Accuracy associated with the activity determination by in situ gamma spectrometry of naturally occurring radionuclides in soils

A. Baeza, J.A. Corbacho¹, J. Guillén

*Environmental Radioactivity Laboratory(LARUEX), Faculty of Veterinary Medicine, 10003
- Cáceres, SPAIN*

Abstract

In situ gamma spectrometry (ISGS) is a technique mainly focused on the determination of man-made radionuclides deposited on soils. It is widely used for the radioactive characterization of soils in which there has been an incorporation of such radionuclides, especially ^{137}Cs . Its use for the activity determination of naturally occurring radionuclides in soils has been more limited, and the accuracy associated with those measurements has yet to be treated extensively. There are numerous factors affecting the accuracy of the activity determination of naturally occurring radionuclides, such as the assumed soil geometry, the soil's geological and mineral composition, its moisture content, etc. The present work studies the accuracy associated with the ISGS determination of the activity concentrations of natural radionuclides in soils using a portable HPGe detector. For ^{40}K and ^{232}Th activity determinations, the uncertainties associated with ISGS are generally of the order of 15%. However, ^{226}Ra activity determined from its daughters ^{214}Pb and ^{214}Bi can be significantly overestimated when there is a major presence of ^{222}Rn in the air around the detector. Finally, absorbed dose rate in air values were calculated from the naturally occurring radionuclide concentration in soils. The results showed good correspondence between the values obtained from ISGS and those obtained from laboratory determinations with the same soils.

Keywords: In Situ Gamma Spectrometry, Naturally Occurring Radionuclides, External Gamma Dose Rate, Multiple Peaks Method

1. Introduction

The in situ gamma spectrometry (ISGS) technique is a powerful tool for determining the activity concentrations of one or more radionuclides in soils. Precise knowledge of these concentrations then allows to calculate the dose rate

¹e-mail: corbamer@unex.es

5 received from external radiation due to the presence of these radionuclides in
 6 the ground. Although this technique consumes far more economical in time
 7 and resource consumption than conventional gamma spectrometry, it has the
 8 drawback that a series of geometrical approximations have to be made to model
 9 the characteristics of the sample, which in this case is the ground. Generally,
 10 the sample is assumed to be a flat, unimpeded surface, in which the horizontal
 11 distribution of the radionuclides is practically uniform (Baeza and Corbacho,
 12 2005). The depth dependence of the distribution of the radionuclides is as-
 13 sumed to correspond to one of the two commonest cases: homogeneous with
 14 depth, or quasi-exponentially decreasing. The former is that used in modeling
 15 the distribution of natural radionuclides in soils, while the latter is characteristic
 16 of radionuclides that were deposited on the surface layer of soil and have since
 17 migrated to deeper layers, provided that the soil has remained undisturbed since
 18 that time. There may be a problem in determining ^{214}Pb and ^{214}Bi activity
 19 concentrations with ISGS. The reason is that, since both belong to the ^{238}U
 20 series and are daughters of ^{222}Rn , they can be present in the air surrounding
 21 the detector because of the emanation of this last radionuclide from the soil.
 22 The processes of ^{222}Rn emanation depend on a multitude of factors (Sakoda
 23 et al., 2011). These include: the content and distribution of radium in the
 24 soil; the soil's grain size, porosity, and permeability; its moisture content; the
 25 radon diffusion coefficient through fractures and interstitial pores; and the air
 26 temperature, *inter alia*. In ISGS measurements, the ^{222}Rn emanation rate from
 27 a soil is assumed to be typically around or below 15% (ICRU, 1994). Under
 28 these conditions, it is partly offset by the contribution of the flux from the same
 29 nuclides in the ambient air (Helfer and Miller, 1988). However, depending on
 30 the geological characteristics of the soil being measured and on the possible
 31 existence of conditions of atmospheric inversion, the emanation rate can be sig-
 32 nificantly higher. The objective of the present study was, on the one hand, to
 33 evaluate the accuracy of ISGS determinations of natural radionuclide activities
 34 at a number of geographically separated locations with different types of geol-
 35 ogy, and therefore with different soil types and, in principle, different exposure
 36 rates. And on the other, once the said natural radioactive content had been
 37 characterized in situ, to evaluate the total absorbed dose and compare it with
 38 that obtained after collecting samples of the same soils and measuring them
 39 gamma-spectrometrically at a low-activity laboratory, a technique which has
 40 been extensively validated and used worldwide [(UNSCEAR, 2000) Report, and
 41 further references cited therein].

42 **2. Material and Methods**

43 We selected 15 sites in various parts of Spain which have different geolog-
 44 ical characteristics. These sites are numbered from 1 to 15. At each of them,
 45 the radioactive content of the soil was measured by ISGS, and a sample of the
 46 vertical profile of the soil was collected to a depth of 30 cm. This sample was
 47 then measured by conventional gamma spectrometry to determine the changes
 48 of the activity concentrations with depth. To determine how the soil's degree

of relative moisture affects the accuracy of ISGS measurements, we made a series of in situ measurements at the same site at different times of the year, coinciding with the seasons of most and least rainfall. The idea was to establish a relationship between the above cited relative moisture of a soil and the concentration of the descendants of ^{222}Rn and ^{220}Rn in the air. This relationship could then be used to evaluate the accuracy with which the soil's ^{226}Ra activity can be determined from the measurement of its daughters. All the soil samples collected for conventional gamma spectrometry in the laboratory were dried to eliminate their moisture content, and then sieved to a less than 2 mm grain size. This process allowed the value of the relative moisture level of each sample to be obtained. The dried soil samples were put into 191-cm³ volume Petri dishes and sealed to prevent losses from ^{222}Rn emanation. A time of 28 days was allowed for secular equilibrium between ^{226}Ra and its descendants to be re-established. The samples were then measured by conventional low-background gamma spectrometry, using a Ge detector of 45% relative efficiency housed in 10-cm-thick lead shielding. The detector was calibrated for the geometry used with the soil samples and for the energy range 60-2000 keV using a standard radionuclide cocktail. The systematically analyzed radionuclides were (Energy lines in keV in brackets): ^{212}Pb (238.6), ^{228}Ac (338.3; 911.0), ^{214}Pb (352.0), ^{208}Tl (583.1), ^{214}Bi (609.3, 1120.3, 1764.5), ^{40}K (1460.7). Different reference materials were also used to check the quality of the measurements: IAEA Soil 327 and IAEA Irish Sea Sediment 385 for gamma spectrometry in lab. All test procedures were validated in accordance with the quality requirements of the ISO/IEC 17025 standard (ISO, 2010). The ISGS measurements were made with a portable coaxial intrinsic (hyperpure) Ge detector of 43.1% relative efficiency, 2.0 keV resolving power, and 1:56 peak-to-Compton ratio for the 1332.5 keV ^{60}Co emission. It was calibrated using the semi-empirical techniques proposed in the literature (Helfer and Miller, 1988). The spectra were acquired for 3600 s, with the detector facing downwards at 1 m above the ground. For the determination of the soil activity concentration of ^{226}Ra , ^{232}Th and ^{40}K , the chosen gamma-emitter radionuclides were respectively: ^{214}Pb and ^{214}Bi average activity, ^{228}Ac and ^{40}K .

3. Analysis and Results

3.1. Determination of the accuracy associated with ISGS measurements of ^{40}K , ^{226}Ra , and ^{232}Th in soils: Relationship with relative soil moisture

The calibration factors of ISGS are dependent on the linear attenuation coefficients of soil, μ_s , and air, μ_a . Given that μ_a is much smaller than μ_s , a 10% variation in μ_a has no significant influence on the calibration factors (Sowa et al., 1989). The ranges of variation of μ_s for various types of soil have been studied and published (ICRU, 1994). At energies below 100 keV, there are significant differences in the absorption properties of soils typically used to tabulate ISGS fluence rates. Above this energy, however, the absorption properties are similar. For these higher energies, the value of the mass attenuation coefficient is dominated by Compton scattering, which does not vary much from

one element to another (ICRU, 1994). For this reason, for many applications
 the precise soil composition is not needed. However, water present in the soil
 will attenuate emitted photons before they reach the detector. Moreover, the
 radon emanation power of a soil depends strongly on its water content (Bossey,
 2003). The presence of water in the interstitial spaces between soil particles
 can favour retention of ^{222}Rn gas, thereby preventing any significant increase
 in its concentration in the layer of air near the ground. The greater or lesser
 concentration of radon gas retained in the soil influences the concentration of
 its daughters (^{214}Pb and ^{214}Bi) in the air surrounding the detector. This is one
 of the causes of the variability in ISGS determinations of soil activity that is
 important to take into account. We made a series of ISGS measurements at the
 site corresponding to Soil 9. This soil consists mainly of slate and greywackes.
 The measurements were made at different times of the year coinciding with the
 periods of most and least rainfall. At each measurement, a sample of topsoil
 (0-5 cm) was taken in order to evaluate its relative moisture. Fig. 1 shows
 the correlation between the values of the soil's relative moisture and the ratios
 between the ISGS and conventional laboratory gamma spectrometry determina-
 tions of the ^{226}Ra , ^{232}Th , and ^{40}K activity concentrations. As can be seen, with
 decreasing relative moisture of the soil, the gap between the two determinations
 of the ^{226}Ra activity increases, reaching up to 50% when the relative moisture
 of the soil is below 2%. This confirms the reasoning given above that ISGS
 determinations of soil activity concentrations may be overestimated due to an
 increased presence of ^{222}Rn and its progeny in the air surrounding the detector,
 especially when the relative moisture of the soil is very low and hence there is
 a significant increase of the rate of radon emanation. This aspect needs to be
 taken into account in arid regions or in those with a marked difference in the
 accumulated rainfall during summer and winter, as is the case of Mediterranean
 regions around the world. The behaviour described above was not observed for
 the ^{232}Th and ^{40}K radionuclides. Whether in soils with a low relative moisture
 level (<10%) or those with a somewhat higher level, the differences between the
 two sets of measurements were those inherent to each technique, of the order of
 20%.

3.2. *Application of Sowa's method for detecting the concentration of the daughters of ^{222}Rn in the air around the detector*

Given the problems with ISGS measurements listed in the previous section,
 it is difficult to know a priori whether one is getting overestimates of ^{226}Ra
 descendants' activity concentrations without conducting a quantitative evalua-
 tion of, *inter alia*, the soil's geology and relative moisture. However, using the
 method of Sowa et al. (Sowa et al., 1989), one can identify whether or not there
 exists an overestimation of the ^{214}Pb and ^{214}Bi activity concentrations. The
 multiple peaks method proposed by Sowa et al. (Sowa et al., 1989) is based
 on the relationship between the different degrees of attenuation experimented
 by photons emitted at different energies by the same multi-emitting radionu-
 clide. This allows a relationship between the relaxation coefficient β and the
 relative variance of the activity to be established. Then, by varying the value

of β , one finds a minimum in the relative variance by a least squares fitting procedure. This allows a procedure to be designed to estimate the systematic error which arises from β values that do not correspond to the real radionuclide distribution. The application of this method to the gamma emitting daughters of ^{222}Rn can provide information on their concentration in the air around the detector. When the presence of ^{214}Bi in the air around the detector is negligible compared to that in the ground, the relative variance is minimized for a value of β reflecting a uniform distribution of that radionuclide by depth in the soil. Conversely, when the presence of ^{214}Bi in the ambient air is non-negligible with respect to that in the soil, the relationship between the values of the attenuation of the photons emitted at different energies from ^{214}Bi in the air and in the soil is different. Then, the relative variance is minimized for a value of β reflecting a non-uniform distribution of ^{214}Bi by depth in the soil, with this result indicating that the ^{214}Bi activity concentration determined for this soil will be overestimated. Based on this working hypothesis, we applied the multiple peaks method to the 15 samples of the soils which we had measured in situ. For this purpose, we used two of ^{214}Bi 's most intense and energy-separated emission lines: 609.3 keV and 1764 keV. The 1120 keV line has been discarded due to their proximity to the last ones, and the rest of the energy lines have been discarded due to their weak intensities. The Sowa's method using only two energy lines have been validated by others authors (Korun et al., 1991) (Rybacek et al., 1992). The results (see Table 1) showed that, in those soils in which the value obtained for the coefficient β is less than 20 g/cm² [Soils 6, 7, 8, and 9], there are substantial differences in the ^{226}Ra activity concentrations determined in situ (ISGS) and those determined in the laboratory. For the remaining sampling sites, where the said coefficient is greater than 50 g/cm², the ratio (ISGS/Lab) between the ^{226}Ra activity concentrations obtained with ISGS and those obtained conventionally in the laboratory is practically unity. By way of example, fig. 2 shows the ^{214}Bi depth profiles obtained for Soil 2 and Soil 8 from laboratory measurements of six subsamples of each soil collected at different depths, and the relationship between the relative variance and the relaxation coefficient, β , obtained by the multiple peaks method. The Soil 2 sampling point is in an area of predominantly clay soils with a small grain size and high water holding capacity. Conversely, the Soil 8 sampling point is located in an area of sandy soils on an arkose substrate. It thus has larger grain sizes than Soil 2 and a lower water holding capacity, and consequently a higher rate of ^{222}Rn emanation. One observes in the figure that, for Soil 2, the relative variance is minimized for a value of β around 80 g/cm², indicating that in this case the presence of ^{214}Bi in the air surrounding the detector is insignificant compared to that in the ground, and therefore that there will be no overestimate in the ISGS determination of ^{226}Ra from its daughters. Conversely, for Soil 8, the value of the relative variance is minimized for a value of β close to 10 g/cm², indicating that the in situ measurement of the soil's ^{214}Bi activity concentration will be overestimated. This is verified by the ISGS/Lab ratios given in Table 1. The ISGS determination of the ^{226}Ra concentration is clearly overestimated, with the magnitude of the overestimation being by a factor of

184 from 1.7 to 3.2 depending on the soil's relative moisture content.

185 The conclusion to be drawn is that the determination by ISGS of ^{226}Ra
186 from its daughters ^{214}Bi and ^{214}Pb can lead to an overestimate of its activity,
187 and that this overestimate is difficult to quantify since it depends on numerous
188 factors, including the ^{222}Rn emanation rate, the soil's relative moisture content
189 or geology, which initially are not usually quantified in situ. Nevertheless, if the
190 soil being measured has not been altered, the vertical distribution of natural
191 radionuclides should be homogeneous. Under these conditions, it is useful to
192 apply the multiple peaks method to determine the ^{214}Bi activity so as to detect
193 whether it is present significantly in the air around the detector due to a high
194 ^{222}Rn emanation rate from the ground. One can conclude from the present
195 results that if the relaxation coefficient β obtained by applying the multiple
196 peaks method to the ^{214}Bi emission lines is less than 20 g/cm^2 then the activity
197 of this radionuclide will be overestimated. In consequence, therefore, the value
198 of the ^{226}Ra activity determined from the average of the in situ measurements
199 of the ^{214}Bi and ^{214}Pb activities, will be an overestimate of the real value by
200 factors ranging from 1.5 to 3.

201 *3.3. Determination of the accuracy in the measurement by ISGS of ^{40}K , ^{226}Ra , 202 and ^{232}Th in soils*

203 Table 1 gives the activity concentrations and the ISGS/Lab ratios for the
204 activities of the radionuclides ^{40}K , ^{232}Th , and ^{226}Ra . Figure 3 shows the corre-
205 lations between the activity concentrations measured by the two techniques for
206 each of the aforecited radionuclides. One observes in the table and the figure
207 that there is a strong correlation between these two sets of activities for the
208 radionuclides considered. This is confirmed by the linear regression lines shown
209 for each of the plots of fig. 3. It is noteworthy that, for the ^{40}K and ^{232}Th
210 activities, the coefficient of determination, r^2 , is greater than 0.94. However, as
211 it was detailed in the preceding sections, this coefficient is slightly lower for the
212 case of the ^{226}Ra activity, 0.85, indicating that the correlation between the re-
213 sults yielded by the two techniques is weaker. This is due to the overestimation
214 of the ^{214}Pb and ^{214}Bi activity in some of the in situ determinations as a result
215 of their high concentrations in the air surrounding the detector.

216 In view of the results, one can assume that, for ^{40}K and ^{232}Th , the dif-
217 ferences between the ISGS and the conventional measurements are around or
218 below 15%, with the exception of the measurements made on sandy soils, when
219 the differences can reach up to 30%. This is not the case with the ^{226}Ra con-
220 centration, whose value is deduced indirectly as an average of the measured
221 concentrations of ^{214}Pb and ^{214}Bi . For soils 6, 7, and 8, the activity concentra-
222 tions registered using ISGS may differ, depending on the relative moisture of
223 the soil, by a factor of up to 3 with respect to the laboratory determinations.
224 It should be noted that the observed outlier value corresponds to the sample
225 Soil 7. This sample was collected in an area due to its geological characteris-
226 tics present, under certain conditions, a relatively significant ^{222}Rn exhalation
227 rates (Ponccla et al., 2005). For the other soils however, the differences do not
228 exceed 15%, with the exception of Soils 11 and 12 for which they reach 30%.

229 With regard to the type of geology of the soils analysed, the sandy soils, such as
 230 those on an arkose substrate, present the greatest difference between the ISGS
 231 and the conventional laboratory measurements of the activity concentrations.
 232 A particularity of this soil type is the high proportion of air space between the
 233 grains. This significantly influences the ^{222}Rn emanation rate, which increases
 234 when the moisture content is low. For all these reasons, it can be stated qualita-
 235 tively that, in the presence of sandy soils, the activity concentrations registered
 236 by the ISGS technique may be affected by overestimates of about 30%.

237 *3.4. Calculation of the absorbed dose in air from the measured concentrations* 238 *of natural radionuclides*

239 We determined the absorbed dose rate in air (ADA) for the soils analysed
 240 from the ^{40}K , ^{232}Th , and ^{226}Ra activity measurements that were made using
 241 both the ISGS and the conventional laboratory techniques. For this, we used
 242 Equation (1), given by Quindós et al. (Quindós et al., 2004):

$$ADA(n\text{Gy}/h) = 0.4551 \cdot C_{Ra} + 0.5835 \cdot C_{Th} + 0.0429 \cdot C_K \quad (1)$$

243 In this expression, C_K , C_{Ra} , and C_{Th} are the concentrations in Bq/kg of
 244 ^{40}K , ^{226}Ra , and ^{232}Th , respectively. In calculating the values of ADA, we
 245 took into account for Soils 6 and 8 the two measurements made with different
 246 degrees of relative soil moisture content. As can be seen in fig. 4, there is
 247 a strong correlation between the ADA values obtained by the two techniques.
 248 This is confirmed by the values of the linear regression coefficients ($y = mx +$
 249 n ; $m = 1.05 \pm 0.5$; $n = -(15 \pm 26)10^{-4}$; $r^2 = 0.95$.) It is important to note
 250 that the variation of the ADA in the ISGS measurements that are affected by
 251 large overestimates of the ^{226}Ra activity concentrations due to the significant
 252 presence of ^{222}Rn in the air is of the order of 12% - 36%. This is a fact that has
 253 to be taken into account when determining the absorbed dose rate in air from
 254 measurements made using the IGSG technique.

255 **4. Conclusions**

256 There is a significant correspondence between the values of the natural ra-
 257 dionuclide activity concentrations in soils as measured by the ISGS technique
 258 and by conventional laboratory gamma spectrometric techniques. In general,
 259 it can be assumed that there may be differences of up to 15% for the activity
 260 concentrations of the ^{40}K and ^{232}Th radionuclides, with the exception of sandy
 261 soils such as those on an arkose substrate in which the differences may reach
 262 30% when there is very little moisture in the soil. The ISGS determination of
 263 the ^{226}Ra activity from its daughters ^{214}Pb and ^{214}Bi in secular equilibrium
 264 may have an additional problem since the concentration in the air between the
 265 detector and the soil of these last two radionuclides it cannot be considered
 266 negligible compared to the concentration in the soil. This is especially likely
 267 in measurements of soils where there is a high level of ^{222}Rn emanation, as in
 268 situations where different factors coincide, such as sandy soils with low levels

of relative moisture content. In such situations, the in situ measurements may overestimate the real values of the ^{214}Pb and ^{214}Bi activity concentrations by up to a factor of 3. Given the difficulty of identifying and quantifying these factors so as to find a correction factor, our suggestion is that Sowa et al.'s multiple peaks method could be used to identify whether or not this type of overestimate will occur. This method is based on the relationship between the different degrees of attenuation undergone by photons emitted at different energies by each of the radionuclides ^{214}Pb and ^{214}Bi . In any case, the ADA values calculated with data from the ISGS technique have a strong correspondence with those obtained from gamma spectrometry measurements of the same soil in the low background laboratory. The greatest differences found, of around 30%, are linked exclusively to the determination of the daughters of the ^{238}U series for the reasons discussed above.

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Figure 1: Correlation between the soil's relative moisture content and the ratio between the ^{226}Ra , ^{232}Th , and ^{40}K activities determined by in situ spectrometry and by conventional techniques in the laboratory.

Figure 2: Up: Relationship between the relative variance of ^{214}Bi 's activity and the relaxation coefficient β for Soil 2 (circles) and Soil 8 (black squares). Down: Depth profile of the concentration of ^{214}Bi at the sites of Soil 2 (circles) and Soil 8 (black squares).

Figure 3: Correlation between the activity concentrations determined in the laboratory and those determined by ISGS. Solid line: $y = x$. Dashed line: Linear fit to the data.

Figure 4: Ratio between the absorbed dose rates in air as determined from the concentrations of ^{226}Ra , ^{232}Th , and ^{40}K found by conventional techniques for collecting the soil sample followed by its gamma measurement in the laboratory (Lab) and the same absorbed dose rates in air determined from the concentrations of ^{226}Ra , ^{232}Th , and ^{40}K found by in situ gamma spectrometry (ISGS).

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Table 1: Geological characteristics and relative moisture content of the soils sampled. Natural radionuclide activity concentrations determined in situ and by laboratory measurements of samples of the soils. Ratio between the activity measured in situ and that obtained in the laboratory. The coefficient β determined for the ^{214}Bi activity by the technique of Sowa et al.(*) Measurements made later at the same site, but after a continued period of rain. Relative moisture of the soil $> 25\%$.

Id. Soil	Relative Soil moisture (0-5 cm)	Geological period	Soil characteristic Rock class	^{40}K (Bq/kg)		Ratio (In situ/Lab)	^{226}Ra (Bq/kg)		Ratio (In situ/Lab)	^{232}Th (Bq/kg)		Ratio (In situ/Lab)	^{214}Bi β (g/cm ²)
				In situ	Lab.		In situ	Lab.		In situ	Lab.		
Soil 1	16	Hercynian	Granite	850±80	860±50	0.97±0.12	52±5	50±5	1.0±0.2	112±11	106±17	1.1±0.2	>100
Soil 2	17	Ediacaran	Clay	430±50	490±50	0.88±0.12	42±8	45±5	0.9±0.2	55±8	59±5	0.9±0.2	75±10
Soil 3	N.D.	Devonian	Slate	540±60	500±40	1.07±0.13	28±6	30±3	0.9±0.2	43±6	42±4	1.0±0.2	>100
Soil 4	11	Ordovician	Slate	560±50	510±30	1.09±0.12	39±5	40±4	1.0±0.2	57±8	50±5	1.1±0.2	50±7
Soil 5	19	Neogene	Clay and quartzites	400±40	350±30	1.1±0.1	35±6	30±3	1.2±0.2	32±5	26±2	1.2±0.2	45±7
Soil 6	9	Neogene	Arkose and limestone	760±80	750±30	1.01±0.11	77±14	50±5	1.5±0.2	92±9	77±4	1.19±0.11	18±3
Soil 6(*)	25	Neogene	Arkose and limestone	670±70	1120±40	0.89±0.11	56±10	66±5	1.1±0.2	75±8	104±6	0.97±0.12	>50
Soil 7	9	Neogene	Arkose and limestone	1230±120	1120±40	1.1±0.1	123±21	66±5	1.9±0.2	138±14	104±6	1.33±0.12	11±2
Soil 8	8	Quaternary	Arkose	1070±110	990±30	1.08±0.11	47±7	15±2	3.2±0.2	26±4	20±2	1.3±0.2	10±1
Soil 8(*)	25	Quaternary	Arkose	1050±110	990±30	1.06±0.11	25±5	15±2	1.7±0.2	20±2	20±1	1.0±0.2	20±1
Soil 9	14	Precambrian	Slate and Greywacke	450±50	560±20	0.80±0.12	45±5	35±2	1.3±0.1	31±3	33±4	0.9±0.2	50±10
Soil 10	N.D.	Precambrian	Conglomerate	320±30	500±40	0.88±0.11	30±6	35±2	1.0±0.2	35±2	33±4	0.83±0.11	>100
Soil 11	N.D.	Cambrian	Black mudrocks	900±100	950±200	0.9±0.2	50±10	40±5	1.3±0.2	22±4	22±5	1.0±0.3	50±10
Soil 12	5	Neogene	Clay and conglomerate	170±17	160±30	1.1±0.2	22±2	17±4	1.3±0.3	20±3	19±9	1.1±0.5	N.A.
Soil 13	4	Neogene	Clay and conglomerate	320±30	280±30	1.11±0.13	22±3	21±3	1.1±0.2	40±4	35±6	1.1±0.2	N.A.
Soil 14	6	Neogene	Clay and conglomerate	270±30	320±40	0.9±0.2	33±3	30±7	1.1±0.3	30±3	35±6	0.9±0.2	N.A.
Soil 15	19	Neogene	Clay and conglomerate	220±20	310±22	0.73±0.13	24±4	27±3	0.9±0.2	24±3	30±6	0.8±0.2	N.A.