Chronology of alluvial sediment using the date of production of buried refuse: a case study in an ungauged river in central Japan

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Abstract Items of buried refuse bearing the date of manufacture permit determination of the date of deposition of alluvial sediment in the Inukami River, central Japan. Three layers were found in alluvial sediments at 1.6 km and 1.8 km upstream from the river mouth. Dates of manufacture could be read from eight items from the top layer (Layer 2) and eleven from the second (Layer 1). Materials younger than 1990 were found in Layer 2, showing that this layer was deposited in 1990. By the same method, we determined that Layer 1 was deposited in 1987. In contrast, at a site 3.5 km upstream of the river mouth, the period of manufacture could be found only from one piece of refuse (made from 1973 to 1976). The composition of pieces of refuse revealed that the top layer was deposited between 1973 and the early 1980s.

Key words alluvial sediment; buried refuse; chronology; date of manufacture

INTRODUCTION

Flood events deposit varying amounts of sediment on alluvial plains. If the date of deposition of the sediment can be determined, we may be able to estimate the amount of sediment supplied by a particular flood by combining dating with a topographical survey. Estimating the amount of the sediment in an ungauged river basin may help to judge the magnitude of the flood.

For archaeological purposes, many artificial materials buried in sediment have been dated using, for example, radioisotope analysis, tephrachronology, and thermo-luminescence analysis (e.g. Fujimoto, 1985; Herbert *et al.*, 2002), indicating that dated artificial materials can be used for dating sediment. Artificial materials have also been buried in recent deposits. For example, Hirakawa *et al.* (2000) found batteries and beverage cans in sandy high-tide sediment, and suggested that these items can be used for dating the sediment.

In Japan, many PET bottles, cans and food packages are illegally dumped in rivers and on riverbanks, particularly since these containers began to be mass-produced in the late 1980s. For example, the share of one-way bottles and PET bottles increased from 0.1% in 1981 to 33.6% in 1987 (Ueda, 1992). Annual production of canned beverages rose from 8×10^8 in 1970 to 2.5×10^{10} in 1989 (Environment Agency of Japanese Government, 1991). Following this change, aluminium can disposal increased drastically, the Environment Agency of the Japanese Government (1991) finding that on average two cans were dumped into each 1000 m^2 of river channel per day. These waste cans are easily mixed with transported sediment during flood events, and thus become buried in channel and flood plain deposits. In addition, since the date of production is printed on this waste, the time of deposition of sediment can be determined from the date on the buried containers (Kibayashi *et al.*, 2002).

The Inukami River is an ungauged river in central Japan. The gravelly alluvium in the middle to lower reaches of this river has been terraced, and trees are established on the terrace surface. Dating of the terraced sediment was carried out using the dates of production of waste containers buried in the sediment. In addition, flood events during which the terraced sediment was transported were determined by comparison with meteorological data obtained from the nearest weather monitoring station.

STUDY AREA AND METHODS

The 27.1-km long Inukami River flows northwest from the Suzuka Mountains to Biwa Lake, draining an area of 104 km^2. A prominent alluvial fan is formed from 100 to 130 m a.m.s.l., and an alluvial plain exists from 100 to 85 m a.m.s.l. Embankments have been constructed on both banks, and braided channels and meandering channels are developed on the alluvial fan area and the alluvial plain area, respectively. The mean annual precipitation is around 1480 mm, and the mean annual temperature is 15.1°C.

The riverbed in the lower reach of the Inukami River was aggrading until the early 1990s, when it began to be incised following dredging at the river mouth from 1992 to 1993 (Kibayashi *et al.*, 2002). Accordingly, the channel deposits have been terraced in the alluvial plain area. Terraced sediments can also be found in the alluvial fan area.

The chronology of the alluvium was established at two sites (Sites 1 and 2) on the alluvial plain and at one site (Site 3) on the alluvial fan (Fig. 1). At each site, one or two buried organic layers were found. The layer between the surface humus and the upper, buried organic layer is named “Layer 2”, and the layer between the upper and the lower, buried organic layers is named “Layer 1”. Kibayashi *et al.* (2002) excavated the alluvium on the terrace scarp of Site 1 using a handheld sickle to find buried artificial materials. In addition, they surveyed the stratigraphy of the alluvium. Whenever buried containers with dates of manufacture were found, their stratigraphic position and other details were recorded. Since any waste dumped in the river between two flood events would become mixed prior to deposition during the next flood, the youngest artificial material becomes the key indicator of the date of deposition of the sediment. When containers known to have been manufactured for a limited period are found, they can be used to estimate a date of manufacture, even if the date of production is no longer visible. To check, manufacturers were asked for production dates of the various types of container (Kibayashi *et al.*, 2002).

In this study, Kibayashi *et al.*’s (2002) method was used at Sites 1, 2 and 3 to try to determine the time of deposition of Layers 1 and 2 at Sites 1 and 3, and Layer 2 at Site 2.

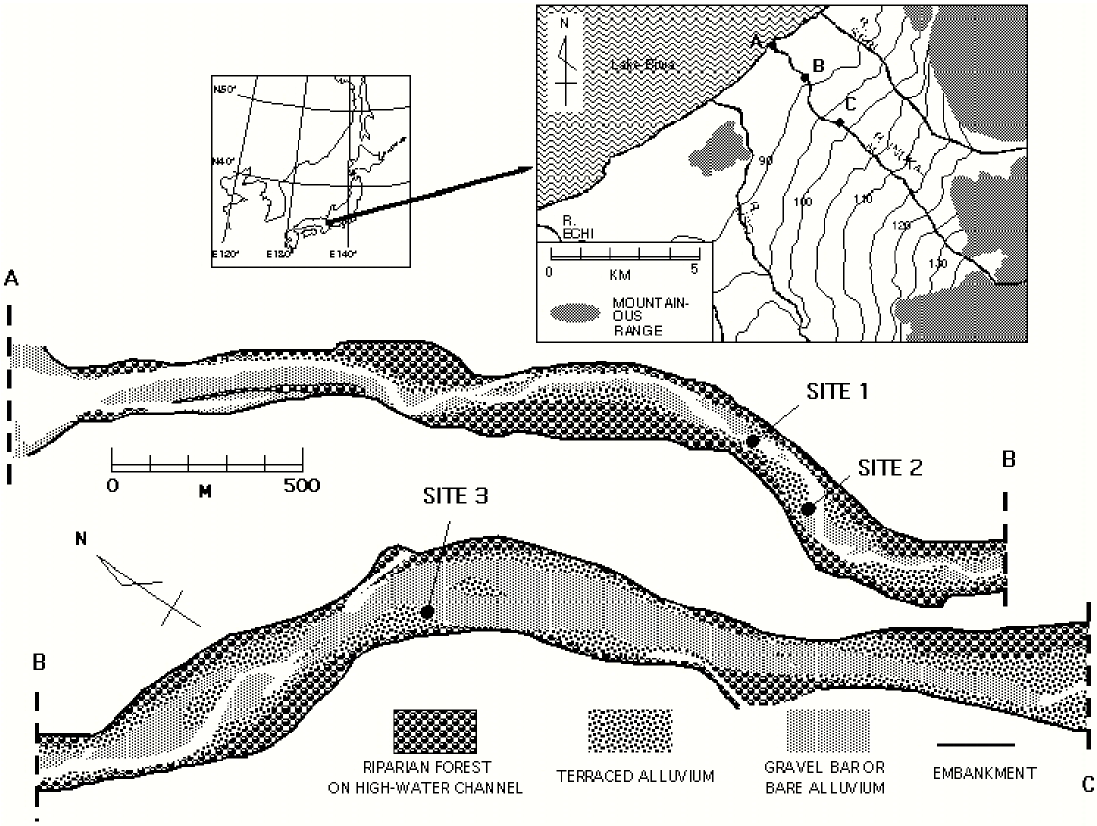

Fig. 1 Map around the Inukami River (top) and the distribution of alluvium between embankments (bottom).

At Site 3, however, dates of manufacture could not be identified on any of the buried containers. The date of deposition of the sediment at Site 3 was thus estimated from various types of buried material. The number of each kind of buried packaging (e.g. food package, pieces of ceramics) was recorded at both Sites 2 and 3.

RESULTS AND DISCUSSION

Determination of time of deposition at Sites 1 and 2

Production dates were found on 13 buried containers at Site 1 and on six buried containers at Site 2 (Table 1). Only two dated items were found in Layer 2 of Site 1, the newest item (a beer bottle) having been made in 1990. This indicates that this layer was deposited during or after 1990. On the other hand, the newest of the six items found in Layer 2 of Site 2 (a sweetmeat package) was made on 13 August 1989, suggesting that this layer was deposited on or after August 1989. In addition, no material made in or after 1991 was found in this layer. Since Site 2 occurs only 250 m upstream of Site 1, Layer 2 was probably formed by the same flood event at both sites. Thus, we could determine that Layer 2 at Sites 1 and 2 was deposited on or after 1990.

From Layer 1 at Site 1, we collected nine buried containers bearing dates of production. For two items (a popsicle package and a chocolate package), the period of

Table 1 List of buried artificial materials whose time of production could be identified.

Site	Layer	Material	Time of production
1	2	Beer bottle*	1990
	1	Beer can*	June 1989
		Soft drink can	1985
		Soft drink can	1985
		Beer can	28 March 1987
		Soft drink can*	18 July 1984
		Potato crisp package*	02 October 1986
		Sweetmeat package*†	02 April 1987
		Chocolate package*	January–February 1986
		Noodle package*	09 November 1984
		Soft drink can*	22 February 1987
		Ice lolly package*†	1987–1990
		Chocolate package*†	1985–1989
2	2	Parts of food package	14 January 1987
		Parts of food package	04 March 1987
		Soft drink can	02 July 1988
		Food package	23 November 1988
		Sweetmeat package	13 August 1989
		Soft drink can†	1975–1989
3	2	Sweetmeat package†	1973–1976

*Data after Kibayashi *et al.* (2002); †Material manufactured in a limited period.

production could be determined. Of the nine items carrying dates of production, the newest was made on 28 March 1987 and none newer than 1988 were found. This indicates that this layer was deposited in 1987. The two other items were also produced in this year, which confirms the date of formation of Layer 1.

Determination of time of deposition at Site 3

No production dates were found on any buried packaging at Site 3. Only one item in Layer 2 (a sweetmeat package) had a clearly defined period of production (from 1973 to 1976, see Table 1). This suggests that Layer 2 at Site 3 was deposited in or after 1973.

In Layers 1 and 2 at Site 3, 22 and 17 items of refuse were found, respectively, (Table 2). Only one food package was found, the other items being mainly construction materials and ceramics. In contrast, many cans, food packages and daily

Table 2 Classification of buried refuse found in each layer at each site.

Site	Layer	Cans	Bottles	Food packages	Daily commodities*	Construction materials†	Ceramics	Other	Total
1	2	4	nf	4	7	7	5	11	38
	1	8	nf	2	9	10	Nf	4	33
2	2	6	2	5	8	10	9	14	54
3	2	nf	nf	1	nf	6	7	3	17
0	1	nf	nf	nf	nf	7	9	6	22

nf, not found; *vinyl, clothes, etc.; †nails, tiles, etc.

commodities were found among buried refuse found at Sites 1 and 2. The variety of buried items at Site 3 was significantly different from that at Sites 1 and 2 (χ^2-test, $p < 0.01$). In contrast, no significant difference was found between the varieties of buried refuse at Sites 1 and 2 (χ^2-test, $0.80 < p < 0.90$).

In Japan, patterns of consumption were dramatically different in the 1980s compared to the 1970s. In particular, the amount of refuse increased markedly after 1989 (Ichihashi, 2000). For example, annual production of aluminium cans in Japan was only 33 million in 1971, compared to 2 billion in 1982 and 8 billion in 1989 (Hino, 1995). Following this change, the numbers of discarded cans in the river drastically increased (Environment Agency of Japanese Government, 1996).

Japanese consumers tend to select newly produced items when they buy foods and drinks at supermarkets and convenience stores. Thus, supermarkets and convenience stores display foods and drinks for only about 65% of their quality guaranteed period (Yahagi, 1994). The guaranteed period of sweetmeat and drinks is up to one year. The discarded foods and drinks were probably bought on the way to the river and were therefore likely to have been consumed at the riverbank within a few months of their production date.

If Layer 2 at Site 3 was formed after the mid-1980s, many items of this date should have been buried in this layer. However, such items were not found, and the variety of buried refuse was significantly different from that in the layers formed after the mid-1980s. Accordingly, Layer 2 at Site 3 was determined as having been formed between 1973 and the early 1980s. Consequently, Layer 1 at Site 3 was considered to have been deposited by a flood before the event that formed Layer 2 of Site 3.

Comparison with dendrochronological results

Kibayashi *et al.* (2002) also determined the time of deposition of Layers 1 and 2 at Site 1 using dendrochronology. The terrace surface was invaded by some *Salix* trees, which only spread on bare soil. In addition, *Salix* seeds sown on bare soil surface have to germinate within 40 days after sowing, otherwise the seeds die (e.g. Ishikawa, 1996). Normally, the terrace surface becomes covered by vegetation within 1 to 2 years after deposition. Thus, the oldest *Salix* tree indicates the time of deposition of the sediment.

Kibayashi *et al.* (2002) tested the age of trees in 2000, and found that the age of *Salix* trees could be classified into three groups: 9 to 10 years, 12 to 13 years and 19 to 20 years. They further investigated the depth of the surface horizon at the time of seedling establishment, and found that the trees with ages of 12 to 13 years and of 9 to 10 years grew on Layers 1 and 2, respectively. This indicates that Layer 1 was deposited around 1987, and Layer 2 around 1990. These dates are consistent with the results from the ages of buried refuse.

Comparison to meteorological data

Table 3 shows rainfall events with total rainfall exceeding 100 mm from 1970 to 2000 at the Hikone Meteorological Station, 2 km north of the Inukami River, and the

Table 3 Rainfall events whose total precipitation exceeded 100 mm and the number of flooded houses during each event.

Year	Date	Total Precipitation (mm)	Cause	Number of flooded houses
1970	14–16 June	162	Front activity	
1971	6–8 July	145	Typhoon	60
	22–27 July	188	Front activity	
	29–31 August	129	Typhoon	
	6–7 September	180	Front activity	
	26 September	105	Typhoon	5
1972	9–13 July	247	Front activity	
	16 September	185	Typhoon	
1974	24–25 July	118	Tropical low	
	25–26 August	147	Typhoon	5
1976	8–13 September	293	Typhoon	
1979	27 June to 2 July	278	Front activity	
1981	8–9 October	126	Temperate low	
1982	1–2 August	157	Typhoon	10
	12 September	101	Typhoon	
1985	21 June to 1 July	347	Typhoon	
1986	21–23 July	123	Front activity	
1987	14–19 July	239	Typhoon	6
1988	2–3 June	113	Front activity	
	8–9 June	141	Front activity	
1990	19–20 September	190	Typhoon	366
1994	16–17 September	154	Front activity	17
	28–29 September	124	Typhoon	
1995	11–15 May	221	Front activity	
	2–6 July	194	Front activity	
1996	27–29 August	195	Front activity	
1997	7–13 July	305	Front activity	
1998	11–13 May	107	Front activity	
	19–23 June	111	Front activity	
	15–18 October	165	Front activity	

number of houses flooded during each event in the northern Shiga Prefecture. The buried items indicated that Layer 2 at Sites 1 and 2 was deposited in 1990. In 1990, only one severe rainfall event was recorded (19–20 September, 190 mm, see Table 3). In addition, 366 houses were flooded, showing that the river water level was extremely high in many rivers in northern Shiga Prefecture. Layer 2 at Sites 1 and 2 was thus determined to have been deposited during the 19 to 20 September 1990 event.

The buried items in Layer 1 at Site 1 showed that this layer was deposited in 1987. In this year, one severe rainfall event occurred from 14 to 19 July (239 mm, see Table 3), and six houses were flooded in northern Shiga Prefecture. In addition, the newest refuse in this layer was produced on 28 March 1987, and was probably discarded a few months later. The time of refuse disposal coincides with the timing of the rainfall event. Layer 1 was thus most likely to have been deposited from 14 to 19 July 1987.

Formation of alluvial terraces

Layer 2 at Sites 1 and 2 was determined to have been deposited from 19 to 20 September 1990. Flood events also have occurred since 1991 (e.g. from 16 to 17 September 1994, see Table 3), but no new deposit was formed above Layer 2. This indicates that terrace formation started after the deposition of Layer 2.

At the river mouth of the Inukami River, 100 000 m^3 of sandy sediment was excavated from 1992 to 1993 for flood control purposes. Due to this excavation, the former delta was lost, and a deep hole was formed at the river mouth (Kibayashi *et al.*, 2002). The consequent drop in base level of the Inukami River initiated vertical incision of the river channel. The terrace formation at Sites 1 and 2 was therefore considered to be caused by the excavation at the river mouth.

In contrast, Layer 2 at Site 3 was determined to have been formed between 1973 and the early 1980s, and no new sediment was found on top of Layer 2. This shows that the sediment supply to Site 3 decreased after the formation of Layer 2. A weir was constructed 10.5 km upstream of the river mouth in 1975 to provide irrigation water for the alluvial fan area. The restriction of sediment supply to Site 3 after the late 1970s is considered to have been caused by the construction of this weir.

CONCLUDING REMARKS AND PERSPECTIVES

Many buried refuse items were found at Sites 1 and 2, and comparison of their dates of production with meteorological data revealed the timing of deposition at the sites. In contrast, only one refuse item was found at Site 3, making it impossible to date that site. Several pieces of buried refuse should be found from any given layer to determine the timing of its deposition.

However, many PET bottles and beverage cans, for example, are now discarded, not only in developed countries but also in developing countries. In developing countries, in many cases these materials are still being discarded rather than recycled. This indicates that many refuse items on which the date of production or the best-before date is printed are thrown into rivers and become mixed with sediment during flood events. This dating method is considered likely to be available and useful in many countries.

Acknowledgements We acknowledge an anonymous referee for helpful comments and kind editorial assistance.

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