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GEOCHEMICAL SAMPLES: BEAUTIFUL SMALL OR BETTER BIG?

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Friedhelm von Blanckenburg

"What are the main challenges for geochemistry in the future?" was a question asked of Al Hofmann, the recent Urey medalist of the European Association of Geochemistry (*Elements*, February 2016, p 68). "The ability to analyze most or all atoms in a very small sample by micro-analytical methods," was his answer. As an Earth surface geochemist interested in large-scale fluxes, my spontaneous response was surprise. Isn't the grandest of all challenges rather to use large spatial scale geochemical signals to reveal processes and fluxes of global significance? Then I contemplated the vast amount of information that has been harvested from the smallest samples. And I began to question whether the "small is beautiful" or "bigger the better" avenues are actually opposing approaches. The editing of my first issue as an *Elements* principal editor, this cosmic dust volume, contributed enormously to a swing of my opinion.

Cosmic dust provides an excellent argument for the "small is beautiful" approach. These tiny samples that cosmochemists have painstakingly collected from the Antarctic ice surface or from small adhesive tapes exposed on high-altitude airplanes have opened a whole new, fascinating window into our past, a past that extends to before the existence of our Solar System. Why the formation environment of these pre-solar components could be disclosed is shown in Figure 1 of Westphal et al. (2016 this issue): the spatial resolution of analytical techniques with acronyms such as ATP, HIM, SXFR, ALCHEMI, CHILI, or NanoSIMS has improved from 10 μm in the 1970s to sub-nm in 2015, which is almost 5 orders of magnitude!

There are of course other, more terrestrial examples of Earth science breakthroughs that are due to microanalytical techniques. SIMS oxygen isotope analysis of single 4.4-billion-year-old zircon crystals showed that the Earth formed continental-type crust quickly after accretion, and that liquid water was stable on the early Earth's surface. Mass-independent sulfur isotopes measured in a tiny pyrite crystal that was enclosed in a diamond 2 billion years in age showed the subduction of oceanic crust into the mantle contained sulfur exposed to the low atmospheric oxygen concentrations of that time. But "small is beautiful" is not only about improving spatial resolution. The ability to

measure ever smaller quantities of materials has allowed $^{39}\text{Ar}/^{40}\text{Ar}$ dating of single feldspar crystals for precise reconstructions of volcanic ash falls or the tracing of the source of organic matter by compound-specific radiocarbon analysis.

In light of these successes, why would I even consider the "bigger the better" future of geochemistry to be "better"? Well, to explain and quantify global geochemical fluxes, we need to measure representative averages of the materials involved. If the task is, for example, to quantify the amount of atmospheric CO_2 withdrawn annually by silicate weathering, we need to determine the global flux of Ca and Mg to the oceans by many rivers. A single sample won't do the job. However, even where samples are readily accessible, performing representative sampling is one of the most difficult of all tasks. Hence, geochemists have become good at "letting nature do the averaging" for us. We measure the chemical and isotopic composition of mid-ocean ridge basaltic glass because the high degree of melting of their source makes them representative of the Earth's upper mantle. We use loess sediment as a probe for the composition of the upper continental crust. We measure the Sr and Li isotope composition of marine carbonate sediment as proxies for past global weathering. And we measure the concentration of rare cosmogenic nuclides in many quartz grains of river sediment to determine the average erosion rate of a basin the size of the Amazon River basin.

So, is there a winner amongst these two apparently divergent approaches? Are these approaches actually opposing? The answer obvious from the above examples is: "the approach depends on the question". The most formidable challenge, however, lies in combining both ends of the analytical spatial scale. This combination can be done *conceptually*. For example, microscale observations provide us with the laws of the governing processes (such as a fractionation factor), which then can be used to constrain the larger-scale process (such as a mass flux). To do this, all geochemical disciplines have adopted both upscaling and classical multi-proxy approaches. Much has already been said and written about this topic, so I do not wish to dwell here.

An even more direct route is the *experimental* combination of large scale applications and microanalytical techniques on a single sample. First, microbeam in situ techniques help to identify the pristine original "fingerprint," unaltered from later perturbations. One example is identification of the original boron isotope composition of foraminiferal tests, which enables the unbiased reconstruction of past atmospheric CO_2 concentrations. Second, microanalyses of many grains rather than measuring only one averaged composition supplies us with important statistical information on the distribution around this average. For example, fast laser ablation of U-Pb (age) or Hf (source) isotopes in many zircon crystals contained in a single or several sediment samples has become a powerful sedimentary

Cont'd on page 156

ABOUT THIS ISSUE

Anyone who lives in an arid environment can attest to the seemingly endless task of cleaning dust off furniture. The *Elements* editorial office is located in sunny eastern Washington (USA) where tumbleweeds and sagebrush are in abundance. And so is the dust. Even though, as contributor Don Brownlee indicated, the dust that quickly coats the editorial office furniture is predominantly not extraterrestrial in origin, it is intriguing to think at that maybe just one or two tiny grains of that dust might just be genuinely cosmic. Not being a specialist in cosmic "anything", I was amazed to learn from the articles in this issue just how remarkable cosmic dust really is. These tiny cosmic dust particles are recorders of the history of our Solar System, comets, asteroids, planets, and moons. They can also be used to date and understand terrestrial phenomena. And, with the rapid advancement of analytical methods available, the information gleaned from these particles about our cosmic neighborhood (and our home) will only increase in the future. I suspect that the extent of future cosmic dust research will be, as Disney's Toy Story character Buzz Lightyear likes to say, "To infinity ... and beyond". Now, if I can only get as equally excited about cleaning those multiplying dust bunnies...



Jodi Rosso

PROPOSING TOPICS FOR FUTURE ELEMENTS ISSUES

Do you think your research area would make an interesting issue of *Elements*? Consider submitting a proposal. Would you like to read about a certain topic? Let the editors know!

Many potential guest editors first send an e-mail of inquiry to one of the principal editors or executive editor about their idea for a thematic issue. These "feeler" e-mails are circulated amongst the editorial team and feedback on the topic and/or proposal is provided.

The principal editors meet twice a year to evaluate proposals (in May and December) and determine the lineup for future *Elements* issues. Currently, we are accepting proposals for consideration for the August/October/December issues in 2018. This 3 issue lineup will be determined during our early December 2016 meeting.

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**Gordon Brown, Bernie Wood,
Friedhelm von Blanckenburg, and Jodi Rosso**

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EDITORIAL *Cont'd from page 155*

provenance indicator. Third, measuring very small samples that have previously been "averaged by nature" is the true champion. Perhaps the most prominent example is the detailed reconstruction of atmospheric trace-gas time series through the late-Quaternary climate cycles from minute amounts of CO₂, CH₄, and CF₄ and its stable isotopes extracted from Antarctic or Greenland ice core bubbles.

With what recommendation should I end this trip through the spatial scales? The first one is rather trivial: if a request for measurements arrives on the desk of the analytical persons amongst us, the mandatory return question should be, "What is the question?" The second is that ultimately, the upscaling, both experimentally and conceptually, between the beautiful small and the better big might be the true grand challenge in geochemistry.

Friedhelm von Blanckenburg
Principal Editor

Westphal AJ, Herzog GF, Flynn GJ (2016) Cosmic dust toolbox: microanalytical instruments and methods. *Elements* 12: 195-200