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Comments on 'The Tertiary Kærven syenite complex, Kangerdlugssuaq, East Greenland: mineral chemistry and geochemistry' by P. M. Holm and N.-O. Prægel

IN a recent paper Holm and Prægel (1988) have described the syenites and alkaline granites of the Kærven syenite complex from the lower Tertiary magmatic province of East Greenland. The province developed during the early stages of the opening in the North Atlantic (e.g. Brooks and Nielsen, 1982; Nielsen, 1987). Holm and Prægel conclude that the syenites and granites of the Kærven syenite complex constitute a comagmatic suite, which developed by mixing of end-members from a common basic parent of T-MORB affinity. They find very limited evidence for interaction with crustal material. These conclusions are not consistent with their own observations and, furthermore, Holm and Prægel have not considered their results in the light of the petrogenic models proposed for comparable syenite complexes in the immediate neighbourhood (see Nielsen, 1987, for references).

Age of the Kærven syenite complex. The Kærven complex is one of several, both older and younger, satellite intrusions to the 800 km^2 50 ± 1 Ma old syenitic Kangerdlugssuaq intrusion (Kempe *et al.*, 1970; Pankhurst *et al.*, 1976). Holm and Prægel quote an Ar^{40}/Ar^{39} age of 58 Ma for the Kærven syenite complex. This is older than other hitherto reported lower Tertiary intrusive complexes in the Kangerdlugssuaq area, which has prompted Holm and Prægel to single out the complex and to try to identify the mantle sources for the initial lower Tertiary magmatic activity in East Greenland in the syenites and granites at Kærven. However, the age of the syenite is not conclusively documented and a zircon fission track age (21 grains) of 51.8 ± 3.2 Ma was obtained from one of the syenites from the Kærven syenite complex (Hansen, 1985). The uncertainty on the age determination of Holm and Prægel is not given and allows no estimate of the time interval between the emplacement of the Kærven syenites and the neighbouring syenite intrusions or to the plateau basalt magmatism (58–55 Ma) related to the opening of the North Atlantic (Nielsen and Brooks, 1981; Brooks and Nielsen, 1982). The unsettled age relationships do not allow the authors to neglect petrogenetic models for very similar Tertiary syenite complexes in the Kangerdlugssuaq area, as presented by Deer *et al.* (1984), Nielsen (1987), Nielsen and Brooks (1987) and Brooks and Nielsen (1988 and in press).

Coherence, comagmatism and relationship to other syenite intrusions. Holm and Prægel conclude that the suite of coarse-grained small syenite, quartz syenite and alkali feldspar granite bodies in the Kærven complex represent a group of liquids. These are thought to have formed by mixing between a monzonitic or syenitic end-member and an alkali feldspar granite end-member, which both evolved from basaltic parents of T-MORB affinities.

The conclusions of Holm and Prægel are based on a suggested coherent geochemical variation and trace element systematics within the defined main suite of syenites and alkali granites (omitting a group of plagioclase-rich granites). They note (see Fig. 4 in Holm and Prægel) that distinct kinks in the element trends are unexplained by the proposed petrogenesis. Their element variations are redrawn in Fig. 1, which shows that the kinks are so pronounced that they cannot be ignored in any proposed petrogenetic scheme. These kinks also seem to exclude both a fractional crystallization and a mixing relationship throughout the syenite–granite suite. On page 443 Holm and Prægel mention Rb as one of the elements that shows the highest correlation with SiO_2 in the 'main trend', but this variation is unfortunately not shown in their Fig. 4.

As shown in Fig. 1 the main suite becomes more easily interpreted if divided into two groups: (1) a syenitic group with $SiO_2 < 66\%$ and (2) a group of granites with $SiO_2 > 66\%$. These two groups show either reasonable linear trends or plot in well-defined groups that are clearly separated for many elements. It is noted that for most elements the nordmarkites of the Kangerdlugssuaq intrusion fall within part of the Kærven syenite group, although Holm and Prægel, throughout their paper, claim major chemical differences between the Kærven syenites and the surrounding syenite intrusions. In Table 1 they have chosen to compare the generally more quartz-rich rocks from Kærven with a barely quartz-normative nordmarkite from the Kangerdlugssuaq intrusion. It would have been fair to select a more typical quartz–nordmarkite for the comparison (Deer and Kempe, 1976).

A comagmatic origin for all the syenites and granites at Kærven is suggested according to Holm and Prægel by a very constant Nb/Zr ratio, in spite of the fact that two distinct groups of syenites and granites can be observed in their Fig. 4. The Nb/Zr ratio diagram (Fig. 6 in Holm and Prægel) also shows two groups, although not the same as in Fig. 4. Most samples show a Nb/Zr ratio of 0.12–0.15 independently of the total Nb concentration, whereas four samples show increasing Nb/Zr ratios at more constant Nb concentrations. If the Nb/Zr ratio of 0.12–0.15 shows the comagmatic origin of the Kærven syenites, the four samples with higher ratios must belong to a different group.

The Th *vs.* Ce variation diagram in Fig. 7 of Holm and Prægel shows a broad linear correlation, which is also used as evidence for a comagmatic origin of syenites and granites in the Kærven syenite complex. No correlation coefficient is given and the Ce/Th ratio appears to vary between 10 and 25. Holm and Prægel include quartz nordmarkites, nordmarkites, pulaskites and foyaites from the Kangerdlugssuaq intrusion in this plot. All the Kangerdlugssuaq intrusion rocks plot within the same band as the samples from Kærven, even though the oversaturated and undersaturated syenites of the Kangerdlugssuaq intrusion (on the basis of major, trace and isotope chemistry and mineral chemistry) cannot be assumed to represent simple evolutionary trends from a common parent (Pankhurst *et al.*, 1976; Brooks and Gill, 1982; Nielsen, 1987). The Th *vs.* Ce plot cannot, therefore, be used as evidence for comagmatism.

Without any discussion of the observations of Deer and Kempe (1976), Holm and Prægel not only claim major chemical but also major mineralogical differences between the syenites at Kærven and in the surrounding syenite intrusions. Deer and Kempe (1976) stress the petrographic similarities. Holm and Prægel attach weight to the supposed lack of Na-rich clinopyroxenes in the rocks from Kærven although Deer and Kempe (1976) describe and give the analysis of ægirine from Kærven. In addition to apatite and zircon, Deer and Kempe also report titanite and chevkinite in the syenites from Kærven. It is not evident that the syenites and granites at Kærven are distinct from some of the syenites in the surrounding

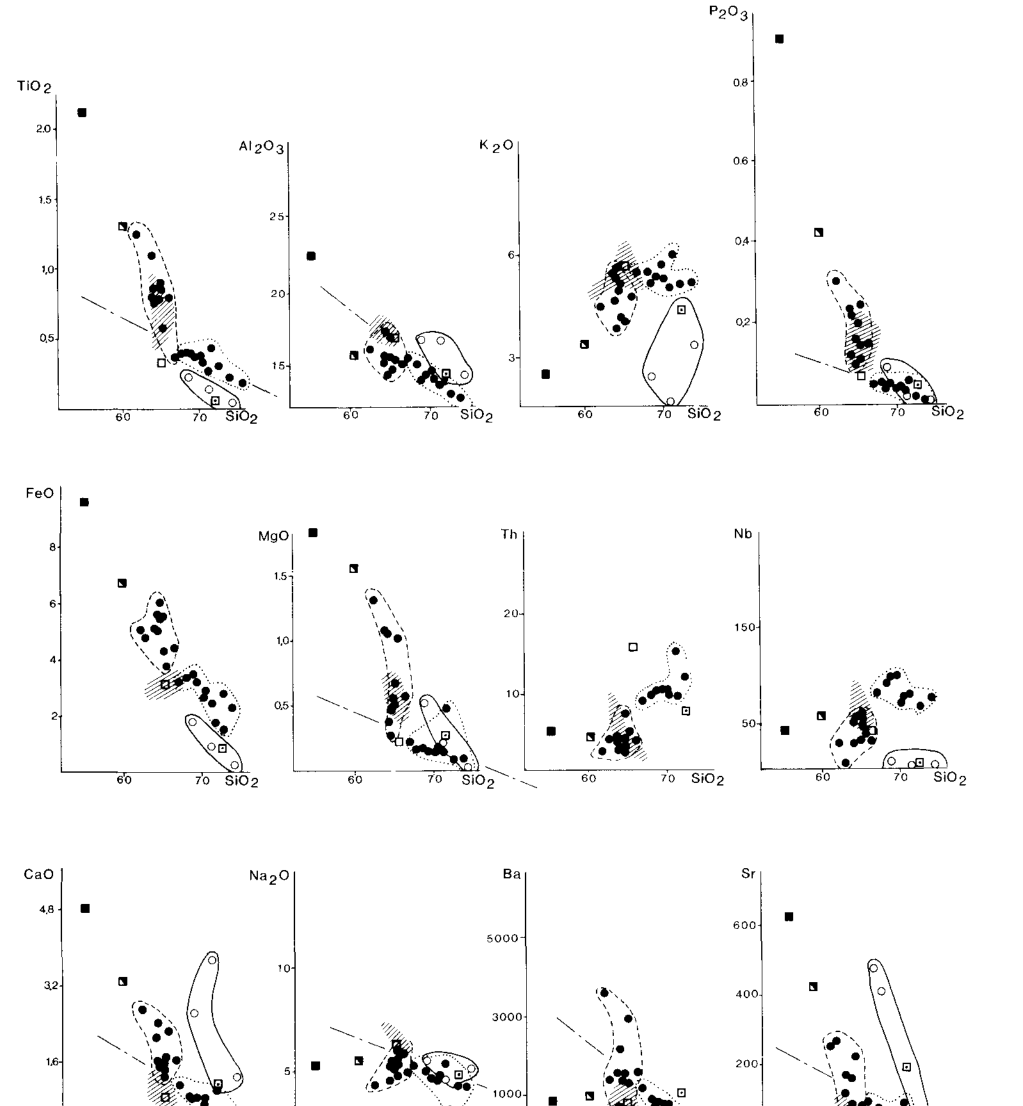

FIG. 1. Figure 4 of Holm and Prægel (1988) redrawn with additional compositions from the Astrophyllite Bay complex, ABC (see text). Filled square—trachyandesite pillow (ABC); half-filled square—hybrid between trachyandesite and crustal-derived syenitic melt (ABC); open square—crustal-derived syenite melt (ABC) and square with dot—metasomatized basement. Full line delimits the field of the restites from Kærven and the metasomatized basement from ABC. Stippled line delimits the granitic group at Kærven and the dotted line delimits the granitic group at Kærven. Ruled field—quartz-normative and saturated syenites of the Kangerdlugssuaq intrusion (after Holm and Prægel, 1988). Holm and Prægel give no Ba and Th values for the tonalitic inclusions.

syenite bodies, e.g. the Snout series and the Bagnæsset syenite at the eastern margin of the Kangerdlugssuaq intrusion just south of Kærven mountain (Deer and Kempe, 1976). Both of these syenites are complicated, consisting of basic bodies of trachyandesitic compositions, a variety of syenites and granites and, in some areas, of significant amounts of metasomatised, partly remelted and assimilated basement gneises (Larsen, 1982; Brooks and Nielsen, 1982 and 1988).

The presented data accordingly do not prove and often contradict the conclusions of Holm and Prægel summarized as conclusion (1) on page 448. Accordingly, it is concluded that:

(*a*) At least two groups of syenites and granites occur at Kærven and as no single coherent trend is shown they may not be comagmatic.
(*b*) The major mineralogical and chemical differences which are claimed between all the syenites and granites of the Kærven syenite complex and the Kangerdlugssuaq intrusion and other satellite intrusions are not shown by the chemical data in Holm and Prægel's paper, nor by the presented mineralogical observations of Holm and Prægel (1988) or Deer and Kempe (1976). Some groups of rocks appear common to all the intrusions.

Interaction with the crust. In contrast to the observations at most other satellite intrusions and in the margin of the Kangerdlugssuaq intrusion (see Nielsen, 1987, for references) Holm and Prægel observe no major interaction between the liquids of the Kærven rocks and the surrounding basement (conclusion 4, page 449).

Holm and Prægel describe a group of inclusions of tonalitic composition, which they regard as being contaminated granitic inclusions, even though the inclusions plot well outside any minimum granitic melt composition (see Fig. 5 of Holm and Prægel). The inclusions are described as being composed of large plagioclases in a fine-grained quartz–alkali–feldspar–plagioclase matrix with amphiboles, possibly of metamorphic origin. The larger plagioclase crystals are described as highly embayed and resorbed and on page 437 the minerals of the inclusions are stated to be in disequilibrium. All these observations suggest that these granitic inclusions are partially melted inclusions of basement gneisses and they may have lost even a major granitic component to the host syenite or granite. This is clearly shown in Fig. 11 of Holm and Prægel, where the tonalite inclusions have multi-element variations very similar to the basement gneiss from the Kærven area except for Ba which is strongly enriched in the inclusions (see Fig. 4). Even a major assimilation of basement gneiss by the host of the tonalitic inclusions can be suggested. The authors do not note in which syenites and/or granites these inclusions occur and they give no isotopic information in support of their interpretation.

Holm and Prægel notice the rather subalkaline nature of the amphiboles in the Kærven rocks, in contrast to the amphibole compositions reported from e.g. the Kangerdlugssuaq intrusion (Brooks and Gill, 1982). As shown in Fig. 2 of Holm and Prægel the more magnesian and alkali-poor amphiboles have compositions not unlike those found in the tonalitic xenoliths. The alkali-poor amphiboles could well be inherited from the basement, which also points to major crustal components at Kærven. Holm and Prægel present no systematic relationship between the amphibole compositions or any other mineral group and the whole-rock compositions, except that the more Fe-rich amphiboles occur in the syenites and granites with the highest Fe/Mg ratio. Thus the alleged mixing throughout the main suite of the syenite and granite groups (Fig. 1) is neither supported by the chemical variations, as shown above, nor by the mineralogy.

Alternative model. The rejection of the models of Holm and Prægel requires the suggestion of an alternative model. Brooks and Nielsen (1982, 1988, and in press) and Nielsen (1987) have described the formation of crystally-derived syenitic liquids in the Astrophyllite Bay complex, in the marginal parts of the Bagnæsset syenite (Deer and Kempe, 1976) is yet another older satellite intrusion to the Kangerdlugssuaq intrusion. In the Astrophyllite Bay complex the emplacement of trachyandesite bodies in a metasomatized granitic basement (1000 ppm Ba) has led to melting of the basement and chilling of the trachyandesite pillows against the crustally-derived melts at their margin and in some places to hybridization between trachyandesite and the crustal melts. This process is clearly seen in the outcrops (Brooks and Nielsen, 1982). The crustal-derived melt is not granitic in composition but syenitic due to a diffusive equilibration between the trachyandesite melt and the crustally-derived melt (Nielsen and Brooks, 1987; Brooks and Nielsen, 1988 and in press).

The chemical compositions of the basement, the crustally-derived syenitic melt, a hybrid and a trachyandesite pillow from the Astrophyllite Bay complex are also shown in Fig. 1. The basement composition is very similar to the tonalitic inclusions in the Kærven rocks which are, therefore, more likely to be partially melted basement inclusions of which some may have lost a granitic minimum melt to the host rock. The composition of the syenitic crustally-derived melt at the rim of the trachyandesite pillows coincides with the low-silica end of the granitic suite and the high-silica end of the syenitic suite at Kærven. It is thus suggested that the granitic group at Kærven ($SiO_2 > 66\%$) represents crustal-derived liquids. The chemical variation in the group results from variable degrees of re-equilibration, metasomatism, the incorporation of variable amounts of restite and mixing. The main chemical differences between the granite group and the tonalitic inclusions are the higher K_2O, Nb, Th, TiO_2 and FeO and the lower CaO, Al_2O_3, Sr and Mg in the granites, a pattern which is consistent with the expected compositions of basement-derived minimum melts and plagioclase-enriched remains of basement inclusions after partial melting and incongruent melting of biotite.

The trachyandesite, the hybrid and the crustal-derived syenitic melt form a trend that for most elements (except Ba) coincide with the spread in the syenitic group ($SiO_2 < 66\%$) at Kærven (Fig. 1). It is thus evident that many of the syenites at Kærven may represent hybrids between crustally-derived and diffusion equilibrated liquids and trachyandesite magmas. This suggestion does not exclude the possibility that some syenites in the area developed by crystal fractionation from trachyandesitic compositions.

Holm and Prægel presented no isotopic evidence for the alleged mantle heritage of all the syenites and granites (excluding the tonalitic inclusions) at Kærven. In the Astrophyllite Bay complex initial Sr-isotope ratios increase substantially from *c.* 0.707 in the trachyandesite to 0.730 and 0.752 in the syenitic crustal melt and the basement (Brooks and Nielsen, 1988 and in press). There is no doubt at Astrophyllite Bay that the intrusive rocks, which bear so many similarities to some of the syenites at Kærven, contain major crustal components. The processes are without doubt very complicated and include fractional crystallization as well as assimilation, contamination and melting of basement followed by diffusion equilibration. Petrogenetic models for not only the Kærven syenite complex but all of the syenite complexes in the Kangerdlugssuaq region require very large amounts of petrographic, geochemical and isotopic information on both rocks and minerals. Such material is not available, but that which is requires very careful consideration and evaluation for the province as a whole and not for restricted areas.

Final comments. With these comments in mind it is thus clear that the trace element ratios do not represent parental basic liquid compositions and that the trace element ratios cannot be used for a determination of the geotectonic setting of the Kærven syenite complex (conclusion 5 of Holm and Prægel, p. 449). Nor can they be used for a characterization of the sources of the visualized parental basic liquids of the syenites and granites in the Kærven syenite complex (conclusion 6 of Holm and Prægel).

Holm and Prægel propose a model which largely excludes interaction with the continental crust. As such interaction can be shown (also by their own data from Kærven syenite complex) to be commonplace in many syenite complexes in the Kangerdlugssuaq region their conclusions must be viewed with extreme scepticism.

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