ELSEVIER

Marine Geology 222–223 (2005) 471–495

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

www.elsevier.com/locate/margeo

Mediterranean river systems of Andalusia, southern Spain, and associated deltas: A source to sink approach

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Received 8 June 2004; received in revised form 28 December 2004; accepted 15 June 2005

Abstract

The northern shores of the semi-isolated Mediterranean Sea with its low tidal range and a relatively voluminous fluvial supply of sediments constitute an ideal delta forming environment. In this paper, we examine the present-day and multi-decadal behaviour of 26 river systems from Andalusia, southern Spain, forming deltas in the Alboran Sea, the westernmost basin in the Mediterranean Sea. Eastern, Central and Western Andalusian watersheds have been defined based on geomorphological, climatological and hydrological characteristics.

A comprehensive data set has been compiled, including satellite images, aerial photographs, a digital elevation model, thematic maps, time series of precipitation, temperature and water discharge, and the damming history of individual river basins. This data set has been used to analyse basin morphology and hydrology, and anthropogenic impact. Several modelling approaches have been applied to obtain the water budget and mean annual sediment yield of 12 of the 26 studied river systems. In addition, the periodicities of water discharge events and their possible link with North Atlantic Oscillation (NAO) fluctuations have been also studied.

A decreasing trend has been observed in most water discharge time series during the last decades, which has been attributed to natural factors. Although it could have been expected that the diminution of water discharge may have caused a reduction in sediment load, calculated sediment discharge time series do not show any significant tendency. In general, sediment yield shows an opposite relationship with basin area.

A comparative analysis of Spanish Mediterranean deltas indicates that in terms of sediment transport Andalusian river systems are quite efficient despite the small size of their catchments. Repetitive flood events and the consequent suspension plumes off river mouths play a major role in the development of deltaic and prodeltaic bodies. Nowadays, 42% of the study area is regulated, although to date the effect of dam building is hardly noticeable on river mouths.

Keywords: river/delta systems; southern Spain; water discharge; sediment load

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doi:10.1016/j.margeo.2005.06.033

1. Introduction

Deltas form where the supply of sediment by rivers exceeds the dispersal capacity of the receptor basin (McManus, 2002). Thus, the semi-enclosed Mediterranean Sea with its micro-tidal range and its relatively important supply of sediments constitutes an ideal delta-forming place. Anthropogenic influence in the Mediterranean region dates from millennia, though it has increased during the last centuries and, specially, during the 20th century (Poulos and Collins, 2002; Vorosmarty et al., 2003). Mediterranean river basins and associated coastal environments are a perfect place to study the processes governing the transfer of water and sediment from continent to ocean and the historically recent human impacts on such transfer.

The Mediterranean Basin (3800 × 800 km approximately) is located at mid-latitude, between 33°N and 45°N. Dominant winds and consequent atmospheric climate are strongly conditioned by mountain ranges such as the Alps and the Central Massif in Central Europe, the Pyrenees, the Iberian Massif and the Betic Cordillera in Spain, the Taurus Mountain range in the Anatolia Peninsula, and the Lebanese mountains (UNEP, 2002). These mountainous barriers together with a considerable land area surrounding a relatively small sea make Mediterranean weather and climate more continental in origin than marine (Hopkins, 1985). There are also important differences within the Mediterranean watershed. Yearly rainfall varies from more than 1500 mm over the European mountain ranges to less than 100 mm inland of northern Africa and western Asia (UNEP, 2002). This explains why runoff is at least one order of magnitude greater in the northern watershed than in the southern one (Cruzado, 1979; Liquete et al., 2004).

During the Holocene, the main Mediterranean river systems (Ebro, Rhone, Po, Axios, Seyhan and Nile) formed 10- to 40-m-thick deltas, while during the 20th century the Ebro, Po and Nile deltas underwent coastal retreats of more than 10 m (Poulos and Collins, 2002). Nevertheless, excluding these few large rivers, most of the fluvial systems draining into the Mediterranean Sea are relatively small and flow into relatively narrow littoral zones. Farnsworth and Milliman (2003) and Milliman and Syvitski (1992) pointed out the importance of small mountainous rivers, usually intermittent and event-driven, to the global sediment budget. However, the prime problem when studying these systems is most often the lack of continuous hydrological data. Their transport patterns are just starting to receive scientific attention (e.g., Kettner and Syvitski, 2003; Kineke et al., 2003; Pavanelli and Pagliarani, 2002). In addition, environmental changes may have a greater impact on these small streams than on larger rivers (Syvitski, 2003).

Fluvial sediment load is sensitive to many hydrologic, geomorphic, climatologic and anthopogenic factors. Parameters such as relief, precipitation, air temperature, runoff, vegetal cover and lithology must be taken into account when evaluating erosion in a river basin (Dendy and Bolton, 1976; Jansen and Painter, 1974; Ludwig, 1997; Pinet and Souriau, 1988; Probst, 1992). These parameters have been considered in this paper to examine the present-day and multi-decadal behaviour of river/delta systems from Andalusia flowing into the Alboran Sea, the westernmost basin in the Mediterranean Sea. It is the first attempt to systematically study a set of neighbouring river systems feeding deltas along 400 km of shoreline in southern Spain and to quantify hydrological and sedimentary budgets.

2. Regional setting

Dozens of river systems feed deltaic and prodeltaic bodies along the Mediterranean shoreline of Spain. These range from the large Ebro system (982 km long and 85 708 km^2 of river basin) to small rivers that are dry most of the year.

All Andalusian fluvial systems flowing into the Alboran Sea and forming deltas have been considered in this work (Fig. 1). These include 26 river basins draining the Betic Cordillera Internal Zone of Andalusia (with peaks up to 3500 m in height), one of the hottest, driest and least vegetated regions in Spain. The eastern part of the study area can be regarded as one of the most tectonically active zones in the Iberian Peninsula (Gimenez et al., 2000).

The Betic Cordillera formed during the Alpine orogeny between 20 and 5 Myr ago (Fontbote and Vera, 1983). The Cordillera resulted from the convergence between the African and the Eurasian plates at a rate of about 0.5 cm/yr (Garcia et al., 2003; Sanz de Galdeano et al., 1995). The collision between the two plates caused continuous compression leading to the