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Depositional evidence for the Kamikaze typhoons and links to changes in typhoon climatology

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ABSTRACT

In the late 13th century, Kublai Khan, ruler of the Mongol Empire, launched one of the world's largest armadas of its time in an attempt to conquer Japan. Early narratives described the decimation and dispersal of these fleets by the "Kamikaze" of 1274 CE and 1281 CE, a pair of intense typhoons "divinely" sent to protect Japan from invasion. These historical accounts are prone to exaggeration, and significant questions remain regarding the occurrence and true intensity of these legendary typhoons. To provide independent insight, we present a new 2000 yr sedimentary reconstruction of extreme coastal flooding from a coastal lake near the location of the Mongol invasions. Two marine-sourced flood deposits date to the Kamikaze typhoons and are the events of record in the reconstruction. The complete reconstruction indicates periods of greater flood activity relative to modern beginning ca. 250 CE and extending past the timing of the Kamikaze events to 1600 CE. Comparisons with additional reconstructions are consistent with greater regional typhoon activity during the Mongol invasions due to the preferential steering of storms toward Japan, and driven by greater El Niño activity relative to modern. Results are consistent with the paired Kamikaze typhoons being of significant intensity, and support accounts of them playing an important role in preventing the conquering of Japan by Mongol fleets. The Kamikaze typhoons may therefore serve as a prominent example for how past increases in severe weather associated with changing climate have had significant geopolitical impacts.

INTRODUCTION

In 1274 and 1281 CE, Kublai Khan, the grandson of Genghis Khan, launched two maritime attacks on the mainland of Kyushu, Japan. These fleets were immense; the second of the invasions may have involved as many as 1500–4400 vessels and 160,000–200,000 soldiers and sailors (Rossabi, 1988; Sasaki, 2008; Uda, 2003). Legend states that despite being significantly outnumbered during both invasions, Japanese defenses were saved both times by the fortuitous destruction of Mongol fleets by intense typhoons, in November 1274 CE and August 1281 CE. These two typhoons are common citations in early Japanese history, later described as Kamikaze ("divine winds"), due to the perception that they were sent from the gods to ensure Japanese sovereignty. Hundreds of years later, excavation of wreckage from the larger 1281 CE Mongol fleet in Imari Bay (Kyushu, Japan) provided the first modern documentation of the event (Fig. 1; see also Kimura et al., 2014). There has been growing doubt, however, regarding the occurrence and documented severity of the Kamikaze typhoons (Turnbull, 2010). This is in part because of inconsistencies with modern typhoon climatology. First, currently typhoons rarely occur in late November, when the first of the Kamikaze typhoons is thought to have made landfall (Uda, 2003). Second, there is a relatively low probability for two major typhoons impacting the site of the Mongol invasions in such close succession today; only one category 2 event (Typhoon Pat in 1985 CE) has occurred, and no major typhoons of category 3 or greater intensity have passed within 90 km of Imari Bay since the onset of the best track data set in 1945 CE (Fig. 1; Chu et al., 2002).

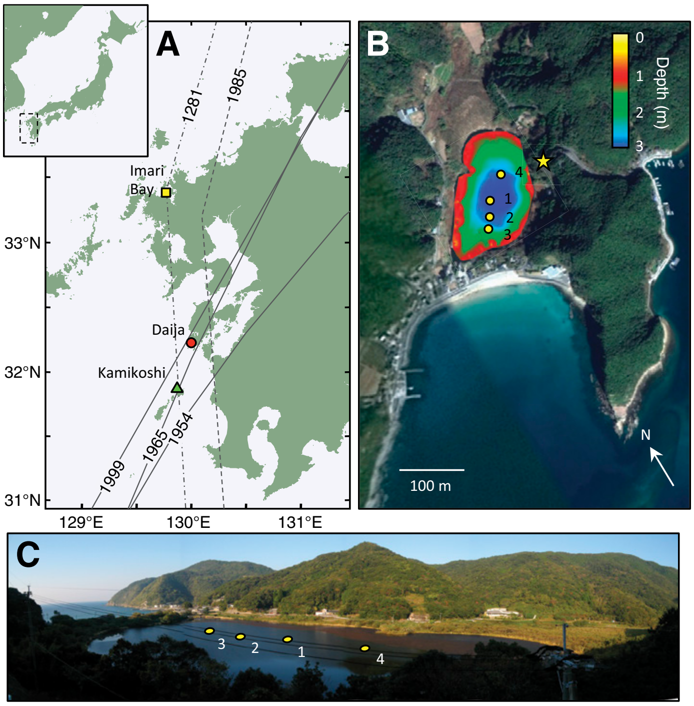

Figure 1. A: Map of the western North Pacific showing study area with locations of Lake Daija (circle), Kamikoshiki (triangle), and site of Mongol wreckage in Imari Bay (square), Japan. Paths of best track category 3 and greater typhoons passing within 90 km of Lake Daija (solid lines) and the most intense best track typhoon to impact Imari Bay (a weak category 2 typhoon in 1985 CE, dashed line) are noted. Path of the 1281 CE typhoon (dot-dash) is based on Turnbull (2010), and has been extended south of Imari Bay with a trajectory similar to that of the 1985 CE typhoon. B: Satellite image of Lake Daija with superimposed bathymetry and core locations (circles). Star indicates location where photo in C was taken. C: Photo of Lake Daija with position of cores. Core positions in sequential order from 1 to 4 are 32.2475°N, 129.98601°E; 32.2472 °N, 129.98576°E; 32.24699°N, 129.98557°E; and 32.24792°N, 129.98666°E.

Event deposits preserved within the sediments from coastal lakes and ponds contain preserved evidence of past periods of extreme coastal flooding, and the means for independently assessing typhoon activity during the Mongol epoch. An analysis of sediments collected from a coastal lagoon on the island of Kamikoshiki, located 160 km south of the Imari Bay (Fig. 1), indicates that the Kamikaze events occurred during a period of more frequent marine-sourced deposition to the lagoon, suggesting that typhoon activity may have been greater during the time of the invasions (Woodruff et al., 2009). However, the Kamikoshiki reconstruction could not distinguish between individual event layers, and it was concluded that additional sites of higher resolvability were required to assess whether observed changes in overwash frequency represented local modifications to barrier morphology or, alternatively, more widespread changes in regional typhoon activity. Motivated by these initial Kamikoshiki results, we present here a new, more highly resolved and comparative record of

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typhoon overwash from an additional back-barrier lagoon located closer to the site of the Mongol wreckage.

SITE DESCRIPTION

Lake Daija is a small back-barrier lagoon situated at the southern end of Amakusa Island, strategically situated between the site of the Mongol invasions and Kamikoshiki (Fig. 1). The lake is located on the more tectonically stable southwestern side of Kyushu, with few active faults and little evidence of any significant tsunami events occurring over the historical period (Woodruff et al., 2009). In contrast, Lake Daija is often impacted by typhoons; the name of the lake translates to "serpent," after two large mythical snakes thought to have caused frequent cyclone strikes to the site. A recent typhoon of note to make landfall near Lake Daija is Typhoon Pat, in 1985 CE, which made landfall ~25 km to the east of Daija at category 2 strength, and later impacted Imari Bay at a similar category 2 intensity (Fig. 1). In addition, within the best track data set, the lake has received three typhoon strikes of category 3 or greater intensity at landfall (Fig. 1): Typhoon Grace in 1954 CE (category 3), Typhoon Jean in 1965 CE (strong category 4 intensity), and Typhoon Bart 1999 CE (category 3).

Lake Daija is separated from the sea by a 300-m-long, 2–3-m-high barrier beach that is secured in place at either end by steep, rocky headlands. Relative sea level has remained fairly stable at the site over the past few millennia; prior works indicate <1.0 m of gradual sea-level rise over the past 6000 yr (Nakada et al., 1991; Yokoyama et al., 1996; Woodruff et al., 2009). In general, the site's geometry and limited sea-level rise over the past few millennia support relatively stable barrier systems (Woodruff et al., 2013a), with barrier heights that are assumed to be roughly fixed relative to regional sea level. Until recently, Lake Daija has been devoid of any significant barrier fortifications. However, following impacts from Typhoon Jean in 1965 CE, a >3-m-high seawall and tetrapod armament were constructed along the barrier that now shelter the lake from significant overwash.

METHODS

Coring locations in Lake Daija were initially targeted with a 200 MHz ground penetrating radar survey of subbottom stratigraphy and bathymetry (Fig. 1B). Based on these surveys, a shore-normal transect of cores was collected using a modified Vohnout-Colinvaux piston corer using methods similar to those in Woodruff et al. (2009, 2013b). Following collection, all cores were immediately shipped to the University of Massachusetts (Amherst, USA), where they were split, described, and stored under 4 °C refrigeration. Prior to sampling, X-ray radiographs and 200-μm-resolution depth profiles of elemental abundances were obtained on working core halves with a nondestructive ITRAX X-ray fluorescence (XRF) core scanner (Croudace et al., 2006). All cores were scanned at the University of Massachusetts using a molybdenum (Mo) target tube operating at 30 kV and 55 mA with a 10s exposure time. Discrete surface samples collected from the site's barrier beach and small freshwater tributary (watershed of ~0.5 km^2) were also run through the XRF to assess the defining characteristics of these two separate sources of allochthonous sediment to the lake. Percent organics were determined on cores through loss on ignition using a combustion temperature of 550 °C (Dean, 1974), at a downcore continuous sampling resolution of 1 cm. Modern age constrains for the 1954 CE onset and 1963 CE peak in bomb-related ^{137}Cs were obtained using a Canberra GL2020R low-energy germanium detector (Pennington et al., 1973). Age constraints prior to 1950 CE were based on ^{14}C activities of small terrestrial macrofossils subsampled from core halves (leaves and seeds). Derived radiocarbon ages and 1σ uncertainties were converted to calendar age probabilities using the IntCal13 radiocarbon calibration curve (Reimer et al., 2013), with methods similar to those of Haslett and Parnell (2008) and Parnell et al. (2008) employed to derive Bayesian age probability distributions at depths between chronological controls, following the techniques described by Brandon et al. (2015).

RESULTS

At the primary core site, Core 2, sediments extend to a depth of 5.5 m, and reveal the steady accumulation of lagoonal mud dating back over 2000 yr (Fig. 2). A rapid drop in density and a concomitant drop in inorganics and marine-sourced strontium (Sr) abundance are observed above a depth of 43 cm (Figs. 2B and 2C), likely marking the fortification of the Daija barrier following Typhoon Jean in 1965 CE. Sr counts in sediments collected from the Daija barrier beach are more than 10× greater than that measured on fluvial samples collected from the site's small freshwater catchment (Fig. 2E). The drop in Sr beginning above 43 cm is therefore consistent with a decrease in marine-sourced material to the pond due to barrier fortification. No event layers were observed within sediments following the timing of seawall construction after Typhoon Jean in 1965 CE, consistent with this fortification reducing the sensitivity of the system to overwash in recent decades.

The most recent event layer in Lake Daija is observed just below the late 1960s CE horizon marking barrier fortification and just above the 1963 CE peak in bomb-related ^{137}Cs (Fig. DR1 in the GSA Data Repository[1]). This deposit is detectable as a dense layer in core X-ray radiographs (Fig. DR1), as well as an anomalous peak in both percent inorganics and Sr abundance (Figs. 2B and 2C). The timing of the deposit is consistent with Typhoon Jean in 1965 CE, with high Sr and inorganic levels marking the deposit's enrichment in clastic, marine-sourced material derived from the barrier. An additional event layer with similar sedimentary characteristic is observed just below the ca. 1954 CE onset of bomb-related

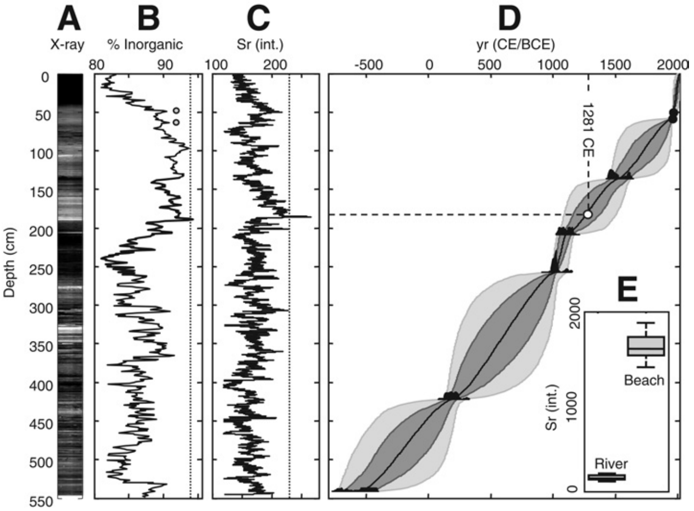

Figure 2. Depth profiles for Core 2 (see Fig. 1 for location). A: Core X-ray radiograph with dense layers represented by light bands. B: Depth profile of percent inorganic. Circles identify deposits dating to typhoons impacting the site in 1954 CE and 1965 CE (Fig. 1A). C: Depth profile of Sr. Results for Sr are expressed as the area integral (int.) of the elements' characteristic X-ray fluorescence (XRF) peak present in the spectrum. D: Bayesian-derived age model with median and 1σ and 2σ uncertainties, along with age constraints for ^{137}Cs (circles) and radiocarbon (black probability curves). The timing for the 1281 CE typhoon is noted along with the assumed depth based on the median age. A more detailed plot of the two modern deposits is presented in Figure DR1 (see footnote 1). E: Sr XRF counts for discrete barrier beach and fluvial samples.

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[1] GSA Data Repository item 2015040, detailing depositional evidence for Typhoons Grace and Jean in Core DAJ2 (Fig. DR1), the multi-proxy criterion for identifying event layers in DAJ2 (Fig. DR2), an alternative automated technique for identifying event deposits (Fig. DR3), and a comparison between the multi-proxy and automated techniques (Fig. DR4), is available online at www.geosociety.org/pubs/ft2015.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

^{137}Cs (Figs. 2B and 2C; Fig. DR1), and can be attributed to the landfall of Typhoon Grace in 1954 CE.

Based on the characteristics of modern deposits associated with Typhoons Grace and Jean, we define older event deposits at the site as anomalously dense layers in the X-ray radiograph with accompanying peaks in Sr and inorganic content. The most prominent peaks in inorganics and Sr abundance in the Daija record are associated with two closely spaced deposits at a depth between 185 cm and 189 cm (Fig. 2). A comparison of X-ray radiography for the transect of cores collected from the site reveals that these event layers begin near the barrier as two closely spaced deposits that thin to one deposit in the more landward cores (Fig. 3). Bayesian statistics based on obtained radiocarbon ages above and below this pair of event deposits provide a median age in the late 13th century for the depth of these deposits (Fig. 2D).

Figure 4A presents a time series of overwash frequency from Core 2 defined by peaks in X-ray density, Sr abundance, and inorganic content, and with depths converted to age using the median age line presented in Figure 2D (see Fig. DR2 for methodology). The time series reveal trends similar to the lower resolution record obtained from Kamikoshiki (Fig. 4B). More specifically, the Daija record begins with a rise in the frequency of intense typhoon occurrences ca. 250 CE and ends with a more quiescent period from ca. 1600 CE through the present day. Several short-term maxima exist in typhoon frequency for the active interval between 250 CE and 1600 CE in Lake Daija; the final of these peaks is centered near the timing of the Mongol invasions (Fig. 4A).

DISCUSSION

Radiocarbon uncertainties prevent an exact matching of the two most prominent deposits in Daija to the1274 CE and 1281 CE Kamikaze typhoons. However, our results indicate that it is highly probable that two intense overwash events occurred in the region during the late 13th century. It is impossible to unequivocally delineate between typhoons and tsunamis as a cause of these late 13th century deposits. However, early historical records for the region contain documentation for two significant typhoon events without reference to any significant tsunami occurrences (Woodruff et al., 2009). Based on this supporting information, we find it highly probable that the late 13th century deposits at Lake Daija are associated with the Kamikaze typhoons. Furthermore, only category 3 or greater events within the best track data set have resulted in preserved event deposits at the site. While a wide variety of storm conditions can result in the same level of flooding at a particular location, storm intensity is in most cases a leading control on flood magnitude (Brandon et al., 2013). Therefore, on the basis of Daija's modern analogue, we estimate the Kamikaze typhoons being of significant intensity (probably category 3 or greater) during their passage of the Daija site.

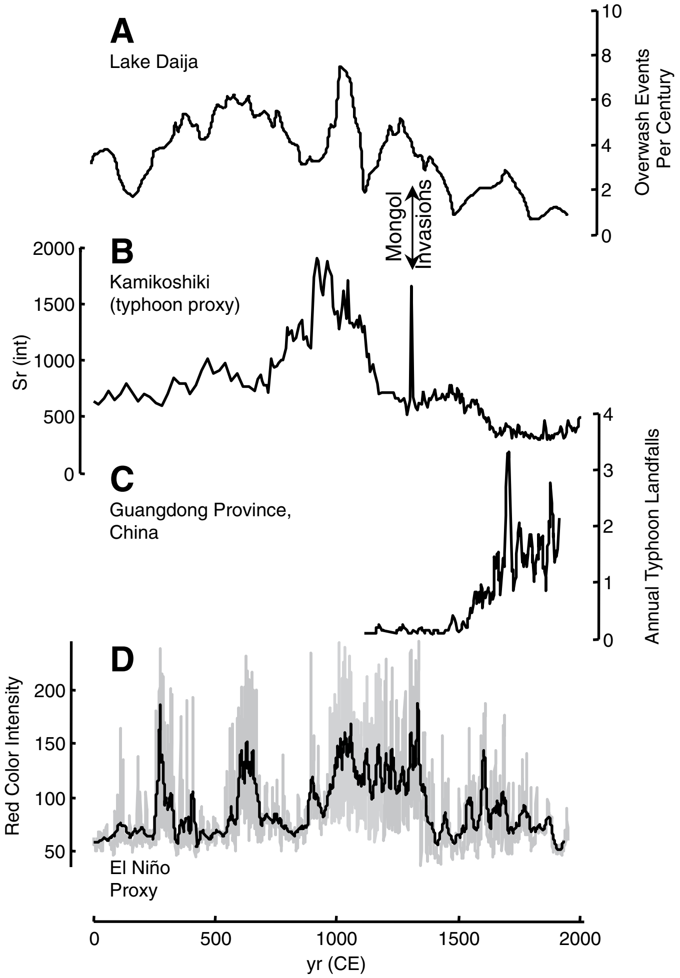

Figure 4. A: Overwash frequency for Lake Daija, Japan (100 yr running mean). B: Kamikoshiki Sr proxy for marine deposition (by Woodruff et al., 2009). C: Documented landfalling typhoon frequency (21 yr running mean) for southern China by Liu et al. (2001). D: Reconstruction of El Niño occurrences from Laguna Pallcocha, Ecuador, after Moy et al. (2002). See Figure DR2 (see footnote 1) for methodology used to construct overwash frequencies in A.

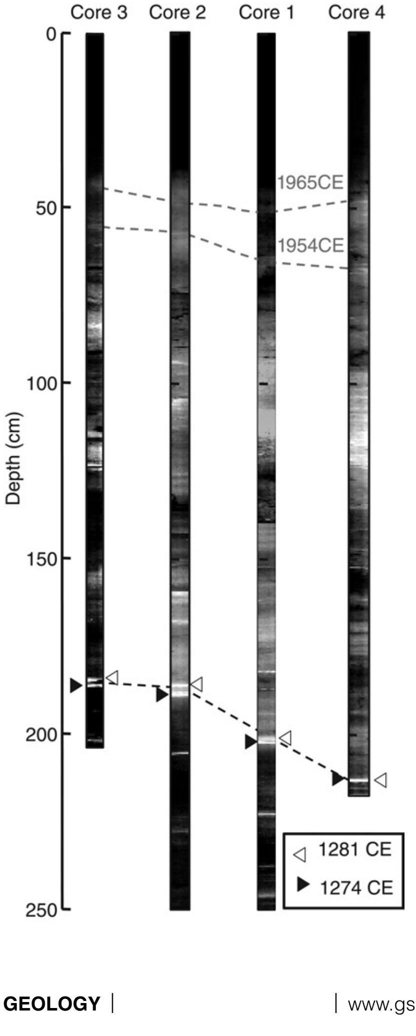

Figure 3. X-ray radiographs for the transect of cores presented in Figures 1B and 1C. Deposits dating to the 13th century in Figure 2 are noted, and traced through transect (black dashed line), along with more recent layers attributed to Typhoons Grace and Jean in 1954 CE and 1965 CE, respectively (gray dashed lines). See Figure DR1 (see footnote 1) for more detailed plots of the 1954 CE and 1965 CE deposits in Core 2.

Periods of increased overwash activity in the Daija and Kamikoshiki records are generally concurrent with periods of more frequent El Niño occurrences (Fig. 4D), as identified with El Niño–related event beds preserved within lake sediments from the equatorial Andes (Moy et al., 2002). Greater overwash frequency at the Daija and Kamikoshiki sites during increased El Niño activity is consistent with more recent instrumental observations of typhoons generally becoming more intense during El Niño years (Camargo et al., 2008), with a bias toward recurving tracks that steer storms toward Japan and Korea (Elsner and Liu, 2003). The decrease in typhoon frequency at Lake Daija and Kamikoshiki at 1600 CE also occurs during a transition to more documented typhoon strikes in the Guangdong Providence of southern China (Fig. 4C; Liu et al., 2001); this is consistent with a southern shift in preferred typhoon tracks away from Japan and toward southern China following a transition toward more La Niña–like conditions, with fewer El Niño occurrences. It is all but certain that a majority of the rise in typhoon counts in the Guangdong record is artificial, due to an increase in the number of reliable storm accounts. However, the pattern toward better typhoon documentation may in part be due to heightened interest resulting from increased typhoon impacts in the region.

CONCLUSION

The Daija reconstruction provides new evidence for a significant shift in typhoon climatology in the western Kyushu region, and a marked increase in typhoon impacts during the Mongol era relative to present day. It is difficult to attribute a pair of stochastic weather events to varying climate. However, our results support the occurrence of two major typhoons during the late 13th century, and indicate that events of this nature were more frequent during the timing of the Mongol invasions of the 13th century when compared to present day. Our results therefore support the paired Kamikaze typhoons playing an important role in preventing the early conquest of Japan by Mongol fleets. In doing so, the Kamikaze events may provide one of the earliest historical cases for the shaping of a major geopolitical boundary by an increased probability of extreme weather due to changing atmospheric and oceanic conditions.

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