

[Supplementary material]

The long-distance exchange of amazonite and increasing social complexity in the Sudanese Neolithic

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1. Analysed materials

Chemical analysis on a selected set of amazonite beads (9 samples) from R12 were carried out to test the hypothesis advanced by Arkell (1953, 1964) that amazonite as a raw material originated from the Tibesti massif. The study sample set includes: two beads from Grave 83 (Middle Neolithic A: Period 1-B2; beads R12a and R12b), one from Grave 116 (Middle Neolithic A: Period 1-B2; bead R12c); a fourth bead was collected on the site surface before the excavation started (bead R12d). A further 5 beads (R12e–i) come from an eroded grave that can be dated, according to the associated pottery materials, to the Middle Neolithic B (Period 2: Multaga Phase) of the R12 cemetery. These archaeological amazonite samples were compared to a number of samples from the amazonite-bearing pegmatites that outcrop in many places across northern and eastern Africa (see for a geological discussion on their distribution: Zerboni *et al.* 2017), obtained from museums and private collections. Pegmatite samples here discussed are from the Tibesti massif (Eghei Zuma area) in southern Libya; Talat Umm Jaraf, Jebel Hafafit, and Jebel Migif in southeastern Egypt; Konso and Kenticha in Ethiopia and a region between Jordan and Saudi Arabia, not far from Wadi Tabuik. These amazonite outcrops are already known and in some cases (Eghei Zuma and the Egyptian sites) they display evidence for archaeological or modern quarrying. A single outcrop of pegmatite with amazonite known in Sudan is located in the Jebel Nuhud and a specimen from this locality was also analysed. Other comparison samples correspond to beads and pendants traded

today across North Africa and belong to ethnographic private collections. These include a modern Tebu bead used as a pendant, nowadays traded in the old market of Omdurman, in Sudan, an ancient bead from Mauritania, and 5 beads part of a traditional necklace from Mali.

2. Description of the analytical method

According to the protocol described in Zerboni and Vignola (2013) and Zerboni *et al.* (2017), chemical analyses on micro-samples of 50-100 μm in diameter, sampled from the inner part of each bead and from the hand specimens from natural outcrops, were performed. Amazonite micro-flakes were enclosed in epoxy, polished, and carbon coated. Quantitative electron microprobe chemical analyses in wavelength dispersive mode (EMPA-WDS) were performed using a JEOL JXA-8200 electron microprobe on at least four points for each sample. The typical perthitic texture of amazonite (i.e., alternating lenses of microcline and albite; Figure S1) is fine, and for that reason we adopted the microprobe thanks to the possibility to identify with high precision on the back-scattered electron (BSE) images the position of each point analysed. This procedure assured to collect information only on the blue microcline fraction (Zerboni *et al.* 2017). For these samples, due to the micro-perthitic texture of the amazonite, it is of great importance to locate the electron beam with micrometric precision, in order to avoid the micrometric-thick albite strips, which may contaminate the result of each analysis (Zerboni *et al.* 2017).

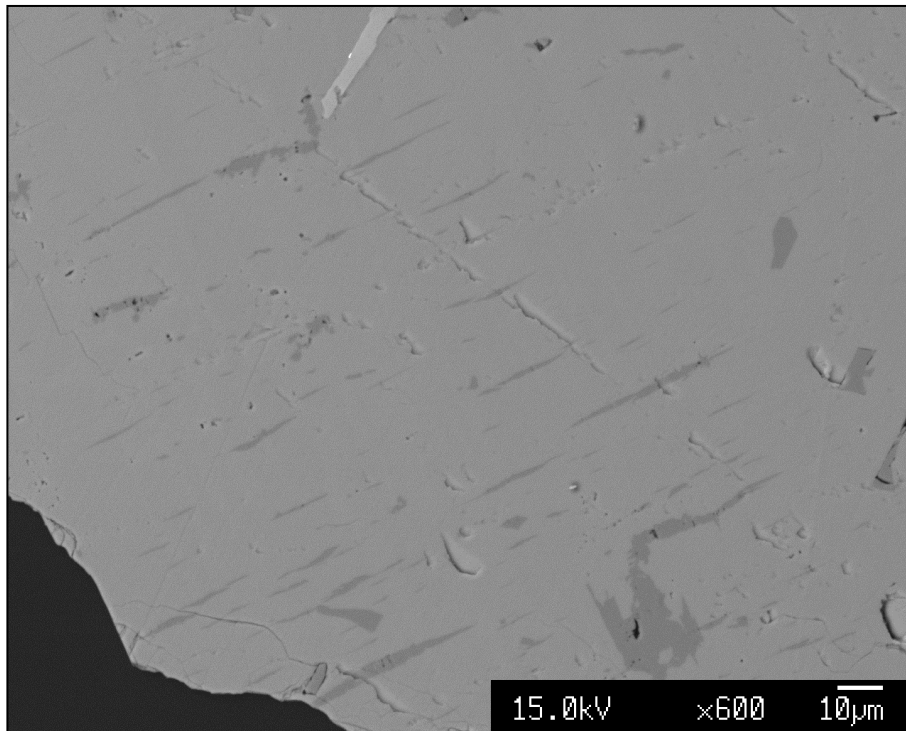


Figure S1. Back-scattered electron (BSE) image showing the perthitic texture of one of the amazonite sample from R12. Note the occurrence of a mixture of dark and light gray areas,

corresponding to albite and microcline respectively; the very light gray lamella is muscovite. The beam diameter of c. 1 μm of the microprobe permits analysis of microcline and avoids contaminations from albite crystals (within rock matrix).

The system was operated with an accelerating voltage of 15keV, a beam current of 5nA, a beam diameter of 1 μm , a counting time of 30sec on the peaks and 15sec on the backgrounds for the principal elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, and K), and 30sec on the peaks and 30sec on the backgrounds for the minor elements (Pb, Sr, Cs, Ba, P, Rb and Cl). The natural minerals grossular for Si ($K\alpha_1$, TAP), Al ($K\alpha_1$, TAP) and Ca ($K\alpha_1$, PET), K-feldspar for K ($K\alpha_1$, PETH), forsterite for Mg ($K\alpha_1$, TAP), omphacite for Na ($K\alpha_1$, TAP), ilmenite for Ti ($K\alpha_1$, PET), fayalite for Fe ($K\alpha_1$, LIFH), rhodonite for Mn ($K\alpha_1$, LIFH), cancrinite for Cl ($K\alpha_1$, PET), pollucite for Cs ($L\alpha_1$, PET), celestine for Sr ($L\alpha_1$, PET), baryte for Ba ($L\alpha_1$, PET), galena for Pb ($M\alpha_1$, PET), “apatite” for P ($K\alpha_1$, PET), and synthetic compound Rb_2MnF_6 for Rb ($L\alpha_1$, PET) were used as standards. The elements Ti, Cl, and P were below detection limits in all analyzed points. The raw data were corrected for matrix effects using the $\Phi\rho Z$ method as implemented in the JEOL suite of programs; mean values between analysed points were calculated (for all analyses the 3σ value was below 1) and summarized into Table 1 of supplementary material.

The chemical composition of all the samples analysed (raw materials and ornaments) in terms of orthoclase, albite, anorthite percentage (Or, An, Ab) of blue-green areas samples plot in the area belonging to perthitic orthoclase-microcline in the ternary plot diagram used for the nomenclature of ordered ternary feldspars (Deer *et al.* 1992). The absence of Ca (anorthite) in the composition of the amazonite samples indicates a temperature of crystallization below 750°C at 1 kbar in the field of crystallization for the shallow level NYF pegmatites at each site and their attribution to amazonite (Fuhrman and Lindsley 1988; Wise 1999; Simmons *et al.* 2003; Černý and Ercit 2005). The geochemical trace elements signature of single minerals (in this case, potassic microcline) from a pegmatitic dike closely reflects the composition of the granitic source (Martin *et al.* 2008). For this reason, each chemical composition obtained is completely representative of the mean geochemical character of the magmatic rocks in its source area.

3. Petrogenetic development of amazonite

Amazonite is a semi-precious green to blue-green variety of microcline with white veins, and is commonly found as a rock-forming mineral in the niobium-yttrium-fluorine or NYF geochemical type of granitic pegmatites (Černý and Ercit 2005), or in pegmatites that reacted with deposits of massive sulphides containing Pb (Wise 1999; Martin *et al.* 2008). Pb also determines the typical

colour of amazonite thanks to its incorporation into the structure of microcline at the expense of K. The replacement of K by Pb induces a structural vacancy that is filled by H₂O, which turns the whitish colour of microcline into the greenish-blue colour of amazonite (Hofmeister and Rossman 1985).

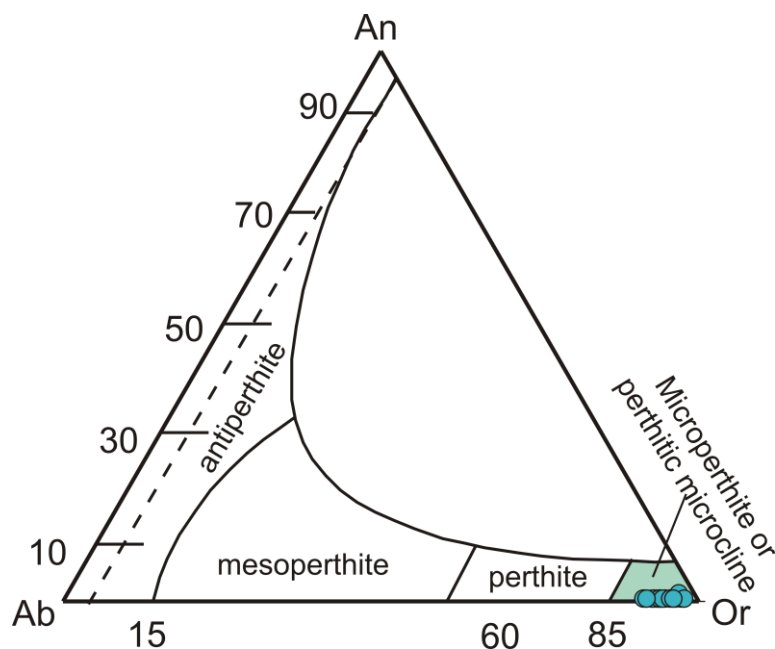


Figure S2. Ternary plot of the composition of K-feldspars in terms of Or-Ab-An (modified from Deer et al. 1992); Or is orthoclase, Ab is albite, An is Anorthite. Dots corresponds to the composition of analysed samples; the whole set of samples falls in the area of microperthite or perthitic microcline.

NYF-type granitic pegmatites are generated by magmatic differentiation of calcalkaline to peralkaline granitic masses related to anorogenic or late-orogenic tectonic environments (Martin and De Vito 2005). The magmatic differentiation of these granitic masses generates swarms of pegmatitic dikes, which present a homogeneous geochemical fingerprint matching the parent granite and are highly enriched in fluorine, yttrium, and niobium. The dikes are zoned, and low-temperature green feldspar forms big masses or single crystals in the intermediate zone (Simmons *et al.* 2003).

On the basis of analytical data (Table 1 of the main text), the chemical composition of all the amazonite samples analysed matches that of a perthitic orthoclase-microcline in the ternary plot of Fig. SM2, used for the nomenclature of ordered ternary feldspars (Deer *et al.* 1992; Wise 1999; Simmons *et al.* 2003; Černý and Ercit 2005). The absence of Ca confirms the attribution of the raw material to amazonite (Fuhrman and Lindsley, 1988). At the microscale of analysis, raw material

outcrops belonging to our dataset presents large crystals of amazonitic microcline embedded in the pegmatitic matrix and displaying the typical perthitic pattern (Figure S3).

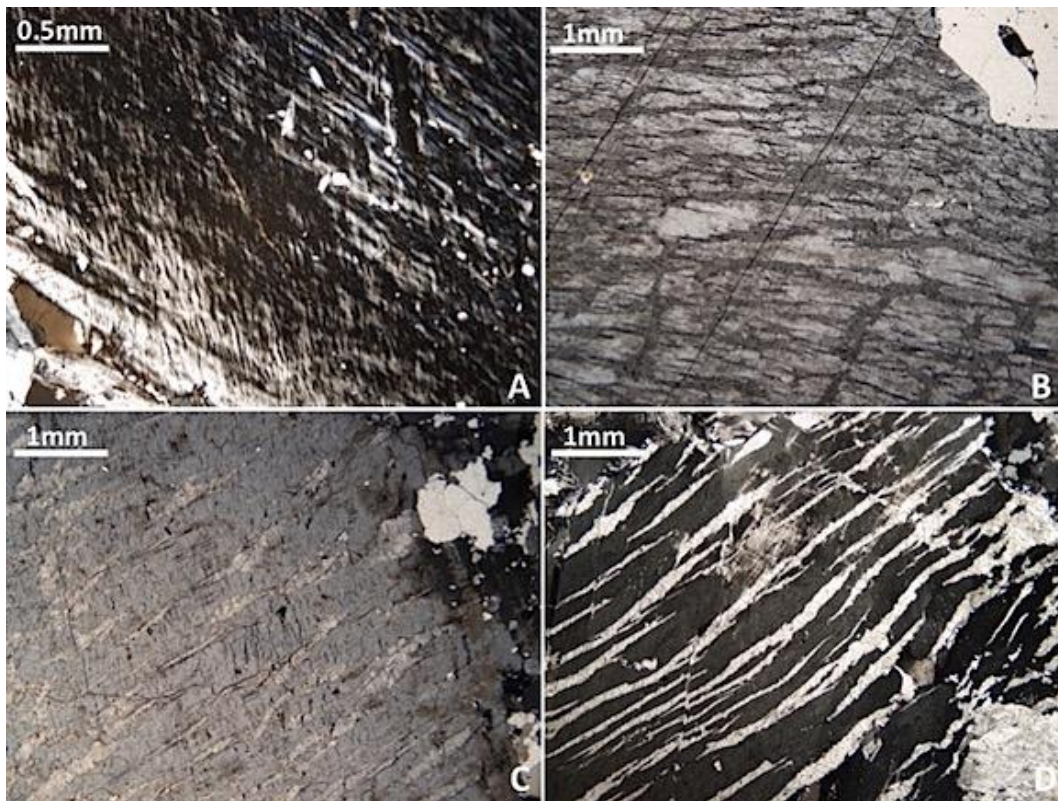


Figure S3. Photomicrograph of amazonitic microcline from selected outcrops in thin section (under cross polarized light) displaying the typical perthitic pattern (note also the tartar twin pattern of A). Sample provenance: A, Eghei Zuma; B, Jebel Hafafit; C, Jebel Migif; D, Konso.

4. Possible sources of amazonite raw material in northeastern Africa and adjoining regions

In Africa, amazonite-bearing pegmatites relate to a series of late- to post-orogenic calc-alkaline to peralkaline intrusive magmatic plutons that formed during the late stages of the Pan-African Neoproterozoic orogenic event *c.* 550mya (Zerboni and Vignola 2013). NYF granitic pegmatites originated after magmatic differentiation of these calc-alkaline intrusive rocks and intruded into the meta-sedimentary or volcanic sequences up to continental-scale mobile belts, joining the Archean cratons. Calcalkaline granitic plutons form a series of outcrops that are roughly aligned in a NE–SW direction, and stretch from the Sinai Peninsula to Nigeria. It is within these late orogenic plutons that the NYF pegmatite swarms originated, and raw material sources of amazonite can be found (Zerboni *et al.* 2017).

Amazonite-bearing pegmatites have been described in Madagascar (Lacroix 1922), Malawi (Martin *et al.* 2008), Namibia (Bezing *et al.* 2008), Ethiopia (Küster *et al.* 2009), between Ethiopia, Djibuti, and Somaliland at Hargeysa in the Mohlileh Hill region (Thoresen and Harrell 2010); Sinai

Peninsula (Katzir *et al.* 2006), between Jordan and Saudi Arabia (Bar-Yosef Mayer and Porat 2008; Wright *et al.* 2008), the western coast of the Red Sea in Egypt (Harrell and Osman 2007; Küster 2009; Harrell 2012), in the Tibesti of southern Libya (Monod 1948), Adrar des Iforas in Mali (Ba *et al.* 1985), along the Hoggar Massif in Algeria (Ghuma and Rogers 1978; Vianello 1985; Balzi *et al.* 1997), in Sudan in the region of Jebel Nuhud and at Kadugli, at Buruku in Nigeria (Obaje 2009), and in the Pare Hills of Tanzania (Thoresen and Harrell 2010). Microcline-bearing pegmatites also exist within the several peralkaline complexes of North Africa including the Jebel Uweinat and Jebel Arkenu in south-eastern Libya (Flinn *et al.* 1991), but amazonite has never been observed at these sites.

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Table S2. Exotic materials recorded at Nubian Early Neolithic (El Barga), Nubian Middle Neolithic (J. Ramlah, Kadruka and R12) and Early Neolithic sites in central Sudan (Ghaba and Kadero). ND: exotic material present, but quantity of pieces not determined. Greyed boxes highlight the presence of specific items.

Site	Location	Exotic shells						References
		<i>Conus</i> sp.	<i>Glycymeris</i> <i>pectunculus</i>	<i>Cypraea</i> sp.	<i>Nerita</i> sp.	<i>Lambis</i> <i>truncata</i> <i>sebae</i>	<i>Engina</i> <i>mendicaria</i>	
J. Ramlah E-01-2	Egypt			1	53	22		Kurzawska 2010
J. Ramlah E-03-1	Egypt					1		Kurzawska 2010
J. Ramlah E-03-2	Egypt			1	4	3		Kurzawska 2010
El Barga	North Sudan	ND	ND	ND	ND			Honegger 2004, 2005
Kadruka 1	North Sudan			ND	>43			Reinold 2005
R12	North Sudan			1	24			Salvatori & Usai 2008b
Ghaba	Central Sudan				4		17	Salvatori <i>et al.</i> 2016
Kadero	Central Sudan				20		1474	Krzyżaniak 2011
Site	Location	Exotic stones						References

		Amazonite beads pendants	Amazonite lumps	Turquoise	Malachite splinters and powder	
J. Ramlah E-01-2	Egypt			1	ND	Kobusiewicz <i>et al.</i> 2010
J. Ramlah E-03-1	Egypt				ND	Kobusiewicz <i>et al.</i> 2010
J. Ramlah E-03-2	Egypt			4	ND	Kobusiewicz <i>et al.</i> 2010
El Barga	North Sudan	ND				Honegger 2004
Kadruka 1	North Sudan	ND			ND	Reinold 2000, 2005
Kadruka 21	North Sudan	3 pendants+ND beads				Reinold 2000
R12	North Sudan	587	23		>50 splinters+powder in 3 graves	Salvatori & Usai 2008b
Umm Melyekta	North Sudan	ND				Fuller 2004
Multaga	North Sudan	ND				Peressinotto <i>et al.</i> 2004
Ghaba	Central Sudan				>276 splinters+ powder in 64 graves	Salvatori <i>et al.</i> 2016
Kadero	Central Sudan	2	1		26	Krzyżaniak 2011

Table S3. Exotic materials recorded at Late Neolithic sites in central and eastern Sudan. ND: exotic material present, but the quantity of pieces not determined.

Site	Location	Exotic shells						References
		<i>Conus</i> sp.	<i>Glycymeris</i> <i>pectunculus</i>	<i>Cypraea</i> sp.	<i>Nerita</i> sp.	<i>Lambis</i> <i>truncata sebae</i>	<i>Engina</i> <i>mendicaria</i>	
Kadada A & B	Central Sudan	1		5			2	Reinold 2007
Kadada C	Central Sudan			4		54		Reinold 1982
Shaheinab	Central Sudan	1			30		4	Arkell 1953
UA53 Kassala	East Sudan			ND				Carannante 2012
Site	Location	Exotic stones				References		
		Amazonite beads pendants	Amazonite lumps	Turquoise	Malachite splinters powder			
Shaheinab	Central Sudan	9	165			Arkell 1953		
Kadada A & B	Central Sudan	444			20	Reinold 2007		
Kadada C	Central Sudan	5	1		6	Reinold 1982		

Geili

Central

ND

Caneva 1988

Sudan

Rabob

Central

ND

Fernandez *et al.*

Sudan

2003
