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# JOURNEY TOWARDS THE CENTER OF THE EARTH

John W. Valley

Who isn't fascinated by caves and volcanoes? They are windows to the interior of the Earth. We know more about places on the Moon, and now Mars, than what lies 100 km beneath our feet. Jules Verne (1864) captured this interest when he fantasized Prof. Lidenbrock's journey to the center of the Earth. The professor, it seems, climbed down a lava tube on the stratovolcano Snaefellsjökull in Iceland and had a series of entertaining adventures with a vast subterranean ocean, an ichthyosaurus, giant diamonds, and prehistoric humans before he was somehow ejected by an eruption and emerged at Stromboli in Italy! The fiction of this account is humorous, but played off scientific advances of its time. Verne's 1864 idea of an earlier primitive human race is said to have been inspired by Lyell (1863), who was influenced by Darwin (1859). The implications of preserved ancient worlds (or time travel?), a cliché today, were novel then. But it is the imaginatively strong rocks and lack of ductility implied by open voids at great depth that I want to discuss. What are the limits of this fiction? When it comes to high-pressure metamorphism, our imagination has sometimes been ductility-challenged.

Before the plate tectonic revolution fully took hold, experiments demonstrated that blueschist mineral assemblages are stable only at high pressure (HP) and low temperature. In combination with field studies, this led to the hypothesis that these crustal rocks were somehow buried to great depth (15–30 km), kept cool, and returned to the surface (Essene et al. 1965; Ernst 1965). How could that happen? The elegant explanation now provided by subduction of oceanic crust was not yet appreciated, and the interpretations of high $P$ and low $T$ were met with some skepticism. Alternate, shallow processes, such as tectonic overpressure, were proposed. If great lateral forces could move continents, could pressures much greater than the lithostatic load be applied to shallow rocks? But like Verne's caves, tectonic overpressure requires that rocks have sufficient strength, which experiments and seismology have shown not to be the case, and HP metamorphism is now recognized as evidence for subduction.

This issue of *Elements* describes more recent and perhaps more remarkable advances in the petrology of UHP (ultrahigh-pressure) metamorphic rocks. UHP index minerals, including microdiamond and coesite, have been found in metasediments of at least 20 terranes that were buried to depths greater than 100 km, possibly much greater, and have somehow returned to the surface. This history and the tectonic implications are fascinating but uncertain, and are reminiscent of the earlier controversies regarding HP metamorphism.

"Je m'imaginais voyager à travers un diamant."
(*I thought I was traveling through a diamond.*)
ILLUSTRATION BY ÉDOUARD RIOU (1867)

An early tenet of plate tectonics was that only mafic ocean crust is dense enough to subduct to depths where it converts to denser-still eclogite, sealing its fate to sink deeper. Such material can only return from the mantle in small pieces—as xenoliths entrained in magma, or perhaps as exotic blocks lubricated by serpentinite. In contrast, continental crust was said to be forever, suggesting that continental growth is the ideal savings account: continuous deposits over the past 4.5 billion years but never withdrawals. Now, UHP mineral equilibria show that even granitic compositions and sediments become dense if buried to mantle depths in a Himalayan-style orogeny. Our savings are not secure; continental crust does subduct. Once this happens, its fate is uncertain. How deep can such rocks be buried and still return to the surface? How much never returns? How is exhumation possible? Are regionally distributed UHP occurrences such as Dabie–Sulu a continuous terrane or an association of UHP outcrops surrounded by other rocks? Ductility (again) suggests surprising new mechanisms, including mantle drips and mantle diapirs.

The six articles in this issue plus a perspective describe the global occurrence of UHP rocks, including their mineralogy and beauty, phase equilibria, the role of fluids, geochronology, and the processes that may form and exhume them. Ruling paradigms are challenged by new ideas. Taken together, these studies define with remarkable detail the pressure–temperature–time–fluid composition ($P$–$T$–$t$–$X$) paths taken by these rocks on their journey towards the center of the Earth and their surprising return. They are our best window on the subcontinental mantle.

**John W. Valley*** (valley@geology.wisc.edu)

* Principal Editor in charge of this issue

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## THIS ISSUE

The story told in this issue developed from a simple observation under the microscope and the curiosity of a scientist to identify the "weird inclusions" he was looking at (you can read about this discovery on page 246). The identification of these inclusions changed the way we thought the continental crust was behaving. Amazing! Guest Editor Jane Gilotti and the cast of authors she assembled tell this story admirably.

This issue contains the first article in what is hoped will be a series under the overall title Mineralogy Matters. The aim of the series is to address the question as to whether research in a particular area of mineralogy (broadly defined to include petrology and geochemistry) has made an impact. Has, in fact, mineralogy "mattered" in the case being discussed. The first subject concerns arsenic and the severe human health problems associated with arsenic contamination of drinking water in several parts of the world. This series is being edited by Past Principal Editor David Vaughan who would welcome suggestions for topics and offers to become involved in writing future articles in the series. He can be contacted via email at david.vaughan@manchester.ac.uk.

## SURVEY HIGHLIGHTS

Shortly after the last issue went to press, I provided Seth Davis of the Geochemical Society with a short text to announce the issue in *Geochemical News* (I also provide such notices to all business managers/society news editors). He thought he would write a special item for *Elements'* 50$^{th}$ issue the following week. I responded by suggesting that it would be interesting to ask people what their favorite issue was. Within a day, we had a survey ready to go, and we asked participating societies to distribute the Web link. Thanks Seth for making it happen!

The survey ran between June 18 and 28. In all, 527 of you responded. Thank you to everyone who participated in the survey and provided a wide variety of useful comments for the consideration of the editors and Executive Committee. For those who are curious, the top 10 favorite issues selected in the survey were (participants could provide up to 5 choices):

- Zircon: Tiny but Timely (v3n1, 2007)
- Rare Earth Elements (v8n5, 2012)
- Granitic Pegmatites (v8n4, 2012)
- Supervolcanoes (v4n1, 2008)
- Early Earth (v2n4, 2006)
- One Hundred Years of Geochronology (v9n1, 2013)
- Diamonds (v1n2, 2005)
- When the Continental Crust Melts (v7n4, 2011)
- Tourmaline (v7n5, 2011)
- Large Igneous Provinces (v1n5, 2005)

These popularity ratings have to be taken with a grain of salt, and the vast majority of the comments dealt with the difficulty of choosing only 5 favorites.

One responder wrote, "This selection is completely arbitrary. I found most of the issues extremely interesting, but often from different points of view – teaching, own research, interest for unknown fields, demonstrating to my university president/faculty members the importance of geosciences." Another mentioned, "As a lecturer, numerous issues of *Elements* have provided excellent introduction to topics for advanced undergraduate courses. Several issues have provided overviews of areas new to me that are becoming important for my own research."

The Editorial, Meet the Authors, Book Reviews, Perspectives, and Triple Point are the most-read regular features. But many of you reported reading *Elements* from cover to cover. 85% of respondents read the society news either always or sometimes: "I have found this to be a worthwhile section that generally has useful/interesting info," commented a respondent. About 2/3 of the survey participants read the print version while the remainder use the online version, and some read both. More than half the respondents listed topics they would like to read about, and this extensive list represents a wealth of information that the editors will review attentively.

## 2012 IMPACT FACTOR

*Elements'* impact factor for 2012 was 3.156, and its 5-year impact factor was 3.612. The 10 most cited articles from the time of publication to July 2013 are:

- Geisler T, Schaltegger U, Tomaschek F (2007) Re-equilibration of zircon in aqueous fluids and melts. Elements 3: 43-50 (*128 citations)*
- Harley SL, Kelly NM, Moller A (2007) Zircon behaviour and the thermal histories of mountain chains. Elements 3: 25-30 (*114*)
- Oelkers EH, Gislason SR, Matter J (2008) Mineral carbonation of $CO_2$. Elements 4: 333-337 (*84*)
- Charlet L, Polya DA (2006) Arsenic in shallow, reducing groundwaters in southern Asia: An environmental health disaster. Elements 2: 91-96 (*83*)
- Cartigny P (2005) Stable isotopes and the origin of diamond. Elements 1: 79-84 (*79*)
- Morin G, Calas G (2006) Arsenic in soils, mine tailings, and former industrial sites. Elements 2: 97-101 (*65*)
- Benson SM, Cole DR (2008) $CO_2$ sequestration in deep sedimentary formations. Elements 4: 325-331 (*63*)
- Campbell IH (2005) Large igneous provinces and the mantle plume hypothesis. Elements 1: 255-260 (*58*)
- Brantley SL, Goldhaber MB, Ragnasdottir KV (2007) Crossing disciplines and scales to understand the Critical Zone. Elements 3: 307-314 (*54*)
- Rubatto D, Hermann J (2007) Zircon behaviour in deeply subducted rocks. Elements 3: 31-36 *(53*)

**Pierrette Tremblay**, Managing Editor

*Cont'd from page 243*

## REFERENCES

Darwin C (1859) On the Origin of Species, or the Preservation of Favoured Races in the Struggle for Life. J. Murray, London

Ernst WG (1965) Mineral parageneses in Franciscan metamorphic rocks, Panoche Pass, California. Geological Society of America Bulletin 76: 879-914

Essene EJ, Fyfe WS, Turner FJ (1965) Petrogenesis of Franciscan glaucophane schists and associated metamorphic rocks. Beiträge zur Mineralogie und Petrographie 11: 695-704

Lyell C (1863) The Geological Evidences of the Antiquity of Man: with Remarks on Theories of the Origin of Species by Variation. J. Murray, London

Verne J (1864) Voyage au Centre de la Terre, Hetzel, Paris