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Site formation process and periodisation of a stratified sequence in arid context – Wadi El-Arab, Upper Nubia (8300-5400 cal BC)

Introduction

Sudan is known for its significant number of Early Holocene sites located in the Nile Valley. Since Arkell's pioneering research in the Khartoum region (Arkell 1949) and the second rescue campaign of the Aswan High Dam in Lower Nubia in the 1960s (Wendorf 1968), a series of important projects have been developed, notably in Central Sudan (Caneva 1983, 1988; Haaland and Magid 1995; Fernández 2003; Salvatori *et al.* 2014; Varadzinová et al. 2017) and more recently in Upper Nubia (Garcea 2015; Honegger and Williams 2015; Osypińska *et al.* 2020).

The formation processes of these open-air sites, which are in contact with the alluvial plain, are complex and diversified, but all of them are subject to the same taphonomic problems inherent to arid climatic conditions: marked erosive phenomena, significant vertical dispersion of the artefacts, stratigraphies with little contrast and difficult to read. Most of these habitation sites have also been regularly occupied at different times, with the development of dug structures and/or graves, which lead to confusions between levels and complicate the reading of the archaeological levels. Consequently, the resulting interpretations are frequently limited to broad chronological and stratigraphic breakdowns, which usually include a mixture of several occupations. This problem of precision has already been noted (Usai 2014) and highlights the importance of a good understanding of the formation processes at each site, as well as of each excavated sector, to enable an objective interpretation of the archaeological remains. This approach involves, among other things, a detailed examination of the stratigraphy, an analysis of the coherence of the distribution of the archaeological remains and absolute dating within the sequence. The excavation methods applied also play an essential role. Even if the weakness of the sedimentary distinctions generally makes it impossible to follow the archaeological layers in plan and that artificial cuts are often used, it is important to try to distinguish possible structures or concentrations of remains, in order to understand the spatial organisation of the sites as well as possible. Closed contexts – pits, semi-subterranean huts (pit-huts), tombs – have a significant informative potential, but few sites have such well-preserved remains. Many of them have suffered significant erosion and are so disturbed that it is futile to try to understand them all. However, it is important to establish this a posteriori, after having thoroughly tested and evaluated the state of conservation of the sequence. Finally, periodisation – the division into phases – results from the comparison and synthesis of stratigraphic, chronological and cultural data.

In this article, we present the archaeological sequence of the Wadi El-Arab site, which is located in Upper Nubia, on the edge of the Kerma Basin. Its interest lies in the fact that the deposits cover an extensive surface and presents a succession of occupations dating back to the first half of the Holocene, preserved in places to a thickness of almost one metre. The sectors excavated have yielded twenty-three structures, ten burials, rich furnishings and preserved faunal remains. These remains are divided into five main chrono-stratigraphic phases, located between 8300 and 5400 cal BC thanks to the results of 45 radiocarbon dates. From a methodological point of view, our intention is to show that the study of this stratified site, in spite of weak sedimentary contrasts that make the reading of the layers difficult, allows us to distinguish the main chrono-stratigraphic units with a good level of resolution, thanks to a critical reading of the results and the use of excavation and analysis techniques adapted to this type of context.

2. Location and description of the site

The site of Wadi El-Arab is located a few kilometres upstream from the 3rd Cataract, on the edge of the Kerma Basin which belongs to the Northern Dongola Reach, one of the largest alluvial plains in Nubia. Today it is 16 km from the eastern bank of the Nile, but in the early Holocene it was much closer to the river. The gradual aridification of the climate and changes in flow have caused the Nile to gradually move towards its present bed (Macklin *et al.* 2013).

The site, which was discovered in 2002, lies on the slopes of a small elevation a few hundred metres in front of the first tabular reliefs of Nubian sandstone, which border the alluvial plain and constitute the regional bedrock (Fig. 1). This elevation extends around a basaltic uplift that outcrops at its summit (Fig. 2). It overlooks a flat area, the El-Hawamra depression, about 10 metres below, which was fed at the beginning of the Holocene by Nile floods and rainwater, and prob-

Fig. 1. Location of the main Early Holocene sites in the Kerma region

ably functioned as a back-swamp (Williams 2012), i.e. a peripheral area of the floodplain, located behind a natural embankment that created a wet or marshy space by retaining water. The surroundings of this wet depression were particularly attractive at the beginning of the Holocene because of the proximity of the two main biotopes, the alluvial plain and the hinterland. Archaeozoological studies confirm the exploitation of several ecosystems: the river, the floodplain, the wetlands and the wooded or drier savannah of the hinterland (Linseele 2012; Chaix and Honegger 2015). As part of the survey programme set up by Honegger and the Swiss Archaeological Mission in Sudan in the early 2000s, many other contemporary sites of Wadi El-Arab were discovered in this peripheral fringe of the plain (Honegger and Williams 2015). Two of them have been excavated: El-Barga (Honegger 2004) and Busharia I (Honegger and Jakob 2022), which lie less than 5 km as the crow flies from Wadi El-Arab along a residual river terrace (Fig. 1).

The surface area of the site covers more than four hectares. Seven excavation campaigns, each lasting three to four weeks, were carried out between December 2005 and January 2013 with students from the University of Neuchâtel. Three test excavations of 4 m^2 each, carried out in the first season, revealed the development of an archaeological sequence of several tens of centimetres (Sectors 95, 165 and 310; see Fig. 2). The following year, the excavation of Sectors 165-175, located on a terrace behind the hilltop, revealed a first structure interpreted as a pit-hut foundation, as well as two tombs. The identification of other burials on the surface led to the opening of two new sectors on the south-western slope of the site (Sectors 421W and 611W). From 2008, the excavation of Sector 611W and its extension to neighbouring sectors (408W-612W) revealed an archaeological sequence of almost one metre with 22 structures (13 pits, an alignment of 4 pit-hut foundations, 2 circular huts with stone wedges and post holes, and 3 hearths), as well as seven burials (Fig. 3). In 2009, the discovery of bifacially retouched flint points near the top of the hill also prompted the opening of a sounding in this area (Sector 155W). By the end of the excavations, almost 450 m^2 had been excavated.

3. Stratigraphy and excavation method

Almost 50 metres of stratigraphy were recorded, to depths ranging from 0.5 to 1.3 metres. Their interpretation was completed by geological observations made by a micromorphologist from the 2005-2006 drill holes, as well as by Williams on the deep stratigraphy in Sector 611W in 2012 (Williams 2012). While each sequence studied is organised according to its own specific features, they all present the same arrangement in four sedimentary units (Fig. 4), three of which include archaeological remains.

3.1. Sedimentary Unit 1 – Surface deposits

This surface level is composed of a desert pavement, or reg, and a superficial layer of sand – up to 10 cm thick – which contains a high proportion of archaeological material, mainly lithic artefacts which have better resisted the erosion due to the impact of the grains of sand transported by the wind (corrasion). It is difficult to assess the thickness of the sediments eroded by wind deflation, but the phenomenon now appears to be attenuated by the presence of reg and induration of the upper horizon of the Sedimentary Unit 2. The presence of graves on the surface suggests that at least 50 to 70 cm of sediment may have disappeared in places.

3.2. Sedimentary Unit 2 – Main archaeological layers

This stratigraphic unit expands in places to over 70 cm. Its matrix is composed of homogeneous, grey-brown silty sands with little contrast, rich in organic matter (ashes, charcoal) and archaeological remains (artefacts, faunal remains, structures). Its upper part, hardened to a thickness of 5 to 15 cm, marks an abrupt boundary with Sedimentary Unit 1. This induration probably results from the washing of fine aeolian particles and the precipitation of illuvial clays. It constitutes a protective cover and one of the main elements that limited the impact of wind erosion on the archaeological sequence.

These sediments are in a homogeneous unit, without intermediate levels allowing it to be split. In fact, the stratigraphy does not indicate any occupational hiatuses. However, their consistency, more or less compact, has made it possible to identify excavated structures with a pulverulent filling. These are pits and pit-hut bases. In this sediment of homogeneous appearance, their exact delimitation remains delicate. Even in cross-section, their profile is not easy to highlight. The anthropic impact on Sedimentary Unit 2 is strong. The succession of occupations has led to numerous rearrangements of the space and the excavation of new

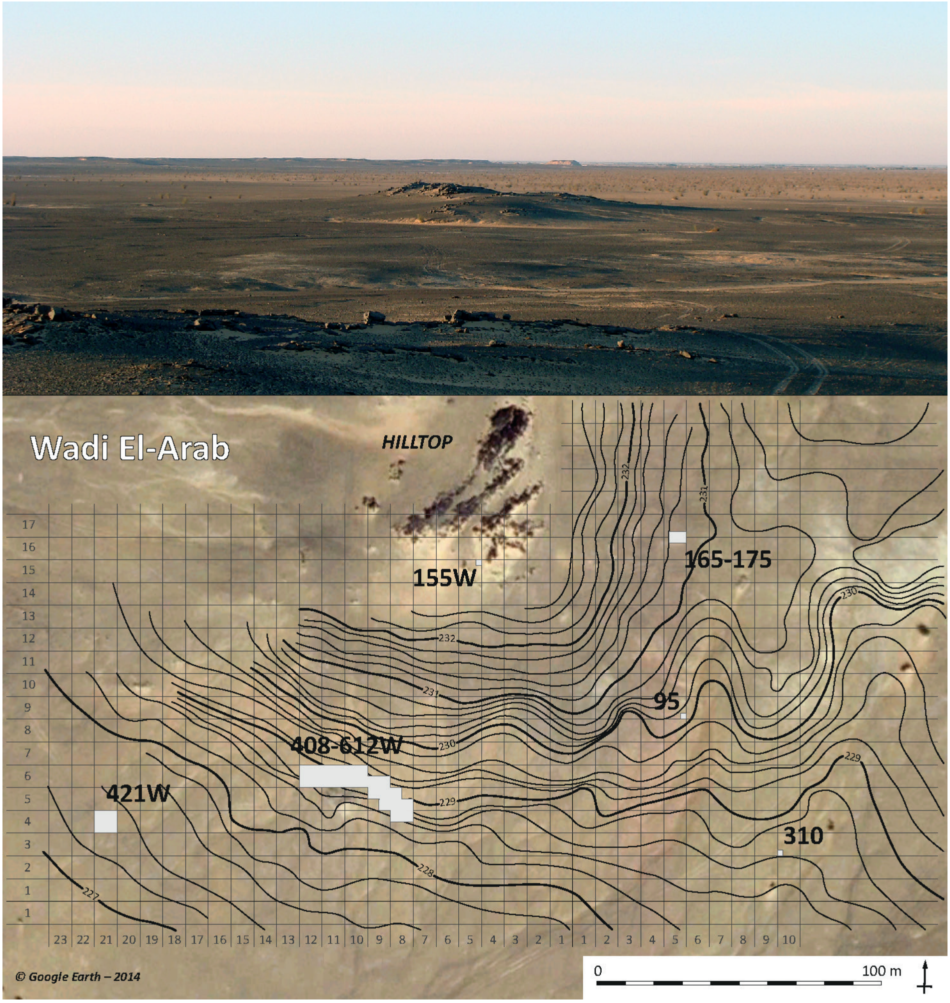


Fig. 2. View of the elevation of Wadi El-Arab from the north-east and plan of the excavated sectors

structures. The micromorphological analysis of a block of sediment from sector 95 shows that the small artefacts are little rolled and have undergone limited transport. This is confirmed by the presence of generally fresh and well-preserved artefacts. Even on the slope of the elevation, the material was little affected by runoff; locally however, the presence of drainage channels was evident. In Sector 612W, for example, a channel disturbed a large part of the excavated surface to a significant depth (< 35 cm), leading to the mixing of material and the destruction of any existing structures (Fig. 3). The radiocarbon dates from Sedimentary Unit 2 range between 7550 and 5400 cal BC.

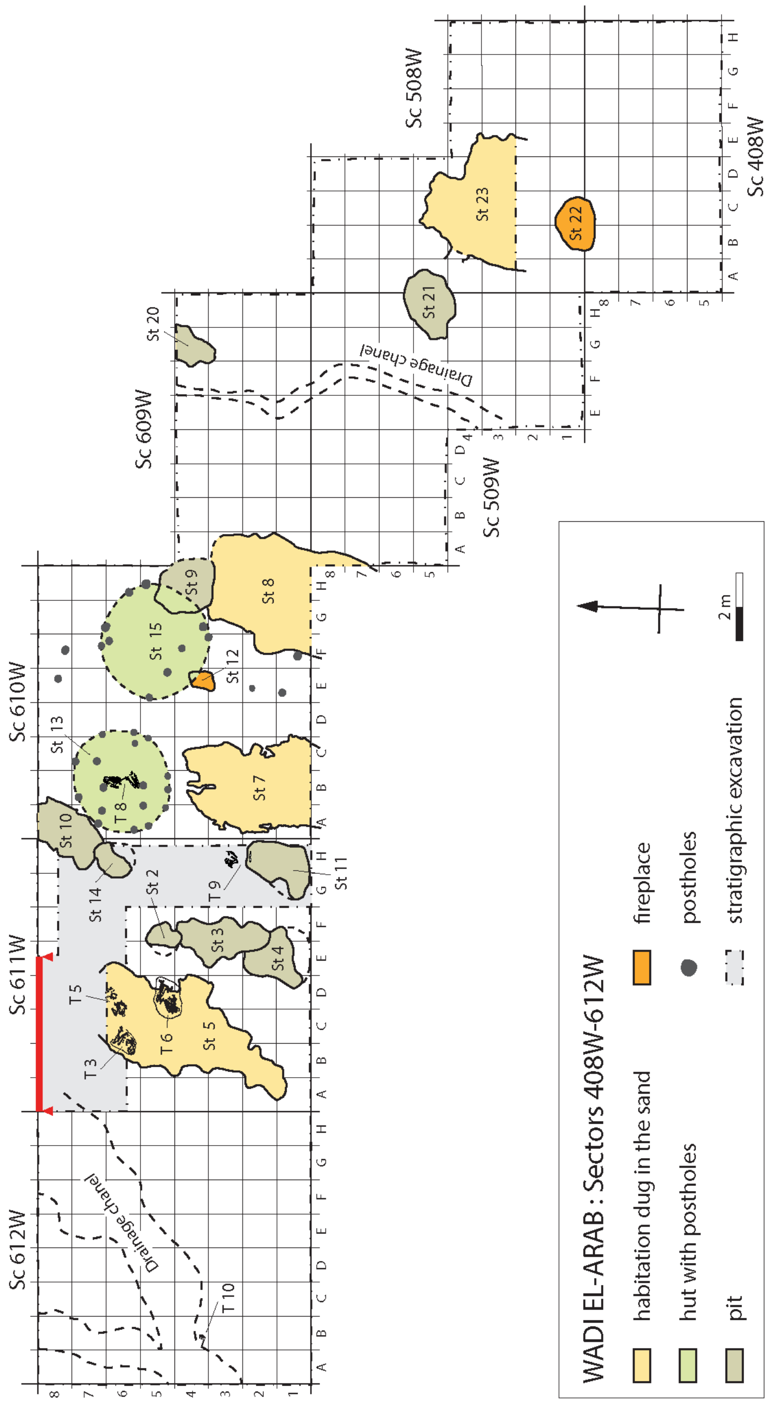


Fig. 3. Plan of sectors 408-612W (Sc) with the main structures (St) and graves observed (T), as well as drainage channels and stratigraphic excavation. In red, location of the stratigraphy shown in figure 4

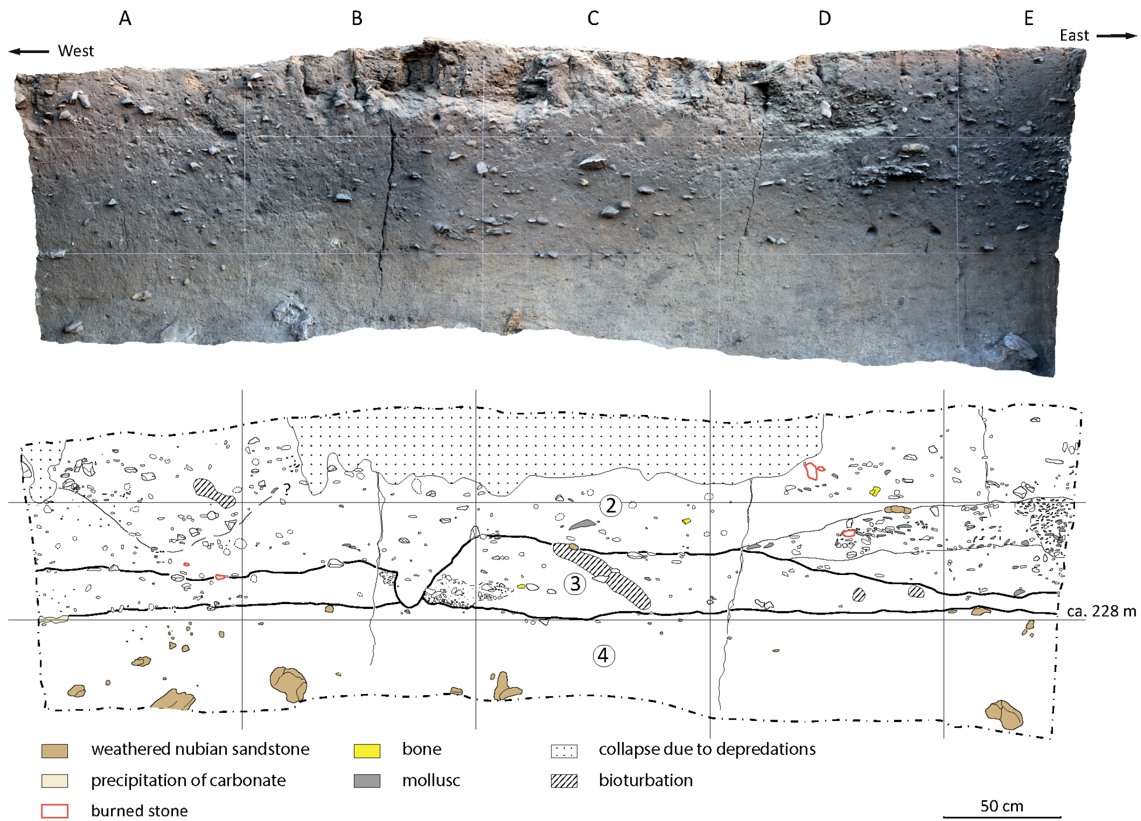


Fig. 4. Photo and drawing of part of the northern stratigraphy of Sector 611W. Sedimentary unit 1 – the surface deposit – is no longer visible. Part of the summit is collapsing due to the depredations of illegal prospectors. In the sedimentary complex 2, which contains the most archaeological remains, several structural boundaries seem to be emerging, including a cluster very rich in shells. In sedimentary unit 3, which is at the interface with the sterile altered substrate (sedimentary unit 4), the bottom of a drainage channel is visible

3.3. Sedimentary Unit 3 – Oldest archaeological remains and interface with the substratum

This sedimentary unit is essentially made up of materials resulting from the surface erosion of the Wadi El-Arab elevation. It has a maximum thickness of 30 cm and is located at the interface of the substrate and the archaeological layers. It is composed of beige-yellow silty sands which gradually turn grey as they approach Sedimentary Unit 2. It has been excavated over small areas, so that the corpus of artefacts collected is limited without any structures having been found. The radiocarbon dates from this complex range between 8300 and 7550 cal BC. An OSL dating was also carried out on a sample from the top of Sedimentary Unit 4 in order to determine when Sedimentary Unit 3 began. The coherent result indicated a development after 9000 BC (10.7 ± 1.5 ka; Honegger and Williams 2015: 149, table 3, sample SUK12253).

3.4. Sedimentary Unit 4 – Altered Bedrock Substrate

The base of the sequence consists of altered Nubian sandstone bedrock. The upper part of this sequence is a relatively soft sandy horizon resulting from the in situ disintegration of the compact sandstone (saprolite). No archaeological remains are present in this sedimentary unit.

Although the structures could be distinguished and treated separately, the homogeneity of the archaeological layers made them difficult to read. For this reason, the excavation was carried out by the removal of thin layers of sediment, 5 to 10 cm thick, following the slope of the excavated sedimentary unit. Up to ten artificial cuts were carried out in a given area. All the sediments were dry-sieved (2 mm grid) so as not to miss microliths, fish vertebrae or other small remains. The material discovered during the excavation or sieving was initially sampled per square metre to enable an analysis of its spatial distribution. Following depredations carried out between 2010 and 2013 in Sectors 610W and 611W – probably by clandestine prospectors looking for gold deposits – the work focused on the individualisation of the structures, to understand the space in situ, and the material sampling system was extended to larger areas, allowing for only a limited analysis of their distribution. A few sediment flotation tests were carried out, but these did not reveal any plant macroremains. A palynological analysis test was also carried out at the Chrono-environment laboratory of the University of Franche-Comté, but no preserved pollen or spores were found.

4. Definition and dating of chrono-stratigraphic phases

The division of the Wadi El-Arab sequence into several phases was elaborated by cross-referencing stratigraphic information and radiocarbon dating. In the absence of clear limits between the layers, we have used the 5-10 cm artificial cuts to split the nearly three millennia sequence into subsets to allow a diachronic analysis. On the basis of radiocarbon dating and without any visible break in the sedimentary sequence, it is not possible to determine the real rhythm of successive occupations of the site (Demoule 1995: 137), which necessarily fluctuated over time with phases of abandonment before being reoccupied. It is therefore necessary to be satisfied with a global definition of chrono-stratigraphic phases, each lasting several centuries.

This definition of chrono-stratigraphic phases is complicated by the numerous plateaus in the calibration curve between the 9th and 6th millennia cal BC. In addition to lengthening the interval of results, these changes in the curve's inflection also paradoxically have a partitioning effect. In many sequences established for this period, the plateau boundary very frequently coincides with phase delimitations. This is because the plateau boundary, determined by a change in the slope of the calibration curve, leads to an abrupt drop in the density curve of the results. This phenomenon is, for example, particularly noticeable for dates No. 32 to 36 (Fig. 5), which all end within a short interval of 20 years, between 7600 and 7580 cal BC, whereas the uncalibrated dates are spread over more than a century. These dates inevitably interfere with the chronological division of a sequence and influence the boundaries of the phases. Consequently, these phases do not reflect historical realities, but rather the limitations of radiocarbon dating (Guilderson *et al.* 2005). This is an important observation to keep in mind.

Forty-five radiocarbon dates were obtained for Wadi El-Arab (Honegger and Williams, 2015: 147-148). The samples dated are mainly fragments of ostrich eggshells (38) and Nile bivalves, Unio sp. (6), present in large numbers in the archaeological layers and structures. Charcoal, rarely preserved, was carefully sought as dating material. Only one sample provided a date, while another unfortunately dissolved during acid/base treatment in the laboratory. Three dating tests were also carried out on bones, but the collagen was not sufficiently preserved, as is often the case in arid environments.

The ^{14}C results from Wadi El-Arab are part of a series of 90 dates obtained by the Swiss Archaeological Mission (Honegger and Williams 2015: 147-148). This important corpus has made it possible to chronologically detail the regional sequence from the Mesolithic to the Kerma period, a period spanning more than 6000 years, between the 9th and 3rd millennia cal BC. This chronological overview, which cross-references the dates obtained from several types of material (charcoal, grass-blades, ostrich egg shells and Nile shells), ensures the consistency of the results established for Wadi El-Arab, where samples of ostrich egg shells and Nile river-shells are almost exclusively used. It is known that these materials can give distorted results. During egg production, the possible absorption of carbonate-containing grit by the ostrich may indeed influence the ^{14}C content of the shell and thus the result of the radiocarbon analysis (Vogel *et al.* 2001). The same is true for river-shells, which can produce earlier dates if old carbonates are present in the watershed of the stream in which they develop. This is known as the hardwater or freshwater effect, a reservoir effect similar to the marine reservoir effect. The regional geological substratum, composed of non-carbonate rocks, seems nevertheless favourable and the comparison of the results on eggshells and river-shells with the large series of dates carried out in the region on various materials ensures their consistency. Adjustments will probably be made in the future, but no bias can be detected at present and the chronological framework established is consistent with that of neighbouring regions.

A first breakdown of the sequence had been proposed by Honegger (Honegger 2014; Honegger and Williams 2015), on the basis of radiocarbon dates and the initial study of cultural material which has led to the identification of four Mesolithic phases at Wadi El-Arab followed by a phase attributed to the Early Neolithic. The reconsideration of these elements coupled with the stratigraphic information obtained within the framework of the doctoral thesis of one of us (B. Jakob), makes it possible to propose a slightly modified chronological breakdown.

4.1. Phase I (8300-7550 cal BC)

The first chrono-stratigraphic phase that emerges includes dates from Sedimentary Unit 3 obtained from artificial cuts 6 and 7 in Sector 95 (2), 5 to 9 in Sectors 165-175 (12) and two dates from the bottom of the stratigraphy of Sectors 610W and 611W. Based on the dates at 2 sigma intervals and rounded to half a century, the start of this phase is established at 8300 cal BC, with its upper limit at 7550 cal BC, between dates No. 30 and 31 (Fig. 5).

The coherence of this long first phase, lasting almost eight centuries, is however challenged by the Bayesian model of all five phases (Fig. 6). This mathematical model, which allows the results of radiocarbon dating to be combined with chronological data from the archaeological or stratigraphic context (Buck *et al.* 1991), was developed in conjunction with the OxCal programme (Bronk Ramsey 2020: v.4.4.2). The proposed model has a satisfactory agreement index (A_{model}=90.2%) and seems representative, with degrees of convergence C never lower than 96.4% (Bronk Ramsey 1995, 2009). It appears, however, that dates No. 45 and 44, the two oldest dates, are problematic with a low agreement index A and even less than 60% for date No. 44 (59.3%). This result does not call the model into question, since it includes more than 20 dates and has a good overall approval rating, but both dates need to be discussed (Bronk Ramsey 2009: 356-357). Located at the end of the 9th millennium cal BC, they are indeed old for Phase I, whose results focus rather on the first centuries of the 8th millen-

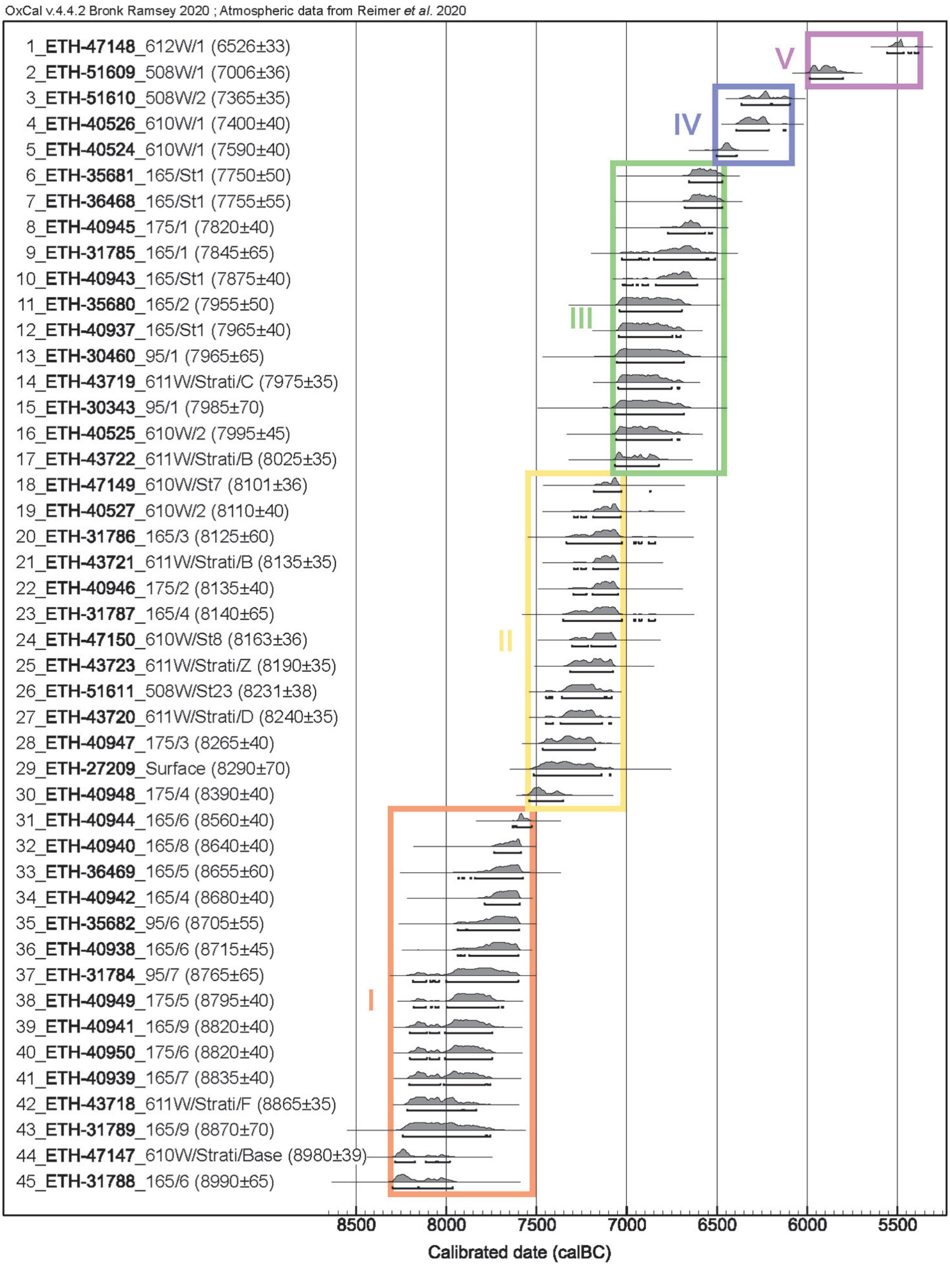


Fig. 5. Visualisation of the 45 radiocarbon dates and the five chrono-stratigraphic phases of Wadi El-Arab

nium. The model certainly points here to a problem of representativeness. It is true that in the field this initial phase from the 9th millennium cal BC was not particularly visible and did not yield enough remains to be clearly distinguished from the later phases.

The presence of a certain number of date inversions within Sedimentary Unit 3 complicates the situation. The oldest date, No. 45, belongs to artificial cut 6, while the most recent date, No. 32, comes from cut 8 (Fig. 5). These inversions correspond to the inevitable mixing caused by desiccation cracks, bioturbations, anthropogenic structures and other sources of disturbance, but they remain confined to Sedimentary Unit 3, as a „package" which stratigraphically has a certain coherence and which we determined corresponded to Phase I. This phase thus keeps a wide chronological range which includes some early elements dating from the 9th millennium cal BC, better described at the neighbouring site of Busharia I (Honegger and Jakob 2022), and mostly more recent elements dating from the first half of the 8th millennium.

4.2. Phase II (7550-7050 cal BC)

The second chrono-stratigraphic phase includes five dates from Sectors 165-175, three dates from the stratigraphy of Sector 611W, the dates from the pit-huts of Sectors 508W and 610W (St 7, 8 and 23), as well as a date from the surface. The beginning of Phase II is not easy to determine. The influence of the plateau boundary, the consideration of an unlocalized surface date, and finally the complexity of the stratigraphy at the interface between sedimentary units II and III, leads us to be prudent in setting the limit around 7550 BC. A more recent date is not excluded, as shown by the range of the Bayesian model between 7600 and 7360 cal BC (2 sigma). The rhythm of the succession of dates makes it easier to determine the end of Phase II (Fig. 5). We set it at 7050 cal BC, based on the Bayesian model which proposes an interval of 7110-6945 cal BC (Fig. 6).

The distinction between Phases II and III is possible thanks to the sequence of Sectors 165-175, which makes it possible to follow the first three phases separately. In Sectors 408-612W, Phases II and III form an indistinguishable whole, the dates from which cover a long time span between 7450-6700 cal BC. Two date inversions from Sector 611W have been noted, which interfere with the separation into two phases. These inversions most likely result from the numerous structures present in this sedimentary unit, all of which may not have been clearly identified in this sector, but which include Structures 7, 8 and 23 which, together with Structure 5, correspond to the remains of an alignment of four contemporary pit-huts (Fig. 3). Phases II and III are the richest in archaeological remains and show the best state of preservation.

Name	Modelled (BC/AD)				Indices A_{model}=90.2 $A_{overall}$=89.4	
	from	to	%	median	A	C
Boundary end phase V	-5610	-4725	95.4	-5375		98
1_ETH-47148_612W/1	-5615	-5385	95.4	-5505	96	99.8
2_ETH-51609_508W/1	-5985	-5785	95.4	-5890	97.8	99.7
Phase V						
Interval phase IV/phase V	0	430	95.4	210		99.8
Boundary phase IV/phase V	-6330	-5880	95.4	-6105		99.7
3_ETH-51610_508W/2	-6375	-6090	95.4	-6240	94.8	99.8
4_ETH-40526_610W/1	-6400	-6095	95.4	-6310	103.5	99.8
5_ETH-40524_610W/1	-6500	-6385	95.4	-6440	100.9	99.8
Phase IV						
Interval phase III/phase IV	0	185	95.4	90		99.8
Boundary phase III/phase IV	-6630	-6435	95.4	-6530		99.8
6_ETH-35681_165/St1	-6690	-6495	95.4	-6600	100.7	99.8
7_ETH-36468_165/St1	-6695	-6485	95.4	-6605	101.2	99.7
8_ETH-40945_175/1	-6815	-6530	95.4	-6650	102.5	99.7
9 ETH-31785 165/1	-7030	-6540	95.4	-6705	104	99.7
10 ETH-40943 165/St1	-7025	-6600	95.4	-6730	100.9	99.7
11 ETH-35680 165/2	-7035	-6690	95.4	-6855	100.1	99.8
12 ETH-40937 165/St1	-7040	-6695	95.4	-6875	99.6	99.8
13 ETH-30460 95/1	-7040	-6655	95.4	-6860	101.1	99.6
14 ETH-43719 611W/Strati/C	-7040	-6695	95.4	-6890	99.3	99.8
15 ETH-30343 95/1	-7050	-6685	95.4	-6870	102.1	99.7
16 ETH-40525 610W/2	-7045	-6700	95.4	-6895	99.9	99.7
17 ETH-43722 611W/Strati/B	-7060	-6775	95.4	-6920	97	99.7
Phase III						
Interval phase II/phase III	0	110	95.4	30		100
Boundary phase II/phase III	-7110	-6945	95.4	-7040		99.9
18 ETH-47149 610W/St7	-7185	-7035	95.4	-7110	99.2	99.8
19 ETH-40527 610W/2	-7310	-7040	95.4	-7115	101	99.8
20 ETH-31786 165/3	-7325	-7040	95.4	-7135	107.8	99.8
21 ETH-43721 611W/Strati/B	-7315	-7050	95.4	-7125	99.6	99.7
22 ETH-40946 175/2	-7315	-7045	95.4	-7130	100.1	99.8
23 ETH-31787 165/4	-7330	-7045	95.4	-7155	106.3	99.7
24 ETH-47150 610W/St8	-7320	-7060	95.4	-7150	100.2	99.8
25 ETH-43723 611W/Strati/Z	-7330	-7070	95.4	-7180	99.9	99.7
26 ETH-51611 508W/St23	-7450	-7075	95.4	-7245	100.9	99.7
27 ETH-43720 611W/Strati/D	-7455	-7080	95.4	-7255	101.1	99.7
28 ETH-40947 175/3	-7465	-7085	95.4	-7290	100.9	99.7
29 ETH-27209 Surface	-7495	-7080	95.4	-7320	100.7	99.7
30 ETH-40948 175/4	-7535	-7330	95.4	-7405	86.5	99.7
Phase II						
Interval phase I/phase II	0	160	95.4	45		99.9
Boundary phase I/phase II	-7600	-7360	95.4	-7505		99.8
31 ETH-40944 165/6	-7710	-7525	95.4	-7585	100.7	99.7
32 ETH-40940 165/8	-7745	-7585	95.4	-7650	99	99.7
33 ETH-36469 165/5	-7940	-7580	95.4	-7675	100.3	99.6
34 ETH-40942 165/4	-7805	-7590	95.4	-7675	99.8	99.7
35 ETH-35682 95/6	-7945	-7590	95.4	-7715	100.5	99.6
36 ETH-40938 165/6	-7945	-7595	95.4	-7715	100.2	99.6
37 ETH-31784 95/7	-8160	-7595	95.4	-7815	103.4	99.6
38 ETH-40949 175/5	-8165	-7655	95.4	-7860	103.3	99.6
39 ETH-40941 165/9	-8175	-7735	95.4	-7895	103.1	99.6
40 ETH-40950 175/6	-8175	-7735	95.4	-7895	103.1	99.6
41 ETH-40939 165/7	-8180	-7745	95.4	-7935	100.1	99.5
42_ETH-43718_611W/Strati/F	-8205	-7820	95.4	-8000	95.9	99.7
43_ETH-31789_165/9	-8215	-7735	95.4	-7975	97	99.6
44_ETH-47147_610W/Strati/Base	-8270	-7955	95.4	-8035	59.3	99.3
	Warning! Poor agreement - A= 59.3%					
45_ETH-31788_165/6	-8280	-7855	95.4	-8035	72.1	99.4
Phase I						
Boundary start phase I	-8345	-7985	95.4	-8150		96.4
Sequence Wadi El-Arab						

Fig. 6. Bayesian analysis of the 45 radiocarbon dates of Wadi El-Arab organised in five phases

4.3. Phase III (7050-6500 cal BC)

The third chrono-stratigraphic phase includes two dates from Sector 95, three from Sectors 165-175, one from Sector 610W, two from the top of the stratigraphy of Sector 611W and finally the four dates from Structure 1, also interpreted as the base of a pit-hut. Date No. 11 (Fig. 5), which comes from Sector 165, also belongs to this third phase. The boundary with Phase IV can be located around 6500 cal BC. Two dates from Structure 1 (dates No. 6 and 7) push this limit to 6450 cal BC, but are a little more recent compared to the other results from the structure and the sector (dates No. 8 to 12) and were not considered to be representative.

4.4. Phase IV (6500-6000 cal BC)

The only three dates for Phase IV are from the Sectors 408W-612W. They are from Sectors 508W and 610W. Including the two dates from the next phase (Phase V) the last millennium of the sequence has only five dates (Fig. 5). This represents a significant deficit, resulting from the effects of surface erosion and the poor state of preservation of these assemblages. The dates for Phase IV only partially overlap. They cover the interval 6500-6100 cal BC, after which there is a hiatus of one century before Phase V. On the basis of the radiocarbon dates, which are too incomplete, it is impossible to define what this hiatus represents. The site has certainly been occupied many times and abandonments must have occurred over three millennia, but the limited data from Phases IV and V do not make it possible to determine whether there was any period of site-abandonment. Moreover, on a regional scale, no chronological gaps have been detected for this period (Honegger and Williams 2015). The calculation of the interval between Phases IV and V, based on the Bayesian model (Fig. 6), also indicates that an overlap between the two phases is statistically possible (between 0 to 430 years at 2 sigma). This reinforces the idea that this hiatus is not significant. For this reason, it is not retained in the periodisation of the sequence. The problem that arises is therefore to establish the date for the transition between Phases IV and V: ca. 6100 cal BC, at the limit of the dates for Phase IV, or ca. 6000 cal BC? Based on the discoveries made at the neighbouring site of El-Barga, the beginning of the regional Neolithic can reasonably be set at around 6000 cal BC (Honegger and Williams 2015). Establishing a start-date for Phase V earlier than 6000 cal BC, would suggest an earlier beginning for the Neolithic, with no data at present to support this. For this reason, we have established the boundary between Phases IV and V at 6000 cal BC, based on date No. 2 (Fig. 5).

4.5. Phase V (6000-5400 cal BC)

Phase V, which is evidenced in the eroded layers at the top of the sequence, has produced only two dates (Fig. 5) which are more than three centuries apart. These have been grouped together in a single phase covering the period 6000-5400 cal BC, which is consistent with the range covered by the Early Neolithic dates from El-Barga (Honegger and Williams 2015: 147), and the hiatus between the two dates cannot be considered real, since the data available for this phase is limited.

5. Evolution of certain cultural markers and validation of the periodisation

The detailed analysis of the Wadi El-Arab sequence made it possible, by extrapolation, to attribute each set of remains, whether from the excavations or structures, to one of the five chrono-stratigraphic phases (Fig. 7). This attribution makes it possible to follow the evolution of the cultural components during three millennia, as well as any possible ruptures. By the length of its sequence, but also by the abundance of artefacts it delivers, Wadi El-Arab becomes a reference site for Upper Nubia and one of the main cultural sequences of the Nile Valley for the Early Holocene, allowing comparisons with sequences from the Western Desert (Wendorf and Schild 2001) and Central Sudan (cf. Usai 2016).

Here we will briefly present the evolution of pottery decorations and the main types of flint tools, which are among the most common attributes used to define cultural entities. The analysis is based on a quantitative approach, which makes it possible to express the frequency of each type by phase, combined with a seriation done using an open access application called "sériographe" (Desachy 2004). Other more technical aspects of the artefacts which also evolve over time, such as the fabric of pottery or flint knapping techniques, will not be discussed here. The coherence of the evolutions thus described should be an additional guarantee of the reliability of the stratigraphic and chronological sequence.

The pottery evolved in several "Sudanese" styles of Impressed Ware. It shows clear affinities especially with the Nubian sequences and those from the Nabta Playa region (Gatto 2002). The classification of the decorations (Fig. 8) has been based on the method used by Gatto (Gatto 2002, 2013), which is itself based on the system of Caneva (Caneva 1988; Caneva and Marks 1990). The impressed patterns represent the vast majority of the decorations that cover the entire surface of the pot's belly. The evolution of all decorations has already been the subject of preliminary comparisons (Gatto 2013; Honegger 2014) and a future publication will give a more detailed account of all the characteristics and similarities with other sites and other regions.

The earliest decorative styles are produced using the alternative pivoting stamp technique (A12, A13, A14, A2 see Fig. 9). The most ancient pattern (A12) is obtained by the return technique. Its presence at the beginning of the seriation is coherent, because this type of decoration is the most numerous in the nearby site of Busharia I where the oldest phase is dated between 8300 and 8000 BC (Honegger and Jakob, 2022). It is probably the first cultural phase of the regional Mesolithic, which is too discreetly represented in Wadi El-Arab to be isolated there.

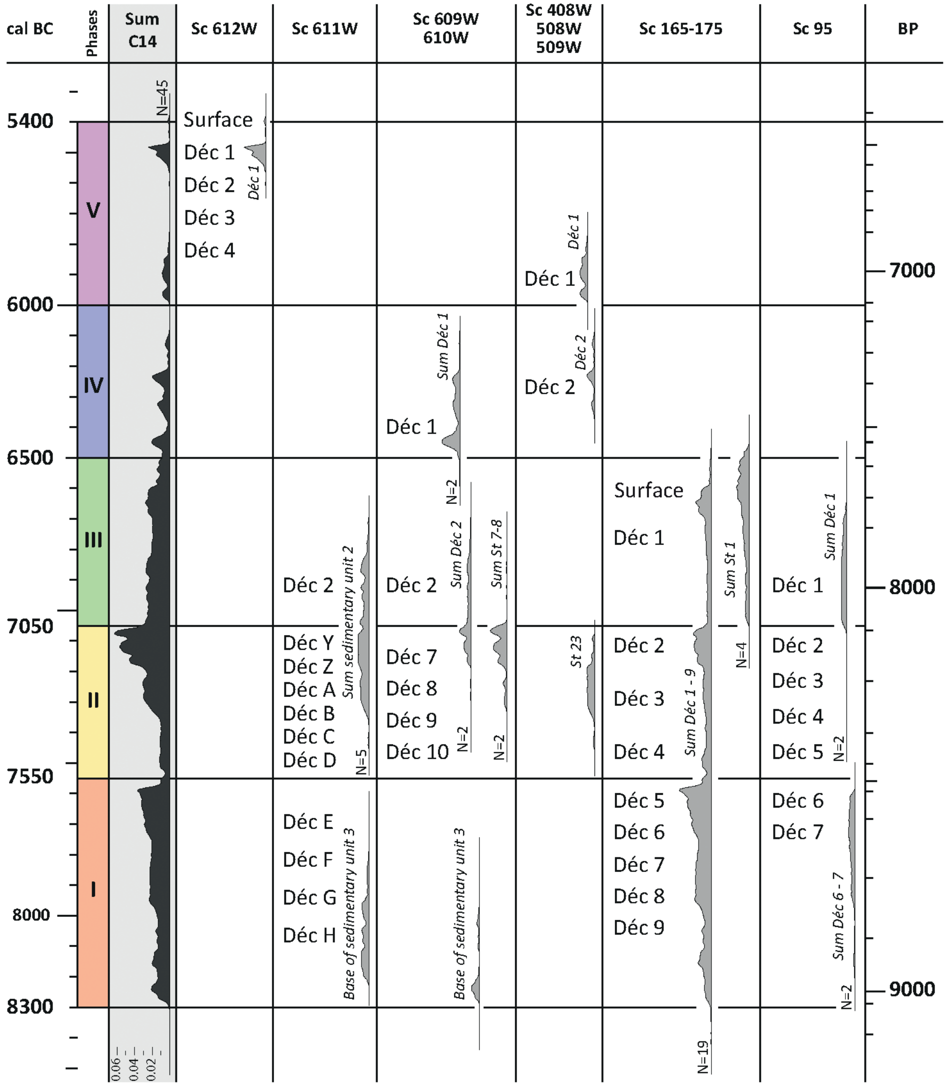


Fig. 7. Summary table of the excavated sectors cross-referenced to the density curves of radiocarbon dates, *décapages* (artificial cuts) and occupation chrono-stratigraphic phases of the Wadi El-Arab site

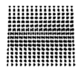
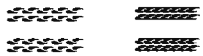
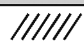
Type	Description	Pattern
Rocker Stamp Technique (R)		
R1	Continuous Packed Dotted Zigzag, Various Pattern	
R2	Zonal Dotted Wavy Line a-b: Dots or Dashes c: Arch-shaped Pattern	
R3 R4 R9	Continuous Spaced Dotted Zigzag Continuous Packed Dashed Zigzag Continuous Spaced Plain Zigzag	
Alternating Pivoting Stamp Technique (A)		
A1	Hering-bone Pattern a: Standard b: Packed c: Horizontal Hering-bone	
A2	Double Grained-shaped Dotted Lines a: Horizontal band b: Zoned-Banded c: Vertical Band	
A3	Packed Double Grained-shaped Dotted Lines a: Horizontal band b: Arch-shaped Band	
A10	Return Technique, Triangle-shaped Pattern	
A12	Return Technique, Double Rounded Dots, Horizontal Lines	
A13 A14	Double Dragged Grains, Zoned-Banded Double Dragged Lines, Zoned-Banded	
Simple Incision (I)		
I1	Simple Incision	
I2	Incised Wavy Line	
Burnished surface (B)		
B1	Coarse (sometimes with tool marks)	
B2	Fine and Regular	

Fig. 8. Schematic classification system of the pottery decorations. After Gatto 2002; 2013, modified

Common in the Central Sahara during the local Middle Pastoral phase (mainly the 5th millennium BC, Caneva 1987), the return technique is a unique feature in a context with such and old date along the Nile valley, but is known in small proportions at later periods (Gatto 2013). The three following types corresponds to patterns with double impressions describing grains or lines, dragged or not (A13, A14, A2). It can be considered as a typical regional characteristic, which finds some parallel in the Nubian Desert or in the Khartoum Variant. These three decorations are largely dominant in Phase I, which is also the case of the filling of the El-Barga pit-hut dated by six ^{14}C analyses around 7500-7300 BC (Honegger 2004, Honegger and Williams 2015). As this pit-hut represents a closed context, it is tempting to extend Phase I until around 7300 BC, instead of stopping it at 7550 BC. More detailed analyses will help to clarify this point, which concerns a complex stratigraphic transition where there is still room for interpretation of the data. However, this will not have much influence on the general typological profile of the sequence of Wadi El-Arab.

The famous dotted wavy line (R2) and the herring-bone pattern (A1) begin during the intermediary phases and finds some parallels with the El-Nabta Phase of the Western Desert and also with the Khartoum Variant (Gatto 2002, 2006). The rocker stamp technique (R) is the most prevalent starting in phase III and becomes dominant in phase IV, where the R1 is the most numerous. A similar evolution takes place in the Western Desert with the contemporary Al-Jerar Phase, which is characterised exclusively by the motif R1. At the end of the sequence, particularly fine patterns (I1, I2, R9) appear, some of them evoking known decorations on Nubian Middle Neolithic pottery (5th millennium BC). Some rare incised wavy line decorations (I2), could be the consequence of late influences from Central Sudan, where this type is common during the Mesolithic. Regular burnished surfaces without decoration (B2) developed at the same time. This type, common in the Middle Neolithic, probably resulted from initial contacts with Egypt, where this new style of pottery appeared at the end of the 7th millennium BC, to progressively supplant the regional traditions (Riemer *et al.* 2013).

The evolution of the pottery decorations in the Wadi El-Arab sequence is broadly consistent and in accordance with the main known trends at other Nubian sites. It is even more complete than what is known elsewhere, particularly due to the presence of its first two phases, rich in artefacts, which also benefit from the comparison with the nearby sites of Busharia I and El-Barga. The sequence between the end of the 7th millennium and the beginning of the 6th millennium BC, which corresponds to the arrival of the first Neolithic components, is also unique on the scale of the Nile valley. A dilution effect can however be perceived in the sequence, with a dispersion of types throughout the sequence, which is reminiscent of the taphonomic problems of the site. On this topic, the representation in

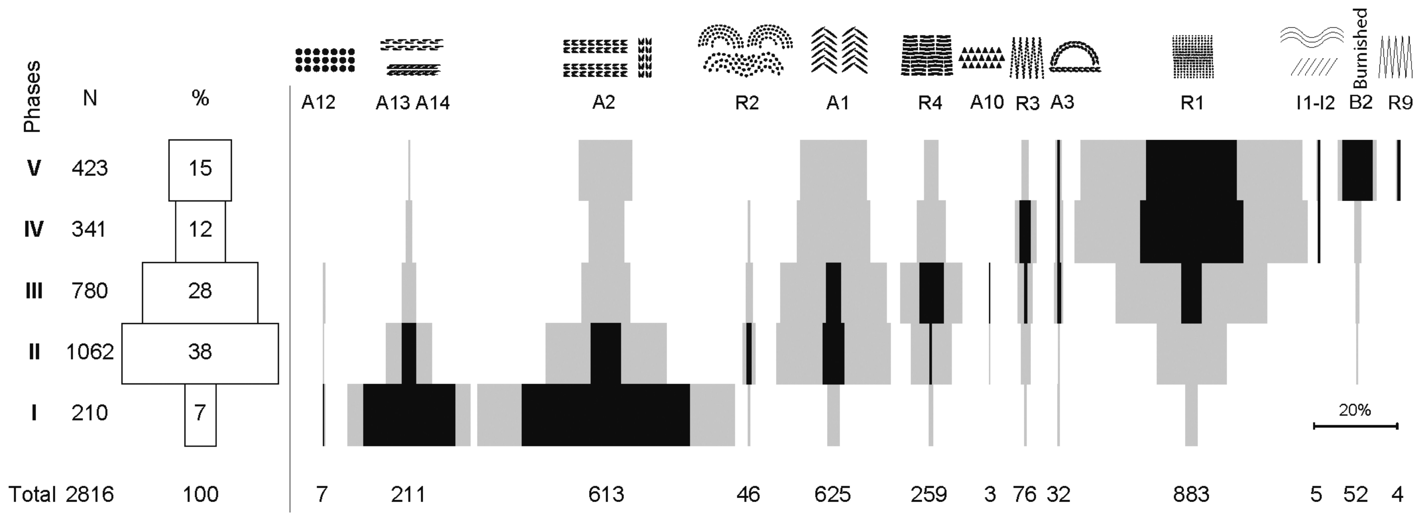


Fig. 9. Seriation of the pottery decorations by chrono-stratigraphic phase (proportion of sherds), with automatic sorting of the columns (analysis made with the open access application of Desachy 2004). Undecorated and undetermined sherds are not retained.
The percentage types of each set are shown in grey; the positive deviations from the mean percentage (EPPM) are shown in black

black on the evolutionary diagram (Fig. 9) of the positive deviations from the mean percentage (EPPM) attenuates the dispersion effect and gives a better idea of the main evolutionary trends.

The effects of dispersion are also perceptible in the seriation of lithic tools. The result remains consistent, but is less contrasted than for the pottery (Fig. 10). The presence of geometric microliths (lunates, triangles and trapezes), borers, pieces with abrupt and regular retouch as well as irregular retouch, are almost constants. It is interesting to note that burins were only found in the earlier phases and that the large lunates and backed points first appear in intermediary phases. The most important rupture is marked by the use of a new technique in Phase IV with the appearance of points made by invasive bifacial retouch. In fact, traditionally, Nubian lithic industries produce microliths and pieces with abrupt retouch. The appearance of these bifacial pieces in the mid-7th millennium cal BC is indicative once again of contacts with Egypt, where this type of point is diffused at the same time (Riemer, Lange and Kindermann 2013). In parallel to these points, a few items made of polished stone also make a discreet appearance at the top of the sequence. These few objects echo the numerous polished stone axe-heads and body ornaments discovered in the necropolis of the nearby Neolithic site of El-Barga (Honegger 2004). The origin of the technique of polished stone in Northeast Africa is not clear. Even if it appears to arrive with the Neolithic in Nubia – especially in the case of axe-heads – other polished artefacts could have older influences originating from the Central Sahara, in Niger for example, where Roset appears to have found a very early production of polished stone objects at the site of Tagalagal (Roset 1983).

6. Conclusion

Despite a difficult stratigraphic reading and the partly eroded archaeological layers, excavation and detailed analysis of the Wadi El-Arab sequence has made it possible to distinguish five chrono-stratigraphic phases. These are not phases of occupation but an artificial division which makes it possible to organise the archaeological remains into groups and to follow their evolution over time. A preliminary study of the artefacts confirms that a meticulous approach, with excavation methods adapted to the terrain and an analysis of the site's formation processes, makes it possible to produce coherent results despite the taphonomic problems inherent in the arid context. Of course, the interpretation of these results must take into account many factors, particularly the effects of dispersion of the material, but this example shows that it is possible to reconstruct reliable chronological sequences from sites with poor sedimentary distinctions. It is however important to have a stratigraphic sequence with sufficiently thick archaeological levels, the further analysis depending on a cross-referenced approach

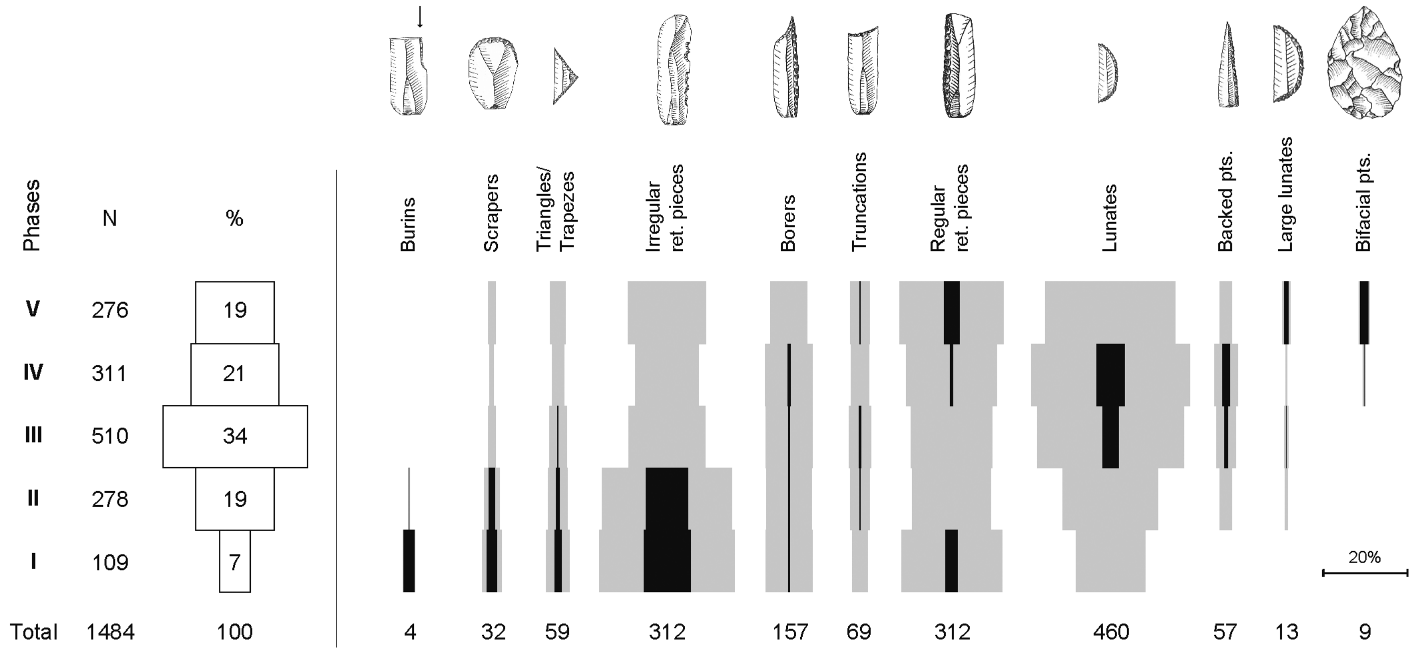


Fig. 10. Seriation of the lithic tools by chrono-stratigraphic phase, with automatic sorting of the columns (analysis made with the open access application of Desachy 2004). The percentage types of each set are shown in grey; the positive deviations from the mean percentage (EPPM) are shown in black. Schematic illustrations of the types from Tixier 1963

between sedimentary readings, excavated levels, radiocarbon dates and artefact series. Typological data from other nearby sites such as Boucharia I and El-Barga will be precious in clarifying certain points presented here, and have only been partially integrated at this stage. A closed complex such as that of the El-Barga hut will always be more valuable in terms of the typological homogeneity of the material it yields, than occupation layers belonging to a stratigraphy.

While old excavations may have shown some weaknesses in the chrono-stratigraphic reconstruction, this is not surprising considering the evolution of excavation and dating techniques. The reliability of the archaeological sequences should not, however, be interpreted by placing too much emphasis on the presence or absence of sedimentary contrasts (cf. Usai 2014), particularly since these remain weak for the most part in Sudan, although a careful reading still allows certain distinctions to be made.

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