C. R. Palevol xxx (2016) xxx–xxx

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Human Palaeontology and Prehistory

Lithostratigraphy of Masol paleonto-archeological localities in the Quranwala zone, 2.6 Ma, Northwestern India

Lithostratigraphie des localités paléonto-archéologiques de Masol dans la zone Quranwala, 2.6 Ma, nord-Ouest de l'Inde

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ARTICLE INFO

Article history:
Received 9 September 2015
Accepted after revision 30 November 2015
Available online xxx

Handled by Anne Dambricourt Malassé

Keywords:
Siwaliks Frontal Range
Late Pliocene
Chandigarh anticline
Quranwala fossiliserons zone
Lithostratigraphy
Paleonto-archeological localities
Transitional fauna

ABSTRACT

Since 2008, the 'Siwaliks' Indo-French Program of Research has surveyed the north of the Chandigarh anticline (Siwalik Frontal Range [SFR], northwestern India) in the Masol inlier known for its Plio-Pleistocene transitional fauna (2.6 Ma). Twelve paleonto-archeological localities have been identified in the Quranwala fossiliferous zone, where many fossils and stone tools are lying on the outcrops or included in the erosional debris of the same layers. Cut-marks on a few fossil bones attest to the presence of hominins. This paper presents the detailed lithostratigraphy of these paleontological and archeological localities and their position in the stratigraphic log of the Quranwala zone reconstructed for the Masol anticline.
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Mots clés :
Chaîne frontale des Siwaliks
Pliocène final
Anticlinal de Chandigarh
Zone fossilifère Quranwala
Lithostratigraphie
Localités paléonto-archéologiques
Faune de transition

RÉSUMÉ

Depuis 2008, le programme de recherche franco-indien « Siwaliks » poursuit ses investigations dans le Nord de l'anticlinal de Chandigarh (chaîne frontale des Siwaliks, Nord-Ouest de l'Inde) dans la boutonnière de Masol, connue pour sa faune de transition Plio-Pléistocène (2,6 Ma). Douze localités paléonto-archéologiques ont été identifiées sur les affleurements fossilifères de la zone Quranwala (fossiles et outils lithiques associés en surface ou dans les mêmes colluvions, dont l'origine stratigraphique est facilement reconnaissable). L'identification de traces de découpe sur quelques ossements fossiles atteste la présence d'homininés parmi une riche faune d'eau douce et d'espèces terrestres dites de

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http://dx.doi.org/10.1016/j.crpv.2015.10.005
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« transition Plio-Pléistocène ». Cet article présente la lithostratigraphie détaillée de ces localités paléontologiques et archéologiques et leur position dans le log stratigraphique de la zone fossilifère Quranwala, reconstitué ici pour l'anticlinal de Masol.
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Introduction

The Siwaliks are geological formations visible all along the southern fringe of the Himalayan Range formed by 5000 m of continental molasses deposited in a wide foreland basin from the Miocene until the Middle Pleistocene (Fig. 1A and B). These formations have been subdivided into three subgroups, the Lower, Middle and Upper Siwalik. The subduction of the Indian plate under the Eurasian plate towards the north compresses these continental deposits. The Upper Siwalik subgroup was uplifted during the Middle Pleistocene forming the Siwalik Frontal Range also called Siwalik Hills. The Upper Siwalik is divided into three formations, the Tatrot, the Pinjor and the Boulder Conglomerate. The Tatrot is dated to the second half of the Pliocene (Ranga Rao et al., 1979); the Pinjor corresponds to the Lower and Middle Pleistocene with a diachronic limit that depends on the formation of the Boulder Conglomerate (BC). The BC was formed beginning about 3.3 Ma in the North-West of the Indian subcontinent; it appears ca. 1.79 Ma towards the south-east, and then to 600 ka (Kumaravel et al., 2005; Nanda, 2002; Ranga Rao et al., 1988, 1995). About 100 km wide in average, it extends over approximately 2500 km from the north-eastern Pakistan to the north-eastern India in Assam (Fig. 1A). The combination of the tectonics and the monsoon has unearthed different fossiliferous layers well known since the very beginning of the 20th century (Pilgrim, 1913). Numerous geologists, palaeontologists, and geomorphologists have conducted studies in order to understand their geochronological and paleoenvironmental context (e.g. Badam, 1973; Delcaillau et al., 2006; Kumar et al., 2003; Nanda, 2002, 2013; Patnaik, 2003, 2013; Ranga Rao, 1993; Sanyal et al., 2010; Singh and Tandon, 2010; Tripathi, 1986).

The Siwalik Range of Chandigarh is a geological structure formed by several anticlines (Fig. 1C); the Masol anticline is known for its sector rich in fossiliferous deposits dated to the Late Pliocene and named Quranwala zone (Sahni and Khan, 1964, 1968). This vertebrate assemblage helped to clarify the transition between the Late Pliocene and the Pleistocene in South Asia (Badam, 1973; Sahni and Khan, 1964, 1968; see more in Moigne et al., 2016) which now coincides with the Gauss-Matuyama geomagnetic reversal dated to 2.588 Ma (Cande and Kent, 1995) well identified in the Masol anticline at the top of the Quranwala zone (Ranga Rao, 1993; Ranga Rao et al., 1995, for a review see Chapon Sao et al., 2016).

Since 2008 the Indo-French program of research "Siwaliks" has surveyed the Masol inlier accessible from the Punjab plain through a seasonal river, or *choe*, the Patiali Rao (Dambricourt Malassé, 2016; Dambricourt Malassé et al., 2016a) (Fig. 1A, Figs. 2 and 3). All the geological strata of the prospected area (30° 50′ N, 76° 50′ E) are clearly below the Gauss/Matuyama reversal (Ranga Rao, 1993; Ranga Rao et al., 1995). This has been confirmed by the study of the magnetic polarities performed as part of the "Siwaliks" program (Chapon Sao et al., 2016). Twelve paleonto-archeological localities have been identified scattered on a surface of about 50 hectares between 400 and 500 m above the sea level, 1500 fossils and more than 200 stone tools (choppers, flakes, hammerstones) have been recovered there (Gaillard et al., 2016; Moigne et al., 2016). The fossil fauna list is rich in freshwater vertebrates with reptiles such as the turtle *Geoclemys*, but relatively few crocodilians (*Crocodylus, Gavialis*), and also mammals with many remains of *Hexaprotodon*; the terrestrial species are also very well preserved, such as the giant terrestrial turtle *Colossochelys*, rare carnivores (*Hyena, Panthera*) and herbivores of all sizes (e.g., small bovids, *Hipparion*, *Equus*, *Stegodon, Elephas Sivatherium*) (the percentages are described in Moigne et al., 2016). A few bones attest to carnivore activities (scavenging and/or hunting). The most remarkable discovery, which justifies the geological fieldwork efforts, are three bovid bones from three separate localities, bearing traces identified as cut-marks made by sharp edges of quartzite pieces. This identification was possible because of the long experience of many traces of butcheries in different prehistoric sites (A.-M. Moigne, pers. comm.) and after comparison with experimental cut-marks. Their observation at the micron scale confirmed their lithic and handmade origins (Dambricourt Malassé et al., 2016b). For this reason, the many stone stools deserve special attention; especially those collected near the cut-marked fossil bones. They were collected on the surface in the same context of intense erosion of the outcrops due to the monsoon.

This paper describes in detail the lithostratigraphy of the two main fossiliferous localities, Masol 1-Masol 2 and Masol 6, with Masol 13 in addition because of the cut-marked bovid splinter discovered first at this locality (Masol 13 R10298) and then at other paleonto-archeological localities. The lithostratigraphic investigations began in 2011 from the bed of the Patiali Rao near the village of Masol on the western riverside, with the recognition of the basal sequence of the Quranwala zone until its highest levels, where a conglomerate marks the boundary between the Tatrot and Pinjor Formations (Ranga Rao et al., 1995).

This work provides: (i) the detailed characterization of different lithological units for these localities including texture, structure, color and relative granulometry of sediment and (ii) the identification of their stratigraphic position in the general log which has been realized within the "Siwaliks" program for the whole available sedimentary sequence (Tudryn et al., 2016).

In addition to this lithostratigraphic description, we present the paleontological and archeological material

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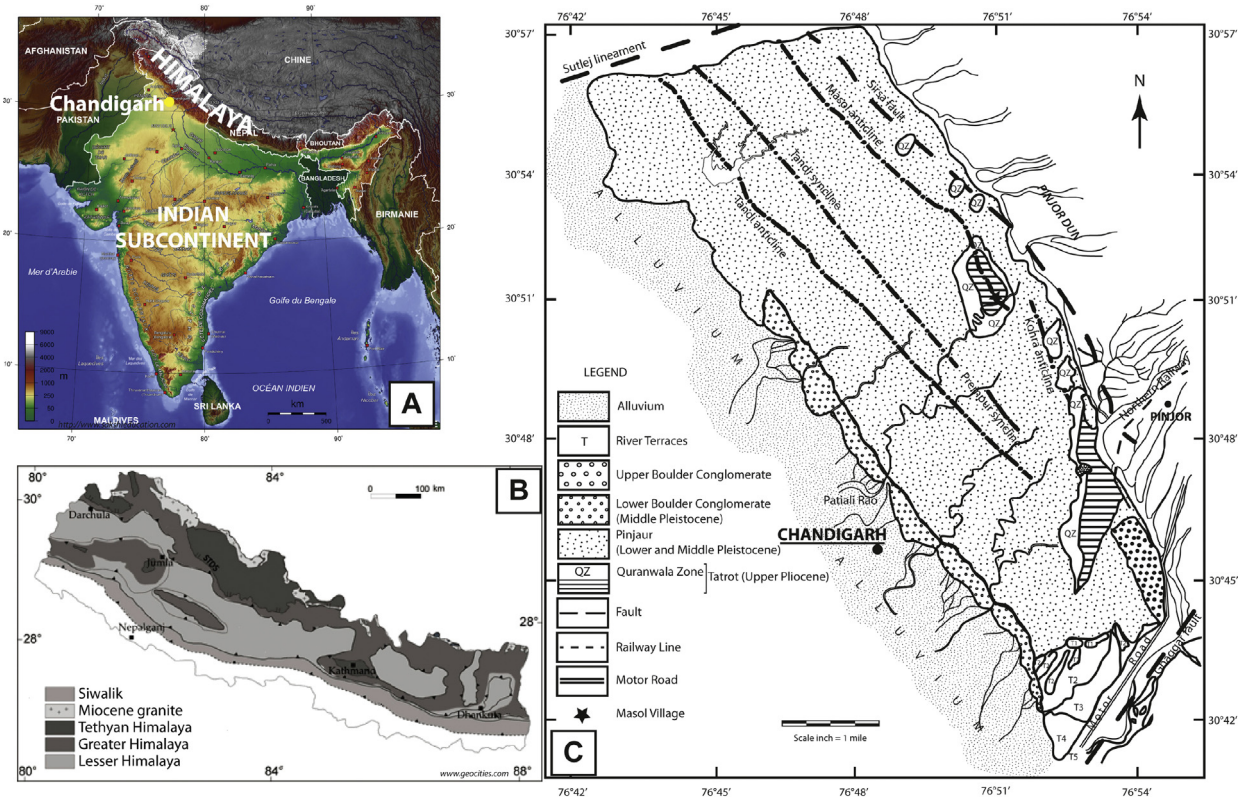


Fig. 1. A. Location of the anticline in the Himalayan foothills; B. Location of the Siwaliks along the Himalayas; C. Geological map of the Chandigarh anticline in the Siwalik Frontal range (Abdessadok, adapted from Sahni and Khan, 1964, 1968).
Fig. 1. A. Localisation de l'anticlinal dans les piémonts himalayens ; B. Localisation des Siwaliks le long de la chaîne himalayenne ; C. Carte géologique de l'anticlinal de Chandigarh dans la chaîne frontale des Siwaliks (Abdessadok, adapté de Sahni et Khan, 1964, 1968).

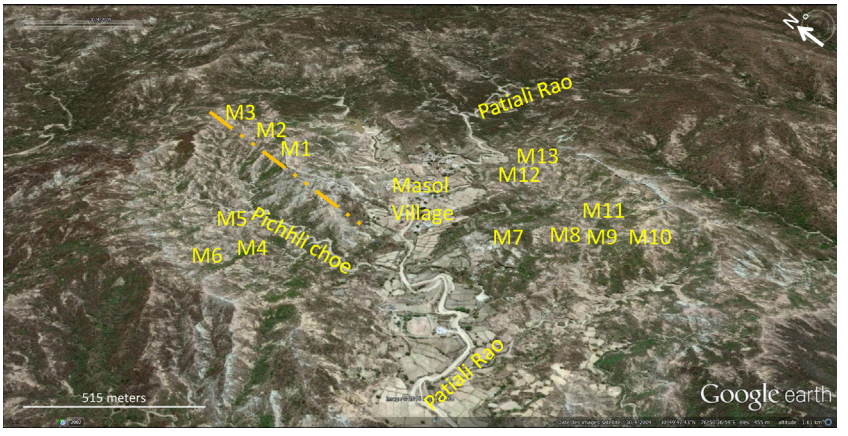


Fig. 2. Overview on the Masol localities 1 to 13, Masol village, Patiali Rao seasonal stream (*choe*) and the watershed of the Pichhli Choe; titled line: the axis of the Masol anticline (Google Earth modified, map data © Google 2015).
Fig. 2. Vue générale sur les localités de Masol 1 à 13, le village de Masol, le fleuve saisonnier Patiali Rao (choe) et le bassin versant du Pichhli Choe ; ligne pointillée : axe de l'anticlinal de Masol (Google Earth, modifié, données de carte © Google 2015).

collected for each main locality. This presentation, the first well-detailed concerning the Masol anticline, aims to situate these materials in their original context of preservation in order to: i) understand the depositional conditions, ii) address the taphonomic and techno-typological questions and iii) understand the hominin activities in this river landscape among a rich terrestrial and freshwater fauna.

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Fig. 3. View of Masol 1. A. On the plateau in the northern direction and at the eastern extremity of the cliffs (photo A. Dambricourt); B: towards M2, dismantling silt and sandstone (photo C. Chapon Sao); C: view on the western side of the mount (photo A. Dambricourt). Caption: 1: Masol 1 locality with the first chopper (2008) collected inside a hillock of dismantling silt and sandstone; 2: the sublocality of the intentionally cut-marked tibia shaft Masol 1 R10084; 3: Masol 1-West; 4: Pichhli Choe; 5: Masol 2-West; S1–S5: location of the samplings.
Fig. 3. Vue de Masol 1. A : Sur le plateau en direction du nord et à l'extrémité orientale des falaises (photo A. Dambricourt) ; B : vers M2, démantèlement de limon et de grès (photo C. Chapon Sao) ; C : vue sur le flanc ouest du dôme (photo A. Dambricourt). Légende 1. La localité Masol 1, avec le premier chopper (2008) récolté dans une butte constituée par le démantèlement de limons et de grès, 2 : sous-localité abritant le tibia aux traces de découpe intentionnelle Masol 1 R10084, 3 : Masol 1-Ouest, 4 : Pichhli Choe, 5 : Masol 2-Ouest, S1–S5 : emplacement des échantillons.

1. Study area

1.1. Structural context

To the north of Chandigarh, the sector of the Siwalik Frontal Range called Chandigarh Hills, about forty kilometres long, is bounded to the northeast by the Sirsa Fault, to the southwest by the Himalayan Frontal Thrust, to the northwest by the Sutlej lineament and to the southeast by the Ghaggar fault (Fig. 1). Before the folding, the main streams flowed from the Himalayan mountains toward the southwest into the Indo-gangetic plain (Singh and Tandon, 2008). The uplift began during the Middle Pleistocene and was associated with the formation of large conglomeratic alluvial fans called the Boulder Conglomerate Formation. The progression of the Indian plate toward the north intensified the folding of the sub-Himalayan foreland basin, forming several parallel anticlines. Uplift of the Siwalik Range started with the Masol anticline that first arose in the south-eastern part and further spread toward the northwest. The southeastern part became an axis culmination, and at its south-eastern extremity, the Masol anticline became a fold culmination; moreover, it extended to the southeast in the Kohra anticline, a second axis (Fig. 1). The parallel Tandi anticline is less pronounced (Ranga Rao, 1993). The Siwalik Frontal Range (SFR) thus became an orographic barrier and diverted the stream flows toward the north-west for the Sirsa and Sutlej Rivers, and toward the south-east for the Ghaggar River (Singh and Tandon, 2008). Since this period, the streams flowing from the northern slopes of the SFR and from the Himalayas are collected in a wide corridor called *dun* drained by the Sirsa River "pinjaur dun" along the northern side of the Chandigarh Hills (Fig. 1).

The Masol inlier is strongly dissected by the erosion continuously activated by the uplift of the Siwalik Frontal Range and the monsoon, the lithostratigraphic study of the Quaranwala zone is easy (Fig. 2).

1.2. Structural geology, geomorphology and topography

The topography of the SFR of Chandigarh is influenced by the geological structure due to the tectonics and the erosion process, and as a result presents a succession of synclinal and anticline dug by rivers or *choes*. One of these *choes*, the Patiali Rao, flows from the NE to the SW, crosses the Masol anticline and divides it on this both riversides in different reliefs, altitudes and structural dips. The western side corresponds to the dome of the anticline whose one sector is dug and drained by a short tributary, the Pichhli Choe (Fig. 2). Thus on this riverside the centre of the anticline is a narrow and flattened with hillocks capped by residual sediments of the upper layers of the trenched anticline. The eastern riverside of the Patiali Rao is a large

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anticline excavated in its centre where the relief is constituted by a bowl-shaped depression, steep slopes and cliffs truncated by vertical active gullies.

The Pichhli watershed is about 1 kilometre length and oriented NNW-SSE along the anticline axis. The Pichhli valley is formed by two short streams in its upstream part separated by several small hills. Several meanders occur in its downstream part before the confluence with the Patiali Rao. The changes of the directional flow are sometimes located at the same places than faults. These faults may have influenced the spatial organisation and growth of the choe. The topography of the Pichhli watershed is asymmetrical; the eastern slopes are abrupt with a set of cliffs whereas the topography of the western side is higher and characterized by massive sandstone bars and steps. Various erosion morphologies are present like cavities due to natural sand excavation, rock fall, landslide and river erosion (Gargani et al., 2016). The Pichhli Choe riversides show two alluvial terraces indexed T1 and T2 (Gargani et al., 2016).

The erosion is very active, outcrops of the geological formations and their colluviums are observed in all the areas. All the paleonto-archeological localities are in the Masol anticline, located in the both sides of the Patiali Rao valley.

1.3. Previous studies

Sahni and Khan (1964, 1968) have drawn the first geological map of the Masol anticline. The oldest units of the Tatrot Formation are not exposed contrary to the youngest attributed to the Late Pliocene (Dambricourt Malassé et al., 2016a). The two geologists noted that grey and red clays are characteristic of the lower Tatrot and that the pink or yellow clays characterize the upper Tatrot rich in vertebrate fossils designated as the Quranwala fossiliferous zone or Quranwala zone. This zone ends with a series of claystone and sandstone devoid of fossils over 20 m thick, capped by a fossiliferous grey clay unit covered by pebbly sandstone. For the two geologists, the grey clay corresponds to the last deposit of the Tatrot, and the pebbly sandstone to the boundary between the Tatrot and Pinjor Formations. The fossiliferous deposits end a few meters above this sandstone rich in pebbles. Later, Ranga Rao et al. (1995) conducted new investigations and observed again an alternation of sandstone and claystone, brown, orange brown, grey-brown, yellow in color, in which the claystones are thicker than the sandstones. The latter are medium to coarse-grained and are gravely in their upper part. Beyond the inlier where the Pinjor Formation is exposed, coarse-grained sandstones become thicker and more frequent upwards than the claystones (Ranga Rao et al., 1995; Sahni and Khan, 1964).

2. Methods

Because the traces of human activities are of major importance, the research program engaged in a fine-scaled investigation of the lithostratigraphy. The detailed lithology of the sediments were described for the main paleonto-archeological localities, Masol 1-2 (M1 and M2), Masol 6 (M6) and Masol 13 (M13), in order to understand the lithostratigraphic context in which the fossils and the artefacts were collected. All the lithostratigraphic units were described with their paleontological and archeological contexts and their characteristics: the thickness, the texture, the structure, the consistency, the relative granulometry and the color and, if necessary, the concretions, the bioturbations and the oxydo-metallic inclusions. Since the thickness of the units can change laterally, the indicated values are given as an example. For the localities M 1-2 and M 6, several stratigraphic sections were necessary to obtain a well-developed composite sequence, whereas only one section at Masol 13 locality was required. For the sake of clarity, the localization of the studied outcrops is done only for the Masol 1-2.

The composite log obtained for each locality was drawn on the scale of 1/10th. The lithostratigraphic units are indexed by letters A, B, C, etc. The localities were described independently, for this reason the letters do not indicate the same lithostratigraphic unit. Each composite log is linked to the synthetic or general log given by Tudryn et al. (2016).

3. Description of the main paleonto-archeological localities

3.1. Masol 1 and Masol 2 localities

The Masol 1 locality (M1) is at the top of the narrow and flattened mount corresponding to the anticline culmination; to the west it extends on the slopes up to the bed of the Picchli choe and to the east, up to the steep ravine that limits the plateau and dominates the village (Fig. 2). The locality is characterized by several residual hillocks from the Quranwala zone, some of them capped by colluvium (Fig. 3A and B).

To draw the most complete lithostratigraphic log, it was necessary to walk fifty metres north-westward of M1 where the outcrops continue with the youngest units at Masol 2 (M2) (Fig. 4). The latter is a bowl-shaped depression dominated by cliffs which form the northern slope of the plateau. The locality is divided in two sectors: Masol 2-east is a first depression at the top of the anticline and Masol 2-west is a second depression located very abruptly on the slope towards the Picchli Choe (Fig. 3C, number 5). By locations the outcrops are topped by colluviums resulting from the dismantling of the upper strata; their thickness varies between several centimetres to more than one meter (Gargani et al., 2016) (Fig. 3B).

Lithostratigraphic description

Four lithostratigraphic sections were necessary to establish the composite sequence of Masol 1 and 2, which totals 36 m of thickness. These sections are located in the upper part of the mount and along its western slope accessible through the gullies (Fig. 4): i) the section of Masol 1, with lithologic units B, C, D, E and F; ii) the section of Masol 1, upstream of the west-south-west ravine with lithological units G and H; iii) the section of Masol 1, downstream of the west-south-west ravine with lithological units I, J, K and L; iv) the section of Masol 2 west, with lithological units A, B+, C+, D+ and E+. The composite log totalizes 16 lithostratigraphic units characterized by alternation of

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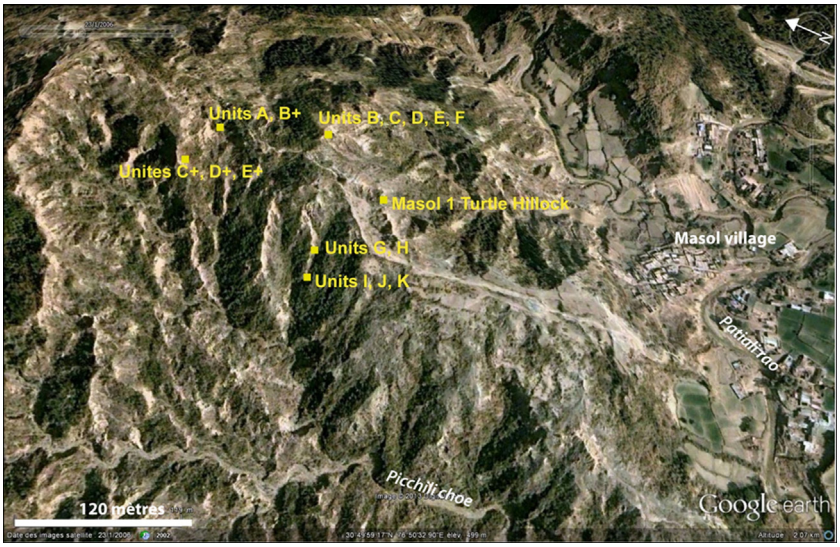


Fig. 4. Location of the stratigraphic sections of the composite log from Masol 1 and Masol 2 localities (Google Earth modified, map data © Google 2015).
Fig. 4. Emplacement des coupes stratigraphiques des logs composites des localités Masol 1 et Masol 2 (Google Earth modifié, données de carte © Google 2015).

Table 1
Lithostratigraphic description of Masol 1 and Masol 2 localities.
Tableau 1
Description lithostratigraphique des localités Masol 1 et Masol 2.

Units	Lithostratigraphic description
E+	Fine-grained sandstone, laminated, pale brown, 1.20 m thick
D+	Silt, brown in color, prismatic structure, from 2.50 to 4 m thick
C+	Fine-grained sandstone, from 0.80 to 3 m thick
B+	Silts, wine in color, 4 m thick
A	Brown silts, 0.80 m thick
B	Medium to coarse-grained sandstone with gravels and clays lenses, interbedded stratification, 2.80 m thick
C	Friable sandstone, whitish grey and locally micaceous, 1.10 m thick
D	Orange silts, 1 m thick
E	Silts, wine in color, 2 m thick
F	Grey sandy silts, 2.50 m thick
G	Yellow-brown silts, 3 m thick
H	Very fine-grained sandstone, 2 m thick, friable, intercalating a thin clay lamina, 5 mm thick and 2 m long. At the top, the sandstone becomes coarser
I	Silts, wine color, prismatic structure, 0.50 m thick
J	Thick sandstone, very hard, cross-bedded, 2 m thick
K	Variegated silts, brown with oxidation marks, yellow-brown in color, with greyish green marks, 2 m thick
L	Friable sandstone, grey in color, at least 3 m thick. The base of the sandstone outcrops in the bed of Pichhli choe

medium-grained sandstones including gravelly lenses and siltstones usually brown in color (Table 1, Fig. 5). The latter are thicker than the sandstones. The sedimentology and mineral composition of Masol 1 are described in Abdessadok et al. (2016).

Fossils remains and artefacts of the Masol 1 locality:

Masol 1 locality yielded the highest number of fossil bones due to its configuration along the 150 m long southern scarps of the plateau and its extension from the Pichhli Choe to the west up to the extremity of the flattened mount to the east (Figs. 3A and C). These fossiliferous scarps are composed of the silts D–E and the sandstones B and C (Fig. 5). They form an erosional front in the Quranwala faunal zone facing south-east in this sector of the mount (Fig. 3A). The fossils are regularly unearthed from silts and sandstones due to the intensive rain during the monsoon. A few fossils have been collected in the silts D–E or in the sandstone blocks of this unit B, the majority recovered in and on recent colluviums resulting from the dismantlement of the silts and sandstones B–C.

The faunal list of Masol 1 (387 fossils) is given in Moigne et al. (2016) and includes a lot of dermal plates from the turtles *Colossochelys* and *Geoclemys*, a few from *Crocodylus*, one fossil of carnivore *(Hyena)*, many bones of Bovidae, Cervidae, Proboscidae such as *Hexaprotodon*, *Stegodon* and Suidae. The cut-marked shaft Masol 1 R10084, discovered in 2009, is yellow with remains of a thin crust of micaceous sand; its cortical bone is well preserved, like two hemimandibles of an antelope collected directly in the yellow silts D, and its medullary cavity is lined with calcite crystals. Its local origin was definitely confirmed by two splinters collected within a perimeter of 2 m^2, the first in 2011 very similar to the shaft but without connection, and the second one in 2013 which was reattached to the shaft during the study of the materials (Dambricourt Malassé et al., 2016a; Moigne et al., 2016). Its stratigraphic origin is very likely the boundary between the yellow silt D and the base of the micaceous sandstone C.

The stone tools in quartzite were recovered in the same conditions; they always occur with fossil bones. The first chopper was collected in 2008 (Dambricourt Malassé et al., 2016a), 30 m from the tibia shaft Masol 1 R10084, in a small butte of redeposited sandstone blocks and silts rich in turtle bones located at the limit of the eastern ravine, named the "Turtle hillock" (Fig. 3A, numbers 1 and 2). Some samples were extracted from this colluvium to be dated by Electron Spin Resonance.

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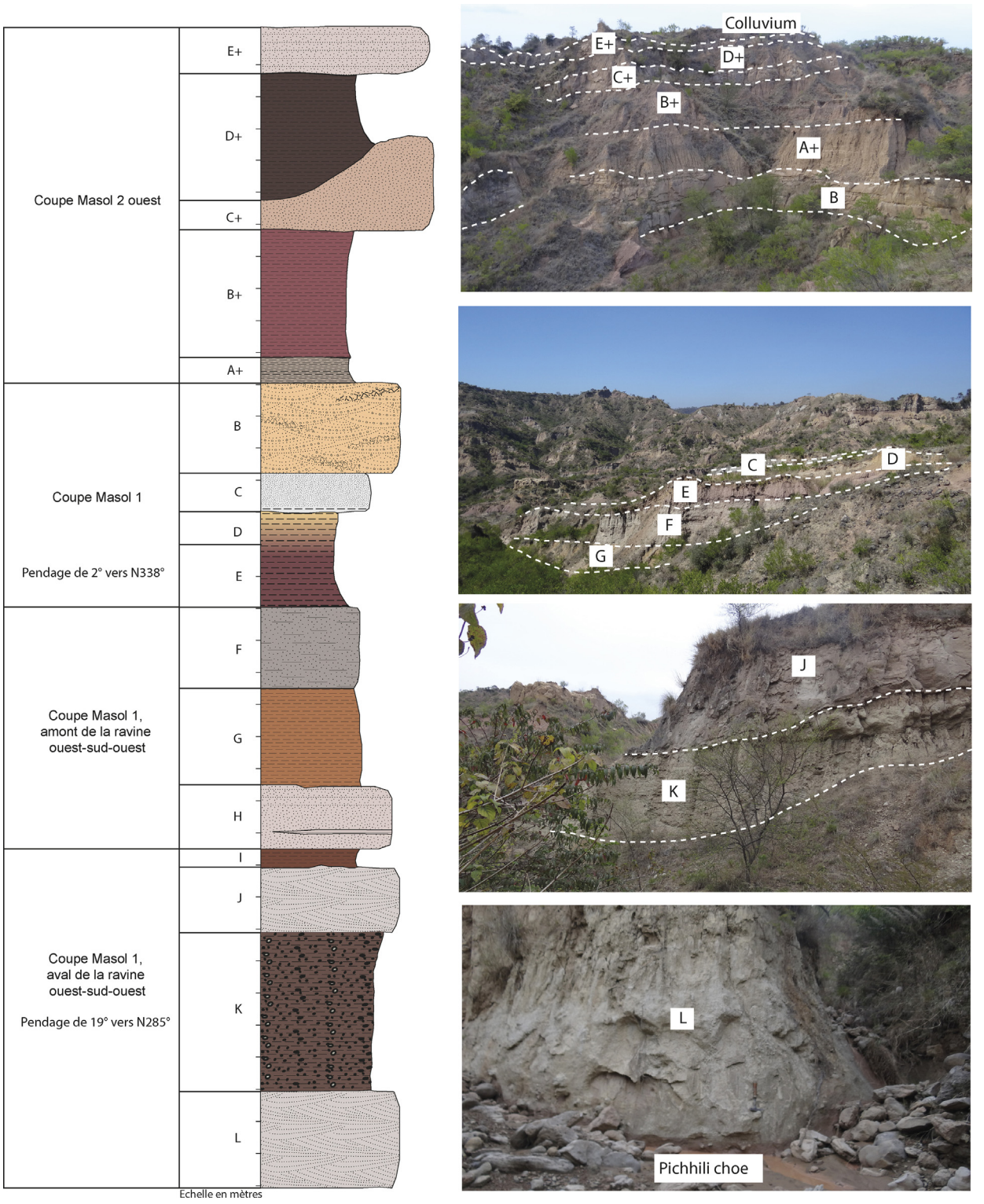


Fig. 5. Composite stratigraphic log and the main lithostratigraphic units of the Masol 1 and Masol 2 localities (photo S. Abdessadok).
Fig. 5. Log stratigraphique composite et principales unités lithostratigraphiques des localités Masol 1 et de Masol 2 (photo S. Abdessadok).

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Then, in 2009, the team collected flakes and a few choppers in the perimeter between the cut-marked tibia shaft Masol 1 R10084 and the "Turtle hillock" and one chopper on the slope of the ravine below this hillock. Later two choppers were found in the perimeter of the tibia shaft Masol 1 R10084 (5 and 8 meters) and another one 40 m to the west of this locality on colluviums from the same silts D and E. Among 3 small pieces of quartzite, 2 are flakes and one is a retouched fragment; the 14 heavy-duty tools are various types of choppers (Gaillard et al., 2016).

There is no layer or lense of quartzite cobbles/pebbles along the 150 m of outcrops but an important concentration of cobbles is visible 80 m beyond to the north at Masol 2, in the colluviums of the silts E and D among blocks of the dismantled units B and C (sandstones). Their sizes vary from 10 to 20 cm long, two trial trenches were open in these colluviums and in their substratum to test the presence of artefacts.

Fossils remains and artefacts of the Masol 2 locality:

The fossils of Masol 2 show little displacement since their exhumation. The most remarkable sublocality is Masol 2-east with a very large, segmented and incomplete tusk, associated to a large fragmented scapula of a proboscid covered by cemented gravel (Moigne et al., 2016). At this place, there is just a fragile residual relief forming a sort of wall composed of silt units D–E, with a very thin layer of C at the top and gravel of the sandstone B (Fig. 6). The fossils were deposited on the silts since the erosion of the gravels. One chopper was recovered near the scapula on the wine-colored silt of unit E. Fossils, flakes and choppers were collected on the other side of this wall where the Masol 2 depression follows the direction of the dip from the east to the west (Fig. 6). These fossils and artefacts were lying along the foot of the small plateau which separates Masol 1 (south side) and Masol 2 (north side). Year after year several specimens were collected: one flake collected directly on the silt of the "wall"; two diaphyses of proboscid in the colluviums; again choppers and flakes, either in the silt, on the slopes or on the surface, a maxillary of *Hexaprotodon*, many splinters of tusks and in the western sector, the important accumulation of quartzite cobbles. Other fossils complete the collection of Masol 2 (Moigne et al., 2016).

Two trial trenches A1 and B1 have been dug in this sector in order to verify whether choppers and flakes could

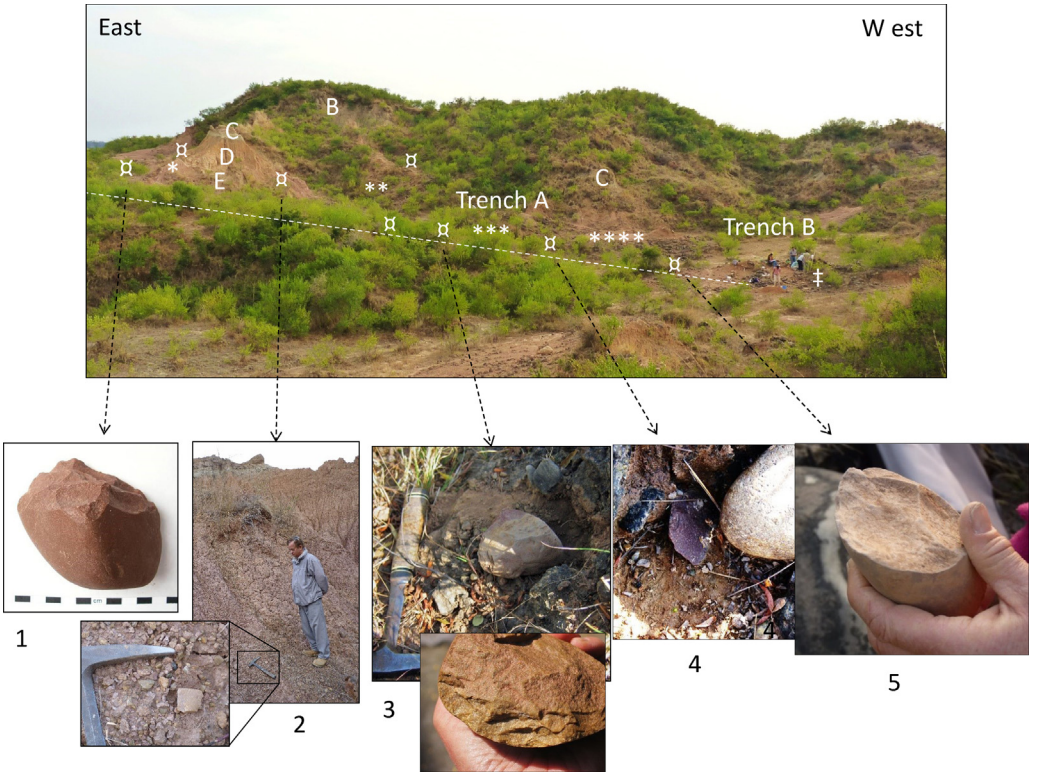


Fig. 6. Masol 2, A: view towards the South on the large cliff separating M1 and M2 with the lithostratigraphic units, the location of the collected material and the two trial trenches A1 and B1. Caption: B, C, D, E: lithostratigraphic units from Masol 1; dotted line, the dip of the layers; ¤: lithic artefacts; * tusk: proboscid scapula; * long bones of very large herbivore; *** *Hexaprotodon* skull; **** tusk splinters; ‡: cluster of quartzite cobbles; B: collected artefacts (non exhaustive), 1: chopper (2010); 2: flake (2011); 3: chopper Masol 2- 28 (2009); 4 chopper Masol 2- 20 (2009); 5: flake (2011).

Fig. 6. Masol 2 : vue vers le sud sur la grande falaise séparant M1 et M2, indication des unités lithostratigraphiques, localisation du matériel collecté et des deux sondages A1 et B1. Légende : B, C, D, E : unités lithostratigraphiques de Masol 1 ; ligne pointillée, pendage des couches ; ¤, artéfacts lithiques ; * défense et scapula de proboscidien ; ** os long de très grand herbivore ; *** crâne d'*Hexaprotodon* ; **** esquilles de défense ; ‡ accumulation de galets de quartzite. B : artéfacts lithiques collectés (non exhaustifs), 1 : chopper (2010) ; 2 : éclat (2011) ; 3 : chopper Masol 2- 28 (2009) ; 4 : chopper Masol 2- 20 (2009) ; 5 : flake (2011).

Photos: A. Dambricourt.

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Fig. 7. A Masol 2, view towards M2-west and location of the trench B1 (rectangle) with indication of lithostratigraphic units B, C, D, E and the dip towards the northeast (dotted line). B: location of the trench B1 and the excavated space (rectangle).
Fig. 7. Masol 2, vue en direction de M2-west et emplacement du sondage B1 (rectangle) avec indication des unités lithostratigraphiques B, C, D, E et du pendage vers le nord-est (pointillé) ; B : localisation du sondage B1 et espace fouillé (rectangle).
Photo: A. Dambricourt.

be in situ near the *Hexaprotodon* (trench A1) and nearby the quartzite cobbles occurring on the surface (trench B1) (Fig. 6 and Fig. 7).

The trial trench A1 (1×2 m) was dug in silt E and excavated to the top of sandstone F. The lithostratigraphic sequence comprises 5 levels, from the top to the bottom: the humic surface, the silt E divided into 3 sublayers, and the top of the unit F (Fig. 8). The layer L1 is rich in blocks of sandstone. The layer L2 is the silt E in situ with many gravels and provided two quartzite cobbles, one with a broken surface (Fig. 8); downwards the silt becomes lumpy and compact until the grey sandy silts F. The trench provided 10 fragmented fossils in each layer but no artefact. Details are given in Fig. 9. The significant observation is the presence of quartzite cobbles in silt E.

The trench B1 (2×2 m) (Fig. 10) was excavated a few meters beyond trench A1, by following the dip toward the western limit of the depression, in a small bank of silt E covered by blocks of sandstone and many quartzite cobbles. The lithostratigraphic sequence is visible along the south-north section on 60 cm high, whereas along the west-east section the layers are beveled by the slope. The trench shows two layers: the upper layer L1 with blocks and nodules of sandstone and quartzite cobbles/pebbles in a silty matrix; the lower layer L2 is a wine-colored silt with some coarse elements in its upper part, while its lower part is lumpy and compact (Fig. 10). The latter corresponds to the silt unit E, the same as in the trench A1, and the layer L1 corresponds to the mixed sediments of the dismantled silt of unit D and sandstone of units C and B. The high concentration of quartzite cobbles and pebbles in L1, in the upper part of L2 and around the small bank, originates very probably from a dismantling of a localized lens of cobbles deposited during the silty phase D–E.

The trench B1 provided 10 very fragmented fossils and artefacts in quartzite in both layers described in Gaillard et al. (2016). In the layer L2, the artefacts are an end-chopper (Masol 2–17), a simple chopper with chipped edges (Masol 2–166), an obliquely broken cobble with chipped cutting edge (Masol 2–43) and a flake (Masol 2–133). Among the 10 fossils (Fig. 9), one is a fragment of upper molar from *Hexaprotodon* and another one is an abraded tooth of Equidae (Masol 2–B1–28) recorded in the lumpy silt (Fig. 11). As in the trench A1, the silt in situ is the base of the unit E with the unit F visible just below. Quartzite cobbles and the four artefacts were collected in the altered part of L2 capped by the colluviums (Fig. 10).

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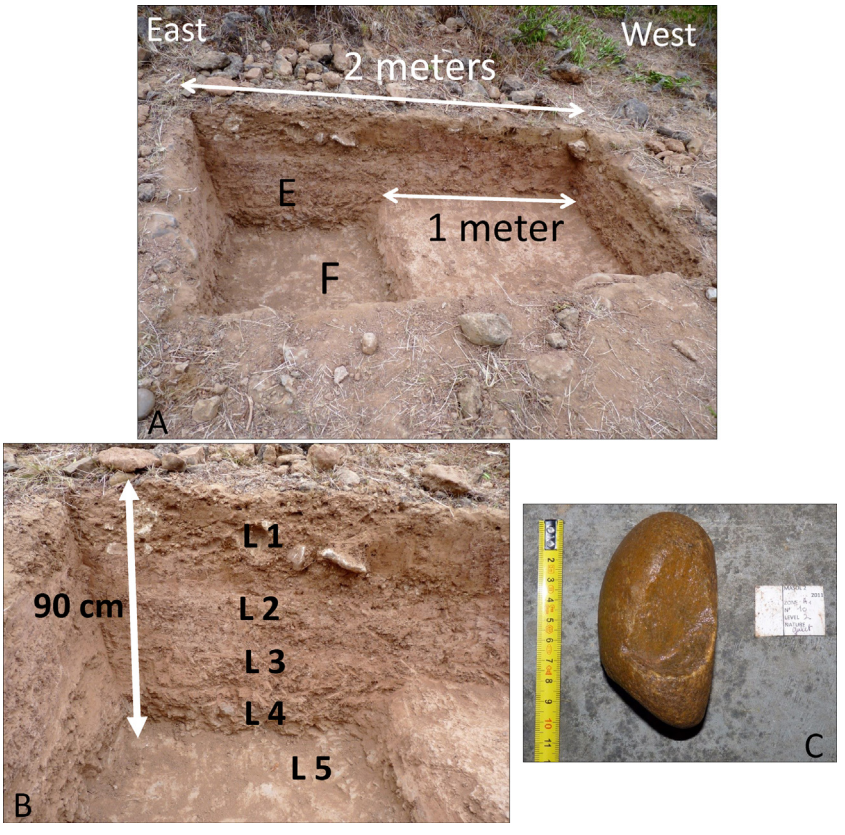


Fig. 8. A and B, trench A1: E and F, lithostratigraphic units; L1, weathered surface; L2, silt rich in gravels with one quartzite cobble; L, lumpy silt; L4, endured silt; L5, sandy silts unit F; C: the broken quartzite pebble from the level 2.
Fig. 8. A et B, sondage A1 : E et F unités lithostratigraphiques ; L1 : surface remaniée ; L 2 L : limon riche en graviers avec un galet de quartzite fragmenté : L3 : limon grumeleux ; L4 : limon induré ; L5 : limons riches en sables de l'unité F ; C : le galet de quartzite fragmenté du niveau 2.
Photo: A. Dambricourt.

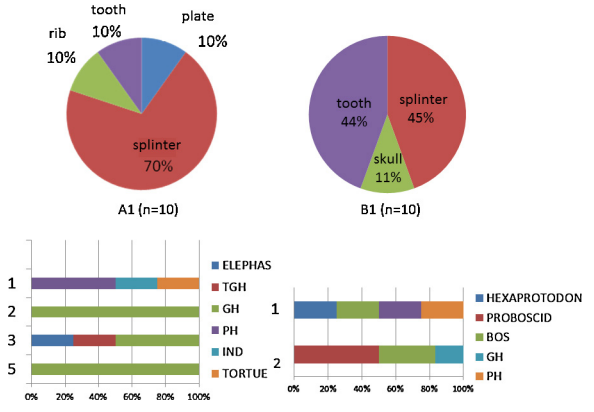


Fig. 9. Percentage of taxa by level of the trenches A1 and B1 at Masol 2. Captions: TGH: VLH: very large herbivore; GH: LH: large herbivore; PH: SH: small herbivore: IND: undetermined.
Fig. 9. Pourcentage de taxons par niveau des sondages A1 et B1 de Masol 2. Légende : TGH : très grand herbivore ; GH : grand herbivore ; PH : petit herbivore : IND : indéterminé.
Photo: A.-M. Moigne.

Masol 2-west is a depression leading the dip of the anticline towards the west at around meters 70 m below the trench B1 of Masol 2, (Fig. 3, number 5); many choppers and splinters, a few very well preserved bones in blocks of sandstone were collected on the outcrops composed of the yellow and brown silts D–E. This is the same configuration than Masol 2 but without clusters of quartzite.

3.2. Masol 6 locality

The Masol 6 locality (M6) is located on the western side of the Pichhli watershed (Fig. 12). This sector of the Masol anticline presents one of the most complete sedimentary sequences. The topography is characterized by a succession of steps formed by cliffs capped by sandstone in alternation with silty series containing occasional sandy lenses. The lithostratigraphy described here includes Masol 6 and parts of the sequence below and above the locality proper on around 70 m thick after the combination of three sections: the lower is divided into 19 lithostratigraphic units, the middle in 26 units and the upper in 15 units.

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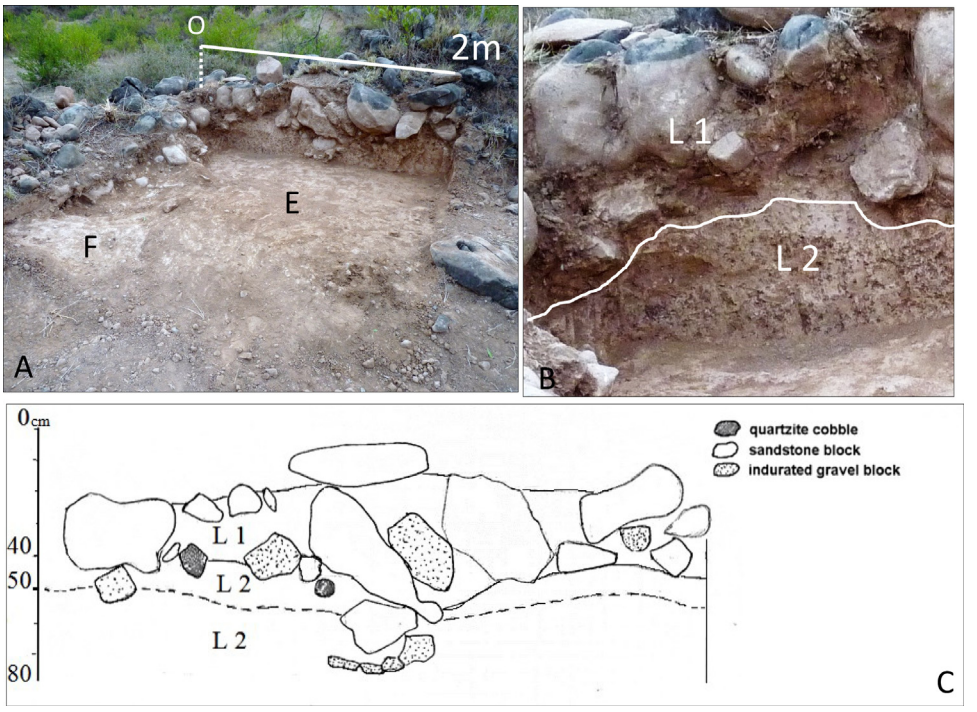


Fig. 10. Trench B1, A: at the end of the excavation, E and F, lithostratigraphic units; B: detail of the two levels, L1 with blocks of sandstone, blocks of indurated gravels and cluster of quartzite cobbles; L2: silt unit E (picture A. Dambricourt); C: drawing section by C. Gaillard with the scale of the depth in cm.
Fig. 10. Tranchée B1, A : à la fin de la fouille, E et F unités lithostratigraphiques ; B : détail des deux niveaux, L1 avec des blocs de grès, de graviers indurés et des accumulations de galets de quartzite ; L2, silt unité E (photo A. Dambricourt) ; C : dessin de la coupe par C. Gaillard, avec échelle de profondeur en cm.



Fig. 11. A: study of the trench B1; B: the equid tooth in the lumpy silt; C: occlusal and lateral view of the equid tooth; D: fragment of *Hexaprotodon* upper molar.
Fig. 11. Étude de la tranchée B1 ; B la dent de l'équidé dans les limons grumeleux ; C : vue occlusale et latérale de la dent d'équidé ; D : fragment de molaire supérieure d'*Hexaprotodon*.
Photo: A. Dambricourt.

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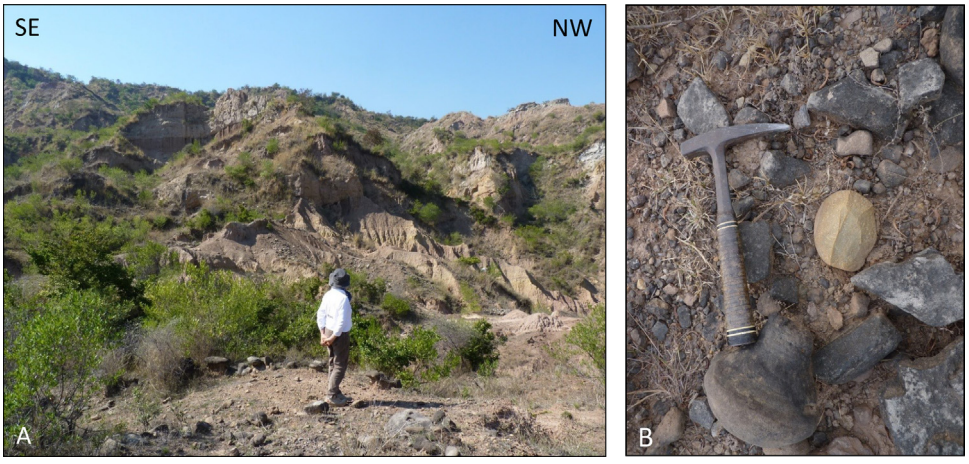


Fig. 12. A. View of Masol 6, cliffs and slopes at the second plan. B. A chopper in a ravine lining the large cliff.
Fig. 12. A. Vue sur Masol 6, falaises et pentes au second plan. B. Un chopper dans un des ravins bordant la grande falaise.
Photos: A. Dambricourt, C. Gaillard.

Lithostratigraphic description of the lower section:

The lower section of 25 m thick begins at the Pichhli Choe and contains 19 lithostratigraphic units indexed from A+ to S+. It is characterized by an alternation of fine-grained sandstone and silts (Table 2, Fig. 13). The latter are thicker than the sandstones.

Lithostratigraphic description of the middle section:

The middle section 18 m thick is divided into 26 lithostratigraphic units and indexed from Z to A. From the units Z to T, the sequence is an alternation of sandstone benches and silts of pink, yellow, orange or brown color while the units from S to A are essentially silts where the subdivision is based on the colorimetry (Table 3, Fig. 14). The sedimentology and mineral composition are described in Abdessadok et al. (2016) and Tudryn et al. (2016).

Lithostratigraphic description of the upper section:

The upper section, 26.5 m in thickness, is divided into 17 lithostratigraphic units ranging from AA to AO and characterized by alternation of fine-grained grey sandstone with sedimentary structures, and pink and yellow silt. The silty sequence is thicker than the sandstone sequence (Table 4, Fig. 15).

Finally the composite log of Masol 6, 94 m thick, presents a recurrence of pink and yellow silts (Table 4). The lithostratigraphic units comprise thick silty layers intercalated with fine to medium-grained sandstones.

Fossil remains and archeology of Masol 6 Locality:

Masol 6 is the richest fossiliferous locality after Masol 1/Masol 2 due to its SE-NW extension along the silty plateau which borders the slopes below the crest. This narrow plateau is mainly composed of the silts of units D to U yielding fossils in situ such as the giant turtle *Colossochelys* recently unearthed, sometimes in block of sandstone. The fauna list includes many dermal plates of turtles *Colossochelys*, *Geoclemys*, *Gavialis* and three bones of *Crocodylus*, one of *Hyena* and one hemi-mandible of *Panthera*, broken tusks and long proboscid bones, *Hexaprotodon, Sivatherium*, bovids, cervids, one *Equus*, one tragulid *Dorcatherium nagrii* and two genera of *Suidae*

Table 2
Lithostratigraphic description of the Masol 6 locality lower section.
Tableau 2
Description lithostratigraphique de la section basale de la localité de Masol 6.

Units	Lithostratigraphic description
S+	Hardened yellow silt, polyhedral structure, the thickness is ranging from 0.80 to 1.50 m
R+	Slightly hardened silt, pink in color. The thickness of the deposits varies between 0.40 and 0.60 m
Q+	Laminated silt, grey-green, friable structure, 1 m thick, recovered at the top by a carbonated concretion
P+	Pink silt of 0.20 m thick
O+	Hardened sandstone of 0.40 m thick, grey color with mamelon. It corresponds to the profile base of Masol 6
N+	Friable silt, pink color, polyhedral structure, 2 m thick
M+	Very hardened sandstone, 0.80 m thick, and grey in color.
L+	Yellow silt, 2 m thick. The structure is polyhedral and of centimeter sizes
K+	Very hardened sandstone of 0.80 m thick, of grey color
J+	Pink silt with centimetrical polyhedral structure, 2 m thick
I+	Sandy silt, 0.70 m thick, slightly hard, light grey at the base passing to yellow at the top
H+	Friable sandstone, grey, laminated at the base and with no sedimentary structure at the top, pinkish color, 2 m thick
G+	Friable pink silt, pluri-centimetrical polyhedral structure, 3 m thick
F+	Yellowish silt, friable, pluri-centimetrical polyhedral structure, about 2.50 m thick
E+	Fine-grained sandstone, friable, around 2.20 m thick. The color is grey but white in the altered zones. Some thin silty intercalations from 0.05 to 0.20 m thick are present. The erosion gives a uniform appearance
D+	Fine-grained sand, light grey, 0.50 m thick
C+	Yellow-greenish silt, friable, prismatic structure. The structure passes in centimeter bedding in the contact of the sand level overlying, 2 m thick
B+	Compact silt, 0.50 m thick, yellow pink, prismatic structure
A+	Fine-grained sandstone, light grey color, friable at the base and hard on the top, 1.20 m thick

(Moigne et al., 2016). The archeological material is quite abundant at Masol 6 with 50 large artefacts and 16 smaller ones (Gaillard et al., 2016). They were scattered on a highly dissected topography wider than Masol 2. They have been

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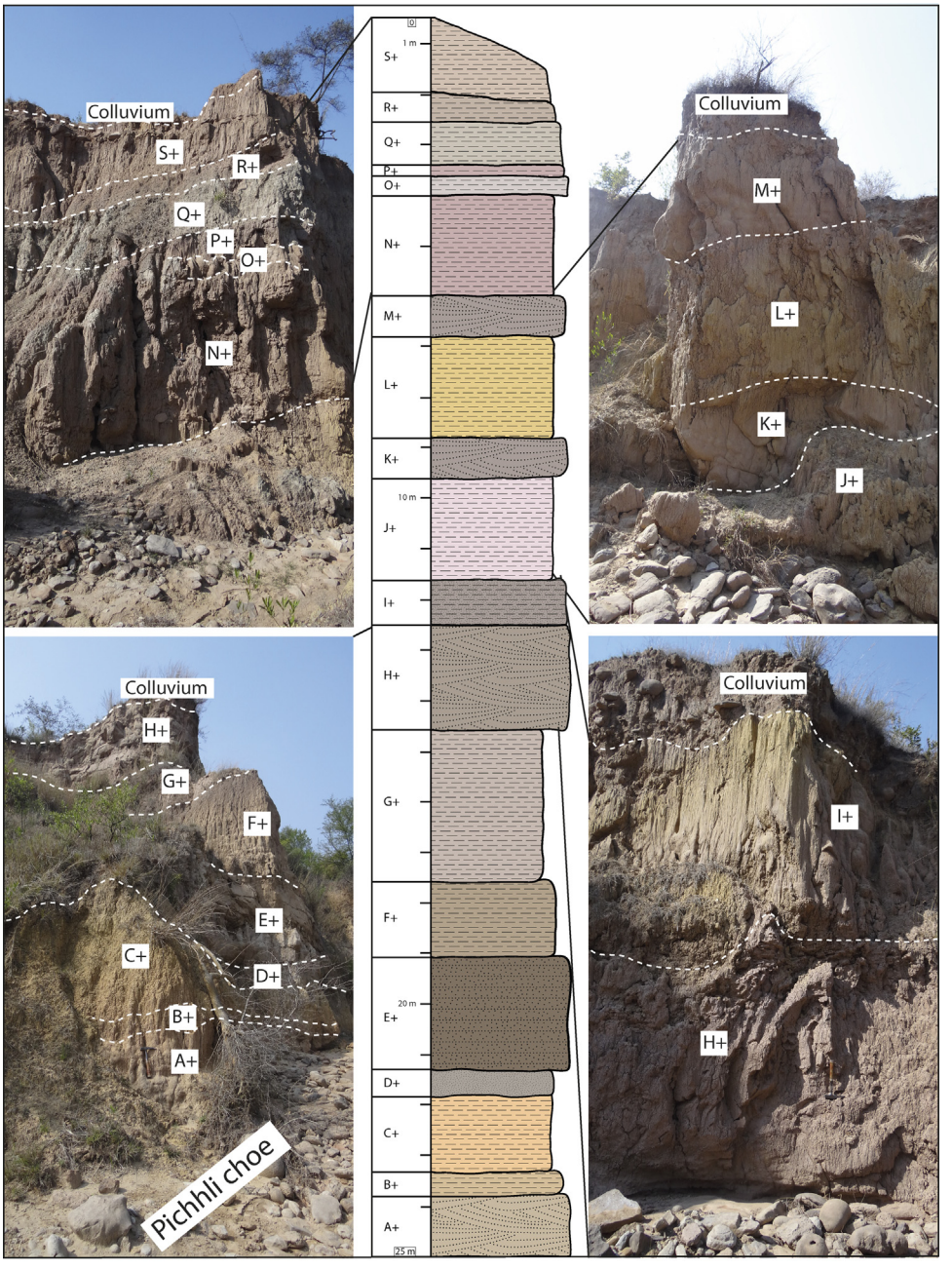


Fig. 13. Stratigraphic log and view on the main lithostratigraphic units of the Masol 6 lower section.
Fig. 13. Log stratigraphique et vue des principales unités lithostratigraphiques de la partie basale de Masol 6.
Photos: S. Abdessadok.

collected on the silty units from I+ to U (Figs. 13–14). One chopper was collected on the oldest silts F+ and G+.

3.3. Masol 13 locality

The Masol 13 locality (M13) is a small hill on the eastern riverside of the Patiali Rao at the northern limit of the large bowl-shaped depression described above; the stratigraphic section has been drawn at the exact locality where the bovid splinter Masol 13 R10298 with cut-marks and stone tools have been collected in 2011 (Fig. 16). The 7 m thick section is subdivided into 4 units: unit A is a fine-grained sandstone rich in silt (4 m thick); unit B is a brown silt without lamination (0.60 m); unit C

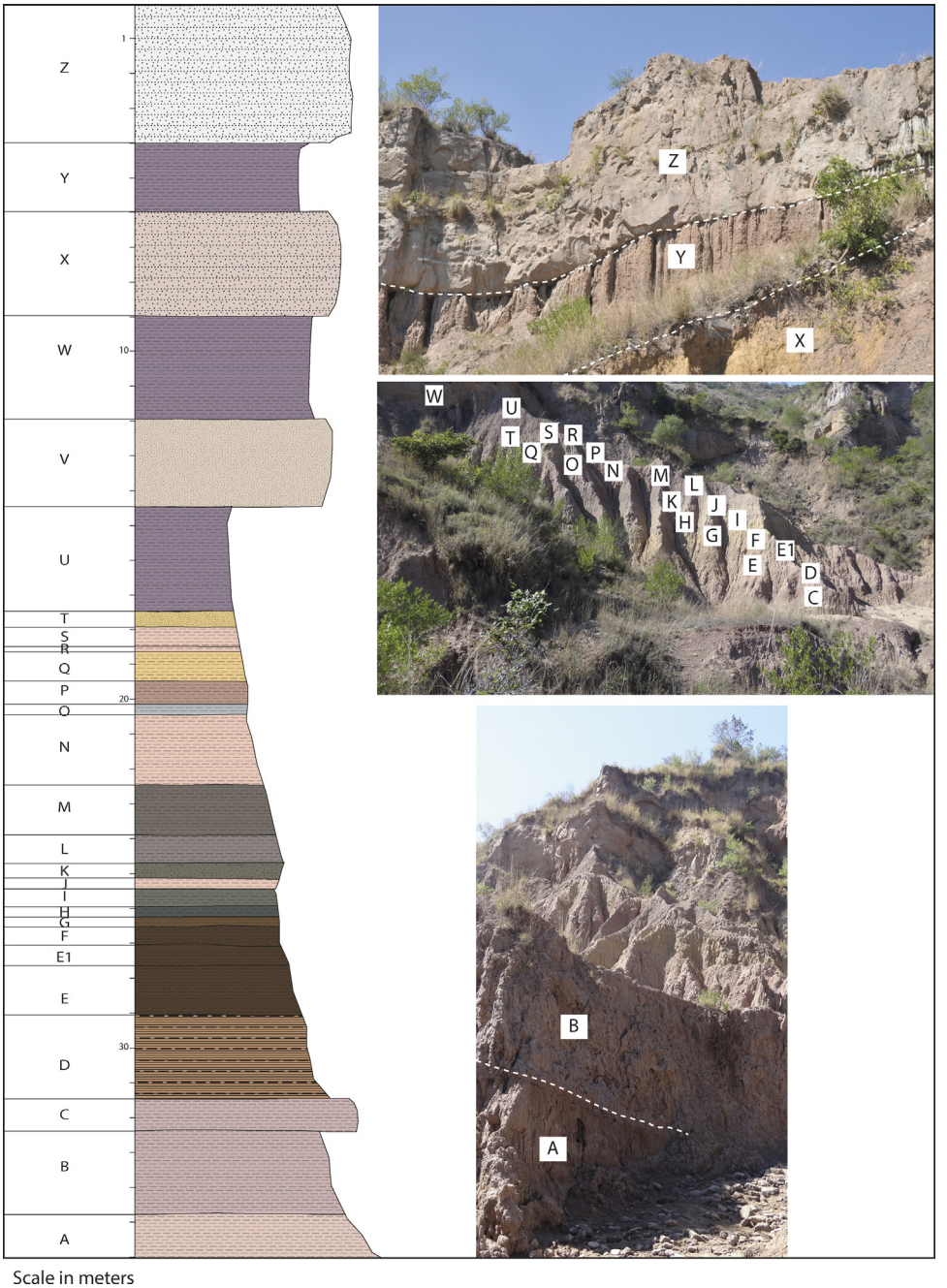


Fig. 14. Stratigraphic log and view on the main lithostratigraphic units of Masol 6 middle section.
Fig. 14. Log stratigraphique et vue des principales unités lithostratigraphiques de la partie médiane de Masol 6.
Photos: S. Abdessadok.

is a brown clay with greenish-grey marks without lamination (1.10 m) and unit D is a grey medium-grained sandstone, crumbling in ball-shaped lumps without structure of sedimentation (0.80 m). The sedimentology and mineral composition are described in Abdessadok et al. (2016).

Fossils remains and archeology of the Masol 13 locality

The cut-marked bovid splinter was collected on the silt C among blocks of the sandstone D and scattered quartzite cobbles. The list of faunal remains collected around the small mount includes 37 fossils with very few reptiles, crocodiles are missing, the majority are bovids (17) including *Hemibos*, and then *Sivacapra, Stegodon*, *Hexaprotodon, Sivatherium* and *Cervus punjabiensis* (Moigne et al., 2016).

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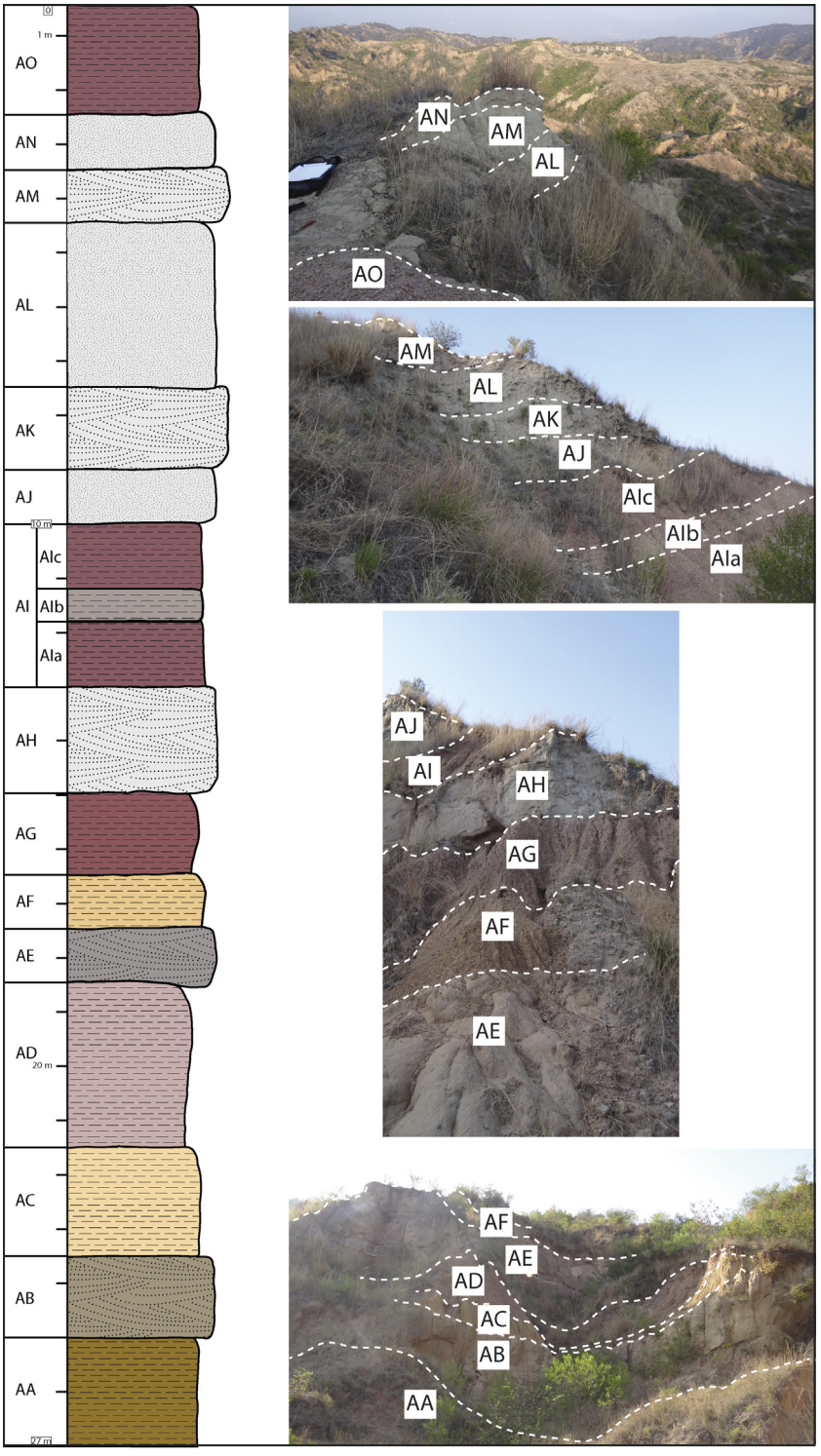


Fig. 15. Stratigraphic log and view on the main lithostratigraphic units of Masol 6 upper section.
Fig. 15. Log stratigraphique et vue sur les principales unités lithostratigraphiques de la partie sommitale de Masol 6.
Photos: S. Abdessadok.

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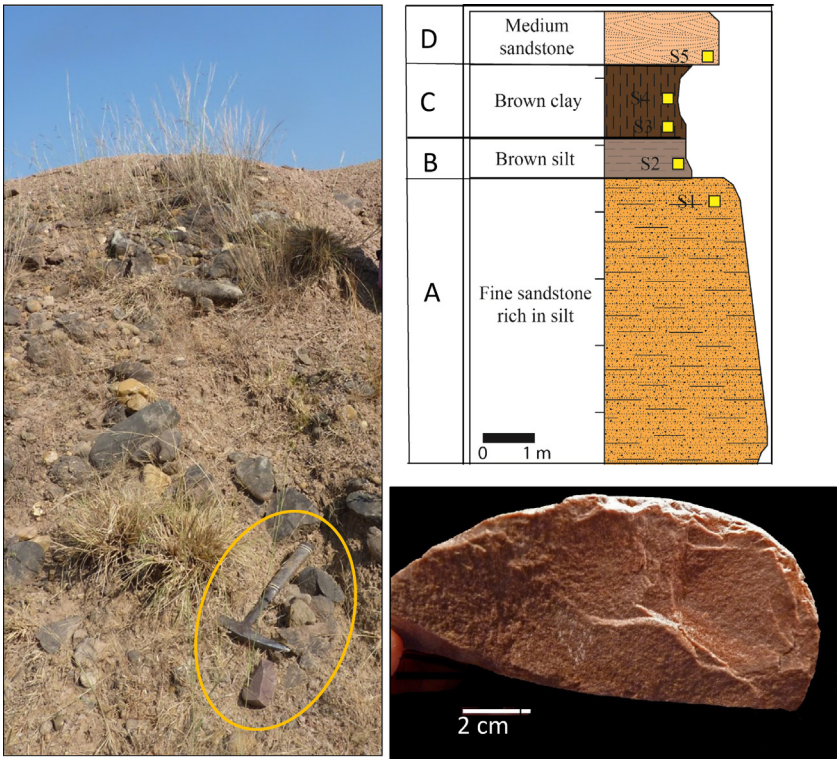


Fig. 16. Masol 13, the slope of the silt unit B with a chopper (close to the hammer) among quartzite cobbles and blocks of sandstone, the log of the M13 section (Abdessadok in Abdessadok et al., 2016) and the chopper Masol 13-281.
Fig. 16. Masol 13, la pente de limon unité B avec un chopper (à proximité du marteau) parmi des galets de quartzite et des blocs de grès, le log de la section M13 (Abdessadok in Abdessadok et al., 2016, infra); C : le chopper Masol 13-281.
Photo: A. Dambricourt.

4. The lithostratigraphic composite column of Masol 1/Masol 2, Masol 6 and Masol 13

All lithostratigraphic sections match and allow to show the relationships between the localities (Fig. 17). This composite log of M1-2, M6 and M13 is linked with the general log (Fig. 17). The sandstone unit B described at Masol 1 is very easy to recognize in the landscape and corresponds to the so-called "Elephant sand" (Tudryn et al., 2016) linked to the sandstone E+ unit of Masol 6. This comparison confirms that Masol 1 and Masol 2 localities are older than the fossiliferous Masol 6 locality. The sandstone A of Masol 13 is correlated to the sandstone B of Masol 1 and to the "Elephant sand", the fossiliferous deposits of Masol 13 are slightly younger and contemporaneous to the lower deposits F+ and G+ of the fossiliferous Masol 6 locality (Fig. 17).

The 94 m thick composite log of Masol 6 presents a recurrence of pink and yellow color. The lithostratigraphic units correspond to thick silty units intercalated with fine to medium-grained sandstones and match with the upper part of the Tatrot Formation according to the faunal list of the Quranwala zone (Moigne et al., 2016).

The units from A to E of Masol 1 match the one from B+ to E+ of the lower section of Masol 6. By referring to the general log and its code for the silts (c) and for the sandstone (s), the stratigraphical sequence of the three paleonto-archeological localities M1/M2, M6 and M13 are characterized by four sedimentary cycles in which the silts are thicker than the sandstones: c3-s3; c4-s4; c5-s5 and c6-s6; the fossiliferous sequence ends with silt c7 (Fig. 17). The lithostratigraphy of the three localities covers all the sequences of the fossiliferous Pliocene and allows us to identify the stratigraphic positions of the nine other paleonto-archeological localities. We have observed that the lower units H to K of Masol 1 are devoid of fossils according to Sahni and Khan (1964, 1968); the base of the Quranwala fossiliferous zone is located at the boundary between the units F and E of Masol 1, or the topmost of c3 from the general log. The clay and the pebbly sandstone, defined by Sahni and Khan (1964), respectively as the end of the Quranwala zone and as the boundary between Tatrot and Pinjor, were observed near the crest above M6 during fieldwork in 2015. Sandstones and clays were sampled there in order to verify the recording of the Matuyama/Gauss magnetic reversal and for dating by cosmogenic nuclide concentration measurements.

5. The lithostratigraphic context of the nine other localities and their correlations with the composite log

Masol 3 (M3) is the most northwestern locality, 190 m from Masol 2 (Fig. 2); the sector is rather flat. Here the

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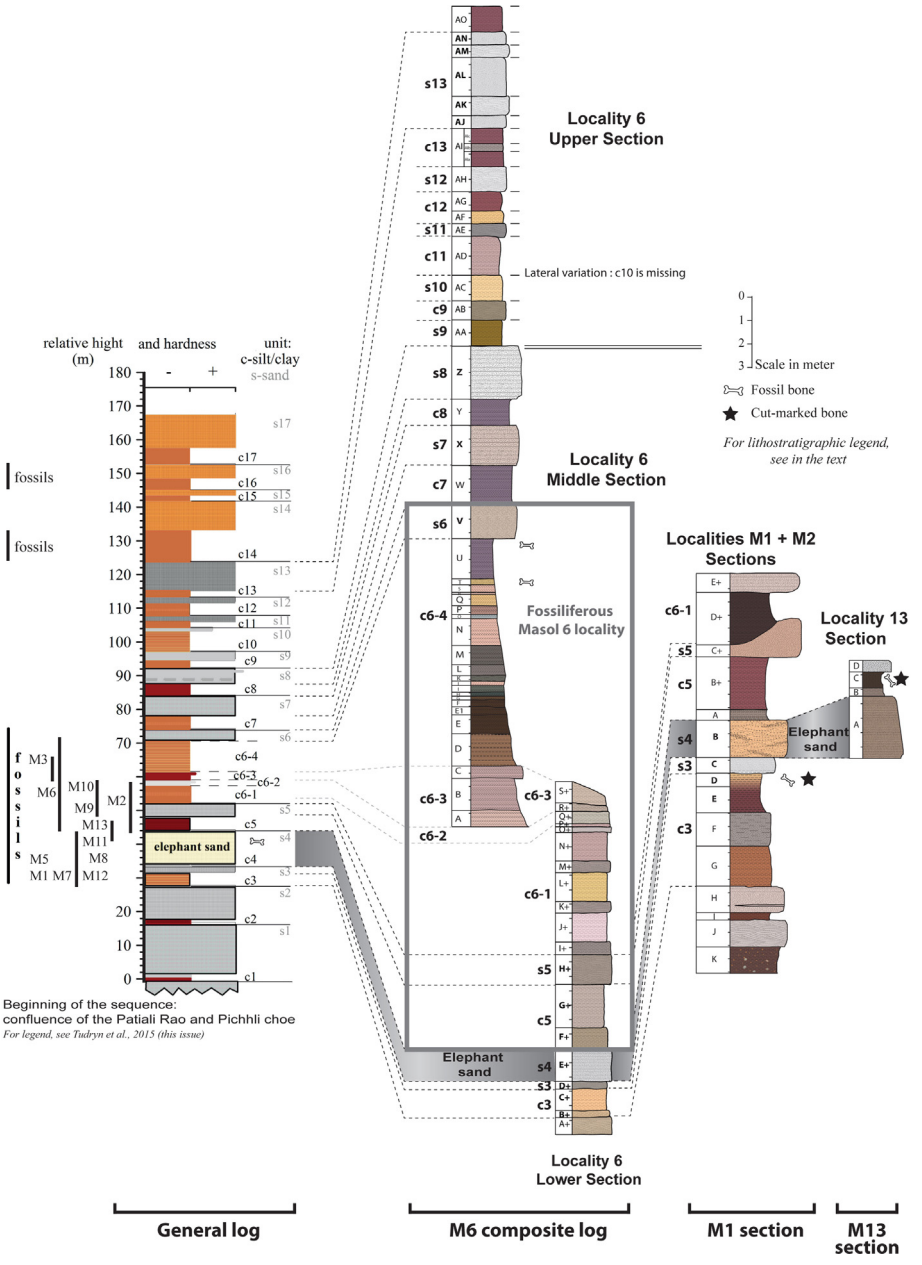


Fig. 17. Stratigraphic position of the paleonto-archeological localities (M) from the Masol Formation in the general log (log from Tydrun in Tudryn et al., 2016) and the detailed lithostratigraphy of Masol 1/Masol 2, Masol 6 and Masol 13 (Abdessadok and Chapon Sao). Caption: c: silt; s: sandstone; capital letter, lithostratigraphic code specific to each locality; drawn bone: location of the fossil bones; star: cut marked bones.
Fig. 17. Position stratigraphique des localités paléonto-archéologiques (M) de la formation de Masol dans le log général (log de Tydrun in Tudryn et al., 2016, infra) et lithostratigraphie détaillée de Masol 1/Masol 2, Masol 6 et Masol 13 (Abdessadok et Chapon Sao). Légende : c : limon ; s : grès ; lettre majuscule : code lithostratigraphique propre à chaque localité ; os dessiné : fossile ; étoile : emplacement des os fossiles avec traces de boucherie.

bottom corresponds to yellow silts with a small cluster of quartzite cobbles (Fig. 18). One chopper was collected among these quartzites near fossils encrusted by manganese, such as a big antler and a bovid long bone. The faunal list includes one tooth of *Hipparion* collected with a third phalanx of *Sivatherium*, rare turtle remains, a cervid mandible, and proboscidean bones. The silt matches c6-3 or c6-4 of the general log and corresponds to the upper units of the fossiliferous Masol 6 locality (Fig. 17).

Masol 4 (M4) is close to Masol 6 (Fig. 2) and provided two large fossil bones, including a proboscid joint and one flake (Masol 4-282), this locality is included in M6.

Masol 5 (M5) is a scarp in the middle part of the Pichhli watershed that leads the dip of the anticline (Fig. 2). Following Gargani et al. (2016), Masol 5 lies in the most recently eroded sector. The perimeter is limited and comprises from the top to the bottom (the bed of a small torrent): sandstone unit B or "Elephant sand", the top of

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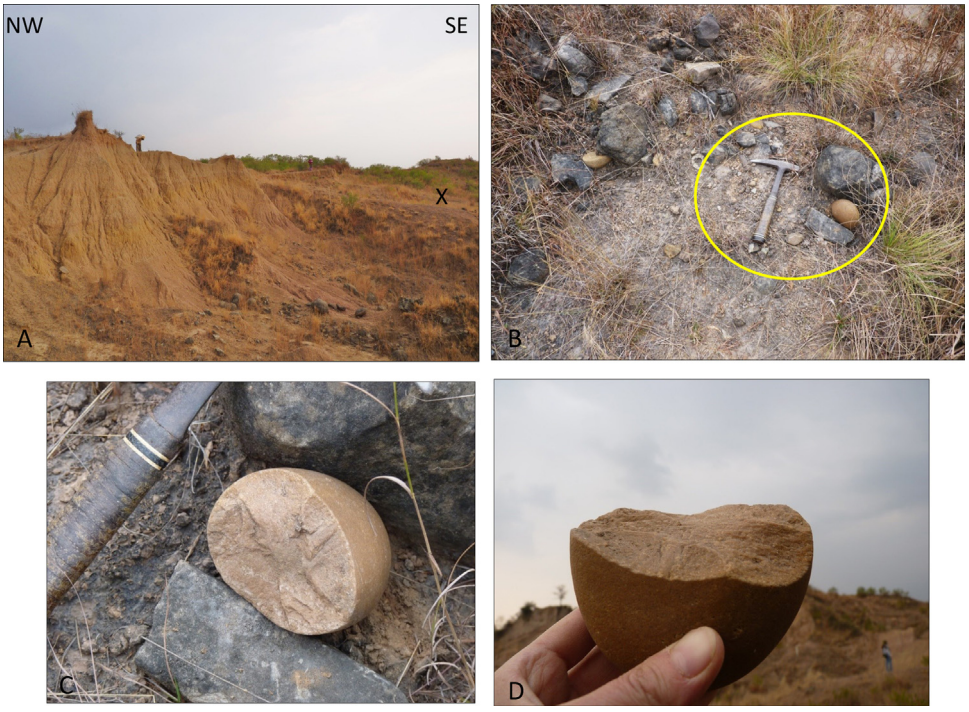


Fig. 18. Masol 3-north, A: the locality (X); B: one chopper–cortical face - among cobbles of quartzite, close to fossilized bone splinters at the two extremities of the hammer (yellow circle); C: the chopper in situ, returned; D: removal negatives of the chopper.
Fig. 18. Masol 3-nord A : la localité (X) ; B : un chopper – face corticale – à proximité d'esquilles osseuses fossilisées aux deux extrémités du marteau (cercle jaune) ; C : le chopper en place, retourné ; D : surfaces d'enlèvement du chopper.
Photo: A. Dambricourt.

which is rich in dermal plates of turtle, sandstone unit C, and silt units D and E, providing important clusters of quartzite cobbles and a rich biodiversity with the discovery of a molar of *Merycopotamus dissimilis* collected in 2014, a very rare species among the fauna list of the Quranwala zone (Moigne et al., 2016). Other remains (88) are one *Pesces*, large dermal plates of turtle, 7 *Crocodylus* (mainly dermal plates), two *Hyena*, and herbivores such as proboscideans (fragmented tusks), *Hexaprotodon*, Bovidae, *Sivatherium*, Cervidae and Suidea. Two artefacts were collected near a large vertebra, one chopper and one core, on the currently eroding slopes of the scarp (Fig. 19). The lithostratigraphy is equivalent to the upper layers of silt c3 and to the sandstone s3-s4 of the general log.

Masol 7 (M7) is a small cirque on the eastern riverside of the Patiali Rao (Fig. 2), dug in the basal sequence of the Quranwala zone exposing outcrops of the silt units D–E and sandstone units C and B ("Elephant sand"). The locality provided broken tusks, two flakes, a large split chopper (about 0.20 m) and a small cluster of quartzite cobbles. The lithostratigraphy is equivalent to Masol 1 with the upper layers of the silt c3 and the sandstone s3–s4 of the general log (Fig. 17). The depression of Masol 7 is bordered eastward by the "Elephant sand" beyond which the Masol 8 locality (M8) lies in a large depression including all localities up to Masol 13 at its northern extent (Fig. 2). M8 is an open and large area with silty mounts bigger than Masol 13. The slopes are dug in the silt capped by blocks of sandstone among which artefacts and bones were collected (Fig. 20) with the scenario of one chopper close to one totally isolated fossil (Fig. 18).

The lithostratigraphic sequence of Masol 8 corresponds to the same units as Masol 13: the base with sandstone unit A or "Elephant sand", silt units B–C and blocks of sandstone from unit D (these letters are not the same as for Masol 1 and Masol 2, Fig. 17). The lithostratigraphy is equivalent to sandstone s4 and silt c5 of the general log. Despite a surface widest than Masol1/Masol2, and Masol 6, Masol 8 yielded only 162 fossils (Masol 1/Masol 2 = 540 and Masol 6 = 360), this difference is probably due to earlier erosion than on the western riverside (Gargani et al., 2016).

Masol 9 (M9) is a small cirque landform overlooking the bowl-shaped depression of Masol 8 (Fig. 2). The bottom is composed of a sandstone equivalent to unit D of Masol 13 and s5 of the general log; eroded silts are attributed to the D+ of M1/M2 and c6-1 of the general log (Fig. 17). A broken skeleton of *Colossochelys* lays at the foot of a small relict hillock capped by redeposited silt. One chopper was extracted at the boundary between this colluvium and the top of the hillock. The small sector around this second "turtle hillock" is rich in quartzite cobbles, pebbles and gravels; choppers and flakes have been recovered here. Some samples were collected in this colluvium to be dated by Electron Spin Resonance and then compared with those of the "Turtle Hillock" at Masol 1, where the scenario is very similar.

Masol 10 (M10) is located a few meters above Masol 9; its stratigraphy is in continuous with M9. Beyond Masol 10 toward the top of high cliffs, there are no more fossils or

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Fig. 19. Masol 5: A, B and C: the chopper Masol 5-229; D and E: a core after remove it from the slope; F: view on Masol 5 with the core in situ (circle against the handle of the hammer).
Fig. 19. Masol 5, A, B et C : le chopper Masol 5-229 ; D et E : un nucléus après son extraction de la pente ; F : vue sur Masol 5 avec le nucléus en place (cercle contre le manche du marteau).
Photos: A. Dambricourt.

quartzite cobbles in the collapses or on the surface. Consequently, the accumulation of quartzite cobbles/pebbles and gravels in the small cirque of Masol 9 was very probably unearthed from the silt unit c6-1 as defined at Masol 6, where numerous clusters of quartzite cobbles are visible.

Masol 11 (M11) is located between Masol 8 and Masol 13 (Fig. 2) and has provided two choppers (Gaillard et al., 2016) collected on the silt units B and C of M13 equivalent to c5 of the general log (Fig. 17).

Masol 12 (M12) is located 80 m beyond Masol 13 towards the south-west (Fig. 2). This area was inventoried because of a stratigraphic section of about ten meters length with a fine layer of quarzitic cobbles/pebbles interbedded in silts (Fig. 21). These silts are attributed to units D and E of M1–M2, also equivalent to c3 and s3 of the general log (Fig. 17). At the very beginning of the fieldwork, one tooth and a split pebble in quartzite were collected on the outcrops which resembled to an artefact. Later, a better knowledge of the pebbles/cobbles showed on the field (Tudryn and Dambricourt Malassé) the impact of the tectonics on their structure and a fragility within the sandy gravels when they are in contact: a weak blow of a hammer could split them. But after a few seconds exposed to the air, they became extremely hard to break.

The last sector that provided a cut-marked bone is terrace T2 of the Pichhli Choe, in the vicinity of Masol 6. At this location, the seasonal stream cuts the basal sequence of the Quranwala zone, especially unit F of Masol 1. The highest unit in this deep sector of the choe is the "Elephant sand" (Fig. 18; Dambricourt Malassé et al., 2016b). The fossil bone is a highly mineralized broken metacarpal of a large bovid. According to its brown color and the good preservation of its surface, this bone seems to have been fossilized in brown silts c3 (general log) outcropping close to the terrace T2. These silts are also visible at Masol 1 far from 370 m towards the north-east.

6. Discussion

The interesting points of the "Siwaliks" program are: i) the recognition of the base of the fossiliferous Quranwala zone and the Plio-Pleistocene boundary, ii) the stratigraphical origin of the clusters of pebbles/cobbles in quartzite, since the cut-marks were made by a piece of quartzite (Dambricourt Malassé et al., 2016), iii) the origin of the fossil vertebrate (Table 5), and iv) the stratigraphic origin of the artefacts.

Delimitation of the Quranwala zone:

The fossiliferous deposits of the twelve paleonto-archeological localities of Masol are characterized: i) by an alternation of sandstone and silt which match with the sedimentary cycles c3 to s6 of the general log and, ii) by

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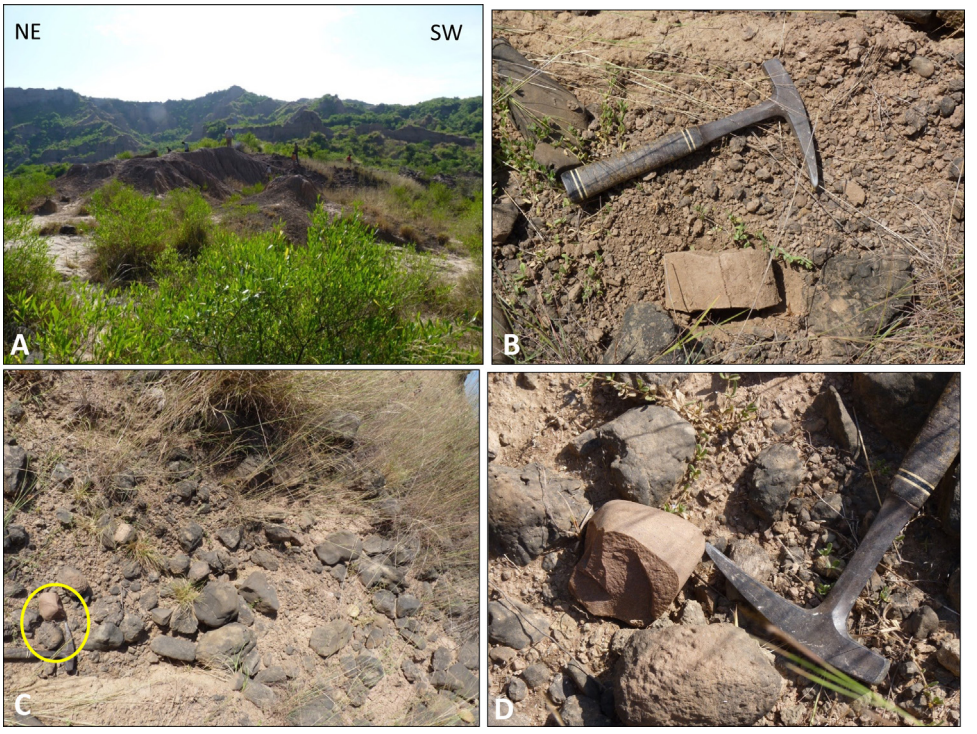


Fig. 20. Masol 8: A: view on Masol 8 towards the south-east; B: rib fragment of large herbivore; C: a chopper less than 1 m from the fossil rib (in the circle); D: the chopper.
Fig. 20. Masol 8 : A : vue sur Masol 8 vers le sud-est ; B : fragment de côte de grand herbivore ; C : un chopper à moins de 1 m de la côte fossile (dans le cercle) ; D : le chopper.
Photo: A. Dambricourt.



Fig. 21. Masol 12, a natural section with a layer of pebbles/cobbles in quartzite, quartz, gravels, imbedded between the silt units D and E from Masol 1/Masol 2.
Fig. 21. Masol 12, une section naturelle avec une couche de galets de quartzite, de quartz, de graviers, intercalée entre les unités de limons D et E de Masol 1/Masol 2.
Photo: A. Dambricourt.

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Table 3
Lithostratigraphic description of the Masol 6 middle section.
Tableau 3
Description lithostratigraphique de la section médiane de la localité de Masol 6.

Units	Lithostratigraphic description
Z	White friable sandstone with lamination, 4 m thick
Y	Very hard purplish-blue silts, 2 m thick
X	Fine-grained sandstone, friable, 3 m thick, lamination and red and coarse-grained sand lenses
W	Very hard purplish-blue silts, 3 m thick
V	Sandstone, from 2.50 to 1.50 m thick
U	Pink silts, polyhedric debitage, 3 m thick, this unit appears with a purple color in the landscape
T	Fine-grained sandstone, friable, no sedimentary structure, 0.50 m thick. It appears with a yellow color in the landscape
S	Light pink silt, 0.50 m thick
R	Light pink silts, prismatic debitage, 0,20 m thick
Q	Yellow silts (yellow-brown in the landscape), prismatic debitage, 0.60 m thick
P	Pinkish brown silts, prismatic debitage, 0.40 m thick
O	Laminated grey silts, 0.30 m thick
N	Pink silts, polyhedric debitage, 2 m thick
M	Silts, dark greyish brown in color, multicentimeter polyhedric debitage, 1.20 m thick
L	Light brown silts, 0.90 m thick
K	Sandy silts, greenish brown, no bedding, polyhedric debitage, 0.35 m thick
J	Pinkish silt, 0.30 m thick
I	Compacted silts, dark greenish brown, prismatic debitage, 0.40 m thick
H	Dark green silts, polyhedric and prismatic debitage, 0.20 m thick
G	Compacted silts, muliticentimeter prismatic debitage, 0.25 m thick
F	Brown silts, with oxide marks, foliated structure, 0.40 m thick
E1	Greenish silts, prismatic debitage, 0.50 m thick
E	Compacted silts, brown with greenish lenses, multicentimeter polyhedron. This unit appears with yellow color in the landscape, 1.20 m thick
D	Brown silts with clays, the color is heterogeneous, 2 m thick. Multicentimeter polyhedron debitage. Thin clays lenses, 0.03 m thick, yellowish brown in color
C	Dark pink hard silts, 0.80 m thick
B	Dark pink silts, homogeneous facies. It is striped by strike-slipe microfaults oriented NW, presence of vertical fissures, 2 m thick
A	Hard silts rich in clays, light pink in color, 1.20 m thick

Table 4
Lithostratigraphic description of the Masol 6 locality upper section.
Tableau 4
Description lithostratigraphique de la section sommitale de la localité de Masol 6.

Units	Lithostratigraphic description
AO	Friable silt, pink, polyhedral debitage, 2 m in thickness
AN	Grey white fine-grained sandstone, 1 m thick, very friable and characterized by horizontal stratified structure of 5 cm in thickness. At the top the sandstone is carbonated
AM	Embossed sandstone of 1 m in height, white grey and crumbly consistency
AL	Fine sand of bedded structure, white grey, very friable whose thickness is 3 m. It contains sandstone plates of 5 cm thick
AK	White grey friable sandstone with mamelon, 1.50 m thick
AJ	White grey fine-grained sandstone, 1 m thick, friable sandstone with 5 cm thick horizontal stratification
AIc	Friable silt, of pink color, polyhedral debitage with a thickness of 1.20 m
AIb	Friable silt, grey, 60 cm thick, polyedral debitage
AIa	Friable pink silt, polyhedral debitage, 1.20 m thick
AH	Grey white friable sandstone, 2 m thick
AG	Pink friable silt, polyhedral structure, 1.50 m thick
AF	Yellowish friable silt, polyhedral debitage. Its thickness is 1 m
AE	Light grey sandstone, northwest-dipping, up to 1 m thick
AD	Pink silt, polyhedral debitage, 3 m thick
AC	Yellowish silt, polyhedral debitage, 2 m thick
AB	Friable fine-grained sandstone, 1.50 m thick, grey
AA	Yellow silt, 2 m thick

Table 5
The faunal list of the paleonto-archeological localities in lower, middle and upper subdivisions of the Quranwala zone lithostratigraphy.
Tableau 5
Liste faunique des localités paléonto-archéologiques selon les subdivisions inférieure, moyenne et supérieure de la lithostratigraphie de la zone Quranwala.

Localities	Reptiles	Carnivores	Herbivores
Upper sequence M3 M6	Turtles Crocodiles	*Panthera*	*Elephas, Stegodon, Hexaprotodon, Propotamochoerus, Sus sp., Bubalus, Hemibos, Hippotragus, Sivacapra, Sivatherium, Dorcatherium nagrii, Axis, Cervus punjabiensis, Equus sivalensis, Hipparion antilopinum*
Middle sequence M8 M9 M13		*Crocuta*	*Elephas, Stegodon, Hexaprotodon sivalensis, Sus sp. Hemibos, Sivacapra, Hippotragus, Cervus punjabiensis, Sivatherium*
Lower sequence M1 M2 M5 M7	Turtles Snake Crocodiles	Hyenidae	*Hexaprotodon sivalensis, Stegodon insignis, Elephas hysudricus, Merycopotamus dissimilis, Sus sp. Hemibos, Hippotragus, Sivacapra, Boselaphus sp., Camelus sivalensis, Sivatherium, Cervids, Equids*

the lack of conglomerate as already noted by Sahni and Khan (1964, 1968). In the stratigraphic sequence of the general log above the unit s6 to unit s13 (towards the upper limit) and below the upper part of c3 (towards the lower limit), the deposits are characterized by an alternation of silt units thicker than the sandstone units, thus they belong clearly to the Tatrot Formation. Nevertheless, no vertebrate fossils, quartzite cobbles and artefacts have been collected in these layers. The fossiliferous Quranwala zone, around forty meters thick, is thus well limited in the Masol inlier. The fauna list is stable along the stratigraphy of these forty meters of fossiliferous deposits, with an abundance of large mammals especially proboscideans, *Hexaprotodon* and Bovidae, with an Anthracothere and a camel in the oldest levels; *Sivatherium* becomes more abundant in the upper levels. Carnivores are rare with a Hyaenidae and

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a large felid. The boselaphine appears only in the oldest levels, while *Dorcatherium* and *Propotamochoerus* are observed only at M6. Elements of Equidae are present in all levels but they were identified as *Equus sivalensis* and *Hipparion antilopinum* only in the upper levels (Moigne et al., 2016).

Quartzite pebble/cobble origin:

The clusters of quartzite pebbles/cobbles are clearly observed on the outcrops between the c3 and s6 units of the general log. The sedimentological study of the three main paleonto-archeological localities (Abdessadok et al., 2016) reveals that the deposits have undergone soft postdepositional chemical weathering. The postsedimentary features are few and limited to precipitation and/or ferromanganic oxyhydroxides inheritance. The sediments of this paleo-sub-Himalayan floodplain result from the erosion of the Higher and Lesser Himalayas as inferred from their mineralogical content. They were transported by rivers and deposited in the alluvial plain. Clusters of quartzite cobbles are visible in stratigraphy at Masol 12 interbedded in the silt units E and D from Masol 1, they are contemporaneous with the fossiliferous silts of Masol 2, Masol 5 and Masol 7 (Fig. 17); they have also been recorded in two trial trenches at Masol 2 in the silt E and at its upper limit capped by colluvium of silt unit D and sandy units C and B defined at Masol 1. Finally, clusters of quartzite cobbles/pebbles observed on the outcrops are coming from dismantled lenses from the upper part of unit c3, unit c5 and c6 identified in the general log. The alternation of silt and sand characterizes a low sinuosity stream with rhythmic deposition (Sahni and Khan, 1964). These pebbly layers indicate that the sedimentation of the silty unit c3 became locally coarser in its upper part, the quartzite cobbles were deposited in paleo channels from a Himalayan river probably during the monsoon.

Fossils origin

The oldest fossil bones are also collected in this upper part of the silty unit c3. Two trial trenches A1 and B1 were dug at Masol 2 at the summit of this unit c3 (unit E from Masol 1) and provided bones splinters as well as fragmented teeth. Then it appears that the fossilized species have been preserved whatever their size and weight in the fine sediments as well as in the sandstones. The taphonomic study revealed that the percentage of the fossilized bones is the same for the axial and the appendicular skeletons, with good preservation of small bones such as metapodials (Moigne et al., 2016). This indicates the natural origin of the bone accumulations with little transport of the dismembered carcasses and rapid burial. As for the clusters of quartzite, such accumulations result very probably from flooding of the Himalayan paleoriver during monsoons (Abdessadok et al., 2016; Moigne et al., 2016; Tudryn et al., 2016).

Origin of the stone tools

The synthesis of the lithostratigraphic distribution of the lithic industry reveals two major features: the majority of the stone tools are very close or associated with the clusters of quartzite pebbles/cobbles: M2, M3, M5, M6 (M4), M7, M9 (M10), M13, but above all, they are systematically in association with fossil bones scattered at the same locality, and often limited to a single chopper. These clusters of quartzite were found close to the carcasses. Four artefacts were recorded in the altered silt E from trench B1 at Masol 2, capped by colluvium from silt D and sandstones C and B, 80 m from the sector of Masol 1 where the cut-marked tibia shaft was recovered from the same layers D–C. These quartztite cobbles could be used for scavenging activities (Dambricourt Malassé, 2016; Dambricourt Malassé et al., 2016a,b).

Nothing contradicts the probability that the major part of the collected artefacts comes from the layers of the Quranwala fossiliferous zone; nevertheless more investigations and new trenches are necessary to reinforce this probability and to find stone tools clearly in situ (Dambricourt Malassé, 2016; Gaillard et al., 2016).

7. Conclusion

The lithostratigraphic units of the main paleonto-archeological localities of the Masol inlier from the Chandigarh Siwaliks Hills in the northwestern Himalayan piemonts have been identified according to their texture and color; the multicolored successions of sandy-silt and silt units (brown, reddish-brown, pink, orange and yellow) are thicker than the sandstone units, whereas these proportions are reversed above the Plio-Pleistocene limit. The stratigraphic logs of the three sections Masol 1/Masol 2, Masol 6 and Masol 13 allow drawing up a detailed composite sequence for the Masol anticline in the sector crossed by the Patiali Rao. They have been integrated into a general composite log established from the bed of the Picchli Choe at the confluence with the Patiali Rao, up to the western ridge of the Pichhli watershed (Tudryn et al., 2016); the log matches well with the geological map of Sahni and Khan drawn in the 1960s (1964, 1968). The fossiliferous sequence of the Quranwala zone is clearly evidenced by the appearance and the disappearance of the vertebrate assemblage typical of this transitional period. By many locations, clusters of quartzite cobbles from 10 to 25 cm cover the silty outcrops nearby vertebrate fossils; lithic artefacts are most often associated to the clusters and collected systematically in association with at least one fossil bone. The conditions of collect are similar for the fossils and the artefacts, either directly on the outcrops (all the localities) or in dismantled silts and sandstones; these associations are isolated from each other and on the both riversides of the Patiali Rao, scattered between the base and the top of the Pliocene fossiliferous deposits of the Quranwala zone. Cobbles or pebbles in quartzite were available in the same environment than the numerous carcasses and could be used for anthropic scavenging activities. The disappearance of this rich fossiliferous zone attesting anthropic activities is the matter of coming lithostratigraphic analyses with special reference to the climate evolution during the Plio-Pleistocene transition in the sub-Himalayan floodplain.

Acknowledgments

The “Siwaliks” Indo-French program of research is under the patronage of Professor Yves Coppens, College of France and Academy of Sciences, Institute of France since 2012, with the financial support of the French Ministry of Foreign Affairs during three years (2012, 2013, 2014), of the

National Museum of Natural History (MNHN), Paris, with the ATM grant (Transversal Action of the Muséum) of the Department of Earth Sciences in 2011 (MNHN, Paris), and with the Department of Prehistory (MNHN, Paris) (2007, 2010, 2011). We are thankful to the Archeological Survey of India and to the Department of Tourism, Cultural Affairs, Archeology and Museums of Punjab Government for survey permit. We are grateful to the Sarpanch of Masol village, for his hospitality. We thank especially Louis Rousseau, University Jules Verne-Picardie (France), for his constructive remarks and comments.

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Please cite this article in press as: Chapon Sao, C., et al., Lithostratigraphy of Masol paleonto-archeological localities in the Quranwala zone, 2.6 Ma, Northwestern India. C. R. Palevol (2016), http://dx.doi.org/10.1016/j.crpv.2015.10.005