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Short communication

Simple soil mass balance approach to interpret the distribution of global terrestrial gamma ray dose rates in relation to geology

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Abstract

A recent literature survey on natural gamma rays has yielded data on the dose rate levels above soils and rocks in the world, classified by their associated bedrock types. For comparison, the data in the Japanese Islands were also collected. The compiled results indicated a strong linear correlation between the soil and the rock dose rates. A soil–mass balance model was used to obtain the quantitative estimate of soil production and inflow rates, respectively, relative to the outflow rate. It was found from the analysis that the degree of mixing of soils, measured by the ratio between the inflow and the production rates, was fairly small in Japan compared to the world average.

Keywords: Terrestrial gamma ray; Dose rate; Soil; Rock; Mass balance; Geology

1. Introduction

Soil at a given site usually consists of weathered rock but may be mixed with soils from other sites, transported primarily by rivers during the formation of flood plains and fans. Wind and glacier may also play a role to some extent in its transport. The dose rate level of terrestrial gamma rays emitted by primordial radionuclides, i.e. uranium (U), thorium (Th) and potassium (K), in the soil at a given site might seem to reflect a low or high radioactivity of the bedrock at that site. However, in reality it may reflect more the overall balance between the rates of soil production and transportation in each continent.

The purpose of this paper is to show that the dose rate levels above the soils on the different types of bedrock can still be traced to the radioactivities of the respective bedrock using a quite simple model. The technique presented in this paper and the parameters deduced from the model are applicable also to other geochemical elements in the terrestrial environment.

2. The model

In this study, we assume a steady state condition for the soil mass flow rates at any area within a landmass. Then, the mass flow equilibrium is

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Table 1
Gamma ray absorbed dose rates in air

Bedrock type	Area (%)	Dose rate ± S.D. (nGy/h)	
		Rock	Soil
World			
Acidics	5	167 ± 55 (693)	75 ± 34 (324)
Intermediates	5	64 ± 21 (328)	43 ± 19 (96)
Basics	6	23 ± 8 (186)	28 ± 17 (91)
Metamorphics	7	90 ± 64 (345)	55 ± 21 (163)
Sedimentaries[a]	44	81 ± 70 (304)	50 ± 19 (694)
Carbonates	15	20 ± 13 (32)	32 ± 24 (46)
Quaternary sediments	18		50 ± 20 (448)
Area-weighted mean		71	47
Japan			
Acid intrusives	11	110 ± 44 (101)	73 ± 24 (205)
Acid extrusives	11	94 ± 44 (28)	57 ± 18 (99)
Intermediates	16	55 ± 33 (65)	38 ± 12 (133)
Basics	2	21 ± 17 (49)	29 ± 12 (44)
Metamorphics[b]	4	73 ± 46 (46)	44 ± 18 (59)
Sedimentaries	39	63 ± 35 (161)	49 ± 15 (794)
Quaternary sediments	17		46 ± 16 (667)
Area-weighted mean		71	50

[a] Excludes carbonates.
[b] Excludes basics origin.
Parentheses represent the number of samples.

expressed by

$$F_O = F_R + F_I \tag{1}$$

Here, F_O and F_I represent, respectively, the soils moving out of and into the area, and F_R the soil produced from rock. If we postulate that the soils are homogeneously mixed everywhere on the land, then the balance would require the following equilibrium between the natural radioactivity of the soil p, and that of the rock q:

$$pF_O = \varepsilon q F_R + \langle p \rangle F_I \tag{2}$$

Here, ε is the radioactivity loss due to leaching and eluviation during weathering of rock. The term $\langle p \rangle$ denotes averaging of the radioactivity over the whole of the landmass.

If we consider the entire landmass, the soil mass moving out of the landmass is equal to that produced from bedrock and hence, the radioactivity loss becomes

$$\varepsilon = \frac{\langle p \rangle}{\langle q \rangle}, \tag{3}$$

where $\langle q \rangle$ is the bedrock activity averaged over all the landmass. From the above equations, we obtain

$$\frac{p}{\langle p \rangle} = \frac{F_R}{F_O} \frac{q}{\langle q \rangle} + \frac{F_I}{F_O} \tag{4}$$

Since the dose rate on the soil surface and that on the rock surface are proportional to the sum of weighted concentrations of U, Th and K of the soil and rock (Beck et al., 1972), we can use the relevant dose rate values in place of p and q. This is because, in practice, it is much easier to obtain a large amount of data on air absorbed gamma ray dose rates of soils and rocks than to collect U, Th and K data. Thus, this presents a way for us to test the equation.

3. Sources of basic data

Gamma ray dose rates in air at a height of 1 m above various types of soil and rock are given in Table 1 along with their percentage in worldwide coverage. The world data of rocks were deduced

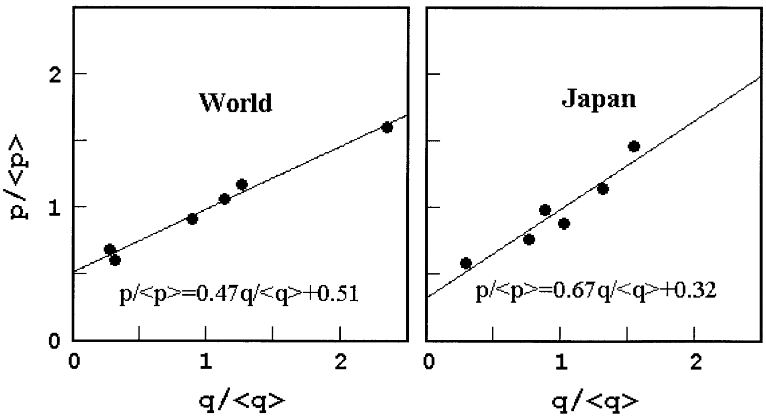

Fig. 1. Relation between the dose rates above bedrocks and the corresponding soils.

from the work of Wollenberg and Smith (1990). The world data of soils were recompiled from the data of Minato (1995) but with new data points amounting to several percents in number added to the original data. The rock and soil data of Japan were both recompiled based on the work of Matsuda and Minato (1999) along with several percents of additional data.

4. Results and discussion

Fig. 1 indicates clearly that the dose rate values of the soils and rocks given in Table 1 show trends in broad agreement with Eq. (4). By performing a least-square fit to the data we could determine the values of F_R/F_O and F_I/F_O. Thus, this provides a quick and novel way to estimate values of these ratios, which hitherto are not obtainable by other means. Furthermore, if one of the three variables, F_R, F_O and F_I, could be estimated independently, the others could then be deduced easily.

Under the steady state assumption, the inflow rate has to be equal to the rate of transport to other sites inside the landmass. This also requires that the amount of soil produced be balanced by the amount of soil transported directly to the oceans by rivers or other means. Consequently, we may consider the ratio between the inflow and the production rates as an indicator of the degree of soil mixing within the landmass. In this respect, Fig. 1 shows a clear difference in the degree of soil mixing between global and Japanese data. It would be interesting if future geomorphologic data could verify whether this is indeed the case.

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