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Late Pleistocene and Holocene sedimentary record of the Bouqaia Basin (central Levant, Syria): A geoarchaeological approach

Sédimentologie du Pléistocène final et de l'Holocène dans le Bassin de la Bouqaia (Levant, Syrie) : une première perspective géoarchéologique

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A B S T R A C T

In this work new data on the archaeological and palaeoenvironmental evolution of one of the main foci for the neolithization, the central Levant region is provided. The study of the Late Pleistocene and Holocene sedimentary record of the Bouqaia Basin (Homs Gap, Syria) makes it possible to define a general stratigraphical framework for the Late Pleistocene and Holocene of the studied area. The sedimentological characterization of the identified fluvio-alluvial sedimentary sequences suggests a Late Pleistocene/Holocene aridification phase. Progressive aridification is reflected by rapid changes in fluvial sedimentary dynamics that can be ascribed to an increasingly seasonal precipitation pattern combined with lowering precipitation rates. The integration of sedimentological and archaeological information from the studied area shows that palaeoenvironmental changes contributed to differentiate settlement strategies in the study area.

R É S U M É

Ce travail présente de nouvelles données archéologiques et paléoenvironnementales provenant de recherches conduites au Proche-Orient, en Syrie, l'un des principaux centres de la Néolithisation. L'étude du registre sédimentaire dans la Vallée de la Bouqaia (Trouée de Homs, Syrie) nous permet de proposer un modèle pour l'évolution de la région d'étude au Pléistocène final et à l'Holocène. Les séquences sédimentaires formées pendant des phases d'aggradation et d'incision indiquent une diminution des précipitations, avec de courts épisodes de sécheresse et d'humidité. La désertification progressive a entraîné des changements rapides de la dynamique de sédimentation fluviale, du fait d'une diminution des précipitations, de plus en plus concentrées durant la saison hivernale. L'association de

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données sédimentaires et archéologiques montre comment les changements paléoclimatiques ont contribué à la différenciation des stratégies d'habitation dans la région d'étude au cours de la Néolithisation.

1. Introduction

The lack of studies focusing on the neolithization of the central Levant makes it difficult to contextualize this phenomenon in the wider Near East region (Harris, 1998). A Spanish-Syrian-Lebanese archaeological mission has recently been set along the high Orontes river valley to fill this gap (Develle et al., 2009; Haïdar-Boustani et al., 2005, 2007; Ibáñez et al., 2008a, 2008b). The research area focuses on the northern part of the Bekaa Valley and the Homs Gap (Haïdar-Boustani et al., 2008); a region selected for its high archaeological potential, its geographical connections with known centers of neolithization, the variety of its natural resources, and the archaeological evidence attesting the local Natufian-Neolithic transition from foraging to farming. The process of animal and plant domestication characterizes Neolithic communities, and is associated with the appearance of complex buildings, as well as technological (i.e., naviform debitage or long tanged projectile points) and symbolic innovations (i.e., the generalization of human iconography) (Cauvin, 1997; Coqueugniot, 2000; Gopher, 1996 ; Stordeur and Abbès, 2002). In spite of its centrality to the understanding of the neolithization process, the central and southern Levant region remains poorly understood (Edwards et al., 2005; Goring-Morris, 2002; Khalaily et al., 2007; Kuijt and Goring-Morris, 2002).

Several authors have highlighted the importance of integrating environmental factors to understand the domestication process, eventually leading to the sedentarization of groups of hunter-gatherers, that is, neolithization, e.g. (Barton et al., 2004). It is therefore necessary to adopt an interdisciplinary palaeoenvironmental and archaeological approach to understand the relationship between behavioral and environmental changes involved in the domestication process (Issar and Zohar, 2007). The present work contributes new palaeoenvironmental and geoarchaeological data from the central Levant.

Three main geomorphological districts have been differentiated within the area investigated (Fig. 1): (1) The Bouqaia Basin to the west; (2) The Homs basaltic plain in the central area; and (3) The Orontes Valley to the southeast, near Qattina Lake. This study focuses on the Bouqaia Basin, where two archaeological sites, Jeftelik and Tell Al Marj, were also excavated. Results presented here include the outcome of systematic archaeological survey (2004–2006), the preliminary geomorphological study of the area, and the study of existing Quaternary sedimentary sequences. Archaeological excavations in the study area have been implemented at two locations: Jeftelik (Natufian) and Tell Al Marj (Neolithic). Geoarchaeological investigations in the study area include the characterization of palaeosoils, sediments and occupation surfaces presenting signs of human activity, including agricultural practices at the beginning of the Holocene.

Understanding present and past sedimentary environments, the underlying formation processes and the resulting geomorphological features is paramount to the palaeoenvironmental contextualization of the archaeological record (Butzer, 1982; Courty et al., 1989; French, 2003; Goldberg and Macphail, 2006; Miskovsky, 1992; Rapp and Hill, 1998). For this purpose, we provide a lithostratigraphic and sedimentological framework for the Bouqaia area, and propose a preliminary sequence of alternating dry and wet palaeoclimatic conditions characterizing the region during the last phases of the Pleistocene and the Holocene.

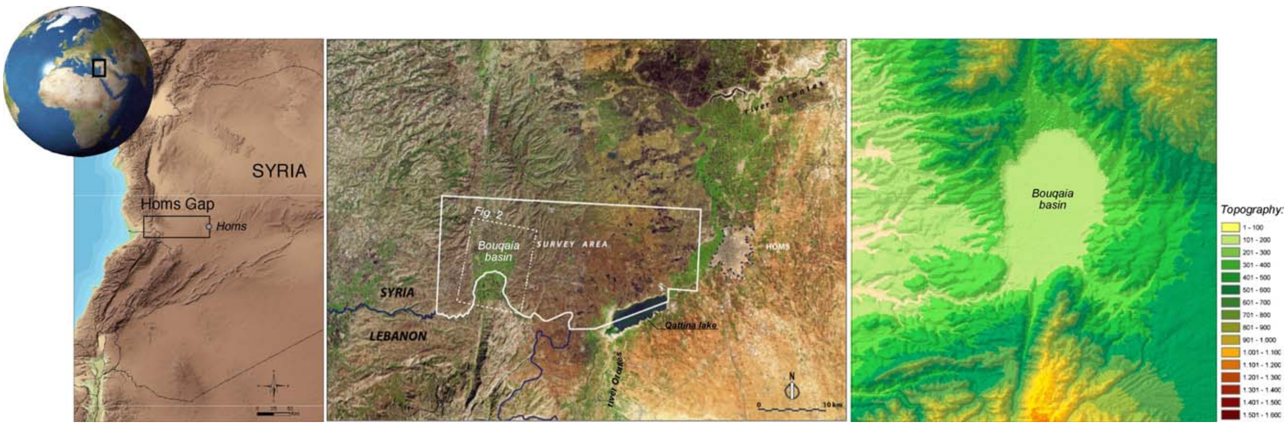

Fig. 1. Satellite image (Landsat) showing location of the study area, the Homs Gap, and a digital elevation model of the Bouqaia Basin from SRTM/NASA data.

Fig. 1. Image satellitale (Landsat) de la Trouée de Homs et MDT du Bassin de la Bouqaia.

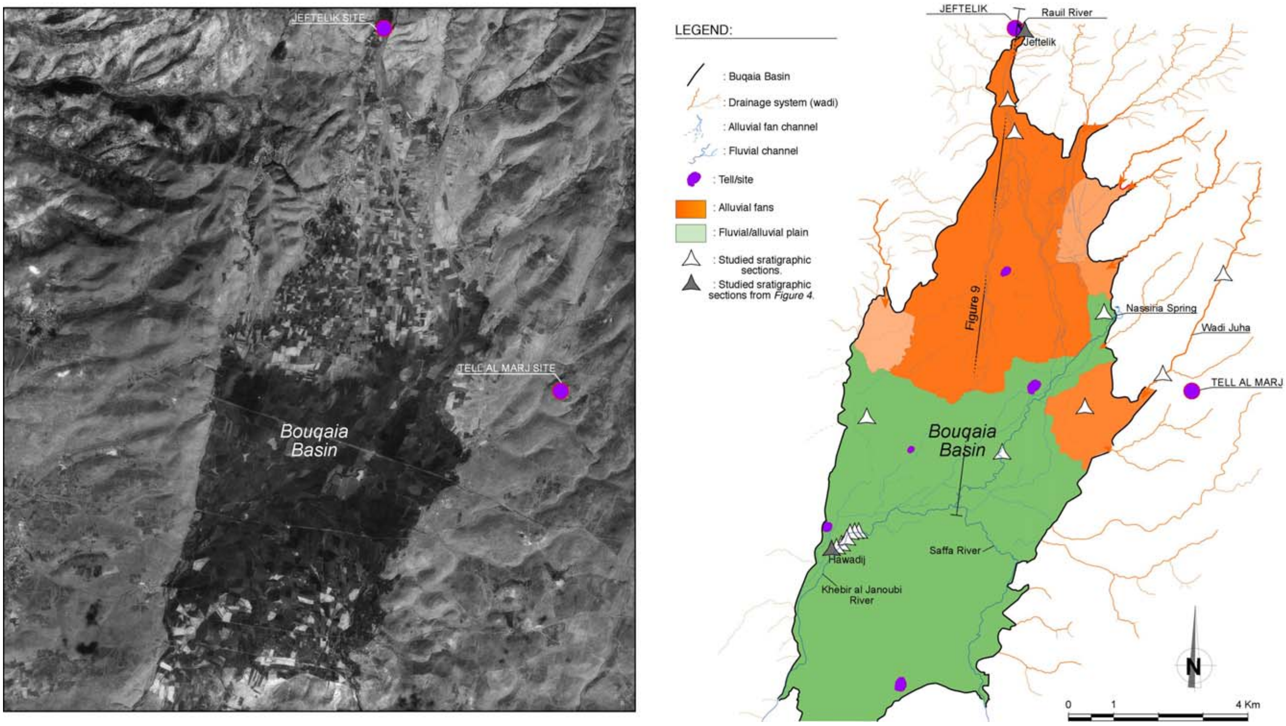

Fig. 2. CORONA satellite image and geomorphological map of the Bouqaia Basin.

Fig. 2. Image satellitale CORONA du Bassin de la Bouqaia.

2. Bouqaia Basin Quaternary record

The Bouqaia depression is a tectonic pull-apart basin situated along the Yammouneh fault that constitutes the Syrio-Lebanese segment of the Dead Sea Fault Zone (Chorowicz et al., 2005; Rukieh et al., 2005). It is structurally limited by normal and strike-slip faults from adjacent Miocene-Pliocene basaltic reliefs, except for its southern margin where Cretaceous limestone outcrops (Butler and Spencer, 1999; Butler et al., 1997, 1998) (Figs. 1 and 2). The subsiding character of the Bouqaia Basin has permitted the sedimentation and preservation of fluvial, alluvial and lacustrine sediments throughout the Quaternary. Its characteristics are similar to nearby Quaternary tectonic sedimentary basins: the Ghab Basin to the north (Wilkinson, 1999; Yasuda et al., 2000) and the Bekaa Valley to the south (Develle et al., 2009; Hajar et al., 2008). The Bouqaia Basin has a radial drainage system made of: (1) numerous wadis crossing its eastern margin; (2) the Rauil river inflowing from the north; and (3) the Saffa inflowing from the south (Fig. 2). The Rauil and Saffa rivers join in the south-central part of the basin forming the Khebir al Janoubi river that outflows through the southwestern margin (Fig. 2). The main rivers and wadis form alluvial fans of different sizes on the basin margins.

The Homs Gap allows the inflow of humid air from the Mediterranean coast to the Bouqaia area. Air becomes dryer eastwards in the arid steppes to the east of Homs. While mean annual precipitation in the Homs area is 460 mm, it reaches 800–1000 mm in the Bouqaia Basin. Precipitation is strongly seasonal with rains concentrated during the cold season ($\sim$70 days between October and May). The dry season extends from May to October with virtually no precipitation. Due to the permeable character of most of the rock outcrops in the area (Jurassic and Cretaceous limestones and fractured Mio-Pliocene basalts), water derived from seasonal precipitation is available during the dry season in karstic springs and reservoirs. The Nassiria water spring, on the northeast margin of the Bouqaia, is one of the major springs within the basin ($\sim$1 m^3/s) (Fig. 2). Artificial water channels built in the 1990s altered the natural drainage pattern of the basin, exposing many informative outcrops. The geomorphological, stratigraphical and sedimentological information exposed here proceeds from the study of the main fluvial valleys, wadis and basinal areas that provide a large quantity of information, complementary to the palaeoenvironmental information obtained from the archaeological sites of Jeftelik and Tell Al Marj, that represent the Natufian-Neolithic transition to domestication.

2.1. The Rauil river valley

The Rauil river valley is straight and narrow due to its development along the Yammouneh fault trace. Near the Bouqaia the river becomes wider and presents well-developed terraces (Fig. 3). Outcrops were studied and sampled along the valley that was mapped using CORONA satellite images (Fig. 2). Different phases of terrace formation and incision were identified. The most extended terraces were observed at +20 m (T20) and +5 m (T5) from the riverbed. The study of these terraces included

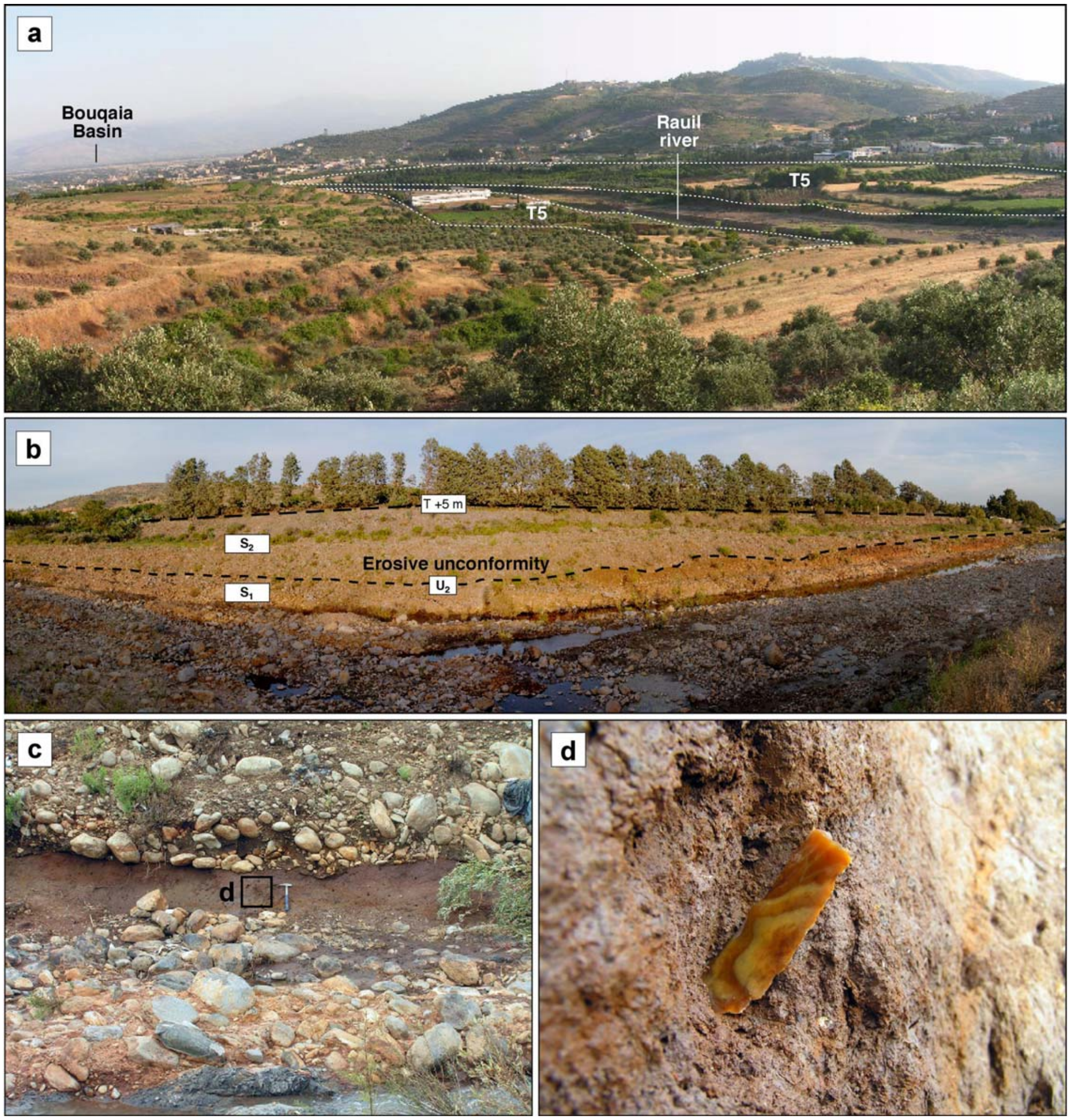

Fig. 3. The Rauil river valley. (**a**) The lower terrace (T5) at 5 m is presently being incised by the river. (**b**) Two sedimentary aggrading phases, meandering (S_1) and braided (S_2) separated by an erosive unconformity (U_2). (**c & d**) The lower meandering river floodplain sediments (S_1) contain Palaeolithic Levallois-type flint artifacts and the upper shallow gravel-bed braided sequence (S_2) is postdated by Neolithic sites in primary position.

Fig. 3. La Vallée du Fleuve Rauil. **(a)** La terrasse inférieure (T5) située à 5 m en-dessus du niveau actuel du fleuve. **(b)** Deux phases d'aggradation, en méandres (S_1) et en tresses (S_2), séparées par une non-conformité érosive (U_2). **(c & d)** Sédiments de plaine alluviale dans la partie inférieure de la T5 avec des artéfacts paléolithiques, les graviers de la séquence en méandres sont post-datés par des sites néolithiques en position primaire.

topographical survey, stratigraphic section description and sedimentological characterization (Figs. 3 and 4a).

The main focus here is on T5, whose formation can be constrained to the Late Pleistocene/Early Holocene. This preliminary chronological determination is based on flint tool typo-chronology. Levallois-type flint tools (regionally associated to Palaeolithic groups) were found embedded within fine floodplain deposits in the lowest portion of the T5 profile (S_1 sequence). Primary concentrations of Neolithic archaeological remains (associated to Early Holocene groups) were found on the surface of T5 (Figs. 3 and 4a). Sediments deposited within T5 are composed of monomictic sandy gravels and fine-grained sediments. Disperse limestone clasts and flint artifacts appear embedded in the sediments. T5 sediments are unconformably deposited above the basaltic substratum (U_1 unconformity) and are 5 to 7 m thick. The sedimentary sequence is superbly exposed thanks to the erosion and incision of the present-day channel (U_3 unconformity) (Fig. 3) and shows two aggradational sedimentary sequences separated by an erosive unconformity (U_2) (Figs. 3 and 4a). The lower sequence (S_1) is 3 m thick and presents alternation of gravelly sediments, arranged in channel-fill facies (point-bar migration sequences and traction carpets), with sandy and fine-grained floodplain sediments (Fig. 3). Floodplain sediments include abundant

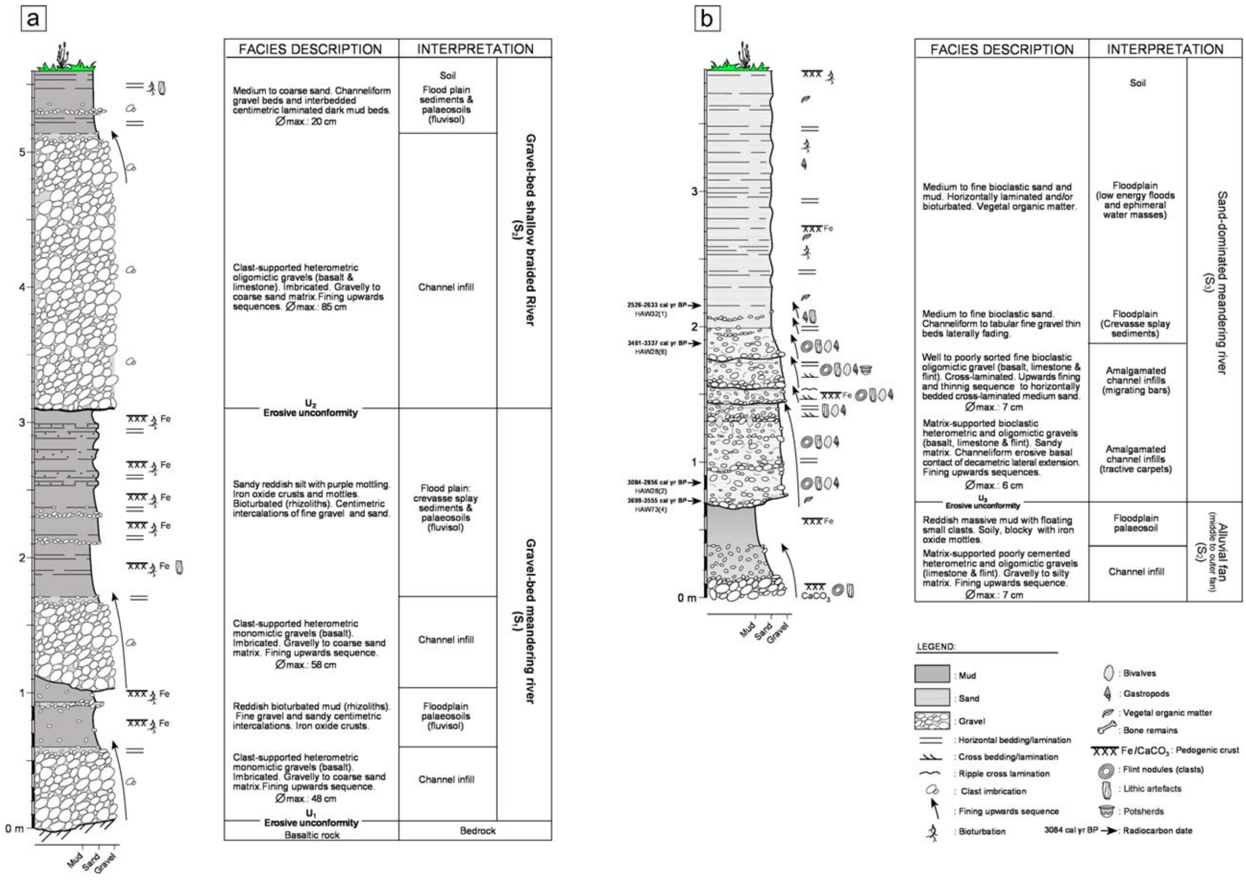

Fig. 4. Examples of different stratigraphic columns from the Bouqaia Basin. (**a**) Sediments of the S_1 and S_2 sequences from T5 in the Rauil river valley near Jeftelik archaeological site. (**b**) Sediments of the S_3 sedimentary sequence near Tell Hawadij. See Fig. 2 for location.

Fig. 4. Exemples des colonnes stratigraphiques réalisées dans la Bouqaia. (**a**) Sédiments des séquences sédimentaires S_1 et S_2 de la T5, le long du Fleuve Rauil, à proximité du site archéologique (Natoufien) de Jeftelik. (**b**) Sédiments de la séquence sédimentaire S_3 à proximité du Tell Hawadij. Voir Fig. 2 pour la localisation.

pedogenic features (e.g. iron nodules and crusts, mottling, bioturbation), representing palaeo-fluvisol sequences with occasional scatters of flint artifacts (Figs. 3 and 4a).

The basal sequence is overlaid by an erosive unconformity (U_2) that precedes the onset of the second sedimentary sequence (S_2). U_2 unconformity is flat, erosional and of kilometric extension. The uppermost sequence (S_2) is almost totally formed by imbricated massive gravel facies with abundant sandy matrix (Figs. 3 and 4a). Upward-thinning sequences and diffuse cross-bedding are the most outstanding sedimentary structures in this sequence. The fine floodplain sediments observed in S_1 are absent in S_2, except for the upper 50 cm of the sequence, where floodplain laminated sandy to clayey sediments showing incipient pedogenic features are present and enclose scatters of flint artifacts (Neolithic and later). These upper levels are partially reworked by modern agricultural activity.

2.2. Peripheral wadis

Wadis flowing into the Bouqaia Basin are more abundant and better developed on the east margin of the depression (Fig. 2). The sedimentary record of the major wadis (e.g. Wadi Juha) was studied to ascertain their Quaternary evolution (Fig. 5).

As for the Rauil river valley, aggradational sedimentary infill was observed for the wadis on the east margin of the Bouqaia, leading to the formation of a 5 m high terrace (T5) incised and eroded by present-day wadi activity. Present-day channels have nearly totally incised the T5 sediments, and are eroding the underlying basaltic bedrock in the upper course of the wadis. The sediments form a single massive sequence ($S_1 + S_2$) made of heterometric imbricated basaltic gravel with sandy matrix (Fig. 5). Normal gradations are present and the diameter of the clasts can exceed 1 m. Present-day stormy precipitation activates the wadis remobilizing the sediments deposited within T5. The upper segments of the wadi channels are narrow and fed by numerous gullies incised in the slopes (Fig. 5). In the lower portion of the wadi course, the channel areas become wider (hundreds of meters), leading to the formation of alluvial fans on the fringe of the Bouqaia depression. The distal alluvial fan facies belt is made of fine-grained sediments enclosing palaeosoils.

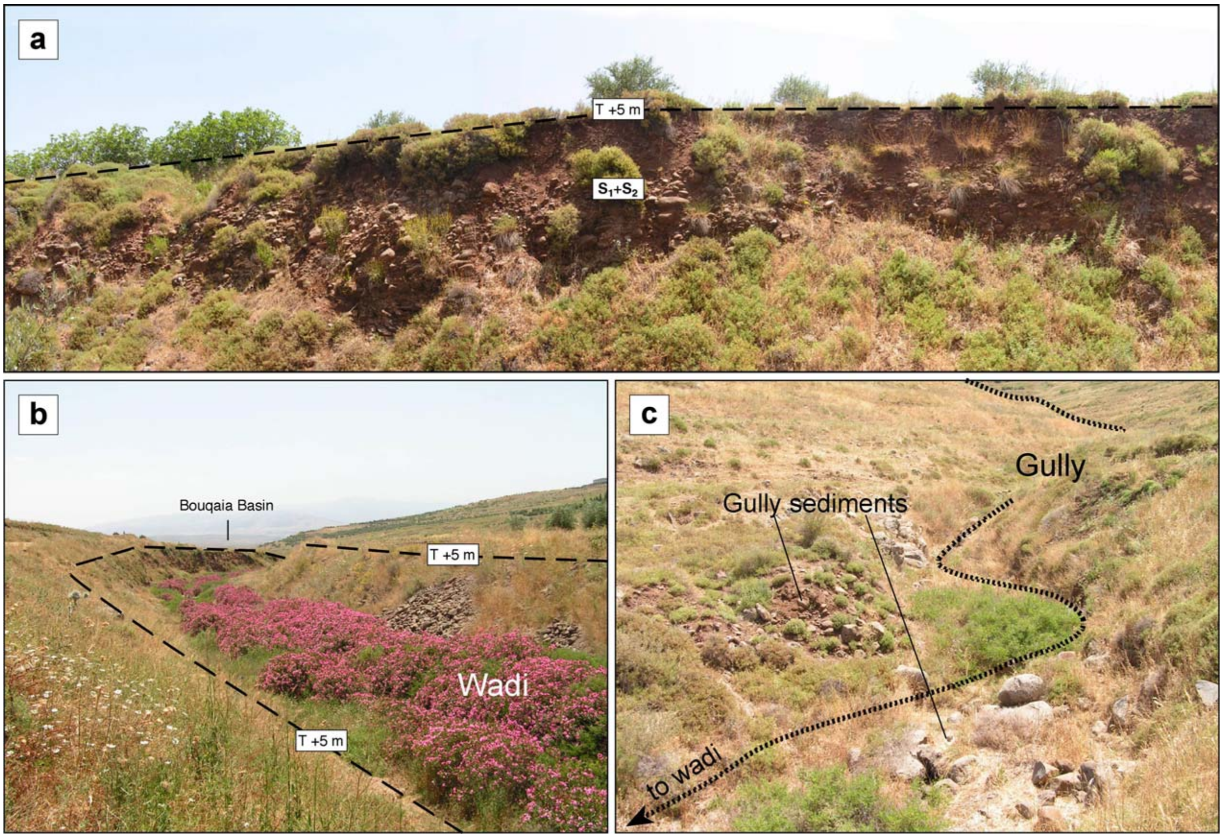

Fig. 5. Peripheral wadis (Wadi Juha). (**a**) Sediments of the T5 terrace in Wadi Juha. (**b**) T5 terrace is being incised by present wadi channel. (**c**) Gully and gully sediments in the upper course of the Wadi Juha.

Fig. 5. Wadi latéral (Wadi Juha). (**a**) Sédiments de la T5 le long du Wadi Juha. (**b**) Terrasse T5 incisée par le wadi. (**c**) Ravinement et sédiments de ravinement dans la partie supérieure du Wadi Juha.

2.3. The Bouqaia depression

The subsiding character of the Bouqaia depression, and the predominant aggradational disposition of its Quaternary sediments, have favored the preservation of Late Pleistocene and Holocene sedimentary units within the basin depocenter. Historical data indicate that the central part of the Bouqaia depression was seasonally inundated (during winter) allowing the formation of ephemeral water masses. These were artificially drained in the 1990s. The excavation of draining channels and irrigation reservoirs has contributed to the exposition of sections (up to 5 m thick) of the surficial deposits (Fig. 6). The sedimentary materials observed correspond to medium and distal alluvial sediments composed of channelized and sheet-like gravels and pedogenized fine-grained sediments (Fig. 6). Finer sediments are more abundant towards the center of the basin. Alluvial sediments change laterally into fluvial sediments, deposited by the rivers crossing the depression (Rauil, Saffa and Nassiria spring rivers). A full reconstruction of the stratigraphical architecture of the depression remains difficult at this stage. However, most of the observed sediments can provisionally be classified as lateral alluvial equivalents of the S_2 fluvial sequence (Late Pleistocene/Holocene) described in the Rauil river. Several archaeological tells found within the Bouqaia depression (e.g. Tell Hawadij, Tell Hiti, Tell Aalek) support this hypothesis, postdating the deposition of these sediments (Fig. 2).

Sediment outcrops were observed in the central part of the depression, along the Khebir al Janoubi river. These show a Late Holocene fluvio-lacustrine sequence (S_3) that rests unconformably (U_3 unconformity) above the alluvial sediments of S_2 (Fig. 6). The contact between S_2 and S_3 is sharp, with at least 1 m of erosional incision affecting S_2 sediments. Sediments in S_3 correspond to gravelly sands and fine-grained sediments that enclose abundant flint, bone, charcoal and pottery, forming an upward-fining sequence (Fig. 4b). Numerous bivalve and gastropod shells are embedded within the lower channel-fill sediments in S_3. S_3 sediments are predominantly basaltic, suggesting that soft water input from the Rauil river was predominant during this period, and the karstic isotopic signal minimal (if at all present). On these bases we consider the dates obtained on bivalve shell representative, and assume reservoir effect to be negligible in this context (Table 1). The upper fine-grained sediments found within S_2 enclose charred cereal grains and charcoal fragments (Fig. 6). Radiocarbon dating of bivalve shells and charcoal samples show that S_3 extends at least over the past 4 ka and is in part contemporaneous with the nearby Bronze Age

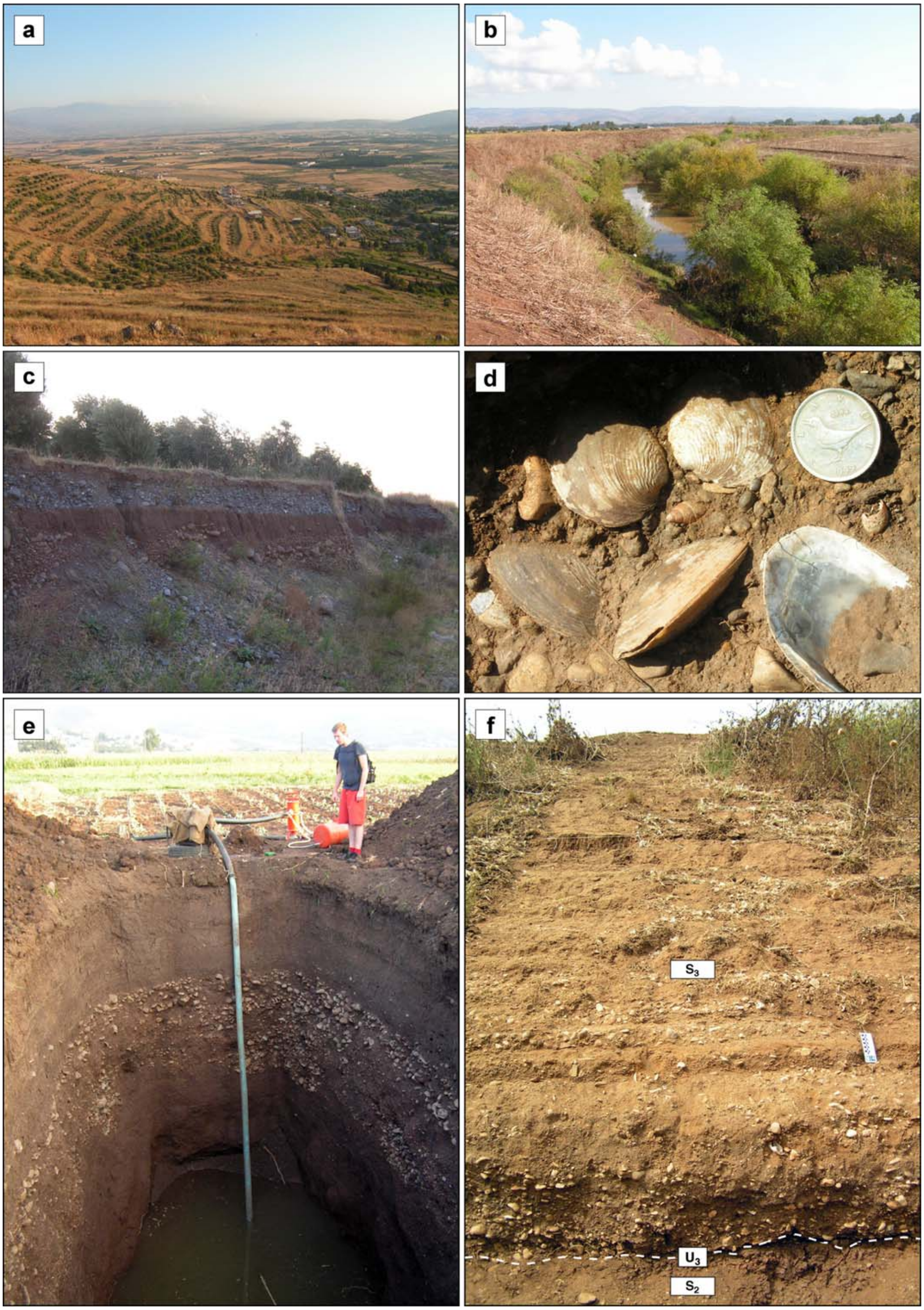

Fig. 6. Bouqaia depression. (**a**) General view towards the south-west of the Bouqaia depression. (**b**) The Khebir al Janoubi riverbanks offer good outcrops of the S_3 Holocene sedimentary sequence. (**c**) Inner/middle alluvial-fan facies (S_2) in the north margin of the Bouqaia depression. (**d**) Bivalves and gastropods from S_3 sedimentary sequence. (**e**) Alluvial plain fine-grained soils from S_2 sedimentary sequence in the central part of the Bouqaia depression. (**f**) The S_3 sedimentary sequence rests unconformably over the S_2 sequence separated by the U_3 erosional unconformity (Hawadij sequence).

Fig. 6. La dépression de la Bouqaia. (**a**) Vue générale vers le sud-ouest. (**b**) Les berges du fleuve Khebir al Janoubi montrant la séquence sédimentaire holocène S_3. (**c**) Faciès internes et centraux du cône de déjection (S_2) sur le côté nord de la Bouqaia. (**d**) Bivalves et gastropodes de la séquence S_3. (**e**) Sols à composante minérale fine de la séquence sédimentaire S_2, dans la plaine alluviale au centre de la Bouqaia. (**f**) La séquence S_3 située au-dessus de la S_2, celles-ci étant séparées par la non-conformité d'érosion U_3 (séquence d'Hawadij).

Table 1
Radiocarbon datations of S_3 sedimentary sequence (HAW) and charcoal from a pit in Jeftelik site (JEF).
Tableau 1
Datations radiocarbone de la séquence sédimentaire S_3 (HAW) et charbons trouvés à la base de la fosse néolithique de Jeftelik (T20).

	Material	Lab #	^{14}C age (BP)	δ^{13}C (‰)	cal BP (2θ)
JEF2B1	Charcoal	CNA450	6870 ± 80	−35.07 ± 0.58	7862–7578
HAW28(2)	Shell[a]	CNA452	2860 ± 45	−11.27 ± 0.31	3084–2856
HAW28(6)	Shell	CNA453	3165 ± 35	−10.48 ± 0.33	3461–3337
HAW32(1)	Charcoal	CNA455	1395 ± 40	−26.99 ± 0.75	2526–2633
HAW73(4)	Shell[a]	CNA456	3375 ± 35	−14.23 ± 0.31	3699–3555

[a]Articulated bivalve in life position. The ages are presented as conventional ^{14}C dates and also as calendar dates using the program CALIB 5.0. Centro Nacional de Aceleradores, Sevilla, Spain.

tells. The inverted date obtained from HAW28(6), a non-articulated bivalve shell, is to be associated with a probable reworking (Fig. 4a and Table 1).

2.4. Soils and palaeosoils

Different types of soils and palaeosoils were identified and characterized within the Late Pleistocene and Holocene sedimentary sequences investigated. Much of them show evidence of anthropic activity, expressed in the field by the presence of archaeological artifacts and structures of different age. A first classification of the observed soils and palaeosoils is presented here for future reference.

In general, two main types of soils are present in the Bouqaia Basin: (1) Basaltic cambisols (alterites), parental soils developed on the basaltic bedrock; and (2) Soils originating from the pedogenic alteration of fluvio-alluvial sediments. The second type can be divided into three subtypes: (2a) Sublaminar fluvisols developed within the floodplains of the river and wadi terraces; (2b) Soils devel-

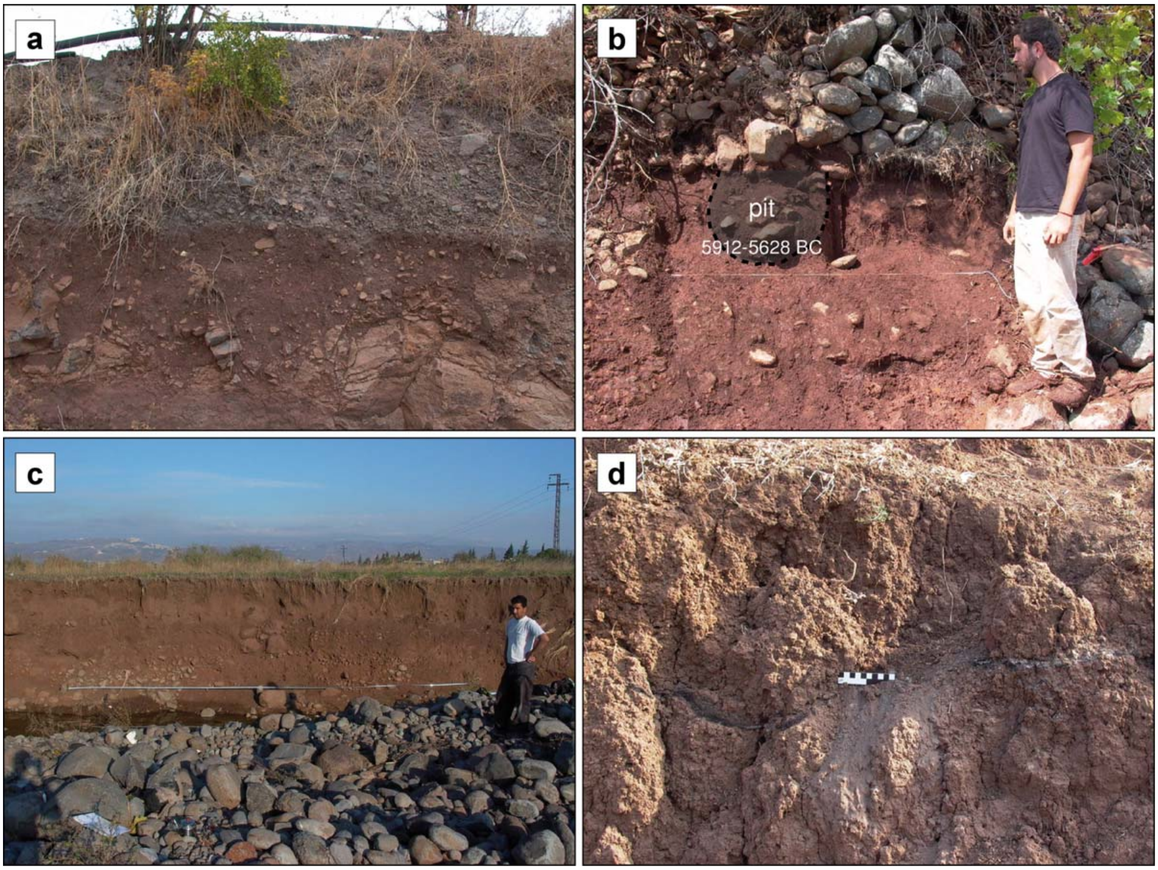

Fig. 7. Soils and palaeosoils. (**a**) Basaltic cambisol from the Rauil valley. (**b**) Neolithic pit and palaeosoil from the top of T20. (**c**) Soils of the mid- to outer-fan area bearing Bronze Age walls, channels and palaeosoil (vertical tape measure is 2 m, horizontal 10 m). (**d**) Floodplain fluvisols from the central part of the Bouqaia depression with abundant dispersed charcoal and ash, fire spots with burned dung, and charred seeds (scale is 10 cm).

Fig. 7. Sols et paléosols. (**a**) Cambisol basaltique dans la Vallée de Rauil. (**b**) Fosse Néolithique et paléosol sur le sommet de la T20. (**c**) Sols de la partie centro-externe des cônes de déjection, avec murs de l'Âge du Bronze, chenaux et paléosol agricole (échelle verticale 2 m, horizontale 10 m). (**d**) Fluvisol de la plaine alluviale au centre de la Bouqaia, riche en fragments de charbon et cendres, avec structures de combustion d'excréments animaux et graines. (barre d'échelle : 10 cm).

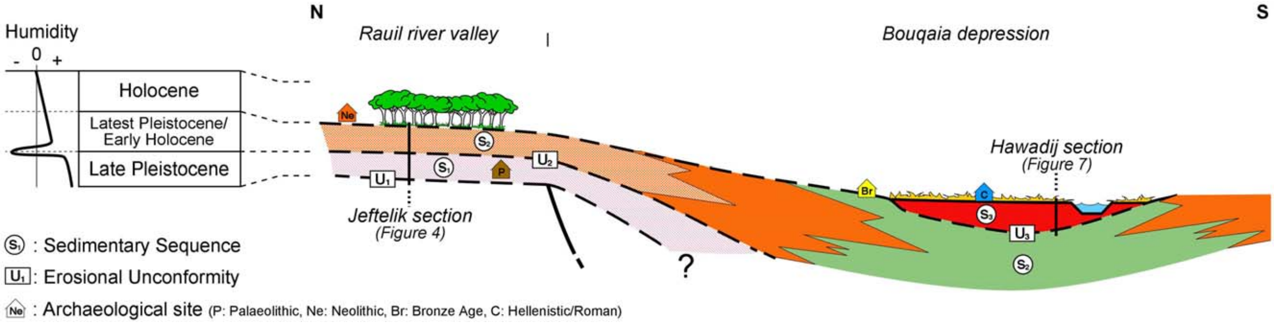

Fig. 8. Simplified stratigraphic framework of Late Pleistocene and Holocene sedimentary sequences from the Bouqaia Basin.
Fig. 8. Schéma stratigraphique simplifié de l'évolution au Pléistocène final et à l'Holocène du Bassin de la Bouqaia.

oped over fine-grained sediments from middle to outer-fan areas; and (2c) Fluvisols of the floodplain sediments within the fluvio-lacustrine sequence S_3.

(1): Basaltic cambisols are dominant in the valley and wadi slopes (Fig. 7). They are thicker in the lower parts of the slopes due to colluviation (observed max. thickness 3 m). The main soil component is massive to blocky fine-grained brownish (Munsell 2.5-7.5YR6/2) sediment derived from the alteration and/or colluviation of the basaltic bedrock. Complete soil sequences present centimeter to millimeter disperse basalt clasts fining upward; dark (Munsell GLEY23/10B) oxides and hydroxide nodules and small crusts are common in the lower horizons. Colluvial sheets of debritic material and gully infillings can overlay or erode locally the soil profile. Archaeological survey showed that this type of soil bears very few archaeological remains.

(2a): Sublaminar fluvisols from floodplain areas of river and wadi terraces are developed within the bottom and middle portions of the valley slopes. They were observed in the S_1 and S_2 sequences of T5, and on the top of T20. They show a prismatic structure of fine-grained reddish (Munsell 5YR4/6) sediments with disperse gravel and sand layers (Fig. 7). The aggradational and incipient character of the soils developed during the terrace aggradational phase limits the possibility of distinguishing the different horizons formed during the later terrace incision phase. Root bioturbation is observed throughout these profiles and horizontal laminations are still preserved in the upper portion. Manganese staining through the profile seems to represent pseudomorphs of organic remains, not otherwise preserved. Dark (Munsell GLEY23/10B) oxide nodules and crusts are abundant in the B horizon. Scattered flint tools (Levallois-type) were found embedded within S_1, and concentrations of Neolithic artifacts were found on the surface of S_2. Numerous flint tools (Neolithic) were found in conjunction with potsherds and a buried pit in the fine-grained floodplain deposits of T20 (Fig. 7).

(2b): Soils developed on fine-grained sediments from middle to outer-fan areas are similar to fluvisols (2a) but are thicker and present stronger pedogenic traits. Primary sedimentary structures are not evident due to bioturbation. In some instances, these sequences bear building structures; channels and other archaeological remains from the Bronze Age (flint tools, bone, pottery), associated with what seems to be organic-matter enriched (possibly cultivated) buried soils (Fig. 7).

(2c): Fluvisols from floodplain sediments of S_3 are distributed along fluvial channels in the central part of the Bouqaia depression. They correspond to the latest phases of the Holocene (4 ka to present). These soils consist of floodplain lime and fine sands with abundant dispersed charcoal, charred seeds and lenses of burned dung (Fig. 7). Soil horizons are not clearly distinguished in this type of aggradational soils.

3. Discussion

The characteristics of the sediments and fluvio-alluvial sequences studied in the Bouqaia Basin suggest a Late Pleistocene to Holocene shift to more arid conditions in the region. Sedimentary sequences formed during aggradation and incision phases point to a decrease in precipitation rates, with intercalated dry/humid short events. The inferred overall aridification is reflected by rapid changes in fluvial sedimentary dynamics that can be ascribed to the establishment of increasingly seasonal precipitation patterns combined with lowering precipitation rates.

3.1. Late Pleistocene to Holocene aridification

The sedimentary sequences preserved within the T5 terrace in the Rauil river valley are undergoing an erosional/incisional phase (U_3 unconformity) activated by the present-day river channel (Fig. 3). Archaeological remains found within the sediments forming T5 strongly suggest a Late Pleistocene to Early Holocene formation for this terrace (Develle et al., 2009; Haïdar-Boustani et al., 2005, 2007; Ibáñez et al., 2008a). This is in accordance with terrace deposits previously described in the Orontes valley, i.e., the Würmian Q_I terrace from (Besançon and Sanlaville, 1993; Bridgland et al., 2003), and at other Syrian localities (Demir et al., 2007; Dodonov et al., 1993, 2007; Oguchi et al., 2008) that formed in the Late Pleistocene. The two aggradational sedimentary sequences (S_1 and S_2) described for T5 are clearly separated by an erosive unconformity (U_2) (Fig. 3). The two sequences show sedimentary facies associations and architectural elements typical of different fluvial systems (Fig. 8).

Sediments from the lower sequence (S_1) correspond to a gravel-bed meandering fluvial system (Miall, 1996), characterized by an alternation of channel-filling gravelly point-bar sediments (lateral accretion deposits) and pedogenized fine-grained floodplain deposits. These fluvial systems are typically composed of one main channel with scattered bars and islands, and occasional subsidiary channels. Sedimentation occurs on large flat-topped point bars and side-bar complexes (Arche, 1983; Miall, 1996). This type of fluvial environment is usually found in hot-humid climates (Miall, 1996), in agreement with the warm and humid palaeoenvironmental conditions proposed for the Levant area during the Late Pleistocene, before and/or after the dry and arid conditions of the Last Glacial Maximum (Issar and Zohar, 2007; Robinson et al. 2006).

The S_1 sequence is overlaid by the U_2 erosive unconformity that precedes the onset of the second sedimentary sequence (S_2). Coarse-grained sediments characterize S_2 (Figs. 3 and 8), indicative of successive pulses of gravel transport/sedimentation and finer sand, infiltrating the clastic framework during waning stages. This suggests rapid changes in flow velocity and shear stress over short periods of time. These changes in river flow and discharge are most likely the result of channel migration and avulsion patterns in a shallow gravel-bed braided river (Miall, 1996).

The U_2 unconformity and the onset of the S_2 sequence reflect an abrupt change in fluvial dynamics (Fig. 8): from a gravel-bed meandering fluvial system (S_1) to a shallow gravel-bed braided river (S_2). This is plausibly the outcome of the onset of a more marked seasonality, with a humid season characterized by strong stormy precipitations. In spite of this abrupt change, the total precipitation rate for the Early Holocene was probably higher than in later Holocene times, as indicated by the aggradational character of the fluvial system. The palaeoenvironmental conditions proposed for the Bouqaia sedimentary record are in accordance with palaeoenvironmental reconstructions proposed by (Robinson et al., 2006) in the Levant area and (Rossignol-Strick, 1995) in the nearby Ghab Basin. The proposed correlation must be considered cautiously until more absolute dates become available for T5.

We propose an Early Holocene date for the end of the aggradational phase (S_2) that led to the construction of T5, and the onset of the present incision phase (U_3). The same age has been attributed to the youngest terrace level (also situated 5 m above the active channel) in the nearby Orontes river valley (Besançon and Sanlaville, 1993; Bridgland et al., 2003; Dodonov et al., 1993). Present-day incision is due to lower transport capacity and lower water flow. This incision is to be related to progressive Holocene climate aridification in the region, leading to a rapid and abrupt change in fluvial dynamics and the lowering of the water-table in the basin. These processes may be linked to humid/dry short cycles (Bridgland and Westway, 2008; Vandenberghe, 2008) that occurred during the Late Pleistocene and Early Holocene (Berger and Guilaine, 2009, Staubwasser and Weiss, 2006; Weninger et al., 2006), in coincidence with the Natufian/Neolithic transition in the area.

The sedimentary record from the peripheral wadis of the Bouqaia agrees with that observed in the Rauil river valley. The wadis show an aggradational sedimentary sequence ($S_1 + S_2$) forming a terrace 5 m above the riverbed, which is presently undergoing incision. This single gravel-dominated sedimentary sequence ($S_1 + S_2$) is interpreted to be the result of the ephemeral activity of shallow gravel-bed braided type rivers. The $S_1 + S_2$ sequence probably encloses both sequences (S_1 and S_2) observed in the Rauil river. The wadis seem to reflect the same ephemeral activity related to higher precipitation events during the different palaeoenvironmental stages proposed for the Rauil river. The sedimentological analogies of $S_1 + S_2$ and S_1 and S_2 sequences point to similarities in their formation processes, concerning punctual (wadis) and seasonal (river) intense fluvial activity, continued by inactive and waning stages, respectively.

Sediments within S_3 sequence reflect a shallow sand-dominated meandering fluvial system dominated by large point-bar lateral accretion units and amalgamated channel-fill facies. These channel infilling facies change laterally and vertically into floodplain fine sandy sediments that enclose ephemeral terrigenous lacustrine facies. The S_3 sequence is most likely the result of Holocene incision and resedimentation of previous aggradational sedimentary sequences (S_1 and S_2). The numerous bivalve and gastropod shells (Fig. 6) found within S_3 point to water inflow from the Nassiria spring and the Saffa river (draining limestone areas). The most depressed area of the Bouqaia Basin was seasonally flooded before artificial draining in the 1990s, suggesting the possible presence of a shallow lake during wet phases of the Holocene and Pleistocene.

Climate change must have been the main control factor influencing sedimentation patterns in the study area. The tectonic uplift of $\sim$400 m that begun in the Late Miocene in the western part of the Arabic plate does not seem to have affected river incision during the Holocene (Bridgland et al., 2003; Demir et al., 2007). Had the shift between different fluvial systems observed in the study area (S_1 to S_2) been tectonically driven, an increase in the general fluvial gradient would have been noted; this would be the expected consequence of tilting and/or different tectonic subsidence rates between tectonic blocks in the catchment area. However, no tectonic compartmentation, offset or angular unconformities were observed within the T5 sediments in the Rauil river valley, pointing to climate as the main forcing mechanism for fluvial system modification in the region. Water exploitation (dams and wells) in the last centuries has probably contributed to lowering the water flow, accentuating river incision.

3.2. Palaeoenvironmental changes and settlement patterns

The geoarchaeological study of the soils, palaeosoils and sedimentary sequences brings new meaning to the archaeological sites and artifacts found during previous surveys. Far from being randomly distributed, when contextualized, archaeological scatters and sites seem to reflect settlement patterns that can in part be connected with the

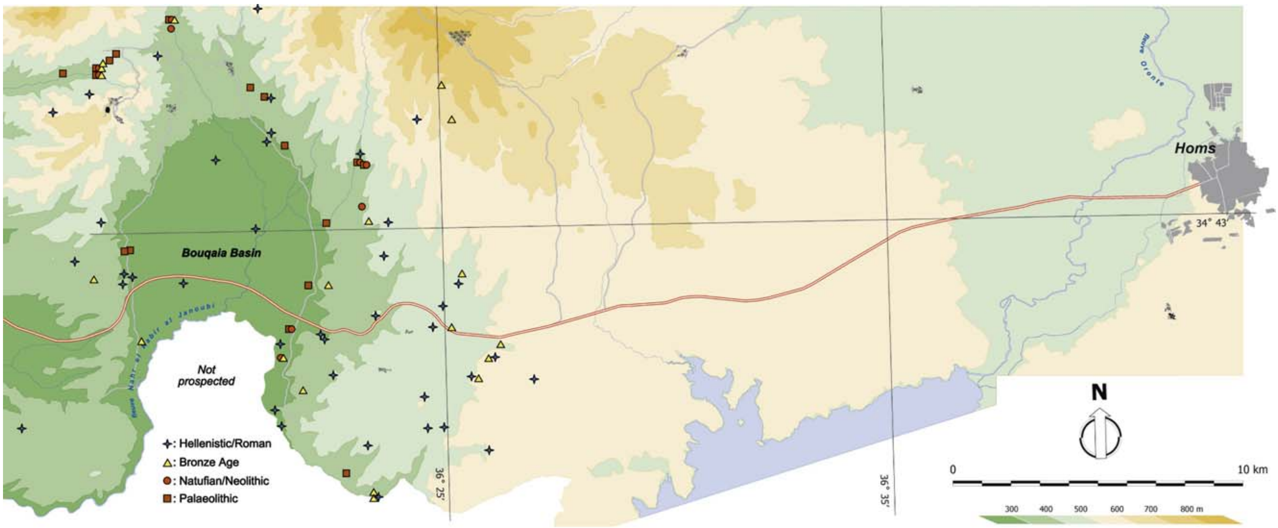

Fig. 9. Location of the main archaeological sites in the Bouqaia Basin area.
Fig. 9. Position des principaux sites archéologiques dans la Vallée de la Bouqaia.

establishment of different climatic and environmental conditions (Figs. 8 and 9).

Most Palaeolithic sites found during archaeological survey (2004–2007) are located in type-2a sublaminar fluvisols, which are found in the floodplain deposits of S_1, in the lowest portion of the T5 terrace, near the valley bottom. These sediments correspond to large flat-topped and stable floodplains flanking the perennial gravel-bed meandering fluvial channels that characterized the river valleys and wadis of the Bouqaia depression in the Late Pleistocene (Fig. 9). This type of channel has a low avulsion frequency and low flooding intensities favoring long-term occupation of the adjacent floodplains.

In contrast, most Neolithic sites have been found on the surface of the Rauil river terraces (T5 and T20), and in elevated sub-horizontal areas (terraces) situated near major wadis on the margins of the Bouqaia depression (Fig. 9). In these settings, type-2a fluvisols and type-1 basaltic cambisols and colluviums predominate. More frequent and intense floods and avulsion processes must have affected the valley floor and the Bouqaia depression when the S_2 sequence was being deposited in the form of braided fluvial channels and alluvial fans. Under those conditions, the valley floors were characterized by the absence of stable floodplain areas, and hence unsuitable for human settlement.

Bronze Age tells are located in the margins of the Bouqaia depression. They are surrounded by coetaneous 2b and 2c-type fluvisols from S_3 and S_2 sequences. The fluvio-alluvial systems seem to have been fairly active, with frequent floods during the Middle Holocene wet phases. Human settlement seems to have been sporadic during this period in the lowest portions of the Bouqaia Basin. Evidence from the sediments and palaeosoils observed in the central portion of the basin suggests this area may have been used for agro-pastoral activities.

Hellenistic and Roman/Byzantine sites are the oldest long-term settlements attested in the central areas of the Bouqaia depression. They are situated on tells surrounded by coetaneous 2b and 2c-type fluvisols from S_3 and S_2 sequences. The incisional character of the youngest fluvio-alluvial systems, and the lower flooding frequency recorded during the late phases of the Holocene, may have contributed to the onset of these settlements.

4. Conclusions

The sedimentological and geoarchaeological study of the Bouqaia Basin shows the potential of Quaternary sedimentary records as a source of palaenvironmental information that can help contextualizing archaeological remains within the broader context of human-environment interaction.

The fluvio-alluvial sedimentary sequences described in this paper suggest an overall aridification trend in the central Levant region during the Late Pleistocene and the Holocene, in general agreement with previous authors (Robinson et al., 2006; Rossignol-Strick, 1995). The aggradation/incision cycle preserved within the investigated sedimentary sequences (S_1, S_2 and S_3) reflects generally diminishing precipitation rates, pulsed with shorter dry/humid events (U_2). Aridification is most likely to be ascribed to increased seasonality and lowering precipitation rates. This tendency is reflected in the rapid transition from: (1) a gravel-bed meandering fluvial system (S_1); to (2) a shallow gravel-bed braided system (S_2); and finally to (3) an incisional sand-dominated meandering fluvial system (S_3).

Clear settlement patterns are emerging from the geoarchaeological study of soils and palaeosoils preserved within the investigated sedimentary sequences. Archaeological sites of different periods are systematically associated with specific pedo-sedimentary units, suggesting that palaeoenvironmental changes played a key role in the definition of settlement strategies among the local groups. Palaeolithic sites and artifacts are associated to floodplain deposits from the (S_1), sequence of the T5 terrace, suggesting that in the Late Pleistocene people settled in meandering river floodplains characterized by low avulsion frequency and low flooding intensity. In contrast Neolithic sites are situated in elevated areas (on the top of T5 and above), where the effects of more frequent and intense floods and avulsion processes (reflected in S_2) would not have been felt. Later, Bronze Age tells are found in the margins of the Bouqaia depression, whose center becomes the focus of agro-pastoral activity. As for the more recent periods (Hellenistic, Roman and later) there is evidence for the lowermost areas of the Bouqaia Basin being populated. Historical evidence suggests that a shallow lake would have persisted here during extended dry periods, when the fluvio-alluvial system progressed in the present-day incision phase (S_3). Undergoing investigations will allow a progressive refinement of the proposed model, further improving our understanding of settlement patterns between prehistoric foraging and farming communities in central Levant.

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