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1 **Gold mineralization related to Proterozoic cover in the Congo Craton (Central African**  
2 **Republic): a consequence of Panafrican events**

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9  
10 **Abstract**

11 Despite its high endowments, the gold mining potential of Central African greenstone  
12 belts is seemingly underrated when compared to equivalent belts in neighbor West Africa.  
13 This is probably because, over the past half century, only minor exploration efforts were  
14 ever made in this region. In the southwest of the Central African Republic, near the locality  
15 of Moboma, gold-bearing quartz veins are hosted in greenschist facies Paleoproterozoic  
16 formations that are intruded by numerous dolerite dykes. These rocks occur in a strongly  
17 deformed terrane that marks the front of the Panafrican Oubanguides nappe, developed  
18 during an E-W regional shortening. Presence of multiple banding indicates repeated  
19 reactivation of the quartz veins and circulation of H<sub>2</sub>O-CO<sub>2</sub>-NaCl fluids, similar to those  
20 characterizing typical orogenic gold-bearing settings. Fluid inclusion petrography and  
21 microthermometry permitted to distinguish two different fluids: one, aqueous-carbonic,  
22 circulated at relatively high temperature (Th = 250–270 °C) and was responsible for the main  
23 stage of Au deposition; a second fluid of low-salinity trapped in microcracks and in a late  
24 quartz generation, interpreted as meteoric, precipitated silver-poor native gold. At a later  
25 stage, supergene alteration caused the formation of discrete gold nuggets in the upper levels  
26 of the mineralization. The competent nature of the dolerite dykes and quartzite intersected  
27 by these quartz veins contributed to focus rock fracturing, localizing fluid circulation and the  
28 mineralization. The alteration assemblage developed in the veins is equivalent to that found  
29 in the dolerite dykes, which was dated at 571 Ma, thus pointing to a Panafrican age for the  
30 mineralization at Moboma.

31 **Keywords:** Quartz veins, Late Panafrican, orogenic gold mineralization, fluid inclusions,  
32 Moboma, Central African Republic

### 33 **1 Introduction and Exploration History**

34 Compared to the neighboring West African Craton, the gold mining potential of Central  
35 African greenstone belts is highly underestimated, due to the much lower exploration efforts  
36 that have been undertaken in this part of the continent in the past. Nevertheless, gold  
37 remains the second mineral resource of the Central African Republic (CAR) and, with a total  
38 endowment that exceeded 12 t between 1929 and 1963, it has occupied a privileged place in  
39 the history of CAR subsoil development. This notwithstanding, gold production has been  
40 declining from 1952 in this country and, by 1980, it had reduced to practically nil (Biandja,  
41 1988; World Bank, 2008), with only a timid climb to this day, official gold production from  
42 the Central African Republic being estimated at 60 kg in 2016 ([https://www.ceicdata.com/  
43 en/indicator/central-african-republic/gold-production](https://www.ceicdata.com/en/indicator/central-african-republic/gold-production)).

44 In a synthesis of the geology and metallogeny of the various countries constituting Central  
45 Africa, Milesi et al. (2006) made an inventory of their mineral resources, distinguishing  
46 between mineralizations in the Archean craton, in Proterozoic and Panafrican belts, and in  
47 Phanerozoic basins. In the CAR, they only report alluvial and eluvial placer mineralizations in  
48 sediments of estimated Paleozoic to Mesozoic ages, with the district of Roandji providing  
49 gold, while the Lobaye and Mambéré basins being source of diamond. However, the vast  
50 majority of primary gold deposits known to date are associated with Archean to  
51 Paleoproterozoic formations (Mestraud and Bessoles, 1982). They occur either in the form of  
52 stockwork of quartz-sulfide veins (pyrite and/or arsenopyrite and gold) intersecting granites  
53 (Bouar-Baboua and Irdéré deposits) or their micaschist host (Ouham deposits); ferruginous  
54 quartzite (Bogoin deposit); and gold-bearing pyritic horizons scattered in shale. All of these  
55 different mineralization styles can be found in the same site, as is the case at the Roandji  
56 deposit.

57 However, there exists yet another population of gold-bearing quartz veins, those of  
58 Moboma, which are located in low-grade metamorphic formations, called "upper group" by  
59 Mestraud and Bessoles (1982). These veins occur in an artisanal gold mining area located in  
60 the Lobaye region (Fig. 1), about 125 km SSW of the capital of the CAR, Bangui. Discovered in

61 1938, the deposit was mined by the Société Minière de la Moboma (SMM) until 1950,  
62 producing a total of 535 kg of gold (Pianet, 1950). Since then, the deposit is exploited only by  
63 the villagers and no new geological data have been published on this region after the  
64 departure of the SMM. Because the only work done in the area has been limited to the  
65 surface, only exceptionally reaching depths past the hematite-goethite oxidation zone  
66 (Barbeau, 1951; Delafosse, 1951), this paper provides the first comprehensive study of the  
67 primary mineralization. In it, we provide new structural and mineralogical evidence on the  
68 gold mineralization, discuss its timing of emplacement, and suggest a model for its  
69 formation.

## 70 **2 Geological Setting**

### 71 **2.1 Regional geological framework**

72 The study area (Fig. 1) is located in the southern part of the CAR, within the Central  
73 African Orogenic Belt, which covers the northern part of the Congo craton and comprises its  
74 metasedimentary Proterozoic cover (Affaton et al., 1991; Alvarez, 1995; Bessoles and  
75 Trompette, 1980; Feybesse et al., 1998; Lavreau et al., 1990; Moloto-A-Kenguemba, 2002;  
76 Ngako, 1999; Toteu et al., 2004) and the Panafrican metamorphic Oubanguides nappe. The  
77 latter, which stretches for nearly 1000 km across central Africa, was thrust southwards  
78 during the Panafrican orogeny, around 620 Ma (Nédélec et al., 1986; Nzenti et al., 1988;  
79 Ouabego Kourtene, 2013; Pin and Poidevin, 1987; Toteu et al., 1994). Two large basins of  
80 Cretaceous age (Carnot and Congo basins), known to be diamond bearing, overlie all  
81 Precambrian formations.

82 The cover formations, little or unaffected by metamorphism, consist of Proterozoic  
83 sediments, specifically, i) arkose formations including the Mbaïki-Bangui-Boali (MBB) series,  
84 which host of the mineralized zone and are analogous to the Pama Boda arkose series to the  
85 North and to the Nola, Sembé and Lower Dja series, in the southwestern extension of MBB  
86 (Bessoles and Trompette, 1980); ii) metasedimentary formations of the Bangui basin,  
87 comprising the Bimbo and Fatima series (Poidevin, 1991). Carbonate formations positioned  
88 above the black Bimbo sandstone have been dated at 575 Ma ( $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic  
89 characteristics of the Bangui limestones, Poidevin, 2007). These Proterozoic formations are

90 discordantly overlain by the Panafrican Oubanguides nappe and by the Mesozoic Carnot  
91 sandstone series.

92 Poidevin (1991) suggests the existence of a prolongation of the Oubanguides nappe under  
93 the Carnot formation, overlapping a western Archean panel and the western part of the  
94 Proterozoic units (cross-section in Figure 1). Poidevin (1991) and Cornacchia et al. (1986)  
95 propose that the boundary between the western and eastern Archean blocks could  
96 correspond to a Paleoproterozoic suture zone, marking a collision chain overthrust on the  
97 Archean domain in the center of the CAR.

## 98 **2.2 Local geology**

99 The Moboma deposit (latitude 3° 42' N and longitude 17° 51' E) is located 80 km  
100 southwest of CAR's capital Bangui (Fig. 2A). Three rock formations are present in the  
101 deposit: a quartzo-pelitic complex, dolerite dykes, and quartz veins (Fig. 2B). The quartzo-  
102 pelitic complex is overthrust from the north-west by the units of the Panafrican  
103 Oubanguides nappe (distant about 50 km) and is overlain to the east by the Neoproterozoic  
104 series of the Bangui basin (whose border is approximately 20 km southeast of Moboma). The  
105 pelite-quartzite transition is gradual and follows the original sedimentary bedding. These  
106 metasedimentary formations are in continuity with the Nola series, which are considered by  
107 Lescuyer and Milési (2004) and Moloto-A-Kenguemba et al. (2008) as being of  
108 Paleoproterozoic age.

109 Several dolerite dykes are emplaced within these metasedimentary formations. They dip  
110 vertically and follow the N-S-trending regional schistosity (Figs. 2B, 3A). Despite the  
111 extremely poor outcrop conditions, it could be estimated that these dykes measure a few  
112 tens of meters in thickness and extend for about a kilometer along strike. Similar doleritic  
113 dykes have been studied by Vicat et al. (1997) and Moloto-A-Kenguemba et al. (2008) in the  
114 neighboring region of Nola (Fig. 1), and by Poidevin (1979) in the region of Lobaye. The  
115 petrographic characteristics described by these authors are identical to those of the  
116 Moboma dolerites, i.e., intergranular to sub-ophitic texture, characterized by a plagioclase-  
117 augite-ilmenite association. Based on their chemical composition, the Nola dolerites are  
118 related to an olivine tholeiite series of continental tholeiite chemical affinity. They were  
119 assigned an age of  $571 \pm 6$  Ma ( $^{40}\text{Ar} / ^{39}\text{Ar}$  on amphibole, Moloto-A-Kenguemba et al., 2008).

120 Numerous quartz veins outcrop in the Moboma deposit. They intersect all formations but  
121 are particularly abundant within the dolerites where they form a dense network (Fig 2B & C).  
122 More details on these veins are provided below.

123 Field evidence indicates that the tectonic history of the Moboma region is dominated by  
124 two successive major deformation phases ( $D_1$  and  $D_2$ ), which are accompanied by minor  
125 deformation phases causing only small local disturbances. The  $D_1$  phase is visible to the west  
126 of the Moboma prospect and is manifested by a schistosity marked by secondary sericite,  
127 chlorite and albite, aligned parallel to the stratification. This  $S_0S_1$  schistosity trends N-S and  
128 dips  $40^\circ$  W, and was observed by Mestraud and Bessoles (1982) at Moboma and by Moloto-  
129 A-Kenguemba et al. (2008) in the Nola formations; the latter authors associate these  
130 structures with the formation of the Oubanguides nappe. Phase  $D_2$ , characteristic of the  
131 Moboma prospect, is evidenced by a  $S_2$  foliation, developed in tight N-S- to N20-trending  
132 vertical planes that are well shown in the metasediments but are more discrete in the  
133 dolerites, overall defining a zone of strong deformation. The  $S_2$  foliation is underlined by a  
134 greenschist-facies assemblage consisting mostly of chlorite-sericite in metasediments (Fig.  
135 3C), and of chlorite-epidote-actinolite-albite in dolerite. It is superimposed on the  $S_0S_1$   
136 schistosity, in most cases obliterating it. Other minor deformation phases consist of local  
137 drag-folds or micro-shears (Fig. 3D), which do not affect the larger structures.

### 138 **3 Material and Methods**

139 Petrographic studies were carried out on about twenty representative outcrop  
140 samples from different rock types (quartz veins, dolerite and metasedimentary rocks) of the  
141 Moboma deposit. A number of samples were also recovered from a depth of about 10  
142 meters from artisanal mining pits. These samples are generally less attained by supergene  
143 alteration. Mineralogy and textural relationships were investigated using optical microscopy  
144 and back-scattered electron (BSE) imaging using a JEOL JSM 6360LV scanning electron  
145 microscope (SEM) equipped with a silicon drift detector analysis system, at the Geosciences  
146 Environment Toulouse (GET) laboratory at the University of Toulouse. The instrument was  
147 also used to obtain energy dispersive X-ray phase maps. Element concentrations in sulphides  
148 and gold grains were determined using a Cameca-SX five electron probe microanalyses  
149 (EPMA) at the Centre Raimond Castaing (University Paul Sabatier – Toulouse III). Operating  
150 conditions were: an accelerating voltage of 25 kV and a beam current of 20 nA. Calibration

151 standards used were chalcopyrite for S, Fe and Cu, and pure metals for Au, Ag, Te and Bi.  
152 Emission lines used were (1) K $\alpha$  for S, Fe, Cu; (2) L $\alpha$  for Ag, Au and Te; and (3) M $\alpha$  for Bi.

153 Primary and secondary fluid inclusions assemblages were identified in 30- $\mu$ m-thick  
154 polished thin sections and doubly polished slices of 150  $\mu$ m thickness, using the criteria of  
155 Roedder (1984) and Goldstein and Reynolds (1994). Microthermometric measurements  
156 were performed at the University of Toulouse, following the procedures outlined by Roedder  
157 (1984) and Shepherd et al. (1985), using a Linkam THMGS 600 heating–freezing stage  
158 mounted on a BX-51 Olympus microscope. The stage was calibrated using synthetic pure  
159 H<sub>2</sub>O inclusions (0° and 374.1°C) supplied by Syn Flic and with natural pure CO<sub>2</sub> inclusions  
160 (–56.6°C) from Camperio (Ticino, Switzerland). Measurements below 0°C are accurate to  
161  $\pm 0.1^\circ\text{C}$ , whereas at the highest temperature measured ( $\sim 400^\circ\text{C}$ ), they are accurate to  $\pm 1^\circ\text{C}$ .  
162 Cryogenic experiments were carried out before heating to reduce the risk of decrepitating  
163 the inclusions. Salinity (expressed as wt.% eq. NaCl), bulk composition, and density data  
164 were calculated using the software package *Fluids* of Bakker (2003).

## 165 **4 Host-Rock Petrography**

### 166 **4.1 Metasediments**

167 The quartzo-pelitic complex is formed by alternating layers of decimetric to metric  
168 thickness, composed of very fine-grained green and red metapelites and metasandstones to  
169 quartzites, the latter being very weakly recrystallized. The quartz, sericite, chlorite, albite  
170 paragenesis widely observed in the metapelitic rocks indicates that metamorphism did not  
171 exceed the greenschist facies in our study area.

### 172 **4.2 Dolerite**

173 Dolerite outcropping in the Moboma area forms a dark, massive rock with a doleritic to  
174 sub-ophitic structure. In the vicinity of quartz veins, this rock is highly altered and contains  
175 only relict crystals of the primary magmatic paragenesis. Plagioclase has secondary albite  
176 composition and clinopyroxene is extensively replaced by actinolite; apatite and ilmenite are  
177 also present. In order of decreasing abundance, the alteration paragenesis consists of  
178 carbonate, chlorite, albite, epidote and quartz. Sulfides are also common (mainly pyrite) as  
179 well as iron oxides and -hydroxides after Fe-Ti oxides (Fig. 3B). The above relationships

180 indicate an assemblage consisting of actinote, albite, epidote and chlorite, consistent with  
181 greenschist facies conditions, similarly to the metapelites. The absence of hornblende-type  
182 amphibole in the Moboma dolerite excludes amphibolite facies conditions as suggested by  
183 Moloto et al. 2008 for the neighboring Nola region.

#### 184 **4.3 Quartz Veins**

185 The majority of the quartz veins display a N40 to N60 orientation and sub-vertical dips; they  
186 vary in thickness from a few to about 50 cm (Fig. 3E, 4A) and extend for up to a hundred  
187 meters along strike. A subordinate NNW-SSE trending fracture system also exists but only  
188 rarely it is host to quartz veins. Contacts between all veins and the doleritic and  
189 metasedimentary rocks are sharp. All veins are composed mostly of quartz (95%) and  
190 contain gold mineralization. Gold forms free native grains occurring with quartz within the  
191 veins, in their selvages, and in the immediately surrounding rocks. The internal structure of  
192 the quartz veins is characterized by a strike-parallel banding (Fig. 4A and B) marked by  
193 variations in quartz crystal size. The middle part of the veins consists of a band of large  
194 crystals (euhedral to subhedral crystals of mm to cm size) while on the vein edges, in contact  
195 with the host, commonly occurs a band of varied thickness, made up of small crystals of only  
196 a few tens of microns in size.

197 Three textural types of quartz are recognized and occur in most veins: a dark quartz  
198 (Qd), a clear quartz (Qcl) and fragmented or crushed quartz (Qcr). The former two quartz  
199 types consist of large crystals that, together, make up the majority of the vein. The dark  
200 color in Qd is due to the presence of abundant fluid inclusions. This variety is found  
201 preferentially toward the exterior parts of veins, just before the fine-grained Qcr quartz that  
202 mark the vein edges (Fig. 4E). Clear quartz is preferentially located in the central part of  
203 veins (Fig. 4E) and displays three main habits: i) isolated subhedral crystals or several  
204 individuals grouped in bands that parallel the vein walls (Fig. 4C); ii) overgrowths on dark  
205 quartz, in crystallographic continuity (Fig 4E); iii) miarolitic quartz with large crystals filling  
206 lenticular geodes of up to several tens of cm in size (Fig. 4B). Locally, this quartz also forms  
207 small veinlets that cut all other features within the veins (Fig. 4C & D). In addition, most  
208 veins contain millimetric to centimeter-thick, more or less continuous borders, formed of  
209 tiny dark and smaller clear quartz crystals (a few tens of microns) recrystallized along grain



210 and sub-grain boundaries (what is named 'crushed quartz', Qcr, Fig. 4C, D & E). The contact  
211 between these fine-grained borders with bands made of larger Qd and Qcl crystals is  
212 generally irregular (Fig 4D & E), although sharp contacts have been observed, particularly  
213 with clear quartz (Fig 4C); these contacts may be marked by alignments of pyrite grains (Fig.  
214 4D) or by iron oxy-hydroxides, in which case they appear as reddish lines (Fig. 3F).

215 The principal mineral phases occurring in the quartz veins are sulfides (pyrite,  
216 chalcopyrite), carbonates (ankerite), white mica, iron oxides and oxy-hydroxides (hematite,  
217 goethite) and, less commonly, galena, arsenopyrite, barite, sphalerite and gersdorffite.  
218 These minerals are associated with the various generations of quartz described previously  
219 and with supergene alteration observed locally on outcrop at the surface.

#### 220 4.3.1 *Dark quartz (Qd) assemblage*

221 Dark quartz (Qd) is generally associated with scattered white mica flakes and an  
222 assemblage of metallic minerals, such as pyrite, chalcopyrite, galena, sphalerite, gersdorffite,  
223 and native gold (Fig. 5A & B). Pyrite, by far the most abundant sulphide, forms euhedral to  
224 subhedral crystals (grain size of 30 to 75  $\mu\text{m}$ ) locally arranged in alignments several crystals  
225 long (Fig. 4E), following the boundaries of the bands (Fig. 4D). This sulphide is often corroded  
226 by iron oxy-hydroxides, contains small crystals of chalcopyrite, sphalerite, and gersdorffite;  
227 most commonly galena overgrows pyrite (Fig. 5A). Gold occurs as visible grains of several  
228 tens of  $\mu\text{m}$  across, which are included within Qd crystals (Fig. 5B) or are interstitial between  
229 Qd grains. Iron oxy-hydroxides occur either as crack filling or at grain boundaries, locally  
230 overgrowing gold grains (Fig. 5B).

#### 231 4.3.2 *Border quartz (Qcr) assemblage*

232 The fine-grained bands that mark the borders of most veins, resulting from local  
233 fragmentation (crushing) and recrystallization of quartz (Qcr) and other vein components,  
234 consist of the same mineral assemblage that accompanies dark quartz, with particularly  
235 abundant interstitial ankerite and white mica. Gold is also present as interstitial grains (Fig.  
236 5C), and has a fineness identical to that of gold grains in dark quartz.

237 4.3.3 *Clear quartz (Qcl) assemblage*

238 Clear quartz (Qcl) occurs in a variety of habits. It can form euhedral crystals,  
239 overgrowth on dark quartz, and fill geodes. Similarly to the above quartz types, it may also  
240 contain visible gold grains (Fig. 5D). Gold in clear quartz, however, differs from the other two  
241 quartz types as its silver grades are distinctly lower (less than 2% Ag, Table 1).

242 4.3.4 *Supergene alteration*

243 In addition to the assemblages that accompany the different types of quartz described  
244 above, all veins near the surface show an important development of a late alteration  
245 consisting of iron oxides and oxy-hydroxides. These occur as: i) overgrowths on quartz near  
246 vein walls; ii) filling fractures in mineralized quartz veins (Fig. 6A) and iii) in zones of  
247 dissolution within the veins (Fig. 6B); iv) pseudomorphs after primary pyrite and ankerite  
248 (Fig. 6C & D); v) thin aureoles surrounding quartz crystals (Fig. 6E). Locally, barite  
249 accompanies these minerals (Fig. 6C). This assemblage clearly indicates a late supergene  
250 weathering and is commonly accompanied by alteration of mica into kaolinite plus hematite  
251 (Fig. 6F).

252 4.3.5 *Gold occurrence and fineness*

253 Textural and chemical data suggest the presence of two generations of gold at  
254 Moboma. In dark and crushed quartz, gold occurs as free-grains of several tens of  $\mu\text{m}$  across,  
255 which are included within Qd crystals (Fig. 5B) or are interstitial between Qcr grains (Fig. 5C).  
256 In both cases, gold contains ~5% Ag (Table 1) and its fineness, calculated from the  
257 relationship  $1,000\text{Au} / (\text{Au} + \text{Ag})$  (wt %) is  $945 \pm 10$ , a value that is characteristic of orogenic  
258 deposits worldwide (fineness > 900; e.g., Morrison et al., 1991; Velásquez et al., 2014). Gold  
259 in clear quartz differs from gold found in the other two quartz types by the size of the grains  
260 which, in the former case, can reach several mm in diameter. The contents of silver are also  
261 different, as they are systematically lower (less than 2% Ag, Table 1) in clear-quartz gold.  
262 Such a low Ag content is commonly reported for gold issued from remobilization of primary,  
263 silver-rich gold.

#### 264 4.4 Fluid Inclusions

265 Although fluid inclusions are abundant in all vein quartz at Moboma, the great  
266 majority are very small (<2  $\mu\text{m}$ ), and many of the larger inclusions show evidence of  
267 decrepitation. Nevertheless, pristine primary inclusions could be identified, either forming  
268 isolated groups or as assemblages defining growth zones in the subhedral quartz crystals.  
269 We therefore carried out a reconnaissance fluid-inclusion study to determine the salient  
270 characteristics of the fluids.

271 Based on their appearance at room temperature and on microthermometric data,  
272 two types of fluid inclusions were defined: aqueous-carbonic inclusions (Type 1), commonly  
273 consisting of an aqueous liquid plus liquid and vapor carbonic phases, and aqueous  
274 inclusions (Type 2). Both types occur in dark quartz (Qd) and in quartz along vein borders  
275 (Qcr), whereas clear quartz (Qcl) only contains aqueous fluid inclusions (Type 2). Results of  
276 microthermometry are listed in Table 2. Salinities were calculated based on the temperature  
277 of clathrate dissociation and of final ice melting, respectively, for Type-1 and Type-2 fluid  
278 inclusions (Bodnar, 2003; Diamond, 2001).

##### 279 4.4.1 Fluid inclusions in dark quartz (Qd)

280 In dark quartz, Type-1 fluid inclusions occur along growth zones, are of small size (<2  
281 to 10  $\mu\text{m}$ ) and show somewhat variable aqueous liquid/carbonic ratios, although the volume  
282 proportions of the carbonic phase remain lower than ~50% (Fig. 7A). The temperatures of  
283 melting of  $\text{CO}_2$  ice,  $T_m(\text{CO}_2)$ , are comprised between -57.9 °C and -57.2 °C, which is lower  
284 than the melting temperature of pure carbon dioxide (-56.6 °C), suggesting the presence of  
285 small amounts of other gases, likely methane, dissolved in the carbonic phase.  
286 Homogenization of the carbonic phase,  $T_h(\text{CO}_2)$ , occurred to the liquid phase, at  
287 temperatures ranging from 16.1 °C to 26.1 °C. Clathrate dissolved in a small range from 8 °C  
288 to 8.5 °C, corresponding to salinities from 3.0 to 3.9 wt.% eq. NaCl. Total homogenization  
289 temperatures show a unimodal distribution with a peak around 260-270 °C and a small  
290 dispersion toward lower temperatures (Table 2). Fluid inclusions of Type 2 in dark quartz  
291 (Fig. 7B) are arranged in parallel planes corresponding to microfractures, and their aspect  
292 and microthermometric properties are the same as those of Type-2 inclusions occurring in  
293 clear quartz (Qcl), described below.

#### 294 4.4.2 *Fluid inclusions in border quartz (Qcr)*

295 In some of the larger grains of crushed quartz occurring in the border zones, we could  
296 observe the presence of Type-1 fluid inclusions. They generally measure only a few microns  
297 or less and contain an aqueous liquid plus liquid and vapor CO<sub>2</sub> phases at room temperature  
298 (Fig. 7C). Locally, two-phase aqueous fluids inclusions (Type 2) can be observed, generally  
299 rich in vapor, aligned along microfractures contained within a quartz grain. However, only  
300 the microthermometric characteristics of the three-phase primary fluid inclusions (Type 1)  
301 could be determined, the aqueous inclusions being too small to observe phase changes ( $\ll 5$   
302  $\mu\text{m}$ ) (Table 2). In Type-1 fluid inclusions, the  $T_m(\text{CO}_2)$  ranged between -58.1 and -57.2 °C,  
303 comparable to values obtained from Qd quartz. The dissolution of clathrate took place  
304 between 5.2 and 7.9 °C, corresponding to salinities between 4.1 and 8.8 wt.% eq. NaCl,  
305 somewhat higher than those obtained for Type-1 inclusions in Qd (3.5 wt.% eq. NaCl, in  
306 average). The homogenization of the carbonic phase  $\text{Th}(\text{CO}_2)$  occurred to the liquid phase  
307 within a temperature range between 11.5 °C and 25.9 °C. The total Th distribution is  
308 unimodal, with a peak around 260-270 °C, which is identical to the values obtained for Qd  
309 quartz.

#### 310 4.4.3 *Fluid inclusions in clear quartz (Qcl)*

311 Only Type-2 fluid inclusions occur in clear quartz. They have consistent L/V ratio, with  
312 the majority showing vapor bubbles occupying less than 50% of the inclusion volume,  
313 although partially decrepitated or necked down occurrences can be observed. They measure  
314 up to 10  $\mu\text{m}$  (Fig. 7D) and are mostly found in clear quartz that overgrows on dark quartz.  $T_m$   
315 (Ice) ranged from -2.4 to -0.7 °C, corresponding to salinities between 1.2 to 4 wt.% eq. NaCl.  
316 Homogenization temperatures varied from 180 to 275 °C.

## 317 5 Discussion

### 318 5.1 Timing of gold mineralization

319 All known gold deposits occurring in Archean greenstone belts in the Central African  
320 Republic (e.g., Bogoin, Banda, Boufoyo) are regarded as pre-Panafrican. They consist of  
321 quartz veins developed within shear-zones (Biandja, 1988), much as are most orogenic  
322 deposits described in the Paleoproterozoic of West Africa (Goldfarb et al., 2017). Although  
323 there are no specific studies done on the dolerites at Moboma, they are in clear continuity

324 with the dolerite dyke swarm occurring in the neighboring Nola region (Fig. 1), are emplaced  
325 in analogous units (the MBB and the Nola series) and are petrographically identical. It is thus  
326 very likely that the Moboma dolerite belong to the Nola dyke swarm, which is known to also  
327 extend to the Lower Dja and Sembé areas, respectively in nearby Cameroon and Congo (e.g.,  
328 Moloto-A-Kenguemba et al., 2008; Van den Hende, 1969; Vicat et al., 1997). Thus, they could  
329 be considered as the northeastern extension of the "doleritic complex" that intrudes the  
330 northern edge of the Congo craton (Vicat et al., 1997).

331 The Nola dolerites have been dated at  $571 \pm 6$  Ma, although this age is considered by  
332 the authors as representing an hydrothermal overprint that took place during retrograde  
333 metamorphism to greenschist facies (Moloto-A-Kenguemba et al., 2008). At Moboma, the  
334 mineralized quartz veins crosscut the dolerite dykes and are affected by the same  
335 metamorphic assemblage, in addition to the ankerite-pyrite alteration related to the  
336 emplacement of the quartz veins. It is thus likely that the quartz veins were emplaced either  
337 contemporaneously, or slightly later, than the metamorphism that affected these dykes,  
338 suggesting that gold mineralization at Moboma may also be related to the same Panafrican  
339 event that was dated at Nola at 571 Ma.

## 340 **5.2 Structural control**

341 The principal structural elements in the Paleoproterozoic formations of the Moboma  
342 region are the N20-trending  $40^\circ$ -NW-dipping schistosity ( $S_0S_1$ ) visible outside of the prospect,  
343 the N-S vertical foliation ( $S_2$ ) and the N40- to N60-trending vertical quartz veins characteristic  
344 of the prospect. A sequence of events that is coherent with these structures would  
345 commence with the emplacement of the Oubanguides nappe, characterized by the  $S_0S_1$   
346 schistosity, recognized about 50 km NW of Moboma. This took place during the Panafrican  
347 orogeny (e.g., Rolin, 1992), as indicated by the 620 Ma U-Pb age on zircon from a  
348 metamorphosed metabasite near Yaoundé (Toteu et al., 1994). Followed the development  
349 of the  $S_2$  foliation, during high-strain deformation that caused the NS-trending, vertical,  
350 transcurrent dextral shear zone under greenschist facies conditions. This led to the opening  
351 of tension gaps that were later filled by quartz and the mineralization.

352 This mode of formation evokes that described for the Ashanti area (Allibone et al., 2002),  
353 with its thick (hundreds of meters) zone of strong deformation. The geological formations

354 present at Moboma are heterogeneous (e.g., metasedimentary series enclosing dolerite  
355 dykes) and responded differently to deformation. For instance, the schistosity developed a  
356 tight, well developed foliation in the metasediments while forms widely spaced planes in the  
357 dolerites. It is thus likely that the emplacement of the quartz veins was controlled to a great  
358 extent by the difference in competence among the host rocks, thus favoring the more  
359 competent dolerite and quartzite (Fig. 8A). The preferential localization of gold-bearing  
360 quartz veins in the dolerites had already been emphasized in the older literature (e.g.,  
361 Barbeau, 1951; Delafosse, 1951; Junner, 1950) and more recently by Moloto (2002). This  
362 metabasite-quartz vein association is reminiscent of those described in several gold deposits,  
363 such as those of Kalgoorlie in Australia (Phillips et al., 1996), Pampe in Ghana (Salvi et al.,  
364 2016) or Sortekap in Greenland (Holwell et al., 2013).

### 365 **5.3 Nature and origin of the ore fluids**

366 The study of fluid inclusions, albeit preliminary, does reveal the existence of a H<sub>2</sub>O-CO<sub>2</sub>-  
367 NaCl fluid of low salinity (~4 wt.% eq. NaCl) (Type 1) related to the earliest quartz generation,  
368 which likely represents the primary mineralizing fluid in the deposit. Values of T<sub>m</sub> (CO<sub>2</sub>)  
369 slightly lower than those of the melting point of carbon dioxide (around -58 °C) indicate that  
370 this fluid could also contain traces of other constituents, such as CH<sub>4</sub>, N<sub>2</sub> or H<sub>2</sub>S. We do not  
371 have independent control on pressure to determine the actual temperatures of fluid  
372 trapping, however, given the relatively low intensity of metamorphism observed in the  
373 metasediments and dolerite, we estimate a correction in the order of about 50 °C (i.e., ca.  
374 320 °C). This type of fluid is typical of the fluids associated with orogenic gold deposits  
375 worldwide (Goldfarb and Groves, 2015), and more particularly the Proterozoic West African  
376 Craton gold deposits (e.g., Béziat et al., 2008; Goldfarb et al., 2017; Lawrence et al., 2013),  
377 and is generally considered to derive from greenschist facies metamorphic devolatilization  
378 reactions taking place at the regional scale (e.g., Gaboury 2019). Although metamorphism is  
379 of very low grade in the Moboma rocks hosting the deposit, conditions were higher in the  
380 underlying Archean metasediments, making them better candidates for producing the fluid  
381 and sourcing gold (e.g., Tomkins, 2013). The CO<sub>2</sub>-free aqueous fluid inclusions (Type 2) found  
382 in some of the quartz generations (mostly Qcl) are also commonly observed in orogenic  
383 deposits and have been considered to result from post-trapping modifications of primary  
384 inclusions (e.g., Velásquez et al., 2018; Wille and Klemd, 2004). However, because their

385 occurrence in the Moboma veins is restricted to the Qcl that overgrowth older quartz  
386 generations, we would rather suggest that they represent trapping of a different fluid that  
387 circulated in the rocks after metamorphism. Given the low homogenization temperatures  
388 and salinity, absence of CO<sub>2</sub>, and limited occurrence to the quartz overgrowths, we suggest  
389 that these fluid inclusions trapped a meteoric fluid.

#### 390 **5.4 Mineralization model**

391 The textural relationships between the various quartz habits in the different bands  
392 observed in the veins suggest a multistage formation mechanism and that the vein systems  
393 formed by several filling episodes (Robert and Brown, 1986), related to the structural  
394 evolution of the region. At the early stages of opening (stage 1), vein filling consisted  
395 essentially of equidimensional quartz crystals growing in contact with the vein walls and  
396 perpendicular to them (Qd). They were accompanied by ankerite, muscovite, and a metal  
397 paragenesis consisting essentially of pyrite, as well as few scattered grains of native gold  
398 containing about 5% Ag. Subsequent reiteration of vein openings caused the veins to extend  
399 laterally and their thickness to increase (stage 2). This episodic reopening phenomenon,  
400 generally explained by an oscillation of stress within the rocks (Ramsay, 1980), resulted in  
401 coupled brecciation and recrystallization of previously deposited quartz, producing a mesh  
402 of very small interstitial grains (Qcr). These phenomena are localized preferentially in the  
403 contact zone between vein and wall rock, as well as in narrow, elongated micro-shear zones,  
404 internal to the vein. The formation of ribbons and miarolitic cavities composed of clear  
405 quartz (Qcl) likely took place after the end of this process, and suggests reopening of these  
406 veins, preferentially in their central parts (Fig. 8B, stage 3). Undeformed, clear quartz also  
407 precipitated as overgrowths on the dark quartz crystals. The occurrence of Ag-poor gold  
408 associated with Qcl may indicate that primary gold was put in solution during this process  
409 and reprecipitated, probably after only little transport. Remobilization commonly produces  
410 gold with higher purity compared to that of primary gold (Table 1) (e.g., Oberthür et al.,  
411 1997b). The meteoric fluid represented by the Type-2 fluid inclusion population,  
412 characteristic of clear quartz, could represent the fluid responsible for the remobilization.

413 At a later stage, supergene alteration affected the mineralization, as evidenced by the  
414 occurrence of a late paragenesis of oxides (hematite), iron oxy-hydroxides (goethite),  
415 accessory barite and clays minerals, more abundant in surface samples than in those from

416 the deepest pits. These secondary processes may have played an important role in the  
417 enrichments observed in some of the veins at Moboma and could be at the origin of the  
418 large nuggets discovered during the eluvial exploitation (Mestraud and Bessoles, 1982).

## 419 **6 Conclusions**

420 Structural and mineralogical studies of quartz veins show that gold mineralization of  
421 Moboma shares a number of characteristics with orogenic Au deposits worldwide (mineral  
422 paragenesis with pyrite + ankerite, nature of H<sub>2</sub>O-CO<sub>2</sub>-NaCl fluids, formation of veins by  
423 multiple open-space filling). These auriferous quartz veins were probably set up in a regional  
424 transcurrent shear zone, posterior to formation of the regional schistosity, itself a  
425 consequence of Panafrican thrusting. Field evidence, together with published data, suggest  
426 that mineralization was contemporaneous with the hydrothermal alteration of dolerite  
427 dykes – dated at 571 Ma – that are crosscut by the gold-bearing veins. Evidence for vein  
428 emplacement during late-Panafrican deformation makes Moboma stand out as an unusual  
429 deposit in Central African Republic. It also highlights the exploration potential of the edge of  
430 the Panafrican nappe.

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609 **Figure captions**

610 **Figure 1**

611 A geological sketch map of the southern part of the Central African Orogenic Belt  
612 (modified from Vicat et al., 2001). The key map shows the location of the Central African  
613 Republic. The dashed segment labelled AB traces the cross-section shown below. The study  
614 area and the position of Figure 2 are highlighted by dark boxes; abbreviations of

615 stratigraphic series are: D: Dja, HS: Haute Sangha, MBB: M’Baïki-Bangui-Boali, N: Nola, PB:  
616 Pama-Boda, S: Sembé.

617 **Figure 2**

618 Geological and structural maps of the West Bangui area (A) and of the Moboma mining  
619 prospect (B); C) shows details of the mining camp (modified from Planet, 1950).

620 **Figure 3**

621 Images illustrating structural elements in the Moboma formations. A) Dolerite dikes  
622 oriented parallel to the regional foliation. B) Photomicrograph (crossed-polarized light)  
623 exhibiting the secondary mineral assemblage of dolerite: carbonate (Cb), albite (Ab), quartz  
624 (Qtz), pyrite (Py) and goethite (Gt) replacing ilmenite. C) N- to NNE-trending S<sub>2</sub> foliation  
625 developed in quartz-schist. D) Late dextral slip affecting a quartz vein. E) Image of a typical  
626 mineralized quartz vein trending NNE and steeply dipping to the W. F) Scan of a thin section  
627 (its position in the sample is marked by a black box) from a mineralized quartz vein showing  
628 tightly folded veinlets filled by iron oxy-hydroxides. The sample originates from the vein in  
629 (E), where it is located by the white rectangle.

630 **Figure 4**

631 A) Vertical section through a subvertical mineralized quartz vein. B) Detail of (A) showing  
632 the banding of the vein border and a pocket of miarolitic quartz in the core. C) ribbon of  
633 undeformed Qcl quartz crystals showing very sharp boundaries; D: aggregates of pyrite  
634 crystals at the boundary between Qcr and Qcl zones (the top of the image is transmitted  
635 light, the bottom is reflected light).. E) Polished thin section of a half quartz vein (the centre  
636 of the vein being on the right side of the image) showing distinct generations of quartz  
637 deposition: Qd) dark, coarsely crystalline quartz with irregular shape, generally elongated  
638 perpendicular to selvages; Qcr) crushed and recrystallized quartz; and Qcl) clear crystals  
639 overgrown on dark Qd quartz. Note the gold grain occurring in Qcr, and the zonation of Qd,  
640 marked by the presence of very abundant tiny fluid inclusions.

641 **Figure 5**

642 Representative mineralization textures and assemblages. A, B and D are SEM  
643 backscattered electron images, C is a photomicrograph under transmitted light.

644 Relationships among sulphides (A), and a gold grain inclusion in Qd quartz surrounded by  
645 goethite (B). C) Gold mineralization in Qcr quartz. D) Association of secondary gold and  
646 goethite in a Qcl miarolitic pocket. Muscovite (ms), ankerite (Ank), pyrite (Py), galena (Gn),  
647 chalcopyrite (Ccp), goethite (Gt), gold (Au).

648 **Figure 6**

649 A) Scan of a thin section from a mineralized vein showing enrichment in iron oxy-  
650 hydroxide in fractured zones. B to F) are SEM backscattered electron images of B) spherulitic  
651 crust of oxide and iron oxy-hydroxide (hematite + goethite) filling dissolution zones; C)  
652 partial destabilization of euhedral pyrite (Py) to iron oxyhydroxide (Gt) plus barite (Brt) in a  
653 Qd quartz groundmass; D) a carbonate crystal pseudomorphosed to goethite plus hematite  
654 in Qcr quartz; E) a corona of hematite surrounding a Qcl quartz grain; F) supergene  
655 association of hematite and kaolinite (Ka), replacing mica (note that the mica sheet structure  
656 is well preserved).

657 **Figure 7**

658 Photomicrographs of doubly-polished sections of quartz crystals (transmitted light),  
659 showing the distribution and types of fluid inclusion. A) Type-1 and B) Type-2 fluid Inclusions  
660 in dark quartz (Qd). C) Type-1 fluid Inclusions in crushed/recrystallized border quartz (Qcr).  
661 D) A primary Type-2 fluid Inclusion in clear quartz (Qcl) within a group of partly decrepitated  
662 secondary fluid inclusions.

663 **Figure 8**

664 Schematic representations of A) the geometry in space of the quartz vein system and B)  
665 quartz vein evolution and mode of formation of the gold mineralization.

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