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Review

A new tectonic and temporal framework for the Tanzanian Shield: Implications for gold metallogeny and undiscovered endowment

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ABSTRACT

The lack of new gold discoveries in recent times has prompted suggestions that Tanzania is mature or approaching maturity, in terms of gold exploration. New tectonic–metallogenic subdivisions proposed in this study are used to explain gold-endowment, assess gold exploration maturity, and suggest the potential for new discoveries from the following three regions: 1) the Lake Victoria Region, comprising the gold-endowed East Lake Victoria and Lake Nyanza Superterranes of <2.85 Ga greenschist–amphibolite facies granitoid-greenstone terranes in >3.11 Ga continental crust. These superterranes are separated by the gold-poor, Mwanza–Lake Eyasi Superterrane, comprising deeply eroded and/or exhumed terranes of gneissic-granulite belts and widespread granitoid plutons; 2) the Central Tanzania Region, comprising the Moyowosi–Manyoni Superterrane, which is largely composed of granitoid and migmatitic–gneissic terranes, and the Dodoma Basement and Dodoma Schist Superterranes, these are underlain by extensive, >3.2 Ga migmatitic-gneisses and granitoid belts with interspersed, relatively narrow, <2.85 Ga greenschist–amphibolite facies greenstone and schist belts. The Central Tanzania Region also includes the East Ubendian–Mtera Superterrane, comprising the East Ubendian Terrane of predominantly Paleoproterozoic belts with cryptic Archean age components, and the ~2.85–3.0 Ga Isanga–Mtera Terrane of thrust-transported migmatitic ortho- and para-gneisses; and 3) Proterozoic Tanzania Regions, comprising various Archean terranes which were once sutured to the Tanzania Craton prior to later Proterozoic orogenic and tectonic events that separated them from the craton and thermally reworked them. These include the Archean Nyakahura–Burigi Terrane in the Northwestern Tanzania Proterozoic Orogen and the Kilindi–Handeni Superterrane in the Southern East African Orogen of Tanzania.

The major metallogenic significance of the new tectonic subdivisions is the recognition of under-explored belts: 1) in the gold-endowed East Lake Victoria and Lake Nyanza Superterranes, Lake Victoria Region. Here deeply weathered belts in the Musoma–Kilimafedha, Kahama–Mwadui and Nzega–Sekenke Terranes and belts, situated in tectono-thermally reworked crustal blocks such as the Iaida–Haidon, Singida–Mayamaya and Mara–Mobrama Terranes, are predicted to be prospective; 2) in the Dodoma Basement Superterrane, Central Tanzania Region, where relatively thin, juvenile granitoid-greenstone belts, similar to the ~2815–2660 Ma Mazoka Belt in the Undewa–Ilangali Terrane, contain small-scale gold systems with analogous terrane-scale geologic settings and evolution histories to those of gold-hosting greenstone belts in the Sukumaland Terrane, Lake Victoria Region. The overall geologic–geometric setting of the greenstone belts in the Central Tanzania Region (Mazoka-type) is comparable to those of the gold-hosting juvenile granitoid-greenstone belts in the South West and Youanmi Terranes, Yilgarn Craton, Western Australia, and North Superior and North Caribou Superterrane, northwestern Superior Craton, Canada; and 3) in the Proterozoic Tanzanian Regions, where terranes that lie in close geographic proximity and regional strike extension to the gold-endowed Lake Nyanza Superterrane are likely to be most prospective. They include the Archean Nyakahura–Burigi Terrane in unroofed thrust windows of the Mesoproterozoic Karagwe–Ankolean Belt of northwestern Tanzania, and the Kilindi–Handeni Superterrane where Archean proto-crust has been reworked by Pan-African tectonothermal events in the Southern East African Orogen.

1. Introduction

Cratons with well-endowed Neoarchean superterranes world-wide are becoming depleted of gold resources as traditional gold districts approach exploration maturity (Goldfarb et al., 2009).

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Although some gold provinces contain several world-class (>100 t Au), one or more giants (>300 or >500 t Au) and rare super-giants (>10,000 t Au) as well as numerous small orogenic gold deposits (Bierlein et al., 2006; Jaireth and Huston, 2010; and references therein), other provinces appear to host only small deposits. The Tanzanian Craton already hosts some world-class to giant gold deposits (referred to as very-large deposits in this paper), but exploration in recent times has so far failed to provide new discoveries. Viewing this as a scale-dependent problem, Groves (2009) explains the lack of discoveries in recent times as being partly a result of ineffective targeting criteria developed from deposit-scale forensic research studies, undertaken mainly on very large gold deposits. This is because both small and very-large orogenic gold deposits are characterised by similar deposit-scale geological, geochemical and genetic features. Instead, Bierlein et al. (2006) and Leahy et al. (2005) suggest that very-large orogenic gold systems are selectively developed in specific terranes that have suitable geologic–tectonic settings, controlled in space and time by lithospheric-scale tectonic processes. In these orogenic gold systems, superterrane boundaries constitute first-order structures that control crustal-scale plumbing systems of mantle-derived magma and hydrothermal fluids from deeper crustal levels to terrane- and domain-scale depositional sites (Goldfarb et al., 2005; Phillips and Powell, 2010; Ridley et al., 1996).

In some goldfields, gold-prospective provinces are linked to other controlling factors such as major lithospheric instabilities following catastrophic events (e.g. slab detachment, roll-back and ridge subduction) in the crust overlying the sub-continental lithospheric mantle (SCLM: Leahy et al., 2005; Bierlein et al., 2006) and delamination of the lower crust (Czarnota et al., 2010a). These events, which produce high-heat flow in the lithosphere and thus provide access to magmas and hydrothermal fluids, are part of global periods of crustal growth, including specific periods of intense felsic granitoid magmatism, which are more-or-less synchronous with peak gold mineralization events (Goldfarb et al., 2001, 2005). The age of these events and their nature are largely constrained by U–Pb geochronology, and Sm–Nd and Lu–Hf isotopic fingerprinting (Belousova et al., 2009).

Revised superterrane boundaries, based on regional to district-scale solid geological maps produced in this study, represent the spatial extent of contiguous crustal blocks with diverse geologic–tectonic frameworks. They are subdivided in hierarchical order into superterranes, terranes and domains, consistent with the approach of Myers (1990, 1997) and Swager (1997). The metallogenic equivalents of these tectonic subdivisions are goldfields, provinces and camps. The tectonic–metallogenic subdivisions introduced are used elsewhere in well-researched and systematically explored provinces of the Yilgarn Craton, Western Australia (Blewett et al., 2010a, 2010b; Czarnota et al., 2010a; Kositcin et al., 2008; Krapež and Barley, 2008; Robert et al., 2005; and references therein), and in the Superior Craton (Ayer et al., 2010; Percival, 2007; Percival et al., 2001; Robert et al., 2005; and references therein), to explain gold-endowments (e.g. Jaireth and Huston, 2010; Figs. 7 and 14) and assist in targeting of new orogenic gold districts and/or camps.

A similar approach is used herein: 1) to explain potential additional gold-endowment of the Lake Victoria Region, where exploration has been presumed to be mature or approaching maturity (Figs. 1, 2 and 4); and 2) to explain the exploration potential of some of the apparently poorly endowed provinces in the Central Tanzania Region and Southern East African Orogen (Figs. 3, 10, and 11).

2. Review of existing geologic–tectonic subdivisions

2.1. Regional geological maps

Three regional geological maps of Tanzania are used to illustrate advances in understanding of the geologic–tectonic subdivisions and flanking mobile belts, and their implications to gold exploration of Tanzania. These are: 1) The Geological Map of Tanzania of Quennell (1956: Fig. 1); 2) The Lake Victoria Goldfields Map of Barth (1990: Fig. 2); and 3) The Geological and Mineral Deposits Map of Tanzania by the BRGM et al. (2004: Fig. 5). The superterrane-scale boundaries interpreted are draped on to these maps to explain endowment and exploration potential, and not the respective shortcomings and/or similarities between the new and old maps.

2.1.1. Geological map of Quennell (1956)

The map of Quennell (1956) shows the older, Early-Archean Dodoman System overlain by the Nyanzian and Kavirondian Systems (Tanzania Craton), flanked by the Late Archean Usagaran and Ubendian Mobile Belts (Stockley, 1936; Grantham et al., 1945; McConnell, 1945; Quennell et al., 1956). The Dodoman System comprises basement rocks of interleaved concordant granitoids, migmatites and schist belts in widespread belts of tonalite–trondhjemite–granodiorite (TTG) and their gneissic equivalents (e.g. Quarter Degree Sheets (QDS) 161, 162, 178, 179). According to Quennell (1956), the Early-Archean crust forms the basement to greenstone belts in the Singida–Geita and East Lake Region Belts (i.e. the Lake Victoria Goldfields of Barth, 1990; Fig. 2). According to Harpum (1970) and Kimambo (1984), greenstones in those belts were formed as roof pendants. They crop out as linear belts where juxtaposed against granitoids and gneisses and as isolated patches where deeply weathered. The boundaries between the Early-Archean craton and the Late-Archean mobile belts are defined by deformation-metamorphic transitions from the craton into: 1) high-grade metamorphic rocks (e.g. Pan-African/Mozambique Belts: Holmes, 1951; Shackleton, 1986); 2) strongly folded and thrusted sedimentary belts (e.g. Karagwe–Ankolean Belt: Cahen et al., 1984); and 3) poly-deformed high-grade metamorphic rocks intruded by a high-density of granitoids (e.g. Ubendian Mobile Belt: Lenoir et al., 1994).

In summary, the geological map of Quennell (1956) was produced at a time when regional-scale geological controls on gold deposits were considered to be less important for targeting than more detailed belt to deposit-scale controls. This is demonstrated by the amount of detailed and high-quality geological, structural, mineral deposits/occurrences data documented on available 1:125,000 and 1:100,000 scale geological maps in Quarter Degree Sheets mapped between the 1930s and 1960s (e.g. Tanzania, 2005, Fig. 6).

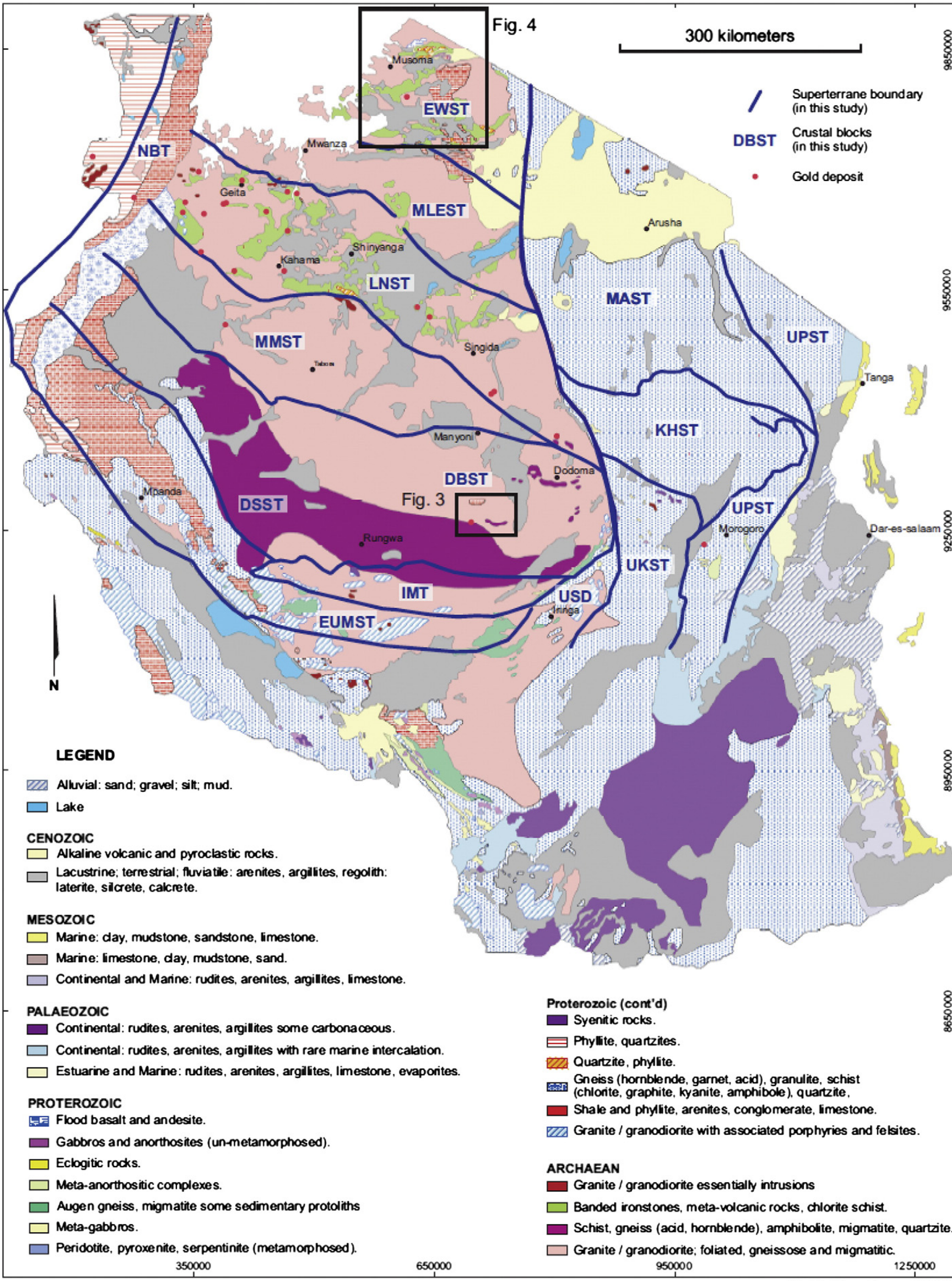
2.1.2. Geological map of Barth (1990)

The 1:500,000 scale geological map of Barth (1990) was produced from geological compilation of 1:125,000 and 1:100,000 scale QDS maps available from the Geological Survey of Tanzania (Tanzania, 2005). The map shows the geology and selected mineral deposits of the Lake Victoria Goldfields. Barth (1990) subdivides the geology of this region from older to younger, into Archean granitoid shield, Archean greenstone belt, Proterozoic–Late Archean intrusive rocks, and Proterozoic and Cenozoic rocks including regolith, and Recent and proto-lake sediments. Structural data on the map of Barth (1990) include only magnetic lineaments and mafic, including gabbroic, dykes.

The map of Barth (1990) was produced during the onset of modern exploration in Tanzania, and, as such, it highlights BIFs and late basins from other greenstones and associated regolith, and linear belts of late-kinematic granitoids in extensive granitoid-gneiss basement. The map clearly shows many gold prospects and old mines, although their spatial relationship with structures cannot be interpreted from the map. This is despite the fact that the importance of structural controls on lode-gold deposits was already known in 1990 (e.g. Groves and Phillips, 1987; Kerrich, 1989).

2.1.3. Geological map of the BRGM et al. (2004)

The map of BRGM et al. (2004) draws much from the work of Pinna et al. (1996) and Pinna et al. (2004b). Their work explains the formation of the Precambrian Shield of Tanzania from the oldest Archean basement, through to the Paleoproterozoic Ubendian and Neoproterozoic Mozambique Belt (see Fig. 5, for a simplified legend, this study;



Modified from Quennell (1956)

and BRGM et al. (2004) for a detailed legend). The map clearly shows the tectonic boundaries of the Archean craton, from oldest to youngest: 1) the ~3.0–2.85 Ga Isangan Group, the ~2.90–2.50 Ga Dodoman Group and undifferentiated Neoarchean migmatite–granitoids, mafic–ultramafic rocks overlain by the Kavirondian sedimentary rocks in the Basement Complex of Barth et al. (1996); and 2) the ~2.9–2.7 Ga Nyanzian Supergroup, Nyanzian–Kavirondian Supergroups, and ~2.75–2.50 Ga Kavirondian Supergroups of clastic-sedimentary rocks (late basins) in the Lake Victoria Goldfields of Barth (1990).

The lack of sufficiently detailed robust geochronology may have led to inconsistent subdivisions or groupings (see subdivisions in BRGM et al., 2004). The structural lineaments in the Archean craton are not analysed to the same degree as their counterparts in the Proterozoic Mobile Belts. As such, their implication for the siting of mineral deposits in the Archean Tanzania Craton is unclear. However, the map clearly shows the relationship between the Tanzania Craton and reworked margins, the major faults and the sub-divisions of the Southern East African Orogen (BRGM et al., 2004).

2.2. Subdivisions and terminologies from published papers

2.2.1. Geological maps of Pinna et al. (1996), (2000), (2004a) and (2004b)

Among other tectonic subdivisions of the Tanzania Craton, as part of the sub-circular Congo Craton (e.g. Goodwin, 1990; Kröner, 1977), Pinna et al. (1996: Fig. 1), Pinna et al. (2000: Fig. 1), Pinna et al. (2004a; Fig. 5) and Pinna et al. (2004b) subdivide the Tanzania Craton into three terranes in terms of the East African Craton. They further suggest that the Tanzania Craton evolved during the ~2.93–2.85 Ga Dodoman and ~2.73–2.53 Victorian orogenies.

In their subdivisions, they outline the ~2.93–2.85 Ga Western Gneissic and Dodoman Terranes that are typified by granitoid gneisses and migmatite, and the >2.71 Ga Mtera Terrane of thrust-transported amphibolite–granulite facies supracrustal rocks and granitoids as the oldest crustal blocks in the craton. They also outline the ~2.73–2.53 Ga Lake Victoria Terrane as comprising high proportions of greenschist- to amphibolite-facies supracrustal rocks and felsic granitoids. The subdivisions of Pinna et al. (1996, 2000) are based on the dominant rock types, structural trends and available K–Ar and Rb/Sr geochronology data at the time (Bell and Dodson, 1981; Cahen et al., 1984; Dodson et al., 1975; Gabert, 1990; Harris, 1981; Priem et al., 1979; Rammlmair et al., 1990; Ueda et al., 1975). With subsequent availability and improvement of geologic and geochronological data, Pinna et al. (2004a) and Pinna et al. (2004b) further subdivide the Lake Victoria Terrane into the Southern and Northern Domains, with component stratigraphic groups and supergroups.

2.2.2. Previous tectonic and metallogenic terminologies

A variety of tectonic and metallogenic terminologies have been used in the past to describe localities (belts), while implying tectonic and/or metallogenic significance in the Lake Victoria Goldfields (Barth, 1990). Other terms were used to describe the geologic setting and controls of lode gold deposits, while implying metallogenic setting. For example, terms such as the Nyanzian Fold Belt, Southwest Mwanza Goldfields, Geita–Kahama Goldfields, and Singida–Geita Belt evolved into the term Sukumaland Greenstone Belt (Borg, 1994). As well, terms such as the Musoma–Mara, Kilimafedha and North Mara Greenstone Belts evolved from the East Lake Region Belt (e.g. Borg, 1992; Borg, 1994; Borg and Krogh, 1999; Borg and Shackleton, 1997; Harpum, 1970; Hester et al., 1991; Kimambo, 1984; Kuehn et al., 1990; Naylor, 1961; Tanzania, 2005; Tyler, 1937; Wellmer and Borg, 1992 and references therein; Chamberlain, 2003; Manya and Maboko, 2003; Manya and Maboko, 2003; Manya and Maboko, 2008b; Manya et al., 2006). In the section below, consistent tectonic, metallogenic and locality terminologies are defined and used to illustrate their critical importance in explaining the tectonic–metallogenic setting of a given crustal block.

3. New tectonic subdivisions

3.1. Significance of the new subdivisions and consistent terminologies

As explained above, terrane-based tectonic subdivisions constitute a modern concept used globally to assist in understanding endowment and in targeting new prospective districts. It invokes orogenic gold deposits as end-products of much larger mineral systems operating at lithospheric scale (Hronsky and Groves, 2008; Jaireth and Huston, 2010; Jaques et al., 2002). For example, superterrane boundaries, which constitute first-order faults/shear zones, can tap lithospheric-scale hydrothermal fluids from deep crustal source regions into favourable terranes and domains via interconnections of first- and second-order fault/shear zones which bound those crustal blocks. The latter comprise lithostructural traps for gold deposition in the district. Because orogenic gold deposits develop late towards final cratonization (Bierlein et al., 2009; Groves et al., 1998), solid geological maps can be used to establish constructional histories of the craton in the context of the entire hydrothermal system (Hronsky and Groves, 2008) in order to explain endowment and predict prospectivity (e.g. Singer, 1995; Jaireth and Huston, 2010). For reasons outlined above, the maps of Barth (1990), BRGM et al. (2004) and Quennell (1956) cannot be used in their present form to establish the geologic–tectonic framework, explain gold endowment, and define the exploration potential of the Tanzania Craton and selected Proterozoic Tanzanian regions (Figs. 1, 2 and 5).

3.2. Methodology and terminology

The process used in subdividing the tectonic units and their associated metallogenic regions (Table 2) is briefly discussed below. Tectonic terms used, and their metallogenic equivalents in brackets, include: 1) superterrane (goldfield); 2) terrane (province); and 3) domain (camp). A gold province contains several gold districts, which may contain very-large gold deposits, several small gold deposits and numerous gold occurrences (Phillips and Powell, 2010; Table 2). The term district is correctly used to describe a metallogenic region covered by a given belt, which is a locality term used to specifically describe an area underlain by similar geological settings within the terrane or domain. The term belt is therefore neither a tectonic nor a metallogenic term.

3.3. Interpretation process

At the superterrane/terrane scale, greenstone lithologies are discriminated from gneisses and granitoids via the qualitative interpretation of mainly geophysical images and geological maps (Fig. 6). Although the country-wide airborne magnetic and radiometric data were captured at widely spaced flight lines (Geosurvey, 1971–1980), they were re-filtered and re-processed using advanced geophysical

Fig. 1. Regional geologic map of Tanzania (Quennell, 1956), showing > 1 t Au gold deposits, superterrane names and proposed suture zones suggested in this paper and outlines of Figs. 3 and 4 (see Figs. 6–8 for the interpretation processes which led to these crustal blocks. From north to south; 1) ELVST: East Lake Victoria, MLEST: Mwanza–Lake Eyasi, and LNST: Lake Nyanza; from the Lake Victoria Region; 2) MMST: Moyowosi–Manyoni; DSST: Dodoma Schist, DBST: Dodoma Basement, and EUMST: Eastern Ubendian–Mtera from the Central Tanzania Region; and from west to east, 3) nbt: Nyakahura–Burigi Terrane in the Northwastern Tanzania Orogen (NWTO) Proterozoic Region, and 4) usd: Usagaran domain from the Tectonic Front Zone; 5) MAST: Mbulu–Masai, KHST: Kilindi–Handeni and UKST: Usagara–Usambara Superterranes from the Central Tectonic Zone; and 6) the Neoproterozoic UPST: Uluguru–Pare Superterrane from the Eastern Tectonic Zone in the Souther East African Orogen (SEO) of the Eastern Proterozoic Region of Tanzania.

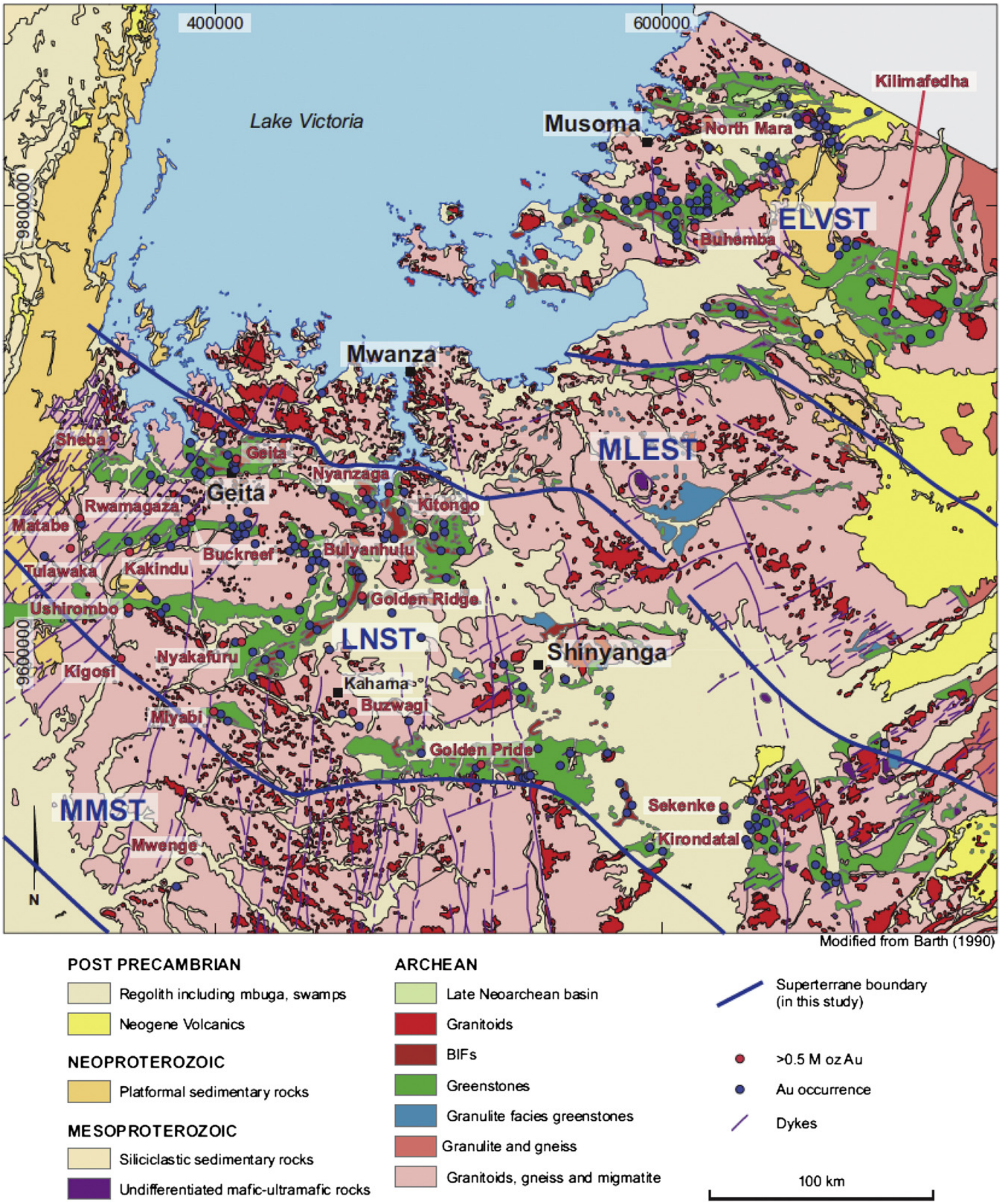


Fig. 2. Geologic map of the Lake Victoria Goldfields of Barth (1990) showing > 1 t Au deposits, outcrop and cover sequences and superterrane boundaries suggested from this study.

programs (Birmingham, 2004) in an attempt to extract as much regional lithostructural information as possible (Figs. 6 and 7). Regional geological maps at 1:125,000 and 1:100,000 scales, in digital and/or hard form from the Geological Survey of Tanzania (Tanzania, 2005; Fig. 6), were scanned and registered in the ARC1960 projection in respective UTM zones, consistent with the location of the area under interpretation. Additional geological information, including company exploration reports from the Ministry of Energy and Minerals, and reconnaissance and detailed geological mapping in selected areas (e.g. Borg, 1994; Chamberlain, 2003; Kabete, 2008; Mbuya, 2003; Wellmer and Borg, 1992), were also used in interpretation.

First-pass definition of lithological associations with distinctive geophysical signatures can be extracted from aeromagnetic images using similar approaches to those of Ford et al. (2007) and Jones et

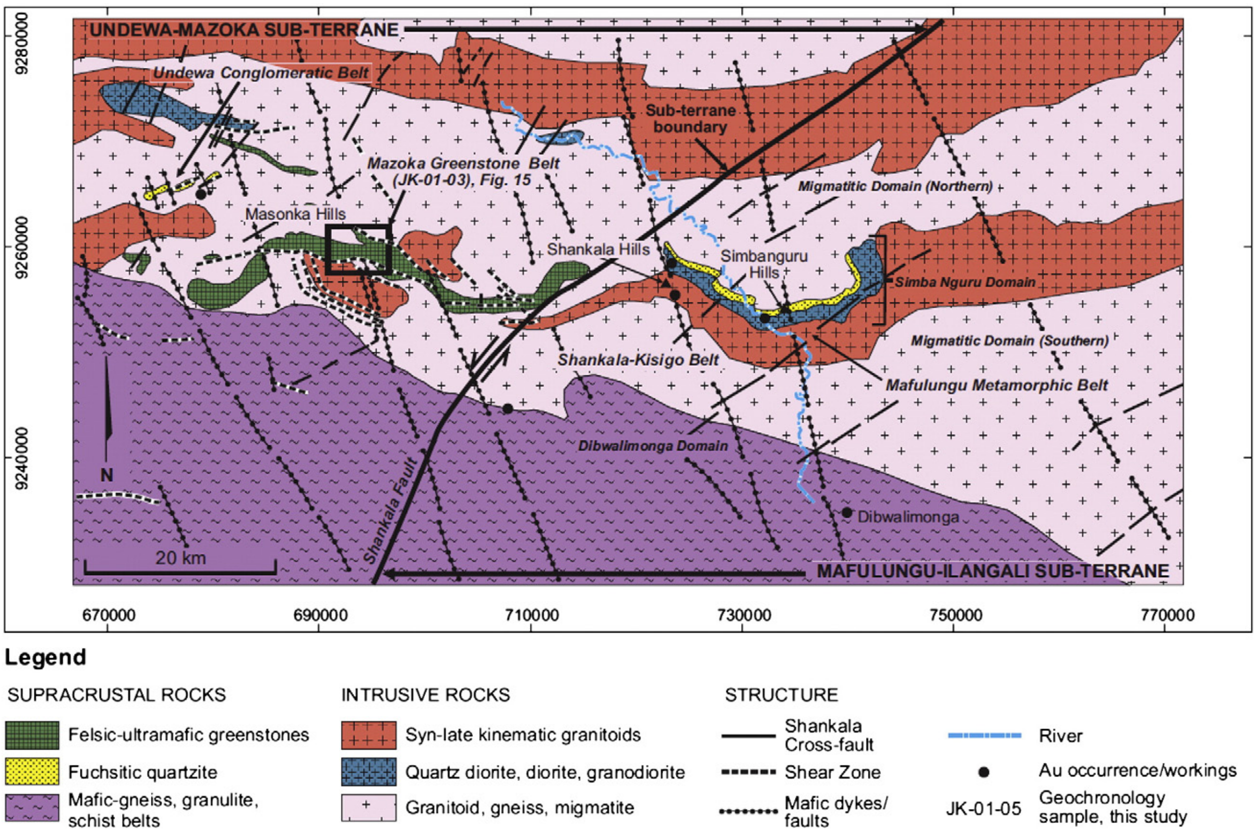


Fig. 3. Regional geologic map showing relative extent of juvenile granitoid-greenstone belts in widespread granitoids and gneisses in the Undewa–Ilangali Terrane, Dodoma Basement Superterrane of the Central Tanzania Region.

al. (1996), among others. The shape and geometries of the strong positive and negative magnetic signatures are assigned to specific rock types from available geological maps (Fig. 7). These are distinguished from moderately, weakly and non-magnetic lithomagnetic bodies, possibly paragneisses (Figs. 8 and 16). Country-wide radiometric imagery, when used in conjunction with available geological and high-resolution aeromagnetic imagery, differentiates strongly magnetic, elongate granitoids from weakly magnetic granitoid gneisses, highly radiometric granitoids, and mafic greenstones, especially in the Lake Victoria Region (Fig. 8). In effect, radiometric images are capable of mapping alternate linear belts of NW–SE-trending K-feldspar granitoids on each side of the tectonic contact between the Lake Victoria (south-western) and Central Tanzania Regions (Moyowosi–Manyoni and Dodoma Basement Superterrane: Fig. 8). Granitoid emplacement along NW–SE trends is interpreted to mark a craton-wide tectonic reactivation event (Fig. 9).

The interpretation of granitoids is critical due to their potential metallogenic significance in directly or indirectly controlling orogenic gold systems (Phillips and Zhou, 1999). Their significance is based on their relative timing with respect to the greenstone rocks, their shape, geometrical orientation, and geochemistry. Pre-greenstone or syn-orogenic granitoids could also represent host rocks and complicate the deformation patterns of intervening greenstone rocks (Figs. 8 and 9). As explained above, late- to post-kinematic granitoids may act as proxies for the heat engines critical for driving hydrothermal systems. Timing of emplacement of granitoids relative to the intervening supracrustal rocks is further constrained from robust geochronology data: for example: 1) Chamberlain and Tosdal (2007) and Manya et al. (2006) in the Lake Victoria Region; 2) Cutten et al. (2006) and Johnson et al. (2003) from the Southern East African Orogen; and 3) Kabete et al. (2008) from the Central Tanzania Region. The craton margin boundary with the Southern East African Orogen, and suture zones within the latter, are consistent with the gravity model of Nyblade and Pollack (1992).

3.4. Geological–geophysical characteristics, Tanzania Craton

Geophysically, bedrocks underlying the Lake Victoria Region comprise alternating crustal blocks of strong E–W-trending linear, open to isoclinal, upright folded, lithomagnetic units that map out greenstone-abundant belts, more specifically belts with BIFs and magnetite-quartzites (Figs. 6 and 7). These are clearly separated from extensive belts of E–W-trending to NW–SE-trending highly magnetic and/or strongly radiometric, syn-orogenic and late-tectonic granitoids in weakly magnetic paragneissic rocks. A linear belt of alternate highly radiometric and/or strongly magnetic anomalies map a wide zone of linear, NW–SE-trending strongly magnetic and highly radiometric K-feldspar granitoids which formed swarms of intrusions in the southern part of the Lake Victoria Region and the entire Moyowosi–Manyoni and Dodoma Basement Superterranes, in the Central Tanzania Region (Figs. 6 and 8). These granitoids overprint a crustal-scale sinistral shear zone evident from re-processed country-wide geophysical data (Geosurvey, 1971, 1980) and high-resolution aeromagnetic and radiometric data (e.g. GTK, 2003). There are E–W- to WNW–ESE-trending narrow corridors of non-magnetic and non-radiometric geophysical features that are coincident with greenschist–amphibolite facies granitoid-greenstone belts (e.g. epidote–amphibole chlorite schist belts: QDS 174 and 175), in the Dodoma Basement Superterrane. These are bounded by highly radiometric syn-late kinematic granitoids, and traversed by E–W- to NW–SE-trending anastomosing lithostructural fabrics, some drag folded along major NW–SE-trending tectonic boundaries between different domains in the Undewa–Ilangali Terrane (Fig. 3). In addition, the Central Tanzania Region contains alternate belts of elongate E–W to NW–SE-trending magnetic anomalies, which map mafic–ultramafic rocks. These strongly magnetic igneous rocks extend westerly from Mtera to Rungwa in the Dodoman Schist Superterrane, and further east of Lake Rukwa where they extend and crop out intermittently between Kapapa and east of Kigoma in the Eastern Ubendian Terrane (Fig. 6B).

3.5. Geological–geophysical characteristics, Proterozoic Regions

3.5.1. Western Tanzania

Crustal domains which make up the Proterozoic Regions west of the Tanzania Craton and east of the Lake Rukwa Basin constitute the Eastern Ubendian Terrane. The domains comprise linear, alternate magnetic-high and magnetic-low bedrock patterns typical of high-grade metamorphic rocks intruded by wide, elongate and strongly magnetic meta-gabbros (e.g. Muhongo et al., 2002). These Paleoproterozoic bodies were emplaced within and/or tectonically juxtaposed on to, the high-grade metamorphic rocks (Lenoir et al., 1994), including reworked Archean basement (e.g. Figs. 6 and 7).

In the north-western part of the Tanzania Craton, mafic–ultramafic rocks defined by linear, strongly magnetic anomalies are interpreted to have been tectonically emplaced within and against tightly folded siliciclastic meta-sedimentary rocks (Evans et al., 2000; Tack et al., 1994; Tack et al., 2010). The belt within hosting these linear mafic–ultramafic bodies represents a tectonic boundary between the Paleoproterozoic collisional belts of the eastern Archean Kasai Craton and the Archean Tanzania Craton (Tack et al., 2010, Fig. 2). In the eastern part of the Kibaran Orogen of Tanzania, strongly conductive sulfidic–graphitic schist and resistive quartzite ridges are tectonically overlain by the Archean granitoid-greenstone inliers, referred to as the Nyakahura–Burigi Terrane in this review (Tack et al., 2010; Fig. 9). These inliers define NE–SW-trending, curvilinear geometries defined by alternate zones of strongly magnetic anomalies, representing deeply weathered Archean greenstones, and highly radiometric anomalies coincident with mapped Archean granitoids (Evans et al., 2000; Tack et al., 2010).

3.5.2. Eastern Tanzania

The Eastern Tanzania Proterozoic Regions constitute the Southern East African Orogen of Tanzania. The latter is made up of diverse, irregular to discontinuous alternating magnetic high-magnetic-low patterns and linear patterns of strong radiometric anomalies, typical of high-grade gneisses and gneissic-granitoids traversed by N–S-trending linear features (Fig. 11). This belt is cross-cut by transverse, E–W- to NE–SW-trending, linear to curvilinear shear zones traversing lithomagnetic domains representing mafic rocks and their alteration equivalents in greenstone belts juxtaposed against domal to elliptical bodies comprising orthogneisses and granitoid gneisses (Figs. 15 and 16). These bodies and the greenstones are interpreted to be linearly distributed in felsic gneissic-granulite basement rocks based on geophysical signatures. The E–W to ENE–WSW-trending discontinuous domains of folded linear, highly magnetic bodies in the Western Granulite Domain represent mafic-amphibolite and garnet gneiss with interspersed demagnetized shear zones, and interbands of magnetic quartzite and sulfidic quartz–silicate veins. In contrary, crustal blocks in the northern and southern parts of the Western Granulite Domain are characterised by a network of irregular sets of alternate magnetic-high and magnetic-low signatures typical of relatively thin mafic amphibolites in gneissic-granulite basement rocks (Figs. 6 and 11). In some places, these geophysical features seem to represent relatively thin rafts of supracrustal rocks in extensive charnockitic–enderbitic granitoids (shown as *ukt*: Figs. 11).

3.6. Lithostructural architecture of the Tanzania Craton

The map pattern of the bedrocks underlying the Tanzania Craton comprises anastomosing NW–SE to WNW–ESE trending deformational-metamorphic fabrics cross-cut by: 1) NE–SW- and N–S trending fractures and mafic dykes in the central and eastern part of the craton, and 2) NE–SW to N–S to NNW–SSE trending curvilinear faults and dykes in the north-western part of the craton (Figs. 6 and 8). The structural interpretation of the lineament patterns (Harris, 1987; Richards, 2000) provides valuable information on the deformation events which produced them during craton-wide tectonic processes, as briefly explained below (Fig. 13).

The lithostructural map pattern of the craton (Figs. 8 and 13) is a result of progressive deformation (D) events. Deformation event D-1 involved early accretion of large volumes of igneous-sedimentary rocks of diverse lithostructural competency, such as volcanic arcs, back-arc mafic–ultramafic rocks and granitoids (e.g. ~2820 Ma back-arc basalts from Geita and Rwamagaza (Fig. 2): Manya and Maboko, 2003), against continental crust (granitoid-gneiss basement). Further compression led to the juxtaposition, folding, thrust-propagated folding, and over-thrusting and uplifting of the supracrustal rocks against and beyond intervening continental crust (e.g. greenstones in the Kahama–Mwadui Terrane: Fig. 9), developing roughly N–S-trending linear belts. Acting on a N–S directed stress field, deformation event D-2 was a major shortening event which refolded the igneous-sedimentary rocks to form E–W-trending recumbent folds and associated drag folds, buckling-related fractures, and axial planar structures preserved in the BIFs (see Borg and Shackleton, 1997; Fig. 1). In the Sukumaland Terrane, for example, this event resulted in the E–W elongation of allochtonous greenstone belts. Further compression caused fracturing in the most brittle and competent autochthonous granitoid-gneissic crust, with resultant N–S-trending fractures, and some reactivated later to allow the intrusion of mafic dykes. Further compressional tectonics caused movements along crustal blocks of diverse competency contrast (transpressional tectonics), which developed the NW–SE-trending through-going shear zones and anastomosing shear-foliation patterns, before final cratonization.

Following the re-orientation of the maximum principal stress regime to a NE–SW orientation, deformation event D-3 reactivated older structural fabrics and extended the crust in a NW–SE direction (Fig. 13), which subsequently allowed the intrusion of NE–SW-trending dolerite and felsic dykes, and the deposition of massive quartz veins (QDS 6 and 14). The latest deformation event D-4 involved NW–SE directed maximum compression, which reactivated lithospheric-scale structures, including the superterrane boundary between the Lake Victoria and Central Tanzania Regions (Fig. 8). The buffer zone to this boundary is marked by swarms of NW–SE-trending K-feldspar granitoids, which intruded following this reactivation event (see late-post tectonic granitoids in Fig. 9).

Recognition of thrust-propagated folds in the Geita Hills (Bansah et al., 2000), within the Sukumaland Terrane, and the presence of relatively thin sheets of greenstone rocks overlying parts of the thick continental crust of the Kahama–Mwadui Terrane, further suggest that NW-to-SE compressional to tectonic transportation events were part of the D-4 event (Fig. 9).

4. Geologic–tectonic framework of the Lake Victoria Region

4.1. Brief description of the geologic–tectonic framework of superterranes in the region

The Lake Victoria Region is made up of the greenstone-abundant and gold-endowed East Lake Victoria and Lake Nyanza Superterranes, which are separated by the gold-poor Mwanza–Lake Eyasi Superterrane. Greenstone-abundant superterranes comprise ~2.6–2.85 Ga (Manya and Maboko, 2003; Tosdal and Chamberlain, 2008) granitoid-greenstone terranes composed of supracrustal rocks and syn-volcanic to orogenic granitoids, which formed, at least partly, on rifted >3.11 Ga continental crust. The Mwanza–Lake Eyasi Superterrane comprises amphibolite–granulite facies

Table 1
Features characteristic of the >30 t gold districts from traditional well-endowed gold provinces in the Lake Victoria Region of Tanzania (see Figs. 2, 3 and 5).

Province	District	Camp	Deposit	Size	Hosting lithostructures	Metamorphic grade
Mara–Mobrama	Nyamongo–Isuria	Nyabirama	Nyabirama,	~150 t Au	Nyabirama: deformed, altered TTG granitoids and meta-gabbro.	Greenschist–amphibolite transition
			Nyabigena		Nyabigena: andesitic tuff, ignimbrite, siltstones, grey wackes intruded by dolerite sills	
Musoma–Kilimafedha	Musoma	Buhemba	Buhemba	~30 t Au	Gently dipping to flat-lying shear zones in carbonate-altered mafic volcanic rocks.	Greenschist facies
Sukumaland	Biharamulo–Geita	Sanza–Geita	All deposits between Nyakanga, Geita and North East Extension	900 t Au	Complexly folded, faulted, brecciated BIF and diorite confined by tuffaceous volcanic–sedimentary rocks in thrust faults and splays	Greenschist facies
		Matandani–Kukuluma	All deposits from Matandani to Kukuluma South		Through-going shear splays in BIF-chert flanked by argillaceous sedimentary rocks and felsic tuffs	Greenschist facies
	Ushirombo–Bulyanhulu	Bulyanhulu–Busulwangili	Bulyanhulu	~550 t Au	Deformed chert (quartz) in pelitic graphitic sedimentary rocks between mafic volcanic rocks and felsic pyroclastic rocks	Greenschist facies
	Sarama–Rwamagaza	Rwamagaza	Buckreef, Rwamagaza Black, Blue,	~50 t Au	Lodes of NE–SW-trending shear foliated zones bounding ~3–15 m zones of en echelon quartz veins in mafic volcanic rocks	Greenschist facies
		Nyakanazi–Dihobaika	Tulawaka	~65 t Au	Quartz vein in mafic amphibolite, volcanic–sedimentary rocks and stockwork quartz in porphyries	Amphibolite facies
Kaniha–Tinde	Mwine–Tinde	Kahama	Buzwagi	~705 t Au	Irregular quartz reef material including sulphidic vein quartz in mica schist and altered granitoids	Greenschist–amphibolite transition
	Miyabi	Miyabi	Miyabi	25 t Au	Shear foliated volcanic–sedimentary rocks	Greenschist–amphibolite transition
Nzega–Sekenke	Nzega	Lusu	Golden Pride	130 t Au	Shear-foliated intermediate to felsic volcanic–sedimentary rocks	Greenschist–amphibolite transition

igneous-sedimentary rocks and granitoid gneisses intruded by numerous late to post-kinematic granitoid plutons (Fig. 8). This terrane has attracted little attention from researchers and is considered to be under-explored.

4.1.1. East Lake Victoria Superterrane

The East Lake Victoria Superterrane comprises the following terranes, named from north to south: 1) North Mara Terrane; 2) Mara–Mobrama Terrane; 3) Musoma–Kilimafedha Terrane; and 4) Ukerewe–

Table 2
Example of the new tectonic subdivisions proposed by Kabete (2008), illustrating consistent use of the tectonic, metallogenic and locality terminologies. Note also that the metallogenic equivalent of superterrane as used in this study is goldfields.

Superterrane	Terrane	Proposed belt (mineral district) names	Gold province
East Lake Victoria	North Mara (NMT)	Mori–Tarime (mtb); Migori (mgb); North Mara (nmb)	
	Mara–Mobrama (MMT)	Nyamongo–Isuria (nib); 2) Nyamongo–Nyabirama (nnb); 3) Mugumu Granitoid (mgb)	Mara–Mobrama
	Musoma–Kilimafedha (MKT)	Suguti–SimbaSirori (ssb); Nigoti–Lobo (nlb); Kilimafedha (kgb)	Musoma–Kilimafedha
	Maswa–Serengeti (MST)	Nasa (ngb); Ngasamo–Baramongi (nbb); Maswa–Serengeti (msb)	Serengeti
Mwanza–Lake Eyasi	Mwanza–Magu (MGT)	Muhandisi–Mavuma Granitoid (mmb); Bukwimba Migmatitic (bmb)	
	Malita–Ngorongoro (MNT)	Malita–Simiyu (msb); Sindayi Granitoid (sib); Itinje–Kamuli (ikb)	
	Iaida–Haidon (IHT)	Lake Eyasi (leb); Haidon Schist (hsb)	Iaida–Haidon
	Sukumaland (ST)	Biharamulo–Geita (bgb); Siga–Mabale (sgb); Bulyankulu–Ushirombo (bub); Sarama–Rwamagaza (srb)	Sukumaland
	Kahama–Mwadui (KMT)	Busangi–Sulwe (bsb); Shinyanga–Mwadui (smb); Kahama–Nyanza (knb)	
Lake Nyanza	Nzega–Sekenke (NST)	Nzega Greenstone (ngb); Iramba–Sekenke (isb); Manonga Gneissic (mgb)	Nzega–Sekenke
	Singida–Mayamaya (SMT)	Kwa Mtoro–Sanzawa (ksb); Haneti Ultramafic (hub); Basutu (bsb); Mayamaya–Hombolo (mhb)	
	Kaniha–Tinde (KTT)	Kaniha–Kigosi (kkb); Miyabi (mib); Mwime–Tinde (mtb)	
Moyowosi–Manyoni	Moyowosi–Uyowa (MUT)	Uyowa Gneissic (ugb)	Kaniha–Tinde
	Tabora–Manyoni (TMT)		Moyowosi–Uyowa
Dodoma Schist	Kaliua–Inyonga (KIT)		
	Malagasya–Rungwa (MRT)	Kitunda–Rungwa (krb); Malagasya (mcb)	
Dodoma Basement	Dodoma Gneissic (DGT)	Bihawana–Ihumwa (bcb); Iluma (icb); Sikonge (scb)	Malagasya–Rungwa
	Undewa–Ilangali (UIT)	Undewa Conglomeratic (unb); Mazoka (mzb); Mafulungu (mfb); Ilangali (ilb)	Undewa–Ilangali
Eastern Ubendian–Mtera	Isanga–Mtera (IMT)	Isanga (isb); Great Ruaha (grb)	
	East Ubendian (EUT)	Mpanda–Kapapa (mkb)	Eastern Ubendian
Kalenge–Burigi	Nyakahura–Burigi (NBT)	Nyakahura (nyb); Ruiza (rub)	Nyakahura–Burigi
Kilindi–Handeni	Mkurumu–Magamba (MMT)	1) Mkurumu–Libabala; 2) Ngeze–Masagali; 3) Magamba–Manga	Mkurumu–Magamba

Maswa–Serengeti Terrane (Table 2). The majority of these terranes are shallowly and/or partly covered by sequences including; 1) the Kavirondian Supergroup of ~2.6 Ga late siliciclastic sedimentary basins (Manya et al., 2006); 2) Neoproterozoic platformal siliciclastic–sedimentary rocks (e.g. Barth, 1990); 3) Neogene phonolitic volcanic flows (Smith and Anderson, 2003; Fig. 4); and 4) greater than 50% by lake sediments and alluvial deposits (Barth, 1990; Figs. 2 and 4).

The North Mara Terrane comprises E–W to ENE–WSW-trending supracrustal belts bounded by granitoid belts to the north and the Utimbaru–Isuria Fault System to the south (Fig. 4). The terrane comprises the Mori–Tarime Greenstone Belt (*mtb*) and Migori Greenstone Belt (*mgb*), collectively forming part of the Musoma–Mara Greenstone Belt of Manya et al. (2006, 2007). These belts are separated by alternating granitoid-gneisses of the North Mara Belt (i.e. *nmb:* Fig. 4). Greenstones in the Migori Belt are predominantly calc-alkaline felsic volcanic rocks with subordinate basalts (Ichang and MacLean, 1991). These rocks extend from Lake Victoria eastwards, where they are intermittently exposed before they thin out towards Kenya (Fig. 8). In the Mara–Mobrama Terrane, relatively thin slices of greenschist to amphibolite facies mafic–ultramafic supracrustal rocks crop out intermittently in a pervasive regional shear-fabric, trending E–W- to SE–NW, in the trondhjemite and trondhjemitic-biotite gneisses (e.g. Nyamongo–Isuria Belt: QDS 6 and 14). In the Musoma–Serengeti Terrane, complexly deformed andesitic to felsic volcanic rocks and magnetic volcanic-sedimentary rocks are juxtaposed against granitoid gneisses and intruded by different generations of granitoids (e.g. Suguti Greenstone Belt: QDS 12; Mtoro et al., 2009). In the eastern part of the terrane, the Nigoti–Lobo Belt (*nlb*) of mafic–ultramafic greenstones shares a tectonic contact with extensive batholiths of TTG gneisses of the Mara–Mobrama Terrane (Fig. 4; southern part of QDS 6 and 14). The geology of the Kilimafedha Belt (*kgb*: Fig. 4) is described by Hester et al. (1991), Tanzania (2005) and Wirth et al. (2004). Deformation intensifies in the southern parts of the East Lake Victoria Superterrane, where isoclinally folded, strongly magnetic, siliciclastic sedimentary rocks and BIFs form repetitive doubly plunging synformal ultramafic–felsic greenstones against domal granitoid bodies (Fig. 4, QDS 24). Some preserve fold limb features attenuated against syn- to late-kinematic biotite granitoid, especially in the Ngasamo–Baramongo Belt (QDS 23 and 24; Fig. 4).

4.1.2. Mwanza–Lake Eyasi Superterrane

The Mwanza–Lake Eyasi Superterrane is distinctive with respect to other superterranes (Fig. 8). It is made up of amphibolite–granulite facies metamorphic belts and voluminous syn-orogenic granitoids and late-kinematic K-feldspar granitoids in its western part, and is dominated by extensive overprints from the Pan-African tectonothermal events in its eastern part (Fig. 8). It extends from the granitoid-dominated Mwanza–Magu Terrane in the northwest, through the largely amphibolite–granulite facies supracrustal-dominated Malita–Ngorongoro Terrane, into the easternmost Iaida–Haidon Terrane of greenschist–amphibolite facies supracrustal rocks (see IHT: Fig. 9). The latter is overprinted by a late-kinematic NW–SE-trending shear-foliation and a NE–SW-trending high-grade metamorphic fabric, closely spaced faults and dolerite dyke intrusions (Fig. 9). A high-density of NE–SW-trending structures in the Iaida–Haidon Terrane, including dolerite dykes intruded along reactivated Archean structures (see Figs. 6 and 7), are, in turn, cross-cut by rift-related structures responsible for the development of Lake Eyasi and other rift-related lakes in the East African Rift System (Fig. 9; QDS 84). Detailed interpretation suggests that some belts in the Iaida–Haidon Terrane were once part of the Nzega–Sekenke Terrane (Lake Nyanza Superterrane) and that the present geometry (e.g. mylonite, phyllonite and cataclasite in the Iaida–Haidon Terrane: IHT), was a result of late to post-tectonic tectonothermal overprints along the craton margins (Figs. 8 and 9; QDS 84). Dashed blue lines in Fig. 9 show an interpretative proto-superterrane boundary before the reactivation and intrusion of NW–SE-trending granitoids at ~2681 ± 5 Ma (near Londoni in Fig. 7; Kabete et al., 2008).

4.1.3. Lake Nyanza Superterrane

The Lake Nyanza Superterrane comprises, from west to east: 1) the Nyakahura–Burigi Terrane, mostly covered by the Mesoproterozoic Karagwe–Ankolean Belt (Tack et al., 2010); 2) the gold-endowed Sukumaland Terrane; 3) the diamondiferous kimberlite-rich Kahama–Mwadui Terrane; 4) the greenstone-abundant Nzega–Sekenke Terrane; and 5) the schist-belt dominant Singida–Mayamaya Terrane (Fig. 9). The bedrock map pattern shows the NW–SE-trending Kigosi–Tinde Domain as being part of the Sukumaland Terrane prior to the latest northwest-to-southeast sinistral transpressional tectonics (Figs. 8 and 13). That event was a cratonic-scale event, which reactivated the tectonic boundary between the Lake Victoria and Central Tanzania Regions. It also allowed the emplacement of a high-density of NW–SE-trending K-feldspar granitoids, on either side of the boundary, especially in the southern part of the Lake Nyanza Superterrane (Kigosi–Tinde Domain), part of the Kahama–Mwadui Terrane, and the entire Moyowosi–Manyoni and Dodoma Basement Superterranes (Fig. 8).

The Sukumaland Terrane (SKT: Fig. 9) comprises the thick, complexly folded and faulted Biharamulo–Geita, Sarama–Rwamagaza, Ushirombo–Bulyanhulu and Siga–Mabale Belts (Barth, 1990; Borg, 1994; Wellmer and Borg, 1992), which, together, define a concave geometry as they disappear under the curvilinear fault-bounded Bukoban Group of sedimentary rocks, layered gabbro and dolerite sills (Figs. 2 and 9). The Archean Kahama–Mwadui Terrane is largely covered by transported sediments and black soils, and there are virtually no greenstone supracrustal rocks in the terrane. However, migmatitic granite gneiss domains, older than 3.11 Ga, based on the K–Ar age of muscovite extracted from a pegmatite vein in a virtually undeformed granitoid (Ueda et al., 1975), are intruded by diamondiferous kimberlite pipes, including the giant Mwadui pipe. The migmatitic gneiss complex is intruded by NE–SW-trending granitoids, whose eastern boundary marks the tectonic contact with the Nzega–Sekenke Terrane (Fig. 9). The NE–SW and N–S-trending granitoids in the Kahama–Mwadui Terrane, as well as those in the Busangi–Sulwe Belt and in the western part of the Iramba–Sekenke Belts, define discordant trends with NW–SE-trending K-feldspar granitoids. The latter probably intruded along sutures separating rigid continental crust (Fig. 9).

The Nzega–Sekenke Terrane (NST) is largely underlain by chemical and siliciclastic rocks of the Nzega Belt (*nzb*: Fig. 9; Geosurvey, 1985a; Geosurvey, 1985b; Tanzania, 2005; Vos et al., 2009) and extensive mafic volcanic rocks of the Iramba–Sekenke Belt (*skb*: Fig. 9: Manya and Maboko, 2008a; McConnell, 1945;). The two belts are separated by NE–SW-trending corridors of closely spaced micro-faults and dykes, which were reactivated during Cenozoic rifting (see a NE–SW-trending fault/shear zone cutting through Lake Eyasi: Fig. 9). The terrane is covered by extensive alluvial deposits and proto-Lake Eyasi sediments (see near deposits number 19 and 22: Fig. 9). Greenstone belts in the Nzega–Sekenke Terrane appear to extend into the Iaida–Haidon Terrane (IHT), where they define an overall geometry similar to that of the Ushirombo–Bulyanhulu (*ubb*) and Siga–Mabale Belts (*smb*) in the Sukumaland Terrane (Fig. 9). With the exception of the disappearance of the Biharamulo–Geita Belt in the Nzega–Sekenke Terrane, the rest of the supracrustal belts, in both the Nzega–Sekenke and southern Iaida–Haidon Terranes, define an overall geometry similar to that defined by greenstone belts in the Sukumaland Terrane.

In contrast to other terranes, the Singida–Mayamaya Terrane is made up of distinctively extensive granitoid-gneiss domains with relatively thin amphibolite-facies greenstone belts: e.g. the Kwa–Mtoro–Sanzawa Belt that hosts the Londoni gold prospects; and the Mayamaya–Hombolo Belt, within which the Manyoni gold prospects are situated (Fig. 8). Greenstones are mainly amphibolite schist, porphyritic andesite, schistose dolerite and rhyolite, which form part of the Bihawana Schist Belt south of Dodoma (Fig. 9). Amphibolite schist in the Kwa–Mtoro–Sanzawa Belt is bounded by through-going NW–SE-trending shear zones and by a 2680 ± 5 Ma biotite-amphibole granite further north (Kabete et al., 2008; Fig. 9).

4.1.4. Anomalous crustal blocks

The Kaniha–Tinde Domain in the south-western part of the Sukumaland Terrane can be either part of the Lake Nyanza Superterrane (this study) or the Moyowosi–Manyoni Superterrane (Fig. 9). The domain constitutes the Kaniha–Kigosi Belt of amphibolite, intermediate volcanic rocks and sporadic silicate-facies BIFs, and the Miyabi Belt of extensive BIFs, flanked by mafic volcanic rocks on both sides. The presence of relatively thin greenstones in widespread early biotite granitoids and extensive late to post-kinematic NW–SE-trending K-feldspar granitoids, typical of the Kaniha–Tinde Domain, is most likely analogous to terranes which make up the western part of the Moyowosi–Manyoni Superterrane (interpreted greenstones around the Mwenge prospect), Central Tanzania Region, rather than the Sukumaland Terrane (Figs. 8 and 9). The Nyakahura–Burigi Terrane comprises inliers of Archean granitoid-greenstone belts in the Mesoproterozoic Kibaran Orogen of north-western Tanzania (NBT: Fig. 8). These deeply weathered rocks have been mapped (QDS 29, 29W and 30), and interpreted as Archean inliers (BRGM et al., 2004; Tack et al., 2010), and further interpreted by Kabete (2008) as having been tectonically dislocated from the Sukumaland Terrane following sinistral reactivation of NE–SW-trending basement faults (Kabete et al., 2008; Klerkx et al., 1993; Tack et al., 1994). The Nyakahura–Burigi Terrane is further described under the Proterozoic Tanzanian Regions (Section 6.1).

5. Geologic–tectonic framework of the Central Tanzania Region

5.1. Brief description of the geologic–tectonic framework

At least four superterranes form the Central Tanzania Region: 1) the Moyowosi–Manyoni Superterrane; 2) Dodoma Basement Superterrane; 3) Dodoma Schist Superterrane; and 4) the East Ubendian–Mtera Superterrane (Fig. 8). In the absence of robust geochronology, and solely based on the regional bedrock map pattern (e.g. Fig. 8), it is possible that the Dodoma Basement and Dodoma Schist Superterranes once formed a contiguous crustal block, prior to the intrusion of NW–SE-trending granitoids, which intruded as swarms in the Dodoma Basement and Moyowosi–Manyoni Superterranes (Fig. 8). Alternatively, it is also possible that the latter evolved concurrently. The most significant differences between these crustal blocks are the lack of juvenile greenstones and significant gold occurrences in the Moyowosi–Manyoni Superterrane (Fig. 7). The Dodoma Basement Superterrane contains juvenile granitoid-greenstone belts in the relatively prospective the Undewa–Ilangali Province (e.g. Undewa Conglomeratic and Mazoka Greenstone Belts: Fig. 3). The Eastern Ubendian–Mtera Superterrane comprises: 1) the Eastern Ubendian Terrane of NW–SE-trending belts of high-grade Paleoproterozoic igneous-sedimentary rocks intercalated with Archean basement inliers (Lenoir et al., 1994; Muhongo et al., 2001; Stendal et al., 2004); and 2) the E–W-trending Isanga–Mtera Terrane of Mesoarchean orthogneiss (mainly TTG), migmatite and paragneiss, thrust transported from the Dodoma Basement Superterrane (Pinna et al., 1996; Figs. 8 and 10).

5.1.1. Moyowosi–Manyoni Superterrane

Although the geology of this contiguous crustal block is mostly covered by transported regolith, including proto-lake sediments (e.g. QDS 96, 97), bedrock map patterns (Geosurvey, 1971, 1980; GTK, 2003), outline at least two contiguous crustal blocks: 1) the E–W- to WNW–ESE-trending Moyowosi–Uyowa Terrane (MUT) typified by syn-orogenic biotite granitoids in orthogneissic-migmatites; and 2) the NW–SE-trending Tabora–Manyoni Terrane (TMT) typified by extensive orthogneissic-migmatites intruded by a high-density of late-kinematic K-feldspar granitoids (Figs. 8 and 9). High-resolution geophysical images and sub-surface geology intersected by drilling at the Mwenge Prospect support the interpretation of the elongate, weakly magnetic, biotite granitoid gneisses with significant mafic xenoliths or rafts, which are further bounded by granitoid-gneisses and

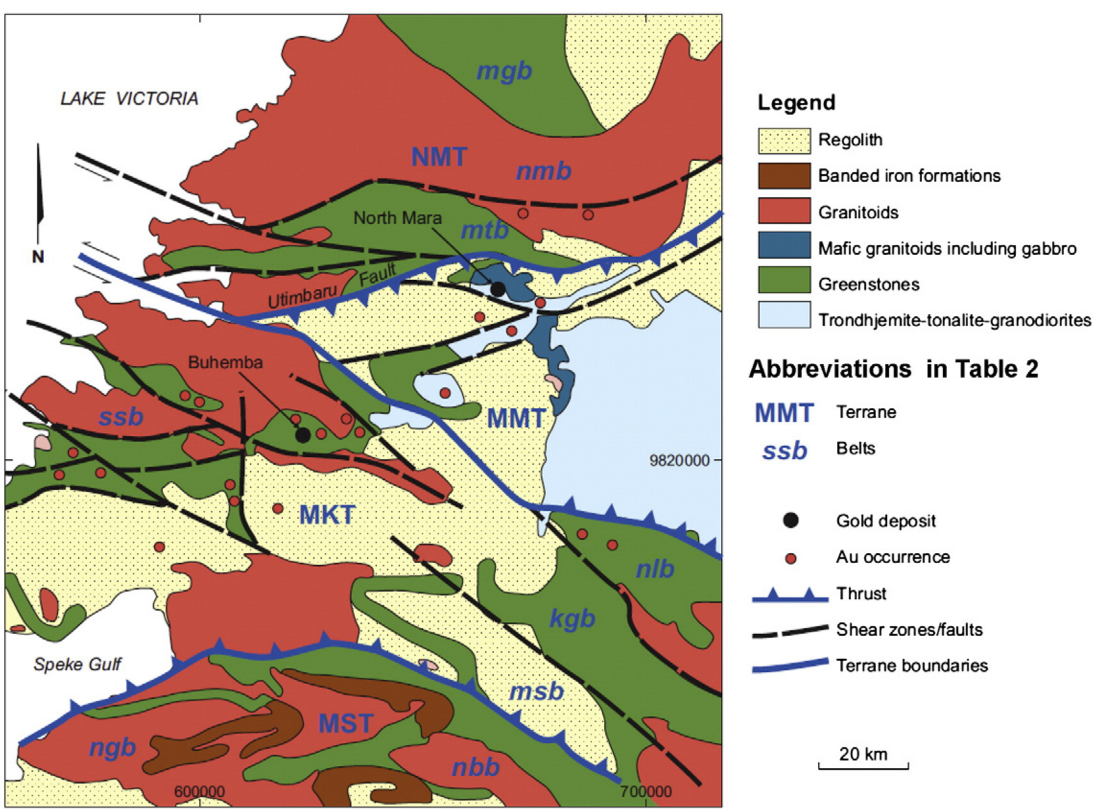


Fig. 4. Regional geologic map of the East Lake Victoria Superterrane illustrating relative extents of the belts in terranes that are almost ~50% covered by regolith sequences. It also shows lack of BIFs in the northern part, structural complexity and presence of BIFs in the southern part and lack of new gold discoveries in the superterrane apart from historical North Mara and Buhemba gold mines. Abbreviations for terranes and belts are defined in Table 2.

migmatite (Fig. 14). A brief description of the sub-surface geology of Mwenge Prospect is provided in Section 7.3.1.

5.1.2. Dodoma Basement Superterrane

The Dodoma Basement Superterrane comprises the wedge-like, E–W-trending Dodoma Gneissic and Undewa–Ilangali Terranes with widespread tonalite–trondhjemite–granodiorite (TTG) gneisses, diorite and felsic granitoids (i.e. granitoid, gneiss, migmatite in Fig. 3). However, the Undewa–Ilangali Terrane also contains relatively widespread greenschist–amphibolite facies greenstones and syn-late-kinematic K-feldspar granitoids (Fig. 3), whereas the Dodoma Gneissic Terrane comprises E–W to WNW–ESE-trending schist and gneissic belts tectonically confined within widespread belts of concordant granitoid-migmatite basement rocks (e.g. QDS 162; Fig. 7). The geology of the Dodoma Gneissic Terrane is not discussed any further. Only the geology of the Undewa–Ilangali Terrane is described in detail, as it contains two important greenstone belts: 1) the greenschist–amphibolite facies Undewa Conglomeratic and Mazoka Greenstone Belts; and 2) the amphibolite-facies Mafulungu Metamorphic Belt (Fig. 3). These belts and contained small-scale orogenic gold systems are further discussed in Section 7.3.3.

5.1.3. Dodoma Schist Superterrane

The Dodoma Schist Superterrane comprises at least two terranes: the Kaliua–Inyonga (KIT) and Malagasya–Rungwa (MRT) Terranes. Both terranes are widely covered by thick lacustrine and fluviatile sediments and transported and, in places, residual regolith profiles (e.g. QDS 173, 174). Whereas the Malagasya–Rungwa Terrane is underlain by some well-exposed TTG gneisses and intervening mafic greenstone belts (Fig. 10), the Kaliua–Inyonga Terrane is widely covered by platformal Neoproterozoic rocks and deep weathering profiles (Fig. 8). Due to the paucity of geological and high-resolution geophysical data, the Kaliua–Inyonga Terrane is not discussed any further. Rather, the Malagasya–Rungwa Terrane is briefly discussed below as it contains significant tracts of greenstone belts, some associated with small-scale gold systems (Figs. 3 and 10). A major tectonic break splits the Malagasya–Rungwa Terrane into two distinctive crustal blocks: 1) strongly strained K-feldspar granitoids with a high-density of aplitic dykes towards the Undewa–Ilangali Terrane (UIT); and 2) extensive, late to post-kinematic alkali-feldspar granitoids in shear-foliated granodiorite gneisses towards the Isanga–Mtera Terrane (IMT: Figs. 8 and 10). Among other belts in the Malagasya–Rungwa Terrane, the Kitunda–Rungwa Greenstone Belt (KRB) comprises relatively extensive mafic-amphibolite greenstone rocks intruded by dolerite and gabbroic sills that are host to small-scale orogenic gold systems (Fig. 10). These amphibolite facies greenstones extend under regolith cover and are mapped by moderate to strongly magnetic anomalies in the north-western part of the belt (Fig. 10). The geology of the Kitunda Greenstone Belt and associated orogenic gold systems is briefly described in Section 7.3.2.

5.1.4. Eastern Ubendian–Mtera Superterrane

The East Ubendian and Isanga–Mtera Terranes are two crustal blocks which make up the East Ubendian–Mtera Superterrane (Fig. 8). The bedrocks underlying the East Ubendian Terrane are traversed by networks of anastomosing structures cross-cut by N–S- and NE–SW-trending faults and dykes, which are part of the Archean Tanzania Craton (Figs. 6 and 7). These cratonic structures terminate along the very strongly linear NW–SE-trending deformational-metamorphic fabric of the Paleoproterozoic Ubendian Mobile Belt (Figs. 6A and 8). In addition, strongly magnetic K-feldspar granitoids and gabbroic rocks in the East Ubendian Terrane, north of the Lake Rukwa Rift System, seem to have intruded proto-Archean crustal blocks which extended south-easterly into the E–W-trending ~3.0–2.85 Ga Isanga–Mtera Terrane (Figs. 8 and 10). Recent work by Manya (2011) suggests that Archean proto-crust in the Eastern Ubendian Terrane most likely represent the slivers of Archean crust in the Proterozoic belts of southwestern Tanzania. The map pattern of the bedrock geology of the East Ubendian Terrane, the Sm–Nd depleted-mantle model ages of 2031–2431 Ma (Manya, 2011) and the presence of Neoarchean basins (i.e. Kavirondian Supergroup: Manya, 2011, Fig. 2), further suggest that the East Ubendian Terrane forms part of the Archean Tanzania craton margin reworked during Paleoproterozoic times. This terrane is likely to contain protolithic Archean exotic fragments following the ~1.95 Ga collision between the Tanzania Craton and the Benguelu Craton (Begg et al., 2009).

6. Selected Proterozoic Tanzanian Regions

Proterozoic Tanzanian Regions include mobile belts situated on the westerly and easterly geographic strike-extension of the Archean Lake Nyanza Superterrane (Fig. 8). The westerly situated Northwestern Tanzania Orogen constitutes the Kibaran Belt (e.g. Cutten et al., 2006; Rumvegeri, 1991; Tack et al., 1994), recently subdivided into two belts along the transverse, NW–SE-trending Paleoproterozoic Ruzizian Belt (Tack et al., 2010). They include the Kibaran Belt to the south and Karagwe–Ankolean Belt to the north. The easterly situated Proterozoic Tanzanian Region constitutes the Southern East African Orogen (Stern, 1994), which is part of the N–S-trending Mozambique Belt (e.g. Holmes, 1951). The orogen is typified by intensely deformed, high-grade metamorphic rocks, in places with slices of greenschist to amphibolite facies supracrustal rocks, including suspect ophiolites (e.g. Shackleton, 1986; 1996). The Northwestern Tanzania and Southern East African Orogens contain two important tectonic–metallogenic gold provinces with potential for preserved and/or reworked orogenic gold deposits.

6.1. Northwestern Tanzania Proterozoic Region

The N- to NE-trending Karagwe–Ankolean Belt, a locality term equivalent to the Kibaran Orogen as used by Tack et al. (2010) in a tectonic sense, is part of the Northwestern Tanzania Orogen, and is characterised by contrasts in deformation intensity and metamorphic grades. The western part is intensely deformed and metamorphosed up to amphibolite facies with a high-density of syn- to late-kinematic granite intrusions, and the eastern part by horizontally folded repetitions of up to greenschist facies siliciclastic-sedimentary rocks and inliers of basement rocks (Brinckmann et al., 1994; Cahen et al., 1984; Goodwin, 1990; Ikingura et al., 1992; Klerkx et al., 1993; Kröner, 1977; Meert et al., 1994; Tack et al., 1994; Tack et al., 2010). Kröner (1977), among previous workers, used the presence of old basement rock inliers as testimony for ensialic evolution of the belt. In contrast, Klerkx et al. (1993) showed that the basin within which the Karagwe–Ankolean Belt evolved developed via dextral reactivation of transcurrent faults in the basement rocks. In this context, juvenile lower-order structures in the Karagwe–Ankolean Belt are derivatives of tectonic reactivation of the basement structures. Rumvegeri (1991) and Tack et al. (1994), on the other hand, suggested that the supracrustal accumulation of the precursor rocks to the Karagwe–Ankolean Belt was a result of subduction and collisional tectonic processes that culminated in easterly directed thrust-transportation.

Qualitative interpretation of the remotely sensed images, in terms of the geological descriptions (e.g. QDS 29, 30) and explanations given above, suggest that the Karagwe–Ankolean Belt is made up of three tectonic units. From west to east, they are: 1) the Western Tectonic Domain of Paleoproterozoic orthogneisses tectonically juxtaposed against amphibolite-facies volcanic-sedimentary rocks, and a high-density of anatectic granitoids; 2) the Tectonic Zone Domain of westerly verging Mesoproterozoic siliciclastic sedimentary rocks, including highly conductive carbonaceous thrust belts, NE-trending shear-foliated mafic–ultramafic rocks, and syn-kinematic A-type granites; and 3) the Eastern Tectonic Domain, comprising thrust-transported Mesoproterozoic carbonaceous schist and phyllite and shallow water, immature clastic-sedimentary rocks tectonically or unconformably overlying Archean rocks, and the Bukoban Group of volcanic–sedimentary sequences and syn-rifting mafic sills. The Eastern Tectonic Domain is described below, as it includes Archean inliers, which are a major focus of this review.

6.1.1. Nyakahura–Burigi Terrane, Eastern Kibaran Sub-Domain

The Archean inliers of the Nyakahura–Burigi Terrane (*nbt*, Fig. 9) include deeply weathered E–W- to NW–SE-trending remanently magnetised volcanic–sedimentary rocks (e.g. Geosurvey, (1971, 1980); Anomaly 18-01: UNDP, 1985), quartz–sericite schist (strongly deformed granitoids), granodiorite and biotite granite. Some granitoids share tectonic contacts with strongly deformed Mesoproterozoic rocks in the Domain (QDS 8, 18, 30). The geological–geophysical bedrock map pattern of the Nyakahura–Burigi Terrane is analogous to the Sukumaland Terrane, further suggesting that the Archean Nyakahura–Burigi Terrane was once sutured to the Tanzania Craton prior to the tectonic events that failed to open the Kibaran Ocean (e.g. Klerkx et al., 1993).

There is increasing evidence to suggest that the basement in the Northwestern Tanzania Orogen was tectonically active from Archean to Paleozoic times. This hypothesis is supported by the following evidence: 1) supracrustal accumulation and subsequent intrusion of the Mesoproterozoic mafic–ultramafic rocks and A-type granites in the Tectonic Zone Domain; 2) dextral transpressional reactivation leading to NE–SW-trending syn-rifting of the Bukoban basin of volcanic–sedimentary rocks and mafic sills (Klerkx et al., 1993; Tack et al., 1994, 2010); 3) concurrent structural reactivation of the Tectonic Zone Domain, leading to strong shearing and dislocation of massive sulphides from associated layered ultramafic bodies to metasedimentary units (Evans et al., 2000); and 4) intrusion of ~1000–900 Ma tin-bearing granites and ~750 Ma alkaline granites, and Paleozoic mafic dykes.

Petrographic studies on drill-intersected bedrocks from the Ruiza Belt (i.e. Anomaly 18-01: UNDP, 1985), in the northern part of the Nyakahura–Burigi Terrane, reveal that the protoliths to the deeply weathered rocks in the inliers are chlorite-amphibolite schist, mafic amphibolite and andesite (BHP Minerals, 1995; Evans et al., 2000). The rocks are visually and petrographically similar to greenstones in the Sukumaland Terrane (BHP Minerals, 1995; Eilu et al., 1999). Petrogenetic studies of the same rocks produced rare earth element (REE) patterns atypical of the Kibaran mafic–ultramafic intrusions and associated country rocks, but typical of Archean greenstone rocks (e.g. Evans et al., 2000). The bedrock geophysical–geological patterns of the Ruiza and Nyakahura granitoid-greenstone inliers comprises alternate domains of E–W- to WNW–ESE-trending geometries bounded by NE–SW-trending curvilinear faults, which are part of the NE–SW-trending Kalenge–Burigi Superterrane. It extends southerly from Lake Burigi to as far as the northern tip of Lake Tanganyika (Fig. 1; QDS 18, 29, 30, 43; Tack et al., 2010, Figs. 1 and 2). Although no robust geochronology dating has so far been conducted, Kabete (2008) suggests that the Nyakahura–Burigi Terrane is part of the Archean Kalenge–Burigi Superterrane, which was sutured to the Archean Lake Nyanza Superterrane prior to Proterozoic orogenic and tectonic reworking. However, it is quite possible that the Nyakahura–Burigi Terrane constitutes exotic Archean crust that was dismembered from another part of the subcircular Congo Craton (Kroner, 1977) during failed Mesoproterozoic rifting events (e.g. Begg et al., 2009).

6.2. Southern East African Orogen, Eastern Proterozoic Region

The northern part of the East African Orogen (Stern, 1994) comprises accretionary juvenile Neoproterozoic granitoid-greenstone belts juxtaposed against high-grade metamorphic terranes (Arabian–Nubian Shield), whereas the southern part comprises intensely deformed high-grade metamorphic terranes and collisional-type orogenic domains (Southern East African Orogen or Pan-African Mozambique Belt). The diagnostic differences between accretionary and collisional-type terranes in the East African Orogen are consistent with the explanations of Vanderhaeghe (2010).

Numerous research projects have taken place in different areas of the Southern East African Orogen (e.g. Collins et al., 2044; Cutten et al., 2006; Fritz et al., 2009; Johnson et al., 2003; Kroner, 1977; Lenoir et al., 1994; Maboko, 1995; Maboko, 2000, 2001; Muhongo, 1994; Muhongo and Lenoir, 1994; Muhongo et al., 2001; Muhongo et al., 2001; Saggerson, 1967; Shackleton, 1986; Sommer et al., 2003; Sommer et al., 2005; Sommer et al., 2008; Muhongo and Tuisku, 1996; Vogt et al., 2006; Wallbrecher et al., 2002). These studies have generally attempted to prove whether the Southern East African Orogen defines a collisional zone between the East and West Gondwana continents (e.g. Storey, 1995; Muhongo et al., 2003). The terranes which make up the Southern East African Orogen are geometrically variably oriented although bounded by consistently oriented crustal-scale faults and shear zones (e.g. Shackleton, 1996). Some of the bounding faults, including: 1) NW–SE-, N–S- to NE–SW-trending buckling-related faults; 2) E–W to ENE–WSW-trending lithotectonic units (e.g. Fig. 15); 3) N–S-trending easterly dipping suture zones; and 4) NW–SE-trending transform faults, have been related to E–W-trending compressional tectonics (Shackleton, 1996, Fig. 2).

Whereas some of the Archean crust in the Southern East African Orogen is partly covered by Proterozoic foreland basins and slices of thrust-transported Neoproterozoic gneisses and granulites (e.g. QDS 198, 216; Fritz et al., 2009), other Archean rocks crop out as inliers in widespread metamorphic rocks (e.g. Maboko, 2001, Fig.1; BRGM et al., 2004; Sommer et al., 2005, Figs. 1 and 2; Hauzenberger et al., 2006, Fig. 13). The geologic–tectonic relationship of Archean crust in the Southern East African Orogen and the Tanzania Craton is briefly explained below.

6.2.1. Tectonic subdivision of the Southern East African Orogen

The Southern East African Orogen of Tanzania is subdivided into three N–S-trending tectonic zones. Each zone is made up of superterranes and terranes sutured together by N–S- and NW–SE-trending transcurrent shear zones and thrust faults (Hepworth, 1972; Shackleton, 1986, 1996; Fig. 11). From west to east, they are: 1) the Tectonic Front Zone consisting of the western foreland of Fritz et al. (2009), made up of the reworked Archean craton margin (*sit* in Fig. 11), the Paleoproterozoic foreland basins of supracrustal rocks and associated granitoids (e.g. Konse and Ndembera Groups), and thrust-transported and obducted ophiolites and eclogites (Collins et al., 2004; *usd* in Figs. 8 and 11); 2) the Central Tectonic Zone, including the Western Granulites (e.g. Fritz et al., 2009; Hepworth, 1972), the Central Tectonic Block (Muhongo et al., 2001), the Central Domain (Johnson et al., 2003), made up of extensive paragneissic-migmatite and mafic-amphibolitic gneisses and granulites, charnockites, enderbites and gneissic granitoids with intense deformational fabric trending N–S (i.e. Mbulu–Masai and Usagara–Usambara Superterranes; Fig. 11). These superterranes are separated by the transverse, E–W-trending Kilindi–Handeni Superterrane, made up of extensive amphibolite-facies greenstone belts in undifferentiated gneisses (Figs. 8 and 11); and 3) the Eastern Granulite Zone, including the Eastern Granulites, Outer Tectonic Zone, Eastern Granulite Domain (Fritz et al., 2009; Johnson et al., 2003; Möller et al., 2000; Sommer et al., 2005, and references therein). This zone is referred to as the Uluguru–Pare Superterrane (Kabete et al., 2008), comprising N–S-trending curvilinear arcs of exhumed high-pressure mafic granulites and anorthosites overlain by paragneisses, tightly folded marbles and quartzite, calc-silicates and mafic–ultramafic rocks (e.g. Muhongo, 1994). Some of the marbles and schist were thrust-transported on to the Central Tectonic Zone (Figs. 8 and 11).

The overall geometry of the tectonic zones, which make up the Southern East African Orogen constitutes a Basin-and-Range setting in the sense of Hyndman et al. (2005), with the Central Tectonic

Zone comprising relatively mobile crustal blocks bounded by strongly competent lithosphere of the Tanzania Craton and an unconstrained craton forming the basement to the Eastern Granulite Zone (Figs. 8 and 11). The geologic–tectonic setting of the Kilindi–Handeni Superterrane is reviewed below.

6.2.2. Kilindi–Handeni Superterrane

The Kilindi–Handeni Superterrane comprises the E–W-trending Mkurumu–Magamba, Songe and Ukaguru Terranes (Fig. 11), among which, the Ukaguru Terrane has been the focus of significant academic studies (e.g. Collins et al., 2004; Cutten et al., 2006; Johnson et al., 2003; Sommer et al., 2005). Fewer studies have been conducted in the Mkurumu–Magamba and Songe Terranes. In the Ukaguru Terrane, extensive batholiths of ~2700 Ma charnockite and enderbitic granitoids are juxtaposed against relatively thin belts of ~2863–2700 Ma amphibolite and garnet-biotite quartzo-feldspathic gneisses recording a ~2640 Ma age of greenschist–amphibolite facies metamorphism (Johnson et al., 2003). These ages are within the ~2670–2630 Ma age window for the emplacement, deformation and metamorphic resetting events dated from a precursor to a ~2670 Ma biotite-quartzo-feldspathic orthogneiss in the Mkurumu–Magamba Terrane (Kabete et al., 2008: Fig. 18F).

Field mapping and petrographic studies from the Mkurumu–Magamba Terrane reveal restricted zones of greenstone and quartzo-feldspathic rocks with overprints of randomly oriented overgrowths of tremolitic–actinolitic and anthophyllite amphiboles, kyanite and garnet on to early-formed deformation-metamorphic fabrics (Fig. 18E, F). There is an unconstrained spatial association between these metamorphic overgrowths and the gold mineralization at Mkurumu, Negero and Magambazi. This association is probably a consequence of superterrane-scale thermal metamorphism restricted to the Mkurumu–Magamba Terrane, a hypothesis further supported by the absence of a ~620–560 Ma tectonothermal overprint in the Ukaguru Terrane (Johnson et al., 2003).

6.2.3. Mkurumu–Magamba Terrane

Four tectonic domains make up the Mkurumu–Magamba Terrane: 1) the Malimongo–Kwamba Domain (*mkd*) comprising extensive mafic gneissic granulites and rafts of E–W-trending quartzite, schist and meta-pelitic rocks; 2) the Ngeze–Mkurumu Domain (*nmd*) of upright to isoclinally folded amphibolite–granulite facies supracrustal rocks juxtaposed against and wrapped around elongate domal-shaped biotite-orthogneisses, migmatitic gneisses and enderbitic–charnockitic granitoids (Fig. 15). These proto-Archean domains are bounded by ENE–SSW- to E–W-trending shear zones, with some as bedding-parallel lithotectonic boundaries (Figs. 11 and 15); 3) the Handeni–Wami Domain (*hwd*) comprising alternate, NW–SE-trending amphibolitic gneisses and granulites, biotite orthogneisses and granulitic-gneisses (Figs. 11 and 16); and 4) the Kwamkono Domain (*kmd*) with tightly folded and faulted mafic–ultramafic schist and gneisses in undifferentiated orthogneisses (i.e. eastern part of Fig. 11). There are also thrust slices of granulites derived from the Neoproterozoic Eastern Granulite Zone, emplaced on to the Central Tectonic Zone (Fig. 11). Late-kinematic, E–W to ENE–WSW strike-slip bedding-parallel shear movements and widely spaced NW-, N–S- to NE–SW-oriented buckling-related faults and shear zones are likely to have developed late as a result of compressional and transpressional tectonic events. However, some of the N–S to NNE-trending faults are probable suture zones (e.g. Shackleton, 1996), bounding individual domains in the terrane (Fig. 11).

There is an increase in the intensity of the overprint of deformation-metamorphic fabrics from west to east in the Mkurumu–Magamba Terrane. The western part preserves very strong evidence for the E–W-trending lithotectonic boundaries and associated bedding-parallel shear zones, which is typical of granitoid-greenstone belts in the Tanzania Craton (Figs. 11 and 15). These are overprinted by relatively weak partial melting (thermal overprints), as is demonstrated by poorly evolved garnet–amphibolite gneisses, and the lack of pegmatoidal veins in the Mkurumu–Libabala Belt. In the eastern part of the terrane, the E–W-trending lithotectonic features are strongly overprinted by NW–SE-trending deformational-metamorphic fabrics, and there are wide domains of garnet-amphibolite gneisses and graphitic pegmatoidal veins, all suggesting a high thermal gradient. Evidence for strong thermal overprints is derived from the descriptions of partial melts of proto-Archean amphibolitic rocks, comprising well-evolved low-strain zones represented by silica-flooded garnet-amphibolite (Fig. 18G, H), pegmatoidal graphitic zones, and a high density of pegmatoidal and aplite dykes, in undifferentiated biotite gneisses in the Magamba–Manga Belt (Fig. 16).

In summary, the overall geometry of the granitoid gneiss-greenstone domains in the Southern East African Orogen is due to buckling-related fragmentation of the E–W-trending gneissic-amphibolite domains following E–W compressive and NW–SE-directed transpressive tectonics (e.g. Shackleton, 1996; Fig. 2).

7. Gold endowment

The gold mining industry in Tanzania has grown very quickly, emerging as the major contributor to the economic growth of the country since 1998 (e.g. Van Straaten, 1984; SADC, 2001; Kabete, 2004; Massola, 2004). However, all major gold deposits have so far been discovered in the Lake Victoria Region. The region is typified by greenschist–lower-amphibolite facies greenstone belts, empirically known for hosting world-class, mesozonal, orogenic gold deposits (Goldfarb et al., 2001). Since the discovery of the Buzwagi gold deposit in 2002, there has been no further major discoveries in Tanzania. This situation has prompted some to suggest that Tanzania is mature in terms of gold exploration. In this study, new terrane-based subdivisions, and the tectonic–metallogenic framework of individual crustal blocks which make up the Tanzania Craton, are used to explain the known gold endowment and propose alternative exploration targets in what is still a prospective country. The study utilises the understanding of the Sanza–Geita Gold Camp in the Sukumaland Province to assess the gold endowment of the other parts of the Lake Victoria Region. The outcome of the review is compared and contrasted with similar controlling factors established from apparently poorly endowed districts from the Dodoma Basement Goldfields, Central Tanzania Region and Kilindi–Handeni Goldfields in the Southern East African Orogen.

7.1. Lake Victoria Region

Although the Lake Victoria Region contains a significant number of gold deposits with >50 t gold-endowment (Table 1; Kabete, 2004; Massola, 2004), they are not all reviewed here (e.g. Paulsen et al., 1991; SADC, 2001). This is because the majority of these deposits are hosted by terranes with poor understanding of their tectonic evolution histories due to lack of detailed geology and robust geochronology (e.g. Chamberlain and Tosdal, 2007; Manya et al., 2006; Wirth et al., 2004). As such, they do not warrant global comparison with similar deposit styles from well-researched terranes. Rather, the ~900 t Au Nyamulilima–Samena, Sanza–Geita and Kukuluma–Matandani Gold Camps (Fig. 12), collectively referred to as the Geita Gold Camp, are briefly described as they are well constrained. Their review has implications not only for understanding of what controlled deposition of very-large gold deposits within the Biharamulo–Geita District, but whether there are similar proxies to domain-scale controlling factors (e.g. geometrical orientation), that can be constrained and thus used to target new areas from the Sukumaland Province and Lake Nyanza Goldfields (Fig. 2). In summary, this section seeks to explain whether the lack of new discoveries in the Lake Victoria Region is due to outdated targeting techniques, inadequate exploration and research, or maturity and/or infertility of the prospective hosting domains.

7.2. Sanza–Geita Gold Camp

7.2.1. Crustal growth

The Sanza–Geita Gold Camp contains a high percentage of the ~1600 t Au endowment of the Sukumaland Province, and constitutes among the world's top gold camps (Goldfarb et al., 2001: deposits 7 and 11 in Fig. 9). Crustal addition, including accumulation of basal mafic and sub-ordinate ultramafic rocks in the inner arc of the Sukumaland Terrane, occurred between ~2843 Ma and 2812 Ma (Table 3), in what Manya and Maboko (2003) assign to a back-arc setting. This event was followed by the accumulation of the upper sequences of felsic volcanic–sedimentary rocks between ~2710 Ma and 2695 Ma, concurrent with protracted emplacement of late- to post-kinematic felsic granitoids between ~2671 and 2642 Ma (Table 3; Fig. 19). Unique lithologic associations, complex domain-scale deformation histories and resultant geometrical orientations in the Sanza–Geita Domain (Fig. 12) and other specific parts of the terrane, such as the Bulyanhulu–Busulwangili and Siga–Mabale Domains (Borg, 1992; Chamberlain, 2003; Chamberlain et al., 2004; Mbuya, 2003; Wellmer and Borg, 1992), contributed significantly to the endowment of the respective camps. The geologic–tectonic setting of the Sanza–Geita Camp is briefly described below.

7.2.2. Geological description, Sanza–Geita Gold Camp

At least 70% of the gold-endowment of the Biharamulo–Geita District is from the giant ENE–WSW-trending Nyankanga–Lone Cone–Geita deposits in the Sanza–Geita Gold Camp, which is part of the Geita Domains. The overall geology of the Biharamulo–Geita District comprises E–W-trending greenstone belts, and variably distributed late-kinematic felsic granites, bounded by WNW–ESE-trending migmatitic-granitoid gneiss domains to the north and south. The gold-endowed Geita Domain is underlain by extensive greenstone rocks of diverse lithologic types, rheology and chemical reactivity, and a high density of linear, E–W- and NW–SE-trending felsic granitoids. The bounding gneisses and granitoids in the Biharamulo–Geita District are cut by strong, NW–SE-trending, sinistral-strike slip shear zones bounding ENE–WSW-trending curvilinear thrust faults and associated shear-foliated quartz veins, and N–S-trending extensional quartz veins, consistent with the deformation history proposed in Fig. 13. Gold-endowment of the Geita Domain (Table 1) is explained below in terms of superterrane to domain-scale controlling factors.

7.2.3. Superterrane-scale controlling factors, Sanza–Geita Gold Camp

The most important superterrane-scale controlling factors include: 1) a late NW-to-SE compressional stress regime (e.g. Bansah et al., 2000; Groves, 2010). This event extended the crust underlying the Sukumaland Terrane, and reactivated structures, which were formed early in the basement, including NW–SE-trending through-going shear zones and major lithotectonic boundaries. The event extended the crust, allowing extensive emplacement of NW–SE-trending felsic granitoids (Figs. 12 and 13); and 2) the presence of ~2686 ± 13 Ma lamprophyre dykes (Bansah et al., 2000) which imply deep melting of subduction-modified mantle due to a thermal anomaly (Rock and Groves, 1988; Rock et al., 1990). The fact that these lamprophyre rocks are deformed supports their earlier intrusion via extensional structures (i.e. $\sigma 1$-D2: Fig. 13).

7.2.4. Terrane-scale controlling factors, Sanza–Geita Gold Camp

The main controlling factors at terrane-scale include extensive thicknesses of the diverse greenstone rocks and preferential intrusion of the dioritic magma in the Sanza–Geita Camp. These greenstone rocks and dioritic bodies are bounded by first-order structures including extensional zones, via which internal felsic granitoids intruded the domain. Multiple intrusions from early basic magma to syn- and late-kinematic emplacement of felsic granitoids implies deep-seated structures and shallow heat supply, which are responsible for the anomalously high gold endowment.

7.2.5. Domain-scale controlling factors

There is probably a transition between domain and terrane-scale controls on the gold endowment of the Geita Gold Camps. This is because the arc-magmatic and volcanic-sedimentary domains in the ENE–WSW-trending Sanza–Geita Domain are at a high angle to the NW–SE-direction of maximum compression at the time of gold mineralization (Groves, 2010; Nugus et al., 2011). The domain comprises complexly deformed BIFs and diorite, which are described by Nugus et al. (2011) as thrust–ramp belts splaying off the NW–SE-trending bounding faults and shear zones. The domain comprises extensive dioritic intrusive rocks and associated trachyandesite dykes (Borg and Krogh, 1999), with numerous rafts and xenoliths of BIF. In contrast, the NW–SE-trending Kukuluma–Matandani Domain comprises regional fold belts of BIFs and deep-basin pelitic-sedimentary and volcanic sedimentary rocks with insignificant dioritic intrusions. In the NW–SE-trending Nyamulilima–Samena Domain, upright folded BIFs and felsic volcanic rocks contain significant intrusions of quartz-feldspar porphyries and preserve tilted dome-basin and/or synformal–antiformal geometries. The three domains which make up the Geita Domains are sutured by NW–SE-trending through-going shear zones (Fig. 12).

Among these domains, the Sanza–Geita Domain is highly gold endowed due to anomalously reactive lithologic units, including complexly folded and faulted oxide- and silicate-facies BIFs and extensive diorite intrusions in that specific corridor (e.g. Bansah et al., 2000; Nugus et al., 2011). The BIFs and dioritic rocks constitute trap rocks that are overlain by thick sequences of relatively impermeable, felsic volcanic–pelitic and tuffaceous rocks which sealed further migration of the hydrothermal fluids, thus ensuring an extended interaction with Fe-rich trap rocks. The ENE–WSW-trending lithologic units of diverse competence and chemical reactivity, failed during deformation in a progressive NW-to-SE maximum compressive stress regime, allowing selective ingress of gold-rich hydrothermal fluids to depositional sites (e.g. Groves et al., 2000: Figs. 4 and 5).

7.2.6. Summary, Sanza–Geita Gold Camp

In summary, there are links between distinctive features of individual domains to terranes and high gold-endowment in the different camps that comprise the Geita Gold Camps. In the Sanza–Geita Camp, for example, important terrane- to domain-scale controlling factors on effective gold deposition include: 1) preferential restriction of E–W-trending arc-magmatic sedimentary rocks against arc–continent terranes largely made up of granitoids and gneisses; 2) preferred geometrical re-orientation of greenstone sequences to favourable ENE to WSW-trending belts bounded by curvilinear faults at high-angles to the direction of maximum shortening (e.g. Fig. 13); 3) NE–SW-trending lithospheric-scale faults, comprising basement structures, as indicated by their multiple reactivation during different Proterozoic times and their exploitation by Paleozoic mafic dykes (e.g. Borg, 1994), which formed deep fluid-tapping structures (Figs. 12 and 13); 4) lithospheric-scale volumes of auriferous hydrothermal fluids which were focused in favourable domain-scale, structurally permeable, Fe-rich, and chemically reactive BIFs and diorite; 5) extensive thickness of impermeable rock sequences of pelitic-sedimentary and volcanic rocks to cap the hydrothermal system; and 6) a high density of felsic granitoids that helped provide the high heat flux required to maintain the hydrothermal fluid systems (Fig. 12).

7.2.7. Age of gold metallogeny, Sanza–Geita Camp

Although there have been many studies on the Sukumaland Gold Province (Bell and Dodson, 1981; Borg and Krogh, 1999; Borg and Shackleton, 1997; Chamberlain and Tosdal, 2007; Manya and Maboko, 2003; Cloutier et al., 2005; Manya et al. 2003; Walraven et al., 1994), the precise timing of gold mineralization in the Province is still poorly constrained. Before the most recent U–Pb SHRIMP geochronology from the Sukumaland Terrane (e.g. Chamberlain and Tosdal, 2007), Borg

Table 3
Available robust isotopic ages from Lake Nyanza Goldfields in the Lake Victoria Region of Tanzania.

Terrane	Belt	Dated feature	Age ± 2δ (Ma)	Method (zircons)	Interpretation	Reference
Sukumaland	Sarama–Rwamagaza	Volcanic	2821 ± 30	U–Pb SHRIMP	Volcanism(pyroclastic tuff)	Chamberlain and Tosdal (2007)
Sukumaland	Siga–Mabale	Felsic	2779 ± 13	U–Pb SHRIMP	Volcanism(pyroclastic tuff)	Chamberlain and Tosdal (2007)
Sukumaland	Siga–Mabale	Rhyolite	2770 ± 9	U–Pb SHRIMP	Volcanism(pyroclastic tuff)	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Diorite	2758 ± 7	U–Pb SHRIMP	magmatism	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Diorite	2758 ± 6	U–Pb SHRIMP	magmatism	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Diorite	2743 ± 14	U–Pb SHRIMP	magmatism	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Gabbro	2743 ± 12	U–Pb SHRIMP	magmatism	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Tonalite	2738 ± 9	U–Pb SHRIMP	magmatism	Chamberlain and Tosdal (2007)
Sukumaland	Bulyanhulu–Ushirombo	Dacite	2719 ± 16	U–Pb SHRIMP	Volcanism(pyroclastic tuff)	Chamberlain and Tosdal (2007)
Sukumaland	Bulyanhulu–Ushirombo	Porphyry dyke	2710 ± 20	U–Pb SHRIMP	Volcanism (minimum)	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	BIF-Sedimentary rock	2702 ± 8	U–Pb SHRIMP	Provenance	Chamberlain and Tosdal (2007)
Sukumaland	Siga–Mabale	Porphyry dyke	2700–3100	U–Pb SHRIMP	Provenance	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Gneiss	2698 ± 12	U–Pb SHRIMP	deformation	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Quartz porphyry	2697 ± 10	U–Pb SHRIMP	Volcanism (minimum)	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Quartz–feldspar porphyry	2695 ± 18	U–Pb SHRIMP	Volcanism (minimum)	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Lamprophyre	2686 ± 13	U–Pb SHRIMP	Au mineralization (minimum)	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Feldspar dyke	2670 ± 21	U–Pb SHRIMP	Volcanism (minimum	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Porphyry dyke	2667 ± 14	U–Pb SHRIMP	Volcanism (minimum	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita	Granitoid	2666 ± 8	U–Pb SHRIMP	deformation	Chamberlain and Tosdal (2007)
Sukumaland	Bulyanhulu–Ushirombo	Sandstone	2659 ± 41	U–Pb SHRIMP	Provenance	Chamberlain and Tosdal (2007)
Sukumaland	Siga–Mabale Belt	Granodiorite	2653 ± 10	U–Pb SHRIMP	magmatism	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita (S. Geita)	Quartzite	2650–2700	U–Pb SHRIMP	Provenance	Chamberlain and Tosdal (2007)
Sukumaland	Biharamulo–Geita (N. Geita)	Sandstone	2650–2700	U–Pb SHRIMP	Provenance	Chamberlain and Tosdal (2007)
Sukumaland	Bulyanhulu–Ushirombo	Granitoid	2646 ± 14	U–Pb SHRIMP	magmatism	Chamberlain and Tosdal (2007)
Sukumaland	Sarama–Rwamagaza	Tonalite	2567 ± 10	U–Pb SHRIMP	magmatism	Chamberlain and Tosdal (2007)
Sukumaland	Siga–Mabale	Rhyolite	2808 ± 3	U–Pb conventional	Volcanism(pyroclastic tuff)	Borg and Krogh (1999)
Sukumaland	Siga–Mabale	Rhyolite	2780 ± 3	U–Pb conventional	Volcanism(pyroclastic tuff)	Borg and Krogh (1999)
Sukumaland	Biharamulo–Geita	Diorite	2699 ± 9	U–Pb conventional	magmatism	Borg and Krogh (1999)
Sukumaland	Siga–Mabale	Rhyolite	2654 ± 15	U–Pb conventional	Volcanism(pyroclastic tuff)	Borg and Krogh (1999)
Sukumaland	Biharamulo–Geita	Lamprophyre	2644 ± 3	U–Pb conventional	Deformation (minimum)	Borg and Krogh (1999)
Nzega–Sekenke	Iramba Sekenke	Diorite	2751 ± 17	U–Pb SHRIMP	Magmatism	Chamberlain and Tosdal (2007)
Nzega–Sekenke	Kahama–Nyanza	Rhyolite	2725 ± 22	U–Pb SHRIMP	Volcanism(pyroclastic tuff)	Chamberlain and Tosdal (2007)
Nzega–Sekenke	Manonga Gneissic	Rhyolite	2717 ± 10	U–Pb SHRIMP	Volcanism(pyroclastic tuff)	Chamberlain and Tosdal (2007)
Nzega–Sekenke	Nzega	Dacite	2695 ± 12	U–Pb SHRIMP	Volcanism(pyroclastic tuff)	Chamberlain and Tosdal (2007)
Nzega–Sekenke	Nzega	Porphyry dyke	2680 ± 13	U–Pb SHRIMP	Volcanism (minimum)	Chamberlain and Tosdal (2007)
Nzega–Sekenke	Nzega	Sandstone	2655–3100	U–Pb SHRIMP	Provenance	Chamberlain and Tosdal (2007)
Nzega–Sekenke	Nzega	Granodiorite	2655 ± 16	U–Pb SHRIMP	Magmatism	Chamberlain and Tosdal (2007)
Kahama–Mwadui	Kahama–Nyanza	Tonalite	2765 ± 25	U–Pb SHRIMP	Magmatism	Chamberlain and Tosdal (2007)
Kahama–Mwadui	Kahama–Nyanza	Granitoid	2680 ± 9	U–Pb SHRIMP	Magmatism	Chamberlain and Tosdal (2007)
Kahama–Mwadui	Kahama–Nyanza	Granitoid	2656 ± 11	U–Pb SHRIMP	Magmatism	Chamberlain and Tosdal (2007)
Kaniha–Tinde	Mwime–Tinde	Migmatitic gneiss	2680 ± 3 Ma	U–Pb conventional	Deformation	Borg and Krogh (1999)

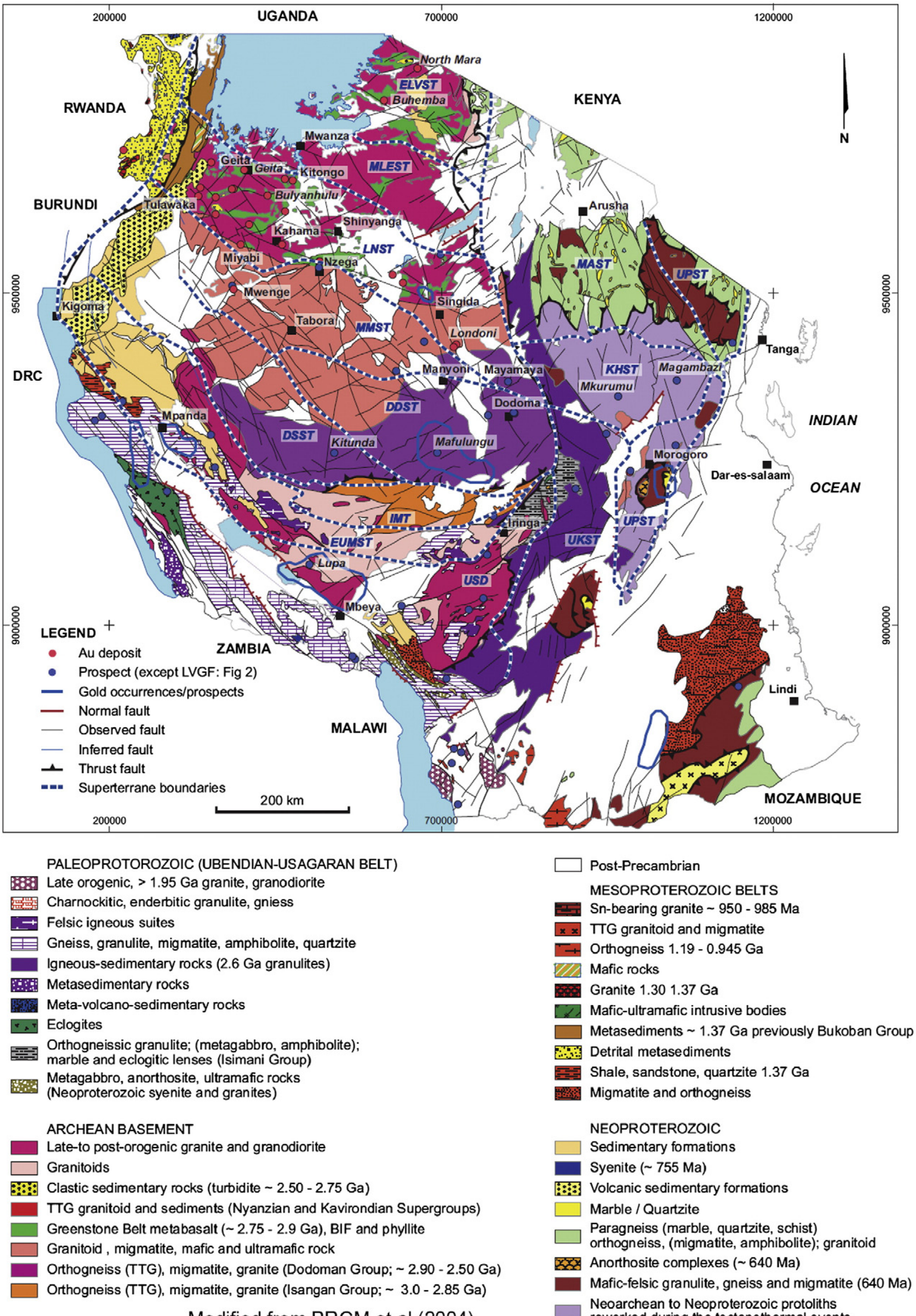


Fig. 5. Regional geologic map of Tanzania (BRGM et al., 2004), showing >1 t Au deposits and superterrane boundaries suggested in this paper (e.g. Figs. 6–8).

Table 4
Selected assay results of the rock chips taken from Mazoka Domain, Undewa–Ilangali Terrane.

Sample number	g/t Au assay	Description
61166	0.227	Silicified meta-volcanic rock.
61122	0.394	3-m of bleached and silicified andesite with stringers of quartz and strong hematite staining.
61102	1.255	Vein quartz impregnations in sericite-altered meta-volcanic rock.
61117	0.542	Strongly silicified sheared basaltic-andesite, fracture filling and blebby pyrite with minor component on arsenopyrite. Sulphides about 10–15%.
61110	0.508	Laminated quartz veins impregnated in sericite and potassic altered basaltic-andesite.
61114	0.958	Thinly laminated quartz stringers in strongly sericite-altered volcanic rock with about 10–15% arsenopyrite and blebby/ disseminated pyrite.
61115	0.773	Chlorite-altered and silicified basaltic-andesite with about 7–10% fracture filling and disseminated arsenopyrite and pyrite.
61116	0.108	Shear-foliated basaltic-andesite with quartz laminations; fracture filling pyrite and arsenopyrite.
61118	>10.00	About 5 m of strongly shear-laminated quartz vein in sericite groundmass with fracture filling and blebby pyrite and needles of arsenopyrite about 10–15%.
61108	0.672	About 1 m of strongly sheared and quartz impregnated and chlorite-altered basaltic-andesite with strong hematite staining.
JK-12D	7.91	About 2 m wide mylonite zone comprising laminated quartz veins in sericitic groundmass.
JK-13A	1.95	Rock chips of a strongly sheared, chlorite–epidote altered andesite with high-density of quartz stringers. Pyrite and pyrrhotite as disseminations and fracture-filling.
JK-12C	2.44	Shear-foliated and silicified biotite–quartz feldspar schist situated near a mylonite zone.

and Krogh (1999) suggested that gold was deposited soon after the emplacement of the deformed and gold-hosting lamprophyre dykes at 2644 ± 3 Ma (U–Pb conventional zircon age) in the Geita Domain. Later dating on zircons extracted by Chamberlain and Tosdal (2007) from a similar dyke produced a U–Pb SHRIMP age of 2686 ± 13 Ma, which, when interpreted in concert with ages for the peak of deformation of 2698 ± 12 Ma and 2666 ± 3 Ma from the Sukumaland Province (Table 3), place the age window for the gold mineralizing event(s) between 2692 and 2632 Ma.

In the Geita Gold Camps, diorite and BIFs constitute major host rocks that were emplaced and/or accumulated between ~2747 and 2687 Ma, some 80–20 m.y. before the ~2673–2662 Ma gold mineralization events. That event is within the ~2692–2632 Ma age window for the gold mineralization events in the entire Biharamulo–Geita Gold District. The absence of zircon xenocrysts with ages of >3.0 Ga in host rocks further implies rapid juvenile crustal growth which did not incorporate older continental crustal material. According to Bierlein et al. (2006), Bierlein et al. (2009) and Groves (2009), rapid growth is related to effective deposition of very-large orogenic gold deposits as it implies thin lithosphere and high heat flux.

7.3. Central Tanzania Region

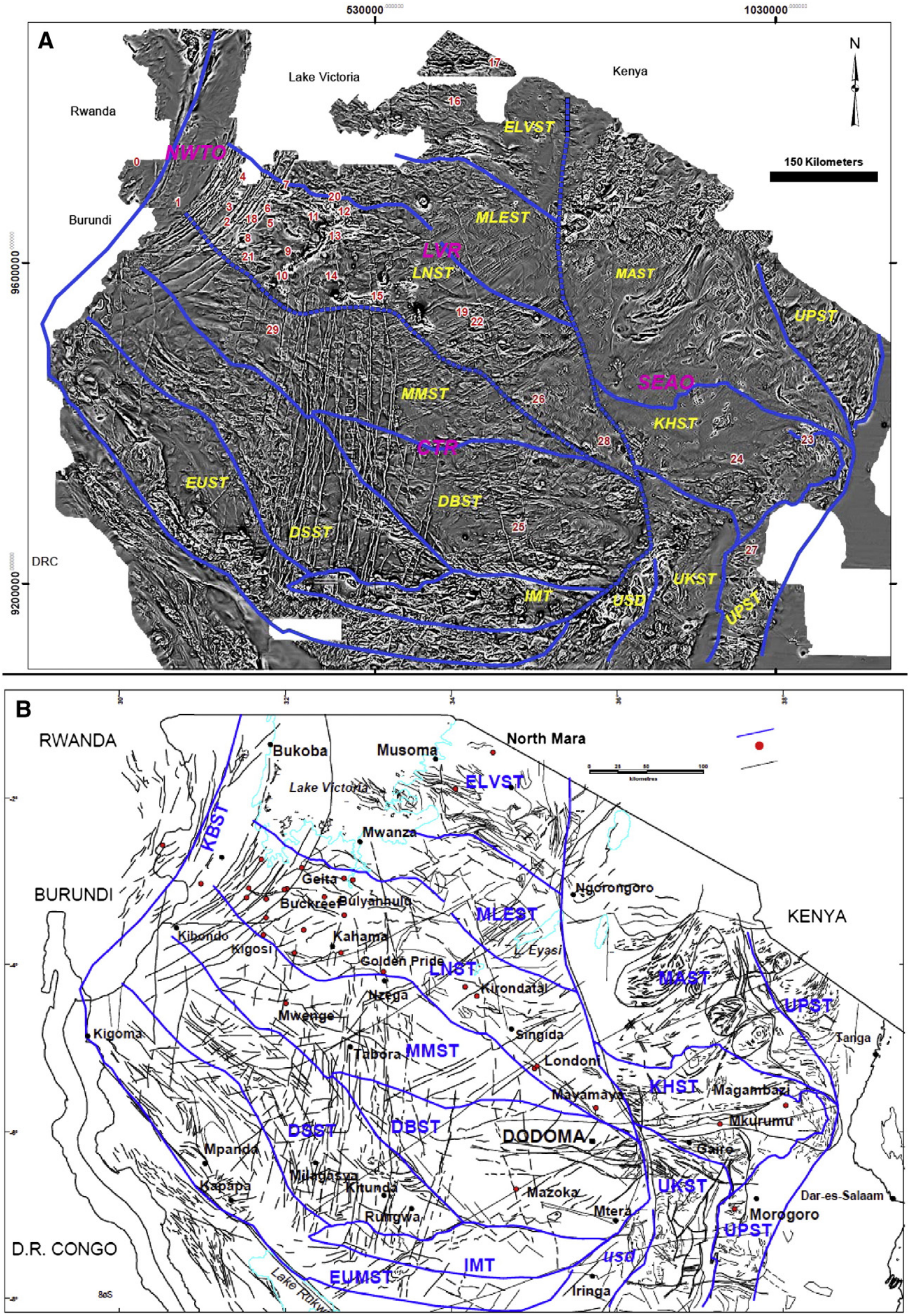
In contrast to greenschist-facies terranes, which are typical of the Lake Victoria Region, and host mesozonal orogenic gold deposits, amphibolites-facies terranes which make up large parts of the Central Tanzania Region are more commonly host to hypozonal gold systems (Groves et al., 2003; Kisters et al., 1998). The latter are normally relatively small, hosted by interlaminations of quartz veins in wide ductile shear zones, and are likely to be buried at deeper crustal levels in the majority of Archean, Paleoproterozoic and Neoproterozoic shields. However, in orogenic mobile belts, tectonic collision, uplift and erosion may have uplifted these hypozonal gold systems close to the surface (e.g. such as the Southern East African Orogen: see Section 7.4). Under some circumstances, mesozonal gold systems may have survived tectonic exhumation and erosion in zones where there has been juxtaposition of juvenile crustal rocks against, or within, high-grade metamorphic belts during orogeny (Goldfarb and Groves, 2011). The Mazoka Domain and associated gold mineralized systems in the ~2815–2660 Ma juvenile greenschist–amphibolite facies greenstone belts are juxtaposed and/or confined within >3140 Ma high-grade metamorphic belts of the Undewa–Ilangali Province (Fig. 3; QDS 176 and 177). These juvenile granitoid-greenstone belts are hypothesised to have survived tectonic erosion in the Central Tanzania Orogen.

Three, relatively small-scale, but significant, orogenic gold systems are described from the Central Tanzania Region in order to establish the background for a review of gold endowment. They are: 1) Mwenge in the Moyowosi–Manyoni Goldfields (Figs. 8 and 14); 2) Madengi Hills (near Dodoma: Williams, 1936; Barth et al., 1996; QDS 162) and Mafulungu (QDS 178; Barth et al., 1996) in the Dodoma Basement Goldfields (Figs. 3 and 8; Kabete, 2008); and 3) Kitunda in the Dodoma Schist Goldfields (QDS 174; Fig. 10), comprising hypozonal gold systems hosted by mafic-amphibolite and/or granitoid-gneisses. These are briefly described in Section 7.4.1 to highlight their diagnostic features, which can be used as proxies for targeting large-scale gold systems in the region. In contrast, gold systems in the Mazoka Domain are described separately in Section 7.4.2, as a representative of potential mesozonal orogenic gold systems preserved in the Central Tanzania Region.

7.3.1. Small-scale orogenic gold prospects, Central Tanzania Region

Gold mineralization at Mwenge in the Moyowosi–Uyowa Province, Moyowosi–Manyoni Goldfields (Fig. 8), is hosted by multiple interbands of <1 m thick laminated quartz veins in wide zones of shear-foliated amphibole–biotite granitoid gneisses (Fig. 14A). These gold-hosting lithostructures originally covered by transported and in situ regolith (QDS 77, 78) were exposed by small-scale miners in 2000. Pit mapping and subsequent reverse circulation drilling by Ashanti Exploration Tanzania Limited (AETL) in 2002 outlined a ~500 m long by 150 m wide block comprising E–W-trending deformed and altered biotite–amphibole granitoid gneisses with relatively thin units of shear-foliated mafic amphibolite (Fig. 14A). Gold-hosting multiple shear zones at Mwenge trend ENE–WSW and are composed of discrete shear zones with intense potassic, silica and pyrite alteration haloes, which are proximal to, and in places within, high grade gold-bearing quartz veins, stringers and shear-laminated sulfidized zones. The best results from AETL's drilling program, include 6 m at 7.0 to

Fig. 6. Re-processed and filtered country-wide grey-scale aeromagnetic imagery used to interpret structural grains characteristic of the bedrocks underlying the Precambrian Shield of Tanzania. These lineaments are used to interpret the lithostructural framework in contiguous crustal blocks (superterranes and terranes). For abbreviations see Fig. 1. Specific names of gold deposits and occurrences are randomly listed because the major aim is to highlight their concentration in the Lake Nyanza Superterrane, in contrast to other crustal blocks. Gold deposits and occurrences shown include: 0) Mumwendo; 1) Lusahunga; 2) Tulawaka; 3) Matabe; 4) Sheba; 5) Buckreef; 6) Rwamagaza; 7) Geita; 8) Ushirombo; 9) Nyakafuru; 10) Miyabi; 11) Bulyanhulu; 12) Kitongo; 13) Golden Ridge; 14) Buzwagi; 15) Golden Pride; 16) Buhemba; 17) North Mara; 18) Kakindu; 19) Sekenke; 20) Nyanzaga; 21) Kigosi; 22) Kirondatal; 23) Magambazi; 24) Mkurumu; 25) Kigosi; 26) Mazoka; 27) Morogoro; 28) Londoni; and 29) Mwenge.



A
530000
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N
150 Kilometers
Lake Victoria
Kenya
Rwanda
Burundi
DRC
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MLEST
MAST
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UPST
MMST
KHST
EUST
DBST
DSST
IMT
USD
UKST
B
RWANDA
BURUNDI
D.R. CONGO
KENYA
North Mara
Bukoba
Musoma
Lake Victoria
Mwanza
Geita
Buckreef
Bulyanhulu
Kahama
Kibondo
Kigosi
Golden Pride
Nzega
Kirondatal
Ngorongoro
Eyasi
Mwenge
Singida
Kigoma
Tabora
Londoni
Mayamaya
Magambazi
Mkurumu
Tanga
DODOMA
Gairo
Mpanda
Kapapa
Mlagasya
Kitunda
Rungwa
Mazoka
Mtera
Dar-es-Salaam
Morogoro
Iringa
Lake Rukwa
KBST
ELVST
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LNST
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KHST
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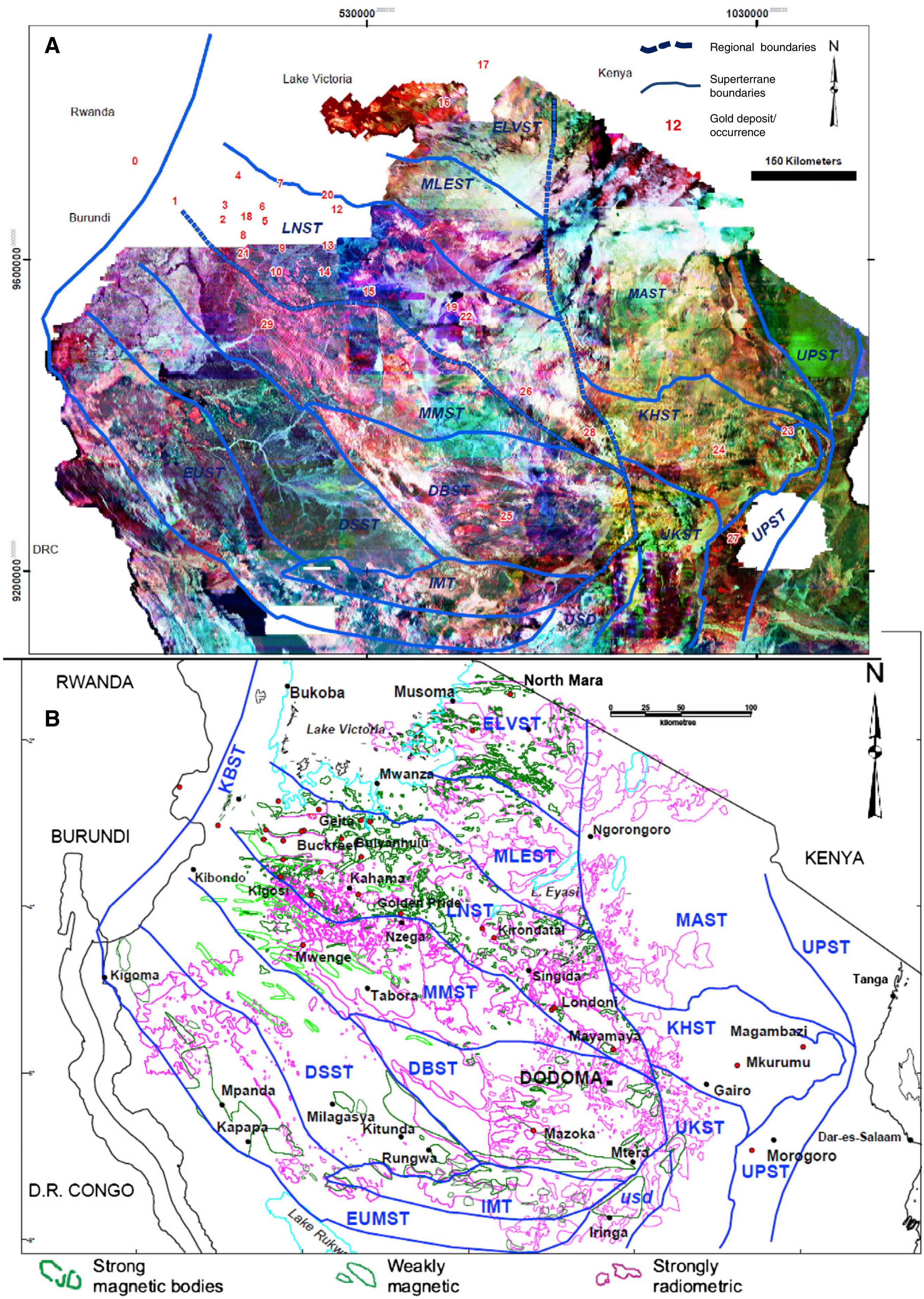
IMT
EUMST
usd


A
530000
1030000
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Regional boundaries
Superterrane boundaries
12 Gold deposit/ occurrence
N
150 Kilometers
Lake Victoria
Rwanda
Burundi
Kenya
DRC
ELVST
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MAST
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RWANDA
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KENYA
D.R. CONGO
Bukoba
Musoma
North Mara
Lake Victoria
Mwanza
Geita
Buckreef
Bulyanhulu
Kibondo
Kigosi
Kahama
Golden Pride
Nzega
Kirondatal
Ngorongoro
L. Eyasi
Mwenge
Tabora
Singida
Londoni
Kigoma
Mayamaya
Magambazi
Mkurumu
DODOMA
Gairo
Tanga
Mpanda
Kapapa
Milagasya
Kitunda
Rungwa
Mazoka
Mtera
Dar-es-Salaam
Morogoro
Iringa
Lake Rukwa
KBST
ELVST
MLEST
LNST
MAST
UPST
MMST
KHST
DSST
DBST
UKST
EUMST
IMT
usd
Strong magnetic bodies
Weakly magnetic
Strongly radiometric

19.9 g/t Au; 3 m at 4.7 g/t; and 6 m at 1.8 g/t Au, with distal-facies alteration zones returning averages between 0.2 and0.75 g/t Au over 3 to 12 m (Fig. 14A). Interpretation of the high-resolution geophysical images (GTK, 2003) in terms of pit mapping and drilling results locate Mwenge Prospect on a regional fold hinge zone of an E–W- to WNW–ESE-trending weakly magnetic unit. This unit is probably part of a relatively thick deformed mafic rock sequence associated with thin slices of mafic amphibolite intersected by the drilling (Figs. 6 and 7).

The Kitunda prospect is situated in the Malagasya–Rungwa Province, Dodoma Schist Goldfields (Fig. 8). It constitutes hypozonal gold systems comprising laminated quartz veins in amphibolite facies mafic–ultramafic greenstone rocks of the Kitunda–Rungwa Greenstone Belt (Fig. 10). These belts form part of elongate, NW–SE-trending rafts of greenstone rocks interpreted to be confined within widely extensive TTGs and related orthogneisses in the Malagasya–Rungwa Terrane (Fig. 10). This Terrane is separated from the Undewa–Ilangali and Isanga–Mtera Terranes by wide low-strain zones of NW–SE to E–W-trending pegmatoidal granite and aplitic veins and linear belts of K-feldspar granites. These tectonic breaks are defined by strong magnetic and high radiometric anomalies (Figs. 6 and 10). Reconnaissance mapping in the Kitunda–Rungwa Belt documented networks of faults and shear zones in TTGs and orthogneisses, open to inclined folds of quartz veins in mafic amphibolite, and local retrograde chlorite, talc and serpentine alteration zones in mafic–ultramafic rocks. Other alteration zones, including potassic alteration and silica-flooding and laminated quartz stringers/veins are common in shear-foliated dioritic schist. Some of these lithostructures are associated with primary gold mineralization in the belt. They either crop out intermittently and/or have been exposed by small scale miners in a zone which seem to coincide with a zone at least 1.2 km by 400 m wide of 20–45 ppb and up to 80–320 ppb gold in soil anomalies in the Kitunda–Rungwa Belt. The bedrock and associated gold in soil anomalies extend along the NNW–SSE trend into deeply weathered areas covered by black cotton soils (QDS 156 and 173).

At Mafulungu, in the Undewa–Ilangali Province, Dodoma Basement Goldfields, gold mineralization is hosted by shear-laminated quartz veins in relatively thin interbands of epidote, actinolite–tremolite and chlorite-altered mafic volcanic rocks, dolerite schist and >3.2 Ga quartz-diorite gneisses. These host rocks are bounded by ~3.60 Ga fuchsitic quartzite, granitoid-gneiss and migmatite, and by biotite-quartzo-feldspathic gneiss and biotite-amphibole granites to the north and south, respectively (Kabete, 2008). Selected channel and grab rock samples from artisanal pits at Mafulungu returned assays of between 99 g/t Au over 3 cm of vein quartz, to 2.2 m at 2.39 g/t Au and 3.75 m at 1.64 g/t Au from shear-foliated mafic volcanic rocks. Five exploratory diamond drill-holes over these and 60–200 ppb Au in soil anomalies, defined by Shanta Mining, returned good intersections, including 7.2 m at 13.44 g/t Au and 2.4 m at 11.61 g/t Au, with a defined resource of 10 t Au (Shanta, 2006).

7.3.2. Mazoka prospect, Undewa–Ilangali Province, Dodoma Basement Goldfields

The Mazoka prospect is chosen to represent the Central Tanzania Region when discussing gold endowment, solely based on its superior domain-scale geology relative to other greenstone-hosted orogenic gold systems. Gold mineralization at Mazoka is hosted by up to 7 m thick multiple zones of mylonite and protomylonite with interbands of shear-laminated quartz veins in quartz-sericite schist, representing a deformed ~2702 Ma biotite granitoid (Kabete, 2008; Table 4; Figs. 3 and 14B). Other host rocks at Mazoka include shear-foliated dolerite sills, basaltic-andesite and volcanic–sedimentary rocks with relatively thin horizons of gossans, sulfidic chert and BIFs (Fig. 18A–D). The greenstone lithologies at Mazoka contain interleaved pyroxenite, gabbro, diorite and quartz-diorite and extensive suites of ~2740 Ma syn-orogenic amphibole-granitoids (Fig. 14B). These are further bounded to the north and south by E–W-trending TTGs and their orthogneissic derivatives, and all are cross-cut by NE–SW-trending faults and felsic dykes of unconstrained emplacement ages.

7.3.2.1. Superterrane-scale controlling factors, Mazoka Prospect. At Mazoka, there are similar superterrane-scale controlling factors to those proposed above in this review. These include: 1) the geometry of the Neoarchean Mazoka-type granitoid-greenstone rocks that are bounded by extensive, >3.12 Ga TTGs and granitoid-gneisses, implying that juvenile greenstone rocks were accreted on to the orthogneissic crust along deep-seated suture zones (e.g. Fig. 8); 2) E–W-trending structures bounding extensive TTGs and syn-orogenic amphibole–granitoid belts in the Undewa–Ilangali Terrane, that are further bounded by shear-parallel lithotectonic boundaries between conformable granitoids and migmatitic gneisses and between rafts of the ~3.6 Ga fuchsitic quartzite and >3.2 Ga orthogneisses (Kabete et al., 2008). These are interpreted to represent crustal-scale lithotectonic boundaries and associated splays (Fig. 3); and 3) indirect evidence for multiple tectonic reactivation events which led to the ~620–570 Ma tectonothermal overprints recorded from ~2815 to 2702 andesitic-basalt (Kabete et al., 2008) and extensive supracrustal accumulation of Phanerozoic rocks in the Undewa–Ilangali Terrane (e.g. QDS 177).

7.3.2.2. Terrane-scale controlling factors, Mazoka Gold Camp. The confinement of the E–W-trending juvenile granitoid-greenstone belts/domains within competent units of orthogneisses and migmatites, and the variable geometrical orientations of the juvenile granitoid-greenstone domains within the Undewa–Ilangali Terrane, have controlled the selective deformation of trap rocks (Figs. 3 and 14B). Tectono-stratigraphic domains oriented at high-angles to the NE-to-SW direction of maximum shortening are favourable for effective gold deposition due to marked competency contrasts between rock types in the terrane (Figs. 3 and 10).

7.3.2.3. Domain-scale controlling factors, Mazoka Gold Camp. Depositional sites in the majority of orogenic gold systems are proximal to linear, alternately spaced misaligned corridors of juvenile granitoid-greenstone rocks bounded by first-order lithotectonic boundaries (Goldfarb et al., 2001; Groves et al., 2000). Similar geometrical settings have been mapped by Kabete (2008) in the Undewa–Ilangali Terrane (Fig. 3). In these settings, specific depositional sites are controlled by the relative orientation of the maximum direction of shortening to the orientation of the lithological units of diverse tensile strength (Fig. 14A, Table 4). The significance of the NE–SW-trending cross-faults and related compartments and/or corridors in the Undewa–Ilangali Terrane is probably similar to that described by Vearncombe (1998) and Groves et al., (2000, Fig. 4). Other lithostructural traps in the Mazoka Domain were probably created as a result of the late-kinematic sinistral reactivation of the E–W-trending lithotectonic boundaries (Fig. 3).

7.3.3. Age of gold metallogeny, Mazoka Gold Camp, Undewa–Ilangali Province

The ~2815–2702 Ma basaltic-andesite of the Mazoka Domain defines the basal part of the ~30 km long and 3 km wide greenstone belt, which evolved during protracted crustal growth events including rifting of a >3.14 Ma orthogneissic basement rocks (Kabete et al., 2008). Rifting is inferred from the bimodal nature of the volcanic rocks, with ~2740–2691 Ma felsic rocks associated with mafic–ultramafic rocks in the Mazoka Domain (Table 3).

Fig. 7. Re-processed and filtered country-wide total count radiometric imagery (A) which resulted in the interpretation of the radiometric bodies in pink (B). A combination of these strong and weak linear magnetic anomalies (green) from different aeromagnetic imageries is used in conjunction with the available geological information to develop Fig. 8.

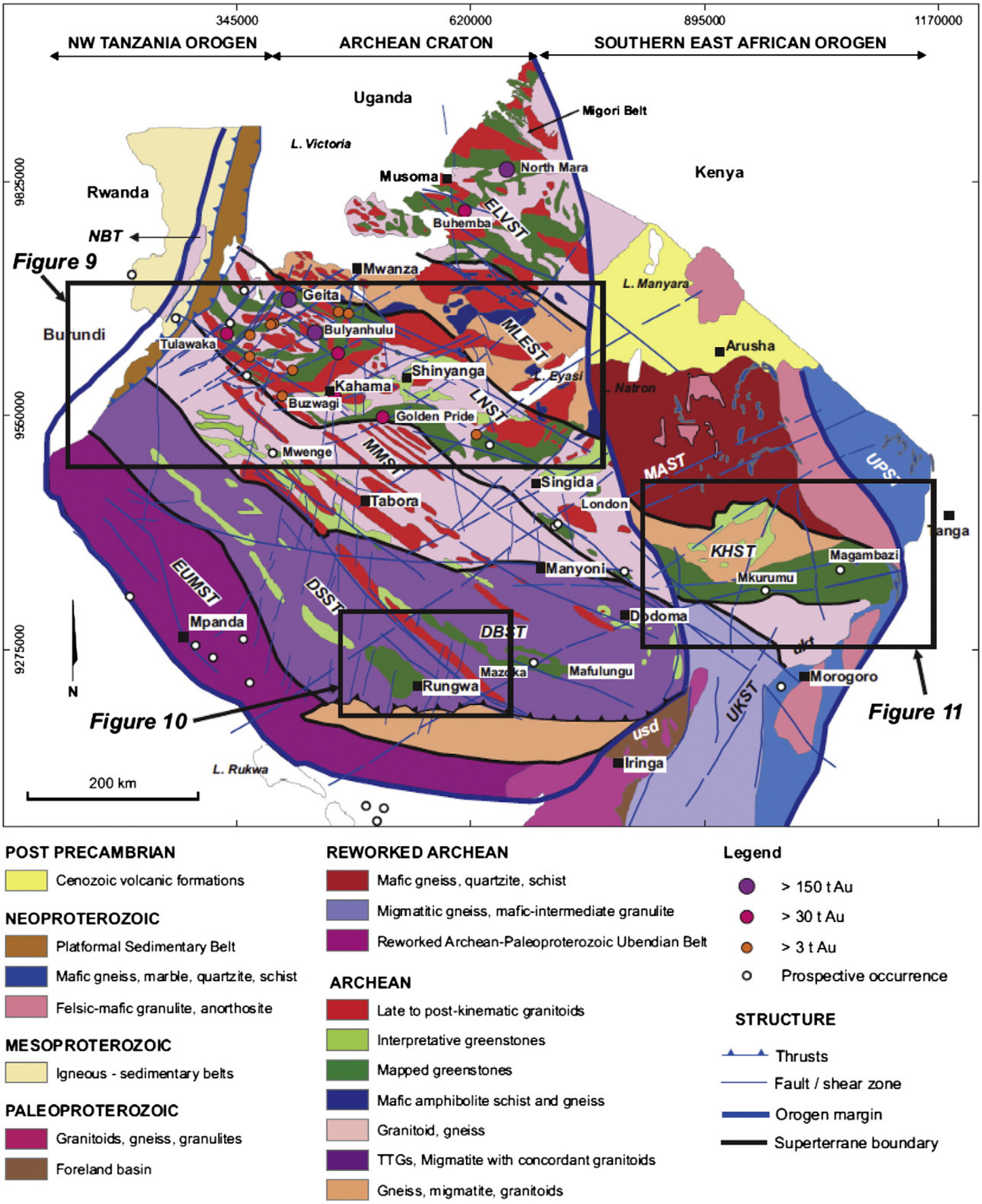


Fig. 8. Solid geological map illustrating three major lithotectonic–geologic regions and contained crustal blocks that make up the Archean Craton and selected Proterozoic Regions, namely Northwest Tanzania Orogen and Southern East African Orogen. Superterranes in respective regions include, from north to south, ELVST MLEST and LNST in the Lake Victoria Region, MMST, DSST, DBST and EUMST in the Central Tanzania Region and NBT in the NWTO and MAST, KHST and UKST in the SEO. For the superterrane acronyms please see caption of Fig. 1.

Gold mineralization at Mazoka was introduced not earlier than ~2702 Ma, the emplacement age of the protolith to sheared and gold-mineralized biotite-granitoid schist, and soon after ~2660 Ma, the resetting age of deformation and/or metasomatism from a deformed and mineralized ~2815 Ma porphyritic andesite (Kabete et al., 2008). Thus, gold mineralization in the Mazoka Gold District is constrained between ~2702 and 2660 Ma.

7.4. Southern East African Orogen, Proterozoic Tanzanian Regions

The Kilindi–Handeni Superterrane is bounded to the north and south by migmatitic–gneissic granulite terranes, which make up the Mbulu–Masai and Usagara–Usambara Superterranes (Figs. 6, 7 and 8). It contains myriads of small-scale gold prospects, including Mkurumu, Negero and Magambazi prospects, mainly hosted by

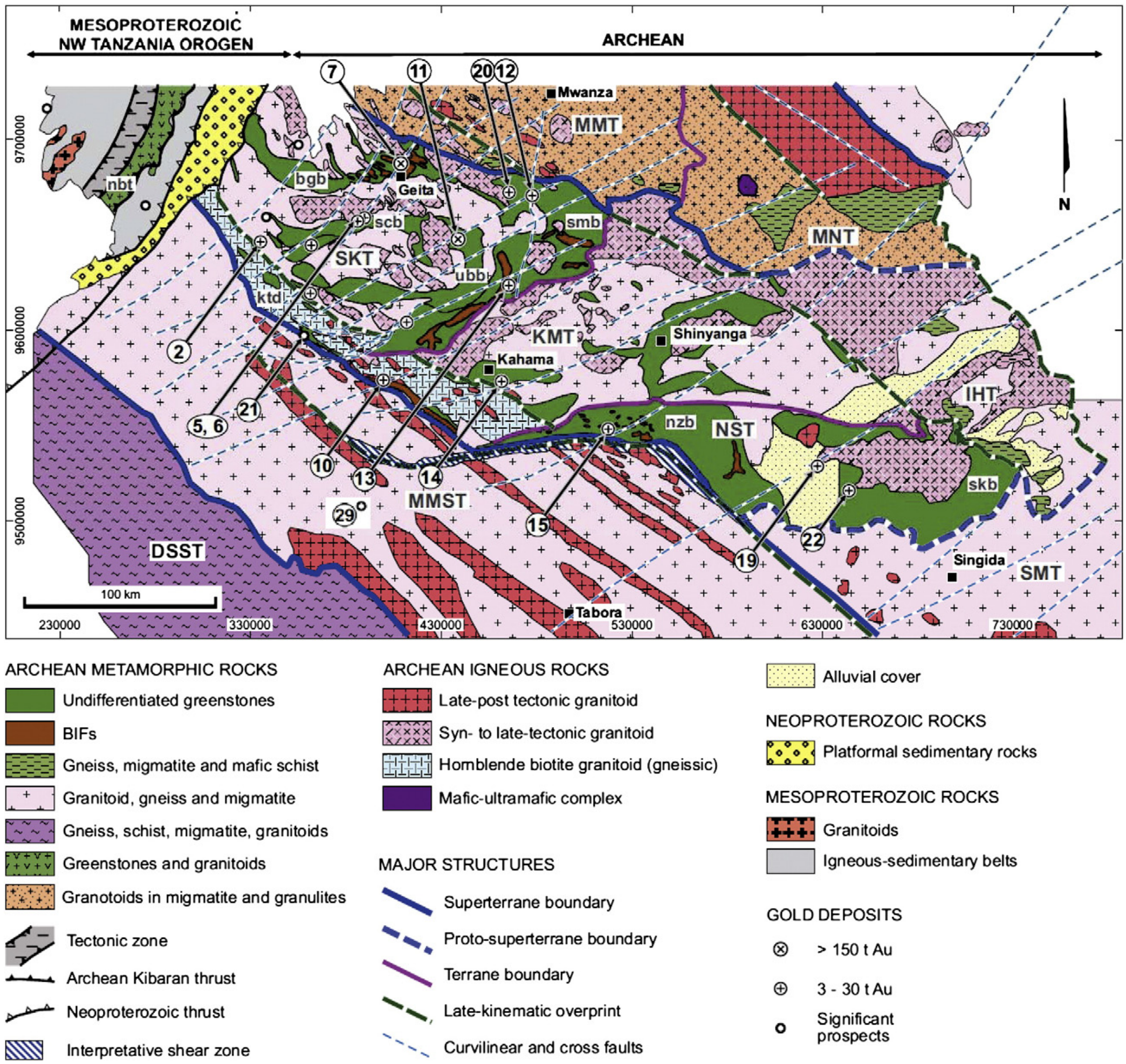


Fig. 9. Geological map of Lake Nyanza Superterrane, contained terranes, and some domains in the Lake Victoria Region, Tanzania. For deposit names and location refer to Fig. 6.

amphibolite-facies greenstones and biotite-quartzo-feldspathic gneisses restricted within the E–W-trending Mkurumu–Magamba Terrane. Host rocks include linearly distributed E–W- to ENE–WSW-trending stacks of amphibolite facies greenstone rocks against domal-syn-formal orthogneissic-granulite and granitoid-gneisses traversed by anastomosing shear zones roughly trending east–west (Fig. 16). A model invoking a prior suturing of the Kilindi–Handeni Superterrane to the gold-endowed Lake Nyanza Superterrane is proposed in this review (e.g. Fig. 8). It implies that the Kilindi–Handeni Superterrane has potential of hosting world-class gold deposits typical of those in greenstone belts to the west (e.g. Zhou et al., 2002; Goldfarb and Groves, 2011).

7.4.1. Apparently poorly endowed gold camps, Mkurumu–Magamba Province

Until the discovery of the Mkurumu prospect in 2003, there were no other bedrock-hosted gold deposits/prospects mapped and/or known in the Mkurumu–Magamba Province (Groves, 2010). Since then, numerous gold prospects, with gold mineralization broadly hosted by almost similar lithologic types (Fig. 18E, F), but with variable strike extents, geometry of mineralization and degree of tectonothermal overprint, have emerged (Figs. 11, 15 and 16). In the western part of the Mkurumu–Magamba Province, Mkurumu, Seita and Vuju, among other prospects within the Mkurumu–Libabala District, comprise gold mineralization in multiple lodes of coarse-grained tremolitic–actinolitic mafic-amphibolite with relatively thin interlaminations of sulphide-quartz-silicate veins (e.g. Fig. 18E). Some of these comprise granoblastic quartz and selective flooding or replacement of amphiboles by garnets, and amphibole-biotite-sericite altered zones in leucosome veins in biotite quartzo-feldspathic gneisses, with overprints of kyanite in melanosome bands (Fig. 18G). The tremolitic–actinolitic mafic-amphibolites preserve shear-laminated multiple zones of granoblastic quartz and silicates overprinted by randomly overgrown tremolite, some brecciated with an actinolitic matrix containing visible gold. The E–W to ENE–WSW-trending amphibolite-facies greenstone rocks and associated orthogneisses are bounded by granulitic–migmatitic gneisses and enderbitic–charnockitic granitoids to the north and

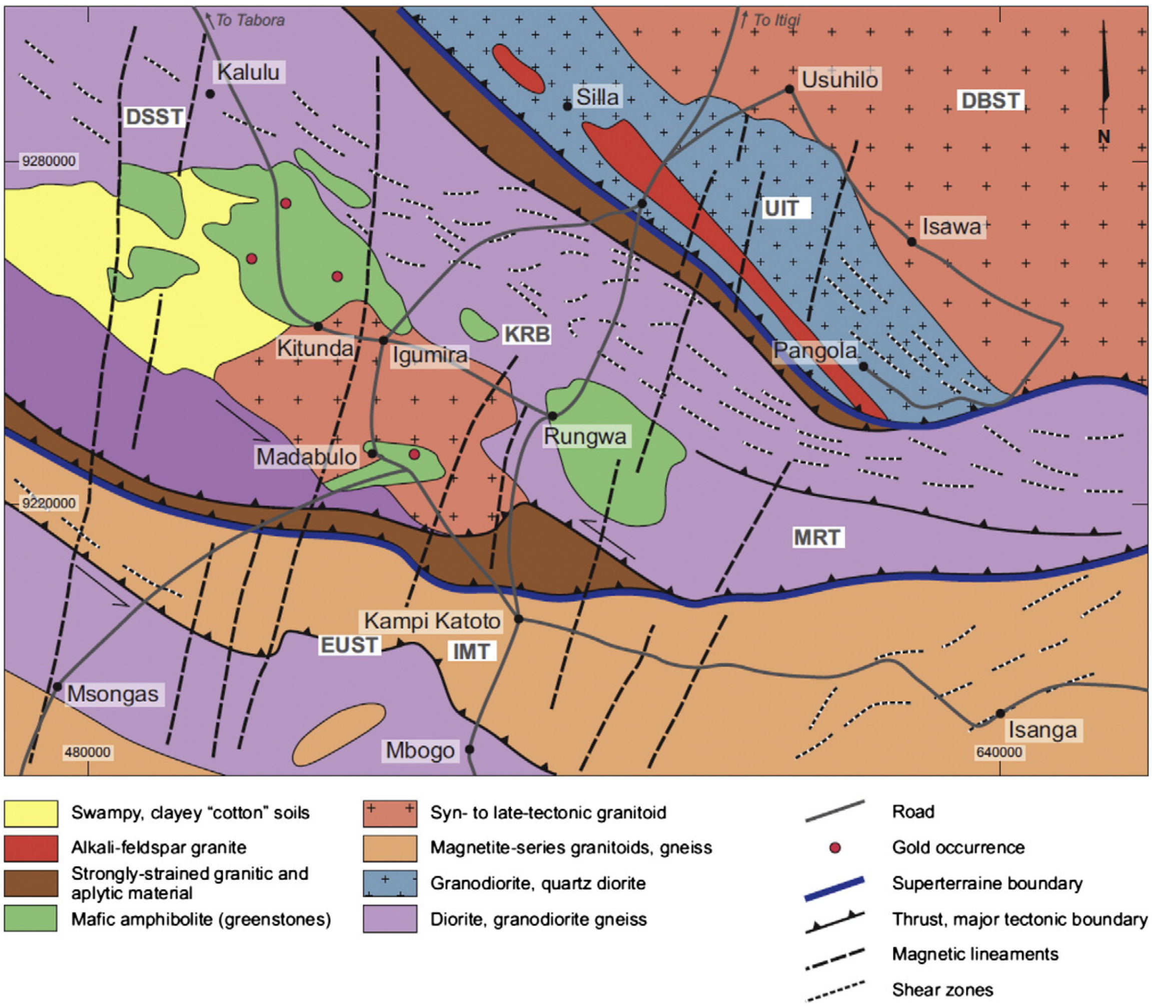


Fig. 10. Interpretative geological map of the Malagasya–Rungwa Terrane, Dodoma Schist Superterrane and adjoining Undewa–Ilangali Terrane (UIT) in the Dodoma Basement Superterrane and Isanga–Mtera Terrane in the East Ubendian Mtera Superterrane (see inset in Fig. 6A bedrock map pattern).

south (Fig. 15). The Mkurumu, Seita and Vuju prospects are also coincident with a ~6 km long by ~70 m wide zone of E–W to ENE–WSW-trending 50–720-ppb Au in soil anomalies in the Mkurumu–Libabala Belt. Selected rock channel and chip samples from the Mkurumu–Libabala District returned assays between 0.5 and 43.1 g/t Au from sulphidic quartz-silicate rock and 0.97–14.1 g/t Au from silicified, tremolitic–actinolitic amphibolite with carbonate stringers.

The Magambazi prospect is hosted by mafic-amphibolite and associated alteration zones confined by undifferentiated biotite-quartzo-feldspathic gneiss in the NW–SE-trending Handeni–Wami Domain, Magamba–Manga District in the eastern part of the Mkurumu–Magamba Terrane (Figs. 11 and 16) The prospect has been systematically explored since 2007 (Groves et al., 2008), and is currently estimated to contain gold endowment of at least 40 t Au (conservative estimates from Canaco, 2011; Groves, 2010). Gold mineralization at Magambazi occurs largely in relatively thick zones of sulfidic, garnet- and silica-flooded mafic-amphibolite proximal to pegmatoidal and graphitic rich zones and towards footwall and hanging-wall biotite-gneisses and granulites. Mapping, soil geochemistry and reconnaissance drilling have so far defined at least 11 km of highly prospective corridors, representing the Handeni Gold Trend, which extends from the Magambazi Hill to Semwaliko (Canaco, 2011; Groves, 2010; Fig. 17). Diamond and reverse-circulation drilling carried out on the Magambazi Hill section of the Handeni Gold Trend to date has defined ore over a strike length of about 900 m, including steeply dipping high-gold-grade and lower-gold-grade lodes in thrust zones underlying the high-grade ore shoots (Canaco, 2011; Fig. 17). These thrust zones possibly constitute flat-ramp lithostructures in the mafic-amphibolite units bounded by undifferentiated quartzo-feldspathic gneissic units (Fig. 17).

7.4.2. Superterrane-scale controlling factors

The transverse geometrical setting and rheological and geochemical lithodiversity constitute critically important superterrane-scale controlling factors for gold mineralization in the E–W-trending Kilindi–Handeni Superterrane. The Superterrane is situated within the relatively mobile Central Tectonic Zone, separated by N–S-trending shear zones from the competent cratonic blocks of the Tanzania Craton and the Eastern Granulite Zone to the west and east; and from the northern and southern part by the competent crustal blocks which make up the Mbulu–Masai and Usagara–Usambara Superterranes (Figs. 8 and 11). An E–W- and/or NW–SE maximum compressive stress regime (e.g. Shackleton, 1996, Fig. 1; Thomas et al., 2009, Fig. 1), acting on the Southern East African Orogen, would have preferentially reactivated terranes which make up the Kilindi–Handeni Superterrane (Kabete, 2008). Other E–W-trending crustal blocks, such as those described by Fritz et al. (2009) and Shackleton (1986), among others, should be affected in a similar manner. The second most important superterrane-scale controlling factor is the geometrical orientation of the crustal blocks and orientations of the bounding fault zones, some of which constitute accretionary terrane boundaries (Shackleton, 1996). As it is most likely that the Magambazi gold mineralization formed in the late Archean and was overprinted

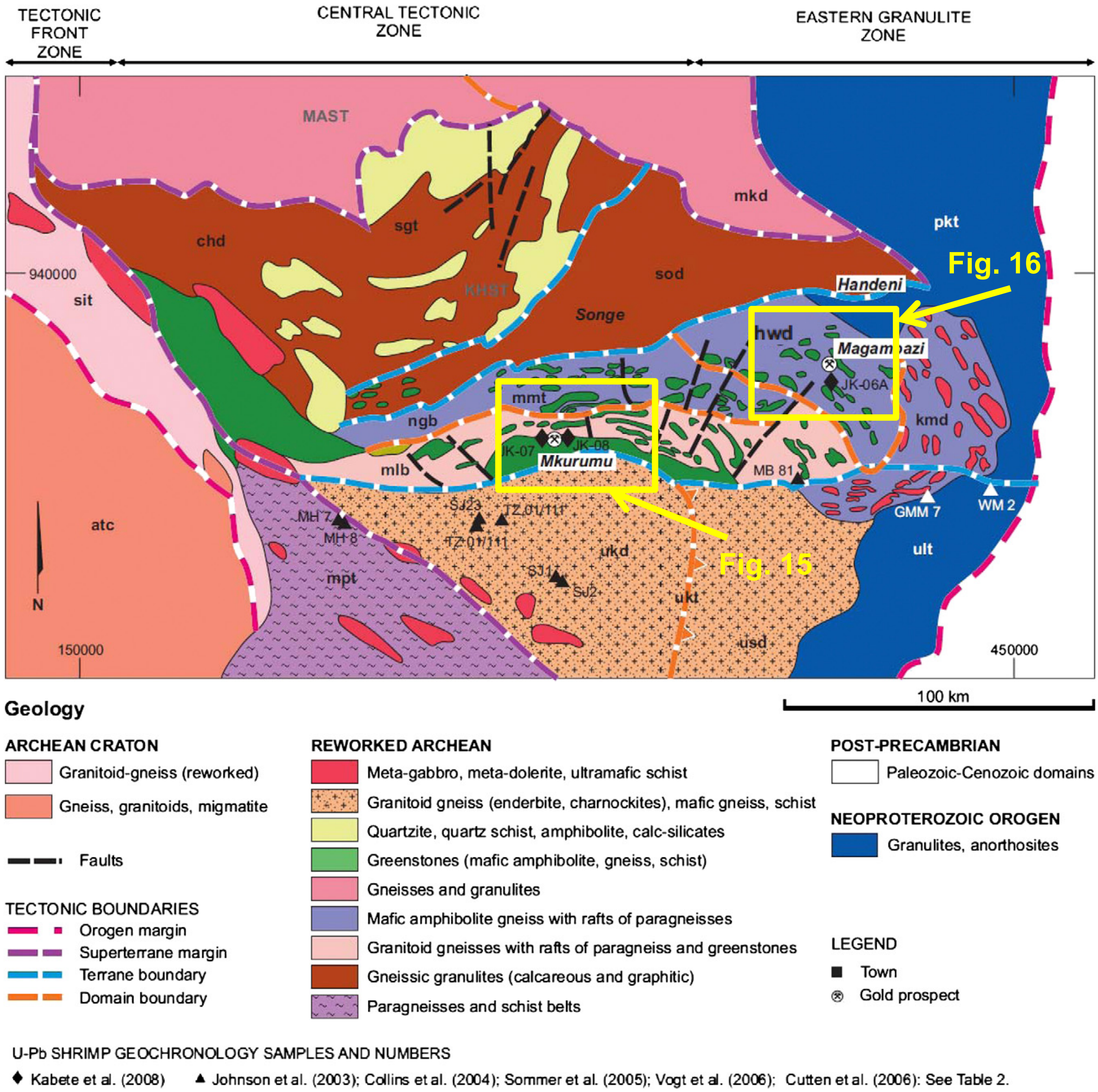


Fig. 11. Interpretative geological map showing contrasting geologic–geometrical setting between the Kilindi–Handeni Superterrane and southern and northern flanking superterranes and major components of the Tectonic Front, Central Tectonic and Neoproterozoic Blocks, and prospective gold occurrences and deposits.

during Neoproterozoic orogenesis, it is difficult to define the precise stress field during gold mineralization. However, extensional vein arrays trend approximately NW–SE, suggesting a NW–SE-directed maximum principal stress field, as interpreted for the Archean Sanza–Geita Domain in the Sukumaland Terrane, several hundred kilometres to the west (Figs. 8 and 12).

7.4.3. Terrane-scale controlling factors

Unlike the Songe and Ukaguru Terranes, which are underlain by extensive gneissic-granulites and orthogneisses, the Mkurumu–Magamba Terrane is underlain by relatively extensive sequences of amphibolite-facies greenstone rocks (Fig. 11). The greenstone rocks comprise elongate to elliptical stacks of mafic-amphibolite schist and gneisses juxtaposed against domal-shaped orthogneisses, traversed by relatively narrow anastomosing shear zones (Fig. 15). These domal to elliptical granitoid-greenstone rocks comprise doubly plunging lithostructures bounded by ENE–WSW to E–W-trending first-order shear zones, crosscut by NW–SE-, N–S- and NE–SW-trending buckling-related faults, and structural geometries conducive to gold mineralization (Fig. 16).

7.4.4. Domain-scale controlling factors

The current host rocks to gold mineralization in the Handeni–Wami Domain and elsewhere in the Ngeze–Mkurumu Domain are now at amphibolite facies (Figs. 15 and 16). The protoliths to the gold-hosting amphibolites in the main mineralized zones at Magambazi were most likely basalts or, less likely dolerite sills. These are adjacent to kyanite and sillimanite-bearing felsic gneisses that probably represent metamorphosed shales and other clastic sedimentary rocks. If gold mineralization was Archean, and prior to the high-grade Neoproterozoic metamorphic overprint, controls on gold

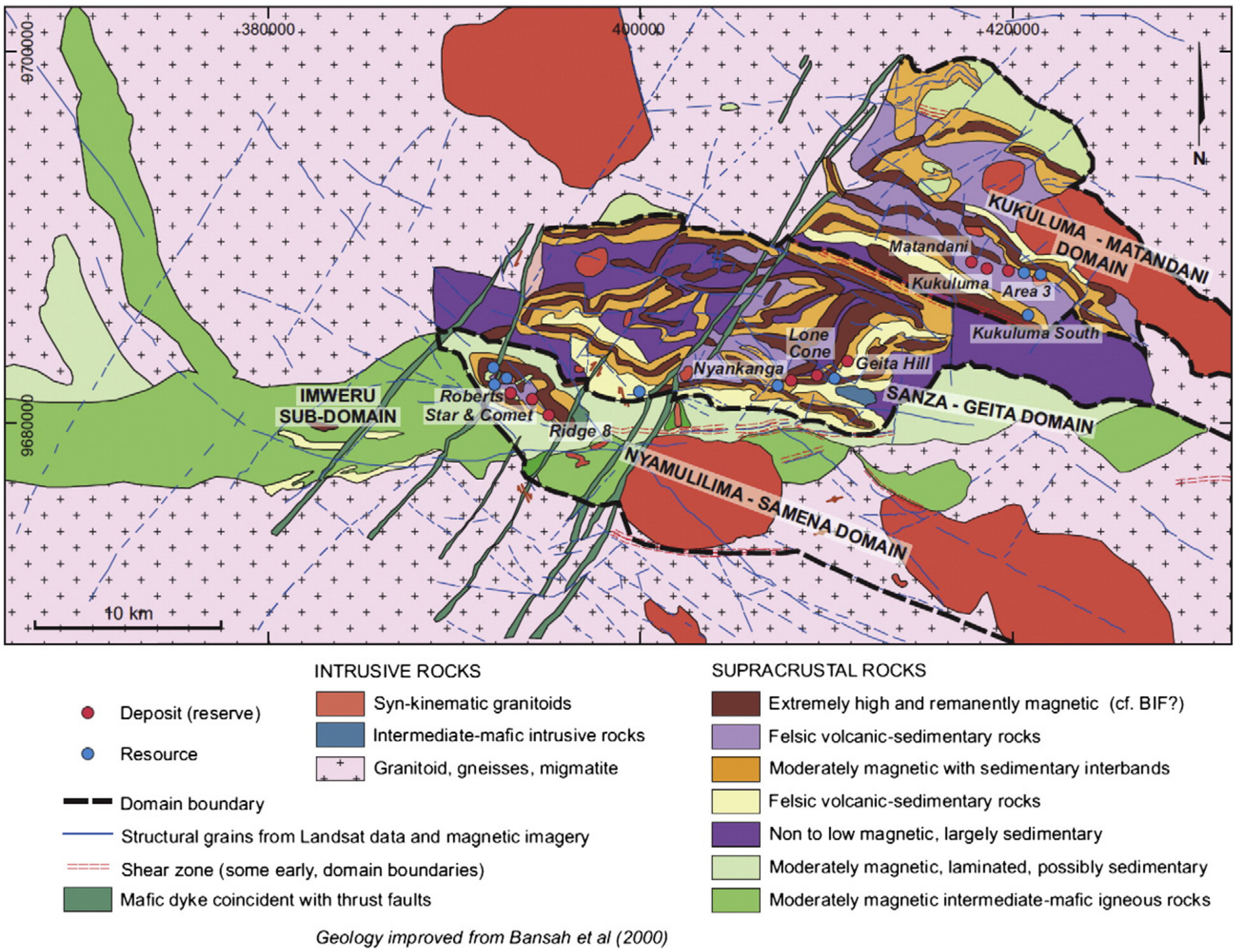


Fig. 12. Geologic map of Biharamulo–Geita Belt showing four domains (Biharamulo–Imweru, Nyamulilima–Samena, Sanza–Geita, and Kukuluma–Matandani Domains), which are host to distinctive gold deposit styles.

deposition would have been similar to those in normal mesozonal gold deposits (Groves et al., 1998). That is, reactive and competent Fe-rich basalts encased in more ductile sedimentary rocks would have acted as traps and caps, respectively, for gold deposition from infiltrating hydrothermal fluids.

7.4.5. Age of gold metallogeny, Mkurumu–Magamba Province

The 2670 ± 18 Ma biotite-orthogneiss (sample JK-08: Kabete et al., 2008; Fig. 18 F) is part of the E–W-trending belt of orthogneisses, which bounds the partially melted, silica-flooded ~620–570 Ma garnet-amphibolite in the Mkurumu, Negero and Magambazi Prospects (Fig. 18 G, H), and the tremolitic–actinolitic amphibolite in the Mkurumu Prospect (Fig. 18E). Zircons from the 2670 ± 18 Ma orthogneiss also record a ~620–570 Ma age related to a thermal overprint. The strong thermal overprint of the ~620–570 Ma event is related to ubiquitous partial melting of the mafic supracrustal rocks and associated development of silica-flooded garnet–amphibolite (Fig. 18H), pegmatoidal and aplyte dykes in the eastern part of the Mkurumu–Magamba Province (e.g. U–Pb SHRIMP zircon age date of 620–570 Ma dated from a silica-flooded, garnet mafic amphibolite from Magambazi: JK-06: Kabete et al., 2008). The strong obliteration of Archean age components by the ~620–570 Ma tectonothermal events in the mafic-amphibolite in the Magamba–Manga District (e.g. Fig. 16), and the weak development of partially melted mafic amphibolite in the Mkurumu–Libabala District (Fig. 15), obscure critical targeting criteria in the Kilindi–Handeni Goldfields without further precise dating.

8. Discussion

8.1. Geologic–tectonic framework and gold metallogeny

Research projects in the gold-endowed Yilgarn Craton, Western Australia and Superior Province, Canada, have progressively improved understanding of the spatial and temporal association between orogenic lode-gold deposits, crustal-scale faults and shear zones, and hosting superterranes (e.g. Blewett et al., 2010a; Czarnota et al., 2010a, 2010b; Henson et al., 2010; Percival, 2007; Percival and Stott, 2010; Robert et al., 2005; Muir, 2002). They explain links between very-large orogenic lode-gold deposits and crustal-scale superterrane boundaries, some of which provided access for the transportation of gold-bearing hydrothermal fluids to depositional sites (Goldfarb et al., 2005).

Also important in the overall understanding of the evolution of granitoid-greenstone belts is the development from models suggesting: 1) greenstones evolving as primordial crust deformed by density inversion processes, suggesting solid-state diapiric intrusion of granitic batholiths occurred concurrently with the sinking of denser mafic–ultramafic volcanic rocks and BIFs (e.g. Hamilton, 1998), to 2) intra-cratonic rifting of the crust and plume-related tectonic processes (Wyman et al., 1999; Barley et al., 1998; Myers, 1997), to 3) evolving plate tectonic models (e.g. de Wit, 1998), invoking arc-related tectonic processes (e.g. Condie and Benn, 2006; Czarnota et al., 2010a; Kositcin et al., 2008; Krapez et al., 2008a, 2008b; Wyman and Hollings, 2006; Wyman and Kerrich, 2009). At the superterrane scale, understanding of accretionary and collisional orogenic processes (e.g. Bierlein et al., 2009) and late development of extensional sedimentary basins (e.g. Vanderhaeghe, 2010)

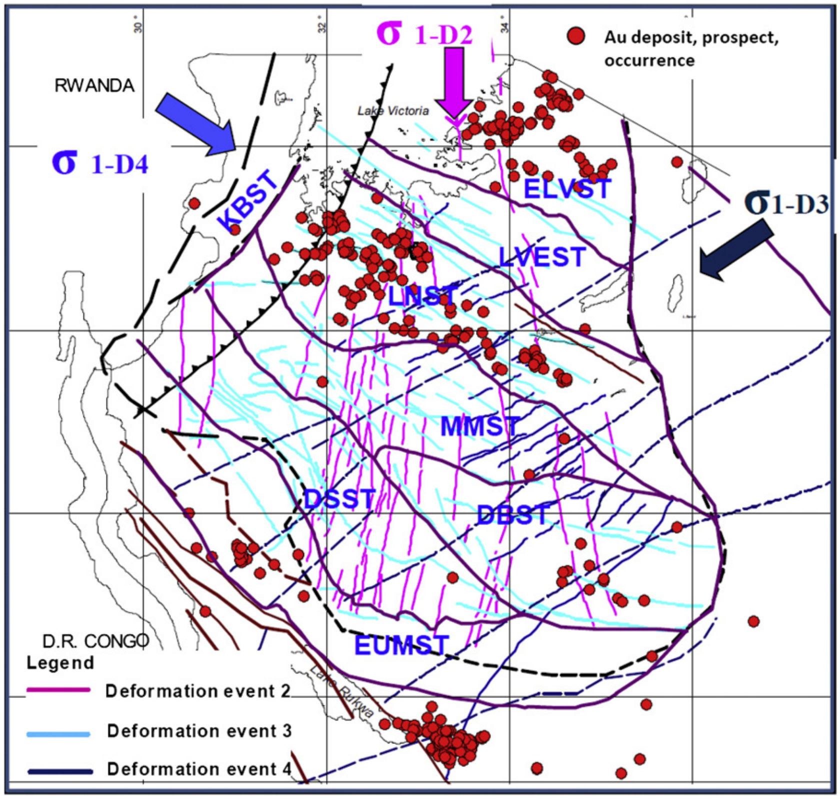


Fig. 13. Structural elements and causative deformation events interpreted from the bedrocks which underlies the Precambrian Shield of Tanzania.

have also contributed to understanding crustal growth and orogenic gold systems.

It is from this evolving research that the concepts of superterranes, terranes and domains have developed, and, with them, an improved understanding of the critical controls on the distribution of orogenic gold deposits at all scales (e.g. Myers, 1990, 1997; Swager, 1997; Blewett et al., 2010a, 2010b; Davis et al., 2010; Miller et al., 2010). These concepts are used below to evaluate gold endowment in the Tanzania Craton and highlight terranes that are more prospective for gold than previously considered.

8.1.1. Tanzania Craton (Lake Victoria vs. Central Tanzania Regions)

Although some mafic volcanic rocks in the Sukumaland Province accumulated at ~2823 Ma, rapid crustal growth did not occur until between ~2747 Ma and 2690 Ma, some 80–20 million years before the peak of the gold mineralization events in the province, somewhere between ~2673 and 2660 Ma (Table 3). In the Central Tanzania Region, eruption of the basal porphyritic andesite occurred between ~2815 and ~2701 Ma, that is before the ~2740 and 2691 Ma period of rapid crustal growth in the Undewa–Ilangali Province (Mazoka Gold District: Fig. 20). Broadly, gold deposition in the Undewa–Ilangali Province (as inferred from the Mazoka Gold District) occurred either soon after the emplacement of a precursor to deformed, altered and mineralized biotite-granitoid schist at ~2702 Ma (Kabete, 2008) or during, and/or after ~2660 Ma, the youngest resetting concordant age from an ~2815–2702 Ma mineralized porphyritic andesite (Kabete, 2008). A relatively weak ~620 to 570 Ma metamorphic resetting age window, dated from the gold-hosting andesite in the Mazoka Greenstone Belt, suggests that there was insignificant reworking of the deposits formed during the ~2702–2660 Ma gold mineralization events. Thus, the broad age window for gold mineralization in the Undewa–Ilangali Province is 2701–2660 Ma, close to that of gold mineralization in the Sukumaland Province (Lake Victoria Region), despite the disparity in their apparent gold endowment.

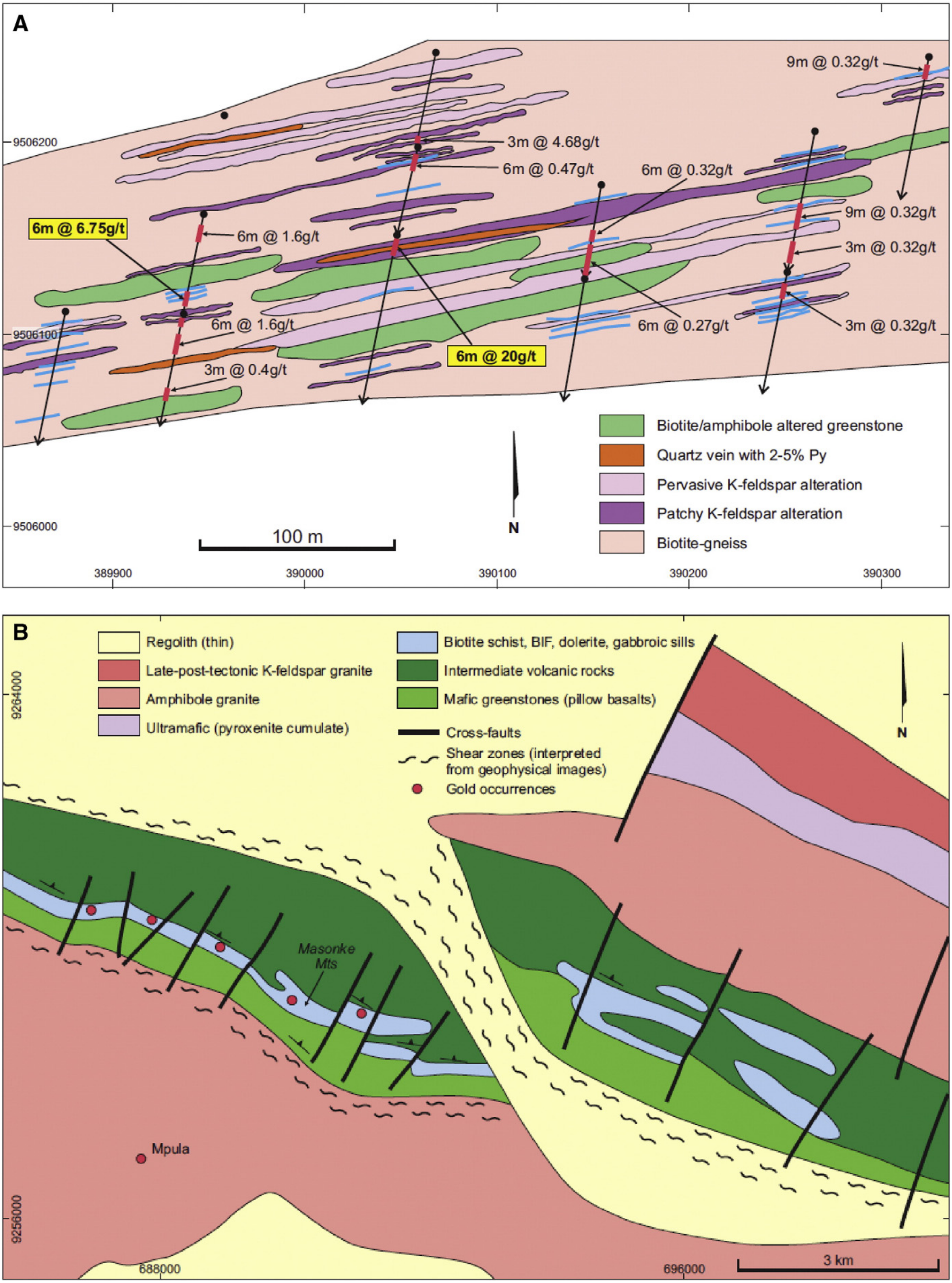
The ~1600 t Au endowment from the Sukumaland Province is a consequence of a combination of lithospheric-scale processes, including rapid juvenile crustal addition and other heat-generating processes. When compared to other provinces in the Lake Victoria Region, the Sukumaland Province has: 1) a high-density of felsic granitoids; 2) maximum lithodiversity as demonstrated by the Geita and Bulyanhulu–Busulwangili Domains (Chamberlain et al., 2004; Nugus et al., 2011); and 3) favourable geometrical orientation relative to the latest NW-to-SE far field stress regime (Groves, 2010); and 4) extensive and rapid juvenile crustal addition between ~2747 Ma and 2690 Ma, before the ~2673–2660 Ma peak of gold mineralisation.

Juvenile crustal addition is cited among other critical controlling factors for the gold endowment in most major orogenic gold provinces worldwide (e.g. Czarnota et al., 2010a; Frimmel, 2008; Goldfarb et al., 2001; Groves et al., 2005; Groves et al., 2006). However, it is still possible that the ~2815–2660 Ma juvenile granitoid-greenstone rocks (Mazoka type), confined within the >3230 Ma orthogneissic basement of the Central Tanzania Region, can host large gold deposits similar to those hosted by isolated greenstone belts in granitic-gneisses and granitoid belts of the South West, Southern Cross and Youanmi Terranes in the Yilgarn Craton, Western Australia (Robert et al., 2005). Although these terranes contain low proportions of greenstones, they host large gold deposits at Marvel Loch and Mount Magnet (Robert et al., 2005).

8.1.2. Proterozoic Tanzanian Regions, Southern East African Orogen

Significant academic research in the Southern East African Orogen of Tanzania (e.g. Johnson et al., 2003; Kabete et al., 2008; Maboko, 2000; Maboko, 2001; Maboko and Nakamura, 1996; Möller et al., 1998, 2000; Muhongo et al., 2001; Reddy et al., 2003; Sommer et al., 2003, 2005), broadly suggests that terranes which make up this Orogen evolved via protracted crustal growth processes, which culminated with the suturing of the West and East Gondwana continents at ~560 Ma.

In the Kilindi–Handeni Superterrane, the Mkurumu–Magamba Terrane, records a ~2670–2630 Ma age window for the emplacement,


A
9m @ 0.32g/t
9506200
3m @ 4.68g/t
6m @ 0.47g/t
6m @ 0.32g/t
6m @ 6.75g/t
6m @ 1.6g/t
9m @ 0.32g/t
3m @ 0.32g/t
6m @ 1.6g/t
9506100
6m @ 0.27g/t
3m @ 0.32g/t
3m @ 0.4g/t
6m @ 20g/t
Biotite/amphibole altered greenstone
Quartz vein with 2-5% Py
Pervasive K-feldspar alteration
Patchy K-feldspar alteration
Biotite-gneiss
N
9506000
100 m
389900
390000
390100
390200
390300
B
Regolith (thin)
Late-post-tectonic K-feldspar granite
Amphibole granite
Ultramafic (pyroxenite cumulate)
Biotite schist, BIF, dolerite, gabbroic sills
Intermediate volcanic rocks
Mafic greenstones (pillow basalts)
Cross-faults
Shear zones (interpreted from geophysical images)
Gold occurrences
N
9264000
Masonke Mts
Mpula
9256000
688000
696000
3 km

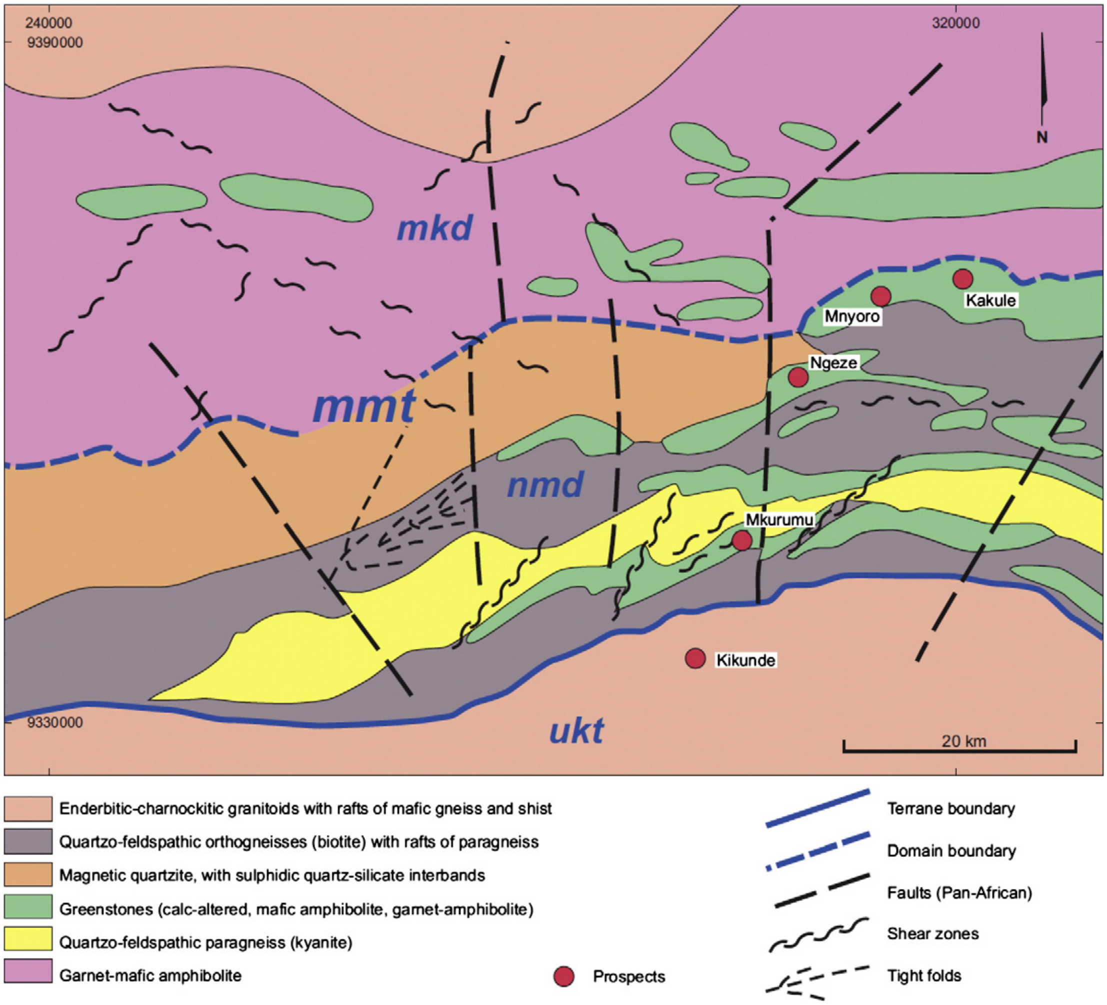


Fig. 15. Geology of the domains which make up the western part of the Mkurumu–Magamba Terrane, Kilindi–Handeni Superterrane in the Southern East African Orogen.

deformation and metamorphic resetting of biotite-orthogneiss in the Mkurumu–Libabala Belt (Kabete et al., 2008). This age window overlaps with a ~2640 Ma age of the peak of metamorphism recorded from a 2638 ± 7 Ma charnockitic granitoid and 2654 ± 8 Ma garnet-biotite gneiss in the Ukaguru Terrane (Johnson et al., 2003; Fig. 11). Thus, there is evidence for Neoarchean precursors to at least some of the high-grade metamorphic rocks that regionally record Neoproterozoic isotopic ages in the broad range of 640 to 560 Ma.

Field mapping, robust U–Pb SHRIMP geochronology dating and petrographical studies in the Kilindi–Handeni Goldfields imply that orogenic gold, probably at mesozonal levels, was deposited in Neoarchean host rocks at ~2640 Ma. These host rocks and associated gold systems were modified during the ~640–560 Ma tectonothermal events to form the high metamorphic-grade rocks and recrystallized gold ores that are exposed now, through exhumation from the Neoproterozoic Southern East African Orogen. As the protoliths to many of the high-grade metamorphic rocks were Neoarchean greenstone lithologies similar to those in the Lake Victoria Region, there is the possibility of discovery of large to very-large gold deposits in the Kilindi–Handeni Goldfields. At Magambazi, the orientations of mineralized structures are similar to those in the Sanza–Geita Gold Camp, implying little reorientation during Neoproterozoic orogenesis. However, such orientation is possible elsewhere, and special conditions of exhumation are required to bring the deposits that were overprinted at hypozonal levels to the current land surface. Hence, gold endowment per unit area is likely to be lower than that for the Lake Victoria Region.

8.2. Alternative gold exploration targets

The search for mesozonal orogenic gold deposits in sub-greenschist to amphibolite facies belts, such as those in the Lake Victoria Region, has been the main exploration strategy for the mineral exploration industry worldwide (e.g. Goldfarb et al., 2001, 2005; Groves et al., 2000). Hosting lithologies are generally diverse (e.g. Paulsen et al., 1991), ranging from back arc and continental arc volcanic and volcaniclastic rocks to sedimentary rocks in accretionary prisms and igneous intrusions (Goldfarb et al., 2005; Groves et al., 2000; Groves et al., 2006). New exploration strategies have allowed exploration of such prospective terranes, presumed to have high exploration maturity where they are covered by relatively younger rocks or regolith (e.g. Anand and Paine, 2002; Smith and Anderson, 2003). Such exploration relies heavily on high-resolution air-borne geophysical surveys, that can penetrate beneath thick cover of post-mineralization sedimentary and volcanic strata, deeply developed regolith, glacial debris, and any other transported overburden (e.g.

Fig. 14. Solid geologic map of the bedrock and gold-hosting lithostructures which underlies Mwenge Prospect in the Moyowosi–Uyowa Terrane, Moyowosi–Manyoni Superterrane (A), and Mazoka Prospect in the Mazoka Greenstone Belt, Undewa–Ilangali Terrane of the Dodoma Basement Superterrane (B): illustrating gold exploration potential from the Central Tanzania Region.

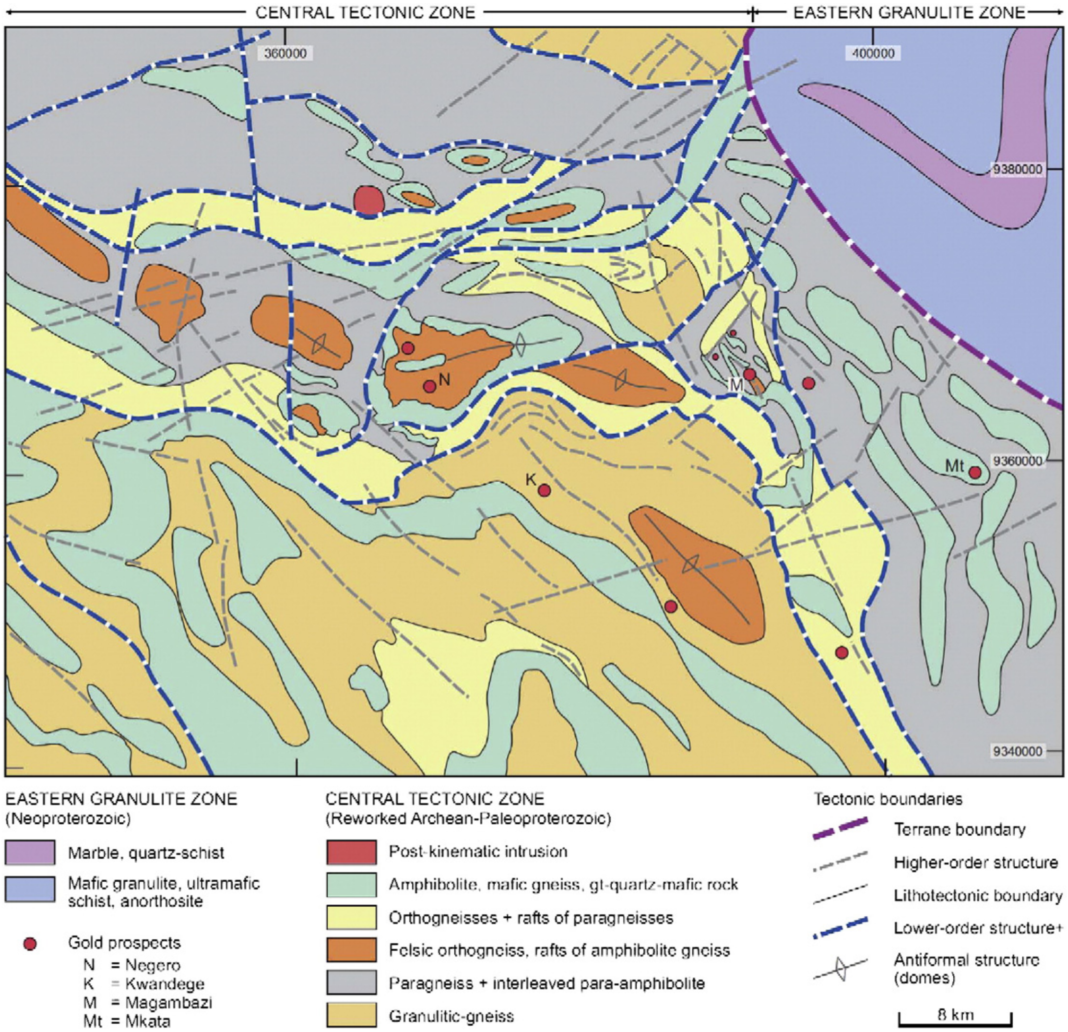


Fig. 16. Geology of the domains which make up the eastern part of the Mkurumu–Magamba Terrane, Kilindi–Handeni Superterrane in the Southern East African Orogen. A result of qualitative interpretation of high-resolution magnetic and radiometric imagery (Benzu, 2011; Canaco, 2011; DLKM, 2011) interpreted in terms of geology.

Chen et al., 2001; Ford et al., 2007; Jones et al., 1996). In such exploration, a thorough understanding of regolith and landscape evolution is as important as understanding bedrock controls on mineralization (e.g. Anand and Paine, 2002; Cornelius et al., 2008).

8.2.1. Lake Victoria Region

More than 50% of the Lake Victoria Region is under regolith cover, including residual and transported black cotton soil (mbuga). Potential exploration targets in this region include covered terranes poorly explored or unexplored due to relatively poor understanding of the regolith, regional bedrock geology and structural patterns (Fig. 2). In this respect, the situation in the Lake Victoria Region of Tanzania is similar to that in Western Australia during the early 1990s (Groves, 2010; Kabete, 2004; Massola, 2004). Several very-large orogenic gold deposits were discovered in Western Australia between 1990 and 2010, suggesting that there are more discoveries yet to be made in the greenstone belts of Tanzania.

The discovery of the Archean Gokona gold deposit, in an area where the gold-hosting Archean greenstones are covered by Tertiary phonolitic lavas (e.g. Mara–Mobrama Province: Smith and Anderson, 2003) underlines the discovery potential of similar Archean granitoid-greenstone belts that are covered by relatively thin, gently dipping Neoproterozoic sedimentary rocks and Tertiary volcanic flows in the East Lake Victoria Superterrane (Figs. 1 and 4; QDS 24 and 25). Other prime targets are covered by Tertiary volcanic flows, flat-lying Neoproterozoic volcano-sedimentary rocks (Bukoban Group), and in situ and transported regolith within the East Lake Victoria and Lake Nyanza Superterranes (Figs. 2 and 4). There are also possibilities for reworked/metamorphosed orogenic gold deposits in the eastern margins of the craton, with similar setting to the Hemlo Deposit in the Abitibi Belt (Muir, 2002). Potential belts are likely to be situated in the Nzega–Sekenke Terrane (NST), Iaida–Haidon Terrane (IHT) and Singida–Mayamaya Terrane (SMT) in the Lake Nyanza Superterrane (Figs. 8 and 9; QDS 83 and 84).

8.2.2. Central Tanzania Region

The ~2850–2660 Ma Mazoka Greenstone Belt in the Undewa–Ilangali Terrane is one of the interpreted juvenile greenstones interspersed within linear metamorphic belts of >3.2 Ga gneissic-granulites in the Central Tanzania Region (Fig. 8). The shape geometries of these greenstone belts are atypical of greenstone belts in other similarly older cratons such as the ~>3.2 Ga Zimbabwe, Pilbara and Kaapvaal Cratons, within which greenstone belts are wrapped around and/or re-focused in low-strain zones (Diener et al., 2005; Kisters et al., 2003; Van Kranendonk et al., 2009; Zegers et al., 2002). These greenstones are widely interpreted to have been deformed against diapiric granitoid batholiths as a result of at least a component of vertical tectonics. Conversely, linear greenstone belts such as the Mazoka Domain

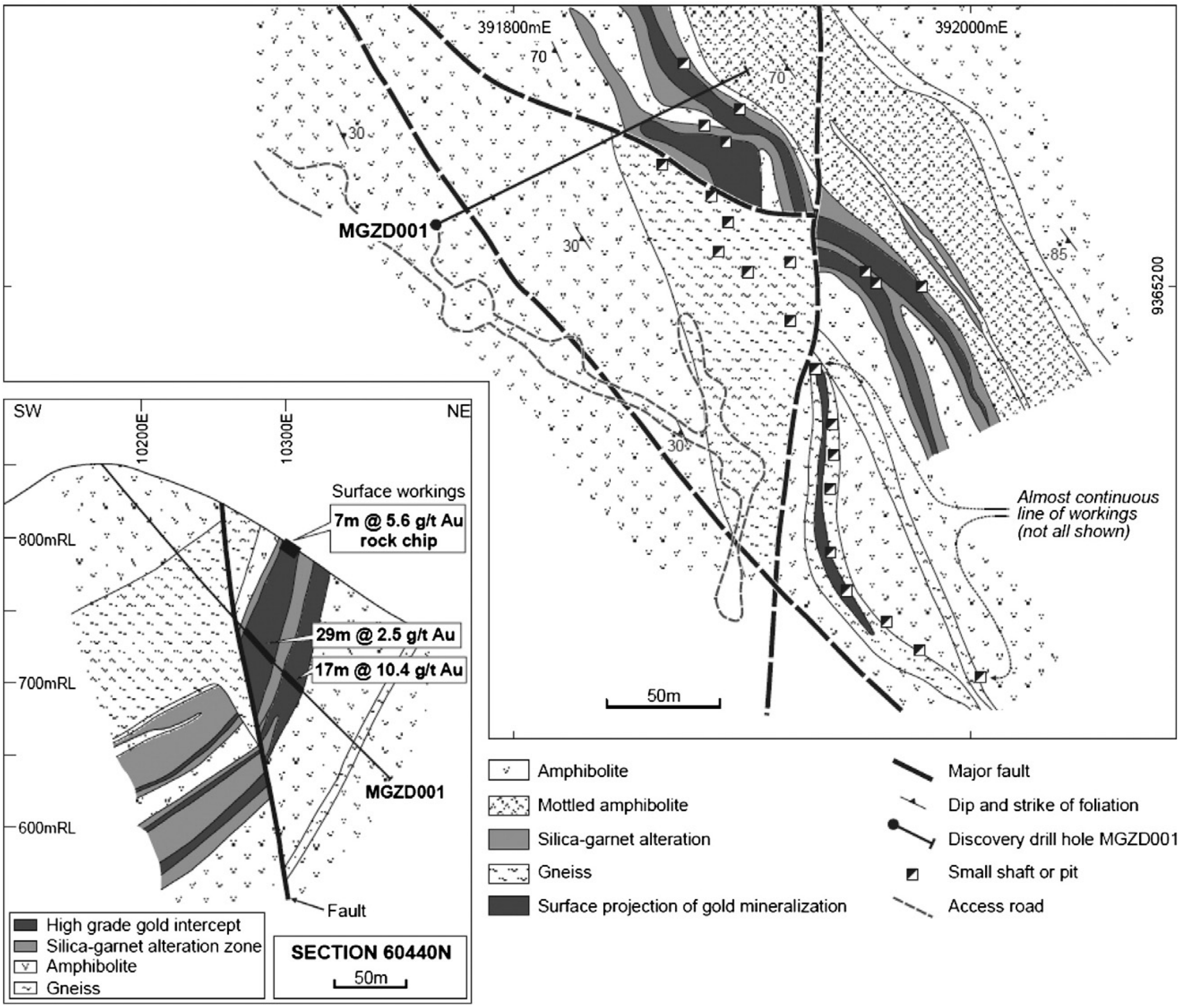


Fig. 17. Detailed geology of the Magambazi Main Block; illustrating deposit-scale controls of the Magambazi gold deposit in the eastern part of the Mkurumu–Magamba Terrane (see Magambazi in Fig. 16).

could be part of accretionary orogens which developed via horizontal tectonic processes (e.g. Lin, 2005; Fig. 13) or by interplay of early-vertical and subsequent-horizontal tectonism such as in the northwest Superior Craton, Canada (Lin, 2005, Fig. 2b). In general, Mazoka and other similar greenstone belts in the Central Tanzania Region preserve an overall geologic-tectonic setting comparable to the setting of the greenstone domains/belts in the North Caribou Superterrane, Superior Craton (Lin, 2005; Percival, 2007) and South West and Youanmi Provinces in the Yilgarn Craton (Czarnota et al., 2010a; Wyche, 2007). In these crustal settings relatively narrow greenstone belts are confined within extensive granitoids and orthogneisses. They host significant, although generally not world-class gold deposits (Robert et al., 2005, Figs. 1 and 2), a similar scenario predicted for greenstone belts which underlie the Central Tanzanian Region.

8.2.3. Proterozoic Tanzanian Regions

Target generation for reworked/metamorphosed orogenic gold deposits along craton margins is increasing (e.g. Bierlein et al., 2006; Doyle et al., 2009; Groves et al., 2003; Jaireth and Huston, 2010; Robert et al., 2005). In the Southern East African Orogen of Tanzania, such targets include proto-Archean terranes with a variable intensity of tectonic and thermal overprints from the ~620–560 Ma Pan-African tectonothermal event. As discussed above, the Kilindi–Handeni Goldfields has a high potential to host significant orogenic gold deposits, especially in Archean granitoid-greenstone belts reworked by the ~620–550 Ma Pan-African tectonothermal events. The prospectivity of such belts in the Southern East African Orogen of Tanzania is demonstrated by the Mkurumu–Magamba Province (Figs. 11, 15 and 16). The deposits can be considered analogous to the giant Plutonic deposit and smaller Marymia deposits in the Capricorn Orogen north of the Yilgarn Craton (e.g. Vielreicher et al., 2002; Robert et al., 2005 Figs. 1 and 2; Fallon et al., 2010), which is a Neoarchean mesozonal orogenic gold deposit metamorphosed to amphibolite facies during Paleoproterozoic orogeny. The recently discovered world-class Tropicana gold deposit in the Albany–Fraser Orogen, south of the Yilgarn Craton (e.g. Doyle et al., 2009; Kirkland et al., 2011, Fig.2) may also be a Neoarchean gold deposit metamorphosed during Mesoproterozoic orogenesis, but there are few definitive published data to be certain (e.g. Clark et al., 2000; Nelson et al., 1995).

Archean inliers in the north-western Tanzania Craton include the gold-hosting biotite–amphibole granitoids of the Archean Nyakahura–Burigi Terrane, situated in the unroofed thrust windows of the Karagwe–Ankolean Belt. These Archean inliers were probably once sutured to the gold-endowed Sukumaland Terrane prior to

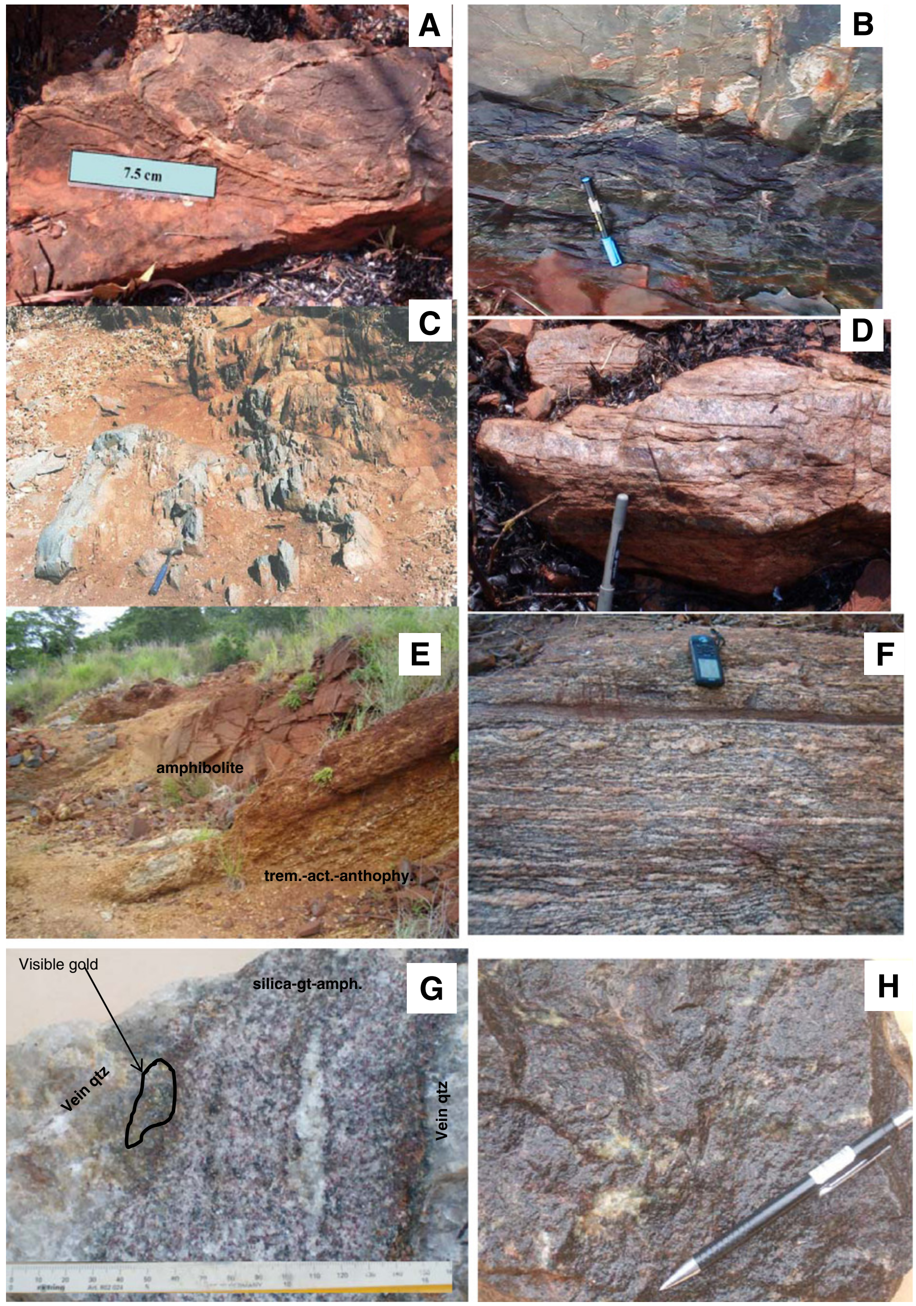


Fig. 18. Photographs showing: A) a pillowed basalt, B) shear-foliated andesitic rock with quartz stringers overprinted by closely spaced cross-faults/fractures, C) shear-foliated intermediate volcanic rock D) shear-mylonitic quartz-sericite schist with interlaminations of quartz veins, a precursor biotite-granitoid schist (samples 61118 and JK-12D in Table 4) from the Mazoka Domain, Central Tanzania Region. From the Mkurumu–Magamba Terrane, E) calc-silicate altered mafic amphibolite and F) a biotite-orthogneiss which bounds mafic-greenstones and their alteration equivalents from the Mkurumu Prospect; G) silicate-vein-quartz interbands, among the gold hosting lithostructures at Negero; H) a polished hand specimen slab illustrating strong deformation and remobilization of vein quartz in a silica-flooded garnet-mafic gneissic (white band on a pencil = 2 cm).

Proterozoic orogenic and tectonic events that developed the Karagwe–Ankolean and Bukoban Belts (e.g. Klerkx et al., 1993). The prospectivity of the Nyakahura–Burigi Terrane can be inferred from the increasing discoveries of as yet small-scale gold prospects, including the Mwiruzi, Nyakahura, and Kalenge prospects, among others. These prospects are host to a variety of orogenic gold systems, including: 1) gold hosted by westerly verging shear zones and stockwork quartz-vein systems; 2) gold in quartz veins and associated westerly verging shear zones at the contacts between the Kibaran and Archean inliers; and 3) quartz veins and associated alteration zones apparently confined within the Karagwe–Ankolean rocks. The westerly verging shear-foliated quartz veins in the Archean granitoid inliers are parallel to sub-parallel to shear-foliated contacts between Archean and Karagwe–Ankolean rocks (e.g. Mwiruzi). These lithostructures are at high-angles to the inferred NW–SE direction of maximum compression (σ1-D4: Figs. 8 and 13; Bansah et al., 2000; Groves, 2010), further underpinning the hypothesis that the NE–SW-trending geometry and the prior suturing of the Nyakahura–Burigi Terrane to the Sukumaland Terrane can be used as predictive targeting criteria.

9. Summary and conclusions

9.1. Geologic–tectonic framework

A new tectonic subdivision outlines three contiguous lithotectonic–metallogenic regions of Tanzania, the Lake Victoria, Central Tanzania,

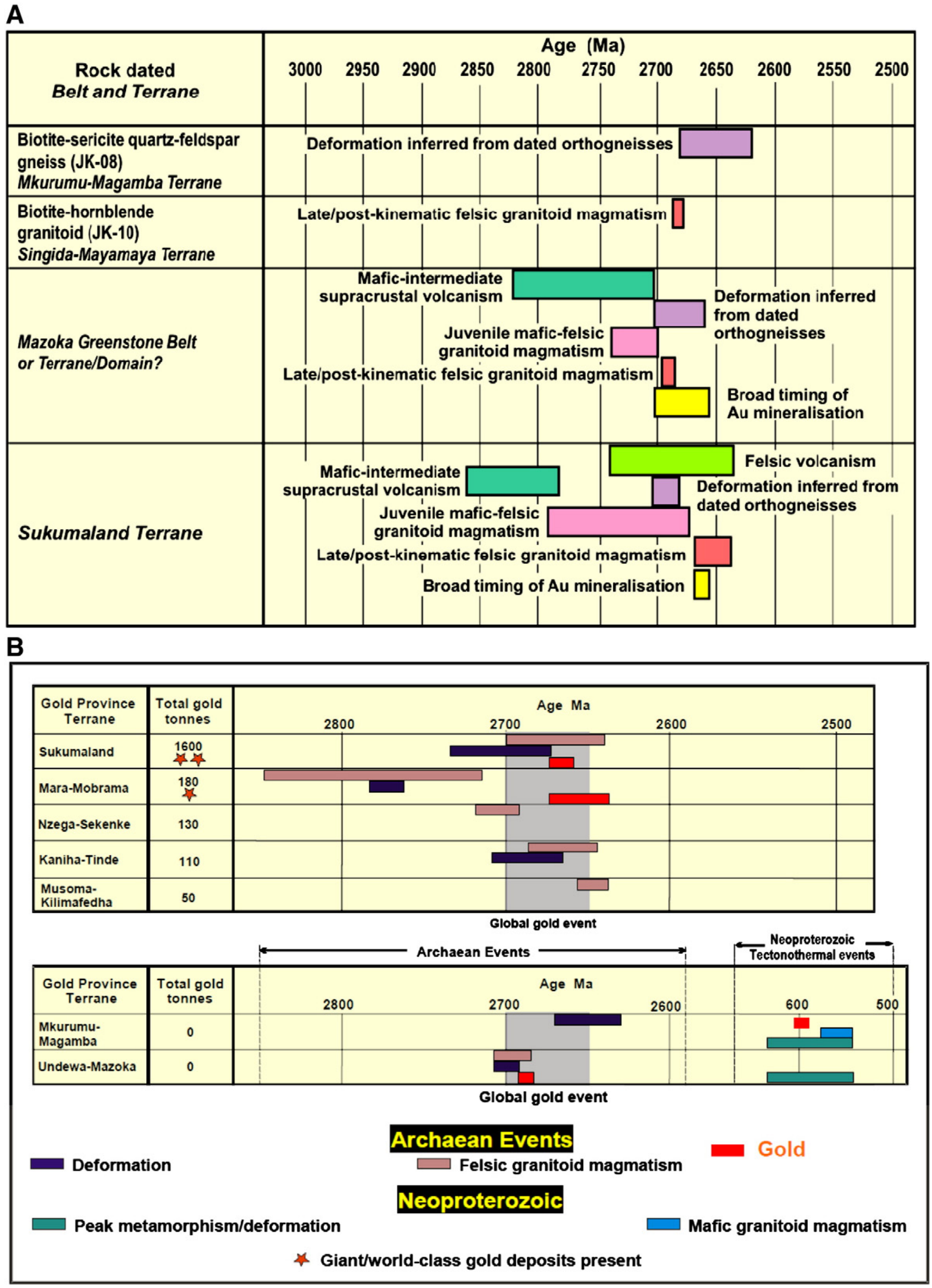


Fig. 19. A: Crustal growth histories of selected terranes from Mkurumu–Magamba Terrane and Mazoka Domain relative to the evolution history of the gold-endowed Sukumaland Terrane; B) relative timing of gold mineralization events in the Lake Victoria Region compared to the broad timing interpreted from the Undewa–Ilangali Province, Central Tanzania Region and Mkurumu–Magamba Province in the Southern East African Orogen of Tanzania.

and Proterozoic Tanzanian Regions, and their contained crustal blocks (Figs. 1 and 8). Apart from crustal blocks which conform to the traditional extent of the Archean Tanzania Craton (Lake Victoria and Central Tanzania Regions), the Central Tanzania Region contains the suspect East-Ubendian–Mtera Superterrane, which forms part of the thick lithosphere at the margin of the proto-Tanzania Craton with the Zambia Craton (Fig. 5). Some of the Archean crustal blocks in the Proterozoic Tanzanian Regions were once sutured to the Tanzania

Craton prior to Proterozoic tectonic events. Conversely, some of those superterranes were probably part of another Archean craton of unconstrained extent and geographical position prior to those Proterozoic tectonic events (e.g. Nyakahura–Burigi Terrane). These events incorporated Archean to Paleoproterozoic terranes of western Tanzania (e.g. East-Ubendian–Mtera Superterrane), Northwestern Tanzania Orogen (Mesoproterozoic Kibaran/Karagwe–Ankolean Belts: Tack et al., 2010) and Eastern Proterozoic Tanzania Region within the Southern East African Orogen of Tanzania. Some Proterozoic Regions of Tanzania are therefore prospective for world-class orogenic gold deposits.

At least four major progressive deformation events led to the Archean geometry of the Tanzania Craton (e.g. Figs. 6, 8 and 13). Deformation event D-1 involved early accretionary tectonic processes which juxtaposed arc/back-arc igneous–sedimentary rocks against continental crust. D-2 involved N–S-oriented crustal shortening, causing folding and refolding of supracrustal belts against continental crust, and extensional faults/fractures, and emplacement of lamprophyre dykes, following cratonization. D-3 involved NE–SW progressive compressional–transpressional tectonics which developed networks of NW–SE and NNW–SSE-trending shear zones, NE–SW-trending extensional fractures/faults, emplacement of felsic and dolerite dykes and deposition of massive quartz veins following cratonization (QDS 6, 14 and 84). D-4 involved NW-to-SE compressional tectonics, which reactivated early structures (D1–D3), including NW–SE-through-going and NNW–SSE-trending anastomosing shear zones and curvilinear faults/shear zones, restricted to the Lake Nyanza Superterrane.

9.2. Orogenic gold exploration opportunities

9.2.1. Lake Victoria Region

The Lake Nyanza Goldfields contains the most gold-prospective provinces and districts in the Lake Victoria Region. This is most likely due to a combination of their superior lithostratigraphy, structural geometry and their diverse settings and short tectonic evolution history. Exploration opportunities for very-large orogenic gold deposits exist under regolith cover, Cenozoic volcanic flows and relatively flat Neoproterozoic sedimentary cover (Fig. 2; QDS 6, 14, 24 and 25). Although at a superterrane-scale, the East Lake Victoria Goldfields could be similarly prospective to the Lake Nyanza Goldfields, there are fundamental differences in the controlling factors at terrane and domain-scales. Most important is the distinctively different geology and structural setting, such as the lack of both thick BIFs and lithostructural complexity in the East Lake Victoria Superterrane. The Neoarchean Mwanza–Lake Eyasi Goldfields is far less prospective for orogenic gold deposits due to the general lack of greenstone lithologies (Figs. 2 and 8). The eastern parts of the Lake Nyanza Goldfields, constituting Nzega–Sekenke, Iahida–Haidon and Singida–Mayamaya Provinces, are considered to be prospective for reworked/metamorphosed Archean orogenic gold deposits (Fig. 9). Given the gold-endowment of the E–W-trending Mara–Mobrama and Musoma–Kilimafedha Provinces, their eastern margins could be prospective for reworked orogenic gold deposits. However, these belts are situated in conservation and wildlife areas prohibited for mineral exploration (Figs. 2 and 4).

9.2.2. Central Tanzania Region

Qualitative interpretation of re-processed airborne geophysical data and mapping reveals the presence of incompetent supracrustal greenstone domains of variable strike extensions and thicknesses in competent, high-grade metamorphic rocks in the Central Tanzania Region. These belts are far more extensive in the Dodoma Basement Goldfields than in the Moyowosi–Manyoni and Dodoma Schist Goldfields. The ~2815–2660 Ma Mazoka Domain in the >3.2 Ga granitoid-gneisses of the Undewa–Ilangali Province has potential for hosting large gold deposits (Fig. 14B). The Mazoka Greenstone Belt, within which the Mazoka Domain is situated, represents other E–W- to NW–SE-trending greenstone domains in the Dodoman Basement Superterrane, evolved concurrently with greenstone belts in the Lake Victoria Region. Their linear geometries is atypical of similarly old terranes (e.g. Diener et al., 2005; Kisters et al., 2003; Van Kranendonk et al., 2009), whose long-lived growth histories are unlikely to be associated with giant gold deposits as consistently argued by many workers including Goldfarb et al. (2004). Notwithstanding that, the shape geometries of the greenstones domains in the Central Tanzania Region are similar to those of the northwestern Superior Craton, Canada and Youanmi Province in the Yilgarn Craton, which are host to significant orogenic gold deposits associated with Neoarchean reactivation of the older terranes (e.g. Lin, 2005, Fig. 2). Maximum lithodiversity, chemical-reactivity, several generations of felsic granitoid intrusion, and NE–SW-trending cross-faults are other critical targeting criteria in the superterrane (Figs. 13 and 14B). The East-Ubendian–Mtera Goldfield is considered to be far less gold-endowed than the more primitive Neoarchean terranes.

9.2.3. Selected Proterozoic Tanzanian Regions

The evidence that the Archean inliers in the Northwestern Tanzania Orogen were sutured to the gold-endowed Sukumaland Terrane, prior to tectonic reactivation of the basement structures (e.g. Klerkx et al., 1993), implies high prospectivity for orogenic gold deposits in the Nyakahura–Burigi Terrane (Fig. 9). Both geological and geochronological studies suggest that the broadly WNW–ESE trends of the superterranes in the Archean Craton of Tanzania can be traced into the Southern East African Orogen of Tanzania (Fig. 8). In that context: 1) the Mbulu–Masai Superterrane is probably the extension of the largely non-prospective Mwanza–Lake Eyasi Superterrane; and 2) the Usagara–Ukaguru Superterrane could be the extension of the Dodoma Basement Superterrane, which has only moderate gold prospectivity. Most artisanal gold prospecting activities and modern exploration interest lie in the Kilindi–Handeni Goldfield, which appears to represent an overprinted and partly reworked extension of the gold-endowed and prospective Lake Nyanza Goldfields. The recent recognition of significant gold prospects in the Kilindi–Handeni Goldfields, including the probable >40 t Au Magambazi deposit in the Magamba–Manga District, and under-explored gold prospects such as Mkurumu, Ngeze, Mnyoro, Kakule in the Mkurumu–Libabala and Ngeze Gold Districts (Fig. 11), emphasises its potential exploration importance. Like most amphibolite–granulite facies Neoproterozoic mobile belts worldwide, the Neoproterozoic (Pan-African/Mozambique Belts) rocks of Southern East African Orogen have extremely limited gold potential if prospective Neoarchean protoliths are absent.

9.3. Future work

1) Further work is required to underpin the superterrane-scale architecture of the craton, in order to highlight contiguous lithostructural patterns, bounding faults/shear zones and associated higher-order splays, and their links to gold-endowed provinces (goldfields) with small to giant gold districts. High-resolution magnetic, radiometric, and electromagnetic surveys and seismic reflection profiles are required across selected blocks, especially in the gold-endowed Lake Victoria Region, in order to define prospective gold districts within apparently poorly gold-endowed provinces.
2) At terrane (province) scale, the three-dimensional (3D) architecture of crustal blocks is needed in order to understand the distribution of lithotectonic boundaries in the early, rift-related architecture of proto-extensional basins hypothesised in the Biharamulo–Geita Belt in the Sukumaland Terrane. Studies of basin inversion, development of thrust folds and faults, and subsequent transpressional tectonics, and other similar studies should be undertaken in the Mkurumu–Magamba Terrane to help understand the relationships

between Archean protoliths and their subsequent orogenic overprinting and exhumation during the Neoproterozoic.

3) At domain (camp) scale, it will be necessary to compile lists of those features that are critical in controlling the distribution of gold camps. For example, it is important to determine if differences in gold endowment between the Nyamulilima–Samena, Sanza–Geita and Kukuluma–Matandani Domains are controlled by lithologic and/or geometrical orientation and the latest direction of maximum compression in the belt.
4) Scale-dependent (superterrane- to domain-scale) computer-aided prospectivity mapping is required to define any critical spacing of small to very-large gold deposits in the craton. This is required to see whether there are prospective terranes: 1) under regolith covers and/or reworked craton margins (East Lake Victoria and Lake Nyanza Superterranes); 2) in relatively thin greenstone belts bounded by extensive crystalline, high-grade metamorphic belts (Central Tanzania Region); and 3) potentially reworked or metamorphosed Archean gold systems (Southern East African Orogen).

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