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Inland Record of the Last Interglacial Maximum in the Western Mediterranean: Revealing the Aljezares Pleistocene Basin (Alicante, SE-Spain)

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Abstract: The search for a continuous continental record of interglacial periods in semi-arid regions is problematic due to the absence of stable and continuous sedimentary systems over time in this type of climate. In this work, a relatively stable basin is described and analyzed during the last interglacial period in a semi-arid region of the western Mediterranean. For this purpose, a geomorphological, stratigraphic and sedimentological study has been carried out, with dating through ^{230}Th. A semi-endorheic Pleistocene section has been identified, with two units that correspond to a fluvial-lacustrine system (unit P1) and an alluvial system (unit P2). Unit P1 has been dated to the MIS 5e interglacial episode. A framework for future studies is described, in which the Aljezares Pleistocene basin can be considered as a possible source of paleoenvironmental and paleoclimatic information in semi-arid regions from the last interglacial period.

Keywords: continental record; MIS 5; semi-arid climate; western Mediterranean

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1. Introduction

The available continental record of recent interglacial episodes is limited, with lake systems, especially in temperate or humid zones, being one of the main sources of terrestrial climate and environmental data [1]. This implies that there are scarce paleoenvironmental and climatic data on dry regions, due to their limited hydrology to form lakes or lacustrine deposits. However, dry coastal areas offer valuable insights into the last glacioeustatic climatic changes during the Pleistocene through the study of coastal terraces [2], although the erosive nature of the coastal environment limits its suitability for preserving continuous paleoenvironmental information.

The southeast region of Spain has a semi-arid Mediterranean climate within the drylands fringe of the Iberian Peninsula [3] (Figure 1a,b). In this region, Pleistocene deposits have been extensively studied, primarily in the coastal environment between Alicante and Almería provinces (SE Spain) where marine terraces provide particularly well-preserved evidence of the last two interglacial episodes [4,5] (Figure 1c). The inland record, however, has received minor attention, mainly because of its limited outcropping and the difficulties to its chronostratigraphic correlation. The inland sedimentary records of the last interglacial period in the context of the Iberian Peninsula consist of palynological studies in lacustrine sequences, which are far from the semi-arid Mediterranean fringe [6,7]. In this study, an example of the inland record from the drylands fringe of the Iberian Peninsula in the Vinalopó River basin (Alicante, SE Spain) is shown.

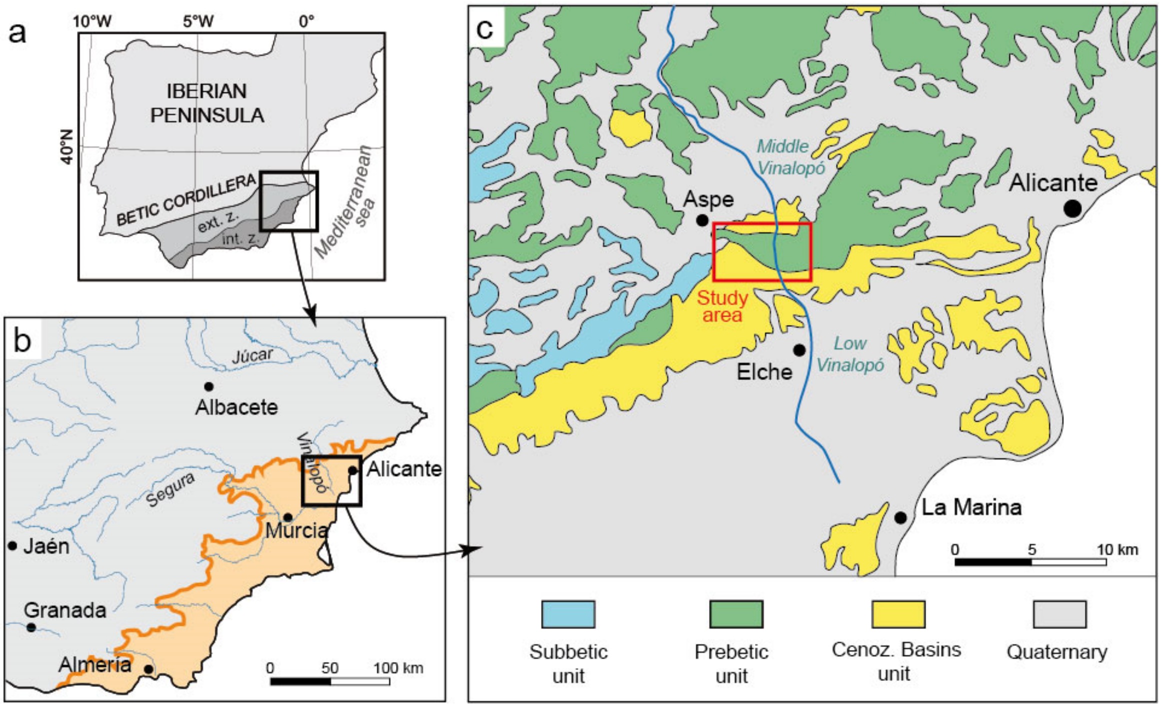

Figure 1. Location maps of the studied area. (**a**) Iberian Peninsula in the western Mediterranean and its relation with the Betic Cordillera. (**b**) Area of drylands environments in the southeast of the Iberian Peninsula where the precipitation is scarce more than 7 months at year (from Machado et al. [3]). (**c**) Geologic map of the eastern part of the Betic Cordillera showing the External Zones units (Subbetic and Prebetic) and the Cenozoic Basins unit. Note the location of the Vinalopó River. Minor Quaternary outcrops are not indicated, see Figure 2.

The Plio-Pleistocene coastal lagoon and alluvial deposits comprised the distal part of the Vinalopó basin [8]. Upstream, the middle part of the basin is mostly constituted by Holocene deposits [9,10], whereas the Pleistocene record is limited to the piedmont of nearby mountains [11]. However, local sequences located within the elevations between the distal and the middle part of the Vinalopó basin show relict Pleistocene deposits that allow the study of the pre-Holocene inland record. This work focuses on the record of one of these local sequences, the Aljezares Pleistocene basin in the Los Aljezares Nature Reserve (Aspe, Alicante), where well-preserved Pleistocene deposits are found. It is important to highlight that for the Aljezares deposits, we will use the term "basin" in a hydrological sense, as part of a larger geological configuration that is the Vinalopó River basin. Additionally, the Aljezares Pleistocene basin preserves the record of the activity of Neanderthal communities, mainly in its path from continental to coastal areas [12]. A Middle Paleolithic archaeological site has been described in the Pleistocene deposits and attributed to the Middle Paleolithic (Pleistocene *s.l.*), based on the type of industry collected (Levallois technology). The site has been interpreted as an open-air, temporary site in gravel areas where flint pebbles were abundant [12].

Therefore, this work aims to introduce and describe the Pleistocene basin of Aljezares for the first time, providing a geomorphological and sedimentary framework of the evolution of a Pleistocene inland record from southeast Iberia, an area with a severe, semi-arid Mediterranean climate.

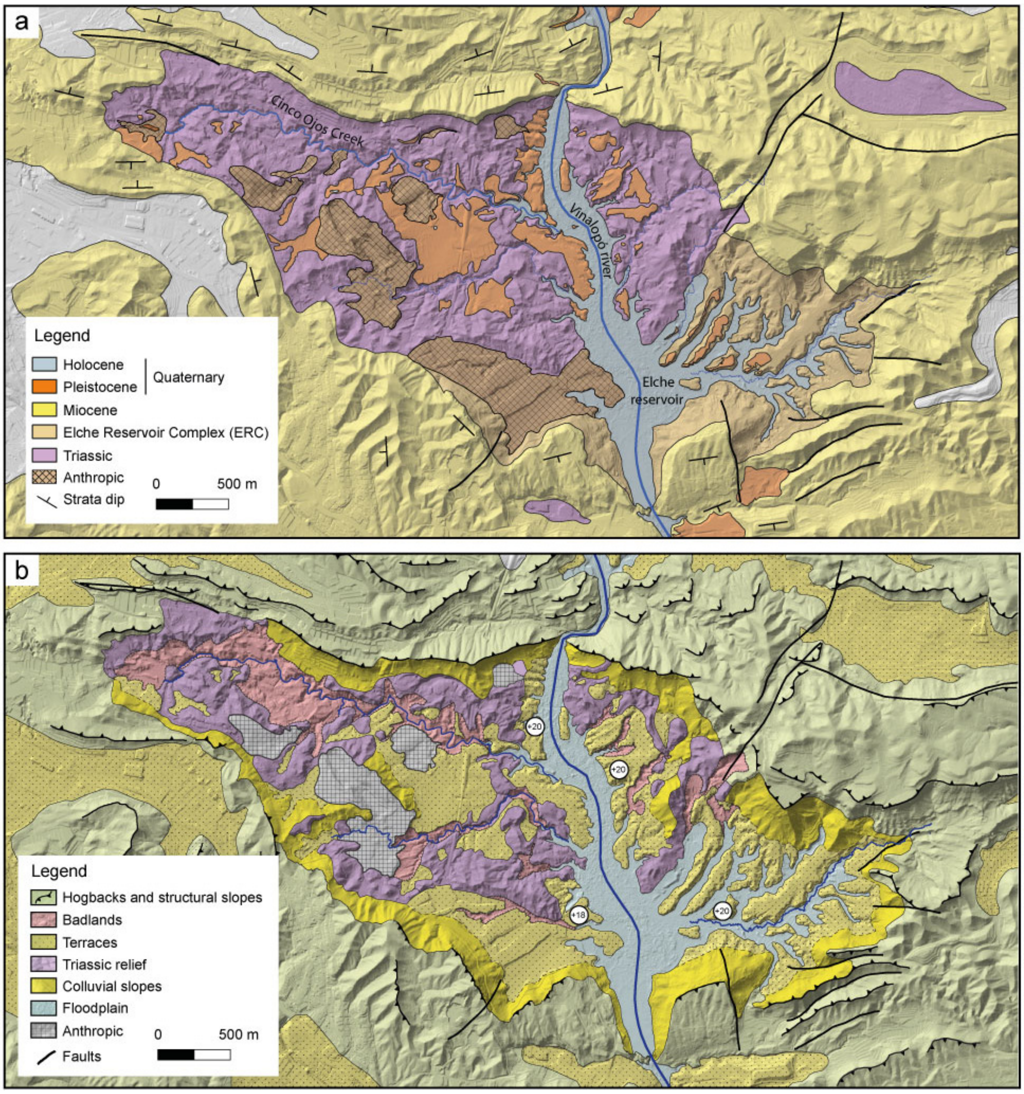

Figure 2. Geology and geomorphology of the Aljezares study area. (**a**) Geologic mapping of studied area (detailed position in Figure 1c). (**b**) Geomorphological mapping showing main morphologies recognized in the area. The height above the talweg of Pleistocene terraces is shown in the white circles.

2. Geological Setting

The Aljezares basin is located near the town of Aspe (Alicante province, SE Spain) in an intra-mountain area within the External Zones of the Betic Cordillera. The study area comprises Pleistocene deposits within wide valleys eroded along the Betic Cordillera (Figure 2a,b), occupying the Prebetic and the Cenozoic Basins units [13]. This zone is crossed by the north-to-south entrenching of the Vinalopó River, and it is the boundary between the middle and the low (distal) part of the Vinalopó River basin (Figure 1c).

Here, the Prebetic unit is mainly constituted by Triassic rocks composed of clays, sandstones, dolomites and gypsum attributed to the Upper Triassic Keuper Facies [12]. The deposits in the Cenozoic Basins unit mainly consist of marls, limestones and conglomerates attributed to the Middle to Upper Miocene (Serravallian-Tortonian stages), and are arranged in a complex tectonic structure [11,14,15].

3. Methods

This study uses a geomorphological, stratigraphic and sedimentological approach, although other geological methodologies have been used. For geomorphological descriptions, aerial photography and a digital elevation model have been used, all of this processed using version 3.18 of QGIS software. These data have been carefully contrasted with field observations to obtain an adequate attribution of the terrain features in the geomorphological mapping. For the stratigraphic description, the use of a stratigraphic panel has been chosen to receive a complete representation of the horizontal and vertical scales in the description of the units, and to indicate the unconformities between units [16]. The units have been characterized in base to the lithology, grain size, sorting, palaeontological content and geometry of the sedimentary bodies, amongst others. Due to the abundance of gastropods in the rocks studied, an analysis of the malacofauna of the most significant species has been included. In addition, a petrographic characterization of the carbonate rocks has been included to expand the paleoenvironmental information. ^{230}Th dating of the continental carbonates has been carried out at the Isotope Laboratory of Xi'an Jiaotong University, using a Thermo Neptune multicollector inductively coupled plasma mass spectrometer (MC-ICP-MS), following the methodology described in [17] and the decay constants reported in [18].

4. Results

The study area is structured as an antiform with an open core known as Clusé [19]. The flanks of the anticline are formed by Miocene rocks, whereas Triassic sequences are found in the core. Overall, it is a difficult to assign unit called Elche Reservoir Complex (ERC), which was remobilized during the Neogene, but closely related to the configuration of the Triassic unit. The core, being more eroded when compared to the flanks, creates a local inland area with an annular shape where the Quaternary deposits are still preserved (Figure 2).

Two chronostratigraphic units can be distinguished within the Quaternary deposits: the youngest is a Holocene unit associated with the Vinalopó River and Elche reservoir located to the south, and the oldest is a Pleistocene unit that outcrops in the form of discontinuous terraces covering the paleo-relief left above after the incision of the Triassic and ERC units (Figures 2 and 3). The most relevant evidence of such pre-Holocene deposits is found in the core of the antiform fold, despite there being small outcrops that are also identified beyond the study area (Figure 2a).

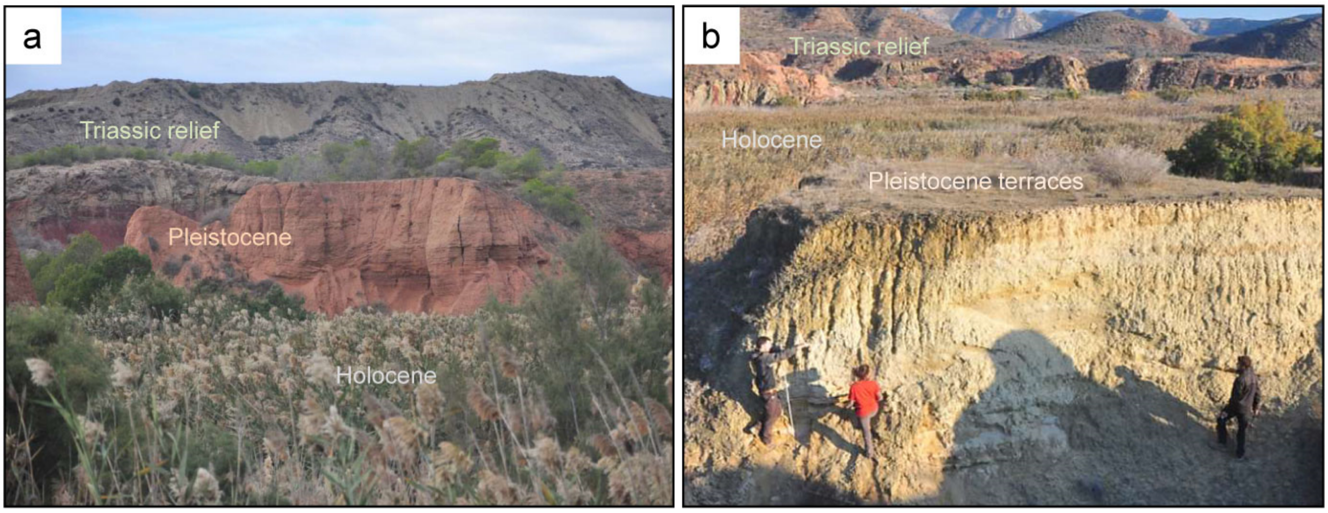

Figure 3. (**a**) Pleistocene deposits in Aljezares occupying the central part of the Quaternary basin in form of sedimentary rocks with vertical scarps and horizontal stratification. In the foreground, riparian vegetation grows on Holocene deposits. In the background, the Triassic relief is observed. (**b**) Detail of the flat tops of Pleistocene terraces.

Due to the small cartographic extension of the Pleistocene deposits in the studied area, the present work is their first documentation, as previous geological studies practically omitted them [15] or provided only partial descriptions of them [14].

4.1. Geomorphology

Geomorphological features in the study area are mainly linked to the erosive and depositional evolution of the Vinalopó river throughout the external and internal parts of the general anticline, and are very constrained by the differences in lithology. In this line, six geomorphological zones have been distinguished as follows (Figures 2b and 4a):

1. Successive hogbacks and structural slopes: This zone, representing the flanks of the anticline, shows a process of strong differential erosion between alternating weak and resistant Miocene bedrock. Linked to the lithology and structure of the anticline, they constituted the ring-shaped hills found encircling the anticlinal structure. The anticline is cut by the Vinalopó River in north-to-south direction.
2. Badlands: This zone is linked to the drainage system of the Vinalopó River within the core of the anticline and it is developed above the less resistant rocks of the Triassic, ERC and Pleistocene units. Its development is mainly associated with the tributary channels existent in the western area of the basin (Cinco Ojos Creek).
3. Terraces: This zone is constituted by isolated flat areas found at the top of the Pleistocene deposits and located T + 18/20 m above the talweg of the Vinalopó River. They occupy tens to hundreds of meters of lateral extension in the center of the basin, extending through the boundaries (Figure 2b). Their configuration is linked to the incision of the Holocene drainage network into the Pleistocene infill, characterized by flat tops and vertical scarps (Figure 3a,b).
4. Triassic relief: This is composed of topographic heights within the anticlinal core that have not been occupied by Quaternary sedimentation, mainly corresponding to the dolomitic or the most massive gypsum and clay units from the Triassic formations which have not eroded (Figure 4a). They show very complex structures with a chaotic appearance in the form of topographic highs scattered throughout the area above the flat terraces.
5. Colluvial slopes: These are conformed by discontinuous patched areas with gentle slopes of logarithmic expression that link the high Miocene and Triassic reliefs with the flat Pleistocene terraces (Figure 4b). They can be described as pediment type depositional/erosive systems from the upper areas of the Neogene ridge relief toward the center of the anticline.
6. Floodplain: This zone is occupied by the Vinalopó River, Elche reservoir and Holocene sedimentation (Figure 4b).

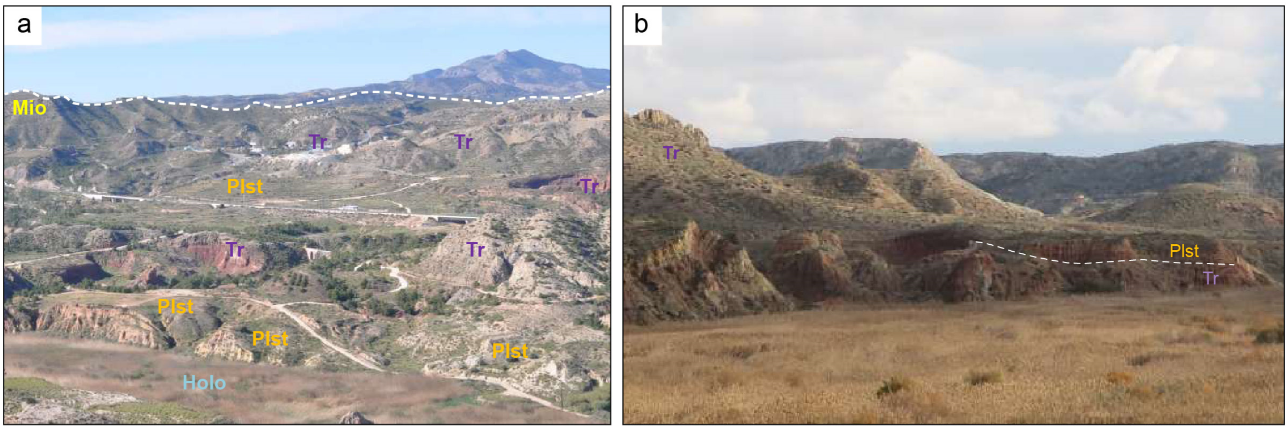

Figure 4. (**a**) Panoramic view of main geomorphological zones. The badlands on Triassic formations (Tr) appear dispersed between the Pleistocene flat terraces (Plst). The white striped line shows the limit of the Aljezares anticline formed by the Miocene units (Mio), with the foreground Betic relief. Notice the high anthropic interventions over Triassic formation, with exploitation of resources like clays and dolomite ballast. Additionally, the trace of the high-speed train line is observed in the center of the image. (**b**) Colluvial slopes connecting the Triassic highs with Pleistocene deposits in the center of the basin.

Geomorphological zones in the Aljezares basin are commonly affected by recent human activity. The major anthropic alterations are observed in old gypsum and clay quarries located in the Triassic deposits, and the recent railroad of the high-speed train line that crosses the Aljezares basin from north-to-south. Additionally, agriculture fields are located along the whole basin in flat terraces, taking advantage of flat or gentle slopes. The factors mentioned above complicate a detailed geomorphological characterization due to an eventual erasing of some geomorphological features.

4.2. Characterization of the Pleistocene Deposits

Pleistocene deposits crop out above the angular unconformity that affects the Triassic and ERC units. The unconformity constitutes a sharp paleo-relief, with deeper areas located close to the present day location of the Vinalopó River, Elche reservoir and Cinco Ojos Creek (Figure 2). Therein, Pleistocene horizontal strata reach up to 16 m of thickness and onlap the irregular unconformity (Figure 5a). Through the boundaries of the basin, low-angle dipping strata gradually lose thickness and pinch out (Figure 5b). The central part of the basin is eroded by the present course of the Vinalopó River, leaving visible and accessible outcrops where the deposits have been described and the stratigraphic panel has been made (Figure 6). Within the Pleistocene deposits, two units can be distinguished (P1 and P2), limited by a minor unconformity described as a paraconformity, which is linked to paleosol development (Figure 5c). Conversely, it shows an erosive disconformity in the central zone (Figure 5d).

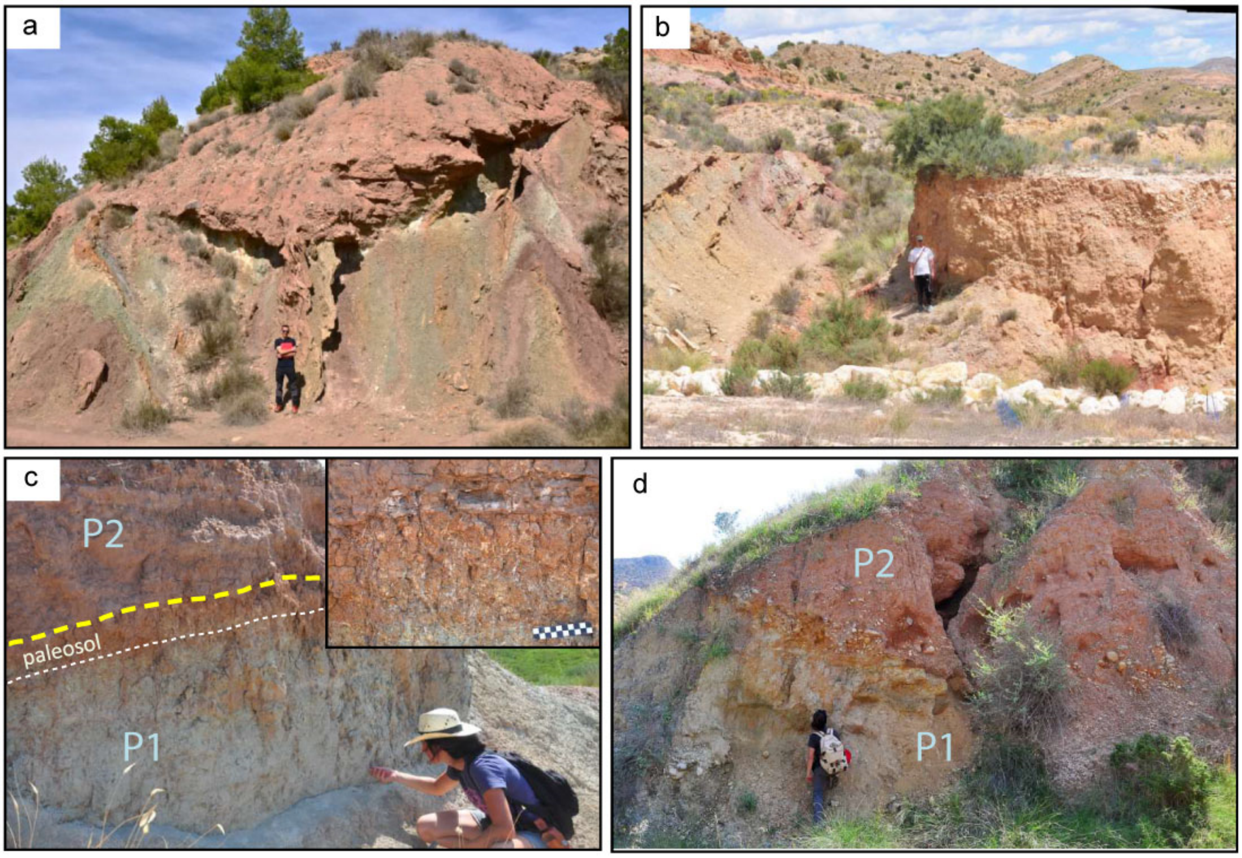

Figure 5. (**a**) Pleistocene and Triassic deposits separated by an erosive irregular unconformity. The expansive onlap filling is shown. (**b**) Pleistocene deposits near the boundary of the basin. The feet of the person is over Triassic rocks, therefore the thickness, marked by the flat terrace, is not greater than three meters. Compare this image with the image shown in Figure 3a. (**c**) Paraconformity (yellow line) with paleosol development (white line), where details of root traces are shown. (**d**) Disconformity near the center of the basin with lag levels.

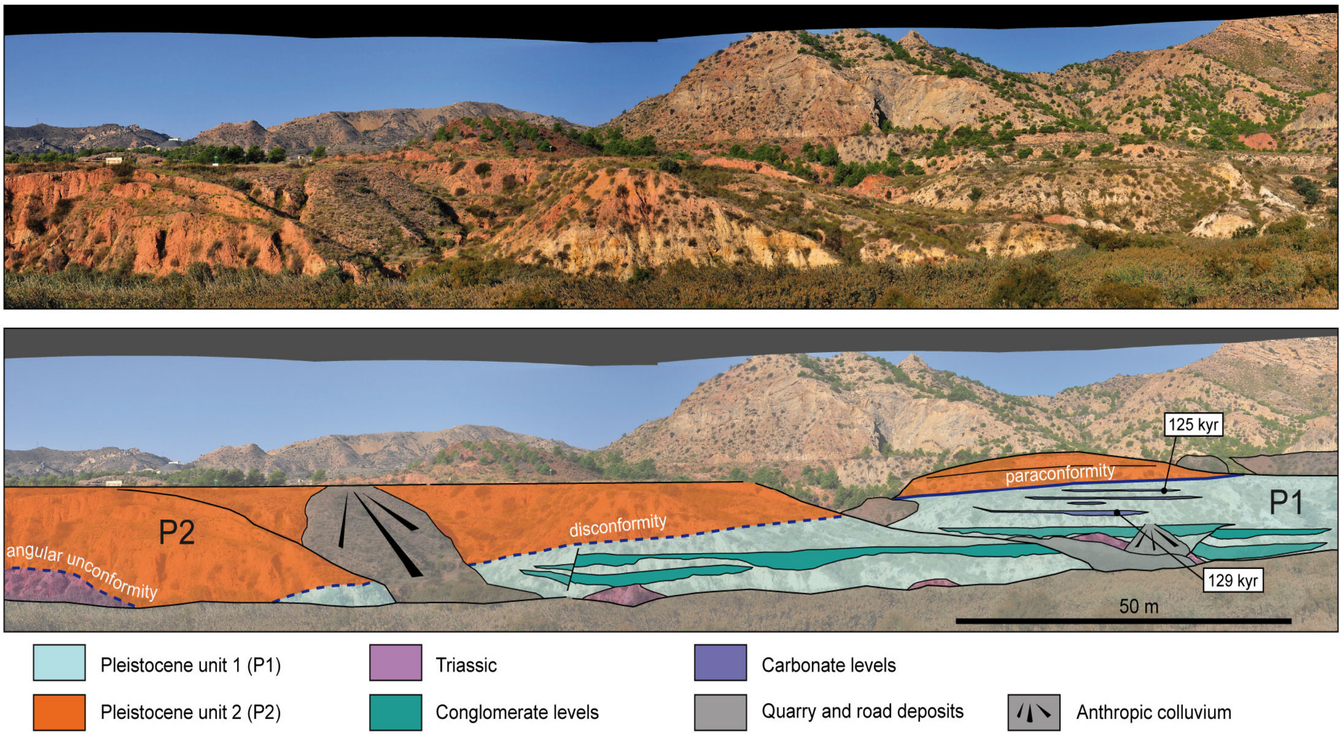

Figure 6. Stratigraphic panel of Pleistocene units (P1 and P2). Between them, a disconformity or a paraconformity is shown. Additionally, the location of carbonates sampled for dating and the ages obtained in this work are shown.

Pleistocene unit 2 is mainly constituted by matrix-supported conglomerates with scattered blocks, fine-to-coarse moderately sorted sandstones and intercalations of thinner tabular and channelized bodies of clast-supported conglomerates with moderate sorting (Figure 7a, Table 1). Pulmonate gastropods such as *Iberus alonensis* and *Sphincterochila candidissima* are very common (Figure 8a). Gastropods mainly appear dispersed within the conglomerates and show very good preservation without signs of reworking, which suggests they inhabited the deposits after sedimentation (Figure 7b).

Table 1. Characterization of Pleistocene deposits of the Aljezares basin.

Description	Malacofauna	Processes	Units
Clast-supported conglomerates with moderate sorting. Flat base tabular bodies with moderate lateral continuity. Pebbles and cobbles of limestone, sandstone and dolomite.	*I. alonensis* *S. candidissima*	Sheet flows	P2
Clast-supported conglomerates with good to moderate sorting. Erosive base and low lateral continuity and thickness. Locally cross-stratification and positive graded.		Ephemeral channels	
Matrix-supported conglomerates with very poor sorting and scattered blocks. Clayey and medium size sandy matrix. Massive bodies with great thickness.		Debris flows	
Clast-supported medium to coarse sandstones with moderate sorting interbedded with thin lutitic layers. Massive or with diffuse amalgamated bodies marked by lutites. Commonly paleosols.		Sandy flat	

Table 1. *Cont.*

Description	Malacofauna	Processes	Units
Lutites and poorly cemented sandstones. Commonly rizoliths and root traces.	*T. fluviatilis* *Melanopsis* sp. *I. alonensis*	Marsh	
Bluish lutites.	*T. fluviatilis* *Melanopsis* sp.	Permanent sheet of water and protected zones	
Clast-supported conglomerates with well to moderate sorting. Erosive base and high lateral continuity of tens of meters. Locally cross-stratification and positive graded. Pebbles and cobbles of limestone and flint.	*I. alonensis* (locally *T. fluviatilis* *Melanopsis* sp.)	Relative stable channels	P1
Stromatolite-like tufa levels.	Often associated with *lumaquela* levels with *T. fluviatilis* *Melanopsis* sp.	Permanent sheet of water and microbial activity over plant debris	

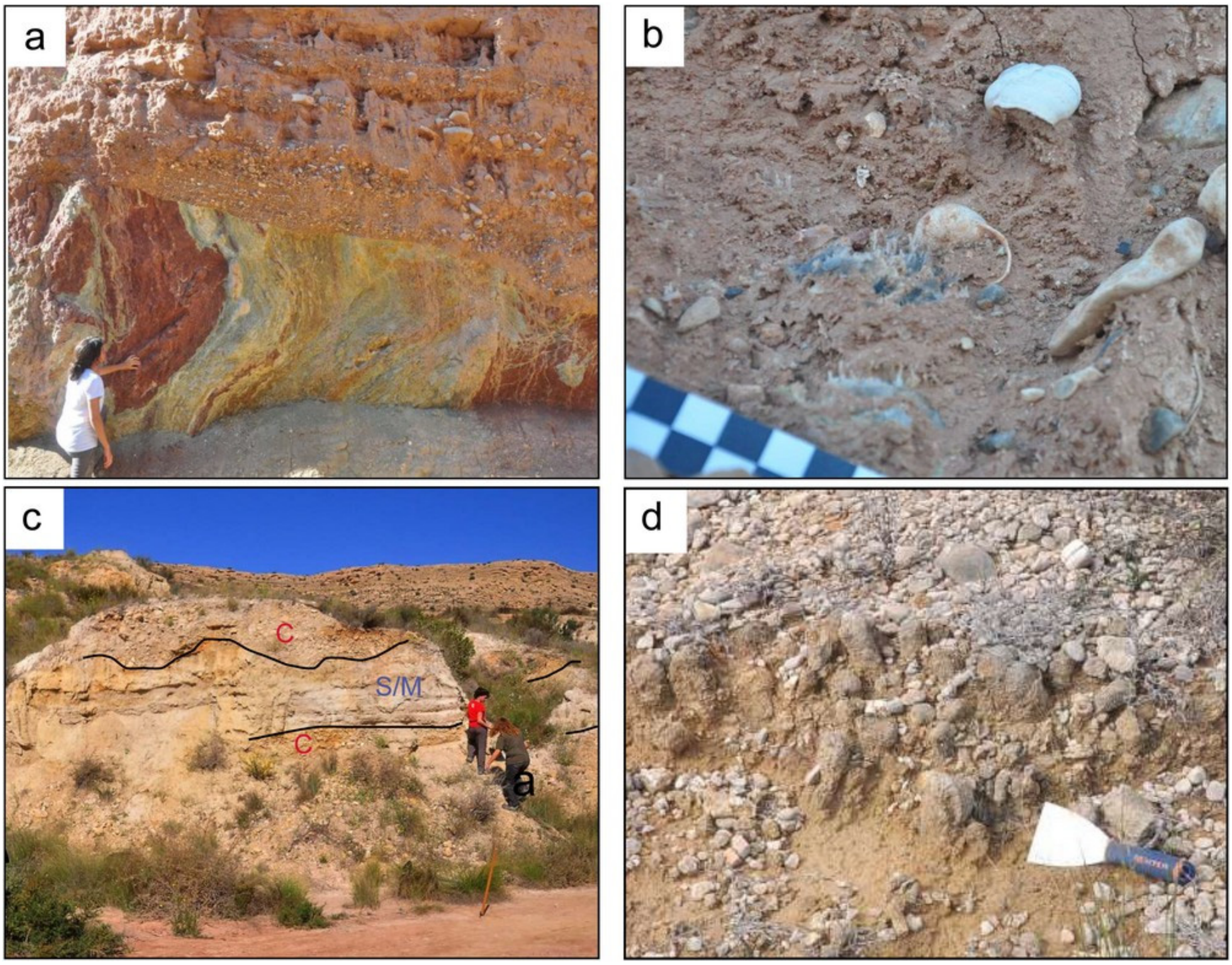

Figure 7. (**a**) Pleistocene unit 2 with thin channelized bodies showing an erosive angular unconformity over Triassic rocks. (**b**) Detail of the pulmonate gastropod *Iberus alonensis* with good preservation in Pleistocene unit 2. (**c**) Pleistocene unit 1 with conglomerates (C) alternated with sandy/muddy deposits (S/M). (**d**) Carbonate level of tubular tufa between sandstones and lutites.

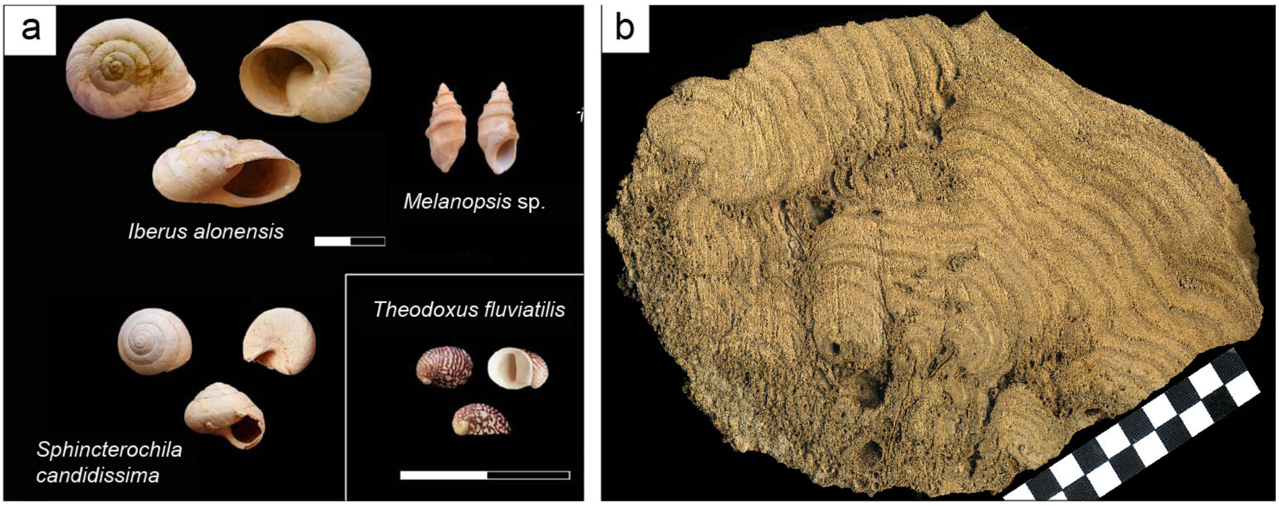

Figure 8. (**a**) Gastropods observed in the Pleistocene deposits of Aljezares Quaternary basin. Scale is 2 cm. (**b**) Stromatolitic type lamination in domical tufa sample. The concentric lamination growth produced by microbial communities can be observed. Scale in cm.

Pleistocene unit 1 consists of a wide variety of facies: conglomerates, carbonates and lutites (Table 1). Conglomerates are well to moderately sorted, lenticular shaped, erosive based and show lateral continuity of tens of meters, and a variable thickness (Figures 6 and 7c). Extra-basinal pebbles derived from the surrounding Miocene rocks are primarily found here. These conglomeratic bodies alternate with bluish and yellowish sandstones and lutites (Figure 7c) where root traces, rhizoliths and well-preserved gastropods of the species *Theodoxus fluviatilis* and the genus *Melanopsis* sp. are observed (Figure 8a). Furthermore, these gastropods can form high-concentration shell accumulations (known as *lumaquela*). Carbonates are boundstone type [20] (Figure 7d) and consist of domical and tubular tufa with stromaltolite type concentric laminations (Figure 8b). These levels have variable thickness from a few centimeters to one meter and good lateral continuity up to 50 m (Figure 6).

4.3. Geochronology

The first numerical dating of sequences from the study area was carried out by Eixea et al. [12] on the calcareous tufa deposits of the P1 unit with a sample of 20 g, analyzed by alpha spectrometry that offered an age of 132.284 + 10.873/−10.022 kyr. This result led these authors to attribute the uppermost part to the Middle to Late Pleistocene, close to the MIS 6/5 boundary.

In this work, new ^{230}Th dating has been carried out on these same carbonates using a more precise MC-ICP-MS technology, giving as a result the dates of 129.406 ± 2.729 kyr and 125.115 ± 2.484 kyr for the P1 unit, which places the chronology more precisely in the Marine Isotope Stage MIS 5e, at the beginning of the last interglacial maximum (Table 2).

Attempts were made to date unit P2, but no optimal materials or deposits were found for reliable dating.

Table 2. ^{230}Th dating results of the carbonate level samples. The error is 2σ.

^{238}U (ppb)		^{232}Th (ppt)		^{230}Th/^{232}Th (Atomic × 10^{-6})		d^{234}U * (Measured)		d^{234}U$_{Initial}$ ** (Corrected)		^{230}Th Age (yr BP) *** (Corrected)	
1727.0	±2.7	339,607	±6814	87	±2	397.3	±1.9	573	±5	129,406	±2729
1192.7	±6.3	186,664	±3870	110	±2	438.2	±3.6	624	±7	125,115	±2485

* $\delta^{234}U = ([^{234}U/^{238}U]_{activity} - 1) \times 1000$. ** $\delta^{234}U_{initial}$ was calculated based on ^{230}Th age (T). *** B.P. stands for "Before Present" where the "Present" is defined as the year 1950 A.D.

5. Discussion

5.1. Geomorphological and Sedimentary Evolution

Considering first the geomorphological analysis, both colluvial slopes and flat terraces zones (T + 18/20) are part of a single ancient geomorphological unit or Pleistocene geomorphological surface. This observation is compatible with a pediment shape that constituted the top level of the sedimentary filling in the Pleistocene basin. This fill had centripetal dynamics with unconfined drainage systems from the Miocene structural ridges and colluvial slopes that surround the basin, covering most of the core of the anticline, except in some high Triassic reliefs. Subsequently, this geomorphological surface had to be dismantled in the development of the badlands systems and recent flat valleys that are controlled with recent fluvial/alluvial dynamics. This Holocene dismantling of the Pleistocene geomorphological surface has been only partial, leaving remains of the terrace systems that can be observed today.

Several stages can be established in the evolution of the Quaternary forms and deposits of the Aljezares basin (Figure 9):

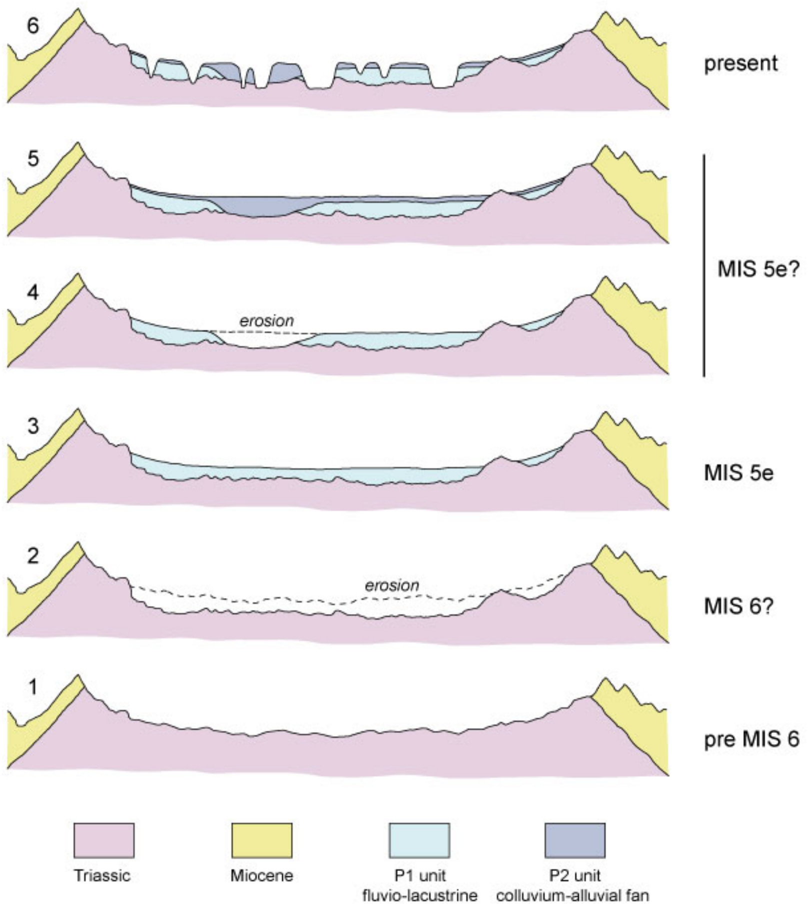

Figure 9. Stages established in the evolution of the Aljezares Quaternary basin. The interpretation of Pleistocene units P1 and P2 is shown.

Stages 1–2: The first event that can be recognized in relation to Quaternary processes is the formation of a paleo-relief on the Triassic and ERC rocks. Afterwards, sedimentation processes occur during MIS 5e (according to the dating and the elevation of the terrace), shaping an unconformity above the paleo-relief; therefore, any erosive event of the bedrock must be triggered previous to the sedimentation. A tentative assignment of this erosive event may point to MIS 6, since it constituted an important global drop in base sea level [21] that would be able to control the processes of channel entrenchment that shaped the Aljezares inner core of the anticline.

Stage 3: Subsequently, the Aljezares basin was filled by the Pleistocene unit P1. This unit is dated to MIS 5e, and corresponds to a fluvio-lacustrine environment system (see below). The location of the unit in the center of the basin suggests a north-to-south feeding in open basinal areas.

Stage 4–5: It starts with an unconformity on the P1 unit. This represents a paraconformity with depositional hiatus, although locally it has erosive features as indicated by the central location of the disconformity and angular unconformity. Over the unconformity, the sedimentation of unit P2 occurs, ending with a pediment-like geomorphological surface related to the colluvial slopes and the Pleistocene terraces described in the geomorphological analysis, located at T + 18/20. This top level of filling is compatible with the highstand that characterizes the last interglacial period [21], so the P2 unit is likely to be related to small eustatic oscillations or tectonic processes, but within MIS 5. Therefore, the P2 unit could represent a minor rupture during the Pleistocene filling, with a brief break in sedimentation and a local entrenchment in a west-east direction, thus dismantling the Triassic materials located in the west part of the Aljezares basin.

Stage 6: During the lowstand isotopic stages (MIS 4-2), the dismantling of the Pleistocene interglacial deposits occurs due to entrenchment associated with the falls of base level during the last glacial cycle. This moment may be the starting point of the development of the current Vinalopó fluvial erosion and the badlands. Finally, during the Holocene a north-to-south axial filling occurs in favor of the previous entrenchment with the development of the deposits of the current fluvial network of the Vinalopó River.

Sedimentological and palaeontological characteristics, together with the geomorphology and cartography of the Pleistocene units, allow interpreting them as deposited in a fluvio-lacustrine system (P1) and a colluvium-alluvial system (P2) with mainly axial supply and centripetal supply, respectively.

The first stage of filling is represented by the P1 unit mainly constituted by a fluvio-lacustrine system. Conglomerates would be the product of high-energy channels with relatively stable water flow [22] and carbonates would reflect stagnant water bodies or permanent ponds, which would also include marshy areas protected from the currents, as recorded by the lutites and sandstones with root signals. Supporting this interpretation, *Melanopsis* sp. and *T. fluviatilis* are aquatic gastropods, with the latter being an indicator of hard-water fluvial and lacustrine environments [23]. Attending to the facies classification for freshwater carbonates proposed by Arenas-Abad et al. [24], most of the boundstone facies correspond to coated streams growing upwards, produced by microbial communities; however, the interaction of bryophytes cannot be ruled out (Figure 7b). This type of tufa is common in aquatic environments, where a more or less stable body of water allows their development (e.g., [25]). Stagnant water bodies and marshy areas would be occasionally crossed by high energy channels characterizing a fluvio-lacustrine system with semi-endorheic behavior. Thereby, the drainage would had been axially connected to the marine base level in high energy events, while in stages of moderate rains it would have maintained an endorheic drainage relatively disconnected from the base level, but stable, since no other unconformities are observed within P1 (i.e., mudcrack surfaces, well-developed paleosols). High-energy channels were fed by north-south currents from outside of the Quaternary basin, and introduced extrabasinal cobbles, including flint cobbles. The work of Eixea et al. [12] describes the archaeological site linked to the use of these flints by Neanderthal communities, where the conglomerates are interpreted as episodic channels related to specific high-energy events. In the same unit, facies compatible with a closed (lacustrine) system have been described, such as sandstones with rhizolites, lutites and levels of stromatolite type tufa. The same authors [12] interpreted this set as stable in underwater conditions, where aquatic gastropod fauna have also been found. Due to the highstand context of the last interglacial maximum, the high-energy events would not have dominant erosive behavior, but rather, they would have episodes of sedimentation that are reflected in the well-developed conglomerate levels where the activity of the Neanderthal communities took place. This intermittent high-low energy dynamic is compatible with a decadal cadence of torrential episodes similar to that currently observed in southeastern Spain [3]. To compare the cadence and magnitude of these decadal events with respect to the current climatic dynamics in this region, detailed paleoclimatic studies are needed in the sedimentary records of lacustrine facies and in continental carbonates to explore such potential links and mechanisms.

Pleistocene unit 2 (P2) is constituted by a colluvium-alluvial fan, with predominant conglomeratic and sandy facies. There, matrix-supported conglomerates would be the result of debris flows in proximal areas of the systems [26], whereas sandstones and clast-supported conglomerates would reflect sandy flats, ephemeral channelized and non-channelized currents in the middle and distal parts [27,28]. Regarding the gastropod fauna, both species are present today in the area and represent a common association with semi-arid environments: for the xerophilic *S. candidissima,* it inhabits arid sun-exposed terrains with thin and dry soils [29], while *I. alonensis* is associated with calcicolous soils related to Mediterranean steppe environments near rivers and farmlands [30]. The types of flows associated with the P2 unit are most likely related to poorly developed channelized bodies in a non-hierarchical network, very common in the proximal to middle parts of alluvial fans. The identified facies can also be related to intermittent, non-seasonal, decadal dynamics. Due to the limited accommodation space available, a stable relative base level that would favor a continuous sedimentary or paleontological record was not developed, since it was close to being completely filled.

5.2. Regional Implications

The Aljezares deposits are compatible in age with those studied by Goy et al. [4], where coastal terraces dated to 120 kyr (MIS5e) are described in the nearby town of La Marina (Figure 1c). In these deposits, Senegalese fauna have been observed, indicative of the warmer and more humid conditions characteristic of MIS5e. This terrace is between 5.5 and 8 m a.s.l., an indicator of the highstand conditions of this period in the western Mediterranean [31], which have also been observed in the configuration of the Pleistocene Aljezares deposits. Although this study has not allowed us to make a detailed climatic and environmental comparison, this geo-chronological relationship and its compatibility with the coastal record makes the Aljezares basin a relevant continental record of the last interglacial period in the western Mediterranean that deserves to be studied in more detail in future works.

6. Conclusions

This paper describes the deposits in the area of Aljezares, a Pleistocene basin in the semi-arid region of the southeast of the Iberian Peninsula. In this area, the Quaternary series are formed by the Holocene deposits of the current fluvial dynamics of the Vinalopó River and the Pleistocene deposits. In the latter, lithic industry associated with the Middle Paleolithic has been found.

The geomorphological analysis shows how the Pleistocene flat terraces and colluvial slopes are parts of a single geomorphological surface that represents the final filling of the Pleistocene sedimentation. Therefore, the morphologies of badlands and present flat valleys must be the result of a subsequent Holocene entrenchment.

The stratigraphic and sedimentological approach has revealed two units. Unit P1 is mainly characterized by fluvial-lacustrine deposits under a semi-endorheic dynamic. In this unit, stromatolite-like tufa structures have been dated using the ^{230}Th method, providing ages of 129.406 kyr and 125.115 kyr, placing unit P1 in MIS 5e. The P2 unit mainly comprises colluvial and alluvial fans deposits that represent the final filling of the Pleistocene sequence of Aljezares.

Along the Pleistocene evolution, several stages are recognized, as shown in Figure 9: (1–2) Formation of a paleo-relief on the Triassic and the ERC during the MIS 6 lowstand. (3) Sedimentation of the P1 unit in a fluvial-lacustrine system where the activity of Neanderthal communities has been recorded. This semi-endorheic dynamic was controlled by periods of low energy, which were eventually interrupted by high-energy channels. This filling dynamic is compatible with a decadal cadence of high-energy episodes that are characteristic of semi-arid climates. (4–5) After a brief process of entrenchment in MIS 5, the filling of the Pleistocene basin continued with the P2 unit until its total infill with colluvium and alluvial fans facies was reached. (6) Dismantling of the Pleistocene sequence during the lowstand of the MIS 4-2 glaciation cycle and configuration of the recent drainage system and sedimentation of Vinalopó river during the Holocene, with a new north-south system. Assuming the differences in the position of the base level between the present and last interglacial period, there is a similarity between the environment and climate dynamics of MIS 5 in Aljezares and the current climate under the decadal high-energy episodes of semi-arid climates in the studied area.

To establish a reliable comparison, further detailed studies will be needed on the records observed and described in this work from the Aljezares basin. This study only aims to describe, for the first time, a relatively continuous sedimentary series in a climatic context where this type of record is usually scarce. Future studies based on detailed sedimentology, palynological and invertebrate records, or stable isotopes in continental carbonates, could offer detailed paleoclimatic trends that may be relevant to the understanding of climate dynamics under warm episodes in the context of the drylands in the western Mediterranean.

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References

1. Bagniewski, W.; Rousseau, D.D.; Ghil, M. The PaleoJump database for abrupt transitions in past climates. *Nat. Sci. Rep.* **2023**, *13*, 4472. [CrossRef] [PubMed]
2. Rovere, A.; Raymo, M.E.; Vacchi, M.; Lorscheid, T.; Stocchi, P.; Gómez-Pujol, L.; Harris, D.L.; Casella, E.; O'Leary, M.J.; Hearty, P.J. The analysis of Last Interglacial (MIS 5e) relative sea-level indicators: Reconstructing sea-level in a warmer world. *Earth-Sci. Rev.* **2016**, *159*, 404–427. [CrossRef]
3. Machado, M.J.; Benito, G.; Barriendos, M.; Rodrigo, F.S. 500 Years of rainfall variability and extreme hydrological events in southeastern Spain drylands. *J. Arid Environ.* **2011**, *75*, 1244–1253. [CrossRef]
4. Goy, J.L.; Hillaire-Marcel, C.; Zazo, C.; Ghaleb, B.; Dabrio, C.J.; González, A.; Bardají, T.; Civis, J.; Preda, M.; Yébenes, A.; et al. Further evidence for a relatively high sea level during the penultimate interglacial: Open-system U-series ages from La Marina (Alicante, East Spain). *Geod. Acta* **2006**, *19*, 409–426. [CrossRef]
5. Zazo, C.; Goy, J.L.; Dabrio, C.J.; Bardají, T.; Hillaire-Marcel, C.; Ghaleb, B.; González-Delgado, J.A.; Soler, V. Pleistocene raised marine terraces of the Spanish Mediterranean and Atlantic coasts: Records of coastal uplift, sea-level highstands and climate changes. *Mar. Geol.* **2003**, *194*, 103–133. [CrossRef]
6. Camuera, J.; Jiménez-Moreno, G.; Ramos-Román, M.J.; García-Alix, A.; Jiménez-Espejo, F.J.; Toney, J.L.; Anderson, R.A. Chronological control and centennial-scale climatic subdivisions of the Last Glacial Termination in the western Mediterranean region. *Quat. Sci. Rev.* **2021**, *255*, 106814. [CrossRef]
7. González-Sampériz, P.; Gil-Romera, G.; García-Prieto, E.; Aranbarri, J.; Moreno, A.; Morellón, M.; Sevilla-Callejo, M.; Leunda, M.; Santos, L.; Franco-Múgica, F.; et al. Strong continentality and effective moisture drove unforeseen vegetation dynamics since the last interglacial at inland Mediterranean areas: The Villarquemado sequence in NE Iberia. *Quat. Sci. Rev.* **2020**, *242*, 106425. [CrossRef]
8. Goy, J.L.; Zazo, C. The role of neotectonics in the morphologic distribution of the Quaternary marine and continental deposits of the Elche Basin, southeast Spain. *Tectonophysics* **1989**, *163*, 219–225. [CrossRef]

9. Ferrer García, C. Dinámica fluvial durante el inicio del Holoceno superior en el curso medio del Vinalopó (Alicante, España). *Bol. Geol. Min.* **2018**, *129*, 305–330. [CrossRef]
10. Cuenca, A.; Walker, M.J. Terrazas fluviales en la zona bética de la Comunidad Valenciana. In *El Cuaternario del País Valenciano*; Roselló, V.M., Ed.; Universidad de Valencia: Valencia, Spain, 1995; pp. 105–114.
11. Leret, G.; Nuñez, A.; Colodrón, I. *Mapa Geológico de España, 1:50.000 Hoja n° 871 (Elda) y Memoria*, 2nd ed.; IGME: Madrid, Spain, 1976; p. 65.
12. Eixea, A.; Cuevas-González, J.; Díez-Canseco, D.; Bel, M.A.; Bonnet, A.; Carrión, Y.; Martínez-Alfaro, A.; Martínez-Rubio, V.; Martínez-Varea, C.M.; Pardo, R.; et al. Los Aljezares archaeological site (Alicante, Spain) and the MIS 6/5 open-air settlement in the Iberian Peninsula. *J. Quat. Sci.* **2022**, *37*, 1091–1111. [CrossRef]
13. Vilas, L.; Castro, J.M.; Martín-Chivelet, J. El Prebético del Sector Oriental. In *Geología de España*; Vera, J.A., Ed.; SGE-IGME: Madrid, Spain, 2004; pp. 361–363.
14. Tent-Manclús, J.E. Estructura y Estratigrafía de las Sierras de Crevillente, Abanilla y Algayat: Su Relación con la Falla de Crevillente. Ph.D. Dissertation, Universidad de Alicante, Alicante, Spain, 2003.
15. Pignatelli, R. *Mapa Geológico de España, 1:50.000 Hoja n° 893 (Elche) y Memoria*, 2nd ed.; IGME: Madrid, Spain, 1972; p. 65.
16. Miall, A.D. *The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis, and Petroleum Geology*; Springer: Berlin/Heidelberg, Germany, 2013; p. 582.
17. Cheng, H.; Edwards, L.R.; Hoff, J.; Gallup, C.D.; Richards, D.A.; Asmerom, Y. The half-lives of uranium-234 and thorium-230. *Chem. Geol.* **2000**, *169*, 17–33. [CrossRef]
18. Cheng, H.; Edwards, L.R.; Shen, C.-C.; Polyak, V.J.; Asmerom, Y.; Woodhead, J.; Hellstrom, J.; Wan, Y.; Kong, X.; Spötl, C.; et al. Improvements in 230Th dating, 230Th and 234U half-life values, and U–Th isotopic measurements by multi-collector inductively coupled plasma mass spectrometry. *Earth Planet. Sci. Lett.* **2013**, *371–372*, 82–91. [CrossRef]
19. Archambault, M.; Lhénaff, R.; Vanney, J.R. *Documents et Méthode Pour le Commentaire de Cartes: Fascicule 2: Les Reliefs Structuraux*; Masson: Paris, France, 1970; p. 166.
20. Dunham, R.J. Classification of Carbonate Rocks According to Depositional Texture. In *Classification of Carbonate Rocks*; Ham, W.E., Ed.; AAPG: Tulsa, OK, USA, 1962; pp. 108–121.
21. Grant, K.M.; Rohling, E.J.; Ramsey, C.; Cheng, H.; Edwards, R.L.; Florindo, F.; Heslop, D.; Marra, F.; Roberts, A.P.; Tamisiea, M.E.; et al. Sea-level variability over five glacial cycles. *Nat. Comm.* **2014**, *5*, 5076. [CrossRef] [PubMed]
22. Miall, A.D. Alluvial deposits. In *Facies Models 4*; James, N.P., Dalrymple, R.G., Eds.; GAC: Ottawa, ON, Canada, 2010; pp. 105–138.
23. Macan, T.T.; Maudsley, R. Fauna of the stony substratum in lakes in the English Lake District. *Int. Ver. Für Theor. Und Angew. Limnol.* **1969**, *17*, 173–180. [CrossRef]
24. Arenas-Abad, C.; Vázquez-Urbez, M.; Pardo-Tirapu, G.; Sancho-Marcén, C. Fluvial and associated carbonate deposits. In *Carbonates in Continental Settings: Facies, Environments, and Processes*; Alonso-Zarza, A.M., Tanner, L.H., Eds.; Elsevier: Amsterdam, The Netherlands, 2010; Volume 61, pp. 133–175.
25. Arenas, C.; Gutiérrez, F.; Osácar, C.; Sancho, C. Sedimentology and geochemistry of fluvio-lacustrine tufa deposits controlled by evaporite solution subsidence in the central Ebro Depression, NE Spain. *Sedimentology* **2000**, *47*, 883–909. [CrossRef]
26. Colombo, F. Abanicos aluviales: Secuencias y modelos de sedimentación. In *Sedimentología: Del Proceso Físico a la Cuenca de Sedimentación*; Arche, A., Ed.; CSIC: Madrid, Spain, 2010; pp. 131–224.
27. Miall, A.D. Architectural-element analysis: A new method of facies analysis applied to fluvial deposits. *Earth-Sci. Rev.* **1985**, *22*, 261–308. [CrossRef]
28. Committee On Alluvial Fan Flooding, National Research Council. *Alluvial Fan Flooding*; National Academy Press: Washington, DC, USA, 1996; 182p.
29. Gasull, L. Las Helicella (Xeroplexa) de Baleares. Gasteropoda pulmonata. *Bolletí Soc. d'Història Nat. Balear.* **1964**, *10*, 3–88.
30. Martínez-Ortí, A.; Robles, F. *Moluscos Continentales de la Comunidad Valenciana*; Conselleria de Territori i Habitatge Comunitat Valenciana: Valencia, Spain, 2003; p. 197.
31. Stocchi, P.; Vacchi, M.; Lorscheid, T.; de Boer, B.; Simms, A.R.; van de Wal, R.S.; Vermeersen, B.L.A.; Pappalardo, M.; Rovere, A. MIS 5e relative sea-level changes in the Mediterranean Sea: Contribution of isostatic disequilibrium. *Quat. Sci. Rev.* **2018**, *185*, 122–134. [CrossRef]