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Mineralogy, geochemistry, and radiocarbon ages of deep sea sediments from the Gulf of Mexico, Mexico

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ABSTRACT

The mineralogy, geochemistry, and radiocarbon ages of two sediment cores (GMX1 and GMX2) collected from the deep sea area of the Southwestern Gulf of Mexico (~876–1752 m water depth) were studied to infer the sedimentation rate, provenance, heavy metal contamination, and depositional environment. The sediments are dominated by silt and clay fractions. The mineralogy determined by X-Ray diffractometry for the sediment cores reveals that montmorillonite and muscovite are the dominant clay minerals. The sections between 100 and 210 cm of the sediment cores GMX1 and GMX2, respectively, are characterized by the *G. menardii group* and *G. Inflata* planktonic foraminiferal species, which represent the Holocene and Pleistocene, respectively. The radiocarbon-age measurements of mixed planktonic foraminifera varied from ~268 to 45,738 cal. years B.P and ~104 to 25,705 cal. years B.P, for the sediment cores GMX1 and GMX2, respectively. The variation in age between the two sediment cores is due to a change in sediment accumulation rate, which was lowest at the location GMX1 (0.006 cm/yr) and highest at the location GMX2 (0.017 cm/yr).

The chemical index of alteration (CIA), chemical index of weathering (CIW), and index of chemical maturity (ICV) values indicated a moderate intensity of weathering in the source area. The total rare earth element concentrations (∑REE) in the cores GMX1 and GMX2 vary from ~94 to 171 and ~78 to 151, respectively. The North American Shale Composite (NASC) normalized REE patterns showed flat low REE (LREE), heavy REE (HREE) depletion with low negative to positive Eu anomalies, which suggested that the sediments were likely derived from intermediate source rocks.

The enrichment factor of heavy metals indicated that the Cd and Zn concentrations in the sediment cores were impacted by an anthropogenic source. The redox-proxy trace element ratios such as V/Cr, Ni/Co, Cu/Zn, (Cu + Mo)/Zn, and Ce/Ce* indicated that the sediments were deposited under an oxic depositional environment. The similarity in major element concentrations, REE content, and the NASC normalised REE patterns between the cores GMX1 and GMX2 revealed that the provenance of sediments remained relatively uniform or constant during deposition for ~4.5 Ma. The major and trace element based multidimensional discrimination diagrams showed a rift setting for the core sediments, which is consistent with the geology of the Gulf of Mexico.

1. Introduction

The major and trace element concentrations of terrigenous sediments are considered as a sensitive tool to investigate the weathering condition in the source area, provenance, and to understand the redox condition in the depositional environment, because sediment composition was controlled by the parent rocks, climatic and tectonic factors of the source region (Armstrong-Altrin et al., 2004; Mortazavi et al., 2014; Ding et al., 2015; Fan et al., 2015; Madhavaraju, 2015; Tetiker et al., 2015; Yu et al., 2016). The immobile elements such as Al_2O_3, TiO_2, Th, Zr, Co, Nb, Sc, and REE are considered as excellent indicators of the parent rocks due to the low mobility and short residence time in sea water (Cullers et al., 1979). For example, the concentration of La and Th is higher in felsic rocks relative to basic rocks, while Co, Sc, Cr, and Ni contents are enriched in basic rocks. Hence, high ratios of La or Th versus Co, Sc, Cr, and Ni may reveal that the sediments were originated from

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felsic rocks, whereas low ratios suggest an origin from basic source rocks (Cullers, 2000). Similarly, size of the Eu anomalies (Eu/Eu^*) is different between felsic and basic rocks, for instance basic rocks consist of slight positive or without an Eu-anomaly, which can be well preserved in sediments as a representative of source area composition (Cullers et al., 1979; Basu et al., 2016). Therefore the trace element concentrations and distribution patterns of REE have been widely used to determine the source of sediments (Prego et al., 2012; Borghesi et al., 2016).

The REE composition and distribution patterns of deep sea sediments of the Southwestern Gulf of Mexico have not been investigated by many researchers. Sediments recovered from the northern part of the Gulf of Mexico were studied by Montero-Serrano et al. (2010). They documented the early Holocene palaeoenvironmental and sedimentary changes in response to North American climate evolution. The major element concentrations of sediments collected during Ocean Drilling Program (ODP Leg 164) and Deep Sea Drilling Project (DSDP Leg 96) were reported by Paull et al. (2000) and Pickering and Stow (1986). Recently, based on the major element geochemistry of sediments Armstrong-Altrin (2015) evaluated the tectonic environment of the southern part of the Gulf of Mexico.

The petrography combined with geochemistry of beach sands along the coastal regions of Gulf of Mexico and its implication on source rocks characteristic were studied by few researchers (Armstrong-Altrin et al., 2012, 2015a; Armstrong-Altrin and Natalhy-Pineda, 2014; Carranza-Edwards et al., 2001; Kasper-Zubillaga et al., 2013). The organic matter and metal contamination of sediments from the estuaries along the coastal regions of the Gulf of Mexico were studied recently by Vera-Mendoza and Salas-de-León (2014), Rosales-Hoz et al. (2015) and Botello et al. (2015). However, previous study on the effect of metal contamination, age, and source of deep sea sediments of the southwestern Gulf of Mexico was very limited. In this study, we analyzed the mineral assemblages, radiocarbon age, major, trace, and REE concentrations in two sediment cores recovered from the Southwestern Gulf of Mexico. Our aim was to determine the age, sediment accumulation rate, intensity of weathering, level of heavy metal contamination, and source rock characteristics of the two sediment cores.

2. Study area

The location of sediment cores GMX1 and GMX2 collected from the southwestern part of the Gulf of Mexico is shown in Fig. 1. The cores GMX1 and GMX2 were retrieved from ~876 to 1752 m water depth located at 19° 10′ 23.47″ N- 94° 19′ 59.55″ W and 19° 09′ 62.71″ N- 95° 07′ 24.64″ W, respectively.

Papaloapan and Coatzacoalcos are the major rivers draining along the southwestern coastal region. The Coatzacoalcos River drains between 17° 46′ and 18° 10′ N and 92° 25′ and 94° 31′ W. The river originates in the Sierra Atravesada (Oaxaca State; Fig. 1) and drains 21,120 km^2 of catchment areas before reaching the Gulf of Mexico, with a mean annual discharge volume of 32,732 Hm^3 (Tamayo, 1991). The Papaloapan River basin (17°–19° N and 95°–97° 40′ W) is the second largest hydrological basin in Mexico, drains 39,189 km^2 of catchment area before reaching the Gulf of Mexico with an annual volume of discharge of 39,175,000 m^3 (Tamayo, 1991).

The lithology of the rivers catchment areas consists mainly of volcanic and volcanic sedimentary rocks. The outcrops along the Southwestern Gulf of Mexico are composed of 1) Quaternary alluvium and soils, 2) Cenozoic volcanic rocks of mafic and intermediate composition, 3) Cenozoic and Mesozoic clastic and calcareous sedimentary rocks, and 4) metamorphic rocks comprising schist and gneiss of Paleozoic and Precambrian ages (Ortega-Gutiérrez et al., 1995).

3. Materials and methods

A total of 40 sediment samples (silt and clay) at different intervals were selected from two piston sediment cores (GMX1 and GMX2) collected from the deep sea area (~876 and 1752 m water depth) of the Gulf of Mexico on-board the research vessel "Justo Sierra" on June 2011 (Fig. 1). The sediment cores were subsampled at 1 cm resolution at different sections to study the textural and compositional differences (15 samples from core GMX1 and 25 from core GMX2). Sediments were dried (40 °C) and powdered using an agate mortar.

A Beckman Coulter particle size analyzer (Model LS230) located at the Instituto de Ciencias del Mar y Limnología (ICML), Universidad Nacional Autónoma de México (UNAM) was used for textural analysis (Folk, 1966). Twenty sediment samples (10 from each core) were selected for XRD study. Mineralogy was determined on < 63 μm (silt) and >2 μm (clay) fractions of the sediments using a Siemens D5000 X-ray diffractometer at the Institute of Geology, UNAM. For the semi quantification of the identified principal minerals, peak areas of the specific reflections of the main clay minerals were calculated and weighted with empirically estimated factors (Rocha, 1993; Olivera et al., 2002; Ghandour et al., 2014; Tetiker et al., 2015).

The semi-quantitative analysis of chemical composition for the deep sea sediments was done by the PHILLIPS XL-30 scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS) at the Petrology Laboratory, Institute of Geophysics, Universidad Nacional Autónoma de México (UNAM). The EDS detector is equipped with an ultra-thin window allowing detection of mineral elements and carbon. EDS provided the elemental composition of the solid phases and helped to identify the point analyses and elemental maps.

An average of 300 specimens of planktonic foraminifera was picked every 10 cm downcore to reconstruct the biostratigraphy of each section. Radiocarbon dating was conducted in 10 samples, using 20 μg of planktonic foraminiferal mixed species from the cores GMX1 and GMX2 measured by the accelerator mass spectrometer (AMS). The conversion of ^{14}C radiocarbon ages into calendar years BP was performed using the CALIB software (Stuiver and Reimer, 1993; version 5.0.2; http://calib.qub.ac.uk/calib). After calibration, ages between dated sections were obtained by linear interpolation.

All the forty sediment samples (15 samples from core GMX1 and 25 from core GMX2) were analyzed for major, trace and REE geochemistry. Major element concentrations were analyzed by using conventional X-ray fluorescence (XRF) spectrometry at the Institute of Geology (UNAM). Powdered samples were heated to 110 °C for 6 h followed by heating in a muffle furnace at 1000 °C for two hours to determine LOI (loss on ignition). Lithium tetraborate was mixed with the samples and heated to 1000 °C to form a fused sample for XRF analysis with a Rigaku RIX-3000 equipped with a Rh tube. Calibration curves were prepared by using international reference materials (Lozano and Bernal, 2005). The geochemical standard JGB1 (GSJ) was used to determine data quality. Chemical analysis for major element has precisions better than 5%. Major-element concentrations were recalculated to an anhydrous (LOI-free) basis and adjusted to 100% before interpretation.

Trace element (Ba, Cr, Sc, Sr, V, Zn, and Zr) concentrations were determined using a Jobin Yvon 138 Ultrace inductively coupled plasma atomic emission spectrometer (ICP-AES) at the Korea Basic Science Institute, Korea. The REE, Co, Cs, Cu, Hf, Nb, Ni, Pb, Rb, Th, U, and Y were analyzed by a VG Elemental PQII Plus inductively coupled plasma mass spectrometer (ICP-MS) using a method given by Jarvis (1988). The analytical precision for trace elements is better than 5%. The United States Geological Survey Standard, BCR-2