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The new Northern Copper Belt of south-western Poland: a summary

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ABSTRACT:

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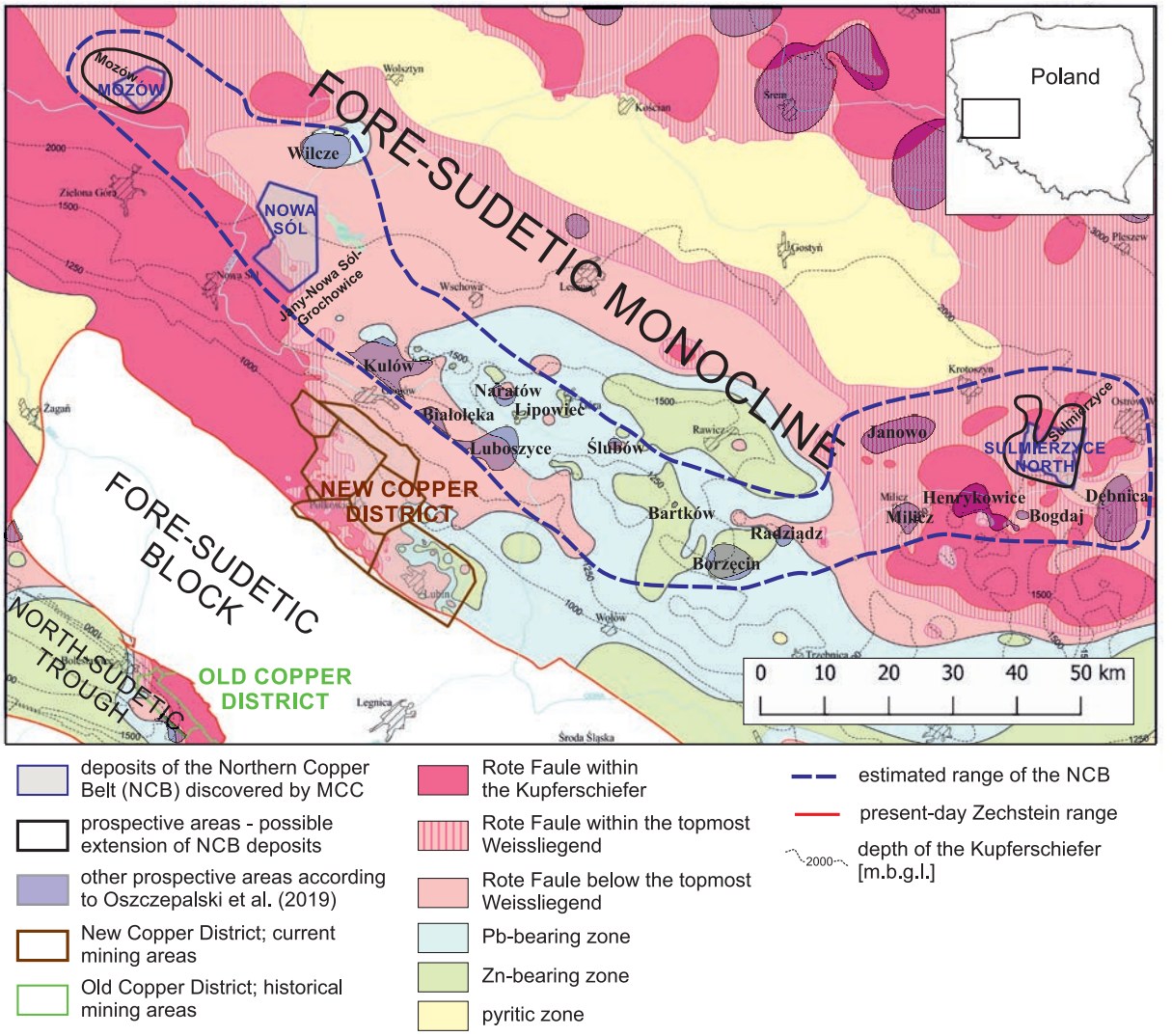
The Northern Copper Belt is located in south-western Poland, a region well known for its copper and silver occurrences of varying significance. This area also includes the abandoned mines of the North-Sudetic Trough (Old Copper District), as well as the currently active New Copper District in the southern part of the Fore-Sudetic Monocline. The vast exploration programme of Miedzi Copper Corp. initiated in 2011 in the northern, deeper part of the Fore Sudetic Monocline provided new data about the deeper parts of this geological unit, located north of the known deposits. A number of prospective areas with Cu-Ag mineralization were investigated, which ultimately resulted in the discovery of three new Cu-Ag deposits. Both the prospective areas and the documented deposits form the so-called Northern Copper Belt, which as a whole has high potential for the identification of new ore deposits and an increase in resources. A description of these three new deposits is provided along with characteristics of the areas of their possible extension, and the additional prospective areas with hypothetical and speculative resources. The new deposits are compared to other Polish Cu-Ag ore deposits, with an emphasis on differences in their geological structure and mineralogy. The paper also presents a brief summary of the applied new exploration tools which have led to this discovery.

Keywords: Deep copper and silver deposits; Northern Copper Belt; Fore-Sudetic Monocline; Stratiform copper mineralization; Kupferschiefer-type deposits.

INTRODUCTION

The Polish copper and silver deposits of the Fore-Sudetic Monocline (FSM) are the largest in Europe. These sediment-hosted stratiform deposits, also referred to as Kupferschiefer-type, occur in a contact zone between the continental red beds (Rotliegend) and Zechstein marine sediments. The ore-bearing series consists of white sandstones (Weissliegend), copper shales (Kupferschiefer) and Zechstein limestones. Kupferschiefer deposits in Poland include those currently being extracted in the New Copper District, as well as historical deposits occurring in the North Sudetic Trough (the Old Copper District, Text-fig. 1). Since the discovery of the first Cu-Ag deposit within the FSM in 1958, the Polish Geological Institute (PGI) has been selectively collecting data on Cu-Ag mineralization in the remaining part of SW Poland, based on the analyses of drill cores originating mostly from oil and gas industry wells, distributed in a scattered and irregular pattern. Based on these limited data, the PGI prepared a first esti-



Text-fig. 1. Location of the Northern Copper Belt (NCB) relative to the old and new copper districts of Poland.

mation of the boundaries and resources of prognostic, prospective and hypothetical areas of Cu-Ag ore (Oszczepalski and Speczik 2011a).

The mines of KGHM Polish Copper operate at depths from 600 to 1200 m. Until recently, it was believed that extraction of deposits situated deeper than 1250 m was economically unjustified, as well as impractical from a technological point of view. However, it is a worldwide trend that copper supplies from easily accessible deposits are steadily decreasing due to the depletion of shallow resources and growing costs of their extraction. In order to satisfy the increasing demand for copper and silver, mining companies have begun to target mineralization which is deeper, but of higher grades. Recent technological progress has enabled the performance of successful mining operations at depths that seemed unachievable several decades ago (Zieliński and Speczik 2017).

In 2011, an analysis of prospective areas of Cu-Ag mineralization in Poland was presented at the SGA Conference in Antofagasta, Chile, along with proposed directions of exploration (Oszczepalski and Speczik 2011b). This material attracted the attention of the Canadian investor Lumina Capital Group, which resulted in the foundation of the Miedzi Copper Corp. (MCC), a company whose aim is to search for deep copper and silver resources in Poland. The following exploration programme has been the first undertaking initiated in the country on such a massive scale in over half a century. Its first phase involved the preparation

of an extensive database by performing MCC's own chemical analyses of drill cores from historical boreholes, in cooperation with the University of Warsaw and the Polish Geological Institute. MCC examined a total of 411 boreholes, 230 of which are located in the area of today's Northern Copper Belt. Among them, the company performed chemical analyses of 2023 core samples from 101 drillholes as well as petrographic analyses of 718 samples from 103 holes. On that basis, MCC demarcated multiple prospective areas (Speczik et al. 2011a, 2011b; Oszczepalski et al. 2012, 2013), among which three were deemed the most promising and selected for further exploration via the company's drilling programme. This in turn resulted in the documentation of three new Cu-Ag deposits (Nowa Sól, Sulmierzyce North and Mozów), which, due to their size, constitutes a major breakthrough at an international level. These deposits, along with their possible extensions and the multiple areas with hypothetical and speculative resources identified around them by MCC, allow for the distinguishing of this entire part of the Fore-Sudetic Monocline as a separate vast zone of deep ore mineralization, collectively labelled the Northern Copper Belt (NCB).

The present paper summarizes the exploration programme which has led to the demarcation of the NCB. It describes its results, presenting the characteristics of the new Cu-Ag ore deposits as well as the prospective areas. It also presents a comparison to other deposits of this type located in SW Poland.

PROSPECTING FOR CU-AG DEPOSITS IN DEEPER PARTS OF THE FORE-SUDETIC MONOCLINE

Mineralization within deeper parts of the FSM (below 1500 m) was reported in the 1950s, but extensive exploration at these depths did not start until 2011. The work of MCC initially focused on 21 exploration targets, the boundaries of which were based on prospective areas suggested by earlier, limited examinations of historical drill cores (Oszczepalski and Speczik 2011a). The first stage of the exploration programme included re-examination of historical drill cores and collection of samples for further discrimination such as detailed petrological and mineralogical studies, chemical analyses, supported by organic matter geochemistry. Moreover, the reprocessing of a wide range of geophysical data was performed using an innovative method of effective reflection coefficients (Speczik et al. 2020b). As a result of the performed studies, the number of exploration areas was reduced in order to focus on the most prospective ones. The drilling programme started in 2013. After its initial stage, the operations were limited to 6 targets with elevated ore grades. Details of the project and the description of its individual steps were presented in Speczik et al. 2021. The exploration programme has led to the identification of three new deep Cu-Ag deposits: Mozów, Sulmierzyce North and Nowa Sól, which along with the surrounding prospective areas form the new Northern Copper Belt of the FSM (Text-fig. 1). The work leading to this discovery received much support from the University of Warsaw and the Polish Geological Institute, with the researchers from both institutions playing a major role in an economic evaluation of the Sulmierzyce North deposit and its surroundings (Smakowski et al. 2017) as well as the first calculation of resources of Nowa Sól (Szamałek et al. 2018).

The most recent achievements in the exploration programme included the approval of the geological documentation of the Mozów deposit by the Polish Minister of Climate and Environment in 2021. The most up-to-date results of mineralogical and petrographic research related to the NCB are presented in Speczik et al. 2021 as well as Bieńko and Pietrzela 2022.

RESOURCES OF THE NORTHERN COPPER BELT

Ore deposits

The world-class Nowa Sól deposit is the largest copper deposit in Poland, and ranks 20th in the world. According to the Polish classification, its documented resources contain 848 Mt of ore with 10.5 Mt of Cu and 36 kt of Ag, distributed over an area of approx. 120 km^2. They were calculated based on 17 boreholes with positive results, and their depth ranges between 1780 and 2160 m below ground level. The average ore grade is 2.96% Cu_e (copper equivalent, taking into account the silver content). The statistically calculated error of estimation of these resources is 27.5% for the major part of the deposit, and 31.6% for its periphery (Speczik 2019). According to Polish regulations, an error of no more than 30% places a deposit in the C_1 category of geological documentation, while an error not exceeding 40% corresponds to the C_2 category. However, since exploration is still underway, MCC decided to assign the C_2 category to all resources, with plans of upgrading it in the future. This category generally corresponds to inferred or indicated

resources according to CRIRSCO (JORC Code 2012), depending on the complexity of the deposit. Ongoing exploration should result in classification of these resources as indicated; currently, they are described as inferred + indicated (Speczik et al. 2021).

In Nowa Sól, 50% of copper resources are hosted in sandstones, 44% in carbonate rocks and 6% in shales. On the other hand, the shales contain 36% of silver resources, with 34% of this metal distributed in sandstones and 30% in carbonate rocks.

Resources of the Mozów deposit amount to 233.2 Mt of ore containing 4.6 Mt of Cu and 6.5 kt of Ag, calculated based on 6 boreholes, and they lie at depths from 2370 to 2540 m below ground level (Speczik 2020b). The area of the deposit is about 32 km^2. The average ore grade is 2.86% Cu_e. The error of estimation of the resources, calculated based on this limited number of holes, is 31%. Therefore, according to the Polish classification of resources, they belong to the C_2 category, which corresponds to inferred + indicated according to CRIRSCO (Speczik et al. 2021). Exploration of this deposit will be resumed as soon as the Polish Ministry of Climate and Environment grants a new exploration concession for this area.

As many as ≈75% of copper resources of the Mozów deposit are present in the carbonate-hosted ore, which also hosts about 58% of silver resources. The shales contain about 25% and 42% of copper and silver resources, respectively, while sandstones are barren.

Current resources of the Sulmierzyce North deposit are 296 Mt of ore containing 5.7 Mt of Cu and 6.9 kt of Ag, covering an area of 61 km^2 at depths ranging from 1635 to 2060 m below ground level. The resources were calculated based on 8 boreholes (Speczik 2020a). The average ore grade is 2.34% Cu_e. In terms of the Polish categories, roughly half of this deposit demarcated by 5 holes belongs to the C_2 category, and the calculated error of estimation of resources for this part is 37%. The remaining part of this deposit has been assigned the more general D category, due to much larger distances between individual boreholes. Due to the use of two different Polish categories, their resources should only be described as inferred according to CRIRSCO (Speczik et al., 2021). An application for further exploration at Sulmierzyce North has been approved by the Polish Ministry of Climate and Environment; drilling operations will be continued.

In terms of lithology, the deposit is dominated by thick and marly shale, which hosts about 81% and 93% of copper and silver resources, respectively. The rest of the copper and silver resources are present in the carbonate ore – approx. 19% and 7%, respectively. Sandstones are largely barren, except for a thin (6 cm) layer of mineralization recorded in a single borehole, with no economic significance.

In all three deposits, the resources of valuable accompanying metals were also calculated. They included Zn, Pb, Co, Mo, Ni and V. In the case of Nowa Sól, additional estimations were also performed regarding the resources of Re and rare-earth elements.

Prospective areas

The shape of the Northern Copper Belt is consistent with the distribution of prospective areas of ore mineralization established upon MCC's analyses of historical drill cores (Speczik et al. 2011a, b; Oszczepalski et al. 2012, 2013, 2019). The first group of these areas includes the ones directly adjacent to the three new deposits, which indicate that their spatial ranges and resources may be extended upon further exploration (Text-fig. 1). Those prospective areas are listed in Table 1.

The Nowa Sól deposit is a part of the vast Jany-Nowa Sól-Grochowice prospective area with estimated resources of 34.748 Mt Cu and 148.256 kt Ag. This means that the resources of this deposit may increase by further 24.165 Mt Cu and 111.846 kt Ag. The Sulmierzyce North deposit is located in the Sulmierzyce prospective area with resources estimated at 7.767 Mt Cu and 17.793 kt Ag, and thus its resources may increase by 2.115 Mt Cu and 10.925 kt Ag (Oszczepalski et al. 2019). The Mozów deposit is situated in the southern part of the Mozów prospective area, the resources of which according to Oszczepalski et al. (2019) are 30.300 Mt Cu and 55.905 kt Ag. However, a portion of this area has depths of the orebody exceeding 2600 m, which has

Ore deposits (current)			Prospective areas		
Name	Cu resources (Mt)	Ag resources (kt)	Name	Cu resources (Mt)	Ag resources (kt)
Nowa Sól	10.583	36.410	Jany-Nowa Sól-Grochowice	34.748	148.256
Mozów	4.586	6.487	Mozów	10	20
Sulmierzyce North	5.652	6.868	Sulmierzyce	7.767	17.793
Total:	**20.821**	**49.765**	**Total:**	**52.515**	**186.049**

Table 1. Prospective areas allowing for the extension of NCB ore deposits.

Resource category (according to Oszczepalski *et al.* 2019)	Area name	Area size (km^2)	Depth range (m.b.g.l.)	Average thickness (m)	Average Cu content (%)	Cu resources* (Mt)	Average Ag content (ppm)	Ag resources* (kt)
Hypothetical	Kulów	49.68	1500–1800	1.59	3.14	6.201	86	–
	Białołęka	6.81	1500–1600	1.8	1.08	0.331	51	1.563
	Luboszyce	38.43	1400–1600	1.42	0.89	1.214	53	7.231
Speculative of high potential	Janowo	42.98	1700–1800	1.11	1.64	1.956	36	4.294
	Henrykowice	28.9	1400–1700	1.08	1.73	1.35	34	2.653
	Dębnica	50.4	1500–1800	0.51	6.21	3.99	167	10.731
Speculative of low potential	Wilcze	35.58	2400–2500	0.23	8.12	1.661	920	18.882
	Naratów	8.15	1400–1500	0.52	2.07	0.219	86	0.911
	Lipowiec	0.16	1400–1500	0.6	2.06	0.005	64	0.015
	Ślubów	2.51	1300–1400	0.2	9.08	0.114	164	0.206
	Bartków	0.47	1300–1400	0.32	4.18	0.016	71	0.027
	Borzęcin	32.15	1400–1600	0.51	4.91	2.013		
	Radziądz	6.44	1600–1800	1.65	0.93	0.247	7	0.186
	Milicz	13.93	1600–1700	1.86	0.89	0.576	26	1.684
	Bogdaj	2.08	1400–1500	1.58	1.52	0.125	34	0.279
					Total:	**20.018**	**Total:**	**65.645**

Table 2. Prospective areas of Cu-Ag mineralization in the NCB, unrelated to the documented ore deposits (according to Oszczepalski *et al.* 2019); * hypothetical and speculative.

been established in MCC's investor's criteria as the maximum depth of economically feasible extraction (Speczik et al. 2020a). These criteria were formulated based on technical reports prepared for MCC (Goodell et al. 2017, Bohnet et al. 2017), and they assume that the mining of such deep deposits as those in the NCB is possible, if it focuses on the portions of the orebody with the highest grade. In the case of the deepest mineable deposits (with depths of 2400–2600 m), the required minimum copper productivity (yield) is 100 kg/m^2, while for depths of 1900–2400 m and ≤ 1900 m, its minimum values are 60 and 50 kg/m^2, respectively. Therefore, the present paper shows a smaller Mozów prospective area (Text-fig. 1), with the position of the mineralization shallower than 2600 m. According to MCC's estimations, its resources are approx. 10 Mt Cu and 20 kt Ag, which indicates a possible increase by 5.414 Mt Cu and 13.513 kt Ag compared to the current deposit.

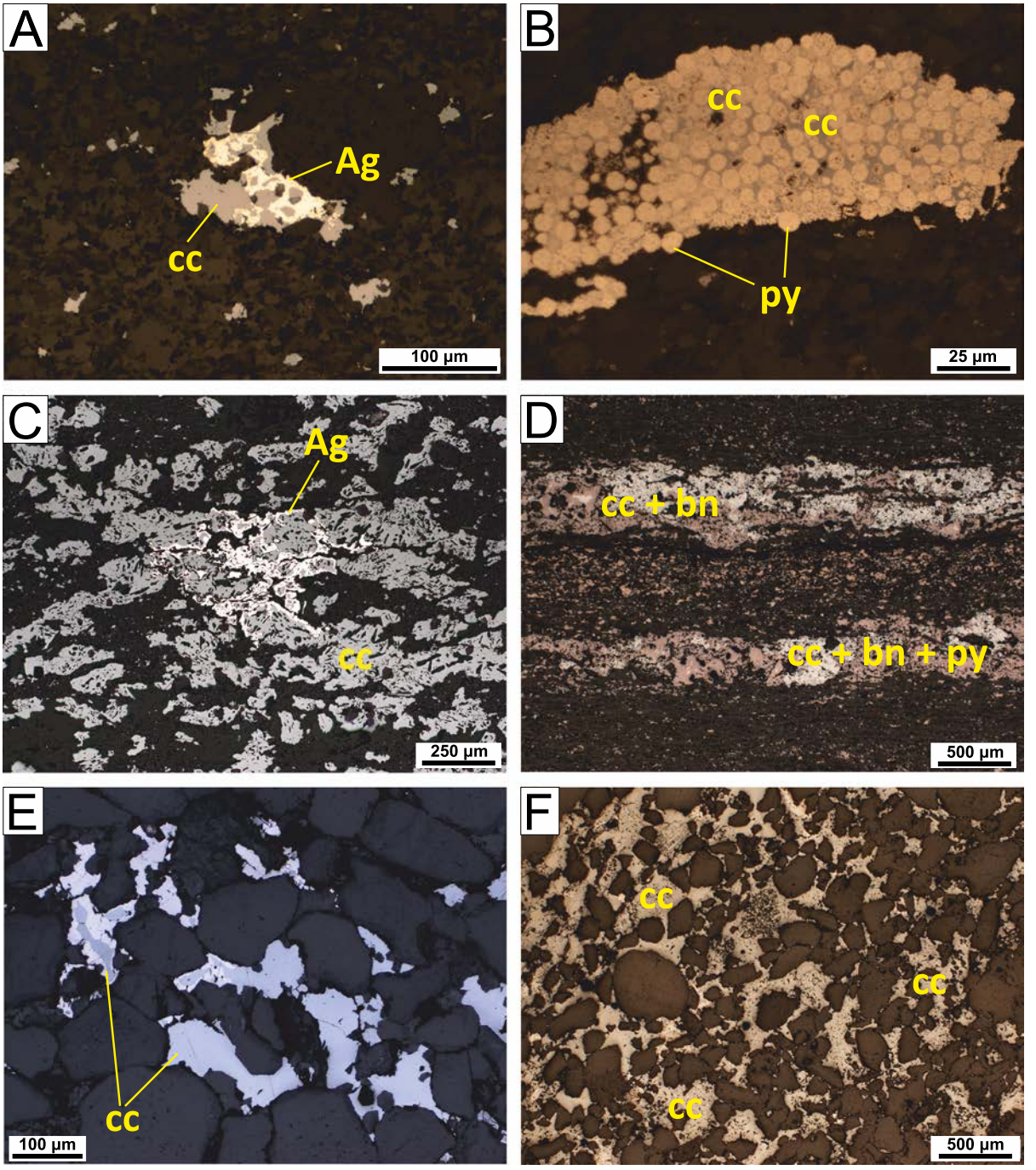
The remaining prospective areas of the NCB have been categorised based on the criteria presented by Oszczepalski et al. (2019). Areas close to the identified deposits have been described as having hypothetical resources. Areas distant from the identified deposits and designated by more than one historical drillhole have speculative resources of high potential, and those designated by a single hole have speculative resources of low potential. The total hypothetical and speculative resources of all these areas are estimated at about 20 Mt Cu and 66 kt Ag (Table 2). It should be noted that most of these areas have a shallower position of the ore-bearing series compared to the three deposits, which means that they represent highly promising targets for future exploration.

ORE MINERALIZATION

Four major styles of mineralization can be distinguished within ore intervals at the Nowa Sól (Text-fig. 2), Mozów and Sulmierzyce North deposits: (1) disseminated, fine-grained mineralization; (2) coarse-grained and semi-massive mineralization, usually in the form of sulphide cementation; (3) sulphide lenses and veinlets concordant with rock lamination/bedding and (4) sulphide nodules, nests and aggregates up to 500 μm in size.

The sandstone ore hosts significant Cu resources only in the Nowa Sól deposit, where the majority of the sulphides occur as fine and very fine (10–50 μm), anhedral to subhedral grains filling interstitial pore spaces. Disseminated sulphide grains and aggregates form elongated clots and laminae parallel to bedding. Moreover, flat-lying rhythmic chalcocite-digenite-covellite bands are observed within the Weissliegend unit in numerous core samples from the eastern and northern parts of the Nowa Sól deposit. In its parts where Rote Fäule oxidation occurs, the white sandstone scarcely hosts disseminated chalcocite mineralization (Speczik 2019).

The basal part of the shale-hosted ore in all the discussed deposits is represented by the black, organic-rich variety of the Kupferschiefer. In this unit, Cu mineralization is usually massive and



Text-fig. 2. Different types of copper ores from the Nowa Sol deposit. A – Nowa Sól C15 borehole, carbonate ore, native silver intergrowths (Ag) in a chalcocite aggregate (cc); B – Nowa Sól C25 borehole, carbonate ore, framboidal pyrite (py) cemented with chalcocite (cc); C – Nowa Sól C30 borehole, shale ore, massive chalcocite mineralization (cc) with native silver intergrowths (Ag); D – Nowa Sól C30 borehole, shale ore, chalcocite-bornite (cc + bn) and chalcocite-bornite-pyrite (cc + bn + py) veinlets following the Kupferschiefer lamination; E – Nowa Sól C30 borehole, sandstone ore, chalcocite (cc) filling intergrain spaces in the Weissliegend; F – Nowa Sól C30 borehole, sandstone ore, massive chalcocite mineralization (chalcocite cement; cc) in the top part of the Weissliegend.

semi-massive, composed of very fine-grained sulphide grains (up to 10 µm in diameter) filling pore spaces. In most boreholes, in which the Kupferschiefer unit hosts economic ore, apart from disseminated mineralization, the uppermost part of the shale ore hosts sulphide veinlets and lenticular

aggregates concordant or diagonal to the shale lamination (Speczik at al. 2021).

In general, two styles of mineralization can be observed in the Zechstein Limestone in all the three deposits – coarse-grained and disseminated. The lowermost part of the Zechstein Limestone, usually enriched in organic matter and clay minerals, is characterised by the occurrence of coarse-grained (up to cm-size) sulphide aggregates, nodules and clots. In this part of the carbonate ore, disseminated mineralization is minor but visible. Some samples of the Zechstein Limestone from all the investigated deposits exhibit massive lenticular sulphide aggregates and mm-size sulphide lenses, located several dozen centimeters above the top of the Kupferschiefer unit. In the uppermost part of the carbonate ore, fine (up to 50 μm in diameter), disseminated sulphide grains represent the most common type of mineralization.

Chalcocite and bornite are the major sulphides in the Nowa Sól deposit. Chalcocite predominates within the sandstone ore, where it can be accompanied by a digenite-covellite assemblage, and in the shale-hosted ore, where it occurs in association with bornite and pyrite. Bornite is the dominant Cu-bearing mineral in the carbonate-hosted ore at Nowa Sól. It forms intergrowths with pyrite and Cu-S-type sulphides (chalcocite, digenite and covellite). Pyrite, chalcopyrite, galena and sphalerite occur commonly in the form of disseminated grains, in the uppermost part of the ore series of the Nowa Sól deposit. The distribution of mineral zones in this deposit has been presented on maps and on a cross-section in a separate publication, which also shows photomicrographs of typical mineral assemblages (Bieńko and Pietrzela 2022). In the Mozów deposit, chalcocite, bornite and chalcopyrite are the major Cu-bearing sulphides, accompanied by digenite and covellite. Pyrite is the main non-copper sulphide, observed in all types of ore. Galena occurs only locally, usually in the topmost part of the mineralised intervals. Sphalerite is almost completely absent (Speczik 2020b). The ore mineral assemblage of the Sulmierzyce North deposit consists of Cu-S and Cu-Fe-S sulphides. The northern part of this deposit is dominated by a chalcopyrite-bornite-chalcocite association, while in the southern part bornite and chalcocite are the major ore minerals (Speczik 2020a).

COMPARISON TO OTHER DEPOSITS IN SW POLAND

The more northerly location of the Northern Copper Belt within the FSM results in its much deeper position compared to the existing mines of the New Copper District. This is not so much a structural difference as a result of later tectonic activity, which has led to the northward dipping of the Fore-Sudetic Monocline. However, this is related to the presence of additional lithostratigraphic units in the overburden of NCB orebodies: the Muschelkalk, the Keuper and the Rhaetian, all absent in the New Copper District.

One more characteristic feature of the Northern Copper Belt is the thickness of the Zechstein Limestone. In the three new deposits, its maximum thickness is about 8 m. In the active mines of the New Copper District it reaches up to 90 m, and should therefore be considered as a major aquifer, which must be isolated for mining operations. The much smaller thickness of this unit in the Northern Copper Belt decreases its significance for the technological processes of mine development (Speczik 2019).

The major difference for the Mozów deposit is the prevalence of carbonate ore, related to its close proximity to the vast Zielona Góra oxidized field and the resulting high position of the Rote Fäule oxidized facies. The abundance of carbonate sediments (limestones, dolostones) also indicates marine sedimentation in the early Zechstein. Shale ore is also present, albeit in minor amounts. Ninety percent of the deposit consists of carbonate ore, hosting 75% of copper resources. Sandstone-hosted ore is absent. Another characteristic feature is the distribution of the accompanying metals. The Zn and Pb admixtures are low, with their highest values recorded in core samples directly above the Cu-Ag interval. The vertical zonation of Cu-Pb-Zn is poorly pronounced. The average Pb content of the copper-bearing interval is 0.02%, much lower than that of the Nowa Sól and Lubin-Sieroszowice deposits – 0.18% and 0.14%, respectively (Speczik 2019, 2020b, Spalińska et al. 2007). All of the abovementioned features are associated with the almost invariable position of the oxidative front across the entire Mozów deposit. Overall, this deposit does not exhibit any pronounced similarities with the currently mined deposits of the New Copper District.

The Sulmierzyce North deposit is characterised by its relatively large thickness of the copper-bearing shale, reaching up to 1.5 m, with an average thickness of 0.91 m (Speczik 2020a). This is considerably more than that which has been observed in the remaining two deposits, but also compared to the Sieroszowice-Lubin and Rudna deposits of the New Copper District (Piestrzyński 2007). The shale is marly, and it resembles the so-called copper-bearing marls (Kupfermergel) of the Old Copper District. This indicates that, during the transgression of the

Zechstein sea, this area represented a vast land depression with marine sedimentation, supplied with clastic material from nearby sources.

The deposit is located close to two large, oxidized fields – the Chwaliszew field and the Ostrzeszów field. This proximity is reflected by two characteristic features, the first of which is the patchy structure of the deposit and its high lateral variability. Positive boreholes with very high ore grades are located relatively close to those with sub-economic mineralization, or even ones where the ore is completely absent. The other result involved the mixing of mineralizing solutions originating from those two sources. This caused the lack of metal zonality typical of most Cu-Ag deposits of the Fore-Sudetic Monocline, where directly above the Cu-Ag orebodies there are lead-bearing strata, themselves overlain by rocks enriched in zinc. In the case of Sulmierzyce North, abundant galena and sphalerite are observed inside the Cu-enriched interval, rather than above it. The proximity to the oxidized fields also results in the paucity of sandstone ore – only 6 cm of mineralised sandstone were recorded in a single borehole; therefore, it has no economic significance (Speczik 2020a).

The Nowa Sól deposit shows no similarities to the remaining two deposits. In terms of ore mineralogy, its southern part can be compared to the southern part of the Polkowice deposit and the western part of the Sieroszowice deposit (Pieczonka et al., 2007). The central portion of the Nowa Sól deposit resembles the eastern part of the Sieroszowice deposit and the south-western part of the Rudna deposit. In the northern part of the Nowa Sól deposit, galena and minor sphalerite occur in the mineralised intervals in much greater amounts than in any other deposit of the Lubin-Sieroszowice Mining District (Pieczonka et al. 2007). Curiously, chalcocite is a dominant copper sulphide in the whole Nowa Sól deposit, only locally being accompanied by bornite, djurleite, tennantite and other Cu-S sulphides, such as digenite and covellite. Chalcopyrite occurs exclusively in the uppermost part of the mineralised interval in carbonate ore, and within the overlying lead-bearing zone.

CONCLUSIONS

- The geological exploration carried out by the Canadian investor Lumina Capital in close cooperation with the Polish Geological Institute and the Faculty of Geology at the University of Warsaw resulted in the documentation of polymetallic copper ore deposits of global significance. The copper ore resources of these new deposits place Poland in the third place in the world ranking.
- The Northern Copper Belt consists of the three newly discovered Cu-Ag ore deposits: Nowa Sól, Mozów and Sulmierzyce North, as well as multiple prospective areas. The deposits show no major similarities to those previously known from the Fore-Sudetic Monocline, except for Nowa Sól which partially resembles deposits currently mined in the New Copper District.
- The resources of the three new deposits have been calculated according to the Polish C_2 (or C_2+D) category of exploration. Further drilling operations are aimed at upgrading them to the C_1 category and increasing their resources, which is possible considering the existence of prospective areas overlapping these deposits. Those zones are the most promising targets for further drilling in the NCB, and they should constitute the next directions of exploration. The C_1 category is also a precondition necessary to apply for a mining license.
- The deposits already present a significant contribution to Poland's copper resources, resulting in an overall increase to a total of 70 Mt of Cu. Technical reports prepared for MCC have shown the feasibility of their future development, and they have served as a basis for the formulation of investor's criteria for determining the boundaries of the deposits.
- The Polish Ministry of Climate and Environment approved the preparation of the documentation of the three deposits based on these criteria, therefore confirming their economic nature. However, the extraction of ore at considerable depths within the Northern Copper Belt will require the application of advanced mining technologies, which have not been used in the existing mines of the active New Copper District.
- Other prospective areas unrelated to the three deposits also exist within the NCB and constitute potential exploration targets for the future. However, the probability of identifying new ore deposits in these areas with hypothetical and speculative resources is lower, and therefore they should be considered as objects of secondary importance compared to the areas directly adjacent to the documented deposits.

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REFERENCES

Bieńko, T. and Pietrzela, A. 2022. Trace element distribution and geochemical zonation in the world-class Nowa Sól sediment-hosted Cu-Ag deposit, SW Poland. *Mineralium Deposita*. Doi: 10.1007/s00126-022-01110-6.

Bohnet, E., Goodell, T. and Jorgensen, M. 2017. Technical Report on Miedzi Copper's Sulmierzyce Project, Poland. Unpublished Report, 48 p. RungePincockMinarco; Lakewood.

Goodell, T., Jorgensen, M. and Bohnet, E. 2017. Technical Report of the Miedzi Copper Project, Poland. Unpublished Report, 168 pp. RungePincockMinarco; Lakewood.

JORC Code 2012 Edition. Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves. https://www.jorc.org/docs/JORC_code_2012.pdf

Oszczepalski, S. and Speczik, S. 2011a. Rudy miedzi i srebra. In: Wołkowicz, S., Smakowski, T. and Speczik, S. (Eds), Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31 XII 2009 r., 76–93. Państwowy Instytut Geologiczny-Państwowy Instytut Badawczy; Warszawa.

Oszczepalski, S. and Speczik, S. 2011b. Prospectivity analysis of the Polish Kupferschiefer – new insight. In: Barra, F., Reich, M., Campos, E. and Tornos, F. (Eds), Let's Talk Ore Deposits. Proceedings of the Eleventh Biennial SGA Meeting, Antofagasta, Chile, 26–29 September 2011, 295–297. Ediciones Universidad Católica del Norte; Antofagasta.

Oszczepalski, S., Speczik, S., Marks, L. and Chmielewski, A. 2012. Lithology, petrography and Zechstein ore mineralisation in selected boreholes from the Żmigród, Milicz, Sulmierzyce and Kalisz region, 247 pp. Polish Geological Institute on commission of Ostrzeszów Copper Sp. z o.o.; Warszawa.

Oszczepalski, S., Speczik, S., Zieliński, K. and Chmielewski, A. 2019. The Kupferschiefer Deposits and Prospects in SW Poland: Past, Present and Future. *Minerals*, **9**. Doi: 10.3390/min9100592.

Oszczepalski, S., Wierchowiec, J. and Chmielewski, A. 2013. Lithology, petrography and Zechstein ore mineralisation in selected boreholes from the Kotla, Niechlów and Zatonie region, 340 pp. University of Warsaw; Warsaw.

Pieczonka, J., Piestrzyński, A., Lenik, P. and Czerw, H. 2007. Distribution of ore minerals in the copper deposit, Fore-Sudetic Monocline, SW Poland. *Biuletyn Państwowego Instytutu. Geologicznego*, **423**, 95–108. [In Polish with English abstract]

Piestrzyński, A. 2007. Okruszcowanie. In: Piestrzyński, A., Banaszak, A. and Zaleska-Kuczmierczyk, M. (Eds), Monografia KGHM Polska Miedź SA, wydanie II, 167–197. Allexim sp. z o.o.; Wrocław.

Smakowski, T., Szamałek, K., Galos, K. and Saługa, P. 2017. Raport z Wyceny projektu prowadzonego przez Ostrzeszów Copper Sp. z o.o. na koncesjach Sulmierzyce i Janowo. Unpublished Report, 43 pp. Polskie Stowarzyszenie Wyceny Złóż Kopalin; Kraków.

Spalińska, B., Stec, R. and Sztaba, K. 2007. Miejsce i rola przeróbki rudy w kompleksie technologicznym KGHM Polska Miedź SA. In: Piestrzyński, A., Banaszak, A. and Zaleska-Kuczmierczyk, M. (Eds), Monografia KGHM Polska Miedź SA, wydanie II, 637–648. Allexim sp. z o.o.; Wrocław.

Speczik, S. 2019. Dokumentacja geologiczna złoża rud miedzi i srebra Nowa Sól, 179 pp. Zielona Góra Copper Sp. z o.o.; Warszawa.

Speczik, S. 2020a. Dokumentacja geologiczna złoża rud miedzi i srebra Sulmierzyce Północ, 158 pp. Ostrzeszów Copper Sp. z o.o.; Warszawa.

Speczik, S. 2020b. Dokumentacja geologiczna złoża rud miedzi i srebra Mozów, 172 pp. Mozów Copper Sp. z o.o.; Warszawa.

Speczik, S., Bieńko, T., Pietrzela, A. and Zieliński, K. 2020a. Dokumentowanie głębokich złóż miedzi i srebra – kryteria inwestorskie. *Górnictwo Odkrywkowe*, **1**, 43–54.

Speczik, S., Dziewińska, L., Jóźwiak, W. and Zieliński, K. 2020b. Application of historical geophysical materials in searching for Cu-Ag ore deposits – A new direction of research. *Minerals*, **10** (8), 725, 1–24. Doi: 10.3390/min10080725.

Speczik, S., Marks, L., Oszczepalski, S. and Chmielewski, A. 2011a. Lithology, petrography and Zechstein ore mineralisation in selected boreholes from Zielona Góra, Czerwieńsk and Sulechów region, 44 pp. Polish Geological Institute on commission of Mozów Copper Sp. z o.o.; Warszawa.

Speczik, S., Marks, L., Oszczepalski, S., Chmielewski, A. and Krzemiński, P. 2011b. Lithology, petrography and Zechstein ore mineralisation in selected boreholes from Nowa Sól-Zabór-Trzebiechów region, 48 pp. Polish Geological Institute on commission of Zielona Góra Copper Sp. z o.o.; Warszawa.

Speczik, S., Zieliński, K., Bieńko, T. and Pietrzela, A. 2021. The prospecting strategy for a deep Cu-Ag ore deposit in Poland – an anatomy of success. *Ore Geology Reviews*, **131**. Doi: 10.1016/j.oregeorev.2021.104053.

Szamałek, K., Mucha, J., Retman, W., Oszczepalski, S., Wasilewska-Błaszczyk, M., Wierchowiec J. and Zglinicki, K. 2018. Dokumentacja geologiczna złoża rud miedzi i srebra Nowa Sól w kat. C_2 + D, etap I. Unpublished Report, 580 pp. Uniwersytet Warszawski, Wydział Geologii; Warszawa.

Zieliński, K. and Speczik, S. 2017. Deep copper and silver deposits – a chance for Polish metal mining industry. *Biuletyn Państwowego Instytutu. Geologicznego*, **468**, 153–164. [In Polish with English abstract]

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