学位論文（要約）

Understanding the rates and mechanisms of erosion in mid-latitude humid regions using in situ-produced cosmogenic nuclides

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Understanding the rates and mechanisms of erosion in mid-latitude humid regions using in situ-produced cosmogenic nuclides

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Abstract

Quantifying erosion rates is important across a diverse range of disciplines in geology, geomorphology, and paleoclimatology. Erosion is often associated with sediment generation, which exposes fresh rock to CO_2-consuming weathering reactions, and with creating soil, changing landforms, and moving mass from continents to oceans. Numerous studies therefore underline the significance and complexity of relationships between erosion, tectonics, and climatic processes. However, quantitative assessment of the contributions from independent environmental parameters is still under debate, due in part to the limitation of the studies in the mid-latitude humid regions.

The aim of this thesis is to investigate rates and mechanisms of erosion in the mid-latitude humid regions. In particular, the first goal of this work is to demonstrate precipitation control and tectonic control on erosion rates, and further develop the techniques necessary to achieve this goal. The second goal of this study is to provide terrestrial analogue that can be used as the fundamental dataset when discussing the surface processes on Mars and the other planets.

First, erosion rates are determined for the Abukuma Mountains, Japan, using both basin-scale and site-specific methods (*Chapter 2*). This is the first comparison of these two commonly used methods in the same region in Japan, where the entire study area is characterized by well-developed saprolite. Considered with density measured in the field, distinct and systematic differences between the two methods are identified. Site-specific rates calculated from depth profiles of *in situ* terrestrial cosmogenic nuclides (TCN) at topographic highs indicate a rate of 67 to 85 mm/kyr, whereas basin-scale averaged erosion rates derived from the concentration of cosmogenic nuclides in fluvial sediments show 114 to 180 mm/kyr. The results indicate that differential erosion rates between valleys and topographic highs reflect increasing local topographic relief of the study area. The results imply that comparison between rates derived from depth profiles and those applicable to the entire basin is useful to understand landscape development. Further, the importance of physical density measurements, as opposed to modeled values, to obtain accurate erosion rates is documented.

Second, effects of precipitation on erosion rates are examined in *Chapter 3* using both basin-scale and site-specific methods. While it is intuitive that paleo-erosion

rates changed strongly as a function of precipitation amount, quantifying this relationship is complicated by difficulty measuring past erosion rates, as well as the effects of non-climatic factors, such as slope gradient, that can obscure climate-induced changes. Here we present data illustrating the variation of paleo-erosion rates in response to glacial-interglacial cycles, which greatly modify climate including amount of precipitation. We use a depth profile of terrestrial in-situ cosmogenic nuclides obtained from the Sefuri Mountains, Japan, where mean annual precipitation exhibited a marked increase by a factor of 1.5 at onset of Holocene. Together with modeling of TCN accumulation, we show the concentration of muon-produced TCN at depths beyond a few meters responds more slowly to erosion than spallation-produced TCN at the surface, which allowed us to reconstruct paleo-erosion rates. The results indicate a stepwise change in erosion rate from 60 +40/-40 mm/kyr to 350 +225/-120 mm/kyr respectively for the last glacial and for the Holocene, consistent with increased precipitation. These observations provide unique empirical evidence for long-proposed coupling between climate and erosion, supporting the previously proposed feedbacks between climate and surface topography.

Third, tectonic control on erosion is explored in *Chapter 4*. The feedback between tectonic uplift and erosion contains important mechanism maintaining topography of mountain. We present TCN-derived erosion rates from the drainage of the Tenryu River in order to document the topographic evolution of the Kiso Range (central Japanese Alps). TCN-derived erosion rates of the tributaries near the main ridgeline of the Kiso Range are 1000–2000 mm/kyr, whereas the southern tributaries show lower erosion rates between 600 and 1000 mm/kyr. In addition to the samples from the modern riverbed, a sediment core was recovered from the mouth of the Tenryu River in order to reconstruct paleo-erosion rates. TCN-derived erosion rates from the core samples shows 700–1000 mm/kyr, implying relatively constant erosion rates through the Mid- to Late Holocene. Furthermore, previously reported sediment yields and apatite fission track ages suggest constant erosion rates of the Kiso Range over 50 yr, 1 kyr, and 1 Myr time scales. These erosion rates are equivalent to the uplift rate of the Kiso Range, indicating that the topography of the range is maintained in a steady state.

Finally, TCN-based methods are utilized to determine the age and geomorphic evolution of Lonar crater (*Chapter 5*). The Lonar impact crater is one of a few craters on Earth formed directly in basalt, providing a unique opportunity to study an analogue for crater degradation processes on Mars. Here we present surface ^{10}Be and ^{26}Al exposure dates in order to determine the age and geomorphic evolution of Lonar crater. Together with a ^{14}C age of pre-impact soil, we obtain a crater age of 37.5 ± 5.0 ka, which contrasts with a recently reported and apparently older $^{40}Ar/^{39}Ar$ age (570 ± 47 ka). This suggests that the $^{40}Ar/^{39}Ar$ age may have been affected by inherited radiogenic ^{40}Ar ($^{40}Ar^{*}_{inherited}$) in the impact glass. The spatial distribution of surface exposure ages of Lonar crater differs from that for Barringer crater, indicating Lonar crater rim is actively eroding. Our new chronology provides a unique opportunity to compare the geomorphological history of the two craters, which have similar ages and diameters, but are located in different climate and geologic settings.

All the TCN-derived erosion rates obtained in this thesis are compiled in *Chapter 6*, suggesting that mean basin slope angles best explain the erosion rates in Japan. Based on the results, an exponential function of basin slope is proposed to explain the variations in erosion rates.

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List of abbreviations used

AFT	Apatite Fission Track
AMS	Accelerator Mass Spectrometry
GPS	Global Positioning System
KC	Kuroshio Current
LGM	Last Glacial Maximum
MIS	Marine Isotope Stage
QF	Quality Factor
TCN	*in situ* Terrestrial Cosmogenic Nuclide
TOC	Total Organic Carbon
TWC	Tsushima Warm Current
XRF	X-Ray Fluorescence

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Chapter 1

General introduction

本章については, 5 年以内に雑誌等で刊行予定のため, 非公開.

Chapter 2

Direct comparison of site-specific and basin-scale erosion rate estimation by *in situ* cosmogenic nuclides: an example from the Abukuma Mountains, Japan

インターネット公表に関する共著者全員の同意が得られていないため，本章ついては，非公開.

Chapter 3

Glacial-interglacial control of paleo-erosion rates in the Sefuri Mountains, Japan

インターネット公表に関する共著者全員の同意が得られていないため，本章ついては，非公開.

Chapter 4

Relation between tectonic uplift rates and erosion rates in the Kiso Range (the Central Alps of Japan) from *in situ* cosmogenic nuclides

インターネット公表に関する共著者全員の同意が得られていないため，本章ついては，非公開．

Chapter 5

Formation and geomorphologic history of the Lonar impact crater deduced from in situ cosmogenic ^{10}Be and ^{26}Al

インターネット公表に関する共著者全員の同意が得られていないため，本章ついては，非公開.

Chapter 6

General discussion

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Appendix

Weak monsoon event at 4 ka recorded in sediment from Lake Rara, the Himalayas

インターネット公表に関する共著者全員の同意が得られていないため，本章ついては，非公開.