ASSOCIAÇÃO PORTUGUESA DE GEOMORFÓLOGOS VOLUME XII

X Congresso Nacional de Geomorfologia

Dinâmicas geomorfológicas no espaço e no tempo

ATAS / PROCEEDINGS

APGeom
Associação Portuguesa de Geomorfólogos

Lisboa
2024

X CONGRESSO NACIONAL DE GEOMORFOLOGIA

ASSOCIAÇÃO PORTUGUESA DE GEOMORFÓLOGOS
LISBOA, 2024

Título: X Congresso Nacional de Geomorfologia.

Editor: Associação Portuguesa de Geomorfólogos

Capa (Conceção): Jorge Trindade

ISBN: 978-972-636-312-5
Lisboa, setembro 2024

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Terraces of the Guadiana River between the Pulo do Lobo water fall and Pomarão - discussions about the evolution of the river in the late Pleistocene and Holocene

Os terraços do rio Guadiana, entre a cascata do Pulo do Lobo e o Pomarão - discussão acerca da evolução do rio durante o Plistocénico final e o Holocénico

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ABSTRACT
The terraces of the Guadiana River were mapped in the stretch between Pulo do Lobo and the Pomarão village. In this work we used the river terraces to estimate the uplift rate and to understand the main controls driving the river's incision throughout the late Pleistocene and Holocene. Four terrace levels were identified upstream of Pulo do Lobo and five terraces in the downstream reach. Uplift rates ranging between 0.071 m/ka and 0.041 m/ka were estimated. Since the mid-Holocene to the Present, the eustatic sea level variation appears to have been the main trigger for river incision.

Key-words: *Guadiana River; fluvial terraces; OSL dating; uplift rate; Holocene evolution*
Palavras-chave: Rio Guadiana; terraços fluviais; datação OSL; taxa de soerguimento; evolução holocénica

1. INTRODUTION
The terraces of the Guadiana River are poorly known in its lower reach, between the "Pulo do Lobo" (PL) water fall and the Pomarão village, located, respectively, at 85 km and 45 km from the river mouth. Feio (1947) carried out a relevant work about the terraces of the Guadiana River, up to Mértola small town, but constrained by the limitations of the topographical base maps from that time. In turn, detailed geomorphological mapping of the Guadiana River terraces downstream of Mértola has yet to be done. In this study we made a review of the cartography of the Guadiana River terraces and also contributed with insights into their chronological understanding. The absence of a chronological framework concerning the Guadiana terraces limits their utilization to determine the fluvial incision rate, or the tectonic uplift rate. An attempt to determine the age of the rocky terrace located about 21 metres above the PL river gorge was made by Ortega-Becerril et al. (2018). The obtained ages do not date the formation of the rock terrace, but the moment of its subaerial exposure, after the dismantling of the alluvial cover that filled the Guadiana valley. However, the model of Guadiana River evolution, suggested by Ortega-Becerril et al., (2018) is highly questionable, as it is not credible that the alluvial cover under which the terrace has been buried could be of Pliocene age. In this work we intend to estimate the rate of tectonic uplift and to shed light on the long-term evolution of the lower reach of the Guadiana River. We also aim to know which have been the driving forces responsible for the river incision during the Holocene.

2. METHODS

Digital terrain models, with a cell size of 10 m resolution, were used to produce detailed geomorphological maps about the terraces of the Guadiana River in the reach between PL and Pomarão. A field campaign was realized to collect samples and to elaborate a stratigraphic log of the sampling site. OSL (Optically Stimulated Luminescence) dating was conducted at the Risø DTU National Laboratory, Denmark, to determine the age of the lower terrace located +10 m above the river bed (a.r.b.). To know the elevation at the coast of the ideal river profiles corresponding to the lower terraces, was used the equation (1) (Hack, 1973). Where H is the river profile elevation, K is the average stream length gradient index (SL Index) and C is the regression intercept.

$$H = C - Kln(L) \qquad \text{Equation 1}$$

3. RESULTS AND DISCUSSION

Four terrace levels were identified at PL and five terraces at Mértola and Pomarão (Fig. 1 and Table 1). At PL, terraces survey was taken immediately upstream of the 15 m high waterfall, downstream from which develops a fluvial canyon until the vicinity of Mértola. In this location, the rocky terrace, T4 +21 m (a.r.b.) is estimated to be at 11 m above sea level (a.s.l.) near the coast, while the T5 terrace (+10 m) should be situated 4 m a.s.l. at the mouth of the Guadiana River. At Pomarão, the T5 is overlain by a probable Middle Holocene sandy cover (new data). The obtained ages are stratigraphically inverted (older to the top and younger to the base) indicate that the Guadiana River has been incising since the Middle Holocene to the present day. The PL waterfall is understood as the upstream limit of an incision wave that has migrated through the valley. In the corrigendum to the 2018 article, Ortega-Becerril et al. (2021) present cosmogenic ages dating the exumation of strath terrace situated +21 m a.r.b. The maximum ages obtained were 78.5 ± 8 ka and 83.2 ± 7.5 ka. However, these ages do not necessarily correspond to the genesis of the strath surface, which will be older. In a first approach hypothesis, the correlation of the T4 with the Last Interglacial (ca. 120 ka) gives an uplift rate of ca. 0.041 m/ka, considering the eustatic sea level 6 m above the present level. In a second approach hypothesis, the correlation of the T4 with the marine isotopic stage (MIS) 7 (ca. 200 ka) gives uplift rates of ca. 0.071 m/ka to 0.043 m/ka, depending on uncertainties related to eustatic levels (Much et al., 2012). These values are consistent with those presented by Cabral (2012) for the coastal region of Algarve and inland Alentejo, which range from 0.033 and 0.066 m/ka. We do not consider it likely that the T4 terrace could be much older than 200 ka, given the similarities in elevation a.r.b. between the terraces of the Guadiana River (at Mértola) and Tejo River (at Muge). These small towns are located at the upstream limit of the tides. Using the extreme uplift rate values of 0.071 m/ka and 0.041 m/ka, the amount of uplift ranges from 0.56 to 0.32 m over the last ~8000 years (the maximum age of the sandy cover overlying the T5). This suggests that the 4 m elevation of terrace T5 at the mouth of the Guadiana River is primarily attributed to changes in the eustatic component from the Middle Holocene to the present day, with a lesser contribution of the apparent sea level falling resulting from continental uplift. This fact is consistent with a higher temperature and eustatic sea level during the Middle Holocene compared to the present day (Briggs et al., 2014; Vinther et al., 2009; Jones, et al., 2023).

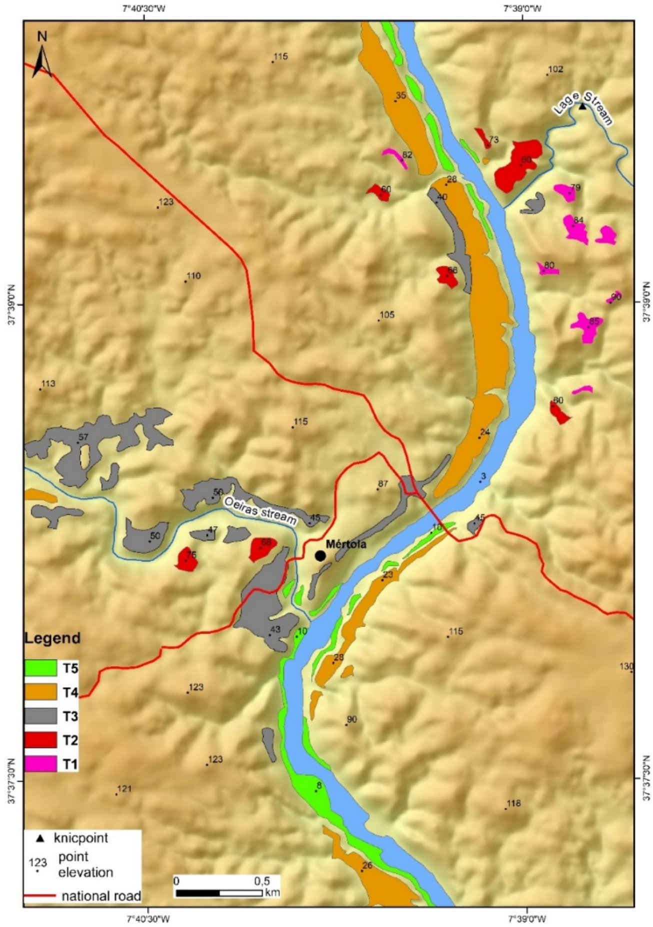

Figure 1. Geomorphological map of the Mértola area, representing the five terrace levels of the Guadiana River. The T4 terrace (+21 m a.r.b.) correspond to the *strath* terrace hanging 21 m above the Pulo do Lobo canyon. The T5 +9 m a.r.b. is buried by an alluvial cover at Pomarão (downstream out of the map). OSL samples were taken there.

Figure 2. Fieldwork was undertaken in 2022 at the Pomarão site to gather samples for OSL dating. The orange hue indicates the presence of sandstone overlying the T5 terrace.

Table 1. Elevation (m) above the river bed (a.r.b.) of the different terrace levels, at Pulo do Lobo, Mértola, Pomarão and at the mouth of the Guadiana River (Castro Marim).

LOCATIONS	T1	T2	T3	T4	T5	RIVER BED
PULO DO LOBO	+70	+51	+28	+6	-	31
MÉRTOLA	+82	+57	+37	+21	+9	3
POMARÃO	-	+58	-	+19	+10	0
AT THE MOUTH				+11	+4	

4. CONCLUSIONS

The Guadiana River boasts the formation of four terraces upstream of the PL waterfall, and an additional five downstream. While absolute ages are still unavailable, certain chronological indicators are discerned on the two lower terraces of the Guadiana River (T4 +21 m and T5 +10 m). The T4 is older than 78.5 ± 8 ka, but it shouldn't be much older than the MIS 7 (ca. 200 ka). The Middle Holocene sedimentary cover, overlying the T5, should be understood as the minimum age of this terrace, whose *strath* surface is older. The low rates of tectonic uplift in the area travelled by the Guadiana River are believed to have had a minimal impact on the Middle Holocene sea level's relative altitude (4 m), as the primary factor influencing this elevation is attributed to the eustatic component.

Acknowledgements

This work was supported by FCT, through the funding of Earth Sciences Institute (UIDB/04683/2020).

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