The philosopher Karl Popper made much of the black swan analogy in his musings on the scientific method. The statement ‘all swans are white’ can never be verified by endlessly counting white swans, but can be falsified by finding just one that is black. It’s the black swans that are the game-changers in science. There is a peculiar pleasure in encountering one. Like real swans the best place to find them is in the field. I’ve spent a lot of my career working on a small layered syenite intrusion in the Mesoproterozoic Gardar igneous province in Southwest Greenland called Klokken (the Bell or Clock), where black swans are abundant.

Klokken can be reached only by helicopter (FIG. 1), so visits are not cheap. Exposure is good, because it is scoured of plant life by violent fohn winds that blow from the Inland Ice. I’ve now been there nine times, including three one-day visits for field workshops with 20+ participants. I’m not getting any younger and had rather given up hope of returning, but I had the great pleasure to visit again in 2013 as part of a small group with interests in the rheology of magmas and crystal mushes. I first went there in 1971, with one research-student companion, with the task of mapping the intrusion for the Geological Survey of Greenland. We had some handwritten notes from an early reconnaissance visit, in Danish, which we didn’t speak, so it was really a step into the unknown. We were set down by a huge S61 helicopter, put up our tents, had a cup of tea, and strolled up the nearest hillside. Very soon we encountered our first black swan (FIG. 2).

In 1971, the thinking about layered igneous rocks was dominated by the work of Wager and Deer on the Skaergaard intrusion, much further north on the east coast of Greenland. There, graded layers are arranged so that denser minerals (olivine and pyroxene) are concentrated at the base and low-density plagioclase feldspar is concentrated at the top. Sorting by density, under the influence of gravity, was the white swan of igneous layering in gabbroic intrusions. In Klokken the density sequence is inverted. The white rock at the bottom of FIGURE 2 is composed mainly of parallel tablets of alkali feldspar (specific gravity 2.6) giving it a strong igneous lamination; the dark, mafic rock at the top is largely made of the iron pyroxene hedenbergite (3.6). In some layers (FIG. 3) the density range is even larger, with iron olivine, fayalite (4.4), and magnetite (5.2) forming the top of the layer. This ‘inversely graded’ modal layering is unique to Klokken. It occurs repeatedly and can be traced laterally around a central focus towards which it dips at roughly 35°. In syenites elsewhere on Earth, layering is normally graded, as in gabbros. Klokken is truly the black swan of mineral layering.

Another type of black swan has glided into FIGURES 3 and 4. About 85% of the Klokken layered series is composed of the coarse-grained laminated syenite with its enigmatic inversely graded layering (FIG. 2). The remaining 15% is composed of discontinuous layers, of variable thickness, of relatively fine-grained ‘granular’ syenite, the brown rock at the top of both figures. The grain size in these layers increases downwards. The feldspathic laminated syenite and granular syenite have nearly the same compositions (they are composed mainly of similar alkali feldspars), but the olivine and pyroxene tell an interesting story. All the pyroxenes and olivines in the laminated syenites and modal layers are very iron-rich and vary little with stratigraphic position. In the granular layers these minerals change in composition systematically, more magnesian at the top, iron-rich at the bottom. This downward mineral evolution is the hallmark of a sequence of rocks formed in a chill zone at the roof of a magma chamber, another celebrated feature of the Skaergaard intrusion. It seems that in Klokken, sheets of syenite in the chill zone became detached from the roof of the magma chamber and sank gently down like giant pancakes onto a crystal mush of laminated syenite.

Yet another black swan in FIGURE 3 is the irregular, lobate interface between the olivine-rich rock and the granular syenite, with upward-pointing flame-like structures. If you know anything about clastic sedimentary rocks, you may be reminded of load structures. Throughout Klokken, at most interfaces between granular and laminated syenites,
The Japan Geoscience Union (JpGU) would like to introduce its new peer reviewed English language open access e-journal Progress in Earth and Planetary Science (PEPS). We aim to make PEPS a top quality international journal covering all of the many fields of Earth and Planetary Science. PEPS is published by the JpGU in combination with Springer, and will print original research articles as well as focusing on high quality review articles. PEPS started receiving manuscripts in October 2013, and the first articles will be published in January 2014.

For more details about PEPS please see http://progearthplanetsci.org/index.html. Information about submitting papers is at http://www.progearthplanetsci.com and from early this year the journal will be available to read or download from this site.

As an open access journal PEPS charges an Article Processing Charge (APC), however the APC for review articles will be waived in 2014 and 2015; all costs will be borne by the JpGU.

We would like to invite researchers from all over the world to consider PEPS when submitting their next paper for publication.
PARTING SHOTS Cont’d from page 70

including their inversely graded layers, there are load structures, often on a scale that far outshines those in sedimentary rocks (Fig. 4). Load structures have been recorded in a few other layered intrusions, but none approach the size or splendour of those at Klokken. Again, it is the density relationships that qualify these structures for black swan status. In sedimentary rocks, load structures form where a dense bed rests on a less dense one. As we see them now, the syenite types in FIGURE 4 have very similar densities, with the upper rock very slightly the more dense, but in FIGURE 3 the lower rock is much denser. And yet there are load structures…! Throughout the intrusion the size of the load structures depends inversely on the density contrast, but the lower unit is often the denser.

Afi cionados of igneous layering will be gritting their teeth because, for brevity, I have been guilty of considerable oversimplification here. Crystal supply, crystal size, crystal nucleation and growth rates, liquid density and viscosity, temperature and water vapour pressure, all changing with time, are among the factors that will have contributed to the formation of these unique structures. If my comrades from last summer have their way, Klokken may become tomorrow's white swan in the field of magma rheology.

Ian Parsons
University of Edinburgh

Analyze up to 12 orders of magnitude larger samples without longer measuring times using Micro-XRF and SEM/EDS with serial sectioning instead of 3D EDS focused ion beam (FIB) analysis! The Gujba meteorite sample shown above was mapped with a M4 TORNADO Micro-XRF spectrometer (36 2D-sections). The 3D reconstruction of the Micro-XRF data (voxel size: 32x32x148 μm) shows the surfaces of Fe,Ni-metal particles in green and sulfides in red. The Ni-content of the metal particles varies from 5 wt% (dark blue) to 8 wt% (light blue). A smaller area was mapped with a QUANTAX EDS system (21 2D-sections). The 3D reconstruction of the EDS data (voxel size: 1.6x1.6x4 μm) shows Fe (blue) and S (red).

More details can be found at: www.bruker.com/elements
GWB10: “Astounding!”

GWB 10.0 is better, easier, faster.
Colloid-facilitated transport, central dashboard, undo-redo, thermo data editor, MATLAB® bindings, axisymmetric coordinates, turbo scripting, and it’s Windows 8 friendly!

Short courses in Wellington, Melbourne, Palo Alto, Sapporo, Vancouver. Please join us!

Visit GWB.com/Workshops