

Soil erosion processes and sediment fluxes in a Mediterranean landscape of marls, Campiña de Cádiz, SW Spain.

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ABSTRACT

Marl landscapes, especially in the Mediterranean, show evident traces of high present-day and past soil erosion rates. The tendency to develop hillslope channels leads even at moderate rainstorm magnitudes to a significant increase of slope-to-slope connectivity, resulting in high amounts of mass transfer from upper parts of the hillslopes towards footslopes and valleyfloors. To analyse the intensity of this transfer a study was conducted focussing on late Holocene sediments correlative to modern-time soil erosion in the marl landscape of SW Spain. Based on field observations and sediment analysis several landscape positions within a medium-scale catchment were explored. Depending on landscape constellation, the sediment characteristics reflect either hillslope processes or alluvial processes or an interchange of them. For a temporal context a method to trace young sediments by analysing nutrients originating from modern-time application of mineral fertiliser was applied. Results show high rates of sedimentation (>1 cm/year) for this young period in several profiles. By identifying the predominant geomorphic components and processes in the study area a conceptual model of the studied system was developed.

INTRODUCTION

Under appropriate climatic conditions marl landscapes are counted among the world's most favourable regions for agricultural land use, offering good physical and chemical soil properties and high crop yield. These formations commonly form a typical landscape of rolling-hills with wide valley floors. Particularly, the Mediterranean marl landscapes of southern Europe have undergone a long history of land use resulted in huge soil erosion rates of up to 120 t/ha on 1000 m² field plots for single rainstorms of high intensity. Such rainfall events in average occur twice to three times per year (Faust, 1995). Especially Mediterranean marl landscapes show evidence of significant soil erosion and landscape degradation in the past and present (e.g. Poesen and Hooke, 1997; Casali et al., 1999; Cerdà, 2002; Bracken and Kirkby, 2005). Several authors point out the tendency to develop linear soil erosion features (rills and gullies) caused by concentrated overland flow (Faust and Herkommer, 1995). Most likely, not only physical properties but also geochemical properties cause this affinity to develop linear soil erosion features (Imeson and Verstraten, 1988; Benito et al., 1993). In our case high sodium saturations of the Miocene marls are reported (Faust, 1995). These erosion features tend to serve as important transport paths and effective links for routing sediment between connected landscape elements (c.f. Poesen et al., 2003). Hence, high intra-slope connectivity and correspondingly high amounts of mass transfer (or flux) towards the valley floors can be expected.

Based on field observations and soil sampling several landscape positions were explored and subsequently, a conceptual model of the predominant geomorphic components and processes controlling the studied system was developed.

GEOGRAPHICAL SETTING

Our investigation focuses on the catchment of the Arroyo Salado de Espera, a direct tributary of the Guadalete river (Province Cádiz). Some facts:

Altitudes in the catchment vary from about 400 m a.s.l. to 35 m a.s.l. Climate is semi-humid with precipitation amounts between 600 to 800 mm/y and mean annual temperature of 18°C. 25 to 50% of all precipitations are heavy rainfalls, which occur in October/November and from February to April.

Parent materials are mainly friable Keuper marls covered by Tertiary marls. Keuper marls show higher clay contents (30-35%) and lower CaCO_3 contents (25-30%), whereas Tertiary marls show higher CaCO_3 contents (>45%) and lower clay contents (20-25%) (Faust and Herkommer, 1995). Holocene sediments are mixed deriving from Tertiary marls and Keuper marls.

Mean slope angle is 5.8° . Due to severe soil erosion complete soil profiles are absent. In fact, upper parts of the slopes are strongly eroded and lower parts are covered by colluvial sediments. 90% of the area is under agricultural use. Large field plots dominate the rolling-hills. The former *Quercus ilex* forest can only be found in protected areas and as remnants of single trees in the cultivated land.

FUNDAMENTAL LANDSCAPE INFORMATION

Concerning our results and interpretation, fundamental landscape information is needed for a better understanding of morphodynamics in such a highly sensitive landscape. In general the landscape shows a wide variety of different soil colours. This is due to the fact that the slopes are formed by different parent material. On the one hand we see Keuper marls with generally brownish, reddish and even greyish colouring, whereas the Tertiary marls are showing mostly creme to white colours. Darkish sediments in depressions are restricted to Tertiary marls. After heavy rainfall events most of these depressions are covered by light coloured hillslope sediments. After subsequent ploughing these light coloured sediments are mixed with the underlying darkish horizon and virtually disappear.

Measured pH-values of more than 100 samples only vary slightly between 7 and 8 because of high content of CaCO_3 (>25%). In consequence we do not expect any significant vertical transport of dissolved fertiliser nutrients. Depth of tillage in most cases does not exceed 15. As a result a hard plough pan develops. Consequently rill incision is blocked at this depth and rills tend to widen. The widening of rills therefore must be seen as the dominant factor that controls the quantity of soil erosion in this area (Faust, 1995).

The whole landscape is characterized by very vast field plots. Plots with extensions of 30 ha or even more are quite common. Runoff is therefore rarely broken by obstacles and barriers, resulting in a high potential connectivity. However, because of the wide range of rainfall magnitudes, effective connectivity varies significantly. For that reason it is hardly possible to clearly define areas of erosion and deposition because on one and the same hillslope position erosion or accumulation could happen according to rainfall magnitude. Valley floors must be seen as the only positions where accumulation predominantly occurs. In these positions drillings were carried out to get a better insight into the sedimentation sequences in order to conduct rough estimates of sedimentation rates.

CONCEPTUAL MODEL OF GEOMORPHIC PROCESSES

As no concept of the actual morphodynamic system for the marl landscape of Andalusia exists, we propose a conceptual model of the predominant geomorphic components and processes controlling the studied system (figure 1.). It focuses on man-induced sediment fluxes in the studied catchment.

During erosive rainstorms in areas of interrill activity soil particles are mostly detached by raindrop impact and transported over short distances by laminar overland flow. As runoff increases surface particles are redistributed by the increasing overland flow (wash) (Martínez-Mena et al, 2002). With concentration of overland flow on large areas of the shoulders and backslopes rill development can be observed. Quantities of eroded material thereby increase rapidly as rills develop. Similar observations are reported in other studies (e.g. Loch and Donellan, 1983) as process limitations change to a predominantly transport limited system because detachment and transport inside the rills is only restricted by hydraulic properties (Polyakov and Nearing, 2003) and shear stress easily detaches gravels and clay-aggregates as the correlative sediments show (see Poesen, 1987). The hierarchical rill systems serve as effective links for sediment transfer down slope where rills end due to decrease of slope and therefore transport capacity, forming large hillslope deposits on foot- and toeslopes (Faust, 1991). Rainfall measurements (Faust 1995) show that in the study area rills develop in backslope positions under rainfall amounts of 20 – 35 mm/d including

some high short-term intensities. Due to high frequencies of this type of rainfall (about 4 times a year) high geomorphic effects can be observed what can be seen in changing backslope – footslope geometry. With a further concentration of overland flow in predestinated topographic positions due to higher magnitude of rainfall shallow ephemeral gullies develop (c.f. Vandekerckhove et al, 1998). Together with rill-networks, ephemeral gullies must be regarded as main sediment sources in the area transferring large quantities of sediment downslope. During erosive rainfalls of high to very high magnitude the incision of such hillslope channels result in larger, mostly permanent gullies (described by Faust and Diaz del Olmo, 1999) transporting remobilised colluvial slope deposits deriving from former events of less magnitude. These channels increase landscape connectivity (Poesen et al., 2003) and, in some cases, couple hillslopes directly with the river channel system, what can be seen during events of very high magnitude. In consequence a change of such drainage pattern due to a reorganisation of the gully network results in a change of the spatial linkage of landscape elements and consequently sediment fluxes. In contrast to the increase of connectivity by channels, hillslope deposits and sedimentation fans on footslopes as a result of less rainfall lower system connectivity dramatically. Sediments are only reworked by high magnitude events. Beside rill erosion phenomena we observe also landslides having a comparable effect. If landslides happen during a rainfall event of lower magnitude the slide mass is stored just in front of the collapse structure, whereas rainfall of higher magnitude runoff will be able to transport the slide masses resulting in a gully system described in Faust & Diaz del Olmo 1999. They propose for this landscape two genetically different gully-systems; a gully-system caused by incision and a gully-system caused by landslide.

As sediment reaches the channel, it is in small parts influenced by channel processes including the development and reworking of channel bars and deposits. In the upper main valley and tributary rivers storage mainly occurs by overbank sedimentation during regularly recurring floods. Such deposits are partly reworked by shallow gullies developing during high magnitude events on toeslopes and valleyfloors. In addition river banks can be eroded by stream forces inside the channel and the development of bank gullies can reactivate large quantities of stored sediments (Oostwoud Wijdenes et al., 2000).

Due to a broad valleyfloor the lower main valley is predominantly characterised by sedimentation of overbank deposits, which are partly reworked by processes of bank erosion. Shallow gullies develop on the wide floodplains only very infrequent and seldom, consequently little sediment is remobilised from the floodplain. Sedimentation rates of 10 to 20 mm/ year attest the high actual storage capacity of the lower main valley floodplain.

As no data on sediment load of the Arroyo Salado de Espera exists, it is very difficult to make any statements on system sediment yield. Further research should therefore focus on the effective system delivery to the downstream lying Guadalete River.

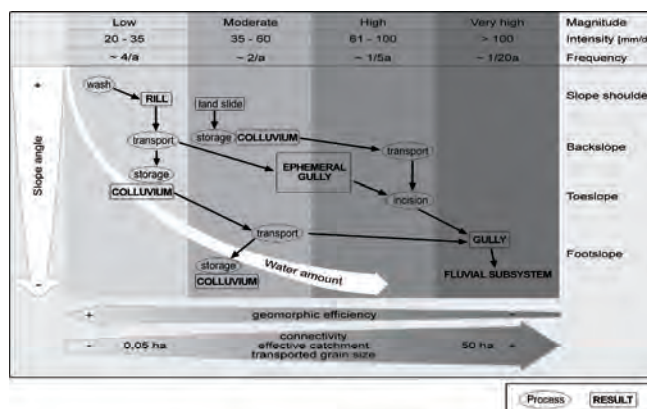


Figure 1: Proposed conceptual model of the predominant geomorphic components and processes controlling the marl landscape of western Andalusia. Arrows denote linkages between compartments and transport directions. Line thicknesses indicate intensity of processes.

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