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Clay mineral provinces in tidal mud flats at Germany's North Sea coast with illite K–Ar ages potentially modified by biodegradation

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ABSTRACT

Mineralogical studies, chemical analyses and K–Ar dating were carried out on clay fractions from tidal mud flats along the Lower Saxony coast and its bays to identify material sources and sedimentary processes at this dynamic interface between air, land and sea.

From the coast into the bays, sediments are enriched in fine-grained smectite relative to the coarser grained illite, chlorite and kaolinite, due to the weakening of the tidal current energy in the bays. In addition, the study area can be divided into two provinces on the basis of the illite K/Rb ratios and Mg contents. To the west [Schiermonnikoog, Dollart, Ley Bay up to Norderney island], longshore currents carry suspensions from the Belgian and Dutch coasts; to the east [from Langeoog island, Jade Bay to the Helgoland mud area] suspensions from the Elbe and Weser rivers are mixed with submarine reworked glacial sediments, whereas the portion of longshore current suspensions from the west decreases, becoming negligible in the Helgoland mud area off the Elbe and Weser estuaries. The illite K–Ar data vary considerably and fail as source indicators due to differential settling and mixing of the clay material and probably to Ar loss from illite by biodegradation during digestive processes. Only further offshore, outside the zone of dynamic sediment dispersion, do the K–Ar data fit provenance patterns.

1. Introduction

Understanding the varied forms of sedimentary transport and supply of detrital components is a fundamental premise of explaining coastal sedimentary processes. Mineralogical, chemical and isotopic compositions of inorganic sediment particles have frequently been used as indicators of the origin of sediments. The provenance history can, for instance, be addressed by evaluating differences in the heavy mineral assemblages in coarse-grained clastic sediments (e.g., Davis and Moore, 1970). Mineralogical and geochemical features of fine-grained detrital clay minerals can also be used for the same purpose, especially in the case of clayey sediments (e.g., Chamley, 1989 chapter 8). Well known is the latitudinal zonation of different terrigenous clays in sediments of the Atlantic Ocean controlled generally by climate, weathering conditions and mineralogical heterogeneity in the source areas. However, each detrital mineral assemblage is by itself a complex mixture of different grain sizes that undergoes further sorting by currents in the marine environment. Similarly, differential flocculation of clay minerals at the fluvial/marine interface has been demonstrated, whereby kaolinite and illite flocculate more rapidly than smectite (Meunier, 2005). Furthermore, smectite material may also be partially disintegrated in estuaries into fundamental particles by delamination, so that the amount of individual clayey flakes increases in coastal waters (Brockamp, 2011). Fecal pellets have also been established as playing a significant role in clay sediment deposition in beach–shore interface zones (Pryor, 1975). Pelletization is obtained both by filter feeding organisms extracting and concentrating fine minerals from suspensions and by animals burrowing in the mud. During digestion, for instance, crystallinity and grain size of clay minerals are drastically reduced and even new minerals may form (Engelhardt and Brockamp, 1995; Needham et al., 2005; Wolanski, 2007). These various sorting processes can effectively modify the primary mineralogical and geochemical features of a detrital assemblage, which complicates the identification of the environmental signatures and geological settings.

The tidal mud flat deposits in the highly complex coastal zone of Lower Saxony between Emden and Wilhelmshaven (Fig. 1) that consist of various sedimentary environments such as barrier islands, sheltered and open tidal flats, bay flats and estuaries, represent a challenge for a study of the clay transport and its coastal

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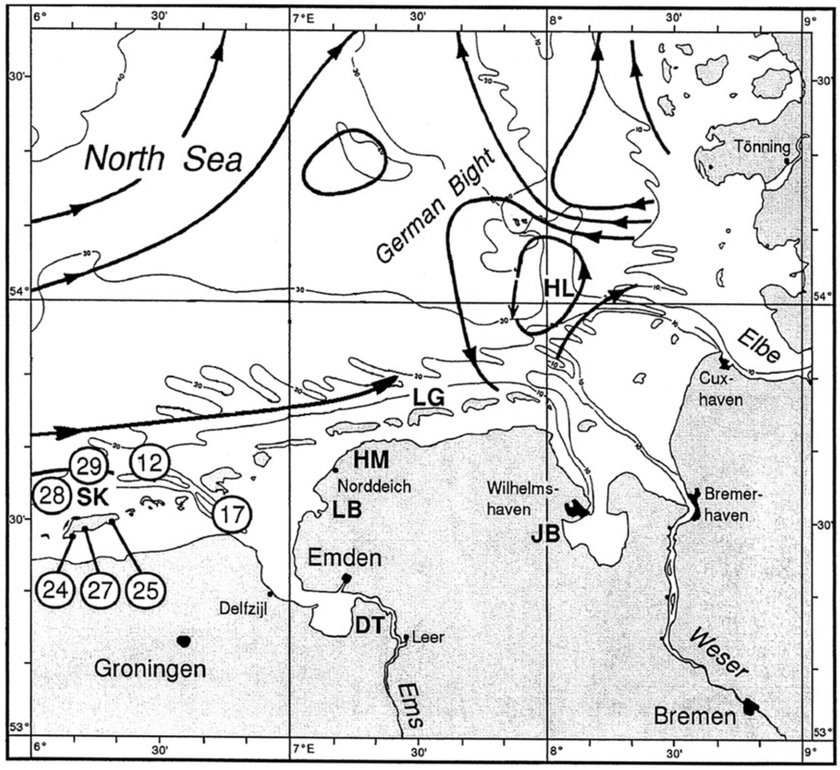

Fig. 1. Direction of the mean near-bottom current at the southern North Sea according to Deutsches Hydrographisches Institut, now Bundesamt für Seeschifffahrt und Hydrographie (BSH) (1983) and Sündermann et al. (2001). Sampling sites: SK = Schiermonnikoog, DT = Dollart, LB = Ley Bay, HM = Hager Marsh, LG = Langeoog, JB = Jade Bay, HL = Helgoland mud area. Sample numbers of SK site are shown in circles.

accumulation. Formed during the Holocene marine transgression of the North Sea (Eisma and Irion, 1988), these mud flats are rich in organic carbon and are part of a major mud belt extending along the Dutch, German and Danish coast over a distance of about 450 km, approximately 2 km wide. These mud-flat sediments on the coast of the shallow North Sea are unusual, as sands generally predominate elsewhere in the North Sea. Among the marine currents along the coast, flood currents play a significant role for the particle transport, and complex current regimes develop within the tidal flats that result from changes in wind direction and its effect on the current energy, so that tidal flat sediments cannot be regarded as being static (Ehlers, 1988). The near-shore currents move mostly from west to east as far as the German Bight and they are also combined with a minor component perpendicular to the coast. A gyre is centered on the German Bight off the Weser and Elbe estuaries. Several bays formed on the Lower Saxony coast during storm surges in the Middle Age (e.g., Dollart, Ley Bay, Harle Bay, Jade Bay), where vast amounts of mud accumulated.

Because of the varied hydrodynamic regimes along the coast and their impact on sedimentation, it is not surprising that alternative opinions exist about the material composition of the muds and their origin. For instance, the proportions of the different clay minerals (illite, smectite, kaolinite, chlorite) have been interpreted to be the same in sediments of estuaries and near-shore areas in the southern North Sea (Rudert and Müller, 1981). On the other hand, there are three different opinions as to the extent to which fluvial suspensions contribute to the coastal sediment composition (significantly, only marginally, or not at all), whereas submarine reworked glacial components are suggested as the remaining material in each case (Zöllmer and Irion, 1996; Zuther et al., 2000; Hoselmann and Streif, 2004). An early study even postulated suspended matter transport from the Dutch coast to as far as the Helgoland mud area off the Elbe estuary (Eisma et al., 1982), where differential settling of clayey particles has recently been reported (Pache et al., 2008). A generalized depletion of fine-grained material in the present coastal sediments has been reported by Dellwig et al. (2000). Fecal pellets possibly play an important role in clay mineral deposition, and in some tidal flats they are the dominant component (Irion, 1994). It should also be recalled that tidal flat sediments are frequently bioturbated by benthic organisms (Reineck and Singh, 1975).

The present study is focused on the remarkable mud flat sediments along the Lower Saxony coast to evaluate and possibly identify the sources of the related clay minerals and to generate additional information about the impact of near-shore processes on the clay mineral characteristics in these coastal lowlands. A regional approach was taken to assess the effect of local small-scale variables.

Analysis of the major and trace elements in the samples and K–Ar dating of illite as it is used here, has already been successfully applied elsewhere for determining source areas (Clauer and Chaudhuri, 1995). X-ray diffractometry (XRD) and infrared spectrometry (IR) were also employed for identifying the minerals. All methods used the separated <2 μm fraction, which is the diagnostic grain size for clay mineral studies.

2. Geological outline of the study area

The tidal flats along the Lower Saxony coast consist of a cyclic sequence of fine sand, silt and clay layers, locally alternating with peat layers. The cyclicity results from complex alternation of transgressive and regressive overlaps indicating shoreline displacements. The clayey muds are concentrated in near-shore zones characterized by limited water movement (Streif, 2004).