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Geomorphological analysis using small unmanned aerial vehicles and submeter GNSS (Gara Soultana butte, High Plateaus Basin, Eastern Morocco)

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ABSTRACT
The High Plateaus Basin is an important region to understand landscape evolution and human occupation in North Africa during the Quaternary. We focused on the Gara Soultana area, applying Unmanned Aerial Vehicles, photogrammetry and a submeter Global Navigation Satellite System, for large scale geomorphological mapping. This work in the upper Moulouya catchment has allowed us to define the landform sequence. Conglomerate platforms previously considered to be fluvial terraces, are interpreted here as exhumed bedrock layers of the Plio-Pleistocene stacked series. The El Haï river incision consists of a first phase, represented only by the exhumation of Gara Soultana butte, and a second phase when five strath terraces developed from +20-22 m to the thalweg, formed since the Middle Pleistocene. Holocene terraces could be associated with brief aggradation phases in the lower Moulouya catchment due to rapid climate changes. Fluvial incision led to the formation of mantled pediments and talus flatirons.

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Fluvial terraces; valley evolution; sUAV; SfM; High Plateaus Basin; Eastern Morocco

1. Introduction

The High Plateaus Basin represents the NW sector of the Intra-Atlas Maghrebian depression (around 127,600 km^2, Figure 1), which is one of the biggest intra-mountain depressions in the Mediterranean catchment and several archaeological findings indicate that it is a key region to understand the Stone Age sequence in North Africa (Aouraghe et al., 2013; Sahnouni et al., 2018; Sala-Ramos et al., 2017; Saoudi, 2012). Nevertheless, few geomorphological studies are available to understand the landscape evolution and their implications in human occupation in the High Plateaus Basin. These studies are necessary to establish the relative chronology of artifacts according to their occurrence on landforms sequence (Despriée et al., 2011), to reconstruct the processes operating in landscape during site formation and to model palaeolandscapes occupied by humans (Benito-Calvo et al., 2017, 2020). In this work, we carried out the first large scale geomorphological analysis of the High Plateaus Basin focused on Gara Soultana hill and the El Haï valley (Za River tributary, Upper Moulouya catchment), where previous regional works mentioned pediments and conglomerates interpreted as fluvial terraces (Laouina, 1990; Muratet, 1991; Russo, 1927; Stretta, 1952; Wengler & Vernet, 1992). Associated with these landforms, several Acheulean to Neolithic archaeological findings were cited (Wengler & Vernet, 1992). These have been investigated since 2006 within the framework of a Spanish-Moroccan bilateral project undertaken in the Aïn Beni Mathar-Guefaït region (Jerada, Eastern Province) (Aouraghe et al., 2013; Sala-Ramos et al., 2017).

Several open access Digital Elevation Models (DEM) are available and tested for geomorphological studies (Boulton & Stokes, 2018), showing spatial resolution of 30 m (SRTM, ASTER, AW3D, ASTER DEM), and 12 m (TanDEMX). Nevertheless, these global WorldDEM still shows limitations for large scale and more detailed geomorphological studies where higher resolution and spatial accuracies are necessary. We addressed this issue by using small Unmanned Aerial Vehicles (sUAV) and Structure from Motion Photogrammetry (SfM), as a low-cost, rapid and portable alternative to produce high-resolution topographic surveys (Hackney & Clayton, 2015; Hugenholtz et al., 2013; Jorayev et al., 2016). These methods may provide better results than ALS data (Air Laser Scanning) (Hackney & Clayton, 2015), when high accuracy ground control points are available, usually surveyed using Global

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Figure 1. Study area, located in the High Plateaus Basin, Eastern Morocco.

Navigation Satellite System (GNSS) assisted by Real Time Kinematic (RTK) or Post-Processing (PP) techniques (Kasprzak et al., 2018). Nevertheless, RTK or PP require quality Virtual Reference Stations (VRS) which are unavailable in the study area. In order to solve this problem, we explored the use of a submeter GNSS, where the accuracy and reliability of GNSS information is improved by signals SBAS (Satellite-based Augmentation System). These methods allow us to generate topographic datasets suitable for large scale mapping, from which we produced a 1:1,500 geomorphological map, in order to detect fluvial terraces separated by low relative elevations and their differentiation from bedrock conglomerate layers located in the area. The aim of such identification is to provide a solid relative morpho-chronological sequence crucial in defining the correct geomorphological context for the archaeological surveys which are being conducted in the region.

2. Geological background

Gara Soultana butte is situated in the High Plateaus Basin (Figure 1), which corresponds to the NW region of the Intra-Atlas Maghrebian depression, between the Middle-Tell Atlas, to the north, and the High-Saharan Atlas, to the south. The High Plateaus Basin is bounded to the north by a major ENE-WSW fault which separates the Cenozoic basin from the Jerada Mountains. In this area, the Paleozoic basement consists of Ordovician and Carboniferous sedimentary, metamorphic, plutonic and volcanic rocks, overlaid by Triassic basalts and Jurassic carbonates (Muratet, 1991, 1995; Russo, 1927; Stretta, 1952). In the Cenozoic basin, Neogene-Quaternary basin fill onlaps the Jurassic bedrock, where several subparallel antithetic faults define a number of horsts and grabens (Bouazza et al., 2013; Bouazza, 2015). Cenozoic outcrops begin with proximal conglomerates, lacustrine limestones and marls of Miocene age identified at the border of the basin (Blain et al., 2013). Overlying the Miocene, a sequence of conglomerates, gypsum, marls, sandstones and palustrine limestones is described (Laouina, 1990; Muratet, 1991; Stretta, 1952), which could belong mainly to the Plio-Pleistocene in light of the small vertebrates described in Guefaït 4 site (Agustí et al., 2017; Sala-Ramos et al., 2017). Accordingly, the palustrine limestones and calcretes capping the sequence were also interpreted as Plio-Villafranchian (Laouina, 1990) or early Quaternary (Muratet, 1991), and form an extensive plateau to the south between 1080 and 940 m (Regional geological map, Supplementary Information). At the Jerada mountain piedmont, the top of this Plio-Pleistocene sequence corresponds to detrital alluvial fans. The plain formed by the limestone plateau and the alluvial fans is explained as a top basin fill surface related to an erosion surface preserved on the Jerada Mountains (Laouina, 1990).

After the sedimentation of the Plio-Early Pleistocene sequence, the dynamics of the basin changed to exorheic conditions, drained by the Charef-El Haï River (Regional geological map, Supplementary Information). The latter belong to the upper Za fluvial system (Moulouya catchment), which is separated from the lower Za river through a knickzone. In the High Plateaus Basin, longitudinal river profiles are characterized by gentle gradients inherited from previous basin palaeotopography, suggesting little channel incision (Pastor et al., 2015). In the High Plateaus Basin, river incision formed erosional and residual landforms (hillsides, buttes and plateaus), and depositional landforms in the valleys. Muratet (1991) mapped at a scale of 1:100,000, slope deposits, encrusted mantled pediments, cones, fluvial terraces and floodplains related to three main Quaternary phases, classified as old, middle and recent periods. In these early interpretations, conglomerates capping Gara Soultana hill were identified as a fluvial terrace formed during the older Quaternary exorheic phases (Muratet, 1991; Stretta, 1952). Later, Wengler and Vernet (1992) mentioned well-developed pediment-terrace systems in the basin formed during Soltanian and Rharbian (Late Pleistocene and Holocene, respectively). These authors differentiated a terrace level at the Late Pleistocene, and three terraces formed during the Holocene, named as Early Rharbian (12120 ± 130–11,360 ± 75 yr BP), Middle Rharbian (5700 ± 110 yr BP) and Late Rharbian (from 3290 ± 130 yr BP to 1480 ± 120 yr BP). This differentiation was proposed mainly to C14 age groups, performed on charcoal, although no mapping or geomorphological identification was presented. Other terraces in the upper Moulouya catchment have been estimated around 62 ± 14 ka and 411 ± 55 ka (cosmogenic nuclide), which lie respectively at +16-55 m and +133-182 m above the channels (Pastor et al., 2015). The latter are used to propose incision rates at ∼0.3 m/ka in the frontal structures of the Middle Atlas to be estimated. On the other hand, a ∼33 m thick fluvial deposition, whose top lies at +24-33 m above the channel, has been dated in the lower Moulouya around ∼1.5–1.1 Ma ago (Bartz et al., 2019).

3. Methodology

Geomorphological mapping focused on fluvial terrace identification and their differentiation from bedrock conglomerate layers and was based on fieldwork and spatial datasets (orthoimage and DEM) derived from aerial SfM photogrammetry. Direct observations in the field were described and collected on a rugged tablet (Panasonic FZ-M1), using QGIS and geotagged pictures. Vertical aerial photographs were taken using the sUAV DJI Mavic Pro. The latter is a very portable folding quadcopter, which includes a 12.71-megapixel camera, controlled by a remote controller supporting an Android mobile device. sUAV flights were GNSS assisted, taking a total of 255 photographs in two flights. These pictures covered a transect area of 0.56 km^2, joining the two valleys draining the Gara Soultana hillsides, in order to analyse the relationships between Gara Soultana butte and the incision sequence of the nearest valleys (Oued El Haï and Oued Bes-Bes). Gara Soultana orthophotograph and DEM were processed with photogrametric software Agisoft Metashape, using submeter GNSS ground control points. The DEM was transformed into contour lines, topographic profiles, and a hill-shaded model in order to enhance and map the terrain features, besides to estimate the relative and absolute position of landforms. Geomorphological landforms were digitalized at 1:500 scale, while the final map was compiled at 1:1,500 scale. Geomorphological elements were classified and symbolized mainly according to the legend proposed by Martín Serrano et al. (2004).

4. Results and Discussion

4.1. Photogrammetry

An initial photogrammetric model was compiled using the position data obtained from Mavic GNSS**.** This provided a 3D error of 2.3 m, which could be already suitable for large scale geomorphological mapping. Nevertheless, in order to achieve a better accuracy, especially in elevation, and produce suitable models for 1:1000-1:2000 scale mapping, we used ground control points (GCP) surveyed with GNSS (Table 1, Figure 2). Because there are no Virtual Reference Stations (VRS) in the field site needed to reach centimeter-level accuracy using real time kinematic or post-processing, we opted to use a submeter GNSS (Leica GS06). Submeter GNSS are very portable, and thanks to the Satellite-based Augmentation System (SBAS), based on the European Geostationary Navigation Overlay Service (EGNOS), provided GCP with 3D Coordinate Qualities (3DCQ) between 0.35 and 0.21 m (Table 1). We collected seven GCP distributed throughout the study area and close to the study area edges (Hackney & Clayton, 2015) (Figure 2). GNSS ellipsoidal heights were transformed into orthometric heights using the Earth Gravitational Model EGM2008. The final photogrammetric model georeferenced by means of GS06 GCP, provided a total 3D error of 0.43 m (Table 1), similar or slightly higher than the errors associated with ALS data (Fonstad et al., 2013; Hugenholtz et al., 2013). This error was considered suitable to compile a geomorphological map at a scale of 1:1,500, covering an area of 0.56 km^2, where we identified landforms $\geq$ 0.20 m^2 and incised at intervals of $\geq$ 2 m. From this model we exported an orthoimage and a DEM into ArcGIS Desktock (Figure 2). Since vegetation is not abundant in this arid area, we did not remove vegetation to obtain the final DEM.

4.2. Bedrock sequence and structure

El Haï valley has been carved in the Plio-Early Pleistocene sequence of the High Plateaus Basin. In the region, this sequence is composed of a basal alluvial succession of red mudstones, sandstones and conglomerates, including diagenetic gypsum and layers of limestones, marls and green mudstones at the base. Towards the SE, limestone and gypsum materials include abundant and meter-sized flint nodules (Soto et al., 2019). Above this unit, the succession continues with a palustrine unit revealed by tufas and palustrine limestones, including local conglomerates and sandstone channels. Overlying these deposits, there is a segment of soft materials, consisting of mudstones, marls and argillaceous limestones affected by nodular calcretes, interlayered with thin hard layers of massive micritic limestones. The top of the Plio-Early

Table 1. Ground control points surveyed with GS06 submeter Leica GS06 and error derived from photogrammetric process.

GROUND CONTROL POINTS (GNSS LEICA GS06)

GCP	Latitude °	Longitude °	Ellipsoidal height (h) m	3DCQ m	Geoid height (N) EGM2008 m	Orthometric height (H) m a.s.l.
GPS0011	34.11982	−2.10476	923.651	0.356	50.7892	872.862
GPS0012	34.12090	−2.10711	906.323	0.303	50.7926	855.530
GPS0013	34.12000	−2.10968	907.093	0.282	50.7943	856.299
GPS0019	34.12293	−2.10812	925.685	0.215	50.7956	874.889
GPS0021	34.12645	−2.11062	950.185	0.264	50.8015	899.384
GPS0023	34.12748	−2.11360	917.038	0.347	50.8055	866.232
GPS0025	34.12888	−2.10971	920.701	0.336	50.8031	869.898

PHOTOGRAMMETRIC ERROR

GCP	**Error m**	**X error m**	**Y error m**	**Z error m**
GPS0011	0.799	−0.770	−0.046	−0.207
GPS0012	0.579	0.030	−0.327	0.477
GPS0013	0.173	0.000	−0.038	−0.168
GPS0019	0.586	0.202	0.228	0.500
GPS0021	0.194	0.014	0.076	0.178
GPS0023	0.384	0.015	−0.174	−0.342
GPS0025	0.306	−0.280	0.124	0.005
Mean error:	**0.431**	**−0.113**	**-0.022**	**0.063**

Pleistocene sediments is dominated by limestones and calcretes which cap the stacked sequence and form the extensive plateaus.

Gara Soultana hill lies in the lower-central part of the El Haï valley, where Plio-Early Pleistocene outcrops belong to the basal red alluvial unit (Figure 3). The sequence in this area consists of a 46 m thick succession of gypsum sandstones and dark brown to red mudstones with diagenetic gypsum crystals (see bedrock sequence on the main map). White layers of limestones and marls and 1-4 m thick layers of conglomerates also appear interlayered in the sequence (Figures 4 and 5). Such conglomerates have been mapped in (1) the thalweg of the Bes-Bes River, partially eroded by the river channel, (2) cropping out on the banks of the El Haï River where they are overlaid by Quaternary strath fluvial terraces through a disconformity (Figure 6), and (3) capping the Gara Soultana hill (Figures 3 and 5, see also cross-section on the main map). All these conglomerates show identical facies (Figure 4), corresponding to cemented conglomerates of rounded to subangular clasts, dominated by

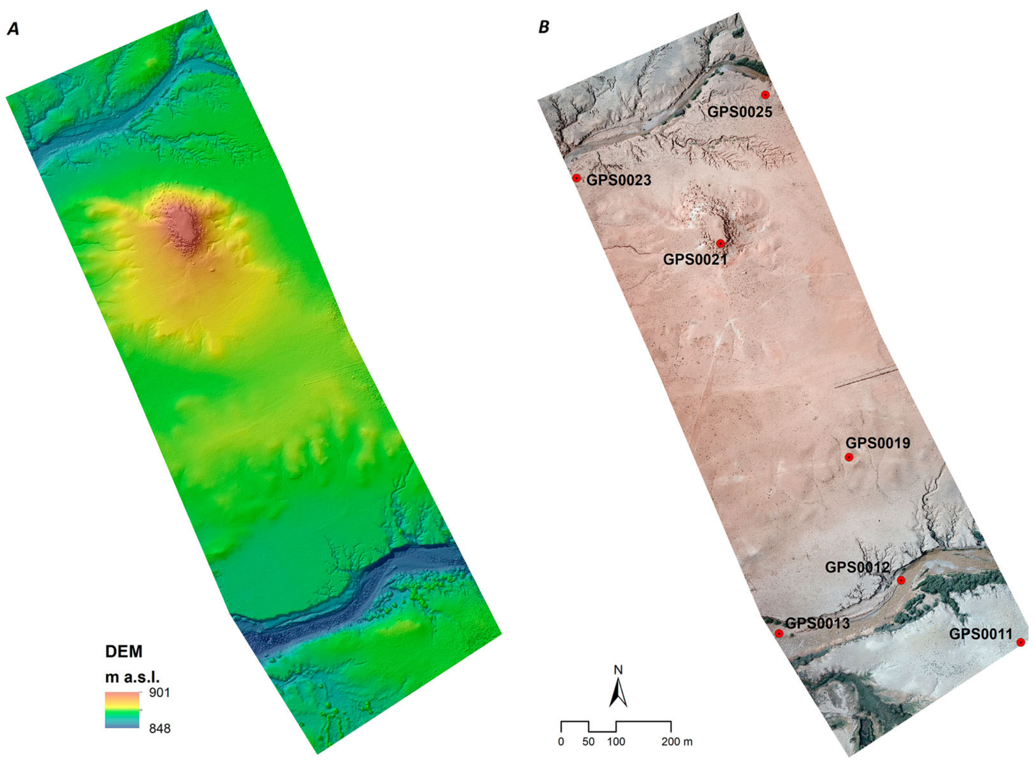

Figure 2. DEM (A) and Orthophoto (B) generated through photogrammetry using submeter GNSS control points (red points, see Table 1).

Figure 3. Aerial view of Gara Soultana butte (901 m a.s.l.), preserved on a 25 m thick succession of gypsum sandstones, dark to red mudstones and white marls, topped by a 1-3 m conglomerate layer.

pebble to cobble sizes, polymictic composition (limestones, metasediments, vulcanites, chert), sandy matrix, and showing massive, normal grading, cross-bedding, scour marks, flute casts, and channel structures. Flute casts described at the base of Gara Soultana conglomerates indicate a NE-SW paleocurrent direction (Figure 5). Although these conglomerates were initially interpreted as Pleistocene fluvial terraces, such as the Gara Soultana conglomeratic top (Muratet, 1991; Stretta, 1952), here we have mapped them as conglomerate layers belonging to the stacked Plio-Early Pleistocene substrate, based on the following evidences: (1) their facies are identical to the conglomerates described in the Plio-Early Pleistocene stacked sequence, (2) in many cases they can be observed interbedded between Plio-Early Pleistocene sandstones and mudstones (Figure 4), (3) their facies are very different from Pleistocene and Holocene fluvial terraces, which consist of loose sediments, composed mainly of sands (Figure 7), and with very poor development of gravel

Figure 4. Plio- Pleistocene conglomerate facies of Gara Soultana, composed of rounded to subangular pebble- to cobble-sized clasts showing through cross-bedding.

Figure 5. Flute casts described at the base of Gara Soultana conglomerates indicating a NE-SW paleocurrent direction.

sediments (Wengler & Vernet, 1992), (4) they are eroded and inset by fluvial terraces lying at the same topographic level (Figure 6). For these reasons, such conglomerates have been explained as exhumed bedrock layers, which develop low residual reliefs in the center of the El Haï valley, such as buttes and mesas. The new interpretation of such landforms and deposits has provided a very different context and chronology for the archaeological surveys that are being conducted so far.

The Plio-Early Pleistocene alluvial unit in this area shows a general subhorizontal structure. At the right bank of the El Haï River, an apparent dip of 2–3° towards the WSW was measured in the gypsum sandstone layers, which is higher than the gradient of the El Haï River (0.12°). If this structure does not change laterally, such geometries would indicate that the oldest Plio-Early Pleistocene sediments cropping out in the valley would be upstream (toward the SE), in the Aïn Beni Mathar high. On contrary, in the El Haï graben, in the NW of Gara Soultana, the current base level of the El Haï River would be currently eroding younger sediments.

4.3. Incised landform sequence

The exorheic geomorphological sequence developed after the formation of the Early Pleistocene limestones with calcretes that cap the Late Cenozoic stacked succession (Laouina, 1990; Muratet, 1991). In the mapped area, structural, colluvial, and fluvial landforms have been described related to the formation of the El Haï valley (Main map, Supplementary Information).

The main landform corresponds to the Gara Soultana butte, preserved on a Plio-Early Pleistocene conglomerate layer. The flat summit reaches an elevation of 901 m a.s.l. and tends to slope slightly towards the SW. Its vertical scarp is 1–3 m high, reaching an absolute elevation of 899 m a.s.l., and it is affected by

Figure 6. Disconformity between Plio-Pleistocene conglomerate and Late Pleistocene-Holocene fluvial terrace, lying at the same topographic level.

fractures which favored the detachment of large conglomerate boulders (Main map, Supplementary Information, Figure 3). The exhumation age of the butte is unknown, but it is 113 m below the plateau formed by the Early Pleistocene limestones topping the stacked sequence, and +46 m above the modern El Haï River (Main map, Supplementary Information).

Regarding the colluvial landforms (Main Map, Supplementary Information), a succession of three talus slopes has been identified around the Gara Soultana butte. In general, they contain debris deposits, including large conglomerate boulders coming from the butte scarp. In some cases, these talus slopes consist of triangular-shaped knolls, forming talus flatirons (Main map, Supplementary Information). Usually, talus flatirons are older the further they are from the scarp. In Gara Soultana butte, the farthest talus slope, or TS1, is below the oldest pediment level or P1, and contains very scarce boulders, suggesting that it formed mainly from the degradation of P1. The closest talus

Figure 7. Characteristic facies of fluvial terraces.

slope to the scarp, or TSindet, should be the youngest, although it connects the butte scarp with pediment P1, suggesting that it also could have formed prior to the incision of this pediment.

The detailed geomorphological mapping (using the UAV photogrammetry data) has allowed us to identify a staircase sequence of five strath terraces (erosional or with a 1–9 m alluvial cover), separated by low relative heights. Their meaning should be corroborated in other locations of the basin, but initially they have been interpreted as fluvial terraces, since the erosional levels are not spatially correlated with resistant bedrock layers and the lower levels are depositional fluvial terraces. This sequence is +20–21 m (T1), +18 m (T2), +15–16 m (T3), +12 m (T4) and +4 m (T5) above the modern El Haï River (Main map, Supplementary Information). In the Bes-Bes valley, only four levels are preserved, at lower relative heights: +14 m (T2), +10 m (T3), +8 m (T4) and +3–4 m (T5). Initially, we have correlated these Bes-Bes levels with the four lower levels described for El Haï valley, since Bes-Bes valley is a secondary tributary characterized by less incision. Nevertheless, future geomorphological studies on the confluence area of both valleys will allow us to check this correlation. The two lower levels of the general sequence include an alluvial cover, while the three higher levels correspond to erosional terraces. These erosional levels, consisting of benches and plains, were recognized at similar relative heights in the valley margins, and they are carved both on soft bedrock lithologies (Plio-Early Pleistocene sands and muds) and on hard bedrock lithologies (Plio-Early Pleistocene conglomerates) (Main map, Supplementary Information). The best-preserved depositional terrace is T4, which consists of up to 9 m thick alluvial deposits, where sands (massive, parallel laminated and cross laminated) and loams are dominant (Figure 7). Additionally, muds and hydromorphic palustrine

Figure 8. Stromatolitic structures lying at +18-15 m above El Haï River.

deposits can also be observed, as well as rare loose gravel layers. Sediments of depositional terraces are very loose and friable, being commonly eroded by dendritic gullies (Main Map, Supplementary Information). Wengler and Vernet (1992) provided C14 ages between 3290 ± 130 yr BP and 1480 ± 120 yr BP for an El Haï fluvial terrace, which is 12 m thick and located immediately to the east of the field site. Such evidences suggest that C14 dates come from T4 defined here, and tentatively could relate this terrace to a brief 10 m thick well-marked alluvial terrace defined at the lower Moulouya valley between 3750 and 395 years cal BC, which includes seismic features (seismites, diaclases, faults) and sub-arid sedimentological characteristics (Zarki et al., 2004). A preliminary Holocene age for T4 would indicate also a Holocene age for T5, and perhaps for T3, since Wengler and Vernet (1992) present chronologies for older fluvial deposits, also very clustered in the Holocene (12,120 ± 130–11,360 ± 75 and 5700 ± 110 yr BP). These C14 chronologies for the younger terraces would imply also very high incision rate phases in the High Plateaus during Holocene, which contrast with the low gradient longitudinal profiles described in this area, interpreted as little channel incision (Pastor et al., 2015), or with general incision rates calculated in other active tectonic areas of the Moulouya catchment, estimated at 0.3 m/ka in the upper catchment from the Middle Miocene, or between 0.01 and 0.03 m/ka in the lower valley from the Early Pleistocene (Bartz et al., 2019). C14 chronologies suggest Holocene climatic conditions for the formation of the three youngest El Haï fluvial terraces. In the lower Moulouya catchment, Holocene palaeoflood records with similar sedimentological characteristics to El Haï lower terraces (thick, well-stratified, and predominantly clayey to silty overbank fine sediments) are related to the high sensitivity of semi-arid rivers, between 4.0 and 1.4 cal ka BP (Zielhofer et al., 2008, 2010). This could associate lower terraces of El Haï River with Holocene rapid climate changes, although higher terrace levels could be related to 100 ka climate cycles as proposed in other Atlas valleys (Stokes et al., 2017). Nevertheless, new works are necessary in the El Haï valley to investigate the chronology of the whole sequence of terraces in order to understand the geomorphological evolution of the exorheic phase and provide a solid correlation with tectonic and global climatic stages.

In the El Haï valley, also a patch of tufa deposits has been recognized (Main map, Supplementary Information). They are composed of basal gravels and green clays, which are overlain by stromatolite sheets (Figure 8). These deposits lie from +18 m to +15 m above El Haï River, which could indicate that they formed related to base level T2, or between T2 and T3.

The main polygenetic landforms correspond to a mantled pediment which is preserved from Gara Soultana butte towards the SW and S. This pediment, or P1, slopes about 4° towards the El Haï valley where it reaches a relative elevation of +21–23 m above the El Haï River, very similar to fluvial terrace T1 (Main map, Supplementary Information). In this area, P1 displays a veneer cover of sediments with no significant outcrops. However, in nearby areas it is composed of colluvial and alluvial sediments affected by a caliche, which shows hardpan and laminar horizons. Below P1, other three pediments were mapped at similar positions of base levels T2, T3 and T4.

Other landforms identified in the area correspond to floodplains, valley beds, alluvial cones, and wetland areas associated with the springs which feed the El Haï River (Main map, Supplementary Information).

5. Conclusions

This work contributed to the first high detailed landscape evolution study of the High Plateaus Basin, in order to understand landscape evolution and contextualize the archaeological surveys that are being conducted in the region. Combining small Unmanned Aerial Vehicles (sUAV) and Structure from Motion

Photogrammetry (SfM), with submeter GNSS SBASS provided a low-cost and portable method to generate decimeter accuracy spatial datasets, which have demonstrated useful for large scale geomorphological analysis in Gara Soultana hill and El Haï valley, where no detailed topographic information and infrastructures are available.

The analysis using these spatial datasets and fieldwork recognition allowed to re-interpret the top of Gara Soultana and other platforms (previously considered as fluvial terraces) as exhumed bedrock conglomerate layers of the Plio-Early Pleistocene stacked series. On the other hand, the geomorphological sequence related to the incision of this El Haï valley sector is compound of a first period, not represented in this area except for the exhumation of Gara Soultana butte, and a second period consisting of five strath levels developed from +20–22 m until the modern el Haï River, whose spacing represent base-level changes. Strath terraces probably formed from the Middle-Late Pleistocene to Holocene. Lower terraces seem associated to brief aggradation phases and palaeofloods in the lower Moulouya catchment which occurred in semi-arid conditions through Holocene rapid climate changes. At the foothill, this incision sequence also led to the formation of mantled pediments (where the oldest pediment level is prominent and encrusted by calcretes), and the retreat of scarp faces, denoted by the presence of talus flatirons. Wetland areas also have been identified, related to tufa patches and hydromorphic areas in the depositional fluvial terraces. These results obtained using large scale methods, will be used in other sectors of the High Plateaus Basin, in order to provide a regional meaning to the identified landforms.

Software

The orthoimage and DEM were generated using the Structure from Motion (SfM) software Agisoft PhotoScan. The digitization and composition of the map have been carried out and exported to pdf using Esri ArcGIS Pro.

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