The current information about the existence of clay minerals on extra-terrestrial bodies leads many to conclude that layered mineral structures facilitated the advent of self-replicating organic compounds on Earth (i.e. life as we know it, here or elsewhere). Coupling this notion with Akihiko Yamagishi’s pioneering work on stereoselective molecular recognition of organics on clay surfaces further supports the long-standing hypothesis of mineral natural selection in biochemistry (see Cairns-Smith, Elements, volume 1, 2005) and the fact that we have much to learn from nature’s world of clay nanocomposites. Also, a quick literature search using “clay nanocomposite” reveals hundreds of citations in seemingly disparate engineering, medicine, geoscience, and materials science journals. All of this collectively suggests that layered mineral structures harbor enormous potential for applications in advanced technologies. The recent publication on this very subject by the European Mineralogical Union, Notes in Mineralogy, volume 11 (EMU 11), edited by M. F. Brigatti and A. Mottana, arrives in a timely fashion to give us the latest insights. The importance of this book is derived from the coverage of the fundamental, yet complex, layered structures that are possible from combining one or more layer types. Such combinations help make new-aged technological materials or enable ways to interpret old-aged geologic materials.

I first digress by noting a slight misunderstanding hampering the explosion of experimental work driven by hopes of discovering polyfunctional layered mineral structures. The incentive for finding new materials is to expand thermal, rheological, time-release, and redox inhibitory/promoting material boundaries for biomedical, engineering, and environmental enterprises. The problem I see is that researchers outside the field of mineralogy view natural layered mineral structures as some sort of reagent-grade compound, like those purchased from a chemical supply store. Natural clays have novel properties, but they are not all alike and are quite variable. A prime example is seen in the kaolin-group minerals, which are used in ceramics, paper coatings, pharmaceuticals, inks, and plastics. Kaolins occur with a wide range of crystallite order/disorder, crystal sizes and aspect ratios, and degrees of isomorphous iron substitution. Committing a career of research to characterizing anisotropic lamellar compounds (including layered double hydroxides) and the need to experimentally do this before, during, and after testing. Following up XRD studies with calculated XRD models will only frustrate those who endeavor but also delay the potential benefits to society.

EMU 11 provides an ideal starting resource for those wanting to learn more about natural layered materials. Chapters 1, 2, 3, and 7, with first authors Brigatti, Guggenheim, Li, and Bergaya, respectively, give overviews of layered silicates, order/disorder schemes, titanosilicates, and intercalation, which collectively serve as a condensed resource for those needing a refresher in systematic clay mineralogy. Larson’s chapter eloquently nurtures the notion of using X-ray diffraction (XRD) to characterize anisotropic lamellar compounds (including layered double hydroxides) and the need to experimentally do this before, during, and after testing. Following up XRD studies with calculated XRD models assures the confidence needed to extract thermodynamic data, formulate reaction mechanisms, and anticipate kinetic and structural effects needed to give new clay composites functionality. Speaking of models, Sainz-Diaz’s delightfully readable chapter on computational mineralogy helps to see how using both classical and quantum mechanical methods specific to layered structures can be applied to interpreting spectroscopic properties, reactivity, and surface interactions with organic and water molecules. This in silico work is supported by discussions of published experimental vibrational and nuclear spectroscopic studies, which keep this book from being an isolated theoretical exercise.

The remaining chapters tackle more uncertain questions, such as “exactly how does water interact with layer charges of common smectite group minerals?” This question has long been of interest to industry. Christidis emphasizes a new, more insightful approach that promotes treating smectitic samples using a variety of saturations, like alkylammonium and potassium, to assess key properties of thixotropy (i.e. the ability to form a gel upon standing and become fluid under stress—an essential process employed every time you brush your teeth). Clay minerals and double hydroxides are not the only layered structures in nature worthy of exploitation. Mottana and Aldega’s chapter broadens the theatrical stage of layered materials to include graphene and addresses the pesky problem of how to define quasi-ordered nanosized intercalated structures. Traditional bulk methods, such as bulk powder XRD, often make hammers out of the materials we are trying to define by averaging both bulk and surface properties. The closer we want to look at an intercalated structure, the less bulk XRD techniques can tell us (perhaps a new variant of Heisenberg to haunt us). The good news is that methods such as grazing incidence XRD and X-ray absorption spectroscopies are reviewed with practical examples to guide us in studying configurations.

The interaction of organic molecules with layered structures and surface properties of clay minerals represents the current frontier for advancement of new materials in technology. The ability to control crystal surfaces for the binding of molecules such as DNA is fundamental for biosensing, environmental science, and catalysis. Valdré and coauthors explore recent advances in surface imaging techniques with atomic force microscopy (AFM) and review some practical advances in understanding decontamination of biological warfare agents, biofilm formation, and prebiotic chemistry. They clearly demonstrate the nucleotide selectivity, using powerful AFM images of DNA ordering with linear confirmations on brucite-like edges of a chlorite sheet, while by comparison the siloxane region topography indicates a very different agglomeration of the same DNA. Being able to control adsorption of nucleic acid bases at different pHs and solution compositions on clay minerals raises the possibility of a genetic code based on purines and a mechanism for protecting biomolecules from degradation.

Next to zeolites, clay minerals and their cousin layered structures (e.g. graphene) provide maximal amount and diversity of surface reactivity sites, coming from outer surfaces, edge surfaces, and interlayer surfaces. Schnoonheydt and Johnston bring closure to EMU 11 by linking water–ion interactions with clay surfaces (most examples being smectites) and the amazing chiral discrimination that occurs when the organic complexes interact on these surfaces. Once these complex interactions are fully understood, the advances in electrochemistry, photochemistry, and catalysis should open the path for novel ways to selectively react enantiomeric (right- and left-handed) compounds. Some day we may realize a device, based on a clay-dye with extreme thermal, mechanical, and chemical stability, small in size, low in energy demand, and high in light-scattering efficiency, that will enable us to biosense medical problems well in advance of what we can do today.

The bottom line is that EMU 11 is a very nice review volume for state-of-the-art layered mineral characterization methods. The references cited within it and peer-reviewed journals give the ultimate resource. The lesson learned from this book is “get to know your layered mineral structure well,” particularly if it is a natural material, and you will be well suited to discover the next nanocomposite to advance technology.

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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 Agpaite, by definition, has a molar ratio of Na to K more 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 alkaline 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 multivariate 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:

- aenigmatite, Na₂(Fe²⁺)₃Ti₁₃O₂₀
- poly lithionite, KLi₂AlSi₆O₁₆(OH)₂
- potassicarfvedsonite, KNa₂Fe²⁺₃⁺Fe³⁺₅Si₆O₂₂(OH)₂
- rinkite, Na(Na(Ca)₂(Ca,Ce)₄(Ti,Nb)(Si₂O₇)(O,F)₄
- skinnerite, Cu₃SbS₃
- steenstrupine-(Ce), Na₅Ce₆Mn²⁺₂Fe³⁺₃Zr₂(Si₆O₁₈)₁₂·OH·3H₂O
- tundrite-(Nd), Na₂Nd₂Ti₂O₇Si₆O₁₄(CO₃)₂
- ussingite, Na₂AlSi₃O₈(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 them...
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.

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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)₄FCl
- kvanefjeldite, Na₄(Ca,Mn)(Si₃O₇)OH₂
- nabesite, Na₂BeSi₄O₁₂·4H₂O
- nacareniobsite-(Ce), Na₃Ca₃CeNb(Si₂O₇)₂OF₃
- orthojoaquinite-(La), NaBa₂(La,Ce)₂Fe²⁺Ti₂Si₄O₁₆(OH,OF)·H₂O
- rohaite, Ti₂Cu₆Sb₂S₄
- sørensenite, Na₂BeSn⁴⁺(Si₃O₉)₂·2H₂O

Naujakasite, Na₆(Fe,Mn)Al₄Si₈O₂₆(OH,OF)·H₂O, 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 arvedsonite 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.

_Cont’d from page 396_
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a&b: Chondrite-normalized REE profiles as determined by EPMA. Monazite cores contrast with monazite rims and associated xenotime.
c&d: WDS maps of Nd and Y distributions.
Points marked on the Nd map show EPMA age determinations in Ma. 2σ
Data acquired on the SX Ultrachron model, courtesy of Dr. Julien Allaz, Univ. of Colorado and Dr. Michael Jercinovic, Univ. of Massachusetts.

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