Zimbabwe's coloured gemstone endowments – A regional geological overview

by A. Mamuse[1], B.P. von der Heyden[2], and T. Blenkinsop[3]

Affiliation:
[1]Department of Geosciences, Midlands State University, Gweru, Zimbabwe.
[2]Department of Earth Sciences, Stellenbosch University, Stellenbosch, South Africa.
[3]School of Earth and Environmental Sciences, Cardiff University, Wales.

Correspondence to:
A. Mamuse

Email:
mamusea@staff.msu.ac.zw

Dates:
Received: 30 Jan. 2023
Revised: 25 Aug. 2023
Accepted: 23 Oct. 2023
Published: January 2024

How to cite:
Mamuse, A., von der Heyden, B.P., and Blenkinsop, T. 2024
Zimbabwe's coloured gemstone endowments – A regional geological overview.
Journal of the Southern African Institute of Mining and Metallurgy, vol. 124, no. 1. pp. 33–42

DOI ID:
http://dx.doi.org/10.17159/2411-9717/2600/2024

ORCID:
B.P. von der Heyden
http://orcid.org/ 0000-0002-4006-9278

Synopsis

Zimbabwe hosts a varied array of coloured gemstones. With the exception of emerald deposits and several world-class pegmatites, few of the gemstone occurrences have received detailed attention from the scientific or mineral exploration communities. In the present contribution we summarize the status of knowledge of the gemstone deposits and occurrences in Zimbabwe, paying particular attention to the geological settings in which they were formed. Synthesis of this regional geological approach reveals that there may be significant exploration potential for further gemstone occurrences, particularly in the extensive pegmatite fields and in Al-enriched orogenic belts that have undergone greenschist to granulite facies metamorphism. Further socio-economic and developmental initiatives will aid in optimizing the value generation from this important sub-sector.

Keywords

Zimbabwe, coloured gemstones, pegmatites.

Introduction

A gemstone is a mineral, rock, or other material that is prized for its beauty, durability, and rarity. Coloured gemstones are gemstones other than diamond (GIA, 1999); an alternative definition to the older subdivision that recognized precious (superior) *versus* semi-precious (inferior) gemstones (GIA, 1999; Lurie, 2000). Diamond, emerald, ruby, sapphire, and pearls were considered precious and the rest of the gemstones such as amethyst, tourmaline, aquamarine, citrine, and garnet were designated semi-precious (Lurie 2000). In the newer, preferred GIA (1999) definition, gemstones other than diamond include amber, ivory, and coral, which are organic materials (GIA, 1999; Lurie, 2000), thus gemstones need not necessarily be inorganic and crystalline.

Although Zimbabwe has a significant gemstone endowment, the country is better known for its platinum group metals, chromite, gold, diamond, and coal resources (Bartholomew 1990). There is less awareness of the country's non-diamond (coloured) gemstone endowment. A notable exception is the global acclaim of the exquisite green Sandawana emeralds, discovered in 1956 (Tyndale-Biscoe, 1968; Bartholomew, 1990), which firmly established the country as one of the emerald capitals of the world. Zimbabwean aquamarine and alexandrite have also earned global recognition, and are mentioned in international general gemmology textbooks such as Cipriani and Borelli (1986) and Read (2005). Other coloured gemstones, including amethyst, ruby, sapphire, tourmaline, garnet, citrine, and iolite, are regarded as the lesser known gemstones of Zimbabwe. Most classes of coloured gemstones, but particularly these lesser known examples, have received only cursory scientific and industrial attention. For example, a search on Scopus using keywords *Zimbabwe AND gemstones* returns only four results, whereas a search for *Zimbabwe AND pegmatites* (a major gemstone host lithology) returns 32 results – most focusing on the economically important Bikita, Kamativi, and Sandawana pegmatites.

The most extensive documentation of Zimbabwean gemstones is Hawadi and Mafara (2018), which contains fundamentals of gemmology, an alphabetical listing of the gemstones with historical production figures, geological descriptions of the occurrences, and geographic coordinates, as accumulated over the years by the Zimbabwe Geological Survey. Although this work covers most known occurrences, it does not provide a systematic overview of the regional geology or metallogeny of these deposits. Metallogeny broadly refers to the study of regional to global distributions of mineral resources in a context of petrological, temporal, and tectonic frameworks. Because metallogenic approaches provide scientific underpinning to promote sound mineral exploration practice, their application to Zimbabwean coloured gemstone endowment is an important step towards encouraging renewed exploration activity in this neglected sector. Towards this end, the present contribution considers each of the main geological provinces within Zimbabwe in the context of its coloured gemstone endowment. Because geological provinces are characterized by discrete ages and tectonic settings, correlating these to gemstone endowment represents an important first step in forming a metallogenic understanding of the local coloured gemstone occurrences. Specific emphasis is placed on the Pfungwe and Mwami gemstone clusters, which represent rich and important gem occurrences in the Pfunzi and Magondi orogenic belts, respectively, which themselves may represent prospective metallogenic settings.

Through our insights and understanding we seek to provide a scientific basis for future exploration for new gemstone discoveries in Zimbabwe. However, for the sector to fully flourish, exploration needs to be augmented with further development of capabilities in gemmological characterization and gemstone beneficiation within the local economy. Discussion and recommendations related to these key considerations are provided in order to further promote future development of Zimbabwe's coloured gemstone exploration sector and downstream value chain.

A brief overview of the main geological provinces of Zimbabwe

Zimbabwe has a geological history that spans over 3.5 billion years (Ga), and has been recently summarized by Blenkinsop (2019), in which more extensive references can be found. Figure 1 provides an overview of the geological evolution of Zimbabwe, with more details provided in following sections devoted specifically to gemstone occurrences within the different geological provinces. Briefly, the oldest rocks on the Zimbabwe craton are found in the Tokwe segment and comprise Sebakwian greenstones that are older than 3.2 Ga (*e.g.* Moorbath, Wilson, and Cotterill. 1976). The remainder of the Archean Eon saw the development of an extensive granite-greenstone cratonic block with interspersed gneissic lithologies. The greenstone volcanosedimentary sequences comprise the Belingwean, Bulawayan, and Shamvaian Supergroups separated by marked unconformities, whereas the granitic component comprises the 2.7 Ga Sesombi Suite granites and other older granites and granitoids and the 2.6-2.54 Ga Chilimanzi Suite granites (Wilson, Nesbitt, and Fanning, 1995). The late Archean was marked by a period of compressional tectonics giving rise to the Pfunzi orogenic belt (formed during the Ngarwe Orogeny) on the northern margin of the craton (Barton *et al.*, 1991; Vinyu *et al.*, 2001), with the contemporaneous development of migmatitic gneisses in the Northern Marginal Zone of the Limpopo belt (Kamber and Biino, 1995). The next major geological event was the intrusion of the PGE- and chromium-rich Great, Dyke mafic-ultramafic body at 2.58 Ga (Oberthür, Davis, and Blenkinsop, 2002). This intrusion may mark the final cratonization of the Zimbabwe craton.

A period of probable rifting took place from around 2.2 Ga onwards resulting in deposition of the Magondi Supergroup, which was subsequently deformed into a low-grade metasedimentary sequence during the Magondi Orogeny around 1.9 Ga (Treloar, 1988; Master, 2010). This was coeval with the development of the Triangle Shear Zone and Central Zone of the Limpopo Belt (Kamber *et al.*, 1995). The next period of sedimentation is recorded by the Umkondo Group in the east of the country (Stocklmayer, 1981) (Figure 1). Sedimentation is constrained to around 1.1 Ga and was closely followed by the outpouring of the Umkondo Large Igneous Province (LIP) (Hanson *et al.*, 1998). Pan-African deformation events affected Zimbabwe during the assembly of Gondwana, specifically manifesting as the Zambezi and Mozambique orogenic belts in the northern and eastern parts of the country respectively, in part overprinting the deformation incurred during the Magondi Orogeny and the much earlier Ngarwe Orogeny (Dirks and Jelsma, 2006; Munyanyiwa *et al*,. 1997). The final major lithostratigraphic unit is the Karoo Supergroup, which represents a significant sedimentary succession deposited prior to 180 Ma (Johnson *et al.*, 1996). Around 180 Ma, Karoo flood basalts were extruded over large parts of the south of the country (Jourdan *et al.*, 2005), swarms of mafic dykes, alkali ring complexes, and other plutonic rocks were emplaced. Since then, the Zimbabwean land surface has been subject to geomorphological sculpting during formation of the so-called 'African erosional surfaces' (Lister, 1987) and has been covered by relatively thin veneers of Cenozoic sediment belonging to the Kalahari Group (Munyikwa *et al.*, 2000).

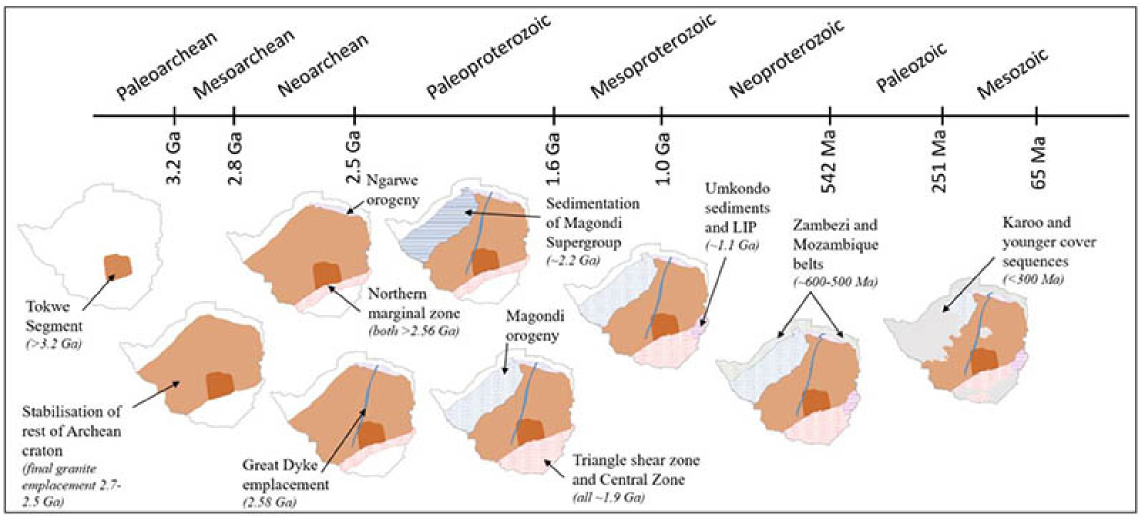

Figure 1—Summarized geological evolution of Zimbabwe (see text for further details)

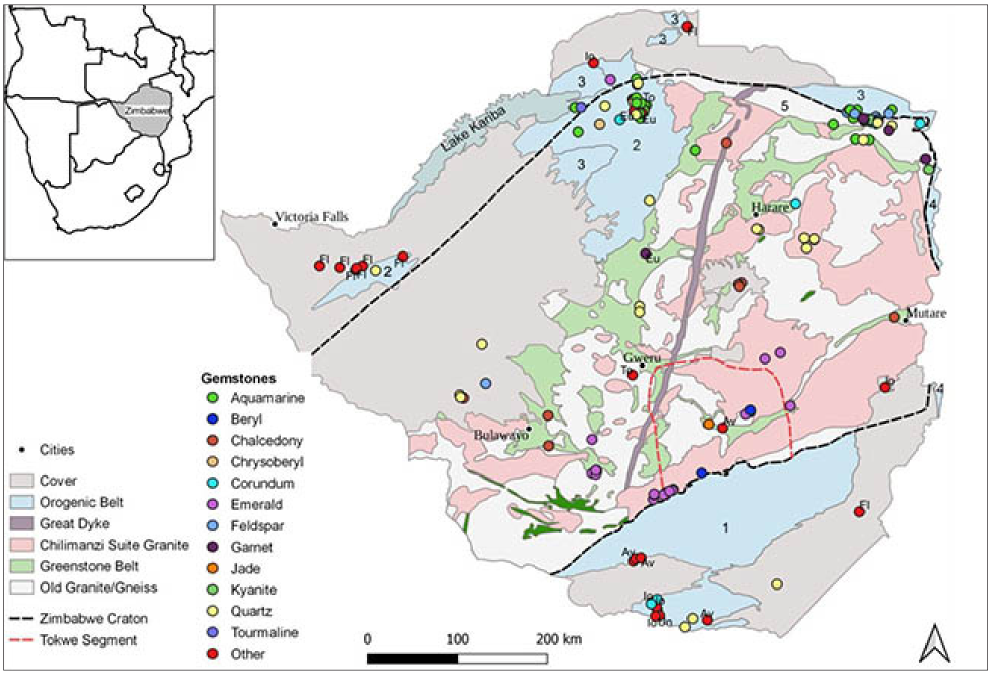

Figure 2—Distribution of gemstone occurrences on the Zimbabwe craton and within orogenic belts. The orogenic belts, numbered 1-5 on the map are: 1. Limpopo Belt, 2. Magondi Belt, 3. Zambezi Belt, 4. Mozambique Belt, and 5. Pfunzi Belt. The gemstone data-points are overlain on a simplified geological map of Zimbabwe (after Blenkinsop 2019, with slight modification) and are further detailed in Table I. 'Other' gemstones are aventurine (Av), fluorite (Fl), iolite (Io), and unakite (Un)

Coloured gemstones in the major geological provinces

Figure 2 shows the distribution of the gemstone occurrences within the various geological and/or metallogenic units that make up Zimbabwe's landmass. Metallogenic approaches have only been sparingly applied to gemstone distributions elsewhere (*e.g.*, Chen and Xing, 2011; Miladinović *et al*., 2016; Li *et al*., 2021), and to the best of our knowledge, have not been applied to the distribution of Zimbabwean gemstones. All gemstone occurrence data (N = 173) reported herein was collated from Bartholomew (1990) and Hawadi and Mafara (2018), complemented by Cipriani and Borelli (1986) and the Gemmology Institute of America (1999) to develop the gemstones classification scheme proposed in Table I. The data is being incorporated into an interactive online map of Zimbabwe's mineral occurrences (https://tblenkinsop.github.io/Atlas-of-Industrial-Minerals-and-Gemstones-in-Zimbabwe/).

Despite the prominence of the Great Dyke in Zimbabwean geology (in terms of both its geological uniqueness and its economic importance for chromium and PGE mining), the only recorded gemstone occurrences in the Great Dyke are those of mtorolite (a chromium-rich chalcedony) and chrysoprase (Ni-rich chalcedony). Mtorolite was named after its type locality in the Mutorashanga area in the northern part of the Great Dyke. The Umkondo Group (including the Umkondo Large Igneous Province) rocks are similarly devoid of recorded coloured gemstones, although a notable black diamond placer concentration is located in the basal conglomerates of this foreland sedimentary sequence (Smit *et al*., 2018; McKechnie, 2019). The Phanerozoic aged rocks (Karoo sedimentary sequences and younger) have formed under an extensional tectonic regime, and the only recorded gemstone occurrences are minor euhedral quartz (including varieties citrine, amethyst, rose quartz, and smoky quartz) and agate which commonly form as cavity fillers in Karoo basalts and are found in the alluvial and elluvial deposits derived therefrom (Bartholomew, 1990). The remainder of this section thus focuses on the geological settings in which coloured gemstones feature more prominently, *viz.* on the granite-greenstone cratonic block, and within the four bounding orogenic or metamorphic belts.

The granite-greenstone cratonic block

The most notable gemstone occurrences located on the southern extent of the cratonic block are clusters of emerald deposits (Figure 1), several of which have been mined and some of which are currently in production. The most famous of these is the Sandawana emerald cluster (formerly the Zeus mine) which is known internationally for its small but exceptionally bright green gemstones (Zwaan, Kanis, and Petsch, 1997; Zwaan, 2006). Emerald is the green variety of beryl ($Be_3Al_2Si_6O_{18}$), in which the colouration derives from incorporation of trace amounts of Cr and/or V. It is a rare mineral, since its formation requires a geochemical interaction between Cr and Be, both of which are relatively sparsely distributed in the Earth's crust (Groat *et al*., 2008). Mafic, and especially ultramafic, rocks are characterized by an enrichment of Cr relative to more felsic rocks, whereas Be is typically associated with pegmatites. Since ultramafic and komatiitic rocks formed prevalently during the Archean when the Earth was hotter than today, the greenstone units of the cratonic block should be prospective for these rock types, and for emerald deposits in areas where subsequent pegmatite intrusion has occurred. This model applies to the Sandawana emerald cluster, where Zwaan (2006) suggests that shearing, hydrothermal fluid flow, and Na-F metasomatism occurred at the contact between pegmatites and komatiites during the Limpopo orogeny (a convergent event between the Zimbabwe and Kaapvaal cratons at ca. 2.6 Ga) that generated some of the world's oldest emeralds. In the northern regions of the cratonic block, the gemstone distributions include 13 occurrences of quartz varieties, four of aquamarine, and one each of corundum, garnet, and euclase (Figure 1).

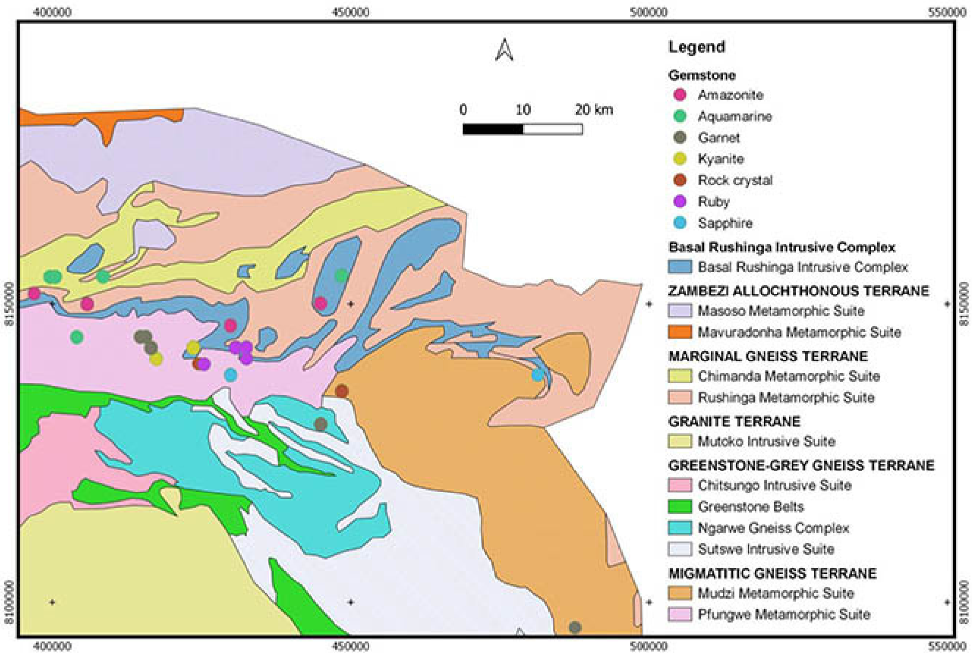

Figure 3—Terranes and lithostratigraphic subdivisions of NE Zimbabwe (after Barton *et al.*, 1991)

The Pfunzi Orogenic Belt: Case study using the Pfungwe gemstone cluster

Figure 3 shows the distribution of gemstone occurrences in the Pfungwe gemstone cluster, which is located within the bounds of the Pfunzi Orogenic Belt, a metacratonic margin of the Zimbabwe Craton that formed before and during the Ngarwe Orogeny (ca. 2.6 Ga; Vinyu *et al.*, 2001). The Pfungwe cluster is located within an area spanning approximately 60 km by 40 km and is centred on a geological unit known as the Pfungwe Metamorphic Suite of the Migmatitic Gneiss Terrane (Figure 3). These rocks comprise high metamorphic grade biotite and hornblende gneisses (including paragneisses of metasedimentary origin), granitic leucogneisses, and migmatites (Barton *et al.*, 1991). Eight deposits or occurrences (three of garnet, and one each of kyanite (Al_2SiO_5), quartz (SiO_2), ruby (Al_2O_3), sapphire (Al_2O_3), and aquamarine ($Be_3Al_2(Si1_6O_{18})$) are contained within the Pfungwe Metamorphic Suite. Several of these gems are metamorphic minerals (*e.g.*, garnet, kyanite, and corundum), and their presence thus highlights the importance of elevated pressure and temperature conditions associated with the development of an orogenic belt. For example, the gem corundum (ruby, sapphire) stability field occurs at pressures in excess of 3 kbar and temperatures ranging between 500°C and 800°C in silica-poor protolith rocks (Ohnenstetter, Fallick, and Fagan, 2014). The primary lithological hosts for these gemstone occurrences are the aluminous quartz-biotite gneisses (garnet, ruby, sapphire, kyanite) and pegmatites (rock crystal, aquamarine). To the east of the Pfungwe Metamorphic Suite lies the Mudzi Metamorphic Suite (Figure 3), which formed during the Ngarwe Orogeny (Barton *et al.*, 1991; Vinyu *et al.*, 2001), and comprises predominantly tonalitic to granitic orthogneisses (Vinyu *et al.*, 2001). Despite having experienced similar pressure and temperature conditions during regional metamorphism, this unit is conspicuously devoid of recorded gemstones except for one sapphire and one garnet occurrence. This highlights the importance of the interplay between P-T conditions and the bulk geochemistry of the protolith rocks. The sapphire occurrence is hosted within biotite augen gneiss in the eastern part of the belt, and the garnet within a porphyroblastic granitic gneiss in the southern part of the eastern N-S arm of the suite towards the Mozambique Belt.

The Magondi Orogenic Belt: Case study using the Mwami gemstone cluster

The Mwami cluster of 21 known gemstone occurrences is located towards the northern extremity of Zimbabwe (Figure 1), predominantly within the metapelitic rocks of the Piriwiri Group, which forms part of the Magondi Supergroup. Figure 4 depicts the distribution of these occurrences, which fall within an area roughly 25 × 35 km. Aquamarine ($Be_3Al_2Si_6O_{18}$) occurrences predominate, with at least ten sites identified where beryl-bearing pegmatites crosscut a range of country rocks including staurolite, staurolite-kyanite, and sillimanite schists. These rocks also host single occurrences of topaz ($Al_2SiO_4(F,OH)_2$), euclase ($BeAlSiO_4(OH)$), and almandine garnet ($Fe_3Al_2(SiO_4)_3$). The higher metamorphic grade sillimanite gneisses to the west of the cluster show a prevalence of chrysoberyl ($BeAl_2O_4$) occurrences, although instances of euclase and amethyst are also noted (Figure 4). To form most of these phases, Be must be added into the system, and this is typically ascribed to pegmatite intrusions or interactions with late-stage magmatic fluids (Groat, 2008 and references therein). Field relationships suggest that the pegmatite intrusions represent the important mechanism for Be addition, and based on available geochronological data for pegmatite emplacement (1.06–0.98 Ga; Glynn, 2017), the mineralization likely occurred relatively late in the Magondi Belt's *ca.* 2 Ga geological history. From the gem mineral chemistry, the other crucial element is aluminium, which is expected to be in excess in the metapelitic units of the deep-marine facies Piriwiri Group.

Other orogenic belts: Limpopo, Zambezi, and Mozambique belts

The Limpopo Belt formed approximately contemporaneously with the northern Pfunzi Belt and relates to the convergent tectonics

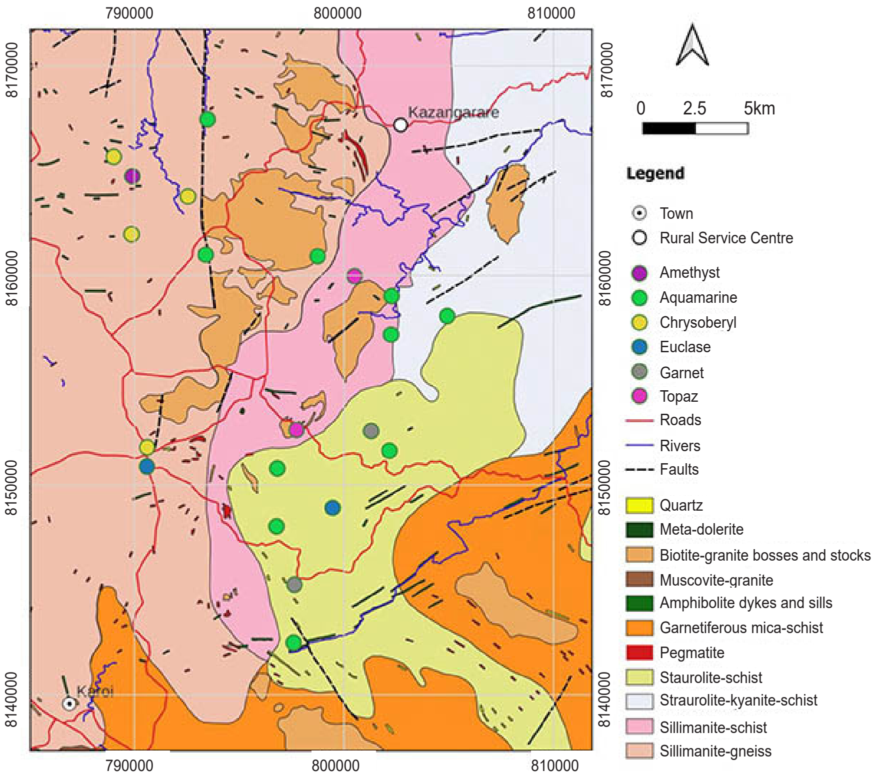

Figure 4 —Local geology of the Mwami cluster of gemstones. Geology taken from Wiles (1961)

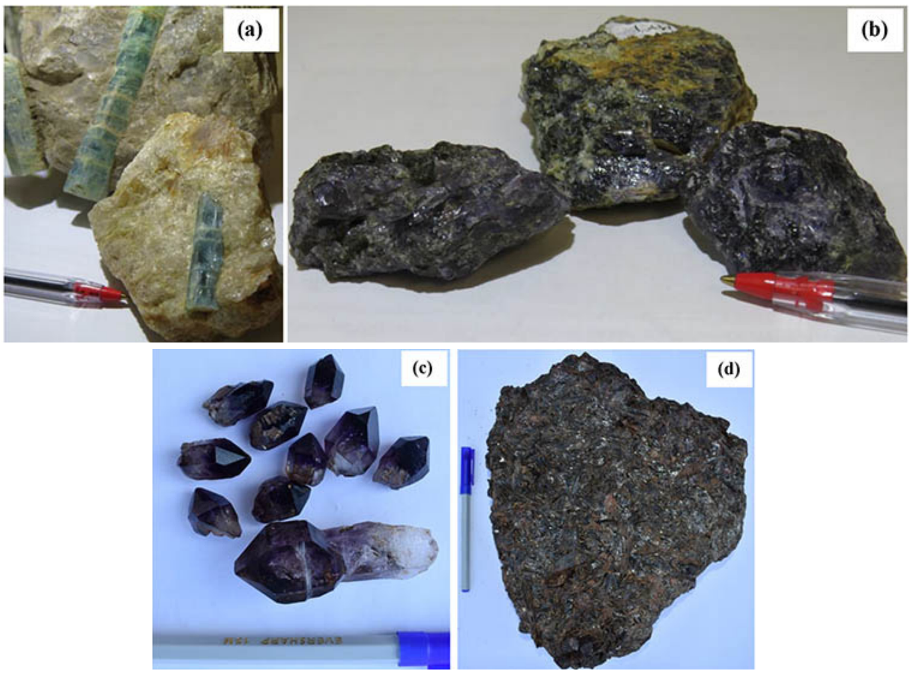

Figure 5—Example specimens of Zimbabwean coloured gemstones. (a) Aquamarine from Hurungwe, Magondi Belt, (b) iolite from Zambezi Belt, NE of Kariba, (c) amethyst from the Karoo near Chiredzi, and (d) host rock (ore) containing large pyrope garnets, from the gneisses of the Pfunzi Belt, northern Zimbabwe. Images (a) and (b) are courtesy of Steffen Kalbskopf, and (c) and (d) are of gemstones collected in the field during this study

between the Zimbabwean cratonic block and Kaapvaal Craton around 2.77–2.57 Ga (Kamber and Biino, 1995). In southern Zimbabwe, the Limpopo Belt is subdivided into the Northern Marginal Zone and the Central Zone. The Northern Marginal Zone seemingly comprises cratonic granite-greenstone rocks that have experienced high-grade metamorphism (Blenkinsop, 2019), and is largely devoid of any coloured gem occurrences, except for three occurrences of aventurine (quartz with fuchsitic inclusions; Figure 1). The Central Zone of the Limpopo Belt comprises a variety of gneisses (Broderick, 1979) which have experienced a complex deformation history, including low-to-medium pressure granulite facies metamorphism prior to 2.56, Ga and a high-grade tectonometamorphic overprint between 2.08 and 1.85 Ga (Holzer *et al*., 1998). The Central Zone hosts a variety of gem occurrences including three instances of iolite (gem cordierite: $(Mg,Fe)_2Al_4Si_5O_{18}$), one of garnet, one of epidote, two unakite (epidotized granite) occurrences, and three gem quartz occurrences. The presence of metamorphic minerals (garnet and cordierite) and metasomatic minerals (epidote) again highlights the importance of the dynamic processes operating during orogenic belt development.

The Zambezi and Mozambique belts are Pan-African orogenic belts formed during three periods of deformation between 1 and 0.5 Ga. The Zambezi Belt is located beyond the northern margin of the Zimbabwe Craton and is separated from the Pfunzi Belt by the Basal Rushinga Intrusive Complex (approx. 830 Ma) (Vinyu *et al*., 1999) (Figures 2, 3). Known gemstone occurrences here are limited to aquamarine and amazonite ($KAlSi_3O_8$), both of which were formed in pegmatites. The Mozambique Belt occurs to the east of the Zimbabwe Craton and manifests as a sub-greenschist facies metamorphic belt in the Umkondo sedimentary sequence. This is known as the Zimbabwe facies of the Mozambique Belt and is devoid of any notable coloured gem occurrences, which can be explained in part perhaps by the fact that sub-greenschist metamorphism is not sufficient to form metamorphic gem minerals such as garnet, corundum, kyanite, sillimanite, or cordierite. Further east, the Mozambique Belt is represented by an allochthonous terrane known as the Mozambique facies, which has experienced amphibolite facies metamorphism and in which kyanite is known to be present (Watson, 1969; Blenkinsop, 2019).

Discussion

Despite the significant efforts of past workers (*e.g.*, Hawadi and Mafara, 2018), the total coloured gemstone endowment within Zimbabwe and the prospectivity for future occurrences, remain poorly constrained. This is in part due to the limited number of dedicated exploration efforts except perhaps for pegmatites during the early phases of the nuclear era (*e.g.*, Wiles, 1961; Gallagher, 1967, UK Atomic Energy investigations), academic investigations, and a few formal attempts to apply metallogenic principles towards understanding the local gem mineral distributions (*e.g.*, Mugumbate, 2014). Our detailed regional geological analysis of coloured gemstone occurrences serves to improve on the current status of knowledge. Importantly, the work has highlighted two main metallogenic settings in which there is high prospectivity for discovering new gem mineral occurrences *viz.* pegmatite belts and orogenic belts which have experienced greenschist to granulite facies metamorphic conditions. It should also be noted that at the time of writing there was a resurgence in pegmatite exploration in Zimbabwe in the search for and characterization of lithium deposits.

Pegmatite belts

The formation of pegmatites has been ascribed to both late stage magmatic fluids derived predominantly from granitic intrusions and crustal-scale anatectic processes. These processes generally concentrate a range of rare and incompatible elements (*e.g.*, Be, Li, Ta, and REE, among others), some of which can react to form gem quality minerals, particularly within miarolitic cavities or in reaction zones with the country rocks into which they intrude (Simmons *et al*., 2012; London and Kontak, 2012). Zimbabwe hosts several notable pegmatites and pegmatite belts, including Bikita the world's largest Cs and petalite deposit (Dittrich *et al*., 2019), Sandawana (world-class green emeralds, Zwaan *et al*.,1997, Zwaan, 2006), Kamativi (Sn, Ta, and Li resource, Shaw *et al*., 2019; Gallagher, 1975 and references therein). Generally, scientific studies focus on individual pegmatites, and even these are relatively sparsely studied in the available scientific literature. Published regional studies on pegmatite belts are similarly limited in number, the most notable being the early work by Wiles (1961) focused on the Mwami mica field in the Magondi Orogenic Belt and the investigation of Li-Be pegmatites by Gallagher (1975). This general dearth in available information is detrimental to exploration efforts to find new pegmatite-hosted coloured gem occurrences. A detailed country-wide overview study is strongly recommended (as has been done for mafic dyke swarms by Söderlund *et al*., 2010), which can be complemented with regional-scale studies on pegmatite prospectivity (*e.g.,* von der Heyden *et al*., 2023).

Orogenic belts

Orogenic belts represent compressional zones in which pre-existing rocks undergo variable degrees of metamorphism and possible intrusion by igneous rocks and pegmatites. These belts have formed around Zimbabwe's main cratonic block during convergence events (*e.g.,* Ngarwe Orogeny (*ca.* 2.6 Ga), Magondi Orogeny (*ca*. 1.9 Ga), and the Pan-African Mozambique and Zambezi orogenies; Figure 1). This broad tectonic environment provides elevated temperature and pressure conditions which, when combined with precursor lithologies that are 'fertile' with respect to gem-forming elements, are highly prospective for high P-T gem minerals (*e.g.*, corundum, garnet, cordierite). Figure 6 compares the relative proportions of the gem-forming cationic elements (normalized per unit oxygen)

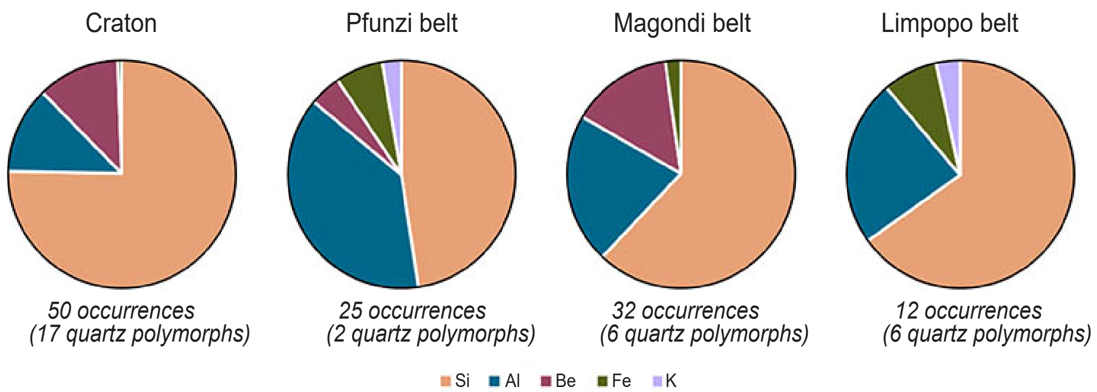

Figure 6—Relative distributions of major elements (normalized to oxygen in mineral stoichiometry) for each of the gem-mineral endowed orogenic belts and for the cratonic block. The number of occurrences per chart are derived from Table I, and the stoichiometry of each gem mineral is assumed to be ideal

between the different orogenic belts found within Zimbabwe using the mineral stoichiometry and the number of mineral occurrences per geological unit derived from Table I. Given that the tabulated list of coloured gemstones is not exhaustive, the pie charts in Figure 6 should be deemed as semi-quantitative representations. The figure highlights the importance of Al, Be, and to a lesser extent Fe in the whole-rock chemistry of orogenic belts that are well mineralized in coloured gemstones aside from the quartz polymorphs. High Al contents are important for the formation of gem minerals such as kyanite, cordierite, topaz, and ruby/sapphire, and the most fertile rocks with respect to Al are pelitic protoliths. This is well demonstrated by the comparisons in the Pfungwe area where the paragneissic Pfungwe Metamorphic Suite is well endowed with gem occurrences, whereas the adjacent and contemporaneously-formed Mudzi orthogneisses are not mineralized. The endowments of these 'fertile' orogenic belts contrast with the cratonic block where, outside of the famous emerald clusters, most of the gem mineral occurrences comprise relatively low-value quartz polymorphs (Figure 6).

The importance of developing the Zimbabwean coloured gemstone sector

Despite the prevalence of coloured gemstone occurrences discussed above, Zimbabwe has not yet developed significant value addition capacity in the sector. More generally, there is a disconnect between the country's natural mineral endowment and its mineral beneficiation capacity. Thus Zimbabwe has yet to genuinely benefit from its mineral resources, including coloured gemstones, and that opportunities therein remain largely under-developed and under-explored. With the estimation that the world produces US$2–3 billion worth of rough coloured gemstones annually (Shortell and Irwin, 2017), mostly from developing countries in the global south (Cross, van der Wal, and de Haan, 2010; Collet, Curtze, and Reed, 2013), these countries, including Zimbabwe, should implement more significant value addition to claim a greater stake within the coloured gemstones sub-sector.

Our recommendations to unlock the value of Zimbabwe's coloured gemstone subsector are as follows.

1. *Stimulate exploration* efforts to further establish the formal Zimbabwean gemstones sub-sector
   The current contribution suggests a regional geology framework that can be used in the early stages of any exploration initiative. This constitutes a step towards developing a formalized metallogenic framework for coloured gemstone exploration in Zimbabwe, and should be followed up with dedicated 'boots-on-the-ground' type exploration efforts by private companies and governmental entities.
2. *Capacity building in the small-scale coloured gemstones subsector*
   Artisanal mining generally plays an important role in sustaining livelihoods within local communities in Africa (*e.g.,* Hilson, 2009; Hilson and Maconachie, 2020) and accounts for the bulk of coloured gemstone production in Africa (Africa Union, 2009) and worldwide (Collet, Curtze, and Reed, 2013). Small-scale miners also play a significant role in the discovery of gemstones, which sometimes culminates in gemstone rushes, but they are generally under-resourced, and work intermittently or seasonally so that no proper exploration is undertaken. Their mining methods are not always optimal or safe. Cutting and polishing operations (value addition), where they exist, are small informal, illicit, or backyard operations. For these workers to optimize their efforts, there is a need for their capacitation through training, including fundamentals of book-keeping, geology, gemmology, environment, and mine health and safety. Technical support from government departments in these fields can further enhance the safety and productivity of small-scale gemstone mining and processing enterprises. In Zimbabwe, marketing of gemstones has to be done via the Minerals Marketing Corporation of Zimbabwe (MMCZ), which also helps identify marketing opportunities for minerals including gemstones. However, due to bureaucratic bottlenecks and price distortions in some cases, illicit trade in gemstones may happen outside the official channels.
3. *Local gemstone value addition through cutting and polishing*
   The value of Zimbabwe's gemstone endowment can be further unlocked through innovative beneficiation strategies based on greater understanding of the gemstones' physical characteristics. Polished gemstones carry a many-fold value addition relative to unpolished or raw gemstones, with some studies (Thomas, 2008) putting the value of the gemstone embodied in the finished product (jewellery) at 11 times that of the original rough material. However, Zimbabwe currently lacks the required research and value-addition capacity and the gemstones themselves are yet to be adequately studied, profiled, quantified, and evaluated. There is therefore need to build local capacity for modern gemmological training, research, and value addition. This can be initiated through collaborations with established gemmological centres and laboratories, with clear terms for technological transfer, including the establishment of well-equipped gemmological research and training facilities in Zimbabwe. The Zimbabwe School of Mines has recently initiated gemmological training courses and has started construction of a gemmological centre. Lessons can also be learned from countries that have earned world acclaim in managing their gemstone sub-sectors, such as India, which has established itself as a world gemstone cutting and polishing centre. Such an effort must be supported by a dedicated marketing drive to develop a brand around Zimbabwean polished gemstones.

Acknowledgements

The authors would like to thank the two anonymous reviewers and the handling editor for the insights that were provided and which helped to strengthen the manuscript. This work was made possible by the financial assistance from the Royal Academy of Engineering (UK) through the Higher Education Partnerships for sub-Saharan Africa (HEPSA) programme.

Author contributions:

AM collated the datasets and wrote a draft version of the manuscript, BvdH wrote the final draft of the manuscript. TGB provided project oversight and manuscript polishing. All authors were responsible for editing and figure generation.

References

African Union. 2009. Africa Mining Vision. 47 pp. https://au.int/sites/default/files/documents/30995-doc-africa_mining_vision_english_1.pdf

Bartholomew, D.S. 1990. Base metal and industrial mineral deposits of Zimbabwe. *Mineral Resources Series* 22. Zimbabwe Geological Survey, Harare. 154 pp.

Table I

Classification of Zimbabwean coloured gemstones (compiled from Cipriani and Borelli (1986), Bartholomew (1990), GIA (1999) and Hawadi and Mafara (2018))

Gemstone Group	Gemstone species	Gemstone Varieties	Location in Zimbabwe	Host geology
Silica	Quartz	Rock crystal	Masvingo, Mudzi, Mutare, Nyanga	Pegmatites
		Smoky quartz	Marondera, Beitbridge, Hurungwe, Gweru	Pegmatites
		Rose quartz	Marondera, Hurungwe, Beitbridge	
		Amethyst	Nyamandlovu, Hurungwe, Hwange, Lupane, Makonde	Karoo basalt cavities (Hwange, Nyamandlovu), zoned pegmatites (Hurungwe), quartz veins in granite (Makonde)
		Citrine	Marondera, Goromonzi, Harare	Quartz monzonites (adamellites)
		Tiger's eye	Zvishavane, Kwekwe	Replacement of crocidolite by silica
	Chalcedony	Agate	Nyamandlovu, Chivhu, Lupane	Karoo basalts cavities
		Mtorolite	Mutorashanga, Mutare	Green chalcedony in narrow veins in ultramafic rocks
		Carnelian	Kadoma (river gravels)	
		Jasper	Hurungwe, Kwekwe, Nyamandlovu	
		Chrysoprase	Great Dyke, Mutare	
		Sard		
		Onyx	Victoria Falls	
		Bloodstone		
	Opal	Common opal	Great Dyke, Mutare	Veins in serpentinites of greenstone belts and Great Dyke.
Feldspar	Microcline	Amazonite	Nyamandlovu, Hurungwe, Rushinga	Pegmatites intruding Zambezi Belt metamorphic rocks
	Orthoclase	Noble orthoclase		
		Adularia moonstone		
	Plagioclase	Albite moonstone		
		Peristerite	Hurungwe, Beitbridge	
		Labradorite	Beitbridge	Pegmatite in serpentinized dunite
		Andesine	Beitbridge	Pegmatite in serpentinized dunite
Beryl	Beryl	Emerald	Gutu, Masvingo, Insiza, Mberengwa, Hurungwe	Be-bearing pegmatites intruding ultramafic rocks.
		Aquamarine	Hurungwe, Mt. Darwin, Rushinga	Pegmatites
		Morganite	Hurungwe, Pfungwe, Mudzi	Pegmatites
		Golden beryl	Hurungwe, Pfungwe, Mudzi	Pegmatites
		Heliodor	Hurungwe, Pfungwe, Mudzi	Pegmatites
		Bixbite		
Garnet	Garnet	Almandine	Mudzi, Rushinga, Marondera, Beitbridge, Hurungwe	Regionally metamorphosed Al-rich schists
		Pyrope	Mudzi, Rushinga	
		Rhodolite		
		Spessantine		
		Grossular		
		Hessonite		
		Andradite		
		Demantoid		
Tourmaline	Tourmaline	Schorl	Hurungwe, Mudzi	
		Rubellite	Hurungwe, Mudzi	
		Green tourmaline	Hurungwe, Mudzi	
		Dravite		
		Achroite		
		Indicolite		
		Siberite		
Corundum	Ruby		Goromonzi, Marondera, Mudzi, Rushinga, Beitbridge Somabula gravels.	Metamorphism of Al-rich inclusions in igneous rocks; desilication of acid igneous rocks in contact with more basic material; hydrothermal alteration and metamorphism of ultramafic rocks.
	Sapphire		Mudzi	
Aluminosilicate	Kyanite	Kyanite	Nyanga, Mudzi, Rushinga, Hurungwe	High pressure, high temperature metamorphism of Al-rich rocks
	Silimanite	Silimanite	Hurungwe	High temperature metamorphism of aluminous rocks.
	Andalusite	Andalusite	Masvingo, Karoi, Mudzi	
		Chiastolite	Karoi, Masvingo	In carbonaceous phyllites (Masvingo)

Gemstone Group	Gemstone species	Gemstone Varieties	Location in Zimbabwe	Host geology
Chrysoberyl	Chrysoberyl	(Golden) Chrysoberyl Alexandrite Cymophane/ Cat's eye	Masvingo, Gutu, Rushinga Masvingo, Somabula gravels Masvingo, Gutu, Rushinga	Phlogopite schist in serpentinite cut by Be-bearing pegmatites Phlogopite schist in serpentinite cut by Be-bearing pegmatites Phlogopite schist in serpentinite cut by Be-bearing pegmatites
Jade (amphibole) Jade (pyroxene)	Tremolite-actinolite clinopyroxene	Nephrite Jadeite	Mashava	Aplite intrusions in serpentinite
Cordierite	Cordierite	Iolite	Makuti, Beitbridge, Chimanimani, Rushinga	High-grade argillaceous metasediments; Al-rich igneous rocks;
Topaz	Topaz	Topaz Somabula Blue	Karoi, Hurungwe, Mutare Somabula gravels	
Titanite	Titanite	Shene	Makuti, Rushinga, Goromonzi	Calc-silicate rocks (Makuti), epidote veins (Rushinga), biotite-muscovite-sillimanite gneisses (Goromonzi).
Other	Fuchsite quartzite Unakite Lepidolite	Aventurine Unakite Lepidolite	Mashava, Beitbridge, Nyamandlovu Beitbridge, Gweru, Bulawayo, Nyamandlovu Chegutu, Harare, Goromonzi, Rushinga, Wedza, Nyanga	Quartz mica schists/ quatzites in which fuchsite occurs in minute inclusions Epidotisation (metamorphism/ hydrothermal alteration) of plagioclase in granite Pegmatites

Barton, C.M., Carney, J.N., Crow, M.J., Dunkley, P.N., and Simango, S. 1991. The geology of the country around Rushinga Nyamapanda. *Bulletin* 92. Zimbabwe Geological Survey, Harare.

Blenkinsop, T.G. 2019. The geology of Zimbabwe. *Mining in Zimbabwe from the 6th to the 21st Centuries*. Prendergast, M.D. and Hollaway, J. (eds). Chamber of Mines of Zimbabwe. 37 pp.

Bonsu, W.A. 2012. Pricing and marketing of minerals from small-scale mining operations: The case of gemstones. Doctoral dissertation, University of Zambia.

Broderick, T.J. 1979. Explanation of the geological map of the country south of Nuanetsi, Nuanetsi and Beitbridge districts. *Short Report* 46. Rhodesia Geological Survey. 108 pp.

Chen, J.L. and Xing, C.X. 2011. Metallogeny of the gem deposits in basalt in Baishan area, Jilin Province. *Geology and Resources*, vol. 20, no. 4. pp. 255–257.

Collet, L., Curtze, L., and Reed, K. 2013. Responsible sourcing of colored gemstones. Applied Research Seminar Report, Graduate Institute of Geneva. 67 pp.

Chigumira, G., Mamuse, A., Dube, C., Chiwunze, G., Mudzonga, E., and Manamike, I. 2016. Benchmark practices for supporting artisanal and small-scale mining in Zimbabwe, ZEPARU, Harare. 65 pp.

Cipriani, C. and Borelli, A. 1986. Simon & Schuster's guide to gems and precious stones. Simon & Schuster, New York. 384 pp.

Cross, J., van der Wal, S., and de Haan, E. 2010. Rough Cut: Sustainability Issues in the coloured gemstone industry. SOMO, Amsterdam. 44 pp. https://www.somo.nl/wp-content/uploads/2010/02/Rough-Cut.pdf [accessed 1 May 2020].

Dirks, P.H.G.M. and Jelsma, H.A. 2006. The structural-metamorphic evolution of the northern margin of the Zimbabwe Craton and the adjacent Zambezi belt in northeastern Zimbabwe. *Processes on the Early Earth*. Reimold, W.U. and Gibson, R.L. (eds). Geological Society of America. pp. 291–313.

Dittrich, T., Seifert, T., Schulz, B., Hagemann, S., Gerdes, A., and Pfänder, J. 2019. Archean rare-metal pegmatites in Zimbabwe and Western Australia: Geology and metallogeny of pollucite mineralisations. Springer. 134 pp.

Gallagher, M.J. 1967. Phosphates and other minerals in pegmatites of Rhodesia and Uganda. *Mineralogical Magazine and Journal of the Mineralogical Society*, vol. 36 , no. 277. pp. 50–59.

Gallagher, M.J. 1975. Composition of some Rhodesian lithium-beryllium pegmatites. *South African Journal of Geology*, vol. 78, no. 1. pp. 35–41.

GIA (Gemmological Institute of America). 1999. Coloured stones essentials. Course notes. Gemmological Institute of America. 22 pp.

Glynn, S.M., Master, S., Wiedenbeck, M., Davis, D.W., Kramers, J.D., Belyanin, G.A., Frei, D., and Oberthur, T. 2017. The Proterozoic Choma-Kalomo Block, SE Zambia: Exotic terrane or a reworked segment of the Zimbabwe Craton? *Precambrian Research*, vol. 298. pp. 421–438.

Gochero, P. and Boopen, S. 2020. The effect of mining foreign direct investment inflow on the economic growth of Zimbabwe. *Journal of Economic Structures*, vol. 9, no. 1. pp. 1–17.

Groat, L.A., Giuliani, G., Marshall, D.D., and Turner, D. 2008. Emerald deposits and occurrences: A review. *Ore Geology Reviews*, vol. 34, no. 1-2. pp. 87–112.

Hanson, R.E., Martin, M.W., Bowring, S.A., and Munyanyiwa, H. 1998. U– Pb zircon age for the Umkondo dolerites, eastern Zimbabwe: 1.1 Ga large igneous province in southern Africa/East Antarctica and possible Rodinia correlations. *Geology*, vol. 26. pp. 1143–1146.

Hawadi M.T. and Mafara, L.S. 2018. Gemstone deposits of Zimbabwe. Mineral Resources Series 30. *Zimbabwe Geological Survey*, Harare. 161 pp.

Hilson, G. 2009. Small-scale mining, poverty and economic development in sub-Saharan Africa: An overview. *Resources Policy*, vol. 34, no. 1–2. pp. 1–5.

Hilson, G. and Maconachie, R. 2020. Artisanal and small-scale mining and the Sustainable Development Goals: Opportunities and new directions for sub-Saharan Africa. *Geoforum*, vol. 111. pp. 125–141.

Holzer, L., Frei, R., Barton, J.M., and Kramers, J.D. 1998, Unravelling the record of successive high grade events in the Central Zone of the Limpopo Belt using Pb single phase dating of metamorphic minerals. *Precambrian Research*,vol. 87. pp. 87–115. doi:10.1016/S0301-9268(97)00058-2

Johnson, M.R., van Vuuren, C.J., Hegenberger, W.F., Key, R., and Shoko, U. 1996. Stratigraphy of the Karoo Supergroup in southern Africa: an overview. *Journal of African Earth Sciences*, vol. 23. pp. 3–15.

Jourdan, F., Féraud, G., Bertrand, H., Kampunzu, A.B., Tshoso, G., Watkeys, M.K., and Le Gall, B., 2005. Karoo large igneous province: Brevity, origin, and relation to mass extinction questioned by new 40Ar/39Ar age data. *Geology*, vol. 33. pp. 745–748.

Kamber, B.S. and Biino, G.G. 1995. The evolution of high-T-low-P granulites in the Northern Marginal Zone sensu-stricto, Limpopo Belt, Zimbabwe - The case for petrography. *Schweizerische Mineralogische Und Petrographische Mitteilungen*, vol. 75, no.3. pp. 427–454.

Kamber, B.S., Kramers, J.D., Napier, R., Cliff, R.A., and Rollinson, H.R. 1995, The Triangle Shear Zone, Zimbabwe, revisited: New data document an important event at 2.0 Ga in the Limpopo Belt. *Precambrian Research*, vol. 70. pp. 191–213, doi:10.1016/0301-9268(94)00039-T.

Li, Y., Chen, R., Yang, Z., Lin, M., Wang, Y., and Zhao, F. 2021. Discussion on several problems of metallogenic geological condition and genesis of Shoushan stone. *Journal of Gems & Gemmology*, vol. 23, no. 1. pp. 1–11.

Lister, L.A. 1987. The erosion surfaces of Zimbabwe. *Bulletin* 90. Zimbabwe Geological Survey, Harare. 173 pp.

LONDON, D. and KONTAK, D.J. 2012. Granitic pegmatites: Scientific wonders and economic bonanzas. *Elements*, vol. 8, no. 4. pp. 257–261.

LURIE, J. 2000. Short course in gemmology. Technikon Witwatersrand, Johannesburg. 86 pp.

MAHONYE, N. and MANDISHARA, L. 2015. Mechanism between mining sector and economic growth in Zimbabwe, is it a resource curse? *Environmental Economics*, vol. 6, no. 3. pp. 81–92.

MALINGA, W. 2018. From an agro-based to a mineral resources-dependent economy': A critical review of the contribution of mineral resources to the economic development of Zimbabwe. *Forum for Development Studies*, vol. 45, no. 1. pp. 71–95.

MASTER, S., BEKKER, A., and HOFMANN, A. 2010. A review of the stratigraphy and geological setting of the Palaeoproterozoic Magondi Supergroup, Zimbabwe - Type locality for the Lomagundi carbon isotope excursion. *Precambrian Research*, vol. 182. pp. 254–273.

MCKECHNIE, W.F. 2019. Diamond exploration and mining in southern Africa: Some thoughts on past, current and possible future trends. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 119, no. 2. pp, 123–131.

MILADINOVIĆ, Z., SIMIĆ, V., JELENKOVIĆ, R., and ILIĆ, M. 2016. Gemstone deposits of Serbia. *Geologica Carpathica*, vol. 67, no. 3. pp. 211–222. doi: 10.1515/geoca-2016-0014

MOORBATH, S., WILSON, J., and COTTERILL, P. 1976. Early Archaean age for the Sebakwian group at Selukwe, Rhodesia. *Nature*, vol. 264. pp. 536–538.

MUCHAENDEPI, W., MBOWA, C., KANYEPE, J., and MUTINGI, M. 2019. Challenges faced by the mining sector in implementing sustainable supply chain management in Zimbabwe. *Procedia Manufacturing*, vol. 33. pp. 493–500

MUGUMBATE, F. 2014. Overview of Zimbabwe's mineral resource potential - Tip of the Iceberg? Zimbabwe Geological Survey, Harare.

MUNYANYIWA, H., HANSON, R.E., BLENKINSOP, T.G., and TRELOAR, P.J. 1997. Geochemistry of amphibolites and quartzofeldspathic gneisses in the Pan-African Zambezi belt, NW Zimbabwe: evidence for bimodal magmatism in a continental rift setting. *Precambrian Research*, vol. 81. pp. 179–196.

MUNYIKWA, K., HAUTE, P. VANDENBERGHE, D., and Corte, F.D.E., 2000. The age and palaeoenvironmental significance of the Kalahari Sands in western Zimbabwe: a thermoluminescence reconnaissance. *Journal of African Earth Sciences*, vol. 30, no. 4. pp. 941–956.

OHNENSTETTER, D., FALLICK, A.E., and FAGAN, A. 2014. The geology and genesis of gem corundum deposits. *Mineralogical Association of Canada Short Course* 44, pp. 29–112.

OBERTHÜR, T., DAVIS, D.W., and BLENKINSOP, T.G. 2002. Precise U–Pb mineral ages, Rb–Sr and Sm–Nd systematics for the Great Dyke, Zimbabwe — constraints on late Archaean events in the Zimbabwe craton and Limpopo belt. *Precambrian Research*, vol. 113. pp. 293–305.

READ, P.G. 2005. Gemmology.. Elsevier, London. 324 pp.

SHANGAHAIDONHI, T. and GUNDANI, B., 2014. The feasibility of value addition in the mining sector in the wake of the indigenization policy in Zimbabwe. *Journal of Emerging Trends in Economics and Management Sciences*, vol. 5, no. 2. pp. 128–137.

SHORTELL, P. and IRWIN, E. 2017. Governing the gemstone sector: Lessons from global experience. *Natural Resources Governance Institute*. 68 pp. https://resourcegovernance.org/sites/default/files/documents/governing-the-gemstone_sector-lessons-from-global-experience.pdf [accessed 1 May 2020]).

SIMMONS, W.B., PEZZOTTA, F., SHIGLEY, J.E., and BEURLEN, H. 2012. Granitic pegmatites as sources of colored gemstones. *Elements*, vol. 8, no. 4. pp. 281–287.

SMIT, K.V., MYAGKAYA, E., PERSAUD, S., and WANG, W. 2018. Black diamonds from Marange (Zimbabwe): a result of natural irradiation and graphite inclusions. *Gems & Gemmology*, vol. 54, no. 2. pp. 132–148.

SÖDERLUND, U., HOFMANN, A., KLAUSEN, M.B., OLSSON, J.R., ERNST, R.E., and PERSSON, P-O. 2010. Towards a complete magmatic barcode for the Zimbabwe craton: Baddeleyite U-Pb dating of regional dolerite dyke swarms and sill complexes. *Precambrian Research*, vol. 183. pp. 388–398.

SPIEGEL, S.J. 2009. Resource policies and small-scale gold mining in Zimbabwe. *Resources Policy*, vol. 34, no. 1-2. pp. 39–44.

STOCKLMAYER, V.R. 1981. The Umkondo Group. *Precambrian of the Southern Hemisphere*. Hunter, D.R. (ed.). Elsevier, Amsterdam. pp. 556–562.

THOMAS, A. 2008. The Gemstones Handbook. New Holland, UK. 256 pp.

TRELOAR, P.J. 1988. The geological evolution of the Magondi Mobile Belt, Zimbabwe. *Precambrian Research*, vol. 38. pp. 55–73.

VINYU, M.L., HANSON, R.E., MARTIN, M.W., BOWRING, S.A., JELSMA, H.A., KROL, M.A., and DIRKS, P.H.G. 1999. U–Pb and 40Ar/39Ar geochronological constraints on the tectonic evolution of the easternmost part of the Zambezi orogenic belt, northeast Zimbabwe. *Precambrian Research*, vol. 98. pp. 67–82.

VINYU, M.L., HANSON, R.E., MARTIN, M.W., BOWRING, S.A., JELSMA, H.A., and DIRKS, P.H.G.M., 2001. U-Pb zircon ages from a craton-margin Archaean orogenic belt in northern Zimbabwe. *Journal of African Earth Sciences,* vol. 32, no. 1. pp. 103–114.

VON DER HEYDEN, B.P., TODD, C., MAYNE, M., and DOGGART, S. 2023. Zipf rank analysis highlights the exploration potential for lithium-caesium-tantalum -type pegmatites in the Northern Cape, South Africa. *Journal of African Earth Sciences*, vol. 197. 104769.

WATSON, R.L.A. 1969. The geology of the Cashel, Melsetter and Chipinga areas. *Bulletin* no. 60. Rhodesia Geological Survey. 85 pp.

WILES, J.W. 1961. The geology of the Miami Mica field (Urungwe district). *Bulletin* no. 51. Southern Rhodesia Geological Survey. 246 pp.

WILSON, J.F., NESBITT, R.W., and FANNING, C.M. 1995. Zircon geochronology of Archaean felsic sequences in the Zimbabwe craton: a revision of greenstone stratigraphy and a model for crustal growth. Special Publication 95. *The Geological Society*, London. pp. 109–126.

ZGS (Zimbabwe Geological Survey). 1994. Geological map of Zimbabwe (1:1million). Harare.

ZWAAN, J.C., 2006. Gemmology, geology and origin of the Sandawana emerald deposits, Zimbabwe. *Scripta Geologica*, vol. 131. 211 pp.

ZWAAN, J.C., KANIS, J., and PETSCH, E.J., 1997. Update on emeralds from the Sandawana mines, Zimbabwe. *Gems and Gemology*, vol. 33. pp. 80–100. ◆