Surface environmental changes in the lower reaches of the Kizu River based on a borehole database analysis: a case study in Kyoto Prefecture, Japan

Yuka Ito[1] and Fujio Masuda[2]
[1]Graduate school of Frontier Sciences, The University of Tokyo, Chiba, Japan.
[2]Deapertment of Environmental Systems Science, Doshisha University, Kyoto, Japan.

Abstract

The surface environmental changes were reconstructed in the lower reaches of the Kizu River, Kyoto, Japan using numerous borehole data. Four fluvial channels formed by lacustrine delta progradation at ca. 0–10m depth in the lower reaches of the Kizu River were clarified based on a subsurface geological analysis. These channels flowed toward the paleo-Ogura Lake and diverged to the north with the gradient decreased toward the end. The lacustrine delta systems were formed from the post–glacial period to the end of the 16th century. The new bedload–dominated rivers with crevasse splay system developed by the reduction in the lake area of the Ogura Lake due to artificial changes such as bank construction and shifting of river channels since the end of 16th century.

Keywords: Lacustrine delta, fluvial channel, borehole database, Holocene, human impacts

1. Introduction

The lower reaches of the Kizu River, southern Kyoto Prefecture, is located in western Japan, and is the basin called the Yamashiro basin. The Ogura Lake served as a flood retarding basin until 1941 in this area. The surface area of the lake was approximately 800 ha and mean of water depth was 0.9 m. Many flood disasters such as flooding and breaking of banks have been occurred because three rivers of the Katsura, Kizu, and Uji Rivers flowed into the lake [1]. Flash flood is particularly prominent in the lower reach of the Kizu River. Flood control measures such as constructing banks, establishing settlements on the levee, and shifting river channel have been adopted in this area and the topography has been changed several times by humans in order to prevent disasters.

Recently, building estate and artificial material are rapidly constructed in paleo-lake area since 1941, hazard risk is increasing. In addition, most of the dikes along the Kizu River are required to improve them due to antiquated levees [2]. Unplanned land reclamation and landform modification by human increase disaster risk and there is a possibility that a disaster such as flooding and liquefaction occur by reflecting former topography [3]. The sustainable disaster prevention measures and vulnerability assessment for flood and seismic hazard is firstly required to understand the paleo geomorphological changes.

This area has been studied in various research fields. The history, geomorphology, and geology of Ogura Lake have been comprehensively described by [4]. The occurrence of floods and the actual damage caused by each flood have been described in detail in many historical documents [5, 6, 7]. Archaeological survey is conducted in the lower reach of the Kizu River and around paleo-lake, distribution of paleo-settlements is revealed [8]. Geomorphological studies of the distribution of flood landforms and former River channels have been analyzed by [9, 10, 11, 12]. The distributions of strata and litho-facies have been revealed by collecting large amounts of borehole data [13].

Few studies, however, have been detail discussed about landform development and paleo-environment of the Yamashiro basin. In particular, the paleo-topography before 16th century is not known mostly in this area.

The purpose of this study is to analyze Holocene deposits and landform in the Yamashiro basin and reconstruct the paleo-environmental changes by using numerous borehole data of database and subsurface geological analysis. The relationship between surface environmental changes and human impact is also discussed.

2. Geological setting

The lower reaches of the Kizu River in the Yamashiro basin, Kyoto prefecture is located at latitude 34°49-53’ N, longitude 135°40-50’E (Figure 1(A), Figure 2). The Katsura, Uji and Kizu Rivers flow into this basin, and then they join at Oyamazaki and discharge into the Yodo River. The Ogura Lake had been served as a flood retarding basin until 1941 in this area (Figure 1(C)). The Kizu River, Uji and Katsura rivers were confluent at this lake. The surface area of the lake was approximately 800 ha. In the end of 16th century, human constructed embankments along the Ogura Lake and separated it from the Kizu, Uji, Katsura Rivers. The lake was reclaimed as a paddy field from 1933 to 1941.

The Kizu river, which has a drainage area of 1596 km^2, flows through several intermontane depressions in the upper reach bends northwest of Kizu Town and then flows north in the study area to the confluence of the Katsura, Uji and Kizu Rivers (Figure 2). The Kizu River carries a large quantity of sandy sediments because it comprises a granite area in the drainage basin. The raised–bed Rivers are formed in tributaries of the Kizu River (Figure 1). As a result of river improvement works in 1910, a significant former river course of the Kizu River near the Yodo Town was abandoned (Figure 2).

The Uji River has a drainage area of 4322 km^2, which, is more than 2.5 times that of the Kizu

River. Sediment discharge downstream of the Uji River is less because the sediments are deposited upstream of the Lake Biwa in Shiga prefecture (small maps in Figure 1(A)). It flowed directly into the Ogura Lake from the Makishima area until the end of the 16th century (Figure 2).

The Yamashiro basin has some characteristic topographies (Figure 2) : channels of the Kizu and Uji Rivers, high embankments created by humans, a former channel, a slight highland or natural levee used as a dry crop field, lowlands used as paddy fields, the Ogura Lake (currently reclaimed land in present) , and a drainage channel such as Furukawa River (Figure 1(A)). Alluvial fans and

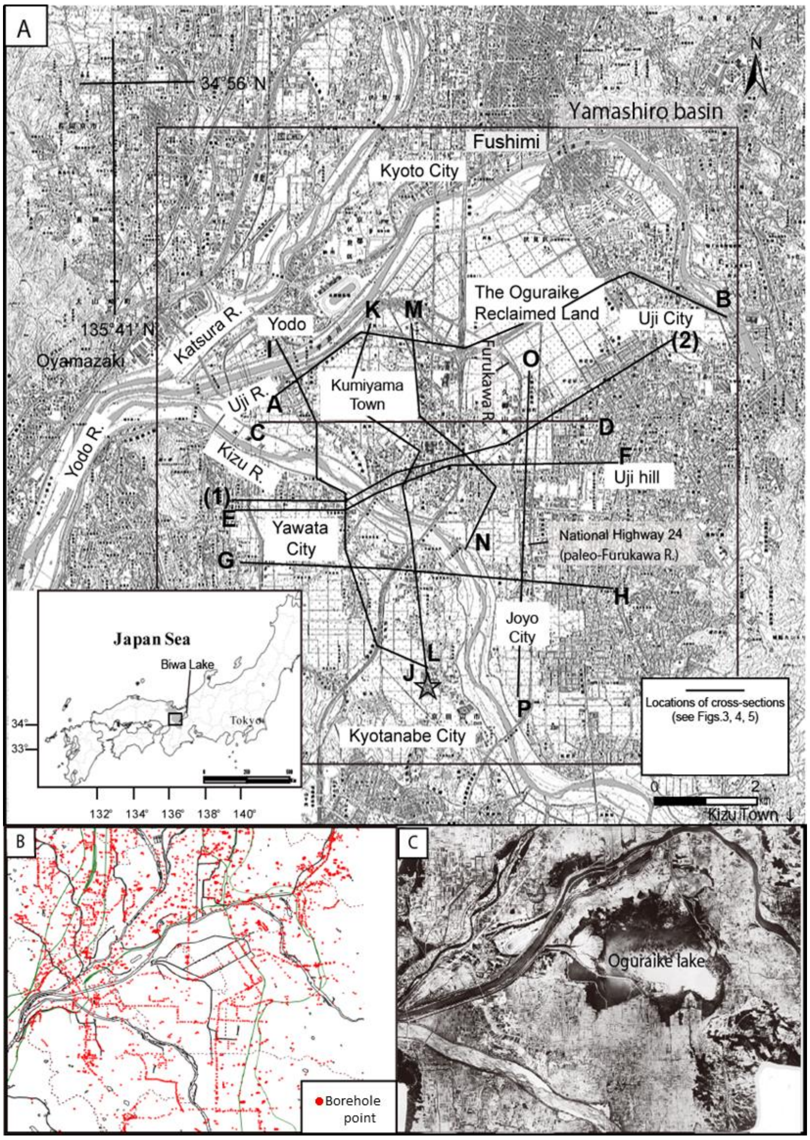

Figure 1: (A) Map showing the location of the lower reaches of the Kizu River in the southern Kyoto. This area is called Yamashiro basin. Base map is from 1:25,000 digital map of GSI, and showing locations of cross–section lines shown in Figures. 3–5. (B) Borehole sites show in Red dots. (C) Aerial photograph was taken in 1932 shows the Ogura Lake.

raised–bed rivers are located around the hills and the base of the mountains. Embankment settlements were established on the slight highland and circular levees constructed in the lowlands.

The subsurface structure of the Yamashiro basin was revealed by [14, 13], based on borehole surveys, a seismic reflection (P waves) survey, and considerable borehole data. The bedrock of Yamashiro basin is located at the Ogura Lake at a depth of –600 to –500 m [14]. The clay layer is deposited from surface to a depth of 10 m at the west of the Ogura Lake and the Kikai-Akahoya tephra (K-Ah) in ca. 6300 years ago is also distributed at a depth of 7 m. Chestnut buried in sandy gravel layer with a depth of 13 m, which are identified as deposits during 12340±220 years based on measurement of the ^{14}C dating [15]. The clay layer with a depth of ca. 10–15 m is identified as Holocene deposit in the Ogura lake area [13, 15]. The basement layer of the Holocene consists of sequence gravels are identified as fluvial bed or alluvial fan deposits in the late glacial period based on measurement of the ^{14}C dating in the Yamashiro basin [13, 15]. The hills formed in this basin are composed of sandy gravel layers with the upper layer composed of marine clay during the early Pleistocene [14].

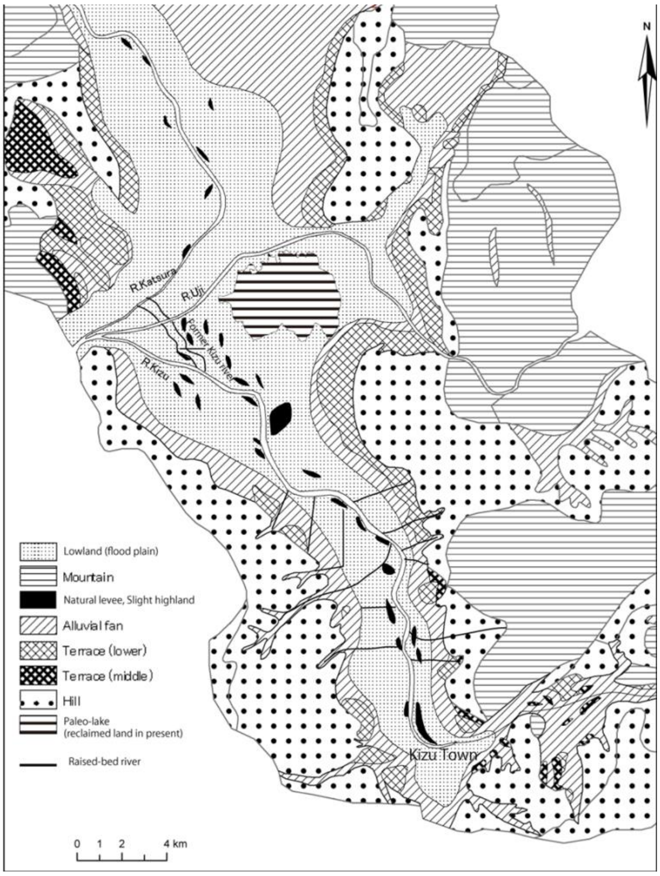

Figure 2: Geomorphological map of the Yamashiro basin.

3. Data and Methods

Stratigraphy, depositional environment, and paleo-geomorphorogical changes were estimated by analysis of subsurface geology using numerous borehole data.

Five hundred borehole data in the Yamashiro basin were obtained from the Kansai Geo-informatics Database of Japan in 2012 (Figure 1(B)). The database contains totally ca. 50,000 borehole log data.

This borehole log data includes information from lithofacies such as gravel, sand, silt, mud, layer thickness, elevation (depth), and N-value (standard penetration test). Sedimentological age and sedimental structure information are not included in this database; however, because this database contains numerous sets of borehole data (minimum range between the boreholes is ca. 2 m), considering continuous strata or spatial distribution of deposits is available. In this study, five transverse and four longitudinal cross sections were created by using borehole logs.

We used Shazam stratigraphy method [16] for interpretation depositional environment and reconstructing paleo-landform. This method is a new analytical method based on facies analysis and sequence stratigraphy and can apply to borehole database. Shapes of lithofacies boundaries in subsurface sections are optimized for sedimentary faces and changes by using this method [16]. The result is regarded as being better reconstruction of depositional systems, geomorphological development [16]. We drew the surface of ground on them by considering present topography such as mountain, terrace, plain (river and floodplain) at first. A lithofacies boundary was drawn on the cross-section of the geologic log by considering the basement boundary, lower and upper gravel, sand, silt, mud, and nexus between the lithofacies such as fine-grained upper succession or coarsening upward succession. The N-value was used to define the top of the gravel basement (N-value:≧50) based on [13].

The transverse cross-sections of the (1)–(2), A–B, C–D, E–F, and G–H sites and the longitudinal cross-sections of the I–J, K–L, M–N, and O–P sites are shown in Figure 1(A). Aerial photographs of scale 1: 10000 were also used in order to analyze the landform of the study area.

4. Results and discussions

4.1. Deposits

In the Yamashiro basin, the Holocene sequence is mainly composed of the lower part of clay and sand, the middle part of clay, sand and gravel, and the upper part of clay and sand. Gravel basement in study area is distributed in the bottom of the Holocene sequence with an elevation +4 to +6 meters below. Depositional environment was interpreted based on the characteristics of lithology, sequentiality and changes of lithofacies, and thickness using the Shazam stratigraphy method [16] (Figure 3, Figure 4, and Figure 5).

4.1.1. Basement of Holocene

The gravel basements are distributed in the paleo-Ogura Lake; the west of the paleo-lake (elevations below: ≤ +4 m), the east of the paleo-lake (elevations below: ≤ +6m) (Figure 3, Figure 4, and Figure 5) and thickness of this layer is more than 10 m. There is inclined from east to west and also from south to north. Especially, the sandy gravel is distributed steeply around Uji hill. N-value shows more than 50. The gravel basement is defined as the basement of the Holocene according to [15] and can be correlated to fluvial deposits or alluvial fan deposits formed during the Upper Pleistocene based on result of ^{14}C data [15]. Fluvial sediments were probably transported by the Kizu River and deposited during last glacial period. The sandy gravel distributed in the Uji hill could be also interpreted as alluvial fan deposits because of mainly composing of gravel and distributing steeply.

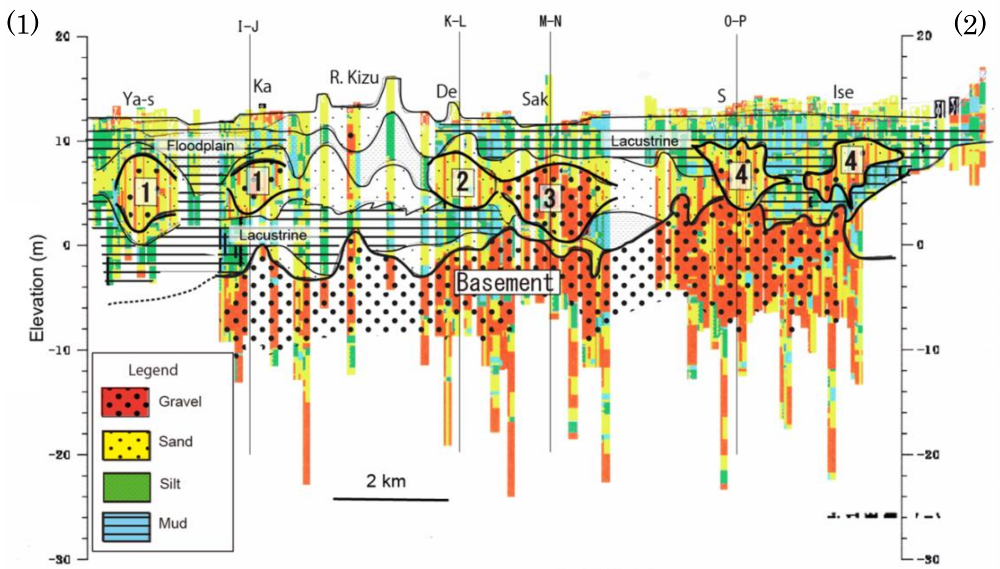

Figure 3: Geological cross–sections (W–E direction) of the lower reaches of the Kizu River, showing lithology distribution (see (1)–(2) in Figure 1 for location). I–J, K–L and so on show location cross–sections in Figure 5.

4.1.2. Holocene sequence

The lower part of unit is almost composed of clay and silt mixtures within peat with a thickness of ca. 10 m (Figure 3, Figure 4, and Figure 5). N-value shows ca. 0 to 5. These are distributed at elevation of ca. −6 to +2 m. The silt and clay are mainly distributed thickly in the plaeo-Ogura lake area and the thickness is increased from east to west. In the Yawata City, distribution of silt and clay with peat is prominent with a thickness of ca. 12 m. ^{14}C age of the lower part of clay was determined 5910 ± 140y B.P. of ^{14}C date [17], which shows that this deposit is Holocene. Depositional environment could be interpreted as lacustrine in the paleo-Ogura Lake and lacustrine or flood plain in area close to the lake such as Yawata City based on spatial distribution of clay and silt. There are shown that marsh or swamp such as floodplain and lake environments were formed in this area because of characteristic of depositing flatly, thickness and including peat [18]. The middle part of sand, sandy gravel and gravel of lenticular sediments with ca. 6 to 11 m thick are distributed between the silt and clay alternation (Figure 3, Figure 4, and Figure 5). They are also distributed continuously from south to north. For instance, in Joyo City (Figure 1), the sand is continuously distributed at an elevation of +2 to +10 m forward to the paleo-Ogura Lake (Figure 5D). These distributions are presented in Figure 6 and are located along traditional settlements such as Kawauchi (Ka) e.g. (Figure 6). These deposits are interpreted as fluvial channels, which were probably flowed from the upper reaches of the Kizu River to the paleo-Ogura Lake based on the

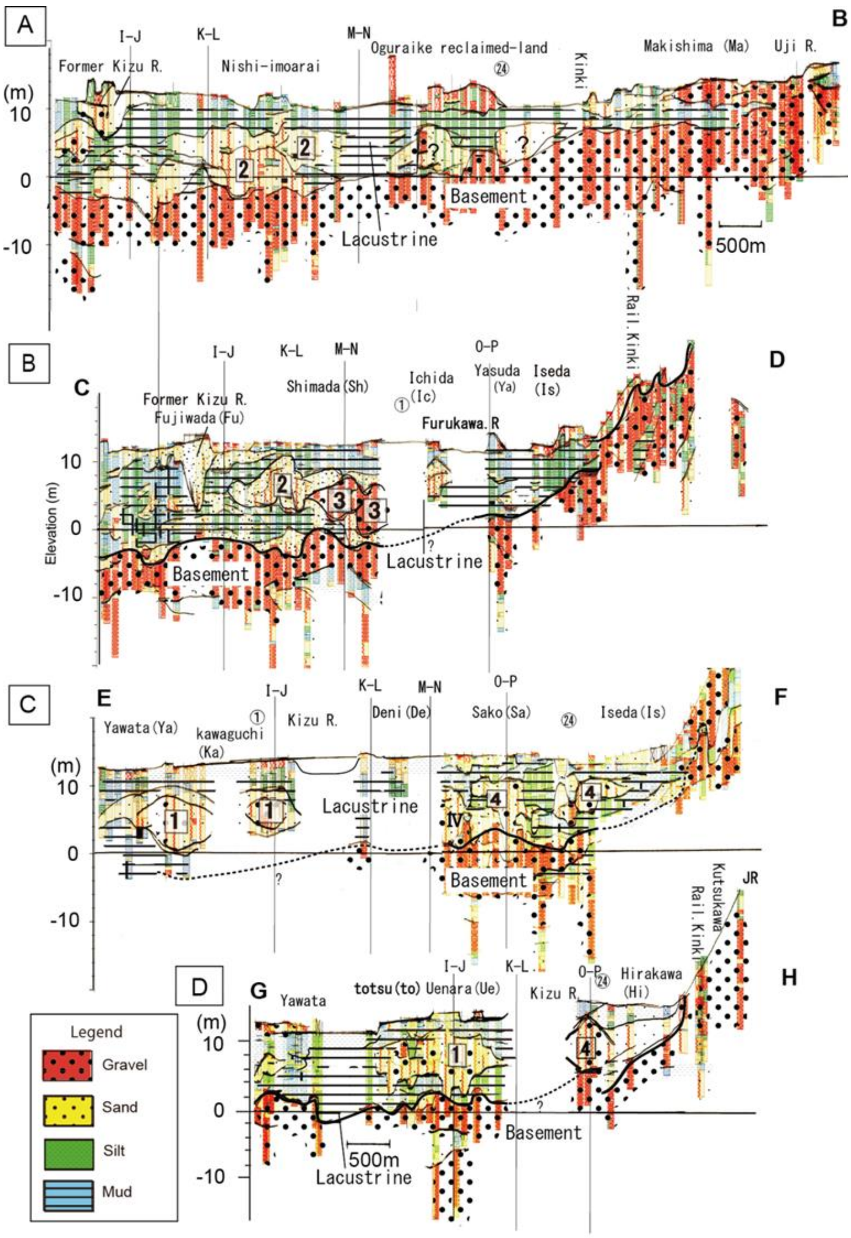

Figure 4: (A)–(D) Geological cross–sections (W–E direction) of the lower reaches of the Kizu River, showing lithology distribution (see location A–B, C–D, E–F and G–H in Figure 1). I–J, K–L and so on show location cross–sections in Figure 5.

characteristic of distribution of the deposits because these features are deposited lenticular bedding (lenses of sand in a muddy matrix) indicating fluvial channel deposits [19, 20]. We call successive sandy channel deposits (Figure 5D) as paleo Furukawa channel (Figure 6(4)) in Joyo City because present Furukawa River flows on this sandy channel. Other three channels are called sandy gravel channel (Figure 6(1)), sandy fluvial channel (Figure 6(2)), and gravel channel (Figure 6(3)). The four fluvial channels are also distributed along traditional settlements at a below from ca. –3 m to –10 m. At least four fluvial channels are recognized in this area (Figure 6).

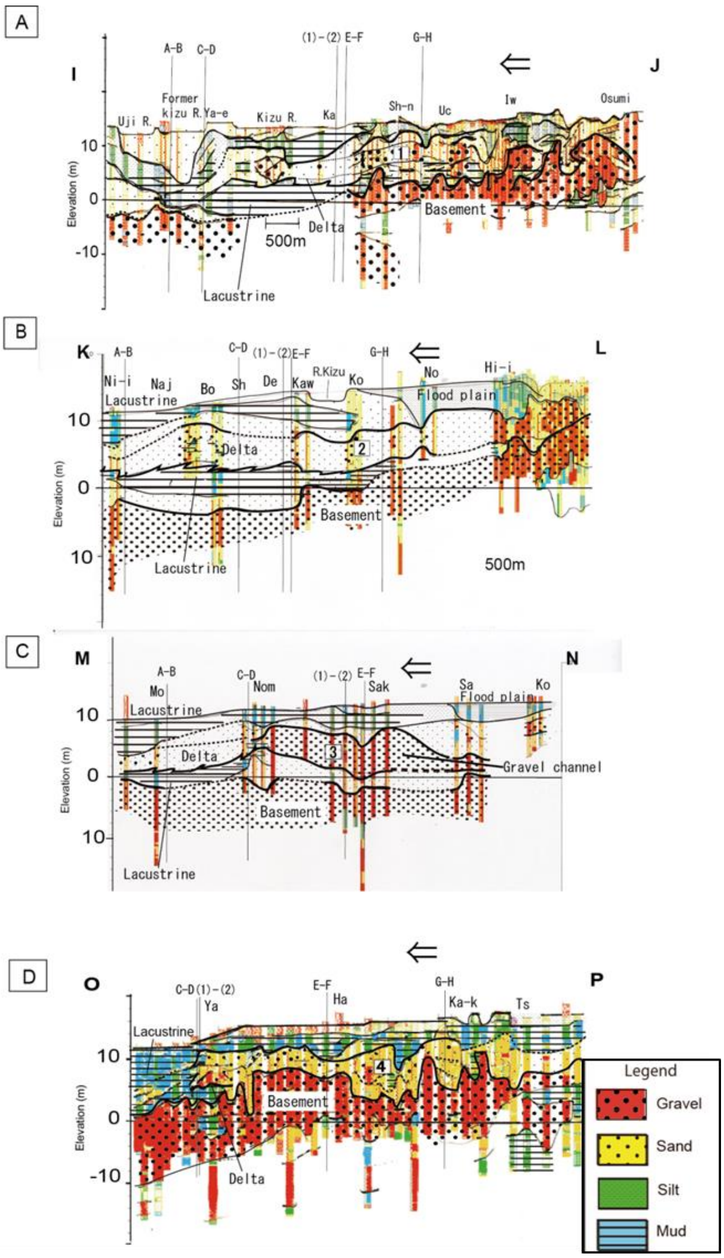

Figure 5: Geological cross–sections (N–S direction) of the lower reaches of the Kizu River, showing lithology distribution. (A) Sandy gravel fluvial channel, delta and lacustrine deposition (B) Sandy fluvial channel, delta and lacustrine deposition. (C) Gravel fluvial channel, delta and lacustrine deposition. (D) Paleo Furukawa River fluvial channel, delta and lacustrine deposition. (see I–J, K–L, M–N and O–P location in Figure 1). (1)–(2), A–B and so on show location cross–sections in Figure 3 and Figure 4.

Delta deposit indicated a coarsening–upward succession from clay of bottomset beds to sand and gravel of foreset beds (Figure 5). The delta of sand gravel channel is interpreted as a fluvial–dominated delta like bird–foot style because fluvial channel deposits dominated in the lacustrine mud deposits and minor lenticular bodies of sand beds [21, 22] (Figure 3, Figure 4(A) to (C) and Figure 5(A)). The planar form shows the main channel dividing into several distributary channel [23] (Figure 6).

The Upper part of units is composed of sandy clay dominated clay (N-value: below 5), which is identified in the whole of study area (Elevation: ca. +10-15 m). These could be interpreted as present floodplain and lacustrine deposits of the paleo-Ogura Lake based on characteristics of distribution of clay [24]. In particular, the clay deposits in the paleo-Ogura Lake are suggested as lacustrine deposits. In the former Kizu River, lenticular sand (N-value: 20) is distributed (Figure 4, Figure 5), which is fluvial channel deposits according to [12].

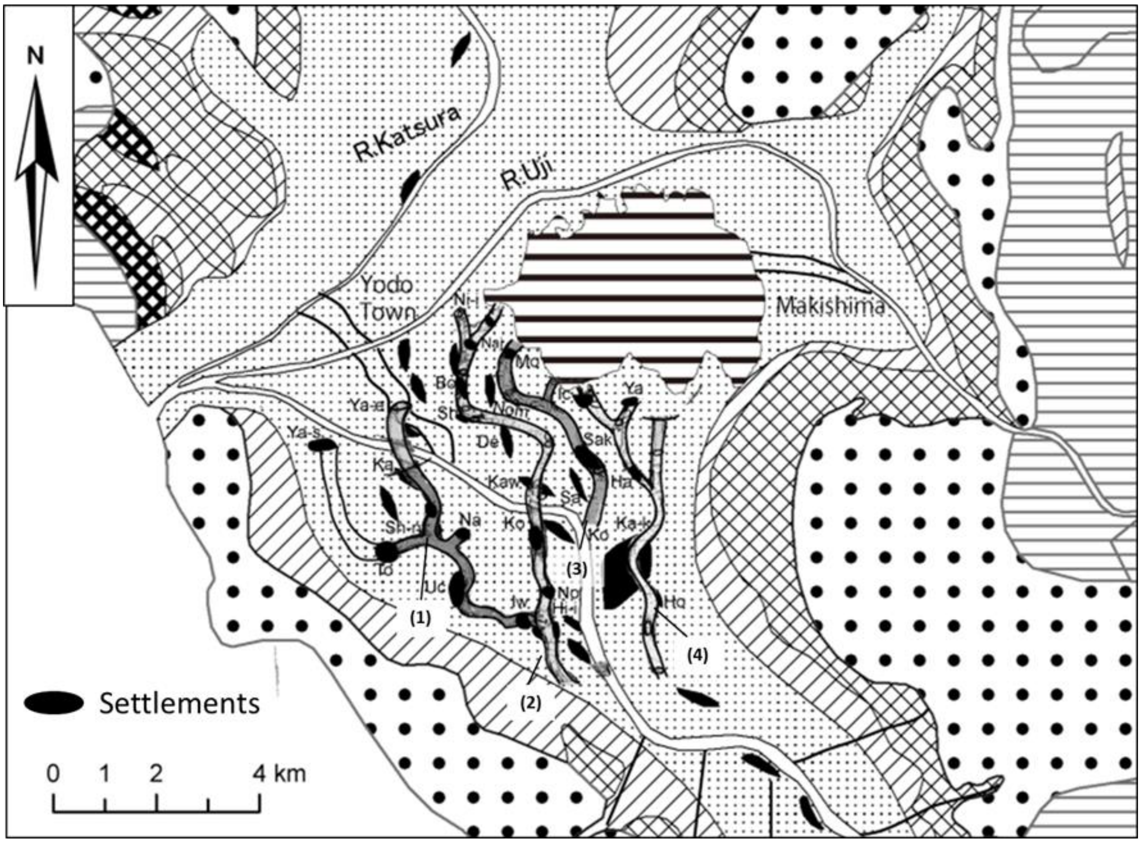

Figure 6: Location of the paleo fluvial channels showing. (1) Sandy gravel fluvial channel. (2) Sandy fluvial channel. (3) Gravel fluvial channel. (4) Paleo Furukawa River fluvial channel. Black distribution is settlements.

5. Stratigraphy of paleo-fluvial channel

Channel gradients of four fluvial channels, the modern and past Kizu River were created based on elevation of each riverbed obtained from the columnar sections, as shown in Figure 7. Stratigraphy of paleo-fluvial channel deposits could be estimated as follow. Gravel channel could be the lowest and the oldest in the four channels, the paleo Furukawa channel and the sandy gravel channel is the second oldest, and the sandy channel is the uppermost and the youngest. The modern Kizu River flows above these four channels. The depositional ages of these four channels have not been specified. These channels in the lacustrine delta system meander and diverge toward the north, and then the riverbed gradient of the channels becomes gentle at the channel terminal (Figure 6, Figure 7). The average riverbed gradient is 1.8/1000 in the sandy gravel and paleo Furukawa river channels and 1.1/1000 in the sandy channel. Both the gradients are slightly steeper than the gradient of the current lower reaches of the Kizu River, i.e., 1.0/1000. The gradient of these channels is gentler than one of the gravely channel of 2.0/1000 on the alluvial fan of the basement during the glacial period in Japan. Therefore, we estimated that gravely channel is the oldest.

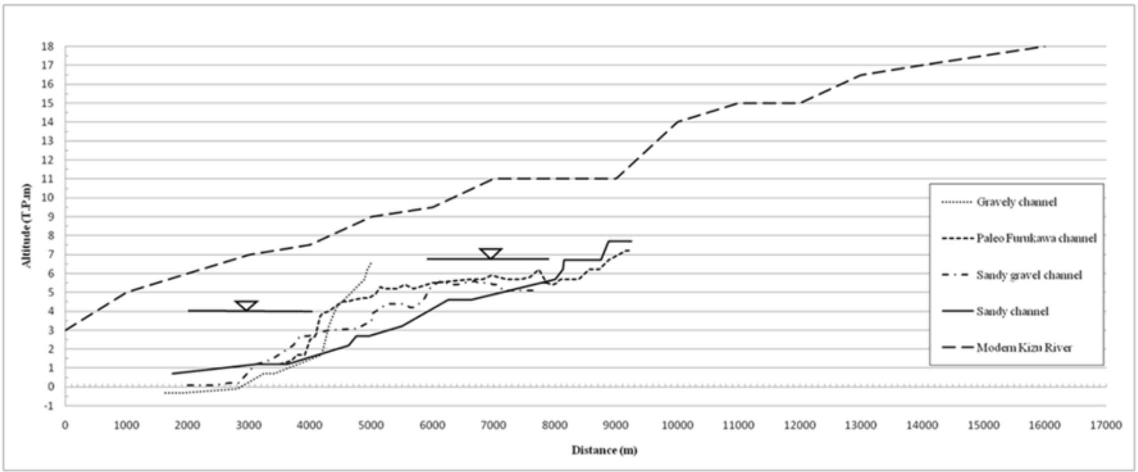

Figure 7: Profile of the four fluvial channels and the modern Kizu River channel. Basement slope of the sandy channel at T.P. 6.5 m in elevation and Paleo Furukawa and Sandy gravel channels at T.P. 4.0 m in elevation show the past lake levels.

6. Paleo-environmental changes

The paleo environmental changes in the lower reaches of the Kizu River are reconstructed on the basis of depositional and geomorphological characteristics and historical map (Figure 8, Figure 9).

The Yamashiro basin might be a swamp into which the Uji and Kizu Rivers flowed, from the post-glacial period to the end of the 16th century. Changes in the channels of the lacustrine delta from the post-glacial period to the end of the 16th century can be estimated. The gravel channel of the lacustrine delta could be developed first (Figure 8(A)), according to stratigraphic interpretation (Figure 7). Afterwards, the lake water level rose once as a result of this channel, which was overlain with lacustrine clay (Figures 3, Figure 4, and Figure 5). When the lake water level decreased (Figure 8(B)), then the paleo Furukawa River channel of the lacustrine delta (Figure 5(D)) could be developed. At the same time or slightly later, the sandy gravel channel of the lacustrine delta (Figure 5(A)) developed from Iwata to Yawata City (Figure 8(B)). The paleo Furukawa River and the sandy gravel channels had the same gradients, which abruptly changed at two or three points (Figure 7). These changes indicate that the paleo Furukawa River and the sandy gravel channels underwent decreases in the lake water level two or three times. The diversion of the channels (Figure 6) could have been caused by a decrease of the lake water level. Since thick mud layers were identified below the channel at the same elevation as the abrupt changes in gradient of both channels (Figure 7), the lake level could be the same elevation as the abrupt changes. Therefore, the Ogura Lake spread to Uchisatouji in Yawata City and Sayama in Kumiyama Town at that time (Figure 8(B)). After that, the lake level rose more than ca. 2.5 m again according to the profile of the sandy channel (Figure 7), and the lake area, where the southern coast of the Ogura Lake reached Iwata, achieved its largest size (Figure 8(C)). Then, the sandy gravel channel and the paleo Furukawa river channel could be abandoned when a lake area expanded because both channels are overlain by lacustrine clay (Figure 5(A), Figure 5(D)). A sandy channel of the lacustrine delta developed to the north at the same time with the lake water level decreasing (Figure 8(D)). The lake seemed to decrease to 10.5–11.0 m later, as estimated from the Uji delta [25].

The lake expansion might be reflected by regional climatic conditions change, subsidence of the lake, and relative sea-level changes [26]; however, this is not yet known in detail for the Yamashiro basin. The lacustrine water level change might be affected by geomorphic phenomenon such as channel shifting or splitting, especially close to the shoreline.

Many old settlements exist in northern Kyotanabe City, Yawata City, and Kumiyama Town (Figure 6 and Figure 8(D)). Old maps show that these settlements were underwater in the 13th–16th centuries, and some old settlements have remains from ca. 3000 years before the present to ca. 1800 years before the present [4]. The sandy gravel channel, sandy channel, gravel channel, and paleo Furukawa River channel were distributed under these settlements or alongside them. The old settlements did not depend on the current geographical system but on topographical features that are buried underground, such as a river-mouth bar or slight highlands of a levee with a lacustrine delta channel. In 1594, an artificial geographical modification was conducted in this area for the first time. The Uji River, which had been flowing directly into Ogura Lake at Maki-shima in Uji City, was diverted to Fushimi (Figure 1(A)) by constructing a levee [4]. At that time, the sandy channel (Figure 6) could be probably flowed directly into the Ogura Lake according to a report of [4].

The current Furukawa River channel was artificially made with the embankment construction. Engineering works such as changing river course and levee construction might be deprived the Ogura Lake of a large amount of incoming water, causing the lake level to be low rapidly; the lake area also decreased since many rivers such as the paleo Uji River or Katsura River no longer directly flowed into the lake [25]. In 1637, the Kizu River channel shifted from being a sandy channel to the former Kizu River in Yodo (Figure 2). These engineering works gradually might be changed the surface environment from the natural lacustrine delta system to current river system.

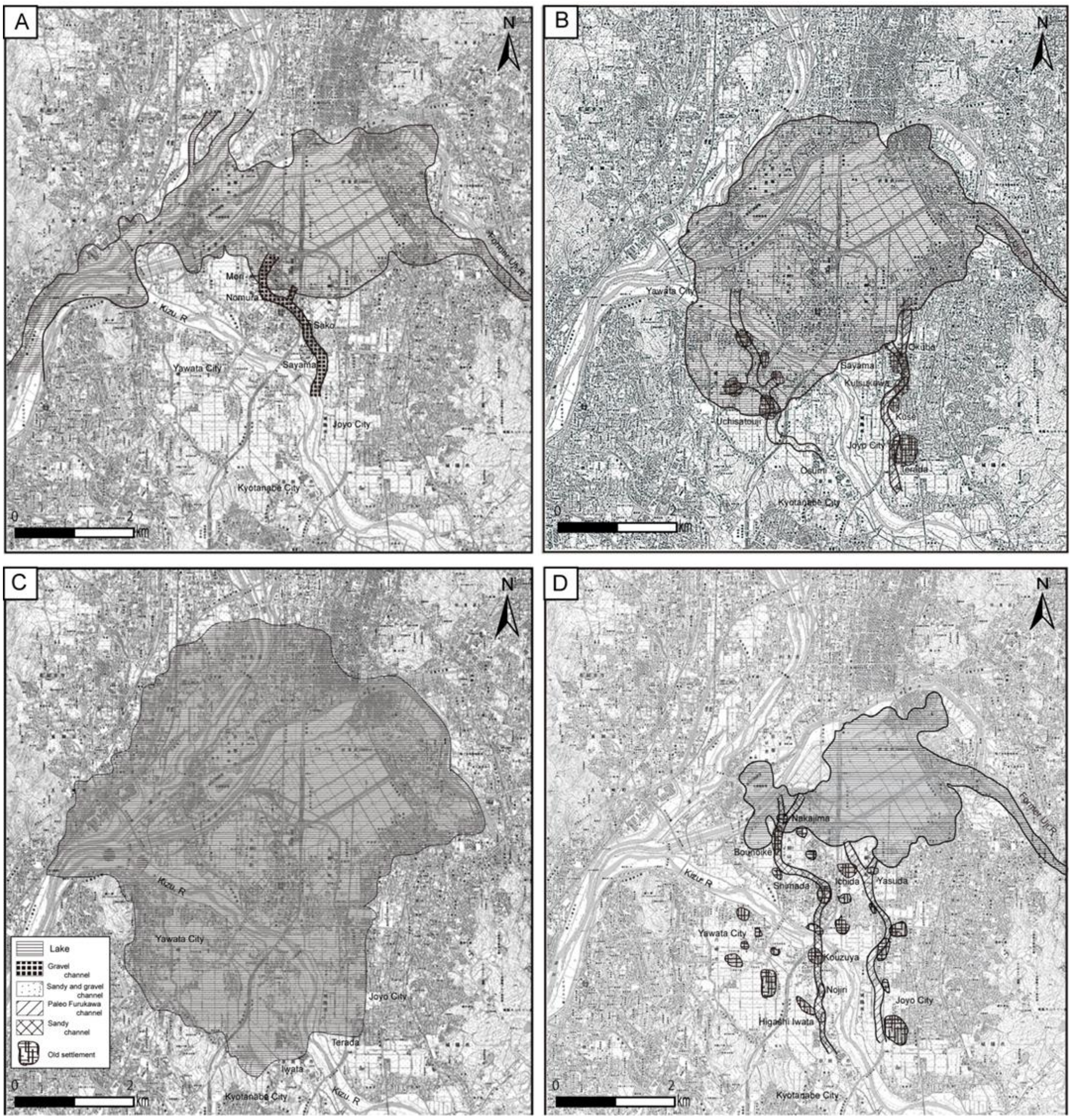

Figure 8: Paleogeographic reconstruction of the Yamashiro basin during Holocene. (A) The gravel channel of the lacustrine delta developed. (B) The lake water level raised once and the paleo Furukawa channel developed and the sandy gravel channel of delta developed from Iwata. (C) Maximum size of the paleo–Ogura Lake. (D) The sandy channel of the lacustrine delta developed. The lake water level decreased to T.P. 10.5–11.0 m. The shoreline of the north part of the Ogura Lake is estimation line.

Floods occurred frequently as a result of levee breaks along the Kizu River from the 1600s to the 1800s, according to the previous studies [5, 6, 7, 11, 12] because the Kizu River and its tributaries were then turned into a raised-bed river as a result of deposition of sandy gravel in the riverbed. The factors are suggested that the amount of sediment increased from above the Kizu River basin as a result of sediment discharge caused by deforestation for the construction of levees and a castle.

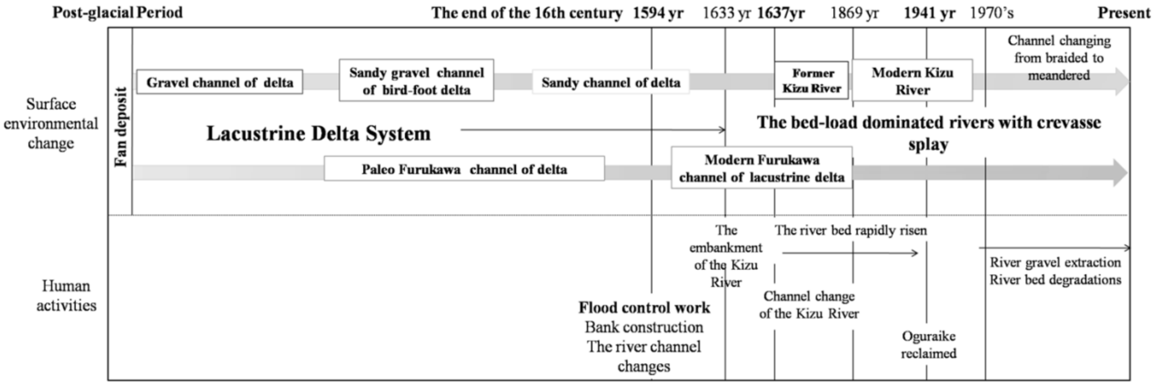

Figure 9: Surface environmental changes in the lower reaches of the Kizu River

In 1869, the Kizu River channel shifted from the former channel at the enclave of Yawata City to the modern Kizu River channel. Although the locations and situations of these floods in the lower reaches greatly changed after the shifting of the Kizu River channel by human, such flood often disasters occurred [11].

Ogura Lake was reclaimed in 1941 [4]. However, after it was reclaimed, the area often suffered flood damage as a result of levee breaks and inside water inundation. Thus, the result of inappropriate river channel fixation of the Kizu and Uji Rivers and land reclamation of the lake caused a levee break because of a lack of places where the flood flow was discharged during flood [3].

The channel of the Kizu River changed from a braided channel to a meandering channel as a result of river gravel extraction in the 1970s and river bed degradation. Bedload-dominated rivers with crevasse splays [27], which transported large amount of soils from granitic rocks, developed the lower reaches of the Kizu River. These geomorphrogical environment changes could be attributable to human activities since the end of the 16th century.

8. Conclusions

The geomorphological changes in the lower reaches of the Kizu River, Southern Kyoto Prefecture, Japan are reconstructed during the post–glacial period to the present using borehole database. The particular depositional environment in the Holocene can be estimated by detailed analysis of numerous borehole data based on Shazam stratigraphy method. The main results of this study are shown as follows.

(1) Four fluvial channels were formed by lacustrine delta progradation at a depth of –10 m to 0 m in the lower reaches of the Kizu River. These channels were as follows: a paleo Furukawa channel, sandy gravel, and gravely channel that developed under the modern Kizu River; a sandy channel that flowed parallel to the above channel to its west. These channels flowed toward the Ogura Lake and diverged to the north and the gradient decreased toward the end.

(2) In stratigraphic interpretation, the gravel channel is the oldest, and the sandy channel is the youngest. Abrupt changes were observed in the channel slope. These points were attributed to the decrease in the lake level and shifting of the channel. This lacustrine delta system formed from the post–glacial period to the end of the 16th century in the Yamashiro basin. Since the end of the 16th century, this area was a low swampy area into which the Uji and Kizu Rivers flowed.

(3) Channels of the lacustrine delta developed in the Ogura Lake during the post–glacial period to the end of the 16th century. The old settlements were identified on the slight highlands of the natural levees and river–mouth bars developed along the channels in the lacustrine delta system. Since the end of the 16th century, the modern Kizu River changed to the form of a bedload–dominated river with crevasse splay, and the river began transporting large quantities of soils from granitic rocks in the area to the north of Osumi in Kyotanabe City and Joyo City. The new system developed because of the reduction in the lake area of the Ogura Lake due to artificial changes such as bank construction and shifting of fluvial channels.

Acknowledgments

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