Mildly peraluminous high-silica granites in the central part of the Oslo graben. In: Andersen T. (1996): Eurogranites-1996, Field Guide

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Introduction

The plutonic rocks of the Oslo graben are distributed in three main complexes, geographically separated by outcrops of Permian lavas and Cambro-Silurian sedimentary rocks (Fig. 1). The northern Akershus graben segment is occupied by the Nordmarka-Hurdalen batholith of mostly syenitic and granitic alkaline rocks and some intrusions of biotite granite and monzonite. Biotite granites of the Drammen and Finnemarka batholiths dominate the central part of the Oslo Graben (northern part of the Vestfold graben segment). These batholiths cover areas of 650 and 125 km^2 respectively, and the Drammen batholith is the largest granitic complex in the rift. Two largely monzonitic batholiths (the Larvik–Siljan and Skrim massifs) occupy the southern part of the southern Vestfold rift segment. The largest peralkaline granite body (the Eikeren massif) forms the northern extension of the Skrim massif.

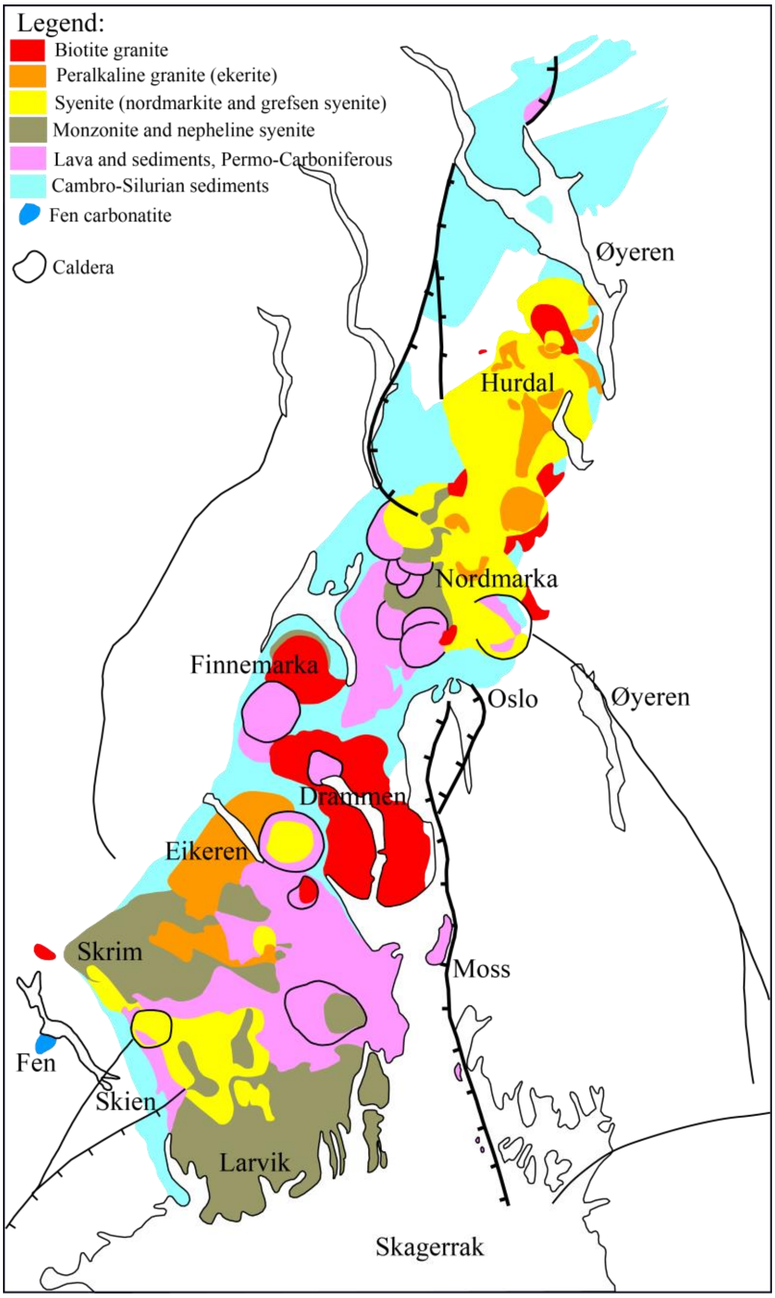


Fig. 1. Simplified geological map of the Vestfold and Akershus half grabens, Oslo Rif

The magmas of the basaltic and latitic (rhomb porphyry) lavas and the large monzonitic (larvikitic) intrusions evolved mainly by differentiation of weakly alkaline and tholeiitic basaltic magmas in the lower crust (Neumann 1980; Neumann et al. 1985). An elongate gravity anomaly along the axis of the Oslo Rift has been associated with dense cumulates and residues from partial melting in the lower crust (Ramberg 1976; Wessel and Husebye 1987; Olsen et al. 1987; Neumann et al. 1986). Based on combined Sr, Nd and Pb isotope systematics and trace element chemistry, Neumann et al. (1988) and Rasmussen et al. (1988) concluded that the anatectic crustal contribution was insignificant for some of the basalts and for most of the larvikites, but that the syenitic and granitic magmas received up to 40-50% anatectic contributions. Samples from the large biotite granite complexes in the central rift segment were not included in these studies, and chemical and isotopic variations within large intrusive bodies were not investigated.

The peralkaline granites (ekerites with alkali pyroxenes and amphiboles) occur mostly in composite batholiths involving monzonitic and syenitic rocks, and commonly show gradual transitions into these rock types, especially in the northern rift segment. Gaut (1981) suggested a two-fold division of the biotite granites. He classifed relatively early intrusions without transitions to other rock types as BG1 and late intrusions intimately associated with syenitic rocks as BG2. The mildly peraluminous Drammen granite, spatially isolated from other intrusive rocks, is the most prominent example of a BG1. Recent mapping by Stenstrop (1989), however, has shown that the most widespread rock type within the Finnemarka batholith is metaluminous to peralkaline BG2 and that peraluminous to metaluminous BG1 is confined to the southern part of the batholith. The northern Finnemarka BG2 is rimmed by intermediate intrusives, and Stenstrop (1989) suggested that the granitic rocks are derived from mafic and intermediate magmas by fractional crystallization.

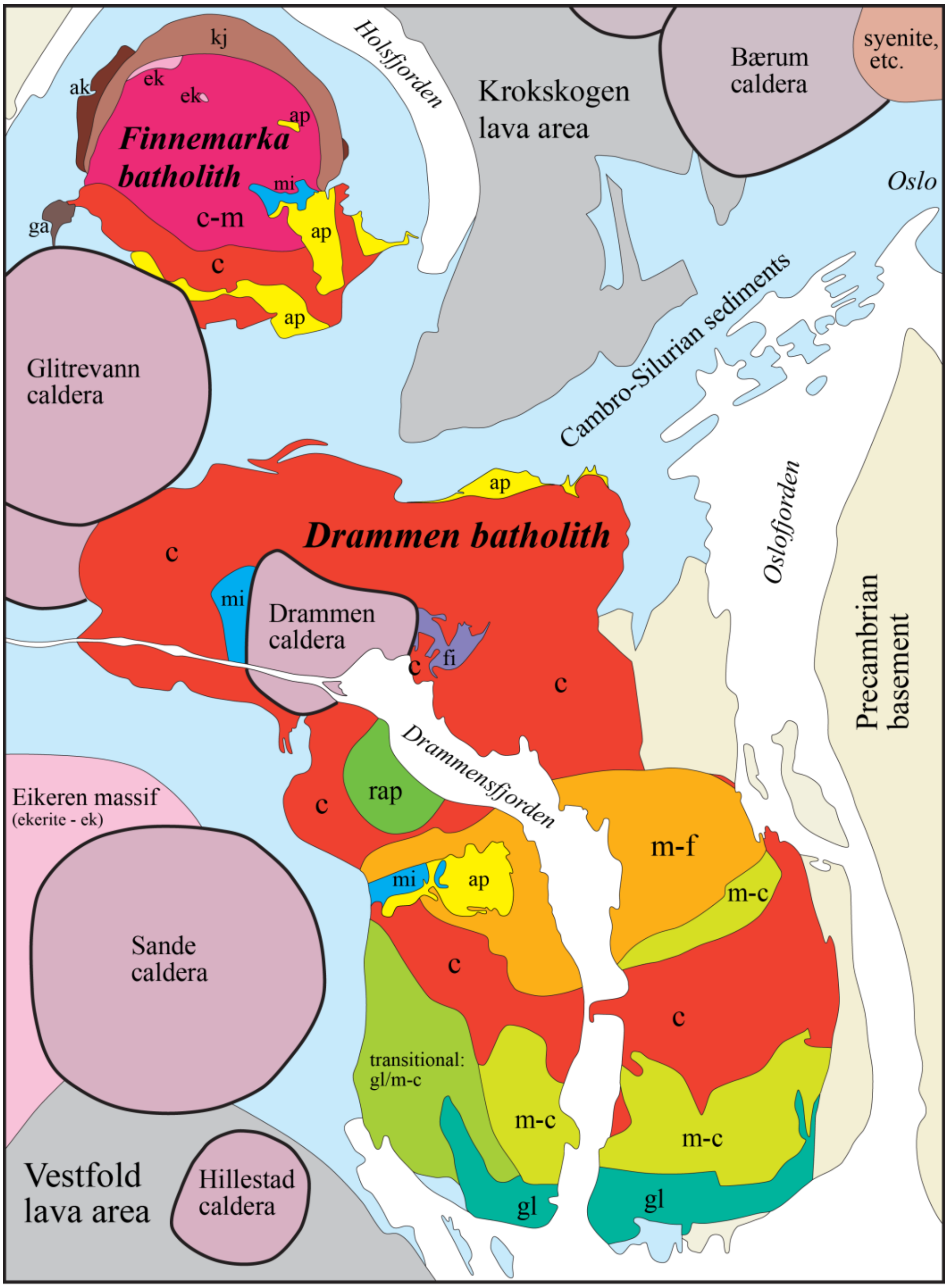
The members of the BG1-category, including the Drammen batholith, are mostly older than the alkaline syenites and granites (ca. 280 Ma versus 270-240 Ma, respectively; Jacobsen and Raade 1975; Sundvoll, 1978; Gaut 1981; Rasmussen et al. 1988; Sundvoll et al. 1990). It is therefore possible that these biotite granites are largely unrelated petrogenetically to the the main Oslo Rift magmatic series, and several authors including Barth (1954, 1962), Killeen and Heier (1975), Ramberg (1976) and Neumann et al. (1977), suggested that they were formed by crustal anatexis. $^{87}Sr/^{86}Sr$ initial ratios, however, indicate that the source regions for the BG2 had relatively low time integrated Rb/Sr-ratios, almost indistinguishable from the other intrusives (Sundvoll 1978). Based on a reconnaissance Sr-Nd-isotopic survey, Jacobsen and Wasserburg (1978) concluded that none of the felsic rocks, including the biotite granites, could have formed by crustal melting.

The apparent contradiction between mildly peraluminous major element chemistry and isotopic mantle signatures of the southern part the Finnemarka and Dranmmen complexes was addressed by Trønnes and Brandon (1992). They found that the southern part of Finnemarka is indistinguishable from the most primitive mafic to intermediate rocks (Neumann et al. 1988) in terms of the Sr-Nd-isotopic compositions and that samples from the northern part of the Drammen complex lies on mixing lines with lower crustal components (20–50% lower crustal components). All of the analysed samples from these two complexes are characterized by less radiogenic Pb-compositions than the most primitive mafic to intermediate rocks (Neumann et al. 1988). In particular, the Drammen and Finnemarka batholiths seem to record a time-integrated lithospheric Th-depletion confined to the northern part of the Vestfold rift segment. The central and southern part of the Drammen batholith have greatly elevated $^{87}Sr/^{86}Sr$-ratios due to significant upper crustal contamination and/or interacition with upper crustal fluids.

Intrusive phases and field relations

<u>*Petrography of the Drammen batholith*</u>

The spatial distribution of the main petrographic varieties are shown in Fig. 2. In addition to these rock types numerous aplite and pegmatite dikes, veins and irregular segregations are found throughout the area but are concentrated in the central part of the batholith. Post-magmatic explosion breccias transecting the granites are observed close to the southern margin of the Drammen Caldera in the coarse grained granite type and 4 km to the southwest in the rapakivi granite.



Abbreviations
ga: gabbro
ak: akerite (qz. monzodiorite)
kj: kjelsåsite (qz. syenomozonite)
ek: ekerite (peralkaline granite)
c: coarse-grained granite
c-m: coarse- to medium-grained gr.
m-c: medium- to coarse-grained gr.
m-f: medium- to fine-grained gr.
ap: aplitic porhyry
mi: microcrystalline porphyry
fi: fine-grained porphyry
gl: glomeroporpyritic granite
rap: rapakivi granite

References:
Finnemarka complex:
Stenstrop (1989, Ph.D. thesis, Univ. Aarhus)
Drammen complex:
Trønnes & Brandon (1992, Contr. Mineral. Petrol. 109, 275-294)

Fig. 2. Simplified geological map of the central part of the Oslo Rift

Perthitic alkali feldspar, recording various stages of albite exsolution, is the dominant mineral in all of the granites, and small amounts of early crystallized plagioclase (oligoclase, An_{20}) grains are present in parts of the coarse grained granite, especially in the northern area. Microcline is absent from all of the granite types. Evenly distributed Fe-oxide dust throughout most of the feldspar crystals give the rocks a distinctly red colour. Partly chloritized biotite is the most abundant mafic silicate, occurring in all of the petrographic types. The biotites are most remarkable for their high F-contents. Minor amounts of amphibole and epidote occur in the course grained granite and the rapakivi granite, and small amounts of muscovite, fluorite, topaz, carbonate and pyrite are present locally, and in particular in the central part of the batholith. Fe-Ti-oxides, titanite, zircon, and apatite are widespread accessories.

The most widespread petrographic variety of the Drammen batholith is an equigranular ***coarse-grained granite*** (3-5 mm grain size) containing generally less than 3-5 vol% of early crystallized oligoclase in addition to the common mineralogy of quartz (30-35 vol%) and perthitic alkali feldspar (60-65%). The area west of the Drammen Caldera and a 0.5-2 km wide border zone along the northeastern margin, contains a variety with up to 5-10 vol% oligoclase. The oligoclase crystals have frequently undergone partial hydrothermal bleaching. Microscopically the late- to post-magmatic bleaching can be recognized by the precipitation of red iron oxide (hematite) along microcracks in feldspar crystals devoid of the otherwise evenly distributed Fe-oxide dust. Locally, the coarse grained granite, and in particular the oligoclase-rich variety, contains up to 25% fine-grained interstitial groundmass.

A coarse-grained ***cumulophyric granite*** is confined to a 2 km wide zone along the southern margin of the batholith. Subhedral and somewhat rounded phenocrysts of perthitic feldspar, (8-15 mm) are incompletely surrounded by a interstitial medium-grained (3 mm) granitic matrix. This granite type has the highest content of the accessory minerals titanite, zircon and Fe-Ti-oxides. Gradual transitions into an equigranular ***medium- to coarse-grained granite*** occur futher northwards.

South of the Drammen Caldera the coarse-grained granite is transected by a sub-circular ***rapakivi granite*** pluton. Zoned feldspar ovoids (5-15 mm in diameter) comprising large perthitic cores and thin albitic rims are set in a fine-grained quartz-rich groundmass (0.5-1 mm). The feldspar ovoids constitute about 50% of the rock volume. The primary magmatic biotite is almost completely chloritized, and epidote and amphibole are quite widespread.

The central part of the Drammen batholith is dominated by a ***medium- to fine-grained granite***, characterized by a remarkably low content of mafic minerals. Muscovite and flourite are more conspicious than in the other rock types. With an average grain size varying from 1 to 3 mm, the granite shows gradual transitions into the aplitic porphyry in the same area.

Three petrographic varieties of quartz-feldspar porphyries are present in the batholith. A ***microcrystalline porphyry*** with 3-5 mm rounded phenocrysts of quartz (30%) and perthitic alkali feldspar (70%) occurs close to the western central margin of the batholith (Røysjø area) and along the western margin of the Drammen Caldera (Landfall area), respectively. Aggregates of ilmenorutile and topaz in a limited area are most likely of post-magmatic, hydrothermal origin. Directly east of the microcrystalline porphyry in the central part of the batholith is an area of mainly quartz-phyric and leucocratic ***aplite porphyry*** (1-3 mm phenocrysts in a 0.5 mm groundmass). A small body of aplitic porphyry is also present along the northern border of the batholith. The ***fine-grained porphyry*** east of the Drammen Caldera contains 5-15 mm phenocrysts of mainly perthitic alkali feldspar and minor quartz in a 1 mm groudmass.

Field relations and intrusive sequence, Drammen batholith

The Drammen batholith intrudes Precambrian gneisses to the east and Cambro-Silurian sedimentary rocks to the north, west and south. Permian extrusives of the Glitrevann Caldera border the northwestern corner of the granite complex (Fig. 2). The emplacement of the granite batholith pre-dates the subsidence of the Drammen and Glitrevann Calderas (Gaut 1981 and Stenstrop, pers. comm., 1991).

Gravimetric data indicate that the batholith is a relatively thin (about 3 km thick) tabular body with one or more root-like extensions in the eastern-central area (Ramberg 1976). Alternatively the data could be interpreted as a pseudo-cylindrical body grading downwards into a mixture of stoped blocks and intrusives. The gravimetric data also indicate that the granite continues beneath the Cambro-Silurian sediments at shallow level for about 3 km southwest of the Drammen Cauldron and beneath the sedimentary rocks and gneisses for at least the same distance beyond the northeastern contact. A negative gravity anomaly along the Oslo Fjord is possibly related to a further 15-20 km subsurface extension of the batholith towards east and northeast. The calculated volume of the batholith without the latter extension is 1811 km^3 (Ramberg 1976).

Most of the granite types within the batholith seem to represent separate intrusive phases. The contact relations, however, are often unclear with gradual transitions and sharp contacts occurring at different locations along the same border between two petrographic varieties. This may be a result of the intrusion of a new magma into an already emplaced, but only partially solidified magma. Where the solidification of the early intrusion is near completion, the boundary to the new intrusion may become sharp, but where the early intrusion is still mostly liquid a more extensive mixing and mutual assimilation may result in a transitional boundary. Partial remelting of contact portions of an early intrusive phase could also lead to transitional or ambiguous contact relations. In addition to the nature of the contacts on an outcrop scale, the topographic relations between intruded roof massifs and underlying intrusions have proven useful for the establishment of the internal intrusive sequence of the Drammen batholith.

The coarse-grained, the medium- to coarse-grained and the cumulophyric granites seem to represent the earliest intrusives of the presently exposed section of the batholith. The transitions between these varieties are mostly gradational, and they may be parts of the same intrusive event. The microcrystalline porphyries (especially in the central part of the batholith) are chemically similar to, and may be genetically related to, the coarse-grained granite. The intrusions of all of the porphyries as well as rapakivi and the medium- to fine-grained granite, however, appear to succed the intrusion of the coarse-grained granite. In particular the fine-grained porphyry and the aplite porphyry show clear intrusive relations to this rock type.

The aplite porphyry and the medium- to fine-grained granite may be parts of the same, final intrusive phase. The porphyry is generally confined to the topographically highest areas west of the Drammen Fjord, and it may represent relatively late stage crystallization of the magma, consistant with a viscosity increase resulting from a drop in the partial pressure of volatiles (mainly H_2O). It is also possible that the aplite porphyry intruded the medium- to fine-grained granite. Limited areas (10-100 m dimensions) of the latter type within the aplite porphyry may represent large xenolithic rafts.

Petrography and intrusive phases of the Finnemarka batholith

The internal intrusive relations within the southern part of the Finnemarka complex appears to be similar to those in the Drammen batholith (Stenstrop 1989) and the central biotite granitic stock of the Glitrevann Caldera (Gaut 1981; Jensen 1985). Aphanitic to microcrystalline porphyries seem to be earlier than or approximately contemporaneous with volumetrically dominant coarse- to medium-grained granites, with final intrusive phases consisting of aplitic granites. The BG2 of the northern part of the central granitic area of the Finnemarka complex, is rimmed by quartz monzodiorite (akerite) and quartz syenomonzonite (kjelsåsite), and a small gabbro intrusion immediatetly west of the complex may also belong to the Finnemarka magmatic series. Within the coarse- to medium grained BG2 granite there are also small areas with peralkaline granite (ekerite).

The batholith is clearly cut by ring faults and dikes of the Glitrevann cauldron (Gaut 1981). Ramberg (1976) concluded that the intrusion is cone shaped, extending to a maximum depth of about 7.5 km, and he estimated the volume to be 336 km^3. The Finnemarka batholith may therefore have a slightly larger average thickness (3.4 km) than the Drammen batholith (2.8 km).

Hydrothermal alteration and mineralization

Ihlen et al. (1982) and Ihlen and Marinsen (1986) described the late- to post-magmatic alteration and mineralization phenomena associated with the Drammen granite, and Olsen and Griffin (1984 a, b) presented fluid inclusion data. In addition to simple exsolution of the perthitic feldspars and the hydrothermal bleaching of the early oligoclase, especially in the northern part of the batholith, the most widespread and pervasive postmagmatic alteration is albitization, mostly affecting the medium- to fine-grained granite in the central part of the batholith. The albitization seems to be closely associated with the exsolution of the perthitic alkali feldspar, and involves additional replacement of red, K-rich domains (finely dispersed Fe-oxide dust) by white (clean) albite. Extensively albitized granite areas appear bleached, and can extend over distances of less than one meter to a few hundred meters. Although bleached samples were avoided in this study, the whole rock chemistry indicates that the analysed samples of medium- to fine-grained granite and the aplite porphyry have undergone some late- and/or post-magmatic Na-enrichment. The high F-content in most of the Drammen granite samples, and especially in the medium- to fine-grained granite, indicate that the elevated Na/K-ratios may also partly be caused by the displacement of minimum melt compositions towards the albite component (e.g. Manning 1981). Mioralitic cavities and small quartz±fluorite veins are relatively widespread within the cumuloporphyritic granite along the southern margin of the Drammen batholith.

Other hydrothermal alterations and mineralizations also occur most frequently in the central area of the batholith. These include quartz-sericite-pyrite ±topaz, sericite-chlorite, and kaolinite alterations, as well as common Mo- and rare W-mineralizations (Ihlen et al. 1982).

Petrogenesis

The eight separate petrographic types of the Drammen batholith range in SiO_2 from 70 to 79 wt% and have experienced variable amounts of fractionation of feldspars, biotite, zircon, apatite, titanite and Fe-Ti-oxides. The initial Sr, Nd and Pb isotopic ratios and a decoupling between the variations in the SiO_2 content and the aluminum saturation index [ASI=Al_2O_3/(CaO+Na_2O+K_2O)] show that the various intrusive phases are not strictly comagmatic.

The ε_{Nd} values of the southern part of Finnemarka (+3.5 to +4) and the northern part of the Drammen granite (+1 to +1.5) are high and indicate insignificant (for Finnemarka) to minor Precambrian crustal or enriched mantle contributions. The very low ε_{Sr} values of all of these samples (-1 to -12, outside the main Oslo Rift magmatic array, Neumann et al., 1988; Anthony et al., 1989), point to a time integrated Rb-depleted crustal contaminant or an EM1 mantle component. The earliest extruded alkali basalts along the southwestern margin of the Oslo Rift are the only other samples within this low ε_{Sr} area, but their isotopic signature may also be linked to a mantle enrichment event (involving an EM1 component), e.g. associated with the Fen carbonatite magmatism 540 Ma ago. For a given $^{206}Pb/^{204}Pb$, the $^{208}Pb/^{204}Pb$ ratios of the Drammen and Finnemarka batholiths are distinctly lower than those of the Skien alkaline volcanics and all other magmatic Oslo Rift rocks. This may indicate that the lithosphere of the central part of the rift had a time integrated Th-depletion.

The samples from the southern part of the Drammen batholith, characterized by the presence of abundant miarolitic cavities, have ε_{Nd} near 0 (-0.7 to +0.4) but strongly elevated ε_{Sr} of +35 to +67. The combined Pb isotopic ratios of all the samples analyzed indicate that the Precambrian crustal anatectic contribution is in the form of time integrated Th- and U-depleted lower crust, and the high ε_{Sr} of the southern part of the Drammen granite results from shallow level wallrock assimilation or magma-fluid interactions. The remarkably low contribution of old crustal components to the Finnemarka and the northernmost Drammen batholiths may result from extensive late Precambrian intracustal differentiation in southwestern Scandinavia, leading to widespread upper crustal granites (~900 Ma) and a correspondingly dense and refractory lower crust, in particular in a zone intersecting the central part of the rift (see e.g. Killeen and Heier, 1975).

Liquidus phase relations and mass-balance constraints permit derivation of the granites from mildly alkaline to tholeiitic melts by extensive crystal fractionation of clinopyroxene- and amphibole-rich assemblages. It is equally possible to form the granitic magmas by partial melting of Permian gabbroic crust. The peraluminous chemistry could be aquired by fractionation (in the form of partial melt separation from the solid residue and/or fractional crystallization) of low-ASI minerals like clinopyroxene and amphibole (Zen 1986). Either scenario is consistent with the isotopic constraints and with the presence of dense cumulates and/or residues in the lower crust. The lack of igneous rocks of intermediate composition associated with the Drammen and Finnemarka batholiths point to an efficient upper crustal density filtering. Considerable amounts of heat would be accumulated in this region if differentiated, intermediate melts could not escape to shallower levels. Successive magma injections would therefore easily result in anatexis (water-undersaturated dehydration melting) of already solidified mafic to intermediate melts and cumulates.

In spite of their largely peraluminous nature the biotite granites have certain characteristics in common with A-type and within-plate granites, in particular in the form of high contents of F, Nb and Y and hypersolvus feldspars. The major and trace element chemical variation within the Drammen granite suite indicate that the different rock types underwent additional and variable fractionation of plagioclase, alkali feldspar, mica, and accessory phases.

Excursion route

The Drammen granite excursion departs from **Sande** and follows the road southeastwards along the shore of the **Sande bay** and then northwards along the western shore of the **Drammen fiord**. Along the road there will be several stops to examine various granite types. In the central part of the complex we will take a small road westwards from the fiord and into the northeastern area of the aplitic porphyry to study a zone of quartz-serisite-pyrite-topaz-wolframite-alteration of the granite and crosscutting quartz-molybdenite veins.

There will be an optional stop to visit contact metamorphic marbles and skarn mineralization (Cu-Zn-Pb-Bi) along the northern margin of the Drammen batholith at **Lierskogen** on the way towards Oslo. Alternatively, we may take a detour over the Krogskogen lava plateau to study some well exposed sections through the rhomb porphyry stratigraphy, displaying various lava flows and interflow conglomeratic sediments.

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