The Guadiana River: the role of tectonics on drainage configuration

O rio Guadiana: o papel da tectônica na configuração da drenagem

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Abstract: Our goal is to determine the Alpine structures that configure Guadiana drainage. We performed a statistical analysis of digital elevation data and obtained a map of Gaussian filtering distribution. Two domains are discriminate: a domain characterized by a small range of values related to Cenozoic basins and old erosion surfaces remnants on Iberian Massif landscapes and another domain that shows a broad range featuring an Appalachian landscape. Linear features, related to domain limits and within them, are associated with E-W to NE-SW Alpine faults that control drainage network. E-W structures contribute to maintain E-W water flow direction. The activity of NNE faults controls the elevation of basement thresholds and the presence of resistant rocks, restricting or impairing westward flow. For example, the lower Guadiana is unable to breach through Messejana-Plasencia Fault and thus changes its direction towards the south. Variscan structures rule tributaries orientations draining SW Iberian Massif.

Keywords: Guadiana drainage basin, Gaussian filtering, Alpine tectonics.

1. Introduction

The Iberian Peninsula shows an asymmetric water divide consisting mostly of short rivers draining into the Mediterranean Sea and longer rivers emptying into the Atlantic Ocean. Drainage pattern is conditioned by the tectonic framework of Iberia. N-S convergence of the Eurasian and African plates created two collision chains at the northern and southern margins of Iberia, the Pyrenees and Cantabrian Mountains and the Betic Range and intraplate ranges as the Central System and Toledo Mountains (Fig. 1).

Between the ranges developed sedimentary basins filled by continental deposits that hosted former watershed. The basin’s opening into the Atlantic Ocean took place in the middle Cenozoic in a landscape featuring vast erosion surfaces. Since, on their way to the sea, Atlantic rivers flow along sedimentary basins and cut hard Variscan basement massifs maintaining a roughly E-W orientation. Drainage network configuration must have been complex and controlled by forces such as those imposed by resistant rocks and fractures networks determining the preferential incision pattern.

The purpose of this work is to examine the role of tectonics on the configuration of the Guadiana river drainage network, the Iberia’s fifth longest river with ~710 km long. As the other western rivers, it runs E-W along a Cenozoic basin in its middle reach, yet unlike them, its lower reach takes sharp turn southward and outflows into the Gulf of Cadiz draining extensive plains sculptured on the Variscan basement. Through the application of a high-pass Gaussian filter to gridded digital elevation data; we explore the tectonic structures controlling the relief of the watershed and neighborhood areas. Results point out the decisive role of E-W tectonic units controlling water flow but NE-SW faults imposed the drainage network geometry.

2. Geologic and geomorphologic setting of Guadiana drainage basin

A widespread outcrop of Variscan basement characterizes the geology of SW Iberia Massif. The area comprises an excellent record of three of the tectonostratigraphic zones...
recognized in the Variscan orogen. These are from NE to SW: Central Iberian, Ossa-Morena and South Portuguese zones (Fig. 2). The Central Iberian Zone consists of Palaeozoic slates and quartzites overlying a thick succession of Proterozoic greywackes and slates. The Ossa Morena Zone includes a complete succession of Proterozoic and Paleozoic rocks consisting of slates, sandstones, quartzites, limestones and volcanics. Batholiths are common in both zones and granitic compositions predominate, although basic rocks also exist in the Ossa Morena Zone. To the SW, the South Portuguese Zone presents Devonian to Carboniferous metamorphic rocks.

Iberian Massif structure is complex. During compression events, thrusts stack up several crustal sheets building the Variscan orogen. NW-SE structures orientation dominate. Crust extension, gravity collapse and erosion dismantled created mountain range thus, at the beginning of the Alpine cycle a vast erosion surface was formed. Although some Mesozoic sediment exists in the easternmost Iberian Massif, these are lacking in the western peninsula. N-S compressive stress field drove Alpine tectonics deforming Variscan basement and giving rise a new tectonic configuration of Iberia. E-W trending ranges flanked by sedimentary basins were built (De Vicente & Vegas, 2009). The middle reach of Guadiana River coincides with a sedimentary basin filled by no more than 200 m of siliciclastic sediments that fringe the Toledo Mountains. E-W to NE-SW thrusts raise up the basement, crosscutting the NW-SW Variscan structures. Precambrian rocks occupy the antiforms core while synforms are formed by a Paleozoic succession where quartzite levels design folds geometry and provide an Appalachian landscape. NE-SW left strike-slip faults offset E-W structures. Two of these faults, the Merida Fault and the well-known Messejana-Plasencia Fault (MPF) play an essential role in the configuration of the Guadiana basin. They are left lateral strike-slip faults that create elevated basement blocks acting as obstacles, which are sometimes insurmountable for river courses (Fig. 2). The Merida Fault divide the Guadiana sedimentary Basin into two sub basins: the Vegas Bajas and Vegas Altas. Both faults raise up their western block, changing rivers paths. MPF vertical offset raises more than 250m the basement west of Vegas Bajas Basin. Recent MPF activity has been documented (Cabral, 1995; Araújo, 2004; Villamor, 2002) and appears to be responsible for the shift to the south of the Guadiana River. Southwards, the most important Alpine structure is the Vidigueira fault (Brum da Silveira et al., 2009). This inverse E-W fault defines the margins of a small Cenozoic depression drained by the Guadiana River (Fig. 2).

3. Methods

We analyzed topography of SW Iberia by means of a statistical analysis. Statistical analysis has a rich history in the earth sciences and has been used to quantify various topographic patterns and landscape-scaling properties (Perron et al., 2008; Garzón & Garrote, 2007, Tejero et al., 2010). We apply a high-pass Gaussian filter, with a cutoff wavelength of 5000 m. We perform the computations using topography data set from the Instituto Geográfico Nacional (DEM resolution 25 m) and the ASTER Global Digital Elevation (spatial resolution ≈30 m). The data set were gridded by kriging every 50 m. Computation was made in the Fourier domain. Gridded elevation data was transformed to the wavenumber domain applying the Fast Fourier Transform, then we applied a high-pass Gaussian filter and we performed the inverse FFT process. In filtering we retained only the high frequencies in order to heighten scarps and abrupt areas from relief. To perform estimations we used the capabilities of montaj MAGMAP Filtering system integrated in the Oasis montaj V7.1 software package.

4. Topography analysis results

Gaussian distribution ranges between -267 to 338 m, but most of the area is between -72 and 60 m. Within this “residual map” of topography, we can distinguish two domains: a domain characterized by values between -15 and 15 m, mainly red, yellow and green colored and a domain which includes the highest figures, negative and positive, blue and pink colored (Fig. 3). The small range domain corresponds to gently relief zones as sedimentary basins and plains, whereas the domain represented by a wider range are related to abrupt relieves as mountainous landscapes driven by alternations of hard and soft rocks giving rise an Appalachian relief. Between the domains can be found intermediate values or linear values discontinuities.
Small range domain of Gaussian distribution
These values characterized the west and central part of the area. Comparing with the geological map they mark sedimentary basins and gently plains developed on basement rocks. Green-yellow colored domains include sedimentary basins as the Guadiana Basin, the Tajo and Guadalquivir basins as well as some small basins located to the west and northwest (Fig. 3). Out of the basins, the domain extents over the basement outcrops pointing remnants of old erosion surfaces i.e. pediments (Fig. 3 and 4). There, the landscape is smooth and undulating and a thin layer of rock alteration or sediments may cover the surface suddenly cut by deeply incised rivers, represented in the map by blue lines that follow rivers courses. River incision is found in the Guadiana lower reach where the river has created a strath terrace that floored the valley bottom now being cut by a narrow river channel (Fig. 3).

Wide range of Gaussian distribution domain
The other domain clearly represents highlands. Distribution shows a dendritic fluvial pattern in the northern area where igneous rocks predominate and alienated pink and blue stripes where the presence of hard
rock as quartzites let to decipher Variscan NW-SE trending structures.

**Linear features**

Gaussian filtering has highlighted linear features. Sometimes they limit Gaussian distribution domains and sometimes coincide with straight valleys or alignments of quartzites that stand out in the landscape and define the Variscan folds geometry. Figures 3A, B and C highlight some linear features related to faults. Figures 3A and B illustrate the Gaussian distribution of MPF topographic features. At the southwest, MPF cut and displaces the Vidigueira Fault whose scarp is delineated by high differences of Gaussian values (Fig. 3A). In this area, MPF signature is not so obvious because values are closer but a clear linear feature can be drawn and it is well defined at a regional scale (Fig. 3). To the north, Gaussian map enhances the linear character of the valley associated with MPF (Fig. 3B), where pull-apart basins develop (Villamor, 2002). Produced map also described E-W faults. Figure 3C shows the northern limit of the Vegas Altas Basin. Differences between mountainous landscape (pink and blue colored) and basin topography define faults traces. Pink fringes mark quarzites outcrops. Figure 4 outlines main lineaments drawn from Gaussian map. NE-SW to E-W linear features correspond to thrusts and reverse faults, whereas NE-SW lineaments are related to left lateral strike-slip faults (Fig. 4). More conspicuous lineaments trend NE-SW reaching a length of more than 100 km. Gaussian map is a good tool to analyze Alpine structure fabric.

**5. Discussion**

Figure 4 draws a scheme of main Alpine faults and the extent of sedimentary basins and erosion surfaces mapped from Gaussian distribution. Basement landscape is characterized by the remnants of an extensive planation surface configured before Paleogene continental basin sedimentation (Ferreira, 1981; Martín-Serrano, 2005). This surface is disrupted by E-W to NE-SW Alpine faults that control Guadiana drainage network and feature linear discontinuities on Gaussian distribution. E-W structures limit uplifted and depressed crust blocks, sources of continental deposits of adjacent sedimentary basins. Linear valleys segments match faults traces but also are arranged according to NW orientations. There is a widespread agreement that NW faults are actives under Alpine stress fields, being outstanding to the north and east of Iberia. Our relief analysis suggests that they are not so important in western Iberian Massif but measured of river segments longer than 5 km show a NW maximum (Fig. 5). The trend is related to Variscan structures orientations (LNEG-LGM; 2010; Rodríguez-Fernández, 2004). Variscan structures provide NW discontinuities as foliation planes, bedding, faults that can accommodate deformation inhibiting reactivation or creation of new NW structures. Differential erosion of basement rocks as well as weakness zones must control surface runoff and stream paths in the Guadiana River lower reach.

If E-W structures drive general direction of water flow, NE-SW faults play a critical role on Guadiana drainage network configuration. North water divide is clearly offset by Messejana-Plasencia and Merida faults (Fig. 4). Both determine abrupt changes on river orientation. Guadiana River describes a “forced” meander to bypass uplifted basement along Merida Fault. To the west, at the edge of the Vegas Bajas Basin, Guadiana River turns south without crossing the relief created by the MPF, which forms the water divide (Fig. 5). Although the maximum level change does not exceed 250 m, the basement rocks are highly resistant to erosion and the river cannot break through. The fault shows recent neotectonic activity (Villamor, 2002; Araújo, 2004) and we can guess the possible youth of landscape and part of fluvial network (Rodríguez Vidal et al., 1993) and the tectonic control of drainage pattern.
6. Conclusions

Gaussian distribution has pointed the Alpine fabric in the SW Iberian Massif in a regional scale. Guadiana watershed development was determined by E-W and NE-SW Alpine faults. E-W structures drove the general water flow. NE-SW faults are responsible for stream reorientation, displacing main drainage directions to produce the confluence of water courses, inducing captures and reorganizing the drainage network according to regional tectonic trends.

Alpine geological history controls the Iberian drainage network and the relief is the consequence of long-term landscape development. The topography of the Iberian Massif may be described as the sum of an exhumed ancient landscape superimposed by a tectonic “landscape”, both reworked by the geomorphic processes of the Alpine post-deformation stage. Studies of the drainage network as a characteristic landscape feature may be a decisive tool for understanding the post-Variscan history of the SW Iberian Peninsula. Our results represent an initial approach to addressing the geological evolution of this area.

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