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The behaviour of the Leeuwin Current offshore NW Australia during the last five glacial–interglacial cycles

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ABSTRACT

The Leeuwin Current is an anomalous eastern boundary current along the western Australian coast. To investigate its behaviour through time, we studied core MD002361 obtained from below the present-day pathway of the Leeuwin Current offshore the NW tip of Western Australia. Planktonic foraminifera assemblages, sea-surface temperature estimates reconstructed from those assemblages, together with the $\delta^{18}O$ and $\delta^{13}C$ signals of near-surface dwelling foraminifera (*Globigerinoides ruber*), were used to reconstruct the vertical structure of the water column for the past 500 ka. Our findings indicate that the Leeuwin Current was present along the western coastline of Australia even during glacial periods. During those times, there was a greater influence of South Indian Subtropical Water (STW) and South Indian Central Water (SICW) due to a 3–4° northward migration of the Indonesian Throughflow Water/South Indian Central Water frontal system. This resulted in an overall 6–9 °C decrease in SST, paralleled by a thickening and greater homogeneity of the mixed layer. The increased influence of STW and SICW also suggests that the West Australian Current, which presently sits below the Leeuwin Current, was strengthened during the glacial periods and contributed to a weakening of the Leeuwin Current. Conversely, the Leeuwin Current was 'stronger' during interglacial periods due to a thicker component of Indonesian Throughflow Water sourced from the Indo Pacific Warm Pool. This was particularly the case during marine isotope stage 5.5 (MIS) and the 'super' interglacial MIS 11.

1. Introduction

Compared to other locations in the southern hemisphere, the Leeuwin Current is anomalous eastern boundary current transporting warm, low salinity water formed within the Indonesian Throughflow and the Central Indian Ocean. The influence of this current extends offshore Western Australia from Northwest Cape in the north down to Cape Leeuwin at the south-western tip of Western Australia and it can, at times, extend as far as the west coast of Tasmania. The Leeuwin Current is seasonal, being more predominant during the Austral winter and has a temporal variability due to variation in the along-shore pressure gradient and prevailing equatorward winds. It is also strongly influenced by ENSO (El Niño Southern Oscillation) being strengthened during La Niña years and weaker during El Niño years.

Past investigations of the Leeuwin Current have been inconclusive, especially in regard to its occurrence during glacial periods. There is evidence that the Leeuwin Current either operated differently or was absent during glacial periods due to a strengthening of the opposing West Australian Current and/or reduction of the along-shore pressure gradient. The studies of Wells and Wells (1994) and Wells et al. (1994) used planktonic foraminifera for sea-surface temperature reconstructions from numerous cores located along the pathway of the Leeuwin Current for the past 130,000 years (see Fig. 1) and suggested that the Leeuwin Current did not flow during glacial periods and upwelling occurred during MIS 6. However, Wells and Wells (1994) did not estimate temperature changes within the mixed layer. However, Martinez et al. (1999) also found a reduction of tropical planktonic foraminifera species (e.g., *Globigerinoides sacculifer*) that coincided with an increase in intermediate (e.g., *Neogloboquadrina dutertrei*) and deep-dwelling species (e.g., *Globorotalia inflata*), suggesting a reduced Leeuwin Current. De Deckker (1997), Martinez et al. (1999), De Deckker (2001) and De Deckker et al. (2002), all suggested that the reduced input of low salinity water from the Indonesian Throughflow (ITF) and different sea-levels would have encouraged the ITF incorporation into the South Equatorial Current (SEC) or South Java Current (SJC) enhancing these systems and, thereby, reducing the Leeuwin Current (see Fig. 1). The dominance of the SEC over the Leeuwin Current was also found by Takahashi and Okada (2000) whose study of calcareous nannofossils similarly indicated that the Leeuwin Current was reduced during the Last

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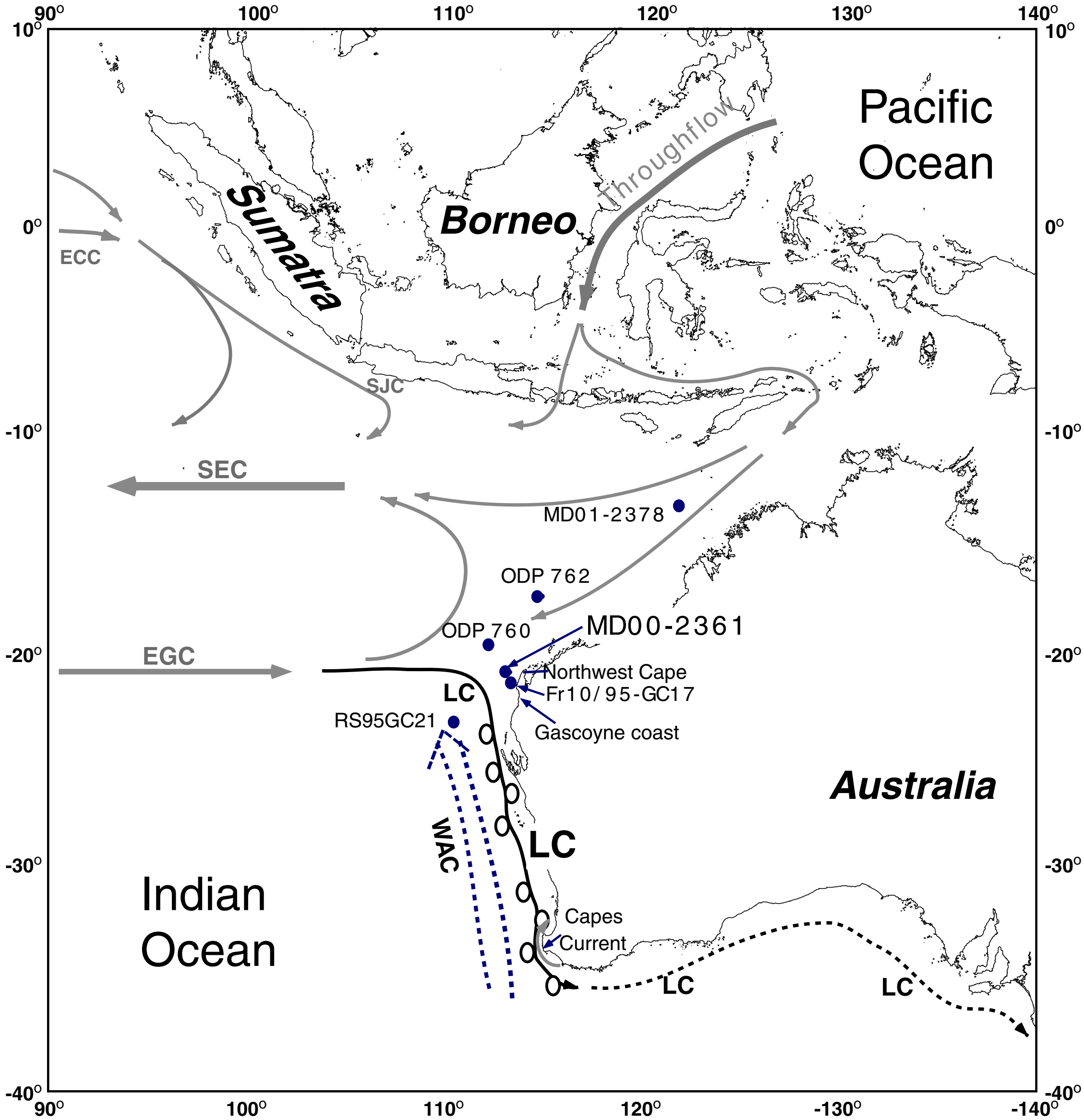

Fig. 1. Map showing the major surface/sub-surface currents in the eastern Indian Ocean and the Indo Pacific Warm Pool region. Abbreviations for those currents are: EEC: East Equatorial Current; EGC: Eastern Gyral Current; LC: Leeuwin Current; SJC: South Java Current. Of interest is the Leeuwin Current which flows southward along the shelf break of Western Australia, while the West Australian Current [WAC] is located offshore and flows northward underneath the Leeuwin Current. The Leeuwin Undercurrent which sits below the LC is not shown here to maintain clarity. The coastal counter current [Capes Current] is shown near the south-western tip of Western Australia. The location of sites mentioned in the text as well of MD00-2361 is shown as well as other cores discussed in this study.

Glacial Maximum (LGM) and suggested that it did not reach the southern core site (111°49.75′E, 24°44.67′S) which they studied.

In addition, it has been suggested that the West Australian Current (see Fig. 1) strengthened during glacial periods, thus reducing the influence of the Leeuwin Current (CLIMAP, 1984; Prell and Hutson, 1979; Prell et al., 1979, 1980; Prell, 1985; Wells and Wells, 1994, 1994; Okada and Wells, 1997; Takahashi and Okada, 2000; Barrows and Juggins, 2005). Barrows and Juggins (2005) updated previous LGM SST estimates provided by Prell et al. (1980), and Wells and Wells (1994), and indicated that lower SST off Western Australia may have been due to cooler waters entering the area via a strengthened West Australian Current, but that the Leeuwin Current probably reached as far as 32°S. This observation is supported by calcareous nannofossil studies of Okada and Wells (1997) and Takahashi and Okada (2000). Further, Gingele et al. (2001)'s analysis of clay minerals from cores in the Indonesian Throughflow region and on the Northwest Shelf gave insight into the pathways of the Indonesian Throughflow (ITF) and the Leeuwin Current during the Last Glacial Maximum (LGM). This latter study suggested that the volume of the ITF decreased during the LGM because less kaolinite and chlorite reached the Timor Passage from the Banda Sea. In addition, offshore Northwest Cape, the same authors suggested that a reduction in chlorite may also have indicated a decreased Leeuwin Current because of the apparent reduction in the flow of the ITF.

There is some evidence of pulses of nutrient-rich water 'upwelling' along the western coastline of Australia during glacial periods (Wells et al., 1994; McCorkle et al., 1994; Rogers and De Deckker, 2007). However, a fully developed upwelling system comparable to the eastern boundary currents offshore Peru and Namibia has never been identified. During interglacial periods, tropical and subtropical planktonic faunas have been used to indicate an enhanced Leeuwin Current at higher latitudes. For example, there appears to be evidence for a stronger-than-present Leeuwin Current resulting in warmer seas around the western and southern coasts of Australia during the last