29. Prokopiev A., Khudoley A., Egorov A., Gertseva M., Afanasieva E. et al. Late Cretaceous–Early Cenozoic indicators of continental extension on the Laptev Sea shore (North Verkhoyansk). *3P Arctic Conference & Exhibition. The Polar Petroleum Potential*. 2013. Stavanger, Norway.
30. Prokopiev A. V., Borisenko A. S., Gamyanin G. N., Pavlova G. G., Fridovsky V. Yu. et al. Age constraints and tectonic settings of metallogenic and magmatic events in the Verkhoyansk–Kolyma folded area. *Russian Geology and Geophysics*. 2018. Vol. 59, Iss. 10. pp. 1237–1253.
31. Shephard G. E., Müller R. D., Seton M. The tectonic evolution of the Arctic since Pangea breakup: Integrating constraints from surface geology and geophysics with mantle structure. *Earth-Science Reviews*. 2013. Vol. 124. pp. 148–183.
32. Senin B. V., Kerimov V. Yu., Mustaev R. N., Mammadov R. A. Morphology and evolution of Eastern Arctic structure and geodynamics. *Gornyi Zhurnal*. 2023. No. 12. pp. 22–28.
33. Altenbernd-Lang T., Jokat W., Leitchenkov G. L. Distribution of oceanic crust in the Enderby Basin offshore East Antarctica. *Geophysical Journal International*. 2022. Vol. 231, Iss. 3. pp. 1959–1981.
34. Mascle J., Lohmann G. P, Clift P. D. et al. Proceedings, Initial reports, Ocean Drilling Program, Leg 159, Cote d'Ivoire-Ghana Transform Margin, Eastern Equatorial Atlantic. 1996.
35. Prokopyev A. V., Toro J., Smelov A. P., Miller E. L., Wooden J. et al. Ust-Lena Metamorphic Complex (Northeast Asia): The first U-Pb SHRIMP geochronological data. *Otechestvennaya Geologiya*. 2007. Vol. 5. pp. 26–29.
36. Somme T. O., Dore A. G., Lundin E. R., Torudbakken B. O. Triassic paleogeography of the Arctic: Implications for sediment routing and basin fill. *AAPG Bulletin*. 2018. Vol. 102, No. 12. pp. 2481–2517.
37. Franke S., Jansen D., Binder T., Paden J. D., Dörr N. et al. Airborne ultra-wideband radar sounding over the shear margins and along flow lines at the onset region of the Northeast Greenland Ice Stream. *Earth System Science Data*. 2022. Vol. 14, Iss. 2. pp. 763–779.
38. Kerimov V. Yu., Potemkin G. N., Shatyrov A. K. Assessment of geomechanical properties of Sakhalin shelf reservoirs based on modeling results. *Rroceedings of higher educational establishments*. Geology and Exploration. 2024. Vol. 66, No. 2. pp. 13–21. EM

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GEOLOGY AND METALLOGENY OF THE MOBILE MAGONDI BELT IN THE WEST OF THE REPUBLIC OF ZIMBABWE

Western Zimbabwe is the Paleoproterozoic Magondi Mobile Belt activated in the Neoproterozoic and Mesozoic. The Paleoproterozoic volcanogenic–sedimentary deposits contain copper and ores deposits attributed respectively to stratiform formations of cuprous sandstone and polymetallic formations in carbonate rocks. As a result of the analysis of geological structure of the deposits, an assumption is made that they belong to the pyritic copper and polymetallic pyrite formations and are related to volcanism. A large number of deposits and ore occurrences of tin, beryllium, tantalum and lithium in granite pegmatites and tungsten in quartz veins are associated with the Neoproterozoic era. Kimberlite pipes are found in the Mesozoic sediments of the cover. Most of the deposits are mined out but the prospects for discovering new objects are far from being exhausted. Despite many years of geological study of the area under discussion, many questions of the genesis of mineralization, its age and connection with geological formations remain insufficiently studied, and no metallogenic studies have been carried out.

New ideas about the origin of the Belt and on the connection of copper and polymetallic mineralization with volcanism are substantiated. Metallogenic zoning of this part of Zimbabwe is carried out on a scale of 1:2500000 with the delineation of metallogenic zones.

The occurrence patterns of the deposits and the metallogenic zoning of the western part of Zimbabwe can allow determining ore contents in the delineated metallogenic zones and estimating the metallogenic potential.

Keywords: *Magondi Belt, Dete-Kamativi Inlier, granite–gneiss, granite, metallogenic zone, pegmatite, copper, lead, zinc, tin, beryllium, lithium, kimberlite*
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Introduction

To the west of the Zimbabwe Craton, the area is characterized by widely occurring strata of the Mesozoic–Cenozoic sedimentary cover. Proterozoic metamorphic rocks that crop out in its fensters belong to heterochronous mobile belts. The craton is bordered in the west by the Paleoproterozoic Magondi Belt. Lying north and southwest of the latter are fensters with strata that respectively belong to the Neoproterozoic Zambezi Mobile Belt and the southern branch of the Neoproterozoic Damara Mobile Belt. In Botswana, deposits of cupriferous sandstones with high silver grades are commonly found in the Ghanzi–Chobe series of the Damara Belt. Confined to the knot of junction between these belts in Zambia is the Choma–Kalomo Block of metamorphic rocks (1.37–1.18 Ga) representing a remnant of the Mesoproterozoic Irumide Mobile Belt. It does not seem possible to clarify the geometry of the belts and their boundaries.

During the Middle and Late Proterozoic, the Magondi Belt underwent metamorphism and magmatism associated with the orogeny of neighboring belts.

In recent years, geologists have begun to view the Magondi Belt as part of the Paleoproterozoic Magondi–Okwa–Kheis mobile belt [1, 2]. This belt presumably stretches north to south from the Zimbabwe Craton through the territory of Botswana up to the western edge of the Kaapvaal Craton (**Fig. 1**) [3]. The belt extends for over 1.5 thousand km and is 250 km across at its widest point.

In Botswana, the outcrops of Paleoproterozoic metamorphic rocks are known in several small inliers (Okwa, Gweta, etc.), whereas in South Africa they occur along the western contact with the Kaapvaal Craton (the Kheis Belt) [1, 3, 4].

All rocks in these exposures are similar in age (~2.0 Ga) and their carbonates exhibit anomalous isotope δ13C — 9–10‰ values indicative of the Lomangundi event (named after the Lomangundi formation in the Magondi Belt), where such values were detected for the first time. It has been found that the same δ13C values are also typical of the rocks in the Transvaal series in South Africa [3]. It is thought that the Earth was undergoing global environmental changes at the time. There was an abrupt increase in oxygen levels and the mechanism of plate tectonics was set in motion.

It is important to note that the rocks of volcanic origin in the Kheis Belt in South Africa turned out to be 80 Ma younger than the Magondi Belt rocks [2], so it is more appropriate to single out Magondi as an independent belt that may have been connected to the Limpopo Belt [5, 6]. However, it is currently impossible to finally solve this issue.

In recent years the origin of the belt has been explained from the standpoint of plate tectonics. The protolith of the belt is thought to have evolved within and along the island arc–back-arc complex brought about by the subduction of the oceanic plate beneath the western margin of the Zimbabwe Craton. In this instance, this part of the craton can be viewed as an active continental margin, on which a rear zone of extension with rift-related basaltic volcanism appeared within a back-arc basin. The presence of subsequent felsic volcanism can be explained by the rollback of the subducting plate and the formation of a mantle wedge underneath the frontal part of the active margin. As a result, the volcanic front migrated from the continent to the ocean, forming a volcanic arc. The partial melting of the mantle wedge material led to rhyolitic volcanism and the influx of related ore-bearing fluids. A similar mechanism has been proposed for the formation of Devonian volcanic series in the Rudny Altai region [7] and is also taken into consideration when developing geologic-genetic models of volcanism-associated pyrite deposits [8, 9].

Geology of the Magondi Belt

Within the Magondi Belt, Paleoproterozoic rocks are exposed in two districts spanning an area of ~ 8.000 km^2 (the northern sector of the belt) and ~ 4.000 km^2 (the Dete–Kamativi Inlier located 200 km southwest of the first district).

The geologic framework and ore content within the northern sector of the Magondi Belt and the Dete–Kamativi Inlier in Zimbabwe have been described in a large number of publications. A major contribution to the belt studies has been made by P. J. Treloar, S. Master, S. McCourt, S. M. Glynn, J. Jacobs, H. Munyanyiwa and many other researchers.

The geochronology of Proterozoic strata is mainly based on absolute age determinations, which are contradictory in many respects. This paper only deals with the findings published in recent years.

In the east the basement of the Magondi Belt consists of Archean granite–gneisses of the Zimbabwe Craton, while in the central part and in the west it comprises Paleoproterozoic paragneisses probably brought about by the reworking of Archean metamorphic rocks (**Fig. 2**). The following six subdivisions of gneisses have been identified: quartz–feldspathic gneisses, sometimes garnetiferous gneisses (Urungwe), biotite–hornblende gneisses formed after graywackes (Escarpment), quartz–feldspathic and biotite gneisses (Chiroti), garnetiferous biotite gneisses (Chitumbi, Kariba and Chipiza) [10–13]. The age of the gneisses is estimated to be between 2.46 and 2.0 Ga.

The Deweras, Lomangundi and Piriwiri series (groups) are commonly found in the northern sector of the Magondi Belt. Their rocks are less metamorphosed than the paragneisses. Detailed stratigraphic columns of these strata are presented in the work by S. Master et al. [3]. The absolute ages of these three groups are within a 2.16–2.07 Ga range.

The rocks of the Deweras series crop out in the east of the belt along the edge of the Archean Craton. They unconformably overlie the Archean rocks of the craton and in turn are unconformably overlain by the Lomangundi series that changes westward along strike to the Piriwiri series occupying the central part of the belt (see Fig. 2). The rocks of the last two series rest upon Proterozoic paragneisses and the contacts with the latter are most often tectonic.

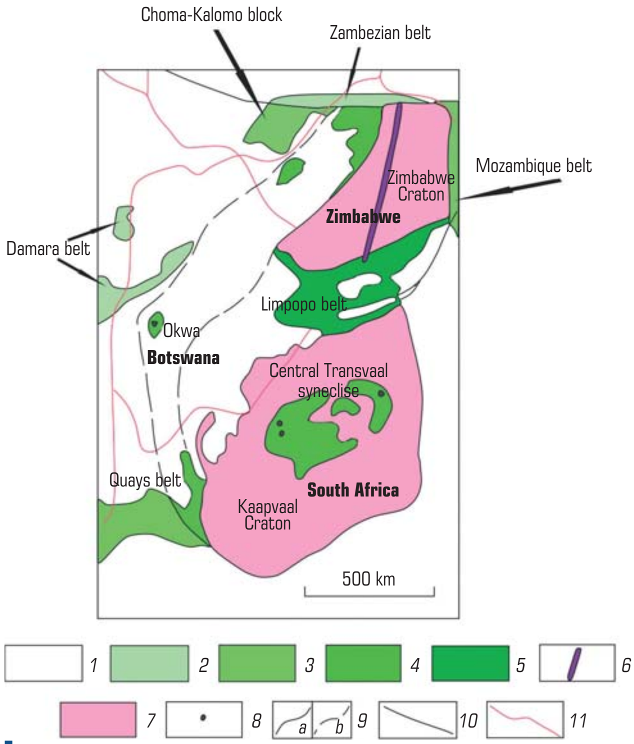

Fig. 1. Layout of the Paleoproterozoic Magondi–Okwa–Kheis Mobile Belt, based on materials [3]:
1 – Mesozoic–Cenozoic sedimentary cover; *2* – Neoproterozoic rock outcropping; *3* – Mesoproterozoic rock outcropping; *4* – Paleoproterozoic rock outcropping; *5* – Archean–Proterozoic rock outcropping (Limpopo Belt); *6* – Great Dyke; *7* – Archean cratons; *8* – points of isotope δ13C +9–10 ‰ in carbonates; *9* – boundary of the Magondi–Okwa–Kheis mobile belt: *a* – traced, *b* – presumptive; *10* – tectonic faulting; *11* – state border *1* – Mesozoic

The Deweras series (2.29 Ga) is dominated by red-colored basal conglomerates changing upsection to basaltic lavas and tuffs, in turn overlain by arkosic sandstones and graywackes interlayered with mudstones and thin dolomite and evaporite horizons generally regarded as alluvial–proluvial deposits. The series attains a thickness of 1 km.

The rocks of the Lomangundi series (2.07 Ga) comprise conglomerates, arkosic and quartzose arenites, felsic volcanic and volcaniclastic rocks, stromatolitic dolostones, banded ferruginous quartzites, and pyrite-bearing graphitic schists characteristic of mixed fluvial and marine settings in a shelf area. The series exceeds 1 km in thickness.

In the Piriwiri series (2.16 Ga), graphitic schists, phyllites, graywackes, dolostones, and Mn-bearing horizons stand out among graphitic and pyritized schists, thinly layered phosphate-bearing schists as well as lavas and tuffs of felsitic composition that formed in deepwater settings, on the shelf and continental slope. A volcanic member makes up an 85 km linear zone of agglomerate tuffaceous pyritized felsites that form a keel of a syncline structure. Some researchers identified several volcanic centers in this zone, southeast of the Urungwe Granite Massif. These centers were interpreted to be composed of exposed agglomerate breccias specific to a vent facies. However, the existence of such centers is currently seen as insufficiently proven. The Piriwiri series attains a thickness of 2 km [3].

The Proterozoic paragneisses and the rocks of the Piriwiri series in the central part of the belt are pierced by the bodies of quartz–feldspathic–biotite granites. The largest of these is the Urungwe Massif (~1.200 km^2). At least two phases are discernible in this massif, i.e. the early phase represented by fine-grained biotite granites and the late phase comprising

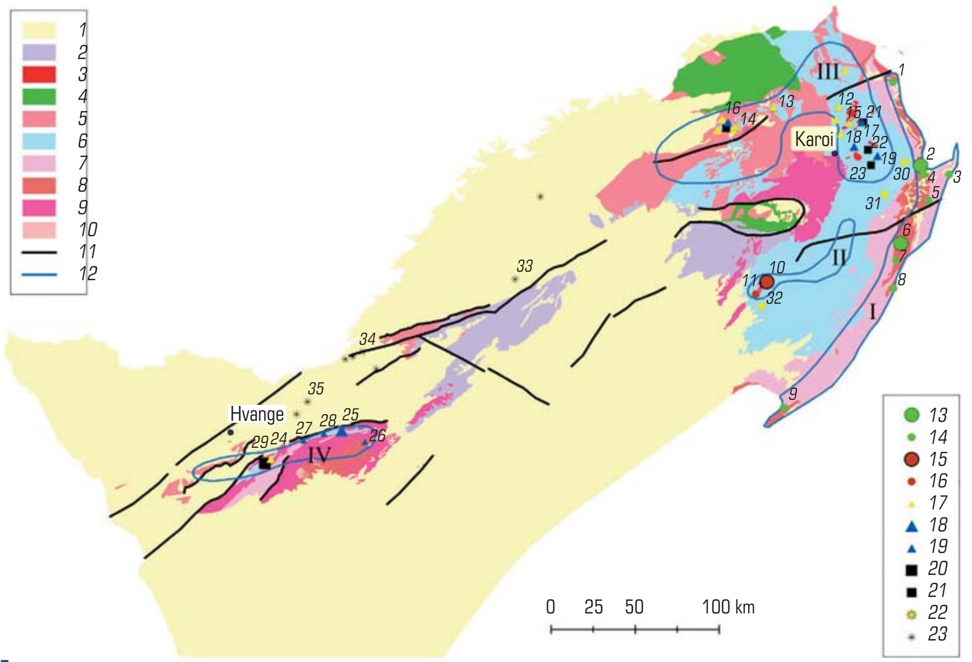

Fig. 2. Geological map of the Magondi Mobile Belt with deposits and identified metallogenic zones

1 – deposits of the Meso-Cenozoic platform cover; *2* – Sizharir series; *3* – Miami granites; *4* – Makuti series; *5* – Urungwe granites; *6* – Piriviri series; *7* – Lomangundi series; *8* – Deveras series; *9* – paragneisses of the Early Proterozoic; *10* – Middle Archean granite gneiss; *11* – discontinuities; *12* – metallogenic zones: I – copper, II – copper–zinc–lead, III – Northern tungsten–beryllium–tantalum; IV – Southern tungsten–beryllium–tin–lithium; *13–20* – deposits: *13–14* – copper pyrites: *13* – large and medium (*2* – Mangula, *6* – Shackleton), *14* – small (*1* – Shamrock, *3* – Silverside, *4* – Nora, *5* – United Kingdom, *7* – Alaska, *8* – Tsedri, *9* – Copper Pot); *15–16* – pyrite polymetallic: *15* – large (*10* – Copper Queen), *16* – small (*11* – Copper King); *17* – small deposits of mica pegmatites (muscovite: 12 – Hendren, 13 – Locust, 14 – Meteor, 15 – Grand Parade; biotite–tourmaline: *24* – Ibik); *18–19* – deposits of rare metal pegmatites: *18* – large (*25* – Kamativi), *19* – small (*16* – Grandeur, *17* – Pumpkin, *18* – Kondo, *19* – Mavala, *26* – Wolf Cube, *27* – Kapata, *28* – Labyrinth); *20–21* – deposits of quartz–wolframite–greisen formation: *20* – medium (*29* – R.H.A.), *21* – small (*20* – Mak Luke, *21* – Miksam, *22* – Honey, *23* – Helen Hope); *22* – small gold deposits (*30* – Redwing, *31* – Anglian, *32* – Emerald); *23* – kimberlite pipes (*33* – Quest, *34* – Binga, *37* – Katete)

porphyric granites. Dolerite dikes of possible Mesozoic age can be encountered in the massif. The age of the granites is estimated at 1997.5±2.6 Ma [2].

The area of the Magondi Belt was activated in the Neoproterozoic and numerous sills and dikes of 'epidiorite' were emplaced. Their number rapidly increases in the northern direction toward the boundary with the Zambezi Mobile Belt. Minor granite massifs of the Miami complex and plentiful bodies of muscovite pegmatites and rare-metal pegmatites were also formed. Although no data are available on the absolute ages of all these strata, geologic maps show areas where 'epidiorite' dikes are intersected by pegmatite veins.

The rocks of the Neoproterozoic sedimentary cover forming graben-like depressions are represented by a rhythmic series of quartzitic sandstones, arkoses, quartzites and dolostones with rare interlayers of schists and graywackes (the Sijarira series). They overlap Proterozoic paragneisses, the Piriwiri series, and the Urungwe Granite Massif (see Fig. 2). Lying close to the massif is the so-called Urungwe Klippe that represents an extensive nappe overlapping the younger Sijarira series and comprising rocks assigned to the Makuti series commonly found in the north. In the north, the Makuti (Rushinga) series comprises mica schists interlayered with amphibolites and pink-colored feldspathic psammites unconformably overlying Paleoproterozoic rocks [12–15].

The Dete–Kamativi Inlier in the south of the Magondi Belt is a vast area within the Mesozoic–Cenozoic platform cover. It is made up of severely deformed supracrustal paragneisses that have undergone amphibolite- to granulite-facies metamorphism and are subdivided into the Malaputese, Inyantue, Kamativi and Tshontanda formations. It also contains granodiorite and granite orthogneisses (see Fig. 2).

The Malaputese formation (2.31 Ga) consists of pink-colored paragneisses with minor interlayers of calcium–silicate and pyroxene leucogneisses, quartzites, graphitic schists and hornblende–andesine amphibolites classified as subalkaline basalts. The sedimentary rocks may correlate with shallow marine shelfal or lagoonal sediments [3].

The Inyantue formation (2.0 Ga) consists of garnetiferous gneisses and schists with disseminated calcareous, graphitic, magnesian and arenitic rocks formed after mudstones interlayered with combustible schists, limestones, dolomitic marls, calcareous sandstones and graywackes.

The Kamativi formation comprises muscovite schists and close-grained biotite schists with a small number of interlayers of arkosic psammites.

The Tshontanda formation (2.14–2.08 Ga) is made up of garnetiferous mica schists and less common sillimanite gneisses with local lens-shaped interlayers of quartzites. The modal composition and bedding of rocks in the Kamativi and Tshontanda formations enable us to infer that their protoliths consisted of mica schists, siltstones with thin interlayers of arkoses and feldspathic arenites. The absence of carbonate rocks suggests a deeper-water character of the deposit compared to the Inyantue formation.

Absolute ages of the formations are between 2.31 and 2.0 Ga and correspond to the age of the formations in the northern sector of the Magondi Belt. The Malaputese and Inyantue formations in the Dete–Kamativi Inlier are thought to be equivalent of the Deweras and Lomangundi formations, while the Kamativi and Tshontanda formations may correlate with the Piriwiri series [5].

About 60 percent of crystalline rocks in the Dete–Kamativi Inlier are heterogeneous accumulations of granitic gneisses varying in composition from quartz monzonite to granodiorite and granite. The majority of granite varieties consist of quartz, sodium plagioclase, K-feldspar, biotite and a minor amount of muscovite, sericite, chlorite, and epidote. Accessory minerals include zircon, apatite, and rare titanite. Although their contact zones with paragneisses are variable, in many cases they are obviously intrusive. The granite gneisses frequently contain xenoliths of Early Proterozoic paragneisses [3, 16]. The granodiorites are dated at 2.159±0.1 Ga, while the age of the granites is estimated at 2.06–2.02 Ga [3]. In terms of their composition and age, granites of the Dete–Kamativi Inlier are similar to the Urungwe granites in the northern sector of the Magondi Belt. Along with Early Proterozoic paragneisses, these rocks contain xenoliths of pink orthogneisses dated as 2.6–2.7 Ga, which is equivalent to the age of the Archean craton rocks [5].

Thus, the rocks that make up the Dete–Kamativi Inlier belong to the Magondi Belt, which originated in the marginal part of the Zimbabwe Craton and comprises deltaic, coastal–marine and marine deposits with an insignificant amount of mafic and felsic volcanics. The belt is pierced by the bodies of Paleoproterozoic granites. The rocks of the Archean craton acted as the basement of the belt and were largely reworked and metamorphosed during the Proterozoic. Some researchers believe that the boundary of the Zimbabwe Craton should be traced west of the northern sector of the Magondi Belt and the Dete–Kamativi Inlier [1].

The Magondi Belt ore content and metallogenic zoning

The Magondi Belt hosts deposits and ore occurrences of the following ore formations: copper–pyrite and pyrite–polymetallic formation, quartz–wolframite–greisen formation (R.H.A., Tung, Makashi, Bergie, Niksam, etc.), formation of muscovite pegmatites (Locust, Hendren, Meteor, Sun Spot, Grand Parade, etc.) and rare-metal pegmatites (Kamativi, Shecting Star, Grandeur, etc.), pitchblende-bearing gold–quartz–carbonate formation (Redwing, Anglian, Emerald, Mambo, A.M.O., etc.), and he formation of diamantiferous kimberlites.

Three metallogenic epochs (Paleoproterozoic, Neoproterozoic and Mesozoic) have manifested themselves within this area.

The first epoch saw the formation of copper and polymetallic pyrite deposits. The earliest deposits are apparently Ag-bearing copper deposits confined to the rocks of the Deweras and Lomangundi groups in the eastern part of the belt (Alaska, Shamrock, Mangula, Silverside, Shackleton, Molly and Nora, etc.). The band of copper deposits extends southwestward for more than 400 km (see Fig. 2). The Gwayi River and Fin copper deposits in the strata of the Malaputese formation within the Dete–Kamativi Inlier are likely to be of this type.

The mineral composition of the ore bodies includes pyrite, chalcocite, bornite, chalcopyrite and hypergene copper minerals. Most researchers previously assigned these deposits to the formation of cupriferous sandstones by analogy with the deposits in the neighboring copper belts (the Damara Belt in Botswana and the Central African Belt in the DRC and Zambia) on the grounds of the stratiform character of their ore bodies represented by multistage accumulations confined to the horizons of dolostones, mudstones and various schists. However, in recent years their genesis has been revised and their epigenetic origin has been inferred based on the veinlet-impregnated appearance of the ores, their occurrence in almost all rock varieties in the Deweras and Lomangundi groups (including basalt horizons), the presence of metasomatites accompanying ore mineralization and other indications. In some deposits, saddle-shaped ore bodies tend to thicken in the hinges of anticlinal folds cut by axial subvertical faults frequently filled with post-ore 'epidiorite' dikes. Sulfide-impregnated hydrothermal metasomatites with anomalous copper grades can be traced down to great depths along these faults that appear to act as migration pathways for hydrothermal fluids [16, 17]. At depth, blanket deposits often merge into a single vast stockwork ore body. The indications given above suggest a pyrite mineragenic type of the copper deposits.

Polymetallic deposits are located in the central part of the areal extent of the Piriwiri series, which hosts abundant horizons of siliceous and graphitic schists impregnated with pyrite due to the influx of sulfuric hydrotherms onto the seabed [3]. The ore-hosting horizon is composed of monotonously alternating phyllites, very coarse-grained, micaceous and feldspathic arenites with ferruginous marble at the bottom. Lead–copper–zinc ore bodies mineralized with silver and associated with a marble horizon have undergone metamorphism under amphibolite-facies conditions along with the host rocks [18]. The deposits were formerly regarded as limestone-related stratiform deposits.

More recent studies have shown that the mineralized zone is traceable roughly north to south for at least 25 km and consists of several discontinuous lens-shaped bodies of massive ores. The lenses of Copper King, Copper Queen and other deposits are 5 to 30 m thick and as much as 300 m long. The mineral composition of the ores comprises chalcopyrite, sphalerite, galena, pyrite, and arsenopyrite. In our opinion, these ores are specific to the pyrite polymetallic formation, which is convincingly evidenced by their telltale appearance (**Fig. 3**).

Thus, copper and polymetallic deposits belong to hydrothermal–metasomatic or hydrothermal–sedimentary deposits, albeit being largely represented by stratiform accumulations in metamorphosed sedimentary rocks. Although they bear a certain resemblance to the deposits of the pyritic formation, they have not been studied from this standpoint and no evidence of their relationship with volcanism processes has been presented in scholarly literature. We assume that the deposit-forming process is linked with a hydrothermal activity that accompanied mild volcanism. Copper pyrite deposits could have formed first due to rifting in the back-arc basin and basalt volcanism (the Deweras series). Pyrite polymetallic deposits could have formed later after the rollback of the subducting plate and are associated with a newly formed volcanic arc with mild manifestations of felsic effusives (the Piriwiri series). A clearer understanding of ore genesis requires additional specialized studies at the deposits.

Formation of belts of pegmatite veins and quartz-wolframite-scheelite veins commonly found both in the northern sector of the Magondi Belt and within the area of the Dete–Kamitivi Inlier is attributed to the Neoproterozoic metallogenic epoch.

The northern sector typically contains the following three types of pegmatites: muscovite pegmatites, beryl-bearing muscovite pegmatites, and columbite-bearing rare-metal–muscovite pegmatites. Hundreds of large and small mines are known here. Some researchers regard the Miami biotite granites as parent rocks for pegmatites. These granites make up five large massifs covering a total area of about 100 km^2 [19]. Absolute age determinations are unavailable for pegmatites and biotite granites and the relations between the different types of pegmatites are unknown. The instances of pegmatite veins crossing widespread 'epidiorite' dikes in the northern portion of the sector near its boundary with the Neoproterozoic Zambezian Belt suggest a probable Neoproterozoic age for both the 'epidiorites' and pegmatites.

Two types of heterochronous pegmatites are found within the Dete–Kamativi Inlier [20].

Assigned to the first type are steeply dipping thin veins of quartz–alkali feldspar–biotite–tourmaline–garnet composition that are conformable with the steeply bedded host rocks. These pegmatites are barren. No data about their absolute age is available.

The second type contains up to 30 m thick flat-lying bodies and dikes of quartz–-albite–muscovite–spodumene pegmatites mineralized with tantalite, columbite, cassiterite and beryl. These bodies are associated with aplite dikes and intersect the schistosity of host rocks. They are often localized in faults cutting the bodies of the first type. A large Kamativi tin deposit was discovered here and has been mothballed since 1994. Recent years have seen a renewed interest in this district due to the discovery of substantial lithium reserves.

The pegmatites of the second type are thought to be Neoproterozoic in age (1030–930 Ma) [21]. In terms of their composition and age, the

Fig. 3. Cu–Zn–Pb–Fe massive sulphide from Copper Queen Formation, Piriwiri Group, Copper Queen Mine [18]

pegmatites of the second type are comparable with the cassiterite-bearing pegmatites of the Kibara Belt in Central Africa [20, 22].

In the northern sector of the Magondi Belt and the Dete–Kamativi Inlier, the pegmatite belts contain well represented quartz veins with large wolframite and scheelite crystals and accompanied by the greisenization of rocks. Several mines are known here, the largest of which is the R.H.A. mine within the Dete–Kamativi Inlier. It has small reserves of very high-grade tungsten ores. Tungsten is still being mined from this deposit, albeit in minor amounts. The data about the age of quartz–wolframite–scheelite veins and their interrelation with pegmatites are non-existent. They are most likely to be Neoproterozoic in age as well.

Redwing is the best studied deposit among the deposits of the gold–quartz–carbonate formation mineralized with pitchblende. It is located in the northern sector of the belt and is confined to a roughly east-west trending ‘epidiorite’ dike that crosses the rocks of the Piriwiri series and extends for about 1 km.

The ‘epidiorites’ are represented by an intensely chloritized tremolite–anthophyllite–talc-rich rock impregnated with magnetite and carbonate. Such minerals are indicative of possibly ultramafic primary composition. The dike is cut by longitudinal and transverse faults. Confined to these faults are quartz and quartz–carbonate veins and veinlets mineralized with pyrite, chalcopyrite and arsenopyrite. Less commonly found are pentlandite, pyrrhotite, cobaltite, tennantite, galena, scheelite and pitchblende. The gold content reaches 6.8 g/t. The origination of ore grade mineralization is attributed to the processes of Neoproterozoic activity. The age of ore grade mineralization is estimated at 600 Ma [23]. Although there is a number of probably similar deposits in the areal extent of the Piriwiri rocks, no information is available about them.

The formation of kimberlite pipes is associated with the Mesozoic stage of tectonic–magmatic activity. They are found on the right bank of the Zambezi River and Lake Kariba and form clusters in three areas known as Katete, Bingo and Quest. All of them occur in the Jurassic strata of the Karoo group and are Mesozoic in age. Some pipes cover an area of up to 10 ha. The pipes in the Katete area occur in the immediate vicinity of the ultramafic–alkali carbonatite ring complex. A salient feature of the Quest pipes is the presence of garnets in disintegrated diamond-bearing eclogites brought to the surface by kimberlite magmatism [24].

Two metallogenic zones have been identified as a result of the metallogenic zoning of the territory assigned to the Paleoproterozoic metallogenic area. These zones respectively exhibit copper pyrite and pyrite polymetallic ore grade mineralization.

The first zone is traceable for more than 120 km in the southwestern direction along the outcropping Deweras and Lomangundi series (see Fig. 2). The zone is about 20 km wide. Such deposits as Shamrock, Mangula, Nora, United Kingdom, Shackleton, Alaska and others are associated with this zone.

The second zone is found in the rocks of the Piriwiri series. It lies 20 km southwest of, and parallel to, the first zone. It is about 100 km long and not more than 40 km across. Confined to this zone are pyrite-polymetallic deposits such as Copper Queen, Sanyati and Copper King, as well several copper occurrences of uncertain mineragenic type located farther north, i.e. Northern Star, Montana and others.

In addition, we have identified two Neoproterozoic-aged metallogenic zones related to the protoactivity of the Magondi Belt and marked by numerous bodies of muscovite pegmatites and rare-metal pegmatites as well as veins of quartz-wolframite-scheelite composition. The first such zone is in the area where the Magondi Belt closes in the north. It is arc-shaped and lies north of the Urungwe Granite Massif. The massif itself is devoid of pegmatites. The largest cluster of pegmatite bodies is observed in the area of the Miami Granite Massif, which is presumably Neoproterozoic in age [19, 25].

The second zone is located within the Dete–Kamativi Inlier. It trends roughly east–west, consistently with the geometry of the window. The zone is about 60 km long and up to 20 km wide.

It is currently impossible to single out a metallogenic zone favorable for Neoproterozoic vein/stockwork gold deposits, as there are no patterns in their occurrence. They are rare and encountered in different parts of the areal extent of the Piriwiri series. Mineralized zones trend in different directions and no relationship with magmatism has been established.

Metallogenic zones with Mesozoic kimberlite pipes are also unidentifiable, as the patterns of their occurrence have not been determined with any certainty. Although the three areas with pipe clusters occur in the Mesozoic strata of the Karoo series and are found along the right bank of the Zambezi River, they are not confined to a common structural element.

It is recommended to conduct further prospecting in this area taking into consideration the potential for discovering new types of deposits in this territory, i.e. gold-bearing conglomerates and ‘unconformity’-type uranium deposits.

Horizons of gold-bearing conglomerates may be discovered in the strata of the Deweras series, which unconformably overlies the rocks of the Zimbabwe Craton, within which there are widely occurring Archean greenstone belts with plentiful endogenic gold deposits.

The ‘unconformity’-type uranium mineralization may be detected at the base of the Neoproterozoic Sijarira series unconformably overlying Paleoproterozoic strata including the Piriwiri series and Urungwe granites. The possible presence of such ore grade mineralization can be indirectly indicated by uranium mineralization in some copper-pyrite deposits (Mangula, Silverside, etc.) and quartz–gold deposits (Redwing).

Conclusions

After summarizing the geologic data on western Zimbabwe, we are able to draw some conclusions as follows.

It is found that almost no metallogenic studies have taken place in the region. There are no schematic maps showing metallogenic zoning, nor metallogenic maps. No spatial metallogenic categories (taxa) have been identified, and age relationships between certain geologic and ore formations are yet studied insufficiently.

Much of the area is made up of Paleoproterozoic shallow-marine and coastal–marine strata of the Magondi Mobile Belt that formed on the active margin of the Archean Craton. The belt is marked by mild manifestations of basalt volcanism that later changed to felsic volcanism. In its northern part the belt is pierced by the Paleoproterozoic-aged Urungwe Granite Massif.

Copper and copper polymetallic deposits are commonly found in the belt and it is doubtful that they belong to the formation of cupriferous sandstones or the polymetallic formation in carbonate rocks. In our opinion, they exhibit indications of volcanic–hydrothermal pyrite mineralization typical of Paleoproterozoic mobile belts.

Proterozoic granitoid complexes have received little study. There are no age dates for the Miami granites and pegmatites in the north of the belt, and age relationships between pegmatites and quartz-wolframite veins are unknown both in the north and within the Dete–Kamativi Inlier.

The origin of rare gold deposits and their connection with Neoproterozoic magmatism remain unclear.

The conducted metallogenic zonation of the Magondi Belt with the identified metallogenic zones will permit further and more reliable substantiation of the outlook for their ore content and evaluation of their metallogenic potential.

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References

1. Jacobs J., Pisarevsky S., Thomas R. J., Becker T. The Kalahari Craton during the assembly and dispersal of Rodinia. *Precambrian Research*. 2008. Vol. 160, Iss. 1-2. pp. 142–158.

2. McCourt S., Hillard P. Armstrong R. A., Munyanyiwa H. HRIMP U–Pb zircon geochronology of the Hurungwe granite northwest Zimbabwe: Age constraints on the timing of the Magondi orogeny and implications for the correlation between the Kheis and Magondi Belts. *South African Journal of Geology*. 2001. Vol. 104, No. 1. pp. 39–46.
3. Master S., Bekker A., Hofmann A. A review of the stratigraphy and geological setting of the Palaeoproterozoic Magondi Supergroup, Zimbabwe-type locality for the Lomagundi carbon isotope excursion. *Precambrian Research*. 2010. Vol. 182, Iss. 4. pp. 254–273.
4. Lockett N. H. The geology of the country around *Dett. Rhodesia Geological Survey Bulletin*. Salisbury. 1979. No. 85. 199 p.
5. Glynn S. M., Master S, Frei D., Wiedenbeck M. U–Pb zircon geochronology of the Dete–Kamativi Inlier, NW Zimbabwe, with implications for the western margin of the Archaean Zimbabwe Craton. *Precambrian Research*. 2020. Vol. 346. ID 105824.
6. Lockett N. H. The Dete–Kamativi Inlier. *Precambrian of the Southern Hemisphere. Elsevier, Amsterdam*. 1981. pp. 717–721.
7. Kuibida M. L. Basaltic volcanism of island-arc–back-arc basin system (Altai Active Margin). *Russian Journal of Pacific Geology*. 2019. Vol. 13. pp. 297–309.
8. Ignatov P. A., Malyutin S. A., Ivanov A. A., Desyatkin A. S., Lanchak M. M. Ring-shape and linear gold mining districts of Zimbabwe: Estimation of residual gold resources. *Proceedings of higher educational establishments. Geology and Exploration*. 2023. Vol. 65, No. 6. pp. 14–25.
9. Shanks V. Geological–genetic and forecasting–search model of pyrite deposits VMS (Volcanogenic Massive Sulfide). *Information and Analytical Materials: World Achievements in Development of Technologies, Methods and Techniques for Forecasting and Prospecting of Deposits. Series: Geological–Genetic Models of Deposits*. Moscow : FSBI VIMS, 2023. 172 p.
10. Dirks P. H. G. M., Jelsma H. A., 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: Geological Society of America. Special Papers*. 2006. Vol. 405. pp. 291–313.
11. Munyanyiwa H., Maaskant P. Metamorphism of the Paleoproterozoik Magondi belt north of Karoi, Zimbabwe. *Journal of African Sciences*. 1998. Vol. 27, Iss. 2. pp. 223–240.
12. Treloar P. J. The geological evolution of the Magondi Belt, Zimbabwe. *Precambrian Research*. 1988. Vol. 38, Iss. 1. p. 55–73.
13. Treloar P. J., Kramers J. D. Metamorphism and geochronology of granulites from Magondi Mobile Belt, Zimbabwe. *Precambrian Research*. 1989. Vol. 45, Iss. 4. pp. 277–289.
14. Hargrove U. S., Hanson R. E. Martin M. W. et al. Tectonic evolution of the Zambezi Orogenic Belt: Geochronological, structural, and petrological constraints from northern Zimbabwe. *Precambrian Research*. 2003. Vol. 123, Iss. 2-4. pp. 159–186.
15. Kuribara Y., Tsunagae T., Takamura Y. et al. Petrology, geochemistry, and zircon U–Pb geochronology of the Zambezi Belt in Zimbabwe: Implications for terrane assembly in southern Africa. *Geosciens Frontiers*. 2019. Vol. 10, Iss. 6. pp. 2021–2044.
16. Master S. The Palaeoproterozoic Magondi Mobile Belt, NW Zimbabwe. *Excursion Guidebook: Palaeoproterozoic of Zambia and Zimbabwe : First Field Meeting*. 1996. No. 302. pp. 27–65.
17. Master S. Stratigraphy, tectonic setting, and mineralization of the early Proterozoic Magondi Supergroup, Zimbabwe: A review. *Economic Geology Research Unit, University of the Witwatersrand*. 1991. No. 238. 75 p.
18. Oberthür T. The Sanyati polimetallic ore deposits in Zimbabwe. *Zeitschrift fur Angewandte Geologie*. 1999. Vol. 45. pp. 3–5.
19. Shmakov B. M. Pegmatite Deposits of Foreign Countries. Moscow : Nedra, 1987. 224 p.
20. Shaw R. A., Goodenough K. M., Deady E. A., Nex P. The Kamativi pegmatite: An opportunity for economic development in Zimbabwe? *The Canadian Mineralogist*. 2019. Vol. 57, No. 5. pp. 791–793.
21. Glynn S. M. Master S., Wiedenbeck M. et al. New U-Pb (zircon and coltan) and ^{40}Ar–^{39}Ar geochronology of the Proterozoic Choma–Kalomo Block (southeast Zambia), and adjacent regions, with regional implications. *Precambrian Research*. 2017. Vol. 298. pp. 421–438.
22. Tkachev A. V., Rundkvist D. V., Vishnevskaya N. A. Historical metallogeny of lithium ore deposits. *Deposits of Strategic and High-Tech Metals of the Russian Federation: Occurrence Patterns, Formation Conditions, Innovative Forecasting and Mining: Scientific Results of Implemented Basic Research Program No. I.48 Supported by the Presidium of the Russian Academy of Sciences*. Moscow : IGEM RAS, 2020. pp. 129–147.
23. Kalbskopf S. Geology of Redwing Mine, Mgangura, Zimbabwe. *Chamber of Mines Journal*. 1986. pp. 25–31.
24. Kharkiv A. D., Romanko E. F., Zubarev B. M. Kimberlites of Zimbabwe: Abundance and composition. *Geology and Geophysics*. 2005. Vol. 46, No. 3. pp. 318–327.
25. Panov Yu. P. Sergo Ordzhonikidze Russian State University for Geological Prospecting is the talent foundry for the geological sector. *Proceedings of higher educational establishments. Geology and Exploration*. 2023. Vol. 65, No. 4. pp. 8–14. EM

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GEOFLUID DYNAMICS OF OIL AND GAS CONTENT OF DEEP STRATA

The studies of the world and domestic experience in geological exploration of deep strata, as well as the analysis of extensive factual material indicate that formation of oil and gas potential at great depths depends on a significantly larger number of factors than at traditional depths. The fundamental research of oil and gas formation and accumulation in deep strata are of current importance. The research makes it possible to develop the theoretical framework for the oil and gas content concept which governs efficiency of oil and gas exploration to a great extent. This paper considers a set of qualitative criteria for predicting oil and gas content at great depths as a case-study of the South Caspian basin. The result of the research is a geofluid-dynamic concept of oil and gas formation in deep strata.

Keywords: *deep strata, geofluid-dynamics, great depths, oil and gas potential, hydrocarbons, South Caspian Basin*
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