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Discriminating hydrothermal and terrigenous clays in the Okinawa Trough, East China Sea: Evidences from mineralogy and geochemistry

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ABSTRACT

The Okinawa Trough (OT) in the East Asian continental margin is characterized by thick terrigenous sediment and ubiquitous volcanic–hydrothermal activities. In this study, the clays collected during IODP Expedition 331 to the middle OT (Iheya North Knoll) were analyzed for mineralogical and geochemical compositions. By comparing with the clays from the East China Sea shelf and surrounding rivers, we examine different clay origins. The hydrothermal field in the mid-OT is dominated by Mg-rich chlorite, while the recharge zone has clay mineral assemblages similar to the shelf and rivers, showing high content of illite, subordinate chlorite and kaolinite and scarce smectite. Compared to the terrigenous clays, the hydrothermal clays in the OT have high concentrations of Mg, Mn and Zr but low Fe, Na, K, Ca, Ba, Sr, P, Sc and Ti, while the hydrothermal clays in the mid-ocean ridge are relatively enriched in Fe and V and depleted in Al, Mg, Zr, Sc and Ti. Different fractionation patterns of rare earth elements also register in the terrigenous and hydrothermal clays, diagnostic of variable clay origins. We infer that the OT hydrothermal clay was primarily formed by the chemical alteration of detrital sediments subject to the hydrothermal fluids. The remarkably different compositions of hydrothermal clays between the sediment-rich back arc basin like OT and the sediment-starved ocean ridge suggest different physical and chemical processes of hydrothermal fluids and fluid–rock/sediment reactions under various geologic settings.

1. Introduction

Clay minerals in terrestrial and marine environments are widely used in the studies of paleoclimatic and paleoenvironmental reconstructions, because they have a direct bearing on climatic and environmental changes, weathering process and sediment provenance. In the marginal sea environment, the clay size particles predominantly come from the river input and eolian dust. Clay minerals including illite, chlorite, kaolinite and smectite and other rock-forming minerals such as quartz and plagioclase are thus the primary components of terrigenous clays in marginal seas and global ocean (Windom, 1976; Chamley, 1989). Almost all detrital clays are sourced from weathering crust by physical disintegration and chemical decomposition at low temperature. The detrital clay is relatively stable in terrestrial environments but may become metastable or unstable in marginal seas and oceans (Galán and Ferrell, 2013). Authigenic clays and alteration of detrital clays occur often in shallow sea and submarine hydrothermal areas where bio-agents and hydrothermal fluid play important roles in clay formation and alteration (Severmann et al., 2004; Dias and Barriga, 2006; Lackschewitz et al., 2006; Glenn and Filippelli, 2007; Snyder et al., 2007; Foustoukos et al., 2008; Cuadros et al., 2011; Manuella et al., 2012; Hazen et al., 2013; Nguetnkam et al., 2014).

Submarine hydrothermal venting is a widespread phenomenon in global ocean, particularly in the mid-ocean ridges (MOR) and back arc basins. Active seafloor hydrothermal systems have extraordinarily high fluxes of energy and matter and thus, are important for chemical evolution of global ocean (Chamley, 1989; Severmann et al., 2004; Dias and Barriga, 2006; Lackschewitz et al., 2006; Miyoshi et al., 2013). Due to the chemical alteration of detrital clays and the formation of clays in these extreme seafloor environments, the indication of clay minerals for paleoenvironmental and paleoclimatic changes may become insensitive and even produce misleading results.

The major sources of hydrothermal clays include submarine weathering of massive sulfides or metalliferous sediments (Haymon and Kastner, 1981; Hekinian et al., 1993), alteration products of oceanic crust (Humphris et al., 1980; Alt and Honnorez, 1984), and direct precipitation from low-temperature hydrothermal fluid (McMurtry et al., 1983). As tracers, mineralogy, chemistry and oxygen isotopic composition of hydrothermal clays have been used to investigate the formation mechanism of clays from various settings, and provide insights into the fluid chemistry and fluid–rock/sediment interaction (Marumo and Hattori, 1999). Mineral assemblages of clays in hydrothermal fields are overall different under various geologic settings, e.g., illite, paragonite, smectite, nontronite, chlorite, anhydrite, zeolite,

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epidote, titanite, quartz, feldspar, pyrite, hematite, magnetite, Mn-oxides and Fe-oxyhydroxides and metalliferous sulfides mostly occurring at MOR (Alt, 1995; Mills et al., 1996; Teagle et al., 1998; Lackschewitz et al., 2006; Wang et al., 2014), while mica, kaolins (kaolinite and halloysite), Mg-rich chlorite, talc, and montmorillonite are present in Jade hydrothermal area in the middle Okinawa Trough (OT), a back arc basin (Marumo and Hattori, 1999). In addition, previous studies also revealed the difference in elemental and isotopic compositions between terrigenous and hydrothermal clays in submarine environments (Elderfield et al., 1988; Mills and Elderfield, 1995; Sheppard and Gilg, 1996; Marumo and Hattori, 1999; Lackschewitz et al., 2006; Boström, 2009).

The Okinawa Trough is located in the southeast of the East China Sea (ECS) and Eurasian continental margin, and is regarded as an incipient intra-continental basin formed behind the Ryukyu arc–trench system (Fig. 1). The hydrothermal activities in the OT, especially in the middle part, have been widely documented (Ishibashi et al., 1988; Halbach et al., 1993; Marumo and Hattori, 1999; Glasby and Notsu, 2003; Hongo et al., 2007; Takai et al., 2011; Tsuji et al., 2012). Over the past decades, the provenances and environmental tracing application of clay minerals in East Asian rivers and marginal seas have been well investigated (Milliman et al., 1985; Yang et al., 2002; Dou et al., 2010a). The detrital clay sediments in the trough mainly derive from the continent via the inputs of the Changjiang (Yangtze River) and Huanghe (Yellow River) and eolian dust as well (Zhu et al., 1988; Dou et al., 2010a), while smectite may partly come from the submarine alteration of volcanic debris (Zhu et al., 1988). Nevertheless, the compositions of clay sediments in the continental margin should be further clarified in terms of their origins, sources and environmental implication. And particularly, the OT clays altered by the hydrothermal activities can provide valuable information about the evolution of hydrothermal activity in this back arc basin.

In 2010, one of the co-authors (S. Yang) participated in the Integrated Ocean Drilling Program (IODP) Expedition 331 to the mid-OT, and collected various hydrothermal samples from the Iheya North Knoll area (Fig. 1). In this study, we report mineralogical and elemental compositions of the clay sediments separated from two drilling sites of this expedition and from the ECS shelf and surrounding rivers. The paper aims to identify the clay origins in the mid-OT with special emphasis on the discrimination of terrigenous (detrital) clays sourced from the China continent or Taiwan Island and hydrothermal clays formed in the trough. The alteration of detrital clays subject to hydrothermal fluid activity will be further investigated. Moreover, the difference in chemical compositions of hydrothermal clays from various geologic settings including the mid-ocean ridge and back arc basin will be revealed in this study.

2. Geologic setting

As an incipient intra-continental basin, the Okinawa Trough has been undergoing rifting since ~2 Ma, and was preceded by an earlier rifting episode during the Miocene (Lee et al., 1980). Seismic reflection data suggests that the mantle at ~6000 m below seafloor (mbsf) overlain by potentially young basalt between ~3000 and ~6000 mbsf, and an igneous layer between ~1000 and ~3000 mbsf, while the thickness of sediment reaches ~1000 m up to the seafloor (Takai et al., 2011). The hydrothermal fluids in the OT are primarily derived from seawater interaction with dacitic–rhyolitic magma rich in K and volatile components (Sakai et al., 1990; Glasby and Notsu, 2003), indicating that the trough is an actively rifting and transitional region between continental and oceanic crusts.

The Iheya North Knoll (27°47′50″N, 126°53′80″E) is located approximately 150 km NNW of Okinawa Island (Fig. 1), and hydrothermal activity was first discovered in this area in 1995. Since then, six active hydrothermal fields have been found in the mid-OT. In the central valley of Iheya North Knoll, the seismic reflection appears relatively disordered as deep as 400–500 mbsf, suggesting the presence of pumicious pyroclastic flow deposits, rather than massive igneous rocks, beneath the surficial hemipelagic sediments (Takai et al., 2011). In numerous gravity cores, thick pumice layers with coarse to fine grain sizes were found just below the seafloor (Oiwane et al., 2008). Combining all the survey data suggests the potential recharge and discharge zones of hydrothermal fluids in these hydrothermal fields.

The major scientific objective of IODP Expedition 331, the Deep Hot Biosphere, was to investigate active subseafloor microbial ecosystems and their physical and chemical settings (Takai et al., 2011, 2012).

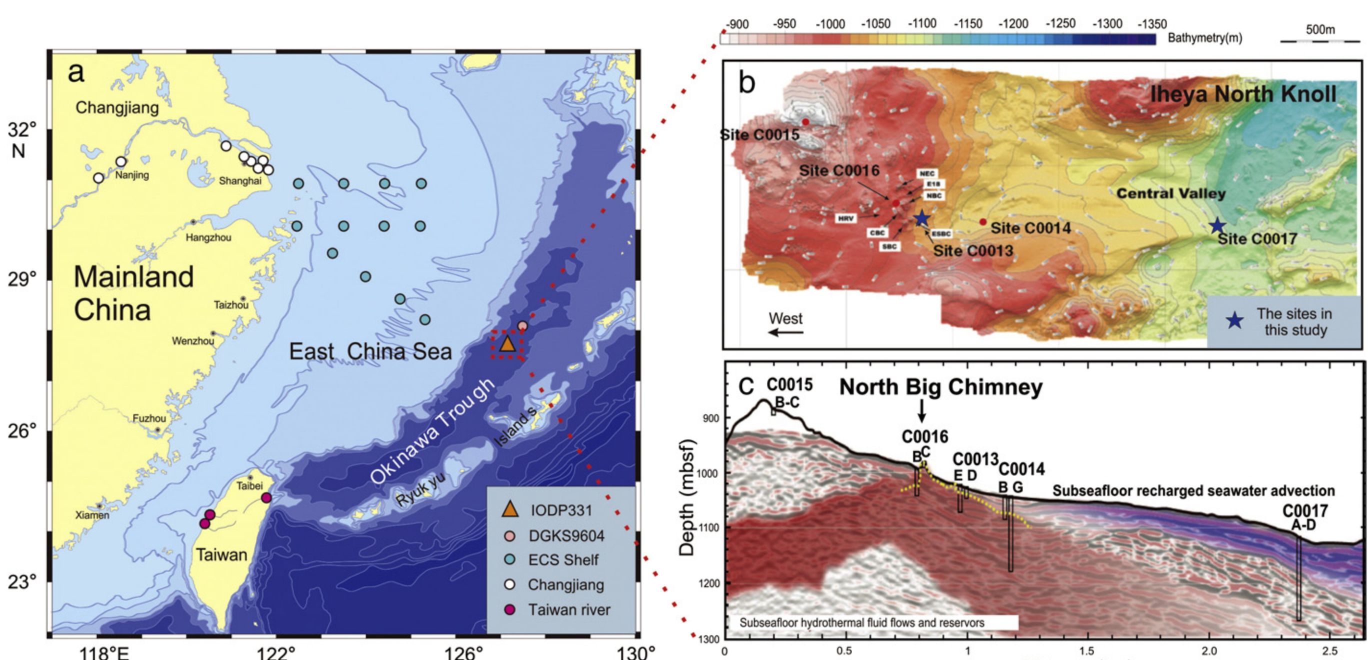

Fig. 1. The map showing the study area and localities of sediment samples from the Changjiang and Taiwan rivers, ECS shelf and Okinawa Trough. The dispersal pattern of hydrothermal fluid in the study area is modified after the post-cruise report of IODP Expedition 331 (Takai et al., 2011).