Geological evolution of Rwanda and its contribution to the genesis of mineral resources

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A b s t r a c t. The Karagwe-Ankole belt, part of Kibaran Belt and where Rwanda is located, is well known for the presence of peralkaline S-type granite-related mineralization of critical metal resources. Although the knowledge on the formation history of these mineralization has largely increased, information about the Country' geology on large scale, mineralogy and geochemistry of the ore minerals is relatively limited. The key objective of this article is to summarize and evaluate what was completed in terms of the geology and mineral resources of Rwanda, identify the gaps in knowledge and give insights on the future geo-scientific research focus.

The present paper is a review of existing information focusing mainly on the regional geo-dynamism, various magmatic events, stratigraphy, structural geology and consequent links with ore mineralogy and geochemistry of different mines throughout the Republic of Rwanda, that is historically known to host cassiterite, ferberite, columbite-tantalite and gold mineralization. The mineralization occurs in quartz veins and pegmatites which are likely associated with the G4-granites of ~986 +/–8 Ma, and which intruded metasedimentary sequences of Palaeo- to Mesoproterozoic age. Mineralogical investigation illustrated little variation in between the different deposits and a strong mineral zoning extending in some areas on up to 6km from the heat source of the mineralizing fluids. This research also illustrates that mineralogy is quite constant in an ore field, while geochemical variation seems to be due to changes in variation in local crystallization parameters.

Keywords: *Rwanda, mineral resources, geological evolution*

The first geological observations for Rwanda were made during the visit of the German Duke Mecklenburg in 1907 in the context of analyzing the range of northern Rwandan shield volcanoes. At the same time, another study was conducted by Hans Meyer, a German geologist. Between 1922 and 1923, the first geological mission conducted by Canon A. Salée, a lecturer at Louvain Catholic University, and F. Delhaye, provided necessary data for the compilation of the first geological map of Rwanda and Burundi at a scale of 1: 200,000.

The mining operations only started in 1930's with two main companies: Société des Mines d'Etain du Ruanda-Urundi (MINETAIN) and Société Miniere de Muhinga-Kigali (SOMUKI) in 1934. Subsequently, some other mining companies were established and included GEORWANDA (1945) and COREM (1948).

In terms of geological and natural resources exploration, the Geological Survey of Rwanda was created in 1960's with its headquarters in the former Ruhengeri Prefecture.

Société Miniere du Rwanda (SOMIRWA) was created on 9th February 1973. The shareholders were the Government of Rwanda (with 49%) represented by the Minister of Finance and the two mining companies (SOMUKI and MINETAIN) with 51%. Immediately after its creation, SOMIRWA faced many problems inherited from the old mining companies from which it had taken over most of the concessions and facilities. To address these problems, a 1970–1980's mineral exploration program financially and technically supported by United Nations Development Program (UNDP) was initiated. Simultaneously, a five-year recovery plan (1977–1981) was introduced with expenditures in the order of one billion Rwandan francs including the construction of a tin smelter. The recovery plan established targets to increase the production of cassiterite and wolframite from 2,200 tons and 825 tons in 1976 to 2,500 tons and 1500 tons per year in 1981 respectively. However, the results of this recovery plan were disappointing and SOMIRWA did not recover from its difficulties. On 23rd July 1985, SOMIRWA went bankruptcy due primarily to low tin prices on international market, heavy investment in the smelter which did not bring enough returns and poor management. After this collapse, from September 1986 to December 1988, the Government provided a care-taking of concessions and their associated properties at the cost of 100 million Rwandan francs per year. The medium to long term solution was the creation of two structures:

- Coopérative de Promotion de l'Industrie Miniere Artisanale au Rwanda (COPIMAR) was founded in 1988 on the initiative of the Government of Rwanda to re-invigorate the sector of artisanal mining that was practically extinct and with financial support from the European Union;
- Régie d'Exploitation et de Développement des Mines (REDEMI), a public company was established in 1989 to continue the work of exploration, mining and minerals trading in the formerly owned Government concessions till the 2006–2007 privatization campaign.

After 1994, there was a gradual recovery of revenues due to increased Government support and focus, with

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exports growing gradually to reach 45.7% of total exports in 2001, the year of "coltan boom". This followed a boom in demand, with global trend for electronic industry (mobile telephones etc.), which has expanded markets for suppliers of raw materials used in their production. In Rwanda, the year 2001 was a year of discovery of multiple new Ta/Nb mineral deposits.

Parallel to the mining operations and since 1980's, intensive geological and mineral exploration programs were carried out in conjunction with various development partners: Sanders and Geophysics LTD (1981), BRGM (1987), Royal Museum for Central Africa (1991), ADROITEC LTD (2006), NRG (2008), PGW (2010), BEAK Consultants (2012–2016), RSCMME (2014–2016), SRK ES (2018–2019), Ngali Mining LTD (2016–2020) and the most recent 2023–2026 Government's mineral exploration program.

The key objective of this article is to summarize and evaluate what was completed in terms of the geology and mineral resources of Rwanda, identify the gaps in knowledge and give insights on the future geo-scientific research focus.

GEOLOGICAL SETTINGS AND MAJOR EVOLUTION EVENTS

There are tectonic, field, and geochronological evidences for a Palaeoproterozoic (1.9 to 2.1 Ga) basement underlying the Akanyaru Supergroup (Fernandez-Alonso et al., 2018). The basement is generally composed of ortho- to para-gneisses of various composition, metasediments and locally exo-migmatites. These basement materials, together with Mesoproterozoic granites, are likely located in the cores of large antiform structures such as the Rubavu–Nyabihu, Huye–Gisagara, Kamonyi–Muhanga–Ruhango and Nyagatare batholiths (Pohl, Gunther, 1991).

Rwanda is occupied by Precambrian suites that are part of the Mesoproterozoic Karagwe–Ankole Belt (KAB), spanning from the Kivu–Maniema region of the Democratic Republic of Congo (DRC) to SW Uganda and NW Tanzania through Rwanda and Burundi (Tack et al., 2010).

This belt is characterized by two structurally contrasting domains (Fernandez-Alonso et al., 2012): the Western Domain (WD) hosting Rwanda and resting on a Palaeoproterozoic basement and the Eastern Domain (ED), resting on Tanzania Archean craton (Fig. 1). They are separated by a boundary zone, the Kabanga-Musongati (KM) alignment of mafic to ultra-mafic Bushveld-type layered complexes (~1.4 Ga).

Rwanda is mostly built up of sedimentary units belonging to the Akanyaru Supergroup and comprising four successive groups of, predominantly, siliciclastic composition and subordinate interlayered metavolcanics with a total thickness of between 5,000 and 6,000 m. They are, respectively from the bottom to top: the Gikoro, Pindura, Cyohoha and Rugezi Groups (Fig. 2). The depositional environments of the Akanyaru Supergroup indicate a shallow-water basin (or sub/basins) with deposition contexts ranging from mud-shelf (bottom) to sandy-shelf with possible emersion (top). The Gikoro and Pindura Groups were deposited between 1.42 and 1.37 Ga (during the early Ectasian), followed by the Cyohoha Group, assumed to be deposited between 1.2 and 1.0 Ga (largely during the Stenian period) and later on the Rugezi Group.

The Rugezi Group has been re-defined to be Neoproterozoic, based on the setting of the diamectites of the Gisakura formation (Fernandez-Alonso et al., 2019) that most probably correlate with equivalents in the Neoproterozoic Itombwe Supergroup of Kivu region.

The KAB shows a long-lived history of an intra-cratonic belt characterized by intermittent depositional activity with periods of hiatus of deposition, erosion, and magmatism.

The deposits indicate a recurrent subsidence trend controlled by SW–NE to E–W structural activity. The KAB is the result of ~1,375 Ma regional *Kibaran tectono-magmatic event*, the Kibara Large Igneous Province (Makitie, 2014), due to intra-cratonic tectonic extension and opening of rift basins which started at around 1,800 Ma. The long-lived history of the KAB as aulacogen of shallow-water intra-cratonic basin(s) within the proto-Congo craton was interrupted only twice by short-lived compressional deformation resulting from the effects of global orogenic events, outside of the proto-Congo craton (Tack et al., 2011). The first compressional tectonic event (D1) is related to the formation

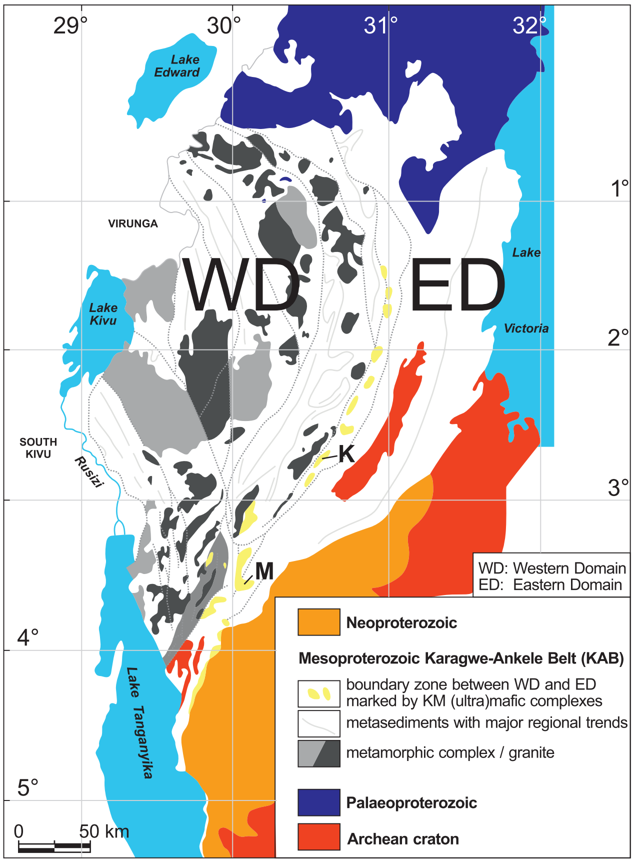

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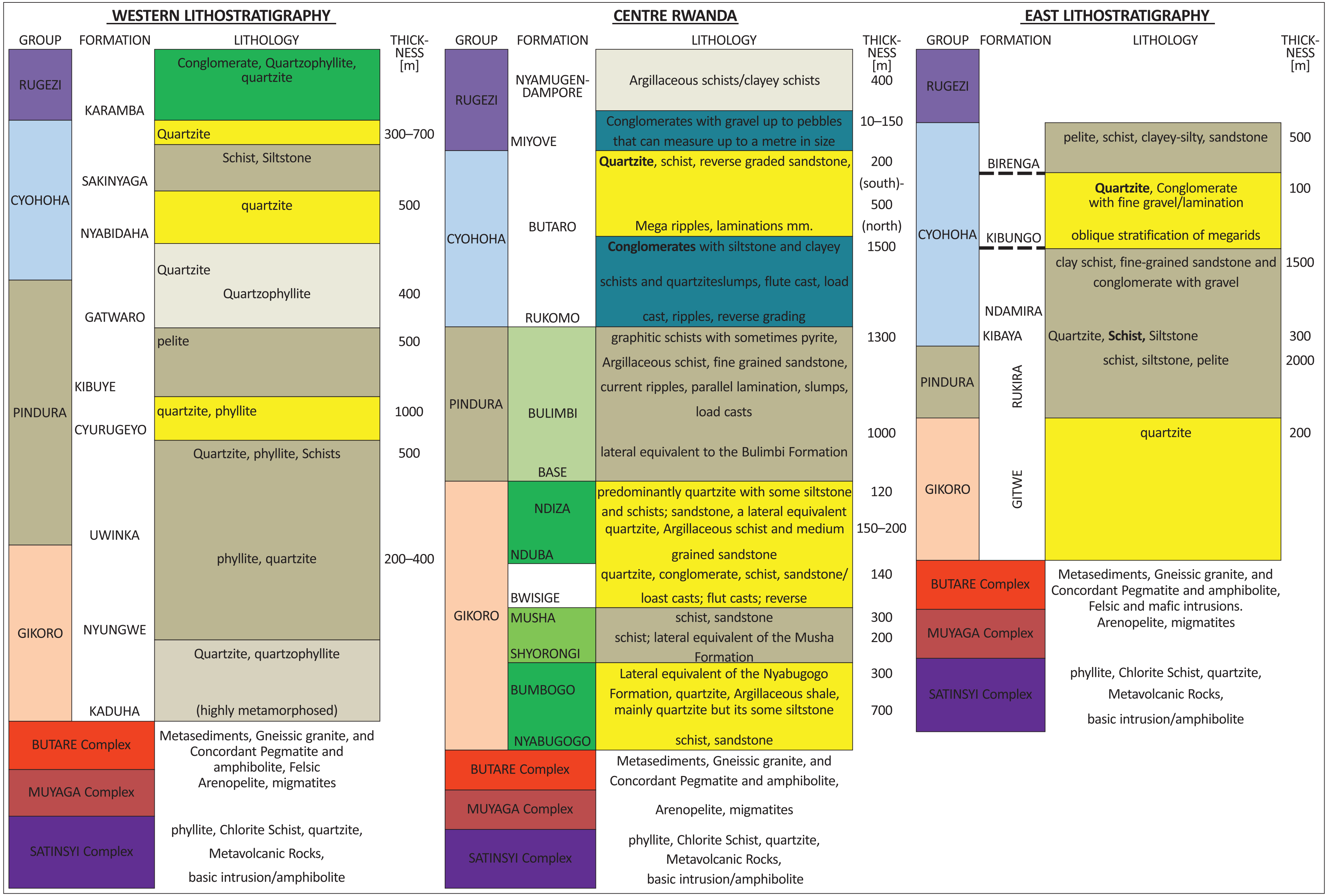
Fig. 1. Location map of the Western Domain (WD) hosting Rwanda and resting on a Palaeoproterozoic basement and the Eastern Domain (ED), resting on Tanzania Archean craton

Fig. 2. Geological map of Rwanda



WESTERN LITHOSTRATIGRAPHY
GROUP
FORMATION
LITHOLOGY
THICK-NESS [m]
RUGEZI
CYOHOHA
PINDURA
GIKORO
KARAMBA
SAKINYAGA
NYABIDAHA
GATWARO
KIBUYE
CYURUGEYO
UWINKA
NYUNGWE
KADUHA
Conglomerate, Quartzophyllite, quartzite
Quartzite
300–700
Schist, Siltstone
quartzite
500
Quartzite
Quartzophyllite
400
pelite
500
quartzite, phyllite
1000
Quartzite, phyllite, Schists
500
phyllite, quartzite
200–400
Quartzite, quartzophyllite
(highly metamorphosed)
BUTARE Complex
MUYAGA Complex
SATINSYI Complex
Metasediments, Gneissic granite, and Concordant Pegmatite and amphibolite, Felsic
Arenopelite, migmatites
phyllite, Chlorite Schist, quartzite,
Metavolcanic Rocks,
basic intrusion/amphibolite
CENTRE RWANDA
GROUP
FORMATION
LITHOLOGY
THICK-NESS [m]
RUGEZI
CYOHOHA
PINDURA
GIKORO
NYAMUGEN-DAMPORE
MIYOVE
BUTARO
RUKOMO
BULIMBI
BASE
NDIZA
NDUBA
BWISIGE
MUSHA
SHYORONGI
BUMBOGO
NYABUGOGO
Argillaceous schists/clayey schists
400
Conglomerates with gravel up to pebbles that can measure up to a metre in size
10–150
Quartzite, schist, reverse graded sandstone,
Mega ripples, laminations mm.
200 (south)-500 (north)
Conglomerates with siltstone and clayey
schists and quartziteslumps, flute cast, load
cast, ripples, reverse grading
1500
graphitic schists with sometimes pyrite,
Argillaceous schist, fine grained sandstone,
current ripples, parallel lamination, slumps,
load casts
1300
lateral equivalent to the Bulimbi Formation
1000
predominantly quartzite with some siltstone and schists; sandstone, a lateral equivalent quartzite, Argillaceous schist and medium
grained sandstone
120
150–200
quartzite, conglomerate, schist, sandstone/
loast casts; flut casts; reverse
140
schist, sandstone
300
schist; lateral equivalent of the Musha Formation
200
Lateral equivalent of the Nyabugogo Formation, quartzite, Argillaceous shale, mainly quartzite but its some siltstone
300
schist, sandstone
700
BUTARE Complex
MUYAGA Complex
SATINSYI Complex
Metasediments, Gneissic granite, and
Concordant Pegmatite and amphibolite,
Arenopelite, migmatites
phyllite, Chlorite Schist, quartzite,
Metavolcanic Rocks,
basic intrusion/amphibolite
EAST LITHOSTRATIGRAPHY
GROUP
FORMATION
LITHOLOGY
THICK-NESS [m]
RUGEZI
CYOHOHA
PINDURA
GIKORO
BIRENGA
KIBUNGO
NDAMIRA
KIBAYA
RUKIRA
GITWE
pelite, schist, clayey-silty, sandstone
500
Quartzite, Conglomerate with fine gravel/lamination
oblique stratification of megarids
100
clay schist, fine-grained sandstone and conglomerate with gravel
1500
Quartzite, Schist, Siltstone
schist, siltstone, pelite
300
2000
quartzite
200
BUTARE Complex
MUYAGA Complex
SATINSYI Complex
Metasediments, Gneissic granite, and Concordant Pegmatite and amphibolite, Felsic and mafic intrusions.
Arenopelite, migmatites
phyllite, Chlorite Schist, quartzite,
Metavolcanic Rocks,
basic intrusion/amphibolite

of the Irumide & Chipata-Tete Belts during the Rodinian amalgamation at the transition between the Meso and Neoproterozoic (Stenian–Tonian). The second event (D2) took place during the late Neoproterozoic (Ediacaran) to early Cambrian and is related to the Gondwana amalgamation. It caused an N–S Pan-African overprint which was in former times often under-estimated.

The deformation history of Rwanda is best known from the Gitarama-Gatumba axis in western Rwanda (Van Daele et al., 2021). The oldest recorded regional tectono-metamorphic event (M1–D1) was of Barrovian type, with peak conditions up to the amphibolite facies. Regional-scale NS to N30W-oriented folds gave the WD its general structural grain, in association with a discrete pervasive axial planar fabric in the metasediments as well as in granites and mafic bodies.

The exact timing of this major (M1–D1) event remains unconstrained to older than 920 Ma. At ~880 Ma, an anorogenic metamorphic event (M2) took place; no compressional deformation is associated with this metamorphism. During the Ediacaran, a third tectono-metamorphic event (M3–D2), which is protracted but less intense than M1–D1, occurred from ~620 Ma up to ~550 Ma.

Metamorphism was of upper greenschist to lower amphibolite facies. Small folds striking between N20W and N60W were locally superimposed on the regional structure, mostly expressed by a crenulation foliation in the fine-grained sediments.

Three magmatic episodes are recognized in the WD:

- ❑ The first one consists of an abundant 1380–1370 Ma coeval bimodal magmatism emplaced under extensional regime during the *Kibara tectono-magmatic event.* This short-lived but prominent event has intra-plate characteristics, is rift-related and indicative of attempted, though unsuccessful continental break-up. The felsic pole is present in the form of massive peraluminous S-type two-mica granitoids (historically known as *G1–G3 granites*), which are devoid of economic minerals. The mafic pole is represented by numerous mafic to ultramafic (Bushveld-type) intrusions. The presence of basic and acid (meta) volcano-sedimentary units in the sedimentary sequences is probably the effusive witness of this magmatic event. Contacts between the S-type granitoids and the parent metasedimentary rocks or basement are intrusive or tectonic;
- ❑ Following this *Kibara event,* A-type granitoids have been emplaced very locally (mapped by Tack in Burundi) at ~1205 Ma along NS oriented, subvertical shear zones;
- ❑ Finally, during the Neoproterozoic (~985 Ma), S-type leucogranites (so-called *G4 or tin-granites*) were emplaced with accompanying Sn, Nb-Ta, W, and Au pegmatites and quartz veins which gave rise to the world class Sn-metallogenic province overprinting large areas of the KAB (Dewaele et al.,

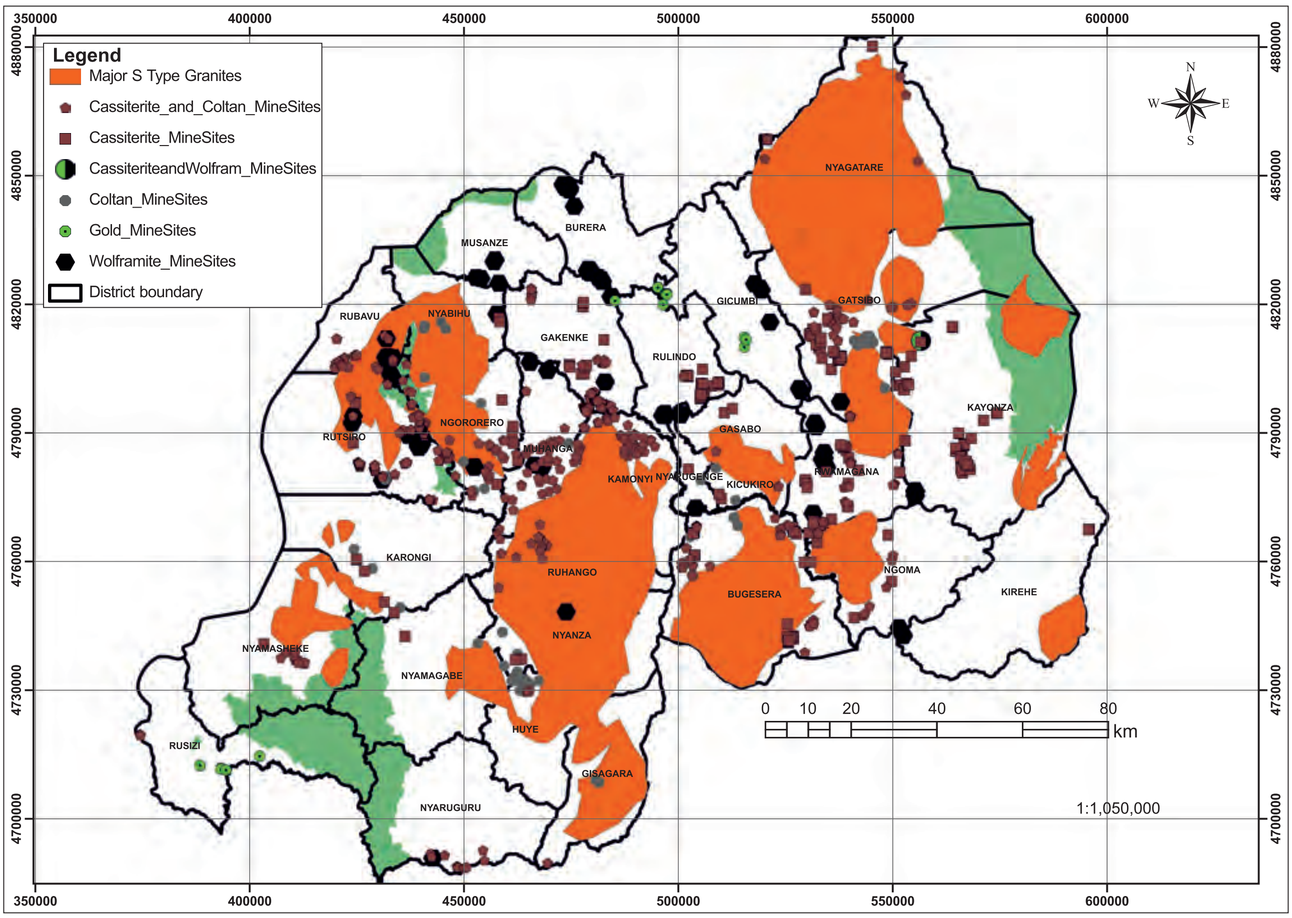


Fig. 3. Mineral occurrences map of Rwanda

2013). Nambaje et al. (2021) reports the emplacement of G5 S-type granite at ~614 ±9 Ma from which late hydrothermal fluids are source of mineralization. Local contact metamorphism is observed around granite, pegmatite, and amphibolite bodies. These contact-metamorphic effects showing metamorphic aureoles are often confined to the metasediments immediately adjacent to the magmatic intrusions.

Bimodal volcanic intercalations associated to the 1,375 Ma event, best described in W Burundi, are present throughout the whole Supergroup in Rwanda. A maximum of volcanics is to be found in the Pindura Group where in particular also magnesium-dominated carbonate lenses were formed during felsic volcanism.

WHAT DOES THE EVOLUTION OF GEOLOGICAL SETTING TELL IN TERMS OF METALLOGENY AND MINERAL RESOURCES?

The general pattern of the Meso-Proterozoic belt in Rwanda comprises resistant cores (high-grade units) characterized by weak deformations separated by N–S to NE–SW *Intensely Deformed Zones*, noted as Shear Zones which are controlling a large number of historical mineral occurrences and workings and presently operating mines, the major commodities being Sn, W, Ta/Nb with Au and a huge range of both gemstones and industrial minerals (Pohl, Gunther, 1991; Ngaruye, 2025).

The primary deposits are pegmatite and quartz veins and are closely related to the post-tectonic and peraluminous S-type granites of the Kibaran Orogeny which functioned as the heat source for the mineralizing fluids (reported as G4-granite of ~986 Ma) and correspond to multiple small to medium fertile pegmatite bodies, mostly hosting Ta/Nb mineralization.

Globally, one third of the cassiterite, columbite-tantalite, amblygonite and beryllium is pegmatite-related. Gatumba and Musha-Ntunga host the most important mineralized pegmatites. Their rock-forming minerals are quartz, K-feldspar, albite and muscovite while accessory minerals include tourmaline, fluorspar, beryl, zinnwaldite and lepidolite, amblygonite, spodumene, zircon and ore minerals such as cassiterite and columbite-tantalite.

Around two third of the ore minerals in Rwanda are hydrothermal quartz vein related where tin and tungsten deposits are associated with steep faults and folds coincident with "highs" on intrusive granite cupolas (Pohl, Gunther, 1991). The gangue minerals are dominated by quartz, muscovite, ilmenite, rutile, feldspar, kaolin, tourmaline, pyrite, arseno-pyrite, chalcopyrite and galena (Ngaruye, 2011; Dewaele et al., 2013).

The Geological Survey of Rwanda, has done a lot of geological reconnaissance and deep mineral exploration surveys for which the results are the discovery of mines, anomalous zones and indices (Fig. 3).

CONCLUSION

Limited number of mineral exploration campaigns have shown that Rwanda hosts important economic deposits of cassiterite, columbite-tantalite, wolframite, gold, and other rare metals related to LCT pegmatites. This is confirmed by the annual production of at least 5,000 tons of cassiterite, 2,000 tons of columbite-tantalite and around 2,000 tons of wolframite.

The primary deposits are of epithermal to mesothermal origins and seem to be a large network of pegmatite and quartz veins which are possibly linked with fertile pegmatites inherited from the youngest granite intrusions. The geometry of the mineralized body is well understood and shows a mineral zoning which is extended between 6 and 10 km away from the fertile granites.

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