Kenji Kashiwaya · Ji Shen
Ju Yong Kim *Editors*

Earth Surface Processes and Environmental Changes in East Asia

Records From Lake-catchment Systems

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Preface

We may be faced with natural and anthropogenic environmental changes never found in instrumental observation records, not only locally but also globally. Generally, it is comparatively easy to find the cause and effect of local and short-term changes, whereas it is difficult to establish causal relationships for global and long-term environmental issues. One of the most significant issues in environmental changes to be discussed is knowing how earth surface environments responded to the changes in the past, because that knowledge is required in order to estimate future environmental responses to changes. We have only limited short-term observational data in the instrumental observation period to provide some clues to find causal relations for the estimation. Most areas lack past quantitative records, especially data available for quantitative discussion, although data on earth surface responses to large and long-term global changes are included in past proxy records.

One of the attempts to overcome this situation is to establish studies on lake-catchment systems (e.g., limno-geomorphology). The systems may provide a key to understanding cause and effect in past environments, because current sediment information can be compared with present observations in the systems (process understanding); environmental information, especially having to do with catchments, may be causally connected with observational data. Lacustrine sediments of the systems are recording media, and phenomena that occurred in the systems are recorded in the media. Comparatively short-term lake-catchment processes and process-recording mechanisms are clarified mainly with instrumental observation. The time interval and precision of recorded data depend on the length of the recording media (thickness of sediments) and resolution (sedimentation rate). These instrumental observation and high-resolution records fundamentally provide clues to clarify past processes and reconstruct past changes, and they will furnish ideas for predicting future changes according to the data length and precision.

A goal of this book is to make clear the relations among climato-hydrological changes, land use, natural disasters, and so on during the recent (geological) past, especially in the periods of rapid environmental shifts (rapid global warming, rapid global cooling, rapid tectonic movement, and others), by using lake-catchment systems in northeast Asia from Mongolia to Taiwan. Northeast Asian districts, located in the middle latitudinal zone, are not only affected by westerly circulation but also controlled by East Asian monsoons. In winter, the cold surge, which sweeps eastern Asia, usually breaks out around Siberia and Mongolian areas. In summer, the Asian summer monsoon flowing through Japan and Korea can reach northeast China as well. In spring, large amounts of aeolian dust (loess) due to the westerlies are transported to northeast China, Korea, and Japan from central Asia and west China. Therefore, climates and environments of these districts are closely related to one another. The districts are under similar climatic conditions with some systematic differences in climatic factors (temperature, precipitation, etc.), tectonic factors, and anthropogenic factors. This means that both proxy and observation data may be available for the East Asian countries in view of their own unique provision as well as common data associated with disasters and climato-hydrological events.

The systems discussed are of various origin: lava-flow dammed lakes, e.g., Terhin Tsagaan Lake (Mongolia) and Jingpo Lake (northeast China); a volcanic debris-flow dammed lake, e.g., Lake Onuma (Japan); tectonic lakes, e.g., Xinkai Lake (northeast China), Lake Biwa (Japan), Lake Yogo (Japan), Qilu Lake (south China), and Ri-yue-tan ("Sun-Moon Lake") (Taiwan); coastal lagoons, e.g., Hwajinpo (Korea), Songjiho (Korea), Bongpo (Korea), Cheonjinho (Korea), Ssangho (Korea), and Soonpogaeho (Korea); artificial reservoirs, e.g., Eurimji (Korea) and Kobe Kawauso-ike (Japan). Especially Xinkai Lake, Jingpo Lake, Eurimji, and Lake Onuma are common targets of joint research among Kanazawa University, the Nanjing Institute of Geography and Limnology, and the Korea Institute of Geoscience and Mineral Resources.

All the systems selected here have varying timescales of information on climatic changes and environmental changes in the recent geological past, including tectonic and anthropogenic activities in the area. We hope that the results contained here along with further information on the systems will provide valuable knowledge of past environments and significant clues for future prediction and provision.

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Chapter 1
Present Earth-Surface Processes and Historical Environmental Changes Inferred from Lake-Catchment Systems

K. Kashiwaya, T. Okimura, T. Itono, K. Ishikawa, and T. Kusumoto

Abstract Environmental changes in lake-catchment systems due to climatic, tectonic, and anthropogenic activities (processes) have been imprinted on lacustrine sediments. Long continuous observation in a small pond-catchment system at Kobe, Japan following the 1995 Kobe earthquake provides good data on environmental changes. These records are available for establishing a mathematical model in which the rate of sedimentation varies in two stages before arriving at the pre-earthquake stage. The model's calculations are fairly consistent with observational results, indicating that the model is acceptable. The 1995 earthquake is faintly recorded in the physical properties of sediments obtained in the system (increase in density and

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slight change in grain size). A combination of grain density (or mineral content) and grain size may be useful as an indicator for the occurrence of comparatively large earthquakes in tectonically active and climatically humid areas. The Tong-hai earthquake of 1970 in Yunnan, China was detected in the combination (density increase and grain size decrease) for the core sediments obtained from Qilu-he. The Kanbun earthquake of 1662 in Lake Biwa catchment was also detected in the corresponding data from some cores obtained from Lake Biwa, Japan.

Keywords Lake-catchment system • Lacustrine sediment • Physical properties

1.1 Introduction

It is difficult to establish the causes of global environmental issues, especially past issues. However, lake-catchment systems may provide a key to understanding cause and effect in past physical environments, because current sediment information can be correlated with present observation in the system (mechanical understanding). Environmental information, especially as recorded in catchments, may be causally connected with observed events, which means that past information recorded in sediments may be useful for reconstructing past environmental changes and for predicting future changes.

Some research in geomorphology aims to combine "present" science, mainly based on instrumental observation, with "historical" science, based on field observation, but most areas lack past records, especially quantitative data available for quantitative discussion. One of the attempts to overcome this situation is to establish geomorphology of lake-catchment systems (or "limno-geomorphology"). In these systems, lacustrine sediments are a form of recording media and phenomena in the systems are recorded in the media. Comparatively short-term lake-catchment processes and process-recording mechanisms are assayed mainly by instrumental observation. The time interval and precision of recorded data depends on the length of recording media (thickness of sediments) and resolution (sedimentation rate). These instrumental observations and high-resolution records provide clues to elucidate past processes and postdict past changes, and they facilitate the prediction of future trends, depending on the quantity and precision of data.

Sedimentary records include much environmental information in addition to hydrological and geomorphological one. However, it is difficult to obtain useful information because observations must be filtered in specific ways for each discipline, such as hydro-geomorphology. Three processes are important for identifying observational results: climatic, tectonic, and anthropogenic activities (processes). In this paper, several processes and environmental changes related to these three activities will be analyzed for the two time windows (present and historical).

1.2 Typical Lake-Catchment Systems for Present Climatic, Tectonic, and Anthropogenic Processes – Observation and Modeling

Most modern lake-catchment systems have been influenced by climatic, tectonic, and anthropogenic processes and their lacustrine sediments record information related to the three processes. Furthermore, the processes have exerted their mutual effects for an extended interval. Dominant processes (events) are comparatively easily detected in sediment records over long intervals, whereas a multiplicity of processes may be identified for recent short intervals. Here we will consider some lake-catchment systems for discussion about the processes and sediment information.

1.2.1 Observation for Kawauso-ike System in Kobe

In Kobe district, several natural disasters caused by heavy rainfall and earthquake have occurred over the past instrumental observation period, in addition to large-scale artificial land transformation, including the development of artificial islands in the 1960s–1990s. The Kawauso-ike pond-catchment system is located in the Rokko Mountains of Kobe City (Fig. 1.1), which is known for its heavy rainfall (Kashiwaya et al. 1984, 1987, 1988, 1990, 1995, 1997) and earthquake records (Kashiwaya et al. 2004, 2012). In this system, several core samples were obtained before and after the 1995 Kobe earthquake. After the earthquake, two sediment traps were set on the bottom surface for nearly 15 years (two circles in Fig. 1.2).

Figure 1.3 shows grain size (solid line) and density (dotted line) fluctuations of core sediments obtained after the 1995 Kobe earthquake, and rainfall intensity measured at Kobe Marine Observatory. Blanc arrows in Fig. 1.3a show the 1938 and 1967 heavy rainfall events in addition to the 1995 Kobe earthquake; 100 mm excess rainfall (solid line; annual summation of excess amount of 100 mm daily rainfall) corresponds to increase in grain size while annual rainfall (dotted line) was not correlated to the grain size fluctuation. The earthquake did not appear to have direct influence on sediment grain size variation, although the sedimentation rate following the earthquake rapidly increased (Fig. 1.4; Kashiwaya et al. 2004).

Events after 1967 constituted comparatively heavy rainfall in 1983 and check (sabo) dam construction in the west tributary in 1984–1985 (a check dam in the east tributary was constructed in 1989–1990) (see Fig. 1.2). Slight increase in grain size between the 1967 heavy rainfall and 1986 sampling may be related to the comparatively large rainfall around 1983. The subsequent decrease in grain density corresponds to the years of 1984–1985, when the check dam in the west tributary was constructed. Materials in the west tributary flowed into Kawauso-ike directly, suggesting that the check dam might play an important role in trapping mineral materials produced in the catchment, while materials in the east tributary, by contrast, flowed into the pond via a delta at the mouth of the river, where some materials might have contributed to delta formation (Fig. 1.2). Potential volume

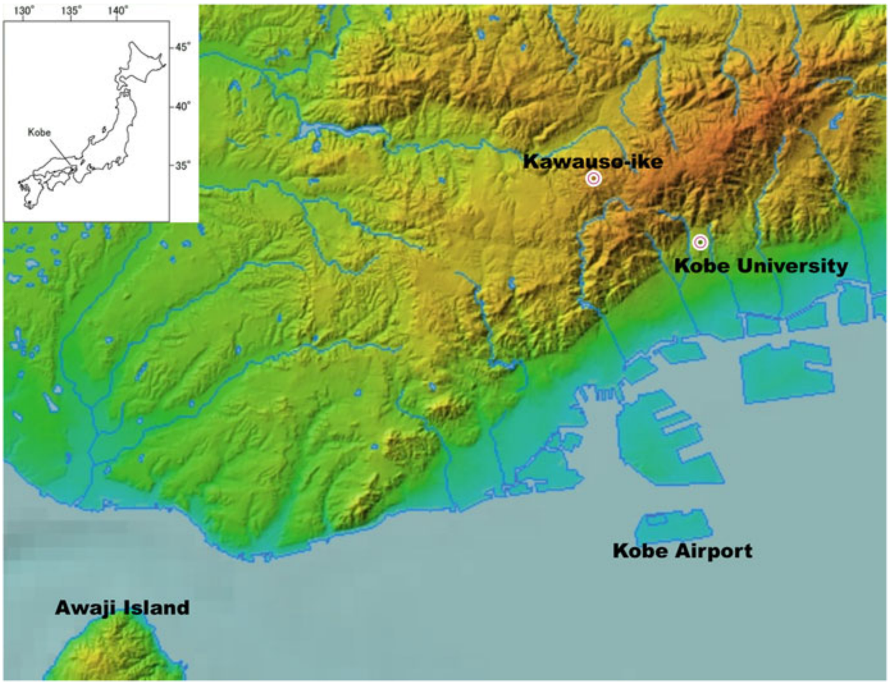


Fig. 1.1 Location map of studied area in Kobe, Japan (original map by Geospatial Information Authority of Japan)

of dam-induced deposition was 540 m^3 for the west tributary and 5,561 m^3 for the east tributary when the check dams were constructed (Kobe City Government). Generally, check dams prevent materials, especially coarse particles, from flowing into reservoirs. This may have been related to the lack of increase in grain size during the 1995 earthquake, although mineral materials increased.

As shown above, climatic (heavy rainfall), tectonic (seismic) and anthropogenic impacts affected the pond-catchment system, and their impacts were surely recorded in lacustrine sediments, suggesting that modern lacustrine sediments may provide clues for evaluating past environmental changes on the basis of understanding of processes.

1.2.2 Modeling Erosion-Sedimentation Processes in a Lake-Catchment System – A Phenomenological Model After the Earthquake

It is necessary to quantitatively express temporal changes in physical phenomena for appropriate understanding of lake-catchment processes, which in turn allows

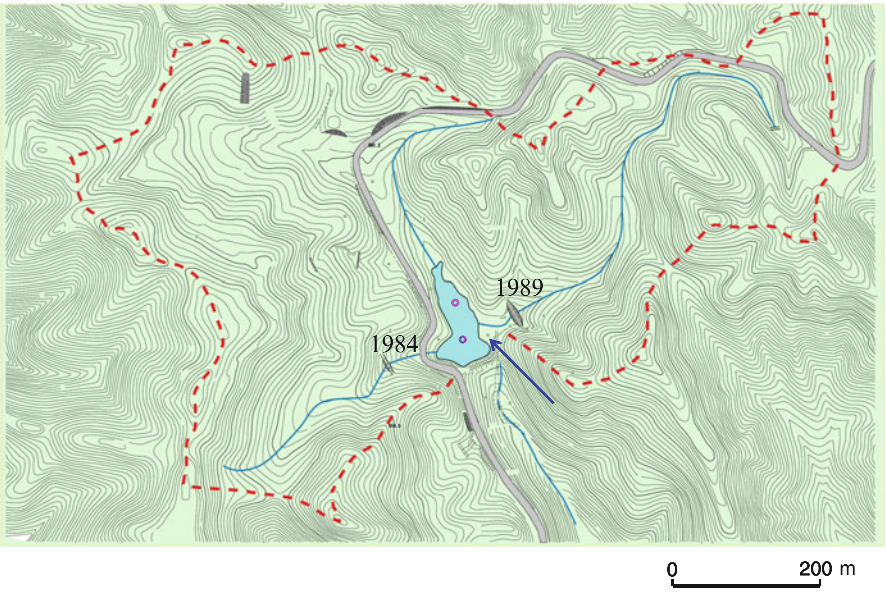


Fig. 1.2 Kawauso-ike pond–catchment system. Figures mean the construction years of the check dams. An arrow indicates a small delta. (original map by Geospatial Information Authority of Japan)

provision and prediction. Hence, temporal observation for the Kawauso-ike system after the earthquake was begun in May 1995. Two sediment traps were emplaced on the pond bed in May 1995 (two circles in Fig. 1.2). Sediments were removed from the traps once or twice a month, so that their physical properties could be measured and analyzed. Meteorological data from the Kobe Marine Observatory were also incorporated into this study.

While a limited study based on the observational results obtained before 2000 was performed by Kashiwaya et al. (2004), we introduce here a mathematical model for temporal changes in the system based on over 10 years of observations.

Figure 1.4a shows temporal changes in the median grain size of sediments collected in traps during the past five years (first stage). This figure also shows little overall difference in the samples, despite small increase and decrease parts for recent years. This may reflect the fact that there was little severe rainfall and few rapid mass movements during this interval.

The annual sedimentation rate inferred from the two sediment traps is shown in Fig. 1.4b. The rate was high just after the earthquake and then gradually decreased (first stage, 1995–1999; Fig. 1.5). Seasonal changes in the sedimentation rate are generally controlled by seasonal rainfall, but no large fluctuation in seasonal rainfall was observed, despite a temporal decrease in the sedimentation rate (1995–1999; Fig. 1.5b). It seems that significant earthquake influence on sedimentation rate

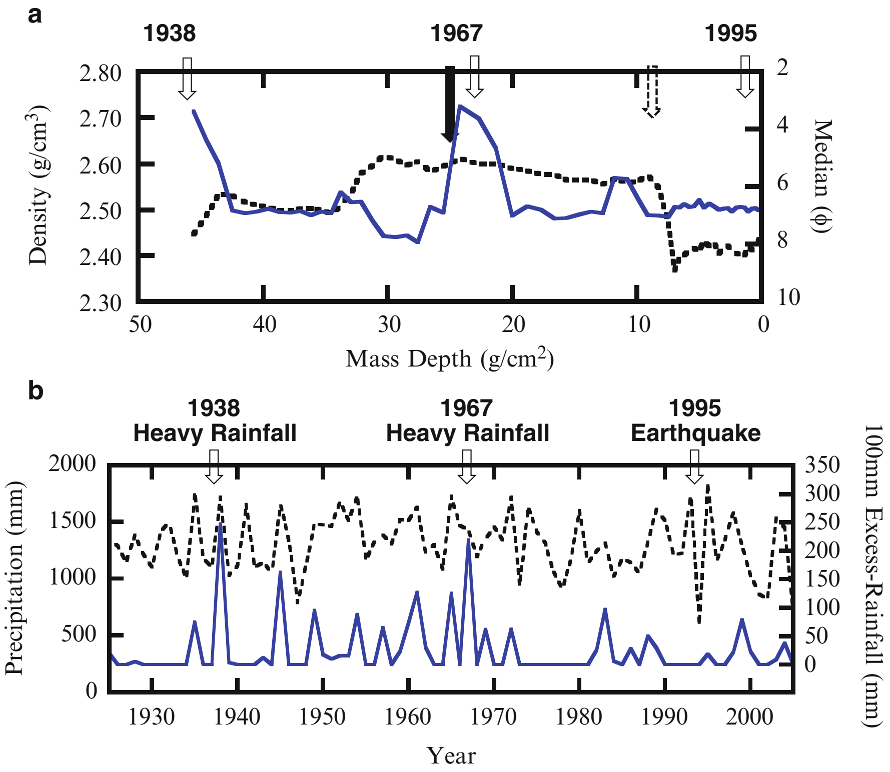


Fig. 1.3 (**a**) Grain size (ϕ) fluctuation. A *solid arrow* indicates the peak of Cs-137 concentration (1963) and a *dotted arrow* means the year of 1984. (**b**) Annual precipitation (mm) and annual excess rainfall (mm) in Kobe

disappeared during the second stage (2002–2007) although the sedimentation rate was larger than before the 1995 earthquake despite some no-observation periods (Fig. 1.5).

Following an investigation based on field observation in the Rokko Mountains and laboratory experiments, Torii et al. (2007) postulated that the increase in material erodibility after the earthquake was related to the destruction of the skeletal structure of weathered materials (granites) by the earthquake. This result suggests that there may be three stages of evolution of the (lake-catchment) system environments after the earthquake: (1) rapid increase and gradual decrease in sedimentation rate, (2) stationary stage; more erodible materials than before the earthquake, and (3) new weathering-limited stage, similar to that before the earthquake. The three stages must be taken into account to establish models (Fig. 1.6).

Conditions after the earthquake may be assumed as shown in Fig. 1.7. A basic model for the system is introduced here (Kashiwaya et al. 2004). First, it is assumed that for the basic model, the sedimentation rate in the lake (*SR(t)*) is proportional to the erosion rate in its catchment (*dE(t)/dt*), which yields

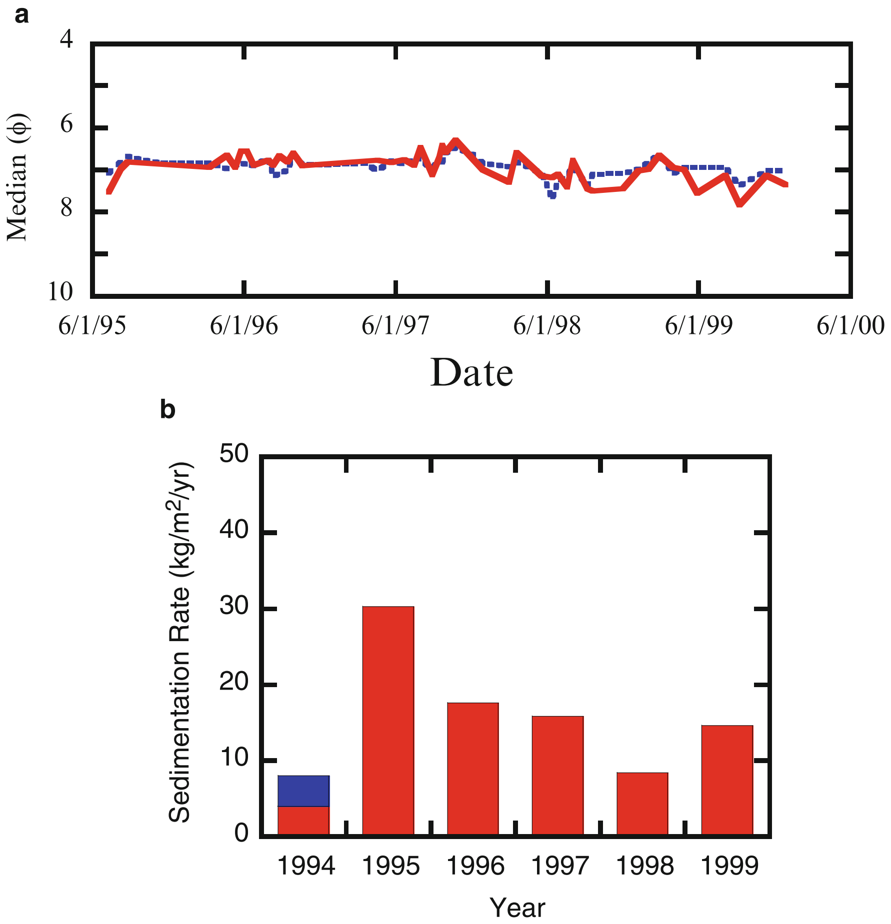


Fig. 1.4 (**a**) Monthly grain size fluctuation in two sediment traps since the 1995 (*solid line*; front trap, *dotted line*; back trap). (**b**) Annual sedimentation rate (kg/m^2/year) (averaged) in the traps and estimated one before 1995 (*blue part*; maximum one)

$$SR(t) = \alpha \frac{dE(t)}{dt}, \tag{1.1}$$

where $E(t)$ is the volume of material moved at time t and α is a proportionality factor (sediment delivery factor related to material conditions) in the catchment. The erosion rate in the catchment is proportional to the volume of material to be eroded at t ($V(t)$):

$$\frac{dE(t)}{dt} = \lambda(t)V(t), \tag{1.2}$$

with $\lambda(t)$, erosion factor related to external forces (e.g., rainfall).

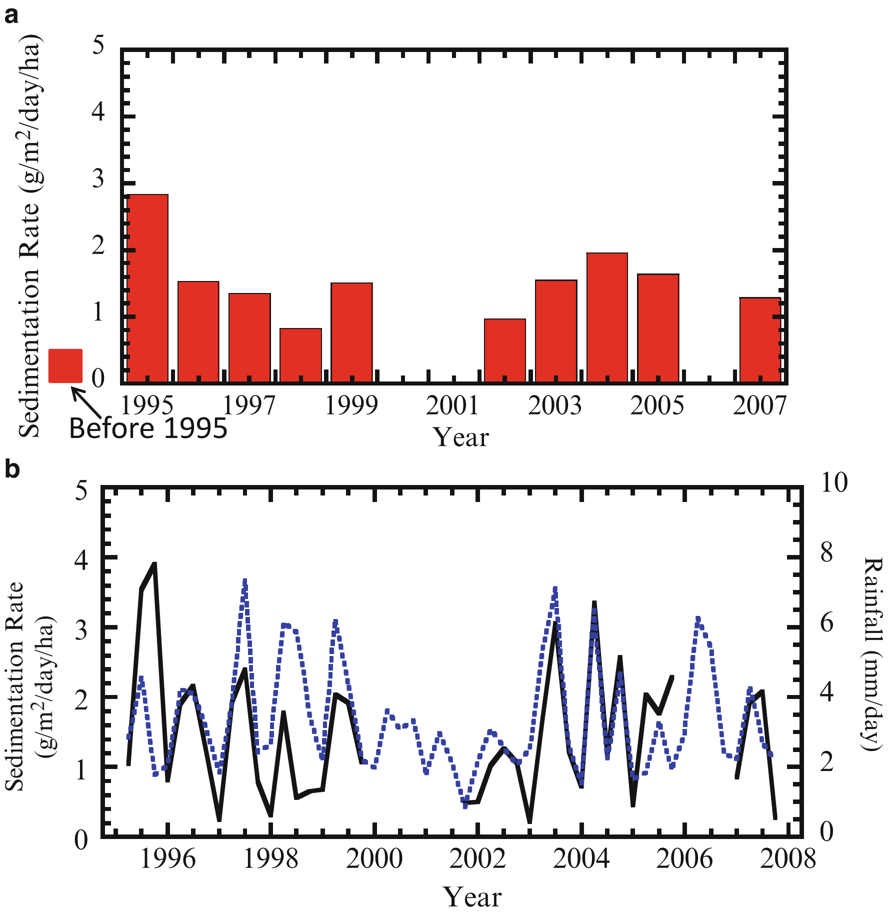


Fig. 1.5 (**a**) Annual sedimentation rate (g/m^2/day/ha) and (**b**) seasonal sedimentation rate (*solid line*; g/m^2/day/ha) and seasonal rainfall (*dotted line*; mm/day) for Kawauso-ike system

Let us consider the first stage for the model. Volume of fine material produced by the earthquake ($V(t)$) to be eroded is expressed as

$$V(t) = V_T - \{V_{DW} + V_W(t) + V_U(t)\} - E(t), \tag{1.3}$$

where V_T is the total volume of material in a catchment area at the initial stage, V_{DW} is the destroyed weathered part of the material, $V_W(t)$ is the weathering part of the material, and $V_U(t)$ is the non-erodible part of the material at time t. Then, we obtain

$$\frac{dV(t)}{dt} = -\frac{d\,\{V_W(t) + V_U(t) + E(t)\}}{dt} \tag{1.4}$$

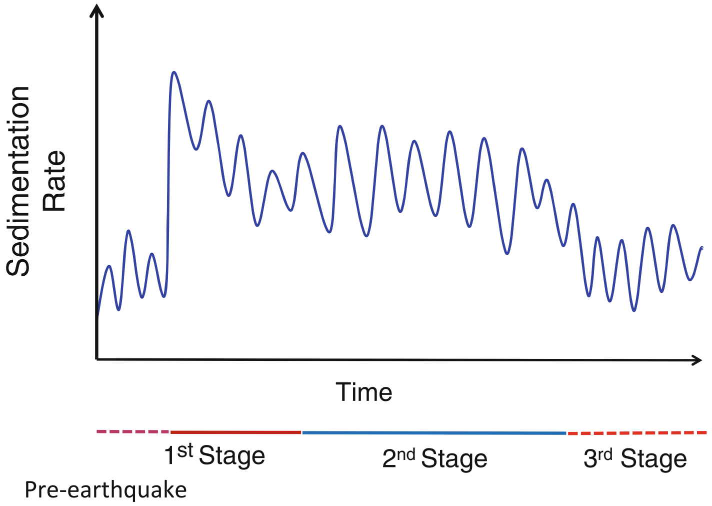


Fig. 1.6 Idealized stages for sedimentational condition in a lake-catchment system after earthquake

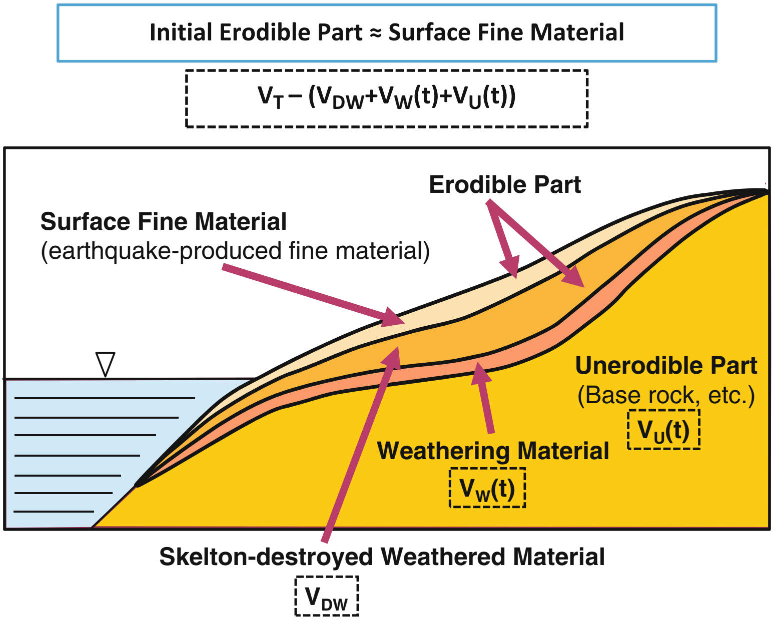


Fig. 1.7 An idealized model for erosion-sedimentation process in a lake-catchment system after earthquake-influence

This leads to

$$-\frac{dV(t)}{dt} = \lambda(t)V(t) + \frac{d\left\{V_W(t) + V_U(t)\right\}}{dt} \tag{1.5}$$

It is assumed that

$$\frac{d\left\{V_W(t) + V_U(t)\right\}}{dt} = f_{WU}(t), \tag{1.6}$$

we have

$$V(t) = e^{-\int^t \lambda(\tau)\,d\tau}\left\{-\int^t f_{WU}(t)e^{-\int^t \lambda(\tau)\,d\tau} dt + V_0\right\}, \tag{1.7}$$

assuming $V(0) = V_0$.

Therefore, the sedimentation rate is expressed as follows

$$SR(t) = \alpha\lambda(t)\left[e^{-\int^t \lambda(\tau)\,d\tau}\left\{-\int^t f_{WU}(t)e^{-\int^t \lambda(\tau)\,d\tau} dt + V_0\right\}\right]. \tag{1.8}$$

In the first stage, it is assumed that only the fine surface materials produced in the earthquake are eroded because no extremely heavy rainfall has occurred since the 1995 Kobe earthquake. Moreover, in the first stage, erodible materials seem to be limited to earthquake-produced fine materials. Then, it may be assumed that

$$V_T - \left\{V_{DW} + V_W(t) + V_U(t)\right\} = \text{const.},\ f_{WU}(t) = 0.$$

Eq. (1.8) becomes

$$SR(t) = \alpha_1\lambda_1(t)V_{01}e^{-\int^t \lambda_1(\tau)\,d\tau}, \tag{1.9}$$

where α_1 is a proportionality factor related to the fine materials, $\lambda_1(t)$, an erosion factor related to rainfall intensity in the first stage, and V_{01} is the initial volume of material before the first step of erosion. The model is checked in the first stage using the data. Then, an erosion factor $\lambda_1(t)$ is assumed to be a temporal function of seasonal rainfall:

$$\lambda_1(t) = \sum_i p_{1\mathrm{i}} \sin q_{1\mathrm{i}}\,(t - t_{1\mathrm{i}}) + r_{1\mathrm{i}}. \tag{1.10}$$

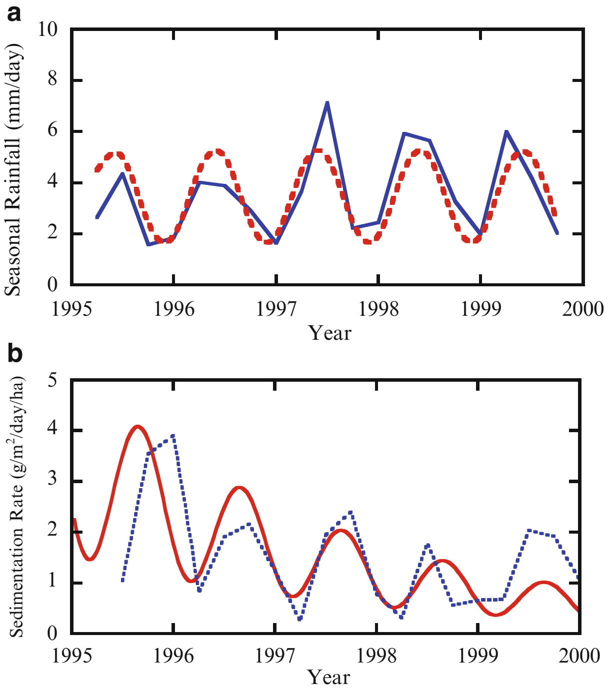


Fig. 1.8 (**a**) Changes in seasonal rainfall (mm/day) for the first stage. *Solid line* is original and *dotted line* is synthesized. (**b**) Changes in seasonal sedimentation rate (g/cm^2/day/ha) in the lake-catchment system. *Solid line* is calculated and *dotted line* is observational

The equation has been introduced with Fourier approximation by using a harmonic analysis (Fig. 1.8a) for the seasonal rainfall data represented by a dotted line. Theoretical sedimentation rate calculated on the basis of Eq. (1.9) (dotted line) and observations (solid line) are shown in Fig. 1.8b, indicating that the erosion factor is expressed as a function of seasonal rainfall and the sedimentation rate is approximately expressed here by eq. (1.5). Therefore, this model is valid for the erosion-related sedimentation processes in the first stage after the earthquake. However, recent (second stage) sedimentation rate seems to be a little higher than before the earthquake, possibly because of the skeleton-destroyed weathered materials (Torii et al. 2007). Therefore, the earthquake evidently continues to influence the earth surface environment. While the direct influence of the 1995 Kobe earthquake rapidly diminished (most earthquake-produced fine materials were transported), the earthquake can also influence physical conditions of the earth surface for a comparatively long time (corresponding to the second stage).

Let us now consider the second stage where most materials to be eroded are the skeleton-destroyed weathered granite (V_{DW} in Fig. 1.7; probably one whose

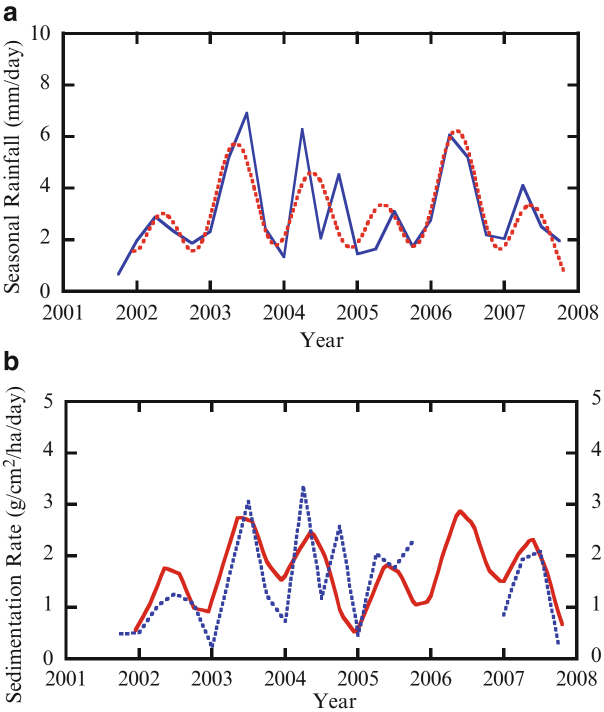


Fig. 1.9 (**a**) Changes in seasonal rainfall (mm/day) for the second stage. *Solid line* is original and dotted line is synthesized. (**b**) Changes in seasonal sedimentation rate (g/cm^2/day/ha) in the lake-catchment system. *Solid line* is calculated and dotted line is observational

structure has been weakened by the earthquake), after the majority of fine materials are removed. In the case of a short interval such as the second stage (2002–2008), the term for weathering and uplifting, $f_{WU}(t)$ in Eq. (1.7) may be disregarded. Then,

$$SR(t) = \alpha_2 \lambda_2(t) V_{02} e^{-\int^t \lambda_2(\tau)\, d\tau}, \tag{1.11}$$

where α_2 is a proportionality factor related to the skeleton-destroyed materials, $\lambda_2(t)$, an erosion factor related to rainfall intensity in the 2nd stage, and V_{02} is initial volume of material in the second step of erosion. The model is checked using the data in the second stage. Then, the erosion factor $\lambda_2(t)$ is assumed to be a temporal function of seasonal rainfall;

$$\lambda_2(t) = \sum_i p_{2i} \sin q_{2i} (t - t_{2i}) + r_{2i}. \tag{1.12}$$

The equation has been developed using a harmonic analysis (Fig. 1.9a) for the seasonal rainfall data shown as a dotted line in the figure. Theoretical sedimentation rate calculated on the basis of Eq. (1.11) (solid line) and observations (dotted line) are shown in Fig. 1.9b, indicating that the model is also valid for the second stage with enough skeleton-destroyed materials. These results suggest that the model introduced here is basically acceptable for the earthquake-influencing interval (first and second stages) after the earthquake.

It is clear that earthquakes generally produce abundant fine materials in addition to various coarse types (rocks). Fine materials are easily moved by relatively light rainfall. The models introduced here are based on simplified assumptions. However, to adequately discuss erosional environments in the catchments after the earthquakes, it is necessary to check thoroughly changes in surface conditions. Additionally, these phenomenological equations will be available for quantitative prediction of surface environments in the near future (10^1-10^2 years), if physical properties for α_1 and α_2 are discussed in detail in relation with material conditions, and if exact values of V_{DW}, V_{01}, V_{02}, etc., are established quantitatively.

1.3 Beyond Observation

Observational data in the recent past may be of great use not only for understanding processes but also for near future prediction in lake-catchment systems. Subsequently, it is necessary for further future discussion to consider the recent past data in areas without instrumental observation system and comparatively long-term data in periods without observation system.

1.3.1 Sediment Information in the Instrumental Observation Period

As shown in the previous section, climatic, tectonic, and anthropogenic activities have been recorded in lacustrine sediments during the instrumental observation period. In the case of the Kawauso-ike pond-catchment system, the 1995 earthquake was identified in observed sedimentation rate, estimated using sediments collected in sediment traps, while heavy rainfall and anthropogenic events were recorded in the physical properties of sediments (Fig. 1.3; discussed below). Generally, it is difficult to obtain flux data such as sedimentation rate without instrumental observation. Therefore, non-flux physical (chemical) properties, which are common in periods both with and without instrumental observation, must be considered for a comparatively long term.

Let us now consider cores obtained before and after the 1995 Kobe earthquake to investigate the earthquake and material physical properties. Figure 1.10 shows the analytical results for the two cores obtained before the earthquake (a) and after the earthquake (b). Two heavy rainfall events (1937 and 1967) and a comparatively

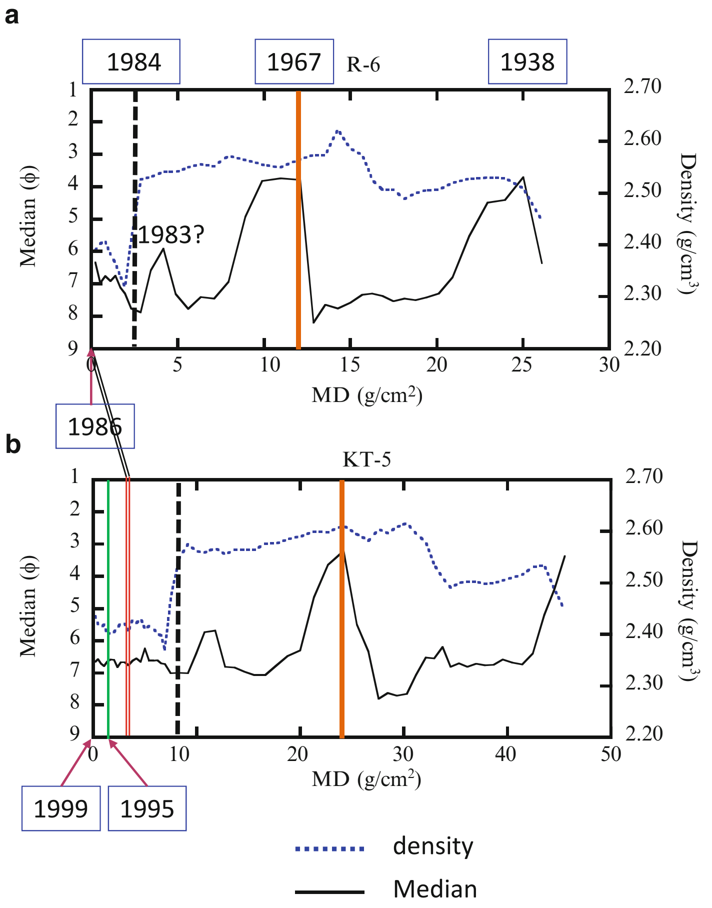


Fig. 1.10 Changes in mineral grain size and grain density of the core obtained in 1986 (R-6) (**a**) and in 1999 (KT-5) (**b**), before and after the 1995 Kobe Earthquake. *Solid lines* mean the year of 1967 heavy rainfall time and *dotted lines* the year of the 1984 check dam construction. A *double line* means the year of R-6 obtained

heavier rainfall event (1983) are detected in the grain size variation (solid line) of both cores. The construction of a check dam in 1984–1985 is also detected in the rapid decrease of grain density in both cores (dotted lines). After the 1986 sampling, although no large change occurred in grain size and grain density variation (Fig. 1.10b), we observe that grain density increased slightly in the core obtained in 1999, compared with that obtained in 1986, which is supported by data from other cores obtained during the same period (Fig. 1.11). Probably, this kind of analytical observation is available in tectonically sensitive zone, such as Japan, Yunnan (China), Taiwan, etc. Sampling sites for the cores are shown in Fig. 1.12. Grain density variations shown in these figures may provide different information.

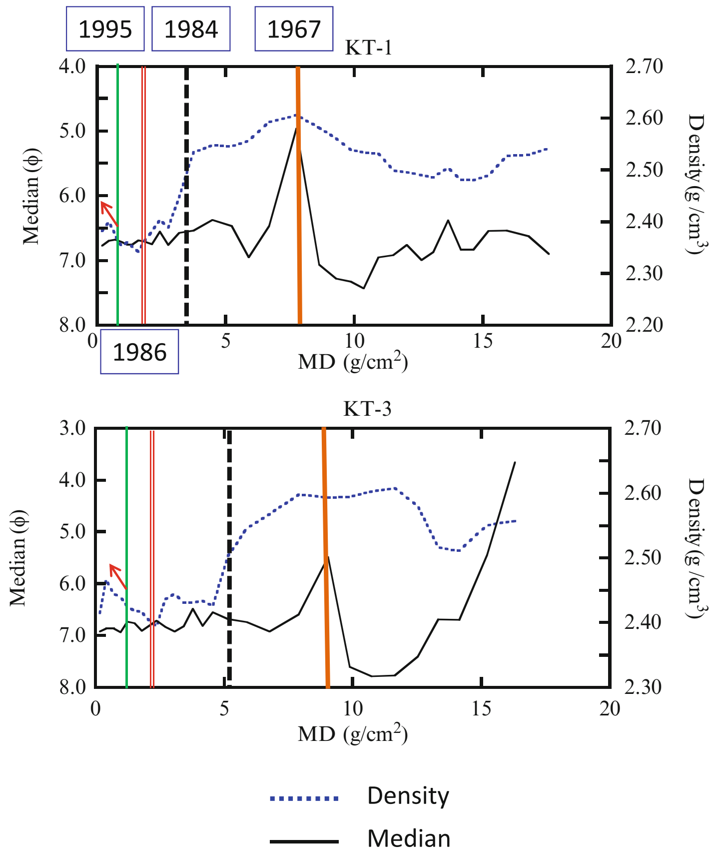


Fig. 1.11 Changes in mineral grain size and grain density in two cores obtained in 1999 (KT-1 and KT-3). *Solid lines* mean the year of 1967 heavy rainfall time and *dotted lines* the year of the 1984 check dam construction. *Double lines* mean the year of R-6 obtained in 1984. Fine *dotted lines* mean 1995 (estimated)

After the 1967 period of heavy rainfall and just before 1986 (the first sampling time), abrupt decrease in grain size density (check dam construction) was detected in all cores. Large sediment accumulation in the check dam may be related not only to a decrease in density, but also to a decrease in mineral content and/or increase in organic content (and bi-SiO_2 content).

1.3.2 Qilu-he System in Yunnan, China

The Yunnan Province is located in the eastern margin of the Tibetan Plateau and has experienced strong tectonic movements related to the collision between the Indian

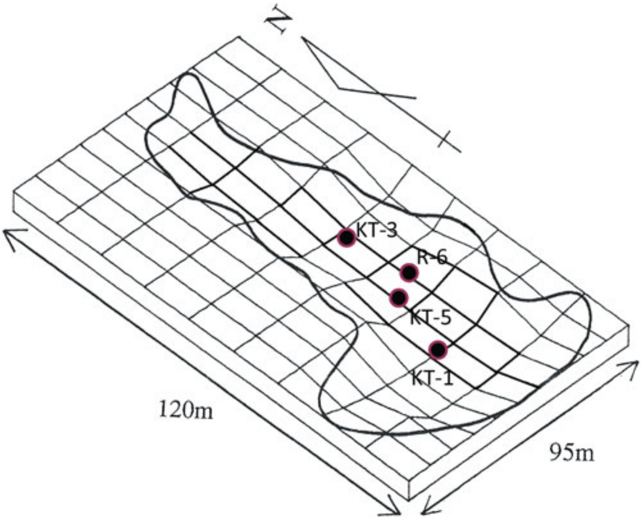
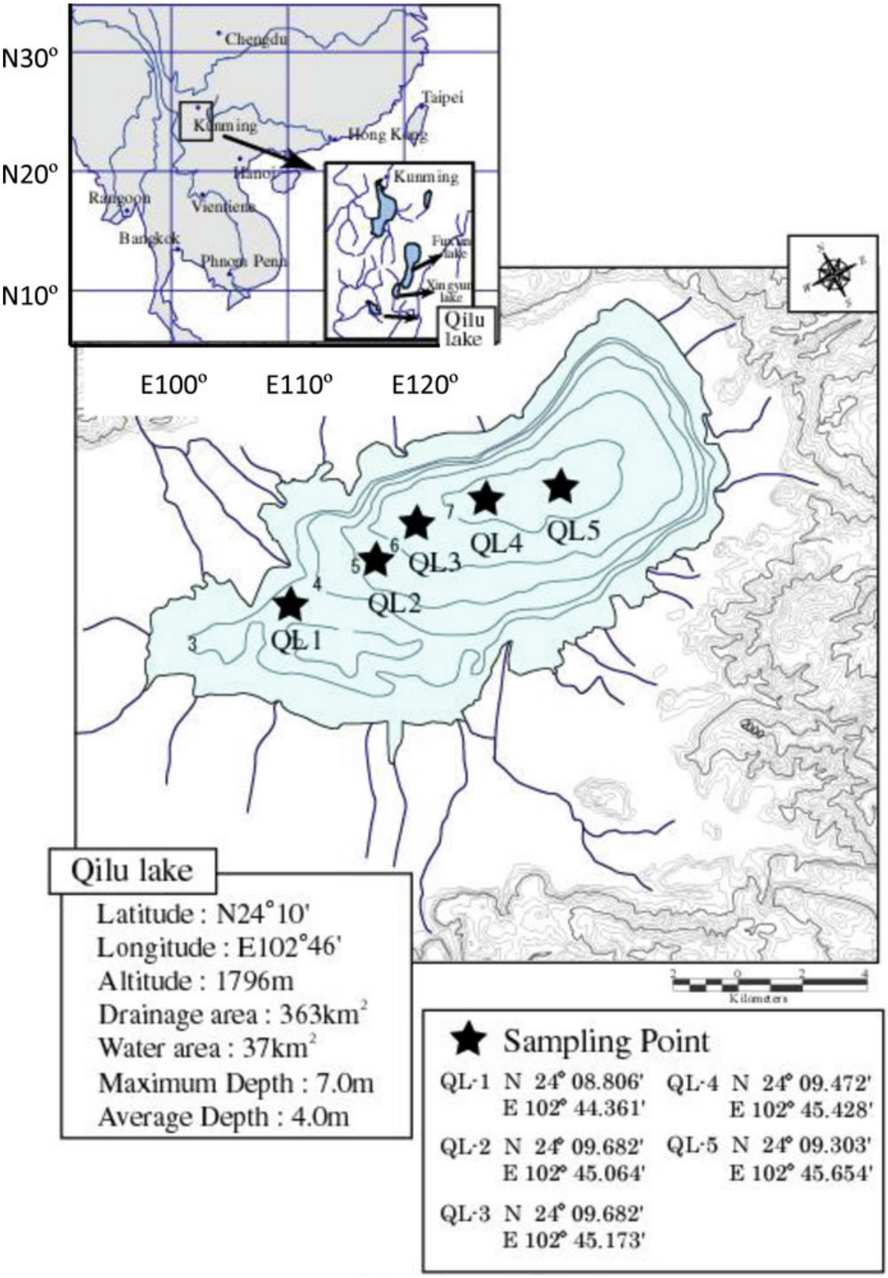


Fig. 1.12 A location map for the cores obtained in 1999

and Eurasian plates. Many earthquakes have occurred in this area. The most recent disastrous earthquake in Northern Yunnan (Zhaotong earthquake; M 6.5), during which more than 600 people were killed, occurred on August 3, 2014. The Lijiang earthquake (M 7.0), which occurred in 1996, also killed more than 300 people. One of the most disastrous earthquakes (M 7.7) in Eastern Yunnan, which was called the Tong-hai earthquake, occurred in 1970. The earthquake killed more than 15,000 people, and also left signs in lacustrine records. It occurred during the period of the Cultural Revolution in China (1966–1976) and, at first, was mistaken for a nuclear attack by the former Soviet Union, which the Chinese central government feared at the time. The occurrence of this earthquake remained a secret until 2000.

Several core samples were obtained in Qilu-he (otherwise, Tong-hai) in 2002 (Fig. 1.13) (Kashiwaya et al. 2006). The epicenter of the Tong-hai earthquake is located at Tong-hai Prefecture in the south of Qilu-he. Age models for the cores are estimated with Cs-137 (Fig. 1.14a). The earthquake effects were detected in Pb-210 concentration and in some physical properties of lacustrine sediments (Figs. 1.14 and 1.15). Water level had often been lowered in this lake since the late 1960s by drought conditions (p.c., information gathered from local fishermen). Increases in HCl-soluble material (open square) and grain size, and decreases in mineral content and grain density since ca. 1963 may be related to the drought conditions (Figs 1.14 and 1.15). However, at about 2.5–4 g/cm^2 part (dotted bars in Fig. 1.14), grain size abruptly decreased, while mineral content and grain density increased. Furthermore, the change in Pb-210 concentration does not show a gradual decrease, which indicates the disturbance of the then bottom surface layer (Fig. 1.14a). Just after the earthquake, increase in grain density (mineral content increase) and decrease in mineral grain size (suggesting no increase in discharge) are often detected in sedi-



Qilu lake

Latitude : N24°10'
Longitude : E102°46'
Altitude : 1796m
Drainage area : 363km^2
Water area : 37km^2
Maximum Depth : 7.0m
Average Depth : 4.0m

★ Sampling Point

QL-1	N 24° 08.806'	E 102° 44.361'
QL-2	N 24° 09.682'	E 102° 45.064'
QL-3	N 24° 09.682'	E 102° 45.173'
QL-4	N 24° 09.472'	E 102° 45.428'
QL-5	N 24° 09.303'	E 102° 45.654'

Fig. 1.13 Sampling sites in Qilu-he, Yunnan, China

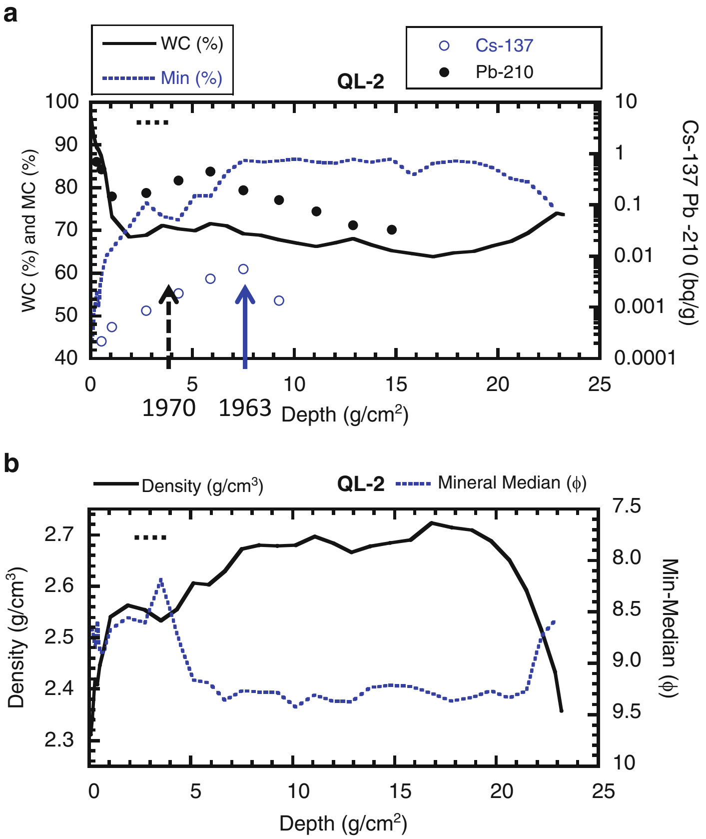


Fig. 1.14 (**a**) Changes in water content (*solid line*) and mineral content (*dotted line*) (*left axis*) and changes in Cs-137 content (*open circle*) and Pb-210 content (*solid circle*) (*right axis*), and (**b**) changes in mineral density (g/cm^3; left axis) (*solid line*) and mineral median (ϕ; *right axis*) (*dotted line*)

ments, as shown by data related to earthquakes mentioned above and below. Hence, the 2.5–4.0 g/cm^2 portion may correspond to the interval around the 1970 Tong-hai earthquake. The results obtained here suggest that finer mineral materials were also accumulated, as shown by the case of the Kobe earthquake (Kashiwaya et al. 2004).

1.4 Long-Term Environmental Changes, and Climatic and Tectonic Activity

In this section, comparatively long-term environmental changes resulting from climatic- and tectonic-related processes will be discussed using the Lake Biwa system.