FOOD FOR GEOLOGICAL THOUGHT

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I recently asked a first-year student what the difference was between a rock and a mineral and he replied, "A rock is like a salad…" His immediate reply started me thinking about using food analogues to teach geological concepts. I subsequently found this approach has been widely studied and proven to be effective. For example, Baker et al. (2004) used the viscosities of common foods as analogues for silicate melts to help teach students about igneous processes. In this study, the viscosities of maple syrup, molasses, ketchup, and smooth peanut butter were all measured at 25 °C and 1 bar and compared with the viscosities of natural silicate melts. The viscosity of peanut butter turned out to be near to that of a rhyolitic melt with ~2 wt% H_2O at 800 °C, and the viscosity of ketchup near to that of an anhydrous, molten tholeiitic basalt at 1,200 °C. Students who had been taught silicate melt viscosities using food analogues retained their knowledge of silicate melt viscosities better than students who had not used food examples. Inspired by this, and seeking a new way to introduce concepts of rheology and phase stability in a class on Earth materials, I turned to a common food that is familiar to all: chocolate. Chocolate is a fascinating and complex material, displaying many properties analogous to Earth materials. And if your interest is piqued, read a more detailed description of the science of chocolate in Stephen Beckett's book of the same name, *The Science of Chocolate* (2008).

Polymorphs of chocolate. (LEFT) The preferred form for taste and texture is V (β_2). (RIGHT) The most stable form, VI (β_1), is shown as a white-colored "chocolate bloom".

Chocolate is made by first mixing sugar with chocolate liquor (cocoa beans that have been fermented, roasted, and ground until they form a liquid of cocoa butter and cocoa solids). This mixture is then ground, and more cocoa butter is added along with the emulsifier lecithin, which makes the ingredients blend together. There may then be additives such as milk powder and/or fruits and nuts. Although we think of chocolate as a solid, it is normally a liquid (the liquor) and is only solidified just before it is ready to be packaged or eaten.

The rheology of the chocolate—how it deforms and flows under the influence of mechanical forces—is very important in producing its correct weight, appearance, and, most importantly, its taste! Chocolate is a non-Newtonian liquid, which means that its viscosity varies with the application of mechanical forces, such as shear stress. A simple experiment demonstrates this concept. Take a piece of chocolate and insert it into your mouth, letting it melt on your tongue. Next, press this highly viscous liquid against the roof of your mouth. Note how the application of the mechanical force decreases the viscosity of the chocolate so that it flows over the surfaces of your tongue and palate. The key to making the best melt-in-your-mouth chocolate depends on its crystal structure.

Of all the ingredients in chocolate, it is the cocoa butter that determines its crystal structure. To complicate matters, there are different ways that the individual molecules of cocoa butter can pack together: these different ways lead to six polymorphic forms, designated as I–VI or, alternatively, as γ, α, β_2', β_1', β_2, β_1. The cocoa butter polymorphs form at different temperatures, the rates of formation being dependent on temperature. The polymorphs greatly affect the taste and texture of a chocolate by controlling its melting point, how easily it snaps, as well as its strength, glossiness, and texture. For example, the thermodynamically most stable polymorph is VI (β_1), which is visually unattractive and has a dull surface. It melts slowly to produce a sandy sensation when being eaten and has a soft texture similar to candle wax. The desired polymorph of chocolate is form V (β_2), which displays a glossy surface, crisp hardness, and produces that pleasant melting sensation in the mouth. The challenge is to make the chocolate crystallize in this metastable, but preferred, form. And this is done by tempering.

Tempering involves melting chocolate to about 50 °C to erase all memory of existing crystalline structures and then cooling the chocolate to about 26–27 °C to form a mix of crystals. It is then warmed back up to 30–32 °C to remove the undesirable III and IV (β') polymorphs, leaving only the V (β_2) crystals which have a melting point of 33–34 °C. In practice, some of the undesired polymorphs remain, so seed crystals of the desired polymorph are added to the partially molten chocolate to promote nucleation. This part of the process also results in a smaller particle size, which gives the chocolate a smooth appearance. Once fully tempered, however, your prized chocolate bar may still undergo undesired changes. Over time, the metastable V crystals will slowly transform into the thermodynamically stable polymorph VI (β_1). Larger crystals of this polymorph will appear on the chocolate's surface to give it a greyish appearance, something often referred to as "chocolate bloom". At room temperature, this reversible transformation limits the shelf life of chocolate to several months, but the shelf life can be extended if such chocolate is stored in a refrigerated environment. Unfortunately, as you may have discovered by

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ABOUT THIS ISSUE

In the February 2016 issue of *Elements* (vol. 12, pp. 27–32), Athanassas and Wagner gave many of us our first glimpse of how dating by optically stimulated luminescence (OSL) was being used to chronologically constrain paleoenvironments and archaeological sites. The concept of luminescence dating is not new: it was initially proposed back in the 1950s. But, within the last 30 years, technological advancements have increased the power and applicability of this technique. Ann Wintle, one of the guest editors of this issue, is a pioneer in the field of luminescence dating. Ann has been at the forefront of its development since her 1974 PhD in which she combined her love of archaeology and applied physics to significantly improve on existing methods of thermoluminescence dating. Rachel Smedley, the other guest editor of this issue, is part of the new generation of scientists who continue to make great strides in improving and expanding the applicability of the technique. Now, in the February 2018 issue of *Elements*, Rachel and Ann have assembled a team of authors to further introduce us to this exciting field of research, one that is advancing our understanding on subjects as diverse as human evolution, mountain building, and climate change.

INTRODUCING JON BLUNDY, PRINCIPAL EDITOR 2018–2020

With the start of 2018, Jonathan (Jon) Blundy joins the *Elements* team as a principal editor. He is taking on the mantle of petrology editor, following in the footsteps of other petrologists who have served with Elements: Ian Parsons, Bruce Watson, Hap McSween, John Valley, and Bernie Wood.

Jon Blundy is an igneous petrologist and is interested in all things magmatic, from magma generation in the crust and mantle to active volcanoes and hydrothermal mineralization. His research uses a combination of field observations, thermodynamics, microbeam analysis, and high-pressure/high-temperature experiments. In the mid-1990s, together with Bernie Wood, he developed the lattice-strain model for trace element partitioning that is now widely used in the modelling of magmatic processes. He worked on the iconic 1980–1986 eruptions of the Mount St. Helens volcano (USA) with Kathy Cashman. More recently, Jon has focused his volcanic interests on the island arcs of the Lesser Antilles, the Republic of Vanuatu, and Kamchatka. Since 2010, Jon has been engaged in industry-funded applied research into the origin of porphyry copper deposits from a volcano petrology perspective.

Jon has been at the University of Bristol (UK) since 1989, where he became Professor of Petrology in 2004. He was elected Fellow of the Royal Society in 2008 and member of Academia Europaea in 2011. He is a recipient of the Clarke Medal of the Geochemical Society (1997), the Murchison Medal of the Geological Society of London (2016), and the Science Innovation Award of the European Association of Geochemistry (2016). He is one of the Mineralogical Society of America's Distinguished Lecturers for 2018. He is a former editor of *Contributions to Mineralogy and Petrology* and is currently an Earth sciences subject editor for *Royal Society Open Science*, a new open access e-journal.

We are delighted to have Jon join the *Elements* editorial team. Jon is already hard at work working with the guest editors and authors of the August 2018 issue on magmatism in the central Andes.

ELEMENTS ON GEOSCIENCEWORLD

GeoScienceWorld

In November 2017, Silverchair Information Systems and GeoScienceWorld (GSW) announced the launch of the new GeoScienceWorld.org web site which now operates on the Silverchair platform. With the migration from HighWire to Silverchair, the site hosting *Elements* (pubs.geoscienceworld.org/elements) received new features that you, the reader, may enjoy using:

- **Split screen display** — allows users to scroll the journal article and the article figures simultaneously and independently, to view larger versions of images, to download images for PowerPoint options, and to view PDFs
- **Faceted searching** — adds flexibility when doing searches for journal, journal section, article type, book series, and GeoRef keywords
- **Integrated OpenGeoSci Map view search results** — allows users to search by geographic location for cross sections, charts, tables, figures, and data from GSW publications
- **Figure abstracts viewable in search results** — thumbnails display with results, so users can scan for relevant content
- **Re-conceptualized treatment of GeoRef Thesaurus** — integrates the traditional thesaurus with search results

Even if your institution does not subscribe to GSW, you can still take advantage of many of the above new features, especially OpenGeoSci, which is the free, public, map-based toolset.

Bernard Wood, **Friedhelm von Blanckenburg**, **Nancy Ross**, **Jonathan Blundy**, and **Jodi Rosso**

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leaving your chocolate in the sun or in a warmed-up car, the undesirable phase transition to polymorph VI (β_2) happens quickly at higher temperatures. If this phase transition occurs, the hard work of tempering the chocolate is lost and you will have chocolate that is dull, soft and melts slowly in the mouth!

I hope you have enjoyed this brief tour of the material science of chocolate and you have identified many of the processes and properties that we also find in the less edible Earth materials. Some food for your geological thought.

Nancy L. Ross, Principal Editor

REFERENCES

Baker DR, Dalpé C, Poirier G (2004) The viscosities of foods as analogs for silicate melts. Journal of Geoscience Education 52: 363-367

Beckett ST (2008) The Science of Chocolate. Royal Society of Chemistry, London, 2nd edition, 240 pp