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VARIABILITY OF COPPER MINERALIZATION IN THE BOUNDARY DOLOMITE (ZECHSTEIN), FORESUDETIC MONOCLINE, SW POLAND: A STATISTICAL EVALUATION*

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Abstract: Cu-grade and thickness variability of the Boundary Dolomite (Zechstein of the Foresudetic Monocline) was studied by means of distribution shape analysis, correlation and surface trend analysis. The results indicate that the copper mineralization in the Boundary Dolomite has an infiltrational character. This process was accompanied by displacement of ore-bearing solutions from the overlying Kupferschiefer into the Boundary Dolomite.

Key words: Cu-ores, Zechstein, Foresudetic Monocline, statistics.

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INTRODUCTION

The copper-ore deposit in the Foresudetic Monocline is of the stratified type. The Cu mineralization is represented by copper sulphides which appear within the following lithostratigraphic units of the Rotliegendes and Zechstein: the Weissliegendes Sandstone, the Boundary Dolomite, the Kupferschiefer and limestones and dolomites (Preidl *et al.*, 1971; Tomaszewski, 1978, 1985). The ore deposit displays a large spatial variability in thickness, copper concentrations and in the mode of development of the ledge series.

The subject of the present paper is the problem of variation of ledge parametres of the Boundary Dolomite in the Lubin copper mine (Figs. 1 and 2). The aim of statistical investigations presented here was to study the regularity of the thickness of this horizon, the distribution of Cu-sulphide mineralization in the dolomite and to attempt an interpretation of the genesis of the Cu mineralization.

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GENERAL DESCRIPTION OF THE BOUNDARY DOLOMITE

The Foresudetic Monocline copper-ore deposit belongs mainly to the lowermost part of the Zechstein. The Boundary Dolomite occurs in the Lubin--Sieroszowice area between the Weissliegendes Sandstone (the top of the Rotliegendes) and the Zechstein Kupferschiefer (Fig. 2) (Preidl *et al.*, 1971; Tomaszewski, 1978, 1985). The thickness of the Boundary Dolomite is usually small and it ranges from several cm to a maximum of 1 m. The Boundary Dolomite consists of dark-grey, fine-crystalline dolomite. Grains of detrital quartz, 0.01 – 0.3 mm in size, are present. Fossils are poorly represented (*Lingula*, impressions of mollusc shells, few foraminifers and ostracods). Two lithological varieties may be distinguished in the Boundary Dolomite, dolomitic and calcareous-dolomitic. Sometimes it is agrillaceous and contains detrital quartz. The Boundary Dolomite usually occurs in one layer, in rare instances it splits into thin layers separated by thin interbeds of tar shale. It is often squeezed down into the underlaying sandstone. In general the Boundary Dolomite is weakly mineralized and the Cu-grade varies greatly between 0.2 and few per cent. The papers on the mineralogy of the ore deposit series (Jarosz, 1968, 1969, 1970) suggest that the qualitative composition of the mineralization in the Boundary Dolomite is similar to that of the tar shale in the overlying Kupferschiefer and the topmost layer of the Weissliegendes and that it varies laterally. It is dominated by chalcocite and bornite in the eastern area, bornite and chalcopyrite in the central area and chalcocite in the western area.

STUDY AREA

The statistical analysis of variation of the Boundary Dolomite parameters was carried out for three mining fields (Fig. 1), which are characterized by different lithology of the ore-deposit series (Fig. 2) (Namysłowska-Wilczyńska, 1980). Area L-1, about 490,000 m^2 is situated in the eastern part of the Lubin mine. Area L-2, situated in the central part of the mine, is formed by two clusters, a pair of inclined drives – X I-II (about 1200 m long) and four cross-cuts – Y I-IV (about 900 m long). Area L-3, about 420,000 m^2 lies in the western part of Lubin. For the present study, single galleries and pairs of adjacent galleries (separated by about 20 m) were also selected (L-1: D-I and D-II: M-I and M-II; L-3: K-I and K-II and Z: N-S).

In the regions L-1 and L-2, the ore deposit is characterized by the preponderance of mineralization in the Weissliegendes Sandstone. The Boundary Dolomite and the Kupferschiefer are on the whole continuous and the carbonate rocks are little mineralized (Namysłowska-Wilczyńska, 1980, 1986).

The average thickness of the entire ore series ranges from 4.31 m in the area of L-1 to 3.18 m (X I-II) and 3.49 m (Y I-IV) in the area of L-2. In the area of

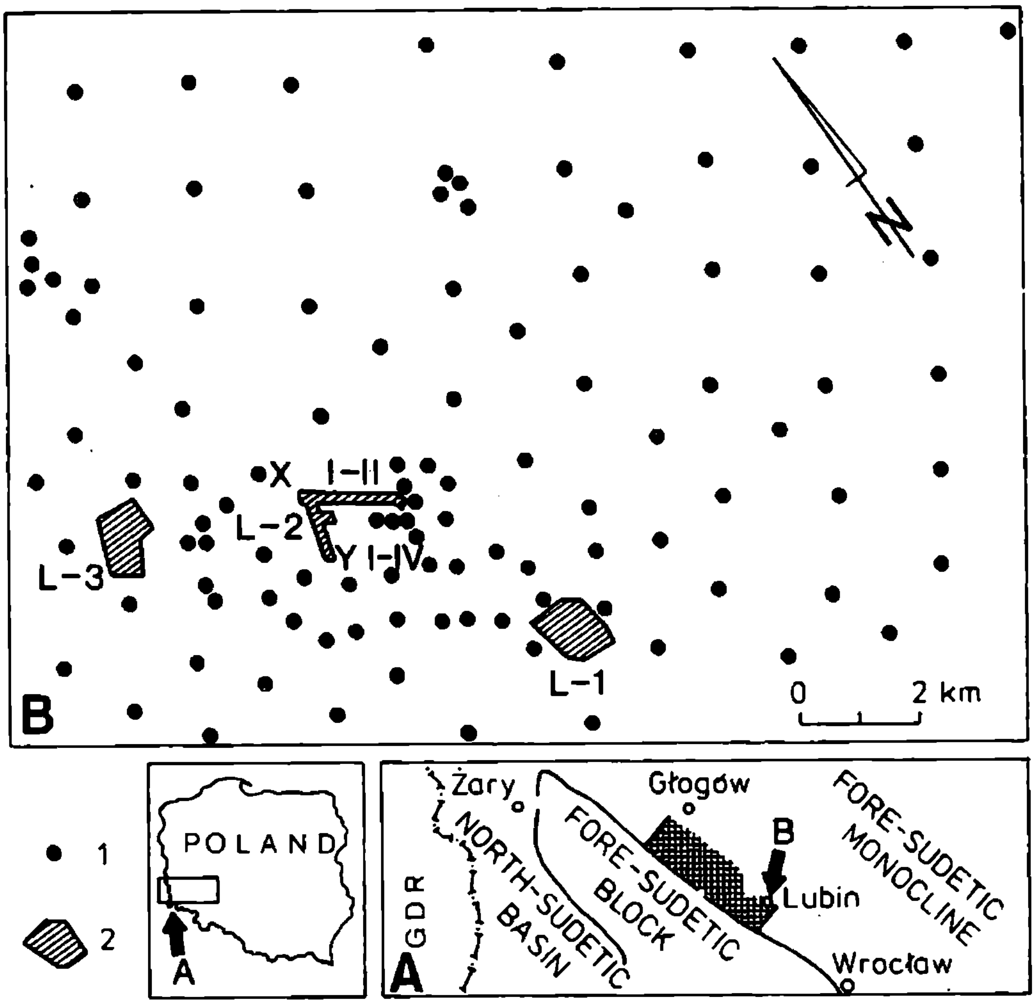

Fig. 1. Map showing location of investigated fields in the area of Lubin Mine: *1* – boreholes; *2* – studied mining regions

L-3, the mineralized zone is formed by a continuous horizon of dolomitic--calcareous rocks and shales and is characterized by an average thickness of 2.26 m. In gallery Z: N-S area, bordering the Polkowice mine, even the sandstones are mineralized and they are found in the form of the beds of variable thickness. The thickness of the ore series reaches 2.86 m.

METHODS OF STUDY

The analysis was focused upon: (1) the shape of thickness and Cu--grade distributions for the Boundary Dolomite, (2) the variation of the basic statistics of the above parameters, (3) the correlation between Cu-grade and thickness, and (4) the existence of non-random variability of the two parameters. Besides such standard statistical methods as the examination of distribution shapes and basic statistics (mean, variance, standard deviation, and variation coefficient), the analysis of surface trends (Krumbein & Graybill,

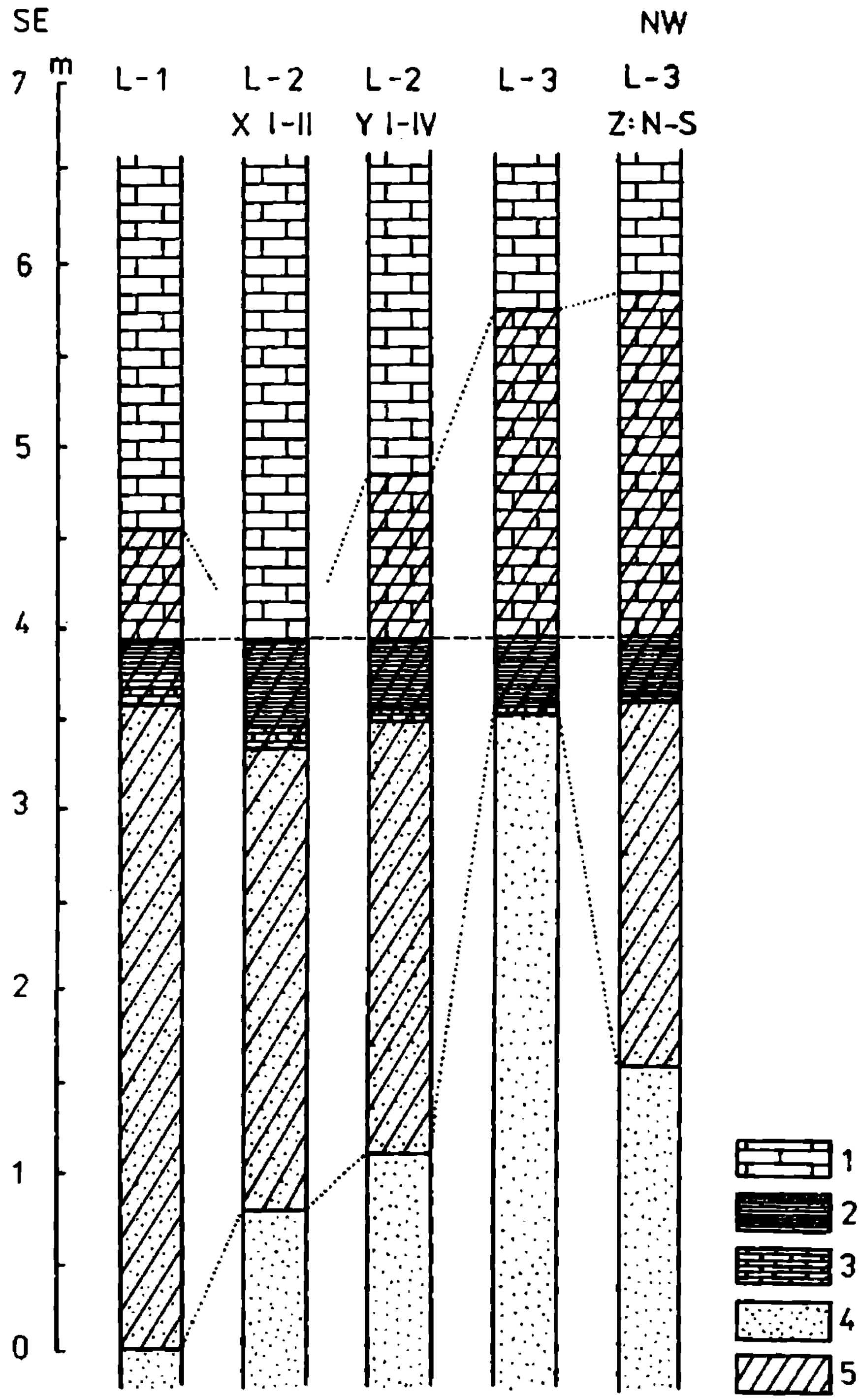

Fig. 2. Generalized stratigraphic columns of the copper-ore deposit in different mine areas (L-1, L-2, L-3), showing distribution of Cu mineralization of commercial value: *1* – limestones and dolomites; *2* – Kupferschiefer; *3* – Boundary Dolomite; *4* – Weissliegendes Sandstone; *5* – mineralized zone

1965; Krumbein, 1966) and correlation analysis (Yule & Kendall, 1966) were used.

In the statistical analysis, Cu contents for rock-groove samples, taken alternately from the two side walls of the galleries, were used. The considered sample populations were two-dimensional and included two features: Cu--grade (in %) and thickness T (in meters). Cu-content determination refers to samples cut through the entire thickness of the Boundary Dolomite.

The studies of the variation of these two parameters (Cu %, T) were carried out using three various sampling schemes (Tables 1, 2 and 3): (1) Rock--groove samples spaced systematically at every 15 – 20 m (the currently used system of sampling), (2) widened grid sampling – about 60 m spacing, and (3) random rock-groove samples (samples taken randomly from a population with 15 – 20 m spacing). Studies performed for different variants of the sampling grid made it possible to assess, how the above considered procedures influence the variation of the ore deposit parameters (Namysłowska-Wilczyńska, 1980; Kotlarczyk *et al.*, 1981). Unlimited dependent sampling, performed in order to estimate the average value, was based on the following formula:

$$n = N/1 + \frac{Nd^2}{u_\alpha^2 s^2}$$

where: n – number of random samples;
N – number of samples;
d – maximum admissible error;
u_α – critical value for the confidence coefficient $1 - \alpha$ from the table of normal distribution (0.1);
s^2 – variance.

When evaluating the variability of basic statistics and Cu-grade and thickness distributions, different schemes of sample spacing were taken into consideration. When looking for regularity in the variation of the Boundary Dolomite ledge parameters, only the widened grid of sampling was used.

When interpreting the results of the statistical analysis of these parameters, estimates of their variation in the adjacent lithological horizons – the Kupferschiefer and the top sandstone layer of the Weissliegendes – were taken into account.

DISTRIBUTIONS OF THICKNESS AND Cu-GRADE

Analysis of histograms of the Cu-grade in the Boundary Dolomite showed distinct variation in the distribution form depending on the lithologic development of the ore deposit and thus on the location of the mining field (Figs. 1 and 2).

Distributions of thickness and Cu-grade for the Boundary Dolomite were presented for the L-1 and L-3 fields of the Lubin mine. For the comparison of distribution shapes representing the studied subpopulations (whole fields, single galleries), an identical class interval, 0.29% Cu, has been assumed. It concerns the copper grade, both in the Boundary Dolomite and in the underlying sandstone. In the case of the histograms of the dolomite thickness, the interval of length 0.025 m was accepted.

AREAS L-1 AND L-2

In the fields in which the main component of the copper-ore deposit is hosted by the Weissliegendes Sandstone the Cu-grade distributions for the Boundary Dolomite are nearly symmetrical (Fig. 3; Namysłowska-Wilczyńska, 1980), with the mode for the L-1 area falling at 1.80–2.09%. A weak positive skewness appears here due to the presence of classes of high metal grade.

Histograms obtained for two clusters of drives of the L-1 field (Fig. 3) render the distribution shape of the total L-1 population well. The observed symmetry of the distribution and the occurrence of identical values of their modal classes provide evidence of almost identical intensity and uniformity of mineralization in the Boundary Dolomite of the whole L-1 field.

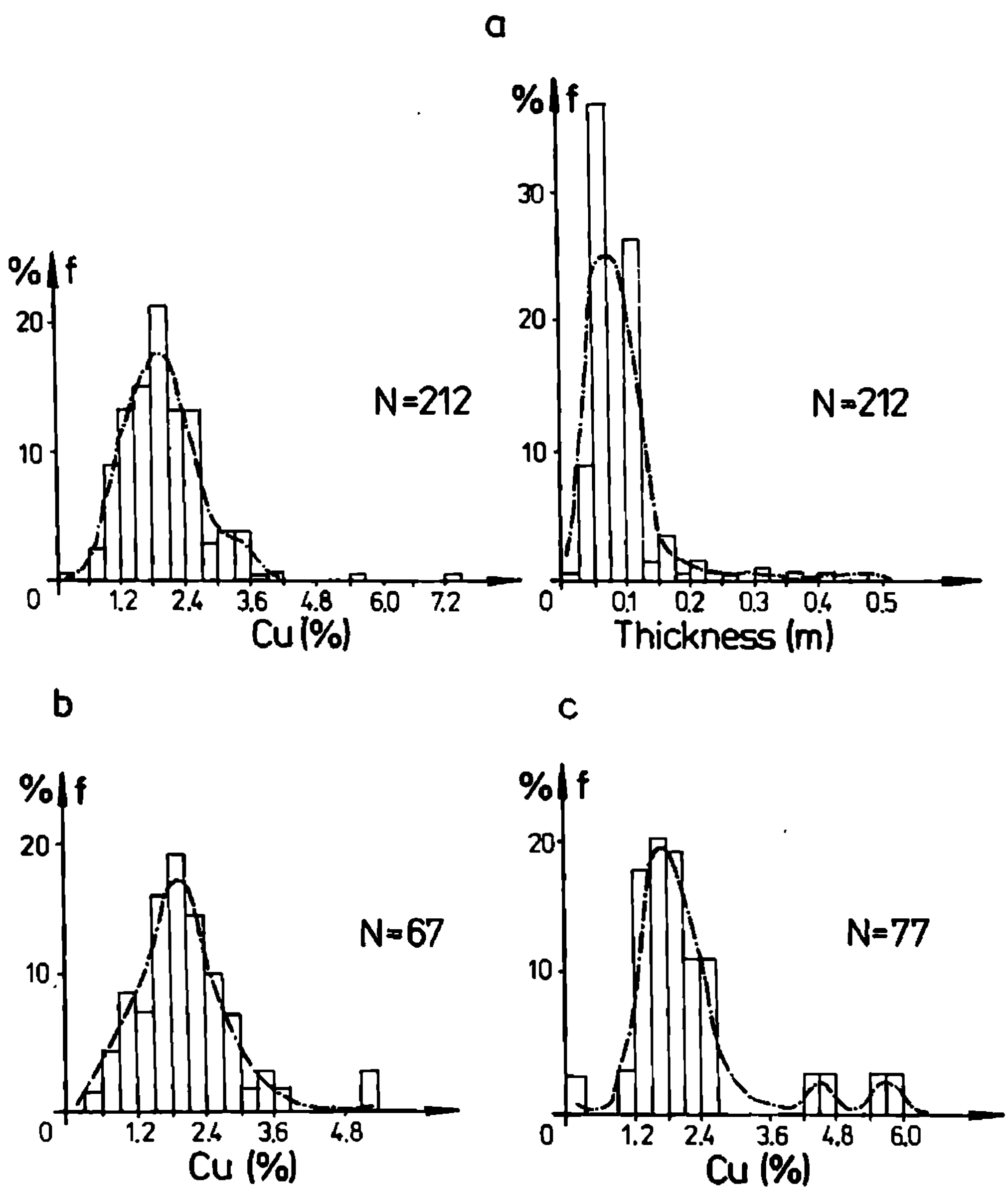

Fig. 3. Cu-grade and thickness histograms for the Boundary Dolomite in the whole L-1 area (*a*), pair of drives D-I, D-II (*b*), pair of cross-cuts M-I, M-II (*c*). *f* – frequency; *N* – number

A symmetrical Cu-grade distribution is also observed for the top layer, No. 1, of the Weissliegendes Sanstone (Fig. 4a). Its symmetry is disturbed only by a few classes of high Cu-grade. Similar distribution with a weak positive skewness was also obtained for the top layer of the Weissliegendes Sandstone in the L-2 field (Fig. 4b). For the two histograms mentioned (Fig. 4a,b), the modal class is the same interval 1.20 – 1.49%, which points to a similar mineralization in the top part of sandstone ore in both areas. The mineralization is markedly lower than that in the Boundary Dolomite. Layer No. 1 consists of light-gray sandstone which is persistent throughout the Lubin-

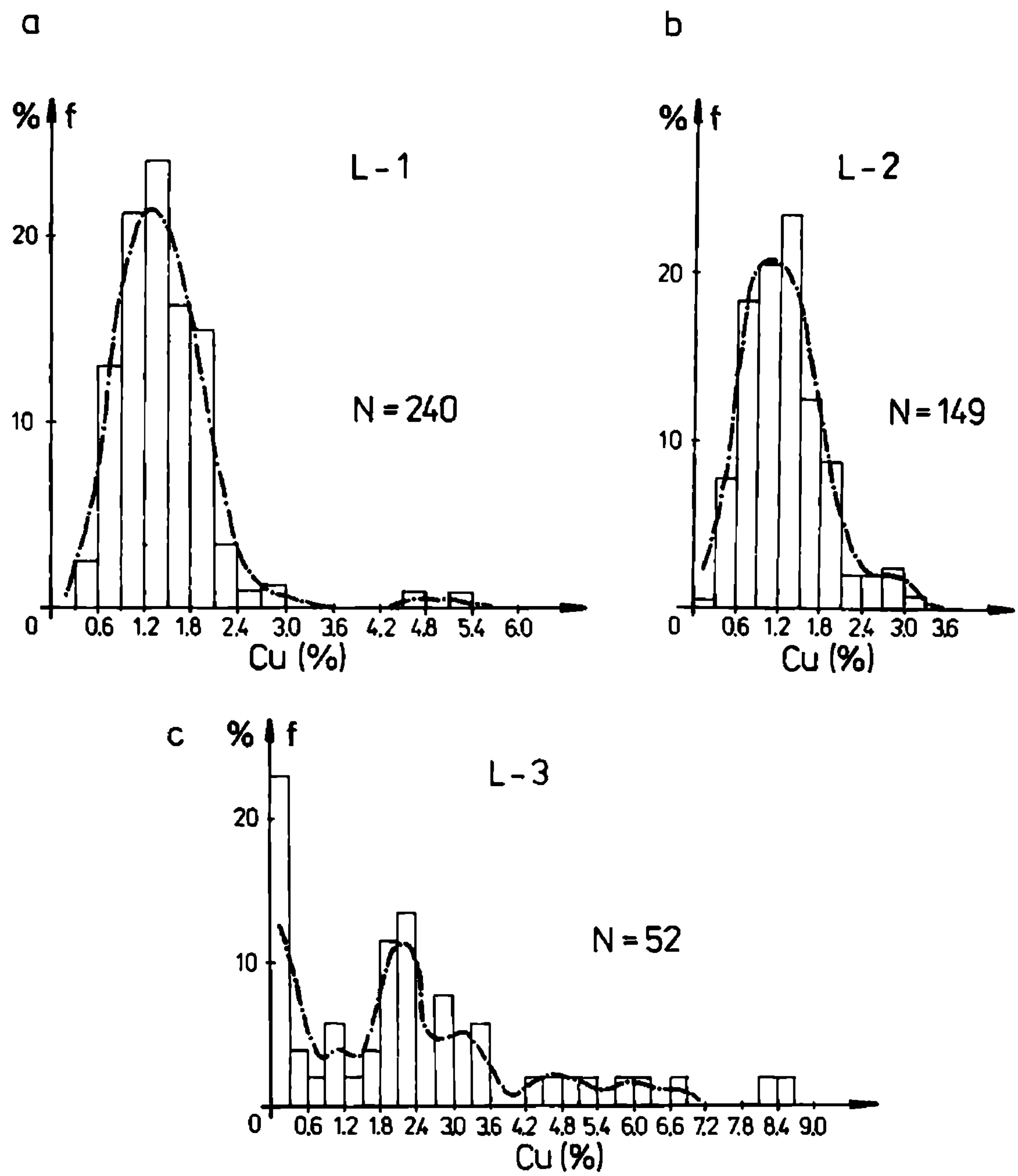

Fig. 4. Cu-grade histograms for the topmost layer of the Weissliegendes Sandstone in three fields of Lubin Mine: L-1 (*a*), L-2 (*b*) and L-3 (*c*). Explanations as in Figure 3

-Sieroszowice area. This layer is 0.06–0.26 m thick and most intensely mineralized of the entire section of the sandstone-hosted ore (Namysłowska--Wilczyńska, 1986).

The thickness distribution of the Boundary Dolomite is characterized by a strong positive skewness and the mode 0.050–0.075 m (Fig. 3). Presence of classes of higher thickness (0.400–0.420, 0.450–0.500), which occur rather rarely in L-1, is recorded. This points to a high lateral variability of the thickness of the Boundary Dolomite.

AREA L-3

Completely different shapes of Cu-grade and thickness distributions are observed for the L-3 field which is dominated by carbonates in the ore deposit series. The Cu-grade distribution is distinctly positively skewed (Fig. 5). The

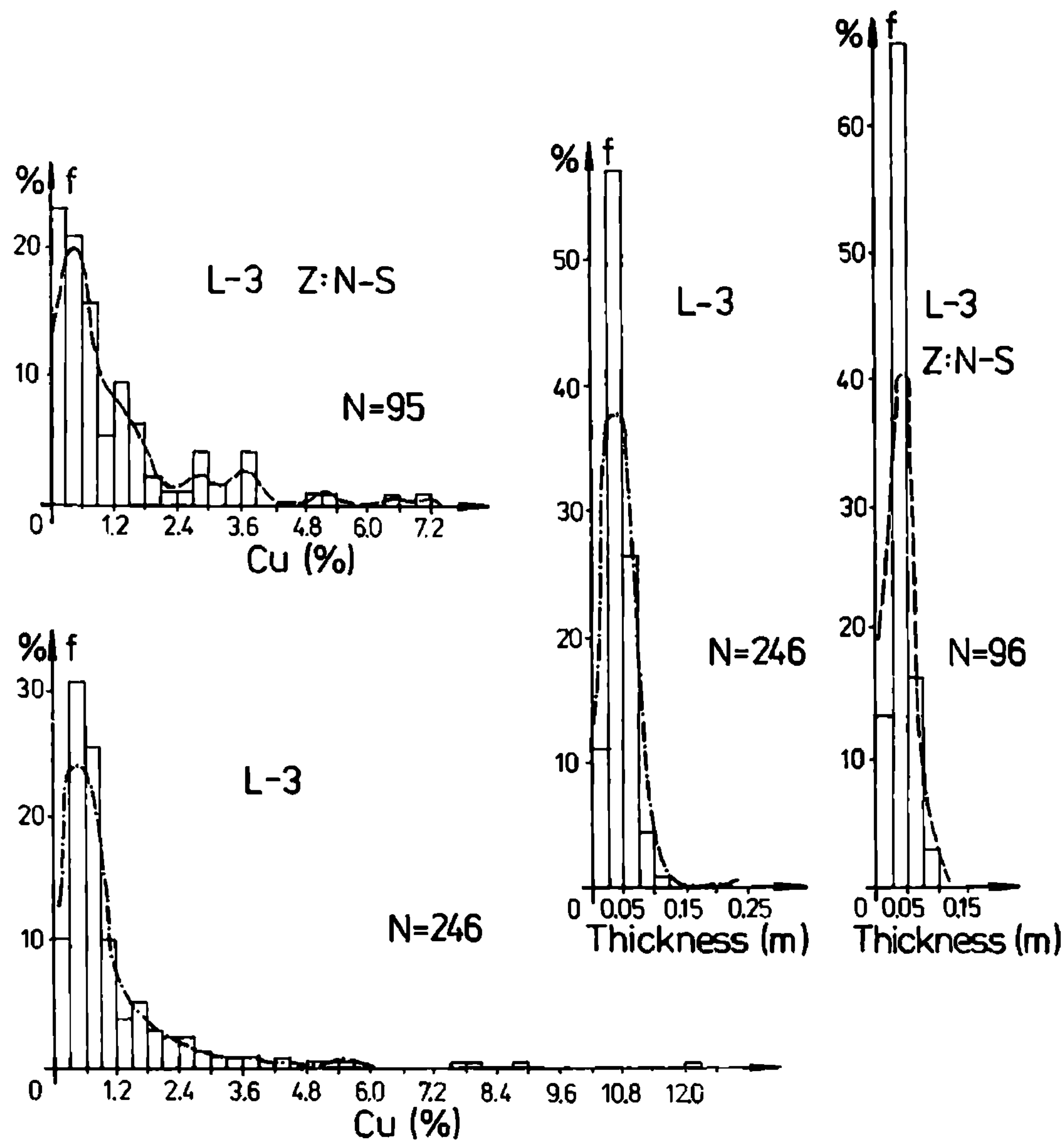

Fig. 5. Cu-grade and thickness histograms for the Boundary Dolomite in the area L-3. Explanations as in Figure 3

modal class comprises considerably lower Cu-grades (0.30–0.59%). On the other hand, the form of the distribution reflects the occurrence of very rich local ore concentrations, not found in the previous regions. The observed enrichments of the Boundary Dolomite is probably due to the strong intensity of mineralization in the overlying shale. Among the considered fields, it is precisely the L-3 area that shows the maximum concentration of Cu-compounds in the Kupferschiefer (Namysłowska-Wilczyńska *et al.*, 1976; Namysłowska-Wilczyńska, 1980). The thickness distribution of the dolomite is nearly symmetrical (Fig. 5). The modal class comprises still lower values of thickness (0.025–0.050) than those for the L-1.

The distributions representative for the whole region are further corroborated by the histograms obtained for the gallery Z: N-S which forms the western boundary of the L-3 field (Fig. 5). The thickness distribution has almost symmetrical shape with the same modal class. In contrast, the Cu-grade distribution is one-tailed, markedly positively skewed and its shape is disturbed by distinct secondary modes of smaller Cu-grade. It displays a strong class, comprising the lowest Cu-grade (0.00–0.29%), which is an equivalent of geochemical background. There are also anomalous ore enrichments here. It turns out that a similar type of distribution-cut-off, with the dominant class in the range of geochemical background, is shown by the histogram of Cu-grade for the Weissliegendes Sandstone topmost layer which occurs only in the area of gallery Z: N-S (Fig. 4c). It is interesting that the metallization of the layer in this area, despite its patchy character, is more intensive than in the overlying Boundary Dolomite.

PEARSON'S SKEWNESS

Skewness values *SK* for the above discussed distributions are diversified. For the Cu-grade of the Boundary Dolomite they vary from 0.09 (L-1) to 0.49 (L-3) and for the dolomite thickness, from 0.04 (L-3: Z: N-S) to 0.45 (L-1). With respect to the Cu-grade in the sandstone layer, values *SK* range from 0.05 (L-2) through 0.24 (L-1) to 1.04 (L-3: Z: N-S).

TESTING FOR NORMALITY

A comparison of the modal classes of all the Cu-grade histograms considered shows that stronger mineralization occurs in the Boundary Dolomite in the L-1 field and of the sandstone layer in the Z: N-S gallery (L-3).

The testing of the distributions on a Laplace-regular grid (Namysłowska-Wilczyńska *et al.*, 1976) and applying Kołomogorov's compatibility λ-test (Namysłowska-Wilczyńska *et al.*, 1976; Namysłowska-Wilczyńska, 1980) allowed us to determine the model of the statistical behaviour of the considered parameters (significance level 0.05).

Populations of Cu-grade in the Boundary Dolomite from the L-1 area show normal distribution – both overall ($1.09_{\lambda\ calc.} < 1.36_{\lambda\ 0.05}$), and partial. A similar type of distribution is also representative of the populations of Cu-grade in the sandstone layer of the L-1 and L-2 fields. However, for the Cu-grade distribution in the Boundary Dolomite of the L-3 area, the normal-logarithmic type, relatively strongly asymmetric, can be regarded as being representative. The situation is reversed in the case of the thickness population (L-1 – asymmetric; L-3 – normal: $0.14_{\lambda\ calc.} < 1.36_{\lambda\ 0.05}$).

The observed normal-logarithmic character of the Cu-grade distribution curves for the region L-3 is corroborated by the distribution representative for the whole Lubin ore deposit area, found for the fields L-1, L-2 and L-3 (Fig. 6). The effect of the subpopulations of the low-grade elementary

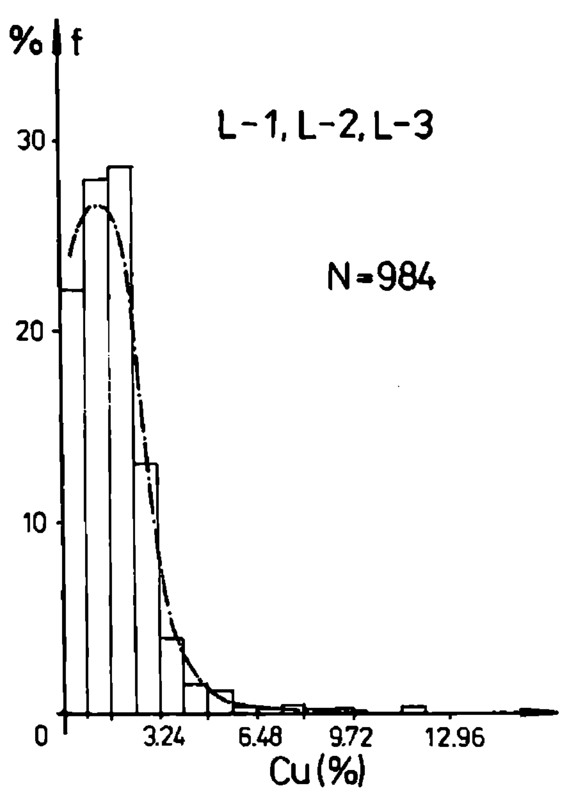

Fig. 6. Cu-grade histogram for the Boundary Dolomite in the whole area of Lubin Mine. f – frequency; N – number

samples (L-3) manifested itself in a shift of the modal class of this distribution towards lower grades whereby its form changed from symmetric to normal-logarithmic.

Summing up, the histogram shapes of the parameters considered for the Boundary Dolomite reflect the intensity and uniformity of mineralization in this layer. Regardless of the number of considered subpopulations and the dimensions of the studied area, Cu-grade distributions representative of the L-1 area are nearly symmetrical. However, in the L-3 field the distributions are generally asymmetric or even extremely asymmetric. The asymmetry of the Cu-grade distributions and hence the degree of its non-uniformity increases in the north-western direction, towards Polkowice. The opposite is found for the thickness distributions, the forms of which reflect the continuity of the dolomite bed. In this case, the asymmetry is observed in the SE part of the mine.

THE BASIC STATISTICS

An assessment of the basic statistics of the Cu-grade and thickness of the Boundary Dolomite showed a strong regional variation of the two parameters (Table 1). Differences between the means and variances were verified by means of Student's t-test and F-Fisher-Snedecor test, respectively.

Table 1

Basic statistics of thickness and Cu-grade for the Boundary Dolomite

Region of mine	Gallery	Sample size n	Copper grade $\bar{X}$(%)	Copper grade S (%)	Copper grade V (%)	Thickness $\bar{X}$ (m)	Thickness S (m)	Thickness V (%)	Sampling scheme
Area L−1	L−1	206	2.01	0.80	39.80	0.09	0.07	72.54	Spacing 60 m
	L−1	97	2.08	0.76	36.54	0.09	0.05	58.86	Random
	D−I	33	1.99	0.83	41.71	0.07	0.04	50.21	Groove samples systematically selected. Spacing at 15−20 m
	D−II	33	2.14	0.90	42.06	0.09	0.04	47.20	
	M−I	38	2.23	0.96	43.05	0.07	0.03	45.91	
	M−II	38	2.03	1.04	51.23	0.06	0.02	32.65	
Area L−2	XI−II	148	1.79	1.10	61.45	0.06	0.01	23.50	
	X−I	77	1.80	1.02	56.67	0.06	0.01	23.50	
	X−II	71	1.77	1.13	63.84	0.06	0.01	23.50	
	YI−IV	188	2.41	1.13	46.89	0.07	0.02	32.00	
	Y−I	44	2.47	0.97	39.27	0.07	0.02	35.00	
	Y−II	44	2.17	1.26	58.06	0.07	0.02	28.57	
	Y−III	48	2.57	1.17	45.53	0.07	0.03	37.86	
	Y−IV	52	2.44	1.05	43.03	0.06	0.02	28.83	
Area L−3	L−3	246	1.12	1.39	124.11	0.04	0.02	44.84	Spacing every 60 m
	K−I	53	0.70	0.74	105.71	0.04	0.02	40.29	Spacing every 15−20 m
	K−II	53	0.80	0.73	91.25	0.04	0.01	32.13	
	Z:N−S	96	1.36	1.95	143.38	0.04	0.01	37.27	

X — mean; S — standard deviation; V — variation coefficient

REGIONAL VARIABILITY

The foregoing analysis showed statistically significant differentiation in Cu--grade and thickness between the studied regions. The differences between values of the variation coefficient V_{Cu} reach 100%, wheras those between V_{T}

reach a maximum of 50%. For Cu-grade the highest values of the variance (0.379^2) and of the coefficient V_{Cu} (143%) are found in the field L-3 (Z: N-S). The lowest were obtained in the L-1 field (0.0058 and 36.5%, respectively). As far as thickness is concerned, the highest values of the variance (0.0049 m^2) and the coefficient V_T (59–73%) are observed for the field L-1 and the lowest (0.0001 m^2 and 23%) – for the cluster X I-II in the field L-2. In this region (cross-cuts Y I-II) the most highly mineralized dolomite ($\bar{X} = 2.41\%$) was found. The field L-1 possesses a similar intensity of dolomite mineralization in block Y I-IV (2.01–2.08%). The lowest concentration of Cu-sulphides is observed in the L-3 area ($\bar{X}$: 1.12–1.36%). The particulary low mineralization in the western area of Lubin has, moreover, an exceptionally non-uniform character (S^2_{Cu}: $0.0194-0.0379^2$ and V_{Cu}: 124–*143*%). Despite the poor mineralization of the Boundary Dolomite, the continuity of this layer (V_T: 37–45%) is not very different from that in field L-2, (V_T: 24–32%). The thickness decreases nearly twice as much ($\bar{X} = 0.04$ m) as in the L-1 field ($\bar{X}$: 0.06–0.09 m).

In the area of the Lubin mine, the decrease of the mean Cu-grade in the Boundary Dolomite accompanied by a simultaneous increase of the coefficient V_{Cu} occurs toward the NW. The mean thickness decreases in the same direction (Polkowice). V_T values on the other hand, increase towards Lubin.

LOCAL VARIABILITY

The degree of local variation of the considered parameters is strictly connected with the area of investigations, being more pronounced for the Cu-grade (Table 1). However, the variation within the fields is generally small. Differences among V_{Cu} values for individual regions range from several per cent (L-1, L-2: X I-II) to as much as 40% (L-3). The analysis of the Cu-grade variation in regions L-1 and L-2 shows, in all the cases, that the differences between the means are statistically insignificant and most of the tests show the same for variances. A strong variation of this parameter occurs in the field L-3, but not in the adjacent galleries. Generally, the differences in the V_{Cu} value for the adjacent galleries do not exceed 10%, or they are negligible. The greatest differences (about 40%) occur when the perpendicular galleries are compared.

Quite different are the results of the thickness analysis. In the fields L-2 and L-3, the dolomite thickness shows a weaker variation than in the L-1 area. Most of the tests did not reveal any significant differences between the statistics. Differences appear when galleries parallel to the structural strike and the cross-cuts are compared. The greatest variation of thickness occurs in the L-1 area, where significant differences in the variances and, in most cases, in the means, were obtained. The coefficient V_T has considerably smaller ranges of the values than the coefficient V_{Cu}. Generally, differences between them reach only a few per cent, and a maximum of about a dozen for the galleries running perpendicularly to each other.

The results of statistical estimation of the mean and the variance of the Cu-grade for the area L-1, based on a random sample population, correspond to the results of systematic population sampling (Table 1). Significant differences can be observed for the mean thicknesses (Table 1).

A comparison of the mean Cu-grade obtained for the Boundary Dolomite and the Kupferschiefer (Namysłowska-Wilczyńska, 1980) brings to light certain regularities in the behaviour of this parameter (Table 2). They are observed only in the eastern (L-1) and the central part (L-2) of the Lubin ore deposit. More intensive mineralization of the Kupferschiefer is accompanied by increased mineralization of the dolomite and vice versa. This regularity is observed both in the case of larger fields and in single galleries. The only exception is the L-3 area, where higher Cu-concentrations in the shaly horizon are accompanied by very poor mineralization in the dolomite. These observations apply to the whole field as well as to particular galleries.

Table 2

Mean values of Cu-grade in different lithostratigraphic units of the copper ore deposit

Unit		Mine field					
		Area L−1		Area L−2		Area L−3	
		mean per cent $\bar{X}$	sample size n	mean per cent $\bar{X}$	sample size n	mean per cent $\bar{X}$	sample size n
Kupferschiefer	Whole field	4.84	214	5.13	208	6.92	253
	Galleries	4.18	36	3.73	150	7.27	55
		4.55	34	5.33	51	6.50	56
		5.70	43	5.18	51	9.30	123
		5.82	42	5.12	54	–	–
Boundary Dolomite	Whole field	2.01	206	2.41	188	1.12	246
	Galleries	1.99	33	1.79	148	0.70	53
		2.14	33	2.57	48	0.80	53
		2.23	38	2.47	44	1.36	96
		2.03	38	2.44	52	–	–
Roof layer of the Weissliegendes Sandstone	Whole field	1.51	240	1.76	225	–	–
	Galleries	–	–	1.31	148	–	–
		–	–	–	–	2.33	52

Interesting results are obtained when the mean Cu-grades for the Boundary Dolomite are compared with those for the top layer of the sandstone-hosted ore (Namysłowska-Wilczyńska, 1980 1986). In those areas of the ore deposit where copper mineralization is associated mainly with sandstones and shales, its intensity in the roof part of the Weissliegendes Sandstone is lower, compared with that in the Boundary Dolomite. The mineralization is closely related to the Cu concentration of the shaly series or, more precisely, to the mineralization of the dolomite adjacent to the sandstone.

This interrelationship between the character of mineralization of the two lithologically different layers is also found in the area L-2 (Y I-IV), although here the carbonate series is also mineralized within a 1 m interval. This regularity is, however, not observed in the area Z: N-S. Despite the inconspicuous mineralization of the dolomite, the average Cu-grade calculated for the top sandstone layer is relatively high. However, the variance for this segment (0.0445^2), is more than 10 times higher than for the fields L-1 and L-2 ($0.0040-0.0043^2$).

CORRELATION ANALYSIS

The previous studies of the interdependence between copper mineralization and thickness of the ore deposit series showed that the correlations between these parameters are determined by the lithological development of the series (Romanowska & Salski, 1977; Kotlarczyk *et al.*, 1981).

A correlation analysis for two parameters was performed for different lithological horizons of the ore deposit and for the whole ore series in the three fields of the Lubin Mine (Namysłowska-Wilczyńska, 1980). Calculated values

Table 3

Correlation coefficients between thickness and Cu-grade for the Boundary Dolomite

Region of mine	Gallery	Correlation coefficient *r*	Sample size
Area L−1	whole field	−0.34	206*
	D−I	−0.34	33**
	D−II	−0.40	33**
Area L−3	whole field	−0.34	206*
	K−I	−0.35	53**
	K−II	−0.39	53**
	Z:N−S	−0.35	96**

All correlations significant at 0.05 level.
*Groove samples systematically selected, spacing 60 m.
**Groove samples systematically selected, spacing 15−20 m.

of the correlation coefficient *r* are given in Kotlarczyk *et al.* (1981). A simple model of linear correlation was assumed. A more detailed analysis was impossible, because some subpopulations did not fulfill the requirement of normality. Table 3 gives significant values of the correlation coefficient.

AREA L-1

In the sandstone-hosted ore deposit (L-1, L-2: X I-II), correlations for individual horizons and the whole deposit series were generally random. It is interesting that the only significant *r* values were obtained for the Boundary Dolomite of the L-1 area and these point to a reverse correlation (−0.34) between the Cu-grade and the thickness of this layer. The calculations of the correlation coefficient, repeated for two clusters of galleries in the L-1 region, yielded different results which were than those for the total population. For adjacent galleries (D-I and D-II) which run along the structural strike, the *r* values obtained (-0.43 and -0.40) agree with the result for the whole field. For galleries running along the dip (M-I, M-II), the correlation between the analysed parameters is insignificant. Similar results were obtained for the L-2 area.

In order to supplement the data on the correlation between the parameters in the remaining horizons of the deposit it is worth of noting that slightly positive correlations are characteristic of the Weissliegendes Sandstone and Kupferschiefer and slightly negative ones of the carbonate rocks and the whole copper-bearing series. The shales in the L-2 region for which a significant negative correlation (-0.54, -0.64), was found, are an exception.

AREA L-3

In contrast to the weak correlations observed for the fields L-1 and L-2; *r* values for the L-3 area, where the carbonate is the dominant host rock, are significant, both for the whole field and for particular galleries. In most cases, there is an inverse correlation between the Cu-grade and the thickness. There is a marked difference between correlations calculated for the individual horizons and those calculated for the whole ore deposit series. In the first case, the values are generally low, in the shales from -0.14 to -0.18 (-0.39 only for the Z: N-S) and in the carbonates, from -0.22 to -0.28.

The *r* coefficients characteristic of the Boundary Dolomite (-0.34 to -0.39) stand out in strong relief against the above results. They reach values similar to those obtained for the L-1 region. A significant negative correlation is found both for the whole field L-3 and for particular galleries. A high positive correlation (0.59) was obtained only for the sandstone-hosted ore in the Z: N-S area.

However, for the whole ore deposit series a significant negative correlation, characterized by markedly higher values (-0.60 to -0.67), was obtained.

Thus, the correlation analysis for the L-3 area corroborates the observations made for the previously discussed regions, i.e. the positive correlations are associated rather with sandstones and negative correlations with carbonates. The occurrence of an inverse correlation for the shales in some areas (L-2, L-3) could be ascribed to the orientation of the considered galleries in respect to the strike and dip, indicating the direction of the migration of ore-bearing solutions; in this case, along the dip.

This hypothesis seems to be suported by the negative correlation for the Boundary Dolomite, which, although characterized by low *r* values, is statistically significant. The above results indicate that the inverse correlation between Cu-content and thickness has a more general character and is applicable to the whole ore deposit series.

SURFACE TRENDS

Studies of regularities in the variation of the ore deposit series parameters by means of lower-order power polynomials from 1 to 6° were carried out in the areas L-1 and L-3. The analysis of Cu-grade and thickness trends was made separately for each lithological horizon of the ore deposit (Namysłowska-Wilczyńska *et al.*, 1976; Kotlarczyk *et al.*, 1981). Results show different trend surface patterns for both particular types of the ore and the analysed areas. The values of the determination coefficient η of the trend surfaces range from 0.4 to 72.%. Depending on the location of a given field, the non-random variability (or periodic variation when the period's length is greater than the dimensions of the mining fields) manifests itself more or less clearly and hence the form of the polynomial which approximates this variation is also different. The basis of calculations was a regular grid of sampling, widened to the distance of 60 m. Rock-groove samples are uniformly spaced. 214 data concerning the parameters of the Boundary Dolomite from the L-1 field and 206 data, taken from the L-3, were used in the calculations. With respect to the parameters of the Kupferschiefer, this number amounted to 253 and 246 in the L-1 and L-2 regions, respectively.

Cu-grade trend maps mainly of the 2nd degree are presented here. Trend surfaces have hyperboloidal shapes with axes oriented NW – SE and NE – SW. Regularities in variability of Cu-grade and thickness for different types of ore (Namysłowska-Wilczyńska, 1980; Kotlarczyk *et al.*, 1981) correspond to the joint trends characteristic of the Zechstein rocks in the Lubin region (Salski, 1975). Since a large part of Cu-sulphides occur in veins, it is concluded that block tectonics could play a certain role in the process of mineralization.

THICKNESS TRENDS

The thickness trends of the Boundary Dolomite (Fig. 7) are more strongly marked than those of the Cu-grade (Fig. 8). For a thickness trend, the surface approximated by polynomials of the 1st, 2nd and 3rd degree are significant.

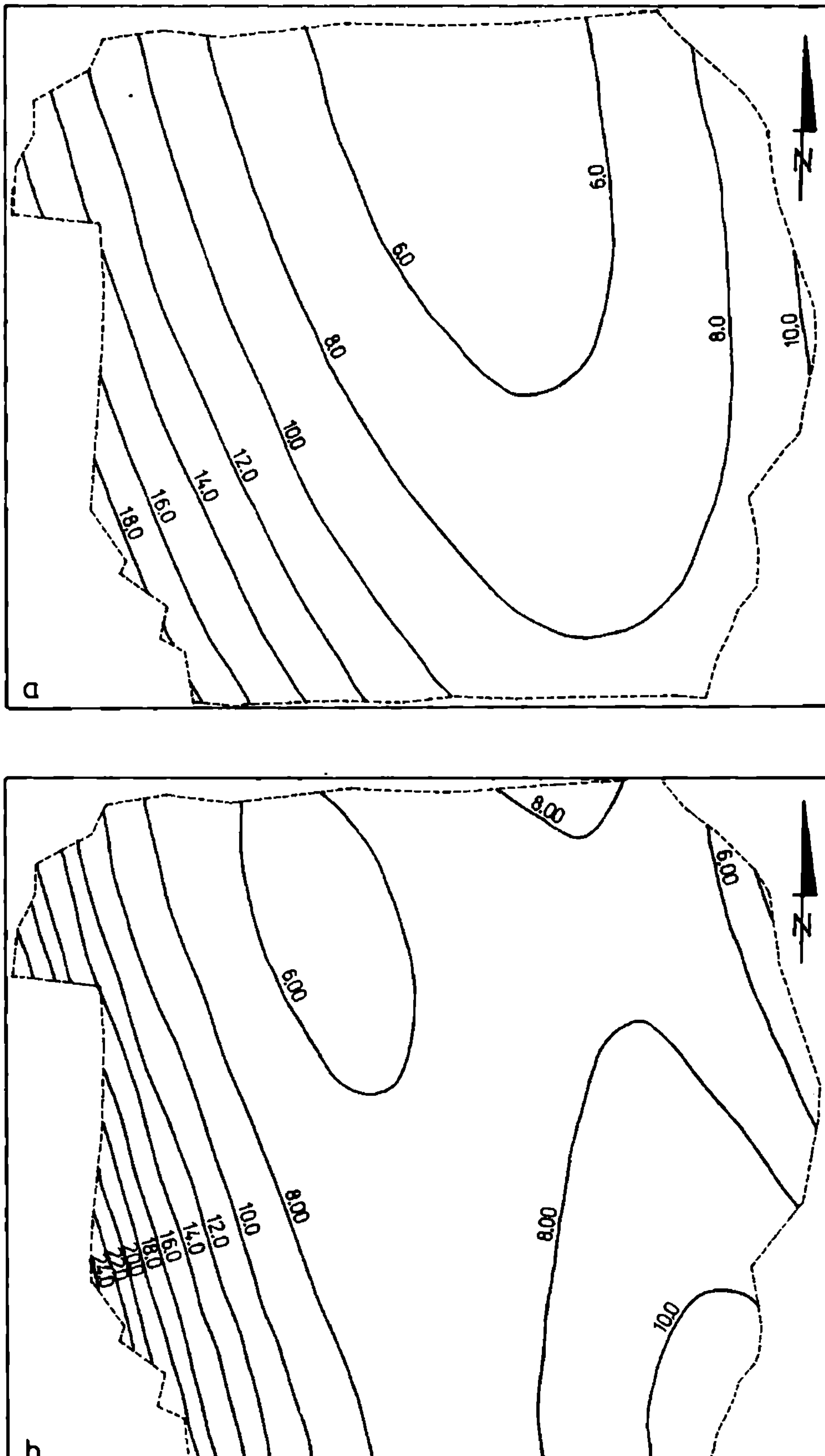

Fig. 7. Trend map of thickness of the Boundary Dolomite for the L-1 area; approximation by polynomial of 2nd degree (*a*) and by polynomial of 3rd degree (*b*)

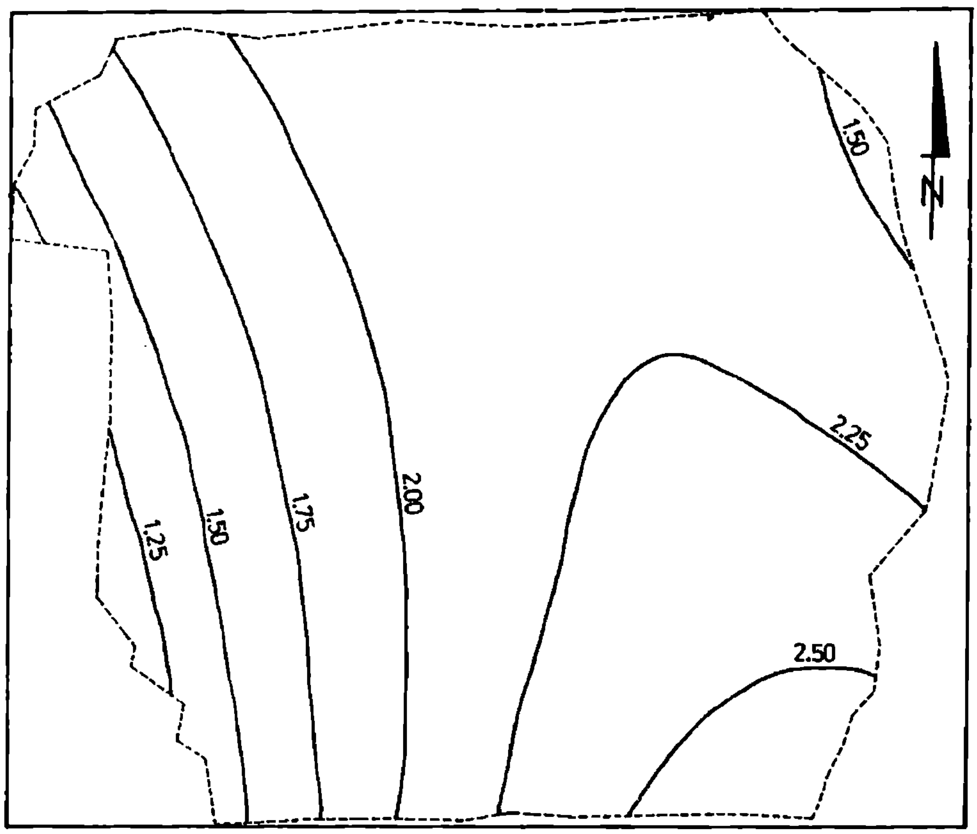

Fig. 8. Trend map of per cent Cu-grade in the Boundary Dolomite for the L-1 area; approximation by polynomial of 2nd degree

The value 42.6% of the determination coefficient η indicates that the thickness trend of the 3rd degree surfaces is marked relatively strongly. On the map of the 2nd degree surfaces (Fig. 7a), the NE–SW direction of variation is visible and maximum values of thickness are grouped in the SW part of the field L-1. The 3rd degree trend surface (Fig. 7b) reflects the main tendency of thickness variation, i.e. from NE towards SW. Two directions of growth become visible – towards the SW and towards the SE. On the contour line map the maximum values of this parameter are observed in the SW part of the field. More distinct variations can be traced along the line SW–NE.

Cu-GRADE TRENDS

The surface approximated by polynomials of the 1st and 2nd degree are significant for the trend of the Cu-grade. The mineralization trend in the Boundary Dolomite is considerably weaker than the thickness trend, and the coefficient η for the surface described by a polynomial of the 2nd degree reaches only 20.1%. The map of the 2nd degree trend (Fig. 8) shows that the Cu-grade has a tendency to increase towards the ENE and E. The maximum metal concentrations occur in the SE part of the L-1 field. Two directions of variation are marked on the map of contour lines, the more significant one, WSW – ENE, and the less distinct one, SSE – NNW.

The results of the trend studies for the shale-hosted ore in the L-1 region (Namysłowska-Wilczyńska *et al.*,1976; Namysłowska-Wilczyńska, 1980) are in agreement with the results for the Boundary Dolomite as far as the degree of approximation of the variability is concerned. For the thickness of the Kupferschiefer, however, η reaches higher values (the surface of 3rd degree is 57.9%). The growth tendencies of the Cu-grade and thickness of the shales (Figs. 10 and 11) are identical for both parameters, i.e. towards the NE, and thus are different than those for the dolomite. Moreover on the trend map (3rd degree surface) of the Cu-grade in the shales, another less distinct direction of variation can be traced, i.e. SE – NW. A map of the original data shows two tendencies of Cu-grade variability within the shales, SW – NE and SE – NW. The maximum of Cu concentrations appears in the NW corner of the L-1 field. However, the thickness values of the Kupferschiefer on the contour maps lines vary mostly along the line W – E. The greatest thickness is observed in SE part of the L-1 area.

In the region L-3, trend analysis was performed only for the Cu--grade in the Boundary Dolomite. The surfaces of the 1st, 2nd and 3rd degree are significant. The determination coefficients have similar values to those for the L-1 region (the surface of 3rd degree is 20.4%). On the map of the 2nd degree surface (Fig. 9*a*), the general direction of variation, NE – SW, persists and the intensity of mineralization grows towards the SW. A similar tendency is also observed on the contour map, the maximum values appear in the SW corner of the L-3 area. On the basis of the 3rd degree surface map (Fig. 9*b*), one can conclude that there are two directions of growth – one, strongly marked, towards the SW and another, less distinct, to the W.

The thickness trends of the Boundary Dolomite were not studied. For the thickness of the Kupferschiefer, the coefficients η of the surfaces described by polynomials of the 1st and 2nd degree were 19.3% and 27%, respectively. The tendency of the thickness variability (Fig. 12) from NE to SW corresponds to the shape of the Cu-grade variability in the Boundary Dolomite (Fig. 9*a,b*). A similar picture can be observed on the isopachyte maps of the shales and shale-hosted ore. For the shales none of the Cu-grade trend surfaces is significant.

A search for regional trends in the parameters of the Boundary Dolomite led to the discovery of their local directional variability in the studied fields, in spite of the fact that the grid of sampling was widened to about 60 m spacing. The discovered directions of the Cu-grade variability are different for both fields. Within the fields, however, the growth tendencies of mineralization intensity and thickness run in opposite directions. Although for the field L-3 only the Cu-grade trends are available, the correlation studies (Table 3) indicating an inverse correlation between mineralization and thickness in this

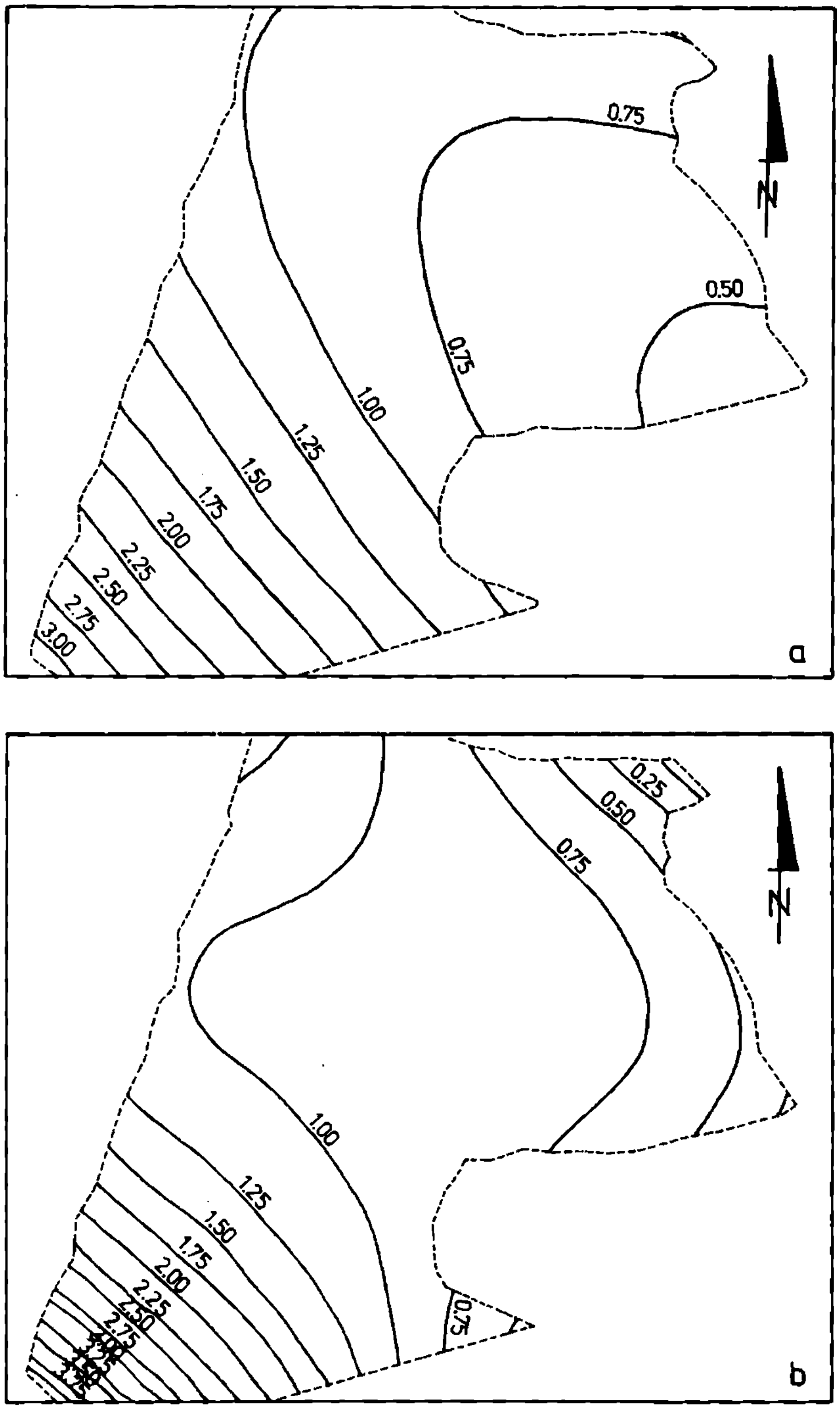

Fig. 9. Trend map of per cent Cu-grade in the Boundary Dolomite for the L-3 area; approximation by polynomial of 2nd degree (*a*) and polynomial of 3rd degree (*b*)

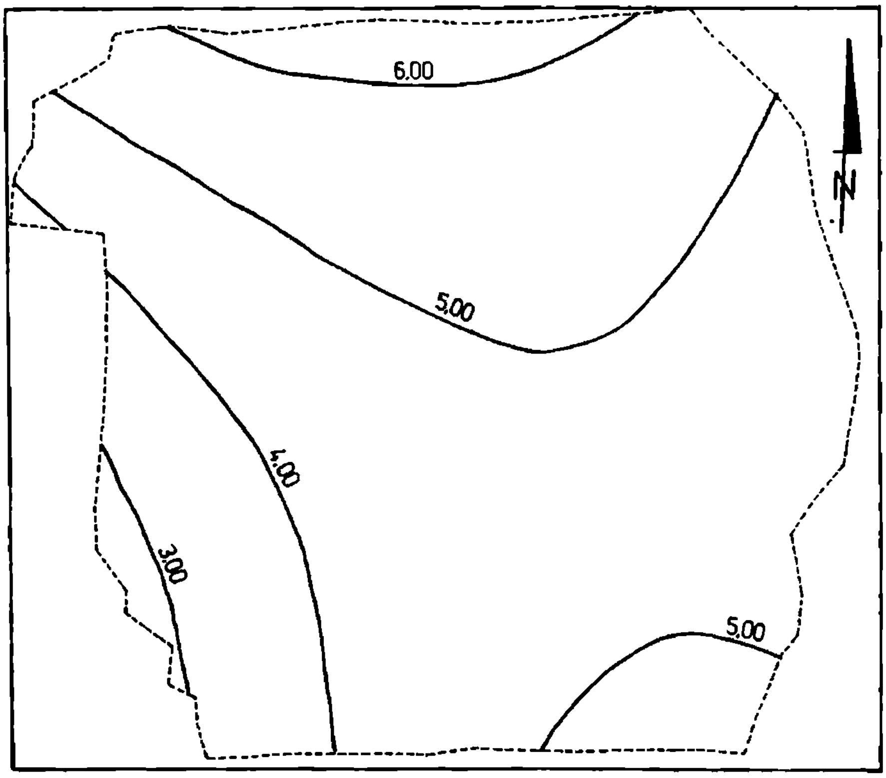

Fig. 10. Trend map of per cent Cu-grade in the Kupferschiefer for the L-1 area; approximation by polynomial of 2nd degree

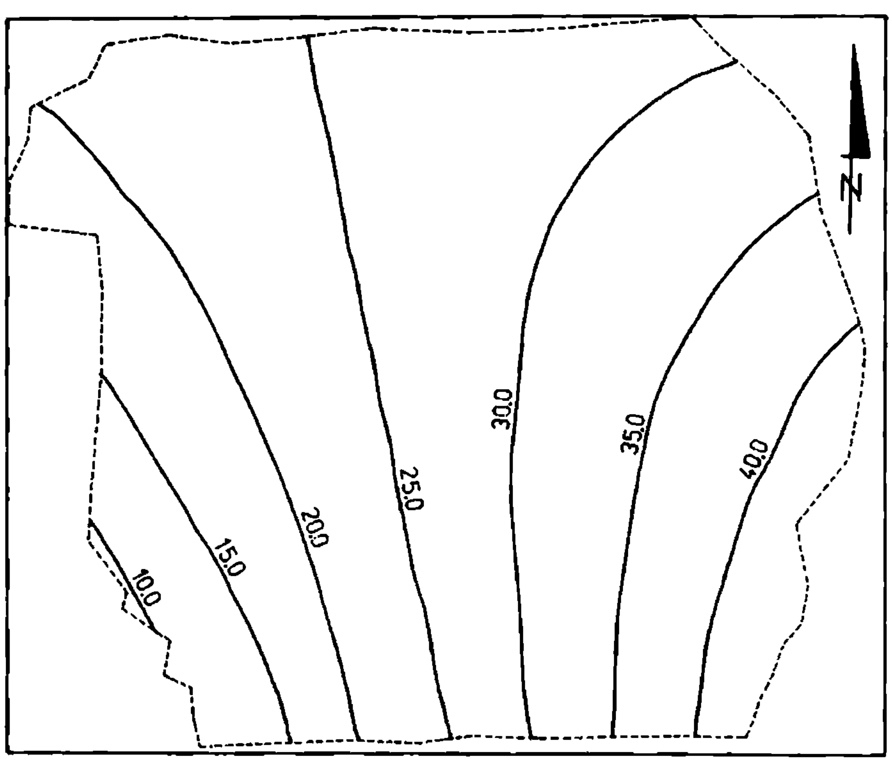

Fig. 11. Trend map of thickness of the Kupferschiefer for the L-1 area; approximation by polynomial of 2nd degree

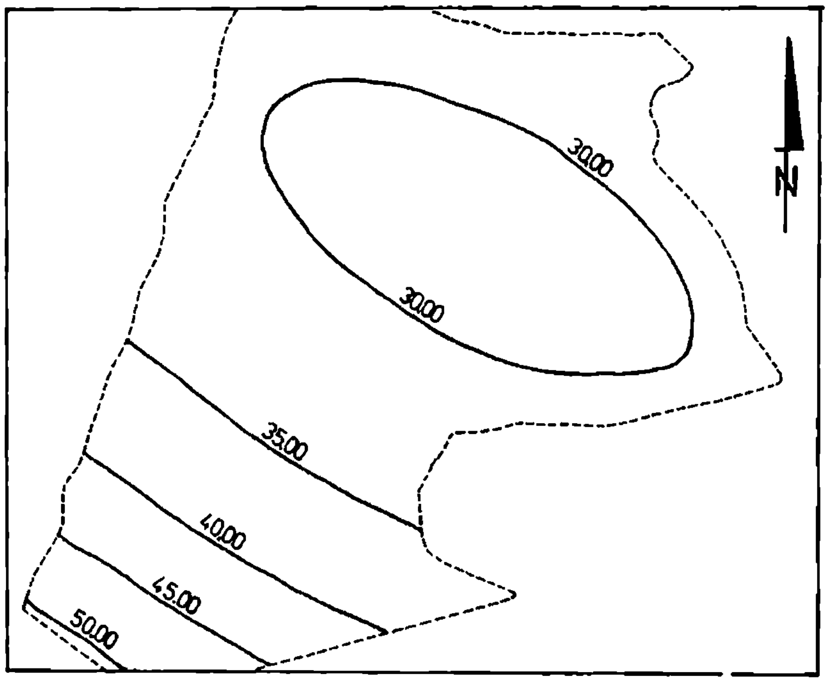

Fig. 12. Trend map of thickness of the Kupferschiefer for the L-3 area; approximation by polynomial of 2nd degree

area support the validity of the above statement. The variable scheme of trend surfaces of the Boundary Dolomite parameters reflects the negative correlation between them.

The above results show that the mineralizations of the Boundary Dolomite and of the Kupferschiefer are interrelated. The identical growth directions of the Cu-grade in the dolomite and the shales, and of the thickness of the latter, observed in the analysed regions of the Lubin mine provide the basis for this interpretation.

CONCLUDING REMARKS

The statistical analysis of the variability of Cu-grade and thickness of the Boundary Dolomite, supplemented with data from the Kupferschiefer and the topmost part of the Weissliegendes Sandstone, indicated that these horizons of the ore deposit series are genetically interrelated. The intensity of individual, ore-forming processes was not uniform in all the areas under consideration being most probably controlled by the host-rock lithology and joint orientations.

The observed correlations between the analysed parameters of the Boundary Dolomite and the direct relationship between its mineralization, the mineralization of the sub- and supra-adjacent lithologies, suggest that the mineralization of the dolomite is of infiltrational origin. This horizon, despite its small and variable thickness, could play the role of a screen for the ore-bearing solutions migrating away from the Kupferschiefer. This statement applies mainly to the sandstone-hosted ore deposit. The mineralization of the Boundary Dolomite in these areas is conspicuous and it is closely related to the intensity of the Cu-grade in the overlying shales. This thesis is also supported by lower, in comparison with the dolomite, mean content of copper in the topmost layer of the sandstone.

The above regularity is less manifested in the regions where the carbonate-hosted ore deposit dominates. Although here the shales have distinctly higher Cu-grades than in other parts of the Lubin mine, the Cu concentrations in the dolomite are low. It is interesting that in spite of that, the intensity of mineralization in the topmost part of the sandstone is considerably higher. In other words, in this area, the Boundary Dolomite did not play the role of a screen for the metal-bearing solutions infiltrating from above. This can be ascribed to the differences in the lithological development of the ore deposit series between the areas considered.

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REFERENCES

Jarosz, J., 1968. *Badania nad poziomym i pionowym rozmieszczeniem minerałów rudnych rejonu Szybów Głównych kopalni Lubin.* Zakład Badań i Doświadczeń KGHM, Lubin (unpublished), 57 pp.

Jarosz, J., 1969. *Charakterystyka litologiczno-mineralogiczna złoża miedzi kopalni Lubin i wnioski dla eksploatacji górniczej.* Zakład Badań i Doświadczeń KGHM, Lubin (unpublished), 32 pp.

Jarosz, J., 1970. *Mineralizacja piaskowców białego spągowca w kopalni Lubin.* Zakład Badań i Doświadczeń KGHM, Lubin (unpublished) 60 pp.

Kotlarczyk, J., Nieć, M. & Wilczyńska-Namysłowska, B., 1981. Model of variability of the Lubin-Polkowice copper deposit and the problems of its origin. (In Polish, English summary). *Pr. Geol., PAN, Oddz. w Krakowie,* Warszawa, 123: 64 pp.

Krumbein, W. C. & Graybill, A. F., 1965. *An Introduction to Statistical Models in Geology.* McGraw-Hill, New York, 475 pp.

Krumbein, W. C., 1966. Classification of map surfaces based on the structure of polynomial and Fourier coefficient matrices. *Comp. Appl. Earth Sci. Comp. Contr.*, 7:

Namysłowska-Wilczyńska, B., 1980. *Analiza ilościowa zmienności przestrzennej wybranych parametrów geologicznych osadów dolnego cechsztynu w rejonie kopalni Lubin.* (Ph.D. thesis – unpublished). Raporty Inst. Geotech., Politechnika Wrocławska, ser. PRE, nr 112, 156 pp.

Namysłowska-Wilczyńska, B., 1986. Analysis of the variability of copper mineralization in Whiteliegendes sandstones in the area of the Lubin Mine. (In Polish, English summary). *Geol. Sudetica,* 21, (2): 72 – 100.

Namysłowska-Wilczyńska, B., Słomka, T., Myszka, R. & Słomka, E., 1976. *Zmienność złoża rud miedzi Lubin.* Archiwum Instytutu Geologii i Surowców Mineralnych AGH, Kraków, (unpublished), 110 pp.

Preidl, M., Dubiński, K., Konstantynowicz, E. & Tomaszewski, J. B., 1971. *Monografia przemysłu miedziowego w Polsce.* Wyd. Geol., Warszawa, 1 – 2: 432 pp.

Romanowska, B. & Salski, W., 1977. Variability of copper ore deposit of Foresudetic Monocline. (In Polish, English summary). *Geol. Sudetica*, 12, (2): 49–75.
Salski, W., 1975. Tektonika okolic Lubina. (In Polish only). *Biul. Inst. Geol.*, 287: 61–193.
Tomaszewski, J. B., 1978. Geological structure of the Lubin–Sieroszowice region (Lower Silesia). (In Polish, English summary). *Geol. Sudetica*, 13 (2): 85–128.
Tomaszewski, J. B., 1985. Złoże rud miedziowo-polimetalicznych monokliny przedsudeckiej i jego związki z osadami cechsztynu. (In Polish only). *Prz. Geol.*, 7: 375–385.
Yule, G. U. & Kendall, M. G., 1966. *Wstęp do teorii statystyki*. (Polish translation). PWN, Warszawa, 684 pp.

Streszczenie

ZMIENNOŚĆ MINERALIZACJI MIEDZIOWEJ W DOLOMICIE GRANICZNYM (CECHSZTYN, MONOKLINA PRZEDSUDECKA) W ŚWIETLE BADAŃ STATYSTYCZNYCH

Barbara Namysłowska-Wilczyńska

Przedstawiono wyniki badań zmienności zawartości Cu i miąższości dolomitu granicznego – poziomu litostratygraficznego złoża rud Cu w rejonie Lubina, zalegającego w spągu serii łupków miedzionośnych. Badania statystyczne wykonano dla trzech pól eksploatacyjnych kopalni Lubin (Fig. 1), reprezentujących różne typy profilu litologicznego miedzionośnej serii złożowej (Fig. 2). Przedmiotem rozważań była zmienność regionalna parametrów dolomitu granicznego oraz zróżnicowanie lokalne w obrębie pola kopalnianego. Analizę zróżnicowania intensywności okruszcowania miedzią w dolomicie granicznym i stopnia ciągłości wykształcenia tego horyzontu przeprowadzono metodami oceny postaci rozkładów (Fig. 3–6) i podstawowych statystyk (Tab. 1–2), korelacji (Tab. 3) oraz analizy trendów powierzchniowych (Fig. 7–12). W świetle stwierdzonych prawidłowości zmian analizowanych parametrów złożowych można stwierdzić, że mineralizacja dolomitu granicznego ma charakter infiltracyjny. Decydującą rolę w okruszcowaniu tej warstwy prawdopodobnie odegrały procesy przemieszczania roztworów kruszconośnych.