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Isotopic records from archeological giant clams reveal a variable climate during the southwestern Pacific colonization ca. 3.0 ka BP

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ABSTRACT

The Lapita colonization, which occurred in the late Holocene, is one of the most remarkable prehistorical human colonizations. To explore the possible influence of El Niño–Southern Oscillation (ENSO) on this event, bulk oxygen ($\delta^{18}O_{shell}$) and carbon ($\delta^{13}C_{shell}$) stable isotope records were obtained from eight fossil *Tridacna* sp. and *Hippopus hippopus* giant clams, unearthed from Lapita archeological sites of New Caledonia and Vanuatu. These giant clams were dated ca. 3.8–2.3 ka BP. These $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ records were used as proxies for combined sea surface temperature and salinity and precipitation. In addition, geochemical records were obtained from modern conspecifics from New Caledonia to create a baseline against which fossil giant clam records could be compared.

The isotopic records revealed the occurrence of two distinct climate states in New Caledonia ca. 3.2–2.3 ka BP: one climate state was characterized by climatic conditions similar to those observed today and the second was comparable to warmer and wetter conditions similar to Vanuatu's modern climate. Considering that previous paleo-climate reconstructions in the West Pacific did not show a shift of the mean climatic state and that they revealed a weak centennial climate variability, our results suggest that the climatic mean state has been alternating between these two states at a decadal or an inter-annual frequency. This strong climate variability recorded in the giant clam shells may reflect an increase in the ENSO variability, supporting the hypothesis of an ENSO-forced Lapita colonization as suggested by Anderson et al. (2006).

1. Introduction

While Near Oceania (Papua New Guinea – PNG, Solomon Islands, and Bismarck Archipelago) was colonized in ca. 40–35 ka BP by populations coming from the Northwest, there is no evidence of further eastward settlement in Remote Oceania (Santa Cruz Islands, Vanuatu, New Caledonia and Fiji) for the next 35,000 yr (Groube et al., 1986; Spriggs, 1997; Leavesley et al., 2002; O'Connell and Allen, 2004). The colonization of the Pacific entered in a new phase ca. 3.5–3.25 ka BP, with the emergence of the Lapita culture in the Bismarck archipelago (Kirch, 1997; Denham et al., 2012). Within a few centuries, the Lapita people established permanent colonies over the previously unexplored Remote Oceania, as far as the western Polynesian archipelagos of Samoa and Tonga located 4500 km eastward from the Bismarck archipelago (Burley et al., 1999; Denham et al., 2012). The fascinating Lapita colonization raises many questions in particular regarding the natural factors that may have influenced this remarkable event.

Coastal navigation between the islands of Near Oceania occurs with permanent sight of the coastline whereas voyages toward Remote Oceania require open-ocean navigation. Atoll emergence, resulting from the decrease in sea level, may have reduced the distances between islands or broadened navigational targets, facilitating the voyage to Remote Oceania (Dickinson, 2003; Nunn, 2007; Lal and Nunn, 2011). Although sea level change may have facilitated the colonization of specific areas in the Pacific, such as Central Micronesia, Anderson et al. (2006) suggested that this observation may not apply to Remote Oceania, as no atoll emerged between the boundary of Near and Remote Oceania, between Solomon and Santa Cruz Islands.

Climate variability may have played a role in the Lapita colonization. The southwest (SW) Pacific is characterized by strong inter-annual climate anomalies referred to as El Niño–Southern Oscillation (ENSO). ENSO anomalies include strong changes of the prevailing wind regime. During El Niño events, the prevailing easterlies collapse and westerlies become predominant, whereas during La Niña events the easterlies strengthen (Philander, 1990; Gouriou and Delcroix, 2002; Anderson et al., 2006; Avis et al., 2007). The intensity and the frequency of ENSO

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anomalies experienced strong variations during the Holocene: the Early Holocene (10–6 ka BP) presented a rather weak ENSO variability compared to modern levels whereas a strengthening of the ENSO variability has been observed ca. 4–3 ka BP (e.g., Haberle et al., 2001; Tudhope et al., 2001; Moy et al., 2002; McGregor, 2004; Koutavas et al., 2006; Duprey et al., 2012). Anderson et al. (2006) suggested that the weak ENSO variability during the Early Holocene (less frequent and less intense El Niño/La Niña events) may have been unfavorable to eastward maritime journeys. However, the increase in ENSO variability ca. 4–3 ka BP (more frequent or more intense El Niño/La Niña events) may have resulted in more frequent and rather predictable wind shifts that may have promoted the discovery of the SW Pacific Islands and the permanent settlement of the Lapita people.

Paleoclimate records from the Western Pacific are either lacking during the Lapita colonization period (Tudhope et al., 2001; McGregor, 2004) or do not provide an accurate temporal resolution (Haberle et al., 2001) to fully assess the change in the climate variability in the SW Pacific, at that time. Moreover, recent studies revealed that the millennial increase in ENSO variability may hide a much more subtle variability pattern (Cobb et al., 2013; McGregor et al., 2013). Consequently, assessing the link between the climate variability and the Lapita colonization requires well dated and local (i.e., SW Pacific) climate records. In this study, we used giant clams collected directly on Lapita archeological sites in Vanuatu and New Caledonia (SW Pacific) as archives to track the past climate variability.

The Sea Surface Temperature (SST) and Sea Surface Salinity (SSS) variations are key variables to track climate changes in the SW Pacific as these variables are very responsive to the fluctuations of the ENSO regime (Gouriou and Delcroix, 2002). The geochemical composition of fossil *Tridacna* and *Hippopus* giant clams have previously been used to reconstruct paleo-records of SST and SSS in the western Pacific (e.g., Aharon and Chappell, 1986; Watanabe et al., 2004; Duprey et al., 2012). Giant clams are abundant in archeological sites in the tropical Pacific area and they were harvested for consumption and/or used as raw materials for tools (Moir, 1989; Galipaud and Kelly, 2007; Seeto et al., 2012).

The stable oxygen isotope composition of giant clam shell ($\delta^{18}O_{shell}$) is driven by both the water temperature (SST) and the oxygen stable isotope composition of seawater ($\delta^{18}O_{sw}$) (Aharon and Chappell, 1983; Jones et al., 1986; McConnaughey, 1989; Watanabe and Oba, 1999; Aubert et al., 2009). Considering that $\delta^{18}O_{sw}$ variations follow the evaporation–precipitation balance, $\delta^{18}O_{shell}$ also reflects SSS variations; therefore, giant clam $\delta^{18}O_{shell}$ is a reliable proxy for both SST and SSS. High $\delta^{18}O_{shell}$ values could indicate colder and/or saltier conditions and low $\delta^{18}O$ values are associated with warmer and/or fresher conditions. The stable carbon isotope composition of giant clam shell ($\delta^{13}C_{shell}$) also provides information of past climate conditions. Although the factors driving carbon isotope fractionation are less well understood than the ones driving $\delta^{18}O_{shell}$ variations, it is believed that marine bivalves' $\delta^{13}C_{shell}$ reflects mostly the isotopic composition of dissolved inorganic carbon (DIC) (Mook and Vogel, 1968; McConnaughey et al., 1997; Gillikin et al., 2006; McConnaughey and Gillikin, 2008; Owen et al., 2008). Because DIC originating from land (river, runoff) is often isotopically lighter than oceanic DIC, $\delta^{13}C_{shell}$ records potentially reflect the proportion of terrestrial versus oceanic DIC in the environment. Low (high) $\delta^{13}C_{shell}$ values reflect a greater (lower) terrestrial (oceanic) DIC influence. As terrestrial DIC inputs depend on the precipitation regime, $\delta^{13}C_{shell}$ variations may thus reflect changes in the precipitation regime.

Fossil *Tridacna* sp. and *Hippopus hippopus* giant clams were collected on Lapita archeological sites in Vanuatu and New Caledonia (SW Pacific) and analyzed for bulk isotopic composition ($\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$). Bulk records allow for characterization of past SST and SSS variation over short time-windows (10 yr or less), therefore, variability of the background climate can be assessed. The climate variability ca. 3.0 ka BP was investigated by comparing the bulk fossil records to bulk isotopic records from modern *Tridacna maxima* and *H. hippopus* giant clams collected in New Caledonia.

2. Climate variability of the southwest Pacific

2.1. Mean state

The climate mean state of the Pacific basin is driven by a broad atmospheric circulation associated with large-scale climate features. This atmospheric circulation is linked to the existence of two main pressure cells: a low-pressure cell in the west tropical Pacific and a high-pressure cell in the east tropical Pacific. The low altitude air masses circulate from the high-pressure cell toward the low-pressure cell, creating an easterly wind regime. The intense convection occurring in the west Pacific drives an eastward high altitude displacement of the air masses towards the high-pressure cell. This atmospheric circulation is referred to as the Walker circulation (review in McPhaden et al., 2006).

This broad atmospheric circulation is strongly coupled to the West Pacific Warm Pool dynamic (WPWP). The WPWP is a permanent warm seawater body located to the east of a virtual line extending from the Philippines to Papua New Guinea (PNG), excluding the warm waters from the Indonesian Archipelago (Wyrtki, 1989). The WPWP is commonly defined by the 28 °C SST isotherm, although a more accurate definition integrates hydrological features and ecosystem dynamics criteria (Le Borgne et al., 2002; Maes et al., 2010). Another important feature of the Pacific climate is the presence of convergence zones. These features are year-long bands of low-level convergence, cloudiness, and precipitation, which are generally defined as the maximum precipitation tongue (Trenberth, 1976; Kiladis et al., 1989; Vincent, 1994). The Pacific contains two convergence zones: the Inter Tropical Convergence Zone (ITCZ), which is located along the equator, and the South Pacific Convergence Zone (SPCZ), which extends south-eastward from PNG and the Solomon Islands to the south of French Polynesia. Observed climate variability in the SW Pacific is mainly driven by changes in the size and location of the WPWP and the SPCZ.

2.2. El Niño Southern Oscillation variability

ENSO is the main mode of variability in the Pacific, this phenomenon is characterized by periodic shifts in the climate mean-state between two intermediate states. The La Niña- and the El Niño phases occur every 2 to 7 yr (Philander, 1990). ENSO variability is also modulated at the inter-decadal time scale. Consequently, the inter-decadal and the inter-annual climate variability of the Pacific is mostly driven by ENSO (Cane, 2005; Collins et al., 2010; Li et al., 2011).

2.2.1. Characteristics of an El Niño event

The El Niño phase is characterized by a collapse of the Walker circulation that causes the wind regime to reverse from an easterly to a westerly regime (Fig. 1a). During the El Niño phase, the southern edges of the WPWP and the SPCZ move northward of their mean position, and the SW Pacific experiences cooler and saltier conditions (Picaut et al., 1996; Delcroix and Picaut, 1998; Gouriou and Delcroix, 2002).

2.2.2. Characteristics of a La Niña event

During the La Niña phase of ENSO, the Walker circulation intensifies across the Pacific Ocean, strengthening the easterlies in the SW Pacific (Fig. 1b). In parallel, the WPWP and the SPCZ move south-eastward, resulting in warmer, fresher conditions in the SW Pacific (Picaut et al., 1996; Delcroix and Picaut, 1998; Gouriou and Delcroix, 2002). Therefore, an anomalous increase (decrease) in SST associated with an anomalous decrease (increase) in SSS indicates the presence of the La Niña (El Niño) phase of ENSO in the SW Pacific region (Gouriou and Delcroix, 2002).