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Tectonic control of the Tejo river fluvial incision during the late Cenozoic, in Ródão—central Portugal (Atlantic Iberian border)

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Abstract

Staircases of strath terraces and strongly incised valleys are the most typical landscape features of Portuguese rivers. This paper examines the incision achieved during the late Cenozoic in an area crossed by the Tejo river between the border with Spain and the small town of Gavião. In the more upstream reach of this area, the Tejo crosses the Ródão tectonic depression, where four levels of terraces are distinguished. During the late Cenozoic fluvial incision stage, the Ródão depression underwent less uplift than the adjacent areas along the river. This is reflected by the greater thicknesses and spatial extent of the terraces; terrace genesis was promoted by impoundment of alluvium behind a quartzitic ridge and the local presence of a soft substratum. Outside this tectonic depression, the Tejo has a narrow valley incised in the Hercynian basement, with some straight reaches that probably correspond to NE–SW and NNW–SSE faults, the terraces being nearly absent. Geomorphological evidence of tectonic displacements affecting the Ródão dissected terrace remnants is described. Geochronological dating of the two younger and lower terrace levels of this depression suggests a time-averaged incision rate for the Tejo in the Ródão area, of ca. 1.0 m/ka over the last 60 thousand years. A clear discrepancy exists between this rate and the 0.1 m/ka estimated for the longer period since the end of the Pliocene. Although episodes of valley incision may be conditioned by climate and base-level changes, they may also have been controlled by local factors such as movement of small fault-bounded blocks, lithology and structure. Regional crustal uplift is considered to be the main control of the episodes of valley incision identified for this large, long-lived river. A model is proposed in which successive regional uplift events—tectonic phases—essentially determined the long periods of rapid river downcutting that were punctuated by short periods of lateral erosion and later by some aggradation, producing strath terraces.

Keywords: Tejo river; Cenozoic; Incision; Terraces; Tectonic uplift; Portugal

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1. Introduction

The Tejo is the longest river of the Iberian Peninsula (1007 km), with a catchment of 86 000 km^2. About 70% of this area is located in Spain (where the river is called the Tajo) and 30% in Portugal (the lower Tejo; Fig. 1). After crossing the Madrid Tertiary Basin in Spain and a craton (the "Meseta Extremeña"; Solé-Sabaris, 1952), the river enters Portugal in a deep V-shaped valley, incised more than 200 m into the extensive planation surface. Strongly incised valleys are characteristics of the majority of Portuguese rivers, except the reaches nearest the mouth areas that have Holocene sediments (Daveau, 1980; Ferreira, 1981, 1991).

From the Spanish border to the river mouth, the Tejo flows mainly over Paleozoic basement in the first quarter of its course (reaches I and II; Fig. 1) and over Tertiary sediments in the remaining sector (reaches III, IV and V).

In the Portuguese transect, the Tejo has terraces, varying in number up to five. However, within the Tertiary Madrid Basin, 13 terrace levels have been identified; up to 22 (between +210 and +5 m above the present-day channel) have been recognized in tributaries (Pérez-González, 1994). In this Spanish area, it has been claimed that the geometry and number of terrace facies were controlled not only by climate but also by tectonics and the lithology of the substrate (Pérez-González, 1982; Silva et al., 1997).

This paper focuses on the evolution of the Tejo river and on a discussion of allogenic forcing. Uplift as a principal controlling mechanism for fluvial incision is a debated subject in the geological and geomorphological literature. Tectonic control on landforms and late Cenozoic deposits, however, seems poorly understood in studies of intraplate areas. This study area was selected because of the very complete sedimentary and geomorphic record in an intraplate location, which documents the infill of the Lower Tejo Basin during the Tertiary and also the later sedimentary emptying, coeval with the long-term fluvial incision during the late Pliocene and Quaternary. In the Ródão depression, a staircase of terraces is present and in the lower terraces some important prehistoric artifacts have been found. Vertical offsets of terraces provide information about the amplitude and the relative chronology of vertical displacements. This terrace dating allows estimation of the rates of fluvial incision and helps to understand the long-term fluvial evolution of the Tejo in this sector. Stratigraphic, sedimentological and geomorphological study, and dating of these late Cenozoic fluvial landforms and deposits aim to characterize the successive fluvial downcutting events that have alternated with periods of aggradation.

The study of the evolution of long-lived river systems, in this case probably covering the last 3.4 Ma, is considered of major importance in documenting fluvial responses to allogenic forcing over both shorter (10^2–10^3 years) and longer time-scales (10^4–10^6 years) (Blum and Tornqvist, 2000). Despite many terrace records from many river systems around the world, it is unusual to be able to trace their drainage evolution over such a long period.

When the lowering of the base-level of a river is not balanced by lengthening of its course, incision will result in changes in profile immediately upstream (Summerfield, 1985). Such incision could, given enough time for the erosion of the substratum, be transmitted throughout the drainage basin via headward erosion through knickpoint recession. However, the upstream effects of base-level changes are in general very limited, particularly in large rivers which tend to accommodate small base-level variations through modification of the internal variables such as sinuosity or channel morphology (Schumm, 1993; Saucier, 1994; Shanley and McCabe, 1994; Bridgland and Allen, 1996).

Recent works tend to emphasize climate change superimposed on tectonically driven basin evolution (Perlmutter and Matthews, 1989; Paola et al., 1992; Sugai, 1993; Bridgland, 1994). Terrace staircases may provide a useful record of crustal movement (Merritts et al., 1994; Kiden and Tornqvist, 1998; Maddy et al., 2000; Lagarde et al., 2000).

If the balance between allogenic controls remains relatively constant for the individual river system under consideration, the river reaches equilibrium conditions after some period of time. In that dynamic situation, the river bevels sideways into the valley (no net change in sediment storage); the geometry is adjusted to prevailing discharge regimes and sediment loads. However, the progressive destruction of relief in upland source terrains leads to a decrease in stream

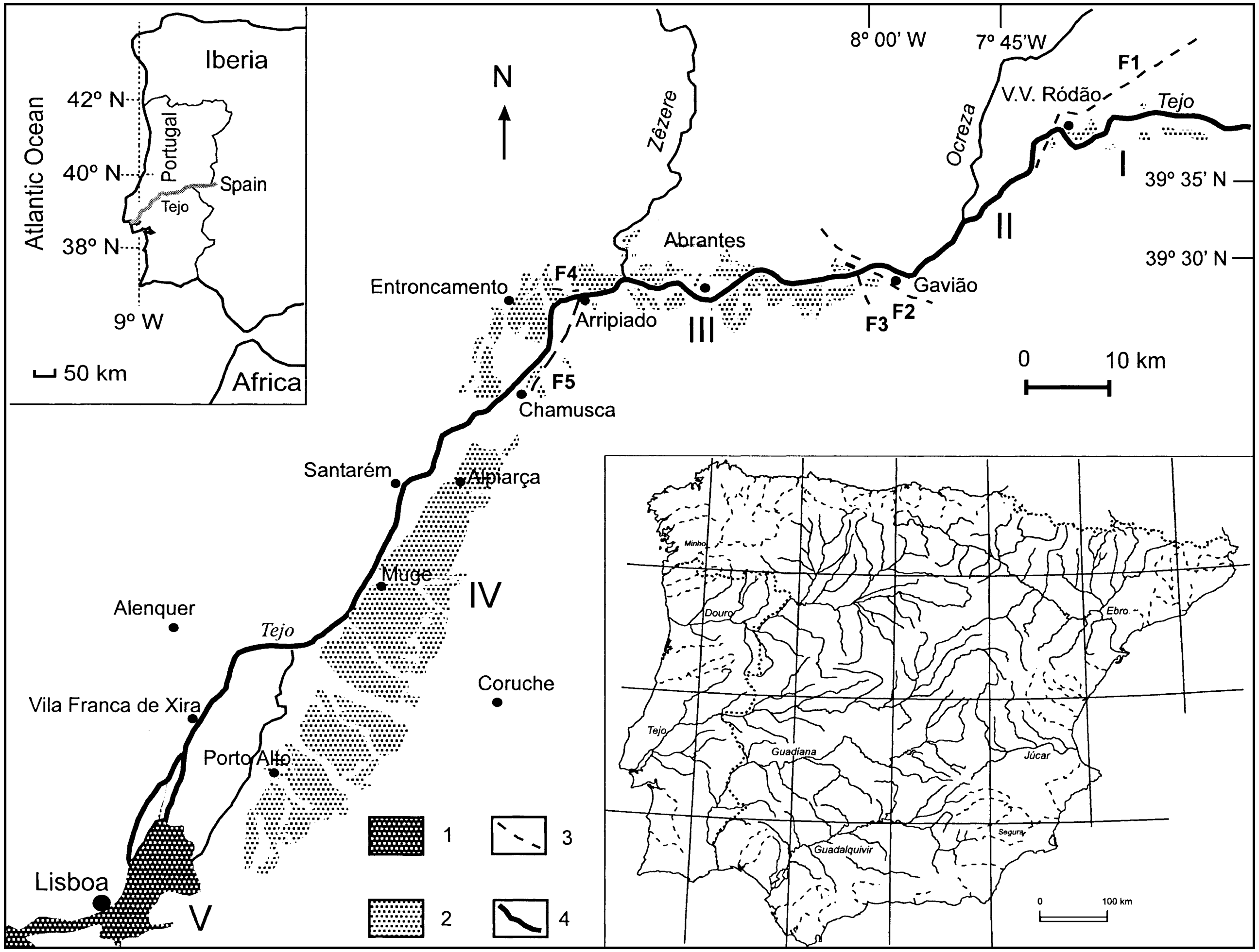


Fig. 1. Main Portuguese reaches in which the Tejo river can be divided (Lower Tejo Basin): I—from the Spanish border to Vila Velha de Ródão (a general E–W trend, mainly consisting of polygonal segments); II—from Vila Velha de Ródão to Gavião (NE–SW); III—from Gavião to Arripiado (E–W); IV—from Arripiado to Vila Franca de Xira; V—from Vila Franca de Xira to the Atlantic shoreline. The faults considered to be the limit of the referred fluvial sectors are represented (F1, F2, F3, F4 and F5). 1—estuary; 2—terraces; 3—faults; 4—Tejo main channel. The main Iberian drainage basins are also represented (this inset modified from Flor, 1999).

power (sensu Bull, 1979), which produces a change to progressive valley aggradation. If a significant change occurs in one, or more, of the allogenic controls, the fluvial system responds with aggradation if the sediment supply exceeds the bedload transport rates or responds with degradation if the stream power exceeds the sediment supply (Blum and Tornqvist, 2000).

The fluvial evolution at different time scales—expressed by fluvial deposits and landforms—is determined by the interaction between the forcing mechanisms (tectonics, eustacy and climate) that determine the balance (stream power vs. resisting power or degradation vs. aggradation). If successive aggradation events are larger than the sum of the degradation events, the sedimentary infill of the valley increases; in the opposite situation, the fluvial valley is deeply incised.

According to Blum and Tornqvist (2000), the upper reaches of drainage networks often possess bedrock channels with small and discontinuous floodplains, and short residence times for sediment as a whole, so there is little potential for records of fluvial response to climate change that cover significant lengths of time. The opposite is true in alluvial valleys within subsiding basins—like those represented by the Tejo river reaches IV and V—where sediments enter preservation space when they subside below maximum depths of incision. Apart from these extreme cases, intermediate situations are common. Lower-gradient mixed bedrock/alluvial valleys with significant drainage areas ($>10^3$ km^2) commonly have continuous floodplains and low sediment delivery ratios. These settings typically show long-term rates of incision that may outpace rates of rock uplift (Hovius, 1999), and serve as the “conveyor belts” for sediment delivery to basin margins, with sediment residence times measured in multiples of 10^4–10^6 years. As a result, mixed bedrock/alluvial valleys—like those represented by the Tejo river reaches I and III—commonly contain records of fluvial landscape evolution over late Cenozoic time-scales, but have little actual sedimentary preservation. Valleys of this type typically show flights of downward-stepping terraces with fills, documenting long periods of valley incision that alternate with shorter periods of predominantly lateral erosion and minor aggradation.

2. Geological and geomorphological setting

From the Spanish border to the river mouth in the Atlantic Ocean, the Tejo crosses some faults which provide a natural subdivision of the river into reaches (I to V, Figs. 1 and 2). The downstream boundary of the Tejo reach I (from the Spanish border to Vila Velha de Ródão) is defined by the Ponsul fault (F1; Fig. 1). Four terrace levels occur in this reach. Reach II is roughly defined between the Ponsul fault and the NW–SE fault system of Gavião and Ortiga (F2 and F3). The Tejo flows over the Paleozoic basement in a NE–SW incised valley for about 30 km and terraces are largely absent. In reach III, downstream to the crossing of the Arripiado and Chamusca faults (F4 and F5), the Tejo proceeds in a general E–W direction and crosses three structural depressions between Gavião and Arripiado; five terraces levels exist. In reach IV the Tejo changes to a NNE–SSW trend, controlled by the Lower Tejo fault belt (Fonseca and Long, 1989; Cabral, 1995; Cabral et al., 2004); four terraces levels can be identified. Reach V corresponds to the Tejo estuary, extending over a wide area, though the connection with the Atlantic Ocean is a gorge. In this area the terraces have not been sufficiently studied.

Well-developed terraces are found where the river has been able to enlarge the valley, as happened in the areas with Tertiary deposits downstream of Gavião and in the tectonic depression of Ródão (Figs. 1 and 2). Terraces are absent or very limited where the Tejo has cut down into the Paleozoic basement, as in reach II. In reach III, the two lower terraces are not present in sectors outside the tectonic depressions of Tramagal, Rossio and Alvega (Fig. 2). These tectonically depressed areas suffered only partial emptying of the Tertiary sediments. Until the formation of the third terrace level, the Tejo ran over Tertiary sediments in the reach III; it was only during the later incision event that the downcutting into the Paleozoic basement began.

The different regional basement lithologies and tectonic structures influenced the unequal development of the Tejo in the several reaches. In reaches I and II, the basement mainly consists of the Beiras Group (Pre-Cambrian to Lower Cambrian), dominated by slates and metagreywackes (Fig. 3). The Ordovician is represented mainly by quartzites, in synclines elongated NW–SE. This basement was intruded by the Nisa and Castelo Branco granites.

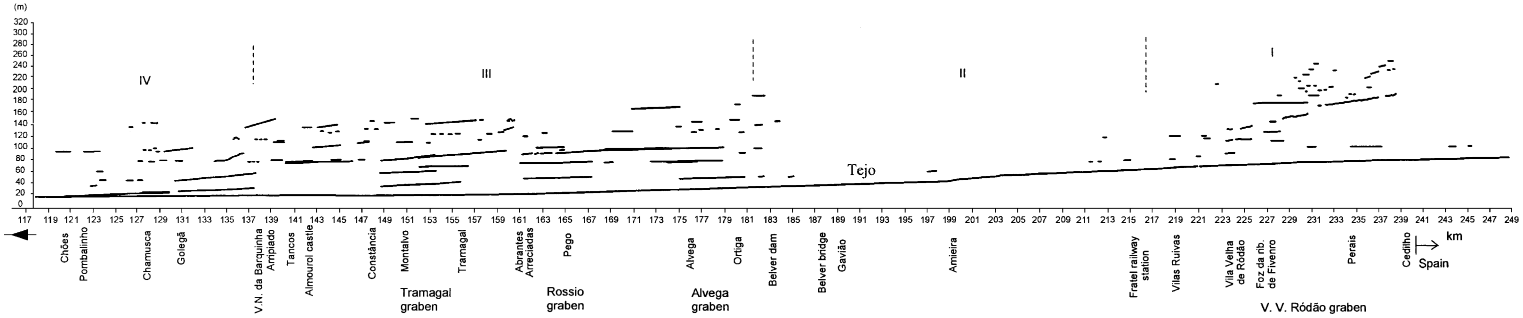
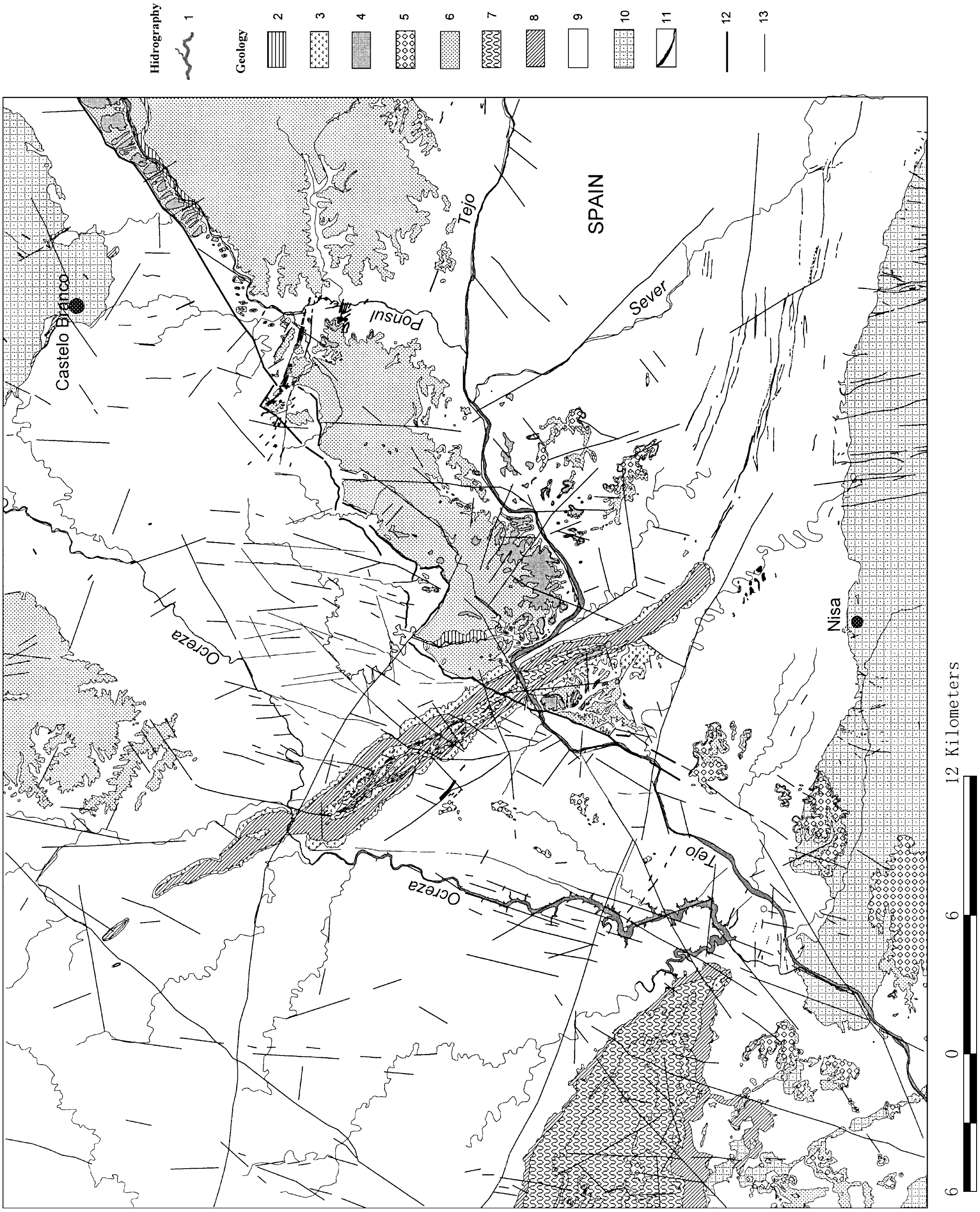


Fig. 2. Longitudinal profiles of the Tejo terraces and modern river bed, along the main reaches: I—from the Spanish border to Vila Velha de Ródão; II—from Vila Velha de Ródão to Gavião; III—from Gavião to Arripiado; IV (only the upper part)—from Arripiado to Chões. The distance upstream from the Atlantic shoreline is indicated. It can be seen the terrace convergence downstream and eventual disappearance of the lower terrace beneath later sediments in the subsiding area of the reach IV; however, this is only a general trend because it is also documented unequal tectonic vertical movement that results of the localized complexity associated with small fault-bounded blocks.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Several Tertiary formations occur in the study area. The Beira Baixa Group (Paleogene to Upper Miocene), mainly comprising arkoses, was deposited by an extensive fluvial drainage system in the Lower Tejo Basin (Cunha, 1992, 1996) sourced by the Nisa and Castelo Branco granites. The Murracha Group (upper Tortonian to middle Pliocene) represents the sedimentary response to the uplift phases of the Portuguese Central Range, being essentially formed by alluvial fan deposits; this group comprises the Torre, Monfortinho and Falagueira formations.

According to Cunha (1992, 1996), during the late Tortonian to lower Pliocene, the basin was endorheic and comprised alluvial fan sedimentation along tectonic scarps, such as the Ponsul-Arneiro fault (F1; Figs. 1, 3, 4). An exorheic drainage system was only developed at the transition to the more humid conditions of the middle Pliocene, the ancestral Tejo becoming a gravelly braided river, with abundant sediment load (Cunha et al., 1993; Barbosa and Reis, 1996). The Falagueira Formation, comprising siliciceous gravel and quartzite clast-supported conglomerates, represents the beginning of an Atlantic fluvial system that captured the drainage network of the Madrid Tertiary Basin (Cunha et al., 1993; Pérez-González, 1994). The Falagueira Formation probably corresponds to the middle Pliocene, as indicated by dating in the more distal sediments of this Atlantic system (Cunha et al., 1993). In the Madrid Tertiary Basin, the Rãna piedmont alluvial system pre-dates the initiation of the current Atlantic fluvial system; its age has not been clearly established but is considered to be about 2.5 Ma in the northern border of the Madrid Basin; however, the Rãna deposits are also found as alluvial platforms related to the incision of the major rivers like the Tajo, Guadalquivir and Guadiana (Pérez-González, 1982; Gutiérrez-Elorza et al., 2002; Alonso-Zarza et al., 2002). The change from the internal to the external (Atlantic) drainage was a diachronous process, progressing inland to the ancient Tertiary basins (Martín-Serrano, 1991), where the Atlantic rivers coupled with the already established intrabasinal channel systems (Alonso-Zarza et al., 2004).

In the area between the Spanish border and Gavião, the top surface of Falagueira Formation shows a gradient of 0.13%. The sedimentary record for times after the deposition of the Falagueira Formation is very limited, because downcutting dominated in the following fluvial stage. During this incision stage, deep valleys were excavated; locally, in tectonic depressions such as the Ródão graben, terrace staircases and diversified sedimentary deposits were formed: alluvial fan deposits, terraces, alluvium and talus. Talus is abundant at the cliff foot of the quartzite ridges.

The regional relief is dominated by elongate NW–SE residual resistant ridges, with altitudes reaching more than 500 m. These ridges are crossed by the Tejo and Ocreza rivers in gorges (Figs. 4 and 5). Below the quartzite ridge crests, the Fundamental planation surface is developed at an altitude of about 300 to 320 m in the areas made of metagreywackes/slates or granites. The Fundamental planation surface is the extension in Portugal of the Meseta Extremeña, which became covered by Paleogene arkoses. After a long period of sedimentation during the Tertiary, the Fundamental planation surface became exhumed and then dissected during the fluvial incision stage.

According to Ribeiro (1943a) and Dias and Cabral (1989), the altitude of some segments of the Ordovician quartzite ridges (285 m; Figs. 5 and 6) and the altitude of the Falagueira Formation (300 to 362 m) indicate that the ancestral Tejo river was superimposed onto the quartzite ridges and on the hanging wall of the Ponsul fault.

The downcutting associated with the first incision episode produced a planation surface defined as the Fratel level (Cunha and Martins, 2000) in the Tejo reaches I and II (Figs. 6 and 7). An equivalent surface, designated the Mora-Lamarosa Level, is also recognized in the same geomorphological position in

Fig. 3. Geological map of the studied region, modified from the Carta geológica de Portugal in the scale 1/500,000 (1992). 1—Stream; 2—alluvium (Holocene); 3—talus or alluvial fan (Pleistocene); 4—terrace (Gelasian ? to Pleistocene); 5—quartzitic conglomerates and quartz sandstones (Falagueira Formation; Piacenzian); 6—arkoses (Beira Baixa Group; Paleogene to Miocene) and conglomerates/clays (Torre and Monfortinho formations; upper Tortonian to Zanclean); 7—slates (Silurian); 8—quartzites (Ordovician); 9—slates, phyllites and metagreywackes (Beiras Group; Pre-Cambrian to Lower Cambrian); 10—granite; 11—aplites and dikes; 12—Ponsul fault; 13—fault lineament.

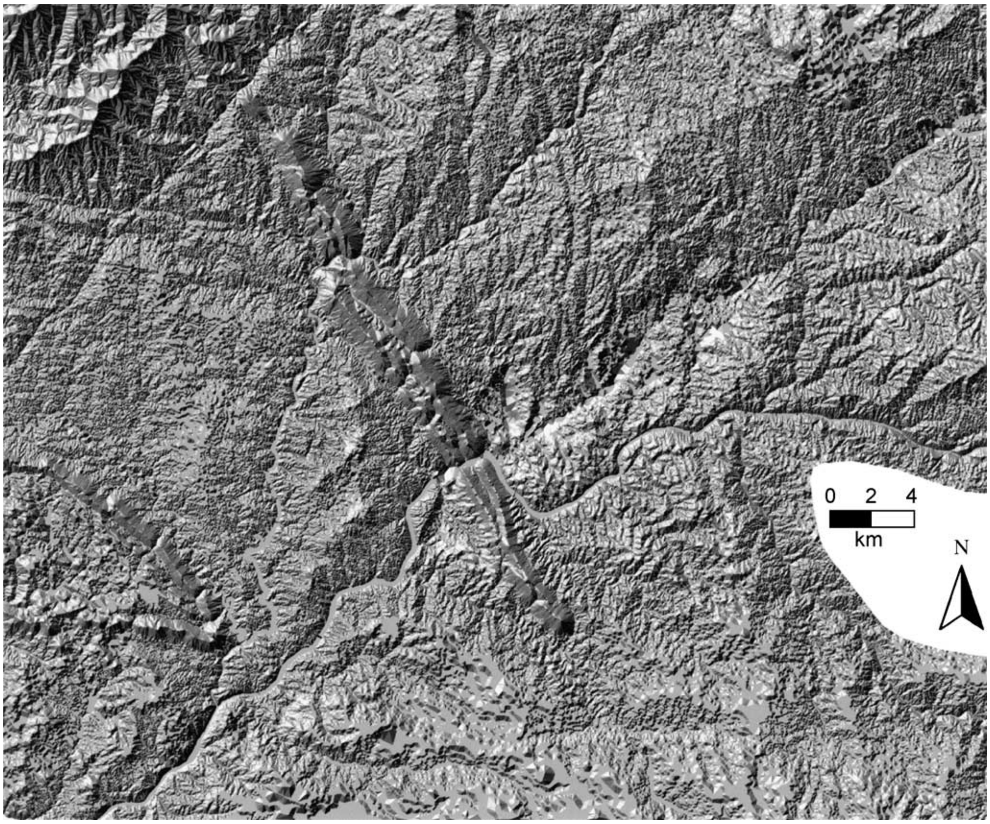

Fig. 4. Digital Elevation Model (DEM; based on 1/25,000 topographic maps) of the area comprising the Tejo reaches I and II.

reaches III and IV (Martins and Barbosa, 1992; Martins, 1999). This surface (N1) has a similar geomorphic setting to the highest and oldest terrace tract (T1) of the Tejo river and represents a period in which the incision tendency was not yet intense. The morpho-stratigraphic position of the Falagueira Formation (that completes the sedimentary infill of the basin) indicates that the N1 surface could have been made during the late Pliocene.

Below the N1 surface three more recent terrace levels can be identified (T2, T3 and T4); they are discontinuous and narrow, but they can be traced along the river valley.

The Tejo longitudinal profile is not entirely graded, as can be seen by the gradient change (rupture) at Amieira (Fig. 2, km 199; reach II). The Tejo main tributaries have a knickpoint that separates a lower gradient upper reach from a higher gradient lower reach. In each tributary, the lower reach presents more steep valley slopes, higher sinuosity and relief increase. The increase in sinuosity of the tributaries in their lower reaches appears to correspond to a fluvial response to compensate the gradient increase associated with the knickpoint upstream migration. These geomorphological features indicate drainage rejuvenation.

Because of the distinctive characteristics of Tejo reaches I and II (Figs. 6 and 7), they will be separately described in the following section.

3. Late Cenozoic records of the Tejo reaches I and II

Continuous and detailed field surveying was made from reach to reach; correlation was based on following surfaces along the main river and tributaries, using 1/24 000 aerial photos.

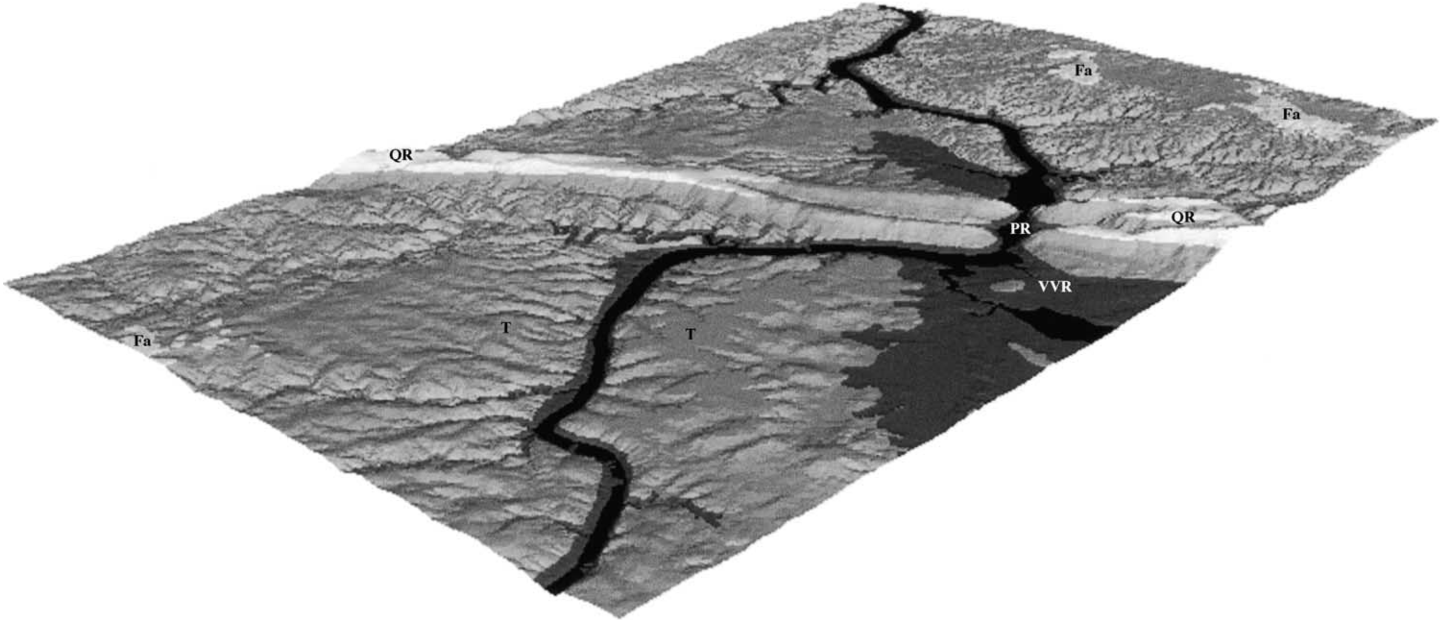

Fig. 5. Virtual view (DEM) towards southwest of the Ródão (VVR) area. Buttes of the Falagueira Formation (Fa), the highest terraces (T), the quartzitic ridges (QR) and the Tejo river entrance in the lifted up compartment (reach II), downstream of the gorge ("Portas de Ródão"—PR) are identified. Altimetry: black, −74 to 82 m; dark gray, −82 to 120 m; gray, −120 to 302 m; white, −302 to 470 m.

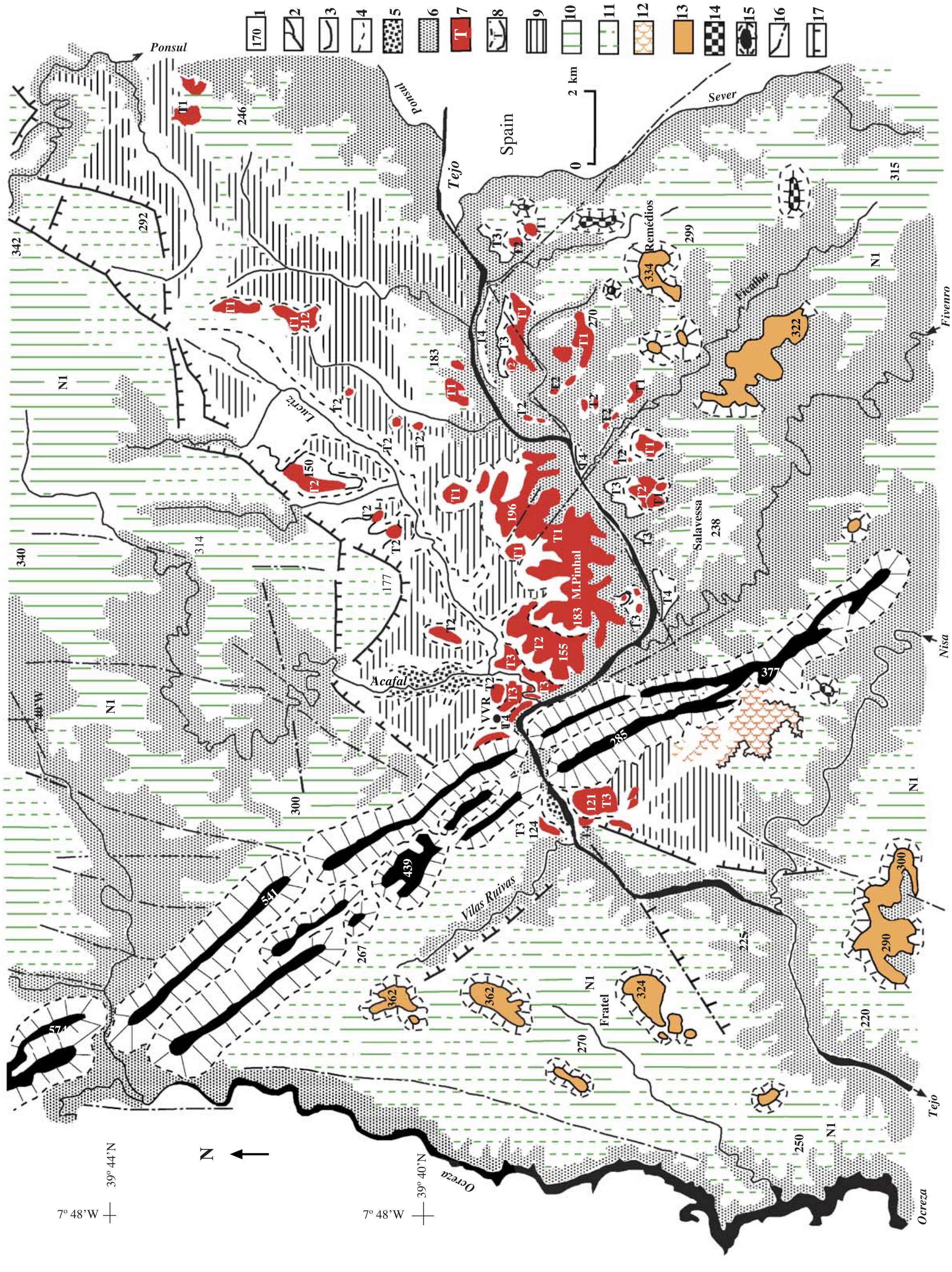
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Fig. 7. Geomorphological map of the Amieira area, corresponding to the Tejo reach II. 1—Altitude (m); 2—dam; 3—channel network; 4—incised valley; 5—Fratel level (N1); 6—degraded Fratel level (N1d); 7—residual relief (top of the Falagueira Formation); 8—concave break of slope; 9—quartzite ridge; 10—non-quartzitic resistant relief; 11—fault scarp; 12—probable fault scarp; 13—tectonic lineament.

3.1. Geomorphological characteristics of the Tejo reach I

In reach I (Ródão area; Figs. 6, 8, 9), below the Falagueira Formation, four terrace levels (numbered T1 to T4, from the upper to the lower) were identified. The terraces have been mapped along the Tejo valley from Vila Velha de Rodão to the Sever river mouth (Figs. 6 and 10). Upstream of the Sever confluence, the Tejo valley is strongly entrenched and without terraces. In the Ródão area some captures have been identified (ex. of the Ponsul and Nisa streams), based

Fig. 6. Geomorphological map of the Ródão area (comprising the Tejo reach I and the upstream part of the reach II). 1—Altitude (m); 2—channel network; 3—convex break of slope; 4—concave break of slope; 5—present-day channel and flood plain deposits; 6—incised valley; 7—terrace with sediments; 8—rocky terrace; 9—Lameira Level (N2); 10—Fratel level (N1); 11—degraded Fratel level (N1d) and ramps of the T2 terrace (N2 level); 12—Taberna Seca alluvial fan deposits; 13—residual relief (top of the Falagueira Formation); 14—non-quartzitic resistant relief; 15—quartzite ridge; 16—tectonic lineament; 17—fault scarp.

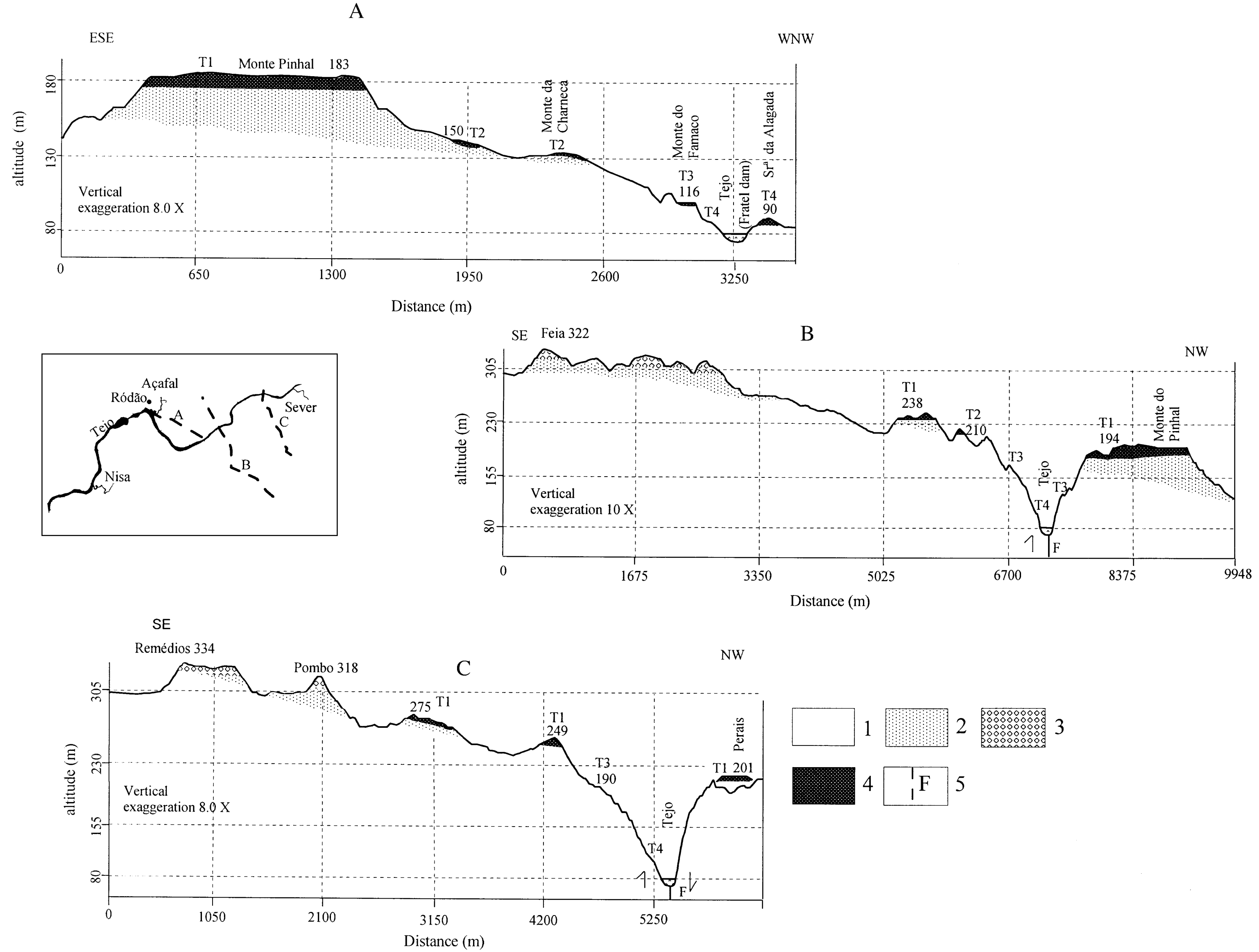


Fig. 8. Transverse profiles in the Tejo reach I. 1—Beiras Group (slates and metagreywackes); 2—Beira Baixa Group (arkoses); 3—Falagueira Formation (conglomerates and quartz sandstones); 4—terraces; 5—fault.

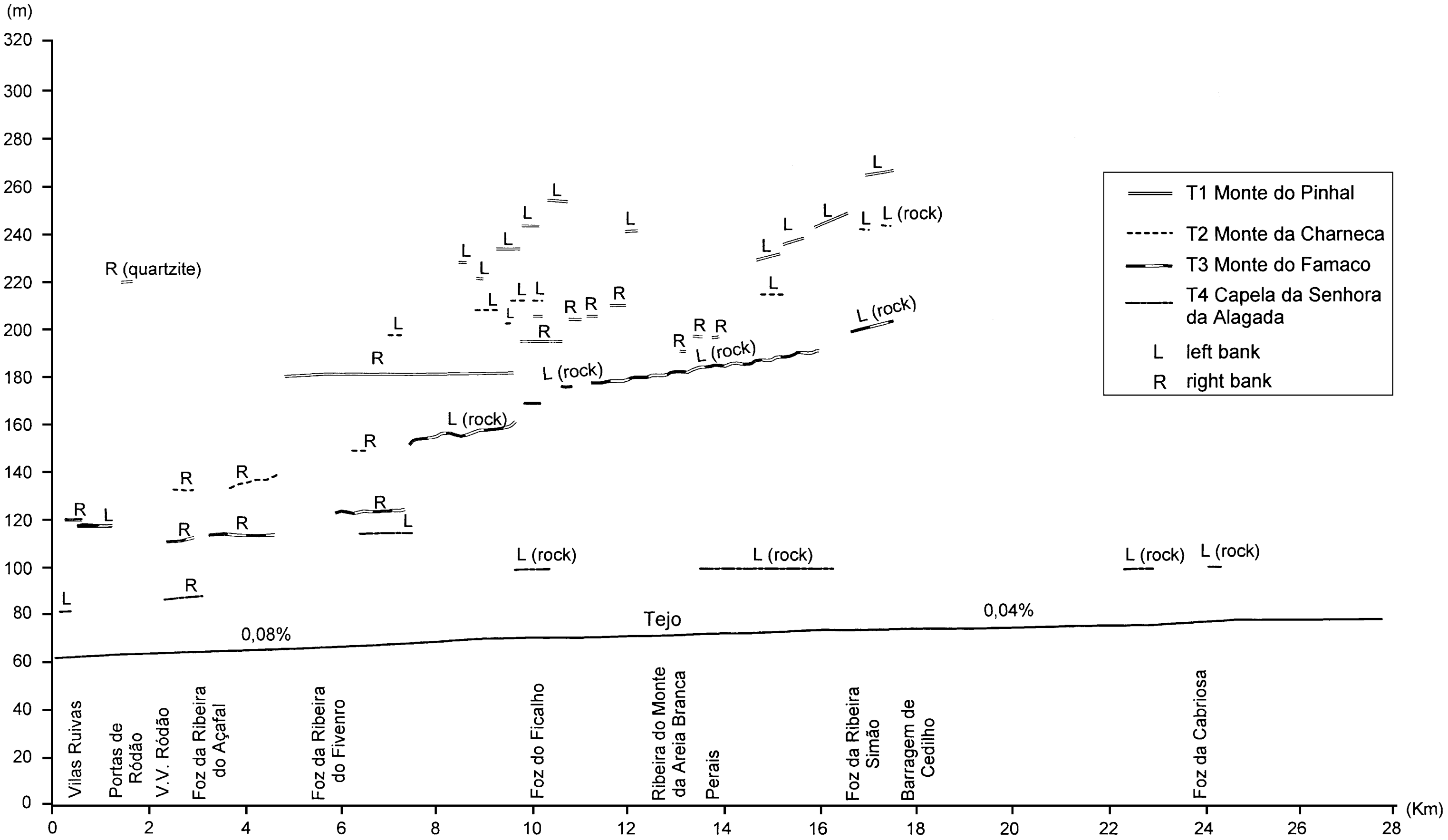
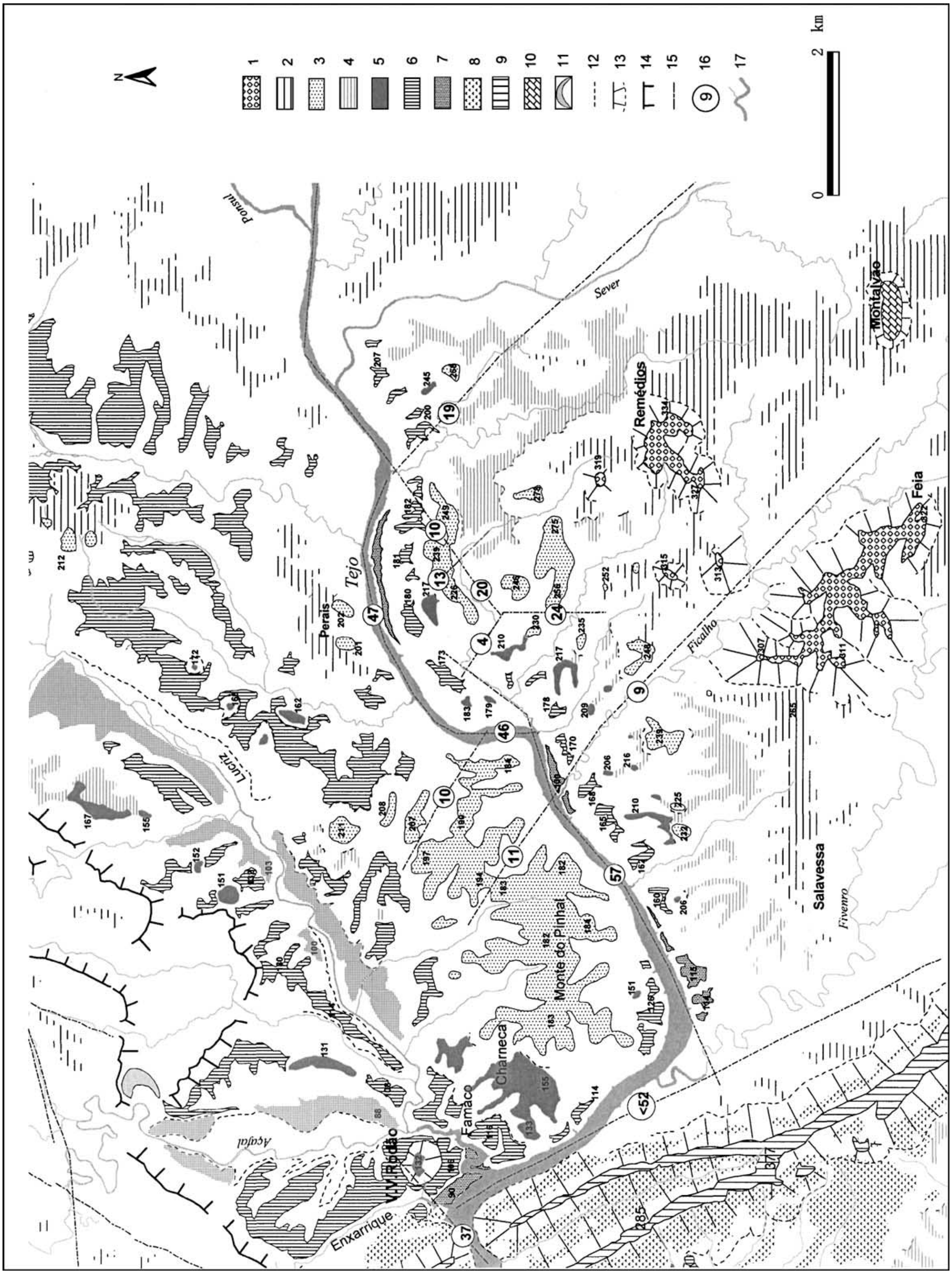


Fig. 9. Longitudinal profiles of the Tejo modern bed and terraces in the reach I, showing their convergence downstream. Notice the more elevated position of the first (T1), second (T2) and third (T3) terrace levels of the Tejo left bank (L), comparatively to the same terrace levels of the opposed bank (R). The distance (km) upstream is indicated. Aggradational terraces are distinguished from the strath terraces (rock-erosional on slates and metagreywackes; quartzite-erosional on quartzites).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on interpretation of ancient drainage patterns, abandoned valleys and terrace remains along the NE–SW trend of the modern Lucriz stream (Fig. 6).

In the right bank of the local NE–SW Tejo reach, the T1 terrace, named the Monte do Pinhal terrace, forms an extensive plateau at altitudes of 183 to 196 m (Figs. 6, 8A, 10); in the left bank, small remnants of this terrace occur at altitudes of 232 to 254 m or locally up to 275 m (Figs. 8C and 10). The T1 terrace appears to pass laterally into the Fratel planation surface (N1). In the right bank, the terrace is 13 m thick (base at 170 m of altitude, top at 183 m), while in the left bank the preserved maximum thickness is only 9 m. Outcrops show a sheet-like unit of massive clast-supported gravel–boulder conglomerates, with poor to moderate sorting. The clasts of quartzite (90% of the total; with weathered cortex) and white quartz reach 40 cm (MPS=32 cm, average of the largest 10 clasts) and show a red patina (iron oxides); they are sub-rounded to rounded. Some of the clasts have been reworked from the Falagueira Formation, which in this area contains quartzite (ca. 80%) and quartz clasts that generally reach dimensions of 25 cm.

South of the Tejo, a poorly sorted debris-flow deposit (the Taberna Seca alluvial fan; Fig. 6) rests on the basement.

The T2 terrace, named the Monte da Charneca terrace, is also a constructional bench, but not so well preserved as the T1 (Figs. 8A and 10). In the right bank of the local SSE–NNW Tejo reach (at the confluence with the Açafal stream), its base is located at 130 m altitude, while the top is at 150–155 m. In the left bank of the local NE–SW reach, T2 has a thin conglomeratic cap (2 to 6 m thick) at an altitude of 210–214 m (Fig. 8B). The deposits of this terrace are massive clast-supported gravel–boulder conglomerates, with a red sandy–silty matrix. The sorting is poor to very poor. The clasts give a MPS of 24 cm and are composed of quartzite (78%; with weathered cortex) and white quartz.

The T3 terrace, named the Monte do Famaco terrace, is a constructional bench near the Vilas Ruivas stream mouth (top at an altitude of 124 m; 6 m thick), Arneiro (121 m; 5 m thick) and Monte do Famaco (116 m; 10 m thick) (Figs. 6, 8A and 10). Upstream of Vila Velha de Ródão, in the left bank of the NE–SW Tejo reach, the T3 is represented by strath terraces at 160 to 207 m altitude (Figs. 8C and 10). The T3 comprises massive, clast-supported gravel–boulder conglomerates, with poor sorting. The clasts are of quartzite (75%) and white quartz; both clasts types are sub-rounded and show a small degree of weathering, with MPS=32 cm.

Archaeological finds are documented at Monte do Famaco and Vilas Ruivas (Raposo, 1995a,b). At the Vilas Ruivas site, the T3 lower sequence—a basal clast-supported conglomerate and gravel pavements interbedded with sandstones—has yielded evidence of a Lower Acheulian (Lower Palaeolithic, >100 ka) lithic industry and is overlaid by a pedologic fersialithic horizon (of “ferretto” type). According to Raposo and Silva (1981) and Raposo (1987), the basal lithic industry can be correlated with the Mindel (Alpine glaciation) and the pedologic fersialithic horizon with an interglacial period (Mindel-Riss?). At the top of the sequence, a silt layer with a palaeosol includes some artifacts attributable to the Mousterian (top of the Middle Palaeolithic; Raposo, 1995a). Thermoluminescence dating of this silt level yielded dates of 51,000 (+13,000; −12,000) and 68,000 (+35,000; −26,000) years (Raposo, 1995b). At the surface in this locality, evidence of an important Magdalenian (Upper Palaeolithic) lithic industry was found (Raposo, 1987). The top silt level with Mousterian artifacts could also be interpreted as a later deposit, sedimented after T3 terrace dissection. As a comparison, Mousterian levels in the Madrid Basin can be found only in terrace levels below +15 m (above the modern river bed) and Acheulian levels below ca. +45 m (Silva, 2003).

At the Monte do Famaco site, the terrace T3 is represented by an extensive basal conglomeratic bed containing evidence for two distinct human occupations. Some rolled artifacts were found inside the conglomerate, similar to those collected at the base of this terrace at Vilas Ruivas, attributable to the

Fig. 10. Geomorphological map of the Ródão eastern sector. 1—Residual relief (top of the Falagueira Formation); 2—N1 level; 3—T1 terrace; 4—N2 level; 5—T2 terrace; 6—N3 level and T3 terrace; 7—N4 level and T4 terrace; 8—talus and alluvial fan deposits; 9—quartzite ridge; 10—residual relief (monadnock); 11—abandoned meander; 12—slope base; 13—steep slope; 14—fault scarp; 15—tectonic lineament; 16—vertical displacement (m) affecting the T1 terrace; 17—stream.

Lower Acheulian and probably corresponding to ca. 350 ka (L. Raposo, personal communication). At the conglomerate top, ca. 1500 quartzitic artifacts—bifaces, axes, raspers, etc.—were collected, some of them showing evidences of wind abrasion but none of them indicating later fluvial transport; these artifacts were considered Middle or Upper Acheulian, corresponding to ca. 150 ka (Raposo, 1987, personal communication).

At Vale do Forno (Tejo reach IV, Fig. 1), artifacts collected in the "Lower gravels" unit of the Alpiarça terrace (T3) have been attributed to the Clactonian–Abevillian (Zbyszewsky, 1946) and others found in the sandy–clay upper part of the terrace indicated a range from the Middle Acheulian to Micoquian (Raposo, 1995b; Raposo and Santonja, 1995). Faunal and sedimentologic data indicate temperate climatic conditions (Raposo, 1995b); the upper part of the terrace yields dates close to the upper TL dating limit (VF01=127 ka+infin. −26 ka; VF02=119 ka+infin. −32 ka; VF05=117 ka+infin.−26 ka; VF06>127 ka) (Mozzi et al., 2000). New TL dating of the upper part of the T3 terrace in two other places in reach IV yields dates older than 115 ka (LTA1—Arneiro das Figueiras, Porto Alto—grey clay in upper fine sands and clays, 0.7 m above lower gravels, >136 ka; LTA 3—Fonte da Burra, Muge—coarse sand with silt, >143 ka; LTA4—Fonte da Burra—grey brown coarse sand with silt, in 8 cm thick layer, between red-brown coarse sands; 4.5 m higher than LTA3, >115 ka).

In Tejo reach I, the Capela da Senhora da Alagada terrace (T4) is located (Fig. 6) at an altitude of: 80 m, in the Tejo left bank, immediately downstream of the Ródão quartzite ridges; 90 m, in the right bank, close to the Açafal stream mouth (SSE–NNW local reach) (Figs. 6, 8A and 10); 100–115 m, upstream of the Ficalho stream mouth (NE–SW local reach), where it is represented by a strath. At the confluence of the Açafal and Enxarrique streams, the T4 is 10 m thick. The base is a massive, clast-supported boulder conglomerate (0.5- to 1 m thick) overlaid by massive very fine sandstones and silts with very thin levels of pedogenic calcareous concretions. The basal conglomerate presents sub-rounded clasts of quartzite (mainly not weathered), white quartz, metagreywackes and slates, with MPS=31 cm. In the Enxarrique confluence, a basal level comprising silts with calcareous concretions provided evidence of a rich in situ Mousterian industry and abundant remains of mammals (deer, horse, auroch, elephant and rhinoceros), birds and fish (Raposo et al., 1985; Raposo, 1987). Th/U ages of three teeth provided an average date of 33,800 years (32,938±1055, 34,088±800 and 34,093±920 years). This faunal association provides evidence of a temperate climate (Raposo, 1995b). The analysis of Portuguese faunal data also indicates that before the late Würm, the Quaternary climate was humid, generally temperate to hot (Cardoso, 1993).

In the vicinity of the Açafal stream mouth, the most recent downcutting of the Tejo river is ca. 24 m in relation to the top aggradation surface of the terrace T4 (at 90 m altitude). The present valley floor is at an altitude of 66 m and the alluvium consists of pebbly gravel (Fig. 8A), estimated to be ca. 4 m thick.

In the Ródão area, the altitude of each terrace was used to estimate the successive downcutting and aggradation phases of the Tejo in the local NE–SW and SSE–NNW reaches (Tables 1 and 2). For the Monte do Pinhal-Vila Velha de Ródão sector, it is not possible to use the altitude of the Falagueira Formation top as the initial reference for the downcutting, because this formation has been completely removed by local erosion. However, if the Falagueira Formation to T1 downcutting value of the Salavessa sector (73 m) is used, the probable local altitude of this formation can be estimated (Table 2).

Upstream of Vila Velha de Ródão, the Tejo river was constrained by a large NE–SW fault, along which vertical movement has taken place, defining two distinct blocks. In the Salavessa block (southern) the terraces are at higher elevations and the aggradations are smaller than those found in the Monte do Pinhal-Vila Velha de Ródão block; this indicates that the Salavessa compartment underwent more uplift than the northern compartment during the stage of long-term incision. Assuming no relevant change in other controls, such as river discharge, the result of the fluvial incision in these two sectors allows an estimate that the local uplift has reached 232 m (Salavessa) or ca. 173 m (M. Pinhal–V.V.Ródão) since the middle Pliocene (ca. 2.6 Ma).

Table 1
Altitudes of the late Cenozoic sedimentary units in the Tejo reach I (immediately upstream of Vila Velha de Ródão)

	Monte do Pinhal–Vila Velha de Ródão (Açafal mouth) sector		Salavessa sector	
	Altitude of the unit top (m)	Altitude of the unit base (m)	Altitude of the unit top (m)	Altitude of the unit base (m)
Falagueira Formation	243 ? (eroded)	233 ? (eroded)	307	300
T1 terrace	183	170	239	234
T2 terrace	155	130	214	210
T3 terrace	116	106	165	165
T4 terrace	90	80	100	100
modern bed	70	66	75	75

See also Fig. 10.

3.2. Geomorphological characteristics of the Tejo reach II

In reach II (Fig. 7) the Tejo flows in a narrow valley cut into the Paleozoic basement. The river bed is at an altitude of ca. 40–50 m and the divides reach ca. 320 m. Quartzite ridges, remains of the Falagueira Formation and the Fratel level (N1), are the main geomorphological features. There are only two small unpaired strath terraces (Figs. 2 and 11). The strath terrace at 118 m of altitude is only locally represented, and extends downstream for 100 m. The lower terrace level is discontinuous downstream, at 70 to 50 m of altitude.

Correlation based on following surfaces is made easier by the proximity (2–3 km away) between the terraces of reaches I and II (Fig. 2). The lower terrace present in reach II seems to match the Capela da Senhora da Alagada terrace (T4; reach I, upstream). The strath terrace at an altitude of 118 m may correspond with the terrace at 120 m of altitude in Vilas Ruivas.

Comparing with the adjacent Tejo reaches, reach II seems to record more continuous incision during the periods immediately following the formation of the Fratel level (N1) and the bench terrace at an altitude of 50 to 60 m.

In reach II, local uplift is estimated to be 277 m (top of the Falagueira Formation at 319 m of altitude and the valley floor at 42 m; Fig. 7) since the middle Pliocene (ca. 2.6 Ma).

3.3. Fluvial evolution in the Ródão area

In the Ródão tectonic depression, where soft Tertiary sediments occur, the enlarging of the Tejo valley was easier than in other areas with hard Paleozoic rocks. Because the river had been super-

Table 2
Characterization of the successive downcutting/aggradation cycles in two sectors of the Tejo reach I (immediately upstream of Vila Velha de Ródão)

Monte do Pinhal–Vila Velha de Ródão (Açafal mouth) sector				Salavessa sector			
Fluvial history	Downcutting (m)	Aggradation (m)	Result (m)	Fluvial history	Downcutting (m)	Aggradation (m)	Result (m)
Falagueira Formation to T1	73 ?	13	60 ?	Falagueira Formation to T1	73	5	68
T1 to T2	53	25	28	T1 to T2	29	4	25
T2 to T3	49	10	39	T2 to T3	49	0	49
T3 to T4	36	10	26	T3 to T4	65	0	65
T4 to modern bed	24	4	20	T4 to modern bed	25	0	25
Total	235 ?	62	173 ?	Total	241	9	232
Subtotal	162	49	113	Subtotal	168	4	164

The aggradation value of one terrace is given by the elevation difference between its top surface (n) and its base (b), corresponding to the terrace sediment thickness. A downcutting value is given by the elevation difference between the top surface of a terrace (N) and the base of the succeeding lower terrace (b). The difference between the downcutting and aggradation is expressed by the formula: $R=(N-b)-(n-b)$.

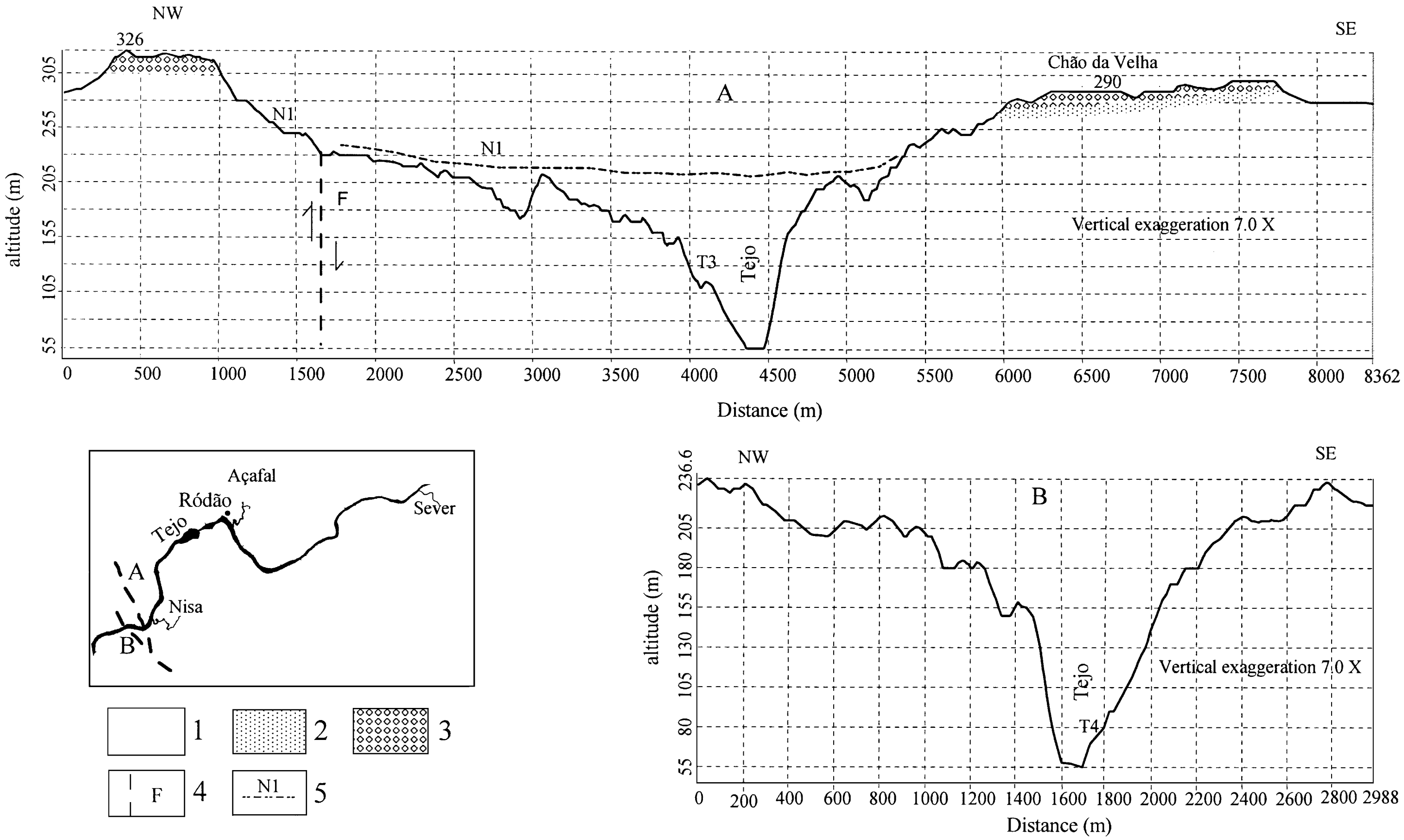


Fig. 11. Transverse profiles in the Tejo reach II. 1—Beiras Group (slates and metagreywackes); 2—Beira Baixa Group (arkoses); 3—Falagueira Formation (conglomerates and quartz sandstones); 4—fault; 5—Fratel level; T3 and T4—terraces.

imposed on the Ródão quartzitic structure, the resulting gorge constricted the flow during high discharge periods and contributed to the upstream development of a large valley with sedimentary terraces, a situation that contrasts with that of reach II. However, by itself, the lithologic characteristics do not explain the existence of terrace staircases in this depression and the near absence in the adjacent reaches. The evolution of the morpho-sedimentary characteristic of the Tejo river and tributaries reveals two main phases of fluvial incision: (1) up to the development of the Fratel level (N1), and (2) the post-Fratel level period. The records of the successive morpho-sedimentary episodes make it possible to summarize the Tejo fluvial evolution in the Ródão area (Fig. 12).

During the middle Pliocene (Fig. 12A) the study area was almost covered by fluvial sedimentation produced by a large gravelly braided river and tributaries: the ancestral Tejo, Ocreza and Sever rivers. The highest summits of the quartzite ridges were not buried by that alluvial plain.

The downcutting associated with the first incision episode (Fig. 12B), starting from the culminating aggradation surface of the Tertiary infill, created a planation surface (Fratel level-N1), probably during the late Pliocene to earlier Pleistocene. The Ródão quartzite ridges supplied the Taberna Seca alluvial fan and talus accumulated particularly against the slopes of the quartzite ridges.

The superposition of the Tejo on the quartzitic ridges created a gorge that constricted the flow and contributed to the upstream development of a large alluvial valley where sediment storage occurred.

During the middle (?) Pleistocene, a second important downcutting episode occurred (Fig. 12C). The sedimentation area upstream of the quartzite ridges was less developed than in the earlier episode and the course of the Tejo was locally fixed along faults (NE–SW and SSE–NNW).

In the following incision episode (Fig. 12D) some captures occurred. Later the streams enlarged their valleys by meander development and lateral erosion. Sedimentation produced by the Tejo (late Pleistocene?) was mainly localized in a small area in the vicinity of the Açafal and Vilas Ruivas confluences.

The fourth incision episode can be ascribed to the late Pleistocene, leading to the formation of incised meanders in several tributaries of the Tejo (Fig. 12E); the later aggradation phase was restricted.

The latest Pleistocene? to Holocene incision episode produced the modern valley floor, which has very limited alluvium (Fig. 12F).

4. Main controls of the long-term dynamics of the fluvial system studied

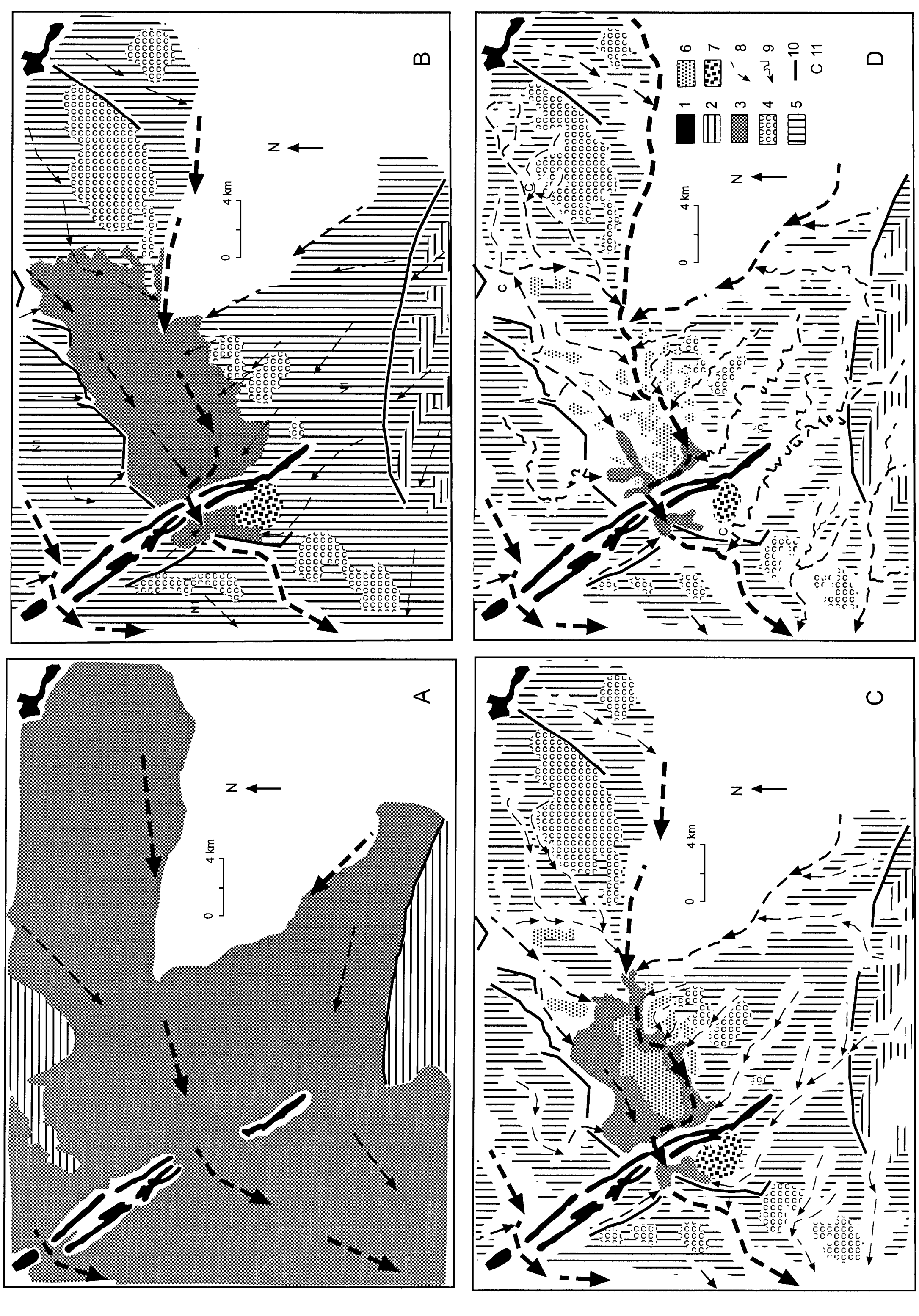
4.1. Sea-level changes

Although late Cenozoic sea-level changes clearly influenced valley incision and sedimentation episodes in the distal Tejo reaches V, IV and, probably, also in reach III (E–W), sea-level control is difficult to recognize in the more proximal upstream reaches (Fig. 1). The study of wells drilled in the Tejo sediments shows that the downcutting forced by sea-level fall during the coldest period of the Last Glaciation (ca. 20 to 18 ka) reached Abrantes (km 161; Tejo reach III) (Martins, 1999) (Fig. 2). Taking into account the oscillatory character of sea level and the Last Glacial Maximum sea-level lowstand (ca. −130 m), we can expect previous influences of this factor in the V and IV Tejo reaches and, eventually, in reach III. However, sea-level changes could hardly have had a significant influence on the downcutting/aggradation episodes of the two reaches analysed in this paper, respectively, located at about 140 km (reach II) and 180 km (reach I) away from the present shoreline.

The lack of correlation between the sea-level/time curve (Pirazzoli, 1996) and the dating of the terraces just summarised above suggests that other factors, such as rock uplift, have been involved.

4.2. Climate control

As considered above, the cyclical character of the long-term late Pliocene to Quaternary climate changes (Shackleton and Opdyke, 1973; Bond et al., 1993; Stanley and Ruddiman, 1995; Winograd et al., 1997) cannot explain the Tejo terrace staircases. Nevertheless, the sedimentary infill should reflect the coeval climatic conditions, which controlled the amount and regime of discharge, weathering and sediment supply. However, the interpretation of the small variations in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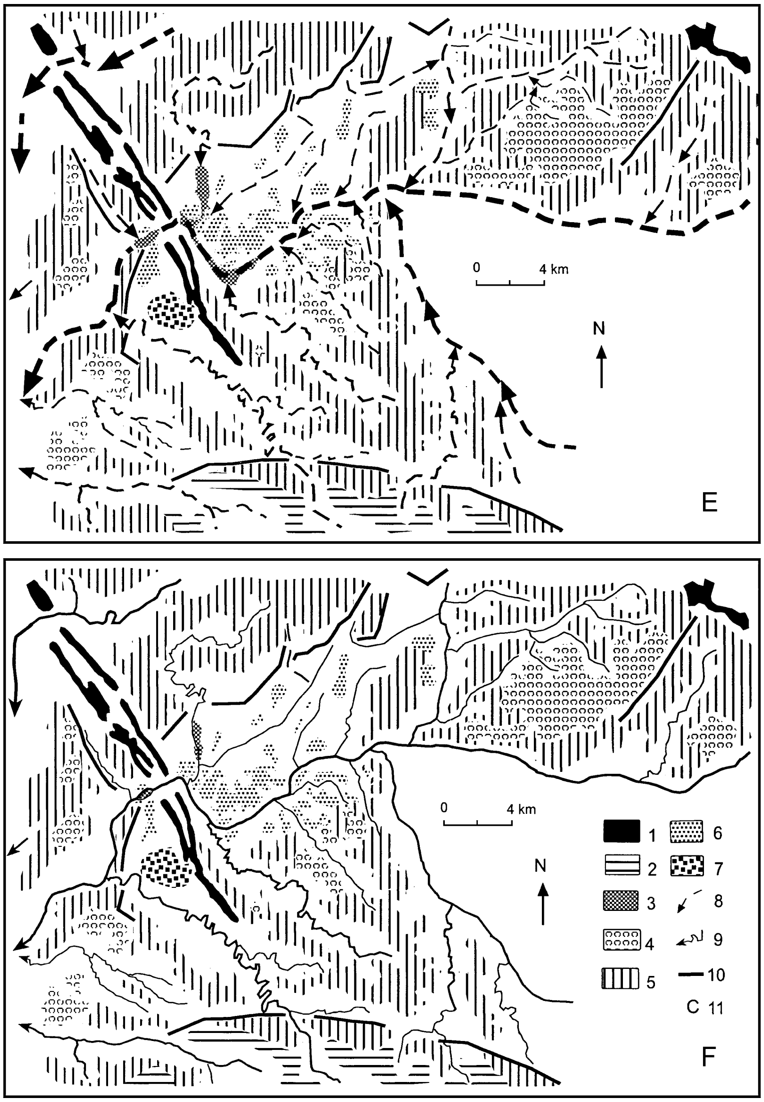

Fig. 12. Evolution of the Tejo river since the Pliocene, in the Ródão area. A—Deposition of the Falagueira Formation (Piacenzian); B—first incision episode (N1—Fratel level, T1—Monte do Pinhal terrace and A1—Taberna Seca alluvial fan deposits) (Gelasian to lower Pleistocene?); C—second incision episode (N2—Lameira Level and T2—Monte da Charneca terrace) (lower to middle Pleistocene?); D—third incision episode (T3—Monte do Famaco terrace) (60 ? to 350 ? ka; middle to upper ? Pleistocene); E—fourth incision episode (T4—Senhora da Alagada terrace) (near the base dated to 32 ka; uppermost Pleistocene); F—fifth incision episode (alluvium) (Holocene). 1—quartzite ridge; 2—Fundamental planation surface (Alentejo peneplain); 3—sedimentation area; 4—residual relief (top of the Falagueira Formation); 5—Fratel level (N1); 6—terraces; 7—Taberna Seca alluvial fan deposits; 8—main palaeodrainage direction; 9—modern stream; 10—scarp; 11—stream capture.

the clastic composition of the Ródão terraces must take into account that in each terrace formation the valley incision promoted incorporation of clasts previously belonging to older sedimentary units. On the other hand, the most recent (and lowest) terrace (T4) already records important downcutting into the metamorphic basement rich in slates and metagreywackes. The terraces with the largest clasts are T1 and T3, which may indicate more intense discharges. However, we should keep in mind that narrowing of the Tejo valley resulting from progressive incision in the basement will have contributed to an increase of flow velocity, and competence, in the most recent times.

4.3. Tectonic control

The tectonic control of drainage was studied by interpretation of asymmetric valley and drainage patterns (ex. Lucriz stream, Fig. 6), fault scarps, tectonic alignments, fracture-controlled valleys, and displacement of planation surfaces or terraces. The characterization of neotectonic structures was made through cartography, field survey and detailed outcrop study of the identified faults.

The Ponsul tectonic structure is a major NE–SW late-Hercynian fault which was reactivated during the late Tortonian to early Pliocene, coupled with some NW–SE strike-slip faults that worked as lateral ramps of the thrusts (Ribeiro, 1943b; Dias and Cabral, 1989; Cunha, 1996; Sequeira et al., 1999). Evidence of Plio-Quaternary reactivation was found at several places, predominantly as a reverse fault, with an estimated average vertical displacement rate of 0.02 to 0.1 mm/year in that period (Dias and Cabral, 1989). However, in Ródão, despite some seismicity, the evidence of its reactivation during the Quaternary is mainly based on the altitude difference of the terrace T3 remains on both Tejo banks, immediately downstream of the Ródão ridges (at 124 m in Vilas Ruivas and at 121 m in Arneiro; Fig. 6).

The rectilinear pattern of the Tejo, independent of lithologies, probably results from preferential drainage along pre-existing NE–SW and NNW–SSE discontinuities. Also, the N–S rectilineal aspect of some streams suggests a recent control by a N–S fault system, already documented in areas nearby by Daveau (1985). These orientations coincide with the regional fault pattern and therefore suggest a structural control.

The differences in terrace elevation of the several sectors are greater in the oldest terraces (Fig. 9), a situation that suggests cumulative fault displacement. The convergence downstream of the first, second and third terrace levels relatively to the lower levels and to the Tejo modern bed (Fig. 9) indicates differential bedrock uplift (Merritts et al., 1994; Burbank and Anderson, 2001), greater upstream. The area that has subsided most is close to the Ponsul fault and located immediately north of Vila Velha de Ródão (Dias and Cabral, 1989). However, this is only a general trend because the local complexity of small fault-bounded blocks has resulted in unequal tectonic vertical movements in several sectors (Figs. 6, 9 and 10).

Scarps occur in different rock types, including metamorphic basement, granites and sedimentary rocks. They are marked by offsets of the topographic surface and rivers (Fig. 4). The probable fracture-controlled valley of the local NE–SW Tejo reach (Table 1; Figs. 8B,C and 10) displaces all the terraces (the northern block is the less uplifted) by about: T1—57 m; T2—55 m; T3—34 m.

The tectonic displacements affecting the Monte do Pinhal terrace (T1) are seen to increase up to 21 m (10+11), across the two NW–SE vertical faults (Fig. 10). One of these faults would coincide with the Ficalho stream (NW–SE). A probable fault along the NNW–SSE Tejo reach (Fig. 10) could be responsible for a vertical separation of ca. 5 m between the terrace T3 remains in the Monte de Famaco (116 m) and in the Arneiro (121m) areas (Fig. 6). Other probable NW–SE faults are indicated by tectonic alignment along the Sever river (Fig. 10) and the Vilas Ruivas fault scarp (Martins, 1999), this one located west of the Ródão ridges (Fig. 6).

A NE–SW strike-slip fault passing along the Tejo gorge (Portas de Ródão) (Figs. 6 and 10) is responsible for a vertical displacement of ca. 36 m in the culminating surface of the Lower Tejo Tertiary Basin (at an altitude of 290 m at Chão da Velha and 326 m at Fratel) and of 25 m in the first incised planation surface (Fratel level-N1) (Figs. 6 and 11). This fault displacement also explains the altitude difference between the Monte de Pinhal terrace (183 m) and the bench cut in the NW quartzite ridges of Portas de Ródão (erosional terrace at an altitude of 220 m; Fig. 9). This fault is represented in the outcrop located in the eastern sector of Vila Velha de Ródão (Senhora da Alagada urbanization; Figs. 13 and 14), whose plan (N42°E, 85°NW) displaces the Tertiary and exhibits slickensides with a 28° SW pitch (Fig. 14). The terrace T2 is tilted towards SE. The fault plan data indicate a right-lateral oblique strike-slip fault, probably activated by a maximum compression along WNW–ESE. The inferred strain pattern involves a short-

Fig. 13. Terraces at the Vila Velha de Ródão área. The terrace T2 (older) is tilted towards southeast (gradient: 3.4%). FPS—Fundamental planation surface; PF—Ponsul fault scarp; T2, T3 and T4—terraces; FEAS—Foz do Enxarrique archaeological site; SAUF—Senhora da Alagada urbanization fault (outcrop).

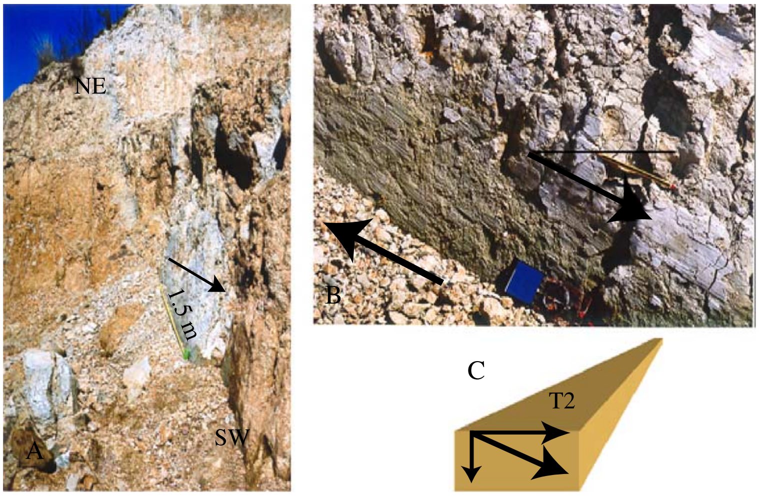

Fig. 14. Characterization of the fault at the Senhora da Alagada urbanization (Vila Velha de Ródão), displacing the Tertiary arkoses (exposed) and the T2 terrace. See Fig. 13 for location. (A) General view of the outcrop (the ruler is 1.5 m long). (B) Detail of the fault plane, where slickensides with a 28°SW pitch can be seen. (C) Interpretative scheme indicating a right-lateral strike-slip fault, with some vertical displacement.

ening direction that strikes WNW–ESE, similar to other Portuguese Quaternary tectonic structures (Ribeiro et al., 1996).

4.4. Incision rates

Taking into account the available dating of the lowest terraces in Tejo reach I, it is possible to estimate the time-averaged incision rate of this river in the Ródão area. The rate can be expressed by the equation: $\beta=(h-\alpha)/i$, where β—average rate of incision, h—altitude of the top surface of the terrace, α—altitude of the present river bed, i—age of the terrace top aggradation surface.

At the Foz do Enxarrique (Sra. da Alagada) archaeological site, the upper aggradation surface of terrace T4 is at an altitude of 90 m and the fossil remains located near its base were dated to 33.8 ka; the Tejo valley floor is at an altitude of 66 m. Thus, the time-averaged incision rate of the Tejo river affecting the period after terrace T4 deposition will be more than 0.7 m/ka (24 m/33.8 ka), since we do not know the age of the final aggradation phase of this terrace.

At the Vilas Ruivas archaeological site, terrace T3 has the silts that constitute the top of the sedimentary sequence located at an altitude of 124 m and dated at 60 ka (TL). So, we can obtain a time-averaged incision rate of 1.0 m/ka (58 m/60 ka), for the period following terrace T3 deposition. If we admit that the base of terrace T3 has an age of ca. 350 ka, based on the Acheulian artifacts in Monte do Famaco (Ródão), it is also possible to estimate that the phase of sedimentary accumulation of the Tejo terrace T3 lasted about 290 ka, which corresponds in Vilas Ruivas to an time-averaged aggradation rate of 0.02 m/ka (6 m/290 ka).

As the geochronology available for the terrace deposits is limited to the last two terraces, it is difficult to calculate longer-term incision rates. However, taking the entire duration of fluvial incision (ca. 2.6 Ma) from the top of the Falagueira Formation to the present Tejo bed in the Remédios sector, a time-averaged incision rate of around 0.1 m/ka is obtained.

This long-term incision rate calculated for the Tejo reach I is similar to previous estimates for uplift in Central Portugal that reach rates of ca. 0.1 m/ka for the last 3.5 Ma and 0.2 m/ka for the last 1.6 Ma near the coast and rather more in the upland areas, respectively, ca. 0.1 and 0.3 m/ka (Cabral, 1995). A geodynamic model of activation of the Portuguese passive margin (Ribeiro et al., 1996) by horizontal compressive stresses seems to be compatible with rates of this magnitude.

4.5. Proposed model for fluvial incision

Although comparison of incision rates should be made with caution, the time-averaged incision rate calculated for the last 60 ka is much greater than the one estimated for the 2.6 Ma period, since the beginning of long-term fluvial incision. This increase in the incision rate is in agreement with the geomorphologic features shown by the Tejo reaches I and II, which document drainage rejuvenation during most recent times.

Fluvial incision is here interpreted as caused mainly by successive regional uplift events. These resulted from the intensification of intra-plate compressive stress field during the Quaternary (Cabral, 1995; Ribeiro et al., 1996). They could also have been controlled secondarily by the minor isostatic response of the crust to the fluvial redistribution of material from upland interior to lowland basin and continental margin. Cloeting et al. (1990) suggested that the increase in the Quaternary uplift rates of areas located around the edges of the North Atlantic basin is the result of major reorganizations of spreading direction and rate, which occurred during the Pliocene along the entire Atlantic spreading system, leading to an increase in the intraplate tectonic stress.

In the temperate latitudes of Eurasia, the normal river development during the late Cenozoic has been to form staircases of terrace deposits (except in areas of subsidence) that have been interpreted as formed in response to climatic forcing, which was considered to have led to cyclic incision and aggradation in synchrony with glacial/interglacial cycles, superimposed upon a background of progressive uplift (Bridgland, 1994, 2000; Maddy, 1997; Maddy et al., 2000). However, we propose an alternative model in which it is the regional successive uplift events (tectonic phases) that mainly determine the long periods of rapid incision (the rock uplift rate is generally higher than the erosional rate) punctuated by short periods of valley enlargement and even minor aggradation. Aggradation could reflect the time lag between external forcing and sediment response (Kooi and Beaumont, 1996 in Burbank and Anderson, 2001). So, although conditioned by climate and base-level change, but also by local factors such as movement of tectonic blocks, lithology and structure, regional tectonic uplift should be considered to be the main control of the valley incision rates and explain the formation of these staircases of terrace deposits.

As an alternative to the classical models of tectonic forcing and landscape response following the theories of Davies, Penck and Hack (see discussion by Burbank and Anderson, 2001), a new model of tectonic forcing is proposed, involving pulses of varying rock uplift. This model suggests that the rock-uplift rate is generally variable and consists of cycles comprising periods of higher rock uplift (that can be called tectonic phases), alternating with other periods with less or even no rock uplift. So, each cycle produces an initial interval of building of topography eventually followed by a period in which rock uplift and erosion become balanced. However, over a larger period, the succession of tectonic cycles produces a long-term "constant", increasing or decreasing time-averaged rock-uplift rate, depending on the regional geodynamic evolution. The sedimentary response to external forcing is determined by the balance between eroding and resisting forces, but some time lag exists. However, a much more detailed geochronological framework is required in order to sufficiently support the proposed model and a larger number of observations needs to be obtained in the Tejo and other rivers that cross the western Iberia.

These successive regional uplift events reflected in the study area should correspond to compressive tectonic phases that affected Iberia. Those dated as Neogene are already well documented in both Spanish and Portuguese basins (Calvo et al., 1993; Cunha, 1996). Dating also suggests that these late Cenozoic tectonic phases are occurring at progressively shorter times.

5. Conclusions

Through the integration of geological and geomorphological data, the long-term drainage evolution of the Tejo river spanning some 3.4 Ma has been established in the study area. After a period of endorheic drainage in the Lower Tejo Basin, probably at the end of the early Pliocene the Tejo river was created as an Atlantic fluvial system that captured the drainage of the Madrid Tertiary Basin. The creation of the Tejo as a transverse drainage across the Ródão quartzite ridges is seen as a result of superposition during incision. The four terrace levels recognized in the Ródão depression have been used for the interpretation of the drainage evolution. The upper terrace matches a regional planation surface but the lower ones are confined in a narrow valley.

In the study area, terraces only exist in tectonic depressions which underwent less uplift than the adjacent areas along the river. The terraces are developed mainly in places where the river has eroded soft rocks allowing the possibility of enlarging the valley. This has happened in areas with Tertiary sediments, but terraces are almost absent in the areas where the river has cut into the hard rocks of the basement. Upstream of the study area, this can explain the larger number of terraces developed by the Tejo in the Madrid Tertiary Basin. The unpaired strath terraces of the reach II can be seen as documenting periods in which the lateral migration rate has exceeded the vertical incision rate (sensu Merritts et al., 1994).

The different tectonic behaviour recorded in the various reaches of the Tejo can be explained as a result of differential uplift along major transverse faults.

Tectonic data demonstrate a link between active and passive tectonics and the Tejo drainage evolution. The tectonic control appears to have been the main driving mechanism of sedimentary morphodynamic and palaeogeographic changes produced in a context of regional uplift during the late Cenozoic. Local tectonics is also responsible for the changes in the geomorphic features of the Tejo reaches and is expressed by vertical displacements of the planation surfaces and terraces. The fluvial landforms of the Ródão area indicate that during the long-term incision stage, the Tejo was constrained in straight NE–SW and NNW–SSE reaches.

An intensification of the regional uplift in most recent times is indicated by the landform rejuvenation and generalised entrenchment of the rivers, and further supported by the estimated time-averaged incision rates.

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