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1 **Rock magnetic investigation of possible sources of the Bangui magnetic anomaly**

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17 **Abstract**

18 The Bangui Magnetic Anomaly (BMA) is the largest lithospheric magnetic field anomaly on
19 Earth at low latitudes. Previous studies investigated its geological source using constraints
20 from satellite and ground magnetic field measurements, as well as from surface magnetic
21 susceptibility measurements on rocks from the Panafrican Mobile Belt Zone (PMBZ). Here
22 we combine magnetic field data modelling and rock magnetic property measurements
23 (susceptibility and natural remanent magnetization, NRM) on many samples from this PMBZ
24 and the surrounding formations. It reveals that NRM is a significant component of the total
25 magnetization (Mt) of the BMA source, which reaches 4.3 A/m with maximum thicknesses of

26 38 and 54 km beneath the western and eastern parts of the BMA. Only the isolated and
27 relatively thin banded iron formations and some migmatites show such Mt values. Thus we
28 suggest that the thick BMA source may be composed either by overlapped slices of such
29 metamorphic rocks, or by an iron-rich mafic source, or by a combination of these two
30 geological structures.

31

32 **Keywords:** Bangui magnetic anomaly, magnetization, geological source, modelling, banded
33 iron formation

34

35 **1 – Introduction**

36 Located in Centrafrican Republic, the Bangui Magnetic Anomaly (BMA) is one of the
37 largest lithospheric magnetic field anomaly on Earth, prominent even at satellite altitude.
38 Different models have been proposed concerning its geological source. First, Regan and
39 Marsh (1982) suggested that a geological metamorphic process affected the entire crust of this
40 area during the Panafrican orogenesis, creating physical property contrasts between cratonic
41 regions and collisional belts. Ravat (1989) reinforced this model but suggested an additional
42 concentrated near-surface ore-like body (see also Ravat et al., 2002 and Langel and Hinze,
43 1998). This shallow body could correspond to the remains of an iron meteorite that fell in this
44 area during the Proterozoic era (Girdler et al., 1992; see also De et al., 1998 and Gorshkov et
45 al., 1996). Shock, thermal and/or chemical remanent magnetizations acquired during and after
46 the impact should have led to this highly-magnetized body. However, the impact hypothesis is
47 less suitable since the impactor material does not survive in significant amount in large craters
48 and thus cannot contribute to such a large magnetic anomaly (Koeberl, 1998). Furthermore no
49 shock remanent magnetization was observed on the rock samples from this area (Marsh,
50 1977). All these studies lack of constraints from magnetic property measurements on the

51 corresponding rocks of this area. Here we combined rock magnetic measurements with
52 magnetic field anomaly modelling in order to investigate the possible source of the BMA.

53 In the first section, we summarize the geological context of the Centrafrican Republic,
54 especially in our studied area. Then, the BMA is introduced before the description of the
55 methods used. The next section details the results of magnetic property measurements and
56 BMA modelling over the studied area. The last section corresponds to a discussion on the
57 origin of the BMA, in the context of the general challenge involved in understanding large
58 and deep crustal anomalies using limited access to rock samples (e.g. Frost and Shive, 1986;
59 McEnroe et al., 2004, Rochette et al., 2005).

60

61 **2 – Geological context**

62 Central Africa is a key area of the African Plate since it constitutes the transition
63 between several old cratons (Figure 1a,b). This transition corresponds to several orogenic
64 belts such as the Panafrican belt (Nickles, 1952; Gérard, 1958; Black, 1966; Mestraud, 1971;
65 Alvarez, 1992, 1995; Rolin, 1995a,b). These belts are mobile zones of the Panafrican
66 Orogenesis at 600 ± 100 Ma (Kennedy, 1964; Rocci, 1965; Black, 1966). During this orogeny
67 plate movements closed oceanic areas leading to a belt of suture zones around the cratons in
68 the African regions of Gondwana. Our study area corresponds to Central Africa (Cameroon,
69 Centrafrican Republic, Chad and Congo) where the West-African and Congolese cratons are
70 separated by the Precambrian and Palaeozoic Oubanguides mobile zones (Figure 1b; Nickles,
71 1952; Gérard, 1958; Mestraud, 1971; Rolin, 1995b). Four geological domains are observed in
72 this area from the rare outcrops of the Archean terranes (about 3.5 Ga), the Eburnean
73 basement (2.4-2.2 Ga), the Neoproterozoic Panafrican cover (600 Ma) and the post-
74 Panafrican domain (Figure 1b,c). We focus our study on the southwestern part of the
75 Centrafrican Republic (Figure 1c) where the Oubanguides Panafrican Belt borders to the

76 north the Congo craton. Syn- and post-glacial Marinoen sediments cover the Neoproterozoic
77 layers (Alvarez, 1999; Rolin, 1995a). A collision of an oceanic plate led to the presence of
78 metamorphic rocks that were sampled in this area (granulites, quartzites including Banded
79 Iron Formations (BIF), migmatites, orthogneisses, metabasalts, metasediments and
80 metaperidotites). All metamorphic grades are found from granulite to green schist. The whole
81 sequence was remobilized during the Panafrican orogenesis in nappes (formation 6 on Figure
82 1c) cut by N140 and N70-trending reverse faults (Figure 1c).

83

84 **3 – Geophysical context**

85 The western part of Central Africa shows one of the most prominent large-scale
86 magnetic anomaly on Earth: the Bangui magnetic anomaly (BMA; Figure 2). It corresponds
87 to a multipolar magnetic anomaly with a negative central lobe and two positive north and
88 south lobes (all are located south to the geomagnetic equator). It reaches about 800 km of N-S
89 wavelength and about 1000 nT of amplitude at ground level. Its E-W axial extension also
90 reaches about 700 km. Near the magnetic equator and in the sub-tropical zone, this is the
91 largest magnetic field anomaly. Here we use the anomaly field from the Magnetic Field model
92 7 (MF7; modified from the MF6 of Maus et al. (2008)) and downward continued to near the
93 Earth's surface (2.5 km altitude – but this is considered as the 'satellite' signal in the
94 following). This model was derived using 2007-2010 magnetic data from the low-Earth orbit
95 CHAMP satellite. It resolves the crustal magnetic field anomalies with wavelengths larger
96 than 300 km, for example the long-wavelength part of the BMA.

97 Ground magnetic data with a heterogeneous spatial resolution are also used in this
98 study. They were acquired by LeDonche and Godivier (1962) in Centrafrican Republic and
99 Chad (therefore no ground data were acquired at the southern lobe of the BMA). The
100 published maps are of the horizontal and vertical components of the total magnetic field, as

101 well as the declination. To recover the total magnetic field (TF) anomaly, they subtracted the
102 corresponding International Geomagnetic Reference Field (IGRF) model values from TF
103 values. We preferred to apply the Definitive Geomagnetic Reference Field (DGRF) model for
104 year 1960 (coefficients published in Finlay et al. (2010)) to derive the anomaly. It should be
105 noted that the TF anomaly values are close to the horizontal component anomaly values, as
106 expected for such low latitudes near the magnetic equator. The shape of the BMA differs
107 between the satellite data map and the ground data map. Indeed the latter reveals that the
108 western limit of the negative lobe of the satellite-derived anomaly is more heterogeneous at
109 ground level, with a local positive E-W elongated central anomaly nearby (5°N , 17°E)
110 surrounding by local negative lobes south and north. Also, the E-W transition between the
111 central negative lobe and the northern positive one on the satellite-derived anomaly map is
112 about 0.3° north than the same transition on the ground data map. This could indicate that the
113 main source body lies in the lower and middle crusts but that only several branches of this
114 source may really reach the upper crust. The negative lobe of the anomaly is more intense (-
115 1000 nT) on the ground data map than on the satellite anomaly map (-400 nT). It is also very
116 well correlated to a negative Bouguer gravimetric anomaly (data from Boukéké et al., 1995)
117 of -125 mGal, indicating that the magnetization contrasts in the crust of this area may be
118 correlated to rock density contrasts from the same source region.

119

120 **4 – Methods**

121 *4.1 – Magnetic anomaly modelling*

122 To investigate the magnetic properties of the BMA source, we first used a modelling
123 method with the observed (ground as well as satellite-derived) magnetic and ground
124 gravimetric anomaly fields. The GM-SYS module of the GEOSOFT Oasis montaj software
125 was used. Gravity (Boukéké et al., 1995) and magnetic anomaly data along the NW-SE

126 profiles shown on Figure 2 were considered. The geometry of the different geological layers
127 was constrained by 1) our own field observations (only near the western profile), 2) data from
128 previous geological maps (Rolin, 1995a), and 3) gravimetric and magnetic anomaly data.
129 Along the western profile, only the surface geology, ground magnetic and gravimetric data
130 really constrained the model, because the satellite-derived magnetic signal cannot reproduce
131 the short wavelengths observed at 2.5 km altitude. On the other hand, along the long eastern
132 profile, too few surface observations, probably representing very 'local' anomalies, exist to
133 consider the interpolated profile as a reasonable constraint. The directions of the remanent
134 magnetization vector of the source body were initially set to the 2011 and 1960 Bangui
135 magnetic field directions (Finlay et al., 2010) for modelling of satellite-derived and ground
136 data, respectively, but could vary if necessary during the inversion. The main aim of the
137 magnetic modelling was to infer the approximate range of total magnetization (Mt) of the
138 most magnetic formation beneath the BMA under the assumptions of induced magnetization
139 constraint and of a source model geometry able to fit the data whatever the location (western
140 or eastern profiles).

141

142 *4.2 – Sampling and rock magnetic measurements*

143 Over 50 large hand samples were obtained in the area of Figure 1c, during several
144 field missions. Sampling was designed to cover all lithologies and degrees of metamorphism
145 observed in this area. Petrography was determined using thin sections and, in some cases, X-
146 ray diffraction and chemical analysis. Low field magnetic susceptibility measurements were
147 carried out using SM30 susceptibility meter (ZH Instruments) for large samples and KLY2
148 susceptibility meter (AGICO) for small samples. Mass susceptibility χ was calculated using
149 the weight of the samples. For remanence and further rock magnetic measurements a first set
150 of samples (chosen to be representative of all lithologies) was completed by all samples with

151 high susceptibility remaining in the collection: therefore the proportion of high susceptibility
152 samples is higher in the studied set. A total of 22 samples were thus fully investigated
153 magnetically. The Natural Remanent Magnetization (NRM) as well as saturation isothermal
154 remanent magnetization (SIRM) acquired at 1 T were measured using a spinner magnetometer
155 Minispin (Molspin) for large samples. In one case NRM was analysed by alternating field
156 demagnetization of a small sample using a superconducting rock magnetometer 760R (2G
157 enterprises). To characterize the magnetic minerals, thermomagnetic curves were acquired
158 using a MFK1 susceptibility meter (AGICO) with CS3 furnace (up to 650°C under argon
159 atmosphere), ambient temperature hysteresis measurements were performed with a vibrating
160 sample magnetometer Micromag 3900 (PMC) and its cryostat allowed measuring low
161 temperature remanent magnetizations.

162 To compare with the magnetic properties of somewhat similar formations within the
163 Panafrican belt, we analysed susceptibility data from East Cameroon (Betaré Oya area, see
164 Figure 1a,b and Kankeu et al., 2009) as well as West Cameroon (after Njanko et al., 2012 and
165 ongoing magnetic anisotropy investigations of amphibolites and granitoids). Some samples
166 from W Cameroon were also measured for rock magnetic properties.

167 Mass normalized rock magnetic measurements were used to evaluate in-situ M_t (in
168 A/m) of the sampled formations using the following formula:

169

170

$$M_t = \rho (NRM + \chi H)$$

171

172 with ρ the rock density (2.7 g/cm³ for all rocks – a typical value for deep continental crust,
173 see Table 1 - except itabirites which were assumed to be 3.2 g/cm³) and H the present
174 magnetic field intensity in Bangui (33.6 μ T, i.e. 26.8 A/m). Using field intensities at the dates
175 of the discussed magnetic field surveys makes negligible changes. This formula assumes that

176 the induced and remanent magnetization components are colinear. Thus the resulting Mt
177 values computed with this equation will be maximum values. The Koenigsberger ratio
178 ($Q=NRM/\chi H$) was also calculated.

179

180 **5 – Results**

181 *5.1 – Magnetic anomaly modelling*

182 The best models to represent the crustal magnetization and density variations beneath
183 the western and eastern BMA profiles are shown in Figure 3, and the parameters associated to
184 each layer are indicated in Table 1. For the most magnetic layer, using a shape similar than the
185 one shown in Figure 3 but with different Mt value and associated thickness, a Mt of 4.3 A/m
186 indeed results in the best predictions of the data along both eastern and western profiles (see
187 Table A1, Figures A1 and A2 in Supplementary Material). Only the 2.5 km-altitude satellite-
188 derived magnetic data of the western profile and the ground magnetic data of the eastern
189 profile are not well predicted, as expected (see explanations in Section 4.1). The resulting
190 magnetization directions are similar to the input values. Similarly to the results of previous
191 BMA modelling studies, the superficial geological layers seem to be weakly magnetized.
192 With the selected shape, the top of the main magnetic source (layer 1) is 9 km deep beneath
193 the short western profile, 5 km deep beneath the long eastern profile. The total magnetic
194 thickness of this layer reaches 38 and 54 km beneath the western and eastern profiles,
195 respectively, even if significant lateral N-S thickness variations are observed beneath the
196 western profile (Figure 3). This confirms that a huge amount of strongly magnetized rocks is
197 preserved in the crust of Centrafrican Republic, even beneath the sampled area near Bangui.
198 The gravity and magnetization contrasts in the models are similar to those of the model
199 proposed by Marsh (1977) and Regan and Marsh (1982) using satellite data only and
200 modelling the whole BMA. In particular, the magnetic source seems to be less dense (density

201 contrast of about -0.03 g/cm^3) than the deep non-magnetic surrounding rocks (mainly layer
202 3), but denser ($> 0.2 \text{ g/cm}^3$) than the superficial non-magnetic formations (not considered in
203 model (b) of Figure 3). Note that a small relief of the Moho is necessary to completely
204 explain the shape of the gravity signal along the two profiles. Concerning the 4.3 A/m
205 magnetization intensity for the most magnetic layer of the best model, using only induced
206 magnetization would require a rather unrealistically high k of $16 \cdot 10^{-2} \text{ SI}$ for the rocks of the
207 studied area. Therefore we arbitrarily separated this M_t value into a NRM of 4 A/m and a
208 volumic susceptibility k of 10^{-2} SI (Table 1).

209

210 *5.2 – Magnetic property measurements*

211 Table 2 shows the magnetic properties of the 22 studied samples. Most of our strongly
212 magnetic samples have Koenigsberger ratios (Q) larger than 1 (minimum values 0.3),
213 stressing the importance of not relying only on susceptibility measurements. Only two
214 samples corresponding to migmatite (8576) and itabirite (8603), have M_t over 4.3 A/m , while
215 five other samples have $0.8 < M_t < 2.3 \text{ A/m}$, from the above lithologies plus granodiorite (8632)
216 and orthogneiss (240). Other lithologies (metaperidotites, metabasalts, granulite and non
217 itabiritic metasedimentary rocks) have negligible M_t . The strong M_t values are coherent with
218 the susceptibility measurements made by Marsh (1977) on outcrops from the area beneath the
219 large Bangui magnetic anomaly, eastward from our own sampling. Those samples with the
220 largest observed magnetic susceptibilities are itabirites from Bakala (k around 0.1 SI) and
221 charnockites from Kaga Bandaro (k around 0.02 SI). We do not elaborate further on Marsh
222 (1977) data obtained using a Bison large coil applied on the outcrops, as their precision and
223 cross-calibration with our more precise data is unknown.

224 Hysteresis loops obtained on chips from the 6 most magnetic samples reveal 4 samples
225 (Figure 4; including 8576) typical of multidomain magnetite $-M_r/M_s < 0.02$, $B_{cr}/B_c > 5$,

226 $B_{cr} < 20$ mT- and two samples (8603 and 240) typical of hematite - $M_r/M_s > 0.5$, $B_{cr}/B_c \approx 1.3$,
227 $B_{cr} > 20$ mT. Hematite appears multidomain for the itabirite sample (8603) and single domain
228 for the orthogneiss (240). To confirm these identifications, we measured low temperature
229 remanent magnetizations on the two most magnetic samples (Figure 5) and high-temperature
230 susceptibility on the 4 samples showing multidomain magnetite (Figure 6). At low
231 temperature, Morin and Verwey transitions are visible on 8603 and 8576 respectively (Figure
232 5), indicating that pure hematite and pure magnetite are indeed present in these rocks.
233 Magnetite Curie point (at 580°C; Figure 6) is observed on all samples but in 8603 and 240
234 over 50% of initial susceptibility remains over 650°C, indicative of hematite that should carry
235 most of the remanence. For sample 240, this weak residual signal may also correspond to
236 instrument drift, but the previous hysteresis measurements have shown hematite.

237 For surface rock samples, the measured NRM intensities can be biased by the viscous
238 remanent magnetization (VRM) component and other possible spurious unwanted
239 magnetizations, especially lightning induced IRM that can generate anomalously high NRM
240 (Verrier and Rochette, 2002). Therefore we scaled measured NRM with saturation IRM, and
241 computed theoretical in situ NRM intensities from measured SIRM. For samples containing
242 magnetite, we applied a theoretical NRM/SIRM ratio of 2% (Gattacceca and Rochette, 2004)
243 using a thermo-remanent magnetization (TRM) in the present magnetic field in Bangui. These
244 modelled M_t values are shown in the last column of Table 2. Only two samples exhibit
245 modelled values significantly different from the value computed using our NRM and
246 susceptibility measurements: magnetite-bearing migmatite (8576) and hematite-bearing gneiss
247 (243). For the latter, modelled value is much higher, possibly due to a multicomponent IRM
248 with opposite directions. Measured value for 8576 is 3 times larger than the modelled M_t ,
249 suggesting that lightning has biased our NRM measurement, although much larger
250 NRM/SIRM ratios are commonly observed for samples affected by lightning (Verrier and

251 Rochette, 2002). An alternative-field demagnetization experiment with REM' ratio computed
252 following Gattacceca and Rochette (2004) does confirm that 8576 NRM is affected by
253 lightning, with REM' peaking at 30%. For samples containing hematite (8603 and 240), the
254 modelled Mt values (using NRM/SIRM = 50% after Kletetschka et al., 2000, and Dunlop and
255 Kletetschka, 2001) are similar to the observed ones (30 to 50%).

256 Finally, we compare the magnetic properties of our samples with those measured on
257 other rock samples from the Panafrican belt in Cameroon (Figure 7). For West Cameroon
258 Fomopea amphibolites (Njanko et al., 2012; geographic position near 5.5N and 10E), among
259 16 sites (with 2 to 4 samples per sites), the maximum k is $9 \cdot 10^{-2}$ SI, with 25% of the sites
260 above 10^{-2} SI. In the Nkambé area (6N and 10E), mostly with granitoids but also with
261 accessory amphibolites, the maximum k is $5 \cdot 10^{-2}$ SI in both lithologies, with 16% of the over
262 1200 samples above 10^{-2} SI (Fozing et al., in preparation). Rock magnetic measurements,
263 including hysteresis loops and thermomagnetic curves, have been performed on a selection of
264 48 samples (Table A2 of the Supplementary Material). They all show a multidomain to large
265 pseudo-single domain magnetite signal. Modelled Mt has been computed after SIRM and
266 susceptibility measurements (Figure 8). Only 15 samples yield values over 1 A/m, a single
267 one being over 4 A/m (at 6.8 A/m). For those strong samples, Q ratio is always over 1
268 (average around 2), stressing again the need to take remanence into account, even for
269 multidomain magnetite. For the East Cameroon study of Kankeu et al. (2009, at 5.5N and
270 14E), the susceptibility of 65 metasediments (schist, quartzite and gneiss) and 18 deformed
271 granites was measured. For these two classes, the maximum k is 2 and $5 \cdot 10^{-2}$ SI, with 5 and
272 61% of the samples above 10^{-2} SI, respectively.

273 It appears from Figure 7 that the mean magnetic susceptibility distribution is roughly
274 similar regardless of the location in the Panafrican belt, with metamorphic rocks derived from
275 basalts and granites having the strongest magnetic susceptibilities. These histograms confirm

276 on a larger scale the conclusion from our samples: no surface lithologies are able to account
277 for the BMA by induced magnetization alone (e.g. Shive, 1989). A review of the extensive
278 magnetic anisotropy work in Panafrican intrusives from NE Brasil (e.g. Archanjo et al., 1995,
279 1998, 2002) confirms this conclusion. When taking into account remanence it appears that
280 magnetite-bearing crustal rocks (granitoids and amphibolite) exceptionally reaches the BMA
281 total magnetization (Figure 8).

282

283 **6 – Discussion**

284 These results indicate that a single lithology -hematite-bearing itabirites, i.e. BIF,
285 interstratified with amphibolites and other metasediments- shows strong enough total
286 magnetization M_t to be the magnetic source of the BMA ($M_t > 4.3$ A/m). Lithologies rich in
287 multidomain magnetite (some amphibolites and granites) fail by about a factor 2 to account
288 for the BMA, assuming no significant enhancement of NRM at depth. No magnetic field
289 observations were made at the itabirite sampling locations (LeDonche and Godivier, 1962),
290 but such outcrops should result in a local small-wavelength high-amplitude magnetic field
291 anomalies. Our assumption that the deep crustal lithologies responsible for the BMA could be
292 outcropping over the BMA relies on the possibility that some slices from these deep
293 lithologies have been brought to the surface through orogenic processes (e.g. Rolin, 1991).
294 Our modelling shows that the deep magnetic source seems to be less dense than the deep non-
295 magnetic surrounding rocks (granulites?), but denser than most of the superficial non-
296 magnetic formations (quartzites and schists). We also note the numerous reverse faults in this
297 Panafrican belt around Bangui that witness a compressive regime which may have favored the
298 thickening of the iron-rich formations (Figure 1c).

299 The total magnetization intensity and the expected volume of the geological source of
300 the BMA are coherent with a mafic (basaltic) lower crust, as Pin and Poidevin (1987) and

301 Hemant and Maus (2005) suggested. This metabasalt or amphibolitic part of the Central
302 Africa's lower crust may be the root of the migmatite basement. However, our results also
303 suggest that BIF may compose the source of the BMA because of their magnetization. These
304 rocks are assumed to compose about 25% of the source of the Kursk magnetic anomaly in
305 Russia (Taylor, 1987; Ravat et al., 1993; Langel and Hinze, 1998). In such case, a positive
306 gravimetric anomaly should be associated to the BMA, as Schmidt et al. (2007) observed on a
307 similar geological formation in Australia (magnetization up to 100 A/m). However as itabirite
308 can be an order of magnitude more magnetized than the BMA source, a volume occupied by a
309 mixture of 10% itabirite (i.e. a maximum thickness of 2 km) and 90% of low density and less
310 magnetic rock can account for the BMA without inducing a significant excess of mass. As
311 mentioned earlier, a negative gravimetric contrast is associated to the BMA in its central part,
312 but a positive one is found west of Bangui nearby Cameroon border (Boukéké et al., 1995),
313 where a positive magnetic anomaly and itabirites are also observed. Finally, the combination
314 of these two possible magnetic formations (itabirites and amphibolite) may explain the long
315 wavelength and large intensity of the BMA.

316 It is interesting to note that probably all Panafrican metamorphic crustal formations,
317 including these magnetic rocks from the lower crust, may be found on surface today in the
318 Centrafrican Republic, while for other large magnetic anomalies like the Beattie magnetic
319 anomaly in South Africa, the source is from the upper and middle crust but covered by the
320 Karoo basin sediments (Quesnel et al., 2009). Two key points of our interpretation are the
321 possible Curie isotherm -deepened in case of hematite-bearing rocks- in the Central Africa
322 lithosphere, as well as the magnetic mineralogy that carries these strong magnetization
323 intensities at such depth (Frost and Shive, 1986; McEnroe et al., 2004). If it is hematite, our
324 study puts forward a candidate lithology: itabirite or BIF. If it is multidomain magnetite, then
325 the candidate lithology has not been sampled at the surface. It should be two times richer in

326 magnetite than the most magnetite-rich granitic and amphibolitic samples studied so far. Such
327 a high Fe amount should correspond to a positive gravity anomaly that is not observed.
328 However, a “homogeneous” tectonic mixing of BIF slices, a few km thick in total, with other
329 metasediments and a few tens of km thick series of magnetite-rich metamagmatic rocks may
330 be the best solution to account for all geophysical data.

331

332 **7 – Conclusion**

333 Using modelling and rock magnetism constraints, we investigated the source of the
334 BMA using samples obtained over the anomaly in Centrafrican Republic, as well as
335 geologically related areas in Cameroon. Modelling implies a total magnetization of the order
336 of 4 A/m on a thickness up to 54 km, possibly associated with relatively moderate density of
337 2.87. No surface sample can account for this magnetization based only on induced
338 magnetization. Large enough remanent magnetization intensities are observed for only two
339 surface samples, but lightning has affected one. This highlights the fact that modelled in-situ
340 NRMs based on IRM and magnetic mineralogy may be a more reliable indicator in magnetic
341 anomaly interpretation, compared to NRM actually measured on surface samples, which can
342 yield strongly-biased values with respect to NRM at depth.

343 The only remaining lithology, with NRM up to 50 A/m, is hematite-bearing itabirites
344 (BIF) that are Neoproterozoic iron-rich metasediments. Other magmatically-derived
345 lithologies rich in multidomain magnetite (migmatite, amphibolite, granite) can account for
346 only a few A/m at most. We suggest that the two types of geological formation may compose
347 the deep crust of this area and particularly the extended deep magnetic source. Further
348 constraints given by drilling or by other geophysical methods like seismics or
349 magnetotellurics are needed to validate (or not) this interpretation and the previously-
350 published models. Concerning magnetics, new high-resolution ground and airborne magnetic

351 field measurement surveys will surely improve the characterization of this source, including
352 its possible extensions toward the surface. In the same time, one should benefit from the
353 upcoming SWARM satellite mission (Friis-Christensen et al., 2006) that will allow the use of
354 lateral and vertical magnetic gradients to study such large magnetic anomalies.

355

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360

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362

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515 **Figure captions**

516

517 **Figure 1:** Location (a), regional (b) and local (c) geological contexts of the studied area. In
518 (a), the black rectangle and disks correspond to the sampled areas in Centrafrican Republic
519 and Cameroon, respectively. The dotted-dashed line delineates the coastline of South
520 America, translated and rotated next to Africa. A zoom is shown in (b) where the relationships
521 between the different Archean blocks are reconstituted. Zone A corresponds to the
522 Paleoproterozoic rocks with Archean inheritances underlining the border of the mega-Congo
523 craton. Zone B are the Pan-African rocks with Paleoproterozoic inheritances. Zone C
524 represents the nappes of the 600 Ma Central African Belt. Zone D corresponds to the
525 Mesozoic sediments of the Benue trough and Zone E are the oceanic rocks. PF, Pernambuco
526 fault; ADF, Adamawa fault; TBF, Tchollire–Banyo fault; dotted-dashed lines: reconstituted
527 South America (SW one) and Africa (NE one) coastlines. This (b) regional map is modified
528 from Penaye et al. (2004), Poidevin (1991), Ferré et al. (1996), Feybesse et al. (1998),
529 Almeida et al. (2000) and Toteu et al. (2001). The dashed rectangle corresponds to the
530 Centrafrican sampled area (c), while the black disks show the approximate locations of the
531 sampled areas in Cameroon. In (c), modified from Rolin (1995a), details about the surface
532 lithology and the structural features of the studied area nearby Bangui are shown. 1, Archean
533 gneissic basement; 2, Paleoproterozoic migmatitic domain; 3, Lower-Neoproterozoic domain
534 with (a) quartzites and (b) itabirites; 4, Upper-Neoproterozoic schists; 5, Upper-
535 Neoproterozoic limestones/marbles; 6, Panafrican Gbayas Nappe with orthogneisses,
536 granulites and granites; 7, Post-Panafrican cover with sandstones and clays. Black filled
537 circles with names indicate the sampling sites.

538

539 **Figure 2:** Interpolated magnetic anomaly maps near the surface over Centrafrican Republic
540 and Chad. On left, gridded data from the satellite MF7 model (derived from Maus et al.
541 (2008) downward continued to 2.5 km of altitude). On right, ground magnetic data
542 interpolated from LeDonche and Godivier (1962). The solid lines correspond to the selected
543 profiles for modelling, while the rectangle indicates the location of Figure 1c.

544

545 **Figure 3:** Crustal magnetic models (bottom panels) along the NW-SE western (a) and eastern
546 (b) profiles (top panels) shown on Figure 2. Sat, satellite-derived magnetic data; Ground,
547 ground magnetic data; Gravi, ground gravity data (Boukéké et al., 1995); Obs, observations,
548 Pred, predictions. For models, layer density and magnetization properties are represented by
549 the filling color and/or pattern (see Table 1 for details). Formation 1 has a total magnetization
550 intensity (Mt) of 4.3 A/m, which corresponds to the best model with this source geometry (see
551 Supplementary Material).

552

553 **Figure 4:** Hysteresis curves (specific magnetization) of four samples. Bc, coercitive field; Ms,
554 saturation magnetization; Mrs, remanent magnetization at saturation; Bcr, coercitive field of
555 the remanent magnetization, derived from the back-field curve.

556

557 **Figure 5:** Low-temperature remanent magnetization (RM) curves for two samples (cooling
558 and subsequent heating of a room temperature IRM), showing the Verwey (in a) and Morin
559 (in b) transitions. For (b) is also shown the induced magnetization (IM) heating and cooling
560 curves, measured in a 0.3 T field.

561

562 **Figure 6:** Effect of heating (black) and cooling (gray) on the normalized magnetic
563 susceptibility of the same four samples as in Figure 4.

564

565 **Figure 7:** Histogram (in logarithmic representation) of k_m , the mean magnetic susceptibility,
566 for Cameroon and Centrafrican Republic (CR) rock samples.

567

568 **Figure 8:** Histogram of modelled total magnetization (Mt) derived from IRM and
569 susceptibility measurements on Panafrican magnetite-bearing rocks from Cameroon (black)
570 and Centrafrican Republic (white).

Figure 1 revised

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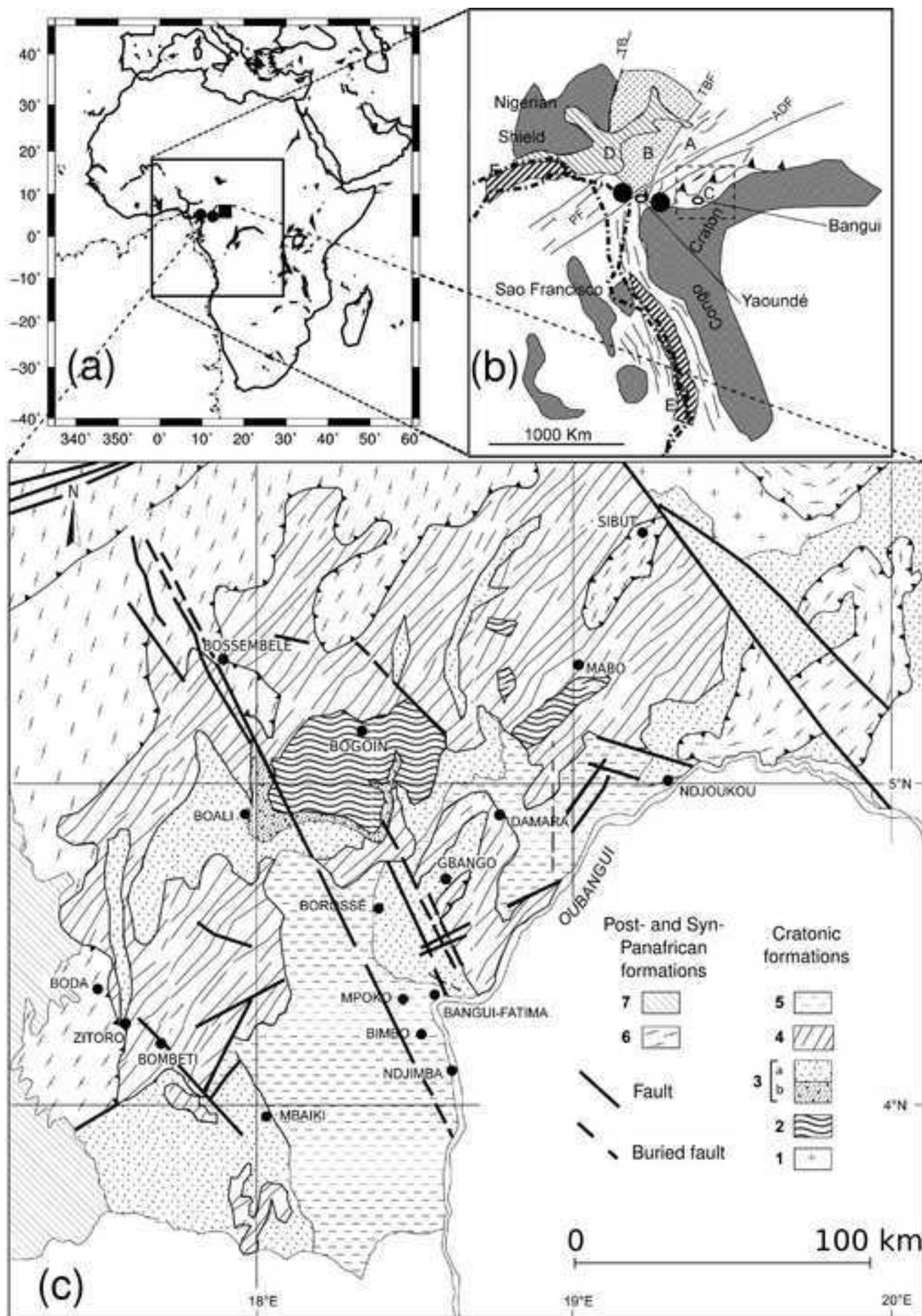


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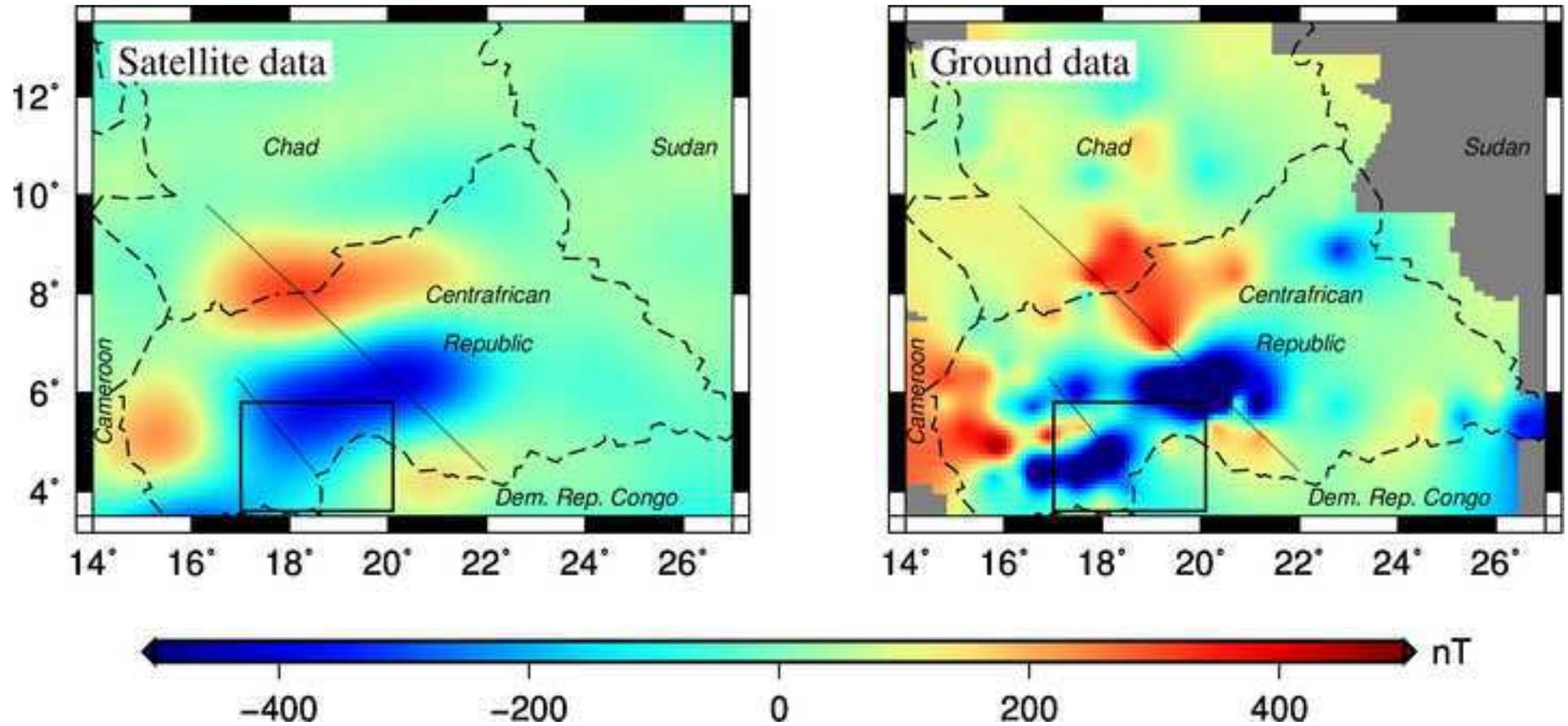


Figure 3 revised

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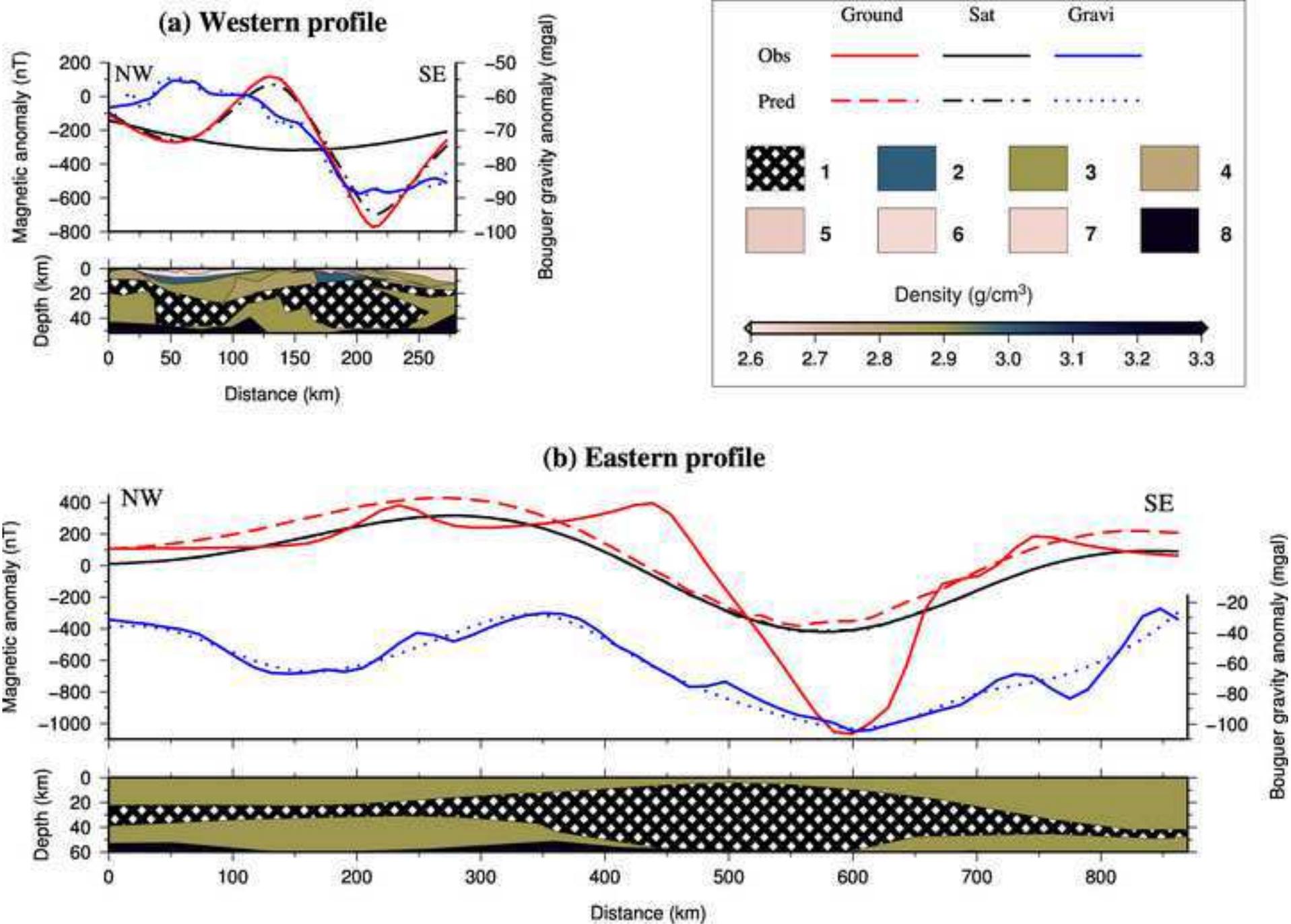


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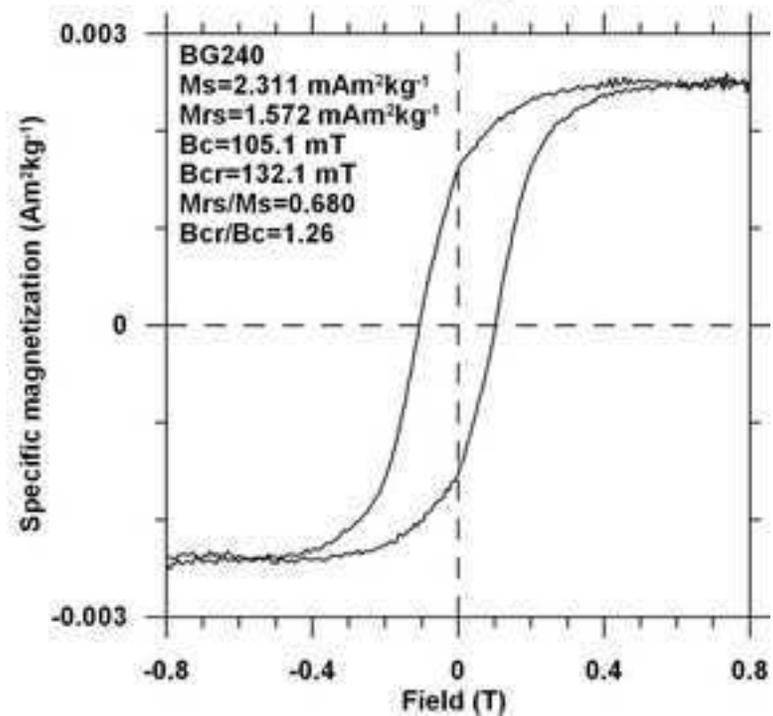
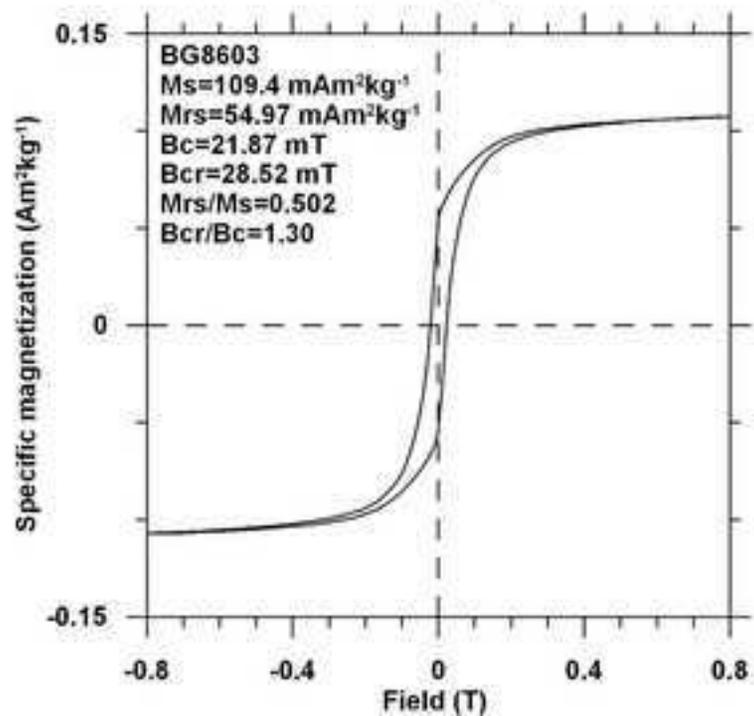
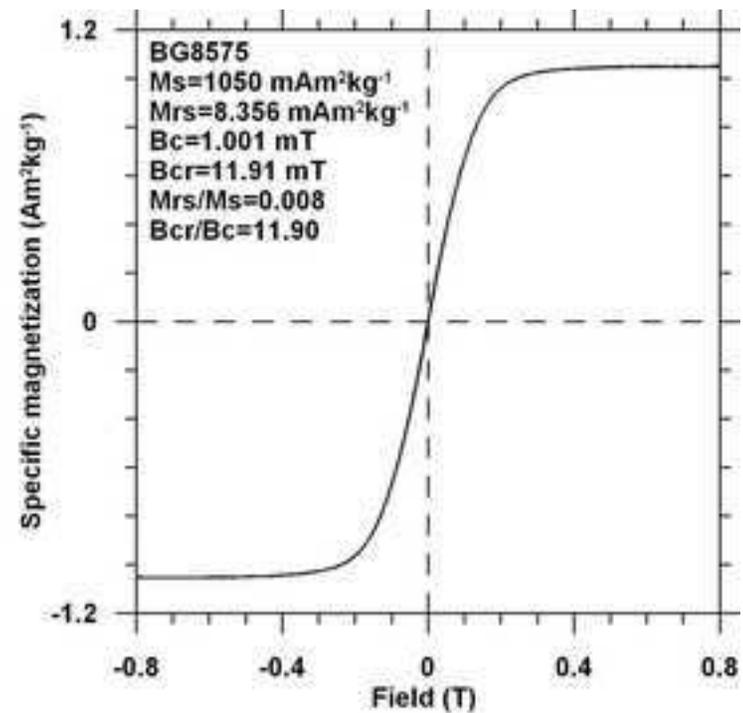
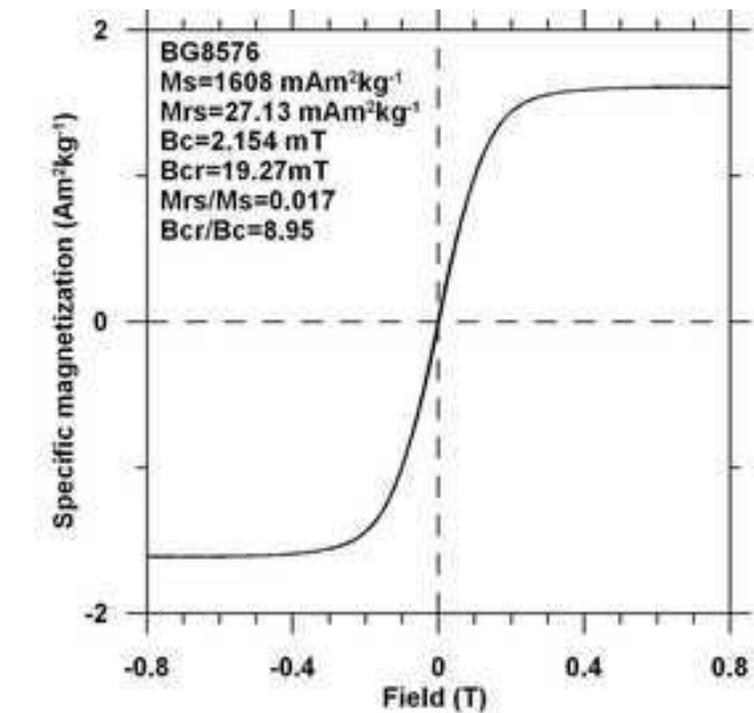


Figure 5 revised

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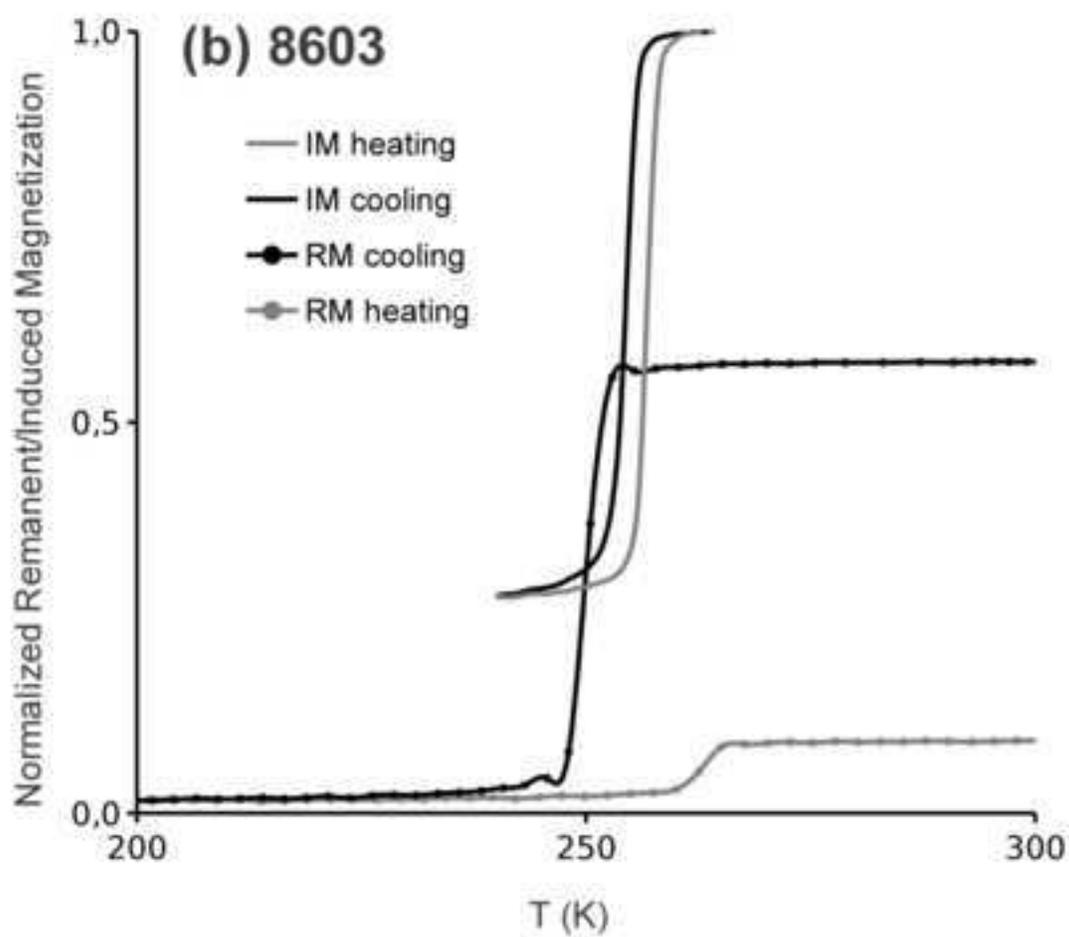
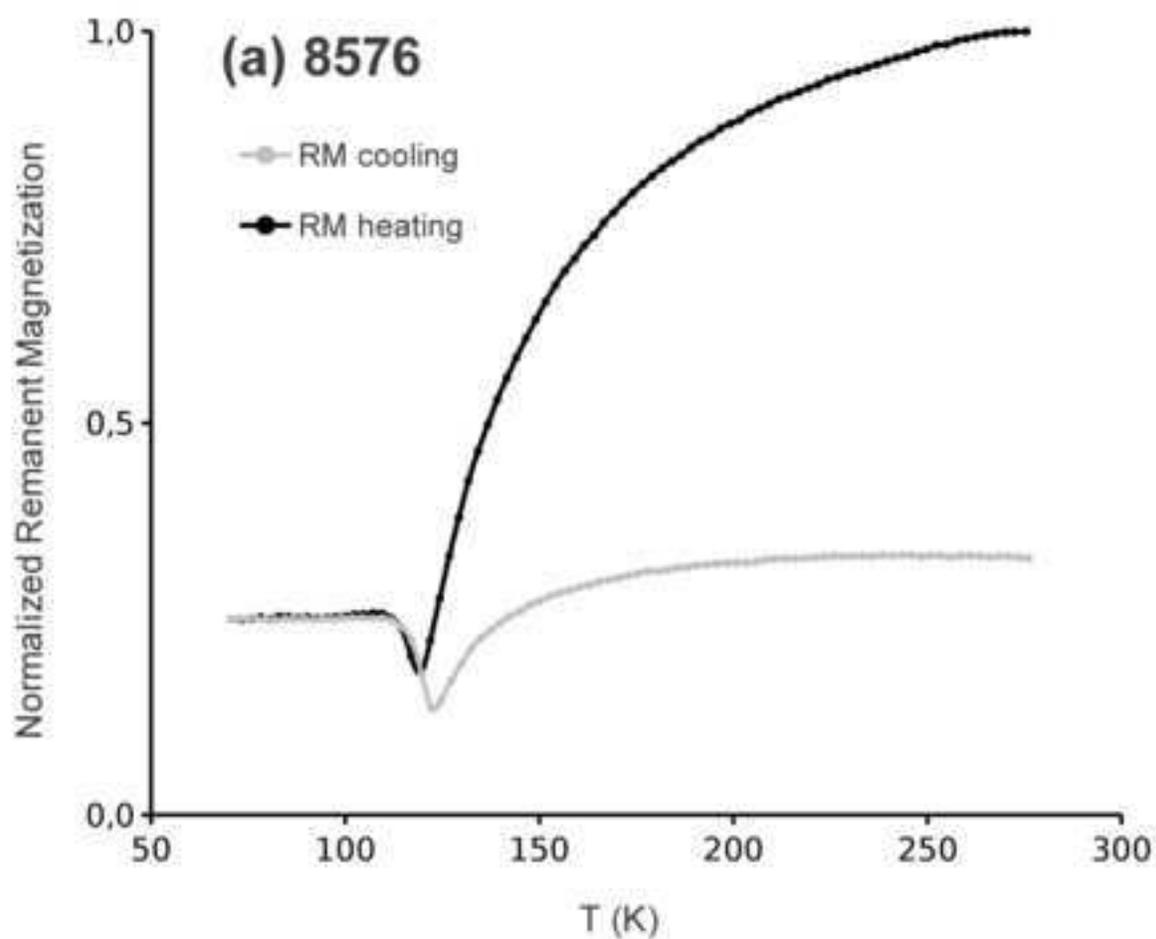


Figure 6
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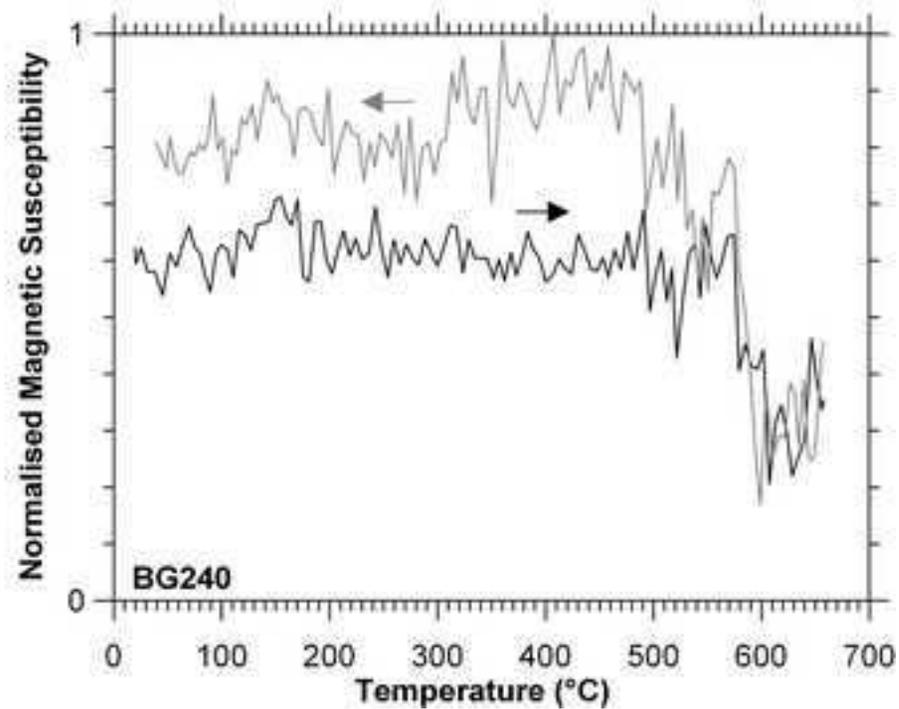
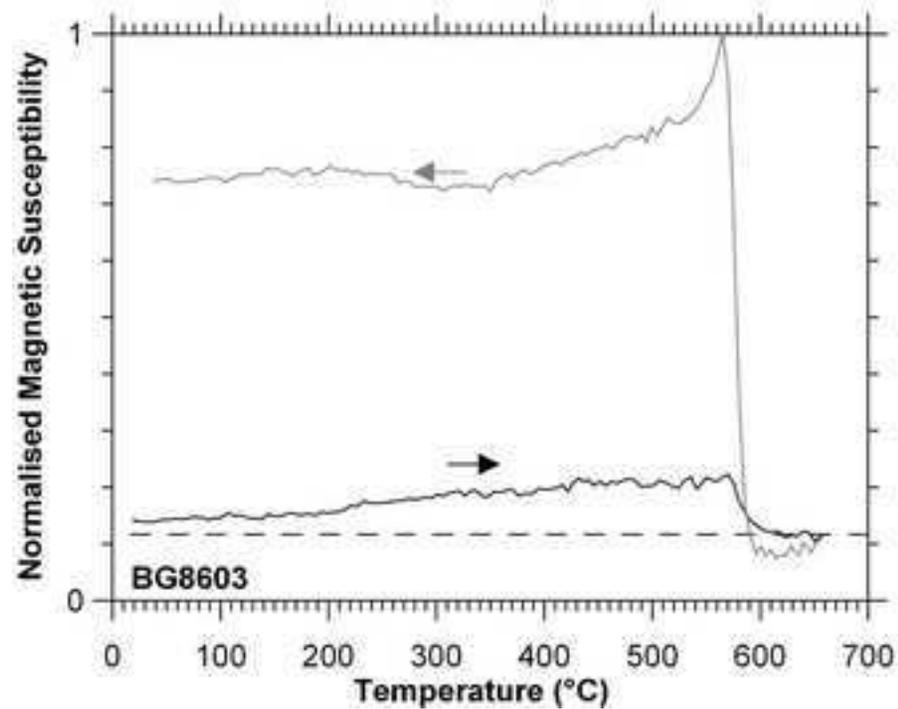
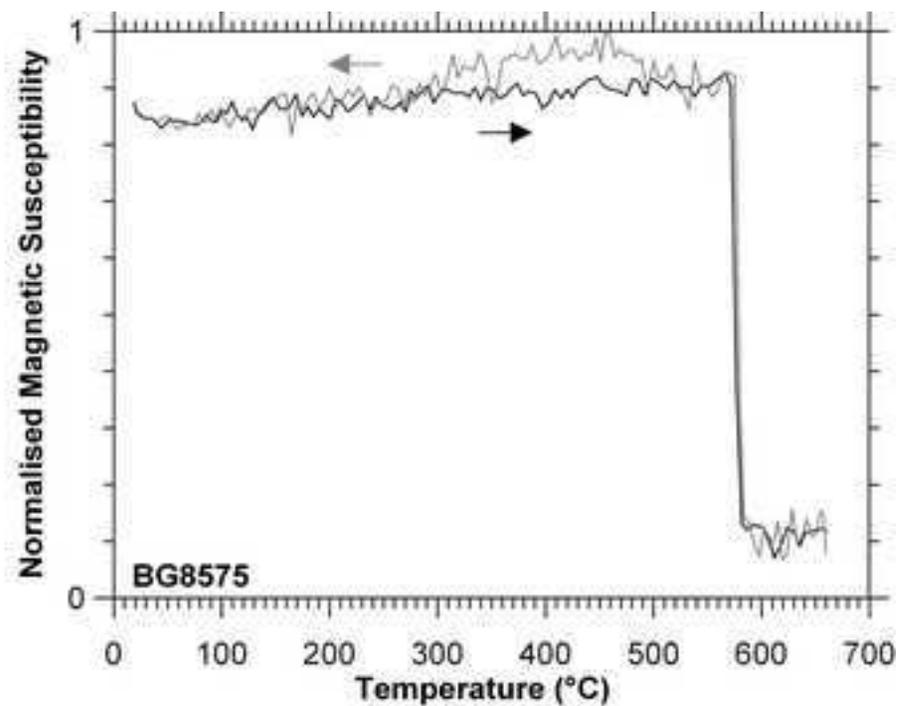
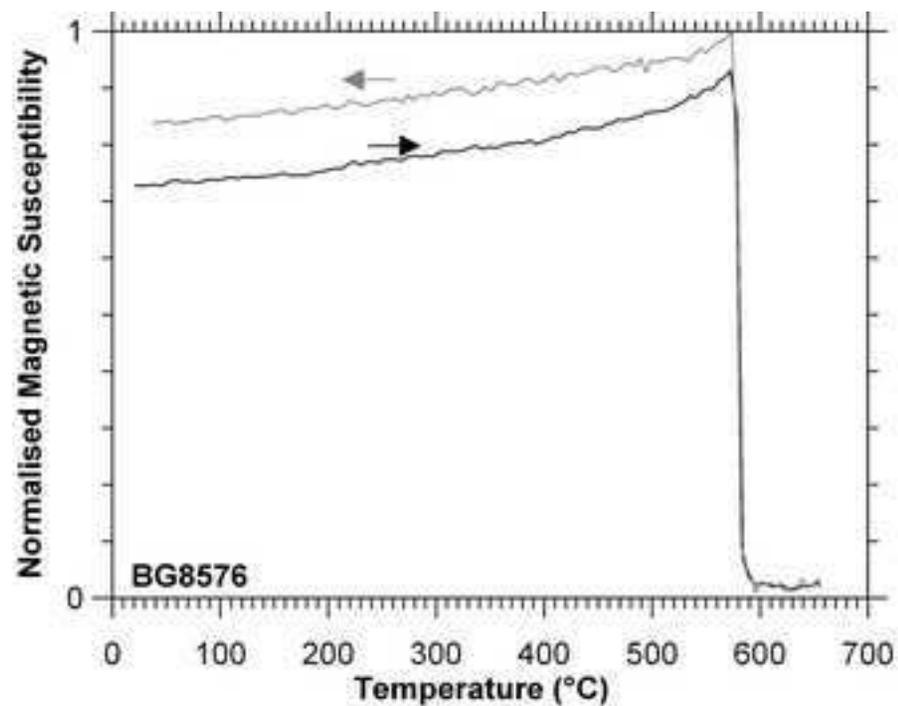


Figure 7 revised
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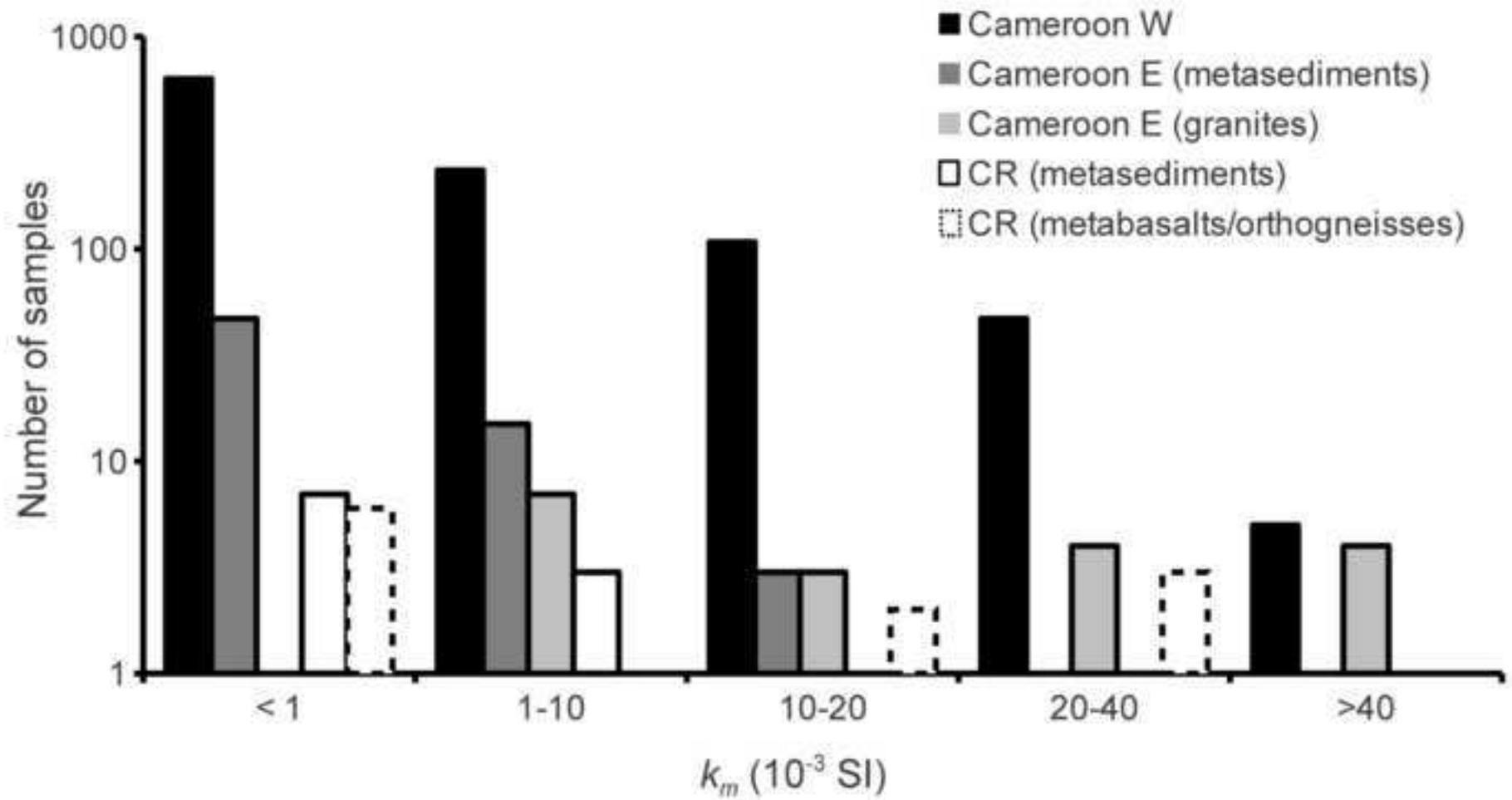
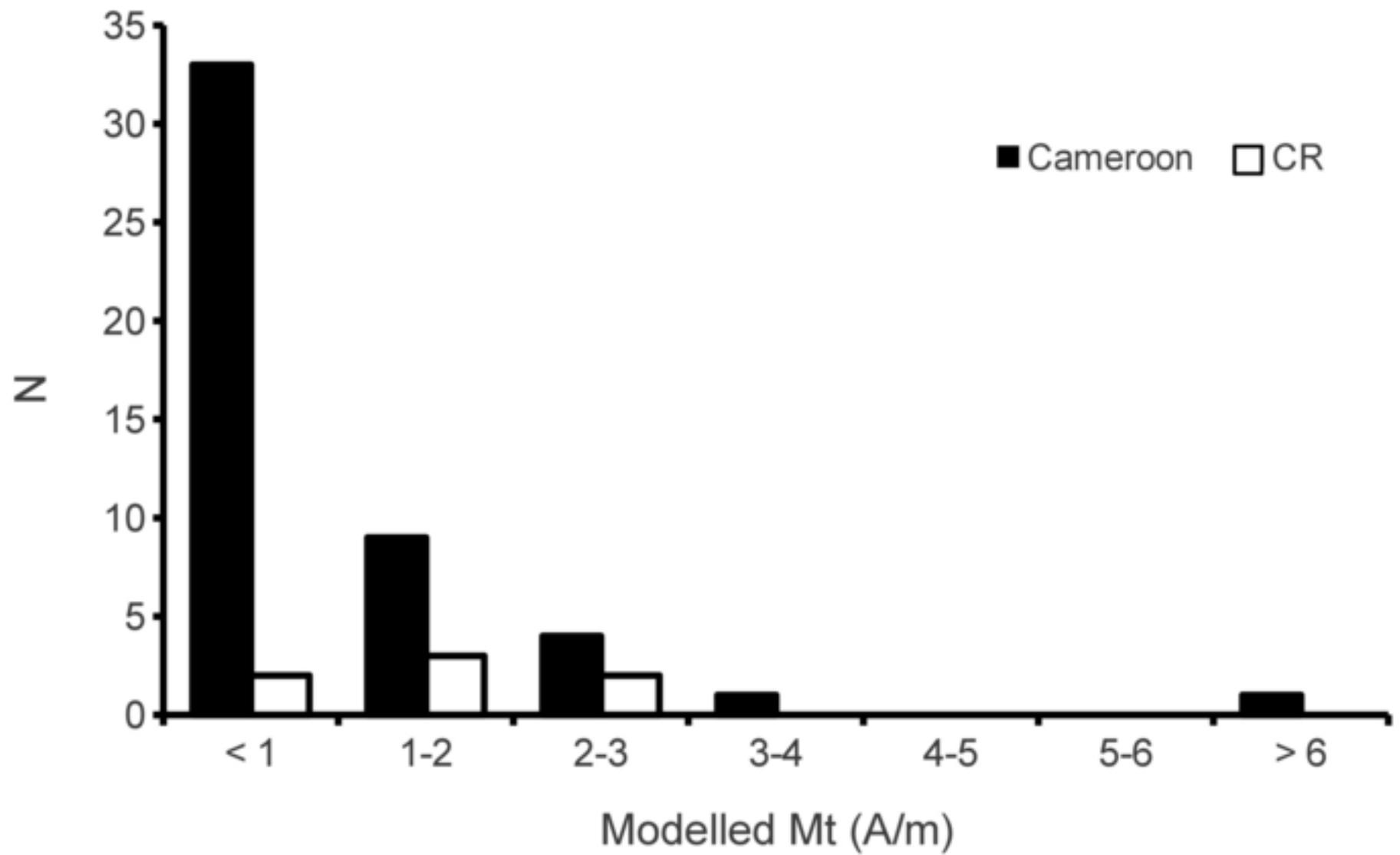


Figure 8 new
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1 **Table 1.** Magnetization* and density contrasts of the best models for the source of the BMA.

<i>Layer**</i>	<i>k</i> (10 ⁻³ SI)	NRM (A/m)	d (g.cm ⁻³)	<i>Rock type***</i>
1	10	4.0	2.870	<i>Magnetic source layer</i>
2	1	-	3.000	<i>Metabasalt</i>
3	1	-	2.900	<i>Granulite/Orthogneiss</i>
4	1	-	2.850	<i>Amphibolite</i>
5	1	-	2.665	<i>Quartzite</i>
6	1	-	2.630	<i>Schist</i>
7	1	-	2.640	<i>Panafrican nappe</i>
8	-	-	3.300	<i>Mantle rocks</i>

2 *all layers have their magnetization oriented in the 1960 (I= -14.5°, D=-5°) and 2011 (I= -16.76°, D=0.3°)

3 magnetic field directions in Bangui for the modelling of the ground and satellite magnetic data, respectively.

4 **see correspondance in Figure 3.

5 ***these rock types are expected with regards as their densities, their magnetization properties and the surface

6 geology.

1 **Table 2.** Magnetic properties of rock samples from the Bangui area.

<i>Lithology</i>	ID	χ ($10^{-9} \text{ m}^3 \cdot \text{kg}^{-1}$)	NRM ($\text{A} \cdot \text{m}^2 \cdot \text{kg}^{-1}$)	Mt (A/m)	Q	NRM/SIRM (%)	Laboratory	<i>Sampling site</i>
							modelled Mt (A/m)	
<i>Itabirite</i>	8603	798	23856.2	76.4	1117.8	43.6	88.1	<i>Bogoin</i>
	243	629	237.5	0.8	14.1	5.1	7.5	<i>Bogoin</i>
<i>Migmatite</i>	8576	12201	2041.1	6.4	6.3	7.6	2.3	<i>Mabo</i>
	8575	8496	66.0	0.8	0.3	0.7	1.1	<i>Mabo</i>
<i>Orthogneiss</i>	240	85	833.8	2.3	365.5	53.1	2.1	<i>Mabo</i>
	234	229	342.8	0.9	55.9	36.1	1.5	<i>Sibut</i>
	235	5165	102.7	0.7	0.7	3.4	0.5	<i>Sibut</i>
	216	23	0.9	0.0	1.4	-	-	<i>Galabadjia</i>
<i>Granodiorite</i>	8632	7587	382.9	1.6	1.9	1.6	1.8	<i>La Mbi</i>
<i>Metaperidotite</i>	8840	5223	76.7	0.6	0.5	0.8	0.9	<i>La Mbi</i>
	8838	1235	105.6	0.4	3.2	-	-	<i>La Mbi</i>
	8836	164	3.0	0.0	0.7	-	-	<i>Sibut</i>
<i>Quartzite</i>	203	1902	82.7	0.4	1.6	-	-	<i>Boali</i>
	8564	5	1.4	0.0	11.0	-	-	<i>Bossebélé</i>
	213	7	0.8	0.0	3.8	-	-	<i>Mbalki</i>
	452	20	0.4	0.0	0.7	-	-	<i>Ouango</i>
<i>Granulite</i>	230	304	38.8	0.1	4.8	-	-	<i>Sibut</i>
<i>Metabasalt</i>	8602	292	0.2	0.0	0.0	-	-	<i>Bogoin</i>
<i>Micaschist</i>	249	171	2.2	0.0	0.5	-	-	<i>Boali</i>
<i>Metasilexite</i>	217	52	1.3	0.0	0.9	-	-	<i>Kamaro</i>

<i>Cipolin</i>	8631	-1	0.4	0.0	-11.9	-	-	<i>Fatima</i>
	8610	-1	0.4	0.0	-13.0	-	-	<i>Ndjimba</i>

Supplementary Material (new)

[Click here to download Supplementary Material: SupplementaryMaterial.pdf](#)