SPP1833
Building a
Habitable Earth

Abstracts

of the Fourth General Meeting

“Early Earth evolution”

March 27-29, 2019

Köln

SPP1833
Building a
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PROGRAMME

General Meeting 2019
SPP 1833 “Building a Habitable Earth”
Geo/Bio-Hörsaal, Zülpicher Straße 49, Köln

Wednesday, March 27th: Evolution of the early solar system and planets

14.00-14.20	Carsten Münker, Köln: Introductory remarks and Update on SPP activities
14.20-14.40	Patrick Barth, Heidelberg: Coupled Atmosphere-Interior Model for Terrestrial Exoplanets
14.40-15.00	Jan Leitner, Mainz: Ongoing isotopic, chemical and mineralogical characterization of organic and inorganic nitrogen-carriers in chondritic meteorites
15.00-15.20	Janos Kodolanyi, Mainz: Iron-60 as a Heat Source for Melting and Differentiation of Earth-forming Planetesimals and Planetary Embryos
15.20-16.10	*Coffee Break*
16.10-16.30	Maxwell Thiemens, Brüssel: Hf/W insights to the early Moon
16.30-16.50	Mario Fischer-Gödde, Köln: The ruthenium isotopic composition of the Earth’s pre-late veneer mantle
16.50-17.10	Mario Trieloff, Heidelberg: Tracing mantle and crustal degassing via the palaeoatmospheric ^{40}Ar/^{36}Ar ratio
17.10-17.30	Markus Pfeifer, Bristol: Applications of the Proteus collision cell MC-ICPMS to Earth evolution studies.
17.30	*Icebreaker Reception and Dinner in the Foyer*

Thursday, March 28th: Archean Processes

9.00-9.20	Jonas Tusch, Köln: Heidelberg: Tungsten isotope patterns of rocks from the Pilbara Craton, Australia
9.20-9.40	Annika Dziggel, Aachen: Evolution of an Archean large hot orogen, SW Greenland
9.40-10.00	Sampriti Basak, Bochum: Can partial melting and differentiation from an early mafic crust yield a tonalitic / enderbitic crust?
10.00-10.40	*Coffee Break*
10.40-11.00	Elis Hoffmann, Berlin: Halogens as a potential novel proxy for early habitats in hydrothermal systems
11.00-11.30	Lena Noack, Berlin: Thermo-chemical modeling of Archaean Earth - from interior to surface
11.30-11.50	Boris Kaus, Mainz: Control of mantle potential temperature on plume-lid interaction and implications for the earliest continental crust
11.50-12.10	Mike Jansen, Köln: Early mantle heterogeneities in modern mantle plumes – new insights from ^{182}W measurements
12.10-14.00	*Lunch Break*

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Thursday, March 28th: Origin and early evolution of Life

14.00-14.20	Allison Enright, Tübingen: Characterizing the ability of silicate particles to shield cells from UV-radiation damage
14.20-14.40	Achim Herrmann, Kaiserslautern: Surviving the ferruginous Archean ocean – Assessing the potential toxicity of Fe2+ on basal Cyanobacterial strains under anaerobic conditions
14.40-15.00	Helge Mißbach, Göttingen: Tackling the origin of organic signatures in early Archean rocks
15.00-15.40	*Coffee Break*
15.40-16.00	Raul Martinez, Jena: The raise and fall of Archean atmospheric oxygen: Did temporary carbon burial as Fe(ox)-DOM complexes play a modulating role?
16.00-17.30	*Poster Session*
16:45-17:30	*Lab Tours*

Friday, March 29th: Early Oceans

9:00-9:50	*General Discussion*
9.50-10.10	Ashley Martin, Hannover: Uranium isotope fractionation in Archean Carbonates: Insights from the Tumbiana Formation, Western Australia
10.10-10.30	Sukanya Sengupta, Göttingen: Triple oxygen isotopes in cherts as a proxy for temperature and δ^{18}O of Precambrian seawater
10.30-10.50	Jakub Surma, Göttingen: Triple oxygen isotope signatures in marine carbonates – insights from high resolution gas source isotope ratio mass spectrometry
10.50-11.10	Sonja Geilert, Kiel: Si isotope fractionation during BIF formation – inferences from a modern Archean ocean analogue
11.10-11.30	David Ernst, Bremen: Non-detrital Gallium and Aluminium in Early Precambrian Marine Chemical Sediments and the Potential Use of the Ga/Al Ratio as a Geochemical Proxy for Metal Sources and Relative Fluxes to the Early Ocean
11.30-11.35	*Conclusion*

Note that only the first author/speaker of each talk is given, all co-authors are cited in the abstracts

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POSTERS

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Wafa **Abouchami**, Cologne: Cadmium isotope fractionation in the Earth-Moon system

David **Ernst**, Bremen: Non-detrital Gallium and Aluminium in Early Precambrian Marine Chemical Sediments and the Potential Use of the Ga/Al Ratio as a Geochemical Proxy for Metal Sources and Relative Fluxes to the Early Ocean

Lanita **Gutieva**, Bochum: The complexity of the Scottish Lewisian Complex: a contiguous Archean craton or several disparate terranes?

Inga **Köhler**, Jena: Tephra associated with microbial mats of the Archean Moodies Group, Barberton Greenstone Belt (BGB), South Africa: Resemblance to potential biostructures and ecological implications

Jonathan A. **Lewis**, Berlin: Elucidating Eoarchean geodynamic processes by multiple sulfur isotopes

Joachim **Reitner**, Göttingen: 3.5 Ga-old “stinky” black barite (Dresser Fm, Pilbara, Western Australia) – a geobiological conundrum

Eric A. **Runge**: Putative impact tsunami deposit of the 3.5 Ga Dresser Fm., Pilbara, Australia

Julia **Schmidt**, Berlin: Understanding and comparing calculations of partition coefficients: how P-T conditions affect the enrichment of trace elements in the crust

Falko **Schulz**, Berlin: Magma oceans and their implications on modelling the early stages of mantle convection

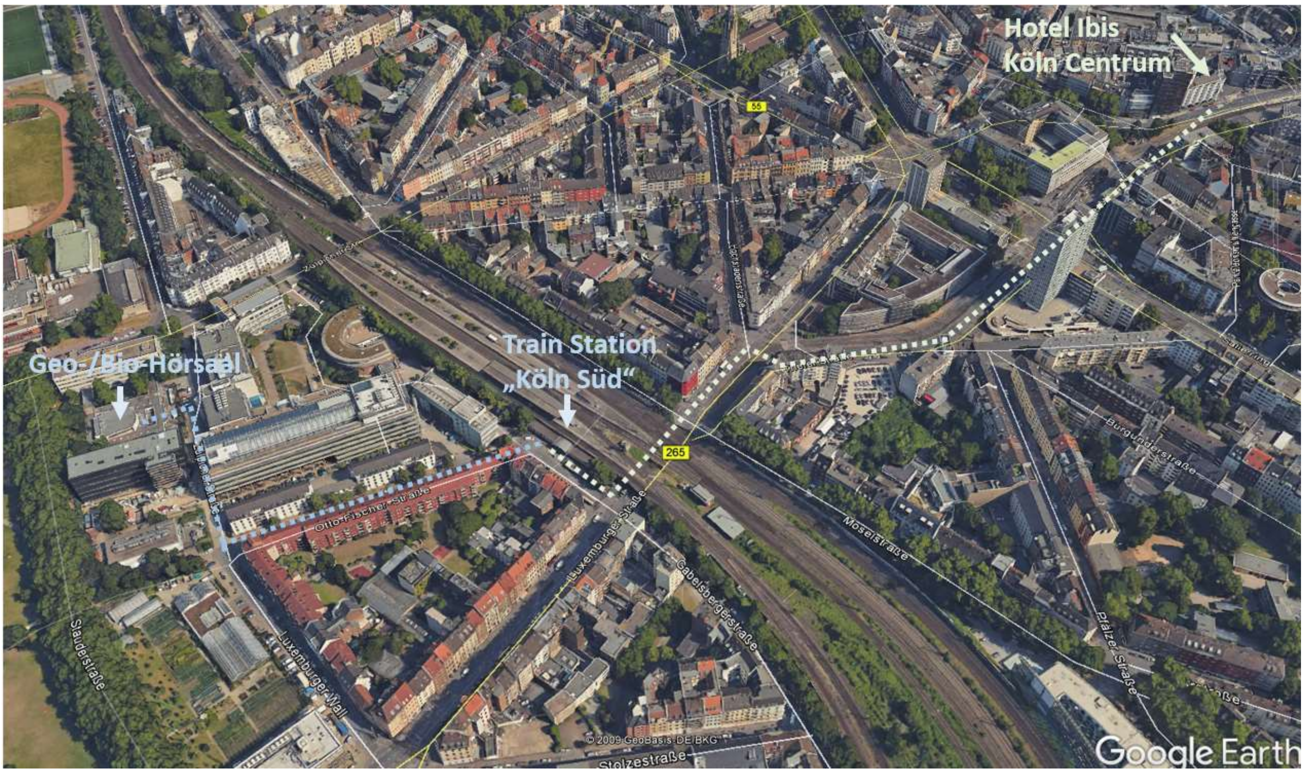
Esther **Schwarzenbach**, Berlin: Sulphur as a tool to identify alteration processes in ultramafic oceanic lithosphere

Sara **Vulpius**, Berlin: Global volatile cycles on early Earth

Matthias **Willbold**, Göttingen: Early Earth mantle heterogeneities – an isotope perspective

Note that only the first author of each poster is given, all co-authors are cited in the abstracts

Map of Cologne and the conference locations



All abstracts are given in alphabetical order of the first author

Cadmium isotope fractionation in the Earth-Moon system

Abouchami*, W., Wombacher, F., Galer, S.J.G.
*Universität zu Köln, Institut für Geologie und Mineralogie, Zülpicher Straße 49b, 50674 Köln, Germany
wafa.abouchami@mpic.de

The mass-dependent stable isotope fractionations of volatile elements, like K, Zn and Ga, in lunar rocks have been linked to giant impact models [1, 2] or to a combination of volatile element losses during the giant impact and the lunar magma ocean stage [3, 4]. So far, Cd stable isotope studies have been limited due to the strong Cd depletion of lunar basalts - about 300-fold relative to CI chondrites and 70-fold relative to terrestrial basalts [5]. The scarcity of Cd isotope data for pristine igneous lunar rocks is largely due to the analytical challenges involved in precise isotopic measurements on sub-nanogram levels of Cd which have until now only been successfully achieved on Cd-depleted seawater and terrestrial rocks samples. Investigating Cd isotope fractionation in lunar materials is particularly important for exploring how volatiles behave in planetary bodies during accretion and giant impacts given the greater volatility of Cd relative to other volatile elements. Similarly, large neutron capture effects in the per mil range for ^{113}Cd(n,γ)^{114}Cd have been reported [6, 7, 8] and attributed to the exposure to secondary thermal neutrons in the upper few meters of the lunar regolith. Such effects may provide constraints on the processes controlling the distribution of Cd in the lunar surface environment [8].

We have undertaken a series of experiments to optimize the chemical separation of Cd, blank levels and Cd isotope measurements on one nanogram amounts of Cd. This has been done as a prelude to acquiring new Cd isotope data on lunar soils and basalts for which Zn isotope data exist, allowing us to compare the systematics of these two elements with different volatilities. Initial data on peridotites and basalt reference materials – BCR-2 and BHVO-2 – were obtained using a ^{106}Cd-^{108}Cd double-spike with varied chemical separation and digestion methods and analysed by thermal ionization mass spectrometry on a Triton [9]. Multiple sessions and analyses of NIST SRM3108 yielded εCd of 0.22±1.10 (2SD, n=29) with internal errors on individual runs less than 2 ε (2σ). Repeated measurements of BHVO-2 and BCR-2 (ca. 2 to 4 ng Cd loads) yielded [Cd] of 92.02 (±0.17, n=5) and 218.3 ppb (±1.3, n=6) and $\varepsilon^{112/110}$Cd of 0.21±1.20 and 0.53±1.11, respectively (n=6). These values agree within errors with earlier measurements, using larger amounts of Cd and a different chemical separation, on different splits of BHVO-2 (0.18±0.14, [Cd] = 96.15 ppb) and BHVO-1 (0.36±0.18, [Cd] = 94.02 ppb). Initial measurements on the ordinary chondrite, Dimmitt H3.7 ([Cd] = 49.69 ppb) using different dissolution methods yielded an $\varepsilon^{112/110}$Cd of +21.54±0.47 (n=2, weighed mean) lower than that of +36 reported by [8], and both are more fractionated than the TIMS results of [10] (-6 ±8 $\varepsilon^{112/110}$Cd). These differences may reflect inherent sample heterogeneities, which is reasonable given that Dimmitt is a regolith breccia that contains H4 and H5 chondrite clasts [11]. Further tests on Cd-poor terrestrial and meteorite samples, digestion procedures and blanks will follow before we proceed with analyses of lunar samples.

[1] Paniello, R. C. et al. (2012) Nature 490, 376-379.

[2] Wang & Jacobsen (2016) Nature 538, 487-490.

[3] Kato, C. et al. (2015) Nat. Comm. 6, 1-4.

[4] Kato, et al. (2017) Science Adv. 2017, 3, 1-5.

[5] Wolf, R. & Anders, E. (1980) GCA 44, 2111-2124.

[6] Sands, D. G., et al. (2001) EPSL 186, 103-111.

[7] Schediwy, S. et al.(2006) EPSL 243, 326-335.

[8] Wombacher, F. et al.(2008) GCA 72,646-67.

[9] Schmitt, A.-D., et al. (2009) JAAS 24, 1079-1088.

[10] Rosman, K. J. R. & De Laeter, J. R. (1978) J. Geophys. Res. 83, B3, 1279-1287.

[11] Rubin et al. (1984) Meteoritics 16, 382-383.

Coupled Atmosphere-Interior Model for Terrestrial Exoplanets

Barth*, P., Carone, L., Barnes, R.
*Max Planck Institute for Astronomy, Königstuhl 17, D-69117 Heidelberg, Germany
barth@mpia.de

During the early stages of their life, terrestrial exoplanets are likely to have had completely molten mantles, so-called magma oceans. These magma oceans can play an important role in the evolution of volatiles in the planets' atmospheres. I.e. they influence the amount of water and oxygen left after the solidification of the magma ocean. Thus, magma oceans determine the habitability of rocky planets. Following the model of [1], I have written a code that models the evolution of magma oceans as a part of the Virtual Planet Laboratory [2]. So far, the model assumes a pure water atmosphere. First results for the Super Earth GJ1132b show that a few percent of the initial water content of the planet's atmosphere will be stored in the solidified mantle, potentially building a secondary atmosphere through outgassing. Further improvements will make the code applicable to different atmospheric compositions and include a more sophisticated model of the magma ocean.

[1] Schaefer, L. et al. (2016) APJ 829(2):63.

[2] Barnes, R. et al. (2018) ASCL:1811.017

Can partial melting and differentiation from an early mafic crust yield a tonalitic / enderbitic crust?

Basak*, S., Cambeses A., Chakraborty, S.
*Institut für Geologie, Mineralogie und Geophysik; Ruhr Universität Bochum
Universitätstrasse 150, D-44801 Bochum, Germany
Sampriti.Basak@rub.de

The Coorg massif region in Southern India is a remarkable terrain because it has a large extent of igneous rocks (mainly enderbites, with mafic and occasional pelitic enclaves) containing a history, as recorded in zircon ages, of events that occurred between *ca.* 3.1 – 3.5 Ga. There is only a minor overprinting signature of approximately Pan-African age (*ca.* 500 – 800 Ma). This time period is considered by a large group of scientists to be the time of initiation of plate tectonics on Earth [1, 2]. Thus, the rocks offer an opportunity to test models of formation of silicic crust from an early mafic continental crust. Exposures of mafic rocks (pyroxene granulites, garnet amphibolites) are found, in addition to enclaves, as individual bodies in the shear zone (Mercara Shear Zone) that demarcates the enderbite core from the neighbouring Dharwar group of rocks.

We have used bulk chemical data to calculate phase diagrams using the Perplex at a variety of conditions to explore the possibility that the enderbites could be derived from the observed mafic bulk rock compositions. The modeling was focused at P-T conditions that were found to be relevant for these rocks from our earlier results of geothermobarometry. It is found that a scenario such as: Melting of a mafic bulk rock at 10 – 12 kbar pressure, followed by ascent of the melt pool and crystallization at shallower depths (*ca.* 5 kbar) may explain the formation of the enderbites and therefore provide a mechanism for silicification of early mafic continental crust. Additional tests using trace elements (e.g. REE) and at different melting conditions are being carried out to further constrain the models, and isotopic criteria will be used to test if two types of rocks are genetically linked.

[1] Dhuime, B. et al. (2012) Science 335, 1334-1336.

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Evolution of an Archean large hot orogen, SW Greenland.

Dziggel, A.*, Diener, J.F.A., Kokfelt, T.F., Kolb, J., Scherstén, A.
* Institute of Mineralogy and Economic Geology, RWTH Aachen University, Wüllnerstraße 2, 52062 Aachen adziggel@iml.rwth-aachen.de

The geodynamic processes that formed the early continental crust are a matter of intense scientific debate, and both plate tectonic and vertical tectonic models have been proposed. In the Meso- to Neoarchean Tasiusarsuaq orogen in SW Greenland, there is compelling evidence for the existence of one-sided subduction, including paired metamorphism and regional-scale compressional deformation that resulted in the juxtaposition of terranes during the Neoarchean [1]. In addition, pseudosection modelling combined with geophysical studies point to a crustal thickness ≥ 60 km during the Neoarchean. Crustal convergence was associated with the emplacement of hot granulite nappes in the hinterland of the orogen (Tasiusarsuaq terrane), and their emplacement was melt-assisted [2]. Our data point to a hot and rheologically weak crust, in which nappe emplacement was tectonically-driven by the underthrusting of cold continental crust of the Færingehavn terrane. The thermal structure and evolution of the Tasiusarsuaq orogen is best explained by a model for large hot orogens such as the Grenville [3]. Large hot orogens are collisional orogens that are large and hot enough to develop plateaus above the overriding plate, because the latter is too weak to sustain significant topographic gradients.

[1] Dziggel, A. et al. (2014) Precambrian Research 242, 22–38.

[2] Dziggel, A. et al. (2017) Precambrian Research 300, 223–245.
[3] Beaumont, C. et al. (2006) Geological Society of London Special Publications 268, 91-145.

Survival of phototrophic Fe(II)-oxidizing bacteria in Strong UV-Light: the Role of Si-Fe Mineral Aggregates in Attenuating UV Flux

Enright, A.*, Mloszewska, A.M., Konhauser, K.O., Kappler, A.
*Center for Applied Geoscience, Sigwartstrasse 10, 72076 Tübingen, Germany
allison.enright@ifg.uni-tuebingen.de

High fluxes of UV-radiation during the Archean posed a tremendous challenge for early life, including marine plankton. Radiation below 254 nm has a destructive effect on DNA, which kills cells within minutes of exposure. Previous experimental work demonstrated that only a fraction of planktonic cyanobacteria would have been protected through the screening properties of amorphous silica and Fe(III) (oxyhydr)oxide particles[1], two minerals known to have precipitated extensively from seawater at that time (e.g., as banded iron formations). However, what is not known is whether those same minerals may have offered greater protection to other marine plankton, such as the anoxygenic phototrophic bacteria known as photoferrotrophs. In this work we experimentally form a series of Fe-silicate mineral phases (including nanoparticles and colloids) and then investigate their properties for UV attenuation through a combined approach of TEM, SEM, UV spectroscopy, and surface charge characterization. Our aim is to determine: (1) the chemical and physical properties of these aggregates, such as aggregate size, morphology, surface charge properties, and particle chemistry; (2) how well these properties affect the attenuation of light from a UV source, and (3) whether a photoferrotrophic bacterium can survive prolonged UV exposure when cultured with suspended Fe-silicate particles.

[1] Mloszewska, A. et al. (2018) Nat. Comms. 9(1), 3088.

Non-detrital Gallium and Aluminium in Early Precambrian Marine Chemical Sediments and the Potential Use of the Ga/Al Ratio as a Geochemical Proxy for Metal Sources and Relative Fluxes to the Early Ocean

Ernst*, D. M., Schier, K., Bau, M.
*Jacobs University, Center for Resource and Environmental Studies, Campus Ring 1, D-28759 Bremen, Germany
d.ernst@jacobs-university.de

Gallium and aluminium are geochemical partners and show coherent geochemical behaviour in most igneous and clastic sedimentary rocks [1-3]. However, fractionation of Ga and Al does occur during weathering and in aquatic environments. Subtle differences in the ionic radii and electron structures of Ga and Al lead to differences between the stabilities of chemical complexes of Ga and Al. This results in the preferred mobilization of Ga, which in turn produces higher Ga/Al ratios in river waters compared to the associated source rocks [4]. Another fractionation process occurs during salt-induced aggregation in estuaries. Due to the higher particle reactivity of Al compared to Ga, the aggregation and subsequent sedimentation of nanoparticles and colloids increases the Ga/Al ratio in estuarine waters. Moreover, compared to river waters, high-temperature hydrothermal fluids exhibit considerably higher Ga/Al ratios.

These differences in Ga/Al ratios offer the potential to further investigate the formation mechanisms of banded iron formations (BIFs), which are one of the most abundant marine chemical sediments deposited in the Precambrian ocean. Based on Ge-Si systematics it was proposed that the Fe-rich BIF bands form during times of intense marine hydrothermal activity (high Ge/Si ratio), while the Si-rich bands precipitate during times of hydrothermal quiescence and dominant riverine input into the ocean (low Ge/Si ratio; e.g. [5]). This model, however, is still controversially discussed and in dire need of verification. Provided that no fractionation of the Ga-Al pair occurs during BIF formation (as has been shown for the REE and Y, and is assumed for Ge and Si), Ga-Al systematics could potentially be applied as a source proxy for Fe and Si in BIFs and, therefore, in the Precambrian ocean.

We will, therefore, investigate the Ga-Al and Ge-Si systematics of BIFs by in situ measurements with LA-HR-ICP-MS on pure, i.e. detritus-free samples in oder to gain a better understanding of the origin of Fe and Si in the Precambrian ocean and, hence, Earth’s early atmosphere-hydrosphere system.

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[2] Fedo, C. M. et al. (1996) Geochim. Cosmochim. Acta 60, 1751—1763.

[3] Breiter, K. et al. (2012) Geological Carpathica 64, 171—180.

[4] Shiller, A. M. (1988) Geochim. Chosmochim. Acta 52, 1879—1882.

[5] Hamade, T. et al. (2003) Geology 31, 35—38.

The ruthenium isotopic composition of the Earth's pre-late veneer mantle

Fischer-Gödde*, M., Elfers, B.-M., Münker, C., Szilas, K., Maier, W.D., Messling, N., Morishita, T, Smithies, H.
*Institut für Geologie und Mineralogie, Zülpicher Str. 49b, D-50674 Köln, Germany (mfisch48@uni-koeln.de)

It has long been suggested that a late veneer consisting of carbonaceous chondrite-like asteroids or comets from the outer solar system could be the source of the Earth's volatiles and water [1,2]. This hypothesis, however, was recently refuted by a Ru isotope study, which concluded that the late veneer was rather made of volatile-poor inner solar system material [3]. The robustness of this conclusion heavily relies on the assumption that the Ru in the Earth's mantle derives predominantly from late veneer [4]. If, as recently suggested, the mantle before the addition of the late veneer already contained a fraction of Ru [5], the isotopic constraints about the nature of the late veneer require revision in consideration of the Ru isotopic composition of the pre-late veneer mantle. To address this issue, we obtained Ru isotopic data for Archean mantle samples from Itsaq and Narssaq (Greenland), Pilbara (Australia), Barberton (South Africa), and Abitibi (Canada).

Our results reveal that Eoarchean chromitite and peridotite samples from Itsaq and Narssaq, Greenland, have relative ^{100}Ru abundances that are on average 17±5 ppm (2 sd) higher than the present-day mantle [6]. The ^{100}Ru excess in these rocks provides evidence that their mantle source was at least partially isolated and did not fully equilibrate with the late veneer [7]. These rocks therefore represent a window into the Ru isotopic composition of the pre-late veneer mantle. Moreover, because the pre-late veneer Ru is enriched in nuclides produced by the slow neutron capture process (*s*-process) of nucleosynthesis its distinct isotopic composition can only be balanced by late accretion of *s*-process depleted meteoritic materials to yield the Ru isotopic composition of the modern mantle. Therefore, these data relax previous constraints on the nature of the late veneer [3] and reopen the possibility for late accretion of water and volatiles with the late veneer [e.g. 2].

[1] Albarède, F. (2009) Nature 461, 1227-1233.
[2] Wang, Z. & Becker, H. (2013) Nature 499, 328-331.
[3] Fischer-Gödde, M. & Kleine, T. (2017) Nature 541, 525-527.
[4] Becker, H. et al. (2006) GCA 70, 4528-4550.
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[7] Willbold, M. et al. (2011) Nature 477, 195-198.

Si isotope fractionation during BIF formation – inferences from a modern Archean ocean analogue

Geilert*, S., Varekamp, J.C., Vogl, J., Frank, M., Cauley, C., Van Bergen, M.
* GEOMAR Helmholtz Centre for Ocean Research Kiel, Wischhofstr. 1-3, 24148 Kiel, Germany
sgeilert@geomar.de

Silica-rich sedimentary rocks like cherts and BIFS, typical for the Archean, have been used to reconstruct temperatures and other properties of the early oceans through the study of their Si isotope variations [1]. Precambrian cherts and BIFS span a δ^{30}Si range of ~7‰, with BIFs being about 2‰ lower in δ^{30}Si than cherts [2]. These lower δ^{30}Si signatures have been attributed to represent contributions from different input sources such as hydrothermal fluids, variable continental weathering regimes or sorption onto Fe oxides/hydroxides [e.g. 2 and references therein]. In this study, fluids and BIF-like sediments have been investigated for their Si isotope compositions in Paulina Lake (PL), a hydrothermally-influenced crater lake in the Newberry Caldera, Oregon, USA. PL lake sediments are rich in silica (~65wt% SiO_2) and are composed of up to 22.5wt% Fe_2O_3, which is comparable to Archean BIFs and thus serve as a modern Archean ocean analogue. We compared our analyses with East Lake (EL), the twin Newberry crater lake without hydrothermal input. Dissolved Si in EL has an average δ^{30}Si signature of +1.55±0.16‰ (1sd) and sediments an average δ^{30}Si signature of +0.18±0.28‰ (1sd). Dissolved Si in PL has an average δ^{30}Si signature of +2.02±0.15‰ (1sd), whereas the sediments show a large range in δ^{30}Si values between +0.59‰ and -1.24‰. PL sediments show a trend towards more negative δ^{30}Si with increasing Fe_2O_3 contents. The magnitude of Si isotope fractionation thus appears to depend on the presence of Fe. This fractionation induced by interaction with Fe precipitation is defined here as the offset in δ^{30}Si between PL and EL sediments at comparable depths ($\Delta^{30}Si_{PL-EL}$). The resulting $\Delta^{30}Si_{PL-EL}$ values range between +0.69 and -1.42‰ and increase with increasing Fe_2O_3 content in the sediments. Our results are the first to quantify the magnitude of Fe-induced δ^{30}Si fractionation observed in a natural analogue of the Archean ocean and can explain the lighter δ^{30}Si signatures found in BIFs.

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[2] Stefurak, E. (2015) GCA 150, 26-52.

The Lewisian Complex of Scotland: a contiguous Archean craton or several disparate terranes?

Gutieva, L.*, Dziggel, A., Johnson, T.E.
*Institut für Geologie, Mineralogie und Geophysik, Ruhr-Universität Bochum, Universitätsstraße 150, 44801, Bochum, Germany

The Lewisian Complex has traditionally been envisaged as a once contiguous block of Archean crust that was later disaggregated along crustal-scale shear zones into blocks that now expose deeper and shallower crustal levels. Recent studies have subdivided the complex into six separate microcontinental fragments ('terranes') that amalgamated along these shear zones and which preserve discrete magmatic and metamorphic histories [1]. The volumetrically-dominant TTG gneisses show a wide range of U–Pb zircon ages between c. 3.0 and 1.9 Ga [1], recording a complex and prolonged tectonothermal evolution involving high-T deformation, metamorphism, and partial melting. The TTG gneisses show negative Ta, Nb and Ti anomalies [2], which are commonly attributed to the partial melting of garnet- and rutile-bearing amphibolites or eclogites in a subducting slab. However, magmas with such 'arc-like' signatures are not clearly diagnostic of a subduction–accretion environment, but may reflect melting near the base of thick plateau-like crust during delamination of dense garnet- and rutile-bearing hydrated mafic source rocks. In addition, such crustal drips may have triggered multi-stage melting of the sub-continental mantle lithosphere as they descended [3].

The currently available data from the Lewisian Complex cannot answer unambiguously whether it formed by accretion of discrete terranes or by disaggregation and reassembly of a larger fragment of Archean crust. Key to unravelling this question lie in correctly interpreting the nature of the crustal-scale shear zones that may represent: (i) terrane boundaries, or; (ii) long-lived ancient structures that formed due to sinking of dense mafic–ultramafic bodies. The project aim is to unravel the complex tectono-magmatic evolution by combining pseudosection modelling with zircon Lu–Hf, U–Pb and O isotopic analyses. The U–Pb ages will date magmatic and metamorphic events across the Lewisian Complex. The Lu–Hf method will aid in identifying discrete mantle sources and provide constraints on the time at which the crust separated from its mantle source. Finally, $\delta^{18}O$ analyses will indicate the degree to which the TTG source rocks interacted with near-surface materials.

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[2] Johnson T.E. et al. (2013) J. Geol. Soc., 170(2), 319-326.

[3] Bédard, J.H. (2006) Geochim. Cosmochim. Acta 70, 1188–1214.

Surviving the ferruginous Archean ocean – Assessing the potential toxicity of Fe^{2+} on basal Cyanobacterial strains under anaerobic conditions

Herrmann, A. J. and Gehringer, M. M.*
*Technical University of Kaiserslautern, Erwin-Schrödinger-Straße 1, D-67663 Kaiserslautern, Germany
mmgehringer@yahoo.com

The oxygenation of early Earth's atmosphere ~2.4 Ga ago, known as the great Oxygenation Event (GOE) was presumably caused by oxygenic photosynthesis by (proto-)Cyanobacteria in the Archean oceans. Up to then the Archean oceans were anoxic with high levels of Fe2+ (40-120 µM Fe2+). Recent studies however suggest that Fe2+ concentrations of >100 µM are toxic to modern, marine Cyanobacteria [1], thereby potentially restricting their colonization of the ferruginous Archean oceans. Studies to date have focused on growing more recently evolved strains of cyanobacteria in closed systems with high CO2 levels, allowing the build-up of O2. This study focuses on investigating the potential toxicity of Fe2+ on two basal strains of marine cyanobacteria in an atmosphere representing the Archean, in both a closed and open culture system [2].

In order to achieve this goal, we have been standardizing growth conditions by acclimatizing Pseudanabaena PCC7367 & Synechococcus PCC7336, to an anoxic, elevated CO2 atmosphere in buffered Media containing Fe2+. Additionally we have determined the optimal light conditions to obtain high levels of C fixation without light stress. Finally, we are standardizing genetic assays to measure the cellular response to elevated Fe2+.

Preliminary experiments using Fe3+ suggest increased photosynthetic rates in cultures of Pseudanabaena PCC7367 exposed to high light conditions. The appearance of larger polyphosphate bodies was observed under exposure to 300 µM ferric citrate. Whether these results occur with elevated Fe2+ under an anoxic atmosphere remains to be determined. By measuring the expression levels of the genes involved in iron uptake and regulation within our strains, we are gaining greater insight into the growth of modern day descendants of ancient cyanobacterial strains under ferruginous Archean growth conditions.

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Halogens as a potential novel proxy for early habitats in hydrothermal systems

Hoffmann, J.E.[1,*]; Jäger, O.[1]; van Kranendonk, M.J.[2]; Gleeson, S.[3]; John, T.[1]
[1]Institut für Geologische Wissenschaften, Freie Universität Berlin, Malteserstr. 74-100, D-12249 Berlin, Germany
[2]School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, Australia
[3]Sarah Gleason, Geoforschungszentrum Potsdam, Germany
*jeh@zedat.fu-berlin.de

The environment and the diversity of sites where ancient microbial life forms developed is currently debated. Potential sites may be related to hydrothermal activity (e.g. black/white smokers, altered oceanic crust including serpentinites, hydrothermal veins, geysir deposits). To evaluate potential sites of microbial activity, we plan to make use of the halogens (I, Br, Cl, F) in combination with conventional stable isotopes (S, O, C). Iodine is largely bound to organic matter, whereas the other halogens partition into water and/or hydrothermal fluids. Stable isotope abundances of sulphur and carbon can also be modified during oxidation by microbial activity. We plan to evaluate the combined use of these proxies on a well characterized early life locality within the 3.5 Ga North Pole locality within the Dresser Fm. of the Pilbara Craton (Western Australia) [1] by measuring the halogen abundances of hydrothermal veins, altered oceanic crust (including pillow basalts), serpentinized komatiite flows, cherts and geysir deposits. Most of the samples will be derived from drill cores, ensuring fresh sample material.

The halogens will be extracted by pyrohydrolysis and trapped in alkaline solution. The technique was recently set up and tested at FU Berlin [2]. Iodine and Br abundances will be measured by ICP-MS using a Thermo Finnigan Element 2 XR at FU Berlin and F and Cl concentrations will be measured using ion chromatography at GFZ Potsdam. In addition, it is envisaged to refine the analytical technique for low abundance samples applying the isotope dilution technique using 79Br and 129I as tracers, an analytical technique already established in food science [3].

Combined with stable isotopes, rare-Earth-elements and concentration data for metals provided by the 'van Kranendonk group', the results may help to better constrain the connection between early microbial life and hydrothermal activity.

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Early mantle heterogeneities in modern mantle plumes – new insights from 182W measurements

Jansen*, M., Tusch*, J., Münker*, C., Tordy, R., Schmitt, V.
*Institut für Geologie und Mineralogie, Zülpicher Str. 49b, D-50674Köln, Germany
mike-jansen@gmx.net

During the last years, the short lived 182Hf-182W isotope-system has become a powerful tool identifying ancient differentiation events on Earth [1]. Terrestrial 182W isotope anomalies in Archean rocks were either explained by incomplete addition of late veneer [1] or as a vestige of early silicate differentiation events [2]. Recent studies have also revealed small 182W anomalies in young ocean island basalts (OIBs), suggesting the persistence of mantle reservoirs that remained isolated since the Hadean [3]. These studies are in line with noble gas approaches and studies of the short-lived 142Nd system that indicate ancient, undegassed and primitive mantle sources for some OIBs [4,5], and also for intraplate volcanic rocks of the central European volcanic province (CEVP) [6]. To further evaluate putative mantle heterogeneities in volcanic rocks, originating from deep mantle plumes, we performed high precision 182W measurements on selected mafic volcanic rocks from the Eifel Volcanic Field (EVF), La Réunion and Ascension Island [7]. Additionally, a detailed consideration of trace element compositions and signatures of the long-lived isotope systems (Pb, Nd, Hf, Sr), in combination with our new 182W data was undertaken in search of possible co-variations between certain mantle endmember compositions and short-lived isotope anomalies. All studied samples display canonical W/Th ratios (0.09-1.77) and are therefore thought to reflect the composition of their respective mantle sources. While rocks from the EVF (PREMA/HIMU) and Ascension Island (E-MORB) overlap with the modern upper mantle val e of µ182W = 0, displaying values ranging from -3 to +3 ppm and uncertainties generally better than ± 4ppm (95% conf. limit), samples from La Réunion (EM/C) reveal a strong heterogeneity of their 182W isotope compositions. While samples from Piton des Neiges are unresolvable from the ambient mantle composition, rocks from Piton de la Fournaise show strong 182W deficits with values as low as µ182W = -9 ± 4 ppm. Our data therefore confirm the survival of early mantle heterogeneities for more than 4.45 Ga, acting as mixing components in the source of some OIBs.

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Control of mantle potential temperature on plume-lid interaction and implications for the earliest continental crust.

Kaus, J.P.*, Piccolo A., Palin, R.M, Reuber, G. and White, R.W.
*Institut für Geowissenschaften, Mainz, 55128, J.-J.-Becher-Weg 21, Germany
kaus@uni-mainz.de

It is usually assumed that the Archean upper mantle was hotter than the modern-day mantle (ΔTP∼ 200°C). Estimate span from 1400– 1600 °C [1][2] and featured a high variability within the same age. These discrepancies have significant implications on the dynamics of the system and on continental crust forming processes, the bulk of which was produced during Archean. The earliest continental crust is mainly formed by Tonalite-Trondhjemite-Granodiorite suites (TTGs), which is widely accepted to be the product of hydrous meta-basalt partial melting. However, there is still no consensus on the geodynamic processes that created continental crust. TTGs melts required to be generated at high pressures. These conditions could be reached in an arc-related geodynamic setting or at the bottom of an evolving oceanic plateau. It is not clear if oceanic arcs were widespread during the Archean, while there is strong evidence that oceanic plateaus were more widespread than nowadays[3]. However, the effects of different TP on the dynamics of plume-lid interactions and on continental crust production are not explored. Since the upper mantle TP estimations vary, we here explore the effect of different upper mantle thermal states on plume-lid dynamics. We combine state-of-the-art thermodynamic models, with the 3D numerical code LaMEM. We performed systematic 2D and 3D simulations, assuming an initial small and short-lived mantle plume (Tp=1600°C, r=150-200 km) and explore the effect of Tp, initial lithospheric thickness and melt extraction parameters. Our results suggest that at higher TP (>1450 °C) even a short-lived mantle plume can potentially trigger a large-scale delamination of the whole lithosphere, inducing an enhanced production of continental crust. Meanwhile at lower TP, the stability of the lithosphere is a function of its initial thickness, the amount of radiogenic heating and the convective Rayleigh number of the upper mantle. In the latter scenario, the amount of continental crust produced is limited, and is mainly concentrated around the rims of the plume. In most experiments, the oceanic plateau gravitationally collapses, while the old oceanic crust is over-thrusted at its rim. There are differences between 2D and 3D experiments, particularly with respect to the pressure at which melting occurs that produces continental crust. 3D experiments feature a consistent lower pressure, while in 2D models the conditions are more variable and shifted towards higher pressures. Both 2D and 3D experiments show a decrease of TP as a result of dripping, which affects the final thickness of newly generated crust. Our results show that TP exerts a strong control on the dynamics of the system and on TTGs formation.

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Iron-60 as a Heat Source for Melting and Differentiation of Earth-forming Planetesimals and Planetary Embryos

Kodolányi*, J., Hoppe, P., Vollmer C.
*Max Planck Institute for Chemistry, Hahn-Meitner-Weg 1, D-55128 Mainz, Germany
j.kodolanyi@mpic.de

The presence of the short-lived radioactive isotope ^{60}Fe (t½ ~ 2.60 × 10^6 years) at the birth of our solar system has been debated, and so has its importance as a heat source for the differentiation of early solar system bodies. In particular, there is a discrepancy between the initial ^{60}Fe/^{56}Fe ratios inferred from bulk rock and in situ mineral data (e.g., [1,2]), with some in situ measurements yielding 1–2 orders of magnitude higher inferred initial ^{60}Fe/^{56}Fe ratios than bulk rock and most in situ data. Our project aims at unequivocally answering the question, whether there was any time or place in the early solar system, with ^{60}Fe present at significantly higher levels than the Galactic background (^{60}Fe/^{56}Fe $< 10^{-7}$ [3]), or the level suggested for the source region(s) of angrite and HED parent body matter (^{60}Fe/^{56}Fe $\sim 1 \times 10^{-8}$, [2]). For this, we are planning to analyse the ^{60}Ni/^{62}Ni and Fe/Ni ratios of troilite and chondrule silicates from primitive chondrites in situ, with the NanoSIMS. Pre-characterisation (detailed petrography, electron microprobe measurements) of Semarkona (LL3.0), NWA8276 (L3.0), and DOM08006 (CO3.0) is already underway. Our first test measurements and Monte Carlo simulations suggest that statistical effects resulting from the low nickel count rates during NanoSIMS analyses do not cause a significant positive bias in the measured ^{60}Ni/^{62}Ni as a function of Fe/Ni ratios. If encountered, minerals with high inferred initial ^{60}Fe/^{56}Fe ratios will be re-analysed with the Chicago Instrument for Laser Ionization. Being able to measure all nickel isotopes simultaneously, the latter instrument can reveal isotope fractionation effects that cannot be detected by the (Nano)SIMS [4]. Transmission electron microscopy is also planned, to track possible disturbance of the iron-nickel system in minerals with apparent initial excess of ^{60}Fe.

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Tephra associated with microbial mats of the Archean Moodies Group, Barberton Greenstone Belt (BGB), South Africa: Resemblance to potential biostructures and ecological implications

Köhler*, I., Heubeck*, C.
*Institut für Geowissenschaften, Burgweg 11, D-07749 Jena, Germany
Inga_koehler@gmx.de, christoph.heubeck@uni-jena.de

Documenting evidence of fossil microbial life on early Earth is made difficult by the paucity of suitable Archean sedimentary rocks, their common metamorphic overprint, the small outcrop areas, and the small size of the objects of interest. Although a large number of putative microfossils dating back as far as 3700 Ma have been described, the syngeneity and biogenicity of many occurrences is debated, and some of the proposed fossils have been found to be either contaminants or abiotic artefacts. The ∼3200 Ma Moodies Group of the Barberton Greenstone Belt (BGB), South Africa, contains locally abundant and remarkably well-preserved microbial mats which show indirect evidence of photosynthetic activity. They also contain microstructures which strongly resemble remains of microbial cells. Detailed morphological and geochemical analyses, however, show that these structures mostly represent fragments of volcanic tephra. Our study demonstrates that opaque microstructures within microbial mats can potentially be misidentified for microfossils even when a strict protocol is followed. It also posits the question to which degree volcanic air-borne fertilization contributed to the remarkable growth rate, high mechanical tenacity and wide extent of these oldest tidal microbial mats in siliciclastic environments.

Ongoing isotopic, chemical and mineralogical characterization of organic and inorganic nitrogen-carriers in chondritic meteorites

Leitner*, J., Vollmer, C., Ott, U., and Hoppe, P.
*Max Planck Institute for Chemistry, Particle Chemistry Dept., Hahn-Meitner-Weg 1, 55128 Mainz, Germany
jan.leitner@mpic.de

Nitrogen is the most abundant component in Earth's atmosphere and one of the key elements for the evolution of Earth's biosphere. However, the types of nitrogen carriers, their abundances and nitrogen isotopic compositions are not well constrained for all potential terrestrial building blocks. We studied the inventories of several inorganic N-carriers (Si_3N_4, TiN, Si_2N_2O, graphite) from a set of enstatite chondrites (ECs), which constitute the best analogue material for the main fraction of Earth´s building blocks, based on isotopic similarities [1]. Si_3N_4 has a $\delta^{15}N_{avg}$ of –62±1 ‰, significantly lighter than bulk N-isotopic compositions of ECs (–24±11 ‰) [2]. For TiN in Almahata Sitta MS-17 (EL3) and Neuschwanstein (EL6), we find average $\delta^{15}N$ values of –45±10 ‰ and –33±4 ‰, respectively, and sinoite (Si_2N_2O) in Neuschwanstein has a $\delta^{15}N_{avg}$ of –45±8 ‰. Abundance estimates indicate that neither the nitrides nor sinoite are major N-carriers in the ECs, contrasting established assumptions. First results for EC graphite indicate a slightly heavier N-isotopic composition than terrestrial ($\delta^{15}N$ ~7–22 %), in agreement with results from previous studies [3]. With an average graphite abundance of ~400 ppm in the ECs [4], we estimate that it contributes ≤10 ppm of the several hundred ppm N present in bulk ECs. Contributions from the various nitrides, sinoite, and organic matter also constitute only a few tens ppm, at best. Thus, the major N-carrier in the ECs is not yet identified, but preliminary results from our investigations indicate the presence of N in both the Fe,Ni metal and silicate phases. Following most recent compositional models for the proto-Earth [1], we estimate that >50 % of total N was accreted as *inorganic* materials, with $^{15}N/^{14}N$ ratios close to the terrestrial value. This also emphasizes that the carbonaceous and ordinary chondrite contributions to Earth's building blocks, despite being a minor fraction, dominate the *organic* N-carriers, and thus the inventory of prebiotic matter, on the early Earth.

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Elucidating Eoarchean geodynamic processes by multiple sulfur isotopes

Lewis, J.A.[1], Hoffmann, J.E.[1,*]; Schwarzenbach, E.M.[1]; Strauss, H.[2]; Whitehouse, M.J.[3]; Münker, C.[4], Rosing, M.T.[5]
[1]Institut für Geologische Wissenschaften, Freie Universität Berlin, Malteserstr. 74-100, D-12249 Berlin, Germany
[2]School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, Australia
[3]Sarah Gleason, Geoforschungszentrum Potsdam, Germany
*jeh@zedat.fu-berlin.de

The style of Archean geodynamic processes and the geodynamic setting of early continental crust formation are currently highly debated. Based on a well-characterized set of Eoarchean samples from the >3.7 Ga Isua Supracrustal Belt and adjacent areas in Greenland, we will investigate how crustal recycling processes operated in the early Archean. We use bulk rock and in situ multiple sulfur isotope compositions of Eoarchean oceanic crust, mantle peridotites and continental crust to trace recycling of material, which interacted with the ocean-atmosphere system, into the mantle and by melting processes into early continental crust. By performing bulk rock and in situ sulfur isotope compositions of sulfides together with petrographic observations, we test if mass-independent fractionated sulfur (MIF-S) was incorporated in hydrothermally altered oceanic crust, then transferred into the mantle and subsequently incorporated in the early continental crust that possibly sourced from thickened proto-arc crust. Thus, we place constraints on the early Archean magmatic and hydrothermal sulfur cycle and investigate, if crustal recycling processes comparable to present-day subduction were operating.

Uranium isotope fractionation in Archean Carbonates: Insights from the Tumbiana Formation, Western Australia

Martin*, A. N., Lazarov, M., Brüske, A. and Weyer, S.
*Institut für Mineralogie, Leibniz Universität Hannover, Callinstraße 3, D-30167 Hannover, Germany
a.martin@mineralogie.uni-hannover.de

Archean carbonates frequently contain stromatolites, which are lithified organosedimentary structures that were likely present at least one billion years before the rise of oxygen on Earth during the “Great Oxidation Event” (GOE; ca. 2.4 – 2.3 Ga). The study of redox sensitive elements in stromatolitic carbonates from the Archean may reveal the surface oxidation state of the ancient oceans. Moreover, uranium (U) isotope fractionation during biotic and abiotic reduction may be used to fingerprint the redox state of the early oceans. Here we present trace element and U isotope data from well-preserved drill core samples from the Tumbiana Formation (2.72 Ga), Western Australia. Relative to crustal values, we find small enrichments in U concentrations but no significant U isotope fractionation. These data suggest that anoxic weathering with insignificant U mobilisation prevailed during carbonate formation. By combining these data with the corresponding extreme ^{13}C depletions and sulfur enrichments [1], we provide further evidence that pre-GOE biological activity in the Tumbiana Formation at 2.72 Ga was likely limited to methanotrophy fueled by anoxygenic photosynthesis.

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The rise and fall of Archean atmospheric oxygen: did temporary carbon burial as Fe(Ox) -DOM complexes play a modulating role?

Martinez, R.E., Hallmann, C.
Max-Planck-Research Group Paleobiogeochemistry, University of Bremen, Am Biologischen Garten 2,
28359 Bremen, Germany.
rmartinez@bgc-jena.mpg.de

Geological indicators, redox sensitive elements (RSE) and rare sulfur isotopes all suggest that the oxygen content of Earth's atmosphere increased dramatically around 2.45 billion years ago (Ga). This great oxidation event (GOE) has been considered the prerequisite for the subsequent evolution of increasingly complex life on Earth. Yet, in fact we observe a relative evolutionary stasis until the Neoproterozoic, while RSE suggest that O_2 levels may have rebound after the GOE, remaining low until a second oxygenation event later in the Neoproterozoic. Understanding the details of early Earth's oxygenation dynamics and the mechanistic drivers behind these represent key questions in geobiological research.

It has long been known that the oxidation state of Earth's surface environments is tightly coupled to the carbon cycle. In order for the atmosphere to receive a boost in O_2 content, some primary produced organic matter must escape short-term recycling and become buried long-term in sediments beneath the sea floor as fossil organic carbon. In this study we focus on the carbon storage potential of banded iron formations (BIF) that were deposited in gigantic abundances throughout the Archean. Despite being nearly devoid of organic carbon at present, multiple aspects of BIF point towards the possibility of a close association with organic matter during deposition and prior to diagenesis. It is hard to envisage how macromolecular organic matter (i.e. kerogen) could have disappeared from these silica-rich iron oxide deposits, either through degradative processes or by thermal destruction. Given the high sorption capacity of iron oxides towards dissolved organic matter (DOM: <0.45 µm fraction) and a higher mobility of the latter, we here explore the idea that BIF could have sorbed large abundances of marine DOM and that such temporally buried, and later remobilized DOM (e.g. during basin subsidence and mineral transformation) could have modulated terminal Archean and early Paleoproterozoic atmospheric oxygenation.

Preliminary results of sorption experiments with purely-cyanobacterial DOM, grown in large-scale cultures, place first tentative constraints on our understanding of Archean aquatic chemistry. High dissolved silica concentrations in the range of 0.6 to 2 mM and an ionic strength of 0.5 moles/L (Crowe et al., 2008) have been suggested for the Archean ocean. We find a decrease in the ability of iron oxides (e.g. ferrihydrite), to adsorb dissolved organic matter at high salinity (0.5 M $NaNO_3$) and high dissolved silica concentrations (i.e. in the range of 2 to 8 mM). Further experiments suggest an enhancement of dissolved silica sorption by iron oxide dissolved organic matter complexes at high ionic strength. These initial data suggest a tight connectivity between dissolved silica, salinity, BIF mineralogy and organic matter sorption, which will form a basis for further studies of DOM-ferrihydrite complexes under simulated catagenesis experiments under elevated temperature and pressure.

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Tackling the origin of organic signatures in early Archean rocks

Mißbach*, H., Duda, J.-P., van den Kerkhof, A.M., Reitner, J., Thiel, V.
*Geobiology, University of Göttingen, Goldschmidtstraße 3, 37077 Göttingen, Germany, hmissba@gwdg.de

Archean organic matter can encode primary biological information and thus provide important insights into earliest life on Earth. However, the interpretation of this organic record is challenging: Primary biological and abiotic signatures have to be discriminated, syngeneity to the host rocks must be proven and later contamination with organic materials must be excluded. Furthermore, primary signatures have likely been obscured by thermal alteration and biodegradation through time. The geobiological analysis of early Archean organic matter therefore requests integrative study designs that combine various complementary approaches. Over the past few years we have successfully demonstrated that the combination of analytical imaging techniques (e.g., Raman spectroscopy, NanoSIMS), biogeochemical approaches (e.g., catalytic hydropyrolysis and gas chromatography – mass spectrometry) and experimental approaches (thermal maturation of organic matter, abiotic Fischer–Tropsch-type synthesis) can indeed help to unravel the early Archean organic record [1-4]. More specifically, we were able to obtain important insights into the complex interplay between biological and abiotic processes in early Archean hydrothermal environments. Unfortunately, however, there is no blueprint for such multifaceted geobiological studies; the strategy has to be specifically tailored to the targeted sample materials. Our ongoing studies on specific chert and barite facies from the Pilbara Craton (Western Australia) e.g. involve, amongst others, detailed analysis of organo-mineral associations encapsulated in fluid inclusions (see Poster by Reitner et al. for more details). Findings from these studies will strongly support the identification of biosignatures in Earth's oldest rocks and profoundly contribute to our understanding of earliest life on our planet.

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Volatile outgassing during early Earth

Noack*[1], L., Guimond, C.[1], Ortenzi, G.[2], Schmidt, J.[1], Vulpius, S.[1], Sohl, F.[2]
[1] Free University Berlin, Institute of Geological Sciences, Malteserstr. 74-100, D-12249 Berlin, Germany
[2] German Aerospace Center (DLR), Institute of Planetary Research, Rutherfordstr. 2, D-12489 Berlin, Germany
*lena.noack@fu-berlin.de

From the geological rock record, we have almost no information with respect to early Earth's atmosphere. The composition and the atmospheric pressure during Hadean Earth is hidden from us, and we have only few boundary conditions (such as existence of liquid water during Hadean Earth, upper proposed pressure limits during Archean Earth, and erosion limits due to noble gas composition that we measure today). This information therefore needs to be complemented by modelling data, relating the chemistry and thermal evolution in the interior to melting processes and volcanic outgassing. In this project, we coupled a 2D mantle convection code with a gas speciation model to infer the influence of the redox state on the composition and amount of outgassed volatiles during the first Gyr of Earth's evolution. The redox state of the silicate rock influences the partitioning of H_2O and CO_3^{2-} into the melt at local temperature and pressure conditions. Extrusive volcanism transports the melt to the surface with the volatiles dissolved in the magma, followed by degassing at the surface depending on the magma temperature and atmospheric pressure. We infer here the ratio of degassing of H_2O, H_2, CO_2 and CO (CH_4 is not stable under our investigated conditions and O_2 outgassing is negligible). We look at different redox state evolution scenarios from the end of the magma ocean to the Archean as proposed in the literature. We infer the variations with respect to outgassed partial pressures of the atmosphere, which will serve as input for climate studies (SPP 1833 project Carone and Noack) and volatile recycling models (SPP 1833 project Noack) for Hadean and Archean Earth.

This work is supported by the German Research Foundation (DFG) within the SFB-TRR 170 "Late Accretion onto Terrestrial Planets" (subprojects C5 and C6).

3.5 Ga-old “stinky” black barite (Dresser Fm, Pilbara, Western Australia) – a geobiological conundrum

Reitner, J.*, Thiel, V., Mißbach, H., Duda, J.-P., Pack, A., van den Kerkhof, A.M., Vonhof, H., Strauss, H.
*Geobiology, University of Göttingen, Goldschmidtstraße 3, 37077 Göttingen, Germany,
jreitne@gwdg.de

The ca. 3.5 Ga Dresser Fm in the North Pole region of the East Pilbara Craton (Western Australia) contains large amounts of barite which is well exposed in large abandoned quarries and natural outcrops. There are two types of barite: (1) barite in veins that are hosted in footwall pillowed basalts and (2) bedded barites. In surface outcrops, the bedded barite is typically associated with oxidized Fe-hydroxide stromatolites. Corresponding stromatolite facies in drill cores from this area (PDP2b&2c), in contrast, are preserved in a reduced sulfidic (pyrite, sphalerite) fashion. The bedded barite immediately underlying the stromatolites is grey-black in color and typically exhibits an intense unusual (“stinky”) smell. Detailed thin section petrography combined with traditional fluid inclusion analysis revealed the presence of abundant inclusions that are syngenetic to the barites. Fluid inclusion analyses and thermodesorption-GC–MS experiments independently demonstrated the presence of various indigenous low molecular weight compounds in these primary fluid inclusions (e.g., H2O, H2S, COS, CO2, CH3SH, CS2, CH4). Water volume fractions in the fluid inclusions vary widely from essentially pure water to non-aqueous, and some of the inclusions are partly or completely cemented by sulfides (pyrite, sphalerite) and/or carbonates (calcite, Fe-rich dolomite, strontianite). The sulfidic phases are generally associated with macromolecular organic material (“kerogen”). Additionally, TiO2 (anatase) and native sulfur were observed in some fluid inclusions. First δ34S analyses of sulfides show a very strong fractionation relative to BaSO4 (-15‰ sulfide versus +5‰ sulfate). Carbonates in the fluid inclusions exhibit δ13C signatures as low as -18‰, which is remarkably low compared to most other carbonates from the Dresser Fm (δ13C typically ~0‰). In an earlier study, Ueno et al. [1] reported the presence of isotopically depleted methane (δ13C of lower than -56‰) in fluid inclusions from Dresser cherts and related this to biological methanogenesis. In the light of this finding, we hypothesize that the observed low δ34S and δ13C values in the Dresser barites may reflect an early metabolic pathway of sulfate-driven anaerobic oxidation methane. However, further analysis of the fluid inclusions and associated minerals is required to validate this hypothesis.

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Putative Tsunami Deposits in the 3.5 Ga Dresser Formation (Pilbara, Western Australia)

Runge, E., Mißbach, H., Duda, J.-P., Reitner, J.*
*Geobiology, University of Göttingen, Goldschmidtstraße 3, 37077 Göttingen, Germany
jreitne@gwdg.de

Well preserved early Archean sedimentary successions are rare and usually consist of chemical sediments (e.g., cherts) and volcanoclastic rocks. Reworked material is extremely scarce in these facies due to the small sizes of continental islands and shelves in this time. Here we report a 5 – 6 m thick by c. 100 m long channel fill within the 3.5 Ga old North Star basalt (North Pole area, East Pilbara, Australia). These channel deposits consist of bedded grey and black cherts, red jasper as well as of brown and grey, mostly laminated carbonates (Fe/Mn-rich dolomites). The sequence is further characterized by two debris flow layers which correspond to distinct flow regimes. The lower layer (c. 50 cm thick) comprises strongly imbricated clasts of 2–3 cm thick bedded chert layers (i.e., flat pebbles). The space between these clasts is filled by carbonate and silicate-rich mm-sized granular material that shows ripples and convolute bedding. The strong imbrication indicates a high velocity flow regime (flash floods) which is for example known from turbidite- and river channels. The upper layer, in comparison, is characterized by laminated, poorly graded carbonates exhibiting several distinct turbidite-beds. Clasts in the second layer show also imbrication, but in an opposite direction to those observed in the lower first layer. For now, we interpret this twin bed as a tsunami deposit, possibly triggered by an impact event and affected by a barrier. Further detailed petrographic and geochemical analyses are in progress to validate the origin of these unusual high-energy flow deposits.

Understanding and comparing calculations of partition coefficients: how P-T conditions affect the enrichment of trace elements in the crust

Schmidt*, J.M., Noack, L.
*Institut für Geologische Wissenschaften, Malteserstr. 74-100, D-12249 Berlin, Germany
julia.schmidt@fu-berlin.de

To integrate partition coefficients into a numerical model, it is crucial to understand the nature of partition coefficient calculation for trace elements. Clarifying uncertainties regarding known calculation methods can help to improve numerical models dealing with mantle differentiation, which will eventually lead to a more complete model on crustal formation on early earth. In this study, the first aim is to find out how well partition coefficients can be calculated using lattice parameters. For this, resulting coefficients were compared to experimentally measured values taken from literature. In a second step, the effect of pressure and temperature changes on the coefficients was investigated.

Because of its importance in mantle geochemistry, we take the radioactive element potassium (K) as an example for REE partitioning behavior. To calculate partition coefficients of K we used the partition coefficient equation of Wood and Blundy 1997. In this equation, the partition coefficients are calculated as a function of temperature, pressure, Young's modulus and ionic radii. As a calculation tool the program Matlab was used and in the resulting code, mean values for the ionic radii were applied. In this study, we focus on the partitioning behavior of K into the mantle phases clinopyroxene, garnet and majorite. As a result, we found that using this method, partition coefficients differ with varying temperature and pressure conditions. A comparison of the resulting values will clarify the accuracy of the applied method and if the results can be incorporated into a broader modelling approach.

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Magma oceans and their implications on modelling the early stages of mantle convection

Falko Schulz*, Nicola Tosi
*Technische Universität Berlin, Zentrum für Astronomie und Astrophysik, Hardenbergstr. 36, D-10623 Berlin, Germany
falko.schulz@tu-berlin.de

Numerical modelling of the convection of planetary mantles is an important tool for the understanding of the thermal evolution of terrestrial planets, the generation of the geodynamo, the formation of the crust and plate tectonics. The initial conditions of these numerical models are crucial.

Based on a globally well mixed magma ocean, the early stage of Mars has been calculated by fractional crystallization [1]. As a result, the uppermost part of the crystallized mantle is enriched in heavy, iron rich and heat producing elements, leading to an unstable density stratification prone to overturn. Consequently, the early stages of mantle convection are chemically driven instead of thermally with implications for the creation of an early crust and magnetic field.

This poster will outline the limitation of typical approximations made in global convection models when those are applied to the dynamics of magma ocean overturn. Global convection models often use a Newtonian rheology instead of a non-Newtonian one. However, the latter one may be influenced by the high stresses associated with the sinking of the heavy cumulates. The second approximation concerns the compressibility of the mantle minerals due to pressure. If compressibility is considered, then the anelastic liquid approximation (ALA/TALA) is typically applied. But this cannot hold for an unstable density stratification as it will turn into a stable one.

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Sulphur as a tool to identify alteration processes in ultramafic oceanic lithosphere

Schwarzenbach, E. M.*
*Institut für Geologische Wissenschaften, Freie Universität, Malteserstr. 74-100, D-12249 Berlin, Germany
esther.schwarzenbach@fu-berlin.de

The oceanic lithosphere undergoes extensive water-rock interaction during and after its formation along mid-ocean ridge spreading centres. Around 25% of ocean floor formed along slow-spreading ridges comprises of serpentinized peridotite as mantle rock is tectonically exposed to seawater [1]. Alteration of peridotite is associated with considerable chemical, physical and mineralogical transformations, and can support microbial communities due to formation of H_2, CH_4, and formate during the serpentinization reaction [2]. Here, I summarize and review recent approaches to resolve the alteration history of peridotite-hosted hydrothermal systems and, in particular, the links between abiogenic fluid-rock interaction and microbial activity. These aims are followed using bulk rock and in situ sulphur isotope geochemistry, multiple sulphur (^{32}S, ^{33}S, ^{34}S) isotope compositions, and detailed petrographic examination of variably serpentinized peridotites drilled by the IODP (International Ocean Discovery Program) and ODP (Ocean Drilling Program), and samples collected in ophiolite sequences. The sulphur isotope geochemistry of these serpentinites reveals that peridotite-hosted hydrothermal systems undergo a complex alteration history of changing temperature and fluid chemistries; High-temperature fluids (>350°C) are recorded by positive $\delta^{34}S_{sulfide}$ and $\Delta^{33}S_{sulfide}$ values and are associated with Ni-, Co-, and/or Cu-rich sulphide mineral assemblages as well as talc, chlorite and amphibole assemblages. In contrast, low-temperature (<100-150°C) fluid circulation is associated with negative $\delta^{34}S_{sulfide}$ values indicative for the presence of microbial sulphate reduction, whereas seafloor weathering is documented by the presence of Fe-oxides and -hydroxides. In addition, combination of $\delta^{34}S$ and $\Delta^{33}S$ of sulphate extracts provides evidence for remobilization of sulphide during late stage seawater circulation. Overall, the combined application of in situ and bulk rock multiple sulphur isotope measurements with petrographic observations provides comprehensive insight into the different episodes of hydrothermal circulation and the temporal changes between abiogenic and biogenic processes that control the sulphur cycling in these systems. These tools are particularly beneficial when reconstructing the alteration history of serpentinites preserved in sequences of obducted, ancient oceanic lithosphere.

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Triple oxygen isotopes in cherts as a proxy for temperature and $\delta^{18}O$ of Precambrian seawater

Sengupta*, S., Pack, A., Reitner, J., Peters, S., Fischer, M., Albrecht, N.
*Georg-August-Universität Göttingen, Geowissecschaftliches Zentrum, Isotopengeologie, Germany
ssengup@gwdg.de

$\delta^{18}O$ of marine chemical sediments continuously decrease over time and this decrease can be explained in three ways. Seawater may have been very hot in the Archean (e.g., [1]) or it had lower $\delta^{18}O$ (e.g., [2]), or the sediments have all been diagenetically altered [3].

Triple oxygen isotope compositions of cherts may reveal more information about Precambrian seawater and paleoenvironment. We analysed cherts belonging to the Precambrian and Phanerozoic. The $\delta^{18}O$ of cherts decrease through time and the $\Delta'^{17}O$ was found to increase with time. The Archean cherts have $\delta^{18}O$ = 15 to 20 ‰ and $\Delta'^{17}O$ = -130 to -90 ppm. The Phanerozoic cherts have $\delta^{18}O$ = 26 to 33 ‰ and $\Delta'^{17}O$ = -220 to -170 ppm. The Proterozoic cherts have values in between these two ranges.

Using silica-water triple isotope thermometer ([4], [5]) it is evident that the cherts are not in equilibrium with a low-$\delta^{18}O$ seawater. The additional $\Delta'^{17}O$ parameter provides this solution; with $\delta^{18}O$ alone this would not have been possible. The cherts are best explained by alteration by meteoric water. The original protolith chert may have precipitated from seawater between 20 and 60°C.

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Triple oxygen isotope signatures in marine carbonates – insights from high resolution gas source isotope ratio mass spectrometry

Surma, J.*, Albrecht, N., Pack, A.
*Georg-August-Universität Göttingen, Geowissenschaftliches Zentrum, Goldschmidtstraße 1, D-37077 Göttingen, Germany
surma@gwdg.de

The analysis of $^{18}O/^{16}O$ isotope ratios in marine carbonates is a classical tool for studies on paleoclimate and ocean evolution. In the Earth's geological record Archaean carbonate deposits demonstrate systematically lower $\delta^{18}O$ signatures than sediments throughout the Phanerozoic [1, 2]. However, possible driving mechanisms for this isotopic shift are still matter of discussion: Primary effects such as a warm (I), or isotopically depleted (II) Archean ocean are opposed by potential diagenetic overprint and isotopic exchange with secondary pore water (III) [3-5].

Recently developed high resolution gas source isotope ratio mass spectrometers provide a new technique for high precision analysis of $^{17}O/^{16}O$ and $^{18}O/^{16}O$ in CO_2 by measuring O^+ fragment ions formed in the ion source. Interfering $^{16}O^1H^+$ and $^1H_2{}^{16}O^+$ fragments can be distinguished from $^{17}O^+$ and $^{18}O^+$ due to a mass resolving power of > 10,000. Repeated analyses of an internal reference carbonate show an external $\Delta^{17}O$ reproducibility which is below 10 ppm (1 SE).

Our study demonstrates the potential of the carbonate triple-O isotope system. We present oxygen isotope data of Phanerozoic and Archaean marine carbonate deposits together with an isotopic model that enables the reconstruction of both, the water temperature during carbonate formation and the isotopic composition of the carbonate mother water.

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Title: Hf/W insights to the early Moon

Thiemens, M., Sprung, P., Fonseca, R.O.C, Leitzke, F.P. & Münker, C.
Institut für Geologie und Mineralogie, Universität zu Köln, Germany & Université Libre de Bruxelles, laboratoire G-TIME, Brussels, Belgique
maxwellmt@gmail.com

Understanding how planets formed in the early solar system is one of the most fundamental tasks of planetology. The Moon itself acts as a palimpsest which provides insights into when and how the Earth formed. Timing the Moon's formation divides scientists into two broad camps, one which favours an "old" Moon, (ca. 50 million years after solar system formation) while the other calls for a "young" Moon (older than 100 million after solar system formation). Key to these arguments is the observation of an excess of 182W found in lunar samples compared to their modern terrestrial counterparts. The idea holds that a "late veneer" of material deposited after planetary formation would have deposited far less material on the Moon than the Earth, and that its inherited signature of unradiogenic W would thus overwrite the previous values.

To investigate this W signature and its origins, we combined recent experimental silicate-melt partitioning data with high-precision isotope dilution concentration analyses of W, Th, U, and high field strength elements on a large suite of lunar samples. Our results indicate that the Hf/W ratio of the lunar mantle (minimum 30) is higher than that of the bulk silicate Earth (Hf/W of 25.8). The results of our study lead to the implication that the 182W excess is the likely result from in situ radiogenic ingrowth, as this would also explain the elevated Hf/W ratio. These results lend credence to the idea of an "old" Moon, and greatly diminish the need for a late veneer to explain the Moon's unique signatures.

Tracing mantle and crustal degassing via the palaeoatmospheric $^{40}Ar/^{36}Ar$ ratio

Trieloff*, M., Hopp, J., Ott, U.
*Institut für Geowissenschaften, Im Neuenheimer Feld 234-236, D-69120 Heidelberg, Germany
mario.trieloff@geow.uni-heidelberg.de

The Earth's atmosphere contains about 1 vol% Argon. Its abundance is the result of ^{40}K decay (half-life = 1.25 Ga) into ^{40}Ar, which is the dominating Ar isotope with an atmospheric $^{40}Ar/^{36}Ar$ ratio of 296. However, the primordial ^{40}Ar abundance is low, and the initial $^{40}Ar/^{36}Ar$-ratio of the Earth can be set approximately zero. Hence, the atmospheric $^{40}Ar/^{36}Ar$-ratio changed with time due to production and degassing of ^{40}Ar from solid Earth reservoirs (mantle and crust). We know that the Earth's mantle lost a significant part (>95%) of its primordial Ar very early in the first few hundred million years, whereas the degassing of continental crust depended on its volume, as well as tectonic and environmental boundary conditions. Knowledge of the secular change of the atmospheric $^{40}Ar/^{36}Ar$-ratio thus can set constraints to degassing models. However, there is very limited information available yet, due to a couple of problems associated with the survival and identification of ancient atmospheric gases in old rocks and the potential superposition of crustal or in situ radiogenic ^{40}Ar.

In this study we investigated the noble gas composition of Neoarchean carbonates from the Transvaal Supergroup (S Africa) deposited in a shallow marine basin, utilizing the stepwise crushing method. These carbonates were affected by silicification during karstification and by a mild thermal overprint in course of the Bushfeld activity 2 Ga ago, as demonstrated by an Ar-Ar age of sericite detritus in one carbonate. In case of the most severely silicified carbonate we identified a minor crustal noble gas component. However, in another carbonate we observed a reasonable correlation in $^{40}Ar/^{36}Ar$ vs $^{4}He/^{36}Ar$ isotope space for crushing steps that mirrors a mixture of ancient atmosphere with in situ radiogenic ^{40}Ar and ^{4}He. The respective $^{40}Ar/^{36}Ar$ ratio is 266±8 (1σ), which is at the upper range of expected model compositions for 2.0 Ga old atmospheric argon. Our results show that carbonates appear to be promising targets for reconstructing the argon isotopic composition during Earth's history.

Tungsten isotope patterns of rocks from the Pilbara Craton, Australia

Tusch*, J., Jansen, M., Marien, C.S., Kranendonk, M.V., Münker, C.
*Universität zu Köln - Institut für Geowissenschaften, Zülpicher Str. 49b, D-50674 Köln, Germany
jonastusch@gmx.de

Recent analytical improvements have revealed the presence of small 182W isotope anomalies in terrestrial rocks ranging in age from the Archean [e.g.1-2] to Phanerozoic [e.g. 3-4]. Both, excesses [e.g. 1,4] and deficits of 182W [2,3], respectively, have been found. The 182W isotope anomalies are vestiges of ancient chemical heterogeneities that have been preserved in Earth's mantle. Incomplete addition of late veneer or early silicate differentiation are the two preferred explanations for the 182W anomalies. A straigthforward interpretation of 182W anomalies, however, is often hampered by disturbed elemental W patterns that are often affected by secondary W enrichments in altered rocks [e.g. 2,5].
Here, we present the first comprehensive high-precision 182W isotope dataset for mafic Archean rocks from the Pilbara Craton, NW Australia, that is one of the best preserved early Archean successions on Earth. Our set of samples covers all major mafic units of the Pilbara Supergroup. All samples were initially screened for W-alteration by isotope dilution measurements of high field strength elements (HFSE), U, and Th. Preferably those samples were further considered that exhibit primary W abundances, as reflected by canonical W/Th ratios. All samples from the Warrawoona Group exhibit positive 182W excesses ranging in µ182W from +7 to +14ppm with uncertainties generally better than ±5 ppm (95% conf. limit). Samples that have undisturbed elemental W patterns are indistinguishable with a mean excess of +12.1 ± 2.1 ppm (95% conf. limit), similar to other Archean cratons [e.g. 1,3,6-7]. At present, the origin and evolution of the 182W isotope anomalies in the Pilbara Craton cannot unambiguously be resolved. However, independent evidence for older depleted mantle domains is provided by consistently superchondritic ε Hf(t) and ε Nd(t), ranging from 0 to +3.2 and +0.3 to +2.0, respectively.

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SPP 1833: Global volatile cycles on early Earth

Vulpius, S.,
*FU Berlin, Malteserstraße 74-100, Room B202 - Building B, 12249 Berlin
sara.vulpius@fu-berlin.de

While Earth is a planet where for present-day processes in the interior and at the surface we have a wealth of information, data for the early evolution of the planet is sparse. One of the questions that still remain to be answered is by which mechanisms volatiles could be recycled into the upper mantle before the on-set of plate tectonics as it operates today. Subsequent melting of recycled, hydrated crust is needed to explain the chemical composition of Earth’s earliest crust.
In the project, we will enhance a thermo-chemical model of Earth’s mantle, lithosphere and crust by including volatile cycles (focussing mainly on H, C and N that form greenhouse gases, but also Xe, Ar and Ne as trace elements) from interior to surface and vice versa. The cycles operate via outgassing, condensation and crustal recycling. We will then compare our model predictions with respect to volatiles to the collected early Earth data. Such a model approach allows to investigate the evolution of volatile reservoirs and isotope relations over time. Using a Monte-Carlo method, we will then model different evolution scenarios for early Earth for random initial thermal and compositional (in terms of volatiles) states of Earth’s interior after the Moon-forming impact. The resulting evolution scenarios can then be matched with field data (especially concerning isotope ratios of noble gases).
Constraints set by the Archaean geological record can also help to indicate how the earliest evolution of Earth needed to evolve to explain the later available geological and geochemical samples.

Early Earth mantle heterogeneities – an isotope perspective

Willbold, M.*, Hegner, E., Hofmann, A.
*Geowissenschaftliches Zentrum Göttingen, Abteilung Isotopengeologie, Universität Göttingen, Goldschmidstr. 1, D-37077 Göttingen, Germany; matthias.willbold@uni-goettingen.de

The onset of planetary-scale mantle convection may have been one of the most pervasive transformation our planet has endured. On its surface, the development of a modern-style plate tectonic regime – the formation of rift systems and subduction zones – was most likely essential in converting the Earth into a habitable realm. It also played a key role in establishing and sustaining a global material cycle that may have erased any traces of Hadean and early Archean mantle heterogeneities that formed within the first few hundred million years after the accretion of the Earth.

The study of the onset of whole-mantle convection and its effect on early-formed isotopic mantle heterogeneities is intertwined with a basic understanding of core formation in a rather peculiar way: Separation of metallic melt from a reduced silicate magma ocean during core formation caused an almost quantitative transfer of siderophile elements from the mantle into the core (e.g. [1]) leaving a diagnostic isotopic signature in the earliest rocks that formed on Earth [2-4]. Yet, shortly after core formation was completed, the Hadean Earth was struck by a limited number of cataclysmic meteorite impacts (e.g. [5]) that injected a small but significant amount of fresh sideropile elements into the mantle, thus partly replenishing their abundances in the silicate Earth [6,7] and implanting an intrinsic isotopic signature into the Earth's mantle.

Here, this planetary-scale tracer experiment will be used to shed light on the internal isotopic heterogeneity of the Early Earth by trying to identify, how this meteoritic material mixed into the Earth's mantle over a timescale of about 1 billion years [8,9]. The W and Pt isotopic composition of the oldest rocks on Earth will be used to characterise the effect that core formation imparted on the isotopic composition of siderophile elements in the mantle before the meteoritic material was completely homogenised. Crustal and mantle-derived rocks from crucial time periods throughout Earth's earliest history will then be analyse to see, over which timescales the newly arrived siderophile elements were mixed into the Earth's mantle. Our findings will thus enable a much better and more detailed characterisation of the evolution of mantle convection on the Early Earth.

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Teilnehmer des General Meeting 2019

Nachname	Vorname	Email	Adresse
Abouchami	Wafa	wafa.abouchami@mpic.de	University of Cologne
Albert	Richard	AlbertRoper@em.uni-frankfurt.de	Goethe Universität
Arndt	Nicholas	Nick.Arndt@sisprobe.com	Univ Grenoble Alpes
Barth	Patrick	barth@mpia.de	Max Planck Institute for Astronomy
Basak	Sampriti	Sampriti.basak@rub.de	Ruhr University Bochum
Bau	Michael	m.bau@jacobs-university.de	Jacobs University Bremen gGmbH
Bragagni	Alessandro	abragagn@uni-koeln.de	Universität zu Köln
Braukmüller	Ninja	n.braukmueller@uni-koeln.de	Universität Köln
Cambeses	Aitor	Aitor.Cambeses@ruhr-uni-bochum.de	Ruhr-Universitat Bochum
Carone	Ludmila	carone@mpia.de	Max Planck Institute for Astronomy
Dziggel	Annika	adziggel@iml.rwth-aachen.de	RWTH Aachen University
Enright	Allison	allison.m.enright@gmail.com	Eberhard-Karls-University Tuebingen
Enzingmüller-Bleyl	Tristan Cosme	bleyl@rhrk.uni-kl.de	Technische Universität Kaiserslautern
Ernst	David	d.ernst@jacobs-university.de	Jacobs University Bremen gGmbH
Feng	Dingsu	dingsu.feng@geo.uni-goettingen.de	Georg-August-Universität Göttingen
Fischer	Meike	meike.fischer@uni-goettingen.de	Georg-August-Universität Göttingen
Fischer-Gödde	Mario	mfisch48@uni-koeln.de	Universität zu Köln
Fonseca	Raoul	raoul.fonseca@uni-koeln.de	Universität zu Köln
Friedrichs	Bjarne	bjarne.friedrichs@geow.uni-heidelberg.de	Heidelberg University
Gail	Hans-Peter	gail@uni-heidelberg.de	Universität Heidelberg
Galer	Stephen	steve.galer@mpic.de	Max Planck Institute for Chemistry
Gehringer	Michelle	mmgehringer@yahoo.com	TU Kaiserslautern
Geilert	Sonja	sgeilert@geomar.de	GEOMAR Helmholtz Centre for Ocean Research Kiel
Gutieva	Lanita	lg50@st-andrews.ac.uk	Ruhr-Universität Bochum
Hallmann	Christian	challmann@bgc-jena.mpg.de	MPI for Biogeochemistry
Hasenstab	Eric	erichasenstab@web.de	Universität zu Köln
Herrmann	Achim	a_herrma@rhrk.uni-kl.de	Technische Universität Kaiserslautern
Hoffmann	Elis	jeh@zedat.fu-berlin.de	Freie Universität Berlin
Hoppe	Peter	peter.hoppe@mpic.de	Max Planck Institute for Chemistry
Hülle	Daniela	huelled@uni-koeln.de	Uni Köln
Jäger	Oliver	jaeger.oliver1@gmail.com	Georg-August-Universität Göttingen
Jansen	Mike	mike-jansen@gmx.net	University of Cologne
Kappler	Andreas	andreas.kappler@uni-tuebingen.de	Eberhard-Karls-University Tuebingen
Kaus	Boris	kaus@uni-mainz.de	Johannes-Gitenberg University Mainz
knittel	ulrich	knittel@rwth-aachen.de	RWTH Aachen
Kodolanyi	Janos	j.kodolanyi@mpic.de	Max Planck Institute for Chemistry
Köhler	Inga	inga_koehler@gmx.de	Friedrich-Schiller Universität

Leitner	Jan	jan.leitner@mpic.de	Max-Planck-Institute for Chemistry
Lewis	Jonathan A.	jonathanaaronlewis@gmail.com	Freie Universität Berlin
Marien	Chris S.	marienc@uni-koeln.de	Universität zu Köln
Martin	Ashley	a.martin@mineralogie.uni-hannover.de	Leibniz Universität Hannover
Martinez	Raul	rmartinez@bgc-jena.mpg.de	MPI for Biogeochemistry Jena
Millonig	Leo J.	l.millonig@em.uni-frankfurt.de	Göthe Universität Frankfurt
Mißbach	Helge	hmissba@gwdg.de	University of Göttingen
Neumann	Wladimir	wladimir.neumann@dlr.de	WWU Münster
Noack	Lena	lena.noack@fu-berlin.de	Freie Universität Berlin
Ott	Ulrich	uli.ott@mpic.de	Universität Heidelberg
Pack	Andreas	apack@uni-goettingen.de	Georg-August-Universität
Piccolo	Andrea	piccolo@uni-mainz.de	Johannes-Gutenberg University Mainz
Reitner	Joachim	jreitne@gwdg.de	Univ. Göttingen
Ronny	Schönberg	schoenberg@ifg.uni-tuebingen.de	Universität Tübingen
Runge	Eric Alexander	e.runge@stud.uni-goettingen.de	Georg-August-Universität Göttingen
Schier	Katharina	k.schier@jacobs-university.de	Jacobs University Bremen
Schmidt	Julia	julia.schmidt@fu-berlin.de	Freie Universität Berlin
Schulz	Falko	falko.schulz@tu-berlin.de	Technische Universität Berlin
Schulz	Toni	tschul22@uni-koeln.de	Universitaet Köln
Schwarzenbach	Esther M.	esther.schwarzenbach@fu-berlin.de	Institut für Geologische Wissenschaften
Sengupta	Sukanya	ssengup@gwdg.de	Georg-August-Universität Göttingen
Surma	Jakub	surma@gwdg.de	Georg-August-Universität
Thiel	Volker	vthiel@gwdg.de	Universität Göttingen
Thiemens	Maxwell	maxwellmt@gmail.com	Brüssel
Trieloff	Mario	mario.trieloff@geow.uni-heidelberg.de	Universität Heidelberg
Tusch	Jonas	jonastusch@gmx.de	Universität zu Köln
Viehmann	Sebastian	sebastian.viehmann@univie.ac.at	Universität Wien
Vulpius	Sara	sara.vulpius@fu-berlin.de	Freie Universität Berlin
Weyer	Stefan	s.weyer@mineralogie.uni-hannover.de	Universität Hannover
Willbold	Matthias	matthias.willbold@uni-goettingen.de	Universität Göttingen
Wombacher	Frank	fwombach@uni-koeln.de	Universität zu Köln
Xiang	Wanli	wanli.xiang@geo.uni-goettingen.de	Georg-August-Universität Göttingen