SPP1833
Building a
Habitable Earth

Abstracts

of the First General Meeting

“Early Earth evolution”

April 6-8, 2016

Cologne

SPP1833
Building a
Habitable Earth

PROGRAMME

General Meeting
SPP 1833 “Building a Habitable Earth”
Department of Geology and Mineralogy, University of Cologne
Geo/Bio-Lecture Hall, Zülpicher Straße 49a

Wednesday, April 6th: Oceans and Atmosphere

14.00-14.15	Carsten Münker, Köln: Introductory remarks
14.15-14.45	Paul Mason, Utrecht: Keynote: Viewing global oxygenation and early life through multiple sulfur isotopes: Recent research from the Barberton Greenstone Belt, Kapvaal Craton
14.45-15.00	Katharina Schier, Bremen: Ge/Si as proxy for the origin of Si in the Archean oceans – Were Si and Fe really decoupled?
15.00-15.15	Florian Kurzweil, Köln: Iron and Molybdenum isotopic evidence for ocean stratification during the deposition of early Proterozoic iron formations
15.15-15.30	Joachim Reitner, Göttingen: Paleoarchean carbonates on early Earth - microbial biosignature versus hydrothermal origin
15.30-15.45	Jan-Peter Duda, Göttingen: Geobiology of a new type of microbial mat facies from the 3.4 Ga Strelley Pool Formation, Western Australia
15.45-16.00	Andreas Pack, Göttingen: New approaches in stable isotope geochemistry – application of high-resolution gas source mass spectrometry
16.00-16.30	*Coffee Break*
16.30-16.45	Sukanya Sengupta, Göttingen: High precision triple oxygen isotope analysis of cherts for determining $\delta_{18}O$ and temperature of Precambrian oceans
16.45-17.00	Jan-Peter Duda, Göttingen: Kerogen in early Archean hydrothermal chert veins: Biotic vs abiotic origin
17.00-17.15	Michelle Gehringer, Kaiserslautern: Determining the effects of iron tolerance on CO_2 assimilation in ‘ancient’ Cyanobacterial species
17.15-17.30	Georg Feulner, Potsdam: Modelling the climate evolution of the early Earth
17.30-17.45	Stefanie Gebauer, Berlin: Atmospheric processes affecting the Evolution of Molecular Oxygen in Earth-like Atmospheres
18.00	*Icebreaker-Barbecue*

Thursday, April 7th: Building Blocks, part I

9.00-9.15	Bettina Rockenbach, Rektorat der Universität zu Köln: Welcoming speech
9.15-9.45	Maria Schönbächler, Zürich (Keynote): Nucleosynthetic isotope contraints on the formation of the Earth and the Moon
9.45-10.00	Bo-Magnus Elfers, Köln: The Hf and W Isotope inventory of sequentially leached chondrites
10.00-10.15	Christoph Burkhardt, Münster: Meteoritic SmNd isotope constraints for Earth's bulk composition and mantle evolution
10.15-10.45	*Coffee Break*
10.45-11.00	Til Birnstiel, Heidelberg: Evolution of Solids in Circumstellar Disks
11.00-11.15	Hubert Klahr, Heidelberg: All Planetesimals are born equal - Why the size distribution of Asteroids and Kuiper Belt objects is so similar
11.15-11.30	Christian Lenz, Heidelberg: Spatial distribution of planetesimals in protoplanetary disks
11.30-11.45	Dmitry Semenov, Heidelberg: Chemistry of the Solar Nebula in the terrestrial planet forming region
11.45-12.00	Hans-Peter Gail, Heidelberg: The spatial distribution of carbon dust in the early Solar Nebula and the carbon content of planetesimals
12.00-14.00	*Lunch Break*

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

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Thursday, April 7th: Building Blocks, part II

14.00-14.15	Jan Leitner, Mainz: Characterization of Nitrogen-bearing Phases in Enstatite Chondrites
14.15-14.30	Christian Vollmer, Münster: The mineralogy and functional chemistry of organic grains from extraterrestrial samples
14.30-14.45	Raphaelle Escoube, Köln: Mercury abundances in chondrites
14.45-15.00	Herbert Palme, Frankfurt: The Earth contains a large fraction of material not represented by meteorites
15.00-16.15	*Postersession + Coffee Break*
16.15-16.30	Frank Wombacher, Köln: Elemental distribution in chondritic meteorites determined by LA-ICP-MS
16.30-16.45	Wladimir Neumann, Berlin: Consistency of planetesimal melting and differentiation models with the Hf-W model ages of iron meteorites
16.45-17.00	David Rubie, Bayreuth: Impact-induced melting during Earth's accretion
17.00-17.15	Gerd Steinle-Neumann, Bayreuth: Crystallizing the Martian Magma Ocean
17.15-17.30	Dominik Hezel, Köln: Digital Data in Geosciences – Science, Strategy & Perspectives
17.30-18.00	*Discussion about field campaigns and future SPP research*

Friday, April 8th: Internal differentiation

9.00-9.15	Catherine McCammon, Bayreuth: The core of a habitable Earth
9.15-9.30	Nicola Tosi, Berlin: Consequences of magma ocean solidification for mantle dynamics and evolution
9.30-9.45	Sylvain Petitgirard, Bayreuth: $MgSiO_3$ and SiO_2 glass densities at high pressure
9.45-10.00	Jens Hopp, Heidelberg: Palaeoatmospheric noble gas isotopes as proxies of atmosphere-crust/mantle interaction
10.00-10.15	Toni Schulz, Vienna: Spherule layers from South Africa as windows into the Paleoarchean meteorite bombardment of the early Earth
10.15-10.45	*Coffee Break*
10.45-11.00	Julia van de Löcht, Köln: Geochemistry of Earth´s oldest mantle peridotites
11.00-11.15	Sumit Chakraborty, Bochum: High resolution thermal and tectonic history of Archean terranes: Development of a tool through a case study from the Coorg block in S. India
11.15-11.30	Annika Dziggel, Aachen: PTt record of Neoarchaean terrane accretion, SW Greenland
11.30-11.45	Christoph Heubeck, Jena: Vertical and/or horizontal tectonics (de-)form Archean greenstone belts
11.45-12.00	Kathrin Schneider, Berlin: Granite-greenstone relationships in the oldest mafic rocks of the Barberton Greenstone Belt, South Africa
12.00	*Conclusion*

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Posters

General Meeting
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Katherine Armstrong, Bayreuth:
The oxidation state of iron in silicate melts as a function of pressure

Michael Babechuk, Tübingen:
Geochemical investigation of the ca. 2.45 Ga Cooper Lake paleosol (Thessalon, Canada)

Annika Brüske, Hannover:
Vanadium and Uranium isotope signatures in Archean sediments: Evidence for metal mobilization and enzymatic reduction in an overall anoxic world

Pedro Cordeiro, Berlin:
Plate tectonics and the permanence of atmospheric oxygen

Michelle Gehringer, Kaiserslautern:
Expanding the “bio” in Biogeochemistry: Cyanobacteria and the Great Oxygenation Event

Christopher Giehl, Kiel:
High pressure and temperature metal-silicate-mineral partitioning of Mn, Cr and V

Inga Köhler, Jena:
Different phases of carbonaceous matter in microbial mats of the Moodies Group in the Barberton Greenstone Belt, South Africa

Vera Laurenz, Bayreuth:
Sulfide-silicate partitioning of Re and Os at high P-T conditions

Christian Maas, Münster:
Influence of planetary rotation on crystal settling in a terrestrial magma ocean

Natascha Manger, Heidelberg:
Pressure trapping solids in proto-planetary disks

Christian Marien, Köln:
Are oceanic plagiogranites from Cyprus Archean TTGs analogues?

Andrea Piccolo, Mainz:
Effects of differentiation on the geodynamics of the early Earth

Manfred Vogt, Heidelberg:
Acquisition of terrestrial volatiles – constraints from Ne and Xe isotopic composition

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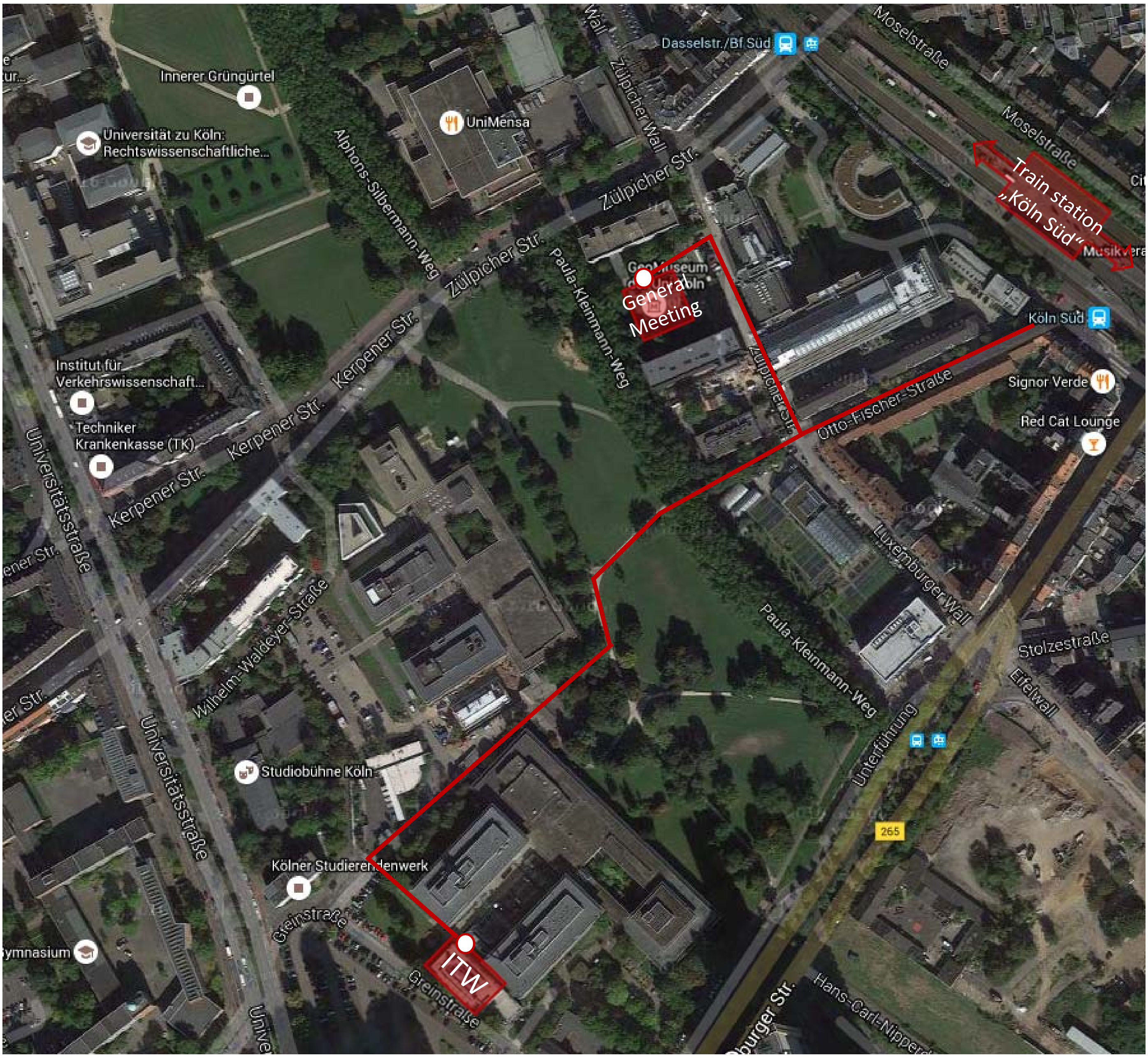
Map of the conference venue



All abstracts are given in alphabetical order of the first author

The oxidation state of iron in silicate melts as a function of pressure

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During accretion the $Fe^{3+}/\Sigma Fe$ ratio of a magma oceanas likely to have been governed by metal-silicate equilibration occurring near its base [1]. Magmas in equilibriumwith iron at low pressures have very low $Fe^{3+}/\Sigma Fe$ ratios. It is possible, however, that melt $Fe^{3+}/\Sigma Fe$ ratios increasewith pressure at a constant oxygen fugacity, as observed for some silicate minerals [2]. A deep magma ocean may then contain higher levels of Fe^{3+} than would be expected for a magma ocean that has equilibrated with iron metal. This would have important implications for the early oxidation state of the mantle. Existing experimental results on melts equilibrated at the Ru-RuO_2 oxygen buffer, however, show $Fe^{3+}/\Sigma Fe$ ratios to decrease with pressure [3].We report results of further experiments where this trend appears to at least flatten at high pressure. This leaves open the possibility that at even higher pressures the $e^{3+}/\Sigma Fe$ ratio of a silicate melt at a fixed fo_2 may start to increase.

[1] Hirschmann M.M. (2012) Earth Planet Sci. Letters, 341-344, 48-57.
[2] Frost D. J. & McCammon C.M. (2008) Annu. Rev. Earth Planet Sci. 36, 389-420
[3] O'Neill H. St. C. et al. (2006) Am Mineral. 91,404-412

Geochemical investigation of the ca. 2.45 Ga Cooper Lake paleosol (Thessalon, Canada)

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The investigation of Precambrian paleosols throughout the 1980s-90s resulted in significant insight into the nature of the Great Oxidation Event (GOE) transition [1]. The marine sedimentary record, in combination with the development of new geochemical paleo-redox proxies (e.g., stable metal isotopes), has since taken front stage in studies seeking to refine the details of the GOE. However, paleosol research has recently regained momentum due to a need to establish better links between the marine and terrestrial geochemical reservoirs and bring the redox evolution of the biospherelithosphere-atmosphere into sharper focus. The Cooper Lake paleosol (developed on a basaltic dyke below the Huronian Supergroup, Ontario, Canada) has been targeted for detailed geochemical analysis. Here, a preliminary report of the paleosol's geology, mineralogy, petrography, and major and trace element geochemistry is presented, building upon earlier studies [2,3].

[1] Rye, R. & Holland, H.D. (1998) Am J Sci 298, 621–672.
[2] Sutton, S.J. & Maynard, J.B. (1993) Can. J. Earth Sci. 30, 60–76.
[3] Utsunomiya, S. et al. (2003) GCA 67, 213-221.

Evolution of Solids in Circumstellar Disks

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The evolution of small solid particles is not only the first step towards forming planets, it is also a powerful probe of the structure and dynamics of the gas disk in which planets form. Furthermore, key volatiles such as water, CO, and complex organic molecules form on the surfaces of grains. These particles efficiently migrate in the disk, therefore solids act as a "conveyor belt" for frozen-out volatiles. Many aspects of the chemical evolution of disks thus depend on the evolution of solids. Dust emission provides a powerful tracer of the dynamical processes that drive disk evolution and dispersal. Upcoming radio interferometers and high contrast imaging are beginning to deliver a wealth of observations of unprecedented resolution and sensitivity. To make use of the observed dust continuum and molecular line emission, the processes that drive the evolution of solids will have to be well understood. I will discuss recent advances in modeling, their impact on disk chemistry, and show how recent observations already foreshadow an exciting future of the field of planet formation and its chemistry.

Vanadium and Uranium isotope signatures in Archean sediments: Evidence for metal mobilization and enzymatic reduction in an overall anoxic world

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Vanadium (V) and Uranium (U) are redox-sensitive trace metals whose redox changes induce characteristic isotope fractionation. Due to this, U isotopes have been used for paleo reconstruction of redox conditions in marine sediments. For example, Mt. McRea black shales (2.5 Ga old) show δ_{238}U pointing to the mobilization of U and subsequent authigenic enrichment by U reduction [1]. Furthermore, experimental findings on U redox behaviour indicate that only enzymatic U reduction may result in a distinct U isotope signature [2]. In this study, we will analyse U and V isotopic compositions in sedimentary rocks that were deposited in the Archean and early Proterozoic (2.1 - 3.5 Ga old). We want to address the question when the first mobilization of metals occurred and whether different metal proxies provide consistent evidence. Potentially (and ideally), we may be able to link the first signals of metal mobilization and reduction to the first occurrence of metal reducing microorganisms. We further aim to characterize the V isotope composition of the most important ocean reservoirs and have been optimizing both the enrichment and purifications methods,as well as V isotope analyses with MC-ICP-MS.

[1] Kendall, B. et al. (2013) *Chem. Geology* **362**, 105–114.
[2] Stylo, M. et al. (2015) *PNAS* **112** no. 18, 5619 – 5624.

Meteoritic SmNd isotope constraints for Earth's bulk composition and mantle evolution

Burkhardt*, C., Borg, L.E., Brennecka, G.A., Shollenberger, Q.R., Dauphas, N., Kleine, T.
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A longstanding paradigm assumes that the bulk silicate Earth has chondritic ratios of refractory elements like Sm and Nd. The greater 142Nd/144Nd of the accessible Earth compared to chondrites may, therefore, reflect a higher than chondritic Sm/Nd and subsequent decay of now extinct 146Sm. This would require differentiation of the silicate Earth within 30 million years of solar system formation, resulting in the formation of a complementary lowSm/ Nd reservoir that either remains hidden in the deep Earth or has been lost to space through collisional erosion. We will show, however, that the 142Nd excess of the accessible Earth compared to chondrites results from Earth's accretion from precursor bodies enriched in Nd produced by the process of nucleosynthesis. After correction for this effect, the 142Nd/144Nd of chondrites and the accessible Earth are similar to within ~5 parts per million, obviating the need for a hidden reservoir or collisional erosion of early formed crust, and implying a chondritic Sm/Nd ratio for the present day bulk Earth.

High resolution thermal and tectonic history of Archean terranes: Development of a tool through a case study from the Coorg block in S. India

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Available chronological constraints appear to suggest a polychronous tectonothermal history of the Coorg massif in S. India with events at c. 3.2-3.1 Ga, 2.5 Ga, 2.3-2.4 Ga, and c. 1.0 Ga that should be suitable for high-resolution diffusion chronometry. In initial investigations we have sampled a number of granulites of different protolith compositions. A garnetiferous, migmatitic mafic granulite has a suitable polyphase history recorded in the following successive stages: (a) an early lowintermediate pressure melting stabilised two Px + Pl assemblage and produced a tonalitic leucosome, (b) formation of two generations of Grt: Grt1 as porphyroblasts and Grt2 (intergrown with Cpx, Kfs and Qtz) and also as overgrowth on Grt1, (c) decomposition of Grt2 to an assemblage of Opx + Pl ± Cpx, (d) terminal hydration and potassic infiltration stabilising Bt with or without ortho- and clinoamphiboles, (e) a late epidote-amphibolite facies, fluid-driven event that stabilised Ath/Cumm + Tschermakitic Hbl ± Ep ± St ± Act ± Dolomitic carbonate. Detailed analysis of these rocks and observations on the rest are in progress.

Plate tectonics and the permanence of atmospheric oxygen

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Oxygen was made available to the atmosphere through a combination of biogeochemical volatility, extreme climatic variations and pronounced photosynthetic oxygen production. All of these factors can be traced back to the influence of plate tectonics. For an instance, an unusual concentration of continental area (supercontinent) in the tropics would allow for both extreme chemical weathering and the development of a global-scale glaciation. However, no supercontinents are reported in relation to the ~2.1 Ga global carbon excursion registered in carbonate rocks, the Lomagundi-Jatuli event. The role of the 2.2-2.0 Ga orogeny that formed the Amazonian-West African and the São Francisco- Congo landmasses has been overlooked both from a supercontinents and paleoclimate perspective. Carbon excursions are intimately related with spikes of atmosphere oxygenation both in the Paleoproterozoic and in the Neoproterozoic, when oxygen reached nearly present levels. Widespread formation of Rhyacian arcs would lead to subduction of vast amounts organic carbon. Orogeny could be the mechanism responsible for removing organic carbon from the oceanic budget and influencing the permanence of an oxygenated atmosphere.

Kerogen in early Archean hydrothermal chert veins: Biotic vs abiotic origin

Duda*, J.-P., Thiel, V., Mißbach, H., Schäfer, N., Bach, W., Van Kranendonk, M.J., Reitner, J.
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Early Archean hydrothermal chert veins commonly contain high amounts of organic matter of unknown origin (abiotic vs. biogenic). Aiming at a better understanding of the source of the organic matter we analysed kerogen contained in a hydrothermal chert vein from the ca. 3.5 Ga old Dresser Formation (Pilbara Craton, Western Australia). Petrography reveals that organic matter is exclusively embedded in the chert matrix but does not occur in later fissures. Raman spectra of the organic matter are in line with the thermal history of the host rock. Taken together, these observations indicate a syngenetic origin of the bulk organic matter rather than emplacement of younger materials. The $\delta_{13}C$
signature of the bulk kerogen (-32.8‰) is in line with a biological origin. During catalytic hydropyrolysis, these kerogens released *n*-alkanes up to n-C_{20}, with a sharp decrease in abundance beyond n-C_{18}. This chain length distribution pattern resembles artificially maturated bacterial biomass, but is strikingly different to organic matter generated via Fischer-Tropsch-like synthesis. We propose that the organic material was biologically produced, and accumulated in the hydrothermal fluids, as it occurs in recent hydrothermal fields. Our findings indicate that a sizeable primary production was established during the Paleoarchean which has to be considered in the interpretation of the carbon cycle on the early Earth.

Geobiology of a new type of microbial mat facies from the 3.4 Ga Strelley Pool Formation, Western Australia

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Department of Geobiology, Geoscience Centre, Georg- August-University Göttingen, Goldschmidtstraße 3, 37077 Göttingen, Germany; 'Origin of Life' Group , Göttingen Academy of Sciences and Humanities, Theaterstraße 7, 37073 Göttingen, Germany
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Paleoarchean rocks from the Pilbara Craton (Western Australia) provide a variety of evidence for early life on Earth. However, some of these evidences could also be explained by non-biological processes. Stromatolites in the 3.35 Ga Strelley Pool Formation are e.g. widely interpreted as biogenic structures, but some authors argue for an abiogenic origin. Further lines of evidences are therefore required to make a good case for the biogenicity of these stromatolites. Here we describe a new type of microbial mat facies which is closely associated with stromatolites in the Strelley Pool Formation. By combining detailed field and thin section observations with various (bio-) geochemical analyses (e.g. SEM-EDX, Raman spectroscopy,ToF-SIMS, NanoSIMS) we draw conclusions on the biogenicity, paleoenvironment, and taphonomical processes of the microbial mat facies. The results do not only confirm the presence of microbial mat systems in the Strelley Pool Formation, but also help to identify potential biosignatures in other Paleoarchean rocks.

PTt record of Neoarchaean terrane accretion, SW Greenland

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The Nuuk region is one of the type localities to study the mechanisms of terrane accretion during the Neoarchaean. High-pressure rocks of the Færingehavn terrane experienced peak conditions of 700°C and 10 kbar at c. 2.72Ga, followed by rapid decompression to conditons of 700°C and 6 kbar [1]. In contrast, rocks of the Tasiusarsuaq terrane record granulite facies grades of 850°C and 7.5 kbar [2], followed by near isobaric cooling during NW vergent thrusting and, finally, the juxtaposition of the terranes. The existence of different thermal regimes and contrasting PT paths, the strong evidence for regional-scale tectonic thickening, as well as the similarity between the timing of collision, high-P metamorphism and exhumation indicate that the terranes represent one of the oldest preserved paired metamorphic belts. However, the lack of extreme PT conditions typical of modern accretionary belts suggests that subduction in the Nuuk region was rather inefficient, perhaps related to frequent slab breakoff and rollback.

[1] Dziggel, A. et al. (2014) Prec.Res. 242, 22–38.
[2] Dziggel, A. et al. (2012) J.Met.Geol. 30, 957-72.

The Hf and W Isotope inventory of sequentially leached chondrites

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The stepwise dissolution of primitive chondritic meteorites allows identification of componentspecific nucleosynthetic anomalies that are otherwise hidden on the bulk rock scale. Here, we present combined Hf and W isotope data for acid leachates of several primitive chondrites, also including some of the first sufficiently precise analyses of p-process $_{174}$Hf and $_{180}$W. Our data reveal significant nucleosynthetic heterogeneities in Hf and W isotopes consistent with [1] and [2]. Our results, including $_{174}$Hf and $_{180}$W, are consistent with variations in the abundance of diverse s-process Hf-W carriers in different leaching steps. Our isotope and Hf and W concentration data further hint at nebular modification of presolar phases rather than alteration on parent bodies as cause for inter-group differences.

[1] Qin L. et al. (2011) *GCA, 75,* 7806-7828.
[2] Burkhardt C. et al. (2012) *AJL, 753*, L6

Mercury abundances in chondrites

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With a half condensation temperature of 252K1, only 70K higher than that of water, mercury (Hg) is the most volatile of all metals. Therefore, Hg presents a high potential to trace processes affecting volatiles in the early solar system. However, the Hg contents are poorly characterized in chondrites and its behavior remains unclear. Recent studies reported large and non-systematic variations in Hg contents from undetectable traces to >10000 ng/g [2, 3, this study]. The high and variable Hg concentrations in chondrites from museum collections may result from contamination (Lodders, 2003 and references therein). We present Hg concentrations for antarctic chondrites in order to evaluate contamination in non-antarctic samples and whether correlations with other volatile elements exist.

[1] Lodders (2003) The Astrophysical Journal 591, 1220
[2] Meier et al. (2015) Lunar Planet. Sci. Conf. 1101
[3] Wiederhold & Schönbächler (2015) Lunar Planet. Sci. Conf. 1841.

Modelling the climate evolution of the early Earth

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Earth's habitability during the Archean eon critically depends on atmospheric greenhouse gases (in particular carbon dioxide) providing sufficient warming despite the faint young Sun. The atmospheric reservoir of carbon dioxide, however, is intimately linked to geological processes determining the early evolution of Earth's crust and its interaction with the atmosphere. Fast zerodimensional climate-and-carbon-cycle models are poerful tools which have been used for a long time to study the common evolution of crust and atmosphere on early Earth. Furthermore, the first spatially-resolved climate modelling studies for the Archean have recently improved our understanding of the early climate system. We will review recent progress in modelling early Earth's climate and its evolution, including our own work in this area. Furthermore we will discuss how a combination of new insights from the geological record, fast carboncycle models and sophisiticated Earth-system models could yield a plausible and self-consistent picture for the early evolution of the coupled crustatmosphere- ocean-biosphere system during the critical time-span when Earth became habitable.

The Lomati River Intrusion – a mafic sill in the Barberton Greenstone Belt?

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The sill-like Lomati River Intrusion (LRI) is the only intrusion in the center of the BGB, Earth's prime study object of early Archean cover-basementinteraction. The LRI is a tubular, bedding-parallel mafic (gabbroic) and medium crystalline body which intruded into folded upper Fig Tree (~3230 Ma) volcano-sedimentary strata just north of the major Inyoka Fault (IF) of the BGB. It extends for > 10 km in NE-SW direction and has a width of only 50 to 500 m. Contact relationships are uncertain due to very poor outcrop conditions. Just south of the IF, a mafic stockwork for which the LRI may have acted as source appears to have intruded unlithified quartzose sandstones of the Moodies Group (3224±1 to 3219±9 Ma). If so, (1) the LRI would be contemporaneous with Moodies deposition and (2) vertical displacement across the IF would be neclectable at this location. However, single grain zircon evaporation dating provides an age of 3141 ± 3 Ma (Heubeck and Kröner, unpubl.). Current work aims at clarifying field relationships, characterizing igneous petrography and establishing new age relationships of this intrusion.

The spatial distribution of carbon dust in the early Solar Nebula and the carbon content of planetesimals

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Carbon dust is abundant in the interstellar medium (ISM) while in terrestrial planets, asteroids, and meteorite parent bodies carbon is low or almost absent. We consider the oxidation and pyrolysis processes in the warm and chemically active inner region of the Solar Nebula that are responsible for the destruction of the pristine carbon inherited from the ISM and its conversion to hydrocarbons and ultimately to CO. The chemical reaction equations are combined with an accretion disk model and the temporal evolution and spatial distribution of the carbonaceous material during the first 3 Ma of the Solar Nebula evolution is modelled. From this we determine the radial distribution of the carbon content of the initial planetesimal population. The results are in reasonable accord with the observed trend of a decreasing carbon content of solar system bodies with decreasing distance to the sun and yield high depletion factors consistent with the low carbon abundance in chondritic parent bodies.

Atmospheric processes affecting the Evolution of Molecular Oxygen in Earth-like Atmospheres

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We show results from our newly-developed Coupled Atmosphere Biogeochemistry (CAB) model. In order to understand the chemical processes leading to the destruction and production of molecular oxygen (O2) we apply a chemical diagnostic tool called the "Pathway Analysis Program" resulting in the first quantitative analysis of catalytic cycles affecting the evolution of atmospheric molecular oxygen in Earth-like atmospheres. In the atmosphere, around the time of the Great Oxidation Rise on Early Earth, results predict that smog-type reactions play a key role affecting O2 removal on lower atmospheric levels whereas in the upper atmosphere photolysis of carbon dioxide is a key source for molecular oxygen. In general, results suggest that uncertainties in atmospheric mixing, ocean solubility and mantle/crust properties could strongly affect net primary productivity and therefore surface O2 fluxes.

Expanding the “bio” in Biogeochemistry: Cyanobacteria and the Great Oxygenation Event

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Our project within the DFG Priority Programme SPP1183: (http://www.habitableearth.uni-koeln.de/12547.html) Building a Habitable Earth will investigate whether ancient Cyanobacterial species could grow in shallow, nutrient rich fresh and/or marine waters prior to the Great Oxygenation event (GOE). A selection of modern-day descendants of ancient cyanobacteria, are being used in experiments mimicking the conditions that existed prior to the GOE, namely increased CO_2 and reduced O_2 atmospheric levels combined with increased levels of iron and silica. We will determine the rates of CO_2 uptake and O_2 generation by cyanobacteria and see how iron cycling and calcium carbonate formation, both important signature compounds for biogeochemical studies of life on Early Earth, were affected by changing O_2 levels. Additionally we will assess O2 induced changes on morphology and in expression of genes involved in these key physiological processes. Data generated in this study will provide essential information on the rates of CO_2 assimilation and O_2 production prior to the GOE and aid in our understanding of the role of cyanobacteria in the early evolution of Earth’s ocean-atmosphere-biosphere system from the first atmosphere until the great oxidation event.

Determining the effects of iron tolerance on CO2 assimilation in ‘ancient’ Cyanobacterial species

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Investigating the early evolution of Earth’s oceanatmosphere- biosphere system from the first atmosphere until the great oxidation event is a challenging but essential research area. We are determining rates of CO_2 uptake and O_2 generation by cyanobacteria under increased CO_2 / reduced O_2 levels and measuring the resultant effects in iron cycling and calcium carbonate formation, both important signature compounds for biogeochemical studies of life on Early Earth. Several modern-day descendants of ancient cyanobacteria species of have been established in our laboratory and their CO_2 assimilation rates determinedunder present day atmospheric conditions over a range of iron (30 – 500 µM) concentrations. Microsensors were used to measure colony surface REDOX and O_2 production levels. Microscopic methodology is still under development to detect changes in cellular morphology and iron precipitation. Our project will provide essential information on the generation of biogeochemical signature molecules such as calcium carbonate and iron, as well as CO_2 assimilation and O_2 production, thereby aiding in our understanding of the role of cyanobacteria in the early evolution of Earth’s ocean-atmosphere-biosphere in shallow water oxygen rich oases.

High pressure and temperature metal-silicate-mineral partitioning of Mn, Cr and V

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The earliest processes - accretion and large-scale differentiation after the Moon-forming impact - determined the bulk element inventory of Earth [1]. During metal-core formation, elements were sequestered into the metallic core according to their siderophile and chalcophile character. Lithophile elements stayed behind as the silicate portion of the Earth. Further element distribution within the silicate portion is driven by elements` compatibility in minerals. Mineral/melt partition coefficients are required to model this quantitatively.
The focus of the present study is on experimentally derived metal-silicate-mineral partitioning. Our results are self-consistent and allow parameterization with respect to fO_2, *P* and *T*. In our experiments (fO_2: IW-5 to IW-1.5; *P*: 1 atm to 16 GPa; *T*: 1300 to 2200 °C), Mn, Cr and V are divalently incorporated in the silicate melt. Hence, Mn/Cr ratios in the silicate melt should be constant at various fO_2, but this is not the case in all runs, pointing to the fact that the presence of mineral phases (olivine, ferro-periclase) strongly fractionate Mn/Cr of the silicate melt and prevail over metal-silicate partitioning.

[1] Ringwood AE & Kesson SE (1977) The Moon 16: 425-464

Vertical and/or horizontal tectonics (de-)form Archean greenstone belts

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Archean greenstone belts (GB) display distinct map patterns of curvilinear faults separating cuspate-lobate volcano-sedimentary sequences from surrounding plutons and show abundant evidence of vertical stretching. This contrasts with evidence of horizontal tectonics from subhorizontal detachments, recumbent isoclinal folds, and low-angle faulting. Consequently, two models, “arc-accretion” and “partial convective overturn (PCO)” have been applied to explain the (de-)formation of GBs, both with strengths and weaknesses. We will investigate the dominance of one over the other by examining stratigraphic and structural evidence from the 3.22 Ga Moodies Group of the Barberton GB, dominated by up to 3.7 km thick quartz-rich sandstones. If Moodies Group strata were deposited during PCO, we would expect (1) symmetrical, inward-thinning sediment wedges from the uplifted margins, (2) sediment transport principally orthogonal to the belt, (3) an initially extensional, then contractional setting, and (4) syndepositional deformation. We will relate deposition and deformation of the Moodies Group through a detailed structural and sedimentological analysis to the tectonic models.

Digital Data in Geosciences – Science, Strategy & Perspectives

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The past decades are characterised by an accelerating increase of data in all fields of geosciences. These data are more and more used for original research [e.g. 1,2]. The increasing amount of data requires a strategy for structured digital archiving. In a subsequent step, archived data might be used to generate topic specific databases such as GEOROC or PetDB. A recent german initiative tries to develop a strategy to archive data, but also find ways to maintain databases such as GEOROC. I will present how digital data can be used for original research, using statistical analyses of GEOROC and PetDB data. These data alone are sufficient to demonstrate a negative bulk Earth Tm anomaly, as recently reported from new measurements by [3,4]. Further, I will present the current german initiative towards data archiving and database production, and the international perspectives, in which this initiative could be embedded.

[1] Keller, C. B. & Schoene, B. (2012) *Nature* 485: 490-493.
[2] Tang et al. (2016) *Science* 351:372-375.
[3] Dauphas, N. & Pourmand, A. (2015) GCA163:234–261.
[4] Barrat et al. (2016) GCA 176:1–17.

Palaeoatmospheric noble gas isotopes as proxies of atmosphere-crust/mantle interaction

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The noble gas isotopic composition of the atmosphere has changed in time as the result of various processes and events, e.g. during a postulated early catastrophic and subsequently during more modest outgassing of the Earths interior, furthermore due to addition of extraterrestrial matter and crustal degassing. The latter is an important source of radiogenic isotopes which led to a gradual change with time in the isotopic composition of several noble gas elements in the atmosphere (e.g. $_{40}Ar/_{36}Ar$). This change of isotopic compositions can be used to test various degassing scenarios. To utilize the noble gas record of the ancient atmosphere it is necessary to investigate samples with a likely palaeoatmospheric fluid component and known formation age. The latter is possible, in principle, by the application of the $_{40}Ar/_{39}Ar$ dating method when well-defined isochron relations are found in ancient samples. This is because an isochron records both the age and the initial $_{40}Ar/_{36}Ar$ ratio. We report results of a preliminary study, discuss the caveats of the method and present an outline of our SPP project.

All Planetesimals are born equal - Why the size distribution of Asteroids and Kuiper Belt objects is so similar

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Asteroids and classical Kuiper-Belt objects have one surprising property in common: they have a characteristic size of about 100 km in diameter. It is under discussion whether this size distribution is the result of an initial collisional growth of bodies from dust grains or the result of a gravitational collapse from huge heaps of gravel sized material. For both models a clear prediction was missing what typical sized objects should form from the individual processes. Especially collisional collapse had shown to form large planetesimals quite rapidly, yet due to limitations in the numerical resolution of the respective simulations, it was not clear whether there is a physical condition defining the mass and size of the smallest planetesimals possibly formed due to this process. Here we show from first principles that there is a minimal size of about 100 km for planetesimals formed via self-gravity, largely independent from the distance from the star and the actual mass distribution in gas and solids in the solar nebula.

Different phases of carbonaceous matter in microbial mats of the Moodies Group in the Barberton Greenstone Belt, South Africa

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The Moodies Group (ca. 3.2 Ga) of the Barberton Greenstone Belt in South Africa is a well-studied and well-preserved siliciclastic tidal Archean deposit. The Moodies Group contains alleged microbial mats that are preserved as kerogenous 0.5 to 1 mm thick laminations. Here, we present Raman spectroscopic data collected on carbonaceous material (CM) present within and in between the laminations. Our data revealed differences in structural order of the CM within one single thin section (ca. 4x2.5 cm). Up to 3 different phases of CM per thin section were identified. The careful analysis of the stratigraphic and paragenetic framework showed no signs of CM redeposition within the rock. We therefore conclude that the variations in structural order either stem from mineral matrixes that act as an intensifier of thermal overprint or from differences in the chemical composition of precursor organic matter.

Eo- to Palaeoarchaean granitoid gneisses in the core of the Zimbabwe craton

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The oldest terrain of the Zimbabwe craton is exposed in the Tokwe and Sebakwe River areas of the Midlands region where zircon ages between 3368 and 3565 Ma were reported (1). We revisted these areas and report on SHRIMP II zircon ages and Hf-in-zircon isotopic systematics from granitoid gneisses, confirming the ancient nature of this cratonic nucleus. Our oldest date of 3631.4±0.4 Ga is for 14 igneous grains recovered from a tonalitic gneiss at Mushandike Dam in the Tokwe area. We interpret this to reflect the time of emplacement of the gneiss protolith. One older zircon core yielded an age of 3706±2 Ma. A similar age was obtained on igneous zircons from a granodioritic Kwekwe Gneiss sampled in the Sebakwe River, Rhodesdale terrane. Although these zircons produced some discordant results, the data define a weighted mean 207Pb/206Pb age of 3632±1 Ma. Two further samples from the Tokwe River are some 100 Ma younger but belong the same granite-gneiss terrane as the 3.6 Ga generation. One tonalitic gneiss yielded an age of 3525.7±1.1 Ma, and an identical age of 3525.0±1.2 Ma was obtained for a second porphyritic trondhjemite sample from the Shashe River. Lastly, we obtained an age of 3342±3 Ma for a well foliated tonalitic gneiss from the Tokwe area near Chidume Dip, attesting to the variety of granitoid generations contained in this ancient region. We suggest that the main structural event leading to interlayering and folding of these rocks must be younger than ca. 3.34 Ga. Hf-in-zircon isotopic data for the above gneiss samples yielded well-grouped Hf(t) values ranging from slightly negative to slightly positive and suggesting that these rocks probably originated from melting of a heterogeneous source consisting of older continental crust, possibly as old as 4 Ga, as well as juvenile material. This isotopic pattern is very similar to those in 3.6-3.5 Ga TTG-gneisses in Swaziland (2).

[1] Horstwood, M.S.A. et al. (1999) Geology 27,707-710. [2] Kröner, A. et al., 2014. Precambrian. Res. 255, 823-846.

Iron and Molybdenum isotopic evidence for ocean stratification during the deposition of early Proterozoic iron formations

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The evolution of oxygenic photosynthesis might have caused the formation of local shallow marine 'oxygen oases' long before atmospheric oxygenation ~2.4 Ga ago with large implications on the mobility, distribution and isotopic composition of redox sensitive elements. Shallow marine carbonate and silicate iron formations of the 2.48 Ga old Koegas Subgroup, South Africa, were deposited in such an 'oxygen oasis' and show a negative correlation between Mn content and both, δ_{98}Mo and δ_{56}Fe values. This highlights the substantial role of Mn for the cycling of Mo and Fe. The δ_{98}Mo-trend reflects the sedimentary flux of Mn oxides and adsorbed isotopically light Mo, which is dependent on the relative position to a Mn chemocline. The δ_{56}Fetrend is related to Fe isotope fractionations during Fe2+ oxidation by Mn oxides, which result in lower δ_{56}Fe values in the uppermost water column. We argue that the preservation of these signals within the sediments implies a very smooth gradient of the chemocline in Paleoproterozoic oxygen oases.

Sulfide-silicate partitioning of Re and Os at high P-T conditions

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It is generally considered that the highly siderophile elements (HSEs) were depleted from the Earth's manlte by core-forming metal, followed by the addition of a late veneer that raised the HSE concentrations to their current levels. It has been proposed that a sulfide melt has also been sequestered to the core [1], which could explain suprachondritic Pd/Ir and Ru/Ir of the Earth's mantle [2]. To assess whether such sulfide segregation is consistent with the long term chondritic Re/Os of the mantle [3] we are experimentally investigating the sulfide-silicate partitioning of Re and Os at high pressure and temperature. First results indicate, that Re and Os behave as chalcophile elements under high P-T conditions. Results will be used to model the influence of sulfide segregation on Re and Os during core formation and to test whether they become fractionated, as is the case for low P-T sulfide-silicate equilibration during MORB genesis.

[1] O'Neill (1991) GCA 55, 1159-1172.
[2] Laurenz et al., submitted to GCA.
[3] Meisel et al. (2001) GCA 65, 1311–1323.

Characterization of Nitrogen-bearing Phases in Enstatite Chondrites

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Nitrogen, the most abundant component in the terrestrial atmosphere, has been one of the key elements for the evolution of Earth's biosphere. The N-isotopic ratios of Earth, Mars and Venus differ significantly from those of the Sun and the protosolar nebula. Thus, other nebular components must have contributed significantly to terrestrial N. O-isotopes and bulk chemistry suggest enstatite chondrites (ECs) as best analogue for the building blocks of the primordial Earth [e.g., 1,2]. Major nitrogen carriers in ECs are nitrides and Si_2N_2O. Organic matter in ECs has about terrestrial Nisotopic composition, but the whole-rock nitrogen isotopy [3], as well as the composition of individual Si_2N_2O grains shows a slightly $_{15}$N-depleted composition [e.g., 4]. A NanoSIMS and SEM-EDS investigation of N-carriers in the meteorites Neuschwanstein (EL6) and Indarch (EH4) is currently in progress.

[1] Wasson, J. T. (2000) Rev. Geophys. 38, 491–512.
[2]Warren, P. H. (2011) EPSL 311, 93–100.
[3] Kung C.-C. and Clayton R. N. (1978) EPSL 38, 421-435.
[4] Hoppe P., Geiss J., and El Goresy A. (1989) Meteoritics 24, 278.

Spatial distribution of planetesimals in protoplanetary disks

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The spatial distribution of planetesimals plays a crucial role for planet formation and thus for the early earth evolution. It dictates, as an important initial condition, where planets will form including the formation of a habitable earth. The planetesimal region and the slope of the spatial distribution highly depends on the disk properties, e.g. strength of turbulence. We developed a parametrized model where the planetesimal formation rate is proportional to the pebble flux. This model was implemented into a coagulationfragmentation code using a typical size of 100 km in diameter for the planetesimals. These gravitational selfbounding objects are forming in pressure bumps, acting as pebble traps, with a typical extend of 5 gas pressure scale heights via gravitational collapse of pebbles.

Influence of planetary rotation on crystal settling in a terrestrial magma ocean

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Like Moon or Mars, Earth experienced one or several deep magma oceans of global extent in a later stage of its accretion. Crystallization of these magma oceans is of key importance for the chemical structure, the mantle evolution and the onset of plate tectonics. Due to the fast rotation of the early Earth and the small magma viscosity, rotation probably had a profound effect on differentiation processes. For example, [1] propose that the distribution of heterogeneities like the LLSVP's at the core mantle boundary is influenced by rotational dynamics of the early Earth and could be of primordial origin [2]. To study the effect of planetary rotation on a vigorously convecting magma ocean, we have developed a numerical model in spherical geometry. This model allows us to study crystal settling and the distribution of crystals in the early magma ocean in a rotating spherical shell. We will present very first results of this model.

[1] Matyska, C. et al. (1994) EPSL 125, 255–266.
[2]Garnero, E.J. and McNamara, A.K. (2008) Science 320, 626–628.

Pressure trapping solids in proto-planetary disks

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Small dust grains are vital in the study of proto-planetary disks by defining their observational structure, as well as forming the main actors in the process of planet formation. To in situ form terestrial planets within a few AU of the host star, the dust grains have to be concetrated. So how can we trap those particles in the inner part of a protoplanetary disk? One answer can be pressure. Small grains, with sizes up to a few meter, are bound to move to the nearest local high pressure region and therefore can be trapped there. We conduct 3D hydrodynamical simulations with the PLUTO code, wherein small dust grains are treated as a second fluid in the short friction time approach. By this method, we can create dust distributions in disks which are turbulent do to pure hydro instabilities like Goldreich- Schubert-Fricke and Convective Overstability, forming vortices inside the disk and thus enable dust grains to be trapped. We present our latest results from our numerical simulations while discussing the prospects of forming planetesimals inside those traps.

Are oceanic plagiogranites from Cyprus Archean TTGs analogues?

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Understanding the petrogenesis of plagiogranites is important for understanding the genesis of Earth´s first continental crust. Although plagiogranites never exceed 1 vol.% of the oceanic crust, it is argued that similar processes have likely occurred in Hadean and Archean, resulting in Archean TTGs (e.g., [1]). Different endmember models are invoked for the petrogenesis of modern oceanic plagiogranites, including high-pressure dehydration melting and fractional crystallisation in deeper levels of oceanic crust (e.g., [2]). In order to evaluate the significance of modern plagiogranites as putative equivalents to Archean crustal lithologies, we performed combined conventional trace element, high precision HFSE, and Sr-Hf-Nd isotope measurements on plagiogranites from the Troodos Ophiolite complex in Cyprus. In line with earlier trace element data [3], most samples exhibit depleted LREE and Rb-Ba contents. Initial Nd-Hf isotope compositions at 90 Ma overlap with those of surrounding mafic rocks (+5.6 to +8.3 and +14.4 to +16.4, respectively). Initial $_{87}Sr/_{86}Sr$ ratios are slightly more radiogenic (0.704-0.707). Ratios of Nb/Ta are relatively narrow (15-16), but two distinctive suites, however, exhibit more variable Nb/Ta (12.3-17.1 and 18.5-19.8, respectively), coupled with positive Zr-Hf anomalies. Compositions of most Cyprus plagiogranites can be explained via fracionational crystallization from 1) ambient arc-tholeiitic melts and 2) depleted tholeiitic/boninitic hybrid melts, respectively. A third suite, high in Nb/Ta, can be explained by dehydration melting of altered oceanic crust in the presence of ilmenite and amphibole. Altogether, HFSE ratios in Cyprus plagiogranites are much less fractionated than in Archean TTGs, reflecting a much shallower environment of formation. Therefore, they are no direct modern analogues for Archean TTGs.

[1] Willbold *et al*. (2009), *EPSL*, **279**, 44-52
[2] Koepke *et al.* (2007), *CMP,* **153**, 67-84
[3] Freund et al. (2014), *CMP*, **167**:978

The core of a habitable Earth

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A habitable Earth depends critically on the presence of the geomagnetic field to shield the planet from the harmful effects of the solar wind that impact not only living organisms, but also the atmosphere [1]. Calculations support a dynamo model where convection of the liquid outer core is driven mostly by the compositional buoyancy due to crystallization of the inner core [2], where the density difference between the outer and inner core and process of crystallisation depends critically on core composition, specifically the nature of the light alloying element(s). The presentation will highlight our progress in determining phase relations and thermoelastic properties of relevant compositions using a laser heated diamond anvil cell, including new innovations in pulsed laser heating, and discuss implications for Earth’s accretion and evolution of the geodynamo.

[1] Wei, Y et al. (2012) J Geophys Res 117, A03208. [2] Lister, J, Buffet, B (1995) PEPI 91: 17-30

Consistency of planetesimal melting and differentiation models with the Hf-W model ages of iron meteorites
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The differentiation of planetesimals is one of the most fundamental processes in the early solar system. It involves physical separation of metal and silicates through the upward migration of lowdensity silicate melts or/and downward segregation of dense metal melts. Magmatic iron meteorites provide direct evidence for these processes and the differentiation of their parent body serves as a case study for the structural evolution of Earth's potential building blocks. Recent measurements of 182W compositions of different iron meteorite groups[1]
provide constraints on the circumstances of the metal-silicate separation on their parent bodies while recent differentiation models[2] provide new insights into the complex process of melting and melt migration during planetesimal differentiation. We construct numerical models for the thermal and structural evolution of iron meteorites' parent bodies. We will present first results and compare them to the metal-silicate separation data available.

[1] Kruijer, T. S. et al. (2014) Science 344, 1150–1154.
[2] Neumann, W. et al. (2014) EPSL 395, 267–280.

New approaches in stable isotope geochemistry – application of high-resolution gas source mass spectrometry
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Conventional gas source mass spectrometers for stable isotope analyses are operated at low mass resolution of ~ 150 with an array of fixed collectors. A new generation of mass spectrometers has been developed. These mass spectrometers combine the stability of an electron impact ionization gas source with a high-resolution mass analyser equipped with moveable and switchable FC and SEM collectors. These mass spectrometers now allow identification and separation of isobaric interferences, which was not possible with conventional mass spectrometers. A new high-resolution gas source mass spectrometer will be installed at the Geoscience Center at the University of Göttingen. The mass spectrometer will be used for a variety of new applications, including triple oxygen isotope paleoclimatology and clumped isotope thermometry and provenance analysis. I will present the outline of planned projects that make use of the new mass spectrometer.

The Earth contains a large fraction of material not represented by meteorites
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Chondritic meteorites have approximately the chemical composition of the photosphere of the Sun for non-gaseous elements. One group of meteorites, the CIchondrites has element abundances identical to the solar photospheric abundances to within 10% for most elements Other groups of chondritic meteorites show some deviations from solar abundances. Based on Al/Si and Mg/Si ratios, two major categories of chondritic meteorites can be distinguished: (1) Non-carbonaceous chondrites (NCC) including enstatite chondrites, ordinary chondrites, and Rumurutiites and (2) carbonaceous chondrites (CC). Both categories show characteristic differences in bulk chemistry and in stable isotope compositions. The composition of the earth, known from the analyses of peridotites, can be viewed as an extension of chemical trends in CC. Stable isotopes (O, Cr, Ni etc.) of NCC are, however similar to stable isotopes of Earth materials, but NCC chemistry is very different from earth's mantle chemistry. The amount of CC material in the Earth is thus limited by stable isotopes, the fraction of NCC material by chemistry. Although bulk Earth may be considered in a broad sense chondritic, only a small fraction of parental material can be derived from existing meteorite groups.

$MgSiO_3$ and SiO_2 glass densities at high pressure

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The density contrast between solid and liquid silicate phases controls the entrainment or settlement of matter in the lowermost mantle. To constrain the density contrast between crystal and amorphous silicates, we have adapted the X-ray absorption method to the diamond anvil cell and measure silicate glasses densities to unprecedented conditions of pressure [1]. We collected data for SiO_2 and $MgSiO_3$ glasses up to 90 and 127 GPa, respectively. Our density values for $MgSiO_3$ glass are considerably higher than those previously derived from Brillouin spectroscopy but validate recent ab initio simulations. At the core–mantle boundary (CMB) pressure, the density of MgSiO3 glass is approximately the same as that of $MgSiO_3$ bridgmanite. Taking into account the partitioning of iron into the melt, we conclude that melts are denser than the surrounding solid phases in the lowermost mantle and that melts will be trapped above the CMB [1].

[1] Petitgirard S. et al., 2015. PNAS 112, 14186-14190.

Effects of differentiation on the geodynamics of the early Earth

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Archean geodynamics processes are not well understood. There is a general agreement that the mantle potential temperature was higher than present, and as a consequence significant amounts of melt were produced. This has likely resulted in crustal differentiation. An early attempt to study the effects of the differentiation on the Archean geodynamics was made by Johnson et al,[1] who used numerical modelling in conjunction with representative phase diagrams. The results show that there is a positive feedback between crust production, metamorphic reactions and crust recycling. Though the simulations gave useful insight, they were simplified in many aspects: 1)the rheology used was temperature dependent viscoplastic rheology with constant yield stress; 2) the 100% of the extracted melt was transformed into volcanic rocks; 3)the effects of the free surface boundary condition were not systematically studied. In order to better understand the effects of this simplification on the geodynamic models, we here present additional simulations in which we employ more realistic rheology, boundary conditions and intrusive/effusive rocks ratio.

[1] Johnson, T. E., et al. (2013) *Nature Geoscience*, *7*(1), 47–52.

Paleoarchean carbonates on early Earth - microbial biosignature versus hydrothermal origin

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Paleoarchean carbonates from the Pilbara Craton (Western Australia, WA) and Barberton Greenstone Belt (South Africa, SA) are almost the oldest known in Earth history, and compositionally variable. Their origin is mostly unclear- formed biologically and/or abiologically. Few stromatolites (e.g. 3.35 Ga Strelley Pool Fm, WA) are still preserved as a dolomite. These dolomites are zoned and exhibit a strong cathodoluminescence. The cores of the dolomites, however, are non-luminescent andrepresent the primary precipitate. Rare earth element characteristics are in part comparable to modern microbialites (e.g. negative Ce and positive Y anomalies). δ13CVPDB signatures of these carbonates (ca. +3‰) are in good accordance with photoautotrophy. A fenestral chert from the same formation strongly resembles a typical microbial carbonate facies from the Upper Triassic of the European Alps, which was deposited in a carbonate lagoonal setting. Within this facies, dolomite rhomboids and chert pseudomorphs after aragonite were observed. The majority of carbonates, however, are mostly primary calcites within inter pillow spaces of the ca. 3.47 Mt. Ada-, the 3.46 Ga Apex-, and the 3.35 Ga Euro Basalt (WA). Calcites in the Apex basalt exhibit δ13CVPDB and δ18Osmow values comparable to modern marine settings (0 ‰ and +13‰, respectively). These carbonates were probably formed during hydrothermal alteration of ultramafic oceanic crust. Hydrothermal carbonates (e.g. kutnahorite and ankerite) in the 3.5 Ga Dresser Fm (WA) are strikingly different. These carbonates exhibit elevated Fe, Sr and Ba concentrations, REE+Y patterns typical for a hydrothermal source (positive Eu anomaly), and distinct $\delta\,_{13}C_{VPDB}$ and $\delta_{18}O_{smow}$ values (-6‰ and +21‰, respectively). Carbonate phases in hydrothermal chert veins and silicified 3.25 Ga sedimentary rocks of the Fig Tree Group (SA) are particularly interesting. These small carbonate crystals (10-20µm) exhibit a strong cathodoluminescence, pointing to enrichments of Mn2+ in the crystal lattice, and are linked to organic flakes (100-200µm), which have δ13CVPDB values of ca. -25 to -30‰ . Various microorganisms are able to precipitate rhodochrosite and kutnahorite. Mn-rich carbonates therefore may precipitated within microbial EPS using reduced Mn2+ directly from the anoxic seawater. While the validity as a microbial biosignature remains to be proven, multiple lines of evidence argue for early Archean carbonates as important environmental archives of microbial activity on early Earth.

Impact-induced melting during Earth's accretion

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During planetary accretion, giant impacts cause large degrees of melting. The depth of melting after each impact determines the *P-T* conditions of metal-silicate equilibration and thus geochemical fractionation during core formation. Accretional collisions that formed the terrestrial planets have been calculated using N-body accretion simulations. Here we use the output from such simulations to determine the depth of melting and thus the *P-T* conditions of metal-silicate equilibration, after each impact, as Earth-like planets accrete. So far, a parametrised melting model has been used that takes impact velocity, impact angle and the respective masses of the impacting bodies into account. The evolution of metal-silicate equilibration pressures (as defined by evolving magma ocean depths) during Earth's accretion depends strongly on the lifetime of magma oceans compared to the time interval between large impacts. In addition, the results depend on starting parameters in the N-body simulations. Thus, there is the potential for combining the results with multistage core formation models [1] to constrain Earth's accretion history.

[1] Rubie et al. (2015) *Icarus* **248**, 89-108.

Ge/Si as proxy for the origin of Si in the Archean oceans – Were Si and Fe really decoupled?

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Ge/Si ratios have been introduced as a geochemical proxy for constraining the origin of Si in Archean BIFs based on different Ge/Si ratios of hydrothermal fluids and continental runoff. High Ge/Si in Fe-rich bands of BIFs have been interpreted to represent water masses influenced by hydrothermal input, while lower Ge/Si ratios in Si-rich bands point towards a continental origin of Si [e.g. 1]. Therefore, interaction of two compositionally different water masses and, hence, a decoupling of Si and Fe sources was proposed [1]. However, preferential scavenging of Ge by Fe(III)oxyhydroxides [2] and the accompanying fractionation of the Ge-Si pair provides an alternative explanation for high and low Ge/Si ratios in Fe- and Si-rich BIF bands, respectively. Therefore, the commonly observed distribution of Ge and Si in BIFs does not necessarily require two different water masses and different sources of Fe and Si, suggesting further studies are required before the Ge/Si ratio in BIF bands may be used as a reliable geochemical proxy.
[1] Hamade, T. et al. (2003) Geology 31, 35-38.
[2]Pokrovsky, O. S. et al. (2006) GCA 70, 3325-3341.

Granite-greenstone relationships in the oldest mafic rocks of the Barberton Greenstone Belt, South Africa

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Constraining the formation history of Archean greenstone belts is of great interest for understanding the tectonic environment on the early Earth. To adress this intriguing question, we investigated whether the mafic and ultramafic rocks of the lower Onverwacht Group (3.46 to 3.53 Ga; [1]) interacted with older crustal material and aimed to characterize the mantle sources from which our samples were generated. Our results show that initial Hf-Nd isotope and trace element compositions resemble those of modern ocean plateau basalts, similar to previous studies on Barberton komatiites [2;3], with only a few samples showing traces of possible crustal contamination. This possibly much older contaminant would be characterized by depleted LREE abundances and unradiogenic Hf-Nd isotopic compositions similar to what would be expected in the lower continental crust.

[1] Armstrong et al. (1990) EPSL 101,90-106.
[2] Chavagnac (2004) Lithos 75,253-281.
[3] Pearce (2008) Lithos 100,14-48.

Spherule layers from South Africa as windows into the Paleoarchean meteorite bombardment of the early Earth

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Impact spherules within distal ejecta can provide information about an impact event even if the source crater cannot be found. Based on their Cr isotope signatures, three spherule layers of Paleoarchean age (exclusively preserved in the Barberton Greenstone Belt, South Africa) represent the oldest impact remnants identified so far on Earth. Two recently recovered drill cores from the Barberton area, with possibly up to 21 new spherule layers of Paleoarchean age, provide an outstanding opportunity to gain new insights into the meteorite bombardment of the Early Earth. Our proposal aims to (i) assess possible correlations between the closely spaced spherule beds from both drill cores, (ii) determine the magnitude and spatial distribution of meteoritic admixtures within them, (iii) characterize impactor types involved, and (iv) assess the number of cratering events they represent. These objectives will be achieved by a combination of insitu and whole rock analyses, including Os and high precision W isotopes, as well as concentrations of highly siderophile elements determined by isotope dilution.

Chemistry of the Solar Nebula in the terrestrial planet forming region

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Based on a 2D radiation-hydrodynamics model of the solar nebula coupled with chemical reaction kinetics we study the combustion of carbonaceous material inherited from the ISM and the formation of complex hydrocarbons. We used this model of a young solar nebula to perform larger-scale chemical post-processing simulations. For that, we utilized the time-dependent gas-grain ALCHEMIC code supplied with the extended deuterium fractionation network with nuclear spin state processes. The chemical post-processing was performed over the time span of 1 Ma, and with the two distinct sets of initial abundances: 1) atomic with H2 and HD and 2) molecular, taken from the chemical modeling of a prestellar core. We show that the nebular chemistry "forgets" about its initial state in the entire nebula and discuss when and why it reaches the equilibrium. We will discuss consequences of the combustion of carbonaceous grains for the synthesis of organic (prebiotic) molecules inside the planetforming zone of the solar nebula.

High precision triple oxygen isotope analysis of cherts for determining □$_{18}$O and temperature of Precambrian oceans

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It has been long debated whether the δ$_{18}$O of marine sediments, like carbonates, cherts etc., suggest a hot ancient ocean (upto 80°C) [1] or a light δ$_{18}$O ocean (e.g., -12‰) [2] or if the sediments' δ$_{18}$O values have been altered by diagenesis [3]. We present high precision triple oxygen isotope data on cherts, from the Archean to the Phanerozoic. Where δ $_{17/16}$ silica–water = (δ $_{18/16}$ silica-water)□silica-water, the equilibrium δ silica-water varies with temperature [4] and serves as an additional parameter in the seawater puzzle. In combination with the classical δ $_{18/16}$ silicawater- T relation and a mass balance model for δ17Oseawater evolution through time, developed in this study, we gain additional information on precipitating conditions of the ancient cherts. Trace element and Si-isotope analyses of samples shall be undertaken in the future.

[1] Knauth & Epstein (1976) GCA 40, 1095–1108.
[2] Perry (1967) EPSL 3, 62–66.
[3] Degens & Epstein (1962) AAPG Bull. 46, 534–542.
[4] Pack & Herwartz (2014) EPSL 390, 138-145.

Crystallizing the Martian Magma Ocean

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In the context of the formation and evolution of terrestrial planets a magma ocean stage is thought to play a critical role; its solidification determines the initial thermal and chemical structure of the mantle and thus the initial condition for the evolution of the planetary interior, controlled by thermo-chemical convection. Modelling magma ocean crystallization requires a detailed characterization of different aspects of mantle petrology at high P and T: (i) location of the liquidus; (ii) phase diagram; (iii) distribution coefficients of major elements between minerals and melt; (iv) density of both the residual liquid and the crystallites. While much progress has been made in addressing these issues, over the P-T range of the Earth considerable uncertainty remains. For the Martian mantle, better constraints are available from experiments and computations and we have compiled new results for (i)-(iv) and developed a model to investigate the crystallization of Mars that reveals a more complex picture than that previously determined [e.g. 1]

[1] Elkins-Tanton, L. et al. (2003), *Met. Planet. Sci.* 382, 1753–1771.

Consequences of magma ocean solidification for mantle dynamics and evolution

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Large-scale melting following the largest accretionary impacts suggests that the mantle of the Earth and terrestrial bodies may have been processed through one or multiple magma oceans. The fractional crystallization of a magma ocean is expected to establish a primordial compositional stratification that can set a suitable initial condition for the subsequent thermal evolution of the interior as well as the formation, mixing, and sampling through partial melting of early-formed geochemical reservoirs. Using numerical simulations of thermochemical convection, we illustrate the consequences of magma ocean crystallisation for the evolution of the interior of various terrestrial bodies. We will also present recent results showing that, under a variety of conditions, solid-state convection can start mixing the mantle before the overlying magma ocean has completely solidified, thereby partly or completely erasing the effects of its fractional crystallization.

Geochemistry of Earth´s oldest mantle peridotites

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Among Eoarchean rocks, the Itsaq gneiss complex (IGC) of southern West Greenland provides particular well preseved exposures. Embedded in ~3.8 Ga trondhjemitic-tonalitic-granodioritic (TTG) gneisses of the IGC are ultramafic units, that have been proposed to represent remnants of mantle peridotites or cumulates [1]. Combined petrological and geochemical investigations, including platinum group element (PGE) and Re-Os isotope data, have identified two localities in the ICG where >3.8 Ga, modern mantle-like peridotites occur. The mantle peridotites display a clear vestige of a chondritic late veneer signature, with PGE compositions similar to Phanerozoic depleted mantle peridotites, thereby questioning models that argue for a protracted mixing of the late veneer into the Earth's mantle. Collectively, >3.8 Ga mantle peridotites from southern West Greenland can therefore offer a direct window into Eoarchean tectonic processes and early mantle evolution.

[1] Friend, C.R.L. et al. (2002) CMP 143, 71–92.

Acquisition of terrestrial volatiles – constraints from Ne and Xe isotopic composition

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A classical problem in planetary science is explaining the origin and evolution of the volatile budget of the Earth. Standard models either demand a gravitationally captured primordial solar-like atmosphere in combination with hydrodynamic escape and planetary degassing [1], or consider the contribution of volatile species by solar wind (SW)-implantation into accreting dust grains [2, 3].
Noble gases as chemically inert and highly volatile tracers, containing both stable and radiogenic isotopes, offer a unique possibility for a combined study on the origin and chronology of terrestrial accretion.
Utilizing a database of Ne and Xe isotopic compositions of micrometeorites (MM) and IDPs with a given size distribution, modeling of SW-irradiated dust accretion will allow us to draw contraints on the timing of volatile acquisition.

[1] Pepin, R.O. (2006) EPSL 252, 1–14. [2] Trieloff, M. et al. (2000) Science 288, 1036–1038. [3] Moreira, M. & Charnoz, S. (2016) EPSL 433, 249–256.

The mineralogy and functional chemistry of organic grains from extraterrestrial samples

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Organic matter is an important constituent of a wide range of extraterrestrial samples, such as carbonaceous chondrites and interplanetary dust particles (IDPs) [e.g., 1]. It consists of small soluble units like amino acids and an insoluble kerogen-like material with a highly branched structure consisting of aromatic and aliphatic units and heterocycles. It has been suggested that this material was an important source of prebiotic molecules for the early accreting Earth. However, complex processes in the molecular cloud, the solar nebula, and respective parent bodies have affected its functional chemistry, e.g., by fluid reactions [2]. In this project, we aim at a deeper understanding of these complex reactions by transmission electron microscopy (TEM) investigations of organic grains from primitive meteorites and IDPs. We will use the aberration-corrected Nion UltraSTEM with superior energy resolution (<0.1 eV) and spatial resolution (<0.1 nm) to investigate the mineralogy and functional chemistry of this material at nm scale.

[1] Busemann, H. et al. (2006) *Science* 312 (5774), 727. [2] Vollmer, C. et al. (2014) *PNAS* 111 (43), 15338.

The evolution of the Earth´s mantle and the continental crust

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The focus is the temporal distribution of the generation of juvenile continental crust (CC). This CCproduction is intrinsically tied to the thermoconvective evolution of the Earth´s mantle. Therefore we numerically solved the full set of physical balance equations of convection in a spherical-shell mantle plus simplified equations of chemical CC-mantle differentiation. Our most significant conclusion is that the actual rate of CC-growth is NOT uniform through time. The kinetic energy of solid-state mantle creep, Ekin, slowly decreases with superposed early separated maxima, the temporal distribution of which is episodic but not periodic. The laterally averaged surface heat flow, qob, shows a similar behavior, but the qob-peaks have a time lag between 15 and 30 Ma compared to the Ekin-peaks. The CC-grow peaks have a delay of 75 to 100 Ma compared to the qob-maxima. The present-day qob- and CC-mass values are in good agreement with observation. Each CC-production episode is separated from the next one by a time interval of quiescence. The main cause for this result is not the variation of the mantle creep velocity but the fact that the peridotite solidus is not only a function of pressure but also of the water abundance. A differentiation period generates a regional water-concentration reduction and thereby an increase of the peridotite solidus and of the regional viscosity. By a plausible variation of parameters, we found a cluster of neighboring runs that reproduce the instants of time of the observed frequency peaks of zircon age determinations without essential change of the other results. Our calculated integrated CC-curve is situated near the curves of GLAM, Begg et al. (2009), Belousova et al. (2010), and Dhuime et al. (2012), however, our curve is not so smooth but shows distinct variations.

Elemental distribution in chondritic meteorites determined by LA-ICP-MS

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The distribution of 26 major and trace elements among chondritic components was determined using femtosecond laser ablation ICP-MS [1], which offers reduced fractionation of volatile elements during sampling [2]. Ablation yields were corrected by internal standardization to the sum of major element compounds, which requires the accurate quantification of all major elements and thus a suitable reference material. To this end, a chondrite analog nanoparticle standard was produced by flame spray synthesis [1, 3] and its composition established by various analytical methods. Data will be presented for refractory, chalcophile and volatile elements along line scans from Allende (CV3), Semarkona (LL3) and Indarch (EH4) thick sections. Apart from chondrules and matrix, one CAI and a sulfide rim in Allende and a large sphalerite grain in Indarch were among the components analysed in this reconnaissance study.

[1] Funk et al. (submitted to JAAS).
[2] Koch et al. (2006) JAAS 21, 932-940
[3] Tabersky et al. (2014) JAAS 29, 955-962.

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