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Clinoform sedimentation along the Apennine shelf, Adriatic Sea

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Abstract

Sedimentation along the central Adriatic coastline of Italy results from a series of small, distributed fluvial sources (i.e., a line source), draining the Apennine Mountains. These rivers deliver $\sim 3 \times 10^7$ t y^{-1} of sediment, contributing to the formation of a shore-parallel shelf clinoform that has developed throughout the Holocene. Across-shelf sediment accumulation rates, calculated from ^{210}Pb (half-life 22.3 years) measurements, are greatest on the clinoform foreset (~ 1 cm y^{-1}), which is characterized by seafloor crenulations in a few areas. However, for some cross-sections of the clinoform, accumulation rates are not significantly higher on the foreset than on the topset and bottomset, indicating that the clinoform may not be actively prograding in those areas today. Accumulation rates increase southward along the shelf and are greatest near the Gargano Peninsula (~ 1.7 cm y^{-1}). Between Ravenna and the Gargano Peninsula, 3.1×10^7 t y^{-1} of sediment accumulate on the Apennine shelf. Although the amounts of sediment supply and accumulation are about the same, additional Po River sediment is thought to enter the system from the north and some sediment is transported beyond the Gargano Peninsula to the south.

Anthropogenic activities, particularly dam construction following World War II, have significantly impacted sedimentation in this region. Changes in ^{210}Pb profiles document reduction in sediment accumulation. However, observations during winter 2002–2003 using the short-lived radioisotope ^{7}Be (half-life 53.3 d) have indicated that some new sediment is delivered to the shelf during periods of elevated discharge, so dam entrapment is not complete.

Keywords: ^{210}Pb; clinoform; sediment; Adriatic Sea; Apennine Rivers; anthropogenic effects

1. Introduction

Clinoforms make up the bulk of stratigraphic sequences underlying continental shelves (Mitchum et al., 1977) and have been observed in many depositional systems (e.g., the shelves near the Amazon and Ganges-Brahmaputra Rivers; Nittrouer et al., 1986; Kuehl et al., 1997), yet much is still unknown regarding their formation and maintenance. This is especially true in the Adriatic Sea, where a shelf clinoform has developed along the central Italian coast in response to sediment delivery from a series of fluvial sources (i.e., a line source) draining the Apennine Mountains. These rivers (collectively termed the "Apennine Rivers" in this paper) together discharge $\sim 3 \times 10^7$ tons of sediment annually (Cattaneo et al., 2003; Frignani et al., 2005; Syvitski and Kettner, in press) and are classified as small mountainous rivers, a type of sediment source recognized globally as important for the marine environment (Milliman and Syvitski, 1992). Most previous investigations into continental-shelf sedimentation have focused largely on sediment delivery from single fluvial sources (e.g.,

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the Po River in the northern Adriatic), and sedimentation resulting from multiple fluvial sources is not well understood. For example, in the Gulf of Alaska, distinct shelf deposits are observed from each individual river (Jaeger et al., 1998), whereas, in the Gulf of Papua, river inputs coalesce into a central locus of accumulation (Walsh et al., 2004). Examination of sedimentation along the Apennine shelf will further elucidate the controlling mechanisms for the formation of sedimentary deposits, particularly shelf clinoforms, in line-source systems.

Sedimentation along the Italian coast has been significantly altered by anthropogenic activities during the last century, mostly through dam construction, river stabilization, and quarrying (Coltorti, 1997; Farroni et al., 2002). Dams alter the discharge of affected rivers and reduce the amount of material delivered to the Adriatic (e.g., the Barrea dam, constructed in 1954, dramatically reduced the sediment load of the Sangro River; Capelli et al., 1997). While there have been many studies investigating the impact of dams on sediment in fluvial systems (e.g., the Ebro River; Ibanez et al., 1996; Batalla et al., 2004), relatively few have assessed the downstream impact on marine sedimentation.

The objectives of this study are to: 1) characterize sedimentation along the Apennine shelf clinoform, 2) construct a ~100-y sediment budget for the western Adriatic coast, and 3) assess the impact of anthropogenic activities on clinoform sedimentation.

2. Background

2.1. Regional setting

The northern Adriatic Sea is a shallow epicontinental sea, corresponding to the most recent Apennine foreland basin (Ori et al., 1986), which is bounded by the Italian and Balkan peninsulas on the west and east, respectively. The surface circulation is driven primarily by thermohaline processes resulting from freshwater input in the north and exchange with the Ionian Sea through the Strait of Otranto in the south. This produces cyclonic circulation with a northward-flowing current along the eastern boundary that turns and flows southward along the western boundary, as the Western Adriatic Current (WAC; Orlic et al., 1992; Artegiani et al., 1997). Wind-driven circulation becomes dominant during Bora and Scirocco events that are generally strongest in winter months. Bora winds are cold, continental, northeasterly winds that cool surface waters, resulting in downwelling and dense-water formation (Hendershott and Rizzoli, 1976). Scirocco winds are moist, southeasterly winds that raise water levels in the northern Adriatic, and frequently cause storm surges and flooding of coastal towns such as Venice (Orlic et al., 1994; Pirazzoli and Tomasin, 2002).

This study investigates sedimentary processes on the western Adriatic coast in the area between Ravenna and the Gargano Peninsula (Fig. 1A), where sedimentation from the Apennine Rivers occurs (see Fig. 5 for sediment-load estimates of individual rivers). To the north, where sedimentation from the Po River is dominant, offshore gradients of the seabed are gentle (~0.02°; Cattaneo and Trincardi, 1999) and water depths are <50 m. However, in the central portion of the study area, the clinoform structure is present and shelf gradients steepen on the foreset (~0.5°; Cattaneo and Trincardi, 1999) and extend to water depths >50 m.

Along the Apennine coast, the shore-parallel shelf clinoform (Fig. 1B) is the major component of the late-Holocene Highstand Systems Tract (HST) recognized on seismic profiles (Trincardi et al., 1996). This deposit is up to 35 m thick in places and is composed of overlapping sigmoids consisting of gently dipping topsets and more steeply dipping foresets. The location of the rollover point (i.e., boundary between the topset and foreset) deepens southward, from 20 m near Ancona to 35–40 m near Ortona (Correggiari et al., 2001).

Previous estimates of sediment accumulation in this area have indicated that rates increase southward alongshelf, reaching a maximum >1 cm y^{-1} near the Gargano Peninsula (Cattaneo et al., 2003; Frignani et al., 2005). Across-shelf rates are generally highest on the foreset of the clinoform but can vary depending on local morphologic features (e.g., sea-floor crenulations, where accumulation rates range from 0.4 cm y^{-1} to 1.6 cm y^{-1} on the dipping and flat surfaces, respectively; Correggiari et al., 2001). Approximately 10% of fluvial input to the western Adriatic shelf is exported beyond the Gargano Peninsula to the southern Adriatic basin and/or the Mediterranean Sea (Frignani et al., 2005).

2.2. Clinoform sedimentation

The term “clinoform” has been used to describe a sloping accretionary feature on continental margins, varying in size from several to hundreds of meters and in age from hundreds to millions of years (Cattaneo et al., 2004). The dimensions and shape of a clinoform are determined by such factors as relative sea level, sediment supply, depositional regime, accommodation space, and sediment type (Pirmez et al., 1998; Driscoll and Karner, 1999). Sedimentary characteristics vary according to the clinoform geometry, which consists of the topset, foreset, and bottomset beds (Alexander et al.,