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1 **OSL chronology of socio-ecological systems during the mid-Holocene in the eastern**  
2 **coast of the Sultanate of Oman (Arabian Peninsula)**

3  
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12

13

14 **Abstract**

15

16 The eastern coast of the Arabian Peninsula is a key region to explore past climatic and  
17 environmental changes and their impact on the coastal ecosystems and Neolithic communities  
18 during the mid-Holocene (~8000-5000 years ago). Indeed, it is located at the frontier zone  
19 between dry and wet tropical systems, where the monsoon has reduced its activity and  
20 gradually shifted southward from the 6<sup>th</sup> millennium BC. Past human adaptation to new  
21 ecological conditions (more arid) and resources is reflected in the archaeological record, as a  
22 response to important climatic and eustatic fluctuations.

23 In order to correlate human occupation during the Neolithic with the local climatic  
24 and palaeoenvironmental records, sediments were sampled at two archaeological sites and  
25 surrounding sabkhas, located in the Ja'alan region, on the eastern coast of the Sultanate of  
26 Oman. Optically and infrared stimulated luminescence dating were applied to quartz and  
27 feldspar grains extracted from sediments coming from both archaeological (Ruways 1 and  
28 Suwayh 1 shell middens) and palaeoenvironmental (current sabkhas) contexts in order to  
29 provide, together with radiocarbon dating, a chronology for this area. The results obtained  
30 allowed constraining human occupation during the Neolithic between  $8340 \pm 480$  and  $5390 \pm$   
31  $290$  years (~6800-3100 years BC) at Ruways 1, and between  $6180 \pm 310$  and  $5480 \pm 270$   
32 years BP (~4500-3200 years BC) at Suwayh 1. These occupations coincide with the  
33 development of a lagoon/mangrove, recorded in sediments from cores drilled under the

34 current sabkha, whose last stage of development is dated to  $5320 \pm 590$  (C2) and  $5220 \pm 570$   
35 (C1) years (3900-2600 years BC) at Khor al Jaramah.

36

## 37 **1. Introduction**

38

39 The study of past groups of coastal fisher-gatherer-herders in their palaeoenvironmental  
40 context is of great interest to understand the resilience of these populations facing important  
41 climatic changes during the mid-Holocene in the Arabian Peninsula. The eastern coast of the  
42 Arabian Peninsula, and more specifically the Ja'alan region in the Sultanate of Oman (Fig. 1),  
43 presents several important archaeological sites documenting human occupation starting from  
44 the middle of the 6<sup>th</sup> millennium BC (~8000-7000 years; Charpentier 2008; Berger et al.,  
45 2005). During the mid-Holocene, this territory suffered climatic (Indian-Arabian monsoon),  
46 eustatic and tectonic fluctuations, which might have directly affected Neolithic populations  
47 that exploited marine, lagoon and deltaic resources (Berger et al., 2005; Berger et al., 2013).

48 More specifically, along the Oman coast, a particular Neolithic economy flourished  
49 during the first half of the mid-Holocene, without pottery and agriculture but with a  
50 significant component of marine resources associated with the presence of a few domesticated  
51 animals (Crassard and Dreschler, 2013). Coastal environments and marine resources have  
52 played a major role in the Neolithic development of eastern Arabia, as an apparent resilience  
53 to climatic variations during the mid-Holocene. After the onset of the humid period around  
54 9000 years (end of the early Holocene), this sub-arid to arid zone suffered rapidly changing  
55 environmental conditions, with past latitudinal monsoon circulation and upwelling activity  
56 changes through time (Jung et al., 2004, Fleitmann et al., 2007, Parker et al., 2008) that  
57 impacted coastal paleoenvironments and biomass productivity (Lézine et al. 2010; Berger et  
58 al. 2013; Bassinot et al. 2011).

59 The effect of climate change on Neolithic populations over a long time, inducing  
60 environmental and economic stress, can be investigated by cross-checking data from human  
61 occupation in shell middens with palaeoenvironmental records. The evolution of coastal  
62 environments can be reconstructed through the study of transects in sections and cores in  
63 archaeological sites and surrounding sabkhas. This study focuses on establishing the  
64 chronology of the occupation phases of stratified shell middens that were produced by the  
65 interaction of aeolian and anthropogenic processes (Ruways 1 and Suwayh 1 archaeological  
66 sites), and the chronology of coastal environmental archives that are preserved under the

67 current surrounding sabkhas (core drilling), with the goal of studying past human behaviour in  
68 its palaeoenvironmental context.

69

## 70 **2. Archaeological and palaeoenvironmental contexts**

71 Ruways 1 (RWY-1) and Suwayh 1 (SWY-1) (governorate of al-Sharqquiyah, Oman)  
72 are located along the coast of the Arabian sea, in a vast plain comprised of sabkhas, which are  
73 seasonally fed by wadis coming from large quaternary alluvial fans at the bottom of the Jebel  
74 Khamis (Fig. 1). RWY-1 is a site featuring a long sequence of occupations (dated by  
75 radiocarbon between 6380 and 3400 years BC) with one potentially dating to the beginning of  
76 the middle Neolithic, which is remarkable in a stratified context in Ja'alan (Berger et al.,  
77 2020). The RWY-1 and SWY-1 sites present great potential for reconstructing the economic  
78 strategies of Neolithic coastal populations, strongly oriented towards the exploitation of  
79 lagoons and mangrove ecosystems (Martin, 2005; Berger et al., 2020).

80 Under the current sabkhas, preserved palaeo-mangroves and lagoons seem to be  
81 correlated with mid-Holocene fossil deltas and estuaries. Episodes of marine transgression  
82 alternated with mangrove and/or lagoon phases are recorded in stratigraphic profiles at the  
83 Suwayh sabkha (Berger et al., 2005). In particular, during the 5<sup>th</sup> millennium BC (around  
84 7000-6000 years), Neolithic sites are associated to an optimum period for mangrove  
85 development, due to sea-level stability (Berger et al., 2013). Around 5000-4500 years, an arid  
86 period led to the expansion of sabkhas and the regression of mangroves (Berger et al., 2013).  
87 This climatic setting may have affected both settlement networks and economic strategies of  
88 the Neolithic populations that occupied the area. To investigate the impact of such  
89 environmental and climatic changes on past human populations, cores were drilled at the  
90 nearby modern sabkhas of Ruways, Daffah and Khor al Jaramah (Fig. 1).  
91 Palaeoenvironmental and climatic data extracted from these cores were used to reconstruct the  
92 landscape at the time of occupation of the Ruways 1 and Suwayh 1 shell middens.

93

### 94 **2.1. Ruways 1 and Suways 1 shell middens**

95 Ruways 1 (RWY-1) is located at the center of a wide, open and flat coastline of the  
96 Arabian Sea. Oriented NE–SW, this coastline associates wadi estuaries with vast sabkhas,  
97 where barchanoid dunes were deposited after the disappearance of the mid-Holocene coastal  
98 lagoon and mangrove systems. The current system shows peri-desert arid conditions since the  
99 increasing aridification of the Late Holocene. The archaeological site extends over 8 hectares  
100 and was discovered in 1996 by Mauro Cremaschi (University of Milan) and later prospected

101 by a French expedition. Ruways 1 was used as a ballast quarry at the beginning of 2010,  
102 leading to the destruction of half of the site but revealing continuous, semi-circular  
103 stratigraphic sections over nearly 80 m in length and 3 m in height in the eastern part of the  
104 shell midden.

105 Ten sedimentary units were identified in the sequence. At the base, cemented gravels  
106 from fluvial-deltaic origin provide the substrate upon which lies the shell midden. Sediment  
107 deposition follows vertical and lateral aggradation phases. Erosion caused by aeolian  
108 processes was identified throughout the section in the form of truncations of some of the older  
109 anthropogenic deposits (Fig. 2). According to two radiocarbon dates obtained on charcoal and  
110 marine shells, the settlement started during the late centuries of the 7<sup>th</sup> millennium BC  
111 (around 8300 years BP; Berger et al., 2020). At the surface, archaeological remains indicate  
112 an occupation until the 4<sup>th</sup> millennium BC (around 6000-5000 years, Berger et al., 2020).  
113 Besides providing information on the subsistence strategy and technological behaviour of the  
114 population, this site contains burials from the Middle Neolithic period that document funeral  
115 rituals and periods of stress recorded in human skeletons. Both lithic and shell technology  
116 have been used to manufacture stone tools, beads, net sinkers and hooks (Berger et al., 2020).  
117 The recovered faunal remains belonged to vertebrates and molluscs, indicating the use of  
118 terrestrial, marine and lagoon/mangrove food resources. Among the species identified,  
119 mammalian remains can be attributed to sheep and goat, while reptile and turtle remains have  
120 also been recovered (Berger et al., 2020). Among the marine shells, the clam *Marcia recens* is  
121 the most abundant and indicates that Neolithic populations exploited species from the silty-  
122 sand of the lagoon. Most of the fish remains were attributed to species living in brackish  
123 waters, such as mullet (*Mugilidae*), sardine (*Clupeiformes*) and sea bream (*Sparidae*). These  
124 species, along with catfish (*Ariidae*), indicate the occurrence of a paleo-lagoon and a  
125 mangrove in the vicinity of Ruways 1 which were preferentially exploited by the Neolithic  
126 populations (Berger et al., 2020). Botanical macro-remains also allow reconstructing the local  
127 environment. *Avicennia marina* is the dominant species identified among the charred wood in  
128 the upper part of the sequence with, to a lesser extent, *Rhizophora cf mucronata* attesting the  
129 existence of a mangrove, today absent. Semi-desert taxa such as *Chenopodiaceae* were also  
130 documented (Berger et al., 2020).

131 Suwayh 1 (SWY-1) is a Neolithic shell midden covering ca. 25,000 m<sup>2</sup> of surface area.  
132 It is located along an old wadi estuary, between modern sabkhas and the Arabian Sea (Fig. 1).  
133 Similar to Ruways 1, the site was partially destroyed when it was used as a ballast quarry 20  
134 years ago. The excavations conducted during the 2000's allowed documenting a stratigraphic

135 sequence of 2 m thick (Fig. 3), with human occupation levels from the 6<sup>th</sup> and 5<sup>th</sup> millennia  
136 (~8000-6000 years BP) and a necropolis in the recent portion of the site (Charpentier, et al.  
137 2003). Seven test pits were opened for documenting the phases of the occupation. Unlike the  
138 tombs, these levels are rich in archaeological material, mainly comprised of fishing  
139 instruments such as stone net sinkers, shellfish hooks and jewellery. Dwellings were  
140 uncovered in different phases of the site (Charpentier et al., forthcoming). SWY-1 is dated to  
141 the Middle Neolithic period (Charpentier, 2008) and is a settlement specialised in shark  
142 fishing (Marrast et al., 2020). The palaeoecological data available for this site indicate that,  
143 starting from ~6500 years ago (~4500 years BC), species from mangroves (e.g., *Terebralia*  
144 *palustris*) are represented and preceded species collected from the lagoon environment  
145 (*Amiantis umbonella*) (Martin 2005, Berger et al., 2005).

146 The sedimentation rate of these two shell middens is highly variable and depends on  
147 the rate of aeolian sedimentation (and truncation events) and anthropogenic deposition. It is  
148 primarily the human accumulation of shells and rocks/pebbles that allowed the construction of  
149 these coastal sedimentary anomalies. They favour the trapping of sand particles during human  
150 occupation and protect it afterwards. The lithostratigraphic and sedimentological study has  
151 revealed sets of sedimentary units that are clearly aeolian (facies with more or less pure  
152 allogenic sand) or clearly anthropogenic (facies rich in ash, charcoal, accumulations of shells  
153 or fish bones linked to past human occupations) and intermediate facies, revealing the more or  
154 less strong reworking of anthropogenic deposits by aeolian processes (Berger et al. 2020).  
155 Sedimentological, magnetic and geochemical analyses are ongoing.

156

### 157 **2.3. Cores**

158

159 In 2017 and 2018, a systematic off-site geoarchaeological and geophysical survey was  
160 performed across the modern sabkhas, associated with electrical resistivity tomography (ERT)  
161 measurements and thermic mechanical coring to depths up to 3-5 m (with a Cobra corer).  
162 Three cores were drilled in the following localities: Ruways, Daffah and Khor al Jaramah  
163 (Fig. 1). Sedimentological data extracted from the cores were used to reconstruct the middle  
164 Holocene landscape: they indicate that the lagoons and mangroves were located under the  
165 modern sabkhas.

166 Four main sedimentary units were distinguished in the upper 10 m: 1) at the base, a  
167 deep and probably late Quaternary alluvial formation (not reached by cores); 2) coarse sandy  
168 to gravelly alluvial pre-mid-Holocene deposits organised in a succession of paleochannels; 3)

169 fine fluvial-lagoon silty-sand formations associated with the maximum marine transgression,  
170 4) red silts and gypsum interbedded with aeolian sands corresponding to the current sabkha  
171 (Berger et al. 2020). OSL dating was carried out on this latter sedimentary unit (upper part of  
172 the core), allowing to date the latest episode of lagoon/mangrove development.

173

### 174 **3. Materials and Methods**

#### 175 **3.1. Sampling and preparation**

176 Sediment samples ( $n = 21$ ) were collected at different localities (Ruways, RWY,  
177 Suwayh, SWR, Daffah, DAF and Khor al Jaramah, KAJ; Tab. 1) during the 2017 expedition  
178 (SOM Figs. S1 to S13). For the archaeological sites, sediments were mostly sampled using  
179 lightproof bags during the night after cleaning the section to avoid any contamination by  
180 newly bleached grains. Regarding the cores, sediments were sampled using a lightproof tube  
181 that was inserted either in the section of the test pit dug near the core (Ruways and Daffah,  
182 SOM Figs. S10 and S11) or directly in the core (Khor al Jaramah; SOM Figs. S12 and S13).  
183 For Ruways 1, sediments were sampled from the base to the top of the sequence (phases I, II,  
184 VII, VIII and IX, SOM Figs. S1 to S8); for Suwayh 1, only the upper levels were sampled  
185 from a test pit (SOM Figs. S9); for the cores, sampling was focused on the lagoon/mangrove  
186 levels.

187 Sample preparation and OSL measurements were conducted at the IRAMAT-CRP2A  
188 (Institut de Recherche sur les Archéomatériaux-Centre de Recherche en Physique Appliquée à  
189 l'Archéologie) at Bordeaux Montaigne University. Wet sieving was performed to extract the  
190 most abundant granulometric fraction, 100-120, 120-160 or 160-200  $\mu\text{m}$  depending on the  
191 sample (Tab. 1). Chemical treatment included HCl (10%) to dissolve carbonates and  $\text{H}_2\text{O}_2$   
192 (30%) to break down organic matter. Feldspars were dissolved using  $\text{H}_2\text{SiF}_6$  (31%) over one  
193 week. Finally, quartz grains were rinsed with HCl (10%) and sieved again (using 100, 120 or  
194 160  $\mu\text{m}$  sieves for the 100-120, 120-160 or 160-200  $\mu\text{m}$  granulometric fractions, respectively)  
195 to eliminate partially dissolved feldspar grains.

196

#### 197 **3.2. Equivalent dose determination**

198 Equivalent doses ( $D_e$ ) were determined by applying the single aliquot regeneration  
199 (SAR) protocol (Murray and Wintle, 2000) to multi-grain aliquots (1 mm  $\varnothing$ ) analysed with a  
200 lexsys SMART TL/OSL reader (Richter et al., 2015) for the quartz samples, and with a  
201 lexsys research TL/OSL reader (Richter et al., 2013) for the feldspar samples.  $D_e$  values were

202 obtained on quartz using the protocol described in Tab. 2. For BDX 19229, whose signal  
203 reached saturation, and for BDX 19235, pIRIR<sub>225</sub> measurements were performed (Tab. 3).

204 Regarding the measurement procedure, green LEDs were used for stimulation  
205 (stimulation power density of 50 mW·cm<sup>-2</sup>) and the OSL signal was detected with a  
206 combination of UV filters (Schott BG-3, 3 mm in conjunction with a Delta BP365/50 EX).  
207 Aliquots were irradiated using the inbuilt <sup>90</sup>Sr/<sup>90</sup>Y beta-sources fitted to the readers. An  
208 infrared stimulation at 50°C for 60 s was performed before each OSL measurement to avoid  
209 potential contamination from remaining feldspars. We observed a dominant fast decaying  
210 OSL signal component for our quartz samples (Fig. 4).

211 For BDX19229 and BDX19235, the pIRIR<sub>225</sub> protocol (Thomsen et al., 2008; Buylaert  
212 et al., 2011) was applied (Tab. 3). Infrared laser diodes were used for stimulation (power  
213 density: 120 mW·cm<sup>-2</sup>) and the signal was detected with a combination of optical filters  
214 (Schott KG3, 3 mm + Chroma D410/30 x for the research reader).

215 Preheat plateau tests were conducted on natural aliquots from samples BDX 19231  
216 and 19232 (Ruways 1) and BDX 19238, 19239 and 19240 (Suwayh 1). For Ruways 1  
217 samples, measurements were done between 180°C and 300°C (cutheat = 200°C) with 20°C  
218 steps; for Suwayh 1 samples, from 170°C to 250°C (cutheat = 160°C) with 20°C steps. Since  
219 low D<sub>e</sub> values were observed after preliminary tests, the preheat temperature tests were  
220 conducted on lower temperatures for Suwayh 1 samples.

221 Dose recovery tests (DRT) were performed on each sample, on three to five bleached  
222 aliquots (*n* = 74; Tab. 4), using the preheat and cutheat temperatures mentioned above. The  
223 aliquots were bleached in a solar simulator (Hölne SOL500) for 1 min. The irradiation dose  
224 applied was similar to the one expected on natural aliquot.

225 All data were processed using the software Analyst v.4.52 (Duller, 2007). The signal  
226 was integrated using the first 1.5 s for quartz and the first 5 s for feldspars, while the  
227 background was subtracted from the last 15 s for quartz and the last 30 s for feldspars. The  
228 following criteria were applied for D<sub>e</sub> values selection: a recycling ratio limit of 10%; a  
229 maximum recuperation of 5% of the natural signal; a test dose signal more than 3 sigma  
230 above background. Equivalent doses were obtained by fitting an exponential function through  
231 the normalised luminescence signals. The statistic treatment of the D<sub>e</sub> values was done using  
232 either the Central Age Model (CAM, Galbraith et al., 1999) or the Finite Mixture Model  
233 (FMM, Galbraith and Green, 1990) for samples exhibiting a large scatter of the D<sub>e</sub> values.

234

235



236 **3.3. Dose rate determination**

237 **3.3.1. Alpha and beta dose rates**

238 A portion of the sediment sampled from the section or the core (see Tab. 1) was dried in an  
239 oven for one week at 40 °C and the water content (wet weight %) measured. <sup>238</sup>U, <sup>232</sup>Th and K  
240 contents were determined using a laboratory gamma-ray spectrometer equipped with a high-  
241 resolution, broad energy Ge (BEGe) detector. Since no HF treatment was applied, both alpha  
242 and beta dose rates were derived from these values taking into account the conversion factors  
243 of Guérin et al. (2011).

244 **3.3.2. Gamma dose rate**

245 For all samples except those collected directly from the KAJ core (BDX 19245 and 19246;  
246 SOM Figs. S12 and S13) and for samples BDX 19232 and 19237 from Ruways 1, whose  
247 location did not allow to safely dig a 30 cm deep hole in the section (SOM Figs. S4 and S8),  
248 the gamma dose rate was measured *in situ* using a portable gamma-ray multichannel analyser  
249 connected to a NaI(Tl) detector. The data were processed following the “threshold” technique  
250 (Mercier and Falguères, 2007). For the other samples, the gamma dose rate was derived from  
251 their <sup>238</sup>U, <sup>232</sup>Th and K contents deduced from BEGe gamma spectrometric analyses.

252 **3.3.3. Cosmic dose rate**

253 The depth of the sampling position was measured from the surface level (Tab. 1). This value  
254 was used to calculate the cosmic dose rate according to Prescott and Hutton (1988).

255

256 **4. Results**

257 OSL ages on quartz and pIRIR<sub>225</sub> ages on feldspar aliquots were calculated with the 1  
258  $\sigma$  error range, taking into account the alpha attenuation and beta absorption factors of Brennan  
259 et al. (1991) and Guérin et al. (2012) respectively. Water content values used for age  
260 calculation range from 3% to 27% depending on the context (measured values, Tab. 5).

261

262 **4.1. Equivalent doses**

263 **4.1.1. Preheat plateau test**

264 Results obtained do not show temperature dependence between 180°C and 280°C for  
265 Ruways 1 samples (SOM Fig. S14), and between 170°C and 250°C for Suwayh 1 samples  
266 (SOM Fig. S15). Measurements were thus conducted using a 260°C preheat temperature and  
267 200°C cutheat temperatures for Ruways 1 samples, and using lower temperatures for Suwayh  
268 1 (210°C preheat; 160°C cutheat) and cores samples (190°C preheat; 160°C cutheat).

269

#### 270 **4.1.2. Dose recovery tests**

271 For Ruways 1 and Suwayh 1 samples, dose recovery ratios range from  $0.96 \pm 0.03$  to  
272  $1.04 \pm 0.05$  (Tab. 4). For the core samples, dose recovery ratios are close to 1 except for BDX  
273 19243 (Daffah C2) that yields a higher recovery ratio of  $1.44 \pm 0.16$ . This high value can be  
274 related to the low irradiation dose applied (0.5 Gy), which is similar to the natural dose, and to  
275 a relatively high residual signal after bleaching.

276

#### 277 **4.2. Interpreting $D_e$ values distribution**

278 The distribution of  $D_e$  values is heterogeneous for most of the samples (Tab. 6), as  
279 shown in Fig. 5 (Ruways 1 phase II). Indeed, when applying the Central Age Model (CAM,  
280 Galbraith et al., 1999), overdispersion (OD) values are higher than 20% for half of the  
281 samples, and 5 out of 21  $D_e$  values have OD >50% (Tab. S1). This indicates that several grain  
282 populations are present, which may result from differential bleaching and/or microdosimetry  
283 effects. The superposition of these populations can be described using the finite mixture  
284 model (FMM, Galbraith and Green, 1990). However, this model must be applied with caution  
285 on data obtained from the analysis of multi-grain aliquots because averaging effects may  
286 occur, even for small aliquots (Arnold and Roberts, 2009; Galbraith and Roberts, 2012).  
287 However, considering that only a small percentage of grains give rise to the OSL signal  
288 (typically ~5% produce 95% of the total light sum, Duller et al. (2000)), the FMM model is  
289 applicable when only a few grains have been measured, which is the case here with our 1 mm  
290  $\varnothing$  aliquots (e.g., Preusser et al., 2011). FMM modelling was thus conducted for samples with a  
291 number of measured aliquots ( $n \geq 22$  and OD >15% (a sigma-b value of 0.10 was assumed) ;  
292 the components (central value and proportion) are presented in Tab. S2. For samples with  $n$   
293 aliquots < 22, only the CAM was applied, including the feldspar samples from Ruways 1  
294 (BDX 19229 and 19235) and some of the quartz samples from the cores (BDX 19242, 19244,  
295 19245 and 19246) (Tab. 6). For pIRIR<sub>225</sub> ages, no residual dose nor fading corrections were  
296 applied. However, considering that the IRSL age for BDX 19235 is in agreement with OSL  
297 ages obtained for Phase II (BDX 19226, 19227, 19228 and 19236, Tab. 6), the effect of these  
298 two variables might have been compensated for this sample.

299  $D_e$  values obtained either using the FMM or CAM model are presented in Tab. 6 and  
300 Tab. S1. FMM  $D_e$  values are systematically lower than CAM  $D_e$  values, but considering the  
301 associated uncertainties, most of the values are indistinguishable (Fig. 6). Nevertheless, the  
302 use of the main FMM component (Tab. S2) help to discard incomplete bleached grains which,

303 when taken into account (as it is the case with the CAM model), induce an overestimation of  
304 the mean  $D_e$  values.

305 For Ruways 1, CAM  $D_e$  values range from  $0.29 \pm 0.05$  to  $8.55 \pm 0.53$  Gy for the  
306 quartz samples and from  $14.78 \pm 1.55$  to  $520.66 \pm 79.78$  Gy for the feldspar samples, with OD  
307 values between  $9 \pm 2$  and  $98 \pm 13$  %. FMM  $D_e$  values range from  $0.13 \pm 0.01$  to  $8.12 \pm 0.17$   
308 Gy for the quartz samples.

309 For Suwayh 1,  $D_e$  values range from  $5.91 \pm 0.13$  to  $7.43 \pm 0.25$  using the CAM (OD  
310 values between  $13 \pm 2$  and  $20 \pm 2$  %). The  $D_e$  distribution is thus more homogeneous for these  
311 samples in comparison with most of the samples collected in a similar context at Ruways 1.  
312 Indeed, some aliquots likely include partially bleached grains, especially BDX 19238 and  
313 19240 (Fig. 7) and the use of the FMM allowed to extract the main  $D_e$  component whose  
314 proportion represents  $\geq 89\%$  (Tab. S2). The resulting  $D_e$  values range from  $5.76 \pm 0.15$  to  
315  $7.08 \pm 0.15$  Gy.

316 For the cores, CAM  $D_e$  values vary from  $1.68 \pm 0.51$  to  $5.39 \pm 0.44$  Gy ( $5.01 \pm 0.26$   
317 Gy for the FMM) for Ruways-C1, from  $0.57 \pm 0.06$  to  $0.70 \pm 0.08$  Gy ( $0.66 \pm 0.06$  Gy for the  
318 FMM) for Daffah-C2 and equal  $7.92 \pm 0.43$  and  $8.46 \pm 0.38$  Gy for the Khor al Jaramah-C1  
319 and C2 samples. Consequently, these values indicate either a large range of dose rates or ages  
320 significantly different for similar contexts.

321

### 322 4.3. Dose rates

323 The main contribution to the dose rate comes from the beta dose rate, except for the  
324 feldspar samples (Fig. 8). Alpha dose rates were taken into account for all samples since the  
325 grains have not been etched. They are low and represent maximum 3% of the total dose rate.  
326 Both were derived from  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and K contents of the sediment samples (Tab. 5). For  
327 Ruways 1, the  $^{238}\text{U}$  content ranges from  $0.53 \pm 0.01$  to  $3.20 \pm 0.04$  ppm and for 7 out of 12  
328 samples, the  $^{232}\text{Th}$  content is lower, ranging from  $0.57 \pm 0.02$  to  $4.62 \pm 0.04$  ppm. These low  
329  $^{232}\text{Th}$  values for the Ruways 1 sediments are not well understood and further investigations  
330 are required to explain the mechanisms. For the Suwayh 1, Ruways-C1, Daffah-C2 and Khor  
331 al Jaramah-C1/C2 samples, the  $^{232}\text{Th}$  content is systematically higher than  $^{238}\text{U}$  content. K  
332 contents vary also considerably, ranging from  $0.16 \pm 0.01$  (RWY, BDX 19226) to  $1.26 \pm 0.02$   
333 (KAJ-C2, BDX 19246). The highest K contents were measured in the core samples where the  
334 sediments were essentially composed of clayey silt.

335 The gamma dose rate was measured *in situ* for most of the samples (Tab. 6). In-situ  
336 measurements values range from  $210 \pm 10$  to  $405 \pm 20$   $\mu\text{Gy}\cdot\text{a}^{-1}$  for Ruways 1, from  $207 \pm 10$

337 to  $345 \pm 17 \mu\text{Gy}\cdot\text{a}^{-1}$  for Suwayh 1, from  $331 \pm 17$  to  $372 \pm 19 \mu\text{Gy}\cdot\text{a}^{-1}$  for Daffah-C1/C2 and  
338 overlap for Ruways-C1 ( $475 \pm 24$  to  $478 \pm 24 \mu\text{Gy}\cdot\text{a}^{-1}$ ). The gamma dose rates calculated for  
339 BDX 19232 and 19237 using the U, Th and K contents ( $444 \pm 3$  and  $276 \pm 2 \mu\text{Gy}\cdot\text{a}^{-1}$ ), fall  
340 within the same range than those measured *in situ*. For Khor al Jaramah samples, the gamma  
341 doses derived from radioelements contents ( $481 \pm 6$  and  $494 \pm 4 \mu\text{Gy}\cdot\text{a}^{-1}$ ) are similar to those  
342 measured using the portable gamma-probe at Ruways-C1 (around  $475 \mu\text{Gy}\cdot\text{a}^{-1}$ ); this is in  
343 agreement with the environmental dose rates that were not measured *in situ* for these samples  
344 (SOM Figs. S11 and S12).

345 For the feldspar samples, a value of  $10 \pm 1\%$  was taken into account for the internal K  
346 content of the feldspar grains. The associated internal dose rate, of  $500 \pm 50 \mu\text{Gy}\cdot\text{a}^{-1}$ ,  
347 represents up to 42% of the dose rate (Fig. 8), thus being an important parameter for the age  
348 calculation.

349 The cosmic dose was calculated considering the present thickness of sediments, then  
350 leading to minimum values. They represent between 14% and 27% of the total dose rate (Fig.  
351 8). However, for the top of the sequence at Ruways 1 (< 60 cm from the top of the section),  
352 human occupation is less frequent and erosion/reworking processes by deflation (sandstorm)  
353 may have occurred, impacting the cosmic dose rate that can therefore not be estimated with  
354 precision.

355

## 356 **5. Age interpretation and discussion**

357

358 FMM ages were used for age interpretation for samples with OD values  $\geq 15\%$  and  $n$   
359 aliquots measured  $\geq 22$  aliquots. Indeed, for these samples, CAM  $D_e$  values appear  
360 overestimated likely due to the presence of partially bleached grains (Tab. S3). CAM ages  
361 were used for interpretation for samples with OD values  $< 15\%$  and/or  $n$  aliquots measured  $<$   
362 22 aliquots.

363 Ages obtained for the archaeological sequence of the Ruways 1 shell midden range  
364 from  $440 \pm 76$  ka to  $100 \pm 10$  years, indicating a deposition time from the Middle Pleistocene  
365 to the late Holocene (Tab. 6 and Fig. 9). Phase I, corresponding to a gravelly substrate,  
366 deposited by a river, is dated to  $440 \pm 76$  ka using pIRIR<sub>225</sub>. Phase II, corresponding to the  
367 first Neolithic occupation, is dated between  $8340 \pm 480$  and  $7740 \pm 580$  years (6800-5200  
368 years BC). A weighted mean age of  $7930 \pm 240$  years is obtained for this unit. Phases VII and  
369 VIII are characterised by aeolian sand sedimentary structures where deflation forms  
370 predominate. Phase VII is dated to  $5930 \pm 370$  years (4280-3540 years BC) and phase VIII,

371 from  $5830 \pm 320$  to  $5390 \pm 290$  years (3100-4100 years BC). For this phase, OD values are  
372 low (9-13%) indicating that quartz grains were well bleached before deposition and leading to  
373 indistinguishable CAM and FMM ages. Finally, ages obtained for phase IX, composed of  
374 sediment that fills a deflation corridor interlocking phase VI, range from  $3410 \pm 190$  to  $100 \pm$   
375  $10$  years. They indicate that the sediment at the top of the sequence was disturbed, which led  
376 to a recent resetting of the OSL signal. The age of  $3410 \pm 190$  years should thus be considered  
377 as a minimum age, the two other samples from this unit being dated to around 250 and 100  
378 years. Consequently, human occupation at Ruways 1 spans the mid-Holocene: OSL ages  
379 indicate a deposition time from the 6<sup>th</sup> millennium BC (phase II) to the 4<sup>th</sup> millennium BC  
380 (phase VIII), with the main occupation occurring during the 4<sup>th</sup> millennium BC (phases VII  
381 and VIII).

382 At Suwayh 1, age results range from  $6180 \pm 310$  to  $5480 \pm 270$  years (4500-3200  
383 years BC) and are contemporaneous with phases VII and VIII at Ruways 1. However, OSL  
384 ages tend to be slightly younger than radiocarbon ages obtained on shells, by 500-700 years  
385 (calibrated with a  $\Delta=0$ , Marrast et al., 2020; Charpentier et al., forthcoming). Two hypotheses  
386 could explain this phenomenon:  $^{14}\text{C}$  ages might be overestimated due to the reservoir effect  
387 that is not well constrained in the region, and/or OSL ages are underestimated because of the  
388 post-burial increase in U in the sediments caused by the proximity to the mouth of the wadi.

389 With regard to the cores, ages range from  $3110 \pm 370$  to  $970 \pm 290$  years for Ruways-  
390 C1, from  $540 \pm 70$  to  $420 \pm 50$  years for Daffah-C2 and are  $5220 \pm 570$  and  $5320 \pm 590$  years  
391 for Khor al Jaramah-C1 and C2, respectively. These age results indicate that the top of the  
392 Ruways-C1 and Daffah-C2 cores are recent deposits that cannot be correlated with the  
393 occupations at the shell middens. Indeed, these deposits belong to the post-Neolithic hyper-  
394 arid phase. However, the ages for BDX 19245 and 19246 (Khor al Jaramah-C1 and C2)  
395 indicate that a phase of lagoon/mangrove development occurred ~5900-4600 years ago (3900-  
396 2600 years BC) and are contemporaneous with human occupation at Ruways 1 (phases  
397 VII/VIII) and Suwayh 1 (Fig. 9). Considering the depth of the sampling (90-100 cm) and that  
398 earlier paleolagoon episodes were identified in a 480 cm-deep core drilled in Ruways (core 4)  
399 and dated using  $^{14}\text{C}$  on shells from ~6700 years BP (5000-5400 years BC) (Berger et al.,  
400 2020), the dates obtained at Khor al Jaramah could be related to the end of the  
401 lagoon/mangrove development.

402 Previous palynological and micropalaeontological analyses and  $^{14}\text{C}$  ages on shells  
403 obtained from cores drilled under the modern sabkhas at Suwayh indicate that an optimum  
404 period for mangrove development occurred ~6000 years ago (Lézine et al., 2002). This

405 episode was followed by two phases of seawater incursion ca. 5100 and 4500 years ago that  
406 led to the formation of a lagoon (Lézine et al., 2002). Based on geological and environmental  
407 data from the Suwayh and Alashkara sabkhas, Berger et al. (2005, 2013) highlighted at least  
408 five sea-level transgressions that occurred between ~6800-6400 and ~4400-4200 years ago.  
409 The resolution of the OSL ages obtained in this study does not allow to correlate the lagoon  
410 episodes recorded in the studied cores with a specific phase. However, both  
411 palaeoenvironmental and palaeoclimatic data extracted from the Khor al Jaramah cores can be  
412 correlated with human occupation phases at Ruways 1 and Suwayh 1, based on our  
413 chronological data.

414

## 415 **6. Conclusions**

416 Luminescence dating (OSL and pIRIR<sub>225</sub>) was performed on sediment sampled from  
417 both archaeological and geological contexts, in order to correlate human occupation at  
418 Ruways 1 and Suwayh 1 shell middens with palaeoclimatic and palaeoenvironmental data  
419 preserved in sediments under the modern sabkhas at Ruways, Daffah and Khor al Jaramah.  
420 This work aimed at establishing the timeline of Neolithic occupation phases at the two shell  
421 middens, as well as providing a chronology for lagoon/mangrove phases that are linked to sea  
422 level variations and important climate change during the mid-Holocene.

423 For most of the samples, the large scatter of the  $D_e$  values suggested the presence of  
424 several grain populations characterised by different levels of bleaching at the time of  
425 deposition, and/or submitted to different dose rates (microdosimetry heterogeneities). For  
426 such samples, the FMM model was applied and the  $D_e$  values were compared with those  
427 calculated using the CAM model. The ages are in agreement with the general stratigraphic  
428 order, allowing the establishment of an OSL chronology for the Holocene levels, especially  
429 for levels with few or no organic remains that can be dated using  $^{14}\text{C}$ .

430 Age results obtained in this study allowed dating human occupation at Ruways 1 from  
431  $8340 \pm 480$  ( $6320 \pm 480$  years BC) for the phase II to  $5390 \pm 290$  years ( $3370 \pm 290$  years  
432 BC) for the phase VIII, and confirm the antiquity of the settlement, as suggested by  $^{14}\text{C}$  ages  
433 (6<sup>th</sup>-7<sup>th</sup> millennium BC, Berger et al., 2020). However, OSL ages obtained for the top of the  
434 sequence are likely underestimated, since two out of three ages obtained are younger than 300  
435 years, indicating a recent resetting of the OSL signal corresponding to reworked sediments.  
436 Ages obtained for the intermediate phases VII and VIII suggest an occupation time spanning  
437 from ca. 6000 to 5000 years BP (~4000-3000 years BC). Chronological data obtained on the  
438 sediment from the Khor al Jaramah cores indicate that the formation of the lagoon/mangrove

439 occurred around ~5900-4700 years ago (3900-2600 years BC), coinciding with the Neolithic  
440 occupation at the shell midden.

441

442

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461

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562

563

## 564 **Figures**

565

566 Fig. 1: Location of shell middens (Ruways 1 and Suwayh 1, red squares) and cores (Ruways,  
567 Daffah and Khor al Jaramah, red circles) in the eastern coast of the Sultanate of Oman.  
568 Modified after Berger et al. (2005: Figure 2).

569

570 Fig. 2: Ruways 1. Stratigraphic profile (east-west) and depositional phases.

571

572 Fig. 3: Suwayh 1. Stratigraphic profile. Drawing by J-F. Berger and G. Davtian. After  
573 Charpentier (2008: Figure 3).

574

575 Fig. 4: Shine-down OSL curve (signal versus stimulation time) of BDX 19226.

576

577 Fig. 5: Ruways 1. a. Abanico plots of equivalent doses obtained for BDX 19226 (a), 19227  
578 (b) and 19228 (c) (Phase II). Overdispersion values are  $23 \pm 3\%$  (a),  $35 \pm 4\%$  (b) and  $32 \pm 4\%$   
579 (c) respectively.

580

581 Fig. 6: Graphic comparison of  $D_e$  values obtained using the FMM and CAM. Samples number  
582 follows the stratigraphic order (depth and layer attribution from Tabs. 1 and 6). For  $D_e$  values  
583  $< 1$  Gy, error bars are not visible due to the scale. For BDX 19234, the FMM and CAM  $D_e$   
584 values are indistinguishable.

585

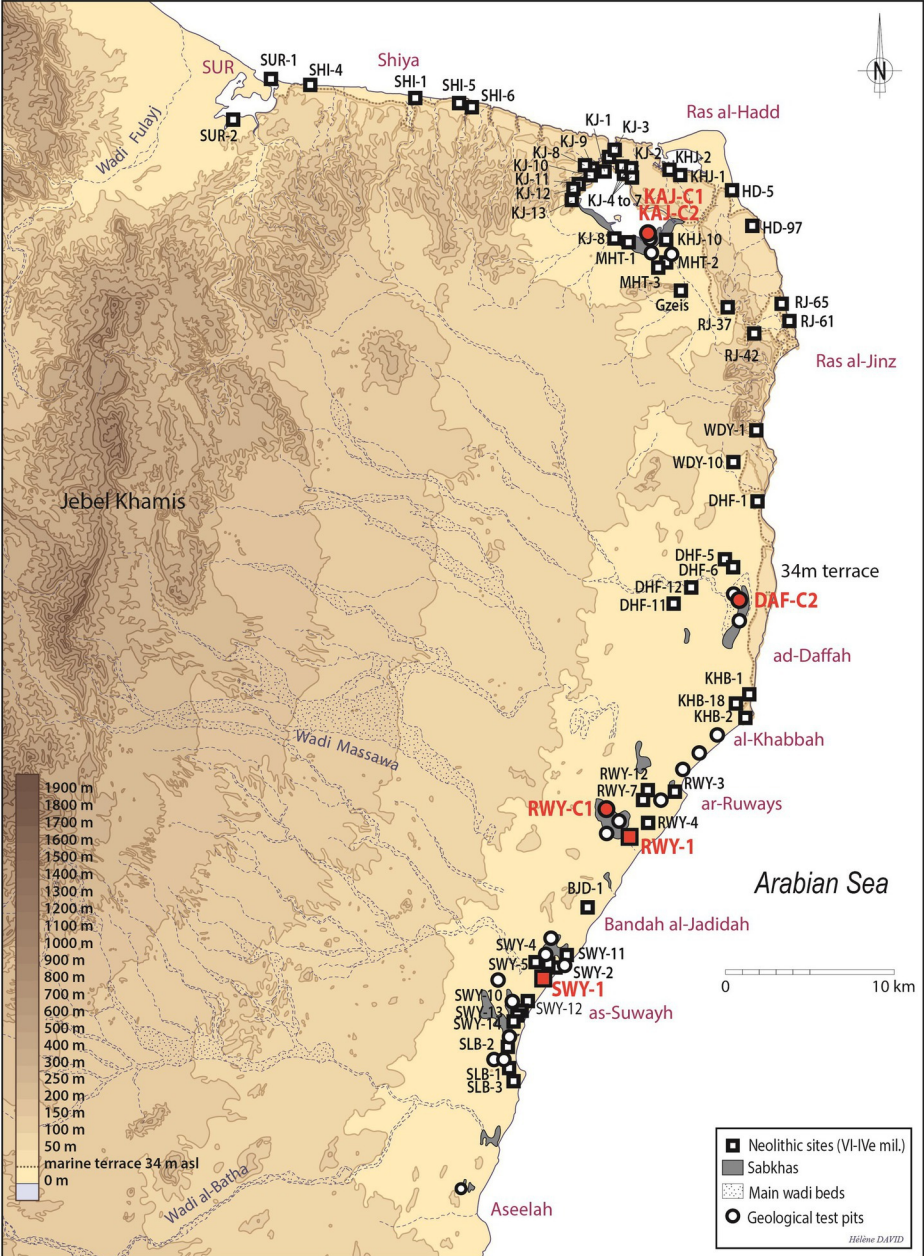
586 Fig. 7: Suwayh 1: Histogram of equivalent doses obtained for BDX 19238 (a), 19239 (b) and  
587 19240 (c). Overdispersion values are  $20 \pm 2\%$  (a),  $13 \pm 2\%$  (b) and  $20 \pm 2\%$  (c).

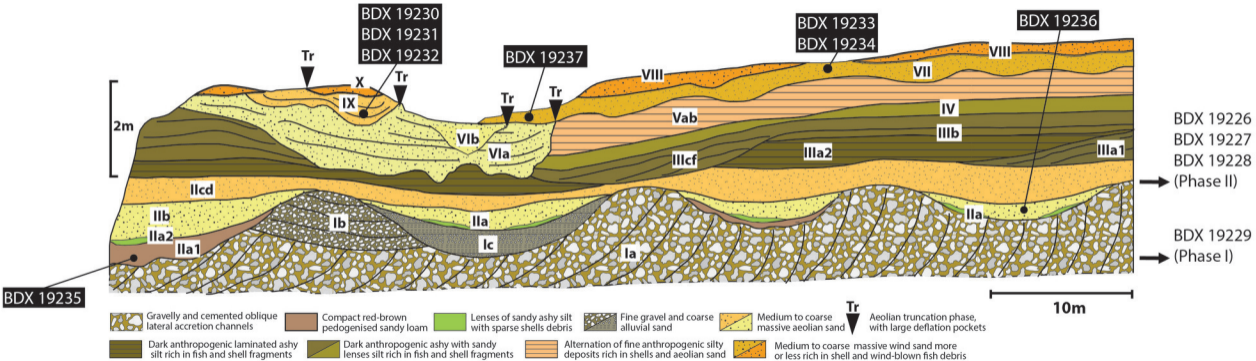
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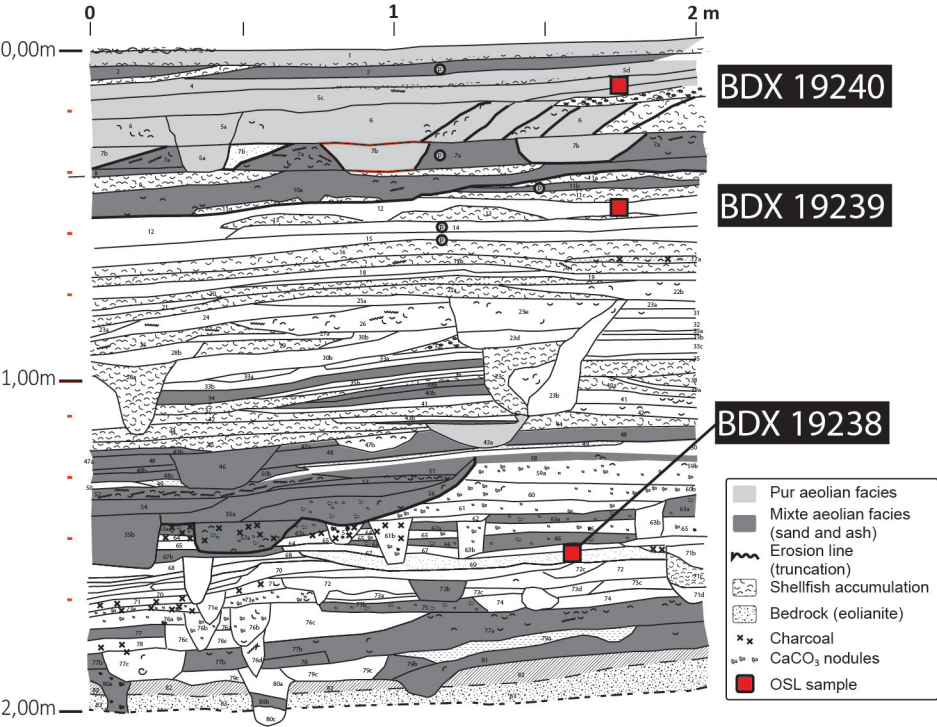
589 Fig. 8: Dose rate distribution (%).

590

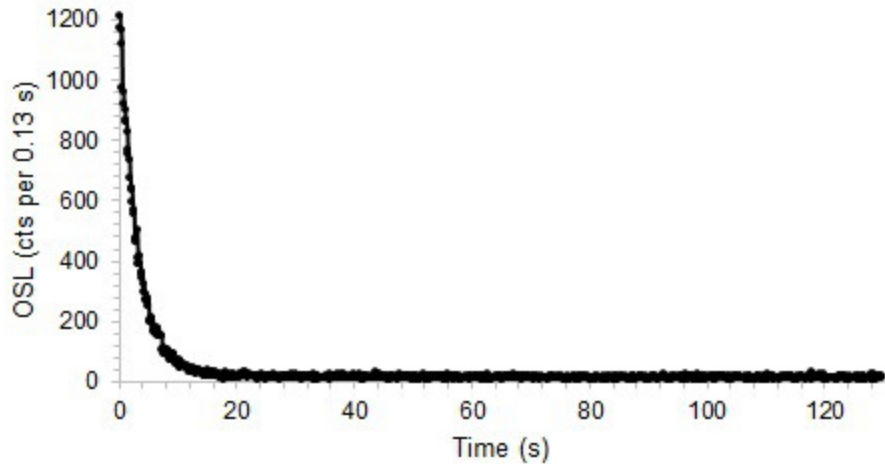
591 Fig. 9: Graphic representation of luminescence ages obtained as a function of depth. For  
592 young ages ( $< 1$  ka), error bars are not visible due to the scale. The samples that fall within  
593 the grey shade can be correlated: the formation of the lagoon in Khor al Jaramah is  
594 contemporaneous with human occupation at Ruways 1 (phases VII/VIII) and Suwayh 1.

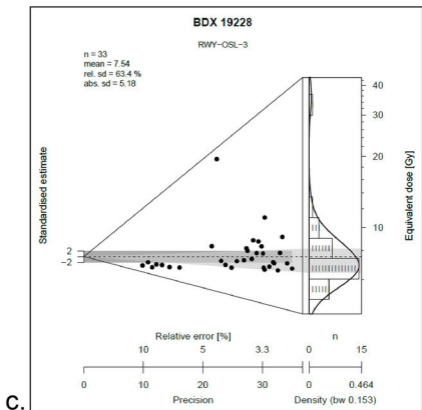
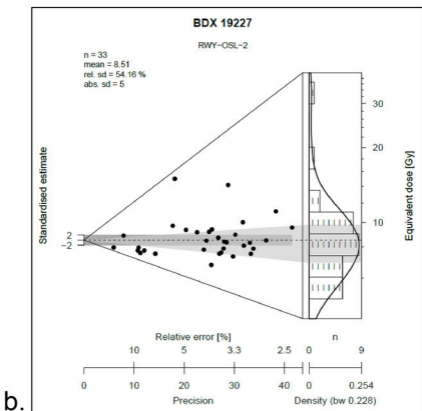
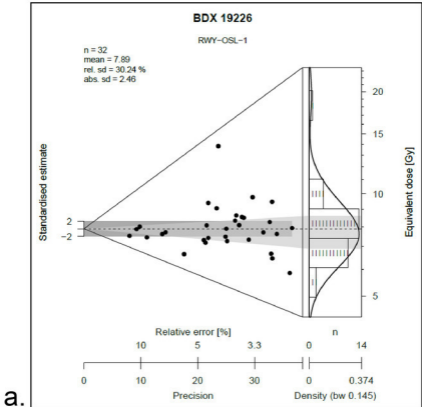




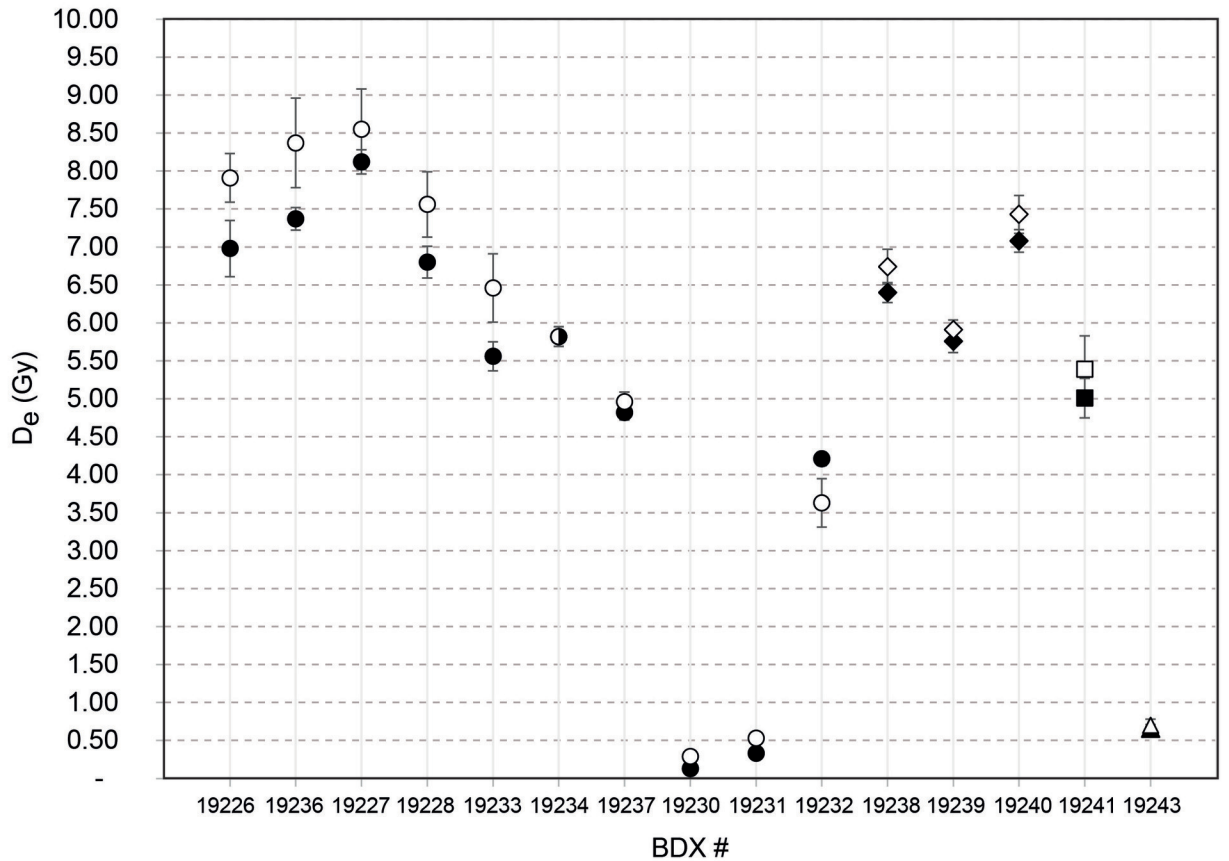


# BDX 19226



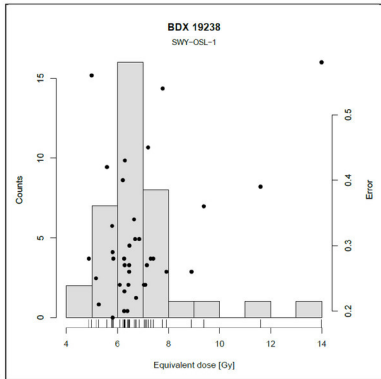




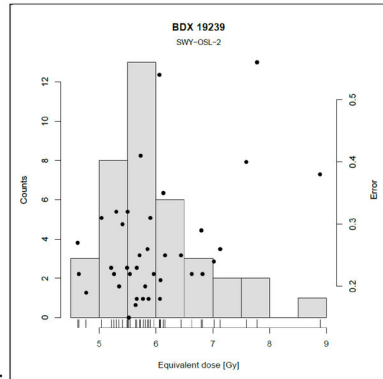


- Ruways 1 (FMM)      ◆ Suwayh 1 (FMM)      ■ Ruways-core 1 (FMM)      ▲ Daffah-Core 2 (FMM)
- Ruways-1 (CAM)      ◇ Suwayh 1 (CAM)      □ Ruways-core 1 (CAM)      △ Daffah-Core 2 (CAM)

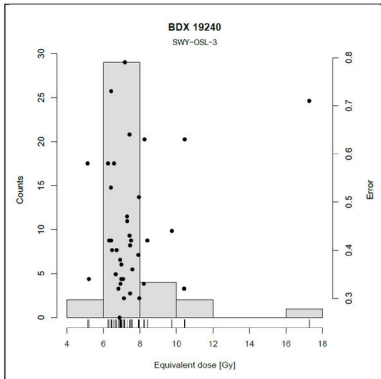
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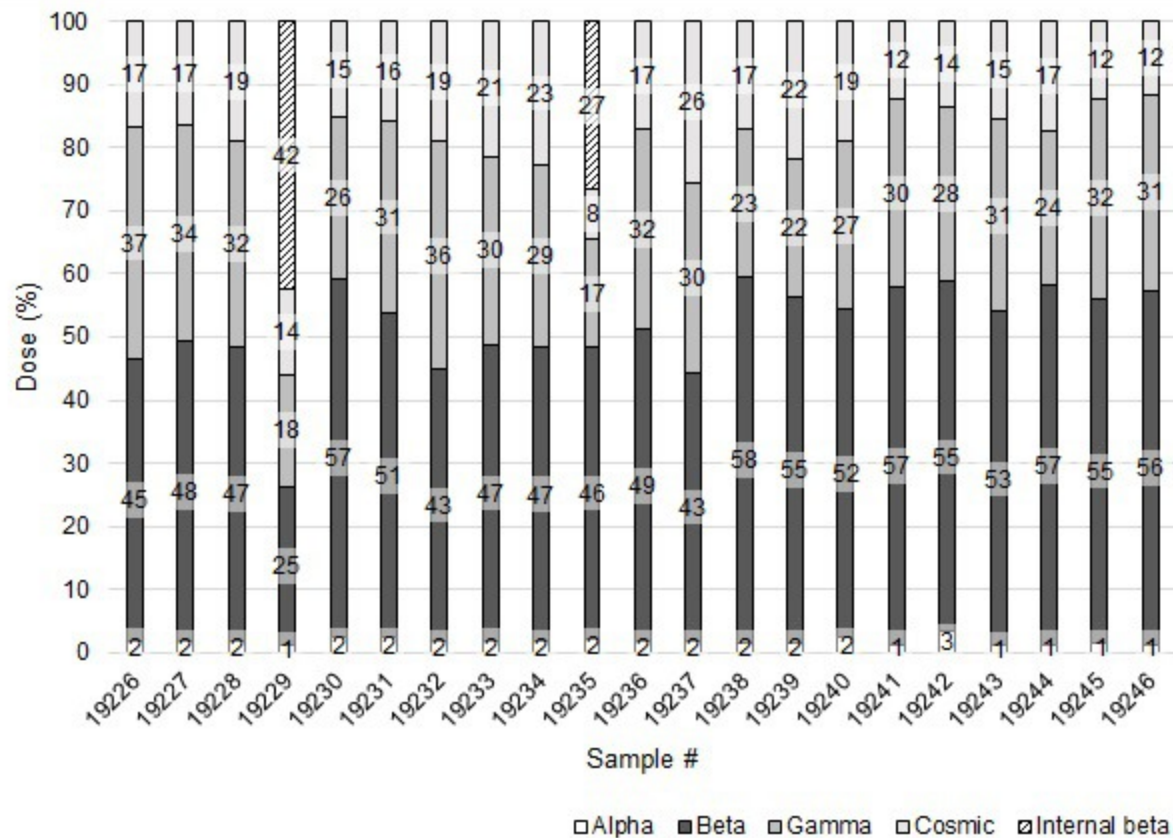


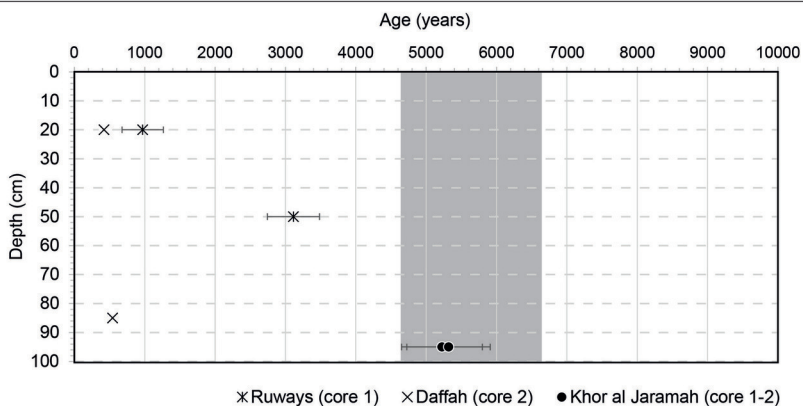
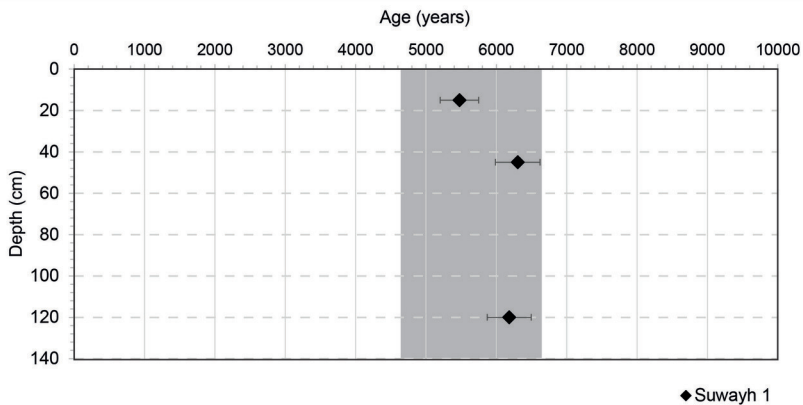
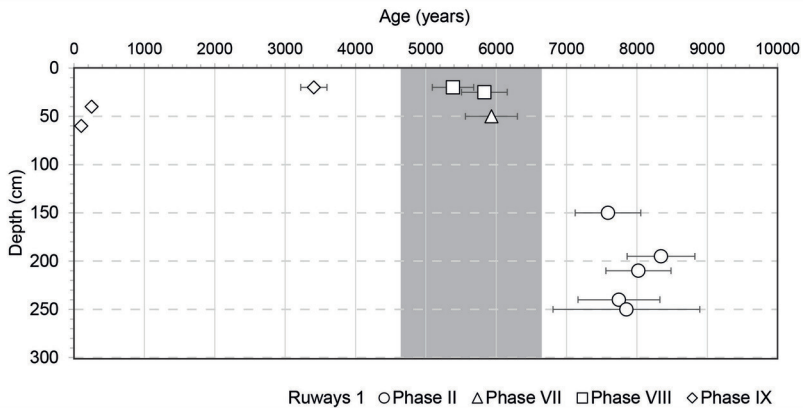
b.



c.







Lab #	Site	Sample #	Depth (cm)	Context	Sample type	Sedimentology	Material <sup>a</sup>	Granulometric fraction
19226	Ruways 1	RWY-1-OSL-1	240	Section	Tube	Fine sand	Q	160-200
19227	Ruways 1	RWY-1-OSL-2	195	Section	Tube	Fine sand	Q	160-200
19228	Ruways 1	RWY-1-OSL-3	150	Section	Tube	Fine sand	Q	160-200
19229	Ruways 1	RWY-1-OSL-4	195	Section	Bag	Sand	F	160-200
19230	Ruways 1	RWY-1-OSL-5	60	Section	Bag	Sandy lens	Q	160-200
19231	Ruways 1	RWY-1-OSL-6	40	Section	Bag	Sandy lens	Q	160-200
19232	Ruways 1	RWY-1-OSL-7	20	Section	Bag	Sandy lens	Q	160-200
19233	Ruways 1	RWY-1-OSL-8	50	Section	Bag	Sand	Q	160-200
19234	Ruways 1	RWY-1-OSL-9	25	Section	Bag	Sand	Q	160-200
19235	Ruways 1	RWY-1-OSL-10	250	Section	Bag	Sand	F	160-200
19236	Ruways 1	RWY-1-OSL-11	210	Section	Bag	Sand	Q	160-200
19237 <sup>b</sup>	Ruways 1	RWY-1-OSL-12	20	Section	Bag	Sand	Q	120-160
19238	Suwayh 1	SWY-OSL-1	120	Section	Bag	Silt	Q	120-160
19239	Suwayh 1	SWY-OSL-2	45	Section	Bag	Silt	Q	120-160
19240	Suwayh 1	SWY-OSL-3	15	Section	Bag	Silt	Q	120-160
19241	Ruways-C1	RWY-C1-OSL-1	50	Core	Tube	Silt	Q	100-120
19242	Ruways-C1	RWY-C1-OSL-2	20	Core	Tube	Coarse sand	Q	100-120
19243	Daffah-C2	DAF-C2-OSL-1	85	Core	Tube	Silt	Q	120-160
19244	Daffah-C2	DAF-C2-OSL-2	20	Core	Tube	Silt	Q	100-120
19245 <sup>b</sup>	Khor al Jaramah-C1	KAJ-C1-OSL-1	90-100	Core	Tube	Silt	Q	100-120
19246 <sup>b</sup>	Khor al Jaramah-C2	KAJ-C2-OSL-1	90-100	Core	Tube	Clayey-silt	Q	100-120

Tab. 1. List of samples analysed in this study. Sample numbers match those provided in SOM.

<sup>a</sup> Material: quartz (Q) / feldspars (F)

<sup>b</sup> no in-situ gamma dosimetry measurements were performed for these samples (see text).

<b>Step</b>	<b>Treatment</b>
1	Given dose
2	Preheat (190-260°C for 10 s)
3	IR stimulation for 60 s at 50°C
4 (L <sub>x</sub> )	Green stimulation for 100 s at 125°C
5	Given test dose
6	Cutheat (160-200°C for 0 s)
7	IR stimulation for 60 s at 50°C
8 (T <sub>x</sub> )	Green stimulation for 100 s at 125°C
9	Return to 1

Tab. 2. OSL SAR measurement protocol applied to quartz.

<b>Step</b>	<b>Treatment</b>
1	Given dose
2	Preheat (250°C for 60 s)
3	IR stimulation for 200 s at 50°C
4 (L <sub>x</sub> )	IRSL stimulation for 200 s at 225°C
5	Given test dose
6	Preheat (250°C for 60 s)
7	IR stimulation for 200 s at 50°C
8 (T <sub>x</sub> )	IRSL stimulation for 200 s at 225°C
9	IRSL stimulation for 60 s at 325°C
10	Return to 1

Tab. 3. pIRIR<sub>225</sub> SAR measurement protocol applied to feldspars.

<b>Lab #</b>	<b>Site</b>	<b><i>n</i> aliquots</b>	<b>DRT</b>	<b>Dose (Gy)</b>
19226	Ruways 1	3	1.00 ± 0.03	5.4
19227	Ruways 1	3	1.00 ± 0.06	5.4
19228	Ruways 1	3	0.99 ± 0.08	5.4
19230	Ruways 1	3	1.04 ± 0.05	0.9
19231	Ruways 1	3	1.01 ± 0.01	0.9
19232	Ruways 1	3	0.96 ± 0.02	5.4
19233	Ruways 1	3	0.98 ± 0.06	5.4
19234	Ruways 1	3	1.00 ± 0.03	5.4
19236	Ruways 1	3	0.99 ± 0.02	5.4
19237	Ruways 1	3	0.96 ± 0.03	5.4
19238	Suwayh 1	5	0.99 ± 0.02	5.3
19239	Suwayh 1	5	0.99 ± 0.03	5.3
19240	Suwayh 1	4	1.02 ± 0.02	5.3
19241	Ruways-C1	5	0.97 ± 0.07	3.5
19242	Ruways-C1	5	1.08 ± 0.23	1.8
19243	Daffah-C2	5	1.44 ± 0.16	0.5
19244	Daffah-C2	5	1.25 ± 0.19	0.5
19245	Khor al Jaramah-C1	5	0.89 ± 0.06	7.1
19246	Khor al Jaramah-C2	5	0.92 ± 0.03	7.1

Tab. 4. Dose recovery test results obtained on quartz. The dose (Gy) is the artificial dose applied after bleaching the samples in a solar simulator (see text).

Lab #	Site	$^{238}\text{U}$ (ppm)	$^{232}\text{Th}$ (ppm)	K (%)	Water content (weight%)
19226	Ruways 1	$2.36 \pm 0.02$	$0.57 \pm 0.02$	$0.16 \pm 0.01$	3
19227	Ruways 1	$2.25 \pm 0.02$	$0.83 \pm 0.02$	$0.25 \pm 0.01$	3
19228	Ruways 1	$2.25 \pm 0.02$	$0.60 \pm 0.02$	$0.19 \pm 0.01$	3
19229	Ruways 1	$0.53 \pm 0.01$	$1.12 \pm 0.01$	$0.30 \pm 0.01$	3
19230	Ruways 1	$3.16 \pm 0.04$	$4.18 \pm 0.04$	$0.36 \pm 0.01$	3
19231	Ruways 1	$3.20 \pm 0.04$	$4.62 \pm 0.04$	$0.28 \pm 0.01$	3
19232 <sup>a</sup>	Ruways 1	$2.42 \pm 0.02$	$2.65 \pm 0.02$	$0.27 \pm 0.01$	3
19233	Ruways 1	$2.36 \pm 0.03$	$0.88 \pm 0.03$	$0.20 \pm 0.01$	3
19234	Ruways 1	$2.31 \pm 0.03$	$0.92 \pm 0.03$	$0.24 \pm 0.01$	3
19235	Ruways 1	$1.57 \pm 0.02$	$3.91 \pm 0.02$	$0.85 \pm 0.01$	3
19236	Ruways 1	$2.19 \pm 0.02$	$0.86 \pm 0.02$	$0.25 \pm 0.01$	3
19237 <sup>a</sup>	Ruways 1	$1.55 \pm 0.02$	$1.11 \pm 0.02$	$0.25 \pm 0.01$	3
19238	Suwayh 1	$1.28 \pm 0.02$	$1.91 \pm 0.02$	$0.62 \pm 0.01$	9
19239	Suwayh 1	$1.18 \pm 0.02$	$1.79 \pm 0.02$	$0.51 \pm 0.01$	9
19240	Suwayh 1	$2.67 \pm 0.02$	$3.28 \pm 0.02$	$0.44 \pm 0.01$	9
19241	Ruways-C1	$1.46 \pm 0.02$	$3.14 \pm 0.02$	$1.15 \pm 0.01$	19
19242	Ruways-C1	$4.07 \pm 0.04$	$6.46 \pm 0.04$	$0.56 \pm 0.01$	12
19243	Daffah-C2	$1.20 \pm 0.03$	$1.50 \pm 0.03$	$0.80 \pm 0.01$	17
19244	Daffah-C2	$1.18 \pm 0.01$	$2.06 \pm 0.01$	$0.92 \pm 0.01$	13
19245 <sup>a</sup>	Khor al Jaramah-C1	$1.07 \pm 0.03$	$4.34 \pm 0.03$	$1.02 \pm 0.01$	17
19246 <sup>a</sup>	Khor al Jaramah-C2	$1.13 \pm 0.02$	$4.48 \pm 0.05$	$1.26 \pm 0.02$	27

Tab. 5. Radioisotopes content measured in the sediment samples using BEGe gamma-ray spectrometry and water content used for age calculation.

<sup>a</sup> no in-situ gamma dosimetry measurements were performed for these samples. The gamma dose rates were derived using U, Th and K content.



Lab #	Site	n	Dose rate ( $\mu\text{Gy}\cdot\text{a}^{-1}$ )						D <sub>e</sub> FMM (Gy)	Age FMM (years)	D <sub>e</sub> CAM (Gy)	Age CAM (years)	Age (years BC)
			Alpha	Beta	Gamma	Cosmic	Internal	Total					
19226 (Q)	Ruways 1 (Phase II)	32	16 ± 3	404 ± 4	329 ± 16	152 ± 10		901 ± 17	6.98 ± 0.37	<b>7 740 ± 580</b>	7.91 ± 0.32	8 780 ± 590	5 730 ± 580
19227 (Q)	Ruways 1 (Phase II)	33	16 ± 3	463 ± 5	333 ± 17	161 ± 10		973 ± 18	8.12 ± 0.16	<b>8 340 ± 480</b>	8.55 ± 0.53	8 780 ± 720	6 320 ± 480
19228 (Q)	Ruways 1 (Phase II)	33	16 ± 3	418 ± 5	291 ± 15	171 ± 10		896 ± 16	6.80 ± 0.21	<b>7 590 ± 470</b>	7.56 ± 0.43	8 440 ± 650	5 570 ± 470
19229 (F)	Ruways 1 (Phase I)	8	14 ± 2	298 ± 5	210 ± 10	161 ± 20	500 ± 50	1183 ± 51	-	-	520.66 ± 79.78	<b>440 000 ± 76 000</b>	438 000 ± 76 000
19230 (Q)	Ruways 1 (Phase IX)	33	30 ± 5	721 ± 10	325 ± 16	194 ± 10		1271 ± 19	0.13 ± 0.01	<b>100 ± 10</b>	0.29 ± 0.05	230 ± 40	-
19231 (Q)	Ruways 1 (Phase IX)	38	32 ± 5	677 ± 9	405 ± 20	207 ± 10		1321 ± 23	0.33 ± 0.01	<b>250 ± 20</b>	0.53 ± 0.08	400 ± 60	-
19232 (Q)*	Ruways 1 (Phase IX)	40	22 ± 3	533 ± 5	444 ± 3	236 ± 10		1235 ± 7	4.21 ± 0.09	<b>3 410 ± 190</b>	3.63 ± 0.32	2 940 ± 290	1 390 ± 190
19233 (Q)	Ruways 1 (Phase VII)	24	17 ± 3	440 ± 8	280 ± 14	200 ± 10		937 ± 16	5.56 ± 0.19	<b>5 930 ± 370</b>	6.46 ± 0.45	6 890 ± 590	3 910 ± 370
19234 (Q)	Ruways 1 (Phase VIII)	22	17 ± 3	465 ± 10	289 ± 14	227 ± 10		998 ± 17	5.82 ± 0.13	5 830 ± 330	5.82 ± 0.12	<b>5 830 ± 320</b>	3 810 ± 320
19235 (F)	Ruways 1 (Phase II)	5	43 ± 8	866 ± 9	323 ± 16	150 ± 20	500 ± 50	1882 ± 54	-	-	14.78 ± 1.55	<b>7 850 ± 1 040</b>	5 830 ± 1 040
19236 (Q)	Ruways 1 (Phase II)	37	16 ± 3	454 ± 6	291 ± 15	158 ± 10		919 ± 16	7.37 ± 0.15	<b>8 020 ± 460</b>	8.37 ± 0.59	9 110 ± 800	6 000 ± 460
19237 (Q)*	Ruways 1 (Phase VIII)	27	17 ± 3	392 ± 4	276 ± 2	236 ± 10		921 ± 5	4.82 ± 0.1	5 230 ± 270	4.96 ± 0.13	<b>5 390 ± 290</b>	3 370 ± 290
19238 (Q)	Suwayh 1	37	16 ± 2	600 ± 7	241 ± 12	178 ± 10		1035 ± 14	6.40 ± 0.13	<b>6 180 ± 310</b>	6.74 ± 0.23	6 510 ± 370	4 160 ± 310
19239 (Q)	Suwayh 1	38	14 ± 2	513 ± 8	207 ± 10	203 ± 10		937 ± 13	5.76 ± 0.15	6 140 ± 320	5.91 ± 0.13	<b>6 300 ± 320</b>	4 290 ± 320
19240 (Q)	Suwayh 1	38	31 ± 5	672 ± 6	345 ± 17	246 ± 10		1293 ± 19	7.08 ± 0.15	<b>5 480 ± 270</b>	7.43 ± 0.25	5 750 ± 320	3 460 ± 270
19241 (Q)	Ruways-C1	24	21 ± 3	913 ± 9	475 ± 24	200 ± 10		1609 ± 26	5.01 ± 0.26	<b>3 110 ± 370</b>	5.39 ± 0.44	3 350 ± 450	1 100 ± 370
19242 (Q)	Ruways-C1	7	57 ± 8	959 ± 8	478 ± 24	236 ± 10		1730 ± 27	-	-	1.68 ± 0.51	<b>970 ± 290</b>	-
19243 (Q)	Daffah-C2	22	13 ± 2	643 ± 13	372 ± 19	187 ± 10		1214 ± 23	0.66 ± 0.05	<b>540 ± 70</b>	0.70 ± 0.08	580 ± 90	-
19244 (Q)	Daffah-C2	14	17 ± 2	769 ± 8	331 ± 17	236 ± 10		1352 ± 19	-	-	0.57 ± 0.06	<b>420 ± 50</b>	-
19245 (Q)*	Khor al Jaramah-C1	9	22 ± 3	829 ± 15	481 ± 6	184 ± 10		1516 ± 16	-	-	7.92 ± 0.42	<b>5 220 ± 570</b>	3 210 ± 570
19246 (Q)*	Khor al Jaramah-C2	7	20 ± 3	893 ± 9	494 ± 4	184 ± 10		1591 ± 10	-	-	8.46 ± 0.38	<b>5 320 ± 590</b>	3 300 ± 590

Tab. 6. OSL ages on quartz (Q) and pIRIR<sub>225</sub> ages on feldspar (F). Ages were rounded to ten years, except for BDX 19229, rounded to thousand years. The error on the age takes into account the systematic error. For samples with less than 22 aliquots measured, no FMM ages were calculated. CAM overdispersion values are presented in SOM Tab. S1 FMM components are provided in SOM Tab. S2. Age values used for interpretation are shown in bold text and are converted in years BC in the last column.

\*no in-situ gamma dosimetry measurements were performed for these samples (see text).