―研究ノート―
Scientific Note

A new sampling technique for surface exposure dating using a portable electric rock cutter

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表面照射年代法における携帯型電動カッターを用いた新たな試料採取方法

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(Received March 12, 2012; Accepted May 16, 2012)

要旨: 宇宙線生成核種を用いた表面露出年代測定法は，地球表層における様々な現象を理解するために非常に重要な年代測定法である．この年代測定法には，年代決定精度が試料形状に依存するという特徴があり，試料採取の際に試料の厚さと形を高精度で測定することが必要となる．しかし，ハンマーやタガネを用いた従来の手法では，このような要求を満たす試料採取は時として困難であった．そこで本研究では，新たに携帯型電動カッターを用いた試料採取手法を提案する．この手法は，迅速かつ精密な試料採取および形状測定を可能とすることから，結果として年代測定精度の向上につながるものである．簡単な理論計算に基づき不完全な試料形状に起因する年代差を求めたところ，試料の採取深度が大きくなるにしたがって年代差が大きくなることが分かり，表面露出年代測定法における精密な試料形状測定の重要性が示された．

Abstract: Surface exposure dating using in situ cosmogenic nuclides has contributed to our understanding of Earth-surface processes. The precision of the ages estimated by this method is affected by the sample geometry; therefore, high accuracy measurements of the thickness and shape of the rock sample (thickness and shape) is crucial. However, it is sometimes difficult to meet these requirements by conventional sampling methods with a hammer and chisel. Here, we propose a new sampling technique using a portable electric rock cutter. This sampling technique is faster, produces more precisely shaped samples, and allows for a more precise age interpretation. A simple theoretical model demonstrates that the age error due to defective sample geometry increases as the total sample thickness increases, indicating the importance of precise sampling for surface exposure dating.

1. Introduction

Surface exposure dating of boulders on moraines and other landforms using in situ

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南極資料，Vol. 56，No. 2，85–90，2012
Nankyoku Shiryô (Antarctic Record), Vol. 56, No. 2, 85–90, 2012

cosmogenic nuclides is a powerful tool for obtaining precise chronological information, which is crucial to regional and global reconstructions of past climates. This method is especially important for environments in which other dating techniques are difficult to apply, such as in East Antarctica (e.g., Mackintosh *et al*., 2007; Liu *et al*., 2010). For example, the most widely applied radiocarbon and optically stimulated luminescence (OSL) dating methods suffer from absences of organic material and soft sediments (soil) in such environments. A distinct advantage of the surface exposure dating method is that it can provide a direct age control for a glacial-geomorphic feature. However, the precision of the interpreted ages estimated by this method is affected by the sample geometry (Gosse and Phillips, 2001).

The interactions between galactic cosmic radiation (GCR) particles and Earth's atmosphere produce a cascade of secondary particles. Some of these particles reach the Earth's surface, where they induce nuclear reactions that produce cosmogenic nuclides (Gosse and Phillips, 2001). Near the Earth's surface, the contribution of neutrons dominates cosmogenic nuclide production (Masarik and Reedy, 1995). Neutron penetration decreases significantly in the upper 2 m of rock at the Earth's surface. This decline can be approximately characterized by an exponential curve (Gosse and Phillips, 2001). Thus, age interpretation in surface exposure dating has to correct for the rate of cosmogenic nuclide production over the actual sample thickness. In addition, this dating method usually assumes that an equal amount of rock sample was taken at each depth (i.e., a cuboidal shape). However, it is sometimes difficult to meet these requirements in the samples obtained from boulders on moraines and other landforms under extreme environments, such as at high altitudes and in Antarctic regions.

In this article, we propose a new rock sampling technique for surface exposure dating using a portable electric rock cutter. This technique makes rock sampling faster and produces more precisely shaped samples, allowing a more precise interpretation of the exposure age. We also discuss the artificial age error associated with defective sample geometry based on a simple model and summarize the advantages and disadvantages of this sampling technique.

2. A new sampling technique

The ideal geometry of a rock or landform surface for this dating method is flat, horizontal, and sufficiently extensive (Gosse and Phillips, 2001) (Fig. 1a). Samples for surface exposure dating are usually collected from rock surfaces using a hammer and chisel. Although this conventional sampling technique has the advantages of portability and simplicity, it is not easy to obtain an equal amount of rock sample at each depth, especially from a flat, extensive rock surface. It is also difficult to measure a sample thickness (depth of the sample pit) precisely because the edges of a sample pit made by a hammer and chisel are usually not sharp. To address the sampling difficulties associated with this dating method, we propose here a new sampling technique using a portable electric rock cutter (Fig. 1b). This technique significantly reduces the sampling time compared to the conventional technique and leaves sharp edges along the sample pit, making it easy to obtain a sample thickness (depth) precisely (Fig. 1c, 1d and 1e).

The portable electric rock cutter consists of an engine body, a cutter blade, and a

Fig. 1. *Photographs of the sampling procedure for surface exposure dating. (a) Overview photograph of a boulder on a moraine. (b) the outline of the sample pit and cross cuts are made on the rock surface using a portable electric rock cutter. (c) Block samples are removed using a hammer and chisel. (d) Sample pit after cutting and block removal. (e) Measuring depth along the sharp edges of the sample pit made by the rock cutter. (f) The portable electric rock cutter, batteries, and other essential tools for this sampling technique. We used a rock cutter designed by the Makita Corporation (GA402DRF).*

battery (Fig. 1f). The total weight is approximately 2.1 kg. The cutter blade can be changed quickly when it becomes dull. The cutting time depends on the type of rock, and a set of spare batteries is required. The first cuts, which are typically orthogonal to the rock surface, are made along the planned outline of the sample pit. A second set of cuts produces several 4- to 5-cm-wide blocks (Fig. 1b). Finally, these blocks are removed using a hammer and chisel (Fig. 1c). Because the blocks are already cut, this stage is easy and quick. Water or other lubricants are not necessary.

3. Age error associated with defective sample geometry

Because age interpretation in surface exposure dating assumes that an equal amount of

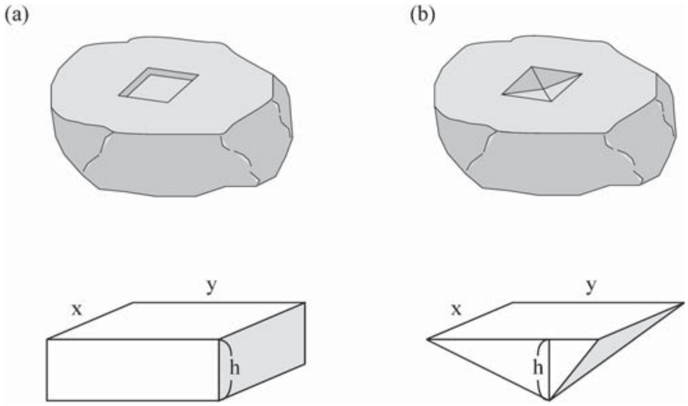

Fig. 2. Schematic figures showing typical sample (pit) shapes for surface exposure dating. (a) Cubic sample pit. (b) Quadrangular pyramid-shaped sample pit.

rock sample is taken from each depth, failure to meet this requirement directly affects the final output of the procedure (age). To estimate the age error associated with defective sample geometry, we performed a simple modelling experiment. We used a cube and a quadrangular pyramid to represent optimal and defective sample geometries, respectively (Fig. 2a and 2b). The quadrangular pyramid is representative of a sample shape obtained using the conventional sampling technique. Although the dominant production of cosmogenic nuclides at greater depths, typically below 100 hg/cm^2, occurs due to rapid muon-induced reactions (Heisinger *et al*., 2002), sampling for surface exposure dating does not normally reach that depth. Therefore, we have ignored the contribution of muons to cosmogenic nuclide production.

The relationship between the cosmogenic nuclide production $P(x)$ and the depth x (cm) within a rock can be described as follows (Gosse and Phillips, 2001):

$$P(x) = P_0 \cdot \exp\left(-\frac{\rho x}{\Lambda}\right) \qquad (1)$$

where P_0 and ρ are the cosmogenic nuclide production rate at the Earth's surface and the density of the rock, respectively, and Λ is the attenuation length of the cosmogenic particles. In our model, we used 160 hg/cm^2 for the attenuation length of a neutron (Gosse and Phillips, 2001) and the global average density of granite (2.67 g/cm^3) for the ρ value (Hall, 1996).

The age errors between the quadrangular pyramid- and cube-shaped samples calculated in this modelling experiment are shown in Table 1. These results indicate that the age error is increased due to defective sample geometry. The age error increases as the total sample thickness increases. For example, the age errors from 10 to 20 cm are 4.2 to 8.4%, which exceed the expected analytical age error (3% for sample analysis and 4% for mass spectrometric measurements) of the dating method (Gosse and Phillips, 2001). Although most surface exposure dating studies use samples collected from the upper 5 cm of the surface, this modelling experiment demonstrates that defective sample geometry leading to the final result (age), the importance of sample shape in this dating method.

The depth profile of spallogenic production due to neutron penetration may be

Table 1. Age error based on the sample shape and depth.

Depth (cm)	Production/cm^2(cubic)*	Production/cm^2(pyramid)*	Age Error (%)
1	0.991	0.995	0.4
2	0.983	0.991	0.8
5	0.959	0.979	2.1
10	0.920	0.959	4.2
15	0.884	0.939	6.2
20	0.850	0.921	8.4

*Normalized by the cosmogenic nuclide production at the rock surface.

uncertain. Masarik and Reedy (1995) have reported that in a numerical simulation, neutron flux is initially flat to a depth of 12 g/cm^2 below a rock surface. In this case, the age error due to defective sample geometry is less obvious, but surface exposure dating methods currently ignore this flattening. Therefore, we did not consider this problem in the present study.

4. Advantages and disadvantages of the technique

The sampling technique presented here has many advantages and a few disadvantages. The portable electric rock cutter is lightweight, readily available, compact, and inexpensive. These factors facilitate sampling from a greater number of sites. Because water and gasoline are not needed, the potential scarcity of these resources is irrelevant. These advantages expand the scientific scope of this dating method, especially in extreme environments such as at high altitudes and in Antarctic regions.

This sampling technique might be unsuitable for hard rock specimens. It has been tested on and works well for granite and gneiss; it is probably well suited for other materials of similar friability and consolidation. For these rocks, the new method is superior to conventional techniques with a hammer and chisel.

However, these advantages are partially offset by some disadvantages. The portable electric rock cutter requires at least one set of batteries per sampling site. The batteries must be recharged, which requires access to electricity and an a.c. charger or d.c. equivalent (we also used ski-doos to recharge these batteries during our field work). Because a large amount of dust is generated during sampling, eye protection and a respirator filter are essential. Although the electric motors are not as loud as gasoline drill motors, hearing protection is still recommended for the operator. After cutting, dust will cover the boulders on moraines and other landforms; therefore, the orientations of the sample and its host rock must be measured before cutting.

5. Conclusion

Surface exposure dating has contributed broadly to the earth sciences. However, the importance of sample geometry (shape and thickness) has been poorly accounted for, although it directly affects the outcome of dating. Here, we propose a new technique for sample collection using a portable electric rock cutter. This sampling technique is faster, produces more precisely shaped samples, and allows more precise age interpretation than the conventional technique using a hammer and chisel. Because a certain amount of age error occurs due to defective sample geometry, as indicated by our simple modelling experiment, precise sampling using the technique described here can improve the results of this dating method.

Acknowledgements

We thank all members of the 51st Japanese Antarctic Research Expedition (JARE-51) and the supporting staff of the National Institute of Polar Research. We also thank Noriyoshi Tsuchiya (Tohoku University) for his advice to use the portable electric rock cutter. This work was partly supported by Grant-in-Aid for Scientific Research (A) 21253001 and (C) 2250099.

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