Persistently strong Indonesian Throughflow during marine isotope stage 3: evidence from radiogenic isotopes

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ABSTRACT

The Indonesian Throughflow (ITF) connects the western Pacific Ocean with the eastern Indian Ocean, thus forming one of the major near surface current systems of the global thermohaline circulation. The intensity of the ITF has been found to be sensitive to changes in rrent

fraction and the authigenic seawater derived fractions of the sediment to reconstruct changes in past water circulation and in climatically driven continental inputs.

2. Radiogenic isotope compositions of the ITF area

2.1. Paleoceanographic reconstructions

Radiogenic isotope compositions have become a widely used tool in paleoceanography to reconstruct changes of ocean circulation and water mass mixing, as well as of the variability in sediment provenance. The radiogenic isotope signatures of neodymium (Nd), lead (Pb), and strontium (Sr), have been extracted from various marine archives. Detrital clay minerals carry information about sediment provenance (e.g., Fagel et al., 2002, 2004; Grousset and Biscaye, 2005; Ehlert et al., 2011; Stumpf et al., 2011) while Fe–Mn crusts (e.g., Abouchami et al., 1999; Frank, 2002; Muiños et al., 2008) and Fe–Mn oxyhydroxide coatings of sediments (e.g., Gutjahr et al., 2008, 2009; Piotrowski et al., 2008; Stumpf et al., 2010), as well as deep-sea corals (e.g., Colin et al., 2010; Copard et al., 2010; van de Flierdt et al., 2010) and benthic foraminifera (e.g., Klevenz et al., 2008) have been used to reconstruct past bottom water circulation. In addition, Nd isotope compositions of surface and near surface water masses have been reconstructed from planktonic foraminiferal calcite in marine sediments (Vance and Burton, 1999; Burton and Vance, 2000; Vance et al., 2004; Stoll et al., 2007; Osborne et al., 2008, 2010; Pena et al., 2013). However, the use of planktonic foraminifera as an archive for past surface water signatures is complicated by contamination with incorporated clays, incomplete removal of early diagenetic Fe–Mn oxyhydroxide coatings, or by exchange processes with pore waters (Roberts et al., 2010; Tachikawa et al., 2013). Furthermore, it has been shown that the oxyhydroxide phases associated with deposited planktonic foraminifera can be used as reliable archive of past bottom water signatures (Charbonnier et al., 2012; Roberts et al., 2012; Kraft et al., 2013) challenging the reliability of earlier reconstructions of past surface water Nd isotope compositions.

For this study we analysed radiogenic isotope compositions of different fractions of the marine sediments (authigenic and detrital phases) in order to constrain reliable proxy data for past water mass mixing and erosional inputs into the easternmost Indian Ocean and to provide a paleoceanographic reconstruction of the Indonesian Throughflow and proximal seas during MIS3.

2.2. Dissolved radiogenic Nd isotope signatures

Although the Indonesian Throughflow has been the subject of numerous oceanographic studies within the last decades, dissolved Nd isotope data of regional water masses are sparse. Amakawa et al. (2000) compiled Nd isotopic compositions of surface waters of the Indonesian Seas (sampled during Austral summer between December and February 1996/97) and showed that western Pacific surface waters (εNd about □4) are strongly modified during their passage through the Indonesian Archipelago (to εNd > □1.5). Unfortunately, no data are available from the Banda Sea itself. However, Nd isotope signatures in the water column of the ITF outflow in the western Timor Sea show less radiogenic values of □3.9 < εNd < □4.6 suggesting intense mixing with Indian Ocean waters. To date, there is only one study by Jeandel et al. (1998) providing dissolved water column Nd isotope profiles within the area of the Timor Sea and the easternmost Indian Ocean (also sampled during Austral summer in February 1992; Sprintall et al., 2002). A profile upstream of this study's core location in the Timor Sea (st. 33; Figs. 1 and 2) documents Nd isotope compositions of intermediate waters between εNd ¼ □4.1 (600 m) and εNd ¼ □4.9 (1600 m). Nearby stations also show only minor stratification in terms of Nd isotope composition in surface and intermediate waters (signatures are close to εNd ¼ □5; Figs. 1 and 2N7mort

3. Material and methods

3.1. Core selection and age model

Sediment core MD01-2378 was recovered within the framework of the International Marine Global Change Study (IMAGES) on the NW Australian shelf margin (Scott Plateau, 13° 04.95′ S and 121° 47.27′ E, 1783 m water depth, Fig. 1) by RV Marion-Dufresne in 2001 (Bassinot et al., 2002). The core site is at a location where the Indonesian Throughflow ultimately enters the Indian Ocean in the western Timor Sea, and is thus well suited to trace changes in ITF intensity and dynamics through time. Analyses of stable oxygen and carbon isotopes, as well as radiocarbon dating indicate a complete recovery of a continuous and undisturbed sequence of hemipelagic sediments since marine isotope stage 12 (Holbourn et al., 2005). The age model for core MD01-2378 is based on radiocarbon dating on planktonic foraminifera and benthic oxygen isotope stratigraphy correlated to available ice core data (Dürkop et al., 2008, and supplementary material therein), and it is available via the PANGAEA database (www.pangaea.de, doi10.1594/PANGAEA.666556).

3.2. Carbonate fraction

Neodymium isotope compositions of differently processed batches of planktonic foraminiferal shells were analysed in order to determine the most efficient method to extract a reliable paleo surface water Nd isotope signature from the cleaned foraminiferal carbonate fraction of this sediment core. The methods varied in terms of foraminiferal species and size fraction, sample weight, and extraction/cleaning protocols. In addition, Mn/Ca element ratios of the sample solutions (batches 1–3) were monitored to assess the efficiency of removal of authigenic Fe–Mn oxyhydroxides. These parameters, as well as the cleaning methods applied to the four different test batches used in this study are described below (see also Table 1). Except the batch 1 samples, which did not undergo a pre-cleaning step, all hand-picked foraminiferal samples were cracked, rinsed and subjected to oxidative and reductive cleaning procedures to remove contaminant phases prior to sample dissolution and element purification.

3.2.1. Batch 1

An average of 5 mg (about 100 specimens) per sample (n ¼ 10) of the planktonic species Pulleniatina obliquiloculata from the size fraction > 250 µm (three samples were taken from > 315 µm) were tested. The foraminiferal shells were dissolved applying a flow-through method developed by Haley and Klinkhammer (2002).

3.2.2. Batch 2

An average of 20 mg of bulk planktonic foraminifera (size fraction > 400 µm, n ¼ 8) were subjected to a batch cleaning method (Boyle, 1981; Burton and Vance, 2000; Vance et al., 2004) adjusted following Kraft et al. (2013).

3.2.3. Batch 3

Repeated sample preparation as for batch 2 (bulk planktonic foraminifera, n ¼ 8, batch cleaning method), but using the size fraction > 315 µm and an average sample weight of 30 mg.

3.2.4. Batch 4

An average of 40 mg of bulk planktonic foraminifera samples (n ¼ 7) of the size fraction > 315 µm (one sample > 250 µm) were subjected to the batch cleaning method. These samples comprise a subset of the samples used for the analyses of the oxide (chapter 3.3) and detrital fractions (chapter 3.4).

3.3. Oxide fraction

The ‘oxide fraction’ refers to the authigenic, early diagenetic ferromanganese oxyhydroxide coatings precipitating on particle surfaces within oxic and suboxic waters close to the sediment–water interface, which incorporate the ambient dissolved trace metal compositions (e.g., neodymium) of bottom waters (Rutberg et al., 2000; Bayon et al., 2002). The extraction of the Nd isotope composition of the bottom waters from the oxide fraction followed a previously published protoonal ; Bayon et al., 20m(m)Tj/F1 that are expected to refl

sample solutions of ‘batches 1–3’ (Table 1). The elevated Mn/Ca ratios, in combination with the uniform bottom water Nd signatures (obtained from the oxide fraction) thus suggest incomplete removal of the Fe–Mn oxyhydroxides from the planktonic foraminiferal tests and the Nd isotope compositions obtained from the carbonate fraction are likely to mainly represent past bottom water signatures instead of surface/subsurface water compositions (Roberts et al., 2010, 2012; Kraft et al., 2013).

within the Indonesian Archipelago. At present day, isotope compositions of detrital surface sediment fine fractions are roughly distributed along a mixing line within the ITF pathway (numbers 1–4 in Figs. 1 and 4, Ehlert et al., 2011). In analogy to this obser-