CHAPTER 5

PALEOLIMNOLOGICAL STUDIES

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Bathymetry and bottom surface sediments

Lake Kizaki has a main basin that stretches N-S with a NNW-SSE trending sub-basin in the south (Fig. 5.1). The main basin plain, 25 to 29 m deep, is quite flat, with the deepest part located in the northern part of the basin. The eastern and western sides of the basin are relatively steeper (5 to 10 degrees) than the northern gentler slope (3 to 4 degrees). These steep slopes may be affected by the active faults related to the Itoigawa-Shizuoka Tectonic Line. The gentle slope seems to have been formed by the burial of sediments from the Middle Nogu River. The sub-basin in the southern margin is much shallower than the main basin, and appears as a wide channel flowing out from the main basin.

The bottom surface that is deeper than 20 m is mostly covered by clayey sediments finer than 8 phi median diameter (Fig. 5.2). Silty sediments (4 to 8 phi median grain-size) are distributed in a narrow zone along the coast, except in the prodelta areas of the Middle Nogu and Inaozawa Rivers, where silty sediments are widely distributed. Sandy sediments (-1 to 4 phi) are relatively restricted to the delta front and coastal areas shallower than several meters. Gravel is restricted to the mouths of the Ittsu and other small rivers. Most parts of the coast are also gravelly. Sandy sediments are widely distributed in the southeastern sub-basin, and gravel occupies the northern margin of the sub-basin. Silty sediment exists in the central, elongated area. There is a complex pattern of sediment distribution in the southeastern sub-basin.

The Middle Nogu River is the largest river entering the lake; it forms a flat, fluvial plain in the lake's northern area. The relatively gentle slope in front of the river mouth seems to be a delta front slope. Although the Middle Nogu River now has many small artificial channels used for irrigation and its original topography is obscure, this river formed a delta plain under natural condition. The Inaozawa River is another major river, and forms a typical fan-delta landform on the eastern coast of the lake. The finest surface sediments occur at positions intermediate between the mouths of both rivers. These two rivers are considered to be the major sources of clastic lake sediments. Gravel sediments along the coast are formed by the washing out of finer sediments by wave action. Finer sediments supplied by river input and wave washout may be transported in suspension into the central or southern parts of the basin.

The southeastern sub-basin seems to be an independent sedimentary unit, because

Lake Kizaki
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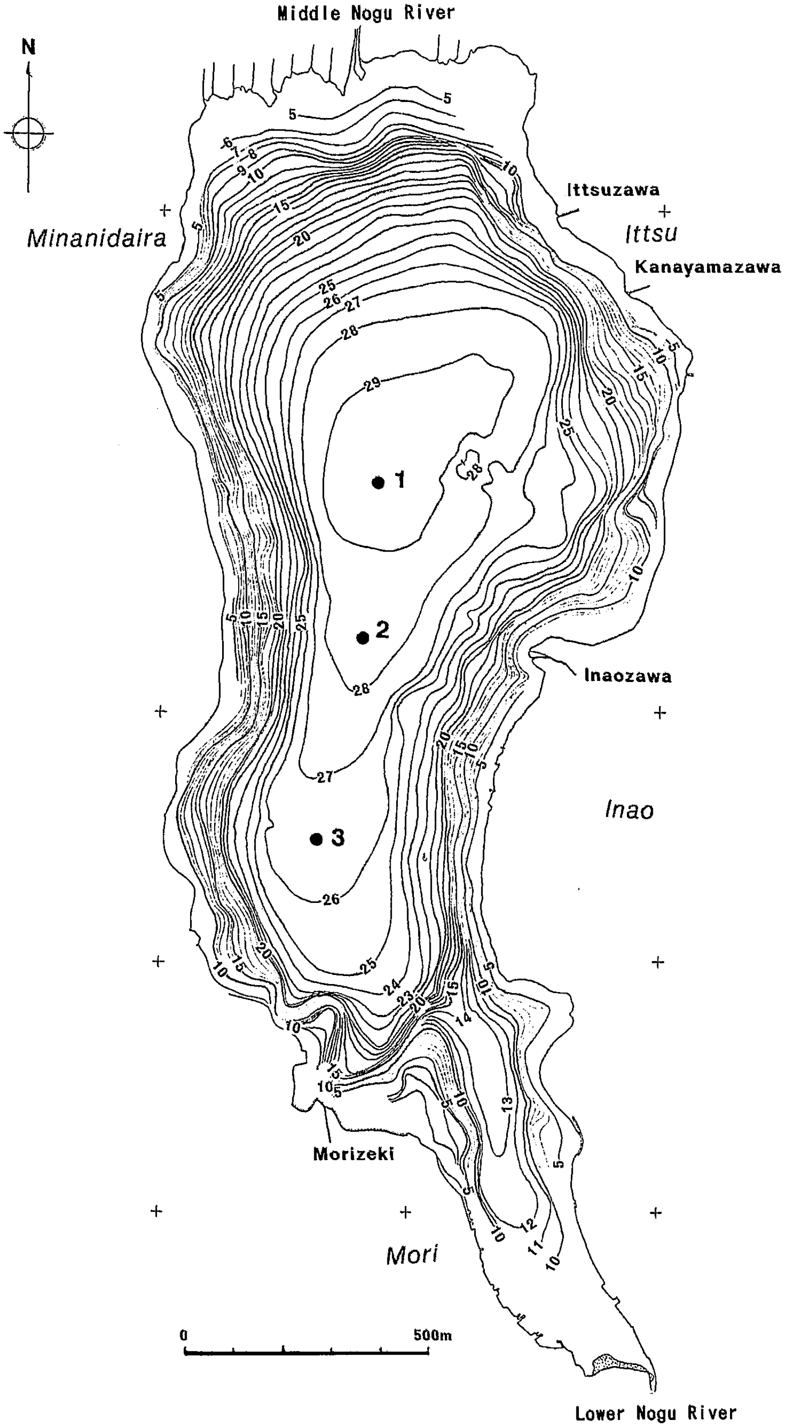

Fig. 5.1 Bathymetric map of Lake Kizaki (after Inouchi *et al.* 1987). The coastal areas shallower than 5 m are not clear due to the limits of the acoustic equipment used for the study.

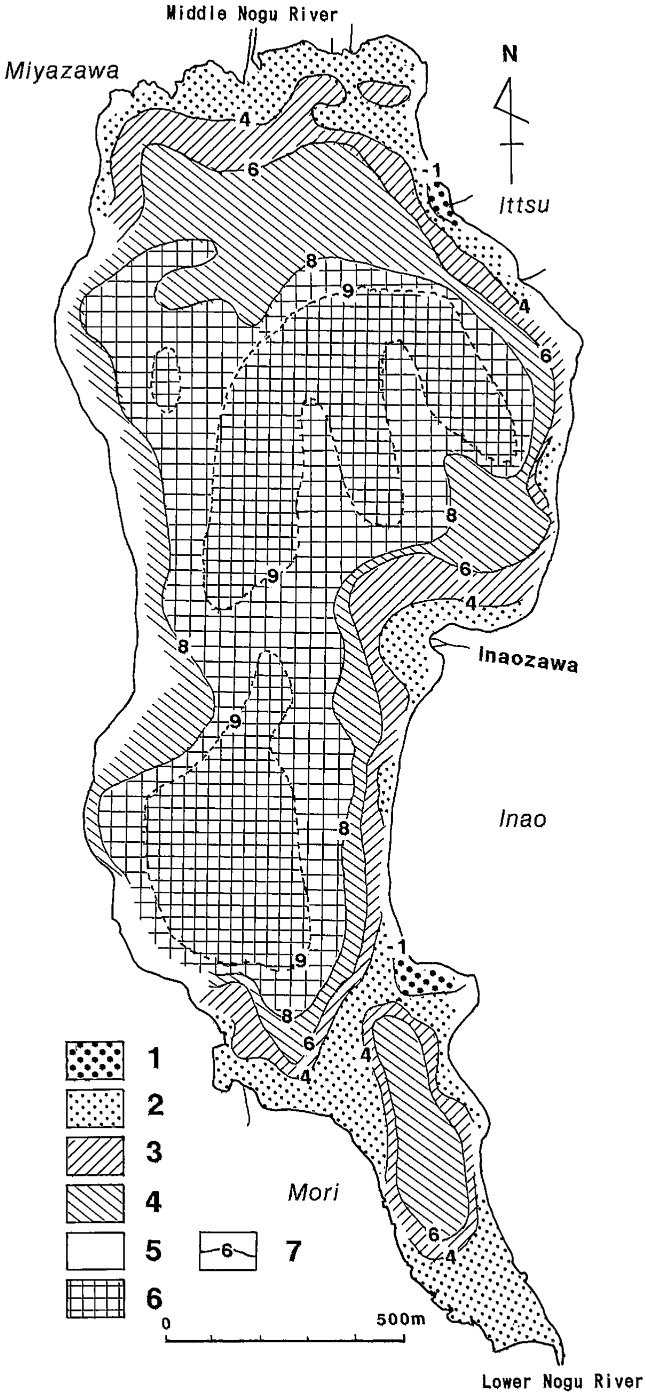

Fig. 5.2 Grain size distribution of the surface sediments in Lake Kizaki (after Kumon & Ide 1999). Sediments are classified based on the median grain size; 1: <-1 phi (gravel), 2: -1 to 4 phi (sand), 3: 4-6 phi (coarse silt), 4: 6-8 phi (fine silt), 5: 8-9 phi (silty clay), 6: >9 phi (clay), 7: contour line of median grain size.

it has its own sedimentary center with a wide distribution of sandy sediments. The sandy sediments of the southwestern coast are rich in quartz and feldspar, unlike the sands of the northeastern coast, which is dominated by rock fragments. This sub-basin may have formed in response to a rise in water-level associated with the growth of the Omachi Fan which may have dammed part of the Lower Nogu River to form the southeastern part of Lake Kizaki.

Sub-bottom sediments

A few studies have investigated the sub-bottom sediments of Lake Kizaki. An acoustic survey using a Uniboom (EG&G: model 230, 700-14,000 kHz) was made, but the reflections below the bottom surface were obscure and were unable to provide useful information. This may have been due to the downward decrease in the density of surface sediments, as will be shown.

Upper sub-surface sediments were cored at three localities in the major basin plain using a Mackereth piston corer. The cores were 2 to 3 meters long, and were mainly composed of clayey silt and silty clay, with thin layers of sand and/or coarse silt. The uppermost part, 5 to 10 cm deep from the bottom surface, comprised fluid to very soft clayey sediments, of black color and smelling of hydrogen sulfide. The lower part was olive-black to olive-gray in color. The ^{14}C ages were measured at two horizons in Site 1 and at one in Site 3, as shown in Fig. 5.3. The average sedimentation rates calculated for calendar years converted from the conventional ^{14}C age, were 1.9 mm yr^{-1} (62 mg cm^{-2} yr^{-1}) at Site 1, and 1.3 mm yr^{-1} (52 mg cm^{-2} yr^{-1}) at Site 3.

Profiles of apparent density (weight of solid materials per unit space) at three sites are shown in Fig. 5.4. The peaks and depressions of apparent density are correlated between sites. The peaks correspond well with the dark layers on X-ray photographs and/or the visible layers composed of sand and coarse-grained silt. The sites of the cored samples are in areas of clayey sediment deposition (Fig. 5.2). Therefore, the density peak seems to have been formed by an unusual current such as a turbidity current. Dense underflows caused by floods have been reported in Lake Brienz in Switzerland (Sturm & Matter 1978). Similar processes may have taken place in Lake Kizaki.

The age of the density peak can be calculated from the sedimentation rate, given certain assumptions. If the turbidite sediments are excluded from the total sediment, the sedimentation rate can be assumed to be uniform, because the turbidite was deposited in a very short time, and the remaining sediments probably settled through normal suspension at a constant rate. Given these assumptions, the sedimentation age of each density peak was calculated. The results for major peaks are shown in Fig. 5.4. The ages of the peaks roughly correspond with the known history of severe floods in the area around Omachi City. The density current formed by a large flood may often flow into the lake and spread widely on the bottom plain as an underflow. In other words, ancient floods are indicated in the sediments of Lake Kizaki as dense layers.

The density profiles generally decrease downward in the uppermost part, from a

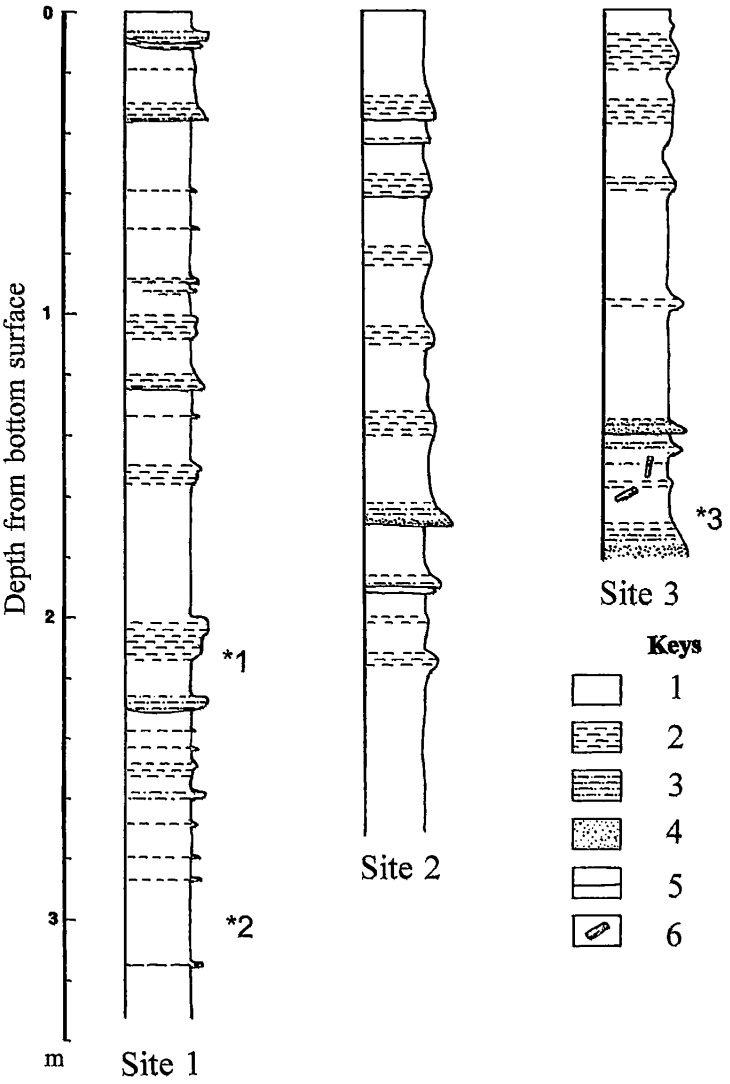

Fig. 5.3 Lithologic columns of three core sediments from Lake Kizaki. Locations of the sites are shown in Fig. 5-1. Conventional ^{14}C ages (AMS method): *1: 1180±50 YBP, *2: 1620±50 YBP, *3: 1390±50YBP. Lithology key: 1: silty clay, 2: silt, 3: sandy silt, 4: sand, 5: sharp boundary, 6: wood fragment.

few tens of centimeters to one or two hundreds in the cored sediments, which is contrary to the usual case. This may explain why the acoustic survey failed, as mentioned above. The trend may be due to the upward increase in siliciclastic materials, or the upward decrease in biogenic products, both of which would reduce sediment density.

Organic carbon and nitrogen concentrations measured at 1 cm intervals were 4 to 7% and 0.5 to 0.8 %, respectively (Fig. 5.5). The C/N ratio is 10 to 13 in most cases, indicating that the organic carbon in the lake sediments is a mixture of major lacus-

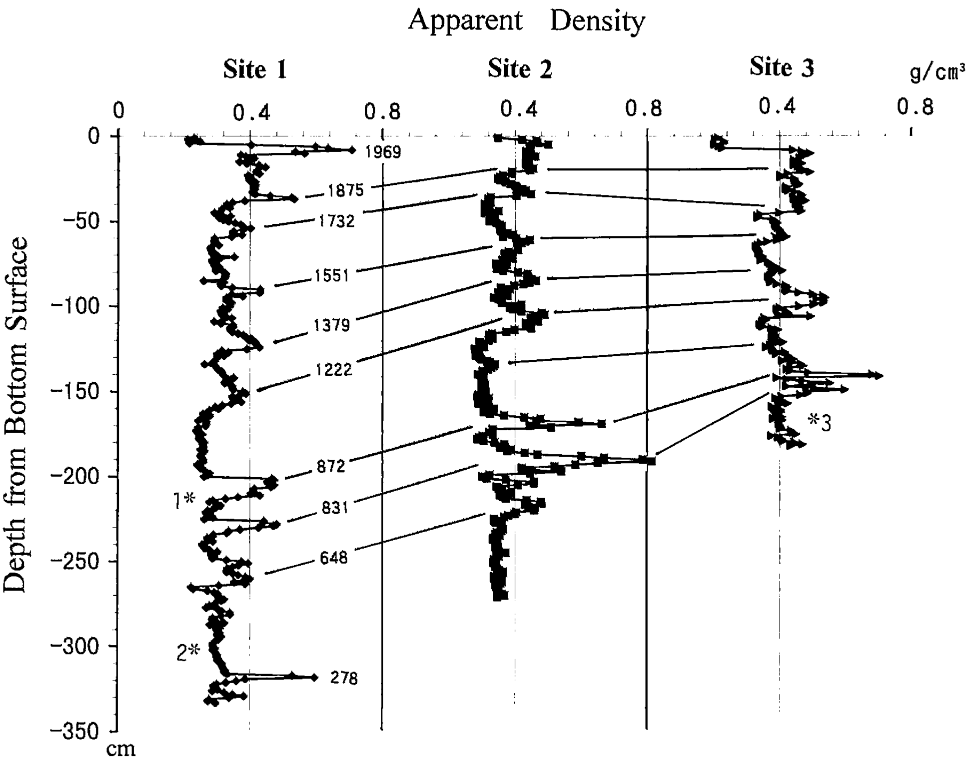

Fig. 5.4 Apparent density profiles of the three core sediments in Lake Kizaki, showing their correlation. Apparent density is dry weight per unit volume of wet sediment. The ages of major peak are based on sedimentation rates excluding turbidite sediments. Control ages are based on AMS ^{14}C dating, and the ages used are intercepts of the calibration curve for a calendar year (INTCAL 98). Controlling ages: 1*: AD 875, 2*: AD 425, 3*: 655.

trine plankton products and minor land plant remains. The carbon content clearly shows only slight fluctuation over a long period but with many short-term peaks and depressions. The fluctuations agree with those for nitrogen, and are the reverse of the C/N ratio. Comparison with apparent density revealed that the amount of organic carbon is low in dense sediments (Fig. 5.5). Clay and other minerals are abundant in flood sediments, and may dilute the organic carbon produced in the lake at that time. Flood sediments may also include a small amount of land plant detritus which has a high C/N ratio. This may explain why the C/N ratio increases in the dense sediments. Therefore, carbon and nitrogen data also indicate that short-term fluctuations reflect flood inputs from the surrounding land to the lake.

Long-term fluctuations may reflect changes in water temperature and so are related to changes in climate. For example, the period of relatively high carbon concentrations between 160 and 200 cm depth correlates with an age of 900 to 1200 AD, which in turn corresponds to the warm period of the early Medieval Age (Medieval Warm Period). On the contrary, low concentrations between 10 to 120 cm depth may partly be due to the high inputs of land detritus, which in turn represent

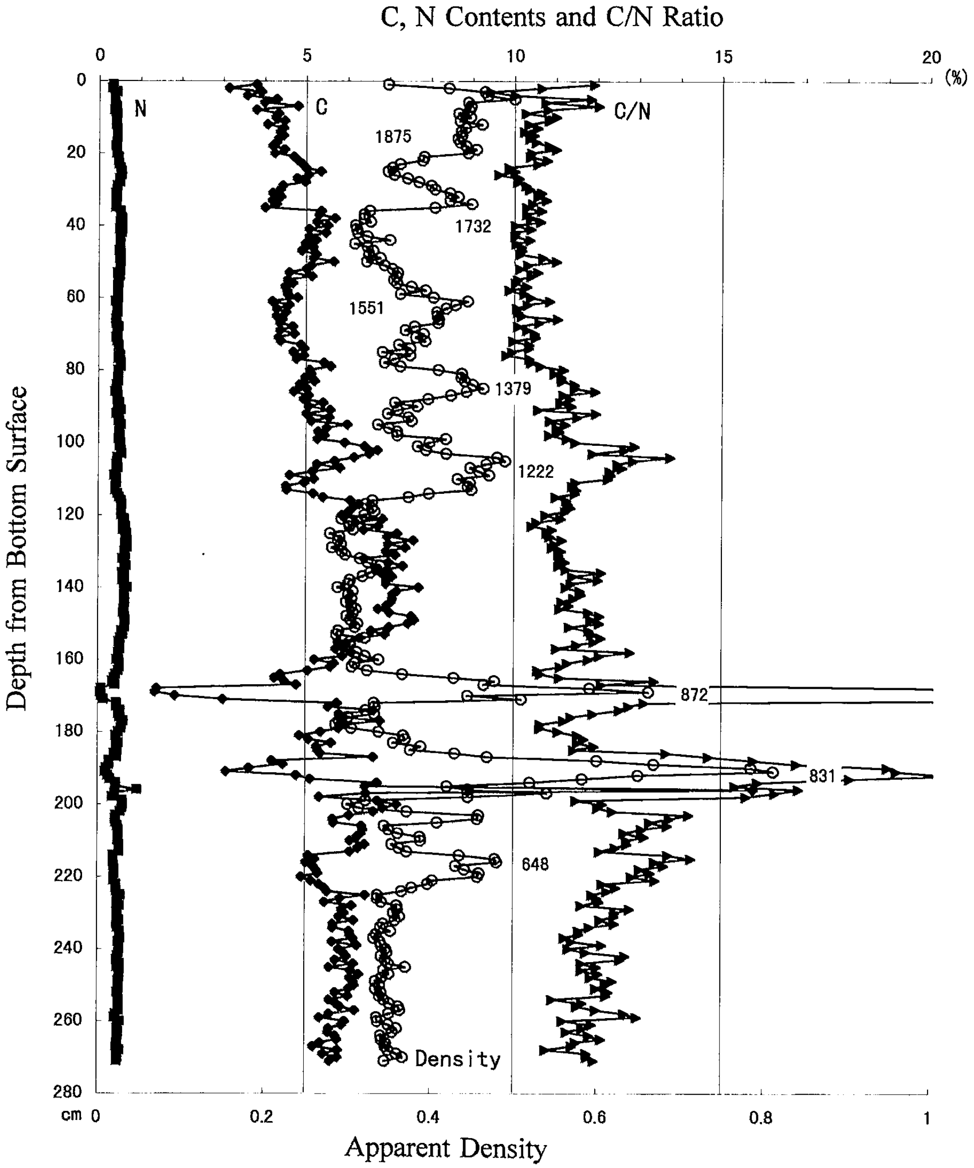

Fig. 5.5 C, N and C/N ratio of the sediments at Site 2 in Lake Kizaki. Apparent density profile is also shown for comparison. The numbers attached to the density profile are the sedimentation ages of major peaks converted to calendar year AD.

the high apparent density. However, in the upper depths (60 to 80 cm), a distinct, low concentration of carbon without dense layers was observed. Grain size of the representative normal sediments except turbidites was checked from the top to bottom of the cored sediments by ultrasonic sieving. There was no systematic increase of grain size through the upper part of the sediments. Therefore, it is probable that the low concentration of carbon between 10 cm and 120 cm depth implies a low biological productivity due to low temperature of the late Medieval Age, the so-called Little Ice Age.

A long core was obtained in 1974 (Horie *et al.* 1980). It was about 10 meters long and comprised mainly clayey-silt associated with sand and coarse silt layers and volcanic ashes. The lowest part of the core was dated at 6380 YBP by ^{14}C. At the same time, Horie *et al.* (1980) tried to confirm the basement of the lake by drilling without obtaining core samples, and met gravel at 28 m depth. Since gravel sediments usually do not deposit in the deeper part of lakes, sedimentation must have started at the top of the gravel. If we assume that the sedimentation rate is historically constant, the lake is estimated to have formed about 20,000 years ago.