ARTICLE IN PRESS

Palaeogeography, Palaeoclimatology, Palaeoecology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Shell and gravel layers caused by storm-induced rip currents during the Medieval Warm Period and Little Ice Age in South Korea

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ARTICLE INFO

Keywords:
Typhoon
Storm deposit
Late Holocene
El Niño
Shell species analysis

ABSTRACT

Five shell-gravel layers (2.2–2.9 m in elevation, 70 cm in thickness) formed by storm-induced rip currents along the southern coast of the Korean Peninsula over the past 1300 years are described. The three radiocarbon dates (S1–S3) and the two optically stimulated luminescence (S4 and S5) dates correspond well with the succession of the five shell-gravel layers. The age of S1, CE 720 ± 60, corresponds to the early Medieval Warm Period (MWP). The dates of the three overlying layers (S2–S4), CE 880 ± 110, 950 ± 70, and 995 ± 120, respectively, coincide with the middle MWP. The fifth date of the uppermost shell-gravel layer (S5), CE 1535 ± 40, coincides with the Little Ice Age (LIA) of Western Europe. The characteristics of shell habitats based on 16 shell species from each layer suggest that the first four layers formed in a slightly erosional to dominantly depositional environment during the MWP, whereas the youngest layer formed in a dominantly erosional environment during the LIA. Analyses of grain size distribution, magnetic susceptibility, and geochemistry of the sediments, and gravel morphology indicate that storm activity at this site during the MWP and LIA occurred within active storm periods in the western North Atlantic (WNA). Comparison of the five storm events and related climatic factors suggests that, although the typhoon track type at the site is similar to recurving tracks typical for El Niño conditions in North China and Japan, tracks during the MWP and LIA were likely shifted not only by changes in El Niño conditions but by other climatic factors such as sea surface temperature, the North Pacific High, and the westerly jet stream. However, storm energy under El Niño years during the middle MWP was likely stronger than that produced in normal years during the early MWP.

1. Introduction

On 5 October 2016, Typhoon Chaba battered Busan and other parts of South Korea with violent winds and heavy rain, left at least six people dead, and forced many factories, ports and schools to close (Korea National Typhoon Center, 2016). Four years earlier, three consecutive powerful typhoons with strong winds and heavy rain hit the southwestern coast of the Korean Peninsula during September 2012 (Fig. 1A). In addition, Typhoon Haiyan, known as Super Typhoon Yolanda in the Philippines, devastated parts of Southeast Asia, particularly the Philippines on 8 November 2013, and was one of the strongest tropical cyclones ever recorded. Such extreme events have led to intense debate about the probable influence of global warming on the intensity and frequency of cyclones (Gaertner et al., 2009; Knutson et al., 2010; Mann et al., 2009; Mendelsohn et al., 2012; Nissen et al., 2014). Projected ocean surface warming patterns caused by increasing greenhouse gas forcing suggest that typhoons striking the eastern mainland of China, Taiwan, Korea, and Japan will further intensify (Mei and Xie, 2016). Modern Atlantic hurricanes are also approximately 60% more powerful than those that occurred in the 1970s, with longer-lasting storms and top wind speeds that have increased by 25% (Emanuel, 2005). The conclusion in the Fourth Assessment Report

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http://dx.doi.org/10.1016/j.palaeo.2017.08.035
Received 26 January 2017; Received in revised form 20 August 2017; Accepted 23 August 2017

Please cite this article as: Yang, D.Y., Palaeogeography, Palaeoclimatology, Palaeoecology (2017), http://dx.doi.org/10.1016/j.palaeo.2017.08.035

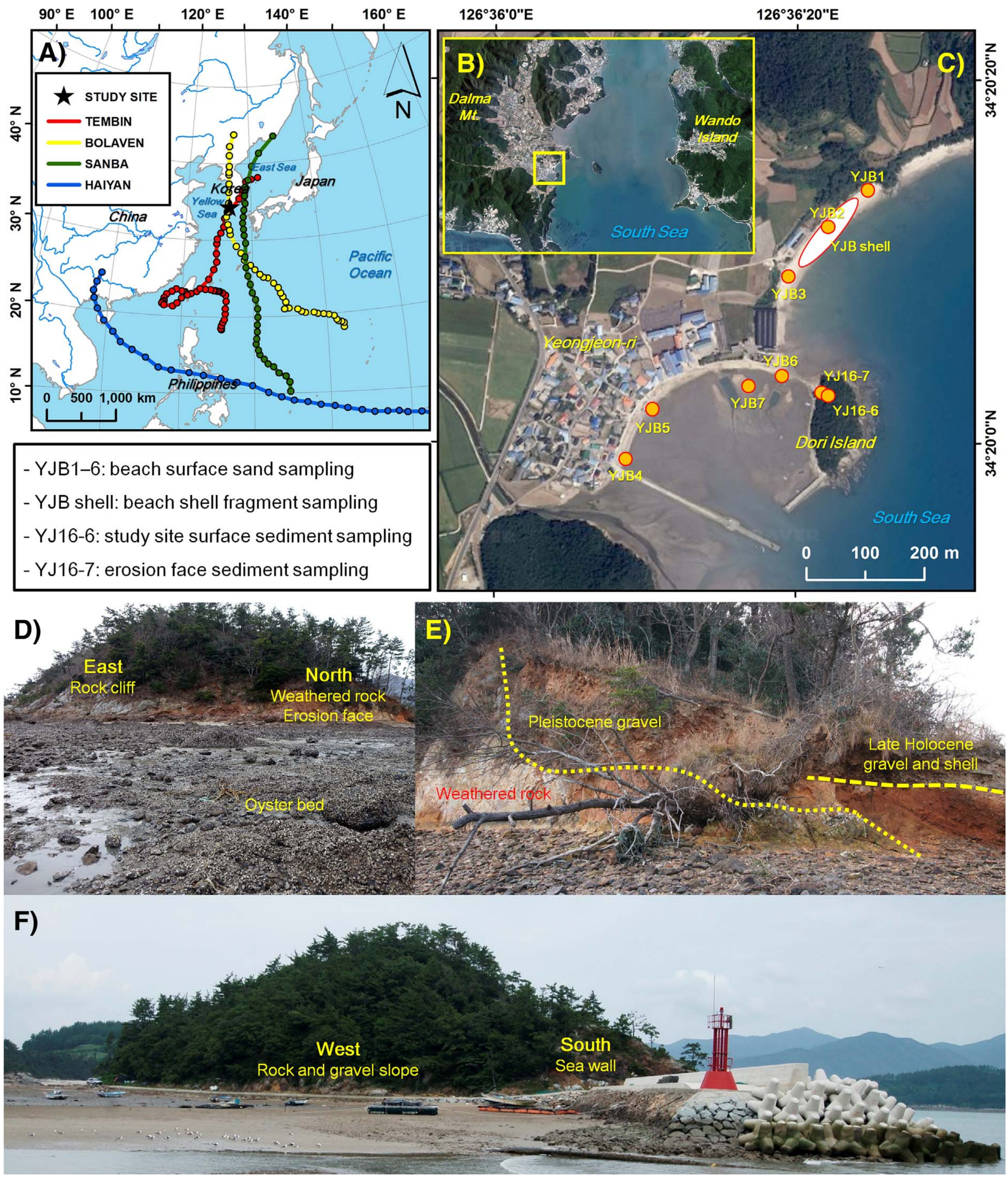

Fig. 1. Location of the study area, geomorphological characteristics, distribution of Holocene and Pleistocene sediments, and sampling locations on the beach and on Dori Island. (A) Typhoon trajectories of Tembin, Bolaven, and Sanba that made landfall in the study area in 2012, and of Super Typhoon Haiyan, which caused destruction in the Philippines in 2013; (B) site location on the southernmost coast of the Korean Peninsula; (C) surface sampling locations on the beach and on Dori Island; (D)–(F) geomorphological characteristics on Dori Island in each compass direction.

(AR4) of the Intergovernmental Panel on Climate Change (IPCC) was that global warming tends to increase the intensity of typhoons; however, significant uncertainty remains regarding typhoon frequency in a warmer climate (IPCC, 2007).

The mean location for typhoon generation generally shifts to the southeast during El Niño years (Chan, 1985; Lander, 1994), which results in longer-lasting typhoons (Wang and Chan, 2002) with greater intensity (Camargo and Sobel, 2005; Chan, 2007). In addition, typhoons that occur during El Niño years tend to recurve to the northeast (Wang and Chan, 2002), which increases the likelihood of a typhoon making landfall in Japan or South Korea (Elsner and Liu, 2003). The inverse correlation between tropical cyclone reconstructions from the WNA and the Kamikoshiki area of Japan may indicate an oscillating pattern in tropical cyclone activity between the WNA and the western North Pacific (WNP) on centennial to millennial timescales (Woodruff et al., 2009). In addition, a large body of research on North Atlantic storms has led to proposal of a correlation between storm frequency and climate dynamics, as indicated by ice-rafted debris (IRD) indices, sea