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The Dodoma Morogoro Handeni-Magambazi Area, Eastern Tanzania

—A Proterozoic Sediment Hosted Vein Deposit

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Abstract

The Handeni area on the eastern edge of the Tanzanian Craton is within the Neoproterozoic Pan African Orogeny Mozambique Belt has been considered the area to be part of the "Sumukuland Corridor". In this paper, it is postulated to be Sediment Hosted Vein Deposits. Tanzania is the third-largest gold producer in Africa with an annual production at 60 tonnes. The Archaean Tanzanian Craton is surrounding Proterozoic Usagaran and Ubendian mobile belts. Outside of the Craton in the Ubendian only one mine is operating, to the southwest and one deposit in the "Kilindi Handeni Superterrane" to the east. The Pan-African Mozambique Metamorphic Belt to the east stretches from the south of Mozambique to Sudan and Ethiopia contain significant amount of gold in the Handeni-Morogoro-Dodoma area. The high metamorphic terrane between Morogoro and Handeni, has "cooked" the original rocks so identifying their origins is tenuous, but has copious amounts of garnets associated with regional metamorphism of sediments and volcanic. The Mozambique Metamorphic Belt represents one of the major sites of Gondwana amalgamation related to the Pan African Orogen, where two major orogenies are superimposed on each other. The Asian SHVs are at major Cratonic collisions part of the Central Asian Orogenic Belt with the Siberian Craton to the north and three Cratons to its south. This belt was the structural preparation of the Tien Shan Area with many deep sutures and thrusts for the deposition of the SHV deposits. These Cratonic collisions of the Asian Continent would be analagous to Gondwana's "collision" of East and West Gondwana. Sediment-Hosted Vein deposits are the largest gold-bearing vein deposits, along paleoTethyan margins of central Asia. The key features of passive margin settings that control mineralization include: 1) an unstable substrate of extended continental crust (comparable to the Tanzanian Craton); 2) a thick sedimentary sequence with associated syn- to post-depositional extension and contraction structures; and 3) reactivation and interplay between these components during fold-thrust deformation to provide pathways for deep-sourced hydrothermal fluids and magma. This south Siberian Craton (SSC) region has deposits and mineralization related to hydrothermal breccias and veins into the Paleozoic sediments as definitive models of SHV deposits. Major "sutures" are present. The Usagaran and Ubendian formations could be in an analogous tectonic zone. In the SSC region, the Central Asian Orogenic belt has identified oceanic assemblages, analogous to the opening and closing of the Mozambique Ocean similar assemblages, southeast and east of the Tanzanian Craton, as opposed to being reworked Archaeon Sumukuland Corridor. The Muruntau gold deposit is situated in Uzbekistan, have several structures, controlling the localization of the ore bodies in metasedimentary units, related to the bedding and schistosity, located sub-parallel to flat-dipping zones of thrust, shear and mylonitization and controlled by brittle deformation behavior of the rocks after metamorphism (not discordant with the Pan African Orogeny). SHV deposits have placer gold deposits and in the Handeni Morogoro area many placer have been found by the locals including the Magambazi deposit. Instead of the overprinting of the Archaean terrane, an accreting sequences of oceanic volcanics and sediments during the closure of the Mozambique Ocean with the formation of Gondwana being subsequently metamorphosed and "thrust" faulted against the Tanzanian Craton with the introduction of "fluid granitic magmas" is suggested. Island arcs are extremely prolific in mineralization. The "Mozambique Ocean" amphibolites as island arc remnants would be natural hosts and structurally "available" to enable mineralization in the Pan African Orogeny. There are oceanic assemblages in the Tien [Tian} Shan Accretionary Belt with less metamorphic intensity. The alternate Sediment Hosted Vein model, is proposed for the Kilindi Handeni Superterrane hydrothermal Orogenic gold deposits with metamorphism and deposition of gold along the continental collision structures. The parameters for a SHV deposit are present in the Handeni area. An "older" North American example of this level of metamorphism, associated with continental "accretion and/or collision" is the Adirondacks and the Grenville geologic province. Comparing the SHV and Archaean Overprint model, for the Orogenic gold mineralization, the SHV model fits.

Keywords

Gondwana, Mozambique Ocean, Sediment Hosted Vein Deposits (SHV), Orogenic Gold Deposits, Neoproterozoic Mozambique Metamorphic Belt, Usagaran Belt, Pan African Orogeny, Tanzanian Craton, Siberian Craton, Central Asian Orogenic Belt, Tien [Tian] Shan Belt, Magambazi Deposit, Muruntau Deposit, Placer Gold, Oceanic Assemblages

1. Introduction

The author has been conducting mineral exploration in Tanzania for almost 20 years and was one of the first geologists to see the new Magambazi discovery in 2005 (**Figure 1**). Although the author's exploration experience in Tanzania covered lots of area, with the 2009 discovery by Canaco (now East Africa Metals—"EAM") of the Magambazi deposit, he increased his focus on the Handeni area. With the exploration knowledge gained the author feels compelled to jump into the fray of speculating on the source of the wide spread occurrences of gold in what would commonly be a terrain that is passed over by geologists.

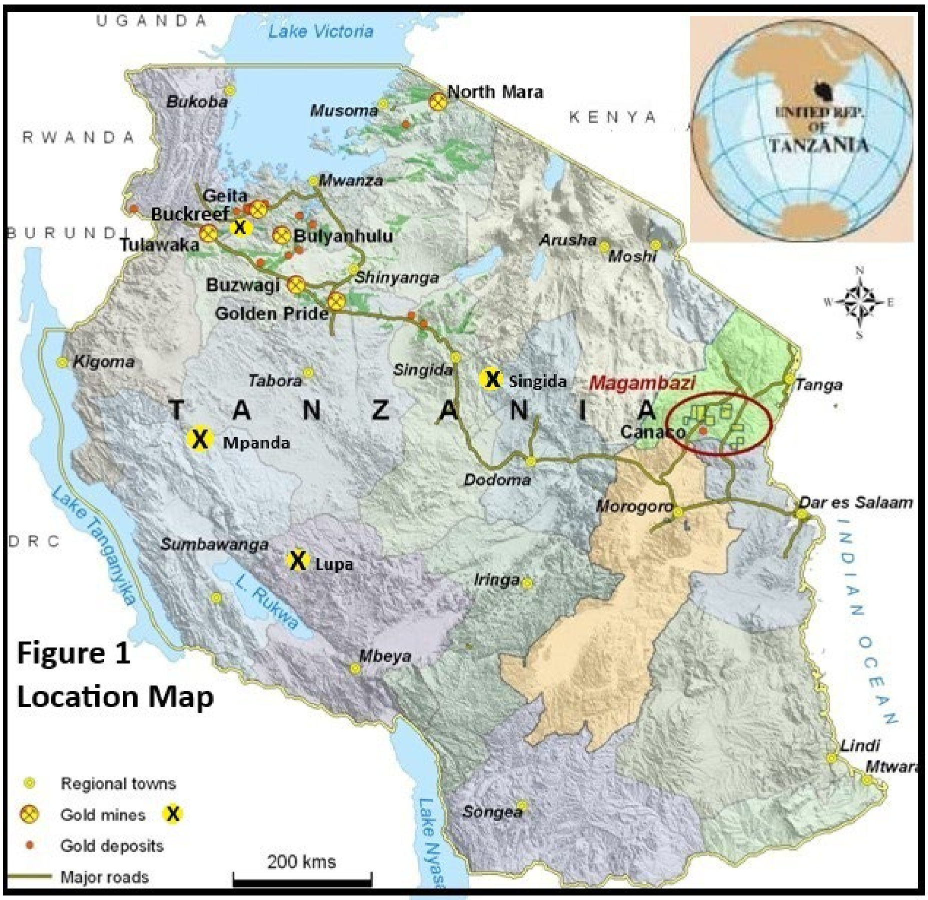

Figure 1. Location map of Tanzania—highlighting the Magambezi deposit area.

Some initial postulating has drawn on the proximity of the Tanzanian Archean Craton, its related greenstones belts and the significant and large gold deposits there (Barrick's Bulyanhulu deposit which has been in operation since the late 1990s and Anglo Ashanti's Geita Mine which has had been in operations since the early 2000s, both have a remaining mine life of, at least, 10 additional years) then projecting them into the terrain to the east, subjecting them to the Mozambique Orogeny that metamorphosed them to amphibolites to granulite facies to match what is present on the ground. Although some possible age dating by Kabete [1] is cited as possible confirmation that the Kilindi Handeni Superterrane is the eastern extension of the "Sukumaland Corridor" (**Figure 2**, Tectonic schematic of Tanzania [2]), the author's experience in the region, the lack of definable Archaeon greenstone remnants or altered equivalents and the 250 - 300 km distance to the lower metamorphosed craton severely limits this postulation.

There has been little research done on the “justification of this postulation.” Groves and Kabete proposed it in 2012 but as the lack of active exploration and development of the Magambazi deposit lessen, the interest in the area waned. The author has been recently involved in the area and his observations of the geology kindled a re-interest in their conclusions which he felt needed to be re-evaluated.

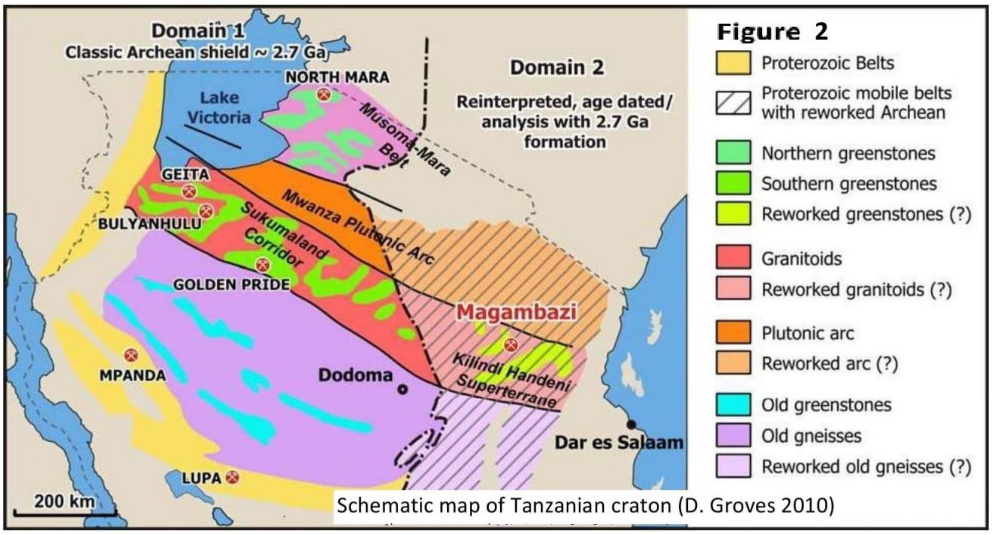

Figure 2. Schematic map of Tanzania craton.

The position of the Handeni area (**Figure 3**, [3]) along the eastern edge of the Tanzanian Craton is within the Neoproterozoic orogeny, related to the Pan African Orogeny, as part of the Mozambique Belt between ~620 - 603 Mya in age. However, Groves *et al.* [1] considered the area to be part of the “Sumukuland Corridor” (**Figure 2**) though to my opinion, this seem to be very unlikely as the area is far from the Sumukuland and the rocks types of the two terrains do not have any geological features [4], resembling it at all, apart from hosting significant amounts of gold. Gold in the Kilindi Handeni Superterrane is postulated by Groves *et al.* [1] to be of metamorphosed, Archean greenstones, orogenic type whereas it is postulated by the author to be to be Sediment Hosted Vein Deposits, based on Paul Klipfel’s outline, in his discussion in the 2005 Geological Society of Nevada 2005 Symposium [5].

This paper is intended to flesh out that postulating origin of the copious amounts of placer and hard rock gold showings throughout the area and inject more discussion into the origin of this mineralization in a terrane that is often if not almost always ignored by mineral explorationists.

Andy Smith of Canaco Resources (Now EAM) in one of his 2005 initial visits to this region stated, profoundly, “We are in an area of geology that according to our theoretic model should have had all the gold and other metals boiled out of it by the grade of metamorphism, yet we see significantly more value from gold production emanating from this region than exploration dollars have gone into it" [6].

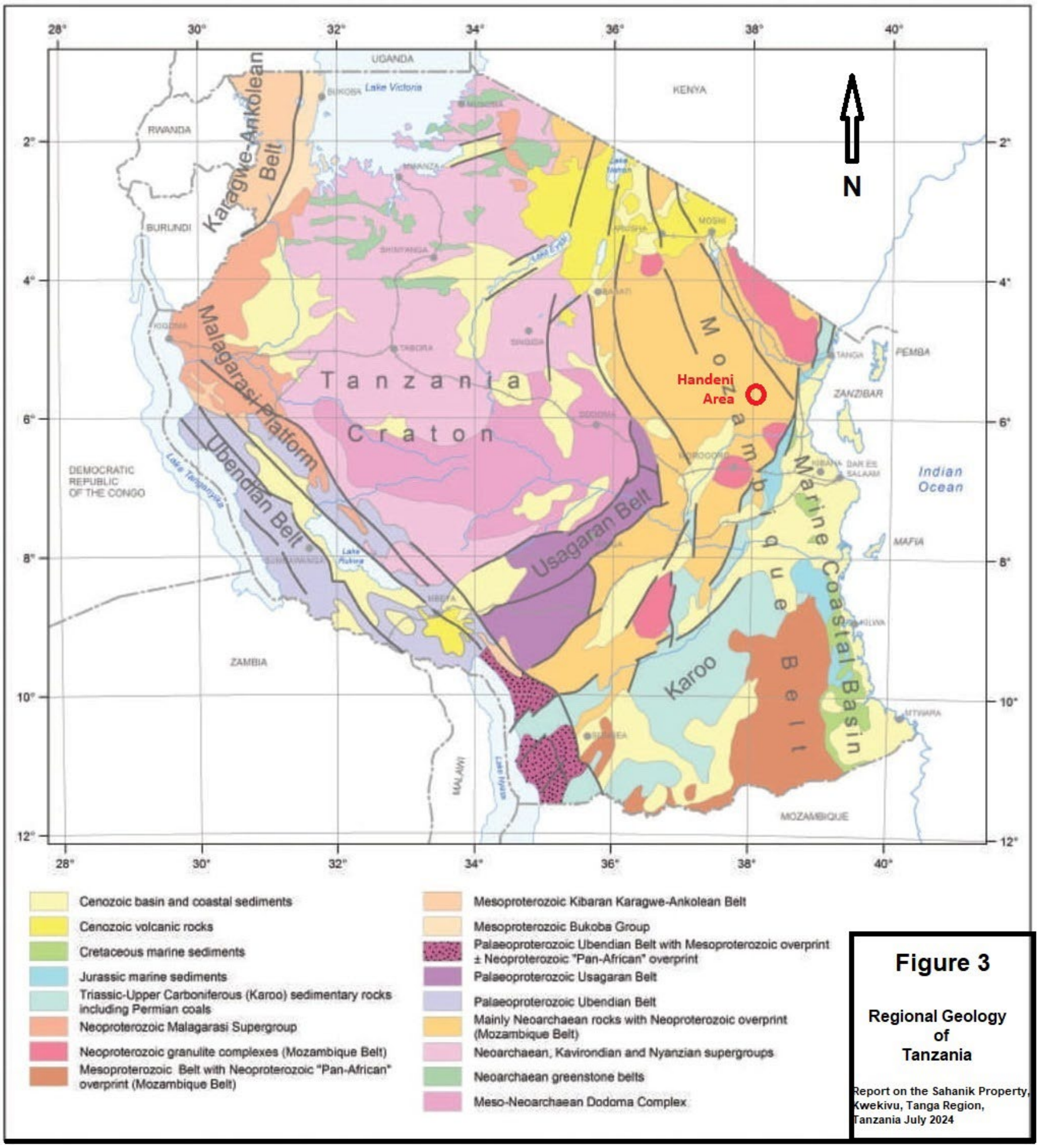

Figure 3. Regional geology of Tanzania.

The author in approaching the first showing in 2005 had to address the contrary impression from the high-grade metamorphic schists and gneisses outcrops passed en route, to the significant workings in this "leverite [leave her right there]" rock type.

Since then, more discoveries have been made in these high-grade metamorphic terranes (*e.g.* Plutonic and Tropicana in Western Australia, Groves *et al.* [1]) although as Dr. Ian Groves states" [most] Proterozoic mobile belts are typically devoid of gold deposits" (p. 241 [2]). Relating the Handeni District to these new emerging genera of gold deposits, is a worthy issue of discussion that might expand the continuing search for new and expanding resources.

2. Gold Production History of Tanzania

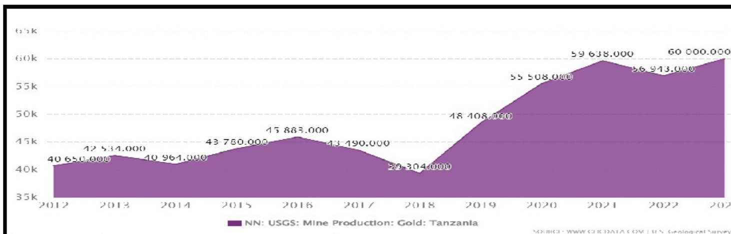

Figure 4 - Gold Production

<---Tanzania 2012-2023

Worldwide Rankings 2022

2022 rank	Country	Gold production (tonnes)[4]	% of total	Non-mined Reserves (tonnes)[5]	% of total
—	*World*	3,100	100.0	52,000	100.0
1	China	330	10.6	1,900	3.7
2	Australia	320	10.3	8,400	16.2
3	Russia	320	10.3	6,800	13.1
4	Canada	220	7.1	2,300	4.4
5	United States	170	5.5	3,000	5.8
6	Mexico	120	3.9	1,400	2.7
7	Kazakhstan	120	3.9	1,200	2.3
8	South Africa	110	3.5	5,000	9.6
9	Peru	100	3.3	2,900	5.6
10	Uzbekistan	100	3.3	1,800	3.5
11	Ghana	90	2.9	1,000	1.9
12	Indonesia	70	2.3	2,600	5.0
13	Burkina Faso	70	2.3	N/A	—
14	Brazil	60	1.9	2,400	4.6
15	Colombia	60	1.9	N/A	—
16	Tanzania	60	1.9	N/A	—
17	Papua New Guinea	50	1.6	1,100	2.1
18	Mali	50	1.6	800	1.5
19	Sudan	50	1.6	N/A	—
20	Argentina	35	1.6	1500	1.5
—	*Rest of the World*	630	20.3	9,400	18.0

Figure 4. Annual gold production For Tanzania 2012 - 2023; worldwide gold producing countries 2022.

Gold was exported from Tanzania following the penetration of Arab traders during the 16th to 19th centuries. However, the first commercial mines were developed in 1909 by German colonists at Sekenke in the Lake Victoria goldfields of the Tanzanian Craton. Following World War I, gold production grew steadily for about 30 years, but then declined. By 1967 output had all but ended as a result of the fixed gold price. There has been a strong revival in gold mining recently, based on changes in economic policies of the country, modern geological models, and technologically advanced recovery methods and strategic investment. Gold production reached 1.75 Moz in 2008, making Tanzania the third-largest gold producer in Africa [7]. Today it is rated as the 3rd largest gold producing country in Africa with an annual production at 60 tonnes (**Figure 4**—Annual gold production For Tanzania) and Worldwide as the 16th largest Gold producing country [8]. As noted above, Barrick operates two mines (Bulyanhulu and North Mara) and Anglo Ashanti one (Geita) that are located in the greenstone belts of the Lake Victoria Greenstone Belts (LVGB) within the Tanzanian Craton. As well, Resolute Mining (Australia) recovered over 2 million ounces from its Golden Pride Mine (1999-2013), and Barrick recovered an estimated 3 million ounces at its Buzwagi Mine (2007-2022) and from several other operations gold was or is being recovered (Buckreef Mine, Singida Mine). All these operations are in the LVGB (**Figure 2**).

Only one mine, the New Luika Mine (Shanta Gold) is operating in the Lupa gold area of the Ubendian orogeny rocks southwest of the Craton and one deposit (Magambazi) east of the Craton in the "Kilindi Handeni Superterrane" are, to date, located outside of the Craton. The Mpanda area had minor operations around 2000 and is actively being explored is west of the Craton (**Figure 1**).

The Magambazi area was first investigated by the author in 2005 when he was following up on the Ashanti Gold exploration work [9]. The artisanal gold miners there, were following up the placer gold in the river alluvium from the rivers draining the area which led to the discovery of the hard rock artisanal mining area. From that discovery by the artisanal miners, the Canaco Magambazi deposit was revealed.

3. Regional Geologic Setting

The Archaean Tanzanian Craton and its surrounding Proterozoic mobile belts underlie much of the Central Plateau of Tanzania (**Figure 3**). The southeast limit of the craton is marked by the Paleoproterozoic Usagaran belt, dated at 2000 Ma, while the eastern part is bounded by the Neoproterozoic (900 - 500 Ma) Mozambique collisional belt. To the southwest, the 2000 Ma Ubendian belt marks the edge of the craton, whereas to the west the boundary is marked by the Mesoproterozoic Karagwe-Ankolean belt and the Neoproterozoic to early Paleozoic Malagarsi Supergroup. Completing the boundary in the northwest is the Ruwenzorian belt of Uganda.

The main part of the Archaean craton has two main components. The Dodoman System comprising of migmatites, biotite gneisses, gneissic granites and local massifs of biotite granites located in the southern portion of the Craton and the Nyanzian greenstone belts (the "Sumukuland Corridor") to the south and east of Lake Victoria, in the northern part of the Craton.

The eastern arm of the East Africa Rift system, with its Kilimanjaro related Tertiary mafic to intermediate volcanics including carbonatites, occurs mainly in the north of the country "flowing" on the east side of the craton and the western East Africa Rift system with its deep lakes (Tanganyika and Nyasa) related to the Paleozoic sediments and volcanic of the Malagarasi (Gagwe) system "flowing" on the west side of the Craton.

Wrapping around the Tanzanian Craton on the southwest south and most of the east and affected by the East Africa Rift System are the Proterozoic Usagaran and Ubendian systems. These systems are postulated by Groves and Kabete [1] as being the metamorphosed edge of the Archean Craton affected by the Mozambique orogeny. However, Fritz *et al.* [10] suggested that "the Usagaran Belt was strike-slip tectonics in an Island arc regime" while the Mozambique Belt was related to the westward thrusting of east Gondwana onto west Gondwana.

South east of the Craton and its surrounding fold belts is found the Paleozoic/Mesozoic Karroo System of mainly continental clastic sediments succeeded towards the coast by continental shelf and marine sediments of the breaking apart of Pangaea in the Mid Jurassic to recent.

Until the Canaco Magambazi discovery in 2009, the Archean greenstone belts of the Lake Victoria Region hosted the major gold deposits in Tanzania. However, there have been related gold discoveries in similar Proterozoic rocks to the south and west (New Luika Mine) of the Archean Craton.

4. The Structural History of the Tanzanian Proterozoic Rocks

Proterozoic rocks in Tanzania include the Palaeoproterozoic Ubendian and Usagaran Belt to the southwest and southeast of the Craton, the Mesoproterozoic Karagwe Ankolean Belt to the northwest of the Craton and the Neoproterozoic Mozambique Belt (the Pan African Belt) to the east of the Craton.

Of note to the discussion is that both Belts represent earlier continental collisions with the Tanzanian Craton, prior to the younger Mozambique Metasedimentary Belt formation.

The Ubendian Belt borders with the Usagaran Belt to the south-east. Together, they surround the southern margin of the Tanzania Craton. The Usagaran Belt strikes to NE-SW to E-W and is composed of continent-continent collision related metamorphic suites; subduction related eclogites and back arc related pillow basalts. The Usagaran subduction event dates between 2.05 and 1.99 Ga indicating that it is slightly older than the 1.9 - 1.86 Ga Ubendian subduction.

The Usagaran belt sinistral transpression deformation took place between 2000 ± 1 Ma and 1877 ± 7 Ma with an indicated post 1877 Ma reactivation of the Isimani Suite (to the south east of the Craton, see **Figure 5**). This reactivation may have taken place during Paleoproterozoic exhumation of the Usagaran Orogen or may be the result of deformation associated with the Neoproterozoic East African Orogen [11].

The age data indicate that the Isimani Suite of the Usagaran Orogen reflects reworking of Archaean continental crust, with subsequent greenschist facies deformation, localized as shear zones on the boundaries.

One explanation is the belt was formed by the collision of two continents if the continents fortuitously had the same protolith ages. A second, more likely scenario is that the protoliths of the mafic eclogites were erupted in a marginal basin setting as either oceanic crust, or as limited extrusions along the rifted margin of the Tanzanian Craton [11]. The Usagaran Orogen may therefore reflect the mid-Paleoproterozoic reassembly of a continental ribbon partially or completely rifted off the craton and separated from it by a marginal basin.

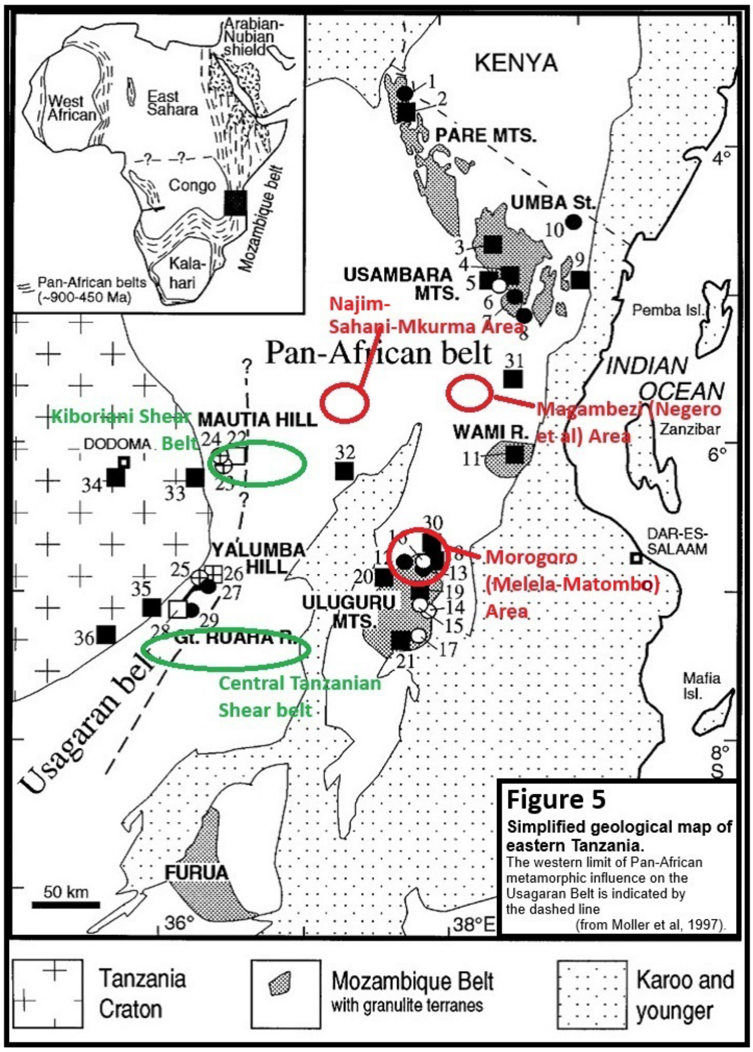

Figure 5. Simplified geological map of eastern Tanzania.

However, there is little structural data published from the Usagaran Orogen, and what data there is, does not constrain the kinematic evolution of the Usagaran rocks.

The Ubendian Belt, further to the west, between the Archean Tanzania Craton and the Bangweulu Block, represents a Paleoproterozoic orogeny of these two constituents of the Congo Craton assembled at ~1.8 Ga, forming the Central African Shield, during the Columbia Supercontinent cycle and consolidated during the Gondwana assembly [12].

All evidences suggest that the Bangweulu Block and the Ubendian Belt participated in the amalgamation of the Central African Shield as separated continents surrounded by oceanic crusts during the Paleoproterozoic Eburnean and the Neoproterozoic Pan-African orogenies. Subduction and accretion in the Ubendian Belt to the Tanzania Craton apparently initiated within the Katuma and Lupa Terranes, and proceeded by fusion of the Upangwa and Nyika Terranes as they recorded the oldest magmatism. The activation of subduction culminated between 1.89 and 1.86 Ga, associated with crustal thickening and gold mineralization

Subsequent collision and accretion between the Tanzania Craton and the Bangweulu Block occurred at ~1.83 - 1.82 Ga. The Ubendian Belt together with the Usagaran Belt evidences an important tectonothermal event: assembly of the Tanzania Craton and the Bangweulu Block with the Congo Craton and forming the Central African Shield as long-lived convergent margin of Archean craton fragments during Paleoproterozoic period and their participation to the Columbia supercontinent amalgamation.

The final continent-continent collision is marked by 530 and 520 Ma eclogites. The 590 - 520 Ma regional tectonothermal event of the Ubendian Belt contemporaneous with Neoproterozoic consolidation of the Central African Shield and final Gondwana assembly by the Pan-African orogeny, and the formation of the Mozambique Metasedimentary Belt.

At least five major magmatic events connected to the assemblage of supercontinents has been observed in this region that would have affected the eastward "continuation" of the Sumukuland Corridor: ~250 Ma (Pangea), ~560 Ma (Gondwana), ~1 Ga (Rodinia), ~1.8 Ga (Columbia/Nuna) and ~2.6 Ga (Kenorland?).

The Bangweulu Block and the Ubendian Belt participated in amalgamation of the Central African Shield as separated continents, surrounding oceanic crusts during the Paleoproterozoic Eburnean orogeny and the Neoproterozoic Pan-African orogeny. The Usagaran Belt possibly a bit older, could be a similar accretion as outlined above, or mid-Paleoproterozoic reassembly of a continental ribbon partially or completely rifted off the craton and separated from it by a marginal basin.

The relationship that the Mozambique Metasedimentary Belt is separate from the Usagaran Belt suggests that the Kilindi Handeni Superterrane units are discrete. Thus, a more pertinent relationship to the younger closing of the Mozambique Ocean should be considered.

The Pan-African belt of metamorphic rocks is a major orogenic belt known as the Mozambique Metamorphic Belt that is along the east coast of Africa, stretching from the south of Mozambique to Sudan and Ethiopia (**Figure 5**, [13] [14]). Old literature wrongly, refer the Mozambique Belt as part of the Usagaran Belt but this usage is not acceptable at present. The age of the Pan-African metamorphic event in Tanzania has been dated at 615 - 650 Ma on the basis of U-Pb monazite geochronology [13]. In addition to the well-known Lake Victoria Goldfields in the Archean greenstone belts, several significant gold targets have been revealed in Early Proterozoic (Ubendian) rocks in Tanzania to the west and south of the Archaean Craton. In some cases, the host rocks are Archaean in age and have been subsequently overprinted by Proterozoic metamorphism. These areas represent areas long established, as potentially viable for gold deposits, with several decades of mineral exploration. The Neoproterozoic Mozambique Belt also contain significant amount of gold mainly in the Handeni-Morogoro-Dodoma area (referred to on **Figure 5** as "Magambazi" (Negero *et al.* area, Najim-Sahani-Mkurmu) area and the "Morogoro" (Melela-Matombo) area and to a small amount, in the Usambara and Pare Mountains to the north.

To the southwest of the Tanzania Archean Craton at Mpanda (**Figure 1** and **Figure 3**), gold deposits occur in Early Proterozoic (Ubendian) rocks, within a suite of metamorphosed sediments intruded by granites and stockworks. The mineralisation is found within northwest-trending shear zones adjacent to the granites. At nearby Lupa, gold is found in shear zones near acid and basic intrusions. The Lupa area mineralisation in lodes and secondary deposits is of greenschist-amphibolite metamorphic grade, considerably lower than the majority of the Ubendian, and may be considered to be reworked Archaean greenstones [1] [2].

I have not seen these rocks but the description and conclusion of Archaean Parenthood is plausible but the proximity of the intrusives and shear zones suggests a typical structural intrusive related interaction not necessarily dependent on the parenthood of the host rocks. Two major mainly E-W shear zones investigated by Fritz *et al.* [10] just south of the two gold areas cited (The Kiboriani and Central Tanzanian **Figure 5**) are referred to as being "oblique crustal scale" which suggests significant structural activity from the unification of Gondwana which tends to negate the "in place metamorphism" required for the Kilindi-Handeni Superterrane to be a continuation of the Sumukuland corridor. As well, it confirms the "deep sutures" are present just as they are in the tectonics of the Asian SHV.

In eastern Tanzania, the newly recognized region of gold deposits associated with the Magambazi deposit in higher grade metamorphic Proterozoic (Mozambique) rocks has been referred to as the Sumukuland Corridor extension to the east (the Kilindi Handeni Superterrane, **Figure 2**) by Groves *et al.* [2] It suggests this southeastern extension of the greenstone belts of the Lake Victoria Gold Fields may host additional gold deposits that may be re-worked Archean deposits.

The author has had recent and extensive exposure to various localities from Morogoro to Handeni in these rocks and it is hard to confirm the original rock type in any shape or form in sufficient surety to broach the 250 - 300 kilometre distance to the greenstone belts of the Lake Victoria Goldfields. Along with Fritz's [10] observations cited above, it makes the conclusion of Archaean Parenthood, less plausible and the lack of notable intrusives and shear zones suggests a different structural environment again, not necessarily dependent on the parenthood of the host rocks. This area was structurally impacted by the 630 - 650 Mya Pan East African Orogeny but the metamorphosed sediments, amphibolites, gneisses also fits with a continental shelf margin to the craton parenthood with associated

"Island arc assemblages" that were developed and added during the formation of the Gondwana paleocontinent, related to the closure of the "Mozambique Ocean (**Figure 6**, [10])."

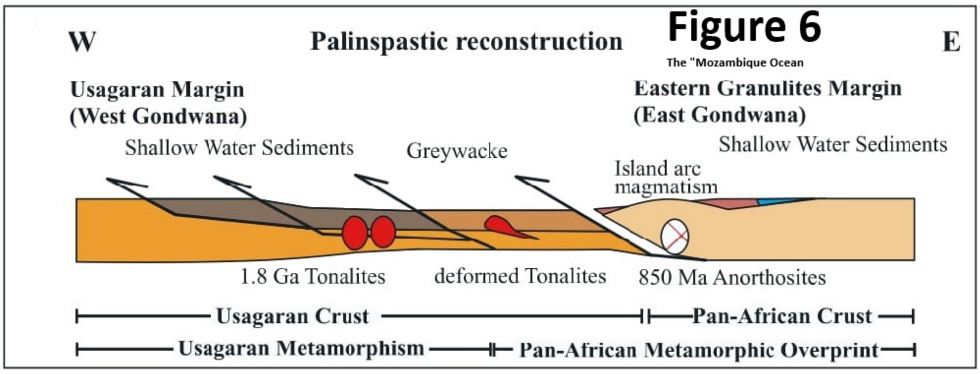

Figure 6. Palinspastic reconstruction (east meets west Gondwana).

The conclusion that the high metamorphic grade Kilindi-Handeni Superterrane, on the east-southeastern edge of the Tanzanian Craton (the LGVB Craton) and on strike to the ESE of the Lake Nyanza Superterrane (the Sumukuland Corridor) is overprinted by Neoproterozoic orogeny comprised of curvilinear metamorphosed supracrustal sequences, including amphibolites, within granitic gneisses which are transected by ENE trending shear zones [1] is an unmoved metamorphic continuation, becomes less tangible and, in my opinion, from the geology observed, not an obvious conclusion.

5. Local Geology

The author observed the high metamorphic terrane between Morogoro and Handeni. What is consistent is that the grade of metamorphism has "cooked" the original rocks to a point that identifying their origins is very tenuous. Little to no petrographic work has been done on the immediate area rocks of the Kilindi Handeni Superterrane. The grade of metamorphism is cited by Kabete [15] who was intimately involved in the Magambazi deposit area. The High grade metamorphism is also cited by Groves *et al.* [1] and extensively by Bitesigirwe [16]. Bitesigirwe did extensive petrographic work and analysis but summarized it as being "high grade metamorphism," namely amphibolite and granulite facies, with garnets associated with both. Fritz [10] also described the metamorphism as Greenschist to Granulite in an area farther to the south.

However, the presence of copious amounts of garnets in almost the whole region associated with mainly the more mafic amphibolitic units is an area trait. Little to no garnet chemistry has been done on them and they are present throughout the region.

Garnets are most common in metamorphic rocks including sedimentary rocks with a high aluminum content (Schists and gneisses) and igneous Basaltic rocks (some Ca-bearing) as Amphibolite [17].

They represent a Metamorphic Environment as a Middle grade regional metamorphism along a convergent plate boundary which was present in the formation of Gondwana. That garnets are associated with regional metamorphism of sediments and volcanic, suggests the original rock type in this area has that affinity (marine sediments, island arc assemblages and ophiolites).

Figure 7. Folded garnet-quartzo-feldspathic granulite outcrop at Melela area, showing low angle dip [18].

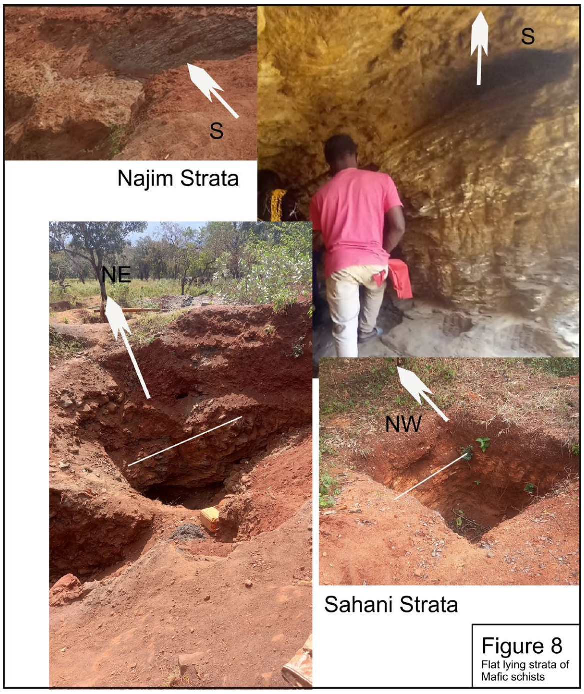

Figure 8. Flat lying strata of Mafic Schists.

In the Morogoro West area (Melela) geological mapping by Charles Mnguto outlined the high-grade metamorphism of the rocks in low angle "bedding" formations (**Figure 7**, [18] [19]). Similarly, to the southeast of Morogoro area (Matombo) and also to the north east, similar low angle formations were observed. Garnets were again ubiquitous to the rock units [19] [20]. The author also observed these same characteristics in the Kilindi area southwest of Handeni associated with the Najim "Mine" and the Sahani Area (**Figure 8**) and in several other locations in the immediate area of Handeni (south and southwest). However, there appears to be less garnets associated with the Sahani area.

Granulites of the western Uluguru Mountains which form a backdrop to the city of Morogoro and a topographical barrier between the Melela area (west) and the Matombo area (east) have composition indicating possible derivation from cratonic and/or Usagaran material, reworked and mixed with a small proportion of younger Proterozoic material during the Pan East African orogeny. This could indicate a suture zone between a western Archean-Proterozoic continental mass (Tanzanian Craton) and juvenile arc-terranes docking on from the east during subduction of the Mozambique Ocean.

A possible boundary between two of these crustal domains lies within the Uluguru Mountains granulite complex and may be marked by an apparent lithological contrast between the eastern and western Uluguru Mountains. The eastern Uluguru Mountains (Matombo) consisting of a supracrustal sequence with dominant marbles and metapelites, whereas the western part (Melela) consists of the granulite complex, is a lithological boundary that may coincide with the age province boundary. Moller based this on Nd model ages: "Granulites of the W Uluguru Mountains have Nd model ages between 2.1 and 2.6 Ga, and highly variable feldspar Pb isotope composition indicating possible derivation from cratonic and/or Usagaran material, reworked and mixed with a small proportion of younger Proterozoic material during the Pan-African orogeny. This could indicate the suture zone between a western Archean–Proterozoic continental mass and juvenile arcterranes docking on from the east during subduction of the Mozambique Ocean" [14].

Continental sediments of the Karoo abut the mountains to the east in a typical flat-floored African Rift environment. Both this, and the Mkata Plains to the north are covered by extensive tracts of mbuga (marshy ground), recent alluvium and thick residual soils.

Many of these rocks in the eastern Uluguru Mountains are of apparent sedimentary origin that have been metamorphosed to upper amphibolite and granulite facies (Part of the Mozambique Ocean, **Figure 6**). Garnet quartzo-feldspathic granulites and marble, generally resistant to weathering, tend to cap the main hills. These rocks overlie garnet-biotite gneisses, amphibolites and mafic granulites. The metamorphic rocks are intruded by pegmatites, pegmatitic quartz and quartz-microcline dykes and veins of Mozambique Metamorphic and post-Mozambique Metamorphic age [20].

The author found it was hard to identify any physical difference between the Garnet quartzo-feldspathic granulite in east or west although a general observation, that the west is more felsic, can be made. In the area of Matombo the units were mostly sub-horizontal, there are steeper dips near the sole thrust zone identified, at the current level of erosion. The general strike of the regional foliation is north-south. In the east, the Matombo Formation marbles lie in a series of gently folded thrusts which have been thrust faulted over the Lukwangule granulites. Together they comprise what is known as the Ruvu Nappe, comprising a northwest-southeast striking open syncline pair. The sole thrust of the nappe strikes north-south for most of its 60 km length. The rift fault between the up-thrown Mozambiquian gneisses and the downthrown Karoo sandstones is exposed in road cuttings on the Matombo-Mvuha road.

Although very little research has been done on structures, folding and dips and their timing relationship (Fritz *et al.* [10] has done some "age dating" to the south) most references attribute it to the Pan African Orogeny. The strikes dips and other structures reported below are from Mnguto's [18] Musira's *et al.* [20] and the author's observations.

The Ruvu Nappe shows the area was under regional deformation as a major tectonic facies, that it is associated with both artisanal alluvial and hard rock mining at various locations along 45 km of its length, in the Dodoma Morogoro Handeni area, suggests that: "a large, sheet-shaped body of rock that has been moved from its original position by folding or faulting. Nappes are a fundamental unit in tectonostratigraphical classification" [21]. It suggests that parts of the Mozambique Metamorphic belt have been "moved" ergo the continuation of the Sumukuland corridor continuing as the Kilindi Handeni Superterrane is suspect.

Evidence of two periods of folding that might have some relevance to the mineralization, dips to the east in the range 20˚ - 40˚ for the north south striking units. Mnguto in his mapping outlined the formational extent and characteristics of the Melela area with the shallow dipping foliation in the 10˚ - 15˚ range (strikes are NE and SE) and shears in the 20˚ - 40˚ range [18]. Two major structures of the interpreted shears, associated with gold mineralisation (at Matambo) are trending WNW-ESE and NNE-SSW. Steeply dipping faults cutting these, trends in a N/S and NE/SW fashion [20].

At the Sahani area the author observed the "strataform" amphibolites striking WNW ESE and dipping 30˚ - 40˚ S or N (A gentile syncline in the area was observed), while at the Najim area the same general characteristic was seen (shallow south dip).

Both areas demonstrate lots of structural interaction that would be expected during the continental formation of Gondwana. It suggests lots of potential tectonic movement.

6. Structural History of the Region

The Mozambique Metamorphic Belt represents one of the major sites of Gondwana amalgamation related to the East African Orogen [22], where two major orogenies are superimposed on each other (**Figure 9**, [22]). The East African Orogeny (as later defined) at ~650 - 630 Mya affected a large part of Arabia, North-Eastern Africa, East Africa and Madagascar. Collins and Windley [23] propose that in this orogeny, Azania, collided with the Congo–Tanzania–Bangweulu

Block. The later Malagasy orogeny at ~550 - 515 Mya affected Madagascar, eastern East Africa and southern India. In it, Neoproterozoic India collided with the already combined Azania and Congo–Tanzania–Bangweulu Block. At the same time, in the Kuunga Orogeny, Neoproterozoic India collided with the Australia/Mawson continent [24] [25].

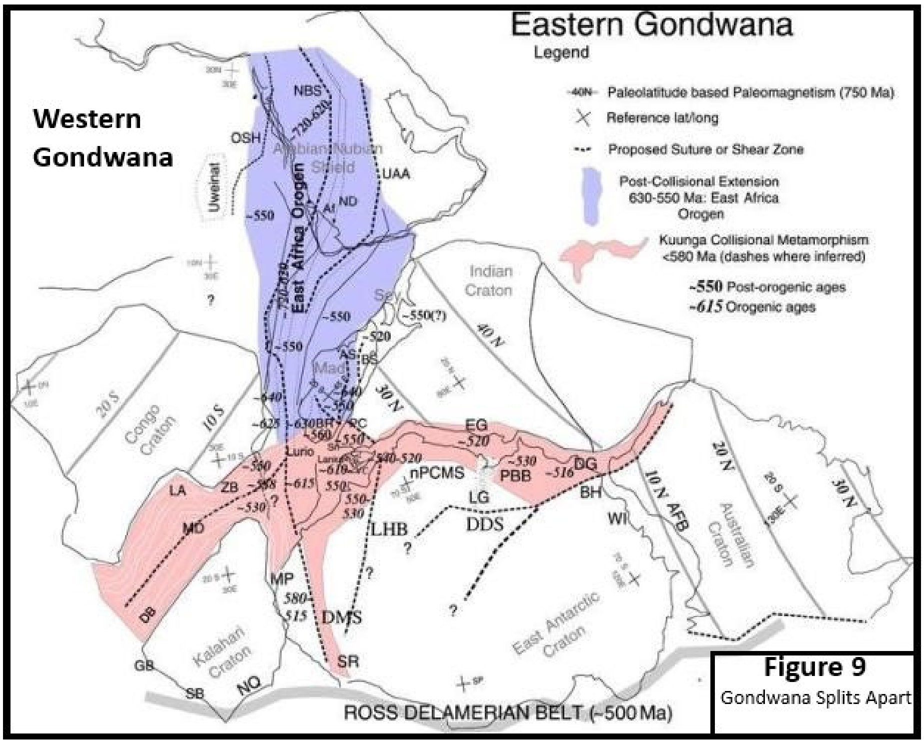

Figure 9. Gondwana splits apart.

This amalgamation continued to grow to the Pangaea supercontinent but in effect after this collision period the pressures were on the splitting of the land masses in this region so that most of the structural preparation had to be complete.

As the proposed collision course of the Indian block would have been from the south east and then the secondary collision of the Australian block (like a multiple rear end collision in traffic), the area between the Tanzanian Archaean Craton and the Azania Block should develop northwest and northeast conjugate structures related to these collisions.

Thus the Mozambique belt as it was being prepared, faced eons of depositional sedimentation as the continental foreland shelf (Figure 6) then with the Gondwana continental collision, prepared structurally and as the super continent broke apart with the Australian and Indian blocks, having done the smashing damage, going on their way, leaving the Mozambique Belt at its current placement on the west side of the Indian Ocean.

It is pretty commonly accepted that the Indian block was part of the formation of Gondwana and left that area, swinging north to interact with the Siberian Continental block forming the Himalayas. The Indian Block having done its "collisional" damage on "Africa" would now smash into the Siberian Continental Block to the north. Although that impact is significantly younger (~60 Mya) than the formation of the Asian SHVs (~300 - 400 Mya) it illustrates the continuous (?) northward tectonic plate movement that would not only create the Himalayas but structurally prepare the ground that hosts the largest SHV deposits known to date (part of the dynamism that created the Central Asian Orogeny?). A coincidence that the Indian Block would be instrumental in creating two separate SHV arenas, is purely speculative but an interesting "speculation!"

The structural preparation of the area has been completed. The presence of significant carbonate formations, as a significant regional formational unit, north of the Magambazi area (just south of Handeni) and in the area southeast and east of Morogoro (Matombo Mkese areas) would be conformable to the SHV model. Kabete and Groves identify the rocks of Songe Terrane of the Kilindi-Handeni area as carbonaceous and graphitic overlying (?) the structural amphibolite formations that extent west in the major structures identified by Groves associated with the Magambazi deposit [1] [2] [26]. These conformable (?) probable shallow sea deposition environment confirms the continental shelf nature of the area units as marine sediment +/− volcanic (Island Arc?) deposited formations.

The Sumukuland Corridor of the Tanzanian Craton is well established but it is the continuation into the Mozambique Metasedimentary Belt, through a very tectonically active area of the various orogenic periods that formed the distinctive Ubendian and Usagaran Belts without geographic movement that is questioned. The sharp contact between the Craton and the MMB (and Usagaran and Ubendian areas) suggests that the "Eastern MMB" rocks are a distinctive unit.

The tectonic model of the opening of the Mozambique Ocean to form Marine sediments, island arc assemblages and ophiolites and then pushing and deforming them to the west with the formation of Gondwana. These features are present in the of the "younger" SHV model seen in the area of the Asian SHV deposits.

Although metallically similar, no research has been completed in this region on the other identified showings or even the Magambazi.

7. The Structural History of the Asian SHV Deposits

The first notable feature of the Asian SHVs is their juxtaposition at the point of major Cratonic collisions with the Siberian Craton being the central figure and the Tamil Craton (to the east—part of or adjacent to the North China craton), the Pamirs Craton, central and the Karakum Craton to the west. Notably all these "collisions" were probably instrumental in the formation of the Central Asian Orogenic Belt (**Figure 10**) and contribute to the structural preparation of the Tien Shan Area for the deposition of the SHV deposits.

That these Cratons were being "subducted" under the Siberian Craton like the Indian Craton is being under the Tibetan "Plateau" [27] that contributed to the Tibetan Plateau mineralization is unknown but that relationship would be interesting to develop.

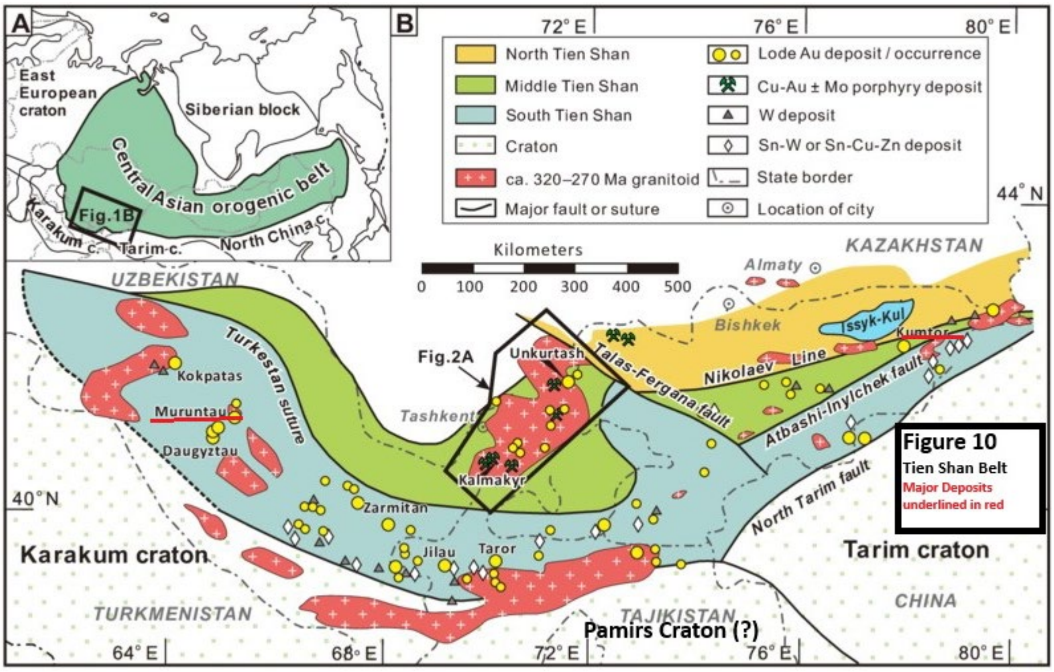

Figure 10. Tien Shan belt-major deposits.

This continental development of the current Asian Continent would be analagous to the formation of the Gondwana continent by the "collision" of East and West Gondwana (Figure 9) in the structural preparation of the current East African continent discussed above. The presence of the many gold occurences in the Tien Shan belt would be homogolous to the many areas of gold in the Neoproterozoic rocks of Eastern Tanzania. The 300 - 500 mya age difference and metamorphism of the Pan African Orogeny (from ~650 mya - ~530 mya) would be relevant in the distortion, distribution and details of these Neoproterozoic gold occurences compared to the "younger" Tien Shan manifestations.

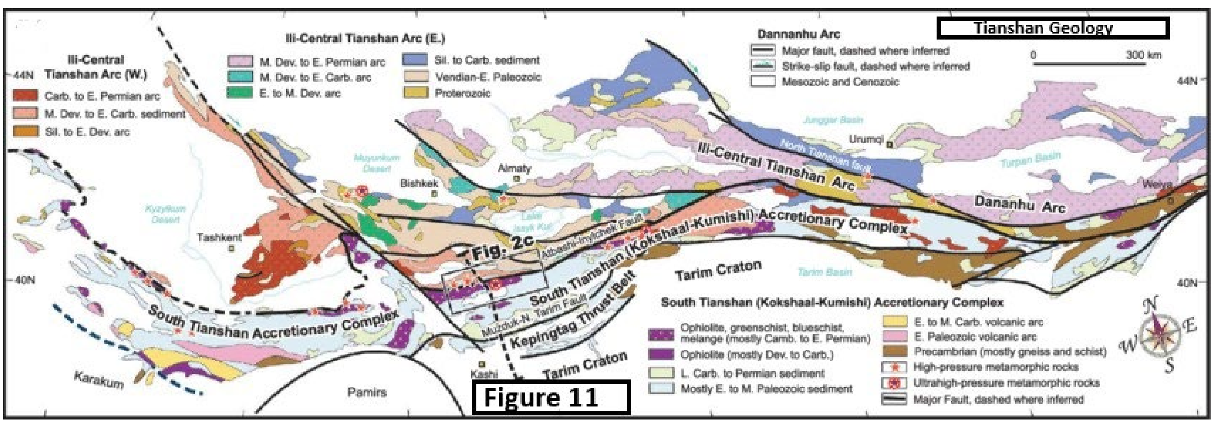

Figure 11. Tianshan geology.

The Tien Shan belt of Asia is in a similar position between the three southerly Cratons of the Indian plate and the northerly Siberian Craton (Aka: The Indian, Antarctica and Arabian cratons to the east and the westerly Congo/Tanzanian Craton). The presence of identifiable Ophiolite and other volcanic formations in the adjacent complexes (Figure 11) is indicated by Berhe [28] (Kenya and Ethiopia) and Kabete as present in the Mozambique Metasediment Belt suggests a similar environment in the older Mozambique Ocean.

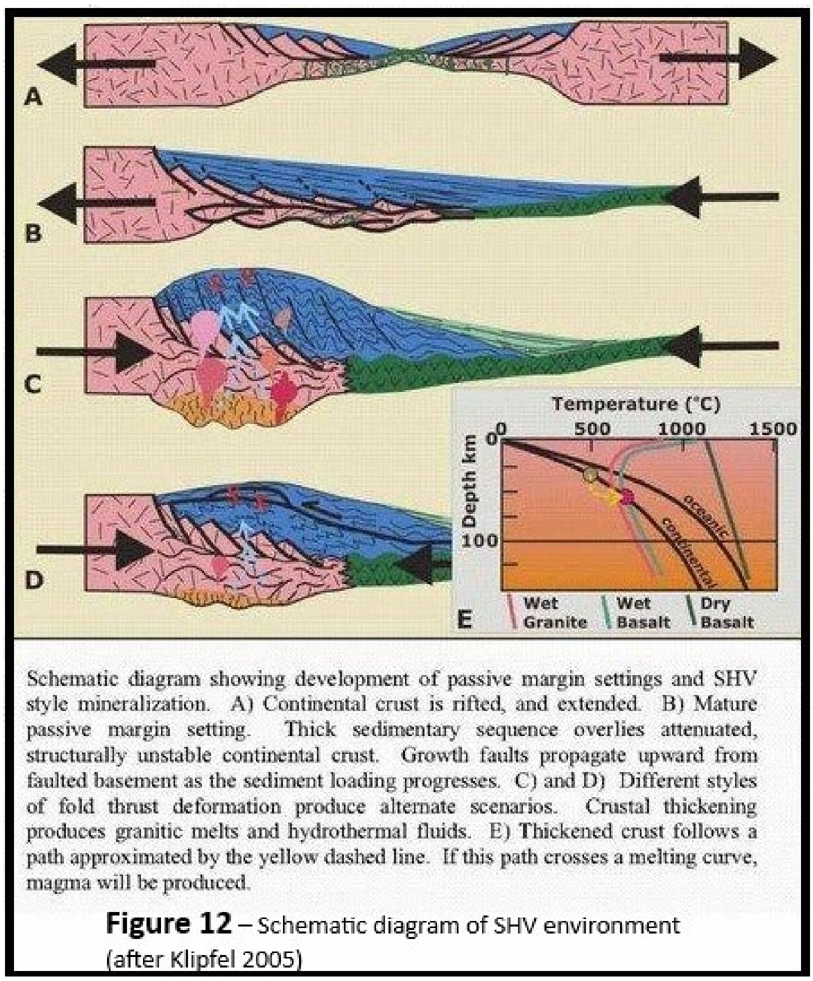

Figure 12. Schematic diagram of SHV environment.

The oceanic assemblages in the Mozambique Metamorphic Belt were noted by Berhe and Kabete. They are illustrated as evidence of occurring in both the Mozambique Ocean and the ancient Asian ocean that was between the Indian/Siberian Cratons. However, they do not appear to be integral in the deposits of that Tien Shan region.

The question of how are they related to the formation of the SHV is suggested by Klipfel's Model as being "conduits" for mineralizing solutions.

The easterly-westerly Tien Shan belt has been actively structurally prepared with many deep sutures, some thrust related (Figure 11—it should be noted that the spelling in this figure is "Tianshan"), the rock units associated with this belt are opholites, island arc volcanics and sediments (marine)—a intercontinental ocean?—not to disimilar to what is found in the northerly-southerly Mozambique metasediments [10] [28]. That there are major sutures identified in the Tien Shen Belt that have/or should be identified in Tanzania, although not obvious, would allow the introduction of granitic magmas, due to this tectonic activity (as postulated in Klipfel's model **Figure 12**) is a characteristic associated with both regions (See the "deep sutures" in—**Figure 6** and compare to those identified in **Figure 10** and **Figure 11**).

8. Sediment Hosted Vein Deposits

If we are going to propose the Handeni area as a Sediment Hosted Vein (SHV) Deposit, we should look at what the deposit type is all about.

The main feature of large-volume gold deposits of Central Asia and Kazakhstan (resources more than 100 tons, low gold grade) is their relation to the suture zones created in the environment of subduction and collision of microplates during amalgamation of Eurasia continent. This would conform to the amalgamation of +500 Mya older Gondwana.

Sediment-Hosted Vein (SHV) and Sediment Hosted Disseminated (SHD) deposits are common in other parts of the world, particularly along paleo Tethyan margins of central Asia. Considering SHD and SHV deposit types in this manner offers a unifying concept that partially explains the location and origin of these deposits. The key features of passive margin settings that appear to control mineralization include: 1) an unstable substrate of extended continental crust (comparable to the Tanzanian Craton); 2) a thick sedimentary sequence with associated syn- to post-depositional extension and contraction structures (the formation and splitting of the paleo continents of Rodinia and Gondwana); and 3) reactivation and interplay between these components during fold-thrust deformation to provide pathways for deep-sourced hydrothermal fluids and magma (The Pan African Orogeny for one). The major characteristics of both Sediment Hosted Vein (SHV) and Sediment-Hosted Disseminated (SHD) deposits are nearly identical although there are a few significant differences but we will focus on the SHVs.

These deposits have typically low grade gold (1 - 3 grams per ton) with some high grade veins making the core but represent some of the largest deposits in the world. Some possibly comparable examples include Muruntau (60-plus million ounces gold), Natalka (40-plus million ounces gold) and Sukhoy Log (30-plus million ounces gold) and the major prospect Kumtor (~8 million ounces) [5]. The Muruntau, and Kumtor deposits are located south of the Siberian Craton in Central Asia (**Figure 12**), while Sukhoy Log and Natalka are east of the Craton.

Klipfel outlined the description of SHV as follows [5]:

"Sediment Hosted Vein deposits constitute a family of gold-bearing vein deposits that occur worldwide, but are found primarily in Asia. This group includes some of the world's largest gold deposits such as Muruntau, Sukhoy Log, Baleyskoe, Maysky and Kumtor among others in Asia and Bendigo and Ballarat and many other smaller gold vein deposits of the Victorian gold fields in Victoria, Australia. Other smaller deposit examples occur in Nova Scotia, Canada; Nome, Alaska, USA and in pre-Cordillera rocks of South America. These deposits are united by common characteristics, which include Late Proterozoic to early Paleozoic passive-margin shale-siltstone host rocks, extended crust as basement to the host rocks, multiple episodes of deformation of which fold-thrust tectonism is the most significant, Au ± As, Sb, W metal suite, neutral, low to moderate salinity hydrothermal fluid chemistry, minimal to moderate grade metamorphism, active granitic magmatism in the crust at or near the time of mineralization, and occurrence within a field of multiple deposits commonly in association with large placer fields."

The SHV deposits in general are Orogenic vein deposits that are described as similar to those found in the Western US and other areas (Klipfel [5]). Remarkably, this list of characteristics is virtually identical to the major characteristics that define Carlin type deposits.

He outlines the differences as: "If these distinctions are considered to be local variations on a grander theme, Carlin and SHV type deposits share some important characteristics that may have contributed to their genesis." and "Understanding the importance of these regional to local scale characteristics and the fact that they are common to some of the greatest gold deposits in the world provides a unique set of exploration criteria. The application of these criteria in the search for both types of deposits may be important" [5].

The major characteristics of the South Siberian Craton ("SSC") are interesting compared to the Tanzanian premise being proffered. The first "coincidence" of general note is that South of Siberian Craton SHVs are in rocks that have been subjected 400 Mya of tectonic action between the Siberian Craton and the Tarim Craton to the Southeast (Northern China), the Karakum Craton to the Southwest and the Pamirs Craton to the south (**Figure 11**; Aka: The Congo (Tanzania) Craton and the Madagascar/Indian Cratons to the East, the West Antarctica Craton to the Southeast and the Kalahari Craton to the Southwest (**Figure 9**), which are responsible(?) for the Usagaran and Ubendian metamorphic zones (up to 800 Mya of tectonics?)).

In the model in **Figure 12**, the left side of Section A would be the Tanzanian Craton (with the Congo Craton abutting further west; Aka—The Siberian Craton) while the right side would be the Madagascar/Indian? Continent (Aka—The Karakum, Pamirs and Tarim Cratons) pulling away. The Mozambique Ocean (Aka—the intra-Asian Ocean) would be formed in its Centre. In Sections B, C, and D, Gondwana (Aka-Eurasia) is made, with the Madagascar/India "merger" and subsequent Australian (Aka—the "Pre-Indian?") "rear ender." Although no "Island Arcs" are in this model, the current East Africa Rift System (EARS) "forefather?" could have been part of the sutures identified by Berthe [28], forming them.

This SSC region has numerous deposits and zones of mineralization related to hydrothermal mineralizing events, which includes mineralized breccias and veins into the definitive sediments of the Paleozoic era (**Figure 10** and **Figure 11**). They stand out as definitive models of SHV deposits. Major "sutures"—conduits of the mineralizing solutions?—are present in the well-defined sediments. The presence of many mineral showings in the Morogoro-Handeni area and through to the west (the New Luika Mine) suggests that this area of the Usagaran and Ubendian formations could be in an analogous tectonic zone. The breccia veins of the Najim and the presence of many mineralized veins (Magambazi, Negero, Benzu and others) suggests that conduits of mineralization were present (Associated with the forerunner of the EARS?).

The SSC region hosting these deposits *et al.*, is part of the Central Asian Orogenic belt that has several identified Island Arc assemblages. This would be analogous to our discussion above, with respects to the opening and closing of the ancient Mozambique Ocean. The identification of oceanic ophiolites, Island arc assemblages in Kenya's Mozambique Metamorphic Belt [10] [28]-[30] suggests that amphibolites and other mafic assemblages in the area southeast and east of the Tanzanian Craton are of this origin as opposed to the Sumukuland Corridor extension as reworked Archaeon.

Little research has been done, not only in the Handeni area but on the SHV deposits on the geological and geochemical character of the regions. The idea of an Archean Overprint model would basically utilize the same process of mineralizing solutions being injected into the overlying rocks. In that case, the model for both ideas would have a lot of the same data as evidence.

Although Kabete has done some work on the rocks but not to my knowledge on the age of the mineralization source. Regardless, the Dodoma Handeni Morogoro area has undergone significant tectonic disturbances around the formation and destruction of the Paleo-continents in the Precambrian to current time (recent reports of the "ongoing dissolve" of the African Continent, to wit) that would not have affected the "unmoved" continuation of the Sumukuland Corridor should not go unchallenged. There are remnants of Archean in the Mozambique Metasedimentary Belt (the Pare (and Usambara) Mountains in north Tanzania and the Uluguru Mountains south of Morogoro) but little research has been done to relate them to any of the known Cratons (Tanzania? Indian? Madagascar? Or other?)

Although the age of the mineralization would be most additive information, but given the tectonic activity—it would as likely be Pan African orogeny related.

The assertion of the SHV model over the Archean Model is based on the criteria outlined: Oceanic sediments, volcanic assemblages, continental collisions, deep sutures, thrusts etc., being thrust against the Tanzanian Craton during the closure of the Mozambique Ocean not on the geochemical signatures. The lack of definable Archaeon greenstone remnants or altered equivalents in the Handeni area raises further questions to the continuation of the Sumukuland Corridor into that area.

A closer look at the "younger" SHV deposits adjacent to the SSC reveals that the two main deposits (there are many additional zones—**Figure 10**), Muruntau and Kumtor are located in the South Tianshan Accretionary complex (South Tien [Tian] Shan; **Figures 10-11**) in Paleozoic sediments with some Island arc and ophiolites units (**Figure 11**). As obvious from the numerous named major faults this area was extremely tectonically active. This would be analogous to the Mozambique Metasedimentary Belt (MMB) and its association with the "Ancient" EARS. Although in SSC area the units have an E-W configuration their 2000 km length would match that of the 2000+ Km length of the N-S EARS system. The Paleo continental interaction as outlined above would also be consistent.

The difference in geology can be related to the metamorphic aging—The Kilindi Handeni area being subjected to Late Precambrian to Cambrian "pressures and events"—at least 500+ Mya—while the SSC area has a maximum 200 - 300 Mya of current activity!

8.1. A SHV Example—The Muruntau Deposit

In detail, the Muruntau deposit gold deposit is situated in the Qizilqum Desert of Uzbekistan. It is being mined in the world's largest open-pit gold mine with production believed to be of the order of two million ounces per annum (56.7 tonnes). The open pit measures about 3.5 by 2.5 km and extends to a depth of 560 m (2012). The gold ore resource in the Muruntau deposit, including production, is about 170 million ounces of gold (4.819 tonnes). This gives the mine a reserves-to-production ratio of 85 years [31].

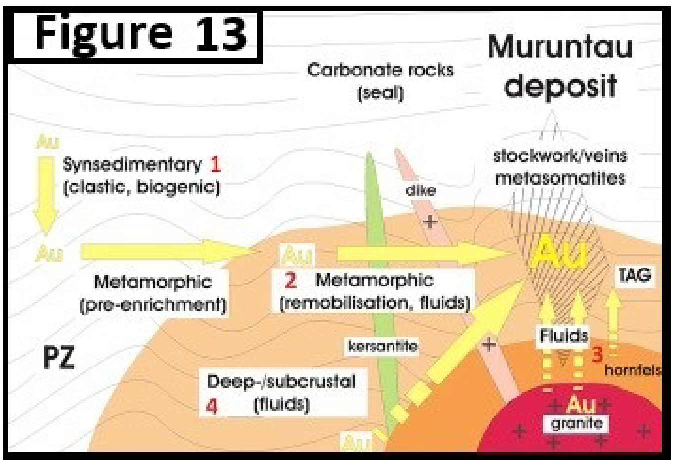

Figure 13. Muruntau deposit (simplified).

Continued study on the ore bodies revealed that there are several structures controlling the localization of the ore zones [32]. One type of structural control is related to the bedding and schistosity of the host rocks including the development of parallel "metamorphic" quartz veins which are complicated by intense folding and boudinage. Other controlling structures are located sub-parallel to the first but relate to later flat-dipping zones of thrust, shear and mylonitization. A third type of structure is controlled by brittle deformation behavior of the rocks after regional and thermal metamorphism with both sub-parallel and cross-cutting vein structures and alteration zones (these would be expected in the Pan African Orogeny and are present in the Kilindi Handeni Superterrane).

In the case where gold mineralization was mainly controlled by "flat" veins or ore-bearing metasomatites, the ore bodies are stratiform-like. Around the "Central" veins with cross-cutting stockwork veinlets the ore bodies are cone-like and steeply dipping (**Figure 13**, [32]).

Although the rock units identified with this deposit are metasedimentary (**Figure 14**, [32]), the processes associated with its formation are not discordant with what was occurring in the Pan African orogeny. As outlined above in the Tanzanian area we are discussing (Handeni-Morogoro-Dodoma) the metamorphic grades tend to blur the rock types.

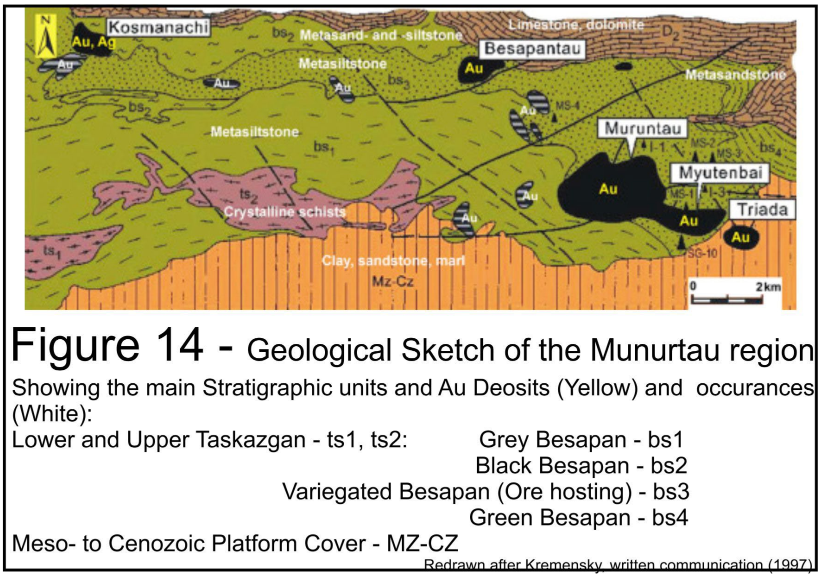

Figure 14. Geological sketch of the muruntau region.

8.2. The Placer Gold Factor

One of the important characteristics of SHV deposits is the presence of placer gold deposits. The Handeni Morogoro area (including the Najim and Sahani areas) has many placer areas including some to the east of Magambazi in very low relief zones, found by the artisanal miners. Placer gold led to the discovery of the Magambazi deposit, were part of the lead up to the Kwadijava prospect. In fact, in that area in 2005, the whole river valley was dug up for placer gold (almost wholly reclaimed by the vegetation it is totally unrecognizable). Placers and hard rock workings (including the Benzu and Negero prospects) were observed, extending to the west, to the north and to the east and south east.

Little to no research has been done on the presence of placer gold deposits in the Handeni area with the high-grade metamorphic schists and gneisses.

In general in the Magambazi and east, the relief is not that rugged, it is moderate to low with only the occasional "knob" (such as at Magambazi) rising 200 metres above the plain in the area of the Magambazi deposit. That low relief and the coarse nature of the placer gold suggest a very nearby source. To my knowledge there has never been any glaciations (and the complete absence of flour gold confirms that) so a local source speculation not related to the Magambazi is valid [33].

In the Morogoro area, in the rugged Uluguru mountains to the southeast (Matambo) not only are their numerous workings throughout the area (mainly centred on the Ruvu River) but there are probably undiscovered placers on some of the side rivers if the Author's experience on Matombo is an example.

Figure 15. Placer "free" gold.

There in August of 2010 a nugget of gold (supposedly on the root of a yam!) led to an influx of upwards 3000 artisanal miners and a gold rush analogous to the Klondike and any other gold rush (including stores, pubs etc.!).

In the western (Melela) area, whole areas have been demarcated for local Tanzanian miners and active placer and hard rock gold mining is present. North east of Morogoro additional operations are observed and reported. In particular the newly discovered Mazizi (Mananila) zone. Both these areas are in relatively low relief. These low energy environments, that have developed free gold (**Figure 15**), plus what was found in the Matombo (which was on a ridge area higher than the main river systems of the area) suggest that there are several, if not, many sources of gold throughout the region. Some that have been identified are associated with veins but several areas have flat lying strata with identifiable quartz rich layers that the local artisanal miners are active on. No geological mapping is done yet several areas have had operations for several years.

9. Models for the Emplacement of Gold

Given this preponderance of gold occurrences over a wide area in a previously deemed low potential geologic environment, some ideas of the source model to help guide exploration and understanding of these prevalences, needs to be understood.

Groves and Kabete [1] have proposed that the mineralization is interpreted as an originally lower metamorphic grade orogenic gold deposit (a continuation of the Sumukuland Corridor of the Tanzanian—Lake Victoria Greenstone Belts-Craton) that has been overprinted by high-grade metamorphism. Magambazi thus demonstrates the potential for discovery of world-class, overprinted, Archaean orogenic gold deposits in the Proterozoic non-traditional exploration terranes of Tanzania [1] [2].

The isotopic composition model ages reveals that Archean crustal material is not restricted to the Tanzania Craton itself but prevails in the Usagaran-Ubendian Belts and is also widespread in the eastern part of the Mozambique Belt (the Usambara and Uluguru Mountains), which has been affected by granulite-facies metamorphism during the Pan-African orogeny tends to support this interpretation. However, the combined isotope data provide strong evidence that parts of the East African crust grew by lateral accretion of Early and Mid-Proterozoic segments onto an Archean nucleus (Moller [14]). As well, Siefe Berthe [28] identified several "island arc" complexes associated with the East Africa Orogenic zone that extends from Saudi Arabia to Mozambique as did Kabete [15] in his description of the amphibolitic sequences. The associated "basalts" identified at Magambazi and the amphibolites at Najim and Sahani (some copper is associated with them as well) could be related to the "sutures" Berthe identified to the north of Tanzania.

Instead of the overprinting of the Archaean terrane, an accreting sequences of oceanic island arcs and sediments during the closure of the Mozambique Ocean with the formation of Gondwana being subsequently metamorphosed and "thrust" faulted against the Tanzanian Craton with the introduction of "fluid granitic magmas" is suggested.

The sharp edge of the Tanzanian Craton where it meets the Ubendian and the Mozambique Metasediments, and the regional flat lying nature of these amphibolite formations of the Magambazi-Mangu, seen throughout the district tends to counter the extension of the Sumukuland into the Kilindi-Handeni Superterrane.

The Magambazi deposit is a north south trending vein within the adjoining host rocks which are possibly originally basalt. Several other veins with high grade gold are present in the area with varying strikes but previous exploration was unable to develop them (Kwandege, Negero and Mangu) [26]. Instead of being metamorphosed Archean greenstone belts, is it not more likely they are accreted and metamorphosed "island arc" or ophiolite volcanics?

Outlined by Kabete [15] for gold in the Magambazi area (**Figure 16**) show many of the geological features and structural relationships of the Proterozoic rocks in the Magambazi area, the "Re-worked Greenstone belts" in the Kilindi-Handeni Superterrane. These amphibolite gneisses and schists "blebs" as they are shown could represent island arcs or ophiolites that were present in the Mozambique Ocean that have been metamorphosed and thrust up against the Tanzanian Craton. Of note, is that the general trend of the Sumukuland Corridor (**Figure 2**) was a pronounced NW-SE orientation while the Kilindi Handeni Superterrane (**Fig-**

ure 16) was slightly north of EW.

Most of these have veins that were or are being, mined by artisanal miners and little to no geological information related to them being recorded.

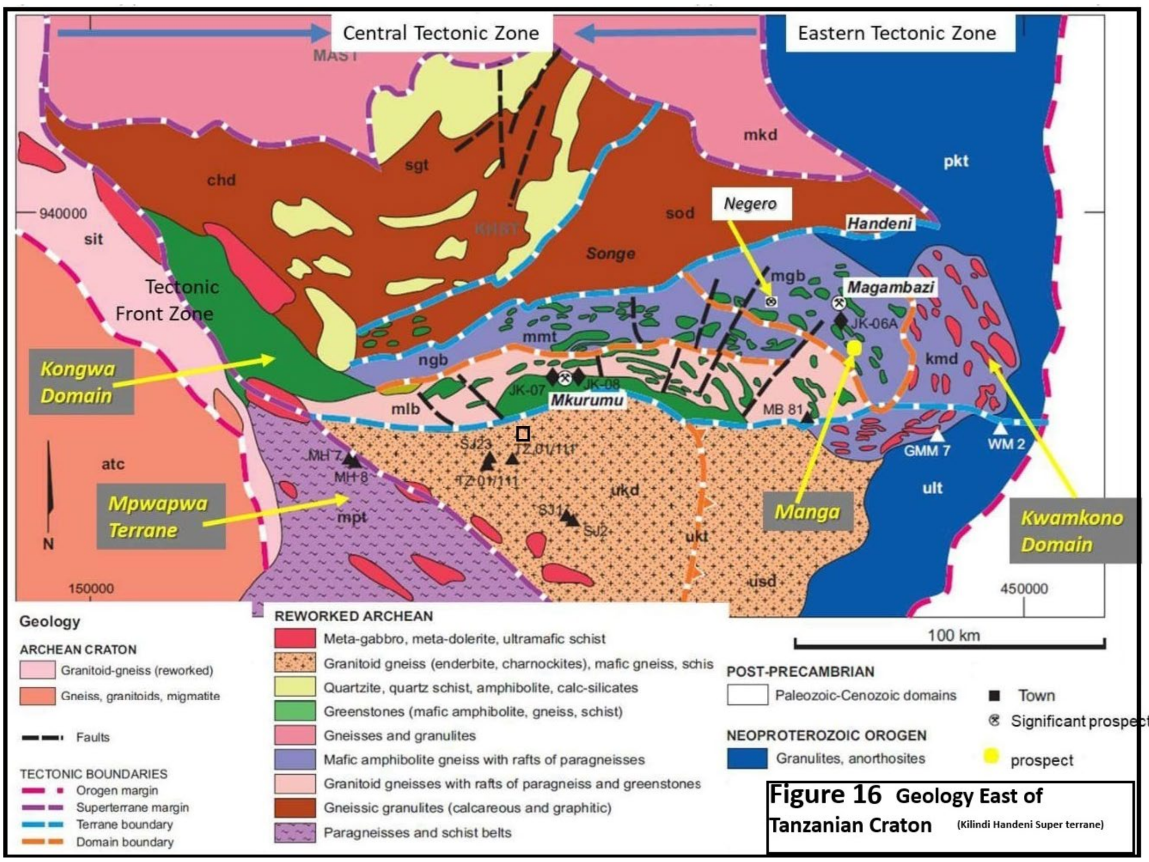

Figure 16. Geology of the east of Tanzanian craton.

Island arcs are extremely prolific in mineralization. Over fifty of the principal gold deposits of the Western Pacific region are associated with them [34] and in the Indonesia archipelago alone are fifteen with six having orebodies or major prospects [35]. The Archean greenstone belts (Ancient Island arcs) worldwide are also prolific.

These "Mozambique Ocean" amphibolites as island arc remnants would be natural hosts and structurally "available" to enable mineralization in the Pan African Orogeny be emplaced. It would not need to survive the prior ~2 billion years of tectonic activity.

An alternate possible model suggested for the Handeni-Morogoro-Dodoma area's hydrothermal Orogenic gold deposits is the Sediment Hosted Vein model as described by Klipfel [5]. It allows for the metamorphism and later solution generating intrusives to deposit the gold along the continental collision structures. It does not require the mineralization associated with the Archaean Greenstones to remain intact, as it introduces them with the "younger" geological history of the area.

The presence of Island arcs and ophiolites in the Tien [Tian] Shan Accretionary Belt (**Figure 11**) with less metamorphic intensity would tend to confirm this model of the Kilindi Handeni Superterrane.

To summarize Klipfel [5] from above parameters for a SHV deposit, he outlines an area of continental shelf sediment emplacement (the Mozambique Ocean) followed by significant tectonic accretion activity related to continental collision (in our case, Gondwana formation) that deformed and metamorphosed the continental shelf sediments creating structural breaks that allow the emplacement of mineralizing magmas along regional structures (**Figure 12** and **Figure 6**).

The structures are present and from our observations, although the gold mineralization has a tendency to be associated with the amphibolites (mafic) rocks that could be originally volcanic. Are they associated with the Archaean Craton 250 kilometres to the west or with the Proterozoic or later, island arc systems that were developed in the "Ancient Mozambique Ocean" and subjected to the tectonism associated with the Mozambique Metamorphic Belt formation?

In favour of the SHV model from Klipfel is the presence of significant carbonate formations, the cap to his model, present as a significant regional formational unit north of the Magambazi and the identified the carbonaceous and graphitic rocks of Songe Terrane (**Figure 16**) of the Kilindi-Handeni area, as described above.

The author has also identified potential intrusive equivalents (Quartz feldspathic gneiss and silica altered porphyry) that hold a central part of the area just north of the Magambazi zone and somewhat similarly distant to the Benzu zone to the west and zones to the north. From previous observations, other intrusives exist at the Canaco Kwadijava zone (granitic porphyry) and possible around the Kwandege area.

These fit Klipfel's model of SHV deposits quite nicely.

All five aspects are present in the Handeni area, with maybe "oceanic-character substrata" amphibolites, the Island Arcs suggested by Berthe. The active EARS and the collision area of the Gondwana fulfill the other aspects outlined. Again, no imprint is needed but the structural preparation and intrusive (metamorphic) generated fluids in Klipfel's model are present.

An aside construct is the durability of the EARS—is this system seen today part of an ancient Precambrian rift system that has been an "unmoving," major factor in ancient continental formation and breaking apart for over 1 Ga? Not unlike the constant "hot spot" that gives rise to the formation of the 2500 km long Hawaiian Islands Archipelago. A question I leave for others to discover!

An "older" North American example of this level of metamorphism, associated with continental "accretion and/or collision" is the Adirondacks and the Grenville geologic province of Southern Ontario, Canada. The Adirondack Mountains are part of the Grenville Province, [36] a large belt of basement rock that almost without exception, are metamorphic-metasedimentary or metavolcanic—that have been subjected to high temperatures and pressures at depths of up to 30 km and have a complex history. The meta plutonic; granitic gneiss; meta-anorthosite; olivine metagabbro; marble and other metamorphic rocks have been folded and sheared by ductile deformation and shattered by brittle deformation, leaving long, straight valleys that run north-northeast marking the most brittle deformation along major faults and fracture zones with an abundance of joints. The Adirondack deformation happened when the comparable to the present Himalayas [23]. This mountain range would have crust of the region was severely compressed during the Grenville Orogeny (continental collision?).

The Grenville Province represents the footprint of the last tectonic event (orogenesis) to shape the Canadian Shield. The Grenville was built step by step along the eastern margin of the Laurentia continent (continental core of North America). It is the root of an ancient mountain range resulted from a continental-continental collision between Laurentia and Amazonia (1090 - 980 Ma; *e.g.* Rivers *et al.*, 1989, 2012), during the assembly of the supercontinent Rodinia.

Outside the Canadian Shield, the Grenville Province stretches southwest to Texas and Mexico and northeast into Newfoundland. Beyond North America, the Grenville Province has been recognized in and according to several authors, it would continue from Central America to Antarctica, and from India to Australia.

Except in the Central Metasedimentary Belt, located about 300 km south of the Grenville/Laurentia contact where some small mineral deposits (referred to below), the 300 - 400+ km between that contact and the southern extent of the Grenville Province (The Adirondacks Mountain) is almost devoid of mineral (base and precious metal) deposits. The particular area between these contacts is highly metamorphosed ("the root of an ancient mountain range") with little recognizable rock type.

Its location on the south east side of the North American Craton (Canadian Shield) is analogous to the Mozambique Belt position and has suffered from significant collision damage. There is little attempt to outline the potential of or identify any reworked or overprinted Archaean terranes which are similarly distant (the Sudbury Timmins greenstones are 400 km to the north). Having spent some time doing mineral exploration on a potential Grenville (Archaean overprint?) volcanic belt, the reasons for this disconnect are clear, it is impossible to identify with certainty the original rock type.

There are gold deposits in the southern Grenville (away from the most intense metamorphism) that are numerous with lots of visible gold but small, associated with metamorphic fluids or intrusive related fluids in most treatises on the area [37]-[41].

The intense deformation Adirondacks/Grenville occurs at Continental/Continental collision tends to obliterate the original rock type identification. We see a lot of that in the Handeni area. That it is not to that level in the Handeni area suggest less pressure and temperature (duration?) in the Handeni area (the collision of East and West Gondwana). A result of the younger age of the Pan African orogeny? The Gondwana Continent soon after formation moving over the Paleolithic EARS and being rendered apart?

However, the sharp contact between the Tanzanian Craton and the Mozambique Metamorphic Belt would be analogous to the Grenville front (Grenville and Laurentia contact). Ergo the continuation of the Sumukuland from the Craton into the MMB is less convincing.

The heavily metamorphosed edge of the northern contact of the Amazonia Continent (the Adirondacks) suggest that significant deformation of the intervening rock units would occur. We don't see that in the Handeni Area, which suggests less intense deformation, consequently, the Lake Victoria greenstone Belts (LVGB) should be observable in the Kilindi Handeni Superterrane. That they are represented by "blobs" (**Figure 16**) suggests an alternative—Mozambique Ocean Island arcs, ophiolites, and marine sediments?

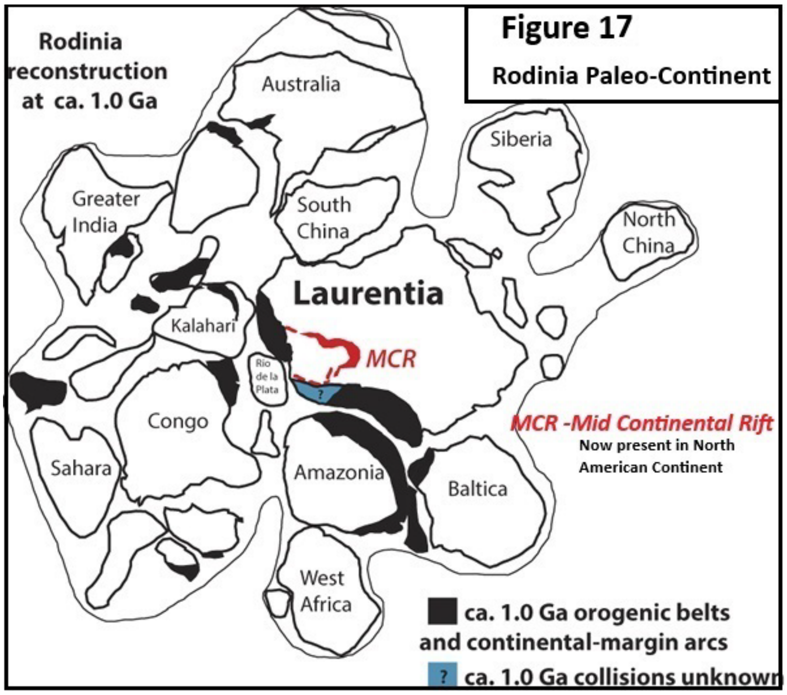

Figure 17. Rodinia Paleo-Continent.

An interesting aside is the Mid Continental Rift (MCR) to the West of the Appalachian Mountains and identified as a possible continuation of the Grenville Front (Stein *et al.* [42]) represented a zone of extension (1.3 - 0.9 Ga). That at that time (ca. 1 Ga) it was part of the Rodinia ancient continental province of Laurentia (**Figure 17**) adjacent to the major orogenic belt between the Congo (plus Tanzania) and Kalahari Cratons which would become the "Mozambique Ocean" and possibly resembles the EARS, suggests that the resulting Mozambique Metamorphic amphibolites could be a result of subsequent Island Arc systems and could have developed and then metamorphosed during the later formation of Gondwana with the Indian Craton collision with them.

Further example of SHV regimes cited above, again on the east coast of Canada, the South Eastern part of Australia and the South Island, New Zealand are the

Meguma Terrane, the Lachian Orogen and Buller Terrane, respectively (does this east side preference have any more meaning than coincidence?), have some similar age and characteristics to the Mozambique belt (also some differences) that support a more active SHV model [43].

Aspects that stand out as potentially playing a critical role in the generation of a Phanerozoic world-class orogenic gold province include 1) the presence of a hydrated, oceanic-character substrate that can provide a fertile "source" rock for both fluids and metals, 2) asthenospheric thermal input to trigger and sustain crustal devolatilisation and melting, 3) the existence of a number of near-vertical, deep-seated faults, 4) substantial transcurrent movement, and 5) evolution of an accretionary-subduction system that promotes development of an extensive fore-arc system with prolonged fluid generation and circulation [42]. These characteristics conforms more to the SHV depositional model than the overprinted Archaean one.

10. Discussion & Conclusion

The Magambazi Discovery in 2009 created a lot of interest in the East African Proterozoic mobile belt which according to the prevailing geologic thought were typically devoid of gold deposits. The "plateauing" of the gold price in 2012/13 and lowering of expectations of the deposit dampened if not completely limited that interest. Except for Groves *et al.* very little research on the region had been conducted during that short window of attentiveness and even less since then.

SHV deposits in Asia have been known for many decades but only since the end of the 20th Century have they been open to extensive "development" by western interests and research.

Klipfel outlined numerous characteristics of them but one of the major similarities between the two regions, not noted is that the Mineralized zones are located in Orogenic areas between the formation of Paleo-Continent (Asia for the Tien Shan Area and Gondwana and later Pangea in the Mozambique Metasedimentary Belt). In reviewing the data, it was revealed that the massive Carlin Trend of the SWUS is at a similar juncture.

The Carlin Trend is characterized by a collision between a tectonic crustal block (terrane, which would be in the African case the Indian and Antarctica Plates—"Crustal blocks") and the North American Plate (the Congo Tanzanian Cratons) during the Mississippian period, known as the Antler Orogeny—a key geological feature associated with the gold mineralization; this collision led to increased crustal temperatures and pressures, facilitating the migration of gold-bearing hydrothermal fluids that deposited the gold within the sedimentary [and volcanic?] rocks of the region. This would not be unlike the Asian SHV Area and possibly the East African Area.

With little incentive (after 2013) minimal research has been completed on the East Africa Proterozoic mobile belts especially in respects to the Magambazi deposit. Berhe noted ophiolites in the Kenya area to the north and Kabete [1] [15] referred to the "volcanic amphibolites" in the Handeni Kilindi as Island arcs which also were present in the Tien Shan Accretionary belt assemblages suggesting that as part of the inter-Cratonic ocean would have been present in Asia (the Central Asian Orogenic Belt Ocean). Their relationship to the Asian SHV has not been established but their presence fits Klipfel's model for the development of "Marine sediments."

With little to no research being done on the granitic magmas in the Asian SHV area, the existence of "fluid granitic magmas" related in Klipfel's model to the closure of the Paleo oceans (**Figure 6** and **Figure 12**) is developing. It remains to be done on the East African Geology. The geochemical signature of the granitic magmas and their role in the formation of the SHV deposit is still being developed but has not been subject to extensive research.

No obvious granitic bodies were found near the Muruntau deposit (Asian SHV) until recent drilling intersected one (the previous known occurrence was over 15 km way).

The "interpretation" of other Areas with similar geologic "histories" separated by hundreds of million years of time that might have relevance to explaining the geology separated by thousands of miles! The comparison of the Grenville *et al.* to the Handeni area demonstrated that the metamorphism seen in Handeni area was not consistent to continental collusions seen in other areas of the world's geology and thus the continuation of the Sumukuland Corridor to the east a less viable theory. The presence of the "blobs" would better fit the closure of the Mozambique Ocean with their assemblages including younger conduits of mineralizing solutions through the structures associated with the Pan African Orogeny.

The Tanzania Craton is older than the surrounding units. The main implication is that the Proterozoic mobile Orogenic Gold deposits (Magambazi *et al.*) are not a reworked Archean gold deposit that has remained relatively in place for 2+ billion years, although being in an active tectonic area (with the creation and dissolution of the Precambrian Rodina and Paleozoic Gondwana continents to name a few) in an area of the active EARS (current and ancient?). Acknowledging the similarity to the Asian *et al.* SHV deposits to this setting of Klipfel's SHV model could be a possible explanation for the copious amount of gold "showings" in the Dodoma Handeni Morogoro region. An area which has been vastly under researched.

The initial assessment that the mineralization is interpreted as an originally lower metamorphic grade orogenic gold deposit is possible but as an eastward extension of Archean greenstone belts (300 km to the west) overprinted by high-grade metamorphism of the Neoproterozoic orogeny is less likely in light of the evidence of Oceanic assemblages (Ophiolites and Island Arcs) that have been thrust against the Tanzanian Craton during the closing of the Mozambique Ocean. That event that occurred from 950 - 530 Mya, could be analogous to the "ongoing" development of the area of Southern Siberian Craton's Sediment

Hosted Vein deposits as found in several areas in the mid to late Paleozoic thrusting and intrusions as exemplified by Klipfel's SHV model. The Late Proterozoic—early Paleozoic rocks south of the Tanzanian Craton could represents a higher grade metamorphic terrane (deeper buried origin?) member of that deposit type. The 400 - 500 Mya age difference subjects the still active Tanzanian area (the EARS) to more metamorphism and conversion of the sediments to more undistinguishable units.

In conclusion, the pros and cons of the SHV and Archaean Overprint being responsible for the Orogenic gold mineralization present in the Handeni-Morogoro-Dodoma region and mainly represented by the Magambazi deposit have been outlined. The interpretation is that the area is more likely to fit in the SHV models (Figure 18) with the implications for exploration and development.

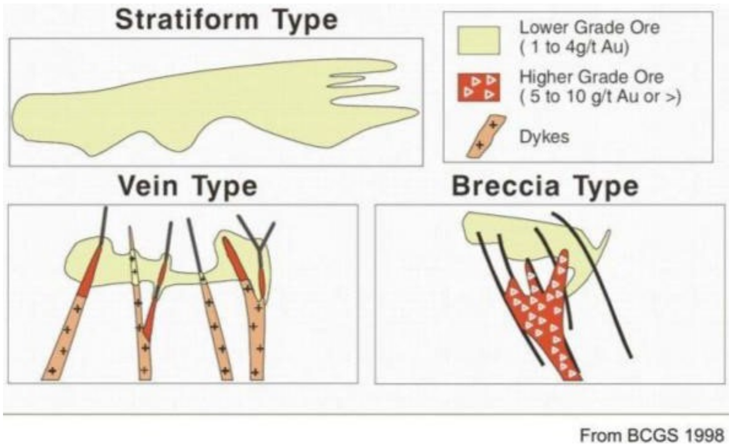

Figure 18. SHV Deposit Models (some potential demarcations).

The previously unknown Mazizi gold deposit, in a mineralized shear zone over intensely leached and schistosed migmatites, gneisses, amphibolites, penetrated by echelon systems of quartz veins and veinlet, steeply dipping bodies of quartz breccia up to 1.0 - 1.5 m thick, an average content is 2.5 - 3.0 g/t, gold could be an example of the SHV deposit.

With the wide extent of mineralization in placer and hard rock of the Handeni-Morogoro-Dodoma district, we have to look at this area as a potential new mineral deposit SHV camp. The numerous free gold showings in this area that, in its short period of Tanzanian gold exploration (from the year 2000 +/−), is more than most or all geologists would see in several lifetimes. An analogy would be the South West USA in the 1850s - 1870s as it was being discovered by "artisanal" miners with little or no geological input (The USGS was not incorporated until 1879!)

The size of the deposits associated with SHV warrants further investigation and research on the Pan African Proterozoic mobile belts.

In Table 1, the Klipfel's and Bierlein's characteristics outlined above are compared to the Handeni-Morogoro-Dodoma area and that area is also linked to the Archaeon Metamorphic overprint model.

Table 1. Characteristics of Sediment Hosted Vein Deposits (SHV) and Archaean Overprinted Greenstone Belt Deposits (Arch OP)—as to their Presence in Morogoro-Handeni Area, Tanzania.

Characteristic	SHV	Arch OP	Comments
Presence of Volcanics K1	Yes	Yes?	Not enough mafic (meta-volcanics?) observed to suggest a greenstone belt
Vein Gold K5	Yes	Yes?	Would gold remain in Archaean Rocks at intensity of Metamorphism observed?
Late Proterozoic-Paleozoic Age K1	Yes	NN	
Passive Margin	Yes	NN	Presence of Marble confirms
Extended Crust as Basement to Host Rock K1, K5 CC1	Yes	NN	Grade of Metamorphism suggest roots of Mountains
Multiple Episodes of deformation (fold Thrusts tectonism) K2 CC1	Yes	NN	Gondwana Formation, collision with India & Australia Sub continents; The Siberian Craton with the Tarim, Karakum and Pamirs Cratons to the South
Au +/− As (Sb & W) K3	Yes	Yes?	Not a necessary Characteristic for Archaean—Significant 1:1 correlation in Handeni area of As:Au In Areas to the west some suggestion of only Au.
Neutral Low to Moderate Salinity K4	No	NA	Any trace of this characteristic—Destroyed by granulite Metamorphism
Minimum to Moderate Metamorphism K5	No	NN	Any trace of this characteristic—Destroyed by granulite Metamorphism
Active Granitic magmatism K5, CC1	Yes	Yes?	Not a necessary Characteristic for Archaean—observed just north of deposit
Placer gold Fields K6	Yes	? NN	Plus, mineralized showings at both TZ and SSC

SSC—South Siberian Craton; TZ—Tanzanian Craton; NN—Not a Necessary Characteristic; NA—Not an Applicable Characteristic.

They are (“K number” represents Klipfel’s (Bierlein’s) Criteria outlined above):

K1: Late Proterozoic to early Paleozoic passive-margin shale-siltstone host rocks, extended crust as,

K2: multiple episodes of deformation of which fold-thrust tectonism is the most significant,

K2A: Presence of major “sutures” Although not directly identified by Klipfel, they are present in most of the areas identified by him especially in the SSC area. The oceanic nature of these rocks suggests that Island Arc and Ophiolites would not be out of place to be rafted up in the closure of these “oceans.”

K3: Au ± As, Sb, W metal suite,

K4: neutral, low to moderate salinity hydrothermal fluid chemistry,

K5: minimal to moderate grade metamorphism, active granitic magmatism in the crust at or near the time of mineralization, and

K6: occurrence within a field of multiple deposits commonly in association with large placer fields.

Figure Another factor (CC 1) not identified by Klipfel but present at the SSC area—Continental collision—this would drive K2; K2A; and K5 and is also present in Tanzania (TZ).

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Over the years, I have worked with and had many discussions with geologists with respects to the geology of the areas of Tanzania cited in this paper. Their insights and contribution to my understanding is appreciated and acknowledged.

As a North American Geologist quite familiar with the major mineral deposits throughout Canada and the US for over 50 years, I hope to bring a different perspective to this region. Throughout this paper I have acknowledged that research is absent. In that opinion, I stress the value of research in developing geologic theories and ideas.

The British Geological survey (Founded in 1835) the Canadian Geological Survey (founded in 1842) and the United States Geological Survey (founded in 1879) have been doing research and geological interpretation for over 140 years, leading to the development of Britain's, Canada's and the US's world leading mining industries. That has not been reproduced anywhere else in the world.

The Gold mining industry in Tanzania has only been initiated in the last 25 - 30 years (Vis a vis the BGS; CGS; & USGS 140 - 180 plus years!), yet as indicated the amount of gold seen in this region, specifically, is "more than most or all geologists would see in several lifetimes."

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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