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Kenji Kashiwaya

Geomorphology of Lake-Catchment Systems

A New Perspective from Limnogeomorphology

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Preface

Geomorphology is an earth science of landform changes and earth-surface processes. The changes and processes have been essentially controlled with tectonic activities and climatic activities. Recently, anthropogenic activities have also been important agents for those processes. One of the ultimate objects of this particular earth science is to predict the altitude (z) of a certain point (x, y) on the earth's surface at a certain time (t). However, it is nearly impossible to make that prediction exactly, even if all present sciences are used because the landform itself is an extremely complex system. It is of great significance, however, to grapple with the issue for the development and elaboration of earth science.

Geomorphology of lake-catchment systems (limnogeomorphology) also aims to contribute to this aspect (prediction) of geomorphology. Proper process-understanding and exact quantitative data are required for estimating future landforms precisely. However, both process-understanding and available data are limited in some phenomena and intervals. That is, only limited landform changes in limited observation intervals are to be quantitatively discussed for future estimation, although landforms have been developed in the geological and historical timescales as well as in the present observation period. Long-term development of landforms is also essential for geomorphology. Therefore, recent process-understanding and available quantitative data have to be extended to historical and geological timescales.

One of the most important procedures for this process is to observe landform phenomena instrumentally and historically–geologically. The lake-catchment system is convenient for observing earth-surface changes both instrumentally and historically–geologically. Present lake-catchment processes and changes can be instrumentally observed, and the changes including surrounding environments may have been recorded in the lacustrine sediments. Generally, the lacustrine records include not only present observational information but also pre-observational (past, historically and geologically) information, and the two kinds of information would be continuous without natural and artificial disturbance. If appropriate relationships between instrumental data and lacustrine (proxy) data are established for the present observation interval, proxy data for the past may be available for quasi-instrumental ones. This could fill a “missing link” between process geomorphology and historical geomorphology.

The first step of discussion of why it is necessary to uncover the “missing link” (connecting instrumental data with proxy data) is to find a way to establish long-term external forces for checking the model on the development of drainage density (Chap. 2). The forces are simply expressed as a function of long-term climatic changes. In a non-glaciated region such as Japan, the precipitation factor (discharge due to precipitation) must be the most promising means for the external force among several climatic factors. This is linked to research of Lake Biwa sediments (Chap. 3). In the 1980s when the model was under consideration, the oldest lacustrine sediments in the world were those obtained from Lake Biwa. The need for establishing appropriate functions for the climatic factors led to the Milankovitch theory (Chap. 9) and Lake Baikal and Lake Khuvsgul research (Chap. 3).

A clue to construction of the model for drainage density (Chap. 2) was derived from a rill network study in a slope system (Kashiwaya 1979; 1980). The model was established with many field observations and then was checked by model experiment in the laboratory before it was finally verified with field experiments (instrumental observations on an experimental slope in the field for 2 years). This suggests the importance of extension and connectivity of short-term laboratory experiments to comparatively long-term field experiments and leads to the idea that short-term instrumental observation should be linked to long-term field observation.

The first step for checking the idea was to make sure of the possibility that the data obtained from lacustrine sediments in instrumental observation intervals in small lake-catchment systems are connected to ones derived from pre-instrumental observation ones at Lake Yogo (Chap. 3). The second step was, unfortunately, related to the Kobe earthquake in 1995. Just after the earthquake, two sediment traps were set on the floor of a small lake to obtain short-term deposited materials for measuring high-resolution physical properties of sediments and to compare measured items with core-sampled sediments (comparatively long intervals; beyond observational limits) (Chaps. 3 and 4). Furthermore, it was possible to establish some models for erosion transportation and sedimentary processes in a lake-catchment system if enough data were given with the measurement (Chaps. 5–7).

Appropriate pre-observational data with exact dates are very important for properly interpreting and reconstructing past processes and changes. Especially, proxy data in the historical period connected to those in the observational period require more precise dates when they are used for quantitative discussion with observational data. Some abrupt events with documentary records (e.g., large earthquakes, volcanic eruptions, nuclear bomb testing) may also be useful for establishing reasonable dates in addition to radiometric dating (e.g., ^{14}C, ^{10}Be, ^{210}Pb). Many seismic and volcanic events have occurred recently in Japan, and some of them, as well as the peak time of nuclear bomb testing, can be used for determining absolute age models in the historical period and the instrumental observation period for natural forces and anthropogenic forces on the earth’s surface (Chaps. 3–5).

If a certain amount of appropriate data is obtained, quantitative expressions for changes in some earth-surface phenomena will be needed for postdiction and prediction. The first stage for quantitative expression is to establish empirical equations for the phenomena. The empirical equations might be partially developed into theoretical (causal) ones if the phenomena were limited to short time interval and a small space (Chaps. 6 and 7). However, most equations for the earth-surface phenomena will be improved with additional data and with causal relationships, keeping empirical expressions (Chaps. 6 and 8). Nevertheless, they are of great meaning because various significant factors among innumerable ones are screened for establishing more reasonable expressions with more cause-and-effect relationships.

The idea of publishing this book came to me when I was a visiting professor at the Department of Geography of National Taiwan University (NTU) in 2014. At that time there was a lecture titled "Limnogeomorphology," which was given to postgraduate and undergraduate students from NTU and NTNU (National Taiwan Normal University). Publications on "limnogeomorphology" or studies on lake-catchment systems from the geomorphological point of view were extremely limited then. Geomorphological studies on the systems, however, are of great significance, as explained above. Hence, I tried to compile research works mainly based on my own works up to that point and to add some new ideas or findings, first published in this book, for completing *Geomorphology of Lake-Catchment Systems*.

To my great sorrow, I lost four respected and intimate colleagues in the course of this study: Prof. T. Masuzawa of Nagoya University, Prof. K. Fukuyama of Mie University, Dr. D. Tomurhuu of the Institute of Geology and Mineral Resources, Mongolian Academy of Sciences (MAS), and Prof. T. Kawai of Nagoya University.

I am most grateful to Prof. JC Lin, his colleagues, and the Department of Geography of NTU and at NTNU. I am indebted to many colleagues for the publication of this book: Prof. Y. Tanaka of Kyung-Hee University (Korea), Prof. N. Hasebe and Dr. S. Ochiai of Kanazawa University, and Dr. JW LaMoreaux (Series Editor of Environmental Earth Sciences) for the critical reading of the first manuscript of this book; Dr. T. Itono of Kanazawa University for the checking of figures; Ms. U. Uyangaa of Kanazawa University (National University of Mongolia) for the interpretation of the Baikal map; and the many junior and senior colleagues who worked with me at Kanazawa University, Kobe University, and Kyoto University for new ideas and new data.

Research results included in this book were supported by many precursors: Prof. S. Okuda of Kyoto University, Prof. T. Okimura of Kobe University, and Prof. A. Yamamoto of Osaka Electro-Communication University. Overseas and domestic fieldwork was successfully completed with Chinese colleagues from the Chinese Academy of Sciences (CAS), Yunnan Institute of Geography, and Yanbian University; Russian colleagues from the Russian Academy of Sciences Siberia Branch (RAS SB); Mongolian colleagues from MAS and the National University of Mongolia; Taiwanese colleagues from NTU; Korean colleagues from the Korean Institute of Geology and Mineral Resources; and Japanese colleagues from the

Japanese Association for the Baikal International Research Program (JABIRP), Lake Biwa Research Institute, Osaka City University, Toyama University, Tateyama Caldera Sabo Museum, and Hokkaido University of Education.

I am also grateful to many close colleagues who established the Japanese Geomorphological Union and those who have joined the East Eurasia Workshops since 2004 from Korea, China, Mongolia, Taiwan, Russia, and other areas. The financial support for the research work from Kanazawa University, the Japan Society for the Promotion of Science (Grants-in-Aid for Scientific Research), and the Strategic International Research Cooperative Program of the Japan Science and Technology Agency (JST) are gratefully acknowledged.

Kanazawa, Japan Kenji Kashiwaya
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Contents

Chapter 1
Introduction

Studies on earth-surface processes and landforms are closely related in geomorphology, which is one of important features, compared with other earth sciences. In other words, "differential" and "integral" studies are inseparably connected. These two disciplines may correspond to process geomorphology (dynamic geomorphology) and historical geomorphology, respectively. The relation between differential equations expressing material transport and integrated landforms describes the temporal changes in landforms (historical geomorphology) on the basis of their developmental processes (process geomorphology). This approach was first described as theoretical geomorphology in the early 1960s (e.g., Scheidegger 1961).

There are some areas in geomorphology which try to combine "present" science (based on instrumental measurements and/or laboratory experiments) with "historical" science (with qualitative field observations) (theoretical geomorphology, physical geomorphology, etc.) (e.g., Scheidegger 1961; Ahnert 1987; Mizutani 1999; Pelletier 2008, etc.). However, most areas lack past quantitative records, especially data suitable for quantitative discussion. One approach overcoming this situation relates to the geomorphology of lake-catchment systems, i.e., limnogeomorphology. Lacustrine sediments are recording media, and most phenomena happened in the systems are recorded with the media as well as measured with instruments. The time interval and precision of the recorded data depend not only on the length of the recording media (sediment thickness) and their resolution (sedimentation rate) but also on the (instrumental) observational interval. Comparatively short-term lake-catchment processes and their recording mechanisms could be clarified mainly through instrumental observations. Long and high-resolution records with present observations fundamentally provide some clues to make clear past processes and postdict past changes, and they will show some ideas to predict future changes, depending on the record length and data precision.

Sedimentary records of lake-catchment systems include significant environmental information in addition to limnological and geomorphological ones. It is not easy to obtain useful information for the lake-catchment studies directly because many appropriate filters have to be applied to retrieve the specific information of

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interest. However, this difficulty is linked to the advantage of this discipline (geomorphology of lake-catchment systems), because both "process" and "historical" information are explicitly included in the systems. Geomorphology should be one of integrated earth sciences where process geomorphology and historical geomorphology are essentially combined.

The term "limnogeomorphology," as roughly defined above, was first used at "Limno-geomorphology Laboratory" at the Institute of Nature and Environmental Technology, Kanazawa University, Japan (Kashiwaya et al. 2004). The term seems to have appeared first in the title of the journal at 2008 (Kashiwaya 2008). It has not always been widely used although it was explained comparatively in detail in the book published in 2015 (Kashiwaya et al. 2015). This is partly because papers directly written with the concept of limnogeomorphology are limited, although many papers related to geomorphology of lake-catchment systems have been published to this date. On the contrary, "limnogeology" in related academic field has been widely used since the first half of the twentieth century (Einsele 1938). Present volume aims to fill this gap.

Predictions relating to earth-surface environments are mainly based on numerical calculations using data from instrumental observations. Most available data for such calculations are limited in the period after the Little Ice Age (LIA), although some precious observational data exist also for the earlier centuries. For example, precipitation data for Seoul (Korea) start at the period of King Sejong of Joseon Dynasty (1418–1450) (Chosen Sotokufu Kansokusho 1917), and continuous data are available after the late eighteenth century. However, to make comparatively long-term predictions (for the next some centuries), obtaining data for various past climatic regimes is necessary, not only instrumental observation data for the warm period after the LIA but also historical proxy data. They are of particular interest for understanding the processes involved and for future projections under various regimes (climato-environmental regimes).

Both observational data with instruments and proxy ones are to be "observed" in the same "observatory" for establishing continuous records for the "observatory." In this respect, lake-catchment systems offer the possibility to acquire continuous records of various regimes and to interpret earth-surface processes with respect to environmental changes. Instrumental observations in such systems provide information on the underlying processes as well as on the environmental changes in progress. Lacustrine sediments in the system will give information on present (observational) and long-term environmental changes (proxy data). If the proxy data are smoothly (logically) connected to the observational data, it would be possible to obtain long continuous datasets for the past climate-environmental changes. Thus, lake-catchment systems may be considered as proxy observatories.

Next, let us discus how to connect proxy data with observational ones on the basis of scientifically reasonable procedures. There are some basic steps in dealing with data on earth-surface processes and temporal changes (Kashiwaya 2012).

(1) Clarifying relations between instrumental observation of lake-catchment processes and sedimentary records, and establishing “instruments” expressing the relationships in the present period: This is deeply related to an understanding of the lake-catchment mechanical processes and the recording process. Data recorded in sediments are compared in detail with hydrogeomorphological observations and measurements in the system; events included in sedimentary records should be quantified. Discussions on event recording process are also important. In addition, considering the validity and limitation of sedimentary records (proxies) in the system is important for appropriate use of the data. These lead to the establishment of some “instruments” (transfer functions). For example, a proxy rain gauge can be established using the physical properties of lacustrine sediments (Shimada et al. 2002). The “measured” data would then be compared with instrumental observation data to ensure their validity and limitation.

(2) Observation of past environments with the above instruments (quantitative reconstruction) based on sedimentary information and documents to delineate the earth-surface processes in the historical period: The established instruments may be extended with some modifications to the historical period if the measured proxy data are supported by documentary records and dated proxy data.

(3) Estimation of long-term environmental changes recorded in sediments, mainly related to cosmic-solar and orbital fluctuations with extended instruments for the pre-historical period: The instruments measuring the sedimentary records in observational and historical periods can be regulated and/or modified using environmental information related to cosmic-solar and orbital fluctuations. Furthermore, understanding of elementary processes in the present system is of great use for interpreting the information and estimating it properly.

Significant hints for understanding the processes in lake-catchment systems may be given through present instrumental and non-instrumental observations. Instrumental observations in present small lake-catchment systems may also be relevant to understand the elementary processes in the past systems. Model experiments and numerical simulations are also of great use for investigating these processes and for establishing basic equations for elementary processes. Accomplishing the above steps is linked to establishing continuous quantitative data from the present to the past in the system. Nevertheless, this is difficult because of the complexity of the systems, especially in the long term. Some assumptions are also introduced at some stages in the steps, and they should be logically checked with data, if any, for establishing some approximate relations, which will be of great help to utilizing paleoenvironmental information for future predictions.

In this present text, some lake-catchment studies of various scales are introduced to develop the above-mentioned ideas; long-term information on environmental changes and processes in large lake-catchment systems are discussed and interpreted through this information with present instrumental observations and understandings in small systems. Finally, the basic concepts and methods of limnogeomorphology (geomorphology of lake-catchment systems) will be understood in this context.

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