Trapped charge dating and thermochronology: recent advances

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Trapped charge dating methods including luminescence and electron spin resonance (ESR) dating are based on the accumulation of unpaired electrons in minerals due to the natural radioactivity. Utilising the most abundant minerals on the earth, quartz and feldspar, the methods can cover the age range from a few years to more than a million years. The methods also have high potential as low-temperature thermochronometers due to the very low closure temperatures (< 100˚C). For the last 15 years, significant methodological advances took place in the luminescence dating and thermochronology, which made the method robust Quaternary geo- and thermo-chronological tools. ESR dating technique is currently not as robust as luminescence, but the method is an attractive alternative to luminescence dating for extending the age range. In this presentation, I outline the principles of luminescence and ESR dating and introduce several important technical developments including, 1) extended age range of infrared stimulated luminescence (IRSL) dating of feldspar using stable signals and its limitation, 2) recent developments of quartz ESR dating using single aliquots and 3) luminescence and ESR thermochronology.

Keywords: optically stimulated luminescence, infrared stimulated luminescence, electron spin resonance, low-temperature thermochronology

The criteria of sampling for ^{14}C dating and its example of application to Kaman- Kalehöyük chronology

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1. Independent

In this study, the first aim is confirmation of the improved result from archaeological real sample checked about the convergence of the dates of ^{14}C dating based on the following criteria which has not been verified in detail, one of it is about the material of the sample. The other criteria are the concentration of the alkaline treatment solution and treatment time on the most basic ABA method of pre-treatment of the carbon sample. In addition, the second aim of the present study is to show the results of analysis by ^{14}C ages from the application of the Bayesian statistical methods to calibration of ^{14}C dates, to reveal a difference between the archaeological chronology and ^{14}C chronology. In this process, the present study focuses on archaeological chronology which is shown the change in the short term than the geological chronology. The archaeological chronology is the past of the natural / social event chronology that is complex of the ages based on the archaeological remains or biological remains. As the result of Atsumi (2010), in the alkaline treatment stage of the ABA method, charcoal samples are treated in a NaOH solution of 1 mol / l and should be omitted the samples which is dissolved of in the solution. In 7 layers of 9, the dates shown good convergence which are observed below 50 ^{14}C yr in the 4 layers, about 66 ~ 85 ^{14}C yr in 3 layers. In other words, there is no old wood effect by old material which back over several hundred years in the site, ages of charcoal samples suggests almost construction age. The ^{14}C dates obtained in the measurement is calibrated by OxCal ver.3.10. Calendar age is analyzed by calibration using INTCAL04. The boundary age between Kaman-Kalehöyük IVa and IVb is provided that had been from the early BC 22 century to the end of the BC 21 th century. The age corresponds to the Ur IIIrd dynasty period in Mesopotamia. In addition, by using the technique of radiocarbon dating and the archaeological chronology, it is able to contrast from the early to the late Bronze Age stratigraphy of Troy in West Anatolia and Kaman-Kalehöyük. As the result of this study, comparison between the stratigraphic analysis which according to the analysis of archaeological remains of Troy and Külltepe, and which ^{14}C ages obtained by present dating, shows a deviation of nearly about one cultural sub-strata.

Keywords: 14C dating(AMS), Archaeological sight, criteria

Elucidating uplift/denudation histories of NE Japan by using low-temperature thermochronology

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The NE Japan is well-known as a typical arc-trench system. The tectonic setting of NE Japan arc is supposed to be controlled by the plate subduction, and the E-W compressive stress caused by the subduction formed mountains and geological structures. Since NE Japan has experienced massive and frequent changes of the stress field, the complex tectonic histories are inferred. Most of the geomorphic reliefs in NE Japan has been formed from Pliocene to Quaternary (Yonekura et al. 2001), whereas the onset of mountain uplift may be different at each region, the fore-arc, the Ou Backbone range and the back-arc side in NE Japan.
The methodologies of estimation of uplift/denudation in upper crust vary in timescale or target area. However, the uplift rate observed by GPS survey does not always agree with the uplift rate on 10^6–10^7 yrs timescale. Furthermore, the number of methods for estimation of uplift/denudation rate on >10^6 yrs timescale is not abundant, so few studies were conducted as to the quantitative evaluation of uplift/denudation rate on >10^6 yrs timescale in NE Japan.
In this study, low-temperature thermochronology was performed for a quantitative evaluation of vertical deformation in NE Japan, and interpretation of complicated tectonic effect on the proceedings of the mountain buildings. This method is used to estimate thermal histories of a mountain region on 10^6–10^7 yrs timescale, conducted across the southern part of the NE Japan arc, the fore-arc, the Ou Backbone range and the back-arc side. To estimate accurate thermal histories at each region, apatite fission-track (AFT) method was performed in south part of NE Japan where Sueoka et al. (2016) obtained apatite and zircon (U–Th)/He (respectively, AHe, ZHe) ages.
AFT ages were estimated at 79.5–66.0 Ma on the fore-arc side, 29.8–5.5 Ma in the Ou Backbone range, and 21.0–17.6 Ma on the back-arc side, respectively. These AFT ages were generally consistent with the previous FT ages and He ages. On the basis of the thermal inverse analysis results, the onsets of the last cooling episodes were determined from ages of nick points of the time-temperature paths. The results were as below: slow cooling pattern since ca. 80–60 Ma on the fore-arc side, rapid cooling pattern since ca. 1 Ma in the Ou Backbone range, and rapid cooling pattern since ca. 6–5 Ma on the back-arc side.
The estimated thermal histories of each region were compared with previous tectonic/geologic information.
1) On the fore-arc side, the amount of denudation since 50 Ma was estimated at ca. 2 km, suggesting a tectonically stable setting over the Cenozoic. Therefore, the tectonics after the opening of the Sea of Japan have a slight influence on the fore-arc side. On the other hand, the uplift/denudation rates estimated by thermochronology (~0.04 mm/yr) and the other methods on 100 kyrs timescale (>0.1 mm/yr) have one order of discrepancy. However, this observation can be explained if the denudation rate increased since the Pliocene or Quaternary.
2) The Ou Backbone range was supposed to be uplifted because of the E-W compression since ~6 Ma or the strong E-W compression since 3–2 Ma (Sato 1994; Nakajima 2013). At the center of the Ou Backbone range, younger AHe ages of 2–1 Ma and AFT ages of 6–5 Ma were obtained. In addition, the result of thermal inverse analysis indicates the rapid cooling since ca. 1 Ma, consistent with the onset of uplift and rapid cooling since 3–2 Ma. On the other hand, the AFT and ZHe ages older than ~30 Ma were obtained

at the margins of the Ou Backbone range. The interpretation of the older ages is difficult because the apparent ages may be partially reset by volcanic activities on late Cenozoic as well as burial and/or volcanism related to the opening of the Sea of Japan. Although these ages may be useful to reconstruct cooling/denudation histories of the NE Asian continental margin prior to ~30 Ma.
3) On the back-arc side, AHe ages of <~10 Ma are obtained, and a nick point of cooling paths obtained by thermal inverse analysis lies around ca. 6–5 Ma. Considering these results, the uplift on back-arc side may be started since at least ~10 Ma. AFT and ZHe ages around 30 Ma, however, may be influenced by the volcanic activities attributed to the Green tuff tectonics or subsiding by the transgression, similar to the Ou Backbone range. The interpretation of the older ages is difficult.

Keywords: thermochronology, (U-Th)/He method, Fission Track method, NE Japan Arc

Zircon U-Pb and (U-Th)/He dating to Omachi Tephra

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Omachi Tephra, one of the Pleistocene marker tephras in Japan, was dated by LA-ICP-MS U-Pb method using zircons. The dated tephras are A1Pm and DPm collected from an outcrop in Omachi City, Nagano Prefecture. At the outcrop, we observed 6 tephra layers: A1Pm, A2Pm, A3Pm, B Scoria, DPm, and EPm in ascending order. The dated tephras (A1Pm and DPm) were identified by measuring refractive indices of orthopyroxene and the stratigraphic order. The obtained U-Pb age of the A1Pm was 0.43±0.02 Ma (error shown as 95% confidence level), which is in accordance with the stratigraphy and some previously reported fission-track ages. On the contrary, the U-Pb age of the DPm was 0.28±0.05 Ma, which is much older than the stratigraphically estimated age of ˜0.1 Ma. Since zircon U-Pb age indicates the time of crystallization in the magma, it does not always show the time of tephra eruption. Meanwhile, zircon (U-Th)/He age indicates the time of tephra eruption. Zircon (U-Th)/He dating is now underway, therefore we will report both U-Pb and (U-Th)/He dating results at this session.

Keywords: Quaternary, tephra, U-Pb dating, (U-Th)/He dating

Temporal change in geochemistry of volcanic rocks in northern Kenya Rift: Insights from $^{40}Ar/^{39}Ar$ geochronology at Paka

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Kenya rift is known as one of the most tectonically active on shore rift due to the analysis of the morphology of the fresh Quaternary caldera volcanoes. In the northern Kenya rift, six volcanic centers locate, erupt basalts and trachytes and form the trachytic shield volcanoes.
One of those volcanic centers, Paka, was investigated by systematic $^{40}Ar/^{39}Ar$ dating of 32 latest fresh volcanics from lava flows and was found that the eruptive activities range continuously from 0.58 Ma to 0.012 Ma. Three relatively pronounced eruptive periods were found as around 0.4 Ma, 0.15 Ma and younger than 0.05 Ma by relative frequency of eruption events. The division of whole Paka eruptive events to three episodes of 0.6-0.35 Ma (I), 0.35-0.1 Ma (II) and 0.1-0 Ma (III) based on the pronounced periods clearly shows that the spatial change of eruptive locations gradually converge to NNE-SSW direction, which is similar to that of the Kenya Rift.
Combination of obtained ages with C.I.P.W. norm mineral calculation of all rocks brought the different figures of the volcanic history of Paka, previously deduced in the report of the geological survey of northern Kenya Rift by Dunkley et al. (1993). The volcanic activity started at 0.58 Ma by the eruption of the nepheline-normative basalt (Lower Basalt), meanwhile hyperthene-normative basalts erupted together with nepheline-normative basalts only in the period from 0.3 to 0.1 Ma, which is the intermediate period of the whole trachytic activities lasted since 0.43 Ma to 0.01 Ma (Fig.).
Dunkley et al. (1993) and our whole-rock geochemical data show that the hyperthene-normative basalts cover the surface more widely around Paka than the nepheline-normative basalts and that the nepheline-normative basalts distribute only at Paka. Additionally, Dunkley et al. (1993) suggested that Paka sits on the hyperthene-normative basaltic lava flows and also that the youngest hyperthene-normative basalts (Young Basalt) erupted as the upper units than Paka and distribute among volcanic centers of Paka, Silali and Korosi. However, the obtained ages did not support this age-model. Instead the hyperthene-normative basalts actually erupted only in the middle period during the formation of Paka and the oldest eruption at Paka was the nepheline-normative basalt.
Nevertheless, this new order of the eruptions could rather more easily be explained as the following simple model for a magma-plumbing system by the high-pressure experimental petrology; a single hot mantle-diapir uprised beneath Paka firstly separates smaller amounts of nepheline-normative basaltic magmas under higher pressures and causes their eruptions, then at the shallower depth separates more voluminous hyperthene-normative basaltic magmas by the higher degree of melting and causes their eruptions.
Furthermore, it is also observed that the incompatible elemental ratios of Nb/Zr in the rocks gradually decrease along the above three episodes. This is also consistent with the model of the single hot mantle-diapir beneath Paka and its repeated segregation of basaltic magmas, because the Nb/Zr ratios in those basaltic magmas separated by the fractional melting decrease due to the slightly higher partitioning coefficient of Zr against mantle minerals and are maintained in the differentiated trachytic magmas.
From these discussions, we conclude that the volcanic activities at Paka could rather simply be explained by the single mantle-diapir model. Although the flood basalts and trachytic shield volcanoes in northern Kenys Rift are often considered as the separate products, our results imply that those magmas could be derived from the identical magma plumbing system and erupt as the products from the identical volcano

in some cases. We also propose the new volcanic stratigraphy at Paka by our $^{40}A/^{39}Ar$ ages.

Reference: Dunkley P. M., M. Smith, D. J. Allen and W. G. Darling (1993): International Series, Research Report SC/93/1, 185pp, British Geological Survey

Keywords: Kenya Rift, Ar/Ar dating, Quaternary volcano, basalt, trachyte, whole-rock chemistry

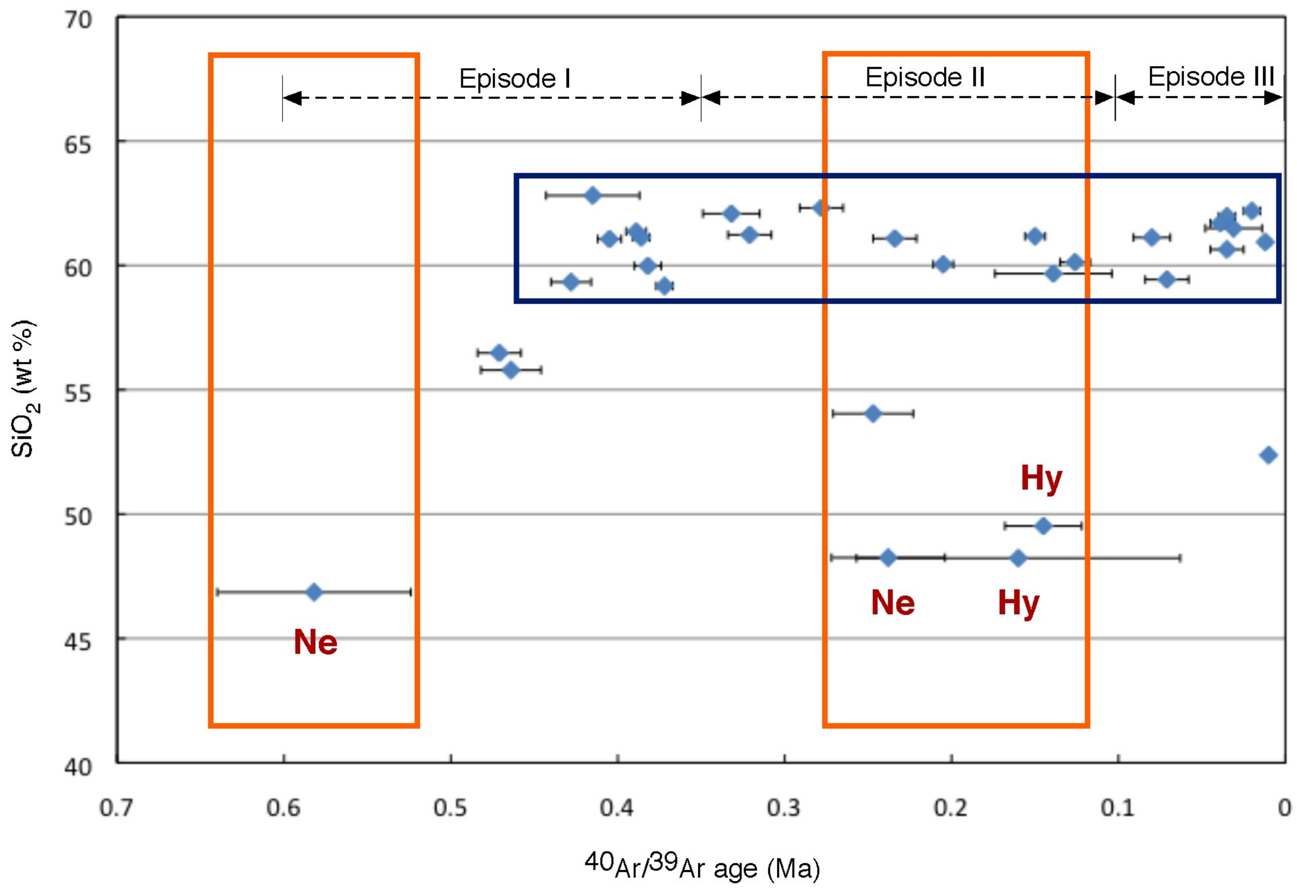

Fig. Plot of SiO_2 contents against $^{40}Ar/^{39}Ar$ ages of volcanic rocks from Paka. Ne; nepheline-normative basalts, Hy; hyperthene-normative basalts.

Unclosure Temperature and Relaxation Time

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A diffusion process in a sphere is analytically solved and, well described in a rigorous form. Dodson (1973) defined a closure temperature T_c as a narrow range of temperature where a radiogenic isotope production exceeds the amount of decease by the diffusion process because of its factor dependence on the Arrhenius relation. A step heating experiment used in $^{40}Ar/^{39}Ar$ dating is a reheating process, and diffusion parameters of various minerals have been obtained from the approximation in a simple analytical form in many diffusion studies. Viewing a cooling process as the reversed direction of a reheating process, a fractional loss of 20% is the minimum requirements to hold the original cooling age, which we named unclosure temperature T_{uc}. The other extreme limit (T_{dc}) is a fractional loss of 99% where diffusion exceeds the production rate of radiogenic isotopes. According to Dodson's definition, closure temperature Tc is analogous to the temperature just below Tdc. Using typical diffusion parameters obtained by previous experiments, T_c, T_{uc} and T_{dc} were compared. They are closer in small grain sizes, but the differences grow as grain sizes become large (>100 microns). The agreement is also depends on the cooling rate. The agreement of T_c is closer to T_{uc} rather than T_{dc}. The meaning of this results is discussed.

Keywords: diffusion, sphere, unclosre temperature

Nucleosynthetic isotope anomalies of trans-iron elements in meteorites: implication for the origin of terrestrial planets

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The chemical composition of the Earth has been a matter of debate for more than several decades. Classical models assumed that the bulk Earth had CI chondrite-like relative abundances for refractory elements. This view has been challenged by the discovery of nucleosynthetic isotope anomalies in bulk aliquots of meteorites; a series of studies on high precision isotope analysis of meteorites concluded that carbonaceous chondrites (CCs) and ordinary chondrites (OCs) have stable isotope compositions resolvable from those of the Earth for a variety of lithophile and siderophile elements (e.g., Ti, Cr, Mo, Ru) [1-3]. By contrast, enstatite chondrites (ECs) have stable isotopic compositions similar to those of the Earth for the same elements. Such observations suggest that a large fraction of the building blocks of the Earth is composed of enstatite chondrite-like materials rather than the other chondrites including CI [4].

Our recent high precision isotope analyses on chondritic and non-chondritic (NC) meteorites for some trans-iron elements (e.g., Sr, Mo, Nd) support this interpretation [5-7]. In the most cases, the extent of isotope anomaly is in the order of Earth ˜ NC ˜ EC < OC < CC, which generally corresponds to the current location of meteorite parent bodies in the asteroid belt as a function of heliocentric distance [8]. This implies that stable isotopes of these elements were nearly homogeneously distributed in the feeding zone of the Earth where parent bodies of ECs and some NCs have formed, whereas distinct isotopic compositions for the same elements are observed in the outer asteroid belt where parent bodies of CCs are located. Unlike this observation, however, some refractory heavy elements (Hf, W, and Os) have uniform stable isotope compositions across all classes of meteorites [9-11], indicating that stable isotopes of these elements were homogeneously distributed from the Earth (1 AU) toward the outer part of the asteroid belt (˜ 5 AU).

The origin of heterogeneous/homogeneous distribution of stable isotopes for the above-mentioned elements within the inner solar system (< ˜5 AU) is poorly constrained. Two contrasting models have been proposed so far to account for the observed isotope variabilities in meteorites. The first model advocates that late injection of a nearby supernova sprinkled isotopically anomalous grains into the protoplanetary disk, followed by aerodynamic sorting of grains in different sizes that resulted in planetary scale isotope heterogeneities [12]. However, recent theoretical studies argue that ccSNe generate only low-mass r-nuclides (A< 130), which contradicts the observed isotope anomalies in Ba, Sm, and Nd. Alternatively, the second model postulates that nebular thermal processing caused selective volatilization of isotopically anomalous components from presolar grains, associated with physical separation of gas and remaining solid [1,13-14]. In this case, isotope anomalies can be observed for elements with intermediate 50% condensation temperature (˜1000 K < $T_{50\%}$ < ˜1600 K), because ultra-refractory and moderately volatile elements are preferentially distributed into the solid and gas phases during the heating event, respectively. Therefore, isotope anomalies in meteorites would be useful for tracking the thermal history of dust grains in the solar nebula, which ultimately provide important clues for understanding the origin of terrestrial planets.

References: [1] Trinquier, A. et al. (2009) *Science* **324**, 374. [2] Burkhardt, C. et al. (2011) *EPSL* **312**, 390.

[3] Fischer-Gödde, M. et al. (2015) *GCA* **168**, 151. [4] Dauphas, N., et al. (2014) *EPSL* **407**, 96. [5] Yokoyama, T. et al. (2015) *EPSL* **416**, 46. [6] Nagai, Y. and Yokoyama, T. (2016) *Goldschmidt conf.* [7] Fukai, R. and Yokoyama, T. (2016) *Goldschmidt conf.* [8] DeMeo, F.E. and Carry, B. (2014). *Nature* **505**, 629. [9] Sprung, P. et al. (2010). *EPSL* **295**, 1. [10] Kleine, T.et al. (2004). *GCA* **68**, 2935. [11] Yokoyama, T. et al. (2010) *EPSL* **291**, 48. [12] Dauphas, N. et al. (2010) *ApJ* **720**, 1577. [13] Burkhardt, C. et al. (2012) *EPSL* **357-358**, 298. [14] Yokoyama, T. and Walker, R.J. (2016) *RiMG* **81**, 107.

Keywords: Nucleosynthetic isotope anomaly, Meteorites, Asteroid belt

Strontium and Hydrogen Isotopes of Apatite Inclusion in Archaean Zircon

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Geochemical records of Archaean era are significantly sparse because they were possibly altered by later metamorphic activities. For example, isotopic composition of carbon in graphite included in apatite from the 3.83 Ga Akilia sedimentary rocks suggested that it has a biogenic origin. However SHRIMP U-Pb dating of the apatite showed younger age of 1.5 Ga and indicated a metamorphic event of 600 C, which may have altered the carbon isotopes. Zircon is the best candidate because it is resistant against heat and corrosion and ubiquitous in the Earth's crust. It is also the "perfect" mineral for U-Pb dating because it contains enough amount of U and excludes Pb from the lattice when it formed. We performed U-Pb dating of zircons from Eoarchaean rocks using NanoSIMS. Then we selected zircons with apatite inclusions and conducted *in situ* isotopic analysis of strontium and hydrogen of the apatite with NanoSIMS.

We collected samples from the tonalitic unit of the Nuvvuagittuq Supracrustal belt in Quebec, Canada. Extracted zircon grains from the tonalite were mounted in epoxy resin disk together with QGNG standard and polished until the mid-section was exposed. Both ^{238}U-^{206}Pb and ^{207}Pb-^{206}Pb dating was conducted by a conventional method using the NanoSIMS. For $^{87}Sr/^{86}Sr$ measurements of apatite, we focused the primary beam of 0.5 nA to 5-micron diameter. Observed data were calibrated against our standard. For D/H measurements, Cs^{+} ion was used as a primary beam with intensity of 200pA and a crater size of 1-micron diameter. Primary beam was rastered in a region of 10x10-micron and secondary ions from the inner part of 2.5x2.5-micron were detected.Observed D/H ratios were calibrated against our standard apatite.

Average of U-Pb and Pb-Pb ages of zircon samples are 3537+/-76 Ma and 3624+/-7 Ma, respectively, showing slightly discordant signature. For apatite inclusions in zircon, $^{87}Sr/^{86}Sr$ ratios vary from 0.7095 to 0.7153. There is a positive correlation between $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios, suggesting either an isochron or two component mixing. D/H ratios and water contents of apatite are ranging from -210permil to 65permil and 0.15% to 1.32%, respectively. There is a positive correlation between the ratio and content, suggesting a mixing trend.

Keywords: Archaean, Strontium isotopes, Hydrogen isotopes, U-Pb dating, NanoSIMS

Uranium-Lead dating of Zagami and RBT04261 phosphates by NanoSIMS

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[1] Introduction

Martian meteorites are only samples of Mars that can be measured directly on the Earth. Zagami and RBT 04261 are classified into basaltic and lherzolitic shergottite, respectively. Although chronological information of shergottites, especially, their crystallization ages are important for constraining the geological history of Mars, there are controversial debates about its geological ages [1][2].

The uranium-lead dating has been used for Martian meteorites because the uranium has a long half-life and two decay series. The ^{238}U-^{206}Pb age of Zagami was 230±5 Ma using TIMS instrument [3]. A recent study reported the ^{238}U-^{206}Pb age of Zagami phosphates as 153±81 Ma using IMS-1280 instrument [4]. On the other hand, the ^{207}Pb-^{206}Pb age of Zagami obtained by mineral separation using MC-ICP-MS instrument gave an ancient age of 4048±17 Ma [2]. It is not settled that the old age shows crystallization or mixing with the Martian surface or terrestrial lead.

For RBT 04261, ^{238}U-^{206}Pb age of baddeleyite grains was reported as 235±37 Ma using SHRIMP instrument [5].

In this study, we conducted uranium-lead dating, lead-lead dating of phosphate minerals in Zagami and RBT 04261 using NanoSIMS instrument installed in Atmosphere and Ocean Research Institute, The University of Tokyo. We also calculated “U-Pb 3D age” from the two chronologies in order to obtain crystallization ages of the meteorites.

[2] Analytical Methods

Polished thick sections of Zagami and RBT 04261 are used in this study. The RBT 04261 section was allocated from NASA-JSC. The sections were firstly observed using SEM-EDS (S-4500) installed in Department of Earth and Planetary Physics and EPMA (JXA-8900) in Atmosphere and Ocean Research Institute. Merrillite [$Ca_9NaMg(PO_4)_7$] grains were identified in the both sample.

The U-Pb dating was conducted using NanoSIMS 50 at Atmosphere and Ocean Research Institute, The University of Tokyo. After ^{238}U-^{206}Pb dating, the ^{207}Pb–^{206}Pb age was determined on the same spots.

[3] Results

The uranium-lead ages are determined as 164±240 Ma for Zagami, and 261±72 Ma for RBT 04261, respectively. All errors are 2-sigma.

The lead-lead ages have large errors and no meaningful ages were obtained.

The 3D ages of the two meteorites were obtained as 245±80 Ma for Zagami and 248±41 Ma for RBT 04261.

The initial lead isotopic ratio (hereafter called common lead) of Zagami was calculated as $^{206}Pb/^{204}Pb$ =14.46±0.82 and $^{207}Pb/^{204}Pb$ =15.45±0.65. The common lead of RBT 04261 was estimated as $^{206}Pb/^{204}Pb$ =10.1±2.2 and $^{207}Pb/^{204}Pb$ =12.7±1.1.

Concordant ages were obtained for both meteorites, indicating that U-Pb system in the phosphates was not disturbed by secondary metamorphism. We claim that the approx. 250 Ma ages show the crystallization of these meteorites.

[4] Discussion

Since the two meteorites differ in common lead, it is possible that they crystallized from either different magma source at the same time or single magma with different common lead. Therefore, we consider that (1) there were a few magmas with different common lead formed in 250 Ma and the two meteorites crystallized independently, or that (2) although Zagami and RBT 04261 crystallized in the same magma in 250 Ma, evolved common lead of Martian surface was mixed into Zagami in the shallow part of Mars, while RBT 04261 keeps primitive common lead in deep. Further discussion is needed about these hypotheses in combination with the information of other radiometric ages or trace elements in the meteorites.

[5] References

[1] Nyquist et al. (2001) SS. 96, 105-164. [2] Bouvier et al. (2005) EPSL. 240, 221-233. [3] Chen and Wasserburg (1986) GCA. 50, 955-968. [4] Zhou et al. (2013) EPSL. 374, 156–163. [5] Niihara T. (2011) JGR. 116, E12008.

Keywords: Martian meteorite, Chronology, Zagami, RBT04261, NanoSIMS, Phosphate

Refining the Geomagnetic Polarity Timescale: High-precision U-Pb geochronology from Late Cretaceous of US Western Interior and NE China

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An accurate and precise reconstruction of the Earth history is essential to resolving the mode and tempo of biotic evolution and its interrelationship to environmental change in deep time. However, this goal cannot be accomplished without high-fidelity intercalibrations of various geochronometers that are used to scale geologic time. Abrupt reversals in the Earth’ s magnetic polarity form the basis of the Geomagnetic Polarity Timescale (GPTS) and serve as ideal timelines for stratigraphic correlation, especially in depositional environments where diagnostic marine fossils are absent. The Neogene part of the GPTS has been calibrated using astrochronological models that are based on orbital forcing of climate manifested in cyclic sedimentary successions. The application of these approaches to the pre-Neogene timescale has nonetheless been complicated given the uncertainties of orbital models and the chaotic behavior of the solar system farther back in time. Absolute calibration of the GPTS can be achieved at high resolution by radioisotopic dating of volcanic ash deposits intercalated with stratigraphically complete successions with well-preserved magnetostratigraphic records.

The Late Cretaceous to Paleocene segment of the GPTS is of particular interest as it encompasses a critical period of Earth history marked by the Cretaceous greenhouse climate, the peak of dinosaur diversity, the end-Cretaceous mass extinction and its paleoecological aftermaths. Here we present a refined calibration of the GPTS based on high-precision U-Pb geochronology of ash beds within predominantly continental strata of the Western Interior Basin of North America and the Songliao Basin of Northeast China. Results from the Songliao Basin (end-C34), Bighorn Basin of Wyoming (end-C32) and Denver Basin of Colorado (C29 to C28) place tight constraints on the Late Cretaceous –Paleocene GPTS, by either directly constraining the chron boundaries and/or by testing their underpinning astrochronological age models. Our new GPTS calibration displays good consistency with those from the most recent astrochronology- and radioisotope-based studies of other coeval continental and marine records. Together, they demonstrate the power of a multi-chronometer approach to the calibration of the Earth history.

Keywords: U-Pb geochronology, Geomagnetic Polarity Timescale, Cretaceous, Western Interior Basin, Songliao Basin

Short-lived U- and Th-series isotopes: Tracers and chronometers of Earth surface processes though Anthropocene to global change time frame

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A large array of short-lived natural U and Th-series isotopes are useful tools for the documenting of on-going geochemical and sedimentological processes as well as for the calculation of geochemical fluxes between reservoirs (e.g., ^{226}Ra, ^{210}Pb, ^{210}Po, ^{228}Ra, ^{228}Th, ^{234}Th, with time scales ranging from ˜ 10^3 to ˜10-1 years). In combination with nuclear fallout isotopes (e.g.,^{137}Cs, ^{241}Pu...), they may be used for estimating the behavior and fluxes of aerosols, soil evolution and weathering processes (across all time scales above), particulate and colloidal transport in continental and marine waters, as well as for the documenting of extreme events (floods, storminess, etc.) and more generally, the fate of sediments in rivers, lakes and the marine realm (from accumulation rates to on-going sedimentological processes). Applications in the domains of hydrothermal systems and of volcanology are also of importance. Examples illustrating the use of a few of the above isotopes for the documenting of Earth surface processes from the Anthropocene (sensu lato) through the present global change frame, will be discussed, with a focus on short-lived isotopes of the U and Th-series. They include (i) downscaling through time-dependent processes in carbonate-rich Mediterranean soils, (ii) the monitoring of geochemical properties of recent basaltic lava flows (Hawaii & Bali), (iii) evolution of hydrothermal systems (Denizli area, Anatolia) (iv) the recording of extreme events in estuarine and costal areas from the Sinaloa coast (Mexico)

Keywords: U-series, short lived isotopes

Uplift and denudation history of mountains and low-temperature thermochronology

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Thermochronology is a branch of geochronology, which can reconstruct thermal history of rock samples because the apparent ages get younger than the formation ages depending on the thermal history. By applying thermochronology to rocks formed in a high-temperature zone at a great depth, regional denudation history can be estimated. Low-temperature thermochronology, e.g., fission-track and (U-Th)/He dating methods, are especially useful to constrain denudation history at the upper crust shallower than several kilometers from the surface. Low-temperature thermochronology has been applied to various tectonic settings all over the world, such as continental collision zones, passive margins, shields, sedimentary basins, continental arcs, and island arcs (see also compilation of Herman et al., 2013, Nature) since the first application in the Swiss Alps (Wagner et al., 1977, Mem. Instit. Geol. Mn. Univ. Padova). Although low-temperature thermochronology is now amongst the most common approaches in tectonic geomorphological and structural geological studies, interpretations of thermochronometric data are often confusing especially for beginners and laypeople; for a successful interpretation, cooling, denudation, and uplift should be taken into accounts as well as geochronological and analytical discussions. This presentation primary aims to expand understanding of thermochronology to wider people, especially to beginners and laypeople. I will review the basic concepts and fundamental terminology in terms of thermochronometric applications to mountaneous regions. In addition, I am planning to introduce some case studies and thermochronometric mapping in the Japanese Islands.

Keywords: uplift, denudation, low-temperature thermochronology

Cooling history of the Higher Himalayan Crystalline nappe and underlying the Lesser Himalayan Sediments in eastern Nepal revealed by fission-track dating of detrital zircons.

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Fission-track (FT) dating of detrital zircon has been applied to the Higher Himalayan Crystalline nappe and the underlying Lesser Himalayan sediments (LHS) distributed along a 120 km long section from Mt. Everest to the Main Boundary Thrust (MBT) in eastern Nepal. In this paper, we report the results of 70 km long southern section between the Main Central Thrust (MCT) and the MBT. We collected rock samples from the Higher Himalayan Crystalline nappe of eastern continuation of the Kathmandu nappe and underlying autochthonous middle Proterozoic sequence of the LHS. Zircon FT ages show younging toward the north from 12.1 Ma just behind the MBT to 3.0 Ma just below the MCT in the root zone at southern slope of the Everest massif. It suggests that the LHS was covered by hot crystalline nappe comprising of metamorphic rocks, and fission-tracks of the detrital zircons have been annealing since 12 Ma. On the basis of retreating rate of isotherm line of closure temperature of ZFT, we estimated average cooling rate of the nappe and underlying LHS as about 7 mm/y, which is as same as 8-7mm/y, reported from the Katmandu nappe in central Nepal (Hirabayashi, MS, 2017). If we applied this rate to the HHS to the north of the MCT in the Everest massif, the location of ZFT age of 0 Ma would be located at 23 km to the north of the MCT, beneath Mt. Kantega (6685 m). It suggests that the underground of Mt. Everest is even now under hot condition higher than 220-350℃ Thus, heat source of hot HHC is ascribed to partially melted middle crust of Tibet, which southern front is located at about 100 km to the north of Himalayan giants.

Keywords: fission-Track age, Himalaya, nappe, zircon

Influence of surface condition on data quality of U-Pb zircon geochronology: an example from AS3 zircon, the Duluth Complex, U.S.A.

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U–Pb zircon geochronology by using microbeam analysis such as SIMS and LA–ICP–MS has played a pivotal role in geochronology because one of the advantages of microbeam analysis in U–Pb geochronology is to select the appropriate analytical spot for U–Pb dating. Many analysts empirically believe that accuracy and precision of microbeam analysis strongly depend on the surface condition of analytical spots. Especially, existence of fractures within the analytical spots is considered to decrease the data quality, but there is no quantitative evidence that the fractures result in some negative effect on the data quality. In this study, we quantitatively discuss influence on the data quality from the surface condition of the analytical spots. AS3 zircons collected from gabbroic anorthosites of the Duluth Complex, Minnesota, U.S.A., were used in this study. Previous work reported that some grains in AS3 zircons yield discordant data due to Pb loss caused by thermal diffusion (Schmitz et al., 2003).

Observation of thin sections by optical microscope and electron microprobe reveals chloritization of amphibole in AS3, which suggests hydrothermal alteration. U–Pb analyses of some AS3 zircon grains yielded discordant data. The analytical spots that yield discordant data can be classified into (1) altered domains characterized by high contents of LREE and non-formula elements, such as Ca, Al, and Fe, and (2) domains containing undersurface fractures. In the case that analytical depth is close to the undersurface fractures, the second domains also show high LREE contents. When the fractures in zircon worked as channels of hydrothermal fluid (Carson et al., 2002), there are possibilities that areas around the fractures was altered like a clad by the fluid. Therefore, selection of the analytical spots for U–Pb zircon dating should be based on observation of fractures not only on the surface but also under the surface. When AS3 zircon is used as U–Pb reference material, it is important to carefully choose analytical spots on the basis of the backscattered electron and optical microscope images for achieving more precise analysis.

Reference

Schmitz, M.D., Bowring, S.A., & Ireland, T.R. (2003) *Geochimica et Cosmochimica Acta* **67**, 3665-3672.
Carson, C.J., Ague, J.J., Grove, M., Coath, C.D., & Harrison, T.M. (2002) *Earth and Planetary Science Letters* **199**, 287-310.

Preliminary report of zircon oxygen isotope record in western part of the Napier Complex, East Antarctica

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The oxygen isotopic composition of zircon is a powerful tool to characterize parental magma, complementing trace element data. Recently technical improvements of a secondary ion mass-spectrometer allow us to obtain highly accurate and precise oxygen isotope data of zircon from thin sections or grain resin mounts. Numerous studies show that non-metamicted zircons can preserve their oxygen isotopic ratios ($\delta^{18}O$) from the time of crystallization, even though high-grade metamorphism and anatexis. The zircon oxygen isotope record is generally preserved despite other minerals that have been disturbed by high-grade metamorphism or intense hydrothermal alteration due to slower diffusion rate.
The Napier Complex in East Antarctica has attracted considerable interest from a viewpoint of long Archaean crustal history from 3800 Ma to 2500 Ma and >1000℃ ultrahigh-temperature (UHT) metamorphism in a regional scale. There are many petrological, geochronological, and geochemical reports, but the zircon oxygen isotope data completely lack. In this study, we tried to analyze the zircon oxygen isotopes in garnet-bearing quartzo-feldspathic gneiss (YH05021606A) collected from Fyfe Hills in the Napier Complex.
The quartzo-feldspathic gneiss, YH05021606A, was collected by Y.H. during the field work at the 2004-2005 Japanese Antarctic Research Expedition. The zircon U-Pb ages of the YH05021606A sample are already reported in Horie et al. (2012) and shows multiple age peaks centered at ca. 3025, 2943, 2883, 2818, 2759, 2674, 2518, and 2437 Ma. Horie et al. (2013) picked zircon grains afresh and analyzed U–Pb ages, Th/U ratios, and rare earth elements (REE) compositions. The oxygen isotope analyses were performed on same resin disc as Horie et al. (2013). The zircon oxygen isotope analyses were carried out by a sensitive high-resolution ion microprobe (SHRIMP II) with the 5-head advanced multi-collector (AMC) at the National Institute of Polar Research, Japan. ^{16}O, ^{17}O, and ^{18}O were detected by the Faraday cups at low mass (LM), Axial, and high mass (HM), respectively, and were measured on 10^{11} ohm resistors in current mode. The surface of the grain mounts was coated by aluminum prior to the analysis.
The U-Pb analysis of zircon yielded similar age population to Horie et al. (2012) and revealed younger ages of ca. 2273, 2195, 2106, and 1980 Ma. C1-chondrite-normalized REE abundance patterns of the YH05021606A zircons were characterized by a large fractionation between light REE (LREE: La, Pr, and Nd) and heavy REE (HREE: Tm, Yb, and Lu), positive Ce anomalies, and negative Eu anomalies. The inherited zircons shows highly fractionated patterns between LREE and HREE. The zircons of ca. 2505 Ma and ca. 2490 Ma are characterized by weakly fractionation between middle REE (MREE: Gd, Tb, and Dy) and HREE. The HREE of ca. 2490 Ma zircons are more depleted than those of ca. 2505 Ma zircons, which indicates that growth of garnet had continued from ca. 2505 Ma to ca. 2490 Ma. The REE patterns of the younger age zircons are characterized by a large fractionation between MREE and HREE. Although the YH05021606A zircons have various U-Pb ages and trace element composition, the oxygen isotope analyses yielded homogeneous $\delta^{18}O$ ratios among zircon grains with various ages (5.68 ±0.30 ‰). The $\delta^{18}O$ values of the YH05021606A zircons are consistent with those of zircon in equilibrium with the mantle (5.3 ±0.6 ‰: Valley et al., 1994). In this presentation, the homogeneous $\delta^{18}O$ ratios in the Fyfe Hills zircons will be discussed. ℃

Keywords: zircon oxygen isotope, SHRIMP, Napier Complex

Precise determination of $\delta^{137/134}$Ba stable isotope ratios by double-spike thermal ionization mass spectrometry

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Barium has seven stable isotopes: ^{130}Ba, ^{132}Ba, ^{134}Ba, ^{135}Ba, ^{136}Ba, ^{137}Ba, and ^{138}Ba. Recent researches focus on seawater, igneous rocks, carbonates, sulfates, and soil-plant systems using the Ba isotope fractionation. Barium is a large ion lithophile element and is usually incompatible in the mantle minerals. Barium is mobile in aqueous fluids and thus an important tracer of water recycling in the Earth's mantle. Miyazaki et al. (2014) first applied stable Ba isotope ratios to igneous rocks using double-spike Multiple Collector-Inductively Coupled Plasma-Mass Spectrometry (MC-ICP-MS) and observed significant difference in $\delta^{137/134}$Ba between JB-2 (slab fluid influenced) and JA-2 (slab or crustal melt influenced). They found that the ratio of BHVO-2 (oceanic island basalt) was between JB-2 and JA-2 and could not distinguish it either from JB-2 or JA-2 because of overlapping analytical errors. Although their analytical repeatability was far better than the previous reports, development of a more precise analytical method is required to apply stable Ba isotopes to igneous processes.
The double-spike method is effective for Ba isotope analyses either in thermal ionization mass spectrometry (TIMS) or MC-ICP-MS. However, isobaric interferences of Xe in Ba isotopes prevent further higher precision analyses due to instability of Xe blanks in the matrix plasma support Ar gas in MC-ICP-MS. We here report development of a high-precision Ba isotope measurement using double-spike TIMS. We modified double spike TIMS method developed for Pb isotopes by Miyazaki et al. (2009). Longer baseline measurement preformed before and after sample measurement is the key technique. This avoids unnecessary sample waste during baseline measurements within sample runs. Use of double Re-filaments and exponential law mass fractionation correction were combined to improve repeatability of $\delta^{137/134}$Ba. The measured repeatability of the Ba standard solution SRM3104a was $\delta^{137/134}$Ba = ± 0.023‰ (2SD, n = 26), 1.4 times better than that achieved by MC-ICP-MS. The SRM3104a normalized $\delta^{137/134}$Ba value of IAEA-CO-9 was 0.013 ±0.029‰ (2SD, n = 24) which is identical with the reported values 0.017 ±0.049‰ (Nan et al., 2015) and 0.014 ±0.046‰ (van Zuilen et al., 2016). Analyses of geological rock standard samples are ongoing and the results will be reported in the talk.

Miyazaki, T., Kanazawa, N., Takahashi, T., Hirahara, Y., Vaglarov, B.S., Chang, Q., Kimura, J.-I, Tatsumi, Y., 2009. JAMSTEC Report of Research and Development, Special Issue, 73-80
Miyazaki, T., Kimura, J.-I., Chang, Q., 2014. Journal of Analytical Atomic Spectrometry, 29, 483-490.
Nan, X., Wu, F., Zhang, Z., Hou, Z., Huang, F., Yu, H., 2015. Journal of Analytical Atomic Spectrometry, 30, 2307-2315.
van Zuilen, K., Nägler, T.F., Bullen, T.D., 2016. Geostandards and Geoanalytical Research, 40, 543-558.

Keywords: Stable Ba isotope, Thermal ionization mass spectrometry, Double spike

The paleo environmental research in southern part of Mongolia by lake sediment analysis

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Lake Boontsagaan, Orog and Olgoy are located in the Valley of the Lakes, Gobi-Altai transition zone, which stretches from central to western Mongolia. The surface area of the lake is 252 km^2 for Boontsagaan, 140 km^2 for Orog lake and 1,79 km^2 for Olgoy lake. The sediment cores were collected from these three lakes in 2014-2016. The sedimentary features (e.g., water content, grain density, grain size, chemical composition) and ages (RI measurenment) were analyzed and correlated to meteorological data of the area (annual temperature, precipitation and wind 1975-2015, Bayankhongor station).

The mean annual temperature was 1.5˚C, mean precipitation is 205 mm and average daily temperatures reached to 15–20˚C (www.ogimet.com/gsodc.phtml).

Totally 6 sediment cores were collected from these three lakes in different locations by Sateke plastic corer and were sliced into 1.0cm intervals from the top. The content of water was measured directly by drying a given amount of the sediment at 105˚C (Lambe and Whitman, 1969; Dringman, 2002). Samples of 50 mg were dried at 77˚C for 24 hours and were then treated by 10% hydrogen pyroxides (H_2O_2) for 24 hours to estimate organic matter concentration. Calcium carbonate in the sediment was dissolved by 1-N hydrochloric acid and concentration was calculated. Analysis of the biogenic silica content follows the method described in Mortlock and Froelich (1989). Grain size was measured for whole sediment and mineral fraction with SALD2200 laser diffraction particle size analyzer. The chronology of sediments was established by ^{210}Pb measurement. We collected outcrop sediment and analyzed by OSL dating method. These outcrops consist of paleo lake deposit and are indicative of high lake water level.

From the result of the unsupported ^{210}Pb, sedimentation rate of Olgoy lake was about 0.5 cm per year for last 40 years. Sedimentation was faster before that. Physical and chemical properties of sediments are compared to meteorological data to interpreted the effect by the local climate change. OSL ages indicate the time when water level was high.

Keywords: lakes, sediment feature, climate data

