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12 **Abstract**

13 Nyankanga gold deposit is the largest gold deposit found in Geita Greenstone Belt of
14 northern Tanzania Craton. The deposit is hosted within an Archean volcano-sedimentary
15 package dominated by ironstones and intruded by a large diorite complex, the Nyankanga
16 Intrusive Complex. The supracrustal package has been fragmented by the intrusion of diorite,
17 and associated igneous rocks forming the Nyankanga Intrusive Complex, and is now included
18 within the intrusive complex as roof pendants. The ironstone fragments contain evidence of
19 multiple folding events that occurred prior to syn- intrusion of Nyankanga Intrusive
20 Complex. The entire package is cut by a series of NE-SW trending, moderately NW dipping
21 shear zones with a dominant reverse component of movement but showing multiple
22 reactivation events with both oblique and normal movement components. One of these shear
23 zones, the Nyankanga Shear Zone, developed mainly along the ironstone-diorite contacts and
24 is mineralised over its entire length. The gold mineralization is hosted within the damage
25 zone associated with Nyankanga Shear Zone by both diorite and ironstone with higher grades
26 typically occurring in ironstone. The mineralization is associated with sulfidation fronts and
27 replacement textures in ironstones and is mostly contained as disseminated sulphides in
28 diorite. The close spatial relationship between gold mineralization and ironstones suggests
29 that the reaction between the mineralising fluid and iron rich lithologies played an important
30 role in precipitating gold. Intense fracturing and microveining, mainly in the footwall of
31 Nyankanga Shear Zone indicates that the activity of the shear zone played an important role
32 by increasing permeability and allowing the access of mineralising fluids. The entire package
33 is cut by a series of NW trending strike slip faults and ~ E-W trending late normal faults
34 which have reactivated Nyankanga Shear Zone and may have played a role in the
35 mineralising event.

36 **Keywords:** gold deposits; Archean; Tanzania Craton; Nyankanga gold deposit; roof pendants

37 **1. Introduction**

38 Archean gold deposits are one of the most important sources of gold worldwide (e.g.
39 Goldfarb et al., 2001). Important mining camps are found in the Yilgarn Craton of Western
40 Australia, the Superior Province in Canada, the Quadrilatero Ferrifero in Brazil, the Dharwar
41 Craton in India, and the Kaapvaal, Zimbabwe and Tanzania Cratons in Africa. Except for

42 gold deposits linked to intra-cratonic basins of which the Witwatersrand gold deposits are by
43 far the largest, the bulk of Archean gold deposits are hosted within, or adjacent to greenstone
44 belts, and share a series of common features commonly linked with orogenic gold deposits
45 (e.g. Grooves et al., 1998). Such common features include: strong structural controls and an
46 association with shear zones within greenschist to lower-amphibolite facies terrains, a
47 hydrothermal origin with low-sulphidation ore assemblages and associated quartz and
48 carbonate alteration, with the main ore forming events being late-tectonic (e.g. Grooves et al.,
49 1998; Goldfarb et al., 2001; Bateman and Bierlein, 2007). By grouping these deposits as
50 orogenic gold deposits it is implicitly assumed that tectonic processes in the Archean were
51 essentially the same as plate-tectonic settings seen today (e.g. Bierlein et al., 2009); a premise
52 that remains contested (e.g. Dirks et al., 2013; Bedard et al., 2013; Gerya, 2014). These
53 deposits are therefore also commonly described with the less generic term Archaean lode
54 gold.

55 Any rock type can host Archaean lode gold deposits (e.g. Anhaesser et al., 1986;
56 Laznika, 2014), but in general most large deposits are found within the volcano-sedimentary
57 greenstone sequences as opposed to nearby granite and gneiss units (e.g. Goldfarb et al.,
58 2001; Laznika, 2014). Large deposits such as Kalgoorlie camp in Australia (e.g. Weinberg
59 and van der Borgh, 2008; Blewett et al., 2010), Timmins camp in Canada (e.g. Robert and
60 Paulsen, 1997; Gray and Hutchinson, 2001), Kolar gold field in India (e.g. Mishra and
61 Panigrahi, 1999) and Bulyanhulu in Tanzania (e.g. Chamberlain, 2003) are intimately
62 associated with mafic metavolcanics. Although there are many Archean BIF (banded iron
63 formation) hosted deposits around the world very few have produced or contain large gold
64 deposits (Steadman et al., 2014).

65 The geological literature on the Geita area of North West Tanzania is extremely limited in
66 spite of the fact that has been recognised to contain a high density of world class/giant BIF
67 hosted gold deposits (e.g. Goldfarb et al., 2001). The Geita Greenstone Belt hosts at least 10
68 separate gold deposits with historical production and estimated reserves of over 0.5 million
69 ounces each, but only the Geita Hill gold deposit has been described in the geological
70 literature (Borg, 1994). This description was based on underground workings that were
71 operated between 1935-65; i.e. before the re-opening and massive expansion of mining in the
72 Lake Victoria gold field. The Geita Hill gold deposit was described as a shear-zone hosted
73 lode gold deposit hosted in an ironstone dominated supracrustal package intruded by diorite
74 dykes and sills (Borg, 1994).

75 By far the largest gold deposit within the Geita Greenstone Belt, the Nyankanga
76 deposit, occurs 1.5km to the SW of the Geita Hill deposit (Fig. 2). The Nyankanga gold
77 deposit was discovered in 1995 based on a weak soil anomaly, which was drilled in 1996.
78 The deposit is located along the same 5km long, NE trending mineralised zone as the Lone
79 Cone deposits. Reported reserves in 2002, at the start of mining, for the Nyankanga gold
80 deposit included 6.3 Moz @ 5.42 g/t (open pit), and 1.04 Moz @ 8.12 g/t (underground)
81 (Marjoribanks, 2003) with significant reserves added by further exploration and with open
82 potential at depth. Although, various aspects of the geology of the deposit have been
83 described and interpreted in a series of internal reports (e.g. Ryan and Speers, 2002; Porter,
84 2003; Skead et al., 2003; Marjoribanks, 2003; Painter, 2004; Krapez, 2008; Basson, 2010;
85 Brayshaw, 2010; Kolling, 2010; Nugus and Brayshaw, 2010), a formal description of the
86 deposit is missing from the geological literature. In this contribution we present a
87 comprehensive description and interpretation of the main factors controlling the gold
88 mineralization in the giant Nyankanga gold deposit.

89 **2. Regional geology**

90 The northern half of the Tanzanian Craton contains a series of roughly E-W trending,
91 narrow segments of NeoArchean (e.g. Kabete et al., 2012; Sanislav et al., 2014) greenstone
92 belts separated and surrounded by granitoid intrusions and gneiss terrains (Fig.1), that are
93 intrusive or sheared contact with the greenstone sequences. The stratigraphy of the
94 greenstone belts has been subdivided into two main units, namely the Nyanzian Supergroup
95 and the Kavirondian supergroup (e.g. Quennel et al., 1956; Gabert, 1990). The Nyanzian
96 Supergroup has been further subdivided into Lower Nyanzian and Upper Nyanzian Groups.
97 The Lower Nyanzian is dominated by mafic volcanic units (amphibolite, pillow basalt, minor
98 gabbro) and overlain by the Upper Nyanzian which is dominated by felsic volcanic and
99 pyroclastic units inter-bedded with banded ironstone, volcanoclastic sequences and immature
100 turbiditic sediment (Kuehn et al., 1990; Borg, 1992; Borg and Shackelton, 1997; Borg and
101 Krogh, 1999; Krapez, 2008). The Nyanzian Supergroup is unconformably overlain by the
102 Kavirondian Supergroup, which consists mainly of coarse grained conglomerate, grit and
103 quartzite. Underlying the supracrustal greenstone units is the Dodoman Supergroup, which
104 consists of high-grade mafic and felsic granulite with subordinate lower-grade schist and thin
105 slivers of greenstone (Kabete et al., 2012).

106 The overall stratigraphy and structural complexity of the greenstone belts and
107 intervening granite-gneiss has not been described in detail and is generally poorly
108 understood. For example the Sukumaland Greenstone Belt (Fig. 1) has been described as an
109 arcuate-shaped belt in which intrusions of syn- to post-tectonic granitoids divide the belt into
110 an inner arc dominated by mafic volcanic rocks and an outer arc dominated by banded
111 ironstone, felsic tuff and volcanoclastic sediment (Borg et al., 1990; Borg, 1994). This
112 subdivision may be too simplistic as indicated by the occurrence of abundant mafic units in
113 the outer arc and abundant sediment and felsic volcanic intercalations in the inner arc with
114 age distributions that are inconsistent with the original stratigraphic interpretations (e.g.
115 Cloutier et al., 2005; Many and Maboko, 2008).

116 The Geita Greenstone Belt (GGB, Fig. 2) constitutes an E-W trending segment of
117 greenstone units situated directly south of Lake Victoria and forming the central northern part
118 of the outer arc of the Sukumaland greenstone belt as defined by Borg et al. (1990). The
119 greenstone belt is bounded by undeformed 2660 and 2620 Ma granites to the north, east and
120 west (Sanislav et al., 2014), and by gneiss to the south. The contact of the greenstone mafic
121 metavolcanics and the gneiss occurs along a steeply dipping E-W trending shear zone. The
122 geochemistry and whole rock Sm-Nd ages for mafic metavolcanics within the SW part of the
123 Geita Greenstone Belt indicate a MORB-like affinity and model ages of ca. 2823 Ma (Many
124 and Maboko, 2008). Their geochemistry and model ages are similar to those of the mafic
125 metavolcanic units occurring further south of GGB (Many and Maboko, 2003) suggesting
126 that the greenstone units in Sukumaland Greenstone Belt may form discontinuous remnants
127 of a once much more widely distributed greenstone sequence, now separated by intrusive
128 granite batholiths (Many and Maboko, 2008). The remainder of the Geita Greenstone belt is
129 dominated by banded ironstone intercalated and overlain by turbiditic metasedimentary units
130 (ranging from mudstone to rare conglomerate) with volcanoclastic beds, and intruded by
131 diorite dykes and sills, and late granitoids. Borg and Krogh (1999) dated a trachyandesite
132 sub-parallel to bedding (and interpreted as an extrusive unit) from Geita Hill, at 2699 ± 9 Ma
133 providing an estimate for the depositional age of the sedimentary sequence in the area;
134 although it must be noted that the unit they dated was probably a fine-grained dioritic sill and
135 not an extrusive unit (Sanislav et al., 2015). NE-striking, Neoproterozoic dolerite dykes
136 cross-cut the GGB.

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3. Host rock types

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3.1. Sedimentary Rocks

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The Nyankanga gold deposit (Fig. 3) is contained within a magnetite-rich sedimentary package (the ‘ironstones’ Fig. 2) consisting of inter-bedded sandstone-siltstone units locally intercalated with laminated chert and conglomeratic sandstone beds and overlain by a thick succession of epiclastics turbidite. The sedimentary succession was intruded by various generations of diorite, lamprophyre, feldspar and quartz porphyry, and has been metamorphosed to low greenschist facies. The ironstones are magnetic and contain at least three texturally distinct generations of magnetite. Primary sedimentary magnetite occurs as fine laminations within shale or chloritic mudstone beds intercalated with chert or fine-grained siltstone. Primary magnetite banding is generally continuous along strike but locally occurs as lenses associated with flaser-like textures. The second generation of magnetite is hydrothermal and forms zones of magnetite enrichment near and along shear zones. Because many shear zones are sub-parallel to bedding (see below) this generation of magnetite may resemble sedimentary magnetite, but can be distinguished by locally crosscutting bedding at a low angle and by bifurcations. The third generation of magnetite is remobilised sedimentary or hydrothermal magnetite present along crosscutting veins and fractures.

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The ironstones can be subdivided into three stratigraphic units or lithofacies with both lateral and stratigraphic transitions observed. The lower most ironstone unit is about 3 m thick and consists of intercalations of graphite-rich magnetic shales or siltstone and laminated chert (Fig. 5a). The middle unit consists of poorly bedded magnetite and chert intercalations. The unit is usually dark-grey in colour and the chert beds are typically translucent pale-grey (Fig. 5b). The upper ironstone unit consists of laminated intercalations of silty, chloritic clastic sedimentary rocks interbedded with chert (Fig. 5c). Magnetite is present along the contact between chert beds and the overlying clastics beds. This unit is usually dark-green in colour with planar, thin laminations. In general the boundaries between each of these units are gradational. Banded magnetite-chert units may occur within laminated ironstone or laminated ironstone within banded chert-magnetite. These ironstone rich units are intercalated with tens of centimetre- up to few meter-thick beds of epiclastic siltstone and coarse grained pebbly sandstone to conglomerate. Similar epiclastic units are present above the ironstone-rich unit where the thickness of individual beds can be in the range of tens of meters. The dominant lithology consists of fine grained chloritic-feldspathic quartzo-

169 feldspathic sandstone and locally conglomerate. Pebble size fragments are common within
170 the sandstones and many beds may contain intraformational fragments of chert and
171 mudstone. Coarse- to very-coarse grained sandstone is found as lenses within thicker beds.
172 The sequence is commonly graded (Fig. 5d), can be massive or stratified and erosional bases
173 and flame structures are commonly preserved. Some sandstone beds grade up to siltstone,
174 shale or magnetic shale and chert. In these situations the magnetic-rich shale and chert
175 represent tens of centimetre thick intervals that overlie the sedimentary sequence. The
176 quartzo-feldspathic sandstone has a detrital matrix composed of rounded quartz, feldspar, and
177 mafic minerals, and may contain cobble size fragments of chloritic-feldspathic sandstones
178 and plagioclase rich porphyries.

179 **3.2. Igneous rocks**

180 The host lithologies to the Nyankanga gold deposit (Figs. 3 and 4) are volumetrically
181 dominated by a suite of intrusive rocks that include diorite (Figs. 5e and 5f) intruded by
182 several generations of feldspar (Fig. 5g) and/or quartz porphyry (Fig. 5h) and lamprophyre
183 dykes (Fig. 5j). Based on mineralogy, two main types of diorite have been identified in the
184 Nyankanga deposit. These are plagioclase-rich diorite (Fig. 5e) and hornblende-rich diorite
185 (Fig. 5f). Both varieties can be equigranular, or porphyritic with a range of matrix grain-size.
186 The two types can grade progressively into each other and zones of hornblende-rich diorite
187 can be found within plagioclase-rich diorite and vice versa; suggesting that this mineralogical
188 variation is the result of magmatic differentiation rather than indicating different timing
189 relationships. Some of the porphyritic diorite may contain up to 20% potassic feldspar in the
190 groundmass suggesting a transition into monzodiorite towards granodiorite. The lack of
191 chilled margins, pepperite microstructures or any sign of soft sediment interaction suggest
192 that the diorite intruded at depth.

193 The felsic porphyries are light to medium grey in colour with obvious feldspar and/or quartz
194 phenocrysts. Their matrix is usually fine-grained and contains quartz, plagioclase and
195 amphibole. They are present usually as dikes.

196 Lamprophyre dykes are only minor occurrences in Nyankanga deposit, occurring as ~ 1 m
197 wide dykes. They are light to dark brown in colour and contain abundant biotite, hornblende
198 and calcite in the matrix and as veins.

4. Structural setting and intrusive history of Nyankanga gold deposit

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The geology of Nyankanga gold deposit and the surrounding geology is dominated by a large, composite dioritic intrusive complex (Nyankanga Intrusive Complex), which was intruded by a series of felsic dykes (Fig. 4). Within Nyankanga pit there are 10-100m scale fragments of ironstone generally trending ENE-WSW and dipping moderately to shallowly NNW; i.e conformable to the regional trend of the surrounding greenstones. These ironstone fragments are wedge/tabular shaped, surrounded and intruded by diorite, and represent large country rocks clasts within Nyankanga Intrusive Complex. Their general orientation is similar to that of the surrounding country rocks suggesting that these large ironstone fragments have maintained their original orientation. Most of these ironstone fragments are fault bounded and one particular fault zone (the Nyankanga Shear Zone) is spatially associated with the gold mineralization. The ironstone unit contains a complex folding history prior to the development of Nyankanga Fault Zone. In the following section we document the sequence of folding and faulting that defines the structural setting of Nyankanga gold deposit.

D1- Bedding parallel foliation and shear (S0 and S1)

Bedding in ironstone is defined by mm- to cm-scale intercalations of chert and mudstone/shales locally interbedded with siltstone and sandstone beds. A fine penetrative cleavage (S1) is commonly developed within the mudstone/shale layers in ironstone. This cleavage is layer parallel, has been refolded during subsequent deformation events and may contain oriented chlorite. In Nyankanga gold deposit bedding has a general NE-SW trend and dips moderately to gently NW (average of $346^{\circ}/44^{\circ}$; Fig. 6a). The variation in bedding orientation is due to a combination of folding, intrusion and faulting. Locally, the bedding planes contain rootless, isoclinal intrafolial folds (D1) which may reflect an early bedding parallel shear event.

D2-First isoclinal folding event

The bedding and S1 foliation are affected by several generations of folds, the earliest of which are referred to as D2 folds (Fig. 7a). D2 folds are generally isoclinal, non-cylindrical and show a wide dispersion in fold axis orientations that plot consistently along a great circle similar in orientation to bedding (S0). Because they are generally isoclinal, D2 folds are most clearly exposed, or most recognisable within D3 hinge zones. It is possible that high strain

231 associated with D3 has further compressed and disrupted F2 folds turning them into
232 parallelism to bedding especially along the limbs. Their isoclinal geometry suggest that
233 actually in many situations layering may be a composite S_{0,1,2} structure.

234 **D3- Dominant folding event**

235 D3 folds (Fig. 7a) are the most common type of folds observed within ironstone rafts in the
236 Nyankanga deposit. They are commonly asymmetric, cm- to m-scale, plunging inclined
237 folds, with moderately NNE dipping axial planes. Throughout Nyankanga deposit F3 folds
238 have a consistent Z-like asymmetry. This suggests that Nyankanga deposit lies on the SW
239 limb of a NW plunging synform closing to the NE. In outcrops where the rocks are less
240 altered and silicified, a spaced cleavage axial planar to the D3 folds is preserved. The
241 cleavage dips moderately to steeply NNE (Fig. 6b; average 012°/67°) suggesting that the
242 limb of the fold that contains Nyankanga deposit may be structurally overturned. The fold
243 axis calculated from the bedding-cleavage intersection plunges 37° towards 301° which is
244 similar to the fold axis calculated from bedding planes (43° towards 325°) and to the average
245 D3 fold axes measured within the deposit (Fig. 6c; average 39° towards 316°). The dispersion
246 in fold axes cleavage orientation is partly due to later fold overprints (see below).

247 **D4 – Open upright folding**

248 D4 folds (Fig. 7b) are common throughout the deposit and are cm- to 50m-scale open to
249 closed, upright folds with near vertical, axial planes (270°/88°) and fold axes that plunge
250 north between 10- 50°. They refold D3 folds and are locally associated with a spaced fracture
251 cleavage parallel to the fold axial plane. In outcrop D4 folds locally display centimetre scale
252 crenulation like geometries.

253 **D5- Open recumbent folding**

254 D5 folds are gentle, rarely open, recumbent folds that have a spaced sub-horizontal (0° to
255 <30°) axial planar fracture cleavage. They refold earlier fold structures (e.g. Fig. 7c), and are
256 associated with small reverse movements along axial planar fracture cleavage planes.

257 **D6- Brittle-ductile shear zones and the Nyankanga Shear Zone**

258 Nyankanga gold deposit is cut by a number of moderately NW to N dipping D6 shear zones
259 (Fig. 8a) with a dominantly reverse movement (Figs. 8b and 8c), one of which is a narrow
260 (0.05-2m wide) semi-ductile shear zone with a strike-length of at least 1.5km spatially related
261 to gold mineralization and referred to as the Nyankanga Shear zone (Fig. 4). In general, the

262 major shear zones dip moderately NW (Fig. 6d; average $335^{\circ}/34^{\circ}$). The Nyankanga Shear
263 Zone consists of an anastomosed array of sharp discontinuities that form discrete slip
264 surfaces, which occur together with complex vein arrays, foliation domains defined by
265 orientated mica (mainly chlorite) and pressure solution seams. Narrow, steeper-dipping shear
266 zones link the imbricate thrusts to form a complex, anastomosing network of shear zones that
267 occur throughout the large open pit at Nyankanga. Only some of these D6 shear zones are
268 associated with mineralisation.

269 Within the Nyankanga shear zone, duplex arrays of slip surfaces at 0.1-1m scale occur
270 within an anastomosed system, with horses separated by shallow-dipping surfaces with
271 reverse slip and the same dip-direction as the shear zone envelope. The shallow dipping slip
272 planes within the shear zone are widely spaced, and usually connect the upper and lower
273 boundaries of the shear zone, leading to internal segmentation of the Nyankanga Shear Zone.
274 The shear domains between the discrete slip surfaces are mostly narrow (0.01-0.3m) and
275 consist of a combination of foliated domains preserving S-C fabrics (Fig. 8b) and domains
276 dominated by gouge of broken rock in a clay matrix. The S-C fabrics consistently show
277 reverse movement (Fig. 8b) along the Nyankanga Shear Zone. Most of the discrete slip
278 planes that separate or occur as discontinuities within the foliated domains, contain
279 shallowly-pitching, quartz slicken-fibres (Figs. 6e and 8c; average 31° towards 309°),
280 consistent with dip slip reverse-sinistral movement. Many slip planes display evidence of
281 overprinting slicken-fibers indicative of oblique slip (Fig. 6e). These lineations are shallowly
282 plunging WSW or NNE and may have both normal and reverse components associated with
283 the oblique movement. Overprinting these oblique slip lineations is a third set of lineations
284 and steps consistent with a normal component of movement (Fig. 8d).

285 The system of D6 shear zones is most clearly developed within diorite and along diorite-
286 ironstone contacts. In general the shear zones widen in areas dominated by ironstone, with
287 damage zones extending into the sediments over several meters. Inversely, shear zones
288 narrow within diorite. There is an array of steep veins and hydrothermal breccias associate
289 with Nyankanga Shear Zone that is best developed in diorite in the proximity of ironstones
290 enclaves (Figs.8a and 8e). .

291 The complex fabric relationships encountered within the D6 shear zones and the presence of
292 multiple shear sense directions indicate the multi-staged history of the D6 shear zones.

293 **D7- Sinistral and dextral shear zones**

294 The intrusive rocks and the ironstones are cut by a series of steeply dipping dextral and
295 sinistral shear zones (Figs. 3, 8f and 9a) with a distinct NW trend (Fig. 6f) which is similar to
296 the one observed from the regional geological map (Fig.2) suggesting that they may have a
297 regional significance or are related to the major NW trending regional shear zones.
298 Associated with these NW trending shear zones is a subset of moderately to shallowly NW
299 dipping sets of faults (Fig. 6f). These NW dipping faults are very similar in orientation to the
300 Nyankanga Shear Zone and D6 shear zones but they have a limited extend and no associated
301 shear fabric (e.g. S-C fabrics). However, they may indicate that D6 shear zones are secondary
302 structures associated with the regional D7, NW trending, shears that bound Nyankanga
303 deposit (e.g. Ryan and Speers, 2003; Painter, 2004). Alternatively, they may be related to the
304 reactivation of D6 structures by D7 deformation. To the west of Nyankanga deposits a
305 regional NW trending dextral strike slip shear zone (Fig. 2; Iyoda Shear in mine terminology)
306 cuts and displaces the entire ironstone package and was interpreted to have played an
307 important role in the development of Nyankanga Shear Zone and gold mineralization (Porter,
308 2004). This major shear zone is poorly studied so its full potential in gold mineralization is
309 yet to be established.

310 **D8 - Normal faults**

311 Throughout the deposit there is a set of well-developed steeply dipping, ~ E-W trending,
312 faults (Fig. 9b) that have a consistent normal component of movement with maximum a few
313 meters observed displacement (typically less than 1 meter). The individual faults are 1-2 cm
314 wide but can form up to a few meters wide deformation zones. They have a clay dominated
315 gouge and a set of carbonate, pyrite and carbonate-pyrite association of thin veins within the
316 deformation zone. They reactivated and displaced (centimetres to maximum one meter) D6
317 and D7 structures.

318 **4.1. Intrusive sequence in relation to deformation**

319 The Nyankanga gold deposit is dominated by a complex diorite intrusion, which in turn was
320 intruded by feldspar and quartz porphyry dykes (Figs 3, 4). The low volume of sedimentary
321 rocks present in the deposit makes the timing relationship between the main diorite and
322 deformation less clear. In general the diorite-ironstone contact (average $321^{\circ}/44^{\circ}$) parallels
323 the bedding orientation (average $336^{\circ}/44^{\circ}$) (Figs. 6a and 6g). It is common for the main
324 diorite to contain enclaves of folded ironstone (Figs. 4 and 9b) preserving F3 folds. In the

325 Nyankanga deposit there is no clear evidence of diorite dykes being folded during D3 which
326 suggests that the main stage of diorite intrusion occurred syn- to post-D3.

327 In the nearby Geita Hill and Lone Cone deposits (Fig. 2) diorite dykes that form part
328 of the Nyankanga Intrusive Complex are folded by F3 folds indicating that the emplacement
329 of Nyankanga Intrusive complex started before the onset of D3 deformation. Figure 9a shows
330 the timing relationships between a hornblende diorite, a lamprophyre, a plagioclase diorite
331 and F3 folds in the northwestern side of the deposit. The hornblende diorite parallels the
332 bedding and possibly intruded during D3. The lamprophyre dyke cuts across the bedding and
333 F3 folds, and the plagioclase diorite cuts the lamprophyre dyke along a fracture with a reverse
334 sense of movement. Although this particular relationship suggests that hornblende rich diorite
335 is earlier than plagioclase rich diorite, there are many situations where zones of plagioclase
336 rich diorite are intruded by small dykes of hornblende rich diorite (Fig. 4) and vice-versa
337 suggesting that the intrusion of hornblende and plagioclase rich diorite varieties alternate.
338 Figure 4 shows a hornblende rich diorite dyke that intruded into the main diorite and cuts
339 across the ironstone fragments at a low angle.

340 The feldspar and quartz porphyry dykes trend NE-SW and dip at slightly steeper angles than
341 the average orientation of the bedding (Figs. 6a and 6h). The quartz porphyries generally dip
342 steeper than and cross-cut the feldspar porphyries. D6 thrusts appear to have played a role in
343 the emplacement of feldspar and quartz porphyries in the sense of providing the structural
344 discontinuities along which these dykes have been emplaced. This is particularly obvious in
345 the case of feldspar porphyries which become shallower when intersecting the Nyankanga
346 Fault Zone, run sub-parallel to the fault zone and sometimes within the fault zone, and then
347 cut across. Feldspar porphyries within Nyankanga Shear Zone have sheared margins with a
348 normal component which is similar to late phases of movement along the shear zone. Both
349 feldspar and quartz porphyries are cut and displaced by D7 dextral and sinistral shears and by
350 D8 normal faults (Fig. 9b) indicating that they have been emplaced between D6 and D7.

351 **5. Alteration features**

352 **5.1. Alteration halo**

353 The alteration in the Nyankanga deposit displays a systematic change in mineralogy
354 with distance from the mineralisation, and can be subdivided into three main alteration zones:
355 a distal zone, a transitional zone and a proximal zone. Distal alteration is characterised by the

356 association chlorite-epidote-calcite±actinolite-pyrite±pyrrhotite and is best developed in
357 diorite, where it can be seen to overprint primary igneous textures. In the diorite, chlorite
358 replaces primary biotite and hornblende while epidote replaces mafic minerals and
359 plagioclase. Calcite occurs both as disseminations and calcite-pyrite or calcite-
360 chlorite±epidote-pyrite veins. In ironstone this alteration zone is less prominent, but it can be
361 recognised by the presence of chlorite in shale, actinolite near magnetite bands and rare
362 calcite-chlorite-pyrite±pyrrhotite veinlets (Fig. 10a).

363 The transitional alteration zone is characterised by biotite-chlorite-calcite±pyrite
364 association. The difference between the distal alteration zone and the transitional zone is the
365 appearance of biotite and increased abundance of calcite. Thin veins of biotite and associated
366 thin biotite haloes occur throughout this zone. Within diorite, the transitional zone is further
367 characterised by the appearance of biotite which replaces primary hornblende.
368 Calcite±quartz-biotite-chlorite-pyrite veins occur throughout this zone (Fig. 10b).

369 Within the proximal alteration zone the dominant mineral association is quartz-
370 calcite-dolomite/ankerite-hematite-pyrite-biotite. In diorite, biotite replacement of mafic
371 minerals is common, and is associated with fine-grained, disseminated magnetite. Increased
372 alteration intensity within this zone has locally resulted in a complete overprint of primary
373 igneous textures due to silicification, carbonation and/or sulfidation. This pervasive alteration
374 is accompanied by an increased vein density and hydrothermal brecciation. Hematite is
375 present up to moderate intensity (Fig. 10c) but is absent where the silica alteration is
376 strongest. Carbonate minerals mainly consist of dolomite and ankerite with lesser amounts of
377 calcite. In ironstone extensive replacement of magnetite beds/lamina by pyrite (Figs. 10d, 10e
378 and 10f) occurs to the extent that the original sedimentary textures are destroyed.
379 Hydrothermal breccias are a common feature in this alteration zone (Figs. 10d and 10e).
380 Hydrothermal brecciation is most commonly developed at the contact between intrusive and
381 sedimentary lithologies.

382 Late calcite±quartz±pyrite veins cross cut all alteration zones. A late hematite
383 alteration overprint can be recognised in the barren feldspar and quartz porphyries with
384 sericite commonly replacing feldspar phenocrysts.

385 5.2. Veins and breccia zones related to the alteration zones

386 Veins

387 Nyankanga gold deposit contains several generations and types of veins across a wide range
388 of orientations (Fig. 6j) and compositions. In general vein thickness varies from microscopic
389 to ~ 30 cm, but some veins are as thick as 1 m. Veins are typically lensoidal to irregular in
390 shape, with incipient brecciation being common along their margins. The overprinting
391 relationship between different vein types is difficult to establish (except locally) due to
392 overall large variations in vein orientation and composition. However, some general
393 overprinting relationships have been established for the main vein types (Fig. 11). The
394 earliest set of veins are cherty in nature, constrained to the ironstone layers and may represent
395 early diagenetic or D1, layer parallel deformation related features. They are overprinted by all
396 other vein generations and are not directly related to gold mineralization. The earliest set of
397 veins linked to the alteration halo consists of chlorite-calcite \pm pyrite veins which are
398 overprinted by biotite-hematite-pyrite \pm quartz veins. These two types of veins are common in
399 the distal alteration zone and are not mineralised.

400 Within the intermediate alteration zone chlorite-calcite and biotite-hematite-pyrite
401 veins are overprinted by calcite-quartz-biotite-chlorite \pm pyrite veins, which in turn are
402 overprinted by biotite-dominated veins. These veins may contain low gold grades, but are
403 mostly unmineralised. They have a low distribution density, at ~1-2 veins per meter, with
404 each vein reaching a maximum thickness of 1 cm and being a few tens of centimetres long.
405 More commonly they are a few millimetres wide and a few centimetres long.

406 Within the proximal alteration zone all previously mentioned veins are overprinted by
407 pyrite-rich, calcite-quartz-dolomite-pyrite and quartz-dolomite-pyrite veins. These veins may
408 contain good gold grades and are spatially associated with the highest grade zones, and may
409 locally form a dense vein network. Late quartz-carbonate \pm pyrite veins overprint
410 mineralization, the felsic porphyries and are barren.

411 Figure 6j shows a stereonet plot of poles to all vein measurements from Nyankanga gold
412 deposit. Two main directions can be observed. That is a set of steeply SW dipping, NNW
413 trending veins and a set of moderately to steeply NW dipping, NNE trending veins. A third
414 set of moderately E dipping veins is less well-defined. In general, the steep NNW trending
415 veins are quartz-carbonate-pyrite or pyrite-rich veins that cut across the diorite-ironstone
416 contact. The quartz-rich variety is the most common vein type across the deposit and some of

417 these veins can be traced for up to 150 meters length. Some appear to predate or be early syn-
418 Nyankanga Fault Zone being displaced across the fault zone. The pyrite rich veins appear to
419 be spatially associated to the Nyankanga Fault Zone. They are better developed in ironstone
420 where they cut across bedding mainly at high angles with a sub-set cutting across bedding at
421 a lower angle and thus being shallower (Figs. 12a and 12b). This steeply dipping, NW
422 trending pyrite rich and quartz veins are may be associated with D3 fold hinge (Figs. 12a and
423 12b) zones and locally may appear to follow D3 folds axial planes but they are much steeper
424 than the axial plane of D3 folds. The sub-horizontal quartz-carbonate veins (Figs. 12a and
425 12b) cut across all vein sets and geological boundaries. Figure 12c shows an example where a
426 set of steeply dipping NNW trending quartz-carbonate veins are truncated by moderately
427 dipping, NNE trending quartz-carbonate veins that developed along a set of fractures that cut
428 across and displace the NNW trending veins. The NNE trending veins have a similar average
429 orientation to Nyankanga Shear Zone and are much better developed in the footwall of the
430 fault zone suggesting a genetic link between the movement of the fault and the formation of
431 these veins. As a general rule NNW trending quartz-carbonate veins appear to predate the
432 NNE trending quartz-carbonate veins. However, the timing relationships between vein sets
433 with different orientation may be more complicated. Measurement of vein orientation within
434 the immediate vicinity of the Nyankanga Fault Zone shows a large variation in orientation
435 and many conflicting overprinting relationships.

436 **Breccia zones**

437 Hydrothermal breccia zones are common in both diorite and ironstone. The breccias are
438 almost exclusively developed in footwall rocks to the Nyankanga Shear Zone (Figs. 8 and
439 12d). They commonly have a jigsaw texture with rock fragments being cemented mainly by
440 massive quartz with important infill of sulphide and carbonate. The breccia zones are
441 generally surrounded by zones of intense stockwork veining (Figs. 8 and 12d) suggesting
442 timing and genetic relationships between breccia formation and veining. Within the breccia
443 zones veins of similar composition but different orientations can be identified. The breccia
444 zones are usually tabular shaped, forming 2 to 4 m and 0.5 to 2 m long zones developed at
445 high angles to lithological contacts and the Nyankanga Shear Zone. In general the long axes
446 of breccia zones appear to plunge shallow W to SW. A distinct breccia horizon that was
447 modelled based on pit mapping and core logging has a tabular shape, about 100 meters long,
448 40 meters wide and 3 to 7 meters thick, dips $\sim 35^\circ$ NE and the long axis is \sim E-W plunging
449 15° towards 280° . The overall shape of breccia zones (Figs. 12d and 13) and their almost

450 exclusive location in the footwall of Nyankanga Shear Zone are consistent with brecciation
451 occurring when Nyankanga Fault Zone was reactivated as a normal fault.

452 **6. Gold mineralization**

453 **6.1. General characteristics**

454 In general the gold mineralization in the Nyankanga deposit occurs in close spatial proximity
455 to the Nyankanga Shear Zone with the bulk of the mineralization being located in the
456 footwall (Fig. 4). The ore envelope at a cut-off grade of 0.5 g/t is tabular with a shallow,
457 ~22°, W to NW dip, i.e. ~10° shallower than dip of Nyankanga Shear Zone. However,
458 steeper mineralised zones up to 10 m thick are common and have a shape resembling
459 imbricate splays in the hanging wall. The mineralization is preferentially located along
460 ironstone-diorite contacts with high grade zones normally hosted by mineralised ironstone
461 enclaves. Within diorite, mineralisation is generally lower grade and more disseminated
462 across dispersed, stockwork zones. As a general rule high grade ore zones usually occur
463 below Nyankanga Shear Zone and have steeper dip than the overall mineralization and the
464 shear zone, and a shallow plunge towards SW and WSW.

465 Gold mineralization is intimately associated with fine-grained pyrite growth and
466 silicification. In the ironstone enclaves, pyrite mineralization occurs as disseminations and
467 stringers preferentially overprinting magnetite bands and occurring along magnetite-chert
468 bedding contacts. In diorite, pyrite occurs as fracture fill in quartz/calcite/dolomite-pyrite
469 veinlets and stockworks. In areas of higher ore grades, pyrite is finely disseminated
470 throughout the groundmass with pervasive silica replacement. Within the proximal alteration
471 halo there is a good relationship between zones of high ore grade and zones of brecciated
472 ironstone characterised by extensive quartz veining and a high degree of sulfidisation. Zones
473 of mineralised brecciated ironstone dip in general 35° NE and plunge ~ 15°W. Breccia zones
474 within the diorite are mineralised but generally at lower grades than the ironstone breccia
475 zones, with a steeper dip and a plunge of ~ 10 SW. There is also a good relationship between
476 high grade mineralised zones and undulations of the fault zone that have produced
477 dilatational jogs that permitted higher fluid influx. Where the Nyankanga Fault Zone is
478 steeper the high grade ore zones are thinner and shallower and where the fault zone is
479 shallower the high grade ore zones become steeper and wider. Mineralised zones are

480 characterised by very sharp upper and lower contacts that commonly display narrow quartz
481 breccia zones and intense pyrite alteration.

482 Based on the local geology controlling the individual ore zones, a few different
483 mineralisation styles can be distinguished. High grade ore shoots usually are related to
484 disseminated ironstone hosted mineralisation and fault-bound breccia and quartz veins. The
485 disseminated mineralisation style is characterised by sulphide altered silicified ironstones
486 with quartz-magnetite-pyrite±hematite alteration. The fault-bound quartz veins and breccia
487 mineralization style form distinct domains in footwall of Nyankanga Shear Zone usually with
488 a steeper orientation than the fault surfaces. The ore mineralogy is dominated by pyrite
489 bearing quartz±carbonate cemented breccia and veins. Medium grade ore zones are usually
490 related to bedding parallel small shear zones overprinted by thin vein arrays and with the
491 mineral association quartz-magnetite-pyrite±hematite. The low grade ore zone are usually
492 dominated by planar sheeted veins developed mainly in the footwall of Nyankanga Shear
493 Zone and a quartz-carbonate-pyrite-chlorite-biotite assemblage.

494 In the hanging wall to Nyankanga Fault Zone there are a series of discontinuous low grade
495 mineralized zones associated with reactivated thrusts having a similar orientation and history
496 to Nyankanga Shear Zone.

497 **6.2. Timing of gold mineralization in relation to structure and intrusive** 498 **rocks**

499 Gold mineralization in Nyankanga gold deposit is spatially associated with Nyankanga Shear
500 Zone and hosted by ironstone and diorite. The bulk of the mineralization sits in the footwall
501 of Nyankanga Shear Zone but some occurrences of isolated and discontinuous zones of low
502 grade mineralisation are found in the hangingwall associated with shear zones along
503 ironstone-diorite contacts that have a similar orientation to Nyankanga Shear Zone. The
504 ironstone units hosting the mineralisation are complexly folded with D3 folding events being
505 the most pronounced. D6 structures and the Nyankanga Shear Zone cut across the ironstone
506 fragments at a low angle while the mineralised envelope (≥ 0.5 ppm) also appears to cut
507 across the ironstones contacts at a low angle. This suggests that the gold mineralization
508 postdates the ductile deformation recorded within the ironstone fragments. Both plagioclase
509 diorite and hornblende diorite host gold mineralisation thus the emplacement of diorite
510 predates gold mineralisation. Feldspar porphyries within Nyankanga Shear Zone contain low
511 grade mineralization indicating a syn to late mineralization emplacement or contamination

512 during emplacement. Quartz porphyries are barren and interpreted to postdate mineralization.
513 Both feldspar porphyries and quartz porphyries are crosscut and displaced by D7 and D8
514 structures. However, these structures are not mineralised outside the mineralised zone but
515 may have played a role in reactivating Nyankanga Shear Zone thus the gold mineralization
516 must have occurred somewhere between D6 and D8 deformation events.

517 **6.3. Relationship between veins, breccia zones and mineralization**

518 Quartz-carbonate-pyrite, carbonate-quartz-pyrite and pyrite rich veins within and near
519 mineralised zones are the only vein types that are mineralised. Chlorite, biotite (small and
520 low density veins) bearing veins are not mineralised. Some of the steeply dipping NNW
521 trending quartz veins may contain up to 5 ppm Au or more even when sampled away from
522 the mineralised zone. An analysis of vein density versus gold grade (Nugus and Brayshaw,
523 2010; the veins were counted for each meter and plotted against gold grades) reveals that
524 although locally a correlation between gold and vein density exists this is not a rule thus gold
525 mineralization can occur in zones with low vein density. Figure 14 shows the relationships
526 between vein density and gold grades from two drill holes passing through the mineralised
527 zone. Figure 14a shows that there is a good correlation between the mineralised zone and
528 increased vein density, the gold content increases where the vein density increases. However,
529 this correlation is valid only within the vicinity of Nyankanga Shear Zone. Figure 14b shows
530 that although there are zones of good correlation between gold grades and vein density there
531 are also zones of high vein density and low gold grades or zones of high gold grades and
532 lower vein density. Figure 14c shows a selection of pyrite rich vein only versus gold grade
533 from an area dominated by quartz veins. There is more consistent relationship between pyrite
534 rich veins density and gold grades. The analyses also show that the relationship between vein
535 density and gold grades is strengthened or exists only in the proximity of Nyankanga Shear
536 Zone.

537 Breccia zones adjacent to Nyankanga Shear Zone are mineralised. However, there is no
538 generic relationship between high grade and breccia zones. As a general rule breccia zones
539 developed in ironstones are more prone to contain high grade than breccia zones developed in
540 diorite but there is no direct correlation between high grade mineralization and the extent of
541 breccia in either lithology. Figure 13 shows an example of breccia zones developed mainly in
542 the footwall diorite and its relationship to mineralization. The breccia zone lies at a high
543 angle to Nyankanga Fault Zone. The breccia zone adjacent to the Nyankanga Fault Zone

544 contains mainly low grade mineralization, further away there is a zone of medium grade
545 which sharply passes into unmineralised breccia. Near the ironstone contact there is a small
546 sub vertical breccia zone that is transected by both a medium and a high grade envelope
547 surrounded by unmineralised diorite and ironstone. The high grade zones in diorite are near
548 the breccia contact, they transect Nyankanga Fault Zone and are mainly related to the
549 disseminated mineralization style.

550 **7. Discussion**

551 Two factors appear to have been essential for gold deposition in Nyankanga gold deposit: the
552 host rock type which acted as chemical traps and the geometry and location of Nyankanga
553 Shear Zone which acted as structural trap and possibly fluid conduit.

554 **7.1. The role of iron rich lithologies in gold deposition (chemical traps)**

555 The gold mineralization in Nyankanga gold deposits is entirely hosted within sulfidised
556 wallrock; that is diorite and ironstone. Depending on the dominant type of Au-complex, the
557 mechanism of gold precipitation may involve one or more of the following mechanisms:
558 increase or decrease in pH, change in O_2 and S_2 fugacity, change in the activity of O_2 , Cl^- or
559 H_2 , change in pressure and/or temperature, fluid mixing and boiling. Assuming that gold was
560 transported in solution as bisulfide complexes changes in temperature and pressure can be
561 eliminated as the cause of gold precipitation. That is because gold solubility from bisulfide
562 complexes changes very little with temperature (e.g. Hayashi and Ohmoto, 1991; Gilbert et
563 al., 1998) and there is no clear evidence of PT changes at the scale of Nyankanga deposit; the
564 proximal alteration assemblage is the same throughout the deposit and of similar grade with
565 the surrounding country rocks. Sulfidation of the wall rock, as the main gold precipitating
566 mechanism, implies change in oxygen and hydrogen fugacity at given PT and consistent
567 water activity and sulphur fugacity (e.g. Candela and Piccoli, 2005; Zhu et al., 2011). The
568 most effective way to precipitate gold is to decrease the activity of reduced sulphur (e.g.
569 Seward, 1973; Likhoidov et al., 2007). This can be done by dilution, oxidation, boiling or by
570 precipitation of sulphide minerals with Fe-rich wallrock. The intimate association of gold
571 with sulphide minerals (gold in pyrite rather than free gold) and the strong spatial correlation
572 between gold mineralization, sulfidation fronts and Fe-rich ironstones and diorite suggest that
573 sulphide deposition by interaction of mineralizing fluid with the chemically reactive wall
574 rocks was an important mechanism in the formation of Nyankanga gold deposit. However,
575 other factors contributing to sulphide minerals deposition, such as boiling, should not be

576 excluded given the presence of mineralized hydrothermal breccias in both diorite and
577 ironstones.

578 **7.2. The role of Nyankanga Shear Zone**

579 The mineralization in Nyankanga gold deposit is spatially related to Nyankanga Shear Zone
580 and hosted within the surrounding damage zone. This close spatial association between
581 Nyankanga Shear Zone and the gold mineralization suggest a genetic link between the shear
582 zone activity and gold deposition. However, Marjoribanks (2003) interpreted Nyankanga
583 Shear Zone and the related shear structures to postdate gold mineralization, with gold
584 mineralization occurring at the intersection of ironstone (and nearby diorite) with a series of
585 sub-vertical NW trending quartz veins and fractures acting as feeders. These feeders
586 exploited a series of closely spaced fractures formed during cooling of the main diorite body
587 forming the Nyankanga Intrusive Complex. In this view Nyankanga Shear Zone postdates
588 mineralization and displaces bedding, diorite contacts and the ore zone. Such a scenario does
589 not explain the intimate association of Nyankanga Shear Zone and the mineralized envelope,
590 the fact that Nyankanga Shear Zone is mineralised over its entire strike length with most of
591 the mineralization found within its immediate vicinity and the fact that the ore zone is not
592 fragmented by fault movement. Moreover, the steep NNW trending quartz veins are only
593 locally mineralised and only within the vicinity of Nyankanga Shear Zone. Most models
594 (Ryan and Speers, 2002; Skead et al., 2003; Painter, 2004; Brayshaw, 2010; Nugus and
595 Brayshaw, 2010; Kolling, 2010) interpret Nyankanga Shear Zone as the mineralised
596 structures playing an important role as a fluid conduit and as a structural trap for gold
597 mineralization. Earlier models (Ryan and Speers, 2002; Skead et al., 2003; Painter, 2004)
598 consider the mineralization in Nyankanga gold deposit to be related to the S-SSW directed
599 thrusting that occurred along Nyankanga Shear Zone. Their interpretation is based on ore
600 shoot plunges that are similar in orientation to the stretching lineations along Nyankanga
601 Shear Zone. More recent models (Brayshaw, 2010; Nugus and Brayshaw, 2010) argue that
602 gold deposition occurred during periods of extension when Nyankanga Shear Zone was
603 reactivated as a normal fault, thus mineralization is late in relation to Nyankanga Shear Zone
604 activity. This interpretation is based on kinematic indicators on slip surfaces showing normal
605 movement that overprint earlier reverse kinematic indicators and on the orientation of breccia
606 zones and veins in the footwall which are consistent with normal movement along
607 Nyankanga Shear Zone. Kolling (2010) advanced the hypothesis that the ironstone units
608 within Nyankanga Intrusive Complex are roof pendants and the competency contrast between

609 the massive diorite and the polydeformed ironstone fragments played a vital role in localizing
610 zones of deformation thus enhancing permeability and creating favourable structural and
611 chemical traps along diorite-ironstone contacts. In this view Nyankanga Shear Zone does not
612 represent a regional feature related to tectonic movement but rather a localized deformation
613 zone due to competency contrast between massive diorite and ironstone. Such an idea is
614 favoured by the preferential location of the shear zone along diorite ironstone contacts and by
615 a lack of mappable displacement along Nyankanga Shear Zone over more than 10 years of
616 open pit mining. Although there is some controversy about the particular role played by
617 Nyankanga Shear Zone in gold deposition most authors agree that Nyankanga Shear Zone is
618 the mineralised structure and most probably the fertile conduit structure. Late timing of gold
619 mineralization relative to the activity of Nyankanga Shear Zone is supported by the complete
620 lack of ore fragmentation which raises the question whether or not the gold mineralization
621 postdates Nyankanga Shear Zone. For example feldspar porphyries, containing low grade
622 gold mineralization, intruded along Nyankanga Shear Zone; they are not deformed but have
623 their contacts sheared within Nyankanga Shear Zone and show an overall normal sense of
624 movement. The close spatial association between feldspar and quartz porphyries with
625 Nyankanga Shear Zone suggest that the shear zone acted as a favourable discontinuity for the
626 emplacement of these dykes. The normal shear sense observed along the sheared contacts of
627 undeformed feldspar porphyries is consistent with the kinematics of D8 structures which may
628 also be responsible for the normal reactivation of Nyankanga Shear Zone. A relationship
629 between gold deposition and D8 normal structures is tentative in this case but D8 structures
630 are mineralised only within the mineralized zone, while Nyankanga Shear Zone is
631 mineralised over its entire strike length. Most probably the reactivation of Nyankanga Shear
632 Zone during later deformation events (D7 and D8), is responsible for the gold mineralization
633 and Nyankanga Shear Zone acted as both fluid conduit and structural trap.

634 The close spatial relationship between gold mineralization and second or third order
635 structures is a very well documented setting for many Archean gold deposits (e.g. Morey et
636 al., 2007; Dirks et al., 2013). However, the exact timing of gold mineralization in relation to
637 the associated structure is less clear (e.g. Blenkinsop et al., 2000; Tripp and Vearcombe,
638 2004; Weinberg and van der Borgh, 2008) and in many cases multiple stages of gold
639 deposition have been demonstrated (e.g. Wilkinson, 2000; Harraz, 2002; Large et al., 2007;
640 Thomas et al., 2011), with local re-mobilization and grade enhancement playing key roles in
641 forming gold deposits. Although, there are no detailed studies documenting different periods

642 of gold mineralization for Nyankanga, a scenario where gold was introduced during multiple
643 mineralising events should not be excluded.

644

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648 **Bibliography**

649 **Bibliography**

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782 **Figures captions**

783 **Figure 1**

784 Simplified geological map of the Northern half of Tanzania Craton showing the main
785 geological and tectonic units. SU – Sukumalanad Greenstone Belt; NZ – Nzega Greenstone
786 Belt; SM – Shynianga-Malita Greenstone Belt; IS – Iramba-Sekenke Greenstone Belt; KF –
787 Kilimafedha Greenstone Belt; MM – Musoma-Mara Greenstone Belt. Super-terrane
788 boundaries are as proposed by Kabete et al., 2012: ELVST – East Lake Victoria, MLEST-
789 Mwanza Lake Eyasi, LNST- Lake Nyanza, MMST – Moyowosi-Manyoni, DBST – Dodoma
790 Basement, MAST – Mbulu-Masai, NBT – Nyakahura-Burigi. Inset map of Africa showing
791 the location of Archean blocks.

792 **Figure 2**

793 Geological map of Geita Greenstone belt showing the location of the gold deposits and the
794 main geological units and structures.

795 **Figure 3**

796 General geological map of Nyankanga gold deposit.

797 **Figure 4**

798 Geological section through the middle of Nyankanga gold deposits showing the relationship
799 between the main rock types, structures and gold mineralization.

800 **Figure 5**

801 Photographs showing the main lithological units found within Nyankanga gold deposit. a)
802 lower-most ironstone unit consisting of intercalations of graphite, graphite-rich magnetic
803 shales or siltstone and laminated chert; b) poorly bedded magnetite and chert intercalations;
804 c) laminated intercalations of siltstone and chert; d) example of centimeters thick graded
805 sandstone bed within a siltstone dominated unit; e) example of typical porphyritic plagioclase
806 diorite forming the main intrusive body in Nyankanga Intrusive Complex; f) example of
807 porphyritic hornblende diorite; g) plagioclase porphyry – note the lack of visible quartz
808 grains; h) quartz porphyry - note the resorbed nature of quartz porphyries; j) coarse grained
809 lamprophyre with intense carbonate alteration.

810 **Figure 6**

811 Stereoplots showing: a) poles to bedding measurements; b) poles to D3 axial planar foliation;
812 c) measurements of D3 fold axes; d) poles to D6 shear zones and Nyankanga Shear Zone; e)
813 measurements of lineations on slip surfaces that form the Nyankanga Shear Zone showing an
814 initial dip slip component of movement which was overprinted by oblique slip movement -
815 note that the latest movement recorded along the slip surfaces is consistent with normal
816 reactivation of Nyankanga Shear Zone; f) poles to D7 shear surfaces showing the main NW-
817 SE trend and the associated NE-SW trending shallower faults; g) poles to sediment-diorite
818 contacts; h) poles to feldspar and quartz-porphyry contacts with the sediments; j) contoured
819 plot of poles to vein measurements from Nyankanga gold deposit – see text for details.

820 **Figure 7**

821 Photographs showing the main overprinting relationships between different folding events. a)
822 isoclinal D2 folds refolded by D3; b) example of open - subvertical D4 folds; c) example of
823 D3 folds being overprinted by D5 folds having a sub-horizontal fracture cleavage.

824 **Figure 8**

825 Photographs showing different structural features within Nyankanga gold deposit. a)
826 exposure of Nyankanga Shear Zone – note the preferential development of breccia and quartz
827 veins in the footwall rocks; b) example of S-C fabrics along Nyankanga Shear Zone showing

828 reverse movement; c) slips surface along Nyankanga Shear Zone showing steps consistent
829 with reverse movement; d) slip surface along Nyankanga Shear Zone showing steps
830 consistent with normal movement; e) example of brecciation in the footwall of Nyankanga
831 Shear Zone; f) example of NW-SE trending, D7, sinistral strike slip shear zone showing an
832 apparent normal displacement – note the beds dip away moderately thus giving an apparent
833 normal sense of movement.

834 **Figure 9**

835 Detailed wall maps illustrating relative timing relationships between different intrusive rocks
836 (a) and between different types of structures and intrusive rocks (b).

837 **Figure 10**

838 Photographs showing alteration features found in Nyankanga gold deposit. a) calcite rich vein
839 with minor chlorite and pyrite – note an earlier magnetite rich vein; b) example of quartz-
840 carbonate-biotite-pyrite vein with minor chlorite – note that fine grained biotite has replaced
841 the hornblende in the matrix; c) biotite-chlorite-pyrite microveining and moderately to
842 intense hematite alteration; d) silica alteration overprinting an earlier sulfide (pyrite
843 alteration) and associated brecciation; e) quartz-pyrite alteration overprinting an earlier
844 hematite-pyrite-quartz alteration; f) pyrite-carbonate alteration with bedding replacement.

845 **Figure 11**

846 Chart showing a simplified interpretation of the relative timing between the main vein types
847 and alteration.

848 **Figure 12**

849 Photograph (a) and interpretation (b) showing the relationships between different vein types
850 in an outcrop. c) wall map showing timing relationships between two vein sets in that part of
851 the deposit. d) wall map showing the relationship between Nyankanga Shear Zone, breccia
852 zones and veining.

853 **Figure 13**

854 Detailed wall map showing the relationship between Nyankanga Shear Zone, breccia zones
855 and gold mineralization.

856 **Figure 14**

857 Series of charts showing the relationship between vein density and gold mineralization along
858 two specific sections across the mineralized zone. Modified from Nugus and Brayshaw
859 (2010). See text for details.

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