As discussed elsewhere in this issue, many of the largest accumulations of rare earth elements (REEs) are associated with rift-related nepheline syenite and alkali granite plutons. The most extreme evolved magmas produced by our planet form the agpaitic suite, named after Agpat on Tunugdliarfiq, a fjord that cuts through the extraordinary Ilímaussaq intrusion in the Mesoproterozoic Gardar rift province in South Greenland (FIG. 1). Agpait, by definition, has a molar Na + K-Al greater than 1.2; in other words, it contains much more Na and K than can be accommodated in feldspars and feldspathoids, and it also contains Na-Ti-Zr silicates.

The modern view is that the Gardar alkaline rocks are the products of extreme fractionation of an alkali basaltic parent magma originating from asthenospheric mantle modified by alkaline, rare-element-enriched metasomatic fluids. The magmas ponded and fractionated, perhaps at multiple levels, on their ascent, and also during their final emplacement, since many rocks are clearly cumulates. In the final evolved juices, we have a blurring of silicate magma and silicate-rich aqueous fluids that precipitate a bewildering array of exotic minerals and concentrate rare elements beyond the wildest fantasies of geochemists. Many components, many phases, and a composition somewhere near the multiphase invariant point that represents the end of Earth evolution through igneous fractionation – full stop for Mother Earth!

Three localities in the Gardar rift (the Narsarsuk pegmatite, the Ivigtut cryolite body [Elements 5: 71, 2009] and the Ilímaussaq intrusion) have provided type samples for a total of 60 mineral species (that’s about 1% of all known species), of which 17 have not been found elsewhere. These minerals, occurring mainly in late pegmatites and veins, are:

- eudialyte, Na₃Ca₃Fe₄Zr₂Si₈O₂₆(O,OH,H₂O)₂(Cl,OH)₂ (strong pink)
- arfvedsonite, an alkali amphibole, Na₄(Fe²⁺,Mg)₄Fe³⁺Si₈O₂₂(OH)₂ (black)
- sodalite, Na₄(Si₆Al₃)O₂Cl (light grey prisms)

The sodalite is a variety known as hackmanite. It is purple on a fresh surface but its 1.13-billion-year-old colour fades to greenish grey in a few minutes on exposure to light. I used to demonstrate this to students, probably the only bit of the course they remembered!

Kangerdluarssuk is the type locality for a further 8 mineral species, all of which have subsequently been found elsewhere on Earth. These minerals, occurring mainly in late pegmatites and veins, are:

- aenigmatite, Na₂(Fe²⁺)₃TiSi₆O₂₀
- polyliithionite, KLi₂Al₄Si₄O₁₂(F,OH)₂
- potassicarfvedsonite, KNa₂Fe₂⁺₂⁺Fe³⁺Si₆O₂₂(OH)₂
- rinkite, Na(Na,Ca)₂(Ca,Ce)₄(Ti,Nb)(Si₂O₇)·(O,F)₄
- skinnerite, Cu₃SbS₃
- steenstrupine-(Ce), Na₃Ce₆Mn²⁺Mn³⁺Fe³⁺Zr(O₄)₇·3H₂O
- tundrite-(Nd), Na₂Nd₂TiO₅SiO₄(CO₃)₂
- ussingite, Na₂Al₅Si₃O₈(OH)

Not only do these formulae attest to the extraordinarily high concentrations of elements that normally occur in parts per million, they also illustrate the extremely alkaline character of the assemblage. Ussingite is essentially albite plus NaOH.

The type minerals in Figure 2 were collected on a remarkable journey started in 1806 by Karl Ludwig Giesecke, a German actor (his original name was Johann Georg Metzler). He had fallen on hard times in Vienna, left in a hurry without paying his bills and settled in Copenhagen, where he moved into mineral dealing. He arrived in Greenland intending to stay for two years, exploring and collecting minerals, but had to stay for seven because of the Napoleonic wars. His samples were sent in a Danish ship to Copenhagen in 1806, but the vessel was taken as a ‘prize’ by the British Royal Navy and the minerals were auctioned in Edinburgh in 1808. Giesecke arrived back in Europe in 1813, causing a stir by turning up in the English port of Hull clad in Inuit furs and feathers, his European clothes having long-since worn out. Every cloud, however, has a silver lining. His samples had been bought as a job-lot by a wealthy Scot, Thomas Allan, who recognised...
This three-day Workshop will provide a forum for discussion of the origin and evolution of REE, Nb, Ta, Li, Mo and In deposits, and related processes in igneous, hydrothermal, metamorphic, and supergene environments.

Geologists, petrologists, mineralogists, geochemists, explorationists, technologists and market experts are all welcome to attend, contribute to the Workshop, and explore wonderful Mongolia!

CM2013, supported by the Geological Association of Mongolia, will be held at the Mongolian University of Science and Technology in Ulaanbaatar. The Workshop will be accompanied by a rich cultural program and followed by a fieldtrip to several large REE and Cu-Au deposits in the Gobi.

For further information, please visit us at: www.criticalmetalsmeeting.com
their importance and invited Giesecke to his home in Edinburgh. Allan was impressed with his mineralogical skills and encouraged him to apply for the Professorship of Mineralogy in the Royal Dublin Society, a post Giesecke occupied until his death in 1833. One of Giesecke's samples was given the name allanite, so everyone was happy!

It is the northern part of the Ilímaussaq intrusion that is currently attracting a lot of attention, mainly around a region of complex pegmatites called Kvanefjeld. So far Kvanefjeld is the type locality of a mere 7 mineral species, but remarkably none has so far been found outside Ilímaussaq. They are:

- kuannersuite-Ce, Ba₆Na₂Ce₂(PO₄)₄FCI
- kvanefjeldite, Na₄(Ca,Mn)(Si₃O₇)OH₂
- nabesite, Na₂BeSi₄O₁₀·4H₂O
- nacareniobsite-(Ce), Na₃Ca₃Ce⁵N₆(Si₅O₁₉)₂OFe₃
- orthojoaquinite-(La), NaBa₂(La,Ce)₂Fe₂⁺Ti₂Sr₂O₇₂(OH,OF)·H₂O
- rohaite, Tl₂Cu₈Sb₂S₄
- sørensenite, Na₂BeSn⁺⁴(Si₃O₉)₂·2H₂O

Naujakasite, Na₆(Fe,Mn)Al₄Si₈O₂₆, is a fascinating mineral (Fig. 3). It is a major rock-forming mineral at Kvanefjeld and over large areas of Ilímaussaq, its silvery, diamond-shaped plates sometimes making up 75% of the rock, but it is known from nowhere else. Nowhere. It mainly occurs in a rock type called arfvedsonite lujavrite, a bizarre peralkaline amphibolite. It is often accompanied by beetroot-coloured villiaumite, NaF, but it is so soluble in water that it does not survive on natural rock surfaces. There is evidence that natrosilite, Na₂Si₂O₅, was also present, although it dissolves very rapidly in moist air, forming – as older readers will know – water glass, once used for preserving eggs. Naujakasite has relatively simple chemistry, not far from a combination of the common minerals aegirine (NaFeSi₂O₆) and nepheline (NaAlSiO₄). Anderson and Sørensen (2005) have provided an intriguing assessment of the physical and chemical conditions that provided the tiny window of opportunity that gave naujakasite its moment as a rock star.

In 1955 Denmark began a programme to evaluate the uranium resources of Greenland, and Kvanefjeld was discovered in 1956. Intensive mapping and drilling by the Geological Survey of Greenland continued until the 1960s, and this work was followed up by detailed studies at the University of Copenhagen under the leadership of Henning Sørensen, whom you can see in Figure 4. Two adits were dug, the largest in 1979–1980. Most of the uranium and REEs are in steenstrupine. The uranium programme was dropped in 1983, but in 2010 the Greenland government lifted its ban on uranium mining and the area has been the subject of an intensive drilling programme by Greenland Minerals and Energy Ltd, whose office address is in Subiaco, Western Australia. Kvanefjeld is now believed to be the second-largest deposit of REEs in the world, and the sixth largest uranium deposit. It has particularly high concentrations of heavy REEs, which are in much demand. It is nice to see that the operators have called one of their exploration zones the Sørensen deposit.

If mining goes ahead, I do not think it will be long before the list of weird minerals found in Ilímaussaq becomes considerably longer. It is a matter of great sadness to me that Mother Earth’s ultimate igneous products will be dug up, but I fear it is inevitable. It is to be hoped that the developers dedicate time and money to systematically recording and interpreting features that they uncover, and take the trouble to preserve crucial sections. Once it’s gone, it’s gone, full stop.

Ian Parsons
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The mineral data were largely taken from Petersen OV and Johnsen O (2005) Mineral Species First Described from Greenland. Canadian Mineralogist Special Publication 8, 184 pp
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