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1 **9000 years of human lakeside adaptation in the Ethiopian Afar: fisher-foragers and the**  
2 **first pastoralists in the Lake Abhe basin during the African Humid Period**

3

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40

41

**Abstract:**

42 **Abstract:**  
43 In this study, new approaches are developed for measuring and understanding the reactivity of  
44 East African amplifier lakes and the societies that occupied their margins to African monsoon  
45 related hydrological changes. Drawing on seven newly discovered archaeological sites in the  
46 Lower Awash valley, corresponding to the northern Abhe Lake basin, we present the first  
47 Holocene human occupation sequence in the Ethiopian Afar. We reconstitute fluctuating Abhe  
48 Lake levels in association with human settlement strategies through correlation of new  
49 archaeological and geomorphological data and 37 new radiocarbon dates. The sites cluster into  
50 three periods of human occupation of the lake margins separated by intervals that lack  
51 archaeological data. These occupation phases span two major humid-arid transitions of the  
52 African Humid Period (AHP) (including the Younger Dryas (YD, ~12.9-11.7 ka), 8.2 ka, and 4.2  
53 ka arid events) during which Abhe Lake levels varied significantly, and the transition from Later  
54 Stone Age (LSA) hunter-gatherers to mixed herding-hunter-gatherer economies. Over a 9000  
55 year period we observe continuity and ruptures in subsistence strategies and material culture  
56 techno-complexes and correlate these with sedimentary formation processes and changing paleo-  
57 shorelines. Our study reveals that flexible multiple resource economies were a human response  
58 to strongly fluctuating environments, even with the onset of herding and associated pottery  
59 traditions unique to the Abhe Lake basin, sometime between 4.8 and 3.3 ka cal. BP .

60

61 Thorough evaluation of littoral morpho-sedimentary data, well-dated human settlements and  
62 associated economic strategies suggests that major cultural and socio-economic changes of  
63 populations inhabiting Abhe paleolakeshores were distinctive ecological responses to  
64 transformations in the local environment and to fluctuating lake levels.

65

66 **Keywords:** *Africa; Holocene; Climate dynamics; Geomorphology, coastal; Ethiopian Afar;*

67 *African Humid Period; Paleolandscape evolution; Lake Abhe; Later Stone Age; Herding*

68



## 69 **1 - Introduction**

70 The East African Rift region is renowned for vast exposed sedimentary formations hosting an  
71 exceptional hominin record. As a result it has attracted research programs focused on the  
72 recovery of our very ancient past at the expense of more recent prehistoric periods. During the  
73 Early to early Late Holocene (11.7-3 ka), global climate changes hosted different transitions  
74 from hunter-gathering to food production across the world that changed the course of humanity,  
75 and yet this period remains largely uninvestigated in the region. Previous studies have tended to  
76 suggest correlations between hydroclimatic change and the spread of agro-pastoralism from a  
77 center outward to explain these transitions (Ashley et al. 2011; Kuper & Kropelin 2006), rarely  
78 taking their inter- and intra-regional arhythmicity or local paleoecological considerations into  
79 account. Poor chrono-cultural, hydroclimatological and paleoecological resolution at the inter-  
80 regional scale are major obstacles to advancing our understanding of the complexity of the  
81 human trajectory – one that is marked by junctures during the Holocene when hundreds of  
82 thousands of years of hunting-gathering were replaced by domestication at different rhythms and  
83 in different ways (Lesur et al. 2014). This is certainly the case in the Horn of Africa, a region  
84 shaped by a mixture of its tropical latitude and the morpho-tectonic patterns of the East African  
85 Rift System into a complex mosaic of steep topography, variable soils, rainfall and vegetation  
86 patterns, and the resulting complex hydrography and sedimentation that characterize it. It is  
87 within this context that we find extremely varied tempos and types of transition to food  
88 production that have likely more to do with local paleoecology than with climate, human  
89 migration or cultural influence per se (Chritz et al. 2019).

90

91 In Ethiopia more specifically, the few Early to Late Holocene archaeological sites recovered  
92 have little in common and are chronologically and spatially dispersed, providing us with  
93 insufficient correlations with which to reconstruct a concrete regional Holocene sequence (Fig.  
94 1.a). Interestingly some of the most comprehensive dated human occupation sequences spanning  
95 the Holocene can be found on paleomargins of large lake basins in the Main Ethiopian Rift  
96 (MER), namely Lakes Ziway-Shala and Abhe (Bon et al. 2013; Brandt 1980; Gutherz et al.  
97 2017; Ménard & Bon 2015; Fig. 1.a). The exceptional sensitivity of water level fluctuations in  
98 rift environment lakes such as these to even moderate climate variation was recorded by Street  
99 (1980) and Street-Perrott and Harrison (1985) who coined the term *amplifier lakes* to distinguish  
100 them from lakes with less variable surface to volume ratios.

101

102 It has been hypothesized that these amplifier lakes may have had a principal role in human  
103 evolutionary trajectories in the East African Rift System (EARS) due to their amplified response  
104 to climatic variation (Maslin et al. 2014). This is explained by the geometry and topography of  
105 the EARS and the contrast between high rainfall in catchment zones and high evaporation rates  
106 in their associated lowland lake basins. Periods of extreme transgression and regression  
107 occurring in these lakes are suggested to have isolated populations and deferred migration along  
108 or across this natural corridor, while periods of stable lake levels encouraged dispersal and  
109 mixing (Maslin et al. 2014; Trauth et al. 2010). It has also been argued that without analysis of  
110 sequence stratigraphy of lacustrine deposits, climate variability can be overstated and its nuances  
111 overlooked (Nutz et al. 2017).

112

113 We often look to climate proxies to understand changes in human behavior, but are less likely to  
114 do the inverse. Moreover, studies rarely attempt to gauge the time lag between hydroclimatic  
115 change in catchment areas and its local effects (including tipping points) on watersheds making  
116 such hypotheses difficult to test. This study aims to demonstrate that correlation of morpho-  
117 sedimentary data, well-dated human settlements and associated economic strategies can function  
118 as an effective multi-proxy for understanding these important subtleties in local paleoecological  
119 transformations. This approach can lead to more accurate reconstructions of human and  
120 environmental responses to the nuances of climate change. The exceptional sensitivity of  
121 amplifier lakes can reflect nuances in climate variability and human adaptation to such  
122 fluctuating environments can better explain changes in human behavior than large scale climate-  
123 driven population diffusion models.

124

125 Major Late Quaternary transgressions and regressions of Lake Abhe, an amplifier lake located at  
126 the tripartite junction of the Nubian, Arabian and Somali tectonic plates in the Central Afar  
127 depression, were reconstituted and interpreted by F. Gasse in the 1970s (1977), mainly through  
128 study of diatoms. However, the low resolution of the resulting lake-level model has provided a  
129 lacunar framework for understanding the evolution of Abhe lake-level fluctuations (Fig. 1.c).  
130 Until archaeological work was conducted in the linked Gobaad basin in the Republic of Djibouti  
131 in the 1980s-90s (Gutherz et al. 1996; Joussaume 1995), no human occupation sequences were  
132 recovered in the context of this research. While archaeological work in Djibouti is ongoing and  
133 has provided a large corpus of mainly Middle Holocene sites (Gutherz et al. 2015, 2017), the  
134 Lower Awash River valley and the majority of the Abhe Lake basin can be found in Ethiopia,  
135 where archaeological work had been lacking prior to this study. Well-developed sedimentary

136 sequences across this basin present an ideal context for the preservation of stratified Holocene  
137 sites that cover the period of economic transition from fishing-hunter-gatherers to the first  
138 herders. This makes it an exemplary watershed in which to begin to correlate human occupation  
139 sequences with Abhe lake-level fluctuations that occurred from the Early to Late Holocene  
140 humid to dry transition (corresponding to the AHP). In this study, new approaches are developed  
141 for measuring and understanding the reactivity of amplifier lakes and the societies that occupied  
142 their margins to African monsoon related hydrological changes.

143

144 Archaeological work conducted since 2014 in the Lower Awash River valley and northern Abhe  
145 Lake basin in the Ethiopian Afar (Fig. 1.a, b) has brought to light 9000 years of well-preserved  
146 prehistoric human occupation sequences. These have allowed us to construct a local chronology  
147 and to begin exploring human, landscape and environmental responses to a fluctuating amplifier  
148 lake in one of the most arid parts of the world.

149

150 Of 40 sites documented in the area (Fig. 1.b), 34 have major prehistoric components that range in  
151 period from the Late Pleistocene to the advent of herding in the Middle Holocene. 37  
152 radiocarbon dates from 7 excavated/sounded sites and associated sedimentary records provide  
153 the most robust chronological sequence to date for late prehistoric occupation in Ethiopia, and  
154 are the first major evidence for semi-continuous LSA to *Neolithic* occupation in the Ethiopian  
155 Afar.

156

## 157 **2 – Regional setting**

### 158 **2.1 – Geological and tectonic control of Abhe Lake basin formation**

159 The Abhe Lake Basin is located along the axis of the Tendaho-Gobaad graben (NE-SW),  
160 corresponding to a subsided floor of basalts from the stratoid series (4.4-2.5 Ma; Varet 1978,  
161 2018) covered by a thick sedimentary series between numerous faults associated with  
162 extensional tectonics (Barberi & Varet 1977; Manighetti et al. 1998, 2001). Plio-Pleistocene  
163 basaltic fissure flows and alkaline rhyolitic flows from axial ranges partially cover the stratoid  
164 series. This igneous palimpsest represents the base bedrock for the Late Pleistocene to Holocene  
165 sedimentary fillings concerning this study. The lacustrine sedimentary sequence accumulation  
166 began during the Early Pleistocene (Gasse 1990), while the sedimentary synthem of the Abhe  
167 basin developed within a topography similar to that of today starting around 130 ka. The greater  
168 part of the sedimentary accumulation seems concentrated in the eastern sector of the Lower  
169 Awash plain and rests on the Gamari and Afambo faults which were probably tectonically active  
170 until the Middle Holocene (Gasse 1975; Fig. 1.b). The Lower Awash Plain is tectonically tilted  
171 toward the eastern graben faults with a 30 m vertical offset over a length of 30 km (Acoccella et  
172 al. 2008). This tectonic activity, coupled with volcanic phenomena localized to the north of the  
173 rhyolitic Borawli Mountain, probably caused the deviation of the Awash River and the  
174 formations of Gamari and Afambo fault pits (Fig. 1.b; Gasse 1975). The final hydrological  
175 tracing of the Awash River (and associated residual lakes) is the consequence of Holocene  
176 tectonic movements and response to magmatic intrusions below the basin axis (Gasse 1975). A  
177 similar phenomenon (6 ka) was also detected almost 80 km away from the Lower Awash valley,  
178 at the Asal Lake (Afar, Djibouti), with a 70 m tectonic subsidence of the axial valley (Abdallah  
179 et al. 1979; Ruegg & Briole 1990). The genesis and evolution of the Abhe Lake basin system is  
180 thus the result of ancient (Early Pliocene) to recent (Holocene) volcano-tectonic activity, which,

181 coupled with climatic control triggered the current morpho-sedimentary and geomorphological  
182 patterns.

183

## 184 **2.2 - Hydro-climatological control of Abhe Lake basin formation**

185 The increase in magnitude of precession-driven insolation in the Northern Hemisphere between  
186 14.8 and 5.5 ka appears to be at the origin of the northward migration of the rainfall belt  
187 associated with the Inter Tropical Convergence Zone (ITCZ) (Collins et al. 2017; deMenocal et  
188 al. 2000; Gasse 2000; Kutzbach & Street-Perrott 1985; Mohtadi et al. 2016; Skonieczny et al.  
189 2019). These changes in convergence zone patterns led to enhanced precipitation in the tropics  
190 which expanded symmetrically in both hemispheres (Costa et al. 2014; Tierney & deMenocal  
191 2013; Tierney & Pausata 2017). This can be correlated to a northward spread of vegetation cover  
192 (Hopcroft et al. 2017), and to the massive extension of African lakes (Gasse 2000; Junginger et  
193 al. 2014) such as Lake Abhe. This continental African Late Pleistocene to Holocene pluvial  
194 period is known as the 'African Humid Period' (AHP; Shanahan et al. 2015).

195

196 Three main lacustrine sedimentary sequences covering the period between 130 and 3 ka and  
197 corresponding to the Late Quaternary ITCZ oscillations, were first distinguished in the Lake  
198 Abhe basin by Gasse (1977): ~100-70 ka (Abhe I), 60-18 ka (Abhe II - Abhe III), and 10-4 ka  
199 (Abhe IV - Abhe V; Fig. 1.c). During the Holocene, Abhe Lake, currently reduced to a small  
200 (~350 km<sup>2</sup>) and shallow (<30 m depth) waterbody was part of a large freshwater filling which  
201 generated the last highstand phases in response to the AHP hydrological regime: Abhe IV (10-8  
202 ka; Fig. 1.c), Abhe V (7.5- 4.5 ka) and Abhe VI and VII (0-2.5 ka). Its maximum water surface  
203 extent at the height of the AHP was estimated by Gasse (1975, 1977) to be around 6000 km<sup>2</sup>.

204  
205 The Central Afar region receives allochthonous freshwater supplies generated by African  
206 monsoon precipitation in the Ethiopian Highlands during the rainy season from June to  
207 September (200 mm/month; Tsidu 2012). Thus, the African monsoon is responsible for the  
208 majority of solid discharge material transported by the Awash River and which constitutes the  
209 Late Pleistocene-Holocene sedimentary synthem of the Abhe lake basin. In particular, the Abhe  
210 Lake system receives its water catchment from the Awash River (Fig. 1a), which is joined by  
211 many affluent rivers as it descends the Ethiopian Highlands, until it meets the Lower Awash  
212 Plain (4000 km<sup>2</sup>) where it continues without freshwater supply until it reaches its final  
213 destination, endorheic Lake Abhe (Fig. 1.b; 230 m a.s.l.).

214  
215 Our study area coincides with this last and arid part of the Awash River course, characterized by  
216 200 mm/yr precipitation, with an evaporation rate of 3500 mm/yr (Rognon & Gasse 1973; Gasse  
217 1990; Varet 2018). This plain, including Tendaho (400 m a.s.l.), Gamari and Afambo Lakes  
218 (339 m a.s.l.) is limited by the Gamari escarpment to the east (1300 m a.s.l.) and Magenta  
219 escarpment to the west (400 m a.s.l.; Fig. 1.b).

220  
221 The dynamics of regression and transgression of the Abhe Holocene lakes played a substantial  
222 role in paleolandscape evolution, on soil development and on paleo-ecological patterns of the  
223 basin surroundings, likely influencing peopling dynamics. In the 1970s, geomorphological  
224 research in the Central Afar region was focused on deep (offshore or distal) lacustrine deposits  
225 (Faure et al. 1976; Gasse 1975, 1977; Rognon & Gasse 1973) with an almost absent regard for a

226 wide range of peri-lacustrine depositional environments and processes (e.g. gilbert-deltas,  
227 pedological horizons, gravity-induced deposits and fluvial or fluvio-lacustrine deposits).

228

229 Since 2014, our current work on Late Quaternary sedimentary systems of the Abhe Lake  
230 paleobasin is focused on pedo-stratigraphical and geochronological investigation of new  
231 archaeological sequences linked to past transgression-regression lake dynamics. This approach  
232 aims to correlate sedimentary formation processes of human occupation layers with  
233 paleolandscape evolution to arrive at a more holistic understanding of the relationship between  
234 climate-change forcing and Holocene human settlement strategies in the Lake Abhe basin.

235

### 236 **2.3 – Prior research on Holocene human occupation in the Abhe Lake basin**

237 Since the 1980s archaeological investigations in the Gobaad basin in Djibouti (Joussaume 1995)  
238 have provided evidence of several late LSA sites characterized mainly by graves with human and  
239 wild faunal remains, and several sites with cattle and caprine domestication in association with  
240 developed impressed pottery and complex built funerary traditions dated today to as early as 4.8  
241 ka BP (Cauliez et al. in press; Lesur et al. 2014). Several Middle-Late Holocene periods are  
242 represented and characterized by chronologically distinct impressed pottery traditions, and more  
243 generally, grinding and pounding equipment, cobble-lined hearths and a lithic tradition of  
244 obsidian backed geometrics associated with *pièces esquillées* tools made almost exclusively from  
245 obsidian (see Gutherz (ed.) 2017; Gutherz et al. 2015). The eastern Abhe lakeshore has provided  
246 the earliest confirmed dates for the onset of herding in the Horn of Africa region, contemporary  
247 with those at the Lothagam North Pillar Site in the region of Lake Turkana (Cauliez et al. in  
248 press; Hildebrand et al. 2018; see Asa Koma & Lothagam Fig. 1.a).



249  
250 Aside from geomorphological and geological studies carried out in the 1970s (Gasse 1977; Varet  
251 2018; Varet & Gasse 1978), the northern Abhe Lake basin lacked archaeological investigation  
252 prior to our work save for a briefly mentioned locality found in the Logiya region in the 1970s  
253 (Faure et al. 1976). Since 2014, the VAPOR-Afar program has investigated the remaining  
254 paleoshorelines of Abhe Lake in the Ethiopian Afar and confirmed the presence of an equally  
255 large number of prehistoric occupations. Some of these sites present nuanced regional and  
256 chronological variation in relation to the eastern shores of the same lake basin in Djibouti and  
257 permit a more holistic understanding of the entire basin's formation, evolution and its occupation  
258 by humans. While Abhe Lake highstands were recorded in the 1970s, relationships between  
259 human occupations and lake fluctuations had never been investigated in this region prior to our  
260 work. This makes Abhe Lake an exceptional case-study that allows us to evaluate human  
261 adaptation to changing lacustrine landscapes and environments over 9000 years.

262  
263 The Abhe Lake basin represents an important region for our understanding of the northeast  
264 African late prehistoric record, and our current work provides a register of new dated sites that  
265 contribute to filling gaps in the local and regional chrono-cultural sequence within the context of  
266 hydroclimatic and paleoshoreline fluctuations.

267  
268 **4 – Methodology and materials**

#### 269 **4.1 – Survey, excavation and sampling strategies**

270 Since 2014, a combination of remote sensing, geomorphological and archaeological survey was  
271 carried out from the lowlands to the fault margin slopes over the totality of the Lake Abhe basin,

272 with a particular regard for littoral morphologies and sedimentary complexes. The building of a  
273 revised lake-level curve permitted us to localize the paleo-shorelines of the Holocene Abhe Lake  
274 during fieldwork, and facilitated identification of peri-lacustrine deposits associated with  
275 archaeological occupation layers.

276  
277 18 test pits ranging from 1 to 1.3 m<sup>2</sup> area were excavated during fieldwork. The richest  
278 archaeological levels were investigated over more extensive surfaces dimensionally adapted to  
279 each site following a 1 m grid system. Fine excavation methods were used and all sediment was  
280 sieved using a 2 mm mesh. Levels with archaeological materials were sieved in their totality. All  
281 archaeological artifacts >2 cm were geolocalized and assigned a unique number. Field pedo-  
282 sedimentary sequence description and systematic bulk sampling were carried out in each  
283 Sedimentary Unit (SU), while selective sampling in controlled undisturbed contexts was  
284 employed for dating material.

285  
286 **4.2 – Cartography and GIS analysis**

287 The project Geographical Information System was constructed using the Esri ArcGIS10.7.1®  
288 and the Clark University TerrSet® programs. All sample locations and maps presented here are  
289 expressed in a geographic coordinate system (WGS84).

290  
291 Using an altimetry survey, a high-resolution (1 m) Digital Terrain Model (DTM) was created for  
292 our study region which enabled us to carry out different mapping operations and to create precise  
293 3D (X, Y, Z) geographic information using a Trimble® Differential Geographic Positioning  
294 System (DGPS) Geo7XT. With a differential correction, artifact coordinates were mapped with a

295 precision of 1-2 cm. The use of a DGPS not only allowed us to record archaeological data but  
296 also to georectify the cartographic database created for the project.

297  
298 Regional and micro-regional cartographic modelling (eg. lake-level modelling) was carried out  
299 using a 12 m resolution DTM (Tandemx) and LandSAT® (28.5 m resolution,  
300 <https://landsat.usgs.gov>) satellite images.

301

### 302 **4.3 - <sup>14</sup>C dating and calibration**

303 The age model of the archaeological sequences is based on 35 Accelerator Mass Spectrometry  
304 (AMS) <sup>14</sup>C measures obtained on charcoal, bone bioapatite, stromatolites and aquatic/terrestrial  
305 mollusk shells (Table 1, 2). Where organic or biogenic carbonate macroremains were absent, <sup>14</sup>C  
306 dating was performed on sediment bulk organic carbon (OC > 1%).

307

308 Dating on bone bioapatite was performed on two faunal remains from the site of Det Bahari-01  
309 (Betba-1291, Betba-11, Table 2). Bioapatite gives minimum ages due to the possible exchange  
310 with dissolved carbonates (Zazzo 2014; Zazzo & Saliège 2011). The age shift is usually quite  
311 low for samples younger than 5000 BP, especially in arid environments like those found in the  
312 Afar.

313

314 The <sup>14</sup>C reservoir effect on lacustrine carbonates can be extremely variable in continental  
315 contexts depending on the periods and water bodies, notably with regards to the water-depth and  
316 the content of dissolved ancient calcium carbonates in the water (eg. Bronk Ramsey 2008; Cohen  
317 2003; Geyh et al. 2005). The reservoir effect in the Awash-Abhe hydrological system has not

318 been estimated to date. However, two new dates on charcoal and shell samples recovered from  
319 the same sedimentary unit (Logiya\_1A, Logiya\_1B, **Table 1**) indicate a ~100 year reservoir  
320 effect. To our knowledge, these are the only dated samples today that allow us to discuss the  
321 existence of a reservoir effect in this hydrological system. Although these samples are isolated,  
322 they enable us to suppose that the reservoir effect is very low if not non-existent in this area. It is  
323 therefore on the basis of this assumption that we do not apply a reservoir correction value on  
324 lacustrine carbonate ages and that the data below are presented.

325  
326 New and previous ranges and Median ages were calibrated with the Oxcal 4.3 program (Bronk  
327 Ramsey 2001) and IntCal13 curve (Reimer et al. 2013). The ages were considered here using  
328 95.4% ranges and are reported in cal. BP or cal. ka BP (calibrated year or kilo annum before  
329 1950). Holocene subdivisions used follow those formally ratified by the International Union of  
330 Geological Sciences (Walker et al. 2018).

331

## 332 **5 – Results**

### 333 **5.1 – Revised Age Model of Holocene Abhe paleo-lake level phases**

334 The revision of the age model of Holocene Abhe paleo-lake water levels is based on the  
335 calibration and the re-calculated elevation of  $^{14}\text{C}$  ages on littoral lacustrine carbonates published  
336 by Gasse (1975, 1977; **A.1**), and on new radiocarbon dates on stromatolites (**Table 1**).

337

338 25 previous ages were selected according to the following criteria (**A.1**): **a**) only ages from  
339 littoral lacustrine material from Abhe basin were considered; **b**) using stratigraphic information  
340 provided by Gasse (1975), inversed ages or ages from reworked sediments were rejected ; **c**)

341 ages from shores of residual lakes were not considered (ex: Gamari or Gargori residual lakes); **d**  
342 ages with incomplete geographic localization (partial GPS points) do not allow proper  
343 correlation with DEM data and were not used for model building; **e**) ages on anthropic material.

344  
345 Stromatolites from African lakes are well known markers of littoral and stable lacustrine  
346 paleoenvironments (Casanova 1991; Hillaire-Marcel et al. 1986; Lisker et al. 2009). These are an  
347 accurate proxy of shallow waters and can complement and confirm lake level models. 14 new  
348 <sup>14</sup>C ages on stromatolites sampled and mapped during fieldwork were compared with previous  
349 revised data with the aim of confirming and refining the paleo-lake level model (for subsequent  
350 new age references, refer to [Table 1](#), [Fig. 2](#)).

351  
352 The first Early Holocene lake highstand is localized at 359 m a.s.l. in the north of the basin. A  
353 stromatolite newly dated to 11210-10805 cal. BP (Strom\_20-SU5) allows us to push back the  
354 onset of this lake transgression (Abhe-IV phase) to ~1000 years earlier than the data presented in  
355 Gasse's (1977) original lake-level model ([Fig. 1.c, 2](#)). After a slight drop in level (342 m a.s.l.;  
356 11086-10253 cal. BP; Gasse\_96, [A.1](#)), the lake level rose again between 10660-10404 and  
357 10565-10295 cal. BP (Strom\_20-SU4, Strom\_20-SU1). This phase of lacustrine highstand was  
358 maintained until 10.2-9.8 ka cal. BP (Logiya\_1A; Gasse\_94, 90, [A.1](#)) with a maximal elevation  
359 of ~420 m a.s.l. and a surface extension of ~6000 km<sup>2</sup>. From 9.8 ka cal. BP Abhe Lake levels  
360 appear to have dropped ~50 m (~370 m a.s.l.), persisting at this level until 8.4 ka cal. BP  
361 (Gasse\_85, 82, 80, 76, 64, 63, 62, [A.1](#); Strom\_10b, 31). This result permits us to add a second  
362 lake highstand of phase Abhe-IV, with respect to Gasse's original (1977) model ([Fig. 2.b](#)). At 8  
363 ka cal. BP a rapid decrease of the water table is recorded with a lowstand level of 238-236 m

364 a.s.l. (Gasse\_57, A.1). The resurgence of rising lake levels is recorded at 7498-6448 cal. BP  
365 (Gasse\_35, A.1; 327 m a.s.l.) followed by lake level stabilization (~360-370 m a.s.l.) which  
366 marks the onset of phase Abhe-V (Fig. 2.b). Between ~8 and ~7 ka cal. BP water-level  
367 modelling was not possible due to an absence of data from lacustrine carbonates. However, an *in*  
368 *situ* archaeological site located at 378.4 m a.s.l. and dated to 7564-7424 cal. BP indicates that  
369 during this period the lake could not have attained this elevation (sample SP-01\_US2\_001, Table  
370 2). The last high waters of the Middle Holocene lake are dated on a stromatolite to 5712-5591  
371 cal. BP (Stromatolis-SU1), which is followed by a slight regression event until 4874-4297 cal.  
372 BP (Gasse\_16, A.1). Low lake-levels probably occur between ~4.5 and ~3 ka cal. BP, however  
373 the lack of data does not allow lake level modelling during this period. During the Late  
374 Holocene, from 3172-2490 cal. BP (Gasse\_13, A.1) a new rise in lake levels corresponds to  
375 phase Abhe-VI which continued until ~1.4 ka cal. BP.

376

## 377 **5.2 - The Abhe basin archaeological sequences: material culture, radiocarbon dating and** 378 **pedo-sedimentary description**

379 Of the 40 archaeological sites identified in our research area (Fig. 1.b), the archaeological  
380 sequences presented here are derived from 16 test pits conducted on nine sites. Six of these are  
381 stratified and were radiocarbon dated on *in situ* materials in undisturbed contexts. With the  
382 addition of the Det Bahari-01 surface site, seven dated archaeological sites are presented in  
383 chronological order, from the oldest to the youngest with a brief pedo-stratigraphic description  
384 and diagnostic material culture presentation.

385

### 386 **5.2.1 - Lakora-03**

387 Sounding 1 (S1) measuring 1.5x2 m<sup>2</sup> was excavated at the site of Lakora-03 (Fig. 3.c) located on  
388 the slopes of a stratoid series basalt ridge NW of the rhyolitic Borawli volcano (Fig. 1.b).

389  
390 Over the basaltic bedrock, a saprolitic layer developed (SU7) presenting a whitish-brown silty-  
391 clayey matrix packing a large amount of weathered basaltic gravels mixed with reworked  
392 calcareous crusts. The following layer (SU6) shows the development of a granular structure of  
393 dark-brown well sorted silts containing few terrestrial shells and rare obsidian artifacts. SU5 and  
394 4 represent two sedimentary phases of the main human occupation level characterized by a very  
395 dark-brown, well to moderately sorted silt with a loose granular structure, containing a small  
396 hearth, charcoal, and a large amount of fish remains and obsidian artifacts (Fig. 3.b, d). SU5  
397 represents the base of a stone line composed of decametric sub-angular basaltic blocks which are  
398 capped at the top by a stromatolitic crust (SU3). Several worked lithics in SU5 were also capped  
399 by the stromatolitic crust SU3. Charcoal recovered in SU5 was radiocarbon dated to 11164-  
400 10737 cal. BP; Table 2).

401  
402 Archaeological materials from SU5 and 4 included abundant faunal remains, namely fish (Table  
403 3), worked obsidian, charcoal, and a single round flat ostrich eggshell bead recovered from the  
404 hearth.

405  
406 The excavation of S1 provided a relatively rich sample of lithic material (n=132) with one refit  
407 (Fig. 4). The lithic materials from the sounding were compared with surface collections of  
408 materials localized quasi-exclusively within a 40x15 m<sup>2</sup> area along the eastern edge and  
409 downslope of the basalt outcrop. Surface collections included both systematic collection of all

410 artifacts in a 1 m<sup>2</sup> area where there was the highest density of materials and a random collection  
411 of cores and shaped tools from the entire surface area (Fig. 4.a-c). Lithic materials from the  
412 sounding were comparable to surface collections from a technological and typological point of  
413 view and are generally very altered, both mechanically and chemically (Fig. 4.d-f). The materials  
414 collected at the site indicate dominant production of large bladelets from cores belonging to  
415 distinct operative schemes. Very few shaped tools were present in both the surface and excavated  
416 collections. These are mostly burins and endscrapers (Fig. 4f). Interestingly, not a single backed  
417 piece was collected or observed at the site.

418

419 The faunal material is dominated by fish, represented mainly by catfish remains, but also by one  
420 tilapia and one Cyprinidae bone. The rest of the fauna includes remains of large mammals,  
421 including bovids. Some shell and ostrich eggshell are also present (Table 3).

422

### 423 5.2.2 - Raso-02

424 A step Sounding 2 (S2) measuring 1.5x2 m<sup>2</sup> was excavated along an exposed section at the site  
425 of Raso-02 (Fig 3.a) located at the base of a stratoid basalt ridge on the NW edge of the Manda  
426 Gargori volcano-tectonic segment (Fig 1.b).

427

428 From bottom to top (Fig. 3.a) the sounding included a saprolitic layer (SU9) that formed over the  
429 basaltic bedrock; a dark-brown muddy sediment rich in secondary carbonate nodules (SU8); a  
430 silty-clayey horizon (SU7 and 6) with a polyhedral structure where secondary carbonates are  
431 reduced and replace the intrapedal porosity as infillings. A channel-morphology erosional  
432 surface marks the end of the lower pedogenic complex. The channel bottom is characterized by



433 few sub-angular and rounded basaltic blocks packed in the gravely-clayey SU5d and gravely-  
434 sandy SU5c which fill the fluvial channel body. SU5b and 5a represent the main archaeological  
435 level which is characterized by common fauna, including a large mammal long bone fragment,  
436 charcoal and obsidian artifacts, packed in a gravely-sandy matrix (SU5b) and massive medium  
437 sand (SU5a). The top of the archaeological level is marked by an erosional surface and by the  
438 installation of massive fine-sand/silty texture patterns (SU4b and 4a), with abundant lacustrine  
439 shell inclusions (SU3). An oncolite layer (SU2) is packed in a brown muddy matrix rich in  
440 lacustrine *in situ* shells, while the SU2/1b interface contains few obsidian lithic artifacts,  
441 charcoal and fish remains. This is followed by a pedogenic event with well-developed clay  
442 granular structure (SU1b), affected in its upper part (SU1a) by desiccation cracks filled by  
443 reworked surface material.

444

445 Charcoal from the base of SU5a was dated to 10744-10418 cal. BP (Raso-02-Sond2-SU5, [Table](#)  
446 [2](#)), while the oncolite layer gives an age range of 5913-5746 cal. BP (Raso-02\_Strom, [Table 1](#)).  
447 In addition, some faunal remains (mammals and fish; n=9) were recovered from SU5a and  
448 abundant fish remains (n=1328) from SU2. Materials collected on the surface of the site include  
449 noticeably large blades and bladelet cores (which produced relatively large blanks). The  
450 extensive surface collection from 1 m<sup>2</sup> area provides similar kinds of materials but shows heavy  
451 mechanic alterations, and particularly double-patina breaks and retouch-like damage. Only a  
452 very limited archaeological sample was recovered from the sounding (n=36), where materials are  
453 also heavily altered. The few illustrative but undiagnostic artifacts are limited to a distal  
454 fragment of a retouched bladelet in SU1, and a large blade and two flake cores (including one  
455 Levallois) in SU5. SU5 is richer and could correspond to material found on the surface but a

456 larger sample is needed to confirm this and to propose a proper technological or typological  
457 description. Besides these limitations regarding sample size, Raso-02 materials do not seem very  
458 different from the Lakora-03 ones.

459

### 460 **5.2.3 - Det Bahari-01**

461 Det Bahari-01 is an open-air site preserved as a residual artifact-rich surface on a low oval  
462 mound located on the eastern edge of the Det Bahari sand plain SW of the town of Dubti (Fig.  
463 6.c). The site dated on hippopotamus remains to 7956-7761 and 7674-7523 cal. BP (Betba-1291,  
464 Betba-11, Table 2) overlies a palustrine deposit dated on *in situ* bivalve shells to 10415-10245  
465 and 10230-10170 cal. BP (Betba01log2A, Betba01log2B, Table 2).

466

467 The good state of preservation of fauna, lithics and basalt groundstone fragments, and evident  
468 refits within the residual archaeological level localized in a ~70x45 m<sup>2</sup> area led us to collect the  
469 totality of surface materials (Fig. 5.a). 1438 artifacts were collected including ~550 knapped  
470 obsidian (90%) and chalcedony (10%) artifacts, and ~750 other mineral items (mostly igneous  
471 rocks). The igneous material can be subdivided in two groups: the largest one is composed of  
472 heavily fragmented mafic rocks (mostly vesicular basalt(?)) with no apparent sign of anthropic  
473 transformation; the second is represented by several artifacts interpreted as pounding stone  
474 fragments (grinding stones?, hammers?) providing functional clues. An important number of  
475 refits were made on materials from this group (60 refit groups, of which 12 groups include 3 or  
476 more artifacts, and 4 groups between 5 or 6 artifacts, or 103 conjoins) (Fig. 5.a). If some of these  
477 refits correspond to natural fragmentation (taphonomic alteration of the most fragile stones,  
478 particularly the vesicular basalts), some refits may indicate intra-site artifact circulation (as an

479 indication, distance between conjoined artifacts are greater than 3 m in 26 cases, and greater than  
480 10 m in 6 cases). A second category corresponds to small size pebbles of various materials. Most  
481 of them do not feature any sign of use and could have been present in alluvial deposits in the  
482 direct vicinity of the site, or perhaps in a dismantled overlying stratigraphic unit. The association  
483 between mafic rocks and cobbles remains uncertain but their overlapping distribution at the site  
484 and complete absence in the direct vicinity of the site could be an indication of contemporaneous  
485 occupation of a single site of limited extent.

486

487 Another component of the lithic material was composed of knapped artifacts (obsidian and  
488 chalcedony, both similarly treated) (Fig. 7). Systematic attempts to find conjoins between all  
489 flake fragments were unfortunately unsuccessful. There was an intense re-use of various  
490 products and particularly of cores which were almost systematically fragmented and reduced to  
491 very small proportions, often by bipolar percussion. Nevertheless, numerous blades and bladelets  
492 (some of them used as blanks for shaped and modified tools) were recovered and are an indirect  
493 indication of the importance of these productions (Fig. 7.a-b). It remains unclear what proportion  
494 of pieces showing bipolar percussion stigmas are core and intermediary tools (*pièces esquillées*)  
495 but some of them are of very reduced dimensions and could not have been cores for the blanks  
496 recovered, at least in their last exploitation stages. Relatively few shaped tools (n=45) were  
497 recovered at the site, however, most of those that were are curved backed bladelets (n=27, Fig.  
498 7.d-f), associated with few endscrapers (Fig. 7.c), thick truncations, and simple burins (angle  
499 burins on break, mostly). In addition to these, numerous blanks show irregular modifications of  
500 various extent.

501

502 The fauna totaled 98 specimens including hippopotamus and crocodile, middle sized bovids and  
503 33 fish remains. The dominance of aquatic fauna suggests the presence of a lakeside settlement  
504 with an economy based on fishing of tilapia and catfish and the hunting of mainly aquatic prey  
505 (Table 3).

506

#### 507 **5.2.4 - Stromatolis**

508 The site of Stromatolis is located between the SE slopes of the late quaternary basalt flows of  
509 Kurub volcano (Fig 6.c). The archaeological findings consist of a small dry wall circular  
510 structure ~150 cm in diameter constructed from naturally sub-angular basalt blocks (SU2; Fig.  
511 5.c). The blocks were laid on a continuous formation of columnar structure stromatolite domes  
512 (SU5) as well as on two thin overlying levels of a clayey silt with terrestrial shell (SU4) and an  
513 aeolian fine to medium cross-laminated sand deposited prior to its construction (SU3) (Fig. 5.b).  
514 The anthropic structure is capped by a second generation of stromatolitic crust (SU1) presenting  
515 laminar structure and ripple marks on their surface. The underlying stromatolite generation  
516 (SU5) was dated to 8978-8598 cal. BP, and SU4 to 8593-8419 cal. BP (Stromatolis\_SU4, Table  
517 2, Strom\_31, Table 1, Fig. 5.b), while the overlying laminar stromatolite generation (SU1) was  
518 dated to 5712-5591 cal. BP (Stromatolis\_SU1, Table 1, Fig. 5.b). No artifact was found in  
519 association with the structure.

520

#### 521 **5.2.5 - MS-01/02**

522 Two soundings (01 and 02) were conducted at the site MS located in an active sand dune field in  
523 the Kurub Bahari plain ~2 km due north of the current Awash River bed (Fig. 6.c). These  
524 soundings reveal alternating aeolian layers and pedogenic horizons to a depth of ~200 cm (Fig.

525 **6.b**). The MS-01 sequence is composed of 20 SU. From bottom to top, SU1 is composed of  
526 clayey-fine silty material with a polyhedral to prismatic structure where several obsidian artifacts  
527 were recovered. This first pedogenic horizon is capped by alternating fine-silty and clayey bed  
528 layers (SU2) containing a discontinuous horizontally oriented line of Fe-Mg oxide nodules in its  
529 uppermost matrix. The archaeological evidence and the similarity of pedological characteristics  
530 of SU1 and 2 allow us to propose a stratigraphic correlation with SU3 and 4 of the MS-02  
531 sounding (**Fig. 6.b**). Along the upper part of the MS-01/02 sequences three types of alternating  
532 layers are defined: thin silty-clayey pedological horizons with prismatic to polyhedric structure  
533 (MS-01\_SU4, 6, 8, 10, 18; MS-02\_SU6, 8), silty horizontally laminated layers (MS-01\_SU7, 9,  
534 11, 13, 15, 17; MS-02\_SU7, 9), and fine to medium sand cross-laminated layers (MS-01\_SU3, 5,  
535 12, 14, 16, 19, 20; MS-02\_SU2, 5). Discontinuous beds of silicic nodules are commonly present  
536 in the silty and sandy layers. Archaeological layer MS-01\_SU1/MS-02\_SU3 was dated to 8190-  
537 8000 cal. BP (MS1\_US1\_001, **Table 2, Fig. 6.b**).

538

### 539 **5.2.6 - SP-01**

540 Site SP-01 is located at 380 m a.s.l. on the stratoid basalt outcrop on the NW ridges of the  
541 rhyolitic Borawli volcano (**Fig. 6.a**). A 1 m<sup>2</sup> test pit revealed preserved sedimentary deposits  
542 trapped within the parallel NNW-SSE oriented fissure flows of the stratoid series formation and  
543 topographically localized above the Holocene lacustrine wave-cut terrace and littoral lacustrine  
544 sedimentary deposits (**Fig. 6.a**). From bottom to top, we observed a massive silty-clayey layer  
545 with abundant gravel inclusions (SU5), a prismatic structure pedologic horizon containing  
546 occasional knapped obsidian artifacts (SU4), and a massive fine-sand ensemble (SU3, 2, 1). A  
547 date on bulk organic carbon from the base of SU4 gives an age of 7519-7424 cal. BP (SP-

548 01\_US2\_001, [Table 2](#)). Obsidian artifacts recovered from the sounding were limited to small  
549 undiagnostic chips, however the small and selective surface collection recovered on the adjacent  
550 outcrop edge, and probably belonging to the eroded pedologic horizon (SU4) correspond to the  
551 production of large bladelets. The only shaped tools collected at the site are curved backed  
552 bladelets of relatively large dimensions.

553

### 554 **5.2.7 – Kurub-07**

555 The site of Kurub-07 was excavated over a 34 m<sup>2</sup> surface area ([Fig. 8.a.3](#)). This open-air site is  
556 exposed on the slopes of a large dune complex in the SW of the Kurub Bahari plain and several  
557 kilometers north of the current Awash River delta ([Fig. 1.b](#), [Fig. 8.b](#)). 43 SU were described  
558 during three seasons of fieldwork on the basis of excavation and pedo-stratigraphic observations  
559 from site sections. We present here only the SU observed on the K\_trench section, which is  
560 representative of the stratigraphic and site formation processes and of the main archaeological  
561 layers ([Fig. 8.a.1](#)).

562

563 SU18 represents the continuous sedimentary basement of the sequence characterized by dark-  
564 brown prismatic structured clays rich in authigenic gypsum which has been interpreted as a  
565 palustrine pedogenised deposit. This layer is dated on bulk organic carbon to 7587-6174 cal. BP  
566 (Kur-07-K15-US18-1488, [Table 2](#)). A paleodune complex represented by SU41 and 13  
567 composed of cross-laminated and well sorted fine sand follows. At the interface between SU41  
568 and 13 we find a phase of occupation characterized by few lithic artifacts, faunal remains and  
569 small charcoal. The following archaeological level SU15 is dated between 3914-3647 and 3830-  
570 3587 cal. BP (Kur-07-K14-US15-1203, Kur-07-L16-US15-1283, [Table 2](#)). SU15 is a silty-

571 clayey polyhedral structured layer rich in secondary carbonate nodules with abundant flat-lying  
572 broken ceramics, semi-articulated faunal remains, charcoal and lithics. SU12, marked by a more  
573 structured matrix, by the lack of secondary carbonates and the persistence of anthropic material  
574 is dated between 3638-3477 and 3568-3407 cal. BP (Kur-07-US12-591, Kur-07-US12-2459,  
575 **Table 2**). SU9/14 are composed of consolidated or non-consolidated aeolian sand and produced  
576 some pottery fragments, wild and domestic fauna, charcoal, lithics and groundstone, namely on  
577 or just below the surface, and cap the underlying pedogenic horizons. The most recent anthropic  
578 layer is a polymorphous oven structure (ST1, **Fig. 8.a.2**) cutting into SU12, 42, 43 and 18 in the  
579 south end of the site (K-L/10-9; **Fig. 8.a.1**). The oven, which is the first of its kind for the period  
580 and region has been dated on charcoal to between 3600 and 3300 cal. BP (Kur-07-US10-667,  
581 Kur-07-US10-1136, **Table 2**).

582  
583 Faunal material from the site is dominated by domesticates (sheep, goat and cattle) which are  
584 present in SU15, 12, 10, and the surface of 9/14. Wild fauna includes mainly middle to small  
585 sized bovids, among which only the Dorcas gazelle could be identified. The rest of the fauna  
586 includes rodents, reptiles and fish remains (Siluriform and tilapia), as well as ostrich eggshell  
587 (**Table 3**).

588  
589 At least two ceramic technological traditions corresponding to two phases of occupation can be  
590 distinguished. Few artifacts are affiliated with the first phase (SU15 and contemporary SU16-17,  
591 **Fig. 8.a.1, 9.a-c**). These are characterized by at least two well-differentiated and refitted vessels  
592 with incised or impressed decorations, simple forms and medium volumetric capacities.  
593 Decoration includes the use of a blunt point and comb impressions on one of the pots (**Fig. 9.a**),

594 pivoting impressions using a flat spatula on the second (Fig. 9.b), and simple impressions by  
595 means of oblique lines in horizontal bands on a third pot (Fig. 9.c).

596  
597 The second phase corresponds to the use of the oven feature (ST1, SU10, SU12, Fig. 8.a.1, 9.d-  
598 k). From a morpho-metrical standpoint, the containers are of average volumetric capacity and of  
599 simple contour like in the preceding phase, but sometimes present rectified edges (Fig. 9.d). Just  
600 as in the previous phase, decoration includes simple impressions with a comb (Fig. 9.g) or  
601 pivoting impressions with a comb or shell (Fig. 9.h, i). However, this phase also presents few  
602 roulette impressions (Fig. 9.f). The compositions are always very airy and do not cover the entire  
603 surface, but are distinguished from the first phase by use of more diverse motifs combined on the  
604 same vessel or the association of two decorative techniques (Fig. 9.e, j). The presence of few  
605 sherd fragments with a red slip applied before firing, testify to the application of colorants on  
606 certain pottery vessels in these levels (Fig. 9.k).

607  
608 In addition, the ongoing study of ceramic raw materials allows us to distinguish between two  
609 cultural phases. The older one (SU15) is mostly characterized by ceramic pastes with inclusions  
610 made of shell tests (e.g. entire gastropods, e.g. *Melanoïdes*), charcoal and bones. The more recent  
611 phase appears to be mostly characterized by inclusions made of rounded volcanic sand and by  
612 other distinctive features such as vegetal remains, grog and diatoms.

613  
614 The lithic material is mainly composed of worked obsidian with an inclination towards flake  
615 debitage, though irregular blades and bladelets are also present. The majority of cores studied are  
616 flake or *pièces esquillées* cores and were fragmented or reduced to small proportions, often by



617 bipolar percussion on anvil. A number of blanks show irregular modifications of various extent,  
618 while very few shaped tools (scrapers, perforators and curved backed pieces) were recovered  
619 from excavations. The presence of rounded and rolled neo-cortex on some obsidian lithics attests  
620 to a partial selection of small obsidian cobbles by populations. While the study is ongoing, there  
621 are similar production tendencies across occupation levels pertaining to potter pastoralist  
622 populations (SU15, 12, 10, 9/14), while lithic material from the earlier SU41 was rare and  
623 therefore difficult to compare.

624

## 625 **6 – Discussion**

626 14 new ages on littoral lacustrine carbonates combined with re-calibrated ages and recalculated  
627 elevations taken from Gasse (1975) allow us to estimate fluctuating paleoshoreline levels of  
628 Abhe Lake and its relationship with other lakes in Ethiopia over the last 12000 years (Fig. 10).  
629 23 radiocarbon dates from 7 excavated sites and associated sedimentary records (Table 2)  
630 provide the most robust chronological sequence to date for late prehistoric occupation in  
631 Ethiopia, and are the first major evidence for semi-continuous LSA to potter-pastoralist  
632 settlement in the Ethiopian Afar.

633

634 Paleo-lake level reconstruction combined with pedo-stratigraphic sounding results allow us to  
635 propose a semi-continuous Holocene chronostratigraphy of peri-lacustrine landscapes in relation  
636 to changes in human settlement, economy and culture across the Abhe Lake basin (Table 4) and  
637 to discuss these results in relation to pertinent patterns observed across northeast Africa.

638

### 639 **6.1 – Early Holocene (~11.7 to ~8.2 ka)**

### 640 **6.1.1 – The Paleolandscape context**

641 Our new dates and geomorphological results show a lack of sedimentary deposits concerning the  
642 Marine isotope stage (MIS)2 to early MIS1 periods (~29-12 ka) in accordance with the lack of  
643 regional lacustrine and continental sedimentation (Beck et al. 2019; Gasse 1977; Gasse & Street  
644 1978; Gillepsie et al. 1983; Lamb et al. 2018; Wagner et al. 2018).

645  
646 At the beginning of the Holocene (~11.1 and ~10.6 ka cal. BP; Fig. 10.d) the water-level of Abhe  
647 Lake was relatively low, oscillating between 340-360 m a.s.l. During this period, dated SU from  
648 two sequences indicate the development of a pedogenic event at the edges of the Awash alluvial  
649 plain in which the oldest preserved anthropic settlements occur (Lakora-03\_SU4-5). Soil  
650 development is followed by a fluvial event dated to ~10.5 ka cal. BP (Raso-02\_SU5), suggesting  
651 the re-activation of the hydrological system leading to the rise of lake-levels at the beginning of  
652 the Abhe-IV transgressive phase (Raso-02\_SU5). Between ~10.3 and ~9.8 ka cal. BP the lake  
653 attained its maximal water-level (~410-420 m a.s.l.) occupying the totality of the Lower Awash  
654 plain. This Early Holocene highstand demonstrates the centennial scale reactivity of the Awash  
655 hydrological system to monsoon magnitude variations associated with the northward migration  
656 of the ITCZ (Fig. 10.d). This period coincides with the highest Holocene precipitation values  
657 recorded in the Ethiopian highlands (Bastian et al. 2017; Costa et al. 2014) and with the maximal  
658 insolation values (corresponding to precession minima) occurring at this latitude (~11°N; Berger  
659 & Loutre 1991; Fig. 10.a, b).

660  
661 The Early Holocene period comes to an end with a reduced stable lake-level (~370-380 m a.s.l.)  
662 until ~8.2 ka (Fig. 10.d), during which contemporary peri-lacustrine sedimentary deposits likely

663 developed. After this period, lake levels did not rise above 380 m a.s.l. probably as a  
664 consequence of channel incision that evacuated water towards the Hanle semi-graben. One  
665 channel incision, which is a likely candidate but requires ground verification was identified using  
666 remote sensing and DEM modelling around Serdo town (Fig. 1.b). The absence of sedimentary  
667 and archaeological data corresponding to Early Holocene high lake stands is likely a result of an  
668 extreme post-lacustrine erosional rate on high basaltic outcrops and by difficult to access  
669 elevated regions during fieldwork (above 400 m a.s.l.).

670

### 671 **6.1.2 – Human adaptation to rising lake levels in the Later Stone Age**

672 The rarity of sedimentary deposits during the YD period (12.9- 11.7 ka; Rasmussen et al. 2014)  
673 is echoed by the lack of sites recovered for this period. Sites recovered immediately after the YD  
674 concern lakeside settlements as the lake was rising and had reached ~ 360 m a.s.l. of the 430 m  
675 a.s.l. it would progressively attain one millennium later. The first evidence of Holocene  
676 occupation at Lakora-03\_SU4-5 and Raso-02\_SU5 occurred as climatic conditions became more  
677 humid after the YD arid event (Foerster et al. 2012). SU5a at Raso-02 dated to 10744-10418 cal.  
678 BP is slightly younger than SU4-5 at the site of Lakora-03. The Raso-02 uppermost layers (SU  
679 1a-1b) may have been redeposited from eroded older levels that can be found preserved under  
680 large stromatolite domes slightly uphill of the studied section. This has been observed from study  
681 of the top sedimentary units at this site which appear reshuffled, and from a radiocarbon  
682 determination on charcoal from the transition between SU1b-2 which provides an inverted age  
683 slightly older and closer in age to the Lakora-03 archaeological level, than the distinctly  
684 underlying SU5.

685

686 The archaeological levels at these two sites present fish and other faunal remains, lithic material  
687 exclusively knapped on obsidian and an anthropogenic feature (hearth at Lakora-03). During this  
688 period the lakeshore was located several kilometers from Raso-02 and at the foot of the Lakora-  
689 03 site. The abundance of fish remains (including burnt) at Lakora-03 confirms that populations  
690 were temporarily settled near the lake edge and that fishing constituted a major activity and the  
691 source of an important part of their diet. The obsidian lithic assemblage has few shaped tools and  
692 is technologically similar on both sites.

693  
694 The Lakora-03 settlement indicates intensive fishing from a slightly elevated basalt promontory  
695 or islet. The faunal assemblage at Raso-02 includes 3 wild mammal remains and one fish remain  
696 and is too small to draw any conclusions. However, comparison with Lakora-03 where fish  
697 remains are abundant and dominate the assemblage may reflect the slight age difference between  
698 these occupations and their respective proximity to the lake edge (Fig. 3.c). Judging by the  
699 exponential rise in lake levels over one millennium, it is likely that these populations adapted to  
700 significant centennial if not generational-scale landscape modifications, following lake edges as  
701 they rose all the while benefitting from the rich and readily available lacustrine resources. Lithic  
702 materials from both sites have features reminiscent of slightly older sites (~14-13.5 ka cal. BP)  
703 from the Ziway-Shala basin (Ménard et al. 2014), with dominant production of blades and  
704 bladelets, few shaped tools and a possible absence of backed pieces. There is unfortunately no  
705 synchronous assemblage in the region to make comparisons with but material collected at  
706 Lakora-03 and Raso-02 could indicate a late persistence of a Late Glacial (if not older) tradition.

707

708 **6.2 – Middle Holocene (~8.2 to ~4.2 ka)**

### 709 **6.2.1 – The paleolandscape context**

710 The Middle Holocene onset period is marked around 8.2 ka cal. BP by rapid decrease (centennial  
711 scale average) of the Abhe Lake water-level (**Fig. 10.d**), which was in phase with an abrupt (300  
712 to 100 year) Holocene cold event at 8.2 ka recorded from Greenland ice cores (Thomas et al.  
713 2007) and recently revisited by the General Circulation Model (Matero et al. 2017). A similarly  
714 abrupt transition from D-depleted to D-enriched waxes in Lake Tana is dated around 8.5-8 ka  
715 cal. BP and is attributed to a reduction of moisture derived from westerly sources (Congo basin,  
716 Atlantic ocean; Costa et al. 2014; Marshall et al. 2011; **Fig. 10.b**). At the scale of tropical Africa,  
717 the first manifestation of less humid conditions which began around 8.4 ka cal. BP is  
718 documented almost everywhere in Africa (Gasse 2000) and is particularly well documented and  
719 dated from large catchment areas such as the Nile and Congo deltaic-fan sediments (Ménot et al.  
720 2020).

721  
722 This latter paleoclimatic scenario is confirmed by the Stromatolis\_SU4 palustrine layer, which  
723 covers a stromatolitic formation and indicates a slight lake regression that began around ~8.5 ka  
724 cal. BP. This corresponds to an average drop in lake-levels of 4 cm/yr between ~8.5 and ~8.2 ka  
725 cal. BP. Lacustrine regression accelerated abruptly between ~8.2 and ~8 ka cal. BP with an  
726 average drop in lake-levels of ~70 cm/yr. This is evidenced by a paleosoil that developed at  
727 8190-8000 cal. BP (355 m a.s.l.; MS-01\_SU1; **Fig. 6.b**) in the southern part of the Kurub Bahari  
728 plain, while the installation of the ensuing drying environmental patterns is observed in a thick  
729 paleodune sequence at MS-01 and by aeolian sands in the Stromatolis site sequence (**Fig. 6.b,**  
730 **5.b**).

731

732 A resurgence of wet conditions may be suggested namely by two hippopotamus bones directly  
733 dated to around ~7.8 and ~7.6 ka cal. BP, and a large aquatic faunal assemblage at the Det  
734 Bahari-01 site (370 m a.s.l.). A pedogenic event is observed and dated to 7519-7424 cal. BP (SP-  
735 01\_SU4; Fig. 6.a) suggesting the reduction of aeolian sediment transport dynamics and the  
736 availability of water supplies. These results are in accordance with rainfall and terrigenous input  
737 increase recorded at Lake Tana starting ~7.7 ka cal. BP (Costa et al. 2014; Marshall et al. 2011;  
738 Fig. 10.b) and from the Nile deep-sea fan archive (Ménot et al. 2020).

739  
740 Across the Abhe basin, rising lake levels were detected on dated stromatolites at ~7 ka cal. BP  
741 (~330 m a.s.l.; Fig. 10.d), reaching a stable level between ~6.6 and ~5.6 ka cal. BP (360-370 m  
742 a.s.l.). From ~5.6-4.6 ka cal. BP we observe a decrease in lake levels at a rate of ~1.5 cm/yr.

#### 743 744 **6.2.2 – Adaptation of Later Stone Age fisher-hunter-gatherers to a fluctuating lacustrine** 745 **environment**

746 A window into the period leading up to and after the 8.2 ka event is visible at the site of  
747 Stromatolis characterized by the first LSA built structure known to date. The sediments that  
748 accumulated during the use of the anthropic circular structure were partially deflated by aeolian  
749 action after its abandonment and prior to the lake submerging the area. Given this *terminus ante*  
750 *quem* for the structure's use, it is, to our knowledge, the oldest possibly non-funerary anthropic  
751 structure in the Horn of Africa, and was likely used during the 8.2 ka arid event.

752

753 Human occupation at MS-01/MS-02 corresponds to a period of continued low lake levels  
754 following the 8.2 ka event, and suggests that human groups were extremely reactive to rapid lake  
755 level oscillations during this period, moving along with the lakeshore.

756

757 The site of Det Bahari-01, occupied between 7.9 and 7.5 ka cal. BP falls within a period where  
758 lake levels are not documented. While the site is a relict surface site, dated faunal remains, lithic  
759 refits, and the homogeneity of the assemblage suggest it belongs to a single or to multiple  
760 occupation events that occurred over a short time. Directly dated hippopotamus bone, and  
761 dominant aquatic fauna suggest the Det Bahari plain was partially submerged at this time and  
762 that the site itself was near the water's edge. This would suppose that an undocumented  
763 transgressive lacustrine phase occurred during the occupation of Det Bahari-01. Lithic traditions  
764 observed at Det Bahari-01 (lamino-lamellar debitage, curved backed pieces) and the presence of  
765 some aquatic fauna on the surface of site SP-01 (~7.5-7.4 ka cal. BP) further support the  
766 continuity of shoreline settlement over the course of ~500 years of oscillating lake-levels.

767

768 Our results establish that the Lower Awash plain which makes up the northern shore of the Early  
769 to early Middle Holocene Lake Abhe was settled before, during and after the 8.2 ka arid event.  
770 Between ~8.1 and ~7.4 ka cal. BP another phase of settlement is identified in the area. These  
771 archaeological sites and their associated aquatic fauna suggest at least one low lake stand before  
772 the Abhe-V stable lake transgression. This period differs markedly from the period prior to 8.2  
773 ka in that while fish remain a staple, there is significantly less than at earlier sites, and more large  
774 aquatic fauna such as crocodile and hippopotamus, notably on sites like Det Bahari-01. While  
775 fishing remained a common practice, the presence of larger quantities of wild aquatic fauna may

776 suggest new technical innovations in hunting and fishing equipment. Use-wear study on a select  
777 number of curved backed pieces show diagnostic impact fractures that suggest their use as  
778 composite projectile points (barbs and axial points likely set into wood or bone shafts) to act as  
779 arrows, spears or harpoons for hunting and/or fishing. Unfortunately the lack of preserved plant  
780 material in the deposits limits our understanding of these populations' relationships with wild  
781 plants and whether or how they may have been used for shelter, food and craft production. The  
782 presence of groundstone implements, and debitage oriented towards the production of bladelet  
783 blanks for composite backed pieces are also departures from traditions observed in the previous  
784 settlement period identified.

785

## 786 **6.3 – early Late Holocene (~4.2 to ~3 ka BP)**

### 787 **6.3.1 – Paleolandscape context**

788 The Late Holocene period is marked by a decrease of lake levels around ~4.5 ka cal. BP and the  
789 spread of arid conditions across the Abhe basin (Fig. 10.d). This change in hydrological patterns  
790 corresponds to the reduction of the African monsoon rainfall regime, which marks the end of the  
791 AHP (Gasse 2000; Shanahan et al. 2015).

792

793 This period likely corresponds to the renowned 4.2 ka event (Kaniewski et al. 2019; Rousseau et  
794 al. 2019) characterized by a rapid (centennial scale average) decrease in precipitation in tropical  
795 Africa that led to the spread of hyperarid conditions. In the Abhe basin, the installation of the  
796 first Middle to Late Holocene aeolian accumulations fall in the range between ~4.5 and ~3.7 ka  
797 cal. BP (Kurub-07\_SU41 and SU13). At the Kurub-07 site we observe alternations between  
798 paleodune layers and aridisols between ~3.7 and ~3.2 ka cal. BP, confirming the persistence of



799 arid conditions. Considering the low altitude of human settlements and the similarity in low  
800 precipitation values during the YD and the 4.2 event in the Ethiopian Highlands (Costa et al.  
801 2014; Fig. 10.b, c), this Late Holocene arid event led to a drastic reduction of Abhe Lake levels  
802 like those recorded during the 8.2 ka event.

803

### 804 **6.3.2 – Multi-resource economies and the transition to herding in the Middle to Late** 805 **Holocene transition**

806 Lower lake-levels and more arid conditions began at ~5.5 ka cal. BP and took hold around ~4.5  
807 ka cal. BP though there is a general lack of lake-level data for this period (Fig. 10.d). The earliest  
808 evidence of herding in the region is attested around 4.8 ka cal. BP on the eastern shores of Lake  
809 Abhe (Cauliez et al. in press; Coudert et al. 2018; Lesur et al. 2014), while we have yet to date a  
810 pottery herding site of this period in the Ethiopian Afar.

811

812 The site of Kurub-07 is exceptional for the region for its discontinuous roughly two-millennia  
813 long human occupation sequence and for the preservation of remains of the first potter  
814 pastoralists who inhabited the area. The site features an older level of human occupation (SU41)  
815 thus far devoid of ceramics or animal domesticates. Three radiocarbon dates from this level are  
816 inverted and have therefore been rejected (Kur\_07\_ST6\_655, Kur\_07\_Spit8\_661, Kur-07-K15-  
817 Spit8-663B, Table 2). However, we can bracket this archaeological level between dates for the  
818 last lake transgression ~4.5 ka cal. BP and the following anthropic level (SU15) radiocarbon  
819 dated to ~3.9-3.6 ka cal. BP.

820

821 After a period of abandonment of the site (SU13), several continuous well-preserved levels of  
822 occupation by potter herders that cover the period from ~3.9 to ~3.3 ka cal. BP follow. Remains  
823 of domesticates including cattle, sheep and goat confirm the presence of a herding economy.  
824 Although small, the spectrum attests to the importance of livestock in the diet. However, the  
825 large numbers of small wild fauna, particularly suited to open and arid plains, and some fish  
826 remains attest to the persistence of hunting and fishing probably carried out in the vicinity of the  
827 site while also suggesting the presence of drier conditions (semi-arid environment).

828  
829 In addition to the introduction of small domestic herds during this period, we observe major  
830 changes in technical traditions with the appearance of pottery for storage, built structures such as  
831 ovens, and bipolar percussion on anvil on small obsidian nodules mainly for flake and to a lesser  
832 degree bladelet production. While few shaped tools were recovered, geometric backed pieces,  
833 *pièces esquillées* and few scrapers and perforators were recovered from excavations. This  
834 diverges from LSA lamino-lamellar debitage traditions but the production of curved backed  
835 composite tools on bladelet blanks is reminiscent of what was identified at Det Bahari-01 (Fig.  
836 7.d-f) and dated to the Middle Holocene.

837  
838 Particularly unique to the Abhe Lake region are the impressed pottery traditions (Fig. 9). The  
839 Kurub-07 ceramic assemblage is lacking in the regional sequence and the site presents an  
840 important milestone that contributes to our understanding of the socio-cultural landscape of this  
841 sector. Ceramics from the first and second phase of occupation of this site show some similarities  
842 to well-defined potter traditions east of Abhe Lake, in particular with the Asa Koma / Wakrita  
843 facies identified on several sites dating to between ~4.8 and ~4 ka cal. BP in the Gobaad Basin in

844 Djibouti (Cauliez et al. 2008; 2017; in press; Gutherz et al. 2015). The analogies are based on the  
845 exclusivity of simple forms in the assemblage and medium sized formats, the absence of  
846 elements in relief, both decorative and for handling, the airy aspect of the compositions, the  
847 diversity of techniques and their combinations, and the place granted to herringbone or diamond  
848 compositions and to pivot impressions. These similarities may suggest that ceramic features  
849 dated to the earliest attestations of herding on the eastern shores of Lake Abhe may have  
850 persisted on the northern and western shores of the same lake between ~4-3.4 ka cal. BP.  
851 However, we see more distinctions than parallels between these traditions, namely with regard to  
852 more diverse decorative motifs on eastern shore sites. It is therefore not yet possible to directly  
853 associate the two phases of Kurub-07 with this tradition.

854

855 A few rare isolated body sherd fragments testify to the practice of applying a red slip to  
856 undecorated surfaces on pottery vessel walls before firing in the more recent occupation phase at  
857 the site of Kurub-07 as well as on other surface sites in the area (Fig. 9.k). This practice has also  
858 been attested at several sites in the eastern sector of Abhe Lake (Cauliez et al. 2016).

859

#### 860 **6.4 – Situating Holocene settlement in the Abhe paleolake basin in the context of Northeast** 861 **Africa**

862 From a wider inter-regional perspective, fishing, hunting and foraging of aquatic resources  
863 characterize many Early Holocene sites in the Saharan belt and the Sahel, at a time when  
864 paleolakes and vegetation flourished in today's arid zones as a result of the mesic conditions of  
865 the AHP. In these regions, populations drawn to the abundant aquatic resources available in  
866 surrounding lakes probably had low residential mobility, judging by the presence of cemeteries,

867 storage vessels and local raw material exploitation (Nash et al. 2011). These lakeside  
868 communities once termed *aqualithic* (Sutton 1974) are commonly grouped in association with  
869 bone harpoons and developed impressed pottery traditions that can first be found as early as ~12-  
870 10 ka cal. BP in the Sahara and Sahel, and as far south as Lake Turkana in Kenya (Beyin et al.  
871 2017; Goldstein et al. 2017; Sereno et al. 2008; Wright et al. 2015; Fig. 1.a). Elsewhere in the  
872 Horn of Africa, namely the Ziway-Shala and Abhe lake basins, aquatic resources played an  
873 important role in the economy while pottery and bone harpoon traditions were entirely absent  
874 (Coudert et al. 2018; Ménard et al. 2014).

875  
876 Through this wide angle, the transition to herding of Mesolithic or LSA fisher-hunter-gatherers  
877 was extremely variable, complementing enduring aquatic economies. The earliest evidence of  
878 herding in adjacent regions can be found in South Arabia between 9-8 ka cal. BP (Martin et al.  
879 2009; Fedele 2008), several millennia after its northern Near Eastern neighbors adopted farming.  
880 In both cases these Neolithic societies remain aceramic for millennia. In northeast Africa,  
881 herding, in association with regionally specific ceramic traditions appeared before farming. This  
882 is evidenced first in the Eastern Sahara and Nile Valley (Honneger 2011; Linseele et al. 2016)  
883 around 9-8 ka cal. BP, then in Lakes Turkana and Abhe around 4.8 ka cal. BP (Cauliez et al. in  
884 press; Chritz et al. 2019; Coudert et al. 2018), only becoming common during or after ~3 ka cal.  
885 BP in Southwest Ethiopia, the Kenyan Rift and Lake Victoria region (Ambrose 1998; Gifford-  
886 Gonzalez 2000; Hildebrand et al. 2010; Lesur et al. 2014: 51; Prendergast 2010; Fig. 1.a).

887  
888 The arid climatic conditions that took hold at the end of the AHP (~4.5-4.2 ka) are thought to  
889 have had a role in the southern spread of herding into East Africa following the retreating

890 monsoon belt (Kuper & Kropelin 2006). It has been argued that mobility associated with herding  
891 may have supported its spread, both through interaction and exchange of livestock with foragers,  
892 and through social networks that enabled them to thrive faced with growing aridity (Marshall et  
893 al. 2011). It has also been suggested that maritime mobility across the Red Sea, confirmed  
894 through obsidian sourcing studies (Khalidi et al. 2018, Oppenheimer et al. 2019) may have  
895 played a role in the spread of herding by means of coastal fisher-herding communities from  
896 southern Arabia (Gutherz et al. 2017; Lesur et al. 2014). However, the current study provides  
897 new data that suggest traditions in the Abhe Lake basin had few to no parallels with those in  
898 surrounding regions across the three periods of settlement documented in the region. Parallels  
899 that can be drawn with adjacent regions are limited to certain lithic traditions, though these have  
900 a large and persistent chrono-regional scope on the African continent and beyond, and to the  
901 domestic sheep and goat populations that were integrated into multi-resource economies  
902 sometime between 4.8 and 3.9 ka cal. BP in the Afar, but which are similar in all neighboring  
903 Neolithic contexts. The unique Abhe traditions are neither in line with Early Holocene harpoon  
904 potters and Mid-Holocene potter herders of the Sahara and Nile corridor, nor with Early  
905 Holocene Epipaleolithic hunter-gatherers and Mid-Holocene aceramic herders of Arabia.

906  
907 Today, the most robust chrono-cultural sequence outside of the Abhe and Ziway-Shala regions  
908 can be found in the Lake Turkana and Victoria basins in Kenya (Ashley et al. 2011; Beyin et al.  
909 2017; Hildebrand et al. 2018; Mirazon Lahr et al. 2016; Owen et al. 1982; Prendergast 2010;  
910 Robertshaw 1991; Robertshaw et al. 2010; Wright et al. 2015). A recent study comparing these  
911 two basins has demonstrated very distinct ecological responses to climatic changes in each, as

912 well as establishing the complexity of relations between these responses and early herding  
913 (Chritz et al. 2019: 129).

914

915 Similarly, correlation with lake-level proxies, human settlement pattern and archaeomaterial data  
916 demonstrate that over 9000 years, major socio-economic changes of populations inhabiting Abhe  
917 paleolakeshores were distinctive ecological responses to transformations in the local  
918 environment and to fluctuating lake levels.

919

## 920 **7 - Conclusion**

921 Through cross-examination of morpho-sedimentary and archaeological datasets we provide a  
922 preliminary reconstruction of the evolution of the Abhe paleolandscape and the lifeways of its  
923 Holocene populations as the lacustrine environment significantly transformed over 9000 years.

924

925 We present the first Holocene chrono-cultural sequence for the Ethiopian Afar including 23 <sup>14</sup>C  
926 dates on archaeological levels ranging between ~11 and ~3.5 ka cal. BP. These cluster into three  
927 periods during which we find preserved human settlement along shifting Abhe paleolakeshores.  
928 These three periods fall within the AHP, which is interrupted by and terminates with two  
929 sedimentologically documented hyperarid events (8.2 and 4.2 ka) hosting human occupations.  
930 Although human occupation levels are not continuous, these windows of site preservation offer  
931 insight into continuities and ruptures in techno-economic traditions of Abhe societies, which we  
932 interpret as ecological responses to local amplifier lake behavior in one of the most arid regions  
933 of the world.

934

935 Our results provide a revised Early to Late Holocene model of lake-level fluctuations linked to  
936 dynamic peri-lacustrine landform evolution. The centennial-scale reactivity of this amplifier lake  
937 to climatic forcing is echoed in the variability of settlement location and strategy, and in the  
938 flexible multiple resource economies of its populations over time. Most interestingly, our data  
939 suggest that the Abhe Lake basin hosted populations with local techno-economic traditions who  
940 relied on aquatic resources even with the introduction of domestic herds. As we have yet to find  
941 continuity in human occupation over 9000 years, it is possible that different populations settled  
942 the area over time, and that stable lake levels attracted more groups to the area, while extreme  
943 lake level rise and fall forced groups to move to higher altitudes or towards isolated oases and  
944 refugia as has been suggested for amplifier lakescapes (Maslin et al. 2014; Trauth et al. 2010),  
945 and more generally for arid environments (see Purdue et al. (eds.) 2018). Throughout the periods  
946 represented, our data are consistent with populations adapted to lakeshore fluctuations, and  
947 populations with continuity in traditions between hyperarid events.

948

949 This local multi-scalar and multi-proxy approach allows a preliminary diachronic restitution of  
950 human ecological responses to local landscape transformation that would normally have been  
951 overlooked and overshadowed by correlations with regional and global climate proxies. These  
952 results provide the first data available on Early to Late Holocene human occupations in the  
953 Ethiopian Afar and on the transformation and resilience of prehistoric human societies in the  
954 context of the dynamic and arid landscape they occupied.

955

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975

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1408 **Figure captions**

1409 **Figure 1. a)** Regional map (after GMTED2010, SRTM) with the location of the VAPOR-Afar  
1410 project area, sites mentioned in the text, and a schematic representation of the earliest attestations  
1411 of herding in the Horn of Africa; **b)** Satellite image (LANDSAT) of the Lower Awash valley in  
1412 the Ethiopian Afar with the location of VAPOR-Afar archaeological sites and modelling of the  
1413 Abhe Lake highstand between 10.2-9.8 ka cal. BP; **c)** Abhe Lake level phases after Gasse &  
1414 Street (1978).

1415  
1416 **Figure 2. a)** Multi-plot of calibrated ages from archaeological and palustrine layers, and littoral  
1417 lacustrine carbonates (OxCal v4.3.2 Bronk Ramsey (2017); r:5 IntCal13 atmospheric curve  
1418 (Reimer et al. 2013); **b)** Abhe paleolake level curve calculated from calibrated ages and  
1419 recalculated elevations taken from Gasse (1975) and from new ages on littoral lacustrine  
1420 carbonates.

1421  
1422 **Figure 3. a)** Raso-02 archaeological site sequence with calibrated ages; **b)** Lakora-03  
1423 archaeological site sequence with calibrated ages; **c)** Satellite image (LANDSAT) with locations  
1424 of Raso-02 and Lakora-03 sites, dated littoral lacustrine carbonates (this study) and dated littoral  
1425 lacustrine markers (Gasse 1975) and modelling of Early Holocene Abhe Lake highstand ~10.6  
1426 ka cal. BP; **d)** Photogrammetry and point plotted artifacts from the main archaeological layer of  
1427 the Lakora-03 site.

1428  
1429 **Figure 4.** Lakora-03 obsidian lithic artifacts: a-c) surface collection, d-f) Sounding 1 (S1); **a)**  
1430 blade core, **b)** bladelet core on dorsal surface of truncated blade (“Kostienki knife” core), **c)** re-

1431 oriented bladelet core, **d**) notched(?) bladelet, **e**) bladelet, **f**) endscraper on retouched blade  
1432 (possibly used as intermediary piece).

1433

1434 **Figure 5.** **a**) DEM (1 m resolution) of the site of Det Bahari-01 with point plotted surface  
1435 artifacts, calibrated ages, and lithic conjoins; **b**) Stromatolis archaeological sequence with  
1436 calibrated ages; **c**) Photogrammetry of the Stromatolis site.

1437

1438 **Figure 6.** **a**) SP-01 archaeological sequence with calibrated ages and a schematic morpho-  
1439 sedimentary model of the littoral lacustrine profile of Abhe Lake; **b**) MS-01/02 archaeological  
1440 sequence with calibrated ages; **c**) Satellite image (LANDSAT) with locations of SP-01, MS-01/-  
1441 02, Det Bahari-01 and Stromatolis sites and modelling of Abhe Lake highstand between 9.8 and  
1442 8.2 ka cal. BP.

1443

1444 **Figure 7.** Det Bahari-01 obsidian lithic artifacts: **a**) technical blade (neocrest), **b**) retouched  
1445 blade fragment, **c**) double-endscraper on blade, **d-f**) backed pieces, **g-h**) splintered pieces.

1446

1447 **Figure 8.** **a.1**) Kurub-07 western section of the K-trench archaeological sequence with location  
1448 of calibrated ages; **a.2**) Orthophotograph of anthropic structure (ST1, oven) excavated at the  
1449 Kurub-07 site with locations of calibrated ages; **a.3**) Aerial kite photograph of excavations at  
1450 Kurub-07 draped with point-plotted artifacts; **b**) Satellite image (LANDSAT) with the location  
1451 of the Kurub-07 site with modelling of the Abhe Lake regression phase between 5.5-4.6 ka cal.  
1452 BP.

1453

1454 **Figure 9.** Decorated ceramics from the site of Kurub-07. *Phase 1:* **a)** Refitted vessel with  
1455 combination incision / simple impression: a line incised with a blunt point under which there is a  
1456 strip composed of multiple tooth comb impressed oblique lines. **b)** Refitted vessel with flat rim  
1457 adorned with oblique lines and chevron pendant followed by pivoting impressions on body. **c)**  
1458 Refitted vessel with simple impressions by means of oblique lines in horizontal band. *Phase 2* is  
1459 characterized by decorated flat or externally beveled rims and diverse motifs combined on the  
1460 same vessel **d):** Vessel with band of oblique comb impressed lines under which parallel  
1461 horizontal dotted lines frame comb impressed lozenges decorated with comb impressed motifs or  
1462 herringbone motifs made with comb impressed oblique lines. **e)** Body sherd with combination of  
1463 incision / simple impression and impressed oblique lines applied with a spatula on the rim. **f)**  
1464 Two body sherds with roulette impressions. **g)** Rim sherd with simple comb impressions. **h-i)**  
1465 Body sherds with pivoting impressions with a comb or shell. **j)** Body sherd with decorations that  
1466 associate two impression techniques: a simple impression with a triangular tipped awl and a  
1467 pivoting impression with a shell or a comb. **k)** Body sherd with red slip applied before firing,  
1468 testifying to the application of colorants on certain pottery vessels.

1469  
1470 **Figure 10.** Holocene paleovariations of **a)** June insolation at 15°N (Berger & Loutre 1991); **b)**  
1471  $\delta D$  WAX (‰; Costa et al. 2014) and Ti (mg/g; Marshall et al. 2011), Tana Lake; **c)** planktonic  
1472 diatoms (%; Chalié & Gasse 2002) and lake levels (Gillespie et al. 1983), Ziway-Shala basin. **d)**  
1473 Abhe paleolake level curve calculated from calibrated ages and recalculated elevations taken  
1474 from Gasse (1975) and from new ages on littoral lacustrine carbonates with plotted calibrated  
1475 dates and elevations of dated archaeological sites of the VAPOR-Afar project sites presented in

1476 this study. e) Regional map (after GMTED2010, SRTM) with localization of Tana, Ziway-Shala  
1477 and Abhe Lakes.

1478

## 1479 Tables

1480 **Table 1.** Radiocarbon ages and elevations from littoral lacustrine carbonates from Abhe  
1481 paleolake in Ethiopia. \* rejected ages.

1482 **Table 2.** Radiocarbon ages and elevations from archaeological sites (VAPOR-Afar project,  
1483 Ethiopia) and associated palustrine layers. \* rejected ages. The site of Det Bahari-01 (correct  
1484 local name) was originally named Bet Bahari-01 based on appellation of the area on a map of the  
1485 region (hence the Betba-01 site label). All samples have retained the old site label.

1486 **Table 3.** Preliminary faunal spectrum from Kurub-07, Det Bahari-01 and Lakora-03 according to  
1487 the NISP (Number of Identified Specimens Parts).

1488 **Table 4.** Aspects of subsistence and technology according to period and Abhe Lake maximum  
1489 highstand.

1490

## 1491 Appendices

1492 **A.1.** Conventional and calibrated radiocarbon ages selected from Gasse (1975) with recalculated  
1493 elevations based on a DEM (TanDEMx at 12 m resolution).

1494

Sample Name	Material	Lab Code	Conventional yr BP	yr cal BP 2 $\sigma$ (range, 95.4 %)	Median yr cal BP	Elevation (DEM $\pm$ 12 m)
<b>Strom_20-SU5</b>	Stromatolite	SacA58238	9689 $\pm$ 40	11210-10805	11125 $\pm$ 113	359
<b>Strom_20-SU4</b>	Stromatolite	SacA58239	9320 $\pm$ 40	10660-10404	10530 $\pm$ 64	359
<b>Strom_20-SU1</b>	Stromatolite	SacA58240	9265 $\pm$ 40	10565-10295	10447 $\pm$ 73	359
<b>Logiya_1A</b>	Lacustrine Shell	Beta 446441	9180 $\pm$ 30	10477-10245	10241 $\pm$ 27	401
<b>Logiya_1B</b>	Charcoal	Beta 446442	9100 $\pm$ 30	10477-10245	10330 $\pm$ 55	401

<b>Strom_10a</b>	Stromatolite	SacA55608	8790 ± 30	10112-9679	9807 ± 81	366.8
<b>Strom_10b</b>	Stromatolite	SacA55609	8075 ± 35	9123-8785	9008 ± 70	366.8
<b>Srom_31</b>	Stromatolite	Poz-113925	7910 ± 50	8978-8598	8743 ± 109	371.7
<b>Strom_13</b>	Stromatolite	SacA55611	5919 ± 30	6829-6666	6738 ± 40	359
<b>Raso-02_Strom</b>	Stromatolite	Poz-113843	5085 ± 35	5913-5746	5815 ± 51	366
<b>Strom_7</b>	Stromatolite	SacA55610	5005 ± 30	5889-5653	5732 ± 69	361.5
<b>Stromatolis-SU1</b>	Stromatolite	Poz-113841	4910 ± 30	5712-5591	5632 ± 29	371.7
<b>Strom_17A*</b>	Stromatolite	Poz-113842	3310 ± 30	3610-3458	3529 ± 40	368
<b>Strom_32*</b>	Stromatolite	Poz-116164	1045 ± 30	1050-921	953 ± 31	406

1495

1496 Table 1

1497

Sample Name	Site	SU	Material	Lab Code	Conventional yr BP	yr cal BP 2σ (range, 95.4 %)	Median yr cal BP	Elevation (DEM ± 12 m)
<b>Lak3-T1-SU5-101</b>	Lakora- 03	5	charcoal	Poz-111634	9590 ± 60	11164-10737	10939 ± 121	365.4
<b>Raso-02-Sond2-SU2*</b>	Raso-02	2	charcoal	Poz-111635	9430 ± 50	11057-10515	10662 ± 92	366
<b>Raso-02-Sond2-SU5</b>	Raso-02	5	charcoal	Poz-111496	9370 ± 60	10744-10418	10595 ± 89	366
<b>MS1_US1_001</b>	MS-01	1	organic sediment	Poz-105343	7290 ± 50	8190-8000	8100 ± 55	355.8
<b>Betba-1291</b>	Det Bahari-01	1	hippo bone	UBA34899	7031 ± 43	7956-7761	7872 ± 49	372.5
<b>Betba-11</b>	Det Bahari-01	1	hippo bone	UBA34900	6749 ± 40	7674-7523	7609 ± 32	372.5
<b>SP-01_US2_001</b>	SP-01	2	organic sediment	Poz-105340	6570 ± 40	7564-7424	7472 ± 37	378.4
<b>Kur-07-K15-Spit4-558</b>	Kurub-07	15	organic sediment	Beta-446445	4920 ± 30	5715-5596	5638 ± 32	352.8
<b>Kur-07-K14-US15-1203</b>	Kurub-07	15	charcoal	LTL17832A	3520 ± 45	3914-3647	3788 ± 64	352.8
<b>Kur-07-L16-US15-1283</b>	Kurub-07	15	charcoal	LTL17833A	3434 ± 45	3830-3587	3692 ± 68	352.8
<b>Kur-07-K10-Spit2-591</b>	Kurub-07	12	charcoal	Beta-446443	3330 ± 30	3638-3477	3565 ± 46	352.8
<b>Kur-07-US29-2443</b>	Kurub-07	29	organic sediment	Poz-116280	3325 ± 30	3636-3476	3556 ± 45	352.8
<b>Kur_07_ST6_655*</b>	Kurub-07	41	charcoal	Poz-116049	3305 ± 30	3607-3455	3526 ± 39	352.8
<b>Kur-07-L10-US10-1136</b>	Kurub-07	10	charcoal	Poz-107746	3300 ± 35	3611-3450	3524 ± 43	352.8
<b>Kur_07_Spit8_661*</b>	Kurub-07	41	charcoal	Poz-117158	3295 ± 30	3588-3451	3520 ± 37	352.8
<b>Kur-07-US26-2383</b>	Kurub-07	26	organic sediment	Poz-117159	3270 ± 30	3572-3409	3501 ± 40	352.8
<b>Kur-07-US12-2459</b>	Kurub-07	12	organic sediment	Poz-116197	3265 ± 30	3568-3407	3495 ± 41	352.8
<b>Kur-07-K15-Spit8-663B*</b>	Kurub-07	41	charcoal	Beta-4477956	3250 ± 30	3562-3400	3473 ± 45	352.8
<b>Kur-07-L10-667</b>	Kurub-07	10	charcoal	Beta-446444	3180 ± 30	3456-3356	3405 ± 30	352.8
<b>Betba01log2A</b>	Det Bahari-01	Palustrine layer	Shell	Beta 446440	9180 ± 30	10477 - 10245	10330 ± 55	372.5
<b>Betba01log2B</b>	Det Bahari-01	Palustrine layer	shell	Beta 446439	9000 ± 30	10236 - 9975	10199 ± 43	372.5
<b>Stromatolis_US4</b>	Stromatolis	4	terrestrial shell	Poz-116165	7730 ± 50	8593-8419	8506 ± 49	371.7
<b>Kur-07-K15-US18-1488</b>	Kurub-07	18	organic	Poz-107669	5990 ± 360	7587-6022	6853 ± 381	352.8



sediment

1498 Table 2

1499

Taxa	Kurub-07	Det Bahari-	
		01	Lakora-03
Large mammals	28	4	67
Hippopotamus ( <i>Hippopotamus amphibius</i> )		12	
Cattle ( <i>Bos taurus</i> )	9		
Bovine (Bovini)	9		
Middle-sized bovid	165	8	
Sheep/goat ( <i>Ovis aries/Capra hircus</i> )	16		
<i>Gazella cf. dorcas</i>	2		
Unidentified rodent	16		
Unidentified bovid	38		1
Nile crocodile ( <i>Crocodylus niloticus</i> )		6	
Unidentified reptile	7		
Large cyprinid (Cyprinidae)			1
<i>Clarias</i> sp.			3
Clariidae			375
Siluriform	2	17	22
Tilapia (Haplotilapinii)	4	2	1
Unidentified fish	5	14	409
<b>Total identified vertebrate</b>	<b>301</b>	<b>63</b>	<b>879</b>
Ostrich eggshell	9		2
<i>Melanoides tuberculata</i>			3
Unidentified gastropod			3
Unidentified bivalve			1
Unidentified shell	6		3
<i>Unidentified</i>	782	35	1678
<b>TOTAL</b>	<b>1098</b>	<b>98</b>	<b>2569</b>

1500 Table 3

1501

Settlement period	Aspects of subsistence	Aspects of Technology	Representative sites	Lake Abhe highstand (m a.s.l.)
Early	Fishing, Hunting,	Blade oriented	Lakora-03	420 – 380

Holocene 11.7 – 8.2 ka	Gathering	debitage  Personal adornment (ostrich eggshell beads)  Bone tools?	Raso-02	
Middle Holocene 8.2 – 4.2 ka	Fishing, Hunting, Gathering	Ground stone  Blade/bladelet orienteddebitage/ curved backed pieces  Simple circular structures	Stromatolis  MS-01/02  SP-01  Det-Bahari-01	380
early Late Holocene 4.2 – 3 ka	Herding, Fishing, Hunting, Gathering  Trade?	Ground stone  Decorated pottery  Flake orienteddebitage/ curved backed pieces  Personal adornment (diverse materials)  Monumental funerary traditions  Complex oven structures  Long-distance interaction	Kurub-07	< 350

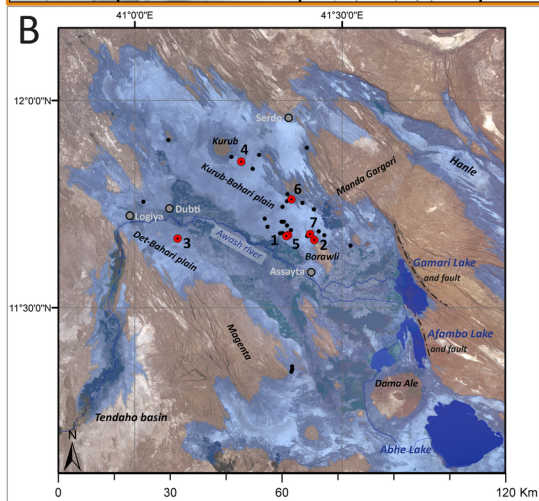
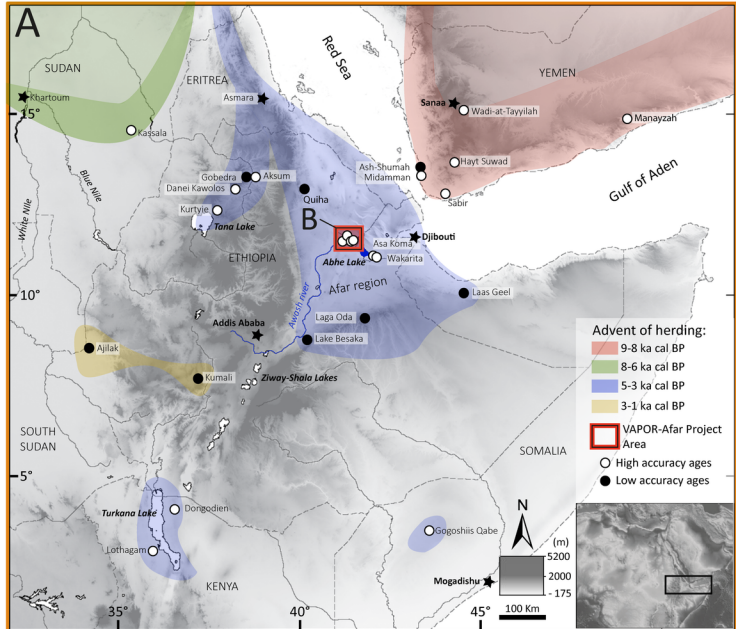
1502 Table 4

1503

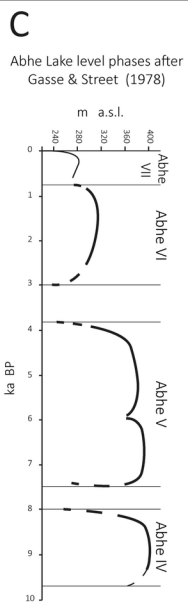
N° (Gasse 1975)	Sample name (Gasse 1975)	Conventional age yr BP	Longitude	Latitude	Selection and rejection criteria	Calibrated ages yr BP (range 95.4 %)	Calibrated ages yr BP (median)	Recalculated elevations (DEM ± 12 m)
Gasse_1	B88	98.8 ± 1.2	41°48'	11°59'		255 – 31	121 ± 78	240
Gasse_2		100.6 ± 0.9	41°52'	11°09'		255 – 31	122 ± 78	231.7
Gasse_6	M 245	110 ± 50	41°50'	11°15'		276 – 9	124 ± 81	256.4
Gasse_7	M 108	1030 ± 100	41°41'	11°29'		1178 – 738	984 ± 115	256.4

<b>Gasse_8</b>	M 104	1300 ± 100	11°37'	11°09'	Gamari residual lake	\	\	\
<b>Gasse_9</b>		1570 ± 60	41°52'	11°09'		1597 – 1337	1464 ± 63	314
<b>Gasse_11</b>		2360 ± 80	41°52'	11°09'		2715 – 2160	2429 ± 140	295
<b>Gasse_13</b>		2720 ± 120	41°52'	11°09'		3172 – 2490	2850 ± 55	285
<b>Gasse_14</b>	M 284	3290 ± 160	41°26'	11°39'	Residual lake	\	\	\
<b>Gasse_16</b>	A 646	4120 ± 110	42°08'27	11°00'34'		4874 – 4297	4643 ± 144	346.8
<b>Gasse_18</b>		4740 ± 150	42°08'27	11°00'34'		5881 – 4983	5455 ± 93	354.9
<b>Gasse_19</b>		4750 ± 230	42°08'	11°05'	Pedological deposit (Fontes et al. 1973)	\	\	\
<b>Gasse_22</b>	M 277	5080 ± 480			Incomplete coordinates	\	\	\
<b>Gasse_29</b>		5775 ± 115			Incomplete coordinates of pedological deposit (Semmel 1971)	\	\	\
<b>Gasse_30</b>	B 38	5830 ± 140	42°09'	11°00'		6972 – 6316	6647 ± 167	355.6
<b>Gasse_33</b>	A 648	5930 ± 130	42°09'	11°00'		7156 – 6468	6769 ± 167	355.6
<b>Gasse_34</b>	A 32	6020 ± 160	41°24'	11°21'		7256 – 6501	6884 ± 196	349.6
<b>Gasse_35</b>		6130 ± 250	41°51'	11°15'		7498 – 6448	7002 ± 271	327
<b>Gasse_38</b>		6290 ± 100	41°52'	11°09'	Lack of interpretation of formation processes (Fontes & Pouchan 1975)	\	\	\
<b>Gasse_39</b>		6335 ± 110			Incomplete coordinates of pedological deposit (Semmel 1971)	\	\	\
<b>Gasse_40</b>		6350 ± 105			Incomplete coordinates of pedological deposit (Semmel 1971)	\	\	\
<b>Gasse_41</b>	M 109	6360 ± 260	41°40'	11°36'	Gamari residual lake	\	\	\
<b>Gasse_43</b>		6610 ± 100			Incomplete coordinates of pedological deposit (Semmel 1971)	\	\	\
<b>Gasse_44</b>	M 105	6630 ± 220	41°41'	11°34'	Gamari residual lake	\	\	\
<b>Gasse_47</b>	M 105	6690 ± 160	41°41'	11°34'	Gamari residual lake	\	\	\
<b>Gasse_49</b>	B 459	6835 ± 160	42°08'	11°05'		7965 – 7432	7697 ± 142	371.3
<b>Gasse_50</b>	S 94	6910 ± 180	40°51'	11°47'	Incoherent age	\	\	\

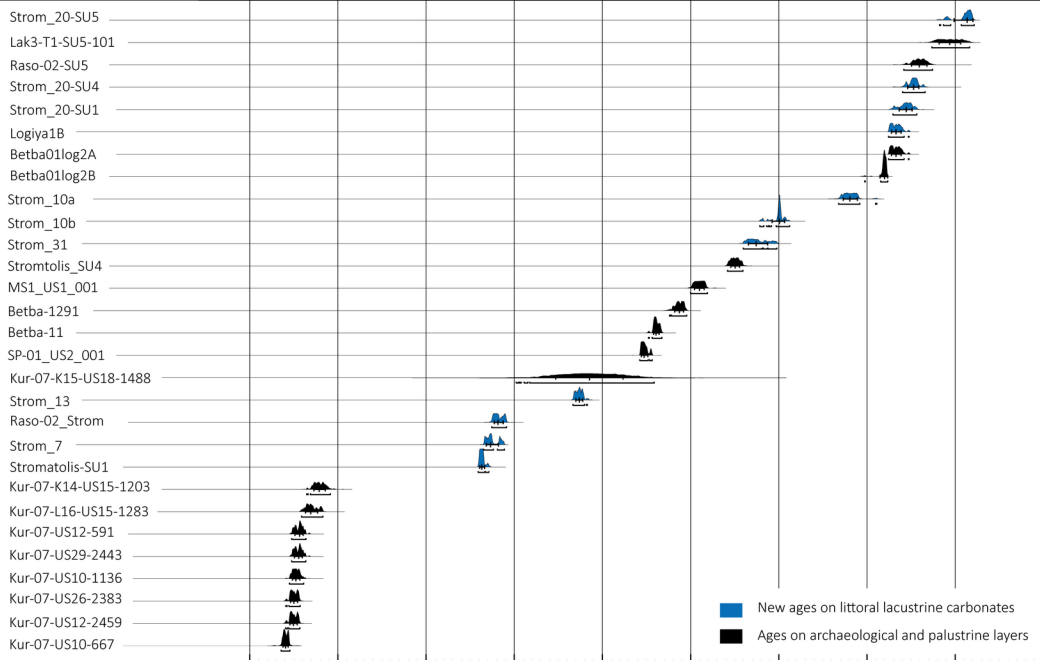
Gasse_53	C7	7000 ± 140	41°53'	11°08'	Deepwater lacustrine deposit	\	\	\
Gasse_54	B 87	7150 ± 320	41°49'	10°59'	Reworked sediment	\	\	\
Gasse_56	B 126	7190 ± 220	41°42'	11°29'	Gamari residual lake	\	\	\
Gasse_57	M 238	7250 ± 150	41°49'35"	11°15'02"		8375 – 7795	8082 ± 148	239.7
Gasse_58		7265 ± 60	42°08'	11°15'	Inverted age with M 238	\	\	\
Gasse_62	B 428	7450 ± 100	42°04'	11°06'		8416 – 8037	8263 ± 99	363.7
Gasse_63	A 30	7460 ± 180	41°22'	11°24'		8630 – 7934	8268 ± 181	362.2
Gasse_64	A 645	7610 ± 140	42°08'27"	11°00'34"		8770 – 8054	8420 ± 158	346.8
Gasse_74	A 100	8000 ± 170	41°29'	11°39'	Residual lake	\	\	\
Gasse_76	M 185	8340 ± 180	41°26'	11°27'		9704 – 8770	9302 ± 219	391.8
Gasse_77		8380 ± 100			Incomplete coordinates	\	\	\
Gasse_79	A11	8450 ± 190	41°?	11°32'	Incomplete coordinates	\	\	\
Gasse_80	A 26	8450 ± 190	41°22'	11°24'		10129 – 8996	9434 ± 255	362.2
Gasse_82	A 6	8530 ± 190	41°04'	11°44'		10154 – 9090	9545 ± 263	369.6
Gasse_84	M 282	8580 ± 160	41°26'	11°34'	Deepwater lacustrine deposit	\	\	\
Gasse_85	M79	8600 ± 140	41°26'	11°38'		10151 – 9305	9633 ± 194	366.5
Gasse_86	M2 246	8620 ± 75	41°45'	11°18'	Deepwater lacustrine deposit	\	\	\
Gasse_87	A 25	8650 ± 160			Incomplete coordinates	\	\	\
Gasse_88		8715 ± 120	41°20'	11°40°	Lack of interpretation and contextualization of formation processes interpretation and contextualisation (Taieb 1971)	\	\	\
Gasse_90	A 22	8770 ± 190	41°19'	11°26'		10273 – 9436	9848 ± 230	432.4
Gasse_93		9180 ± 220	41°51'	11°?	Incomplete coordinates	\	\	\
Gasse_94	S 119	9230 ± 180	40°54'	11°48'		11084 – 9917	10444 ± 260	408.2
Gasse_96	M 135	9380 ± 130	41°27'	11°35'		11086 – 10253	10623 ± 216	342.1
Gasse_100	M 101	10760 ± 220	41°42'	11°28'	Gamari residual lake	\	\	\
Gasse_103	M 161	13170 ± 170	41°53'	11°08'	Residual groundwater carbonates	\	\	\



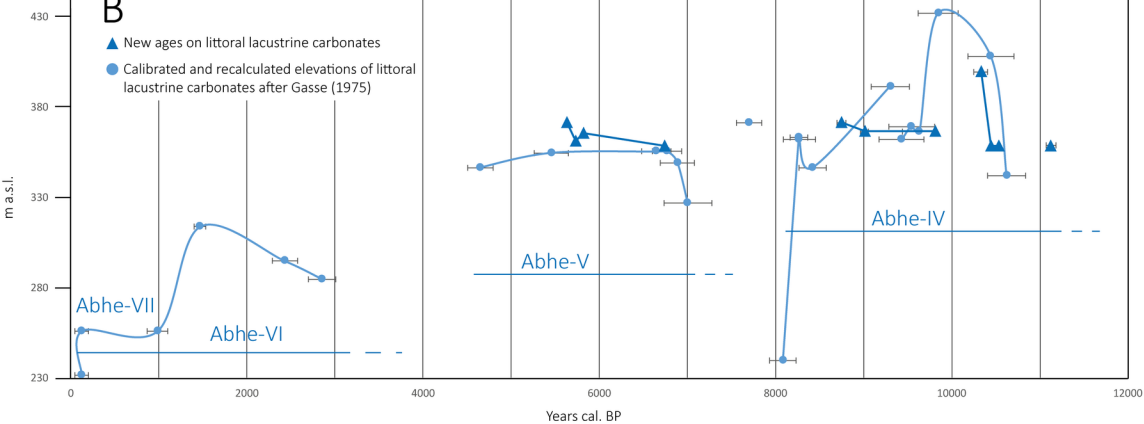
- Dated archaeological sites
  - Other archaeological sites
  - Modern towns
1. Kurub-07
  2. SP-01
  3. Det-Bahari-01
  4. Stromatolis
  5. MS-01/02
  6. Raso-02
  7. Lakora-03



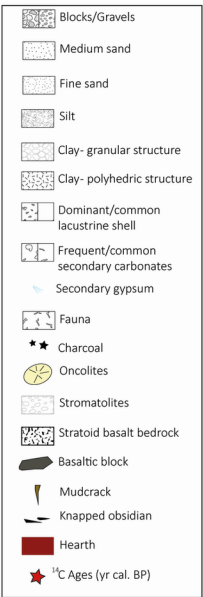
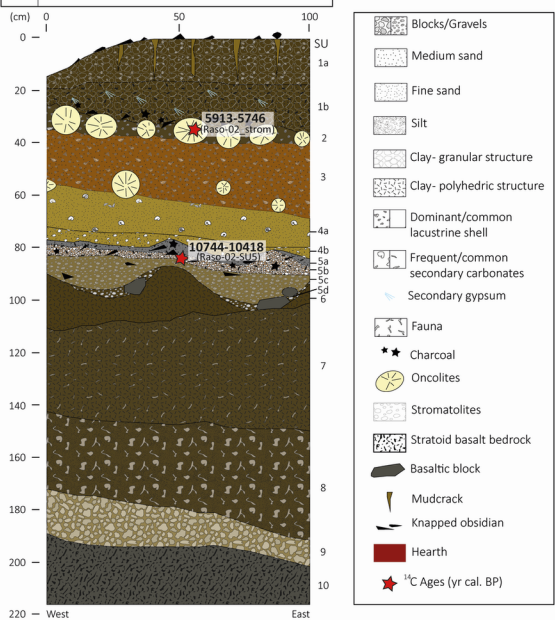
A



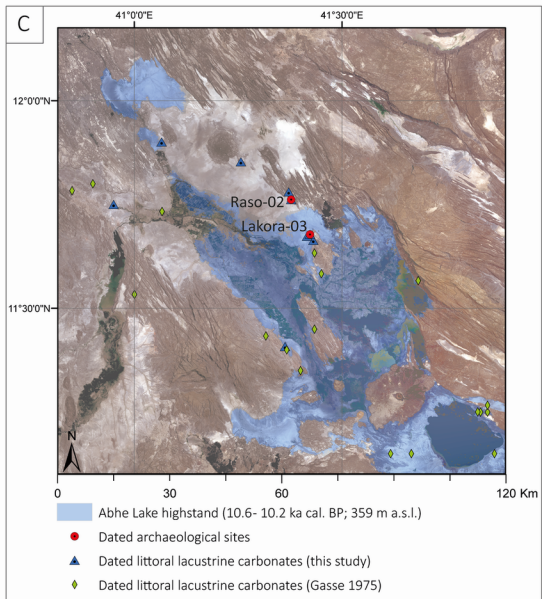
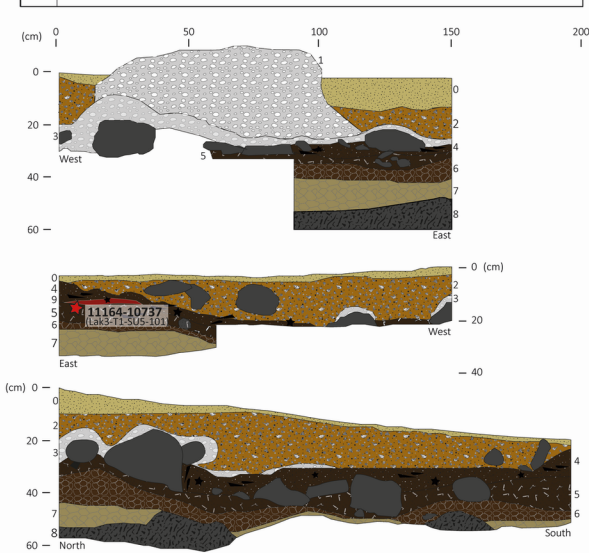
B



### Raso-02



### Lakora-03

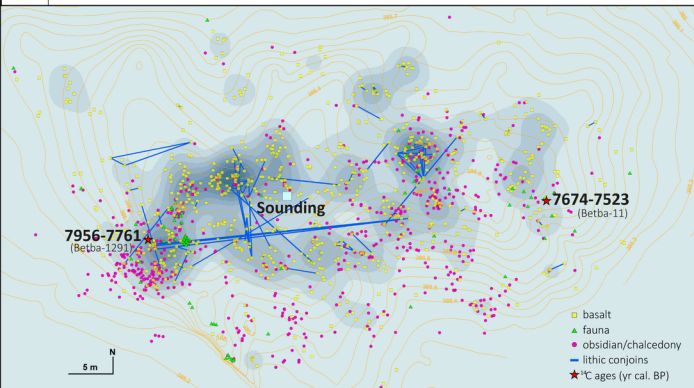


■ = Artifacts from main archaeological level (SU 4) of Lakora-03 site



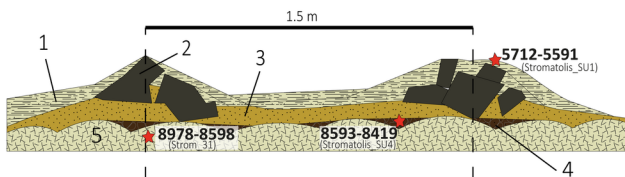
A

Det Bahari- 01



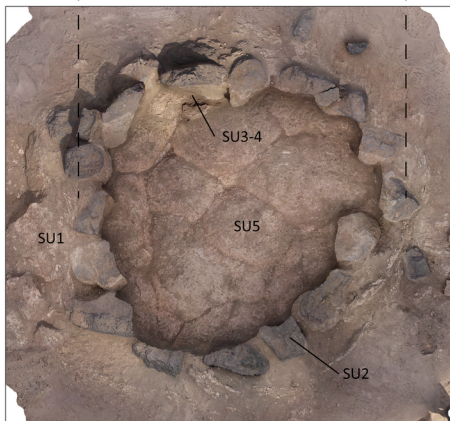
B

Stromatolite schematic section



C

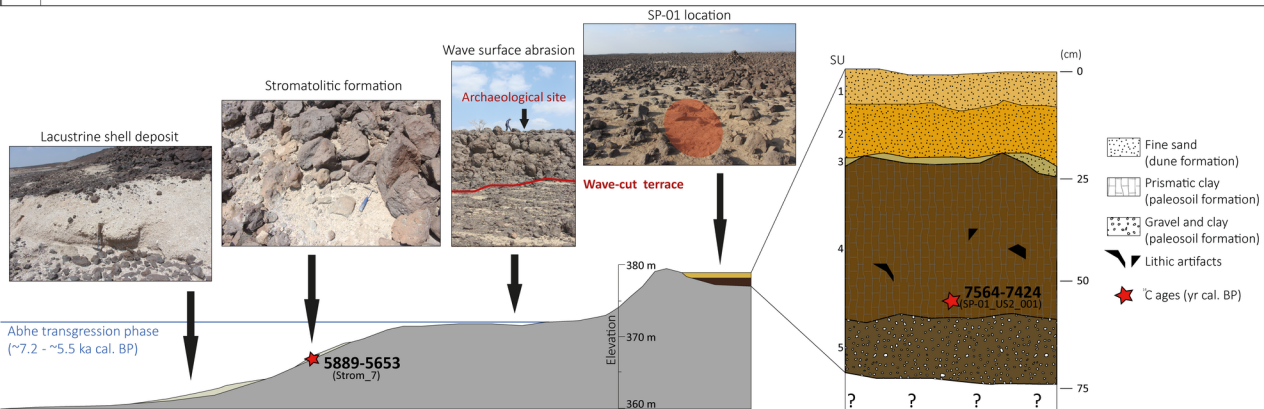
Stromatolite orthophoto



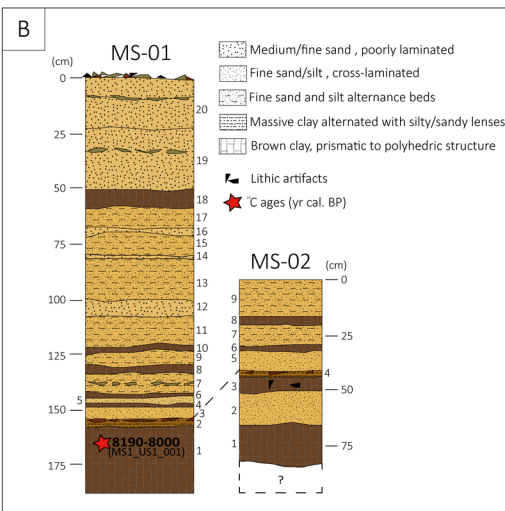
1. Second generation stromatolites (laminated structure, ripple marks)
  2. Basaltic blocs, circular anthropic structure
  3. Aeolian fine/medium sand
  4. Clay-silt, granular structure with terrestrial shells
  5. First generation stromatolites (columnar structure)
- ★  $^{14}\text{C}$  ages (yr cal. BP)



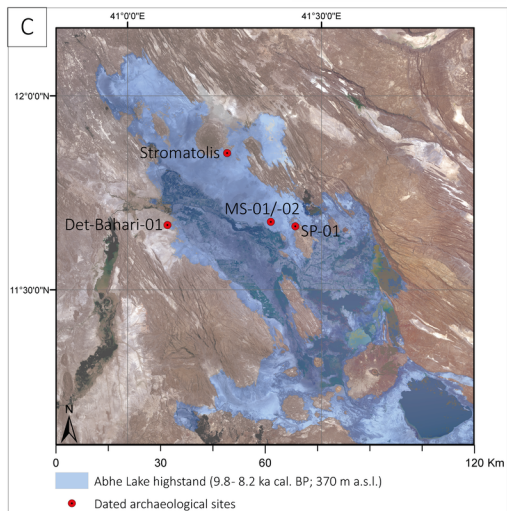
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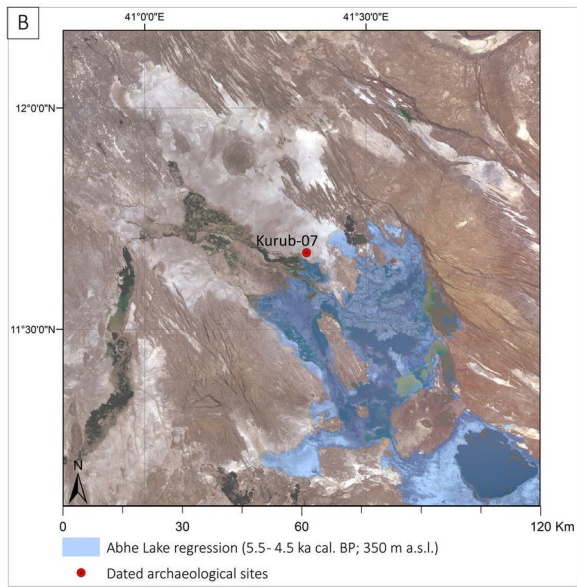
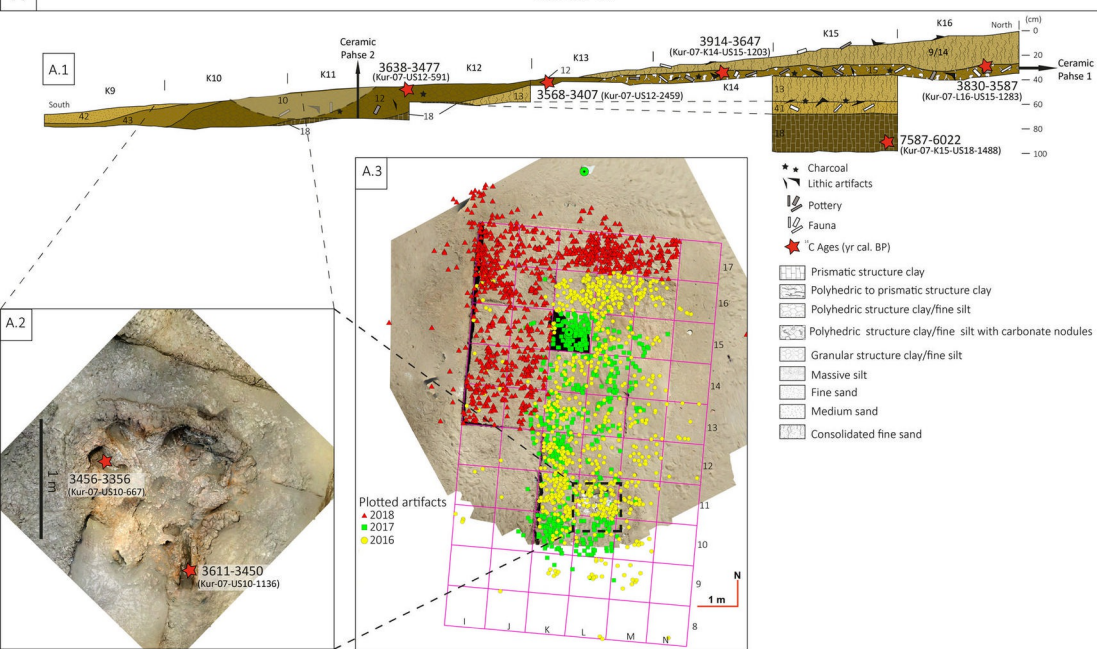
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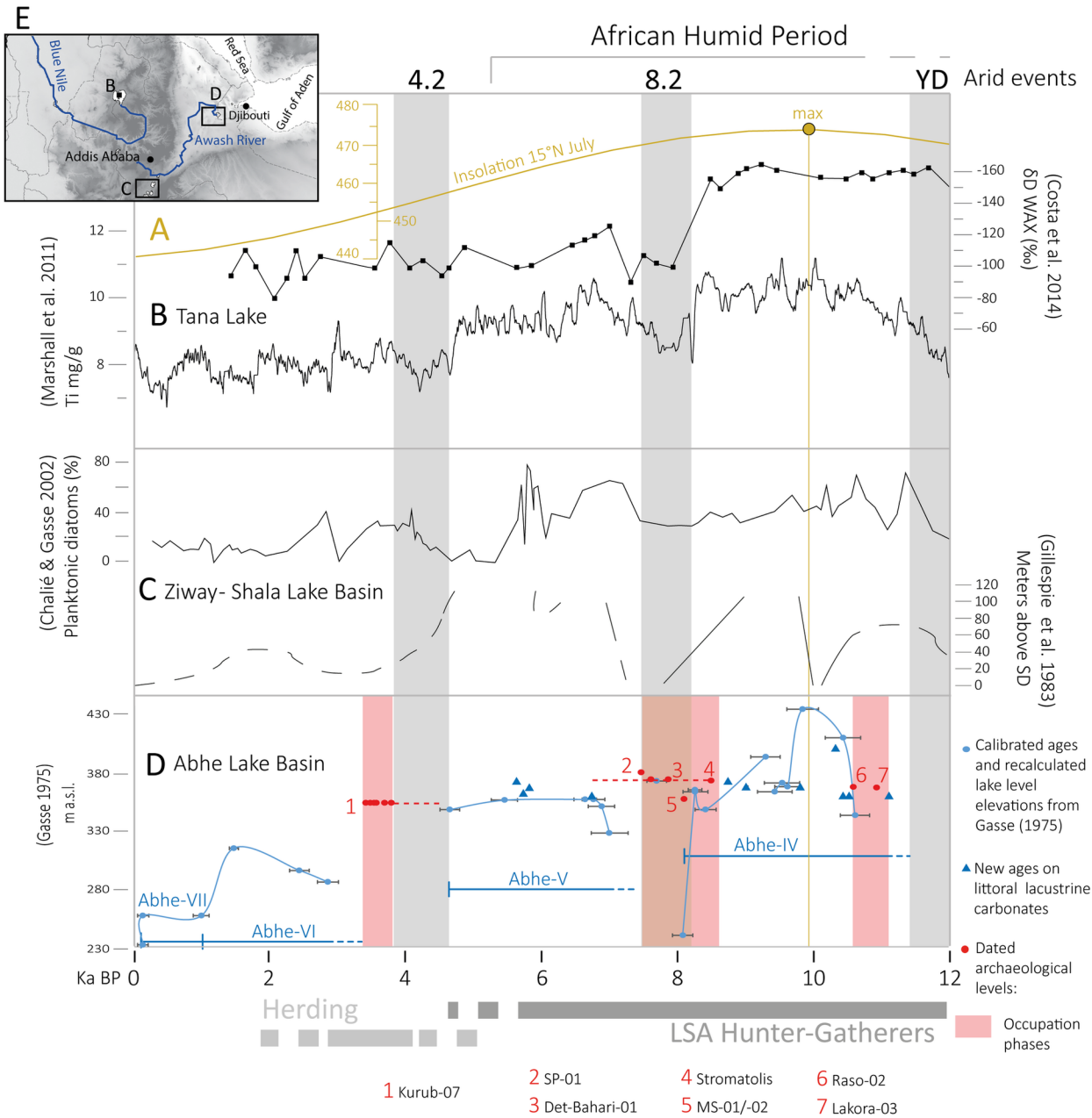


C



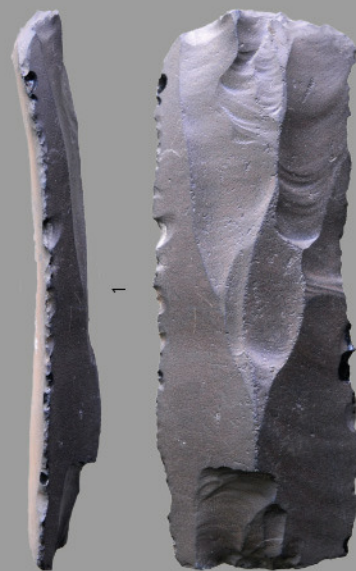
# Kurub-07



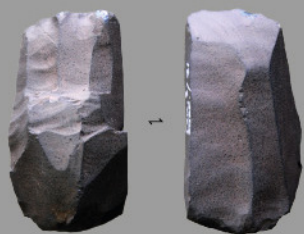




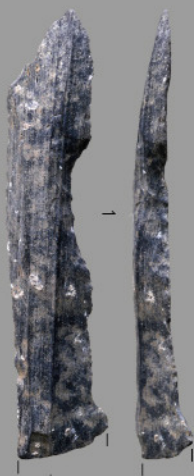
(a)



(b)



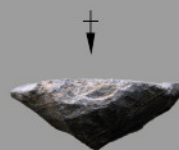
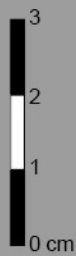
(c)



(d)



(e)



(f)



