Earth and Planetary Science Letters 430 (2015) 30–42

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Fluxes of clay minerals in the South China Sea

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ARTICLE INFO

Article history:
Received 9 February 2015
Received in revised form 27 July 2015
Accepted 1 August 2015
Available online 24 August 2015
Editor: M. Frank

Keywords:
clay minerals
provenance
transport processes
sediment traps
South China Sea
deep water settling

ABSTRACT

In order to assess dominant settling processes that change the composition of the detrital clay fraction during transport from neighboring estuaries to a deep sea basin, we studied relative clay mineral abundances and absolute clay mineral fluxes of clay-sized sinking particulate matter collected by eight sediment trap systems deployed from shallow to deep water depth in the South China Sea. This is the first basin-wide study on recent sedimentation processes in the western Pacific marginal seas.

Annual averages of relative clay mineral abundances at the shallow traps are temporally more variable and regionally more diverse, resembling those of surrounding drainage basins. In contrast, higher fluxes of material reach the deeper traps. Their characteristics trend temporally and spatially towards uniformity and are enriched with smectite in the entire deep basin.

Sinking particulate matter that reaches the shallow traps spends less time in pelagic transport and is affected by monsoonal current reversals. The enrichment in smectite in the deeper traps is a result of longer duration in transport at low velocities, which may increase the effect of differential settling during transport. The trend is caused by lateral advection driven by the cyclonic deep circulation, and this is considered as the main transport process in the northern and central deep basin. The high fluxes in the south-western deep basin could be the result of laterally advected re-suspended sediments from the neighboring shelves.

The effects on the composition of the detrital clay fraction caused by oceanographic control, which indirectly include those by differential settling, mask the climatic signal from surrounding drainage basins in the deep basin sediments. This strongly affects the interpretation of the clay mineralogical record in sediments deposited under recent conditions in the South China Sea deep basin.

1. Introduction

Clay minerals in recent marine sediments are mainly detrital in origin (Griffin et al., 1968; Petschick et al., 1996; Velde, 1995) and as such have been widely used to trace the provenance of terrigenous particles in oceanic settings (Gingele and De Deckker, 2004), to constrain the intensity of continental weathering in the source region and hence climate changes on adjacent landmasses (Chamley, 1989) and to delineate the transport routes of suspended sediment loads from source to sink (Oliveira et al., 2002; Gingele et al., 2001). The relative abundances of the four major clay mineral groups (smectite, illite, chlorite and kaolinite) in sediments are used as proxies for silica weathering, sea level change and current intensities (Fagel et al., 1997). In the South China Sea (SCS) detailed and systematic clay mineral studies have been completed for much of the shelf, slope and basin sediments and adjacent rivers (Aoki, 1976; Chen, 1978; Tang and Wang, 1993; Z. Liu et al., 2008, 2010a, 2015; Li et al., 2012; J. Liu et al., 2013). They were cored and surface-sampled in high resolution to reconstruct weathering intensities (Boulay et al., 2005; Z. Liu et al., 2003, 2007b), sea level change (Steinke et al., 2008), provenance and contribution of sources (Z. Liu et al., 2010a; J. Liu et al., 2013).

The latter was calculated by clay mineral end member modelling under the assumption that the composition of the detrital clay fraction in sinking particulate matter is nearly unaffected by sorting or alteration during transport (Z. Liu et al., 2010b; J. Liu et al., 2013, 2014). However, the mapping clay of mineralogical characteristics of recent surface sediments of the north-eastern South China Sea revealed sediment zonation (Z. Liu et al., 2010a), which is likely the result of differential settling among clay minerals during transport across the shelf, as it had been proven for the Amazon River delta, the Niger delta and during labo-

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http://dx.doi.org/10.1016/j.epsl.2015.08.001
0012-821X/

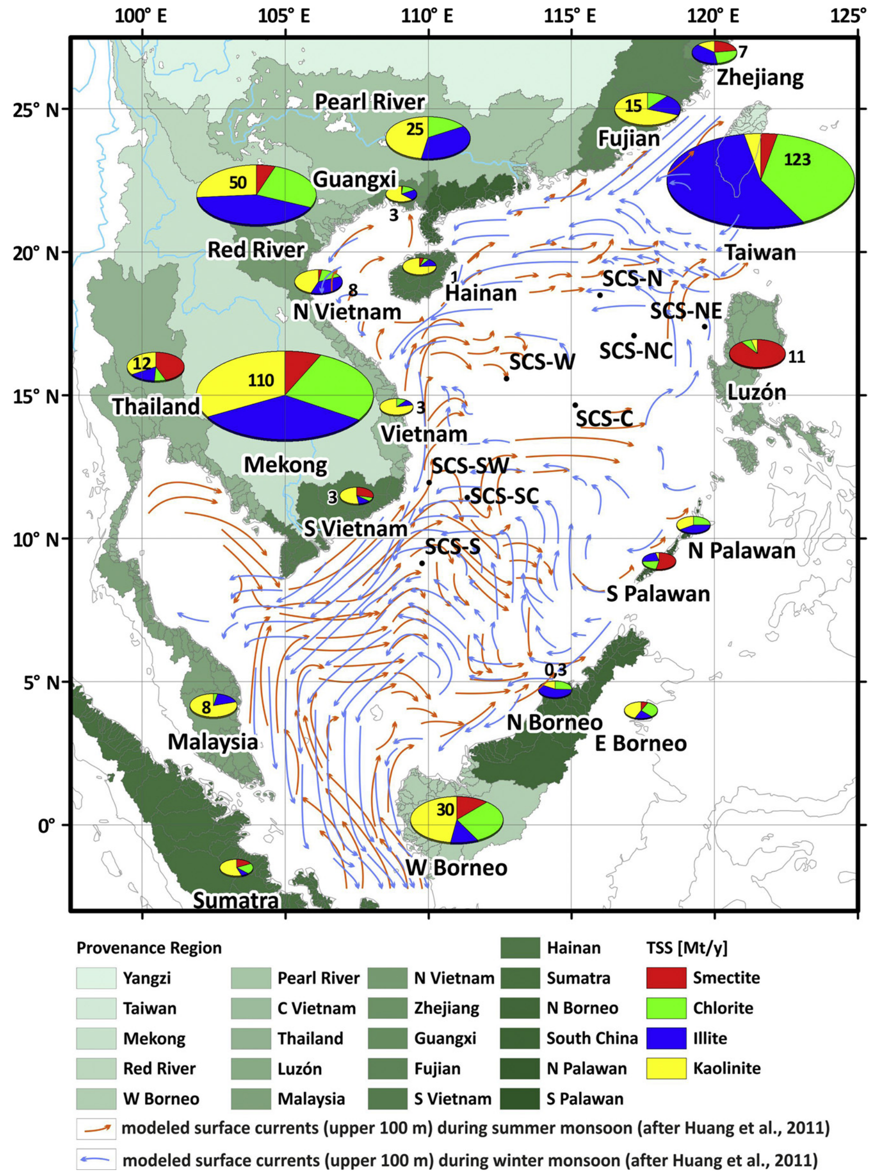

Fig. 1. Sediment trap mooring stations (Supplementary data table) are located along two trajectories across the South China Sea. Green areas represent drainage basins (Naval Research Laboratory, 2014) and groups of smaller drainage basins according to the average clay mineral assemblages of the dischargers (Liu et al., 2015). Sizes of the pie charts represent the drainage basins' contribution to the basin wide total suspended solids (TSS) in percent of the total discharge into the SCS calculated from the Global River Database (Milliman and Farnsworth, 2011). Current directions in the upper 100 m water layer reverse from NE-wards during summer monsoon to SW-wards during winter monsoon along the Indochina and Chinese Coasts; in the central basin currents are less variable (Huang et al., 2011). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ratory studies (Gibbs, 1977; Porrenga, 1966; Whitehouse et al., 1960). Also in the South China Sea, clay minerals' depositional patterns may reflect rather transport routes of suspended sediment loads than source area characteristics, as it was demonstrated for other study areas (Fagel et al., 1997; Oliveira et al., 2002; Gingele et al., 2001). Therefore the role of segregation and redistribution processes during transport, which may modify suspension's composition, may need to be considered more carefully when interpreting proxies.

The aim of this study is to bridge the observation between the input of detrital particles at river mouths and their deposition in deep oceanic basin, to assess the processes apt to modify the clay mineral assemblages during transport in the open SCS. To achieve this we compare the fluxes and compositions of clay mineral assemblages intercepted by sediment traps in shallow, mid- and deep water across the basin with those of the surrounding rivers' sediments.

1.1. Study area

The South China Sea (SCS) is a semi-enclosed basin which is connected to the open oceans by several shallow and narrow straits and the deeper Luzón strait (P. Wang et al., 2009). Its basin is confined by broad shelves of less than 100 m water depth in the north (the South China Shelf) and west (the Vietnamese and Sunda shelves) and by narrow shelves off Taiwan and Luzón (Fig. 1). Morphology and monsoonal wind stress determine the complex and variable circulation patterns at the surface, which include seasonal current reversals from NE-wards during northern summer to SW-wards during northern winter (Bonjean and Lagerloef, 2002; Shaw and Chao, 1994; Qu, 2000). The monsoonal reversal was also modelled for the water column down to 100 m (Chu et al., 1999; Huang et al., 2011) (Fig. 1). According to their thermohaline characteristics, the monsoonally driven layers of surface and subsurface waters reach from 0–350 m water depth (Li et al., 2002). The in-