The Eurim Lake and its Hosting Valley: A Unique Ancient Reservoir with Bank Constructions in Korea

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Abstract

The Eurim Lake is the oldest artificial reservoir in Korea, and its hosting valley possesses ancient embankment facilities. The historical documents give us information about two probable stages of the lake construction: the late Iron Age (ca. 2000 BP) and the time of King Jinheung of the Silla Dynasty at 540–576 AD (1460–1424 BP). This article presents new sediment coring data (three boreholes), which allowed us to reconstruct the history of the lake and substantiate the stages of its construction, and new geomorphologic data, which suggest the timing and scenarios of the activities linked to the construction of valley embankments. The artificial bank of the lake consists of i) old alluvial deposits (<307 m a.s.l.), ii) pre-damming lake deposits (307–310.4 m), iii) artificial materials of the dam (310.4–315.4 m), and iv) post-damming artificially contaminated and disturbed sediments (>315.4 m). These four bank units suggest two major stages of the lake development, pre-damming and post-damming, which are also recognized in the lake sediments. The AMS \(^{14}\)C dating shows that the lake existed between ca 1920 and 1370 cal. BP as a naturally or artificially dammed basin. During this period the normal sedimentation in the lake proceeded at a rate of 4 mm/yr. The further development of the lake was disturbed by dam construction after the middle of the 7\(^{th}\) century AD. The age of the lake sediments, suggesting their accumulation before the construction of the dam, and our geomorphologic observations in the lake valley allowed us to hypothesize about a scenario of as early as ca. 2000 BP irrigation activities of ancient people.

Key words: Eurimji Valley, reservoir dam, embankment materials, bank construction, sediment core, borehole logging, sedimentation rate

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Introduction

The Eurim Lake is located at Mosan-ri, near the Se-Myeong University, in Jaecheon County of Korea (Fig. 1). It is known as a geopark and has been carefully maintained as one of the best natural sceneries in Korea (Yang, 2010). In addition, this oldest historical lake is special for its ancient hydraulic embankment facility (Lee, 1959). According to historical books, Lake Eurim was dammed either in the end of the late Iron Age, i.e., at about 2000 BP (Lee, 1956), or during the period of King Jinheung of the Silla Dynasty at 540-576 AD (1460-1424 BP) (Yang, 2010). Evidence for the latter is relatively weak and comes from a legendary written story about Uruk, who was a famous musical master of Gayakeum in the Jaecheon area.

The downstream part of the Eurimji Valley is famous for its ancient irrigation facilities and embankments, which were constructed for managing the water resources. The embankments are located near the Youngho castle. It was proposed that the time of the construction of those embankments coincide with the time of Eurim Lake damming (Kim et al., 2009a, b, 2010). In addition, there is a third point of view, which considers the construction during the late Bronze Age, i.e., at 800-900 BC (2900-2800 BP) (Lee, 2006, 2010).

This paper presents new data on the stratigraphy and the age of the bottom sediments and embankment materials of the Eurim Lake and contributes to the debates on its formation and reservoir dam history. The time of the construction of Eurimji

![Fig. 1. Location of the Eurim Lake in Jaecheon, South Korea.](image-url)
Valley embankments and its environment are constrained from our geomorphologic observation.

**Geomorphologic and environmental settings**

The Eurim Lake is located in the Eurimji Valley, at its outlet to a small intermountain depression. The lake starts at the narrowest part of the valley, between two piedmont spurs (Fig. 2). The valley downstream of the lake includes several alluvial cones (fans) consisting of gravel with sand patches, which formed during the Late Pleistocene glacial period (Kim, 2001; Kim et al., 2000a, b, 2006; Fig. 3). The fan system exhibits three steps of incision, which are recognized as low terraces I, II, and III (Kim et al., 2008; Lee, 2010; Fig. 4). The terraces exhibit signs of frequent landslides, which are seen along the fore-edges and escarpments (Fig. 2d).

The basement rock units are dominated by Precambrian gneiss and Jurassic granite, the latter outcropped along the valley and in its bottom. The gradient of the valley ranges from 29 m/km up the Eurim Lake to 17 m/km below the dam. Near the Eurim Lake, the valley deepens as a result of strong differential erosion as a result of former episodic flooding and/or increased precipitation.

The valley is topographically protected from severe annual winter monsoons and therefore it is favorable for agriculture. In addition, the valley is good for producing high-quality water for drinking. It was assumed that the construction of agricultural paddies

Fig. 2. The landscape (satellite imagery; A), bathymetry (B), GPR profiles (C) and 3D topographic model (D) of the Eurim Lake.
started in the beginning of the late Bronze Age (close to 2800 yrs BP) based on the occurrence of paddy remains in the middle part of South Korea, which are assigned to the Songgug-ri culture (Lee, 2006).

Fig. 3. River bed forms and terraces of the Eurimji Valley.

Fig. 4. The aerial photography showing the stepwise distribution of Eurim terraces (modified from Lee, 2010).
The Japanese Geomorphological Union

Methods

The paper discusses the results of the echo-sounding and ground penetration radar surveys of the Eurim Lake (Fig. 2b, c; Kim et al., 2000a, b) and the geomorphologic interpretation of the airborne images of the Eurimji fanglomerate mouth (Lee, 2010).

We present sedimentological borehole logging and ¹⁴C age data on three cores of lake bottom (EL-3-1) and bank (BH-1 and BH-2) sediments (Fig. 2a; Table 1). The cores were drilled in 2008 and 2009, by adopting the rotary drilling with percussion without any use of circulation water for the interval of soft clays and sands. Core BH-1 was used for sedimentological studies. It was cut and sliced at an interval of 0.5 m. The profiles of natural gamma radiation, electric resistivity and rock porosity were obtained by the in-site loggings by using geophysical logging devices including MGX-II (Mount Sopris Co.), Micro-logger II (Robertson geologger Co.) and Optical Televiewer. Core EL-3-1 was used for accelerated mass-spectroscopy (AMS) dating, which was performed in KIGAM using a HVEE AMS/multipurpose beam line-MPS 4130-Tandetron device.

Table 1. Borehole information of Eurimji Bank and Eurim Lake.

<table>
<thead>
<tr>
<th>Boreholes</th>
<th>Coordinates</th>
<th>Length (m)</th>
<th>Altitude (m, a.s.l)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH-1</td>
<td>N 37°10'05.86&quot; E 126°12'36.33&quot;</td>
<td>18.00</td>
<td>321.41-303.41</td>
<td>Eurimji Bank</td>
</tr>
<tr>
<td>BH-2</td>
<td>N 37°10'05.76&quot; E 126°12'36.35&quot;</td>
<td>18.50</td>
<td>321.41-302.91</td>
<td>Eurimji Bank</td>
</tr>
<tr>
<td>EL-3-1</td>
<td>N 37°10'06.97&quot; E 126°12'38.69&quot;</td>
<td>6.98</td>
<td>314.23-307.25</td>
<td>Eurim Lake Bottom</td>
</tr>
</tbody>
</table>

Results

(1) Core description

The BH-1 core consists of the following embankment materials: 1) sand and gravel (< 310.4 m a.s.l.), 2) gray mud (310.4-315.4 m a.s.l.), and 3) reddish-brown, brown and yellow muds (315.4-320.4 m a.s.l.) (Fig. 5). The reddish brown layer in the upper part of the core contains iron-oxides (hematite), whereas the yellow layers formed due to granite alteration/weathering. The yellow mud-gravel layers at the top were mounded artificially by men. The gray mud layer in the middle part contain abundant organic material: seed, twigs, leaves, etc. (Kim et al., 2009a, 2010).

The EL-3-1 core is 6.98 meters long (Table 1) and consists of the following lake bottom sediments: 1) sand and fine gravels (< 308 m a.s.l.), 2) gray silty sand (308-310.4 m a.s.l.) with plant fragments, 3) gray muddy sand to sandy mud with plant fragments in lower part (> 310.4-311.9 m a.s.l.), and 4) yellowish brown mud and sandy mud (311.9-314.2 m a.s.l.) (Fig. 5).
Fig. 5. Photos of bank materials in core BH-1. Each core sample is 0.5m long (vertically). A part of the core between 310.0 and 310.5m a.s.l. was lost.
(2) **AMS dating**

The results of the AMS dating are shown in Tables 2 and 3. The oldest age of sediments in core BH-I is 4800 ±60 yrs BP (Table 2), i.e. the whole sedimentary sequence is younger than the Middle Holocene. The oldest age of lake bottom sediments is ca 1900 yrs BP (Table 3), which is indicative of a younger formation of the Eurim Lake. The gray mud layer with plant fragments yielded an age of 1200 yrs BP from core BH-1 and an age of about 1400 yrs BP from core EL-3-1. However, the bulk sediment samples from the gray mud layer yielded an age of about 2,000 yrs BP suggesting the presence of “old” carbon.

### Table 2. The results of the AMS radiocarbon dating of Eurimji bank core materials (BH-1).

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Sample ID</th>
<th>Material</th>
<th>Altitude (m)</th>
<th>Age BP year</th>
<th>Error year</th>
<th>d13C</th>
<th>Calendar year</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB-1</td>
<td>ISA080136</td>
<td>sediment bulk</td>
<td>315.56</td>
<td>1530</td>
<td>50</td>
<td>-22.8</td>
<td>AD 514±62</td>
<td>Upper part</td>
</tr>
<tr>
<td>EB-2</td>
<td>ISA080137</td>
<td>sediment bulk</td>
<td>314.73</td>
<td>1800</td>
<td>50</td>
<td>-23.2</td>
<td>AD 222±74</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-3</td>
<td>ISA080138</td>
<td>sediment bulk</td>
<td>313.92</td>
<td>3570</td>
<td>60</td>
<td>-19.7</td>
<td>BC 1913±91</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-4</td>
<td>IWD080274</td>
<td>plant fragment</td>
<td>313.78</td>
<td>1120</td>
<td>50</td>
<td>-26.9</td>
<td>AD 906±62</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-5</td>
<td>ISA080139</td>
<td>sediment bulk</td>
<td>312.96</td>
<td>1880</td>
<td>50</td>
<td>-21.4</td>
<td>AD 135±61</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-6</td>
<td>ISA080140</td>
<td>sediment bulk</td>
<td>312.03</td>
<td>1950</td>
<td>50</td>
<td>-22.2</td>
<td>AD 44±56</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-7</td>
<td>IWD080275</td>
<td>plant fragment</td>
<td>311.99</td>
<td>1200</td>
<td>50</td>
<td>-25.9</td>
<td>AD 810±70</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-8</td>
<td>ISA080141</td>
<td>sediment bulk</td>
<td>311.14</td>
<td>1990</td>
<td>50</td>
<td>-21.6</td>
<td>AD 1±52</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-9</td>
<td>IWD080276</td>
<td>plant fragment</td>
<td>311.03</td>
<td>1210</td>
<td>50</td>
<td>-24.9</td>
<td>AD 799±71</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-10</td>
<td>ISA080142</td>
<td>sediment bulk</td>
<td>310.61</td>
<td>2650</td>
<td>50</td>
<td>-23.0</td>
<td>BC 839±38</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-11</td>
<td>IWD080277</td>
<td>plant fragment</td>
<td>310.59</td>
<td>1120</td>
<td>50</td>
<td>-25.8</td>
<td>AD 906±62</td>
<td>Middle part</td>
</tr>
<tr>
<td>EB-12</td>
<td>ISA080143</td>
<td>sediment bulk</td>
<td>307.31</td>
<td>4800</td>
<td>60</td>
<td>-23.1</td>
<td>BC 3580±61</td>
<td>Lower part</td>
</tr>
</tbody>
</table>

*Calendar year is calibrated by CalPal2007 (Danzeglocke et al., 2008).

### Table 3. The results of the AMS radiocarbon dating of Eurim Lake bottom core sediments (EL-3-1).

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Sample ID</th>
<th>Material</th>
<th>Altitude (m)</th>
<th>Age BP year</th>
<th>Error</th>
<th>d13C</th>
<th>Calendar year</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL-1</td>
<td>ISA090031</td>
<td>sediment bulk</td>
<td>311.7</td>
<td>2,110</td>
<td>50</td>
<td>-25.0</td>
<td>BC 143±68</td>
<td>disturbed layer</td>
</tr>
<tr>
<td>EL-2</td>
<td>ISA090032</td>
<td>sediment bulk</td>
<td>311.1</td>
<td>2,020</td>
<td>50</td>
<td>-25.1</td>
<td>BC 38±62</td>
<td>disturbed layer</td>
</tr>
<tr>
<td>EL-3</td>
<td>IWD090005</td>
<td>plant fragment</td>
<td>310.4</td>
<td>1,390</td>
<td>50</td>
<td>-26.5</td>
<td>AD 633±30</td>
<td>Stable layer</td>
</tr>
<tr>
<td>EL-4</td>
<td>ISA090033</td>
<td>sediment bulk</td>
<td>309.5</td>
<td>1,420</td>
<td>50</td>
<td>-26.0</td>
<td>AD 613±32</td>
<td>Stable layer</td>
</tr>
<tr>
<td>EL-5</td>
<td>ISA090034</td>
<td>sediment bulk</td>
<td>308.1</td>
<td>1,740</td>
<td>50</td>
<td>-23.6</td>
<td>AD 297±61</td>
<td>Stable layer</td>
</tr>
<tr>
<td>EL-6</td>
<td>ISA090035</td>
<td>sediment bulk</td>
<td>307.5</td>
<td>1,920</td>
<td>50</td>
<td>-24.0</td>
<td>AD 79±54</td>
<td>Stable layer</td>
</tr>
</tbody>
</table>

*Calendar year is calibrated by CalPal2007 (Danzeglocke et al., 2008).
(3) Borehole logging and rock physical properties

Embankment (bank) materials were examined in two boreholes: BH-1 (inner wall) and BH-2 (outer wall) (Figs. 5 and 6). The logging profiles of natural gamma radiation, electric resistivity, rock porosity and the optical tele-view images indicate sand and gravel below 310.4 m a.s.l. (lower part), gray mud between 310.4 and 315.4 m (middle part), and brown mud above 315.4 m (upper part) (Fig. 6). The natural gamma radiation and the electric resistivity decease up the core. Both parameters are higher in the lower part of the core compared to the middle and upper parts. The magnitude of peaks of gamma radiation in the lower and middle parts is larger than that in the upper part. All these differences of sediment properties suggest variations of their porosity, content of water and humus. The porosity drastically increases above 310.4 m a.s.l. The trends of natural gamma radiation and electric resistivity are opposite to those of porosity. The natural gamma radiation curve of core BH-1 is similar to that of core BH-2 because both cores include similar sources materials. However, the resistivity in BH-1 is much higher than that of BH-2 implying higher porosity and water content in the bank.

![Diagram of borehole logging data for BH-1 and BH-2 cores.](image)

**Fig. 6.** Borehole logging data for the BH-1 (inner wall) and BH-2 (outer wall) cores. The distribution patterns for bank materials show that the porosity decreases as natural gamma radiation increases towards the lower part of the bank of Eurim Lake.
materials of the inner wall (BH-1) (Fig. 6). Therefore, the bank materials of the inner wall below 310.4 m a.s.l. have different mineral and/or physical properties from those of the outer wall.

**Discussion**

The lake bottom sediments contain three sedimentary layers which formed in connection with an anthropogenic impact on the natural sedimentation processes. The sedimentary layers formed during four stages: 1) the post-dam-construction upper mud layer; 2) the middle layer of the artificial fill related to the dam construction, 3) the lower lake layers, and 4) the lowermost alluvial layer of the initial valley (Kim et al., 2009a, b, 2010).

Due to the major construction of the artificial bank in the southern part of the Eurim Lake many parts of the old lake bottom sediments between 315.4 m and 310.4 m (a.s.l.) were disturbed and the bank materials were mixed with older lake bottom sediments. Evidence for this suggestion comes from the ages of 1120 and 2650 yrs BP for the sediments at the same level, 310.5 and 310.6 m a.s.l., respectively (Table 2). However, the lower layer of lake bottom sediments yielded an age of ca. 1920 yrs BP (Table 3). The stable sedimentation in the lake continued from 1920 until 1420 yrs BP (Table 3) at a stable rate of about 4 mm/yr.

In addition, the lake bottom sediments contain more sandy mud compared to the gravel-dominated bank materials, which occur at the same topographic altitude, i.e. between 308.2 and 310.2 m (Fig. 7). This level matches the level of the lower part of the bank core (bank drilling core: BH-1) suggesting that the bottom sediments of the Eurim Lake had accumulated before the major bank construction at about 1200 yrs BP. Thus, the lake bottom sediments may be as old as 1920 yrs BP. The lake obviously initially formed due to a natural or artificial stone dam. Our data allowed us to suggest that ancient people could build artificial levees by using the gravel and sand material deposited on the bottom of the Eurimji Valley. The age of the valley gravel and sand is Early to Middle Holocene or pre-LGM (Kim et al., 2006; Kim, 2001). Evidence for this comes from several local dams, which were built to get water by using the advantages of the natural step-like river-bed profile and natural barriers/blocks of basement rocks, which were abundant in the Eurimji Valley. Ancient people could also use the sub-angular gravel material of the valley to maintain its bottom horizontal for constructing artificial levees. They could make bank stone dams almost parallel to the present Eurimji bank by connecting the bottom with outcropped basement rock blocks. Those primitive stone dams consisting of sand and gravel were precursors of the modern construction and allowed ancient people to have water reservoirs at the valley mouth of the Yongdu Mountain as early as the late Iron Age or even during the late Bronze Age.

For example, in Korea, the Songgug-ri type pottery culture has been known for their agricultural practices using rice paddy fields since 800-900 yrs BC (Lee, 2006).
The organic mud at 310.6 m a.s.l., which yielded an age of 2650 yrs BP (Table 2), allowed us to suggest that the sediments of the Eurim Lake already existed on the lake bottom at that time, although we could not obtain good sediment samples below 307.2 m in the borehole EL-3-1 (Tables 1 and 2). The sediments at 307.5 m in borehole EL-3-1 yielded an age of 1920 yrs BP, and we believe that sample older 2000 yrs BP could be found/drilled in future.

The idea about large-scale dam construction and irrigation activities in the present Eurimji Lake is supported by both historical documents and systematic analysis of sediment cores. Previously, the Eurimji reservoir was thought to be constructed by stone dams in the late Iron Age or at 540-576 AD, i.e. in the time of King Jinheung of the Silla Dynasty (Yang, 2010). But the presented results of the study of Eurimji bank materials rather indicate the initiation of the construction of the present embankment during the time of the Unified Silla Dynasty, i.e. in the 9th century AD. As far as the bank core material contains wood fragments, twigs, leaves and seeds, we suggest that ancient engineers constructed the earth dam by mixing tree debris with tampered clays.

Fig. 7. Comparison of the lower part of Eurimji artificial bank material (core BH-1) and the natural bottom sediments of the Eurim Lake (core EL-3-1), which occur at the same altitude.
to prevent water seepage from inner reservoir towards its outer wall. Since the 9th century AD, the bottom sediments of the Eurim Lake at a level of ca. 310.4 m have been repeatedly artificially disturbed either due to the bank construction or by historical repair practices.

**Conclusion**

The sediment layers of the Eurimji reservoir consist of 1) old alluvial (valley-fill) deposits in the lower part (< 307 m a.s.l), 2) pre-1400 yrs BP pre-damming natural lake deposits in the middle part (307–310.4 m), 3) con-construction artificial material (310.4–315 m) and 4) post-damming heavily contaminated and disturbed lake deposits in the upper part (> 315 m). The presented data allowed us to suggest a minor episode of stone bank construction at ca. 2000 yrs BP, i.e. during the late Iron Age. The major stage of the construction obviously took place during the time of the Unified Silla Dynasty, i.e. in the 9th century AD, when ancient people could apply a typical ancient technique of "leave-tree-mud" and "tampered clays" for constructing hydraulic facilities, mainly by vertically extending and successively connecting the valley-fills of the bottom of Eurimji Valley and the piles of artificial boulder stones since the Late Bronze Age, ca 2800 yrs BP.

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