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Geodinamica Acta

An overview of anorthosite-bearing layered intrusions in the Archaean Craton of southern West Greenland and the Superior Province of Canada: Implications for Archaean tectonics and the origin of megacrystic plagioclase

--Manuscript Draft--

Full Title:	An overview of anorthosite-bearing layered intrusions in the Archaean Craton of southern West Greenland and the Superior Province of Canada: Implications for Archaean tectonics and the origin of megacrystic plagioclase
Manuscript Number:	TGDA-2017-0027R1
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Keywords:	Archaean layered intrusion; megacrystic anorthosite; leucogabbro; magma chamber; suprasubduction zone
Abstract:	<p>Anorthosite-bearing layered intrusions are unique to the Archaean rock record and are abundant in the Archaean craton of southern West Greenland and the Superior Province of Canada. These layered intrusions consist mainly of ultramafic rocks, gabbros, leucogabbros and anorthosites, and typically contain high-Ca (>An70) megacrystic (2-30 cm in diameter) plagioclase in anorthosite and leucogabbro units. They are spatially and temporally associated with basalt-dominated greenstone belts and are intruded by syn-to post-tectonic granitoid rocks. The layered intrusions, greenstone belts and granitoids all share the geochemical characteristics of Phanerozoic subduction zone magmas, suggesting that they formed mainly in a suprasubduction zone setting. Archaean anorthosite-bearing layered intrusions and spatially associated greenstone belts are interpreted to be fragments of oceanic crust, representing dismembered subduction-related ophiolites. We suggest that large degrees of partial melting (25-35%) in the hotter (1500-1600°C) Archaean upper mantle beneath rifting arcs and backarc basins produced shallow, kilometre-scale hydrous magma chambers. Field observations suggest that megacrystic anorthosites were generated at the top of the magma chambers, or in sills, dykes and pods in the oceanic crust. The absence of high-Ca megacrystic anorthosites in post-Archaean layered intrusions and oceanic crust reflects the decline of mantle temperatures resulting from secular cooling of the Earth.</p>

An overview of anorthosite-bearing layered intrusions in the Archaean Craton of southern West Greenland and the Superior Province of Canada: Implications for Archaean tectonics and the origin of megacrystic plagioclase

ABSTRACT

Anorthosite-bearing layered intrusions are unique to the Archaean rock record and are abundant in the Archaean craton of southern West Greenland and the Superior Province of Canada. These layered intrusions consist mainly of ultramafic rocks, gabbros, leucogabbros and anorthosites, and typically contain high-Ca ($>An_{70}$) megacrystic (2-30 cm in diameter) plagioclase in anorthosite and leucogabbro units. They are spatially and temporally associated with basalt-dominated greenstone belts and are intruded by syn-to post-tectonic granitoid rocks. The layered intrusions, greenstone belts and granitoids all share the geochemical characteristics of Phanerozoic subduction zone magmas, suggesting that they formed mainly in a suprasubduction zone setting. Archaean anorthosite-bearing layered intrusions and spatially associated greenstone belts are interpreted to be fragments of oceanic crust, representing dismembered subduction-related ophiolites. We suggest that large degrees of partial melting (25-35%) in the hotter (1500-1600°C) Archaean upper mantle beneath rifting arcs and backarc basins produced shallow, kilometre-scale hydrous magma chambers. Field observations suggest that megacrystic anorthosites were generated at the top of the magma chambers, or in sills, dykes and pods in the oceanic crust. The absence of high-Ca megacrystic anorthosites in post-Archaean layered intrusions and oceanic crust reflects the decline of mantle temperatures resulting from secular cooling of the Earth.

Keywords: word; Archaean layered intrusion, megacrystic anorthosite, leucogabbro, magma chamber, suprasubduction zone

1. Introduction

Although they are volumetrically small, Archaean anorthosite-bearing layered intrusions are widespread both in western Greenland and the Superior Province of Canada (Windley, Herd, & Bowden, 1973; Myers, 1985; Daigneault, ST-Julien, & Allard, 1990; Ashwal, 1993, 2010; Owens & Dymek, 1997; Peck, Messing, Halden, &

1 Chandler, 1998; Dymek & Owens, 2001; Gilbert 2007; Windley & Garde, 2009;
2 Hoffmann, Svahnberg, Piazzolo, Scherstén, & Münker, 2012; Percival et al. 2012; Zhou
3 et al., 2016; Ashwal & Bybee, 2017). Anorthosites are also a ubiquitous component of
4 Proterozoic orogenic belts and Phanerozoic ophiolites (Table 1), and have been
5 recovered from modern oceanic crust (Ashwal, 2010). Archaean anorthosites are
6 distinct from Proterozoic and Phanerozoic counterparts in that they commonly contain
7 equidimensional, rounded high-Ca (An₇₀₋₉₃) plagioclase ranging from 2 to 30 cm in
8 diameter, and are associated with layers of leucogabbro, gabbro, and ultramafic rocks
9 (Myers, 1985; Ashwal, 1993; Peck, Messing, Halden, & Chandler, 1998; Polat et al.,
10 2009; Ashwal & Bybee, 2017). These layered intrusions are typically associated with
11 tholeiitic to calc-alkaline basalt-dominated volcanic rocks in greenstone belts, and are
12 intruded mainly by syn- to post-tectonic tonalite-trondhjemite-granodiorite suites
13 (TTGs) (Davis, Sutcliffe, & Trowell, 1988; Daigneault, ST-Julien, & Allard, 1990;
14 Leclerc et al., 2011; Zhou et al., 2016; Polat, Wang, & Appel, 2015).

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Despite their widespread occurrence, Archaean megacrystic anorthosites are among the least understood rock types in the Earth's crust (Phinney, Donald, & David, 1988; Ashwal, 1993, 2010; Ashwal & Bybee, 2017). Several outstanding petrogenetic and geodynamic questions remain to be resolved to constrain their origin. These questions include: (1) How did anorthosites originate in the first place? (2) How were they emplaced into the crust? (3) What type of crust (oceanic versus continental) did they intrude? (4) Why do they have plagioclase crystals up to 30 cm in diameter? (5) What was the geodynamic setting(s) that produced these rocks? (6) Why are they rare in post-Archaean times?

In this contribution, we use the geological and geochemical characteristics of well-studied Mesoarchaeoan to Neoarchaeoan anorthosite-bearing layered intrusions in western Greenland (Ivisaartoq, Fiskenæsset, Naajat Kuuat complexes) and the Superior Province of Canada (Bad Vermilion Lake and Doré Lake complexes) to address the above questions and propose a new geodynamic model for the petrogenetic origin of these rocks (Figs. 1, 2). Emphasis is placed on the megacrystic anorthosites and leucogabbros in the Fiskenæsset Complex where most stages of anorthosite and leucogabbro development are well exposed (Figs. 3, 4). In addition, we present new major and trace element and petrographic data from the Sinarssuk area in the Fiskenæsset region to provide new constraints on the origin of megacrystic anorthosite

1 and leucogabbros. Analytical methods of major and trace elements for the new analyses
2 are the same as described in Polat et al. (2011). The method used for Scanning Electron
3 Microscope–Energy Dispersive Spectroscopy (SEM–EDS) analyses is given in Price
4 (2012).
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7 8 9 **2. Regional geology**

10 ***2.1. Archean craton of southern West Greenland***

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12 The Archean terrain of West Greenland is composed of Eoarchaean to
13 Neoproterozoic tectonically-accreted crustal blocks, consisting predominantly of TTG and
14 granitic gneisses, basalt-dominated **greenstone belts (volcanic and sedimentary rock**
15 **associations)**, anorthosite-bearing layered intrusions, and granites (Friend & Nutman,
16 2005; Steenfelt, Garde, Moyen, 2005; Windley & Garde, 2009; Polat, Wang, & Appel,
17 2015). The poly-deformed and metamorphosed **greenstone belts** and anorthosite-bearing
18 layered intrusions occur as meter- to kilometer-scale conformable layers within the TTG
19 gneisses. Contacts between the TTG gneisses and **greenstone belts** and anorthosite-
20 bearing layered intrusions are characterized predominantly by 5 to 20 meter wide
21 mylonitic shear zones with rare intrusive relationships (Windley & Garde, 2009; Polat,
22 Wang, & Appel, 2015). The anorthosite-bearing layered intrusions are commonly
23 spatially associated with **volcanic rocks** and are interpreted to have been emplaced into
24 oceanic basaltic to gabbroic rocks, and they are in turn intruded by syn-tectonic TTGs
25 (Myers, 1976; Windley & Garde, 2009; Hoffmann, Svahnberg, Piazzolo, Scherstén, &
26 Munker, 2012). The **greenstone belts** consist of tholeiitic to calc-alkaline basalts,
27 boninites and picrites with minor **siliciclastic** sedimentary rocks. The anorthosite-
28 bearing layered intrusions are composed mainly of cumulate layers of anorthosite,
29 leucogabbro, gabbro and ultramafic rocks (Fig. 4). Field, geochronological and
30 geochemical investigations suggest that the Archean craton of southern West
31 Greenland grew at convergent plate margins through accretion of island arcs and
32 continental blocks (Nutman, Friend, & Bennett, 2002; Friend & Nutman, 2005; Garde,
33 2007; Windley & Garde, 2009; Kisters, van Hinsberg, & Szilas, K., 2012; Szilas et al.,
34 2012; Szilas et al., 2013; Dziggel, Diener, Kolb, & Kokfelt, 2014; Polat, Wang, &
35 Appel, 2015). Despite poly-phase deformation and amphibolite to granulite facies
36 metamorphism, primary structures (e.g., pillows) in the **volcanic rocks** and cumulate
37 textures and igneous layering in the anorthosite-bearing layered intrusions are well
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1 preserved (Chadwick, 1985, 1990; Myers, 2001; Windley & Garde, 2009; Polat et al.,
2 2008; Polat et al., 2011; Polat, Wang, & Appel, 2015).

3 **Windley and Garde** (2009) divide the Archaean craton of southern West
4 Greenland into six Mesoarchaeoan to Neoarchaeoan (ca. 3000–2720 Ma) tectonic blocks
5 that display similar geological cross-sections (Fig. 1). These blocks consist of the
6 Ivittuut, Kvanefjord, Bjørnesund, Sermilik, Fiskefjord and Maniitsoq (Fig. 1). Each
7 tectonic block is made of a southerly upper and a northerly lower zone (**Windley &**
8 **Garde, 2009**). These blocks are composed predominantly of TTG orthogneisses
9 containing numerous layers of anorthosite-bearing layered intrusions and amphibolite
10 facies metavolcanic rocks.
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20 **2.2. Superior Province of Canada**

21 The Archaean Superior Province of Canada consists of approximately east-west-
22 striking TTG dominated-plutonic, greenstone-granitoid, high-grade TTG-gneissic and
23 meta-sedimentary subprovinces (Fig. 2) (Card & Ciesielski, 1986; Stott, 1997; Percival
24 et al., 2012). These subprovinces represent a tectonic collage of numerous fragments of
25 continental blocks, oceanic island arcs, oceanic plateaus and orogenic flysch deposits.
26 These lithotectonic terrains were assembled through subduction-driven, >1500 km long,
27 accretionary and collisional processes, which took place diachronously from north to
28 south between 2720 and 2680 Ma (Stott, 1997; Percival et al., 2012). Layered intrusions
29 consisting mainly of gabbro, anorthosite and ultramafic rocks are exposed in many areas
30 particularly in the northern Abitibi and the western Wabigoon greenstone-granitoid
31 subprovinces and the North Caribou terrane (see Fig. 3 in Percival et al., 2012). Like
32 those in the Archaean craton of southern West Greenland, the anorthosite-bearing
33 layered intrusions in the Superior Province display well-preserved megacrystic textures
34 (Ashwal, 1993) and are spatially and temporally associated with tholeiitic to calc-
35 alkaline basalt-dominated volcanic rocks, and are intruded by syn- to post-tectonic
36 TTGs (Davis, Sutcliffe, & Trowell, 1988; Bédard, Leclerc, Harris, & Goulet, 2009;
37 Leclerc et al., 2011; Wu et al., 2016; Polat, Frei, Longstaffe, & Woods, 2017).
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54 **3. Summary of the geological and geochemical characteristics**

55 **3.1. West Greenland**

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1 An assemblage of leucogabbro and anorthosite is spatially and temporally
2 associated with the ca. 3075 Ma Ivisaartoq greenstone belt and is intruded by ca. 2963
3 Ma old tonalites and granodiorites (Fig. 1) (Chadwick, 1985, 1990; Friend & Nutman,
4 2005; Polat et al., 2008). In addition, gabbros in the Ivisaartoq belt contain up to 15 cm
5 long, deformed anorthositic inclusions (xenoliths), consisting primarily (>90%) of Ca-
6 rich plagioclase and 5-10% amphibole (Fig. 5a, b; Polat et al., 2008). These xenoliths
7 are interpreted to be anorthositic cumulates that were transported to the oceanic crust by
8 upwelling gabbroic magmas. The xenoliths display Th- and LREE-enriched trace
9 element patterns with large positive Eu but negative Nb and Ti anomalies (Fig. 6a), and
10 have large positive initial ϵ_{Nd} (+4.8 to +6.0) values, consistent with a long-term depleted
11 mantle source (Polat et al., 2008). Volcanic and intrusive rocks of the Ivisaartoq
12 greenstone belt share the geochemical characteristics of Phanerozoic subduction zone
13 magmas (Polat et al., 2008; Ordóñez-Calderón et al., 2009; Szilas et al., 2016).
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16 The Mesoarchaeon Naajat Kuuat Anorthosite Complex in southern West
17 Greenland is composed of megacrystic anorthosite and leucogabbro, gabbro and
18 ultramafic rocks, and is spatially associated with metavolcanic amphibolites (Fig. 1)
19 (Hoffmann, Svahnberg, Piazzolo, Scherstén, & Münker, 2012). The meter- to kilometer-
20 long slices of the Naajat Kuuat Anorthosite Complex are interleaved with the intrusive
21 TTGs. The anorthosites have arc-like trace element patterns, whereas the ultramafic
22 rocks and metavolcanic amphibolites display MORB- to arc-like geochemical
23 characteristics (Hoffmann, Svahnberg, Piazzolo, Scherstén, & Münker, 2012). The
24 anorthosites ($\epsilon_{\text{Nd}}=+1.6$ to $+3.6$; $\epsilon_{\text{Hf}}=+2.5$ to $+5.8$), ultramafic rocks ($\epsilon_{\text{Nd}}=+0.4$ to $+2.0$;
25 $\epsilon_{\text{Hf}}=+4.2$ to $+5.6$) and amphibolites ($\epsilon_{\text{Nd}}=+1.7$ to $+3.7$; $\epsilon_{\text{Hf}}=+1.6$ to $+5.3$) have
26 depleted mantle Nd and Hf isotopic compositions. On the basis of field observations
27 and geochemical data, the Naajat Kuuat Anorthosite Complex and spatially associated
28 amphibolites and TTG are interpreted to have formed in a suprasubduction zone setting
29 (Hoffmann, Svahnberg, Piazzolo, Scherstén, & Münker, 2012).
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32 The ca. 2970 Fiskenæsset Anorthosite Complex, Western Greenland, is probably
33 the largest and best-preserved Archaean anorthosite-bearing layered intrusion in the
34 world, consisting of ca. 550 m-thick cumulate layers of anorthosite, leucogabbro,
35 gabbro and hornblende-bearing ultramafic rocks (Figs. 3, 4) (Windley, Herd, &
36 Bowden, 1973; Windley & Smith, 1974; Myers, 1985; Polat et al., 2009; Polat, Frei,
37 Scherstén, & Appel, 2010; Polat et al., 2011; Polat et al., 2012; Rollinson, Reid, &
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Windley, 2010; Huang, Polat, Fryer, Appel, & Windley, 2012; Huang, Fryer, Polat, & Pan, 2014). Field characteristics indicate that the Fiskenæsset Anorthosite Complex was emplaced into Mesoarchaeon oceanic crust as multiple sills and dykes of magma and crystal mush, and is intruded by 2950-2750 Ma TTGs (Polat, Frei, Scherstén, & Appel, 2010; Polat et al., 2011; Polat et al., 2012; Huang, Polat, & Fryer, 2013). The Fiskenæsset anorthosites and leucogabbros display diverse REE patterns with variable La/Sm_{cn} and Gd/Yb_{cn} ratios, and have variably negative Nb and Ti but positive Eu anomalies (Polat et al., 2009; Polat et al., 2011; Huang, Polat, Fryer, Appel, & Windley, 2012). All rock types in the complex share the trace element characteristics of modern subduction zone igneous rocks, and have depleted mantle Nd (average initial $\epsilon_{Nd} = +3.3$), Pb and O primitive isotope ($\delta^{18}O = 5.8 \pm 0.5\%$) compositions (Polat et al., 2009; Polat, Frei, Scherstén, & Appel, 2010; Polat et al., 2011; Huang, Polat, Fryer, Appel, & Windley, 2012; Polat et al., 2014; Polat & Longstaffe, 2014).

For this study, we analysed seven samples of megacrystic plagioclase from the leucogabbros of the Sinarssuk area (Fig. 1; Table 2). These plagioclase megacrysts have small variations in SiO₂ (46.7–48.2 wt.%), CaO (14.9–16.2 wt.%), and Al₂O₃ (31.9–35.5 wt.%) (Table 2). They have low MgO (0.18–0.33 wt.%), Fe₂O₃ (0.48–1.1 wt.%), TiO₂ (0.01–0.02 wt.%) and Na₂O (1.65–2.55 wt.%) contents. Mg-numbers span from 37 to 52 (Table 2). Anorthite (An%) contents vary from 78 to 86. Al₂O₃/TiO₂ (1440–4440) ratios are extremely super-chondritic.

The Sinarssuk megacrystic plagioclase samples are characterized by strongly fractionated REE patterns (La/Sm_{cn}=3.0–13.9; La/Yb_{cn}=6.2–83.7; Gd/Yb_{cn}=1.79–4.92), and positive Eu (Eu/Eu*=2.91–8.3) anomalies (Fig. 6b; Table 2). Cerium anomalies are minor to absent (Ce/Ce*=0.96–1.05). On the N-MORB-normalized diagram, they have large positive Pb (Pb/Pb*=186–3740), and negative Nb (Nb/Nb*=0.06–0.55) and Ti (Ti/Ti*=0.13–0.29) anomalies. Zirconium anomalies (Zr/Zr*=0.36–6.65) vary from negative to positive.

3.2. Superior Province

The Superior Province contains several well-preserved Neoarchean anorthosite complexes including the Bad Vermilion Lake, Doré Lake, Shawmere, Pipestone, Pikwitonei and Bird River complexes (Ashwal, 1993; Peck, Messing, Halden, & Chandler, 1998; Gilbert, 2007; Yang, Gilbert, & Houlé, 2012). We have high-precision

1
2 trace element data only for the Bad Vermilion Lake and Doré Lake complexes (Zhou et
3 al., 2016; Polat, Frei, Longstaffe, & Woods, 2017). Accordingly, we focus on these two
4 complexes.

5 The Bad Vermilion Lake Anorthosite Complex is located in the western
6 Wabigoon subprovince of the western Superior Province (see Ashwal, Morrison,
7 Phinney, & Wood, 1983; Percival et al., 2012; Zhou et al., 2016). It consists
8 predominantly of anorthosite, leucogabbro and gabbro and intrudes the 2720 Ma
9 tholeiitic to calc-alkaline volcanic rocks of the Bad Vermilion Lake greenstone belt
10 (Davis, Sutcliffe, & Trowell, 1988; Blackburn, John, Ayer, & Davis, 1991; Zhou et al.,
11 2016). The Bad Vermilion Anorthosite Complex is intruded by ca. 2716 Ma granitic
12 rocks (Ashwal, Morrison, Phinney, & Wood, 1983; Zhou et al., 2016). The complex has
13 depleted mantle-like Nd ($\epsilon\text{Nd}=\text{ca. } +2$) and near-primitive O ($\delta^{18}\text{O} = +5.5$ to $+6.7$ ‰)
14 isotope signatures and subduction zone-like trace element patterns (Fig. 6c; Ashwal,
15 Morrison, Phinney, & Wood, 1983; Zhou et al., 2016). The spatially associated mafic to
16 felsic volcanic rocks with the complex also have subduction zone trace element
17 characteristics (Wu et al., 2016).

18 The ca. 2728 Ma Doré Lake Complex is located in the northeastern segment of the
19 Northern Volcanic Zone of the Abitibi subprovince and is composed predominantly of
20 megacrystic anorthosite and leucogabbro, and gabbro (Daigneault, ST-Julien, & Allard,
21 1990; Bédard, Leclerc, Harris, & Goulet, 2009; Leclerc et al., 2011; Polat, Frei,
22 Longstaffe, & Woods, 2017). The complex intrudes the basalt-dominated volcanic and
23 sedimentary rocks of the Roy Group and is in turn intruded by the 2714 Ma tonalitic
24 Chibougamau pluton (Ludden, Francis, & Allard, 1984; Daigneault, ST-Julien, &
25 Allard, 1990; Mortensen, 1993; Bédard, Leclerc, Harris, & Goulet, 2009; Leclerc et al.,
26 2011). The Nd ($\epsilon\text{Nd}=+ 2.6$ to $+5.0$) and O ($\delta^{18}\text{O}=+6.05$ to $+7.85\%$) isotope systematics
27 are consistent with a depleted mantle source (Polat, Frei, Longstaffe, & Woods, 2017).
28 Like the Bad Vermilion Lake anorthosites and spatially associated volcanic rocks, the
29 Doré Lake anorthosites and **spatially** associated volcanic rocks (see Figs 8-10 in Leclerc
30 et al., 2011; Polat, Frei, Longstaffe, & Woods, 2017) also have subduction zone trace
31 element signatures (Fig. 6d), although Leclerc et al. (2011) do not attribute the origin of
32 Th- and LREE-enriched patterns with negative Nb, Ta and Ti anomalies in the tholeiitic
33 to calc-alkaline volcanic rocks to Archaean subduction zone processes.

4. Geodynamic origin of Archaean anorthosites

Numerous studies on the thermal history of the Earth suggest that the ambient temperature of the Archaean mantle (1500–1600°C) was 200-300 °C higher than today's mantle (1300–1400 °C) (e.g., Nisbet, Cheadle, Arndt, & Bickle, 1993; Korenaga, 2008; Davies, Sutcliffe, & Trowell, 2009; Lee, Luffi, Plank, Dalton, & Leeman, 2009; Herzberg, Condie, & Korenaga, 2010). The higher mantle temperatures beneath the Archaean oceanic spreading centres would have produced 25-35% partial melting, resulting in three to four times more voluminous basaltic magma than the 7-10% partial melting beneath present-day spreading centres (see McKenzie & Bickle, 1988; Herzberg, 2004; Herzberg, Condie, & Korenaga, 2010). Such high degrees of partial melting would have generated 25-35 km thick oceanic crust, in contrast to the 7-10 km thick crust produced at modern ocean ridges (Sleep & Windley, 1982; Bickle, 1986; Herzberg, Condie, & Korenaga, 2010). Although petrological models predicting higher mantle temperatures for the Archaean are based on the composition of non-arc basalts (e.g., Lee, Luffi, Plank, Dalton, & Leeman, 2009; Herzberg, Condie, & Korenaga, 2010), the presence of arc picrites, boninites and high-Mg andesites in Archaean greenstone belts might also imply higher ambient mantle temperatures beneath Archaean arcs and backarcs (Polat & Kerrich, 2006). We propose that 25-35% degrees of partial melting in the Archaean upper mantle would have resulted in a large volume of basaltic magmas underplating rifting arcs and/or backarc basins, generating large, shallow magma chambers (Fig. 7). Higher geothermal gradients in the Archaean oceanic crust would have allowed these shallow magma chambers to cool slowly, providing optimal conditions for differentiation and stratification to produce cumulates of dunite, peridotite, chromitite, pyroxenite, (\pm hornblendite), gabbro, leucogabbro and anorthosite (Fig. 7) (Polat et al., 2009; Namur et al., 2015). The Fiskensæset Complex contains numerous small-scale (50 centimetres to 5 meters thick) examples of differentiated sills representing smaller versions of magma chambers that solidified to form such cumulate layers, including hornblendite, in the oceanic crust (Fig. 4a, b; see Myers, 1985; Polat et al., 2011).

Archaean plagioclase megacrysts, including those in the Fiskensæset Complex, are typically characterized by high-Ca content (An_{70-93}) (see Ashwal, 2010; Ashwal & Bybee, 2017). Previous studies have shown that plagioclase grains in the anorthosites and leucogabbros of the Fiskensæset Complex typically have high anorthite (An)

1 contents, ranging between 75 and 98% (Windley & Smith, 1974; Myers & Platt 1977;
2 Rollinson, Reid, & Windley, 2010; Huang, Fryer, Polat, & Pan, 2014). The plagioclase
3 megacrysts from the Sinarssuk area of the Fiskenæsset region (Figs. 1, 3) also have
4 high-Ca contents (An₇₈₋₈₆). Additional analyses of plagioclase in leucogabbros and
5 hornblendites on the island of Qeqertarssuatsiaq also indicate high An contents (An₆₆₋₉₁)
6 (see Data Repository Table 1). These high An contents are attributed to hydrous
7 parental melts in a subduction zone environment (see Müntener, Kelemen, Grove, 2001;
8 Tagaki, Sato, & Nakagawa, 2005; Ashwal, 2010).

9 **Virtually** all rock types and structures that are associated with Archaean
10 anorthosite-bearing layered intrusions (Myers, 1976; Myers, 1985; Daigneault, ST-
11 Julien, & Allard, 1990; Davis, Sutcliffe, & Trowell, 1988; Polat, Wang, & Appel, 2015;
12 Wu et al., 2016) have analogues in Phanerozoic convergent plate margins and orogenic
13 belts. Although the details of tectonic processes that produced Archaean anorthosite-
14 bearing layered intrusions and spatially associated volcanic rocks and TTG intrusions
15 remain to be determined, trace element data and field observations indicate that their
16 origin can be explained best by subduction zone tectonic processes (Chown, Daigneault,
17 Mueller, & Mortensen, 1992; Mueller, Daigneault, Mortensen, & Chown, 1996;
18 Daigneault, Mueller, Chown, 2002; Windley & Garde, 2009; Percival et al., 2012; Polat
19 et al., 2009; Polat et al., 2011; Polat, Frei, Longstaffe, & Woods, 2017). Available Nd
20 and O isotope data for Archaean anorthosite complexes suggest that they originated
21 from long-term depleted mantle sources that were overprinted by subduction-derived
22 melts and/or fluids (Polat et al., 2008; Polat, Frei, Scherstén, & Appel, 2010; Polat, Frei,
23 Longstaffe, & Woods, 2017; Polat & Longstaffe, 2014; Zhou et al. 2016). None of the
24 Archaean anorthosite-bearing layered intrusions discussed in this contribution displays
25 evidence for extensive crustal contamination. Hence, the Th- and LREE-enriched and
26 Nb- and Ti-depleted trace element patterns in these rocks (Fig. 6) reflect subduction
27 zone geodynamic processes rather than emplacement into older continental crust.
28 Collectively, we interpret the anorthosite-bearing layered intrusions in the Archaean
29 craton of western Greenland and the Superior Province as remnants of rifted oceanic
30 arcs or backarc basins (Fig. 7).

5. Anorthosite-bearing layered intrusions and the nature Archaean oceanic crust

Given their absence in the Phanerozoic rock record, Archaean anorthosite-

1 bearing layered intrusions and associated greenstone belts are not generally considered
2 part of oceanic crust because they do not have a Penrose-type ophiolite lithological
3 association. Thus, these rock associations are not interpreted to be ophiolites (Hamilton,
4 1998; Stern, 2005; Kamber, 2015). Recent studies on Phanerozoic ophiolites and
5 Archaean greenstone belts have shown that the original Penrose ophiolite definition
6 (Anonymous, 1972) is too simplistic and has major limitations for understanding the
7 evolution of the oceanic crust and its diversity in the rock record (Kusky, 2004; Şengör
8 & Natal'in, 2004; Dilek & Furnes, 2011; Kusky et al., 2013; Furnes, Dilek, & de Wit,
9 2015). Therefore, this definition is not recommended to be used as a guide to define
10 ophiolites in Archaean terrains that are typically characterized by polyphase
11 deformation, and multiple generations of metamorphism and granitoid intrusion. Given
12 that the Penrose ophiolite definition cannot be readily applied to the Precambrian rock
13 record, Dilek & Furnes (2011) proposed a broad definition ophiolite as "suites of
14 temporally and spatial associated ultramafic to felsic rocks related to separate melting
15 episodes and processes of magmatic differentiation in particular tectonic environments".
16 On the basis of new definition, ophiolites are divided into two major types: (1)
17 subduction-related ophiolites that form in backarc, forearc and arc tectonic settings; and
18 (2) subduction-unrelated ophiolites that originate in rifted continental margins, mid-
19 ocean ridges and plume-derived oceanic plateaus. The subduction-related ophiolites
20 constitute about 85% of the ophiolites in the rock record (Furnes et al., 2015), reflecting
21 mainly their biased preservation. Because of its buoyancy, suprasubduction crust is less
22 prone to the subduction and recycling than "normal" oceanic crust produced along mid-
23 ocean ridges. Most Archaean greenstone belts have Phanerozoic subduction zone-like
24 lithological and geochemical characteristics, representing dismembered fragments of
25 oceanic island arcs and backarcs (Furnes, Dilek, & de Wit, 2015).

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45 On the basis of their lithological and geochemical characteristics, we interpret
46 Archaean anorthosite-bearing layered intrusions and spatially associated greenstone
47 belts to be subduction-related Archaean ophiolites using the new ophiolite concept
48 developed by Dilek and Furnes (2011) and Furnes, Dilek, & de Wit (2015). These rock
49 associations represent relict fragments of Archaean suprasubduction zone (arc-backarc-
50 forearc) crust, marking the closure of ocean basins and formation of suture zones in
51 Archaean orogenic belts (Polat, Frei, Longstaffe, & Woods, 2017).
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Modern oceanic lithosphere forming at spreading centres consists generally of a mantle section (dunite, lherzolite, harzburgite) at the bottom, mafic to ultramafic cumulates (gabbros, pyroxenites) in the middle, and a mafic crustal section (isotropic gabbros, sheeted dykes and basalts) at the top. The thickness of the mafic rocks in modern oceanic crust and Phanerozoic ophiolites varies between 5 and 10 km, which is much smaller than the predicted 25-35 km thickness of Archaean oceanic crust (Sleep & Windley, 1982; Herzberg, Condie, & Korenaga, 2010). In contrast to Phanerozoic oceanic crust, Archaean oceanic crust was likely composed of an association of 25-35 km thick basaltic flows and sills of gabbros, anorthosites, leucogabbros and differentiated ultramafic rocks (Fig. 7b) (Dilek & Polat, 2008).

6. Magma chamber dynamics and the origin of megacrystic plagioclase

Textural analyses of layered intrusions and theoretical studies of magma chamber dynamics suggest that if a magmatic system with a single mineral, like plagioclase growing in a liquid at the top of a magma chamber, remains at high temperatures close to the liquidus of that mineral, large crystals will develop at the expense of small ones (Ostwald ripening), resulting in a megacrystic grain size (Higgins, 2005, 2011). Field observations of the Fiskensæset Complex indicate that plagioclase crystals separated from the residual liquid and floated to the top of the magma chamber, forming a crystal mush of leucogabbro and anorthosite (Fig. 4a, b, c; see Scoates, 2002; Higgins, 2005; Namur et al., 2011). Floatation of plagioclase was likely facilitated by the presence of denser residual liquid, which mostly crystallized to hornblende (Figs. 3, 4). The presence of plagioclase laminations, erosional surfaces, slump structures and trough layers (Myers, 1985), and the injection of plagioclase crystal mush into a gabbroic magma (Fig. 4d-f) are consistent with a dynamic, vigorously convecting magma chamber (see Higgins, 2005; Namur et al., 2015). The presence of amphibole inclusions in chromite grains in the Fiskensæset Complex is attributed to a hydrous magma composition (Rollinson, Reid, & Windley, 2010; Polat, 2012). The Fiskensæset Complex provides field evidence for most stages of crystallization of plagioclase in hydrous melts to form megacrystic anorthosites and leucogabbros (Fig. 3). This hydrous magmatic system likely remained at high temperatures (1000-1200 °C) for a long period of time, resulting in the formation of megacrystic (2-15 cm in diameter) plagioclase grains. Plagioclase grain size varies from 2 mm to 30 cm and some megacrysts appear

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to have formed by coalescence of smaller megacrysts (Figs. 3 and 8). Most plagioclase grains display field and petrographic evidence for metamorphic recrystallization (Figs. 8). The continuity of albite twinning for 6-8 cm in the least deformed and recrystallized megacrysts in samples 508144 and 508146 collected from the least-deformed outcrops in the Sinarssuk area (Figs. 1, 9; Table 2), however, clearly demonstrates their formation as single crystals, rather than coalesced, in the magma chamber. The megacrystic magma either solidified in place or was transported as crystal mush into the overlying oceanic crust to form sills, dykes or pods of anorthosites and leucogabbros (Fig. 7). These plagioclase megacrysts grew further by interaction with either new melts and/or melts expelled from the lower parts of the magma chamber, producing grains up to 30 cm in length (Fig. 3). Collectively, large grain sizes in Archaean megacrystic anorthosites and leucogabbros can be interpreted as the product of slow cooling conditions close to the plagioclase liquidus temperatures that stemmed from the higher geothermal gradients in the Archaean oceanic crust.

7. Conclusions

Anorthosite-bearing layered intrusions in the Archaean craton of southern West Greenland and the Superior Province of Canada were emplaced into basalt-dominated greenstone belts, and were intruded by syn- to post-tectonic granitoids. All these three rock associations share the trace element signatures of modern subduction-related magmas, suggesting that they originated in a suprasubduction zone setting, representing Archaean subduction-related ophiolites. Anorthosite-bearing layered intrusions and spatially associated greenstone belts are interpreted as fragments of suture zones, marking the closure of Archaean ocean basins. These intrusions in Greenland and Canada are mostly located close to the major tectonic boundaries separating different tectonic blocks/terranes (Figs. 1, 2), suggesting a close relationship between the formation of anorthosite-bearing layered intrusions and major tectonic processes that led the amalgamation of different blocks/terranes.

Ashwal (2010) and Ashwal & Bybee (2017) addressed the temporality of anorthosites, showing that high-Ca (An=61–94%, average An=80%) megacrystic Archaean and massif-type Proterozoic anorthosites (An=30–70%, average An=53%) are restricted in space and time, whereas continental layered mafic intrusions and ophiolites do not show clear time-restriction. Field studies indicate that Archaean anorthosites

1 originated mostly in oceanic settings and are spatially and temporally associated with
2 basalt-dominated greenstone belts, whereas Proterozoic counterparts are spatially
3 associated with granitoid rocks and thought to have formed in continental arcs.
4 Anorthosites in Phanerozoic ophiolites (Table 1) originated mainly in suprasubduction
5 zone settings (e.g., oceanic arcs, backarc basins, and forearcs) and are characterized by
6 millimetre grain size and centimetre to decimetre thick layers, in contrast to hundreds of
7 meters to several kilometres thick Archaean megacrystic anorthosites.
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10 We suggest that changes in the nature of anorthosites occurring in oceanic settings
11 in Archaean and post-Archaean times reflect the thermal evolution of the Earth.
12 Irreversible heat loss of the Earth led to upper mantle cooling by the end of the
13 Archaean to a level at which it could no longer produce 25-35% partial melting, except
14 within mantle plumes, beneath oceanic arcs and spreading centres. Large degrees of
15 partial melting in the Archaean mantle led to the formation of mineralogically-stratified,
16 km-scale magma chambers beneath spreading centres and magmatic arcs. These magma
17 chambers consisted mainly of olivine-, pyroxene-, hornblende-, and plagioclase-rich
18 crystal mushes (Fig. 7), and cooled slowly in response to higher geothermal gradients in
19 the oceanic crust and magmatic arcs, providing optimum petrological conditions for the
20 formation of megacrystic plagioclase in anorthosites and leucogabbros (Fig. 7). In
21 addition to higher mantle temperatures, the presence of water in Archaean
22 suprasubduction zone magmas might have played an important role in the formation of
23 plagioclase megacrysts by enhancing the magma cooling time and element diffusion
24 rates. Because of declining ambient mantle temperatures and geothermal gradients in
25 the oceanic crust, the generation of large, mineralogically stratified magma chambers
26 decreased and eventually ceased by the end of the Archaean Eon, leading to the
27 termination of the formation of high-Ca megacrystic anorthosites in post-Archaean
28 oceanic environments.
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Table and Figure Captions

Table 1. List of known anorthosite-bearing Phanerozoic ophiolites and their interpreted geodynamic setting.

Table 2. Major (wt.%) and trace element (ppm) compositions and significant element ratios of megacrystic plagioclase in leucogabbros at Sinarssuk, Fiskeneset Complex.

Data Repository Table 1. Scanning Electron Microscope (SEM)-Energy Dispersive Spectroscopy (EDS) major element (wt.%) data and An content of plagioclase in leucogabbros and hornblendites in the Fiskeneset Complex.

Figure 1. Simplified geological map of southern West Greenland showing the Mesoproterozoic crustal blocks of Ivittuut, Kvanefjord, Bjørnesund, Sermilik, Fiskefjord, and Maniitsoq (modified from Windley & Garde, 2009).

Figure 2. (a) Simplified tectonic map of the Superior Province (modified from Percival et al. 2012). A: Ashuanipi; B: Bienville; DH: Douglas Harbour; E: Eastmain; ERB: English River Belt; G: Goudalie; HBT: Hudson Bay Terrane; ILD: Island Lake Domain; KU: Kapuskasing Uplift; LG: La Grande; LM: Lac Minto; MRVT: Minnesota River Valley Terrane; MT: Marmion Terrane; NCT: North Caribou Terrane; O: Opatoca; Op: Opinaca; OSD: Oxford-Stull Domain; PB: Pontiac Belt; Q: Qalluviartuuq; QB: Quetico Belt; T: Tikkerutuk; U: Utsalik; UD: Uchi Domain; WAT: Wawa-Abitibi Terrane; WRT: Winnipeg River Terrane; WWT: Western Wabigoon Terrane.

Figure 3. Field photographs of megacrystic leucogabbro and anorthosites in the Fiskeneset Anorthosite Complex, western Greenland, showing the various stages of anorthosite development. Permanent marker has a length of 15 cm. (b) modified from Polat et al. (2009); (c) modified from Huang, Polat, Fryer, Appel, & Windley (2012).

Figure 4. Field photographs of leucogabbros, anorthosites, and differentiated sills in the Sinarssuk area of the Fiskeneset Anorthosite Complex, West Greenland. (a) modified

1 from Polat et al. (2011); (b) and (d) modified from Polat et al. (2009); (c) and (f)
2 modified from Huang et al. (2012).
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5 **Figure 5.** Field photographs of anorthosites in the Ivisaartoq greenstone belt (a and b),
6 and the Bad Vermilion Lake (c and d) and Doré Lake (e and f) anorthosite complexes.
7 (e) modified from Polat, Frei, Longstaffe, & Woods (2017).
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12 **Figure 6.** N-MORB-normalized trace element patterns for the Ivisaartoq (a) Fiskenasset
13 (b), Bad Vermilion Lake (c), and Doré Lake (d) anorthosites. Data for (a), (b), (c) and
14 (d) from Polat et al. (2008), Polat et al. (2009), Zhou et al. (2016), and Polat, Frei,
15 Longstaffe, & Woods, (2017), respectively. Normalization values are from Sun &
16 McDonough (1989).
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23 **Figure 7.** Simplified geodynamic model for the origin of Archaean anorthosite-bearing
24 layered intrusions (modified from Polat et al., 2008). (c) shows an example of
25 mineralogically stratified sill, representing a small version of Archaean magma
26 chambers.
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32 **Figure 8.** Field photographs of plagioclase megacrysts in the Fiskenasset Complex.
33 Dark to grey cores are relict igneous plagioclase, whereas clear to white rims and
34 patches represent the recrystallized metamorphic plagioclase. (b) modified from Huang,
35 Fryer, Polat, & Pan (2014); (d) modified from Polat et al. (2009).
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42 **Figure 9.** Photomicrographs across two megacrystic plagioclase grains, illustrating the
43 preservation of igneous plagioclase in the Fiskenasset Complex despite deformation
44 and metamorphism. Optical continuity (e.g., albite twinning) in igneous plagioclase
45 grains suggests that they formed as 6-8 cm long single crystal in a magma chamber.
46 Albite twins in large igneous crystals are overprinted by smaller metamorphic crystals.
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**An overview of anorthosite-bearing layered intrusions in the
Archaean Craton of southern West Greenland and the
Superior Province of Canada: Implications for Archaean
tectonics and the origin of megacrystic plagioclase**

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Figure 1

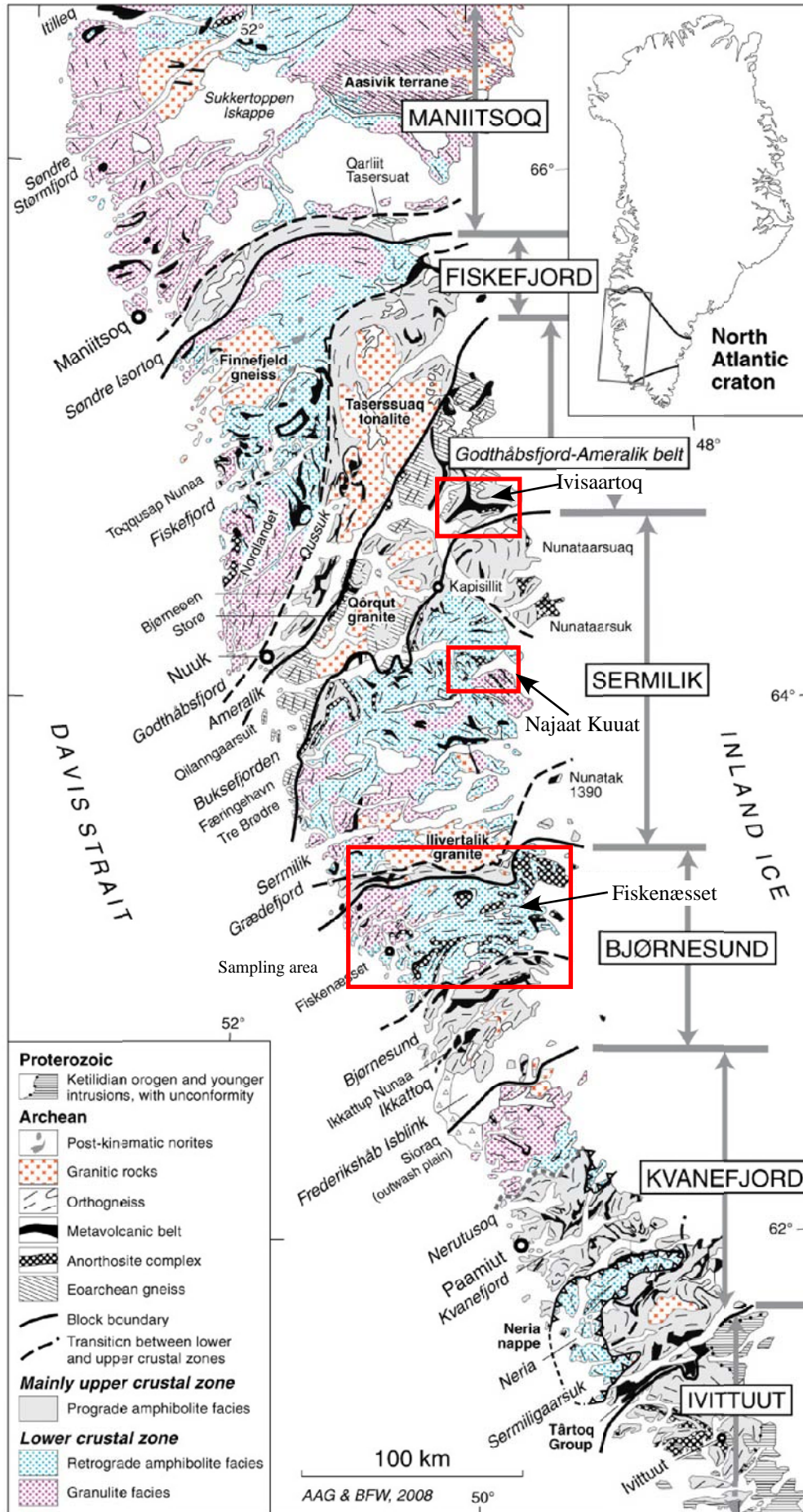


Figure 2

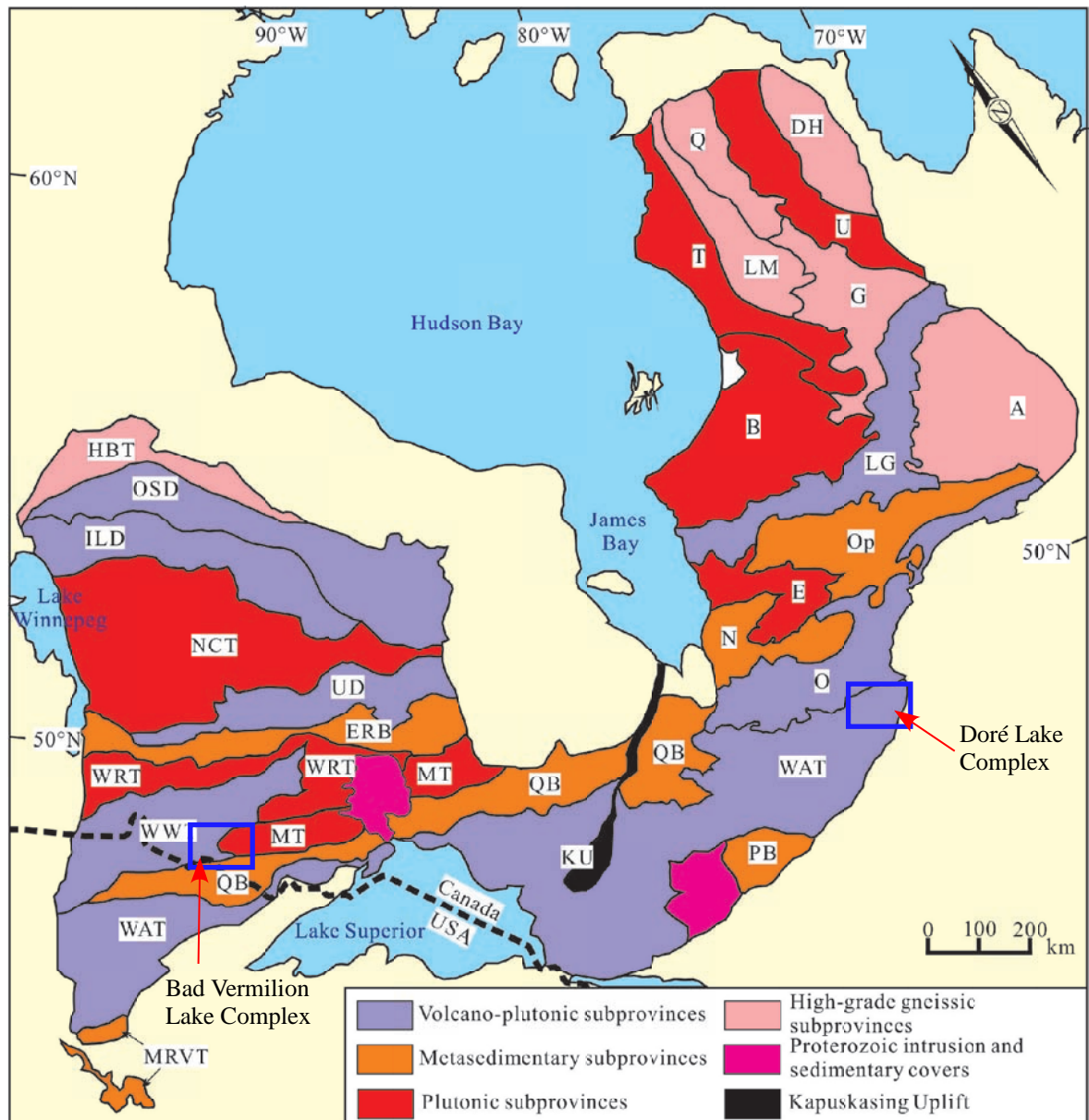


Figure 3

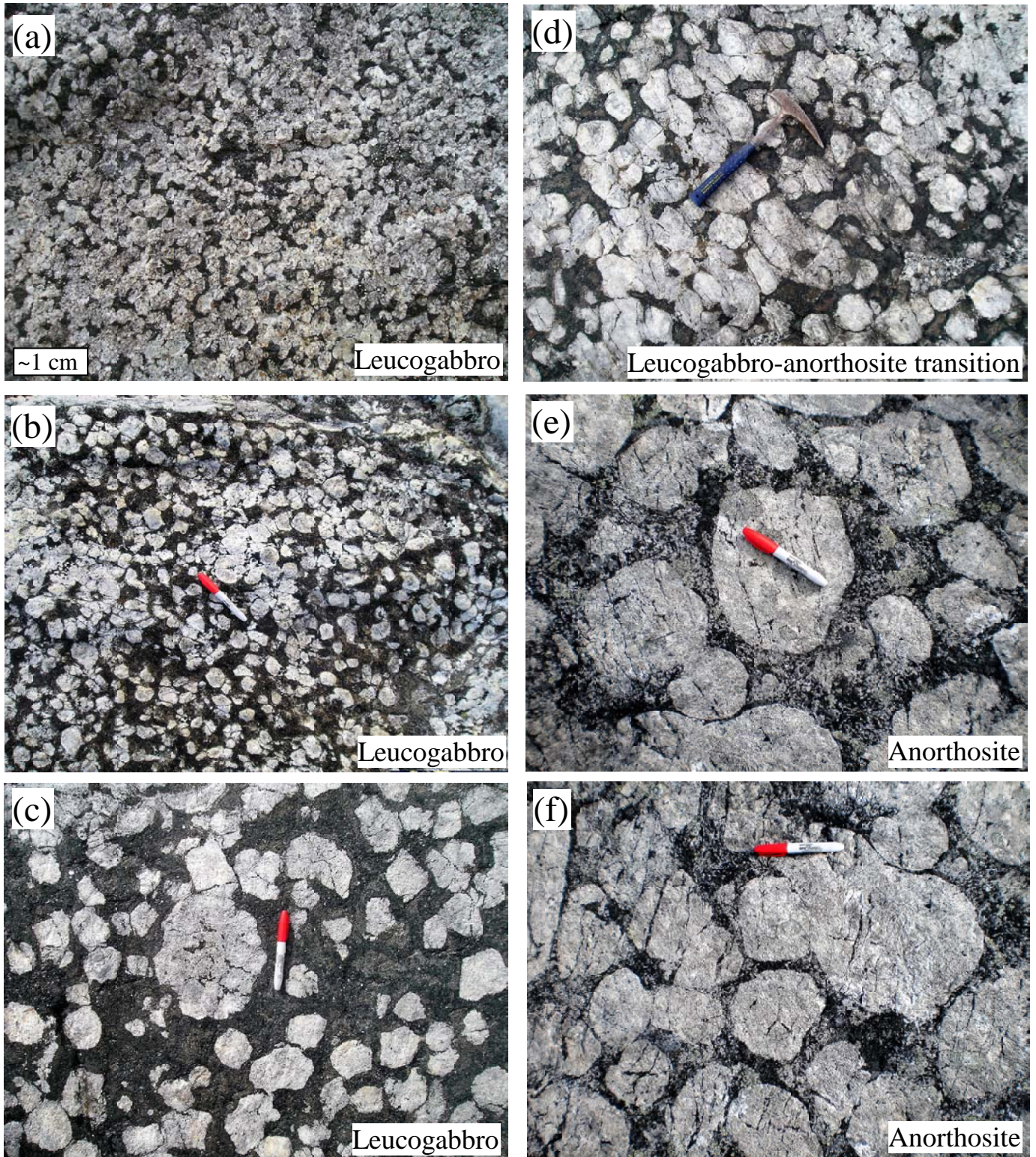


Figure 4

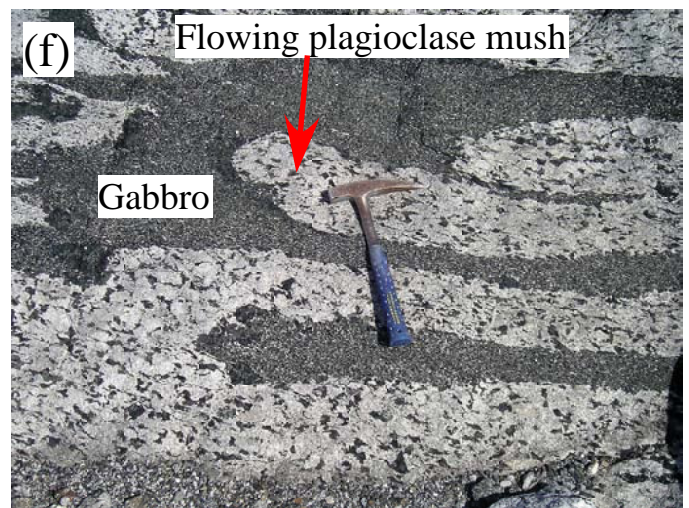
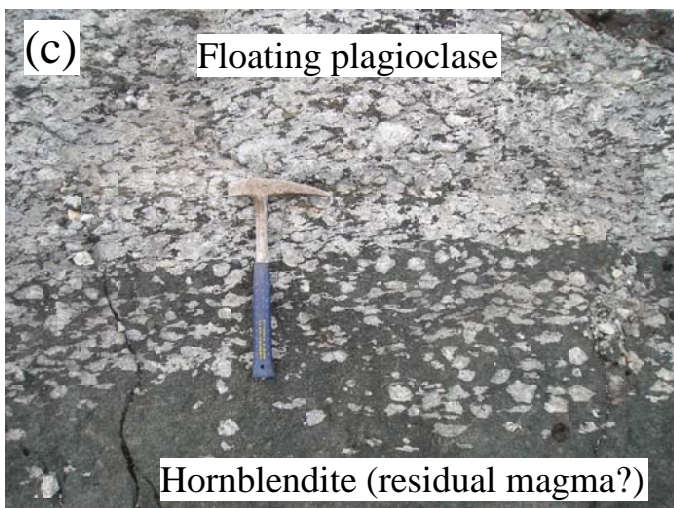
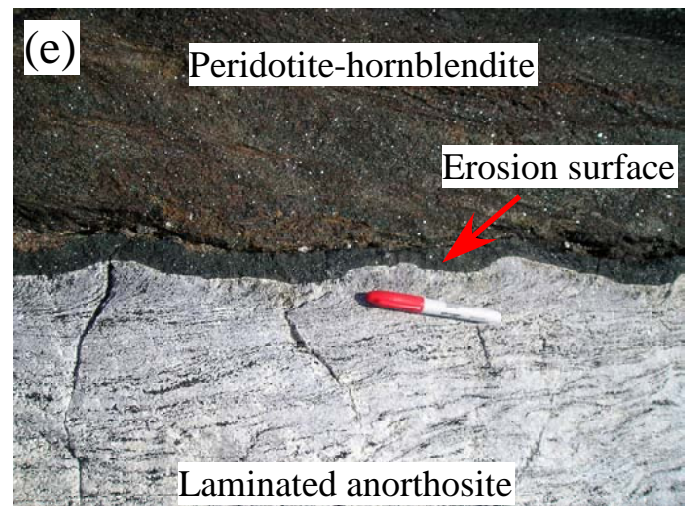
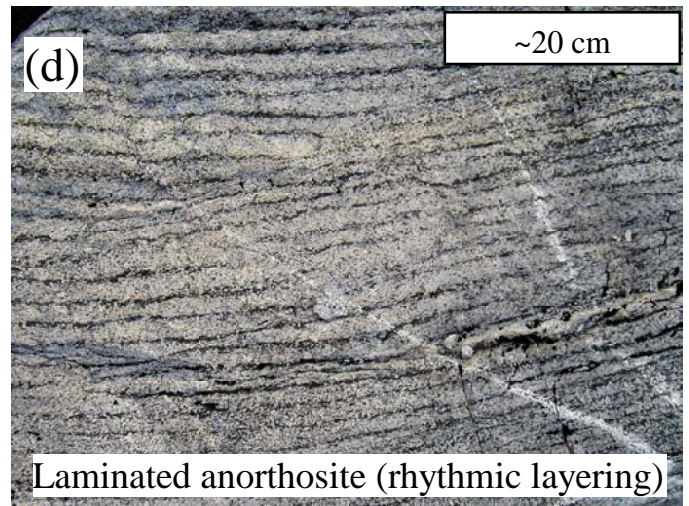
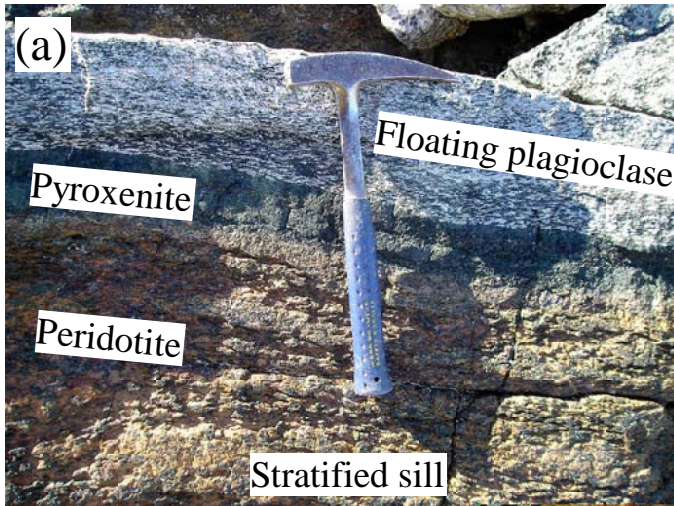


Figure 5



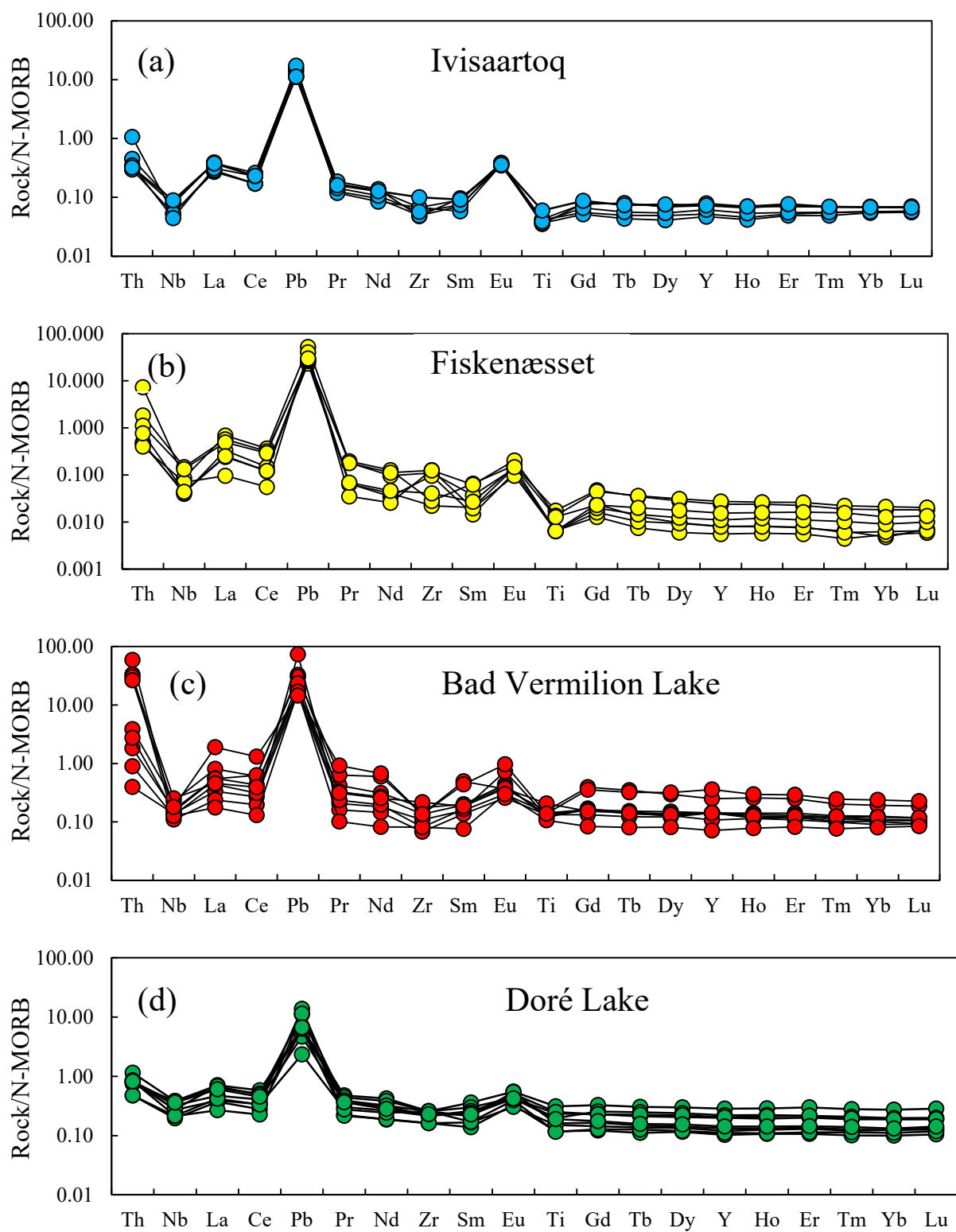
Figure 6

Figure 8

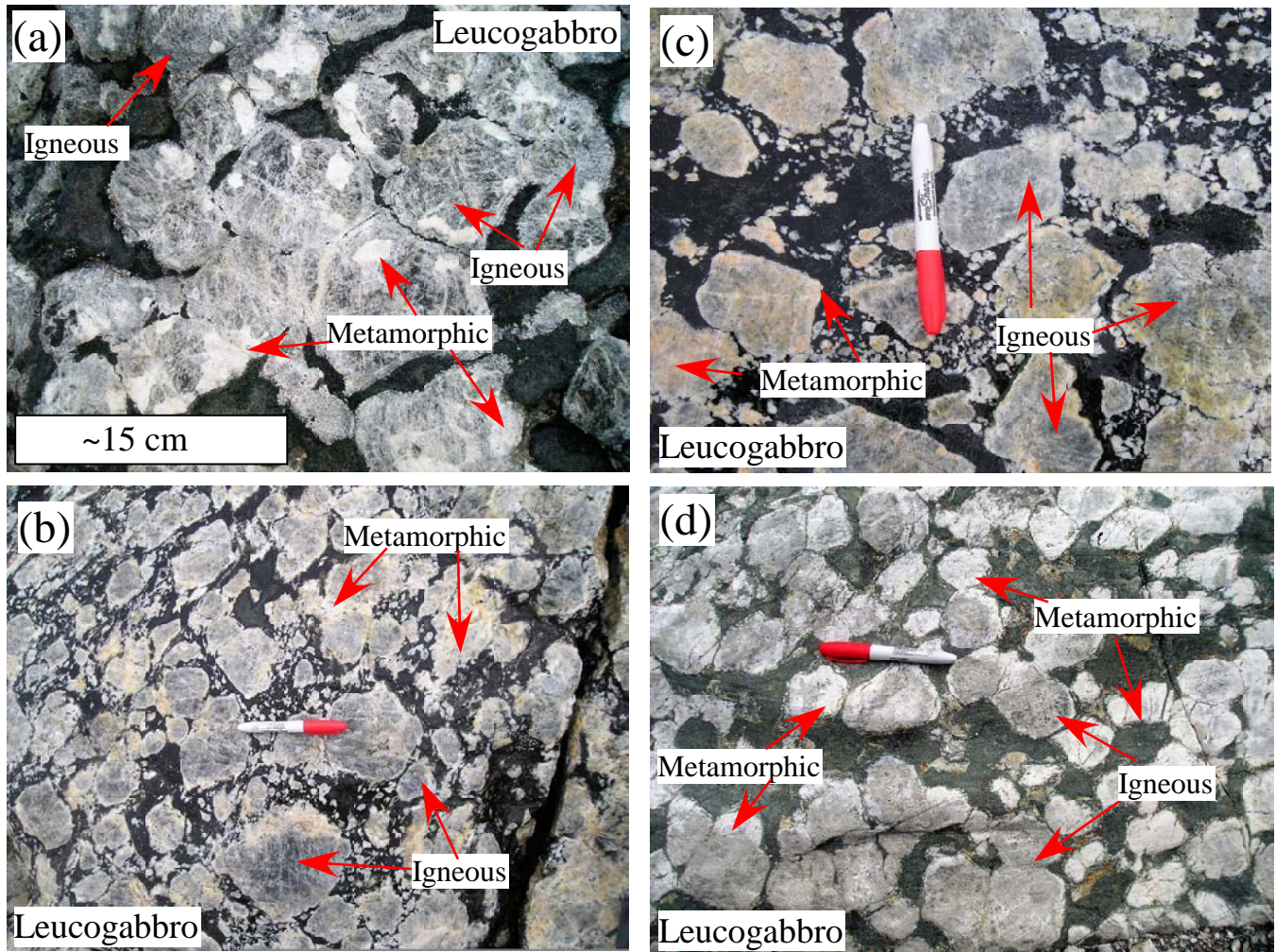
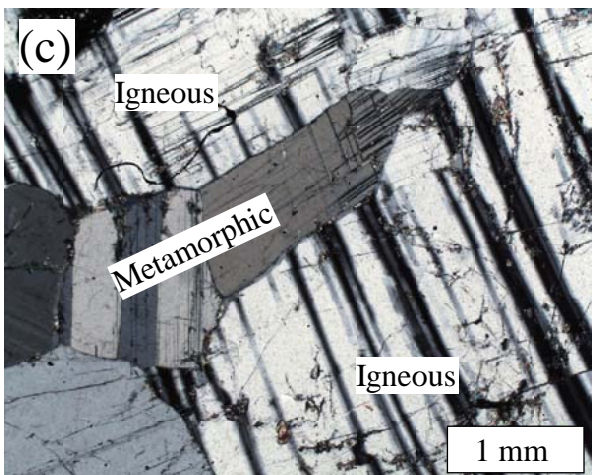
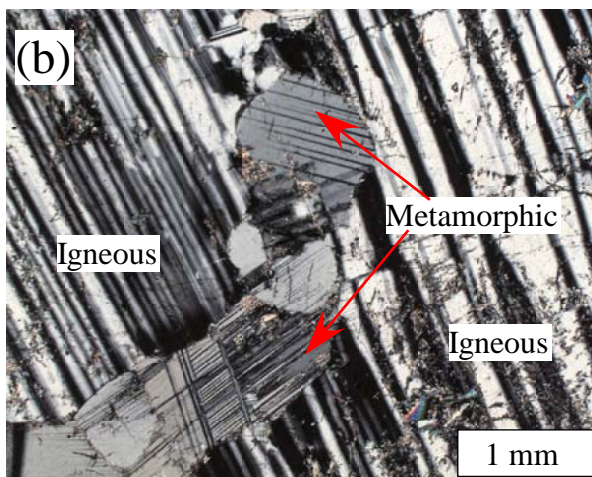
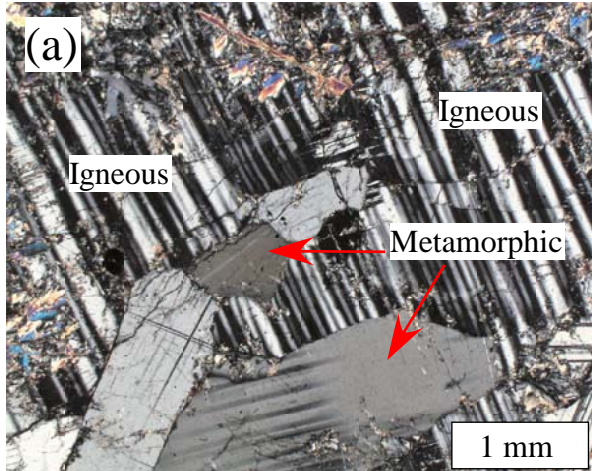


Figure 9

Sample 508144



Sample 508146

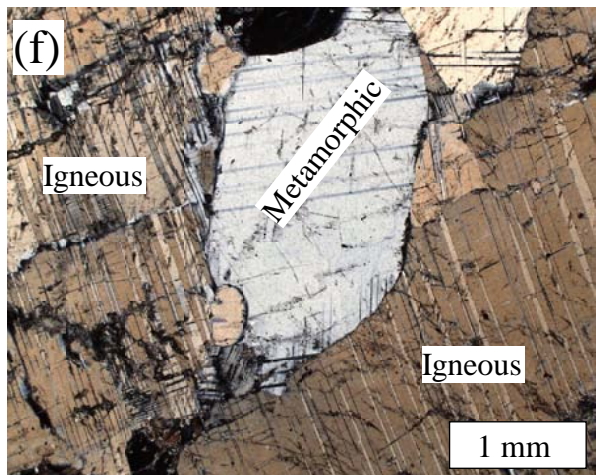
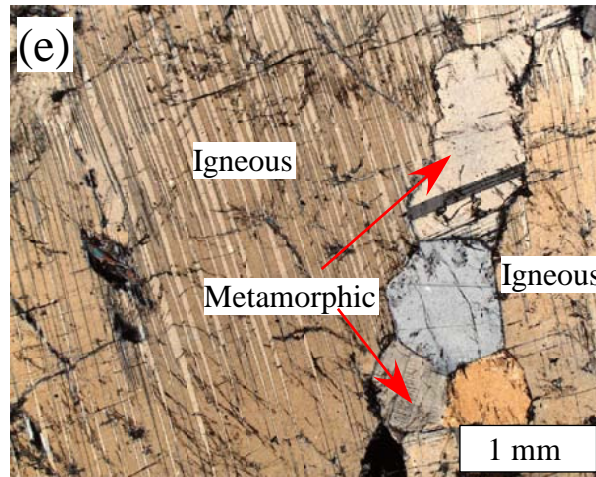
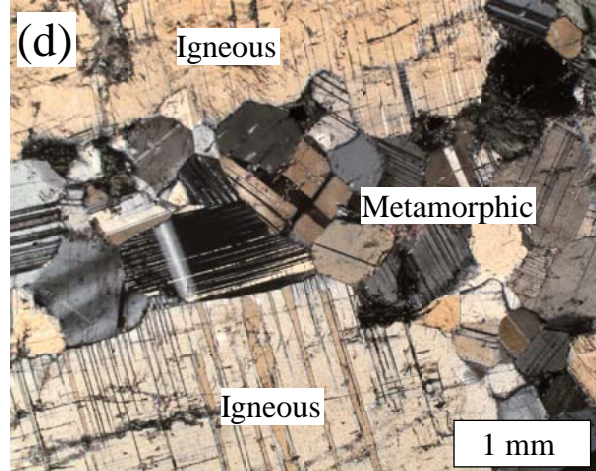


Table 1. List of known anorthosite-bearing Phanerozoic ophiolites and their interpreted geodynamic setting.

Ophiolite	Age	Interpreted geodynamic setting	References
Camaguey Ophiolite, Cuba	Jurassic	Suprasubduction zone	Henares et al. (2010)
Mazhalyk Ophiolite, Russia	Ordovician	Suprasubduction zone, island arc	Borodina et al. (2004)
Zambales Ophiolite, the Philippines	Eocene	Suprasubduction zone	Hawkins (2007)
Talazhinskiy Ophiolite, Russia	Paleozoic?	Suprasubduction zone	Yurichev and Chernyshov (2014)
Chilas Complex, Pakistan	Jurassic - Cretaceous	Suprasubduction zone, island arc	Khan et al. (1989)
Bay of Islands Ophiolite, Newfoundland (Canada)	Ordovician	Suprasubduction zone	Komor and Elthon (1990)
Zhaheba Ophiolite, China	Cambrian-Ordovician	Suprasubduction zone	Jian et al. (2003)
Halifax County Complex, North Carolina (USA)	Early Paleozoic	Suprasubduction zone, island arc	Kite and Stoddard (1984)
Troodos Ophiolite, Cyprus	Cretaceous	Suprasubduction zone, backarc basin	Zirner et al. 2013
Urmia Ophiolite, Iran	Devonian	Suprasubduction zone, island arc	Fazlnia and Alizade (2013)
Solonker Ophiolite, China and Mongolia	Permian-Triassic	Mid ridge to island arc	Jian et al. (2010)
Kahnuj Ophiolite, Iran	Jurassic-Cretaceous	Mid ocean ridge	Arvin et al. (2005)
Mariana Arc, the Philippines	Cenozoic	Suprasubduction zone, backarc basin	Newman et al. (2000), Hawkins (2007)
Buck Creek Ophiolite, North Carolina (USA)	Paleozoic	Suprasubduction zone	Peterson et al. (2009)
Karayasmak Alaskan-type intrusion, Turkey	Carboniferous	Suprasubduction zone	Eyuboglu et al. (2010)
Hongliugou Ophiolite, China	Cambrian-Ordovician	Suprasubduction zone	Yang et al. (2008)
Lizard Ophiolite, England	Devonian	Suprasubduction zone	Leake and Styles (1984)
Oman Ophiolite, Oman	Cretaceous	Suprasubduction zone	Boudier and Nicolas (2011a, 2011b)
Jinshajiang Ophiolite, China	Carboniferous?	Unkonwn	Jian et al. (1999)
Leka Ophiolite, Norway	Cambrian-Ordovician	Unkonwn	Austrheim and Prestvik (2008)
Othrys Ophiolite, Greece	Mesozoic	Suprasubduction zone?	Mitsis and Economou-Eliopoulos (2001)
East Sulawesi Ophiolite, Indonesia	Cenozoic	Suprasubduction zone, mid ocean ridge	Partkinson (1998); Kadarusman et al. (2004)
Elder Creek Ophiolite, California (USA)	Mesozoic	Suprasubduction zone, forearc	Shervais (2003)

Table 2. Major (wt.%) and trace element (ppm) compositions and significant element ratios of megacrystic plagioclase in leucogabbros at Sinarssuk, Fiskenæsset Complex

	508142	508144	508146	508148	508154	508156	508161	Average (n=7)
SiO ₂	47.72	46.90	46.71	47.68	48.72	48.22	47.09	47.58
TiO ₂	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01
Al ₂ O ₃	32.76	32.99	33.51	33.22	31.90	32.35	32.86	32.80
Fe ₂ O ₃	0.48	0.90	0.52	0.53	0.83	0.80	1.10	0.74
MnO	0.02	0.01	0.02	0.02	0.01	0.01	0.02	0.02
MgO	0.18	0.30	0.22	0.31	0.30	0.22	0.33	0.27
CaO	15.34	16.14	16.77	14.94	15.31	15.79	16.22	15.79
K ₂ O	1.81	0.97	0.48	1.48	0.33	0.28	0.40	0.82
Na ₂ O	1.65	1.75	1.77	1.80	2.55	2.28	1.96	1.97
P ₂ O ₅	0.01	0.03	0.01	0.01	0.03	0.02	0.01	0.02
LOI	2.64	1.77	1.13	1.66	0.99	0.97	0.74	1.41
Mg-number (%)	43	40	46	53	42	36	37	42
An-content (%)	82	86	86	82	78	80	85	83
Co	2	2	2	2	3	2	3	2
Rb	63	38	18	54	10	10	12	29
Sr	165	145	112	172	143	177	122	148
Cs	0.44	0.52	0.14	0.79	0.12	0.13	0.09	0.32
Ba	232	115	51	307	45	41	65	122
V		8.1		5.1	7.1	5.0	7.1	6.5
Ta	0.018	0.007	0.015	0.018	0.034	0.035	0.012	0.02
Nb	0.201	0.092	0.100	0.162	0.342	0.310	0.102	0.19
Zr	8.15	7.13	1.64	9.35	2.07	9.23	3.02	5.80
Hf	0.189		0.038	0.208	0.063	0.235	0.053	0.13
Th	0.881	0.059	0.055	0.048	0.221	0.134	0.093	0.21
U	0.446	0.018	0.023	0.097	0.113	0.085	0.071	0.12
Y	0.23	0.16	0.22	0.31	0.67	0.77	0.43	0.40
La	1.712	0.827	0.604	0.240	1.428	1.223	0.625	0.95
Ce	2.722	1.118	0.903	0.417	2.382	2.198	0.911	1.52
Pr	0.238	0.086	0.084	0.046	0.257	0.236	0.091	0.15
Nd	0.706	0.252	0.297	0.187	0.922	0.812	0.339	0.50
Sm	0.097	0.038	0.053	0.052	0.172	0.163	0.071	0.09
Eu	0.140	0.116	0.145	0.098	0.164	0.208	0.149	0.15
Gd	0.087	0.047	0.059	0.073	0.173	0.164	0.084	0.10
Tb	0.009	0.005	0.007	0.010	0.023	0.024	0.014	0.01
Dy	0.044	0.027	0.042	0.056	0.128	0.141	0.081	0.07
Ho	0.008	0.006	0.008	0.012	0.024	0.027	0.016	0.01
Er	0.022	0.017	0.023	0.033	0.066	0.077	0.048	0.04
Tm	0.003	0.002	0.003	0.005	0.009	0.010	0.007	0.01
Yb	0.015	0.016	0.019	0.028	0.055	0.065	0.039	0.03
Lu	0.003	0.003	0.003	0.005	0.008	0.009	0.006	0.01
Cu	6.0			19.9	4.9	8.5	8.0	9.45
Ga	87	64	50	108	47	49	51	65
Pb	15.7	7.0	8.0	12.1	8.1	8.6	8.9	9.8
Li	19.9	14.0	14.4	19.3	13.5	11.5	12.9	15.1
La/Sm _{cn}	11.41	13.91	7.31	3.00	5.35	4.83	5.66	7.35
La/Yb _{cn}	83.7	36.2	22.8	6.2	18.6	13.6	11.5	27.5
Gd/Yb _{cn}	4.92	2.39	2.59	2.17	2.60	2.10	1.79	2.65
Eu/Eu*	4.66	8.30	7.88	4.91	2.91	3.88	5.88	5.49
Ce/Ce*	1.05	1.03	0.98	0.97	0.96	1.00	0.94	0.99
Pb/Pb*	327	591	845	3741	186	222	900	462
Al ₂ O ₃ /TiO ₂	3988	3994	4144	4046	1438	1883	2019	3073
Nb/Nb*	0.06	0.15	0.20	0.55	0.22	0.28	0.15	0.23
Zr/Zr*	2.18	5.05	0.91	6.65	0.36	1.77	1.36	2.61
Ti/Ti*	0.13	0.20	0.17	0.17	0.26	0.20	0.29	0.20
North	63° 21' 24.2"	63° 21' 24.2"	63° 21' 22.6"	63° 21' 21.4"	63° 20' 56.7"	63° 20' 56.7"	63° 21' 06.2"	
West	49° 16' 42.3"	49° 16' 42.3"	49° 16' 42.5"	49° 16' 41.8"	49° 16' 17.2"	49° 16' 17.2"	49° 16' 28.7"	

Supplementary Data Table 1. Scanning Electron Microscope (SEM)-Energy Dispersive Spectroscopy (EDS) major element (wt.%) data and anorthite (An%) content of plagioclase in leucogabbros and hornblendites in the Fiskenæsset Complex

Sample#	509193 (Leucogabbro)							
Spot#	1	2	3	4	5	6	7	8
Na ₂ O	2.1	3.2	2.3	2.3	1.6	2.5	2.3	3.0
Al ₂ O ₃	33.9	31.7	33.8	33.4	34.7	33.3	33.2	32.2
SiO ₂	49.2	51.9	49.7	49.6	48.1	49.8	50.0	51.3
CaO	14.8	13.1	14.2	14.7	15.7	14.4	14.5	13.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
An (%)	76	66	75	75	81	74	74	68

Sample#	509092 (Leucogabbro)					
Spot#	1	2	3	4	5	6
Na ₂ O	2.3	1.6	1.7	1.9	1.9	1.6
Al ₂ O ₃	33.7	34.7	35.0	34.1	34.2	34.7
SiO ₂	49.0	48.0	47.9	48.7	48.2	48.0
CaO	15.0	15.7	15.4	15.4	15.8	15.7
Total	100.0	100.0	100.0	100.0	100.0	100.0
An%	77	81	82	79	80	81

Sample#	509103 (Hornblendite)										
Spot#	1	2	3	4	5	6	7	8	9	10	11
Na ₂ O	1.11	1.04	1.08	0.99	0.89	0.97	1.04	1.12	0.93	1.00	1.07
Al ₂ O ₃	36.76	36.62	36.91	37.12	36.67	36.65	36.5	36.84	36.3	36.42	36.76
SiO ₂	45.54	45.62	45.24	45.09	45.84	45.67	45.56	45.79	47.26	45.64	45.62
CaO	16.59	16.71	16.77	16.79	16.6	16.71	16.9	16.24	15.51	16.95	16.55
Total	100	100	100	100	100	100	100	100	100	100	100
An (%)	92	93	90	90	90	90	91	90	90	90	91