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Isotopic Composition of Lu, Hf and Yb in GJ-01, 91500 and Mud Tank Reference Materials Measured by LA-ICP-MS: Application of the Lu-Hf Geochronology in Zircon

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Abstract

The Lu-Hf method has been used in the investigation of geological samples in order to understand processes and sources of magmatic rocks. This paper discusses the reference materials GJ-01, 91.500 and Mud Tank isotopic composition by LA-ICP-MS to investigate how suitable they are for the zircon analysis through this technique. The results show that the three zircons have homogeneous compositions for the proposed objectives. Considering that relatively high Yb contents produce isobaric interference, the results of this work have shown that the Mud Tank is the best reference material, since it has lower values of this element. Thus, the Mud Tank allows to obtain more reliable results due to lower correction requirements. In addition, it should be emphasized that the presented data corroborate the application of Hf isotopes for geological evolution and characterization of magmatic sources. The high abundances of Hf in the zircon grains allow to preserve the isotopic signatures of its crystallization from magmatic sources, allowing to characterize the isotopic signatures of the reservoir (s) that gave origin to that rocks, and in case studies of paleoclimate and paleoceanographic records and/or of sedimentary basins evolution, it allows to identify the origin of the sediments or temporal and spatial changes of the source of sedimentary particles.

Keywords: Lu-Hf Isotope Method. Isobaric Interference. High Spatial Resolution Analysis. Zircon. Georeference Materials Calibration. Analytical Research.

1. Introduction

Since the 80's, numerous investigations were carried out aiming to demonstrate that the combined use of different isotope systems can be very useful in the study of sediments provenance or their metamorphic counterparts (Gerdes and Zeh, 2006). The Sm-Nd isotope system has been applied in many studies aiming to characterize the ultimate protolith or source area of sedimentary successions, e.g. by estimating the temporal variations of average crustal residence ages (TDM) or εNd values (O'Nions et al., 1983; Rousseau and Allègre, 1983; Davis et al., 1985; Thorogood, 1990; Nance et al., 1991). However, this method only allows a rough characterization of the sedimentary materials provenance, and frequently the results leads to inconsistent interpretations (Arndt and Goldstein, 1987). However, the age spectrum of populations of detrital zircon grains can provide a robust information about the sediment provenance, since the data can indicate the timing of magmatic and metamorphic events in the source areas, allowing to perform detailed palaeogeographic reconstructions and interpretations of

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whole rock isotope signatures such as εNd and εHf (Claesson, 1987; Ross and Parrish, 1991; Corfu and Sage, 1992; Gerdes and Zeh, 2006).

The geochronological methods U-Pb and Lu-Hf in LA-ICP-MS should be consigned to the relative simplicity, sensitivity and speed of analysis. When used together, they represent a robust tool where the model ages can subsidize important inferences about the analyzed rocks, not only regarding the age of mantle extraction, but also about its possible evolutionary history, provenance and related studies. These methods have been used together because the former provides the crystallization age and the second one provides the crustal age of residence. They are also faster and with lower cost than Sm-Nd geochronological method. Zircon can be used for the application of both isotopic methods, it is a common accessory mineral, present in a great variety of rocks, and for this reason it can be used in several geological studies.

The Lu-Hf isotopic system is one of the most innovative and powerful tools in zircon geochronology (e.g. Griffin et al., 2000, 2002; Woodhead et al., 2004; Gerdes and Zeh, 2006, 2009; Hawkesworth and Kemp, 2006; Zeh et al., 2007). It has been widely used for understanding crustal evolution and mantle/crust differentiation.

The Lu-Hf method was initially identified by Herr et al. (1958), using Gadolinite, with high concentration of Lutetium and Hafnium. Lutetium comprises the ^{175}Lu and ^{176}Lu isotopes, with abundances of 97.4% and 2.6%, respectively. The ^{176}Lu decays to ^{176}Hf and to ^{176}Yb, being the ytterbium in quantity that can be neglected for calculations. Hafnium comprises the isotopes ^{174}Hf, ^{176}Hf, ^{177}Hf, ^{178}Hf, ^{179}Hf and ^{180}Hf. The decay of ^{176}Lu to ^{176}Hf presents $\lambda = 1.867 \pm 0.07 \times 10^{-11}$ and half-life of 3.71×10^{11} years (Scherer et al., 2001; Faure, 2005).

The Lu-Hf technique is applied to zircon grains because this mineral has high Hf concentration, due to its substitution by Zr, and to preserve the initial ratios of Hf. The blocking temperature of the Hf in the zircon is about 200 °C higher than the Pb (approximately 1,100 °C), indicating that the Hf isotopic system is closed during almost all thermal events, such as high-grade metamorphism, maintaining the isotopic ratios present in the zircon crystallization (Duchene et al., 1997; Choi et al., 2006; Schmidt et al., 2008). The models of Hf isotopic evolution have been proposed based on the hypothesis of the use of the Hafnium as a marker of the geochemical differentiation between mantle and crust (Patchett et al., 1981; Amelin et al.,1999; Vervoort and Blichert-Toft, 1999; Hawkesworth and Kemp, 2006). In this sense, interpretations of ε_{Hf} values are similar to that of ε_{Nd} values being able to indicate mantle-derived rocks or rocks originating from crustal magmas (if the values are positive or negative, respectively).

The current Lu-Hf analytical procedure had an important contribution of Patchett and Tatsumoto (1980) and allowed the purification and better ionization of these elements with the consequent dating routine in several isotopic laboratories in the world. An important aspect for the successful application of this method was the development of laser ablation isotope analyzes coupled to mass spectrometers with multicollectors, eliminating the need to use the isotope dilution technique and avoiding the purification problems of these elements and the consequent interferences of other elements in the detectors. LA-ICP-MS analyses also avoid problems to reach the ionization temperature in the thermal ionization mass spectrometers.

In situ analyzes of Hf isotopes using laser ablation allows rapid analyzes on a large number of zircon crystals with a reasonable accuracy of ± 1-1.5 ε_{Hf} (Griffin et al., 2006). In comparison to solution analyzes this accuracy is in the range of ± 0.5 ε_{Hf} (2 S.D.). The better precision using solution in relation to laser ablation is compensated by the speed and ability of the method to combine measurements of isotopes of U-Pb and Hf *in-situ* in zircon, and it is possible to perform small size analyzes in different areas of zircon growth, thus offering different information in high spatial resolution.

The implementation of Lu-Hf methodology at the MultiLab laboratory facilities, Universidade do Estado do Rio de Janeiro (UERJ), represents an advance in geotectonic studies providing Lu-Hf analytical information related to the crustal evolution of complex terrains as an important tool to characterize the source of magmatic rocks, as stressed by Patchett and Tatsumoto (1980, 1981) and Tatsumoto et al. (1981) in the early application for crustal evolution and similarities with Sm-Nd method as reported by Schärer et al. (1997), Griffin et al. (2006) and Chauvel et al. (2014).

This work aims to establish and describe a Lu-Hf isotope procedure for high spatial resolution analysis of zircon reference materials using LA-ICP-MS. The proposed method emphasizes the optimization of Yb isobaric interference and performs the correction and quantification of the analyzed georeference materials calibration: GJ-01, Mud Tank and 91.500.

2. Materials and Methods

The Multilab laboratory of the Universidade do Estado do Rio de Janeiro (UERJ), presents in its infrastructure a multicollector Thermo (Neptune plus) coupled plasma induction mass spectrometer (ICP-MC-MS) and a laser ablation (Photon Machines, 193 mm). The Neptune plus is a state-of-the-art instrument equipped with nine Faraday collectors and six ion counters. The laser ablation has a high spatial precision camera and has the ability to emit high energy density through a laser beam with ArF and

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ablation the material in various sizes of craters (4 µm - 110 µm) with frequency rates varying from 3-10Hz and power ranging from 10 -100%. As a laboratory routine, the U-Pb zircon method was implanted using LA-ICP-MS as described by Geraldes et al. (2015) and Costa et al. (2017). From the results of U-Pb ages in zircon it was possible to develop and install the Lu-Hf method in zircon also using laser ablation. Initially, the Faraday detector configuration was chosen (Fig. 1), the laser conditions and the routine were defined with the corrections of isobaric interferers.

The collectors were positioned as follows (Table 1): in the central collector the mass ^{176}Hf, in the collectors H1 mass ^{177}Hf, H2 mass ^{178}Hf and H3 mass ^{179}Hf. In the collectors L1 the mass ^{175}Lu, L2 the mass ^{174}Hf, L3 the mass ^{173}Yb and in L4 the mass ^{171}Yb. The isobaric corrections were installed in the mass spectrometer software, so that the interferences ^{176}Lu and ^{176}Yb have their abundances obtained through the measurements of the masses ^{173}Yb and ^{175}Lu. Thus, the correction factors of 0.795015 and 0.026580, respectively, were used. The correction of the isotopic fractionation of the mass spectrometer is performed from the constant ratios ^{179}Hf/^{177}Hf (true value 0.7325) and ^{171}Yb/^{173}Yb (true value of 1.123456).

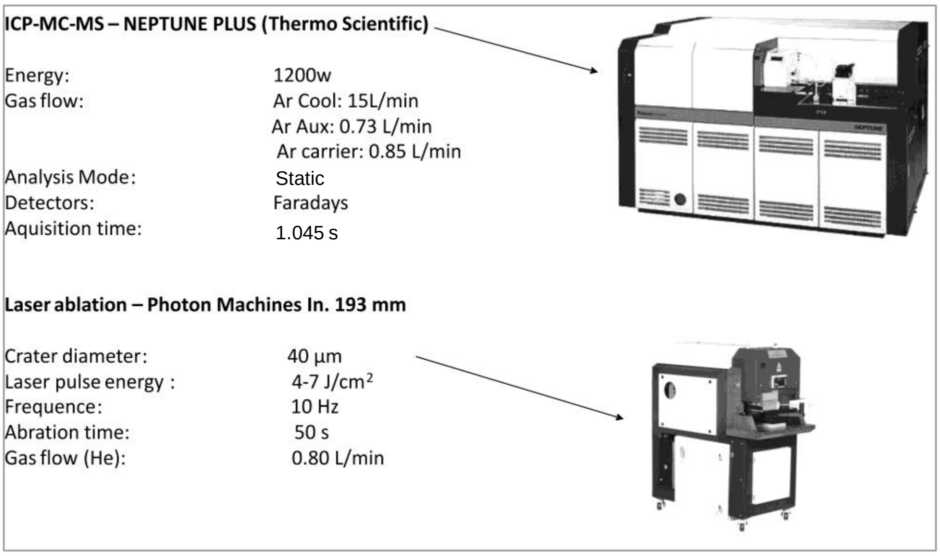

Fig. 1. Operating conditions of LA-ICP-MC-MS in the Lu-Hf method.

Tab. 1. Configuration of the Faraday collectors used for the Lu and Hf analyzes.

Faraday collectors	L4	L3	L2	L1	C	H1	H2	H3
Isotopes	^{171}Yb	^{173}Yb	^{174}Hf	^{175}Lu	^{176}Hf	^{177}Hf	^{178}Hf	^{179}Hf
Interferers			^{174}Yb		^{176}(Yb+Lu)			

A calibration procedure of faraday detectors (Table 1) was then performed using the reference material in solution (JMC475) through plasma settings and gas (Ar-He) flows. Isotopic data were obtained using the static mode through 50 cycles of 1.054 seconds acquirement time with a gas inlet flow (Ar) of 15 L / min, auxiliary flow (Ar) 0.8 L / min, transport gas flow 0.80 L / min (Ar) in MC-ICP-MS. The laser was connected and suitable He (two input streams with volumes of 0.580 l / m and 0.220 l / m, totaling 0.800 l / m). Repetition of the laser was at 10-8 Hz, with 5-6.5 J / cm^2 (60-35%) output power and 40 µm crater size.

2.1 Zircon grains preparation and treatment of data

The steps of preparation and mineral mounting were performed according to the flowchart of the Geological Laboratory of Preparation of Samples, LGPA-UERJ. The grains were mounted in epoxy (Fig. 2), followed by Scanning Electron Microscope (SEM) imaging (QUANTA 250). The Lu-Hf results were obtained at MultiLab using Neptune MC-ICP-MS in UERJ. The analytical procedures perform the reading of isotope abundance in zircon grains where material was removed from the grain surface by a laser ablation shot.

The analytical results obtained in mass spectrometry are saved in Neptune software files, with the abundance of each analyzed mass reported in volts. These results are transported to an off-line spreadsheet created in the Excel program especially for the treatment of Lu-Hf data. This spreadsheet is operated by the bracketing method where the analytical data of the unknown samples are corrected by blank and zircon reference material with Hf isotope ratios published in literature. In this sense, the GJ-01,

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91.500 and Mud Tank reference materials are analyzed (Fig. 2). Then 10 unknown samples, a second group of 91.500 and GJ-01 reference materials are analyzed, finishing a blank analysis (Fig. 3).

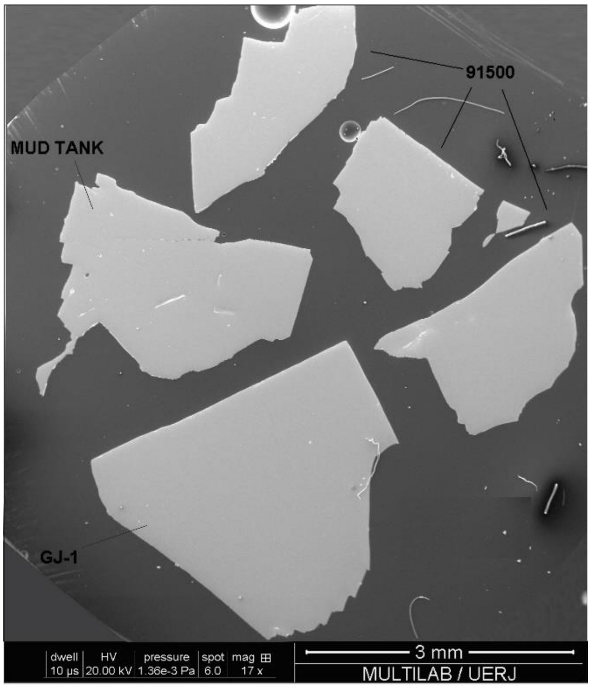

Fig. 2. SEM images of the reference materials used for calibration of the Lu-Hf method in LA-ICP-MS in the MultiLab laboratory.

This treatment allows the correction of isotopic fraction results of instability of the mass spectrometer. The final data comprise the model ages, the ε_{Hf} values and respective errors. The analytical results obtained with this treatment are transferred to a second Excel worksheet to plot the Hf isotopic evolution diagrams.

2.2 High spatial resolution analysis by laser ablation

Laser ablation is a successful application to improve spatial resolution in the analysis of solid samples for assessing isotopic abundances on the sub-mm scale. Alongside significant time savings laser ablation offers the additional advantage of reduced spectral interferences caused by oxide and hydroxide species. An additional challenge is correction for possible variations in ablation efficiency, which may be caused by a variety of parameters difficult to control including changing the position of the sampling area relative to the Ar flow during ablation and spatial inhomogeneities in the structure, density or color of the material under investigation.

The study of zircon morphology and textures provides important information about the geochemistry and crystal formation, and helps to better understand the results obtained in the geochronological analysis. Therefore, for the correct interpretation of Lu-Hf ages it is important to understand the dynamics of crystallization and recrystallization of zircon (Lenz, 2010).

Zircon can crystallize either by association with a fluid (magmatic or metamorphic) or in the solid state. However, some processes may modify zircon crystals, among them is the dissolution, recrystallization (in crystals with or without evidence of metamictization), re-precipitation and diffusion or loss of elements (Moller et al., 2003).

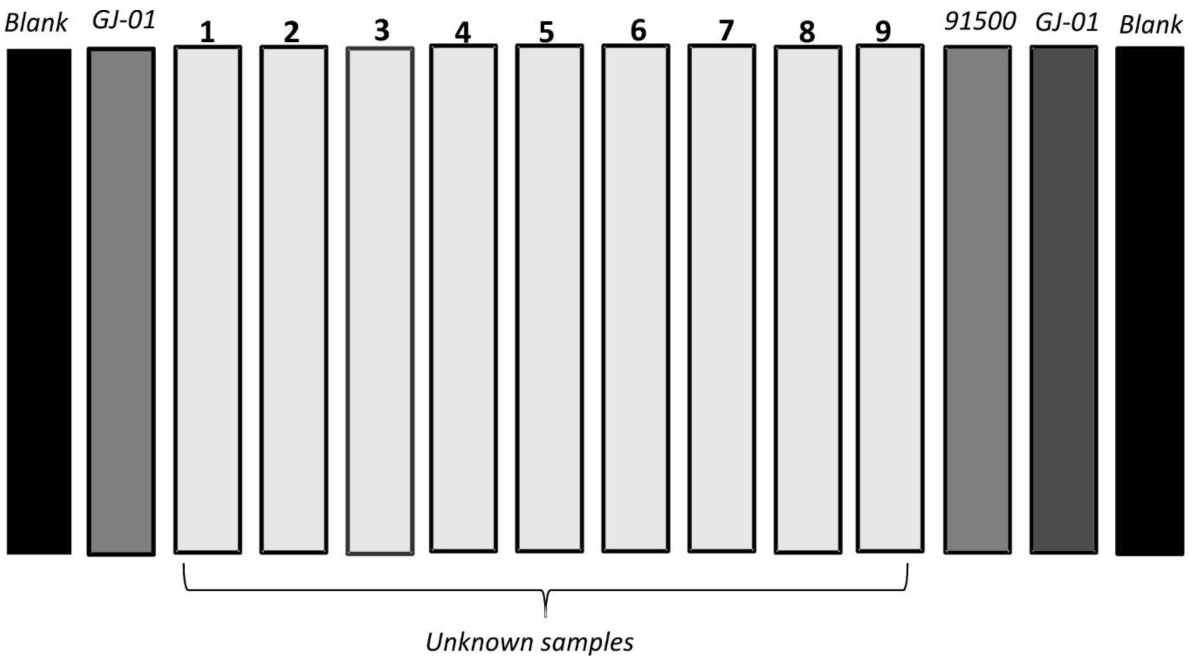

Fig. 3. Blanketing procedure used for reference material and blank corrections.

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In the crystallization associated with a magma crystallization, morphology is euhedral and depending on the crystallization velocity may acquire a high length-to-width ratio. When the cathodoluminescence image of these minerals is observed, the classical texture will be the oscillatory zonation (Fig. 4 A), characterized by the alternation of light and dark bands (Hoskin and Black, 2000). Metamorphic fluids can cause large disturbances in the distribution of trace elements within the zircon. The convoluted zonation (Fig. 4 B) is an example of internal zoning in which redistribution of trace elements results in a chaotic texture (Lenz, 2010).

When crystallization occurs in the solid state, associated with high-grade metamorphism, the most common morphologies are oval and rounded (Fig. 4 C). Such a shape is directly related to the fact that these grains crystallize mostly in the interstices of larger minerals. In these cases, the homogeneous and local zoning textures are the most common. The homogeneous texture can be explained by slow crystal growth (slow diffusion, thus generating areas with similar concentrations of trace elements (Watson and Liang, 1995; Watson, 1996).

The calculation of the model age by the Lu-Hf method differs from the Sm-Nd method in several ways. The first major difference is that in the Sm-Nd method an aliquot of total pulverized rock is used, which is dissolved and the elements of interest are separated by ion change columns. In the case of the Lu-Hf method, total rock can be analyzed in the same way, but the zircon laser ablasion technique has become popular among geochronology laboratories, once, by laser ablation, the zircon is volatilized and ionized by the plasma and subsequently measured the abundances of the isotopes of interest in the Faraday detectors.

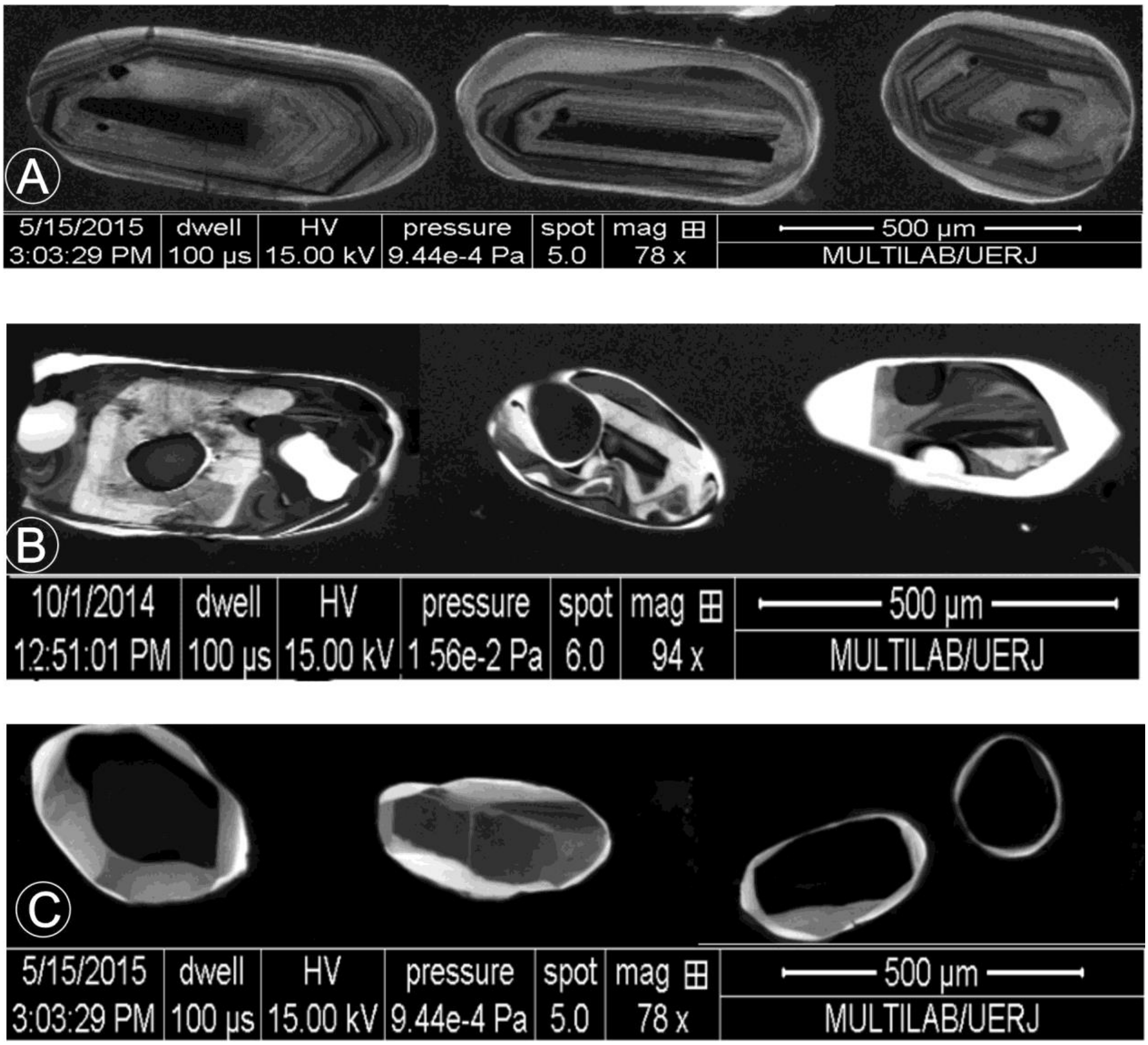

Fig. 4. Common morphology in zircon grains with (A) oscillatory zonation with high frequency band spacing; (B) zircon grains with trace element inhomogeneities distribution; (C) grains of high-grade metamorphic rocks with rounded morphology and homogeneous color and texture.

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Another important difference is that the Sm-Nd method needs to analyze the concentration (in ppm) of the Sm and Nd elements, in order to calculate the Nd isotope evolution curve in rocks and also its precursor magma, since it can be assumed that the Sm/Nd ratio (concentration) is similar both in the rock and in the magma that gave origin to it. Thus, the model age is obtained by the intersection of this curve with the Nd isotope evolution curve in the depleted mantle (Fig. 5). In these terms, the obtained age is interpreted as crustal age of residence of the studied sample. In addition, at the age of crystallization (for example, obtained by the U-Pb method in zircon), the value of ε can be calculated for this age and inferred the environment of this magma formation.

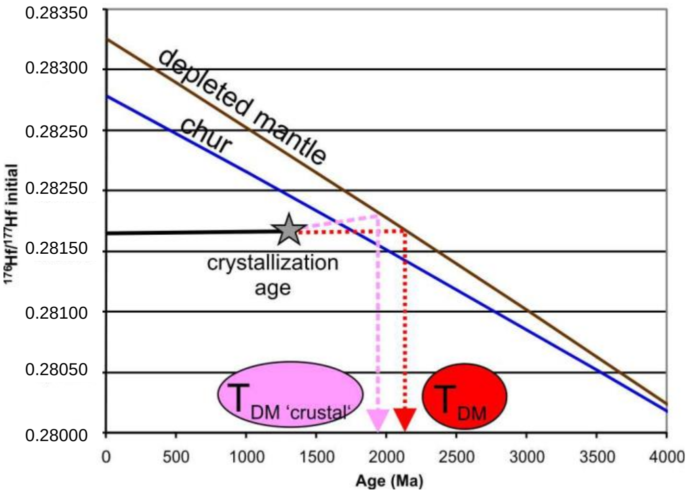

Fig. 5. Aspects of calculating age model in the Lu-Hf method.

In the case of the Lu-Hf method the Lu/Hf ratio differs greatly between zircon (because of high Hf values) and the magma from which the study rock originated and from where the zircon was obtained. In this sense, to continue calculating $^{176}Hf/^{177}Hf$ sample evolution between the present and the age of crystallization (obtained by the U-Pb method in the same zircon) it can be assumed that the amount of ^{176}Hf created by the decay of ^{176}Lu is insignificant because of the high concentration of Hf in the zircon and the obtained value is equivalent to the crystallization period of zircon.

When a zircon grain results of the crystallization of a mantle-derived magma (as shown in Fig. 4A), the U-Pb crystallization age is coherent with the $^{176}Hf/^{177}Hf$ mantle evolution, resulting in a Lu-Hf T_{DM} age very similar to U-Pb age, the ε_{Hf} is positive and the rocks are described as juvenile.

When a zircon grain results of the crystallization of a crust-derived magma (as shown in Fig. 4B and C) it is necessary to calculate an extension (see diagram of Fig. 5) from the crystallization epoch and the interception with depleted mantle curve. For this purpose, several options can be used to calculate the model age (T_{DM}), as follows:

1) using the same zircon ratio $^{176}Hf/^{177}Hf$ and continue an extension of this ratio over time to define the Hf isotope evolution curve for the intersection with the mantle curve; this calculation results in the age of the model is called TDM and is not normally considered for interpretations of geological evolution.
2) using the Lu / Hf ratio of the mean of the earth's crust; it is necessary to continue with this ratio over time to define the isotope evolution curve of Hf for the intersection with the mantle curve; this calculation results in the age of the model called "crustal" TDM and is preferred by many researchers.
3) using the Lu / Hf ratio of the studied rocks, obtained by means of analyzes for lithogeochemical investigations, and proceed with these ratios over time to define the curve of isotope evolution of Hf for the intersection with the mantle curve; this calculation results in the more robust and more accurate TDM model age.
4) Mean values of granitic rocks or mafic rocks (according to the case study) can be used, generating well-adapted age models for studies of the geological evolution of the terrain, as suggested by Pietranik et al. (2008).

3. Results and Discussion

3.1 Calibration Results

In the calibration of the Lu-Hf method using laser ablation, the $^{176}Hf/^{177}Hf$ ratios of the GJ-01 reference material were initially analyzed. The GJ-01 reference material (GEMOC, Macquarie University, Australia) comprises a large amount of zircon crystals approximately 1 cm in size from African pegmatites (Elhlou et al., 2006; Morel et al., 2008) with crystallization age of 608.5 ± 0.4 Ma (Jackson et al., 2004). The zircon grains show no visible zoning, which makes it convenient to be used as the reference material. The GJ-01 (Fig. 6A) is used in large scale by geochronology laboratories being reference material for U-Pb and Lu-Hf isotopic analysis. The isotopic ratios $^{176}Lu/^{177}Hf$ and $^{176}Hf/^{177}Hf$ of this reference material are reported in the literature with values of 0.00025 and 0.282005 ± 5, respectively (Elhlou et al., 2006; Griffin et al., 2006; Moreal et al., 2008). In the calibration of the method using laser, the $^{176}Hf/^{177}Hf$ ratios (Appendix 1) of the GJ-01 reference material (Fig. 7) were obtained. Its mean value is 0.282016 ± 5, which is almost identical to the recommended value in the literature.

The Mud Tank Pattern (Fig. 6B) represents a natural zircon present in a carbonatite that outcrops in Strangways, northern Australia, about 150 km northeast of Alice Springs. The carbonatite has an age of 732 Ma with large amounts of zircon and apatite crystals up to ten centimeters. The obtained isotopic ratios $^{176}Lu/^{177}Hf$ and

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^{176}Hf/^{177}Hf (Appendix 2) indicate values of 0.000042 ± 6 and 0.2882507 ± 6 (respectively, shown in Fig. 8) and are equivalent to those described in the literature for the Mud Tank reference material (Hergt et al., 2005; Woodhead and Hergt, 2005).

The 91500-reference material (Fig. 6C) represents a single crystal of zircon (238 g initial mass) from a syenite pegmatite from the Renfrew County mine, Ontario, Canada, crystallized at 1065 ± 6 Ma. The mineral was part of the Harvard museum collection and was carefully prepared as a reference material after a preliminary characterization, including Lu-Hf isotopic analyzes. Zircon 91500 has been widely adopted by many laboratories as reference material for U-Pb and Lu-Hf analyzes. The isotopic ratios values (Appendix 3) of 0.000311 ± 8 (^{176}Lu/^{177}Hf) and 0.2882305 ± 8 (^{176}Hf/^{177}Hf) were determined (Fig. 9) and are consistent with the reported true value.

3.2 Comparisons of Lu, Hf and Yb isotopic abundance of the GJ-01, 91500 and Mud Tank

The GJ-01, 91500 and Mud Tank reference materials were analyzed in order to determine the Lu, Hf and Yb isotopic abundance. The objective of the analyzes was to identify the abundances of ^{176}Lu and ^{176}Yb and thus to identify the best reference material among the three used zircons, with lower abundance of these isotopes.

For this purpose, in each reference material (GJ-01, 91500 and Mud Tank; Tables 2, 3 and 4, respectively) the abundances of ^{176}Hf, ^{177}Hf, ^{178}Hf, ^{179}Hf, ^{175}Lu, ^{174}Hf, ^{173}Yb and ^{171}Yb were measured.

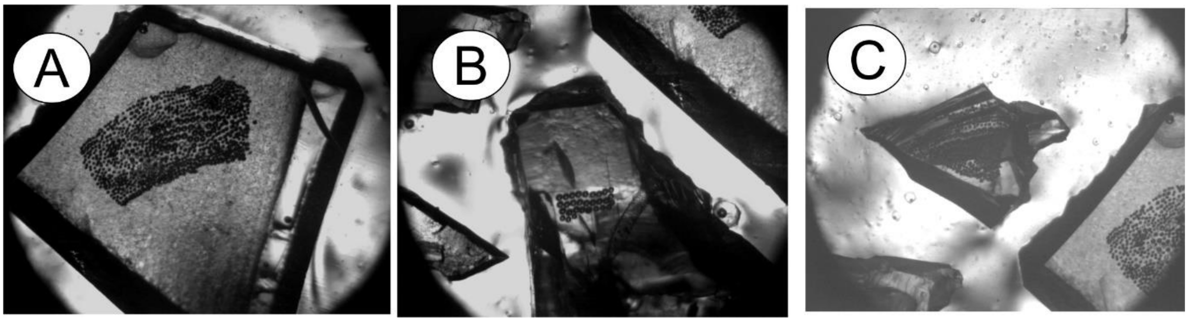

Fig. 6. Images of the spots realized in the reference material analyzed in this work. (A). GJ-01; (B). Mud Tank and; (C). 91.500.

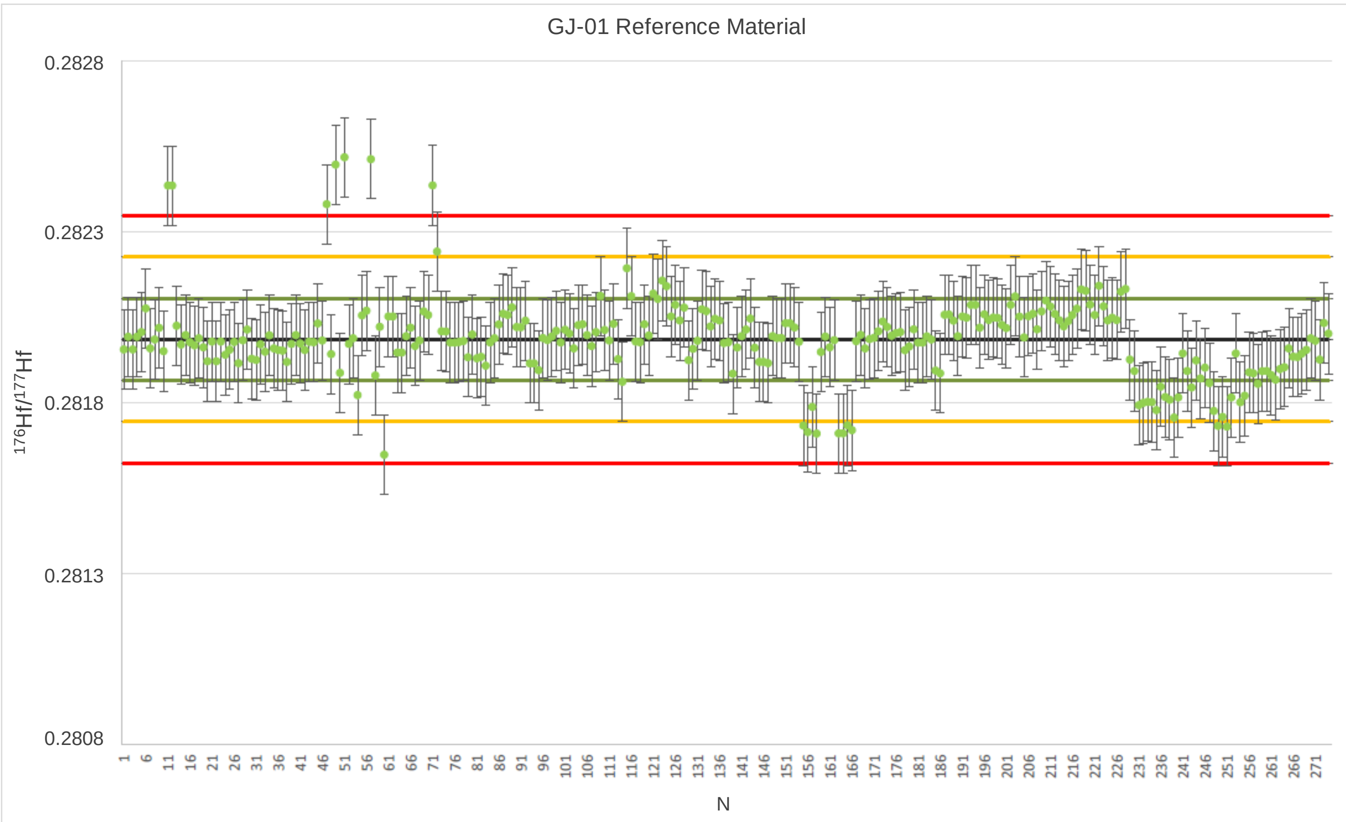

Fig. 7. ^{176}Hf / ^{177}Hf ratio values of the GJ-01 reference material performed through an LA-ICP-MS in the Multilab laboratory.

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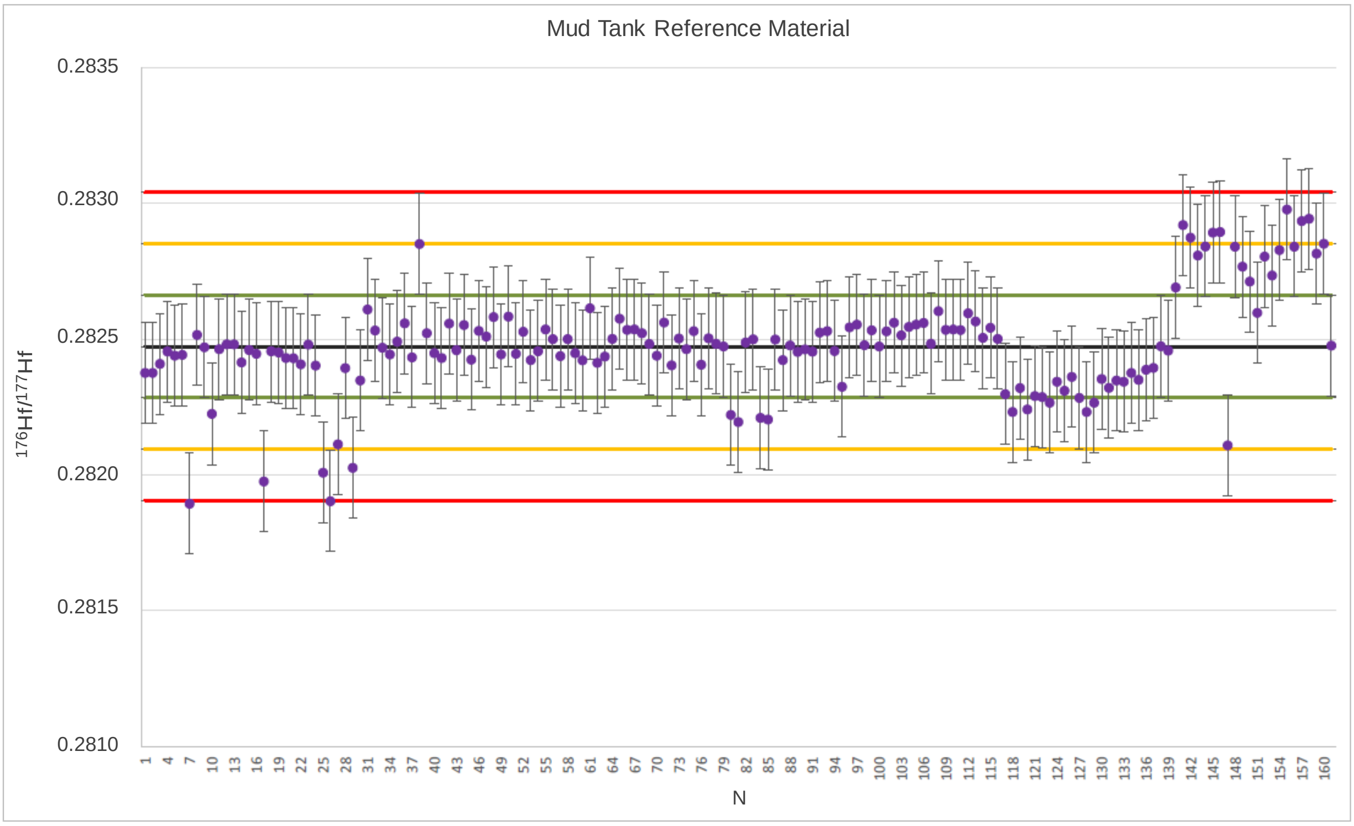

Fig. 8. ^{176}Hf / ^{177}Hf ratio values of the Mud Tank reference material performed through an LA-ICP-MS in the Multilab laboratory.

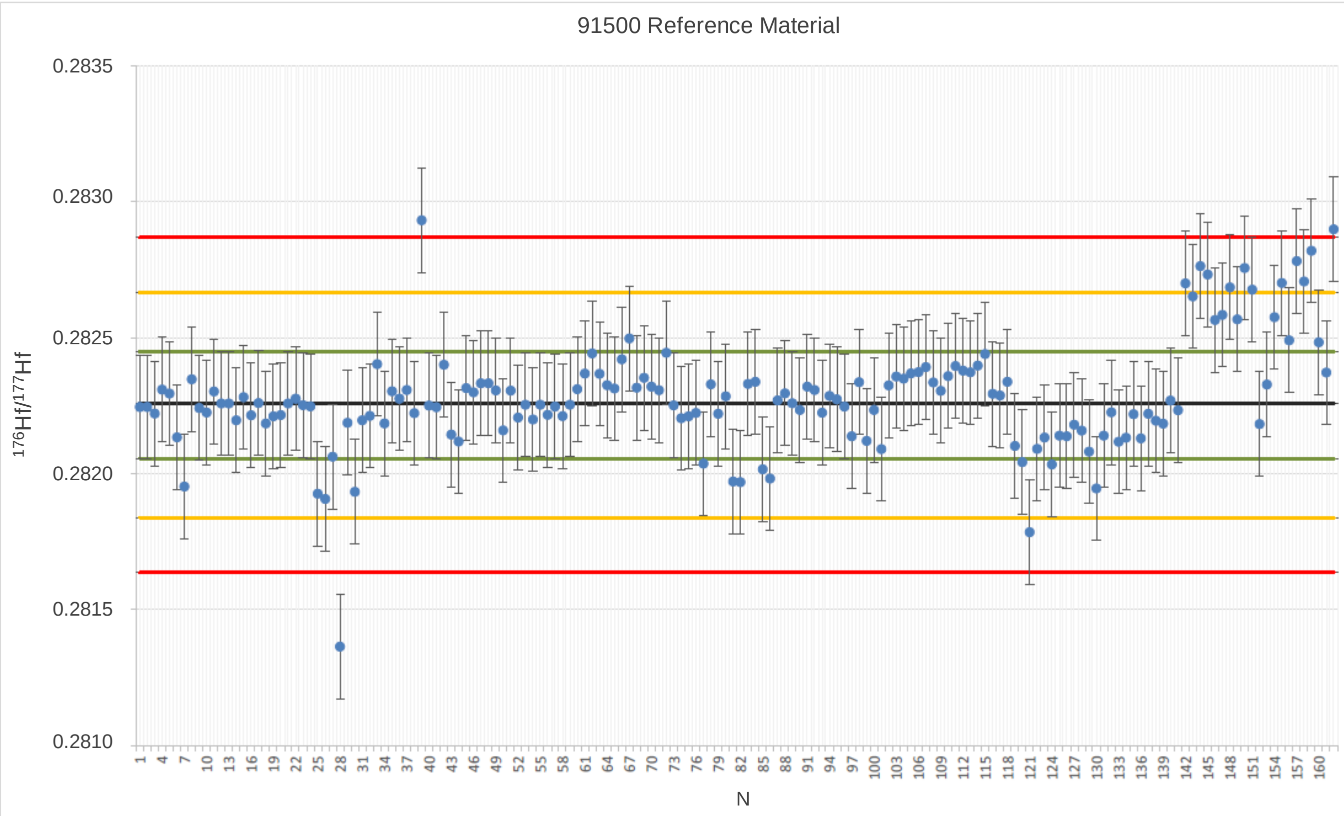

Fig. 9. ^{176}Hf / ^{177}Hf ratio values of the 91500-reference material performed through an LA-ICP-MS in the Multilab laboratory.

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Tab. 2. Results (counting per second) *versus* time measurements of masses of interest showing the relative abundance between ^{176}Hf, ^{176}Yb and ^{176}Lu for the zircon reference material GJ-01.

Run	^{176}Yb	^{176}Lu	^{176}Hf	^{176}(Hf+Yb+Lu)
1	0.023561	0.000505	0.382271	0.40633739
2	0.023033	0.000496	0.375972	0.39950135
3	0.022953	0.000496	0.375045	0.39849392
4	0.023285	0.000503	0.381841	0.4056295
5	0.02349	0.00051	0.385212	0.40921193
6	0.023862	0.00052	0.394165	0.41854738
7	0.025299	0.000548	0.41513	0.44097795
8	0.026983	0.000583	0.443179	0.47074484
9	0.028634	0.00062	0.471686	0.50094007
10	0.030043	0.00065	0.495313	0.5260054
11	0.029936	0.000649	0.495596	0.52618081
12	0.028885	0.00063	0.481342	0.51085707
13	0.027686	0.000603	0.461858	0.49014766
14	0.026517	0.00058	0.444349	0.47144525
15	0.025418	0.000556	0.424752	0.45072578
16	0.024667	0.000538	0.412586	0.43779068
17	0.02382	0.000521	0.398401	0.42274166
18	0.023031	0.000503	0.386196	0.40973043
19	0.022267	0.000485	0.373192	0.39594437
20	0.021897	0.000479	0.367305	0.3896805
21	0.021678	0.000476	0.365131	0.38728473
22	0.021223	0.000465	0.3582	0.379888
23	0.02112	0.000465	0.355904	0.37748818
24	0.020281	0.000446	0.343996	0.36472413
25	0.020385	0.000448	0.345067	0.36590007
26	0.020577	0.000449	0.347498	0.36852385
27	0.0202	0.000444	0.342431	0.36307373
28	0.019925	0.000437	0.337945	0.35830712
29	0.019383	0.000427	0.330125	0.34993473
30	0.019212	0.000425	0.327597	0.34723488
31	0.019177	0.000423	0.327101	0.34670145
32	0.0191	0.00042	0.325951	0.34547134
33	0.019271	0.000421	0.327773	0.34746557
34	0.018953	0.000418	0.323907	0.34327813
35	0.018521	0.000407	0.316601	0.33552893
36	0.018145	0.000399	0.310885	0.32942846
37	0.017907	0.000394	0.30698	0.32528109
38	0.017622	0.000387	0.302992	0.3210009
39	0.017601	0.000386	0.301667	0.31965324
40	0.017491	0.000385	0.299686	0.31756203
41	0.017303	0.000379	0.297985	0.31566716
42	0.017017	0.000376	0.294225	0.3116182

Tab. 2. (cont.) Results (counting per second) *versus* time measurements of masses of interest showing the relative abundance between ^{176}Hf, ^{176}Yb and ^{176}Lu for the zircon reference material GJ-01.

Run	^{176}Yb	^{176}Lu	^{176}Hf	^{176}(Hf+Yb+Lu)
43	0.01681	0.00037	0.290171	0.30735164
44	0.016624	0.000366	0.287958	0.3049489
45	0.016433	0.000363	0.285287	0.30208295
46	0.016237	0.000359	0.28292	0.29951553
47	0.016164	0.000359	0.28188	0.29840276
48	0.015904	0.000353	0.277753	0.29401006
49	0.015918	0.000354	0.279088	0.29535956
50	0.015724	0.00035	0.27641	0.29248425

Tab. 3. Results (counting per second) *versus* time measurements of masses of interest showing the relative abundance between ^{176}Hf, ^{176}Yb and ^{176}Lu for the zircon reference material 91.500.

Run	^{176}Yb	^{176}Lu	^{176}Hf	^{176}(Hf+Yb+Lu)
1	0.01519	0.000309	0.272501	0.28800002
2	0.01517	0.000312	0.274263	0.28974409
3	0.015163	0.000313	0.274866	0.29034173
4	0.014888	0.000308	0.271673	0.28686889
5	0.014925	0.00031	0.274617	0.28985274
6	0.014781	0.000311	0.27362	0.28871217
7	0.014596	0.000308	0.270905	0.2858084
8	0.01448	0.000306	0.269016	0.28380233
9	0.014839	0.000314	0.276069	0.29122151
10	0.015595	0.000328	0.287323	0.30324538
11	0.016001	0.000338	0.297062	0.31340118
12	0.017094	0.000359	0.317256	0.33470966
13	0.01903	0.0004	0.352648	0.37207831
14	0.020522	0.000427	0.378016	0.39896507
15	0.021555	0.00045	0.398054	0.42005826
16	0.021541	0.000453	0.400529	0.42252315
17	0.020559	0.000435	0.38325	0.40424349
18	0.019753	0.00042	0.369185	0.38935802
19	0.018971	0.000404	0.356136	0.37551119
20	0.018925	0.000404	0.356007	0.37533697
21	0.018574	0.000399	0.349104	0.36807736
22	0.018022	0.000386	0.339773	0.35817975
23	0.017502	0.000376	0.330186	0.3480652
24	0.016828	0.000365	0.318336	0.33552852
25	0.015998	0.000344	0.302425	0.31876749
26	0.015348	0.000332	0.290566	0.30624689
27	0.014676	0.000317	0.278143	0.29313615
28	0.014121	0.000305	0.268856	0.2832824
29	0.013961	0.000303	0.266246	0.28051026

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Tab. 3. (cont.) Results (counting per second) *versus* time measurements of masses of interest showing the relative abundance between ^{176}Hf, ^{176}Yb and ^{176}Lu for the zircon reference material 91.500.

Run	^{176}Yb	^{176}Lu	^{176}Hf	^{176}(Hf+Yb+Lu)
30	0.013633	0.000294	0.257972	0.27189936
31	0.013305	0.000288	0.252693	0.26628509
32	0.013122	0.000283	0.248838	0.26224279
33	0.013105	0.000285	0.247466	0.26085515
34	0.012895	0.00028	0.243985	0.25715958
35	0.01278	0.000275	0.240807	0.25386158
36	0.012669	0.000277	0.240058	0.2530036
37	0.012574	0.000272	0.237643	0.2504891
38	0.012378	0.000267	0.233638	0.24628243
39	0.012001	0.00026	0.227222	0.23948192
40	0.011944	0.00026	0.22624	0.23844448
41	0.011686	0.000255	0.221606	0.23354708
42	0.011669	0.000254	0.21766	0.22958193
43	0.01255	0.000268	0.212669	0.22548773
44	0.012684	0.000273	0.212611	0.22556737
45	0.012289	0.000265	0.211556	0.2241086
46	0.011727	0.000251	0.208713	0.22069114
47	0.011399	0.000247	0.207352	0.21899692
48	0.011162	0.000238	0.204786	0.2161861
49	0.010925	0.000237	0.201366	0.21252831
50	0.010878	0.000236	0.1996	0.21071435

Tab. 4. Results (counting per second) *versus* time measurements of masses of interest showing the relative abundance between ^{176}Hf, ^{176}Yb and ^{176}Lu for the zircon reference material Mud Tank.

Run	^{176}Yb	^{176}Lu	^{176}Hf	^{176}(Hf+Yb+Lu)
1	0.005438	9.51E-05	0.482586	0.48811906
2	0.005602	9.78E-05	0.493377	0.49907707
3	0.005654	0.0001	0.50283	0.50858442
4	0.005839	0.000104	0.518311	0.52425475
5	0.006063	0.000107	0.536446	0.54261611
6	0.006163	0.00011	0.546415	0.55268779
7	0.006078	0.000107	0.544251	0.55043544
8	0.005981	0.000107	0.53794	0.54402776
9	0.006038	0.000108	0.542079	0.54822434
10	0.006105	0.000109	0.551127	0.55734213
11	0.006055	0.000109	0.547006	0.55317073
12	0.005989	0.000106	0.545766	0.55186143
13	0.006045	0.000109	0.546612	0.55276699
14	0.005979	0.000108	0.53975	0.54583697
15	0.005854	0.000107	0.534464	0.54042458

Tab. 4. (cont.) Results (counting per second) *versus* time measurements of masses of interest showing the relative abundance between ^{176}Hf, ^{176}Yb and ^{176}Lu for the zircon reference material Mud Tank.

Run	^{176}Yb	^{176}Lu	^{176}Hf	^{176}(Hf+Yb+Lu)
16	0.005767	0.000104	0.528675	0.53454616
17	0.005456	0.000101	0.501877	0.50743401
18	0.005182	9.43E-05	0.484629	0.48990551
19	0.005237	9.59E-05	0.479366	0.48469857
20	0.005124	9.43E-05	0.466116	0.47133472
21	0.00488	8.94E-05	0.450594	0.45556324
22	0.00491	8.78E-05	0.444983	0.44998158
23	0.004834	8.63E-05	0.439401	0.44432178
24	0.00462	8.67E-05	0.430608	0.4353153
25	0.004702	8.42E-05	0.429841	0.43462772
26	0.004739	8.72E-05	0.431513	0.43633935
27	0.004711	8.46E-05	0.429386	0.43418132
28	0.004734	8.54E-05	0.433668	0.43848716
29	0.004712	8.47E-05	0.427039	0.43183531
30	0.004708	8.49E-05	0.425709	0.43050221
31	0.004486	8.14E-05	0.412066	0.41663373
32	0.004384	8.17E-05	0.399687	0.40415218
33	0.004457	7.97E-05	0.40018	0.40471666
34	0.004364	7.92E-05	0.397707	0.40215055
35	0.004341	8.09E-05	0.391819	0.39624114
36	0.004177	7.75E-05	0.384887	0.38914163
37	0.004199	7.49E-05	0.378673	0.38294658
38	0.004202	7.82E-05	0.380322	0.38460302
39	0.00419	7.38E-05	0.377956	0.38221999
40	0.004135	7.6E-05	0.375481	0.37969163
41	0.004162	7.65E-05	0.375315	0.37955338
42	0.003992	7.32E-05	0.364651	0.36871568
43	0.003963	7.4E-05	0.355903	0.35993988
44	0.00398	7.28E-05	0.360862	0.36491481
45	0.003942	7.18E-05	0.361391	0.3654054
46	0.003896	7.18E-05	0.353406	0.35737394
47	0.003881	7.02E-05	0.353465	0.35741586
48	0.003961	7.16E-05	0.356083	0.36011624
49	0.003897	7E-05	0.34773	0.35169717
50	0.003803	6.88E-05	0.344937	0.34880906

From the values of ^{173}Yb and ^{175}Lu, the abundances of ^{176}Lu and ^{176}Yb were calculated and subtracted from the values of ^{176}Hf, thus obtaining the abundance of this corrected isotope of its isobaric interferences. The correction of the values of ^{176}Lu was performed through abundance measures of ^{173}Yb and ^{175}Lu masses and correction factors of 0.795015 and 0.026580, respectively. A zircon pattern with the least possible amount of Yb

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results in the application of lower correction factors, and may result in more accurate results.

The measured values of mass 176 (Lu + Hf + Yb) are shown in the diagram and corresponds to the highest intensity value (data in cps - counts per second). In the same diagram the values of ^{176}Lu, ^{176}Hf and ^{176}Yb were plotted individually, so it is possible to evaluate the absolute amount for each of these isotopes (Fig. 10). When comparing the curve of the sum of the measurements of the three masses (^{176}Lu, ^{176}Hf and ^{176}Yb) and the curve of ^{176}Hf, we can see that the GJ-01 and 91500 zircons have significant values of ^{176}Lu and ^{176}Yb, but Mud Tank zircon shows values of ^{176}Lu and ^{176}Yb closer to zero, which facilitates the correction of the isobaric interferences.

As a consequence, it is possible to characterize the Mud Tank as the zircon with less abundance of Yb, and thus to indicate this reference material as the best among the three when evaluated by the need for isobaric interference correction of ^{176}Lu and ^{176}Yb over ^{176}Hf.

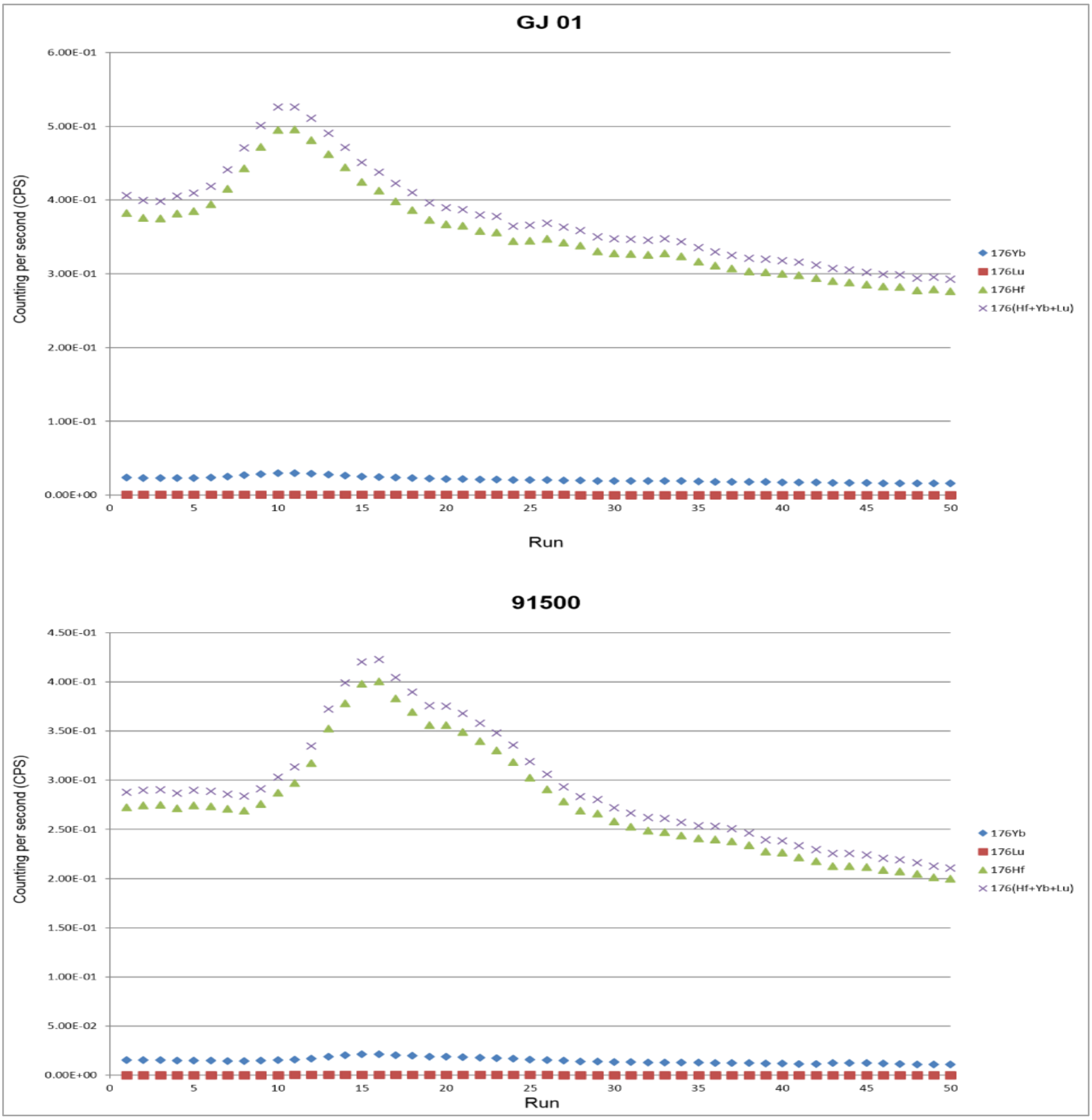

Fig. 10. CPS (counting per second) *versus* time measurements of masses of interest showing the relative abundance between ^{176}Hf, ^{176}Yb and ^{176}Lu for the zircon reference material GJ-01, 91.500 and Mud Tank.

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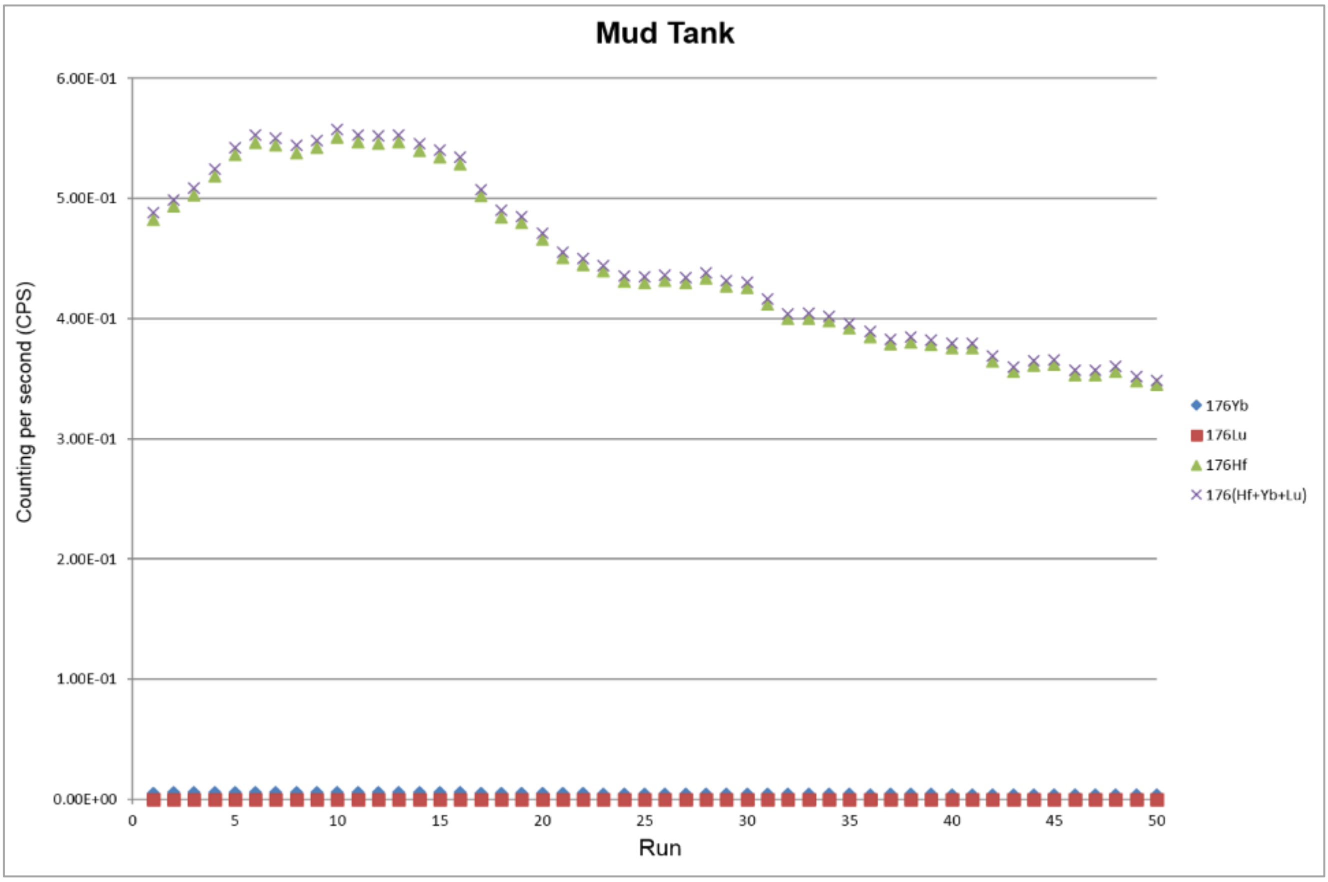

Fig. 10. (cont.) CPS (counting per second) *versus* time measurements of masses of interest showing the relative abundance between ^{176}Hf, ^{176}Yb and ^{176}Lu for the zircon reference material GJ-01, 91.500 and Mud Tank.

4. Conclusion

The Lu-Hf methodology described and applied at the MultiLab Laboratory of the Universidade do Estado do Rio de Janeiro for *in situ* analyzes of zircon grains by LA-MC-ICP-MS was successfully installed according to the isotopic results of reference materials reported in this work to be similar to the true values (reported in the literature). The instruments used to make the measurements were the Neptune plus, with nine Faraday detectors, which allows the simultaneous analysis of all the isotopes of interest to the Lu-Hf method. The results obtained by this method are very useful for the characterization of the reservoir isotopic signatures, to identify the origin of magmatic and metamorphic rocks, and to identify the sediment fonts or temporal and spatial changes of sedimentary particles sources, which as a great interest in paleoclimate and paleoceanographic studies and/or to give support to sedimentary basin evolution studies.

The calibration protocol started with the analysis of reference materials (JMC475) with introduction as solution, with injection through the nebulizer, which caused the reproducibility of the certified values. The second calibration procedure involved the connection of the laser (Photon Machines Excimer) with the optimization of the gas flow (Argon in ICP-MS and Helium in laser ablation), which allowed the intensity, sensitivity and stability of the signals, giving a significant gain in the accuracy of the results obtained from *in situ* analyzes of the isotopes of Lu, Hf and Yb in minerals bearing Hf.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) is a challenge in microanalysis of geological samples. Laser beam allow high resolution determination of isotopic abundance and detailed characterization of selected areas of zircon grain. This study highlights the possibility to achieve suitable spatial resolution, accuracy and precision for geological samples even at spatial resolutions of the order of 40 µm allowing a robust interpretation of geologic evolution.

The values of the abundances of the Hf, Lu and Yb isotopes were shown to be effective and the three-reference material used (GJ-01, Mud Tank and 91500) during the analyzes reproduced the values with error margins comparable to the literature data, with intensity of signals enough to obtain stable and statistically reliable results.

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The Mud Tank zircon has the lowest abundances of ^{176}Yb (relative to the GJ-01 and 91.500 zircon reference materials) and requires ^{176}Hf isobaric insignificant interference corrections producing the most reliable results. Once the calibrations of reference material solutions and zircon reference material were carried out, the Lu-Hf method may be used for unknown samples.

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SUPLEMENTARY DATA

Appendix 1. Lu and Hf isotopic results of the GJ-01 reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
1	0.2819553	0.0004	6.1E-05	0.0003516	7.8E-07	1.4672414	7.5E-05	0.7456532	7.7E-05	1.151536	0.00253
2	0.2819922	0.0004	5.9E-05	0.0003539	7.3E-07	1.4672872	9.2E-05	0.7456398	7.9E-05	1.151627	0.00252
3	0.2819553	0.0004	6.1E-05	0.0003516	7.8E-07	1.4672414	7.5E-05	0.7456532	7.7E-05	1.151536	0.00253
4	0.2819922	0.0004	5.9E-05	0.0003539	7.3E-07	1.4672872	9.2E-05	0.7456398	7.9E-05	1.151627	0.00252
5	0.282006	0.0004	6.5E-05	0.0003529	7.3E-07	1.4672874	8.1E-05	0.7456403	7.7E-05	1.1499012	0.00268
6	0.2820751	0.0003	4.3E-05	0.0003515	8.2E-07	1.4673517	9.5E-05	0.7456578	7.8E-05	1.1467748	0.00231
7	0.2819578	0.0003	4.4E-05	0.0003567	1.3E-06	1.4672674	7.2E-05	0.7450345	7.4E-05	1.151279	0.0018
8	0.2819842	0.0004	6.4E-05	0.0003555	7.6E-07	1.4672968	8.1E-05	0.7454111	8.5E-05	1.149725	0.00201
9	0.2820183	0.0003	4.8E-05	0.0003473	1.5E-06	1.4671831	8E-05	0.7454528	8.4E-05	1.1532692	0.00221
10	0.28195	0.0005	7.2E-05	0.0003411	8.6E-07	1.4671952	8E-05	0.7456076	7.4E-05	1.1524816	0.00324
11	0.2824342	0.0005	8E-05	0.0002911	1.4E-06	1.4672196	0.00013	0.7454035	7.1E-05	1.1490325	0.00573
12	0.2824342	0.0005	8E-05	0.0002911	1.4E-06	1.4672196	0.00013	0.7454035	7.1E-05	1.1490325	0.00573
13	0.2820243	0.0005	7.4E-05	0.0003522	9.1E-07	1.4672248	8.5E-05	0.7455078	7.5E-05	1.1488412	0.00311
14	0.2819689	0.0005	6.9E-05	0.0003519	9.6E-07	1.4672144	0.00012	0.7456237	9.2E-05	1.1522351	0.00282
15	0.2819969	0.0003	4.8E-05	0.0003561	6.4E-07	1.4672677	8.5E-05	0.7453897	5.5E-05	1.1515674	0.0027
16	0.2819758	0.0005	6.6E-05	0.0003529	9.1E-07	1.4673019	8E-05	0.7455825	6E-05	1.1521521	0.00292
17	0.2819666	0.0003	4.7E-05	0.000351	8.5E-07	1.4672442	9.2E-05	0.7456232	6.9E-05	1.150999	0.00288
18	0.2819878	0.0004	5.3E-05	0.0003452	7.8E-07	1.4672838	7.7E-05	0.7458004	5E-05	1.1515624	0.00239
19	0.2819611	0.0003	5E-05	0.0003491	5.9E-07	1.4673193	7.5E-05	0.7458194	6.1E-05	1.1541211	0.00238
20	0.2819205	0.0003	4.7E-05	0.0003471	6.5E-07	1.4672675	7.1E-05	0.7458194	6.6E-05	1.1524065	0.00224
21	0.281978	0.0004	5.9E-05	0.0003488	5.5E-07	1.4672954	7.8E-05	0.7457927	6.2E-05	1.1521088	0.00275
22	0.2819205	0.0003	4.7E-05	0.0003471	6.5E-07	1.4672675	7.1E-05	0.7458194	6.6E-05	1.1524065	0.00224
23	0.281978	0.0004	5.9E-05	0.0003488	5.5E-07	1.4672954	7.8E-05	0.7457927	6.2E-05	1.1521088	0.00275
24	0.2819393	0.0003	4.8E-05	0.0003524	7.5E-07	1.4672962	6.4E-05	0.7450844	7.1E-05	1.1530101	0.00235
25	0.2819544	0.0003	4.5E-05	0.0003476	8.7E-07	1.4672749	7.9E-05	0.7457996	5.2E-05	1.1536553	0.00262
26	0.2819766	0.0004	5.3E-05	0.0003449	8.9E-07	1.4673155	5.4E-05	0.7447971	6.7E-05	1.150819	0.00274
27	0.2819149	0.0003	4.1E-05	0.0003462	7.6E-07	1.467255	6.2E-05	0.7454563	4.9E-05	1.1532047	0.00234
28	0.2819817	0.0003	5E-05	0.0003435	9.6E-07	1.4673582	8.1E-05	0.7454203	8.3E-05	1.152249	0.00226
29	0.2820132	0.0004	5.1E-05	0.0003466	1E-06	1.467297	6.2E-05	0.7456038	5.6E-05	1.1510622	0.00283
30	0.2819277	0.0004	5.2E-05	0.0003448	7.1E-07	1.4673048	8.9E-05	0.7455436	8.4E-05	1.1536716	0.00203
31	0.2819243	0.0004	5.1E-05	0.0003446	8.7E-07	1.4673021	8.7E-05	0.7455364	6.5E-05	1.1547701	0.00249
32	0.2819697	0.0003	4.3E-05	0.000346	6.7E-07	1.4673447	5.9E-05	0.7459746	5E-05	1.1524858	0.00215
33	0.2819482	0.0003	3.7E-05	0.0003483	9.2E-07	1.4672437	6.9E-05	0.7459624	6.8E-05	1.1531852	0.0021
34	0.2819967	0.0003	4.2E-05	0.0003437	7.4E-07	1.4673046	7E-05	0.7459341	5.4E-05	1.1500251	0.00237
35	0.281958	0.0004	5.3E-05	0.0003427	7.5E-07	1.4673174	7.1E-05	0.7459033	7E-05	1.1507755	0.00248
36	0.2819529	0.0003	4.6E-05	0.0003425	8E-07	1.467321	8.2E-05	0.7458473	5.4E-05	1.1539979	0.00178
37	0.281951	0.0004	5.7E-05	0.0003437	9.3E-07	1.4673579	7.6E-05	0.7458987	6.2E-05	1.1534759	0.00264
38	0.2819187	0.0003	4.8E-05	0.000345	1.2E-06	1.4672859	6.3E-05	0.745864	6.9E-05	1.1541617	0.00208
39	0.2819714	0.0003	5E-05	0.000346	8.4E-07	1.4672701	7.1E-05	0.7459551	6.4E-05	1.1528254	0.00251

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Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
40	0.2819972	0.0004	5.8E-05	0.0003441	8.8E-07	1.4672305	7.8E-05	0.7459141	5.8E-05	1.1515251	0.00219
41	0.2819725	0.0003	4E-05	0.0003438	8.9E-07	1.4673339	7.2E-05	0.745857	6.4E-05	1.1506967	0.0023
42	0.2819531	0.0003	4.1E-05	0.0003638	7.8E-07	1.4672781	6.4E-05	0.7456103	6.6E-05	1.1519206	0.00137
43	0.2819775	0.0003	4.4E-05	0.000351	6.6E-07	1.4673251	7.4E-05	0.7461932	6.3E-05	1.1532965	0.00199
44	0.281976	0.0003	4.4E-05	0.0003478	8.4E-07	1.4671822	6.3E-05	0.7460263	6.6E-05	1.1510955	0.00155
45	0.2820311	0.0003	4.6E-05	0.0003465	6.8E-07	1.4672925	6.7E-05	0.7460112	4.5E-05	1.1498481	0.00174
46	0.281981	0.0006	8.7E-05	0.0003541	1.4E-06	1.4672508	0.00011	0.7465376	7.8E-05	1.1523321	0.00408
47	0.2823797	0.001	0.00014	0.0002959	1.3E-06	1.4671802	0.00014	0.7466599	9.2E-05	1.1457049	0.00513
48	0.2819416	0.0008	0.00012	0.0003356	1.7E-06	1.4671687	0.00017	0.7468052	0.00011	1.1514736	0.00608
49	0.2824955	0.0005	8.5E-05	4.524E-05	1.2E-06	1.4672815	0.00014	0.7467236	8.3E-05	1.123692	0.0287
50	0.2818863	0.0009	0.00014	0.000346	1.6E-06	1.4672285	0.00016	0.746792	0.00013	1.1497501	0.00669
51	0.2825172	0.0011	0.00016	4.406E-05	1.3E-06	1.4672144	0.00014	0.7468976	9.1E-05	1.1444236	0.04189
52	0.281971	0.0006	0.0001	0.0003557	1.4E-06	1.4672918	0.00014	0.7465397	0.00014	1.1508117	0.00439
53	0.2819879	0.0008	0.00015	0.0003502	2E-06	1.4670835	0.00015	0.7467305	0.00016	1.151923	0.00528
54	0.2818211	0.001	0.00015	0.0003507	1.7E-06	1.4671235	0.00015	0.7467237	0.00012	1.1551239	0.0055
55	0.2820543	0.0007	0.00011	0.0003511	1.6E-06	1.467289	0.00015	0.7468374	9.3E-05	1.1499522	0.0054
56	0.2820683	0.0008	0.00013	0.0003472	1.7E-06	1.4670944	0.00017	0.7469765	0.00019	1.1457666	0.00506
57	0.282512	0.0008	0.00012	5.093E-05	1.3E-06	1.4673467	0.00013	0.7469536	9.6E-05	1.1484795	0.03248
58	0.2818786	0.0004	6.5E-05	0.0003631	1.3E-06	1.4673681	0.00011	0.7428502	8E-05	1.1491949	0.00318
59	0.2820213	0.004	0.00058	0.0003743	6.4E-06	1.4671843	0.00034	0.7443749	0.0003	1.1515367	0.01754
60	0.2816467	0.0011	0.00017	0.0003583	2.1E-06	1.4672322	0.00019	0.7442148	0.00014	1.1543076	0.00819
61	0.2820518	0.0007	9.6E-05	0.0003957	1.1E-06	1.467172	0.00013	0.7467657	9.8E-05	1.1520781	0.0032
62	0.2820518	0.0007	9.6E-05	0.0003957	1.1E-06	1.467172	0.00013	0.7467657	9.8E-05	1.1520781	0.0032
63	0.2819458	0.0004	5.8E-05	0.0003366	9.6E-07	1.4672788	9E-05	0.7456331	8.8E-05	1.1538543	0.00287
64	0.2819458	0.0004	5.8E-05	0.0003366	9.6E-07	1.4672788	9E-05	0.7456331	8.8E-05	1.1538543	0.00287
65	0.2819939	0.0009	0.00013	0.0003926	1.3E-06	1.4673132	0.00013	0.7465526	0.00011	1.1503504	0.00278
66	0.2820188	0.0007	0.0001	0.0003926	1.6E-06	1.4673156	0.00014	0.7466377	8.5E-05	1.1550123	0.00363
67	0.2819649	0.0009	0.00013	0.0003905	1.4E-06	1.4673323	0.0001	0.7465363	9E-05	1.1538888	0.00351
68	0.281981	0.0006	9.5E-05	0.0003904	1.3E-06	1.4672781	0.00011	0.7465756	9E-05	1.1536995	0.00298
69	0.2820662	0.0008	0.00011	0.0003888	1.1E-06	1.4672416	0.00014	0.7466436	9.5E-05	1.1524852	0.00298
70	0.2820556	0.0006	8.3E-05	0.0003989	7.8E-07	1.4673127	9.4E-05	0.7468713	8.3E-05	1.1538878	0.00216
71	0.2824351	0.0012	0.00018	0.0003122	2.8E-06	1.4684903	0.00017	0.7445673	0.00012	1.1520949	0.00934
72	0.2822414	0.002	0.0003	0.0003171	5.1E-06	1.4683092	0.00026	0.7447555	0.00022	1.156004	0.02089
73	0.2820084	0.0005	7.3E-05	0.0004028	9.4E-07	1.4675616	0.0001	0.7468052	9E-05	1.1527985	0.00196
74	0.2820076	0.0005	9.4E-05	0.0003899	1.1E-06	1.4674758	0.00014	0.7465713	8.6E-05	1.1526377	0.0031
75	0.281975	0.0007	9.9E-05	0.0004025	9.7E-07	1.4673607	0.0001	0.7473964	8E-05	1.1527732	0.00228
76	0.281975	0.0007	9.9E-05	0.0004025	9.7E-07	1.4673607	0.0001	0.7473964	8E-05	1.1527732	0.00228
77	0.2819769	0.0007	9.9E-05	0.0004028	9.8E-07	1.4673634	0.0001	0.7474216	8E-05	1.154424	0.00228
78	0.2819798	0.0005	6.5E-05	0.0003942	9E-07	1.4675304	9E-05	0.7469223	7.1E-05	1.1528998	0.00186
79	0.281932	0.0006	9.9E-05	0.0003916	9.3E-07	1.4675543	0.00012	0.7465555	7E-05	1.1541936	0.00286
80	0.2819991	0.0006	9.6E-05	0.0003963	9.8E-07	1.4674596	0.00012	0.7468481	8.4E-05	1.1530348	0.00267
81	0.2819291	0.0007	9.6E-05	0.0003972	1.1E-06	1.4674821	0.00011	0.7468284	7.5E-05	1.1544736	0.00267

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Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
82	0.2819336	0.0006	8.8E-05	0.0003928	1E-06	1.467568	9E-05	0.7465781	7.2E-05	1.1552787	0.0026
83	0.2819076	0.0012	0.00017	0.0004568	2.4E-06	1.4672292	0.00014	0.7480185	0.00014	1.1588693	0.00367
84	0.2819756	0.0005	7.5E-05	0.0003941	8E-07	1.4675416	8.6E-05	0.7467893	7.5E-05	1.1542319	0.0022
85	0.281988	0.0006	9E-05	0.0003993	1E-06	1.4674502	0.00011	0.7472127	8.4E-05	1.1551233	0.00227
86	0.2820278	0.0006	9.4E-05	0.0004033	1.3E-06	1.4673249	0.00012	0.7478208	0.00011	1.1542175	0.00293
87	0.2820595	0.0006	9.3E-05	0.0004037	1.2E-06	1.4674305	0.00011	0.7476656	9.6E-05	1.1543327	0.00258
88	0.2820556	0.0006	8.4E-05	0.0003995	1.5E-06	1.4674324	0.00013	0.7474746	8.6E-05	1.1539131	0.00243
89	0.2820779	0.0008	0.00011	0.0004026	1.2E-06	1.4673392	0.00011	0.747615	7.2E-05	1.1517902	0.00312
90	0.2820204	0.0007	0.0001	0.0004126	1.2E-06	1.4674394	0.00013	0.7475379	7.7E-05	1.1539972	0.00289
91	0.2820198	0.0008	0.00011	0.000413	1.3E-06	1.4673168	0.00011	0.7476713	9.6E-05	1.1533092	0.00281
92	0.2820389	0.0007	9.6E-05	0.0003999	1.3E-06	1.4672923	0.00014	0.7475121	9.6E-05	1.1538409	0.00271
93	0.2819144	0.0006	9E-05	0.0004187	1.5E-06	1.4674219	0.00013	0.7476325	8E-05	1.1549742	0.00243
94	0.2819144	0.0006	9E-05	0.0004187	1.5E-06	1.4674219	0.00013	0.7476325	8E-05	1.1549742	0.00243
95	0.2818943	0.0007	9.9E-05	0.0004231	1.4E-06	1.4672478	0.00014	0.7479047	9.7E-05	1.1577221	0.00242
96	0.2819885	0.0006	8.3E-05	0.0004026	9.8E-07	1.4673412	0.00011	0.7473653	7.1E-05	1.1546307	0.00225
97	0.2819824	0.0006	8.3E-05	0.000403	9.9E-07	1.4672839	0.00011	0.747373	7.1E-05	1.1548223	0.00225
98	0.2819927	0.0006	8.8E-05	0.0004023	9.7E-07	1.4672298	0.00011	0.7474047	8.7E-05	1.1554323	0.00231
99	0.2820097	0.0005	8E-05	0.0003932	1.1E-06	1.4672592	0.00012	0.7472608	9.4E-05	1.1542533	0.00222
100	0.2819752	0.0006	8.8E-05	0.0003908	1.1E-06	1.4673208	0.00011	0.7471712	8.1E-05	1.1533813	0.0027
101	0.2820125	0.0006	8.8E-05	0.0003912	1.1E-06	1.4673796	0.00011	0.7471119	8.1E-05	1.1531387	0.0027
102	0.2820017	0.0007	9.7E-05	0.0003958	1.1E-06	1.4673561	0.00011	0.7470794	7.5E-05	1.1540052	0.00275
103	0.2819583	0.0007	9.7E-05	0.0003953	1.1E-06	1.467385	0.00011	0.747107	7.5E-05	1.1538412	0.00275
104	0.2820264	0.0006	8.7E-05	0.0003856	9.4E-07	1.4674305	0.00012	0.7470434	7.6E-05	1.1529905	0.00234
105	0.2820285	0.0006	8.7E-05	0.0003852	9.4E-07	1.4673507	0.00012	0.7470703	7.6E-05	1.1533824	0.00234
106	0.2819973	0.0007	0.0001	0.0003859	1.2E-06	1.4672303	0.00011	0.7471028	8.5E-05	1.1546086	0.00261
107	0.2819647	0.0007	0.0001	0.000387	1.2E-06	1.4672745	0.00011	0.7470724	8.5E-05	1.1557279	0.00262
108	0.2820057	0.0005	7.8E-05	0.0003938	1E-06	1.4673345	0.00014	0.7470986	8.7E-05	1.1541566	0.00226
109	0.2821116	0.0005	7.5E-05	0.0003933	1E-06	1.4673129	0.00014	0.747104	8.7E-05	1.1525049	0.00226
110	0.2820117	0.0005	7.7E-05	0.0003964	1E-06	1.4672603	9.2E-05	0.7470912	9.7E-05	1.1535794	0.00199
111	0.2819813	0.0005	7.7E-05	0.0003962	1E-06	1.467251	9.2E-05	0.7470482	9.7E-05	1.1533004	0.00199
112	0.2820296	0.0005	7.7E-05	0.0004011	9.5E-07	1.467237	0.0001	0.7470216	8.3E-05	1.1512813	0.00207
113	0.2819264	0.0005	7.8E-05	0.0004017	9.6E-07	1.4672948	0.0001	0.7470562	8.3E-05	1.154485	0.00204
114	0.2818604	0.0006	8.1E-05	0.0004041	1E-06	1.4673193	0.0001	0.7469288	7E-05	1.1568345	0.00227
115	0.2821929	0.0013	0.00018	0.0004251	1.8E-06	1.4672608	0.00016	0.7480527	0.0001	1.1522505	0.00346
116	0.2821108	0.0006	8.3E-05	0.0004155	1.2E-06	1.467344	0.00011	0.7474459	8.5E-05	1.1528724	0.00199
117	0.2819779	0.0006	8.4E-05	0.0004162	1.2E-06	1.4673104	0.00011	0.7474568	8.5E-05	1.1558845	0.00203
118	0.2819759	0.0006	9.1E-05	0.0004094	1E-06	1.4673027	9.3E-05	0.7472366	9E-05	1.1573105	0.00262
119	0.2820287	0.0007	9.6E-05	0.0004092	1E-06	1.4673298	9.3E-05	0.7472339	9E-05	1.1562798	0.00262
120	0.2819957	0.0006	8.4E-05	0.000405	1E-06	1.4673434	9.8E-05	0.7470564	8.6E-05	1.1547391	0.00175
121	0.2821181	0.0009	0.00013	0.0004065	1.4E-06	1.467424	0.00011	0.7473105	8.2E-05	1.1516635	0.00328
122	0.2821027	0.0005	7.4E-05	0.0004085	1.5E-06	1.4672903	0.00013	0.7472912	8.5E-05	1.1513164	0.00231
123	0.2821565	0.0005	7.4E-05	0.0004082	1.5E-06	1.4672614	0.00013	0.747328	8.5E-05	1.1505173	0.00232

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Appendix 1. (cont.) Lu and Hf isotopic results of the GJ-01 reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
124	0.2821401	0.0007	0.0001	0.0004133	1.2E-06	1.4672006	0.00011	0.7472876	8E-05	1.1524221	0.00301
125	0.2820514	0.0007	0.00011	0.000414	1.2E-06	1.4672097	0.00011	0.747275	8E-05	1.1534001	0.003
126	0.2820854	0.0007	0.0001	0.0004147	1.2E-06	1.4672976	0.00013	0.7472712	9.1E-05	1.1530554	0.00293
127	0.2820397	0.0007	0.0001	0.0004141	1.2E-06	1.4672586	0.00013	0.7472888	9.1E-05	1.1542532	0.00294
128	0.2820775	0.0009	0.00013	0.0004162	1.4E-06	1.4673101	0.00012	0.747213	9.6E-05	1.1512223	0.00281
129	0.2819233	0.0008	0.00012	0.0004129	1.3E-06	1.4672661	0.00011	0.747118	7.6E-05	1.1534791	0.00257
130	0.2819569	0.0008	0.00011	0.0004116	1.2E-06	1.4673051	0.00012	0.7472163	8.5E-05	1.1533096	0.00287
131	0.2819806	0.0008	0.00011	0.0004126	1.2E-06	1.4672985	0.00012	0.747235	8.5E-05	1.1543451	0.00288
132	0.2820725	0.0007	0.0001	0.0004109	1E-06	1.4672955	9.5E-05	0.7472557	8.4E-05	1.1531099	0.00291
133	0.2820672	0.0007	0.0001	0.0004104	1E-06	1.4672879	9.6E-05	0.7472907	8.4E-05	1.1541454	0.0029
134	0.2820222	0.0006	9.2E-05	0.0004101	1.6E-06	1.4672265	0.00012	0.7472913	0.00011	1.154516	0.00239
135	0.2820446	0.0006	9.2E-05	0.0004097	1.6E-06	1.4672125	0.00012	0.747296	0.00011	1.1532507	0.00239
136	0.2820397	0.0007	0.0001	0.0004072	1.2E-06	1.4672681	0.00011	0.7471514	9.1E-05	1.1533332	0.00281
137	0.2819734	0.0007	0.0001	0.0004085	1.2E-06	1.4672758	0.00011	0.7471039	9.1E-05	1.1554927	0.00282
138	0.281976	0.0008	0.00012	0.000419	1.4E-06	1.4673231	0.00013	0.7471164	8.6E-05	1.1536278	0.00299
139	0.2818838	0.0009	0.00013	0.0004131	1.3E-06	1.4674718	0.00014	0.7471568	0.0001	1.1567562	0.00335
140	0.2819605	0.0009	0.00013	0.0004201	1.4E-06	1.4673503	0.00015	0.7473401	9.7E-05	1.1554775	0.00299
141	0.2819937	0.0005	7.8E-05	0.0004095	8.7E-07	1.4671969	1E-04	0.7475387	7.6E-05	1.1543182	0.00186
142	0.2820131	0.0007	0.0001	0.0004192	1.5E-06	1.4672555	0.00014	0.7475113	0.0001	1.1547675	0.0028
143	0.2820453	0.0007	0.0001	0.0004089	1.6E-06	1.4673424	0.00012	0.7476168	8.7E-05	1.1535463	0.00238
144	0.2819602	0.0006	8.7E-05	0.0004128	9.4E-07	1.4673279	0.00011	0.7475183	7.5E-05	1.155485	0.00184
145	0.2819188	0.0008	0.00016	0.0004151	1.8E-06	1.4674304	0.00016	0.7477082	0.00012	1.1564742	0.00327
146	0.2819184	0.0006	8E-05	0.0004177	9E-07	1.4672709	9.4E-05	0.7476172	6.6E-05	1.1567809	0.00192
147	0.281915	0.0007	0.00011	0.0004109	1.6E-06	1.4673375	0.00012	0.7476084	9.1E-05	1.1569141	0.00315
148	0.2819941	0.0004	5.6E-05	0.0004095	7.2E-07	1.4673227	6.9E-05	0.7475465	5.8E-05	1.1543263	0.00138
149	0.2819881	0.0003	4.3E-05	0.0003912	5.5E-07	1.4672941	7.1E-05	0.7470349	6.8E-05	1.155452	0.00094
150	0.2819881	0.0003	4.3E-05	0.0003912	5.5E-07	1.4672941	7.1E-05	0.7470349	6.8E-05	1.155452	0.00094
151	0.2820318	0.0003	4.4E-05	0.0003914	5.6E-07	1.4672949	7.1E-05	0.7470328	6.9E-05	1.1540694	0.00095
152	0.2820318	0.0003	4.4E-05	0.0003914	5.6E-07	1.4672949	7.1E-05	0.7470328	6.9E-05	1.1540694	0.00095
153	0.2820194	0.0002	2.9E-05	0.0003706	1.3E-06	1.4673164	5.7E-05	0.7467824	5.5E-05	1.1532689	0.00073
154	0.2819775	0.0002	3.6E-05	0.0003712	1.1E-06	1.4673424	6.2E-05	0.746673	6.5E-05	1.1533777	0.00096
155	0.2817321	0.0002	2.8E-05	0.0003273	1.2E-06	1.4673519	5E-05	0.7456507	5.1E-05	1.1543369	0.00117
156	0.2817128	0.0002	3E-05	0.0003283	7.8E-07	1.4673136	5E-05	0.7454436	6.8E-05	1.1546483	0.00124
157	0.2817867	0.0002	3E-05	0.0003151	8.4E-07	1.4674161	5.3E-05	0.7458274	4.3E-05	1.1516204	0.00124
158	0.2817087	0.0002	3.4E-05	0.0003175	1.8E-06	1.4673213	5E-05	0.7456919	4.4E-05	1.1546827	0.00155
159	0.2819478	0.0003	4.9E-05	0.0003788	7.4E-07	1.4672698	5.7E-05	0.7469349	8.7E-05	1.1543556	0.00069
160	0.2819925	0.0003	4.6E-05	0.000366	1E-06	1.4672892	7.1E-05	0.7467836	9.8E-05	1.1537681	0.0008
161	0.2819613	0.0002	3.4E-05	0.0003707	1.4E-06	1.4673272	5.3E-05	0.7467028	6.4E-05	1.1539389	0.00074
162	0.281982	0.0002	3.6E-05	0.0003621	8.8E-07	1.4673125	5E-05	0.7467292	6.5E-05	1.153574	0.00075
163	0.2817093	0.0002	2.8E-05	0.000318	1.6E-06	1.46743	5.1E-05	0.7458511	4.3E-05	1.1542363	0.00127
164	0.2817093	0.0002	2.8E-05	0.000318	1.6E-06	1.46743	5.1E-05	0.7458511	4.3E-05	1.1542363	0.00127
165	0.2817327	0.0002	3.2E-05	0.0003211	9.8E-07	1.4673979	5.4E-05	0.7457742	4.9E-05	1.1538947	0.0015

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Appendix 1. (cont.) Lu and Hf isotopic results of the GJ-01 reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
166	0.2817184	0.0002	3.5E-05	0.0003157	1.4E-06	1.4673987	5.1E-05	0.7457198	3.8E-05	1.1546303	0.00191
167	0.2819789	0.0003	4.3E-05	0.0003828	1E-06	1.4673781	5.2E-05	0.7473039	6.5E-05	1.1547141	0.00115
168	0.2819974	0.0003	4.5E-05	0.0004081	9E-07	1.467331	6.8E-05	0.7473303	5.1E-05	1.1546083	0.001
169	0.281958	0.0002	3.1E-05	0.0003815	1.6E-06	1.467555	6.6E-05	0.7470147	5.3E-05	1.154372	0.00085
170	0.2819852	0.0003	4E-05	0.0003946	1.5E-06	1.467332	6.8E-05	0.7476878	5.3E-05	1.155206	0.001
171	0.2819888	0.0003	4.3E-05	0.00039	1.1E-06	1.4673991	6.4E-05	0.7474547	6.4E-05	1.154166	0.00113
172	0.2820083	0.0003	3.8E-05	0.0003935	1.4E-06	1.4674201	7.1E-05	0.7473977	6.8E-05	1.1544267	0.00115
173	0.2820365	0.0003	4.2E-05	0.0004015	1.7E-06	1.4673708	5.9E-05	0.7473234	4.9E-05	1.1538443	0.0009
174	0.2820207	0.0003	4.1E-05	0.0003952	1.8E-06	1.4673895	7.1E-05	0.7472604	6.2E-05	1.1533273	0.00105
175	0.2819955	0.0003	4.5E-05	0.0003903	1.5E-06	1.4673205	7.1E-05	0.7472998	6.9E-05	1.1545088	0.00108
176	0.2820029	0.0003	4.8E-05	0.0003897	8.5E-07	1.467336	7.4E-05	0.7472932	7.2E-05	1.1541558	0.00113
177	0.2820055	0.0002	3.4E-05	0.0003669	7.4E-07	1.4675236	6.2E-05	0.7468594	5.7E-05	1.1533434	0.00122
178	0.2819528	0.0003	4.1E-05	0.0003619	5.2E-07	1.4675998	6E-05	0.7466125	4.2E-05	1.1534873	0.00117
179	0.2819635	0.0003	4.4E-05	0.0003305	1.6E-06	1.4673012	6E-05	0.7434717	6.8E-05	1.1493567	0.00139
180	0.2820139	0.0003	4.2E-05	0.0003263	8.9E-07	1.467303	6.7E-05	0.7431333	5.3E-05	1.1462359	0.00149
181	0.2819748	0.0002	3.4E-05	0.0003253	1.3E-06	1.4673203	7.2E-05	0.7431558	6.3E-05	1.14715	0.00153
182	0.2819748	0.0002	3.4E-05	0.0003253	1.3E-06	1.4673203	7.2E-05	0.7431558	6.3E-05	1.14715	0.00153
183	0.2819935	0.0003	4E-05	0.0003336	1E-06	1.4672796	5.6E-05	0.7435846	6.5E-05	1.1486277	0.00105
184	0.2819842	0.0003	4.4E-05	0.0003301	1.6E-06	1.467294	6E-05	0.7434633	6.8E-05	1.1492098	0.00139
185	0.281893	0.0005	7.1E-05	0.0003494	8E-07	1.4679215	8.9E-05	0.7453156	6E-05	1.1487823	0.00213
186	0.2818853	0.0004	5.3E-05	0.0003405	5.9E-07	1.4679274	9.5E-05	0.7450652	7.7E-05	1.1478595	0.00175
187	0.2820562	0.0003	3.6E-05	0.0003391	6.3E-07	1.4682048	5.4E-05	0.7440791	5.2E-05	1.1484634	0.00099
188	0.2820574	0.0002	4.3E-05	0.0003358	8.7E-07	1.4682959	7.7E-05	0.7437902	7.5E-05	1.1481784	0.00167
189	0.2820392	0.0003	4E-05	0.0003375	6.4E-07	1.4682404	6.6E-05	0.7438905	7.5E-05	1.1498537	0.00122
190	0.2819942	0.0003	5.5E-05	0.0003533	1.4E-06	1.4681507	7E-05	0.7449222	6.9E-05	1.1496376	0.00199
191	0.2820518	0.0003	6E-05	0.0003534	1.5E-06	1.4681377	7.2E-05	0.7449536	6.8E-05	1.1474778	0.00206
192	0.2820479	0.0002	3.6E-05	0.0003402	6.6E-07	1.4682461	5.3E-05	0.7442904	5.9E-05	1.1484863	0.00153
193	0.2820856	0.0003	4E-05	0.0003376	6.4E-07	1.4682405	6.6E-05	0.7439031	7.5E-05	1.1494071	0.00122
194	0.2820856	0.0003	4E-05	0.0003376	6.4E-07	1.4682405	6.6E-05	0.7439031	7.5E-05	1.1494071	0.00122
195	0.2820188	0.0003	3.8E-05	0.0003423	8E-07	1.4682537	6.4E-05	0.7443656	6.6E-05	1.1499608	0.00115
196	0.2820576	0.0003	3.8E-05	0.0003391	6.7E-07	1.4682122	5.9E-05	0.7440741	5.7E-05	1.1489063	0.00105
197	0.282041	0.0002	3.6E-05	0.00034	6.6E-07	1.4682604	5.3E-05	0.7442768	5.9E-05	1.149172	0.00154
198	0.2820485	0.0003	4.2E-05	0.0003511	1.2E-06	1.4682614	5.9E-05	0.7441963	5.8E-05	1.1484982	0.00143
199	0.282047	0.0004	6.1E-05	0.000354	1.3E-06	1.4683129	6.9E-05	0.7449876	6.7E-05	1.1508861	0.00213
200	0.2820268	0.0004	6.3E-05	0.0003602	9.2E-07	1.4683639	6.7E-05	0.7448187	6.6E-05	1.1505658	0.00183
201	0.2820175	0.0004	6.3E-05	0.0003603	9.2E-07	1.4683298	6.7E-05	0.7448326	6.7E-05	1.1512234	0.00182
202	0.2820856	0.0003	4.6E-05	0.0003544	1.6E-06	1.4683093	8.4E-05	0.7448139	5.6E-05	1.1513522	0.00172
203	0.2821105	0.0003	4.5E-05	0.0003542	1.6E-06	1.468349	8.4E-05	0.7448205	5.6E-05	1.1492856	0.00168
204	0.2820511	0.0003	5E-05	0.0003539	8.9E-07	1.4683273	8.3E-05	0.7447736	5.5E-05	1.1488603	0.00164
205	0.2819903	0.0003	5E-05	0.0003542	8.8E-07	1.4683008	8.3E-05	0.7447437	5.5E-05	1.1509212	0.00164
206	0.2820522	0.0004	6.1E-05	0.0003628	1.3E-06	1.468249	6.7E-05	0.7447126	7.9E-05	1.1502276	0.00173
207	0.2820595	0.0004	6.1E-05	0.0003628	1.3E-06	1.4682403	6.6E-05	0.7447287	8E-05	1.1505542	0.00173

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Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
208	0.2820135	0.0004	5.5E-05	0.000371	9.4E-07	1.4682706	7E-05	0.7448319	6.7E-05	1.1506548	0.00191
209	0.2820666	0.0004	5.4E-05	0.0003708	9.5E-07	1.4682731	7E-05	0.7448155	6.7E-05	1.1496787	0.0019
210	0.2820979	0.0003	5.1E-05	0.0003752	7E-07	1.4682931	8E-05	0.7448883	6.7E-05	1.14921	0.00158
211	0.2820805	0.0003	5E-05	0.0003756	6.9E-07	1.4683112	7.9E-05	0.7448964	6.7E-05	1.149011	0.00158
212	0.2820587	0.0004	5.4E-05	0.0003758	6.1E-07	1.4682279	7.2E-05	0.7448639	6.4E-05	1.1497983	0.00197
213	0.2820405	0.0004	5.4E-05	0.0003757	6.1E-07	1.4682115	7.2E-05	0.7448719	6.4E-05	1.1504308	0.00197
214	0.2820225	0.0003	4.8E-05	0.0003767	6.4E-07	1.4682039	8.5E-05	0.7449114	6.8E-05	1.1497215	0.00182
215	0.2820377	0.0002	3.4E-05	0.0003446	9E-07	1.4683184	6.9E-05	0.7440402	5.4E-05	1.1494735	0.00107
216	0.282056	0.0002	3.6E-05	0.0003515	1.2E-06	1.4682877	6E-05	0.7439965	5.8E-05	1.1480574	0.00113
217	0.2820745	0.0002	3.6E-05	0.0003514	1.3E-06	1.4682821	6E-05	0.7440001	5.8E-05	1.1474688	0.00113
218	0.2821308	0.0003	4.6E-05	0.0003593	6.6E-07	1.4683335	6.3E-05	0.7439612	6E-05	1.1479885	0.00149
219	0.2821266	0.0003	4.6E-05	0.0003591	6.7E-07	1.4683259	6.3E-05	0.7439771	6.1E-05	1.1482969	0.0015
220	0.2820863	0.0003	4.6E-05	0.0003616	5.2E-07	1.468362	5.9E-05	0.7438827	7.2E-05	1.1488388	0.0014
221	0.282056	0.0003	4.6E-05	0.000362	5.3E-07	1.4683703	5.9E-05	0.743867	7.2E-05	1.1500457	0.00141
222	0.282141	0.0003	4E-05	0.0003624	5.3E-07	1.4683996	6E-05	0.7438917	5.1E-05	1.1469434	0.00157
223	0.2820809	0.0003	4.8E-05	0.0003678	5E-07	1.4682375	6.4E-05	0.7445135	6.3E-05	1.1486027	0.00141
224	0.28204	0.0003	4.6E-05	0.0003707	6.8E-07	1.4683106	6.8E-05	0.7446988	5.4E-05	1.149841	0.00156
225	0.2820481	0.0003	4.7E-05	0.0003709	6.9E-07	1.468313	6.8E-05	0.7447149	5.5E-05	1.1497134	0.00157
226	0.2820411	0.0003	4.6E-05	0.0003709	6.9E-07	1.4682394	8.3E-05	0.7447465	6E-05	1.1504474	0.00132
227	0.2821237	0.0004	5.9E-05	0.0003666	6.4E-07	1.4684046	6.7E-05	0.7444836	6.2E-05	1.1486209	0.00167
228	0.2821322	0.0003	4.5E-05	0.0003641	7.1E-07	1.4683252	6.6E-05	0.744307	5.7E-05	1.1484477	0.00145
229	0.2819252	0.0002	3E-05	0.0003318	8.5E-07	1.4719191	5.9E-05	0.7417691	5.3E-05	1.147827	0.0006
230	0.2818917	0.0002	3.1E-05	0.0003358	7.7E-07	1.4717115	5.8E-05	0.7419262	6.2E-05	1.1478052	0.00082
231	0.2817919	0.0003	4.1E-05	0.0003616	8.4E-07	1.4718297	7.3E-05	0.7408948	5.6E-05	1.1480763	0.00147
232	0.2817982	0.0002	3.4E-05	0.0003585	3.8E-07	1.4714794	7.8E-05	0.7411577	7.9E-05	1.1476771	0.00095
233	0.2818017	0.0002	3.4E-05	0.0003589	3.8E-07	1.4714658	7.8E-05	0.7411674	7.9E-05	1.1477044	0.00094
234	0.2818012	0.0003	3.7E-05	0.0003556	6.1E-07	1.4702011	6E-05	0.7428449	7.4E-05	1.1492496	0.0011
235	0.2817773	0.0002	2.6E-05	0.0003503	3.6E-07	1.4700538	5.2E-05	0.7430457	4.4E-05	1.1502927	0.00073
236	0.2818462	0.0002	2.4E-05	0.0003488	6.4E-07	1.4700339	5.2E-05	0.7430317	5E-05	1.1489179	0.0007
237	0.281816	0.0002	2.9E-05	0.0003479	7.4E-07	1.4701903	5.5E-05	0.7427176	5.9E-05	1.1486301	0.00092
238	0.281808	0.0002	3.2E-05	0.0003473	9.2E-07	1.4702317	5.5E-05	0.7427255	6E-05	1.1491559	0.00078
239	0.2817559	0.0003	4.3E-05	0.0003499	6.9E-07	1.4701469	5.3E-05	0.7428239	5.6E-05	1.1501492	0.00124
240	0.2818147	0.0003	4.9E-05	0.0003329	1.2E-06	1.4727938	7.7E-05	0.740474	8.1E-05	1.1477373	0.00156
241	0.2819434	0.0003	4E-05	0.0003815	6.1E-07	1.4705536	7.6E-05	0.743452	6.1E-05	1.1492657	0.00141
242	0.2818917	0.0002	3.6E-05	0.0003739	1.3E-06	1.4705272	6.8E-05	0.7434526	5.8E-05	1.1490285	0.00111
243	0.2818438	0.0002	3.6E-05	0.0003785	5.6E-07	1.4705466	6.5E-05	0.7434335	4.9E-05	1.1506203	0.0011
244	0.2819227	0.0004	5.7E-05	0.0003805	7.8E-07	1.4706739	7.8E-05	0.7434137	5.7E-05	1.1498694	0.00169
245	0.2818702	0.0002	3.4E-05	0.0003788	6E-07	1.4705127	5.8E-05	0.7434385	4.7E-05	1.1505159	0.00096
246	0.2819017	0.0002	3.3E-05	0.0003789	4.9E-07	1.4705571	5.5E-05	0.7434445	5E-05	1.1499504	0.00114
247	0.2818564	0.0003	4E-05	0.0003803	7.6E-07	1.4704644	6.2E-05	0.7434881	6.2E-05	1.1492507	0.0009
248	0.281775	0.0002	3.6E-05	0.0003486	9.1E-07	1.4724287	7.1E-05	0.7408936	5.8E-05	1.1493181	0.00142
249	0.2817313	0.0003	3.7E-05	0.0003413	1.5E-06	1.4737086	8.2E-05	0.7393599	6.8E-05	1.1468905	0.00137

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Appendix 1. (cont.) Lu and Hf isotopic results of the GJ-01 reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
250	0.2817578	0.0004	5.4E-05	0.0003354	1.6E-06	1.4735648	7.6E-05	0.7397181	7.9E-05	1.1487509	0.00218
251	0.2817295	0.0003	3.8E-05	0.0003336	1.4E-06	1.4746532	0.00011	0.7382963	9.5E-05	1.1462622	0.00137
252	0.2818147	0.0003	4.9E-05	0.0003329	1.2E-06	1.4727938	7.7E-05	0.740474	8.1E-05	1.1477373	0.00156
253	0.2819434	0.0003	4E-05	0.0003815	6.1E-07	1.4705536	7.6E-05	0.743452	6.1E-05	1.1492657	0.00141
254	0.2818006	0.0002	2.7E-05	0.0003513	1.3E-06	1.4718689	4.7E-05	0.7415629	5E-05	1.1495607	0.00094
255	0.2818197	0.0002	3.4E-05	0.0003425	4.9E-07	1.4722962	6E-05	0.7408805	6.9E-05	1.1478071	0.00123
256	0.2818885	0.0003	4.4E-05	0.0003606	7.4E-07	1.4705337	6.4E-05	0.7432805	5.5E-05	1.1495821	0.00104
257	0.2818854	0.0002	3.1E-05	0.0003733	4.8E-07	1.4705369	6.3E-05	0.7432228	5.2E-05	1.1497575	0.00112
258	0.2818539	0.0003	3.9E-05	0.0003734	5.7E-07	1.4706185	7.6E-05	0.7432007	5.8E-05	1.1496016	0.00101
259	0.281891	0.0002	3.2E-05	0.0003719	4.4E-07	1.470584	6E-05	0.7431082	4.6E-05	1.149402	0.00099
260	0.2818916	0.0003	3.9E-05	0.0003566	6.6E-07	1.4714371	5.7E-05	0.742175	4.4E-05	1.1481623	0.00093
261	0.2818801	0.0003	3.6E-05	0.0003619	1.2E-06	1.4707814	6.2E-05	0.7430709	5.6E-05	1.1496047	0.00104
262	0.2818666	0.0003	4.6E-05	0.0003558	1.6E-06	1.4706775	5.8E-05	0.7431144	6.3E-05	1.1504549	0.00128
263	0.2818973	0.0003	4.8E-05	0.000352	6.5E-07	1.4707176	6.9E-05	0.7431026	6E-05	1.1503522	0.00134
264	0.2819032	0.0003	4.4E-05	0.0004091	6.5E-07	1.4670489	5.8E-05	0.7459641	5E-05	1.1528927	0.00098
265	0.2819582	0.0003	4.6E-05	0.0003631	5.9E-07	1.4672551	5.3E-05	0.7448868	4.6E-05	1.150187	0.00138
266	0.2819341	0.0003	5E-05	0.0003537	8.4E-07	1.467218	6.2E-05	0.744903	4.5E-05	1.1507936	0.00148
267	0.2819326	0.0003	5E-05	0.0003539	8.3E-07	1.4672155	6.2E-05	0.7449178	4.6E-05	1.1510217	0.00148
268	0.281943	0.0003	3.8E-05	0.0003473	1.2E-06	1.4672597	6.9E-05	0.7449467	6.3E-05	1.1510984	0.00147
269	0.2819536	0.0003	3.9E-05	0.000352	7.5E-07	1.4672308	6.4E-05	0.74493	4.1E-05	1.1514526	0.00116
270	0.281988	0.0002	3.7E-05	0.0003476	7.2E-07	1.4672962	6.5E-05	0.7450159	5E-05	1.1513451	0.00136
271	0.2819806	0.0002	3.7E-05	0.0003475	7.2E-07	1.4672899	6.5E-05	0.7450172	5E-05	1.1514353	0.00136
272	0.2819251	0.0003	4.2E-05	0.0003453	5.2E-07	1.4672407	6.7E-05	0.7450475	4.5E-05	1.1519918	0.00128
273	0.2820324	0.0002	3.6E-05	0.0003911	1.6E-06	1.4673831	6.6E-05	0.7474651	5.8E-05	1.1532657	0.00104
274	0.2820012	0.0003	4.6E-05	0.0003851	1.4E-06	1.4673319	6.9E-05	0.7472999	4.9E-05	1.1539217	0.00097

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Appendix 2. Lu and Hf isotopic results of the Mud Tank reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
1	0.2823757	0.00033	4.8E-05	5.04E-05	3.7E-07	1.4672605	7.5E-05	0.7456398	0.0001	1.163558	0.009384
2	0.2823757	0.00033	4.8E-05	5.04E-05	3.7E-07	1.4672605	7.5E-05	0.7456398	0.0001	1.163558	0.009384
3	0.2824087	0.00042	6.1E-05	4.72E-05	4E-07	1.4672853	9.3E-05	0.7454487	0.00011	1.161601	0.009664
4	0.2824547	0.00019	2.7E-05	4.13E-05	3.9E-07	1.4673041	5.3E-05	0.7451296	4.6E-05	1.148874	0.007482
5	0.2824389	0.00033	4.8E-05	4.7E-05	5.6E-07	1.4672846	9E-05	0.7453869	0.00011	1.161906	0.010222
6	0.2824423	0.00037	5.3E-05	4.66E-05	4.7E-07	1.4672935	7.5E-05	0.7455218	5.8E-05	1.161743	0.013601
7	0.2818941	0.00037	5.6E-05	0.001157	7.5E-05	1.4671476	0.0001	0.7454424	6.3E-05	1.150916	0.001086
8	0.2825156	0.00029	4.5E-05	3.16E-05	5E-07	1.4672919	7.1E-05	0.7456469	7.3E-05	1.141644	0.017415
9	0.28247	0.00031	4.6E-05	4.6E-05	4.6E-07	1.4672771	7.3E-05	0.7454859	5.8E-05	1.150062	0.0143
10	0.2822246	0.00033	4.9E-05	0.000297	8.2E-07	1.4672971	9.1E-05	0.7453463	5.9E-05	1.150538	0.003588
11	0.282463	0.00029	4.2E-05	4.02E-05	4.2E-07	1.4672636	7.2E-05	0.7458086	7.7E-05	1.150445	0.014643
12	0.2824812	0.00026	3.7E-05	4.82E-05	4.5E-07	1.4672582	8.6E-05	0.7458616	5E-05	1.147977	0.010151
13	0.2824812	0.00026	3.7E-05	4.82E-05	4.5E-07	1.4672582	8.6E-05	0.7458616	5E-05	1.147977	0.010151
14	0.2824146	0.0002	2.9E-05	5.25E-05	3.4E-07	1.4672746	7.3E-05	0.7454196	6E-05	1.155942	0.007638
15	0.2824603	0.00033	4.7E-05	4.91E-05	4.5E-07	1.4673512	7.1E-05	0.7449968	6E-05	1.152992	0.011677
16	0.2824463	0.00025	3.6E-05	5.1E-05	4.9E-07	1.4673048	7.2E-05	0.7454879	7.1E-05	1.156869	0.008724
17	0.2819759	0.00038	5.4E-05	0.000344	7.5E-07	1.4672253	7.7E-05	0.7455685	5.4E-05	1.151755	0.002359
18	0.2824551	0.00023	3.4E-05	4.61E-05	4.7E-07	1.4672764	7.3E-05	0.7460121	4.7E-05	1.154723	0.010688
19	0.2824507	0.00026	3.8E-05	5.17E-05	3.6E-07	1.4672779	5.6E-05	0.7459388	5.7E-05	1.157651	0.009507
20	0.2824306	0.00029	4.2E-05	4.19E-05	3.7E-07	1.4672432	6.5E-05	0.7459014	6.4E-05	1.165106	0.010681
21	0.2824301	0.00034	4.9E-05	4.75E-05	4.4E-07	1.4672975	7.5E-05	0.7459422	5.9E-05	1.163914	0.010439
22	0.2824071	0.00027	3.9E-05	4.62E-05	4.3E-07	1.4673125	6.5E-05	0.7459839	5.8E-05	1.165131	0.011593
23	0.2824798	0.00022	3.1E-05	4.24E-05	2.6E-07	1.4672825	6.1E-05	0.74581	6.5E-05	1.149044	0.008339
24	0.2824027	0.00026	3.7E-05	4.41E-05	3.9E-07	1.4672549	6.6E-05	0.7460912	5E-05	1.154086	0.009262
25	0.2820081	0.00114	0.00016	0.000235	2.2E-06	1.4672879	0.00016	0.7465973	0.00012	1.161932	0.007354
26	0.2819035	0.00058	8.4E-05	0.001094	2E-05	1.4671502	0.00014	0.7465858	0.00013	1.153221	0.00164
27	0.282113	0.00066	0.0001	0.001485	5.2E-05	1.4673262	0.00018	0.746739	0.00013	1.151565	0.001786
29	0.2823933	0.0008	0.00012	3.19E-05	1.2E-06	1.4671984	0.0001	0.7468613	0.0001	1.185863	0.034011
30	0.2820262	0.00097	0.00014	0.001899	0.00011	1.4673908	0.00014	0.7466978	0.00013	1.153284	0.00126
31	0.2823476	0.00051	7.6E-05	3.38E-05	1.2E-06	1.4673354	8.9E-05	0.7431533	7.9E-05	1.151043	0.016485
32	0.2826091	0.00133	0.0002	3E-05	2E-06	1.4675401	0.00017	0.7441672	0.00017	1.093533	0.056827
33	0.282532	0.00089	0.00013	3.22E-05	1.3E-06	1.46739	0.00013	0.7440171	0.0001	1.129409	0.028191
34	0.2824683	0.00062	8.9E-05	5E-05	8.3E-07	1.4673347	1E-04	0.7466111	8.5E-05	1.150294	0.01388
35	0.2824436	0.00032	4.6E-05	4.32E-05	4.3E-07	1.467266	6.3E-05	0.7457101	5.5E-05	1.14168	0.009819
36	0.2824912	0.00058	8.4E-05	4.87E-05	9.1E-07	1.4674441	9.3E-05	0.7465745	7.7E-05	1.152594	0.015194
37	0.2825578	0.0006	8.7E-05	4.76E-05	9.9E-07	1.4672018	0.00012	0.7466723	9.4E-05	1.142091	0.014536
38	0.2824332	0.00049	7.1E-05	4.84E-05	1E-06	1.4673863	0.00012	0.7466192	9E-05	1.159017	0.013797
39	0.2828507	0.0015	0.00022	4.92E-05	2.4E-06	1.4684494	0.00016	0.7445817	0.00017	1.196863	0.071893
40	0.2825217	0.00054	7.7E-05	4.75E-05	7.4E-07	1.4674613	7.9E-05	0.7468862	7.4E-05	1.14038	0.01207
41	0.2824481	0.00094	0.00013	5.54E-05	1E-06	1.4672934	0.00013	0.7480054	9.8E-05	1.165391	0.017349
42	0.2824309	0.00047	6.7E-05	4.81E-05	8.4E-07	1.4673559	8.4E-05	0.7473517	7.5E-05	1.143851	0.010624

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Appendix 2. (cont.) Lu and Hf isotopic results of the Mud Tank reference material.

Analysis	^{176}Hf/^{177}Hf	2SD	2SE	^{176}Lu/^{177}Hf	2SE	^{178}Hf/^{177}Hf	2SE	^{179}Hf/^{177}Hf	2SE	^{173}Yb/^{171}Yb	2SE
43	0.2825577	0.00032	6.6E-05	4.9E-05	1.1E-06	1.4674996	9.5E-05	0.746635	0.00011	1.142975	0.011712
44	0.2824594	0.00042	6.1E-05	5.02E-05	8E-07	1.4675452	8E-05	0.7466127	7.3E-05	1.148926	0.012734
45	0.2825522	0.00079	0.00011	5.4E-05	1.2E-06	1.4671629	0.00012	0.7479995	9E-05	1.14659	0.017031
46	0.2824248	0.00051	7.3E-05	4.92E-05	6.6E-07	1.4673788	9.7E-05	0.7471415	5.7E-05	1.155757	0.010965
47	0.2825301	0.00059	8.4E-05	5.07E-05	8.1E-07	1.4673982	9.9E-05	0.7476434	7.9E-05	1.148195	0.014503
48	0.2825093	0.0005	7.3E-05	5.06E-05	8.6E-07	1.4672393	0.00011	0.7477726	8.1E-05	1.157392	0.012537
49	0.2825816	0.00046	6.7E-05	5.32E-05	8.7E-07	1.4673735	0.00011	0.7475129	7.7E-05	1.140188	0.010798
50	0.2824435	0.00067	9.5E-05	5.21E-05	7.6E-07	1.4673968	0.00012	0.7474437	8E-05	1.16435	0.014721
51	0.282583	0.0005	7.2E-05	5.57E-05	7.9E-07	1.4673755	0.00011	0.7479159	7.7E-05	1.149777	0.008072
52	0.2824462	0.00056	8.1E-05	4.99E-05	7.7E-07	1.4672898	8.4E-05	0.747609	8.3E-05	1.156744	0.01146
53	0.2825275	0.00053	7.7E-05	4.98E-05	6.6E-07	1.467358	0.0001	0.7471773	7.1E-05	1.146333	0.011961
54	0.2824227	0.0005	7.2E-05	5.21E-05	6.5E-07	1.4672258	8.6E-05	0.7472028	8.1E-05	1.164432	0.011541
55	0.2824556	0.00049	7.2E-05	4.73E-05	6.8E-07	1.4673096	8.1E-05	0.7470934	7.2E-05	1.156048	0.0142
56	0.282536	0.00048	6.9E-05	4.82E-05	6.2E-07	1.4672647	9.3E-05	0.7470576	6.6E-05	1.142855	0.011636
57	0.2825	0.00053	7.6E-05	4.82E-05	8.1E-07	1.4673369	8.8E-05	0.7470052	7E-05	1.150342	0.011218
58	0.2824373	0.00058	8.2E-05	4.87E-05	8E-07	1.4673563	0.0001	0.7470059	7.7E-05	1.173355	0.015758
59	0.2824998	0.00043	6.2E-05	4.7E-05	7.1E-07	1.4673601	0.0001	0.7469494	7E-05	1.156192	0.012805
60	0.2824483	0.00043	6.3E-05	5.15E-05	6.5E-07	1.4672025	7.6E-05	0.7469535	6.3E-05	1.159212	0.011795
61	0.2824221	0.00081	0.00011	5.69E-05	1.3E-06	1.4672992	0.00015	0.747969	8.8E-05	1.168491	0.016422
62	0.2826139	0.00054	7.8E-05	5.37E-05	8.3E-07	1.4672904	0.00011	0.7474523	6.7E-05	1.143535	0.011905
63	0.2824126	0.00046	6.8E-05	4.81E-05	6.6E-07	1.4671987	8.5E-05	0.747203	8.3E-05	1.160345	0.011902
64	0.2824357	0.00068	9.8E-05	4.87E-05	9.4E-07	1.4672939	0.0001	0.7473003	9.6E-05	1.151878	0.012814
65	0.282501	0.00062	9E-05	5.31E-05	9.2E-07	1.4672559	0.00011	0.747222	7.5E-05	1.144434	0.013514
66	0.2825754	0.00054	7.8E-05	4.64E-05	8.1E-07	1.4673445	0.0001	0.7472627	8.2E-05	1.134759	0.016602
67	0.2825341	0.00056	8E-05	5.09E-05	1.1E-06	1.4673431	0.00012	0.7472096	8E-05	1.144861	0.013038
68	0.2825358	0.00058	8.4E-05	4.67E-05	9.1E-07	1.4672891	0.00011	0.7471601	0.00011	1.139182	0.016558
69	0.2825215	0.00062	9.1E-05	5.13E-05	9.7E-07	1.4673392	0.00012	0.7471305	8E-05	1.147901	0.015937
70	0.2824822	0.00053	7.5E-05	5.34E-05	9.8E-07	1.4673254	0.0001	0.7472175	7.1E-05	1.152412	0.012281
71	0.2824393	0.00052	7.7E-05	5.22E-05	1E-06	1.4673392	9.4E-05	0.747248	9.7E-05	1.155658	0.014085
72	0.2825613	0.00042	6.3E-05	5.79E-05	9.3E-07	1.4672198	9.2E-05	0.747175	7.7E-05	1.144123	0.012179
73	0.2824039	0.00055	8.1E-05	5.68E-05	9.1E-07	1.4673523	0.0001	0.7470852	7.5E-05	1.159649	0.012414
74	0.2825029	0.0005	7.3E-05	4.76E-05	6.1E-07	1.467253	7.3E-05	0.7476013	6.2E-05	1.157005	0.011143
75	0.2824634	0.00078	0.00012	5.63E-05	1.7E-06	1.4673404	0.00015	0.7474788	9E-05	1.161957	0.015034
76	0.2825294	0.00092	0.00013	4.73E-05	1.3E-06	1.4673684	0.00014	0.7478906	0.00013	1.145816	0.018534
77	0.2824056	0.0007	9.9E-05	4.54E-05	9.2E-07	1.4674451	0.00011	0.7475877	9.2E-05	1.159408	0.016111
78	0.2825031	0.00019	2.7E-05	5.09E-05	3.7E-07	1.4673618	5E-05	0.7469931	6.6E-05	1.152064	0.005447
79	0.2824836	0.00018	2.6E-05	3.84E-05	2E-07	1.4672992	4.9E-05	0.7468983	3.6E-05	1.148101	0.004497
80	0.2824731	0.00019	2.7E-05	6.39E-05	2.5E-07	1.4673086	4E-05	0.7467679	4.5E-05	1.15414	0.002279
81	0.2822212	0.00016	2.3E-05	4.64E-05	2.2E-07	1.467325	4.4E-05	0.745612	4.8E-05	1.151185	0.004547
82	0.2821948	0.00017	2.5E-05	4.75E-05	2.7E-07	1.467359	4.7E-05	0.7458604	5E-05	1.16121	0.005681
83	0.2824875	0.00016	2.4E-05	6E-05	2.7E-07	1.4673142	4.9E-05	0.7469328	5.5E-05	1.152114	0.002344

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Appendix 2. (cont.) Lu and Hf isotopic results of the Mud Tank reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
84	0.2824995	0.00021	3.1E-05	5.74E-05	2.8E-07	1.4672994	4.5E-05	0.7467244	5.5E-05	1.151575	0.003409
85	0.2822104	0.00019	2.7E-05	5.04E-05	2.9E-07	1.4673643	4.4E-05	0.7458079	4E-05	1.157416	0.006229
86	0.2822039	0.00017	2.4E-05	4.75E-05	2.6E-07	1.4673468	4.8E-05	0.7455503	4.8E-05	1.15605	0.005291
87	0.2824983	0.00022	3.2E-05	5.75E-05	3.5E-07	1.4673864	5.8E-05	0.7473761	4.4E-05	1.149996	0.003606
88	0.2824232	0.00019	2.7E-05	5.53E-05	2.1E-07	1.4675633	5.2E-05	0.7468158	4.4E-05	1.155628	0.002736
89	0.2824769	0.00021	3E-05	6.17E-05	2.7E-07	1.4673358	5.6E-05	0.7475116	6.6E-05	1.155786	0.003404
90	0.2824532	0.00019	2.8E-05	5.21E-05	2.7E-07	1.4673491	5.6E-05	0.7473155	4.5E-05	1.157889	0.003575
91	0.282462	0.00026	3.7E-05	5.31E-05	3E-07	1.4674218	5.7E-05	0.7472658	4.6E-05	1.152991	0.005479
92	0.2824538	0.00016	2.5E-05	5.09E-05	1.9E-07	1.4675215	5E-05	0.7467413	4.7E-05	1.150957	0.003043
93	0.2825238	0.00022	3.2E-05	3.89E-05	3.3E-07	1.467284	6.7E-05	0.7433921	5.1E-05	1.139338	0.00763
94	0.2825298	0.00019	2.8E-05	5.24E-05	2.3E-07	1.467283	5.5E-05	0.7434051	5.1E-05	1.137659	0.005231
95	0.2824563	0.00023	3.3E-05	5.21E-05	3.1E-07	1.4672144	6E-05	0.7434603	4.5E-05	1.155252	0.004839
96	0.2823249	0.00038	5.5E-05	5.62E-05	5.7E-07	1.4678646	6.6E-05	0.7452932	7.2E-05	1.152965	0.009966
97	0.2825432	0.00022	3.2E-05	3.94E-05	3.2E-07	1.4682201	5.8E-05	0.7439147	4.9E-05	1.146836	0.007278
98	0.2825534	0.00025	3.5E-05	3.39E-05	3.1E-07	1.4682719	5.8E-05	0.7436879	5.6E-05	1.143407	0.008115
99	0.2824777	0.00027	3.8E-05	4.16E-05	2.5E-07	1.4682334	6.4E-05	0.7444103	5.2E-05	1.147072	0.007893
100	0.2825325	0.00018	2.6E-05	4.15E-05	2.7E-07	1.4682471	5.7E-05	0.7438126	5.5E-05	1.148415	0.006255
101	0.2824734	0.0002	3E-05	3.53E-05	2.3E-07	1.4681829	6.2E-05	0.7441618	6.6E-05	1.148773	0.008646
102	0.2825286	0.00024	3.4E-05	3.63E-05	3.1E-07	1.468217	5.7E-05	0.7442406	5.7E-05	1.14291	0.008835
103	0.2825608	0.00032	4.7E-05	5.65E-05	3.4E-07	1.4683071	6.8E-05	0.7449497	5.4E-05	1.147028	0.00828
104	0.2825137	0.00028	4.1E-05	5.64E-05	4E-07	1.4683113	6E-05	0.7448721	5.9E-05	1.149862	0.006734
105	0.2825447	0.0003	4.4E-05	4.41E-05	3.9E-07	1.4682638	6.9E-05	0.7447997	6.2E-05	1.154026	0.010218
106	0.2825537	0.00027	3.9E-05	4.21E-05	3.8E-07	1.46835	6.5E-05	0.7448676	5.6E-05	1.145838	0.008784
107	0.2825601	0.00027	3.9E-05	5.09E-05	4.3E-07	1.4683509	6.6E-05	0.7448541	5E-05	1.151661	0.006364
108	0.2824832	0.00024	3.5E-05	5.61E-05	4.7E-07	1.4682554	5.9E-05	0.7448833	5.4E-05	1.158053	0.007266
109	0.2826031	0.00028	4E-05	6.03E-05	3.8E-07	1.4682952	7.6E-05	0.7449683	4.7E-05	1.140451	0.006072
110	0.2825345	0.00028	4E-05	5.43E-05	4E-07	1.4682776	6.1E-05	0.7448712	6.1E-05	1.146391	0.007158
111	0.282536	0.00024	3.6E-05	5E-05	3.5E-07	1.4682609	4.9E-05	0.7440926	5.6E-05	1.15038	0.00597
112	0.2825338	0.00022	3.2E-05	5.44E-05	3E-07	1.4682723	5.8E-05	0.744077	5.4E-05	1.14902	0.005139
113	0.2825956	0.00026	3.7E-05	5.81E-05	3.2E-07	1.4682996	5.4E-05	0.7439825	4.7E-05	1.143039	0.005451
114	0.2825652	0.00022	3.1E-05	4.88E-05	3.4E-07	1.468291	5.5E-05	0.7438962	5.7E-05	1.143687	0.006221
115	0.2825046	0.00023	3.3E-05	4.7E-05	4E-07	1.4682409	5.8E-05	0.7447219	5E-05	1.149791	0.00554
116	0.2825421	0.00022	3.2E-05	4.91E-05	3.6E-07	1.4682744	5.3E-05	0.7447353	5.5E-05	1.150672	0.006203
117	0.2825014	0.00023	3.3E-05	4.79E-05	3.4E-07	1.4682786	6.1E-05	0.744489	6.2E-05	1.154174	0.006049
118	0.2822975	0.00018	2.5E-05	3.81E-05	2.2E-07	1.4682537	4.9E-05	0.7444588	4.8E-05	1.153593	0.005797
119	0.2822319	0.00021	3.1E-05	5.39E-05	3.6E-07	1.4717816	6.8E-05	0.741021	5.9E-05	1.15322	0.006492
120	0.2823199	0.00033	4.7E-05	3.7E-05	4.3E-07	1.4713415	6.5E-05	0.7413726	6.9E-05	1.143806	0.011297
121	0.2822412	0.00016	2.3E-05	3.75E-05	1.8E-07	1.4700796	4.5E-05	0.7430268	5.3E-05	1.146972	0.004231
122	0.2822903	0.00016	2.3E-05	3.47E-05	1.9E-07	1.4700549	5.1E-05	0.7429493	5.7E-05	1.145372	0.004852
123	0.2822866	0.00015	2.2E-05	3.77E-05	1.8E-07	1.4702115	4.1E-05	0.7427648	4.5E-05	1.147873	0.004251
124	0.2822662	0.00024	3.6E-05	5.37E-05	4.4E-07	1.4727107	6.3E-05	0.7405248	7.2E-05	1.147661	0.007323

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Appendix 2. (cont.) Lu and Hf isotopic results of the Mud Tank reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
125	0.2823431	0.00019	2.8E-05	3.4E-05	2.6E-07	1.4705566	4.9E-05	0.7434015	4.4E-05	1.155406	0.006814
126	0.2823101	0.00018	2.7E-05	6.03E-05	3E-07	1.4706625	5.7E-05	0.7433769	4.4E-05	1.150555	0.004235
127	0.2823612	0.00029	4.2E-05	5.22E-05	2.6E-07	1.4705184	6.8E-05	0.7435044	8.2E-05	1.148172	0.005852
128	0.2822838	0.00021	3E-05	3.91E-05	2.1E-07	1.4726007	4.7E-05	0.7408345	5.2E-05	1.144065	0.006918
129	0.2822318	0.00027	3.9E-05	4.47E-05	2.9E-07	1.4736689	6.2E-05	0.739525	7.3E-05	1.145377	0.007148
130	0.2822662	0.00024	3.6E-05	5.37E-05	4.4E-07	1.4727107	6.3E-05	0.7405248	7.2E-05	1.147661	0.007323
131	0.2823534	0.00022	3.2E-05	3.77E-05	2.4E-07	1.4718043	6.5E-05	0.7416873	6.9E-05	1.14873	0.007068
132	0.2823207	0.00024	3.5E-05	3.18E-05	2.4E-07	1.4705941	6E-05	0.7432641	6E-05	1.160391	0.007058
133	0.2823476	0.00022	3.1E-05	3.88E-05	2.3E-07	1.4707091	6.4E-05	0.7431147	4.3E-05	1.153329	0.005861
134	0.2823429	0.00025	3.6E-05	2.97E-05	3E-07	1.470773	5E-05	0.7431218	4.9E-05	1.161495	0.009992
135	0.2823761	0.00028	4E-05	3.75E-05	2.8E-07	1.4707988	5.9E-05	0.7431121	3.7E-05	1.147943	0.009077
140	0.2823504	0.00037	5.3E-05	6.28E-05	4.7E-07	1.4671816	7.1E-05	0.7454893	6.3E-05	1.158313	0.006932
141	0.2823874	0.00032	4.6E-05	4.88E-05	4.3E-07	1.4671692	5.3E-05	0.7447666	5.4E-05	1.15629	0.00743
142	0.2823945	0.00025	3.7E-05	4.43E-05	3.9E-07	1.4672627	5.7E-05	0.7447901	4.5E-05	1.149694	0.008273
143	0.282474	0.00026	3.8E-05	4.97E-05	3.5E-07	1.4672988	6E-05	0.7447673	4.5E-05	1.148009	0.005667
144	0.2824576	0.00032	4.6E-05	4.92E-05	5E-07	1.4672857	6E-05	0.7448957	4.8E-05	1.153432	0.009192
145	0.2826907	0.0009	0.00013	4.55E-05	1.3E-06	1.4682913	0.00011	0.7443607	0.00011	1.193646	0.038126
146	0.2829201	0.00073	0.00011	4.42E-05	1.6E-06	1.4684549	0.00012	0.7442077	9.4E-05	1.138062	0.045156
147	0.2828737	0.00035	4.9E-05	4.22E-05	6.8E-07	1.468332	9.2E-05	0.7427606	6.1E-05	1.140098	0.017208
148	0.2828082	0.00037	5.2E-05	4.26E-05	6.9E-07	1.4683547	9.2E-05	0.7427618	6.1E-05	1.158599	0.017501
149	0.2828408	0.0004	5.7E-05	4.32E-05	7.5E-07	1.4683179	8.8E-05	0.7430975	6.6E-05	1.139279	0.020406
150	0.2828921	0.00041	6E-05	4.87E-05	8.6E-07	1.4683611	8.5E-05	0.7434204	7E-05	1.127886	0.023235
151	0.2828947	0.00057	8.2E-05	4.06E-05	8.3E-07	1.468241	0.00018	0.743521	0.00036	1.124121	0.030424
152	0.2821093	0.00446	0.00066	#NÚM!	#NÚM!	1.467883	0.0004	0.7445922	0.00024	1.543245	0.366477
153	0.2828405	0.0009	0.00013	4.1E-05	1.6E-06	1.4684028	0.00014	0.7442289	9.9E-05	1.150813	0.052548
154	0.282767	0.00086	0.00012	4.23E-05	1.5E-06	1.4683657	0.00015	0.7442717	0.0001	1.181153	0.046246
155	0.2827124	0.00116	0.00017	4.42E-05	2.1E-06	1.4684082	0.00017	0.744377	0.00013	1.211336	0.051441
156	0.2825967	0.00125	0.00018	4.77E-05	1.8E-06	1.4681695	0.00013	0.7443901	0.00013	1.274325	0.061353
157	0.2828041	0.00128	0.00018	4.03E-05	2.4E-06	1.4683971	0.00017	0.7444467	0.00012	1.151948	0.064082
158	0.2827346	0.00133	0.00019	4.27E-05	1.8E-06	1.4683396	0.00018	0.7443565	0.00015	1.198007	0.073006
159	0.2828282	0.0006	8.6E-05	3.94E-05	8.8E-07	1.4682769	1E-04	0.743506	7.4E-05	1.157099	0.028637
160	0.2829777	0.00054	7.9E-05	4.28E-05	8.8E-07	1.4684702	9.4E-05	0.7435529	6.3E-05	1.11237	0.023182
161	0.2828407	0.00055	7.9E-05	4.32E-05	8E-07	1.4686453	9.6E-05	0.7428783	6.7E-05	1.148755	0.025811
162	0.2829351	0.0004	5.8E-05	4.82E-05	8.3E-07	1.4686982	9.1E-05	0.742814	6.4E-05	1.143711	0.013478
163	0.2829434	0.00041	5.9E-05	4.21E-05	8.6E-07	1.4686765	8.4E-05	0.7428492	8.4E-05	1.127996	0.017937
164	0.2828151	0.00038	5.4E-05	4.32E-05	5.6E-07	1.4684879	7E-05	0.7429572	5.3E-05	1.150316	0.014425
165	0.2828514	0.00055	8.1E-05	4E-05	9.1E-07	1.4687134	9.7E-05	0.7428781	7.3E-05	1.154647	0.028305
166	0.2824759	0.00027	3.9E-05	6.51E-05	2.9E-07	1.4673296	5E-05	0.7474126	6.8E-05	1.155149	0.003053

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Appendix 3. Lu and Hf isotopic results of the 91500-reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
1	0.2822453	0.00047	6.9E-05	0.0003042	1E-06	1.4673204	0.00011	0.745555	9.4E-05	1.1544633	0.00407
2	0.2822453	0.00047	6.9E-05	0.0003042	1E-06	1.4673204	0.00011	0.745555	9.4E-05	1.1544633	0.00407
3	0.2822209	0.00046	6.7E-05	0.0003005	8.1E-07	1.467262	0.00011	0.745638	7.4E-05	1.1565608	0.00325
4	0.2823093	0.00037	5.4E-05	0.0003028	9.9E-07	1.4673552	8.6E-05	0.745163	6.3E-05	1.1499375	0.00259
5	0.2822941	0.00058	8.4E-05	0.0002931	1E-06	1.467251	0.00011	0.745491	9.7E-05	1.1513672	0.00485
6	0.2821334	0.00056	8.2E-05	0.0003018	1E-06	1.4672309	0.00011	0.745517	1E-04	1.1549769	0.00436
7	0.2819524	0.00038	5.7E-05	0.0006163	8.2E-06	1.4672291	9.8E-05	0.745563	5.7E-05	1.1503939	0.00188
8	0.2823472	0.00052	7.9E-05	0.0002083	9.7E-07	1.4673139	0.00011	0.745506	9.7E-05	1.1490921	0.00414
9	0.2822409	0.00033	4.9E-05	0.0002976	8.2E-07	1.4673094	9.1E-05	0.745328	5.8E-05	1.149849	0.00359
10	0.2822246	0.00033	4.9E-05	0.0002972	8.2E-07	1.4672971	9.1E-05	0.745346	5.9E-05	1.1505376	0.00359
11	0.282302	0.00036	5.3E-05	0.0002924	8.8E-07	1.467332	8.6E-05	0.745785	7.5E-05	1.1493066	0.00356
12	0.2822578	0.0004	5.8E-05	0.0002916	9.8E-07	1.4672793	7.6E-05	0.745776	7.6E-05	1.1512581	0.00337
13	0.2822578	0.0004	5.8E-05	0.0002916	9.8E-07	1.4672793	7.6E-05	0.745776	7.6E-05	1.1512581	0.00337
14	0.2821961	0.00034	4.9E-05	0.0002953	1E-06	1.4673161	7.8E-05	0.745501	5.6E-05	1.1529638	0.0031
15	0.2822811	0.00039	5.6E-05	0.0002982	6.1E-07	1.4672294	7.9E-05	0.745099	7.8E-05	1.1499627	0.00256
16	0.2822146	0.00031	4.4E-05	0.0002889	9E-07	1.4673445	7.2E-05	0.745408	6.9E-05	1.1534399	0.00306
17	0.2822594	0.00035	5E-05	0.0002907	7.3E-07	1.4672954	5.9E-05	0.745486	6.4E-05	1.1522111	0.00252
18	0.2821845	0.00036	5.3E-05	0.000301	6.9E-07	1.467247	7.6E-05	0.745842	8.2E-05	1.1536011	0.00305
19	0.2822109	0.00029	4.2E-05	0.0002928	7.9E-07	1.467252	6.8E-05	0.745898	7.1E-05	1.1534389	0.0029
20	0.2822156	0.00034	5E-05	0.000293	6.2E-07	1.4672163	6.5E-05	0.745863	7.5E-05	1.1544247	0.00283
21	0.2822579	0.00034	4.8E-05	0.0003006	6.3E-07	1.4673069	6.6E-05	0.745833	6.9E-05	1.1517569	0.00238
22	0.2822757	0.00036	5.2E-05	0.0002992	8.7E-07	1.4672525	8.7E-05	0.745919	0.0001	1.1524148	0.00265
23	0.282252	0.00028	4.1E-05	0.0003123	6.6E-07	1.467308	5.4E-05	0.745877	6.6E-05	1.1523201	0.00172
24	0.2822474	0.00037	5.4E-05	0.0003016	9.9E-07	1.467265	6.7E-05	0.745957	7.9E-05	1.1533003	0.00256
25	0.2819265	0.00037	5.3E-05	0.0005519	7.7E-06	1.4672059	9.4E-05	0.745535	5.4E-05	1.1515404	0.00176
26	0.2819069	0.00074	0.00017	0.0031313	0.00014	1.4671386	0.00023	0.747022	0.00028	1.1533529	0.00064
27	0.2820623	0.00082	0.00014	0.0010808	3.7E-05	1.4672383	0.00015	0.746668	0.00014	1.151043	0.00245
28	0.2813646	0.00051	7.7E-05	0.0003043	5.4E-06	1.4673601	0.00012	0.746578	8.4E-05	1.1516439	0.00368
29	0.2821867	0.00078	0.00012	0.0002103	1.8E-06	1.4671393	0.00016	0.746794	0.00013	1.1582723	0.00756
30	0.2819334	0.00038	5.7E-05	0.0009011	8.1E-06	1.4672041	9.7E-05	0.745534	5.7E-05	1.151152	0.00187
31	0.2821965	0.00074	0.00011	0.00021	1.4E-06	1.4674252	0.00011	0.744152	9.2E-05	1.1539686	0.00554
32	0.2822126	0.00188	0.00028	0.0002167	3.6E-06	1.467215	0.00019	0.7441	0.00017	1.1518374	0.01222
33	0.2824024	0.00094	0.00014	0.0002143	2.1E-06	1.4672682	0.00017	0.744327	0.00014	1.1432176	0.00745
34	0.2821846	0.00087	0.00013	0.0003673	1.9E-06	1.4674126	0.00013	0.746478	0.00011	1.1552657	0.00342
35	0.2823031	0.00044	6.3E-05	0.0003044	1.1E-06	1.4672635	8.7E-05	0.745598	8.8E-05	1.1475059	0.00315
36	0.2822759	0.0009	0.00013	0.000368	1.8E-06	1.4673567	0.00015	0.746671	0.00013	1.1524569	0.00384
37	0.2823075	0.00119	0.00017	0.0003697	1.7E-06	1.4673031	0.00015	0.74651	0.00013	1.1516897	0.00456
38	0.2822227	0.00069	0.0001	0.0003709	1E-06	1.4673382	0.00013	0.746413	9.1E-05	1.1540794	0.00284
39	0.2829318	0.00268	0.0004	0.0002805	6E-06	1.4687671	0.0003	0.744503	0.00028	1.140591	0.03175
40	0.2822508	0.00071	0.0001	0.0003723	1.3E-06	1.4674657	9.8E-05	0.746576	7.5E-05	1.1530336	0.00286
41	0.2822444	0.00094	0.00014	0.0003857	1.5E-06	1.4673698	0.00014	0.747571	0.0001	1.15508	0.00464

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Appendix 3. (cont.) Lu and Hf isotopic results of the 91500-reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
42	0.2824004	0.00066	9.4E-05	0.0003726	1.8E-06	1.4675181	0.00012	0.746927	8.6E-05	1.1494275	0.00242
43	0.2821438	0.00086	0.00012	0.0003728	1.4E-06	1.4673823	0.00013	0.746852	0.00011	1.1557745	0.00326
44	0.2821184	0.00086	0.00012	0.0003743	1.4E-06	1.4674013	0.00013	0.746806	0.00011	1.1546321	0.00324
45	0.282315	0.00049	7.2E-05	0.000373	9.8E-07	1.4673613	0.0001	0.74696	7.3E-05	1.1521961	0.00227
46	0.2822991	0.00088	0.00013	0.0003886	2.2E-06	1.4673348	0.00012	0.747668	9.8E-05	1.1546701	0.00362
47	0.2823321	0.00091	0.00013	0.0003886	1.6E-06	1.4674731	0.00014	0.747563	0.00012	1.1528672	0.00335
48	0.2823324	0.00081	0.00012	0.0003869	1.4E-06	1.467336	0.00014	0.747575	8.9E-05	1.1541583	0.00297
49	0.2823065	0.00096	0.00014	0.0003866	1.7E-06	1.4672773	0.00013	0.747433	9.6E-05	1.1522149	0.00406
50	0.2821591	0.00096	0.00014	0.0003858	1.7E-06	1.4672634	0.00013	0.747456	9.6E-05	1.1539978	0.00406
51	0.2823051	0.00075	0.00011	0.0003776	1.5E-06	1.4672273	0.00012	0.747353	8.4E-05	1.1530253	0.00247
52	0.2822067	0.00076	0.00011	0.0003746	1.8E-06	1.4672847	0.0001	0.747315	9.8E-05	1.1579614	0.00282
53	0.2822538	0.00065	9.5E-05	0.0003756	1.3E-06	1.4674491	0.00011	0.747085	9.3E-05	1.1540686	0.00309
54	0.2821996	0.00084	0.00012	0.0003751	1.2E-06	1.4672077	0.00012	0.747185	0.00011	1.1574055	0.00304
55	0.2822538	0.00078	0.00011	0.0003743	1.6E-06	1.4674073	0.00012	0.74688	8.7E-05	1.1520868	0.00365
56	0.2822161	0.00088	0.00013	0.0003753	1.3E-06	1.4673662	0.00013	0.747047	8.2E-05	1.1539484	0.00341
57	0.2822465	0.00067	9.8E-05	0.0003742	1.3E-06	1.4673257	0.00011	0.747005	9.9E-05	1.1541111	0.00296
58	0.2822117	0.00065	9.5E-05	0.0003685	1.8E-06	1.4672857	0.00013	0.746976	8.7E-05	1.1540131	0.00311
59	0.2822539	0.00082	0.00012	0.0003686	1.5E-06	1.4672904	0.00014	0.746953	8.7E-05	1.1538126	0.00336
60	0.2823109	0.00067	9.9E-05	0.000371	1.2E-06	1.4672956	0.00014	0.746875	8.5E-05	1.1519598	0.00321
61	0.2823681	0.00056	8.2E-05	0.0003763	1.4E-06	1.4673721	0.00012	0.747449	8.8E-05	1.1545374	0.00255
62	0.2824423	0.00071	0.0001	0.0003686	2E-06	1.4672641	0.00012	0.747184	7.4E-05	1.1521286	0.00304
63	0.2823669	0.00092	0.00013	0.0003684	1.5E-06	1.4672894	0.0001	0.746999	9.7E-05	1.154829	0.00421
64	0.2823253	0.00089	0.00013	0.0003754	1.8E-06	1.4672974	0.00013	0.747255	0.00011	1.1535741	0.00355
65	0.2823128	0.0009	0.00013	0.0003752	1.6E-06	1.4673856	0.00013	0.747061	9.9E-05	1.1510261	0.00372
66	0.2824205	0.00091	0.00013	0.000371	1.6E-06	1.467283	0.00014	0.747175	0.00011	1.1498071	0.00365
67	0.282497	0.00086	0.00012	0.0003773	1.3E-06	1.4673086	0.00013	0.747202	9E-05	1.1488324	0.00235
68	0.2823161	0.00092	0.00014	0.0003731	1.6E-06	1.4673828	0.00012	0.747183	8.8E-05	1.1528137	0.00388
69	0.2823528	0.00069	0.0001	0.0003783	1.6E-06	1.4673952	0.00013	0.747182	0.0001	1.1526729	0.00297
70	0.2823201	0.00101	0.00015	0.0003774	1.7E-06	1.4673569	0.00012	0.746996	0.0001	1.1531668	0.00363
71	0.2823065	0.00102	0.00015	0.0003757	1.7E-06	1.4673846	0.00015	0.747276	0.00011	1.1565325	0.004
72	0.2824443	0.00108	0.00016	0.0003755	1.9E-06	1.4672867	0.00013	0.747083	0.00011	1.1512337	0.00423
73	0.2822515	0.00099	0.00014	0.0003816	1.9E-06	1.4673183	0.00015	0.747162	0.00011	1.1566461	0.00395
74	0.2822038	0.00057	8.2E-05	0.0003792	1.2E-06	1.4672742	0.00011	0.74754	9.3E-05	1.1568369	0.00242
75	0.2822112	0.00072	0.00011	0.0003788	1.2E-06	1.4673738	0.00011	0.747453	8.9E-05	1.1592118	0.00312
76	0.2822234	0.00065	9.2E-05	0.0003885	1.4E-06	1.4672825	0.00013	0.747658	7.7E-05	1.1547717	0.00211
77	0.2820367	0.00045	6.7E-05	0.0004092	9E-07	1.4672917	9.3E-05	0.747519	6.4E-05	1.1542725	0.00193
78	0.2823288	0.00038	6.6E-05	0.0003559	8E-07	1.4672912	8.3E-05	0.747118	6.7E-05	1.1526668	0.00184
79	0.2822203	0.00065	9.3E-05	0.0003883	1.4E-06	1.4672972	0.00013	0.747708	7.7E-05	1.1570119	0.00212
80	0.2822844	0.00019	2.8E-05	0.0003328	3.9E-07	1.4673349	7.4E-05	0.746751	6.6E-05	1.1531801	0.00086
81	0.281971	0.00028	4E-05	0.0002865	7.1E-07	1.4673464	6.1E-05	0.745509	5.4E-05	1.1528519	0.00202
82	0.2819692	0.00024	3.6E-05	0.0002868	1.8E-06	1.4673703	6.5E-05	0.745715	6.7E-05	1.1575507	0.00174

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Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
83	0.2823298	0.00033	4.8E-05	0.0003332	1E-06	1.4672998	7.8E-05	0.746845	0.00011	1.1518213	0.00079
84	0.2823376	0.0003	4.2E-05	0.0003298	2.7E-06	1.4673075	6.6E-05	0.74685	7E-05	1.1521677	0.00114
85	0.2820158	0.00022	3.3E-05	0.0002975	1.7E-06	1.4674	6.6E-05	0.745723	7.1E-05	1.1547501	0.00136
86	0.2819825	0.00024	3.4E-05	0.0002884	5.3E-07	1.4672944	6.5E-05	0.745723	4.7E-05	1.1560387	0.00178
87	0.28227	0.00031	4.5E-05	0.0003632	2.1E-06	1.4673727	6E-05	0.74732	7.1E-05	1.153992	0.00118
88	0.2822951	0.00032	4.6E-05	0.0003606	6.5E-07	1.4674473	7.6E-05	0.747282	7.1E-05	1.1545335	0.00126
89	0.2822586	0.00031	4.4E-05	0.00036	3.3E-06	1.4673224	6.5E-05	0.747411	6.6E-05	1.1537115	0.00104
90	0.2822339	0.00034	4.8E-05	0.0003541	1.3E-06	1.4674129	6.8E-05	0.747235	6.3E-05	1.1552718	0.00115
91	0.2823201	0.00031	4.5E-05	0.0003549	1.1E-06	1.4674109	7.3E-05	0.747284	5.9E-05	1.1544459	0.00113
92	0.2823079	0.00029	4.3E-05	0.0003552	1.2E-06	1.4673874	8E-05	0.747303	6.1E-05	1.1529232	0.00153
93	0.2822239	0.00026	3.8E-05	0.0003349	1.5E-06	1.4676817	5.5E-05	0.746452	4.1E-05	1.1533495	0.00096
94	0.2822864	0.00034	5E-05	0.0002951	4.9E-07	1.4672922	8.5E-05	0.743143	6.8E-05	1.1464094	0.00215
95	0.2822736	0.00032	4.5E-05	0.0002951	6.3E-07	1.4672955	6.5E-05	0.743108	6.8E-05	1.1475079	0.00173
96	0.2822468	0.00034	4.8E-05	0.0003011	3.3E-06	1.4672325	7.7E-05	0.743446	6E-05	1.1483855	0.00236
97	0.2821378	0.00044	6.4E-05	0.0003122	6.6E-07	1.467932	7.8E-05	0.745146	5.9E-05	1.1496982	0.00212
98	0.2823364	0.00024	3.4E-05	0.0003106	7.1E-07	1.4682943	5.9E-05	0.743803	5.2E-05	1.1479229	0.00167
99	0.2821203	0.00033	4.7E-05	0.0003363	4.5E-07	1.4683144	7.2E-05	0.743495	6.5E-05	1.1473596	0.00142
100	0.2822343	0.00035	5E-05	0.0003159	6.1E-07	1.4681662	6.8E-05	0.744248	6.3E-05	1.1521407	0.0019
101	0.2820904	0.00027	3.9E-05	0.0003354	4.7E-07	1.468257	5.7E-05	0.743792	6.9E-05	1.1474858	0.00137
102	0.2823248	0.00023	3.5E-05	0.0003084	4.5E-07	1.4682299	6E-05	0.743974	5.2E-05	1.149138	0.00143
103	0.2823575	0.00032	4.6E-05	0.000313	5.8E-07	1.4682407	6.5E-05	0.744186	6.4E-05	1.1462764	0.00225
104	0.2823491	0.00048	7.1E-05	0.00032	8.2E-07	1.4682805	8.7E-05	0.744793	7.5E-05	1.1503851	0.003
105	0.2823686	0.00049	6.9E-05	0.0003219	7.5E-07	1.468341	8.6E-05	0.744715	6.9E-05	1.1492898	0.00263
106	0.2823733	0.0005	7.1E-05	0.000326	7.1E-07	1.468324	8.2E-05	0.744748	7.4E-05	1.1499241	0.00209
107	0.282392	0.0005	7.3E-05	0.0003299	8.8E-07	1.4683339	9.4E-05	0.744772	7.8E-05	1.1478722	0.0025
108	0.2823351	0.00046	6.6E-05	0.0003295	6.7E-07	1.4682798	9.6E-05	0.744864	7.6E-05	1.1517962	0.00283
109	0.2823048	0.00048	7E-05	0.0003318	8.5E-07	1.4682024	9E-05	0.744869	6.8E-05	1.1512013	0.00216
110	0.2823584	0.00052	7.5E-05	0.0003328	2.3E-06	1.4682533	8.9E-05	0.744835	8.7E-05	1.1504339	0.00262
111	0.2823957	0.00052	7.6E-05	0.0003316	8.6E-07	1.4683598	8.5E-05	0.744872	6.5E-05	1.1477431	0.00305
112	0.2823784	0.00041	5.9E-05	0.0003091	5.4E-07	1.468289	8.6E-05	0.744001	7.3E-05	1.1470391	0.00213
113	0.2823723	0.00035	5E-05	0.0003166	5.9E-07	1.4683312	7.4E-05	0.743856	5.8E-05	1.1475231	0.0019
114	0.2823975	0.00037	5.3E-05	0.0003156	1E-06	1.4683812	6.4E-05	0.743774	5.8E-05	1.1478513	0.00182
115	0.28244	0.00034	4.8E-05	0.0003122	6.5E-07	1.4683155	8.2E-05	0.743812	7.5E-05	1.1474605	0.00222
116	0.2822935	0.00043	6.2E-05	0.0003218	8.3E-07	1.4682083	8E-05	0.744678	5.9E-05	1.1507171	0.00205
117	0.2822872	0.00042	6.1E-05	0.0003213	7.1E-07	1.4682095	7.8E-05	0.744605	5.9E-05	1.1501252	0.00166
118	0.2823381	0.00038	5.5E-05	0.000319	6.8E-07	1.4682616	6.6E-05	0.744408	6.4E-05	1.1494258	0.00211
119	0.2821023	0.00026	3.7E-05	0.0003171	2.8E-06	1.4686478	6.9E-05	0.743409	5.9E-05	1.147403	0.00131
120	0.2820424	0.00097	0.00014	0.0003055	1.6E-06	1.471289	0.00015	0.741216	0.00013	1.1447037	0.00544
121	0.2817852	0.00045	6.5E-05	0.0003016	7.4E-07	1.4763653	0.00012	0.736023	9.8E-05	1.142372	0.00283
122	0.282091	0.00027	3.9E-05	0.0003198	1.2E-06	1.4700565	6.1E-05	0.742955	6.2E-05	1.1486001	0.00132
123	0.2821327	0.0002	2.8E-05	0.0003134	3.9E-07	1.4702111	5.2E-05	0.742734	4.8E-05	1.148082	0.00107

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Appendix 3. (cont.) Lu and Hf isotopic results of the 91500-reference material.

Analysis	$^{176}Hf/^{177}Hf$	2SD	2SE	$^{176}Lu/^{177}Hf$	2SE	$^{178}Hf/^{177}Hf$	2SE	$^{179}Hf/^{177}Hf$	2SE	$^{173}Yb/^{171}Yb$	2SE
124	0.2820336	0.00028	4E-05	0.0003214	1.1E-06	1.4701432	7.5E-05	0.742757	5.7E-05	1.1492501	0.00169
125	0.2821401	0.00039	5.6E-05	0.0003274	9E-07	1.4704587	8.8E-05	0.743484	7.4E-05	1.1507046	0.00216
126	0.2821372	0.00029	4.2E-05	0.0003244	4.5E-07	1.4705318	6.5E-05	0.743429	5.3E-05	1.1509085	0.00158
127	0.2821798	0.00033	4.8E-05	0.0003245	4.8E-07	1.4704984	5.7E-05	0.743429	5.9E-05	1.1487764	0.00138
128	0.2821583	0.00031	4.5E-05	0.0003249	5.7E-07	1.4704144	8E-05	0.743434	5.6E-05	1.1498082	0.00192
129	0.2820812	0.00046	6.8E-05	0.0003062	7.8E-07	1.4738442	8.3E-05	0.739292	7.3E-05	1.1458656	0.00282
130	0.2819456	0.00046	6.7E-05	0.0003068	7.8E-07	1.4747922	0.00011	0.738294	9.2E-05	1.1491228	0.00301
131	0.2821401	0.00039	5.6E-05	0.0003274	9E-07	1.4704587	8.8E-05	0.743484	7.4E-05	1.1507046	0.00216
132	0.2822259	0.00034	4.9E-05	0.0003075	6.8E-07	1.4722096	6.3E-05	0.740861	5.2E-05	1.1445633	0.00159
133	0.2821174	0.00035	5E-05	0.0003214	5.5E-07	1.4706431	7.5E-05	0.74309	5.9E-05	1.1505871	0.00142
134	0.2821319	0.00038	5.5E-05	0.0003275	5.4E-07	1.4705733	6.9E-05	0.743058	6.9E-05	1.1493833	0.00149
135	0.2822187	0.00025	3.7E-05	0.0003279	5E-07	1.4716664	6.3E-05	0.74275	4.9E-05	1.1508966	0.00117
136	0.2821295	0.00032	4.6E-05	0.0003204	5.2E-07	1.4707394	6.8E-05	0.743094	5.2E-05	1.1499961	0.0015
137	0.2822205	0.00043	6.2E-05	0.0003311	6.5E-07	1.4672049	8.5E-05	0.744874	6.2E-05	1.1501706	0.00225
138	0.2821948	0.00053	7.7E-05	0.0003248	7E-07	1.4672762	7.6E-05	0.744955	6.7E-05	1.1518479	0.00244
139	0.282184	0.00035	5.1E-05	0.0003232	6E-07	1.4672197	7.7E-05	0.7449	5.3E-05	1.1517897	0.00147
140	0.282269	0.00033	4.7E-05	0.0003138	4.9E-07	1.4673227	7.7E-05	0.744929	5.8E-05	1.1501689	0.00181
141	0.2822332	0.00039	5.6E-05	0.000312	5.8E-07	1.4673429	6.6E-05	0.744928	4.6E-05	1.150684	0.00189
142	0.2826998	0.00134	0.00019	0.0002837	2.3E-06	1.4683581	0.00017	0.744259	0.00012	1.1443794	0.01224
143	0.2826517	0.0014	0.0002	0.000286	2.5E-06	1.4684805	0.00015	0.744327	0.00012	1.1468858	0.01371
144	0.2827634	0.00058	8.4E-05	0.0002841	1.2E-06	1.4683415	0.00012	0.743017	7.7E-05	1.1438411	0.00626
145	0.2827324	0.00069	9.9E-05	0.0002867	1.3E-06	1.4683882	0.00014	0.743087	7.1E-05	1.1446776	0.00637
146	0.2825648	0.00091	0.00013	0.0002867	1.7E-06	1.4684188	0.00012	0.743422	9.3E-05	1.1453663	0.00764
147	0.2825836	0.00083	0.00012	0.0002862	1.5E-06	1.4682105	0.00012	0.743467	0.00011	1.147104	0.00804
148	0.2826854	0.00089	0.00013	0.0002839	1.5E-06	1.4682035	0.00013	0.7435	9.9E-05	1.15073	0.00836
149	0.2825674	0.00169	0.00025	0.000289	3.6E-06	1.4681236	0.00021	0.744661	0.00015	1.1691737	0.01833
150	0.282756	0.00142	0.00021	0.0002865	3.3E-06	1.4683537	0.00025	0.74423	0.00015	1.1525987	0.01285
151	0.2826761	0.00156	0.00022	0.0002858	2.8E-06	1.4685591	0.00016	0.744379	0.00016	1.1553078	0.01324
152	0.2821826	0.00192	0.00028	0.0002907	3.6E-06	1.4684623	0.00022	0.744294	0.00015	1.1709794	0.01802
153	0.2823278	0.00162	0.00023	0.0002883	3.5E-06	1.4684134	0.00022	0.744239	0.00019	1.1656352	0.01498
154	0.2825753	0.00123	0.00018	0.0002847	2.7E-06	1.4682692	0.00025	0.744415	0.00017	1.1561792	0.01243
155	0.2827013	0.00201	0.00029	0.0002842	3.8E-06	1.4683472	0.00025	0.744353	0.00017	1.1596735	0.01596
156	0.28249	0.00083	0.00012	0.0002855	1.6E-06	1.4682434	0.00011	0.743679	8.1E-05	1.1542654	0.0089
157	0.2827814	0.00117	0.00017	0.000287	2E-06	1.468383	0.00014	0.743607	0.00012	1.1453122	0.01227
158	0.2827065	0.00075	0.00011	0.0002915	1.5E-06	1.4686519	0.00014	0.742722	0.0001	1.141966	0.00718
159	0.2828194	0.0009	0.00013	0.0002909	1.7E-06	1.4685793	0.00016	0.742817	0.00011	1.1441027	0.00677
160	0.282483	0.00117	0.00017	0.0002893	1.6E-06	1.4686575	0.00017	0.742728	0.00011	1.1518065	0.00881
161	0.2823721	0.00092	0.00013	0.0002914	1.9E-06	1.4686318	0.00017	0.743232	0.00011	1.1624717	0.00809
162	0.2828981	0.0011	0.00016	0.0002887	2.1E-06	1.4686677	0.00019	0.742824	0.00012	1.133572	0.01004