American Mineralogist, Volume 103, pages 648–649, 2018

Presentation of the Mineralogical Society of America Award for 2017 to Dustin Trail

E. Bruce Watson[1]

[1]Department of Earth & Environmental Sciences, Rensselaer Polytechnic Institute, Troy, New York 12180-3522, U.S.A.

Dustin Trail began his scientific career as a computer science major in the early 2000s at the University of Colorado, Boulder. Fortunately for our community of mineralogical scientists, Dustin enrolled (as a third-year student) in Steve Mojzsis' course in Earth History for the purpose of fulfilling a science elective. Anyone who knows Steve or who has heard him speak understands why this might have been a life-changing experience for an impressionable young scientist-in-the-making: Steve is a passionate, mesmerizing speaker who can draw his audience into a story like few others in our field. As it turned out, Steve lured Dustin Trail irretrievably into a new future profession.

Dustin completed his B.S. in computer science at Colorado (with a minor in applied mathematics), but he had come under the spell of Earth history, and he continued on as a Master's student in geology with Steve. His early research efforts centered on ion microprobe studies of Hadean zircons from the Jack Hills metaconglomerate of Western Australia. As the oldest materials on our planet, these samples are extraordinary in every way; however, because they are detrital and therefore removed from context, they present special challenges as recorders of information on their history and of the character of their original host rocks. Dustin's investigations as a Master's student were pathbreaking in showing that depth-profiling of oxygen isotopes by SIMS could be used to identify post-crystallization thermal (metamorphic) events experienced by these ancient zircons, and also that oxygen isotopes could be used in combination with key trace elements to shed light on provenance.

As unlikely as this might seem—considering my own laboratory-based comfort zone—I met Dustin Trail on a field expedition in the outback of Western Australia organized by Mark Harrison in June of 2005. We visited the Jack Hills "type locality" to obtain samples of the famous conglomerate that would ensure the future supply of Hadean zircons at RPI and elsewhere (contrary to the bewildering rumors that surfaced later, we left the Jack Hills outcrop intact, hauling away only ~800 kg of conglomerate). In 2005, Dustin was completing his Master's work with Steve Mojzsis; if I had not known that, I would have judged him to be a young professor on the basis of his intellectual sophistication and his mature perspective on science. Not long after we returned to our home institutions, I contacted Dustin to say that if he wanted to embark on something entirely different for his Ph.D., I would be pleased to take him on as a student of experimental geochemistry. I considered this overture as a long shot because Dustin was already on the radar of several outstanding scientists as a potential doctoral student, and also because Troy, New York, does not beckon to everyone. True to his adventuresome spirit, however, Dustin chose to come to RPI in 2006 for the purpose of learning an entirely different approach to studying Earth history: peering into tiny noble-metal containers that had been subjected to deep-crustal pressure-temperature conditions.

It is probably not necessary to say that Dustin set his sights on zircon as the target for his first experiments. Specifically, he wanted to calibrate oxygen isotope fractionation between zircon and quartz—with a view toward placing natural calibrations on a firmer footing—and then move on to figure out how hydrogen species are incorporated into the zircon structure (he saw the latter project as a first step toward a zircon-based "H_2O barometer" that could provide insight into the nature and "wetness" of Hadean magmatism when applied to the Jack Hills zircon suite). It would be an understatement to say that growing measureable-sized zircons in the laboratory at geologically realistic conditions is a challenge. Dustin ignored my hints that he might want to take on something easier for his first experimental project—and it's a good thing he did, because he was able to extract high-quality data in both of these challenging studies. The oxygen isotope project necessitated recovery of zircon separates from ~20 mg of experimental run product; the "H_2O barometer" project involved preparation of doubly polished sections of *oriented* 30 μm zircons. Both these projects would have challenged the skill and ingenuity of even the most experienced and talented experimentalists. It was Dustin's completion of this work that alerted me to the fact that he brought a remarkable level of creativity, tenacity and skill to the business of experimental geochemistry.

The crowning achievement of Dustin Trail's doctoral research was still to come. This involved the laboratory calibration and application of an oxygen fugacity "sensor" recorded in magmatic zircons. Dustin crystallized zircons in the presence of rare earth elements and demonstrated that the uptake of cerium is sensitive mainly to the prevailing oxygen fugacity (f_{O_2}) of the system and to temperature. The dependence on f_{O_2} occurs because the Ce^{4+}/Ce^{3+} ratio increases with increasing f_{O_2}, and the 4+ ion is much more suited to incorporation in the zircon lattice. Combined with measurements of Ce and other rare earths in Hadean zircons, the results of Dustin's experiments made it possible for him to conclude that gases associated with Hadean magmas would have been characterized by a relatively oxidized assemblage of molecular species: CO_2, H_2O, N_2, and SO_2, rather than CH_4, NH_3, and H_2S as is commonly hypothesized for early Earth. It would be difficult to overstate the importance of this finding: Dustin's study gave us *the first direct insight into the nature of the gases emanating from early Earth*. Two simple assumptions are key to his arguments—the first being that the Jack Hills zircons are mostly magmatic (a small percentage may not be, but few knowledgeable researchers dispute the dominantly igneous origin). The second assumption is that the Hadean magmas from which the zircons crystallized contained dissolved volatiles, which is also widely accepted given the hydrous nature of the inclusion assemblage and the low temperature range of zircon

0003-004X/18/0004–648$05.00/DOI: http://doi.org/10.2138/am-2018-AP10343

crystallization. Dustin's Ce-based oxygen barometer thus tells us that the molecular gases exsolved from Hadean magmas must have been relatively oxidized—much like those of geologically recent times. Importantly, this finding *does not* imply that appreciable free oxygen was present in Earth's early atmosphere, but it may have implications for early life and the prevalence of abiotic synthesis though Miller-Urey type processes. Regarding the importance of Dustin's result, the key realization is that all ideas about the early atmosphere that preceded his work were based on models whose outcomes were critically dependent upon somewhat uncertain starting assumptions. His zircon oxygen barometer provides the first direct insight into the molecular make-up of magmatic emanations feeding the early atmosphere. The significance of this work is underscored by the fact that Dustin's *Nature* paper (Trail et al. 2011) and more comprehensive *Geochimica et Cosmochimica Acta* companion paper (Trail et al. 2012) have already been cited a total of ~300 times.

I want to point out in closing that, despite the early-Earth focus of Dustin Trail's research to date, his contributions are sufficiently fundamental to have enormous value in the study of Earth and planetary materials of all ages. Given the broad relevance of knowledge of the behavior of redox-sensitive elements such as Ce, for example, the importance of Dustin's work extends well beyond the most ancient zircons.

Please join me in congratulating Dustin Trail on the occasion of his recognition with MSA's prestigious early-career award for the fundamental contributions he has made to the mineralogical and geochemical sciences, and to knowledge of our planet in its infancy.

References cited

Trail, D., Watson, E.B., and Tailby, N.D. (2011) The oxidation state of Hadean magmas and implications for early Earth's atmosphere. Nature, 480, 79–82. doi: 10.1038/nature10655

——— (2012) Ce and Eu anomalies in zircon as proxies for the oxidation state of magmas. Geochimica et Cosmochimica Acta, 97, 70–87. doi: https://doi.org/10.1016/j.gca.2012.08.032