Proceedings of the 4th Mini Conference on Noble Gases in the Hydrosphere and in Natural Gas Reservoirs
held at GFZ Potsdam, GERMANY, 28.02.-02.03.2007

The GFZ Noble Gas Lab: Equipment and Recent Research

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Here we would like to present the noble gas laboratory at GeoForschungsZentrum Potsdam, the hosting institution of MINOGA 2007, to its participants.

Equipment

There are two complete noble gas lines which are both used for the whole spectrum of noble gases, from He to Xe. Each line comprises an ultrahigh vacuum extraction furnace, a purification line, a cryogenic adsorber system, and a VG5400 noble gas mass spectrometer. In the resistance furnaces, rock samples up to ~2 g in size can be heated to a maximum of 2000°C in a Ta crucible with Mo liner using heating elements made of graphite. Extracted gases are admitted to the purification line, where in a first step water is frozen to a dry ice-cooled trap, and subsequently the remaining chemically active gases are removed by two Ti sponge and two SAES (ZrAl) getters. The cryogenic adsorbers, which are used for separation of different noble gases from each other, look a bit different on the two lines. One is equipped with two cold heads containing a stainless steel frit for adsorption of Ar, Kr and Xe at 50 K and activated charcoal for He and Ne adsorption at 11K, respectively, whereas the other one contains a charcoal finger only but can be heated up to 400 K for complete Xe release from the charcoal. In both cases the cold heads are sequentially heated after complete noble gas adsorption in order to allow individual admission of each noble gas to the mass spectrometer.
In addition to the furnace, one line includes an ultrahigh vacuum crusher, where minerals or glasses are crushed between two hard-metal jaws to mechanically extract gases from grain boundaries, fluid inclusions or vesicles. The other system comprises a water degassing line, which allows the separation of a gas phase from the water by ultrasonic agitation and making use of a laminar gas flow through a capillary to a liquid nitrogen-cooled trap. Gas samples can also be attached to this line and suitable volume splits can be admitted to the purification line for further treatment as described above.

Mantle Geochemistry

The predominant part of research done in the GFZ noble gas lab is based on measurements of rocks, with one of the two main research fields being mantle geochemistry. He and Ne isotopic and abundance studies of mid-ocean ridge basalts (MORB) and ocean island basalts (OIB) have provided important insights into the formation, evolution and composition of the Earth's mantle. Basic concepts on mantle structure and evolution (e.g. "layered mantle models") are primarily based on the interpretation that mantle ^{3}He and ^{22}Ne reflect primordial, undegassed mantle material, with deviations from primordial isotope signatures having increased during Earth's history due to the production of radiogenic ^{4}He and nucleogenic ^{21}Ne, which are both related to U and Th decay [e.g. 1]. Mantle He and Ne isotopic ratios are thus controlled by the ratios of [primordial ^{3}He]/[U+Th] and [primordial Ne]/[U+Th], respectively.

DOI: 10.2312/GFZ.mga.048

However, OIBs from individual mantle plumes, such as Hawaii, Easter or Foundation, display a distinct isotopic variability, which is probably related to mixing processes in the mantle and thus interpreted in terms of sampling different mantle reservoirs. Little is known about the contribution of magmatic processes in mantle plumes to those heterogeneities. Without an understanding of these processes and their contribution to geochemical tracers it is difficult to accurately explain the composition and evolution of the Earth's mantle. Thus our current projects are concerned with the detailed study of the noble gas isotope compositions of fresh, submarine and subaerial basaltic rocks from the Hawaii, Easter and Foundation plumes in order to resolve (1) the spatial and temporal distribution of plume material, (2) the magmatic and mantle dynamic processes in the plumes and (3) the compositions and developments of their mantle sources. Up to now the following results have been derived:

- He isotopes in olivine separates of subaerial Mauna Kea lavas from the Hawaii Scientific Drilling Project show an evolution towards higher $^3He/^4He$ with age [2] confirming earlier studies [3].
- Submarine Mauna Kea lavas erupted during the main shield-building stage show a spike-like pattern of high $^3He/^4He$ between ~12 and 23 R_A [2, 4].
- The Ne isotopic signature shows no depth dependence in the drill core, remaining plume-like over the whole length of the Mauna Kea and Mauna Loa sections of the borehole [2].
- He isotope data obtained from fresh, submarine glasses of the Easter Microplate (EMP)–Easter Seamount Chain (ESC) (26 R_A) and the Pacific-Antarctic-Rise (PAR)–Foundation Seamount Chain (FSC) system (12 R_A) establish that the plumes feeding those chains belong to the group of high ^3He plumes, comparable to Galápagos and Iceland [5].
- Ne isotope data of glasses from the ESC belong, similar to data from Iceland [6], to the most primitive Ne data obtained from a hotspot setting today. This indicates that the solar Ne component within the Earth's mantle may have survived virtually unchanged throughout Earth's history and that the He-Ne isotopic systematics can be decoupled, since the primitive Ne coincides with non-solar $^3He/^4He$ ratios [5].
- For the first time, coupled He, Ne and Ar isotope and relative abundance data from the EMP-ESC and PAR-FSC systems establish from a geochemical point of view that source material mixing in plume-ridge settings occurs in the physical state of melts and not in the form of solids or solid-melts.
- He, Ne and Ar fusion data from fresh, submarine volcanic glasses of a number of Mid-Atlantic Ridge off-axis seamounts show that He isotopes can be susceptible to interferences during melt formation and evolution resulting in a decoupling of He from Ne [6]: All obtained He data are indistinguishable from the MORB range, while Ne isotopic compositions show a clear plume signature.

Surface Exposure Dating

The second major focus of our research is connected to the method of surface exposure dating, which is based on the interaction of high-energetic cosmic ray particles with rocks on the terrestrial surface. In such interactions, nuclear reactions produce a variety of "cosmogenic" nuclides, among which a few long-lived radionuclides and rare noble gas isotopes (^3He, ^{21}Ne) can be used to investigate various processes shaping the Earth's surface [e.g. 8,9]. The main recent activities of our group within this field include:

Age of a coastal terrace in Asturias: Along the western Asturian coast of northern Spain, an up to 3-km-wide marine terrace extends for ~100 km and reaches an elevation of up to 100 m. It was formed as a wave-cut platform below sea level and was later uplifted, but both the time when it formed and the rate of uplift have been unknown. We have compared the concentrations of cosmogenic ^{21}Ne in quartzitic bedrock samples with those of ^{10}Be and

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^{26}Al in order to deduce the history of that terrace. Exposure ages calculated from the three nuclides differ considerably, indicating that the terrace had a complex exposure history involving periods of burial by sediment or water. It was most probably formed during the Pliocene or early Pleistocene, and maximum uplift rates are 0.1-0.2 mm/a [10].

Production rate of cosmogenic ^{38}Ar: In addition to ^{3}He and ^{21}Ne, ^{38}Ar may be another noble gas isotope suitable for surface exposure dating. However, the production rate of cosmogenic ^{38}Ar in terrestrial surface rocks has not been known so far. We have measured He, Ne and Ar in pyroxene samples separated from Ferrar dolerite boulders that were exposed in the Antarctic Dry Valleys for up to several Ma. Since Ca is the only relevant target element for production of cosmogenic ^{38}Ar in these minerals, we were able to deduce the ^{38}Ar production rate from Ca based on their ^{3}He and ^{21}Ne exposure ages, resulting in a value of ~220 at/(g Ca)$^{-1}$ a^{-1} [11].

Exhumation history of Southern Africa: High-elevation passive margins and their associated escarpments are the most prominent landforms resulting from continental break-up in Southern Africa. Using apatite fission-track (AFT) analysis combined with cosmogenic nuclide dating, we hope to track the long-term denudation history of various portions of Southern Africa's highlands. Our preliminary results indicate much lower rates of denudation in Late Cenozoic to recent times as compared to certain periods in the Mesozoic to Early Cenozoic. They provide estimates of vertical denudation rates between 0.5 and 3 m/Ma on the interior plateau and ~8 m/Ma along the margin of the escarpment.

CRONUS-EU: The ultimate goal of this EU-funded project (**C**osmic-**r**ay-pr**o**duced **nu**clide **s**ystematics on Earth – The **Eu**ropean contribution) is the development of an internationally accepted protocol allowing age determinations with accuracies better than 5%, rather than the 10-20% achievable at present. The GFZ contribution involves the determination of ^{3}He and ^{21}Ne production rates in olivines from Ar/Ar-dated lava flows in the Grand Canyon area (Arizona, USA) as well as the comparison of production rates of several cosmogenic nuclides in various minerals suitable for surface exposure dating, such as olivine, pyroxene, quartz and magnetite. For the latter purpose we have sampled landslides in Argentina and Norway and the non-basaltic volcanic flow of Bishop Tuff (California, USA). First results will be presented at the EGU meeting in Vienna (April 2007).

Hydrology: Specialization on deep crustal fluids and gas samples

The third scientific focus of the lab concerns noble gas isotope investigations applied to deep crustal fluids and drill mud gas samples.

- A prominent recent result of *drill mud gas analysis* is the disclosure on the origin and spatial distribution of fluids at seismogenic depths of the San Andreas Fault [12]. In that study, Ne/Ar ratios have been used to identify the source of the atmospheric contribution, which is generally abundant in drill mud gas. Besides atmospheric Ne and Ar isotopic compositions, the samples show Ne/Ar ratios indistinguishable from air with no evidence for the contribution of an air-saturated water source. Hence, air correction of the measured $^{3}He/^{4}He$ ratios was performed using the measured ^{20}Ne concentration and the $^{4}He/^{20}Ne$ ratio of air (0.319). The air-corrected $^{3}He/^{4}He$ ratios fall between 0.2 R_A and 0.9 R_A and clearly differ between the Pacific Plate and the North American Plate. Whereas at most ~5% of the helium on the Pacific Plate is derived from the mantle, the contribution of mantle-derived helium reaches 10-12% on the North American Plate and increases with greater distance from the fault core. However, the overall contribution of mantle-derived helium to the total helium inventory of the San Andreas Fault is relatively low. We conclude that other, more permeable faults situated on the North American Plate act as main conduits for mantle-derived fluids.

DOI: 10.2312/GFZ.mga.048

• Results of the investigations of *deep crustal fluids* by means of noble gas analysis have been published shortly after the final installation of a quantitative water degassing line in the lab [13,14]. The most prominent result is related to the model age determination of ultra-deep fracture water in a South African mine. On the one hand, the study of the inert gases has shown that the Mponeng water has been isolated from the surface for about 20 Ma; on the other hand that water has been demonstrated to host life forms which are independent from the energy of the sun [15]: The bacteria exist without the benefit of photosynthesis by harvesting the energy of natural radioactivity to create food for themselves. The discovery of a stable, light-independent life form raises hopes of finding similar creatures on other planets.

Acknowledgement

For the above mentioned research projects funding has been provided by the Deutsche Forschungsgemeinschaft, the European Union and the GFZ Potsdam.

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