

Institution: University of Oxford		
Unit of Assessment: 15 - Archaeology		
Title of case study: Improving public understanding of the Lake Suigetsu sediment record		
Period when the underpinning research was undertaken: 2005 – Dec 2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Prof. Christopher Ramsey Dr. Victoria Smith	Professor of Archaeological Science Associate Professor, Senior Research Fellow in Tephrochronology	Since 1998 Since 2009
Dr. Paul Albert	Postdoctoral Researcher; Leverhulme Early Career Fellow	2013-2014; 2015-2019
Period when the claimed impact occurred: 1 August 2013 to 31 Dec 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact (indicative maximum 100 words)		
<p>Since 2005, researchers in the School of Archaeology, University of Oxford, have examined the sediment record from Lake Suigetsu, Japan in collaboration with researchers in Japan. They have used physical samples to produce data allowing radiocarbon measurements to be converted to calendar dates more accurately (now a global standard for establishing geological time scales worldwide), and have also more clearly defined the magnitude and tempo of large volcanic eruptions in the area. Portions of the core spanning the last 50,000 years are exhibited in a new purpose-built permanent museum, the Fukui Prefectural Varve Museum, established to showcase the novel University of Oxford-generated research that informs visitors on radiocarbon dating and environmental history, and volcanic eruptions. The creation of the museum boosted tourism to the area and public understanding of the science, and enhanced the local economy, creating more than 17 local jobs. Aspects of the research were included as case studies in high school textbooks used by Japanese children nationally.</p>		
2. Underpinning research (indicative maximum 500 words)		
<p>The University of Oxford's involvement in the Lake Suigetsu project started in 2005. Professor Takeshi Nakagawa (Kyushu University) approached Prof. Christopher Bronk Ramsey to propose that they generate a radiocarbon calibration dataset using radiocarbon measurements of plant material and counting annual layers (varves) preserved in the Lake Suigetsu sediments. The abundance of plant remains and the well-preserved nature of the varves, associated with seasonal inputs into the lake, make this record unique. It is ideal for generating a calibration dataset that extends to the radiocarbon dating limit (approximately 50,000 years). To ensure a continuous sequence was obtained, which was essential for this dating research, the lake was carefully cored from 4 parallel boreholes using NERC funding in 2006. The composite sediment sequence extends to 76m and spans approximately 150,000 years. The extracted cores are unique: the only other direct (terrestrial) record of atmospheric carbon comes from tree rings, but this only goes back to 12,593 years ago. At the time, the Lake Suigetsu record increased the direct radiocarbon record by more than 40,000 years (with subsequent developments and verifications undertaken by others more recently). The new information provided from the Lake Suigetsu record has led to comparisons with the Greenwich Prime Meridian, in the way it serves as a worldwide benchmark for geological time.</p> <p>Prof. Christopher Bronk Ramsey has led the radiocarbon research on Lake Suigetsu, and his team performed more than 600 radiocarbon measurements of organic material from the sediment cores. He then combined these data with varve counts to produce an independent chronology. This research was published in the journal <i>Science</i> in 2012 (R1), and he helped to integrate this new dataset into the internationally accepted calibration dataset that was published in 2013 (IntCal13). The IntCal13 dataset (R2) is used to convert radiocarbon measurements into calendar ages, and is invaluable to all studies that use chronology such</p>		

Impact case study (REF3)

as archaeology, geography and earth science. IntCal13 has been cited over 9,700 times since it was published.

The research into the volcanic ash (tephra) layers preserved within the sediment cores has advanced understanding on the timing and dispersal of large eruptions from volcanoes in Japan and the surrounding region. This research commenced in late 2009 when Associate Professor Victoria Smith joined the Lake Suigetsu Project. Smith leads the Oxford Tephrochronology Group (including Dr Paul Albert), who have established the glass chemical fingerprints of tephra layers within the Lake Suigetsu sediment record and carried out extensive sampling around volcanoes across Japan to obtain comparable data of particular eruptions for robust correlations (**R3**, **R4**, **R5**, **R6**). Although there are 30 visible ash layers (more than 1mm thick), the tephra record was significantly extended by applying density separation techniques to identify non-visible ash layers within the sediments (**R4**). The sections that have been studied reveal that only a quarter of the tephra layers are visible (**R4**). The Oxford Tephrochronology Group have correlated almost all the tephra layers to known eruptions and refined the dispersal of the events. They have also used the Suigetsu chronology to constrain significantly the tempo (i.e. the variations in frequency) of more than 70 individual eruptions that deposited tephra in Lake Suigetsu (**R3**, **R4**, **R5**, **R6**). The tephra layers are also key to correlating the Lake Suigetsu record to others across East Asia: the glass chemical fingerprints of the tephra layers now allow the unrivalled chronology to be imported into other archives that contain the same tephra, and the synchrony of climate change can be investigated.

3. References to the research (*indicative maximum of six references*)

- R1. Bronk Ramsey, C.**, Staff, R. A., Bryant, et al. (2012). 'A Complete Terrestrial Radiocarbon Record for 11.2 to 52.8 kyr B.P.' *Science*, 338(6105), 370–374. <http://doi.org/10.1126/science.1226660> [output type: D]
- R2. Reimer, P.J.**, Bard, E., Bayliss, A., Beck, W., Blackwell, P.G., **Bronk Ramsey, C.**, et al (2013) IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. *Radiocarbon* 55:1869–1887. https://doi.org/10.2458/azu_js_rc.55.16947 [output type: D]
- R3. Smith, V. C.**, Staff, R. A., Blockley, S. P. E., **Ramsey, C. B.**, Nakagawa, T., et al. (2013). 'Identification and correlation of visible tephra layers in the Lake Suigetsu SG06 sedimentary archive, Japan: chronostratigraphic markers for synchronising of east Asian/west Pacific palaeoclimatic records across the last 150 ka.' *Quaternary Science Reviews*, 67(C), 121–137. <https://doi.org/10.1016/j.quascirev.2013.01.026> [output type: D]
- R4. McLean, D.**, **Albert, P.G.**, Nakagawa, T., Suzuki, T., Staff, R.A., Yamada, K., Kitaba, I., Haraguchi, T., Kitagawa, J., SG14 Project Members, **Smith, V.C.** (2018) 'Integrating the Holocene tephrostratigraphy for East Asia using a high-resolution cryptotephra study from Lake Suigetsu (SG14 core), central Japan.' *Quaternary Science Reviews*, 183, 36–58. <https://doi.org/10.1016/j.quascirev.2017.12.013> [output type: D]
- R5. Albert, P. G.**, **Smith, V.C.**, Suzuki, T., et al (2018). Constraints on the frequency and dispersal of explosive eruptions at Sambe and Daisen volcanoes (South-West Japan Arc) from the distal Lake Suigetsu record (SG06 core). *Earth-Science Reviews*, 185, 1004–1028. <https://doi.org/10.1016/j.earscirev.2018.07.003> [output type: D]
- R6. Albert, P. G.**, **Smith, V.C.**, Suzuki, T., et al (2019) 'Geochemical characterisation of the widespread Japanese tephrostratigraphic markers and correlations to the Lake Suigetsu sedimentary archive (SG06 core).' *Quaternary Geochronology*. <https://doi.org/10.1016/j.quageo.2019.01.005> [output type: D]

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4. Details of the impact (*indicative maximum 750 words*)

Context and providing the centrepiece of the Fukui Prefecture Varve Museum

The early research which contributed to the radiocarbon dating achievements in **R1** and **R2**, had been the subject of substantial media coverage worldwide (and heavily in Japan) in late 2012. The significance of the Lake Suigetsu research (and worldwide reaction to it) reached the governor of the Fukui Prefecture. In 2013 he approached Prof. Takeshi Nakagawa to discuss a museum centred on the research from Lake Suigetsu for education that would increase tourism to the region (**E1**). Nakagawa confirms this interest was because the governor saw potential to “*generate tourism and public education based on the varve study and radiocarbon calibration*”. (**E1**) In order to **provide the key physical display material** for the museum, Lake Suigetsu was cored again in 2014. Further demonstrating the centrality of the Oxford research as central to the **creation of the museum**, this was led by the Oxford Tephrochronology Group (Smith, Albert, and doctoral student D. McLean), who spent two months in Japan to recover sediment from another 4 boreholes that extended right through the sediment pile (approximately 90m). This 2014 core would also be used for research in its own right, providing a basis for some of Smith & the Tephrochronology Group’s later research (e.g. **R4**, **R5**, **R6**).

Prof Nakagawa (who is also the Research Manager of the Fukui Prefectural Varve Museum and Head of the Research Centre for Palaeoclimatology, Ritsumeikan University - the official alliance partner of the Fukui Prefecture) outlines the pivotal role of the Oxford research across the themes and displays of the museum: ‘*The Varve Museum has two main themes: (i) radiocarbon calibration and (ii) environmental history. The first theme is almost entirely based on the outcomes from the work package led by Oxford [e.g. R1, R2]. The second theme has two subtopics: climate change and volcanic eruptions, and the latter is also (almost exclusively) featuring research [sic] (e.g. R3, R4, R5) by Oxford team led by Dr. Victoria Smith*’ [e.g. **R3**, **R4**, **R5**] (**E1**). The 2014 core provided the visual centrepiece for museum visitors: thin samples of the core sections of the composite sequence are displayed, extending 46m across the museum. This means visitors can see the ‘varve’ and volcanic ash layers for themselves as an aid to their understanding (see photographs **E2**, also museum website, **E3**, tourism promotional video **E4a**, and in the Museum curator’s testimony, **E5**).

Improving tourism, public understanding of varves, and the local economy through the Fukui Prefectural Varve Museum

The Fukui Prefectural Varve Museum (or ‘Varve Museum’) opened in September 2018. The total project investment in the development or construction of the museum was JP¥1,480,000,000 or GBP10,800,000. The museum, which was purpose-built to highlight the research on the Lake Suigetsu sediments, has increased understanding of radiocarbon dating, volcanic hazards and climate-related issues amongst a wide range of Japanese audiences, including museum visitors and school children, as well as generating further scientific interest. The curator of the Varve Museum reports that despite its relatively recent establishment, “*the lake is being regarded by Fukui citizens as a ‘Treasure of Fuku’*” (**E5**).

The museum has led to a range of benefits for the Fukui region and further afield, and the Curator of the museum underscores how the museum would not be possible without contribution of the Oxford team: “*since... the achievement of the international research team with Oxford University... the Lake Suigetsu varves have become of interest not only [to] researchers but also of general public and policy makers. The Suigetsu varves are now far beyond the scope of one study and play an important role in the culture, education, tourism and economy of the local community and beyond.*” (**E5**)

In its first months of opening, the museum was attracting around 5,000 people per month. In August 2020, nearly 100,000 people had visited the museum since it opened two years ago (**E5**). The curator of the Varve Museum confirms that as a new attraction, it has brought in more visitors to the rural area, and that other museums are reporting significantly higher museum visitors which are attributable to the creation of the new museum: “*Wakasa Municipal Archaeological Museum (or ‘Jomon Museum’ in common) [is] just in front of the Varve Museum. Since the opening of the Varve Museum, the number of visitors to the*

Jomon Museum increased by 243%, resulting in an increase in admission revenue. Similar effect can be observed everywhere in the region” (E5). In a graph provided, this equates to a change in visitor numbers at the Jomon Museum from 15,315 in Sept 2017 to 37,328 in Sept 2018 (E5).

Further information from or about the visitors demonstrates evidence of **increases in understanding of** the significance of the Lake Suigetsu varves and research processes, and the **enjoyment of the new cultural provision**. In addition to the physical core, content deriving from Oxford-led research in the interpretation of these varve layers is included in more than 75% of the museum’s displays. The letter from the museum’s curator (E5) outlines with photos where these contributions are particularly apparent (i.e. the introductory board which name-checks Smith, Bronk-Ramsey and former doctoral student Richard Staff; other boards highlight sections on “27 volcanic ashes identified by the Oxford University research team” (i.e. relating to R3, R4 and R5) and a panel called ‘Radiocarbon’ [which] is exhibited as a monumental research result that was a decisive trigger for Fukui Prefecture to decide to build the Varve Museum” (i.e., R1, R2, R3).

The visitors to the Varve Museum are almost all Japanese, and more than 4,000 children have visited in school groups. Of the museum visitors polled (3,500 people), more than 90% are satisfied to very satisfied with what is presented, and more than **80% have a better understanding of the natural world (E5)**. Several Japanese residents have written blog entries describing their respective museum visits, often outlining in significant detail the explanation of varves, and their significance (as well as the contribution of the Oxford team). One blog by a German-Japanese couple (designed to promote business links between the two countries) has an in-depth piece based on a visit to the museum, that highlights how: “*it took four years for a scientist from the University of Oxford to... analyse the fossil leaves, pollen and plankton using the radiocarbon method C14.*” (E6b). There is also further evidence of how the Museum has helped Fukui residents to reflect on the value of their local archaeology, and its importance worldwide. One local relates: “*there were 30-50 people in the museum, and we saw real varves. I learned that the varves of Lake Suigetsu were found in 1991, and more than 30 researchers from Japan, the Netherlands, England, and Germany have been researching these varves for about 30 years. I think that Lake Suigetsu and the varves are a treasure of the world*”. (E6a).

In addition to the static displays, there are a number of interactive media displays and others showing short videos. Additional information on past climate and eruption events can be accessed by scanning Quick Response (QR) codes (E7) shown on the displays using a smart phone, and these pages have been accessed via the QR codes more than 70,000 times in the last two years (E7). The Museum, and QR codes have been showcased in tourism promotional materials developed by the ‘Experience Fukui’ campaign, run by the Prefecture, both in print and video; the information accessible via the QR codes is particularly highlighted in the latter (E4a).

The museum has generated important local economic benefits: **at least 17 jobs have been created as a result of the museum**. These positions include museum guides and cleaners and have been filled by locals. The museum also created **new business opportunities for locals**; one runs the coffee shop in the museum and 14 other businesses make and sell Lake Suigetsu-related merchandise, for example ‘varve layer-cakes’ (E5). The Varve Museum is named in the Fukui Prefecture’s 2020-2040 Strategy for the region (‘Let’s create Fukui’s future together’), as part of discussions around developing the Museum into a ‘global varve research centre’ (E8, p.57) and as part of an ongoing commitment to support tourist facilities that support local history and nature (E8, p.247), as part of wider regional development.

Learning and language: Shaping educational content for Japanese schools and museum visitors; changes to the Japanese dictionary

The earlier media interest also prompted Japanese educators to write textbooks for Japanese junior high (ages 12-15) and high school (ages 15-17) students (E5). As a

Japanese citizen and as a key outreach presenter of the research, Prof. Nakagawa confirms that aspects of the Lake Suigetsu research conducted at the University of Oxford were included in case studies in various school textbooks that have been published since 2015, “...including science (radiocarbon and age determination), mathematics ([radiocarbon] decay as an example of an exponential function) and history (prehistoric timescale).” They continue: “I think it is fair to say that, today in Japan, it is not even possible for school pupils (there are about 1.1 million of them every year) to grow without learning about Lake Suigetsu and the research outcomes generated by the collaboration with Oxford” (E1). Sample pages from these textbooks can be seen in E9, and the contribution of the research to the textbooks is also confirmed by the museum curator, who outlines that it can be particularly seen in sections on ‘varves as a measure of geological time’ (Science), ‘role of varves in archaeological studies’ (History) and ‘Varves and radiocarbon dating’ (Geology/History) (E5).

The Varve Museum itself has carried out an extensive educational outreach programme for school pupils. The museum curator reports figures for numbers of individuals visiting as part of formal educational visits – a total of 4,626 between 2018 and 2020, with the biggest audiences being middle school pupils (2,712), followed by primary school pupils (1,321). High school students have more commonly attended special summer schools put on by the museum, with 165 pupils attending sessions which are supported by locally-based Suigetsu researchers (E5). The museum is also supporting continued professional development for teachers: Prof. Nakagawa (as research outreach lead) led 2 training days for the education supervisors of Fukui Prefecture in summer 2020: “The aim is to spread the value and the significance of the varve studies from the supervisor to teachers at each school and from teachers to students” (E5). The Oxford team have continued to support these initiatives in person when possible, and Victoria Smith and Christopher Bronk Ramsey gave public lectures at the Museum in 2017 and 2019 (presented published research; R1-R4), respectively (E5 and E10). E5 confirms that 300 Fukui residents attended the 2019 talk.

The Suigetsu research has even resulted in a word being added to the Japanese language. The Varve Museum curator said: “in 2018 the word ‘nenkou’ which is the Japanese word to mean varves, was added into the 7th edition of the most common dictionary for Japanese vocabulary called ‘Kojien’. That means varve officially became Japanese word for common use [sic]” (E1).

5. Sources to corroborate the impact (indicative maximum of ten references)

- E1) Letter (August 2020) from Research Manager of the Fukui Prefectural Varve Museum and Head of the Research Centre for Palaeoclimatology, Ritsumeikan University (the official alliance partner of the Fukui Prefecture) [in English]
- E2) Photos (taken in 2018 and 2019) of the Fukui Prefectural Varve Museum displays
- E3) The Varve Museum website [in Japanese, with some limited English pages] <http://varve-museum.pref.fukui.lg.jp/en/>
- E4a) Experience Fukui promotional video https://www.youtube.com/watch?v=c_SwCFA-Jc&feature=youtu.be [in English]
- E4b) Varve Museum promotional leaflet, Fukui Prefecture [in Japanese]
- E5) Letter (August 2020) by Curator of the Fukui Prefectural Varve Museum [in English]
- E6) Visitor Blogs:
- 6a: <https://taru-fukui-album.com/the-miracle-lake-in-fukui-prefecture-japan/> [in English, by Japanese author]
 - 6b: <https://shoganai.com/varve-museum/> [in German]
- E7) Examples of the QR codes, plus Google Analytics webpage data for QR codes and photos from museum displays (2018 and 2019)
- E8) Fukui Prefecture 2020-2040 Strategy [in Japanese]
- E9) Sample pages from books and school textbooks (2015 onwards) [in Japanese, physical copies available upon request]
- E10) Photos of public lectures by Associate Professor Victoria Smith and Professor Christopher Bronk Ramsey (February 2019).