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25 Abstract

Knowledge of the average composition of the upper continental crust is crucial to
establish not only how it formed but also when. While well constrained averages
have been suggested for its major and trace element composition, no values exist
for its Nd and Hf isotopic compositions even though radiogenic isotopic systems
provide valuable information on its average model age.

31 Here we present Nd and Hf isotopic data determined on a large number of loess 32 deposits from several continents. We demonstrate that these deposits have very 33 uniform Nd and Hf isotopic compositions. We obtain an average Nd isotopic 34 composition that is similar to previous estimates for the upper continental crust 35 $(\varepsilon_{Nd} = -10.3 \pm 1.2 (1\sigma))$ and we establish a new Hf average value at $\varepsilon_{Hf} = -13.2 \pm 2$ (1σ) . This average falls on the "Terrestrial Array", demonstrating that the two 36 37 parent-daughter ratios are not decoupled during crust formation. Trace element 38 data acquired on the same set of samples allow us to calculate an average 39 ¹⁴⁷Sm/¹⁴⁴Nd ratio for the upper continental crust: 0.1193±0.0026, a value 40 slightly higher than previous estimates. Based on the relationship between 41 Sm/Nd and Nd isotopes, we estimate the average Nd extraction age of upper 42 continental crust from the depleted mantle at $T_{DM}(Nd) = 1.82\pm0.07$ Ga. This 43 model age is entirely consistent with previous suggestions made for example by 44 Goldstein et al. [1984].

45 Assuming that for each individual sample, the Hf model age cannot be younger 46 than the Nd model age, our new Nd-Hf isotopic data provide a value for the very 47 poorly known $^{176}Lu/^{177}Hf$ ratio of the upper crust. Our estimate is $^{176}Lu/^{177}Hf$ = 48 0.0125±0.0018, a value significantly lower than commonly used values [0.0150 – 49 0.0159, Griffin et al., 2002; Goodge and Vervoort, 2006; Hawkesworth et al., 2010] 50 but higher than Rudnick and Gao's [2003] estimate of 0.0083. The impact of our 51 new ¹⁷⁶Lu/¹⁷⁷Hf ratio on crustal model ages of zircon populations is not simple to 52 evaluate but the Hf model ages calculated with this new Lu/Hf ratio could be 53 younger by up to 500 Ma.

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59 **1 - Introduction**

60 The formation of the continental crust was certainly one of the most important events that affected the overall composition of the Earth, because the isolation at 61 62 the surface of a light and enriched layer left behind a depleted residue in the mantle. This observation explains why so many studies concentrate on the 63 64 processes that produce continental crust and on the timing of crustal growth 65 [e.g., Armstrong, 1968; McCulloch and Wasserburg, 1978; Armstrong, 1981; 66 Allègre and Rousseau, 1984; Goldstein et al., 1984; Taylor and McLennan, 1985; Condie, 1993; Wedepohl, 1995; Gallet et al., 1998; Vervoort et al., 2000; Griffin et 67 68 al., 2002; Rudnick and Gao, 2003; Harrison et al., 2005; Hawkesworth and Kemp, 69 2006; Blichert-toft and Albarède, 2008; Belousova et al., 2010; Hawkesworth et al., 70 2010; Kemp et al., 2010; Dhuime et al., 2011; Garçon et al., 2011; Iizuka et al., 71 2013]. In this study, we focus on the information provided by two isotopic systems, Sm-Nd and Lu-Hf. The two systems are strongly coupled during 72 73 magmatic processes leading to the definition of the "Terrestrial array", an array 74 along which all terrestrial magmas fall [Vervoort et al., 1999; Vervoort et al., 75 2011]. However, even though crustal magmas fall on the "Terrestrial Array" the 76 location of the average composition of the continental crust remains unknown.

77 Knowing the position of present-day average crust on the Terrestrial array is 78 important because it provides information not only on the processes active 79 during the formation of the crust but also because the two isotopic systems 80 record the past history of crustal materials and can be used to calculate an 81 average extraction age of crust from the mantle. Finally, by using the constraints 82 provided by the Sm-Nd isotopic system and those coming from the Lu-Hf isotopic 83 system, we can evaluate the average crustal ¹⁷⁶Lu/¹⁷⁷Hf ratio, a very poorly 84 known but crucial parameter necessary to calculate crustal residence ages of 85 zircon populations [e.g., Griffin et al., 2002; Harrison et al., 2005; Kemp et al., 86 2007; Blichert-toft and Albarède, 2008; Belousova et al., 2010; Kemp et al., 2010;
87 Condie et al., 2011; Yao et al., 2011; lizuka et al., 2013].

88 To address all these issues, we focus on a combined Nd and Hf isotopic study of a 89 variety of recent loess deposits from several continents. Loess deposits result 90 from the local accumulation of windblown dust coming from usually large 91 continental areas. They represent natural mixtures of erosion products of 92 continental surfaces and were therefore used by several previous workers to 93 determine the average composition of the upper continental crust [e.g., Taylor 94 and McLennan, 1981; Taylor et al., 1983; Taylor and McLennan, 1985, 1995; 95 Barth et al., 2000]. We show that they are excellent proxies for the average 96 composition of large areas of upper continental crust for both the Sm-Nd and the 97 Lu-Hf isotopic systems. We then suggest an average value for the upper 98 continental crust for the two systems and we determine an average model age. 99 Finally, the combined Nd and Hf isotopic data allow us to suggest a value for the 100 ¹⁷⁶Lu/¹⁷⁷Hf ratio of the upper continental crust.

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102 **2 - Source of samples**

103 The samples in this study were collected from several locations around the 104 world: Western Europe, Tajikistan, China and Argentina (see Figure 1). Most 105 were previously studied by Gallet and co-workers [Gallet et al., 1996; Gallet et al., 106 1998; Jahn et al., 2001] who reported major and trace element data as well as Nd 107 and Sr isotopic compositions for loess samples from China, Western Europe and 108 Argentina. The Tajikistan loess deposits come from the Chashmanigar section 109 and were previously studied by Ding et al. [2002] and by Yang et al. [2006] who 110 used sedimentological and major element data to constrain climate conditions 111 during the past 1.8 Ma. However, they did not perform any trace element or 112 isotopic analyses. Finally, two samples of Sahara dust collected in southern 113 France were also analyzed.

114 The samples belong to two different types of loess deposits. The Western Europe 115 Loess samples are periglacial deposits that were produced during the last glacial 116 period by mechanical erosion of the crust followed by transport by wind over 117 limited distances [Haase et al., 2007]. The situation is rather similar for the 118 Argentinian loess deposits whose origin is mainly the Andes [Smith et al., 2003]. 119 The Chinese and Tajikistan loess deposits represent much larger volumes and 120 have a very different origin: the materials come from large desert areas. For the 121 Chinese loess, particles come mainly from the deserts located Northwest in 122 Mongolia [Sun, 2002]; in southern Tajikistan, the particles originate from the 123 Karakum and Kyzylkum deserts located northwest in Turkmenistan, Uzbekistan 124 and Kazakhstan [Ding et al., 2002]. In both cases, the deserts developed on 125 continental crust that formed over large periods of geological time [e.g., *Lee et al.*, 126 2011; Yoshida, 2012] and particles were transported over long distances by highenergy winds to accumulate in protected areas [Ding et al., 1999; Ding et al., 127 128 2002; Guo et al., 2002]. Consequently, they represent the average composition of 129 much larger crustal areas than the periglacial deposits. Finally, the dust blown 130 from the Sahara over Southern France does not constitute a real loess deposit 131 [Grousset et al., 2003], but it provides valuable information on the average 132 composition of the largest desert area in the world.

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134 **3 - Analytical techniques**

135 All samples were crushed using an agate mortar. Trace element concentrations 136 were obtained after dissolution in a HF-HClO₄ mixture using Parr bombs. The 137 complete procedure is that of Chauvel et al. [2011], but the dissolution time was 138 increased to insure complete dissolution of the very resistant minerals, an issue 139 particularly important when using the relationship between REE and Hf 140 concentrations and when measuring Hf isotopes. Both accuracy and 141 reproducibility of the data are estimated as better than 5% for most trace 142 elements, as shown by the analyses of international rocks standards and 143 duplicate analyses of samples (see Supplementary table).

Neodymium and hafnium were isolated from an aliquot of the solution prepared
for trace element analysis and using standard ion-chromatography as described
by Chauvel et al. [2011]. Total procedural blanks were less than 100 picograms
for both Nd and Hf. The Nd and Hf isotopic compositions were measured using
the Nu Plasma HR MC-ICP-MS at ENS Lyon. Mass bias corrections for Nd and Hf

149 isotopic compositions were performed using $^{146}Nd/^{144}Nd = 0.7219$ and 179 Hf/ 177 Hf = 0.7325 respectively. Over the course of analyses, daily averages 150 151 obtained for the Nd Ames-Rennes standard ranged between 0.511958±19 and 152 0.511976±14, while those obtained for the Hf Ames-Grenoble standard ranged 153 between 0.282165±9 and 0.282168±19. All isotopic ratios reported in Table 1 154 are normalized to the reference values of 0.511961 and 0.282160 as published 155 by Chauvel and Blichert-Toft [2001] and Chauvel et al. [2011]. Complete 156 duplicate analyses of several samples show that the reproducibility of isotopic 157 measurements is better than 100 ppm for both Nd and Hf isotopic ratios (Table 158 1).

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160 **4 - Results**

161 New trace element data for the loess are provided in the Supplementary table. 162 Some samples had been previously analyzed for their trace element contents by 163 Gallet et al. [1998] and by Jahn et al. [2001] but these were reanalyzed because some key elements (e.g., Hf) were not measured in many of these older studies. 164 165 The new values reported here are generally similar to those previously published but there are notable exceptions. For example, the new 166 167 determinations of REE, Th, Zr and Hf concentrations are systematically higher 168 than those reported by Jahn et al. [2001] suggesting that dissolution of samples 169 in 2001 was incomplete, leaving some non-dissolved zircon and monazite grains 170 (see supplementary figure).

171 Figure 2 shows the trace element patterns obtained for all loess samples. As 172 previously shown by Gallet et al. [1996] and Jahn et al. [2001], the Chinese loess 173 are remarkably homogeneous with normalized trace element concentrations 174 close to the Upper Continental Crust values of Rudnick and Gao [2003] (see 175 Figure 2b). The new Tajikistan data shown in Figure 2c display similar features. 176 This is not the case, however, for the periglacial loess sampled in Western 177 Europe and shown in Figure 2a. The latter samples have much more variable 178 concentrations and they display large positive Zr-Hf anomalies, most probably 179 due to the presence of excess zircon. Finally, the Argentinian loess samples and 180 the two Sahara dust samples shown in Figure 2d have trace element patterns

generally parallel to the average upper continental crust (UCC) value, withoutpositive Zr-Hf anomalies, but with more variability.

183 The Nd and Hf isotopic compositions of all loess samples analyzed in this study 184 are listed in Table 1. The data are plotted in Figure 3 where they are compared to 185 data published in the literature for MORB, OIB, oceanic sediments and crustal 186 rocks. With the exception of the Argentinian samples, all loess define a restricted 187 range of ε_{Nd} and ε_{Hf} values (-10.3±1.2 and -13.8±4.2) and lie on the terrestrial 188 array of Vervoort et al. [2011] in the field of crustal materials. The Argentinian 189 loess have less negative values (ε_{Nd} = -1.7 and ε_{Hf} = -2.8), a feature attributed to 190 the abundance of Andean volcanic rocks in the source area [*Gallet et al.*, 1998; 191 *Smith et al.*, 2003].

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193 5 - Discussion

194 Constraining the average composition of the continental crust is a very active 195 field of research [e.g., Armstrong, 1968; McCulloch and Wasserburg, 1978; 196 Armstrong, 1981; Allègre and Rousseau, 1984; Goldstein et al., 1984; Taylor and 197 McLennan, 1985; Condie, 1993; Wedepohl, 1995; Gallet et al., 1998; Vervoort et 198 al., 2000; Griffin et al., 2002; Rudnick and Gao, 2003; Hawkesworth and Kemp, 199 2006; Belousova et al., 2010; Hawkesworth et al., 2010; Dhuime et al., 2011; 200 *Garçon et al.*, 2011]. Several studies have suggested average values for the upper continental crust but these mainly focus on its major and trace element 201 202 composition (see Rudnick and Gao [2003] for a review). Knowing its radiogenic 203 isotopic compositions is also important since it provides constraints on the 204 timing of crust formation through geological time. Several Pb isotope 205 compositions have been suggested for the upper continental crust [e.g., Zartman 206 and Doe, 1981; Newsom et al., 1986; Rudnick and Goldstein, 1990; Garçon et al., 207 2013b] as well as some average Nd model ages [Allègre and Rousseau, 1984; 208 Goldstein et al., 1984; Goldstein and Jacobsen, 1988; Jacobsen, 1988]. These show 209 that the continental crust formed, on average, about 1.8 to 2 Ga ago. Here, we will 210 use loess as a proxy to more precisely constrain the Nd and Hf isotopic 211 composition of average upper continental crust. We will then use these data to 212 re-evaluate when the upper crust separated from the mantle and use the combined Nd and Hf isotopic data to constrain the Lu/Hf ratio of upper
continental crust. It could be argued that the sample set might not be
representative of average upper crust and we will demonstrate that it is.

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5.1 - Loess: an excellent proxy for the average upper continental crust Nd isotopic ratio

Loess has been widely used by Taylor and McLennan [1985] to establish the
average REE composition of the upper continental crust because these sediments
represent the average composition of large surface areas. Since the REE content
is representative of the upper continental crust, loess can be used to evaluate its
Nd isotopic composition [*McCulloch and Wasserburg*, 1978; *Taylor et al.*, 1983; *Gallet et al.*, 1998].

225 The measured Nd isotopic ratios of nearly 50 loess samples are remarkably 226 uniform and define two groups (Figures 3 & 4). The first comprises only the 227 Argentinian loess and is relatively radiogenic with an average ε_{Nd} of -1.7. Gallet et 228 al. [1998] concluded that the unusual composition of these samples was due to 229 the overwhelming presence of recent volcanic products coming from the Andes 230 and could not be considered as representative of large areas of the upper 231 continental crust. We concur with their conclusion. The second group of samples 232 consists of all other analyzed loess samples (Figure 3). While the Chinese and Tajikistan loess have indistinguishable isotopic compositions ($\varepsilon_{Nd} = -9.82 \pm 0.44$ 233 234 and ε_{Nd} = -9.46±0.36, respectively), the two Sahara dusts have lower ε_{Nd} at -12.4. Finally, the Western European loess are more heterogeneous and average at ε_{Nd} 235 236 = -11.25 ± 1.28 . We attribute this larger range of isotopic compositions to 237 processes acting during the formation of periglacial loess, when relatively small 238 volumes of material were produced by erosion of proximal sources during the 239 last glacial period. Such small volumes of glacial sediments were not well mixed 240 by long distance transport and their composition is a function of the diversity of 241 local terranes in Western Europe. In contrast, the Tajikistan and the Chinese 242 loess are remarkably homogeneous, a feature consistent with their origin as dust 243 blown from large desert areas [Ding et al., 1999; Ding et al., 2002]. Nevertheless,

taken together, all these samples define a well-constrained average at ϵ_{Nd} =-10.3±1.2 (1 σ) (see inset of Figure 3).

246 Given the large number of Chinese and Tajikistan samples in our data set, it could 247 be argued that our average ε_{Nd} value is only representative of the upper 248 continental crust present in Russia and Central Asia. However, similar ε_{Nd} values 249 have been reported for all sorts of other areas in the world: The Carpathian loess 250 deposits in Eastern Europe have an average ε_{Nd} value at -10.21±0.34 [Újvári et 251 al., 2012] and a placer deposit that averages the area drained by the Rhone River 252 in Western Europe has an ε_{Nd} value of -9.3 [*Garçon et al.*, 2011]. This suggests 253 that most of the European continent has an ε_{Nd} value at about -10. The only two 254 US loess samples analyzed for Nd isotopes have lower values at -13 and -15 255 [*Taylor et al.*, 1983] which might indicate that the American upper crust could 256 have a different average value. However, the ε_{Nd} values reported by Goldstein et 257 al. [1984] and Goldstein and Jacobsen [1988] for particulates collected on major 258 rivers from the American continent do not confirm these low values but provide 259 a range between -20.8 and -4.4. Worldwide aerosols can also be used to estimate 260 the composition of exposed continental crust. Grousset and Biscaye [2005] 261 compiled the existing data and showed that aerosols have much more variable 262 compositions than loess or river particulates, but they could estimate that the 263 world mean *ENd* value was around -11 [Grousset and Biscaye, 2005]. Finally, 264 Goldstein et al. [1984] analyzed a large number of river sediments and aeolian dusts from various continents and provided an average ϵ_{Nd} value at -11.4±4 for 265 266 all these deposits. Given the similarity of all the values listed above, we suggest 267 that our estimate (ε_{Nd} =-10.3) is probably accurate and representative of continental crust exposed today at the surface of the Earth. Estimating the 268 269 uncertainty is more difficult. Here we use the 1σ error based on our data set 270 (±1.2) but we acknowledge that with a larger set of samples, the value could 271 change.

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5.2 - Loess: also a good proxy for the average upper continental crust Hf isotopic ratio

275 Several authors have argued that the Zr and Hf contents of loess should not be 276 used as analogues for their source [Taylor et al., 1983; Barth et al., 2000; Rudnick 277 and Gao, 2003]. These arguments are based on the observation that the loess 278 that they had studied had a very large excess of Zr and Hf relative to the REE, a 279 feature attributed to the presence of excess zircons. All the samples that they 280 studied, however, are periglacial loess sediments. Our Western European loess 281 samples have the same large positive anomaly in Zr and Hf (see Figure 2) and we 282 argue that many or all periglacial loess deposits contain this feature. In contrast, 283 the Tajikistan, Chinese and Argentinian loess deposits as well as the Sahara dusts 284 either have no anomaly or a slight negative anomaly (Figure 2). Since zircons are 285 rich in Hf and have usually very unradiogenic Hf isotopes, their presence has 286 strong impact on the whole rock Hf isotopic composition. As a result, the 287 measured Hf isotopic ratios reported in the Table 1 for the Western European 288 loess cannot be directly used to establish the average composition of the upper 289 continental crust. It is, however, possible to correct for the "zircon effect" by 290 using the relationship between Nd/Hf and $\Delta \varepsilon_{\text{Hf}}$ (the vertical deviation from the 291 terrestrial array as defined by Carpentier et al. [2009]) as shown in Figure 4. 292 Nd/Hf is well constrained in all estimates of upper continental crust, while $\Delta \varepsilon_{\text{Hf}}$ is 293 a good measure of mineralogical sorting during sediment formation [Carpentier 294 et al., 2009; Vervoort et al., 2011; Garçon et al., 2013a]. In Figure 4, loess deposits 295 define a positive correlation. The Western Europe loess have low Nd/Hf (i.e., 296 positive Hf anomalies), lie below the terrestrial array of Vervoort et al. [2011] 297 and have negative $\Delta \varepsilon_{Hf}$ values, as expected by the presence of excess old zircons. 298 In contrast, the Tajikistan loess samples have relatively high Nd/Hf (i.e., slight 299 negative Hf anomalies) and slightly positive $\Delta \varepsilon_{\rm Hf}$ values, as expected for 300 sediments deficient in zircon relative to their crustal source [Carpentier et al., 301 2009; Vervoort et al., 2011; Garçon et al., 2013a]. The Chinese and Argentinian 302 loess have compositions that plot in between these two end members. Using the 303 values recommended for the Nd/Hf ratio of upper continental crust, we can 304 therefore estimate the $\Delta \varepsilon_{\text{Hf}}$ value for average upper continental crust. The most 305 recent estimation of (Nd/Hf)_{UCC} provided by Rudnick and Gao [2003] constrains 306 the $\Delta \varepsilon_{\text{Hf}}$ value for upper continental crust at +1.6 with an error of less than ±2, 307 based on the range of estimated (Nd/Hf)_{UCC} (see Figure 4).

This $\Delta \varepsilon_{\text{Hf}}$ value translates into an ε_{Hf} value of -13.2 ±2 (1 σ) using the average ε_{Nd} value of -10.3 determined above and the terrestrial array equation of Vervoort et al. [2011] (ε_{Hf} = 1.55. ε_{Nd} +1.21). Such value is not identical to the average of all loess measurements (-13.8±4.2) but it is similar and the error on the average is smaller. These ε values correspond to a ¹⁴³Nd/¹⁴⁴Nd of 0.512102±67 and a ¹⁷⁶Hf/¹⁷⁷Hf of 0.282412±56 (see Table 2).

The combined Nd and Hf isotopic values for average upper continental crust define the point shown as a red star in Figure 3 at $\varepsilon_{Nd} = -10.3\pm1.2$ (1 σ) and $\varepsilon_{Hf} = -$ 13.2 ±2 (1 σ), an average that plots, within error, on the terrestrial array thereby supporting the long-standing observation that the parent-daughter ratios Sm/Nd and Lu/Hf are coupled during magmatic processes both in the mantle and the crust. It also provides a value for the average upper continental crust, a value that is very useful in modeling how the continents formed.

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322 **5.3 - Nd model age of upper continental crust**

323 To model the average formation age of the upper continental crust, we need 324 well-constrained values not only for Nd and Hf isotopic compositions but also for 325 Sm/Nd and Lu/Hf ratios. Data listed in Table 1 show that both the loess Nd 326 isotopic compositions and their ¹⁴⁷Sm/¹⁴⁴Nd ratios (0.1193±0.0026, recalculated 327 using the Sm and Nd concentrations) are extremely constant. This feature arises 328 from the uniform Sm/Nd ratio of most crustal minerals [Taylor and McLennan, 329 1981; Goldstein et al., 1984; Taylor and McLennan, 1985; Garçon et al., 2011]. 330 When compared to the ¹⁴⁷Sm/¹⁴⁴Nd ratio recalculated from previously published 331 UCC estimates [Taylor and McLennan, 1985; Condie, 1993; Gao et al., 1998; 332 Rudnick and Gao, 2003], our value is slightly higher (0.1193 vs. ≈0.1050) a 333 feature that may be related to the poor precision of the Sm and Nd concentration 334 estimates used in these publications (typically 10%, see Table 2). Our value is 335 similar, however, to values proposed by Jahn and Condie [Jahn and Condie, 1995] 336 and in studies when the ¹⁴⁷Sm/¹⁴⁴Nd was determined with better precision 337 [McCulloch and Wasserburg, 1978; Allègre and Rousseau, 1984; Goldstein et al., 1984]. Using this value for 147 Sm/ 144 Nd (0.1193±0.0026), our UCC estimate for 338

¹⁴³Nd/¹⁴⁴Nd, the depleted mantle values listed in Table 2 and the following
equation,

$$T_{\rm DM} = Log\left(\frac{(\frac{143Nd}{144Nd})_{\rm UCC} - (\frac{143Nd}{144Nd})_{\rm DM}}{(\frac{147Sm}{144Nd})_{\rm UCC} - (\frac{147Sm}{144Nd})_{\rm DM}} - 1\right)/\lambda$$

341 (with $\lambda = 6.54 \cdot 10^{-12}$ year⁻¹) we can calculate a model age for the extraction of the 342 crust from the depleted mantle.

We obtain a Nd model age of 1.82±0.07 Ga (1σ) for the separation of crust from
the mantle. Such value falls within the range of previous estimates based on Nd
isotopes [e.g., *Allègre and Rousseau*, 1984; *Goldstein et al.*, 1984; *Hawkesworth and Kemp*, 2006], but has a much smaller error than previous estimates.

347 The calculated model age depends heavily on the chosen parameters for the 348 depleted mantle source. Here, we consider that depletion started at the 349 beginning of Earth history and we chose a very depleted mantle (see Table 2). Other authors prefer more subdued values. For example, Gale et al. [2013] 350 351 recently provided an estimate based on the average composition of MORB while 352 Dhuime et al. [2011] suggested that the source of newly formed continental crust 353 was less depleted than the MORB mantle (see Table 2). When these references 354 are used, we calculate that the Nd model age of upper continental crust would be 355 200 Ma younger. An extra complication has been introduced recently by Jackson 356 and Carlson's [2012] suggestion that the Earth has a superchondritic 357 composition. Gale et al. [2013] already discussed the issue and showed that a 358 serious problem occurs because the present-day isotopic composition of a 359 superchondritic Earth is identical to their estimate of present-day depleted 360 mantle. Indeed, this leaves no space for the development of a mantle that had 361 become depleted as a consequence of the extraction of enriched continental 362 crust. If we accept that the Earth is superchondritic and that the depleted mantle 363 is more depleted than suggested by Gale et al. [2013], with, for example, a Nd 364 isotopic composition similar to our chosen estimate (see Table 2), then the entire 365 mantle would have to be depleted to compensate for the extraction of the 366 continental crust.

368 **5.4** - ¹⁷⁶Lu/¹⁷⁷Hf ratio of upper continental crust and Hf model age

369 To establish the average Hf model age of the upper continental crust is not as 370 straightforward as for Nd because the ¹⁷⁶Lu/¹⁷⁷Hf ratio of continental crust is 371 poorly constrained, yet has a major impact on the calculations. In Table 2, we list 372 estimates of ${}^{176}Lu/{}^{177}Hf_{UCC}$ that have been suggested in the literature. The 373 ¹⁷⁶Lu/¹⁷⁷Hf values calculated using upper crustal Lu and Hf contents range mostly from 0.0057 to 0.0106 [Shaw et al., 1967; Shaw et al., 1976; Taylor and 374 375 McLennan, 1985; Condie, 1993; Wedepohl, 1995; Gao et al., 1998; Rudnick and 376 Gao, 2003] but higher values have also been suggested: Goodge and Vervoort 377 [2006] suggest a ¹⁷⁶Lu/¹⁷⁷Hf ratio of 0.0150 for new Proterozoic crust, while 378 Hawkesworth et al. [2010] suggested a value of 0.0159 on the basis of over 7000 379 measurements of granitoids. Finally, Condie and co-workers [Condie et al., 2011] 380 suggest a value as high as 0.020. The range of suggested values is therefore very 381 large.

382 Unfortunately, the measured $^{176}Lu/^{177}Hf$ ratios of the loess samples cannot be 383 used to estimate the ¹⁷⁶Lu/¹⁷⁷Hf of the upper continental crust because loess 384 deposits are affected by sedimentary processes that sort minerals eroded from 385 crustal rocks. In contrast to their generally uniform ¹⁴⁷Sm/¹⁴⁴Nd ratios, all minerals do not have similar ¹⁷⁶Lu/¹⁷⁷Hf ratios, and their relative proportions 386 387 strongly influence the whole-rock ¹⁷⁶Lu/¹⁷⁷Hf ratio, which might be quite 388 different from that of the crustal precursor. One mineral, zircon, is particularly 389 important because it dominates the whole-rock ¹⁷⁶Lu/¹⁷⁷Hf ratio with its very 390 high Hf content and its extremely low ¹⁷⁶Lu/¹⁷⁷Hf ratio. In addition, it is very 391 resistant to alteration processes and survives even extreme weathering. If a high 392 proportion of old zircon is retained in a loess deposit, then the whole rock has 393 low ¹⁷⁶Lu/¹⁷⁷Hf and unradiogenic ¹⁷⁶Hf/¹⁷⁷Hf, as is the case with the Western 394 European loess deposits (see Table 1 and Figure 4). In contrast, if the proportion 395 of zircon is lower, as is the case for the Tajikistan loess samples, then the 396 ¹⁷⁶Lu/¹⁷⁷Hf is higher and ¹⁷⁶Hf/¹⁷⁷Hf is more radiogenic. Thus, the large range of 397 ¹⁷⁶Lu/¹⁷⁷Hf ratios reported in loess deposits is likely controlled by sedimentary 398 sorting processes and these values cannot be considered as representative of the 399 ¹⁷⁶Lu/¹⁷⁷Hf ratio of the crustal precursors. We therefore use a different approach that combines the constraints provided by the Sm-Nd and Lu-Hf
isotopic systems to determine the best estimate for the upper continental crust
Lu/Hf ratio.

403 In Figure 5, we plot Hf model ages of individual loess samples as a function of 404 their Nd model age. For each sample, we use the measured ¹⁴⁷Sm/¹⁴⁴Nd and 405 ¹⁴³Nd/¹⁴⁴Nd ratios as well as the depleted mantle values shown with an asterisk 406 in Table 2. To calculate the Hf crustal model ages, we used the measured 407 ¹⁷⁶Hf/¹⁷⁷Hf ratios together with a range of ¹⁷⁶Lu/¹⁷⁷Hf ratios as published for 408 upper continental crust, and the depleted mantle values shown with an asterisk 409 in Table 2. Because the range of possible ¹⁷⁶Lu/¹⁷⁷Hf ratios in average upper 410 crust (between 0.0057 and 0.0200, see Table 2) is very large, it introduces a very 411 large range of possible Hf model ages T_{DM} (Hf) (shown by vertical lines in Figure 412 5). If the upper crust has a high 176Lu/177Hf ratio of 0.0200, as suggested by Condie et al. [2011], then the T_{DM} (Hf) of all loess (excluding the Argentinian 413 414 loess) averages 2.47±0.13 Ga, a value that is 600 Ma older than the average Nd 415 model age (1.82±0.07 Ga); if the crustal ¹⁷⁶Lu/¹⁷⁷Hf ratio is 0.0159, as suggested 416 by Hawkesworth et al. [2010], then the T_{DM} (Hf) average at 2.05±0.11 Ga, still 417 over 200 Ma older than the average Nd model age. In contrast, using a low 418 ¹⁷⁶Lu/¹⁷⁷Hf ratio at 0.0057 provides much younger Hf model ages (1.45±0.08 419 Ga). Finally, a ¹⁷⁶Lu/¹⁷⁷Hf ratio of 0.0083, as suggested by Rudnick and Gao 420 [2003], gives an average Hf model age of 1.57 ± 0.09 Ga.

421 Considering the overall geochemical behavior of REE and Zr-Hf during magmatic 422 and sedimentary processes [Vervoort and Patchett, 1996; Vervoort and Blichert-423 Toft, 1999; Vervoort et al., 1999; Chauvel et al., 2008; Carpentier et al., 2009; 424 Vervoort et al., 2011], it seems unlikely that the Nd model age of upper 425 continental crust should be older than its Hf model age. The opposite is, in fact, 426 much more likely because most Hf present in crustal materials is sequestrated in 427 zircon, a mineral phase that is extremely robust during alteration and reworking 428 of continental crust.

429 To constrain the ¹⁷⁶Lu/¹⁷⁷Hf ratio of the upper continental crust, we assume here 430 that T_{DM} (Hf) and T_{DM} (Nd) should be identical for each individual loess and dust 431 sample and we calculate the necessary ¹⁷⁶Lu/¹⁷⁷Hf ratio for each individual 432 sample. Results of the calculation are shown in Figure 6 where they are also 433 compared to the range of suggested values from literature. On average, we 434 estimate that the ${}^{176}Lu/{}^{177}Hf$ ratio of upper continental crust is 0.0125 ± 0.0018 435 (1 σ).

436 In summary, the loess data suggest that the average model age of upper 437 continental crust is 1.82 ± 0.07 Ga (1σ) based on Nd isotopes. Assuming that Hf model ages cannot be any younger than Nd model ages, the loess data also 438 439 provide constraints on the ¹⁷⁶Lu/¹⁷⁷Hf ratio of upper continental crust, which 440 cannot be smaller than 0.00125 ± 0.0018 , the value that corresponds to 441 concordant $T_{DM}(Hf)$ and $T_{DM}(Nd)$ ages. Higher values, such as those suggested 442 previously by other authors [Goodge and Vervoort, 2006; Hawkesworth et al., 443 2010] are also plausible, but would result in an average upper crust T_{DM} (Hf) age 444 over 200 Ma older than the $T_{DM}(Nd)$ age.

445

446 **6 - Conclusions**

447 Our Nd-Hf isotopic study of a large number of loess samples provides new 448 constraints on the average isotopic composition of the upper continental crust. 449 We estimate that present-day upper continental crust has the following 450 characteristics: ¹⁴³Nd/¹⁴⁴Nd= 0.512101±60 and ¹⁷⁶Hf/¹⁷⁷Hf=0.282412±60. Using 451 the bulk silicate Earth values determined by Bouvier et al. [2008], these isotopic 452 ratios translate into ε_{Nd} =-10.3±1.2 (±1 σ) and ε_{Hf} =-13.2±2 (±1 σ) and fall within 453 error on the terrestrial array of Vervoort et al. [2011].

The uniform ¹⁴⁷Sm/¹⁴⁴Nd ratio (0.1193±0.0026) of loess deposits can also be considered as representative of the upper continental crust value. Combining the parent/daughter ratio with the average Nd isotopic composition, we calculate that the average Nd model age of upper continental crust is 1.82±0.07 Ga.

Finally, we constrain the ¹⁷⁶Lu/¹⁷⁷Hf ratio of the upper continental crust using the relationship between Hf and Nd isotopes. Our preferred estimate corresponds to 0.0125±0.0018, a value that is significantly higher than most previous estimates but lower than the ratio suggested by Goodge and Vervoort [2006] and Hawkesworth et al. [2010]. We emphasize that 0.0125 represents the 463 lower limit for ¹⁷⁶Lu/¹⁷⁷Hf because any lower estimate makes the Hf model ages younger than the Nd model ages, a very unlikely situation given the geochemical 464 behavior of Hf and REE. The impact of this new ¹⁷⁶Lu/¹⁷⁷Hf ratio on crustal 465 466 differentiation ages of zircon populations such as those calculated by numerous 467 authors [e.g., Griffin et al., 2002; Harrison et al., 2005; Kemp et al., 2007; Blicherttoft and Albarède, 2008; Wang et al., 2009; Belousova et al., 2010; Kemp et al., 468 469 2010; Yao et al., 2011; Iizuka et al., 2013] is quite variable, but the ages can be 470 younger by up to 500 Ma in the most extreme cases.

471

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- 724

725 Table captions:

- 726
- 727 **Table 1**: Nd and Hf isotopic results for all loess samples.
- 728 Footnotes: All ϵ_{Nd} and ϵ_{Hf} values were calculated using the BSE value suggested
- 729 by Bouvier et al. [2008]. Dup stands for complete duplicate analyses. The
- 730 ¹⁴⁷Sm/¹⁴⁴Nd and ¹⁷⁶Lu/¹⁷⁷Hf are calculated using the Sm, Nd, Lu and Hf
- 731 concentration data listed in the Supplementary table.
- 732

Table 2: Compilation of the parent-daughter ratios and Nd and Hf isotopiccompositions of various reservoirs.

735 Footnotes: Numbers in italics correspond to ratios recalculated using published concentrations. *: values used to calculate T_{DM}. Data sources: Allègre and 736 737 Rousseau [1984], Bouvier et al. [2008], Chauvel et al. [2008], Condie [1993], 738 Condie et al. [2011], Dhuime et al. [2011], Gale et al. [2013], Gao et al. [1998], Goldstein et al. [1984], Goodge and Vervoort [2006], Griffin et al. [2002], 739 740 Hawkesworth et al. [2010], Jahn and Condie [1995], McCulloch and Wasserburg 741 [1978], Rudnick and Gao [2003], Salters and Stracke [2004], Shaw et al. [1967; 742 1976], Taylor and McLennan [1985] and Wedepohl [1995].

743

Supplementary table: Trace element concentrations measured on all loess
samples as well as values published by Gallet et al. [1996] for the Luochuan loess.

746 Supplementary figure: Comparison between the new trace element data and747 the data published previously by Jahn et al. [2001].

748

749 **Figure captions**:

Figure 1: Map of the world showing the location of loess deposits. The precise locations of Western European, Chinese, Argentinian and Tajikistan loess samples were provided by Gallet et al. [1996; 1998], Jahn et al. [2001] and Ding et al. [2002]. The Sahara samples blown over Southern Europe were collected close to Grenoble and at 2900 m altitude in the Alps. Latitudes and longitudes are given in the Supplementary Table.

756

Figure 2: Trace element patterns of the loess samples. All concentrations are
normalized to the upper continental crust average of Rudnick and Gao [2003]. a)
Western European loess, b) all Chinese loess including data published by Gallet
et al. [1996], c) Tajikistan loess and d) Argentinian loess and Sahara dust.

Figure 3: Nd and Hf isotopic compositions of loess samples. ε_{Nd} and ε_{Hf} were 762 763 calculated using the BSE value of Bouvier et al. [2008]. The terrestrial array corresponds to ε_{Hf} = 1.55. ε_{Nd} +1.21 as recently compiled by Vervoort et al. [2011]. 764 765 Data for MORB and OIB were compiled using the PetDB and Georoc databases 766 and also include some unpublished values of Chauvel. Oceanic sediments plotted 767 here were published in the literature [White and Dupré, 1986; BenOthman et al., 768 1989; McLennan et al., 1990; Godfrey et al., 1997; Albarède et al., 1998; Pearce et 769 al., 1999; Vervoort et al., 1999; David et al., 2001; Woodhead et al., 2001; Vlastelic 770 et al., 2005; Prytulak et al., 2006; van de Flierdt et al., 2007; Carpentier et al., 771 2008; Bayon et al., 2009; Carpentier et al., 2009; Chauvel et al., 2009; Vervoort et al., 2011]. Data source for continental crust were published by Vervoort and 772 773 Patchett [1996] and by Vervoort et al. [1999; 2000]. The inset shows how our 774 estimated upper continental crust composition (red star) relates to the range of 775 known isotopic values in the Earth.

776

Figure 4: Nd/Hf versus $\Delta \epsilon_{\text{Hf}}$ for all the analyzed loess samples. The inset shows schematically how the $\Delta \epsilon_{\text{Hf}}$ values are calculated for each sample. The terrestrial array used to calculate $\Delta \epsilon_{\text{Hf}}$ values corresponds to $\epsilon_{\text{Hf}} = 1.55^* \epsilon_{\text{Nd}} + 1.21$ as recently reevaluated by Vervoort et al. [2011]. Shown by arrows along the horizontal axis are various estimates for Upper Continental Crust: Taylor and McLennan [1985], Shaw et al. [1967; 1976], Rudnick and Gao [2003], Condie [1993] and Gao et al. [1998].

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785

Figure 5: T_{DM} (Nd) versus T_{DM} (Hf) for all loess samples.

The T_{DM} (Nd) are calculated using the ¹⁴⁷Sm/¹⁴⁴Nd ratio measured for each sample. They are well constrained with an error smaller than the horizontal bars. The T_{DM} (Hf) ages are calculated using a single stage Lu/Hf evolution for the samples coming from China, Tajikistan, Argentina and Sahara, and using a two stages evolution for the samples from Western Europe. For the latter, we assumed that the average crystallization age of the excess zircons was 0.9 Ga, an

793 age consistent with the Archean to Proterozoic materials that have been repeatedly reworked during the Cadomian and Hercynian orogenies [Peucat et 794 795 al., 1988]. For all samples, the vertical bar corresponds to the range of ages 796 obtained with a ¹⁷⁶Lu/¹⁷⁷Hf ratio going from 0.0057 (the youngest ages) to 0.0200 (the oldest ages). The inset shows how the two-stages calculation 797 798 operates. A "zircon stage" is calculated between present-day and a crystallization 799 age T_{cryst} of 900 Ma, and using a ${}^{176}Lu/{}^{177}Hf$ ratio of 0.0001. Prior to T_{cryst} , the 800 evolution follows the same range of UCC ¹⁷⁶Lu/¹⁷⁷Hf ratios as for all other 801 samples. The inset also highlights how single stage crustal model ages become 802 significantly too old if the zircons did not crystallize recently.

803

Figure 6: Measured ¹⁴⁷Sm/¹⁴⁴Nd versus calculated ¹⁷⁶Lu/¹⁷⁷Hf for all loess
samples.

806 As in Figure 5, a single stage history is assumed for the Argentinian, Chinese, 807 Tajikistan and Sahara samples and a two-stages history for the Western 808 European samples. The grey field corresponds to the range of published values 809 for the Lu/Hf ratio of upper continental crust [Shaw et al., 1967; Taylor and 810 McLennan, 1985; Condie, 1993; Gao et al., 1998; Griffin et al., 2002; Rudnick and 811 Gao, 2003; Goodge and Vervoort, 2006; Hawkesworth et al., 2010; Condie et al., 812 2011]. The two red lines show our estimated averages and the orange fields 813 correspond to the calculated error at 1σ .

Highlights

- > First estimate of the average Nd-Hf isotopic composition of upper continental crust
- > The average (ε_{Nd} = -10.3±1.2 and ε_{Hf} = -13.2±2) falls on the terrestrial array
- > The average Nd model age of upper continental crust is 1.82±0.07 Ga
- ➤ The upper continental crust ¹⁷⁶Lu/¹⁷⁷Hf ratio is 0.0125±0.0018













Figure 6

Table 1: Nd and Hf isotopic compositions of the loess samples

Sample	Location	¹⁴³ Nd/ ¹⁴⁴ N	25	e	¹⁴⁷ Sm/ ¹⁴⁴ N	¹⁷⁶ Hf/ ¹⁷⁷ H	25	e	¹⁷⁶ Lu/ ¹⁷⁷ Hf
Campie	Looution	d	23	∽Nd	d	f	23	CHL	
Western Europe									
HOT1 whole rock	St Brieuc, France	0.512106	0.000009	-10.2	0.1219	0.282209	0.000008	-20.4	0.00574
HOT1 < 160 mm	St Brieuc, France	0.512098	0.000010	-10.4	0.1193	0.282213	0.000007	-20.2	0.00541
PR RT (whole rock)	Port Racine, Normandy, France	0 540070	0.000000	40.0	0 4 0 0 0	0 202205	0 000040	20 E	0.00477
	Fougères France	0.512076	0.000009	-10.0	0.1222	0.202200	0.000013	-20.3	0.00477
	Sobles d'or France	0.512029	0.000000	-11.7	0.1107	0.202210	0.000006	-20.1	0.00537
	Nantois Franco	0.512130	0.000009	-9.0	0.1174	0.202210	0.000013	-20.1	0.00013
1004	Spitsbergen (Svalbard)	0.512121	0.000000	-9.9	0.1210	0.202252	0.000012	-10.9	0.00034
P2E1	Spitsbergen (Svalbard)	0.511997	0.000010	-13.5	0.1152	0.202203	0.000010	-10.2	0.00303
K14	Kesselt Belgium	0.512000	0.000000	-12.4	0.1100	0.202103	0.000006	-22.7	0.00717
R 11	Rocourt Belgium	0.512000	0.0000011	-11.6	0.1200	0.202174	0.000000	-21 5	0.00303
SCII	Scilly Island England	0.512030	0.000008	-11.6	0.1145	0.2822110	0.000018	-20.0	0.00464
		0.012004	0.000000	11.0	0.1140	0.202210	0.000010	20.0	0.00404
China									
JX-4	Jixian	0.512110	0.000008	-10.1	0.1203	0.282442	0.000011	-12.1	0.00987
JX-6	Jixian	0.512101	0.000015	-10.3	0.1188	0.282448	0.000013	-11.9	0.00855
JX-10	Jixian	0.512115	0.000009	-10.0	0.1162	0.282406	0.000011	-13.4	0.00843
JX-2	Jixian	0.512106	0.000007	-10.2	0.1189	0.282435	0.000008	-12.4	0.00976
XF-10	Xifeng	0.512124	0.000009	-9.9	0.1176	0.282470	0.000009	-11.1	0.01011
XF-6	Xifeng	0.512131	0.000011	-9.7	0.1201	0.282451	0.000013	-11.8	0.01010
XF-2	Xifeng	0.512162	0.000008	-9.1	0.1199	0.282438	0.000013	-12.3	0.01344
XF-4	Xifeng	0.512160	0.000010	-9.2	0.1209	0.282429	0.000014	-12.6	0.00948
XF-4 dup	Xifeng					0.282443	0.000008	-12.1	
XN-2	Xining	0.512102	0.000009	-10.3	0.1169	0.282414	0.000009	-13.1	0.01078
XN-4	Xining	0.512120	0.000011	-9.9	0.1243	0.282388	0.000010	-14.1	0.00880
XN-10	Xining	0.512108	0.000008	-10.2	0.1191	0.282421	0.000010	-12.9	0.00911
XN-6	Xining	0.512094	0.000008	-10.5	0.1196	0.282413	0.000008	-13.1	0.00835
L3	Luochuan	0.512146	0.000010	-9.4	0.1216	0.282421	0.000007	-12.9	0.01110
L4	Luochuan	0.512138	0.000010	-9.6	0.1257	0.282457	0.000014	-11.6	0.01082
L5	Luochuan	0.512150	0.000012	-9.4	0.1211	0.282437	0.000008	-12.3	0.01227
L6	Luochuan	0.512158	0.000009	-9.2	0.1213	0.282429	0.000005	-12.6	0.01114
L7	Luochuan	0.512140	0.000009	-9.6	0.1227	0.282460	0.000007	-11.5	0.01145
L7 dup	Luochuan	0.512158	0.000009	-9.2	0.4470	0.282459	0.000009	-11.5	0.04000
L9	Luochuan	0.512137	0.000009	-9.6	0.11/2	0.282475	0.000006	-11.0	0.01023
L1	Luochuan	0.512125	0.000010	-9.9	0.1229	0.282456	0.000014	-11.6	0.01194
L2	Luochuan	0.512109	0.000012	-10.2	0.1209	0.282467	0.000010	-11.2	0.01243
Argentina									
12-14	Argentina	0.512515	0.000009	-2.2	0.1201	0.282650	0.000005	-4.8	0.00821
24-26	Argentina	0.512577	0.000009	-1.0	0.1251	0.282762	0.000007	-0.8	0.01140
32RT	Argentina	0.512576	0.000008	-1.1	0.1263	0.282737	0.000006	-1.7	0.00984
32RT dup	Argentina	0.512580	0.000008	-1.0		0.282758	0.000006	-1.0	
40RT	Argentina	0.512534	0.000007	-1.9	0.1264	0.282698	0.000004	-3.1	0.00846
LUJA	Argentina	0.512476	0.000006	-3.0	0.1226	0.282647	0.000005	-4.9	0.00807
Sahara									
Sahara dust collected in Meylan	Meylan, France	0.511980	0.000007	-12.7	0.1161	0.282331	0.000008	-16.1	0.01020
Sahara dust collected at 2900m altitude	Alpes, France	0.512011	0.000007	-12.1	0.1164	0.282485	0.000005	-10.6	0.01220

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TJK2772	Chashmanigar, Tajikistan	0.512163	0.000007	-9.1	0.1178	0.282526 0.000006	-9.2	0.01152
TJK2773	Chashmanigar, Tajikistan	0.512168	0.000011	-9.0	0.1213	0.282523 0.000005	-9.3	0.01206
TJK2930	Chashmanigar, Tajikistan	0.512115	0.000006	-10.0	0.1180	0.282482 0.000006	-10.7	0.01117
TJK3012	Chashmanigar, Tajikistan	0.512154	0.000006	-9.3	0.1221	0.282517 0.000004	-9.5	0.01163
TJK3070	Chashmanigar, Tajikistan	0.512157	0.000007	-9.2	0.1183	0.282518 0.000007	-9.5	0.01145
TJK3148	Chashmanigar, Tajikistan	0.512145	0.000006	-9.5	0.1207	0.282530 0.000006	-9.0	0.01189
TJK3179	Chashmanigar, Tajikistan	0.512154	0.000006	-9.3	0.1182	0.282534 0.000007	-8.9	0.01221
TJK3198	Chashmanigar, Tajikistan	0.512131	800000.0	-9.7	0.1192	0.282479 0.000006	-10.8	0.01146
TJK2814	Chashmanigar, Tajikistan	0.512146	0.000007	-9.4	0.1182	0.282520 0.000006	-9.4	0.01141
TJK3165	Chashmanigar, Tajikistan	0.512117	0.000009	-10.0	0.1148	0.282512 0.000007	-9.7	0.01056

Table2: Compilation of the parent-daughter ratios and Nd and Hf isotopic compositions of various reservoirs

Reservoir	Source	¹⁴³ Nd/ ¹⁴⁴ N d	e _{Nd}	Sm (ppm)	Nd (ppm)	¹⁴⁷ Sm/ ¹⁴⁴ N d	¹⁷⁶ Hf/ ¹⁷⁷ Hf	e _{Hf}	Lu (ppm)	Hf (ppm)	¹⁷⁶ Lu/ ¹⁷⁷ Hf
Bulk Silicate Earth	Bouvier et al. 2008	0.512630	-			0.1960	0.282785	-			0.0336
Most depleted MORB*	Chauvel et al. 2008	0.513270	12.48			0.2172	0.283381	21.08			0.0403
Depleted mantle	Salters and Stracke 2004			0.27	0.713	0.2289			0.063	0.199	0.0449
Average MORB	Chauvel et al. 2008 Gale et al. 2013	0.513072 0.513074	8.62 8.66			0.2106 0.2107	0.283208 0.283000	14.96 7.6			0.0384 0.0360
"	Gale et al. and Hf on terrestrial array	0.513074	8.66			0.2107	0.283199	14.63			0.0383
Source of new crust	huime et al. 2011 and Nd on terrestrial arra	0.513027	7.74				0.283158	13.2			
Upper Continental crust				. –							
	Rudnick and Gao TOG 2003			4.7	27	0.1052			0.31	5.3	0.0083
	l aylor and McLennan 1985			4.5	26	0.1046			0.32	5.8	0.0078
	Gao et al. 1998			5.09	30.4	0.1012			0.35	5.12	0.0097
	Snaw et al. 1967&1976			4.61	25.9	0.1076			0.233	5.8	0.0057
	Condie 1993			5.09	30.4	0.1012			0.32	4.3 F 0	0.0106
	McCullach and Wasserburg 1079			4.7	20.9	0.1097			0.27	J.0	0.0000
	Coldetoin et al. 1094					0.1150					
	Goldstein et al. 1964					0.1100					
	Allegie and Condia 1994					0.1120					
	Goodge and Verycert 2006					0.1100					0.0150
	Griffin et al. 2002										0.0150
	Hawkesworth et al. 2010										0.0150
	Condie et al. 2011										0.0200
Our estimate for Upper Continental Crust		0.512101	-10.3			0.1193	0.282412	-13.2			0.0125
uncertainity at one sigma		±0.000060	±1.2			±0.0026	±0.000060	±2			±0.0018

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