LETTER

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Earliest evidence for the use of pottery

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Pottery was a hunter-gatherer innovation that first emerged in East Asia between 20,000 and 12,000 calibrated years before present[1,2] (cal BP), towards the end of the Late Pleistocene epoch, a period of time when humans were adjusting to changing climates and new environments. Ceramic container technologies were one of a range of late glacial adaptations that were pivotal to structuring subsequent cultural trajectories in different regions of the world, but the reasons for their emergence and widespread uptake are poorly understood. The first ceramic containers must have provided prehistoric hunter-gatherers with attractive new strategies for processing and consuming foodstuffs, but virtually nothing is known of how early pots were used. Here we report the chemical analysis of food residues associated with Late Pleistocene pottery, focusing on one of the best-studied prehistoric ceramic sequences in the world, the Japanese Jōmon. We demonstrate that lipids can be recovered reliably from charred surface deposits adhering to pottery dating from about 15,000 to 11,800 cal BP (the Incipient Jōmon period), the oldest pottery so far investigated, and that in most cases these organic compounds are unequivocally derived from processing freshwater and marine organisms. Stable isotope data support the lipid evidence and suggest that most of the 101 charred deposits analysed, from across the major islands of Japan, were derived from high-trophic-level aquatic food. Productive aquatic ecotones were heavily exploited by late glacial foragers[3], perhaps providing an initial impetus for investment in ceramic container technology, and paving the way for further intensification of pottery use by hunter-gatherers in the early Holocene epoch. Now that we have shown that it is possible to analyse organic residues from some of the world's earliest ceramic vessels, the subsequent development of this critical technology can be clarified through further widespread testing of hunter-gatherer pottery from later periods.

On the basis of evidence from East Asia, North Africa, the Americas and Northern Europe, it is now widely accepted that pottery production precedes the emergence of farming and should be considered a hunter-gatherer innovation. From radiocarbon dates of an archaeological sequence excavated at Xianrendong Cave, Jiangxi Province, China, it has been proposed that ceramic container technology extends in age to about 20,000–19,000 cal BP[1], some 10,000 yr before the earliest evidence of rice cultivation in that region. Regional case studies[4,5] have explored the origins, adoption and dispersal of ceramic container technology, dates are being refined and pushed back, and models are emerging that encompass economic, technological, social and environmental factors that both facilitated, and potentially inhibited, pottery innovation in different parts of the world[6]. Yet the actual uses of these early pottery vessels have not been addressed beyond assumed functional roles such as cooking and storage, or speculative associations with available animal and plant resources[7–9].

An understanding of how pottery was used is necessary to elucidate both the social and the economic context for its innovation and also to explain why the technology flourished in some hunter-gatherer groups and not others. Direct evidence of pottery use can be gained through molecular and stable isotope analyses of lipid residues and other organic matter preserved in association with ceramics[10,11]. Although such investigations have been widely conducted on vessels associated with early agricultural or pastoral communities[12,13], the use of earlier hunter-gatherer pottery has been largely ignored or considered only for late forager groups[14,15]. The main challenge limiting systematic investigations of early hunter-gatherer pottery use is the extent to which molecular evidence is preserved after such long-term exposure to the burial environment. The earliest known pottery use in Eurasia gradually developed, probably independently, in Southern China, the Amur River basin (Russian Far East) and Japan at the end of the Late Pleistocene[1,5], necessitating the recovery of organic residues at least 3,000 yr older than has so far been reported[12]. The rarity of the very earliest pottery vessels also limits widespread destructive residue analysis. Here we present an investigation of Late Pleistocene pottery use, focusing on the Japanese ceramic sequence known as the Incipient Jōmon, using small subsamples (~20 mg) of charred deposits adhering to the inside and outside of potsherds. We investigated the carbon and nitrogen stable isotope characteristics of the charred deposits using bulk isotope ratio mass spectrometry (IRMS). Where the sample was large enough, lipids were extracted and analysed by gas chromatography mass spectrometry (GCMS) and GC combustion IRMS (GC-C-IRMS) to determine their structural and carbon isotope characteristics[10,11].

Incipient Jōmon pottery is thought to have been invented in Japan ~16,000 cal BP[2], and became established across the major islands of the Japanese archipelago during the last 4,000 yr of the Late Pleistocene[16]. Much is known about the glacial foragers who developed this pottery. Their sites have been well dated[17] and the pottery sequence has been intensively studied[7]: three major phases of typological development have been identified, each broadly mapping onto different climate phases of the final Pleistocene (Fig. 1). Japanese Late Pleistocene pottery containers were produced in only very small quantities (Fig. 1b) and their estimated volumes were also relatively low. Therefore, pottery may have initially been reserved for specialized subsistence activities or ritual use, rather than being a widespread technology integral to everyday culinary practices. Nevertheless, this long-lived nascent phase, which in some regions endured severe climatic fluctuations, led to an extremely rapid expansion in pottery production in the early Holocene, possibly in response to a warming climate, demographic expansion and intensification of resource exploitation.

Charred surface deposits were sampled from 101 Incipient Jōmon vessels from 13 sites, dating from 15,300–11,200 cal BP (Supplementary Table 1) and encompassing a wide range of different environments across the archipelago (Fig. 1a). Potsherds from different phases (II and III; Fig. 1b) broadly corresponding to the Bølling–Allerød interstadial and the Younger Dryas stadial were included. Variations in vessel shapes are known to exist in this period[7,16] but could not be discerned

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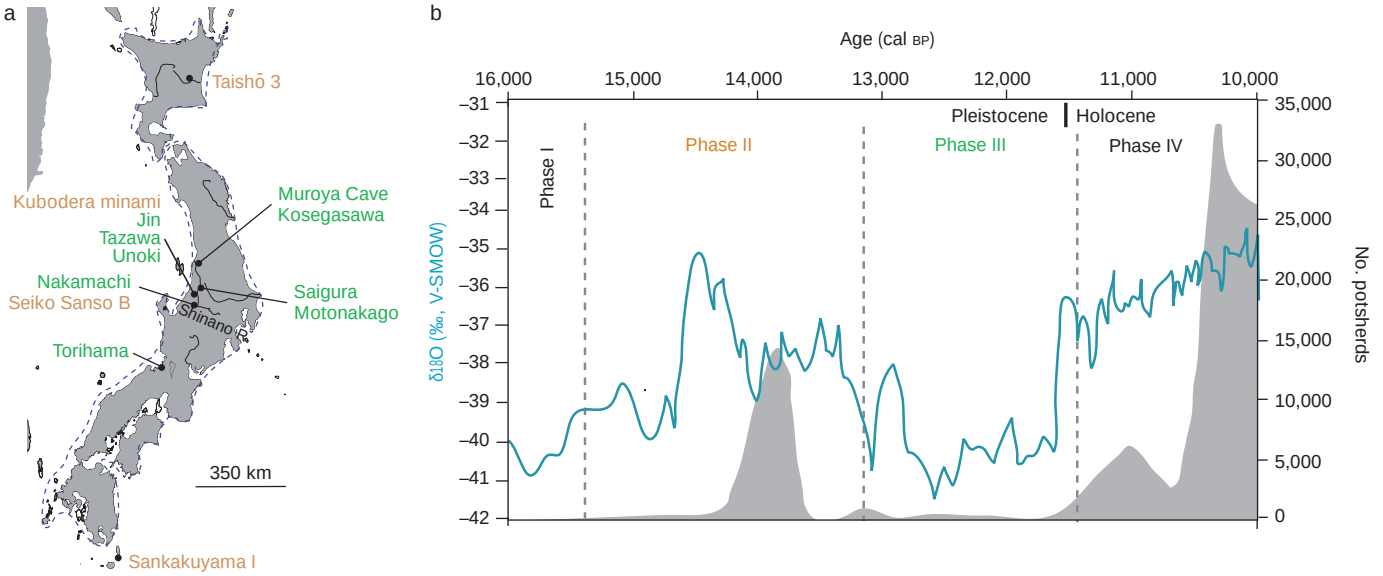

Figure 1 | Locations of sites sampled and temporal changes in early pottery production against Greenland ice-core oxygen isotope record. **a**, Potsherds were selected from assemblages at different sites, dating to chrono-typological phase II, that is, linear-relief wares (orange), and phase III, that is, punctate-marked, nail-impressed and cord-marked wares (green). At Torihama, pottery from both phases was sampled. The coastline corresponding to the Younger Dryas stadial (~65 m below present-day sea level[22]) is shown. **b**, The Greenland Ice Sheet Project 2 ice-core $\delta^{18}O$ values (blue) generally reflect temperature, with lower $\delta^{18}O$ values corresponding to lower temperatures. Potsherd quantities (grey) are as previously reported[7,16], calculated from 52 site reports and chronologically assigned by their typology and by 118 associated ^{14}C dates.

because of the fragmentary nature of the assemblages. Bulk carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratio values obtained from each charred deposit were variable across the whole sample and between individual sites (Fig. 2a). Despite this variability, more than 75% of the samples had $\delta^{15}N$ values greater than 9‰ (median, 10.8‰) consistent with the processing of high-trophic-level aquatic (that is, marine or freshwater) products, as has been observed experimentally (Fig. 2a) and on pottery from different archaeological sites associated with the exploitation of fish and marine mammals[14,18,19]. To confirm this interpretation, lipids were extracted from 57 charred interior deposits and four exterior deposits from Incipient Jōmon vessels and analysed by GCMS (Table 1). Seventeen samples from the Torihama site, Western Honshu, and one from the Taishō 3 site, Hokkaido, produced distinctive lipid profiles typically consisting of medium- and long-chain saturated (C_{14}–C_{24}) and mono-unsaturated ($C_{16:1}$–$C_{22:1}$) fatty acids, isoprenoid fatty acids and long-chain (C_{18}–C_{22}) ω-(o-alkylphenyl) fatty acids (Fig. 3 and Supplementary Table 2). These profiles are typical of degraded aquatic oils, meeting the established criteria for their identification in archaeology[20] and providing compelling evidence that freshwater and/or marine foods were processed in these vessels. Such lipid profiles were not observed in the four exterior surface deposits and are highly unlikely to derive from the depositional

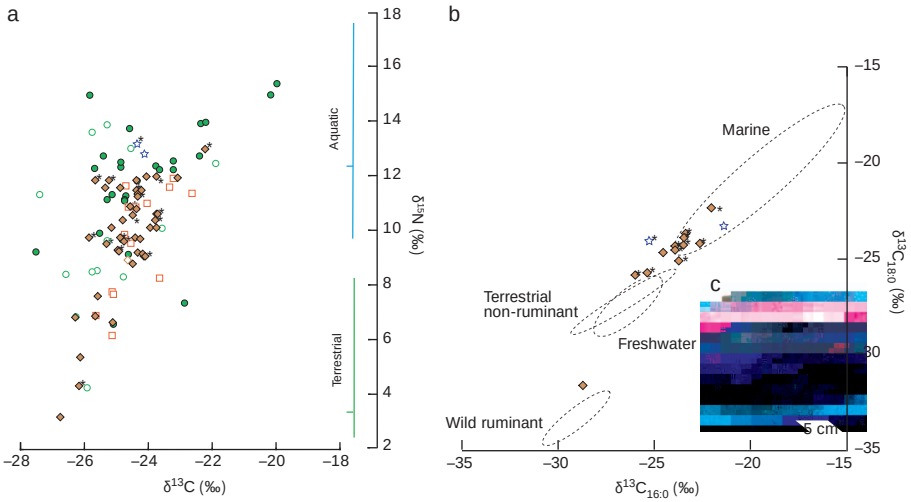

Figure 2 | Bulk carbon and nitrogen stable isotope ratios and fatty acid stable carbon isotope ratios from Incipient Jōmon pottery. **a**, Bulk stable isotope values are discriminated according to site location and period. Torihama, orange diamonds; Shinano river sites, green circles; Sankakuyama I, red squares; Taishō 3, blue stars. Filled symbols indicate phase III and open symbols indicate phase II. The blue and green vertical bars show 95% confidence intervals and the median stable nitrogen isotope value from experimentally charred aquatic (blue, n = 9) and terrestrial (green, n = 8) organisms (Supplementary Table 3). **b**, Plot of the $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ fatty acids from charred deposits on pottery from Torihama and Taishō 3. These are compared with reference fats from wild terrestrial non-ruminant (n = 5), wild ruminant (n = 10), freshwater (n = 9) and marine (n = 17) organisms (Supplementary Table 4). Data are plotted with 68% confidence intervals (using STATISTICA v.7). Samples that produced aquatic biomarkers are marked with asterisks. **c**, Photograph of a reconstructed Incipient Jōmon vessel from Torihama.

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