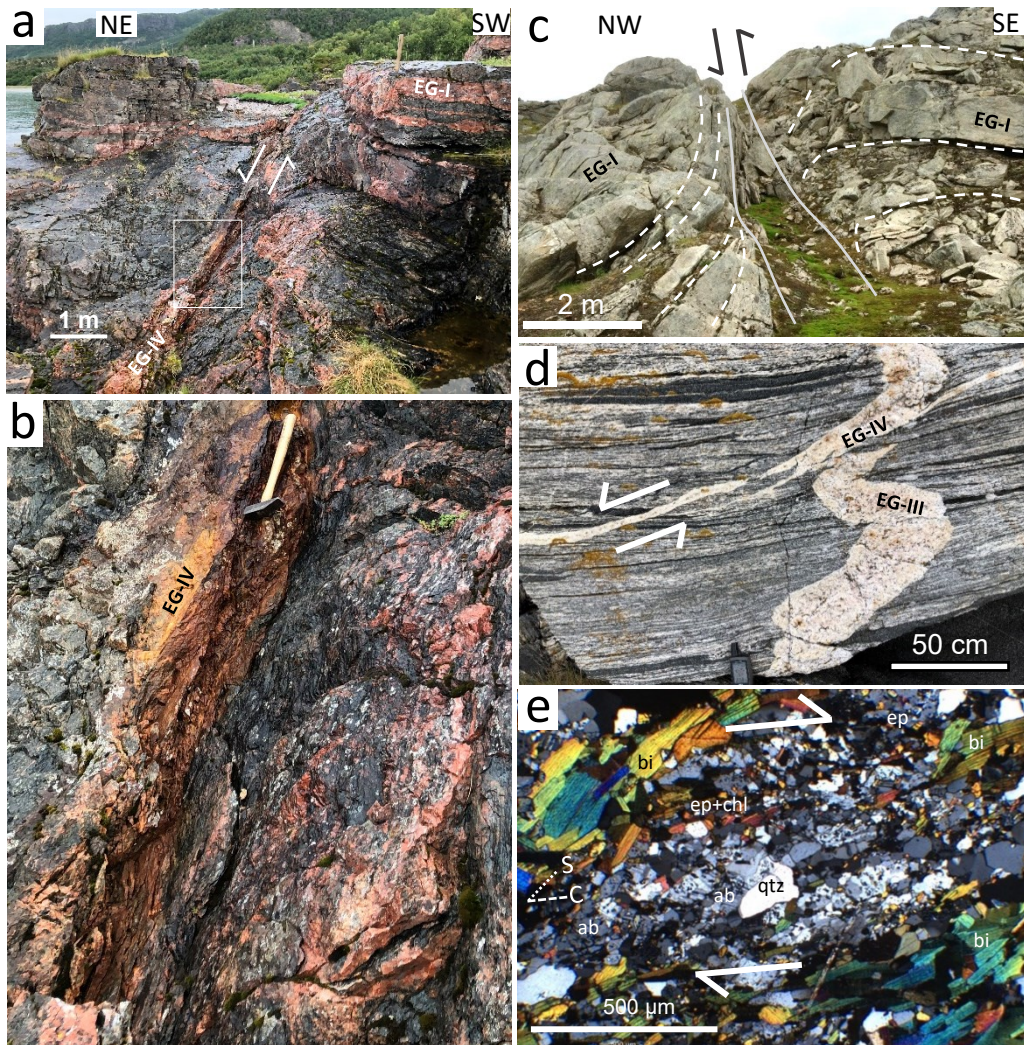


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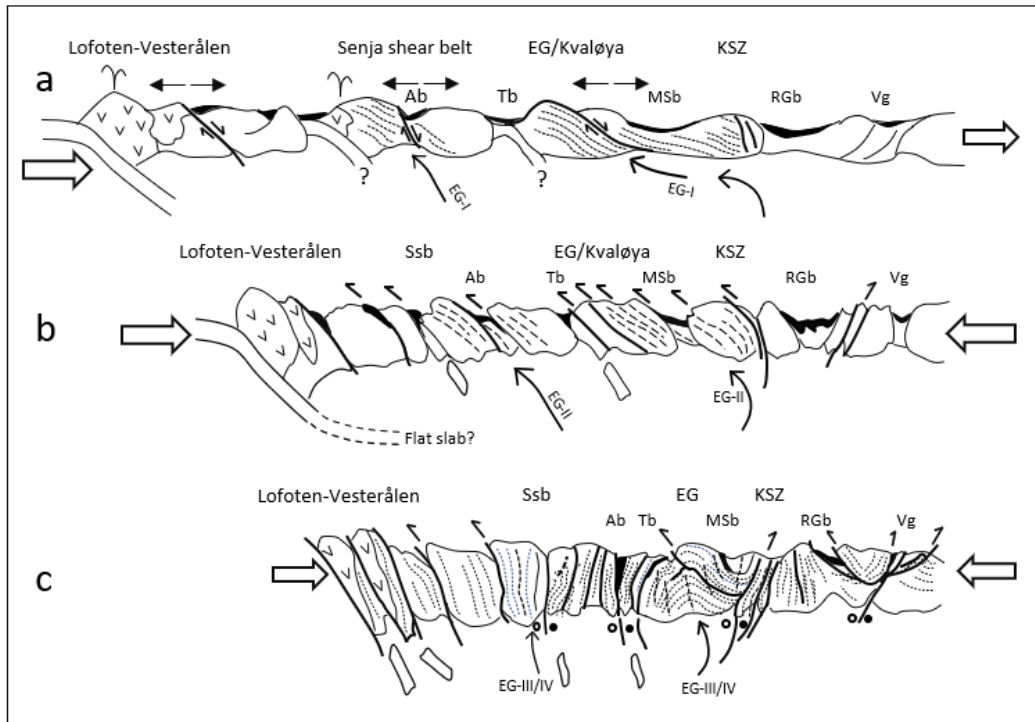
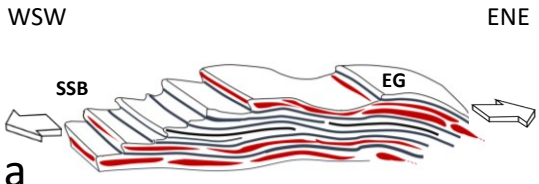
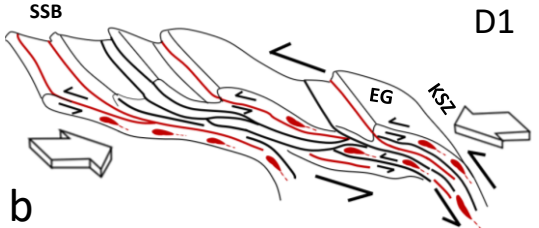
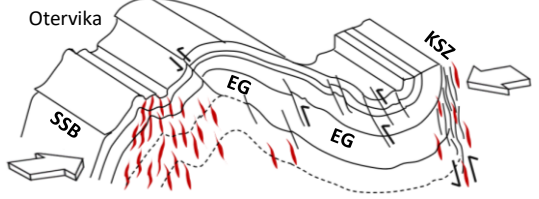
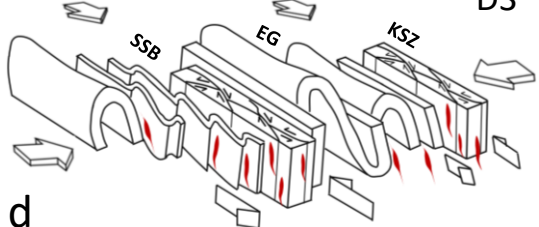


Figure 15.

Intrusion	Absolute ages (Kvaløya, Senja)	Structure, kinematics & contact relations	Metamorphic grade (mineral assemblage)	Tectonic setting	Structural evolution and melt emplacement
EG-I (pre-D1)	1792 ±5 Ma 1798-1784 Ma	<ul style="list-style-type: none"> - Regional sheets/sills - Pervasive magmatic banding - Conformable mafic migmatite zones (pendants) - Intrusive, sharp contacts 	Primary igneous minerals: K-fsp + plag + qtz + amph + bi + mu ± epidote/allanite, ti, magn, ap, zr	Pre-collisional extension in back-arc setting	WSW ENE  a
EG-II (syn-D1)	1784-1775 Ma (?) 1758 Ma	<ul style="list-style-type: none"> - Foliation-parallel sills - West-directed nappe stack - Imbricate ductile thrusts - Recumbent isoclinal and west-vergent folds - Stretching lineation 	Amphibolite facies (prograde): Amph + garnet + bi + mu + Kfsp + plag + qtz	<ul style="list-style-type: none"> - Syn-orogenic NE-SW crustal shortening - Basement-involved fold-thrust nappes - Accretionary orogen (advancing) 	 b D1
EG-III (syn-D2)	1774 ±5 Ma 1769 ±3 Ma	<ul style="list-style-type: none"> - Steep, axial-planar dykes (granite pegmatites) - Intrusive and thrust contacts - Regional upright folds - Mylonitic thrusts with top west shear-sense - Sigma-/mica fish/S-C bands 	Low amphibolite to upper greenschist facies (retrograde): Epidote + sericite + saussuritized plag + bi + mu + Kfsp + qtz	<ul style="list-style-type: none"> - Continued coaxial orogenic shortening relative to D1 - Accretion and crustal uplift 	 c D2
EG-IV (syn-D3)	1751 ±8 Ma 1745 Ma	<ul style="list-style-type: none"> - Steep dykes and sills - Sharp intrusive contacts - Subvertical folds - Steep mylonitic shear zones - Transpressive ductile shear zones (oblique/strike-slip) - Sinistral & dextral shearing 	Greenschist facies (retrograde): Bi + mu + epidote + chlorite + saussitized-/sericitized plag + qtz + Kfsp	<ul style="list-style-type: none"> - Late-orogenic NW-SE oblique shortening - Strike-slip shearing - Transpressive accretionary orogen - Crustal uplift 	 d D3
EG-V (post-D3)	1633-1562 Ma	<ul style="list-style-type: none"> - Irregular clusters and dykes - Intrusive contacts 		Post-orogen reworking and rejuvenation	