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Geological setting of the Silesian-Cracow Zn-Pb deposits

In the present paper, the position of the Silesian-Cracow Zn-Pb deposits, on the background of the geological structure of their host area, is discussed and shown on maps and cross-sections. The connection of the ore mineralization with disjunctive tectonics is evidenced. The Zn-Pb deposits distribution follows Variscan (and older) as well as Alpine tectonic patterns of that area.

INTRODUCTION

The Zn-Pb deposits of the Silesian-Cracow area are studied since almost 200 years but still consensus has not been achieved concerning the essential genetic problems, i. e. the source of the ore substance and the mechanism of the ore-forming fluids migration. This paper presents the above problems. An attempt to establish the regularities of the Silesian-Cracow deposits location on the background of the geological structure of the hosting area, is the aim of this paper. Hitherto, despite of intensive drilling and prospecting activity, especially in seventies and eighties, the recognition of the relation of the ore mineralization to the geological background is insufficient. Elaborations presenting the problem as a whole, taking into account the results of the new drillings, are also absent.

The present publication is based on the published and unpublished reports, including geological-ore-deposits exploration results and drilling logs performed by Państwowy Instytut Geologiczny (Polish Geological Institute) and Przedsiębiorstwo Geologiczne w Krakowie (Geological Enterprise in Cracow). The extensive archives records, exceeding significantly the frames of this paper, were not listed in the references. Presenting the deposit contours on the geological maps, the recently used

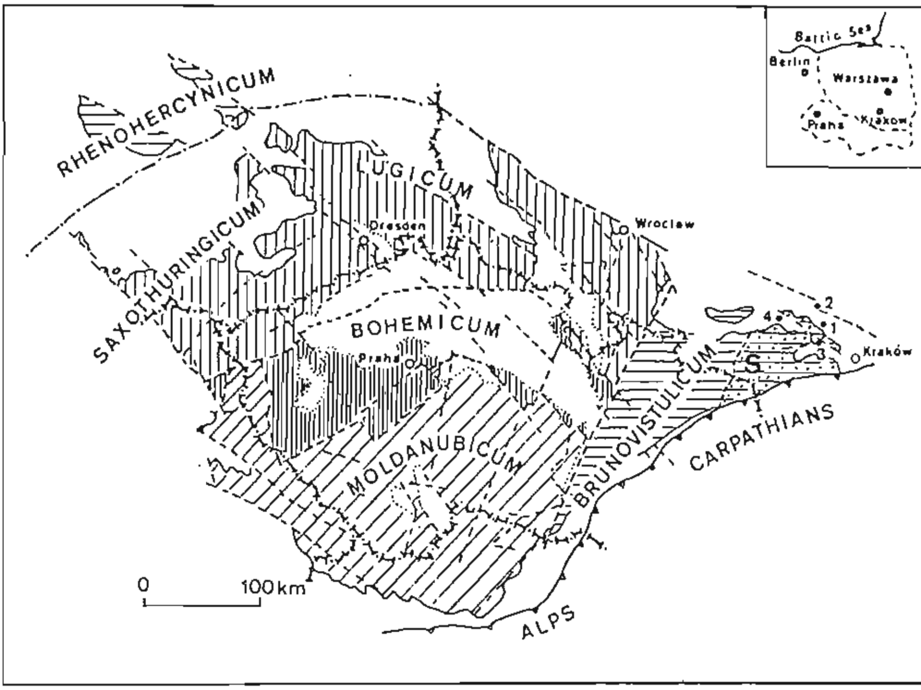


Fig. 1. Distribution of the Silesian-Cracow Zn-Pb deposits in relation to the Bohemian Massif (tectonic sketch map after J. Chaloupský, 1989)

Lined areas — Variscan massifs; S — Upper Silesian Massif; Zn-Pb deposits (marked by the present author): 1 — Olkusz region, 2 — Zawiercie region, 3 — Chrzanów region, 4 — Bytom region

Położenie śląsko-krakowskich złóż Zn-Pb w odniesieniu do Masywu Czeskiego (szkic tektoniczny według J. Chaloupský'ego, 1989)

Obszary zakreskowane — masywy waryscyjskie; S — masyw górnośląski; złoża Zn-Pb (zaznaczone przez autorkę): 1 — rejon olkuski, 2 — rejon zawierciański, 3 — rejon chrzanowski, 4 — rejon bytomski

criteria for the commercial ore (cut-off) 1.7% for Zn and 2% for Pb were used. Moreover, the term „Zn-Pb deposit" was used for sulfide (ZnS, PbS and FeS_2 in variable proportions) ores accumulations in Mesozoic and Paleozoic carbonate rocks.

GEOLOGICAL BACKGROUND

CALEDONIAN AND VARISCAN TECTONIC EPOCHS

The Silesian-Cracow Zn-Pb deposits occur in the border zone of Bohemian Massif (Fig. 1). In general, the geological structure of this ore district consists of two tectonic-sedimentary complexes. The Mesozoic sediments of the Alpine complex cover nearly horizontally the folded Paleozoic rocks that were eroded to various depth, yielding a surface with marked relief (the Kraków — Myszków Zone and the Upper Silesian Coal Basin), see Figs. 2-5. When considering the deeper structure, the Kraków — Myszków Zone is located between the two structural units: the Upper Silesian Massif in the west and the Małopolska Massif in the east. The first massif represents a microcontinent of Precambrian consolidation, the second one is an incorporated unit of Early Caledonian consolidation (A. Kotas, 1982; W. Brochwicz-Lewiński et al., 1983; S. Bukowy, 1984). The pre-Mesozoic geological developments of the Upper Silesian Basin and the Kraków — Myszków Zone quite differ during Early Paleozoic and Upper Carboniferous; however, during Devonian and Lower Carboniferous there was no distinct difference between these two regions. The essential formation of these regions was connected with the Variscean tectonic epoch, but the structure of the deep basement, which is poorly known, was determined mainly by the development of the older consolidated structural units.

The Upper Silesian Coal Basin is developed in the forefield of the Moravian-Silesian folded zone of Variscides as the foredeep filled by molasse sediments bearing coal beds (R. Unrug, Z. Dembowski, 1971; A. Kotas, 1982; A. Kotas, J. Porzycki, 1984). Thickness of these sediments of Namurian and Westphalian age is variable. In the western part of the basin it achieves about 8500 m, and decreases towards SE to about 1600 m, resulting from the reduction of several sedimentation units. Precambrian metamorphic and magmatic (granitoids and gabbro) rocks of the Upper Silesian Massif, covered by clastic sediments of Cambrian and next by clastic and carbonate Devonian and Lower Carboniferous beds (*op. cit.*), are the basement of the coal-bearing series.

Tectonic character of the ca. 20-25 km broad Kraków — Myszków Zone was not unequivocally explained yet. This zone has been interpreted as a branch of a Caledonian geosyncline, finally folded before Upper Silurian, which was included during Upper Paleozoic in platform structures (F. Ekiert, 1971; J. Znosko, 1974, 1984; C. Harańczyk, 1982). According to J. Znosko (*op. cit.*), the cover complexes of Devonian and Carboniferous, submitted to block-folded deformations together with their rigid basement, yielded a system of block mountains. S. Bukowy (1984) in an extensive elaboration describes geosynclinal and orogenic features of the discussed zone, both in Caledonian and Variscan epochs. According to that author, Paleozoic complex was folded during the Variscan orogeny to form asymmetric anticlines, small thrust sheets and synclines of the NE vergence and general NW-SE strike. The anticlines are formed of Lower Paleozoic and Devonian beds, synclines of the Lower Carboniferous beds.

Other investigators accept non-geosynclinal origin of the Kraków — Myszków Zone, considering it as an aulacogen being a branch of a rift system formed during Cambrian (W. Pożaryski, Z. Kotański, 1979), a Caledonian lineament having tectonic folded-intrusive features (K. Bogacz, 1980) or as possible zone developed on a regional deep-seated discontinuity of Precambrian origin and active to various degree during several tectonic cycles (A. Kotas, 1982). Such a zone could belong to the structures of the Moravian-Silesian basement (*op. cit.*).

The Caledonian structural stage consists of Cambrian, Ordovician and Silurian rocks. A share of the uppermost Precambrian incorporated in the structure of the

Fig. 2

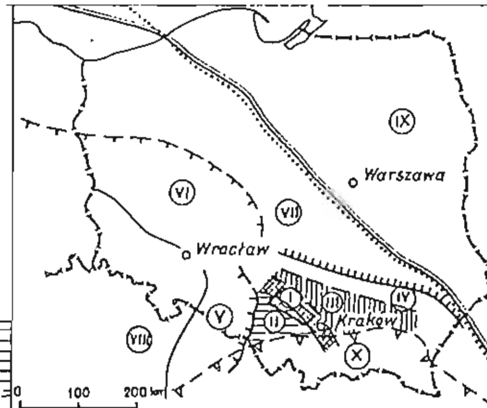
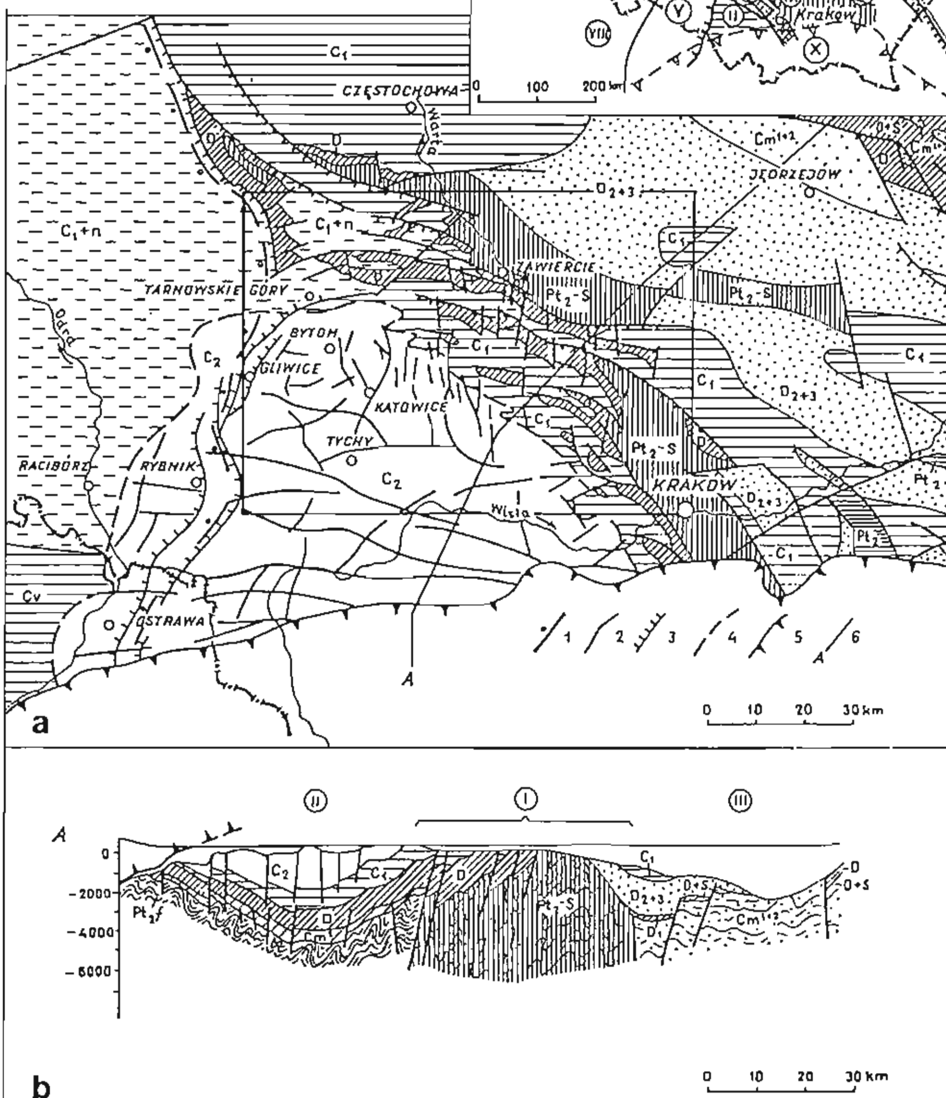

IX
Warszawa
VI
VII
Wrocław
I
II
III
IV
V
VIII
X
Kraków
0
100
200 km

Fig. 3


C1
CZĘSTOCHOWA
Warta
D
Cm1+2
O+S
JĘDRZEJÓW
D2+3
C1+n
ZAWIERCIE
Pt2-S
TARNOWSKIE GÓRY
BYTOM
GLIWICE
KATOWICE
TYCHY
C2
Odra
RACIBÓRZ
RYBNIK
KRAKÓW
Wisła
Pt2
Cv
OSTRAWA
A
1
2
3
4
5
6
0
10
20
30 km
a
II
I
III
0
-2000
-4000
-6000
Pt2f
Cm1
D+S
b

Caledonian stage suggested by certain scientists (e.g. C. Harańczyk, 1982), has been ambiguous (S. Bukowy, 1984).

Most of Early Paleozoic sediments have been altered under conditions ranging from advanced diagenesis to initial stages of regional metamorphism (W. Heflik et al., 1977; W. Ryka, 1978). Locally (e.g. in the vicinity of Myszków), the alterations took place in shallow and middle stages of the greenschist facies (*op. cit*). In general, Early Paleozoic sediments are represented by phyllitized metapelites, metaaleurites and metagreywackes (carbonate sediments have been found in Ordovician), bearing sings of intensive tectonic activity, boudinage, mylonitization, cleavage, cataclasis, brecciation and fissures of numerous generations (as described e.g. by S. Bukowy, 1984).

The Early Paleozoic deposits are discordantly overlaid by the Epicaledonian platform cover built of Devonian (mainly carbonate) and Lower Carboniferous sediments. Paleogeographic schemes of the mobile Devonian and Lower Carboniferous platforms are different (M. Narkiewicz, 1987; Z. Bełka, 1985).

In the Kraków — Myszków Zone, block-folded Variscan tectonics rebuilt and obliterated to a considerable degree the older structures of imperfectly consolidated Caledonian orogen (e. g. F. Ekiert, 1971; J. Znosko, 1974, 1984). In the deep-seated discontinuity zone bordering the Upper Silesian Coal Basin, the platform pattern of

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Fig. 2. Tectonic sketch map of Poland (after W. Pożaryski, 1982)

I — Kraków — Myszków Zone; II — Upper Silesian Massif; III — Małopolska Massif; IV — Kielce Zone; V — Moravia-Silesia Zone; VI — Late Variscan Fore-Sudetic Zone; VII — Epicaledonian platform zone; VIII — Bohemian Massif; IX — East-European Platform; X — Carpathians; the area under discussion marked by the rectangle

Szkic rejonizacji tektonicznej Polski (według W. Pożaryskiego, 1982)

I — strefa Krakowa — Myszkowa; II — masyw górnośląski; III — masyw małopolski; IV — strefa kielecka; V — strefa Morawo-Silezidów; VI — młodowaryscyjska strefa przedsudecka; VII — epikaledońska strefa platformowa; VIII — Masyw Czeski; IX — platforma wschodnioeuropejska; X — Karpaty; prostokątem zaznaczono omawiany obszar

Fig. 3. Pre-Permian geological map (a) and cross-section (b) of the Silesian-Cracow area (after W. Pożaryski, Z. Dembowski, 1984)

Pt_2, Pt_2f — Upper Proterozoic; Pt_2-S — Upper Proterozoic and Lower Paleozoic; Cm^1 — Lower Cambrian; Cm^{1+2} — Lower and Middle Cambrian; O+S — Ordovician and Silurian; D — Devonian; D_1 — Lower Devonian; D_{2+3} — Middle and Upper Devonian; C_1 — Lower Carboniferous (Dinant); C_1+ n — Lower Carboniferous and Namurian; Cv — Visean (and lowermost Namurian A); C_2 — Upper Carboniferous; 1 — margin of Variscan orogen; 2 — faults and dislocations; 3 — reversed faults and overthrusts; 4 — boundary of Upper Silesian Coal Basin; 5 — frontal Carpathian Overthrust; 6 — line of geological cross-section; I — Kraków — Myszków Zone; II — Upper Silesian Coal Basin (in the deeper basement — Upper Silesian Massif); III — Małopolska Massif; the area under discussion marked by the rectangle

Mapa geologiczna (a) i przekrój (b) przedpermskiego podłoża obszaru śląsko-krakowskiego (według W. Pożaryskiego i Z. Dembowskiego, 1984)

Pt_2, Pt_2f — proterozoik górny; Pt_2-S — proterozoik górny i paleozoik dolny; Cm^1 — kambr dolny; Cm^{1+2} — kambr dolny i środkowy; O+S — ordowik i sylur; D — dewon; D_1 — dewon dolny; D_{2+3} — dewon środkowy i górny; C_1 — karbon dolny (dinant); C_1+n — karbon dolny i namur; Cv — wizen (łącznie z najniższym namurem A); C_2 — karbon górny; 1 — granica orogenu waryscyjskiego; 2 — uskoki i dyslokacje; 3 — uskoki odwrócone i nasunięcia; 4 — granica Górnośląskiego Zagłębia Węglowego; 5 — czołowe nasunięcie karpackie; 6 — linia przekroju geologicznego; I — strefa Krakowa — Myszkowa; II — Górnośląskie Zagłębie Węglowe (w głębszym podłożu — masyw górnośląski); III — masyw małopolski; prostokątem zaznaczono omawiany obszar

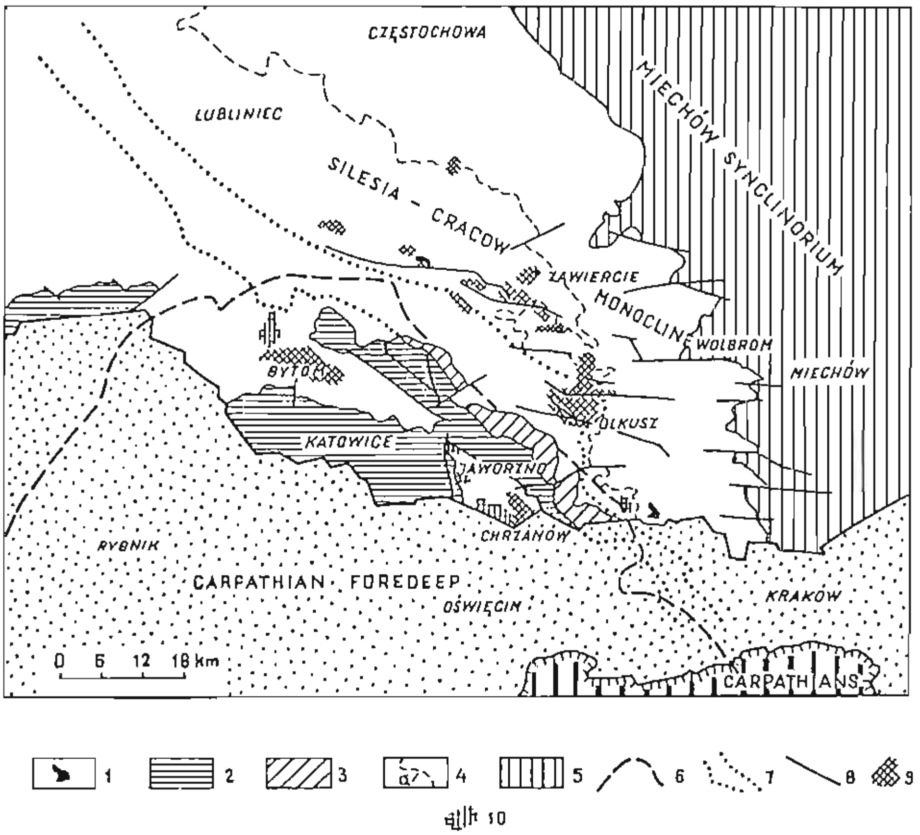

Fig. 4. Distribution of main Zn-Pb deposits in the Silesian-Cracow area (geology after S. Bukowy, 1974; Zn-Pb deposits by the author)

1 — Devonian; 2 — Carboniferous; 3 — Permian; 4 — Triassic and Jurassic (a — Jurassic boundary); 5 — Cretaceous; 6 — boundary of Upper Silesian Coal Basin; 7 — extent of Permian graben; 8 — dislocations; 9 — Zn-Pb deposits (proved and mined); 10 — Zn-Pb deposits totally exhausted

Położenie głównych złóż Zn-Pb na obszarze śląsko-krakowskim (geologia według S. Bukowego, 1974; złoża Zn-Pb według autorki)

1 — dewon; 2 — karbon; 3 — perm; 4 — trias i jura (a — zasięg występowania jury); 5 — kreda; 6 — granica Górnośląskiego Zagłębia Węglowego; 7 — zasięg występowania permskiej struktury rowowej; 8 — dyslokacje; 9 — złoża Zn-Pb (udokumentowane i eksploatowane); 10 — złoża Zn-Pb całkowicie wyeksploatowane

the Late Variscan tectonics, represented by a fold or brachyfold system, has been recently evidenced by K. Bogacz (1980) and by W. Bogacz and J. Krokowski (1981). Those folds of the prevailing strike close to a parallel of latitude (Figs. 3a and 6; cf. also A. Morawska, 1985), were cut by faults along the fold axes and shifted by transversal faults. Anticlines were formed of Devonian and Lower Carboniferous rocks and synclines of Lower Carboniferous ones. Upper Carboniferous, mainly Namurian sediments, occur locally in depressed structures. Moreover, the morphology, extension and tectonics of the discussed Variscan structures are also legible in the residual gravimetric anomalies (Fig. 7; see also H. Kurbiel, 1978). Regional analysis of the deep tectonics and of the magnetic anomalies (Fig. 8) allows to link the basic features of tectonics of the described discontinuity zone with the influence of the right strike-slip movements in the deep basement (J. Bednarek, 1978; K. Bogacz, 1980; W. Bogacz, J. Krokowski, 1981; A. Kotas, 1982).

Similar style of the Variscan tectonics, i.e. generally longitudinal and latitudinal orientation of the important folded structures, consisting of flat elevations and depressions cut by the faults network, is observable in the central and eastern parts of the Upper Silesian Coal Basin (Figs. 3a and 6; S. Siedlecki, 1954; E. Herbich, 1981). One may distinguish the Chrzanów and Bytom synclines with the W–E striking axes (S. Siedlecki, 1954). The Main Anticline borders the southern side of the Bytom Syncline. Echelon-oriented domes of this anticline are interpreted by E. Herbich (1981) as a result of the left strike-slip movement of the deep basement (the Upper Silesian deep fracture; see Figs. 6, 7 and 8). On this basis A. Kotas (1982) suggested the relative eastward movement of the central part of the Upper Silesian Basin basement. The distribution pattern of the Variscan structures in the described area, and especially their breakdown at the Katowice — Olkusz line (Figs. 6 and 8), seems to confirm this hypothesis. Moreover, the faults and fault zones distinguished in the Paleozoic basement are not exclusively of Variscan age, but they were in many cases rejuvenated in the Alpine tectonic epoch. The western part of the Upper Silesian Basin was affected in the Variscan epoch by the fold tectonics, subordinated to the Moravian–Silesian (NNE–SSW) direction and eastern vergence.

The rocks of the both Paleozoic stages are cut by intrusions of magmatic rocks, especially in the vicinities of Myszków, Zawiercie, Pilica and Krzeszowice (Fig. 6). Magmatic phenomena are connected with the local, linear or circular magnetic anomalies (Fig. 8). Linear anomalies indicate fissure intrusion forms (H. Kurbiel, 1978). One should mention that in the whole characterized area the similar ΔZ direction is marked (NW–SE), which changes to W–E westward of Myszków. The anomaly of Tychy, occurring in the SW part of the area, is caused by deep-seated crystalline rocks of the Upper Silesian Massif.

The magmatic rocks represent petrographically differentiated rocks complex of various age. Till now, an unambiguous relation has not been found between the rock types and age sequences. In general, magmatic rocks consist of gabbro, diabases, lamprophyres and following granitoids: rhyodacite and dacite porphyries, albitophyres, microgranites and microgranodiorites (T. Wieser, 1957; O. Juskowiak et al., 1978; C. Harańczyk, 1979; E. Górecka, A. Nowakowski, 1979; J. Ślósarz, Ł. Karwowski, 1983). Acid magmatic rocks prevail, forming usually subvolcanic dykes and granodiorite stocks. Magmatic formations are attributed to different ages as well as to numerous phases diastrophic cycles. According to prevailing opinions, however, the acid intrusions have developed with in the platform, in zones of extensive tectonic activity. The most intensive tectonic movements, that caused deep faulting, took place during the last two Variscan phases (Asturian and Saalian). The K–Ar geochronological examinations of granitoids of the Myszków area yielded the result of about 300 mln years (K. Jarmołowicz-Szulc, 1985).

The acid intrusions are surrounded by zones of contact metamorphosed rocks of various thickness. They are represented mainly by magnesium and calcium exoskarns (C. Harańczyk, 1979, 1988; E. Górecka, A. Nowakowski, 1979).

Magmatic rocks are usually hydrothermally altered. Predominantly they have undergone albitization, sericitization, silicification, carbonatization, chloritization and potassium metasomatosis. Alterations of the biotitization, propylitization and argillitization type are less common. All the above mentioned types of alterations have also been found within the wall-rocks where they recurrently reveal their character of near-ore alterations, e.g. zonally developed aureoles of alterations around mineralized veins (*op. cit.*).

Acid magmatism is associated with Cu-Mo-W porphyry-type mineralization (C. Harańczyk, 1979; E. Górecka, A. Nowakowski, 1979; J. Ślósarz, Ł. Karwowski, 1983; J. Ślósarz, 1988; Ł. Karwowski, 1988). Usually they formed minute mineralization, the only larger ore deposit type accumulation has been documented only in the Myszków area (Fig. 6; K. Piekarski, 1985, 1988). Due to uncertain magmatism age, which is interpreted by various modes, also the age of postmagmatic processes, leading to the formation of ores, is often controversial. Moreover, an important role was played by fault tectonics which have developed in several stages. The systems of hydrothermal veins healed complicated systems of fissures and dislocations cutting magmatic bodies and Paleozoic sediments.

Terrestrial Lower Permian sediments (conglomerates, sandstones, clays), associated with volcanics (diabases, porphyries, melaphyres and their tuffs), occur in a narrow tectonic zone, bordering the north-eastern side of the Upper Silesian Coal Basin (Figs. 4–6; A. Siedlecka, 1964). Tectonic movements distinctly marked in Lower Permian, led to the formation of grabens and horsts (S. Bukowy, 1984; H. Kiersnowski, A. Maliszewska, 1985). In Upper Carboniferous and Permian time erosion removed a significant part the Paleozoic rocks, reaching Lower Paleozoic sediments. On the uneven surface of the Paleozoic platforms karst processes developed (e.g. S. Kurek, 1988).

ALPINE TECTONIC EPOCH

In the Silesian-Cracow area the Mesozoic formations, together with the Permian ones, build a cover stage (Fig. 5). Denudation of Variscides lasted till Roethian (locally till Muschelkalk) when in the whole Silesian-Cracow area the epicontinental sediments of uniform facial development formed (S. Śliwiński, 1969; J. Wyczółkowski, 1982). Sediments of the cover, mainly carbonates, are mostly of Triassic and Jurassic age; the Cretaceous and Miocene sediments occur locally in grabens and morphological depressions (Figs. 4, 9).

The authors considering the structural evolution of the cover stage (recently J. Krokowski, 1984) distinguish two tectonic cycles: Early Alpine (Cimmerian-Laramide) and Late Alpine (Tertiary). These cycles have different structural patterns.

The influence of the Early Cimmerian Phase on the spatial position of the Triassic and Jurassic beds is not fully elucidated. One indicates the discordance existing

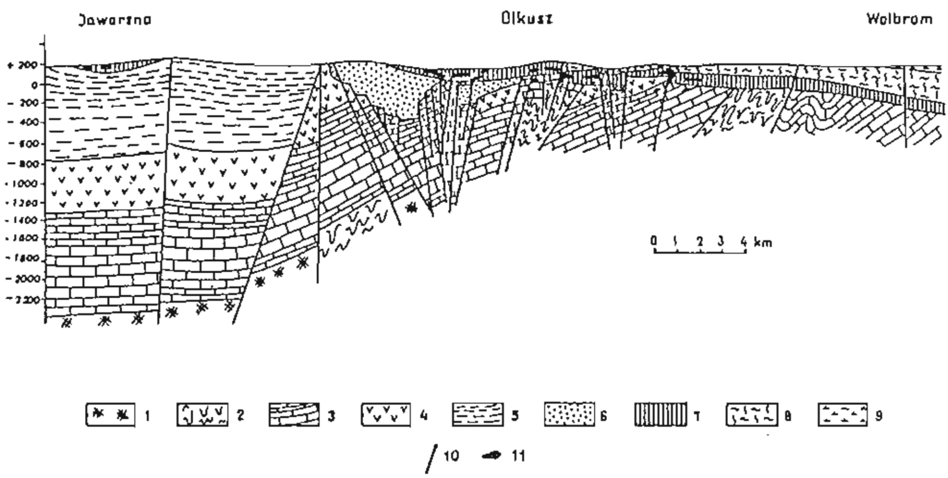

Fig. 5. Geological cross-section (geology after S. Bukowy *fide* A. Różkowski et al., 1979)

1 — Precambrian; 2 — Early Palezoic; 3 — Devonian; 4 — Lower Carbouiferous; 5 — Upper Carboniferous; 6 — Permian; 7 — Triassic; 8 — Jurassic; 9 — Cretaceous; 10 — faults; 11 — Zn-Pb deposits marked schematically by the author

Przekrój geologiczny (geologia według S. Bukowego *fide* A. Różkowski i in., 1979)

1 — prekambr; 2 — starszy paleozoik; 3 — dewon; 4 — karbon dolny; 5 — karbon górny; 6 — perm; 7 — trias; 8 — jura; 9 — kreda; 10 — uskoki; 11 — złoża Zn-Pb zaznaczone schematycznie przez autorkę

between Triassic and Jurassic sediments and a significant vertical mobility of the Silesian-Cracow area after the Muschelkalk sediments formation (W. Bilan, 1976). Generally one accepts that due to the Early Cimmerian Phase movements, the Triassic cover underwent large-size distortions and insignificant disjunctive deformations. Probably flat folds and small faults formed then, as well as rarer flexural, dislocation-adjacent deformations of the Triassic sediments. The directions of the Early Cimmerian dislocations frequently followed the tectonic directions of the Paleozoic basement.

During the Late Cimmerian Phase, the Silesian-Cracow Monocline, generally inclined to NE started to form, definitely obtained its present shape during the very intensive activity of the Laramide Phase (W. Burzewski, 1969; J. Kutek, J. Głazek, 1972). After J. Krokowski (1984), in the pattern of the Early Alpine tectonic cycle, the direction NW-SE to NNW-SSE (the so-called central Polish direction) was the longitudinal one of the regional importance, along which there also occurred the right strike-slip movements. The Laramide movements had most probably an essential influence on the joint fissures opening and formation of the NW-SE and NE-SW as well as NNW-SSE and NNE-SSW fault systems, and, to lesser degree, on the fault system oriented approximately to parallel of latitude i.e. WNW-ESE (*op. cit.*).

Due to the Tertiary tectonic movements, connected with the formation of Flysch Carpathians and their foredeep, a significant rearrangement of the Cimmerian-Laramide structures took place (S. Dżułyński, 1953; K. Bogacz, 1967; J. Krokowski, 1984;

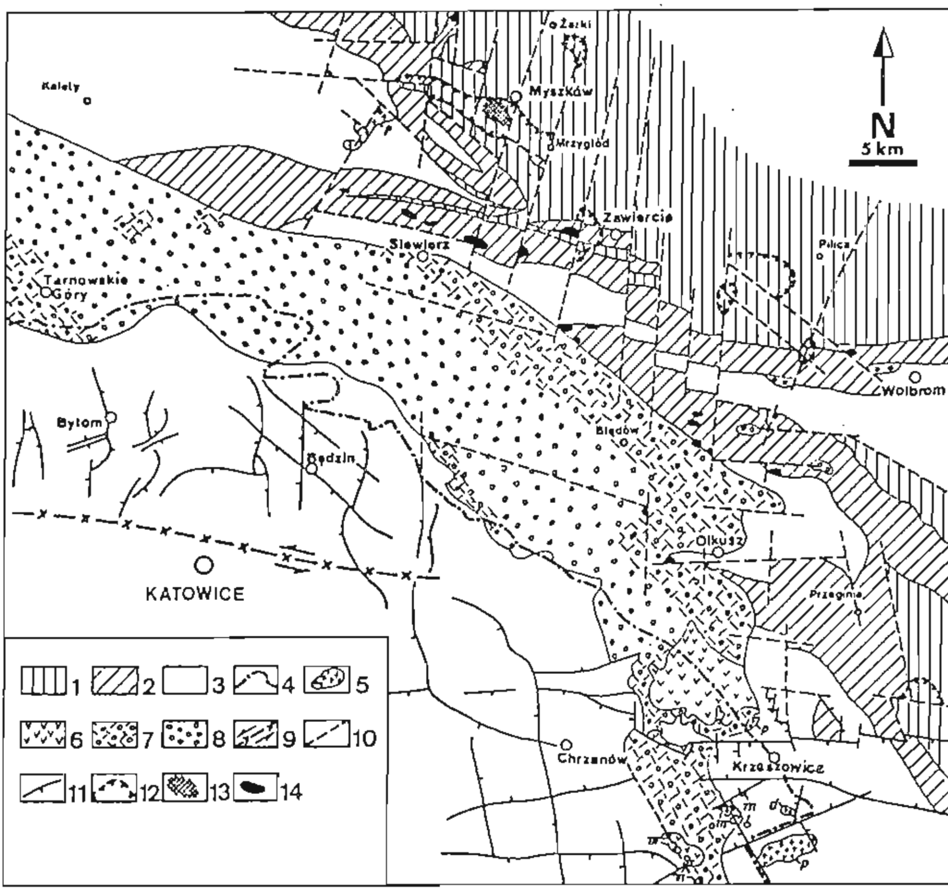

Fig. 6. Occurrences of ore mineralization in the Paleozoic basement of the Silesian-Cracow area (based on the unpublished reports and publications: A. Siedleeka, 1964; F. Ekiert, 1971; E. Górecka, 1972; S. Rulski, 1973; H. Kurbiel, 1978; J. Bednarek, 1978; C. Harańczyk, 1979; E. Herbich, 1981; S. Bukowy, 1984; K. Piekarski, 1985; S. Kurek, 1988)

1 — Early Paleozoic; 2 — Devonian; 3 — Carboniferous; 4 — boundary of Upper Coal Basin; 5-8 — Upper Carboniferous — Lower Permian: 5 — intrusive and effusive rocks (p — porphyry, d — diabase, m — melaphyre), 6 — tuffs, 7 — areas of predominance of porphyry-carbonate and porphyry-tuffaceous conglomerates, 8 — areas of predominance of carbonate conglomerates (locally sandstones and clayey-carbonate-sandy sediments); 9 — Upper Silesian deep fracture;10 — presumed dislocation zones; 11 — faults; 12 — inferred boundaries of polymetallic mineralization found in boreholes; 13 — Cu-Mo-W deposit (proved); 14 — Zn-Pb mineralization found in boreholes (few deposits are proved)

Wystąpienia mineralizacji kruszcowej w podłożu paleozoicznym obszaru śląsko-krakowskiego (na podstawie materiałów archiwalnych i publikowanych: A. Siedlecka, 1964: F. Ekiert, 1971; E. Górecka, 1972; S. Rulski, 1973; H. Kurbiel, 1978; J. Bednarek, 1978; C. Harańczyk, 1979; E. Herbich, 1981; S. Bukowy, 1984; K. Piekarski, 1985; S. Kurek, 1988)

1 — starszy paleozoik; 2 — dewon; 3 — karbon; 4 — granica Górnośląskiego Zagłębia Węglowego; 5-8 — karbon górny — perm dolny: 5 — skały intruzywne i efuzywne (p — porfir, d — diabaz, m — melafir), 6 — tufy, 7 — obszary z przewagą zlepieńców porfirowo-węglanowych i porfirowo-tufowych, 8 — obszary z przewagą zlepieńców węglanowych (lokalnie piaskowce i osady ilasto-węglanowo-piaszczyste); 9 — rozłam

J. Bednarek et. al., 1985). At that time tension and significant vertical mobility of the area played an important part. Dense fault network, striking parallelly to latitude and longitude, resulted in blocky character of this area, where large blocks were broken into lower rank blocky units. The blocks borders were the places of a high concentration of tectonic displacements. Commonly, the influence of the basement dislocations on the overlying beds deformations and the propagation of the older disjunctive structures from the basement upwards, are indicated.

In this context one may distinguish the main dislocation zone extending from Krzeszowice to Bytom (the so-called Cracow — Będzin Zone) which, west of Krzeszowice, in the area of the Upper Silesian Basin, changes its strike from W–E to NW–SE (Fig. 9; see also K. Bogacz, 1967). To southwest of this zone occur Chrzanów, Jaworzno and Bytom troughs (synclines?) filled with Triassic sediments. Their Variscan pre- -foundation was proved by S. Siedlecki (1954). The second tectonic zone of Paleozoic pre-foundation with similar strike was found along the line: Kolbark (WSW of Wolbrom) — Siewierz (J. Bednarek et al., 1985). To the north of Olkusz, this zone crosses with the Jurassic cuesta which is assumed to be a tectonic zone parallel to latitude, coinciding with the belt of right strike-slip faults in sub-Mesozoic basement (*op. cit.*).

The overlapping of the subsequent structural patterns caused, that the most legible and densiest dislocation network (frequently of the antithetic and pivotal types) in the Mesozoic cover is usually connected with the Tertiary movements. The dip-slip faults and oblique-slip faults prevail, frequently with associated flexural deformations. These faults form the presently observed system of horsts and grabens (e. g. the Krzeszowice Graben; Fig. 9).

DISTRIBUTION AND FORM OF THE Zn-Pb DEPOSITS

The main deposits occur in the area between Bytom, Chrzanów Olkusz and Zawiercie (Figs. 4, 9). In this area of more than 2000 square kilometres, there are two economically significant mining regions: Olkusz and Chrzanów. The rich Bytom deposits and other shown on the Fig. 9, are presently exhausted. Exploratory works have resulted in the discovery of several new Zn-Pb deposits in the Silesian-Cracow district, mainly in the Olkusz — Zawiercie — Siewierz area.

The extent of ore mineralization in the vertical profile is related to the geological structure (*vide* S. Przeniosło, 1976; E. Górecka, 1972, 1973; C. Harańczyk, 1979; T. Gałkiewicz, 1983; T. Gałkiewicz, S. Śliwiński, 1985). It is larger (Devonian-Jurassic) in the areas where the basement is built of pre-Triassic elevations of Devonian and Lower Carboniferous carbonate sediments, buried under the Mesozoic cover (Olkusz and Zawiercie regions), and smaller (mainly Lower Muschelkalk) in places where the

górnośląski; 10 — przypuszczalne strefy dyslokacyjne; 11 — uskoki; 12 — prawdopodobne granice zasięgu występowania mineralizacji polimetalicznej stwierdzonej wierceniami; 13 — złoże Cu-Mo-W (udokumentowane); 14 — mineralizacja Zn-Pb stwierdzona wierceniami (kilka złóż udokumentowano)

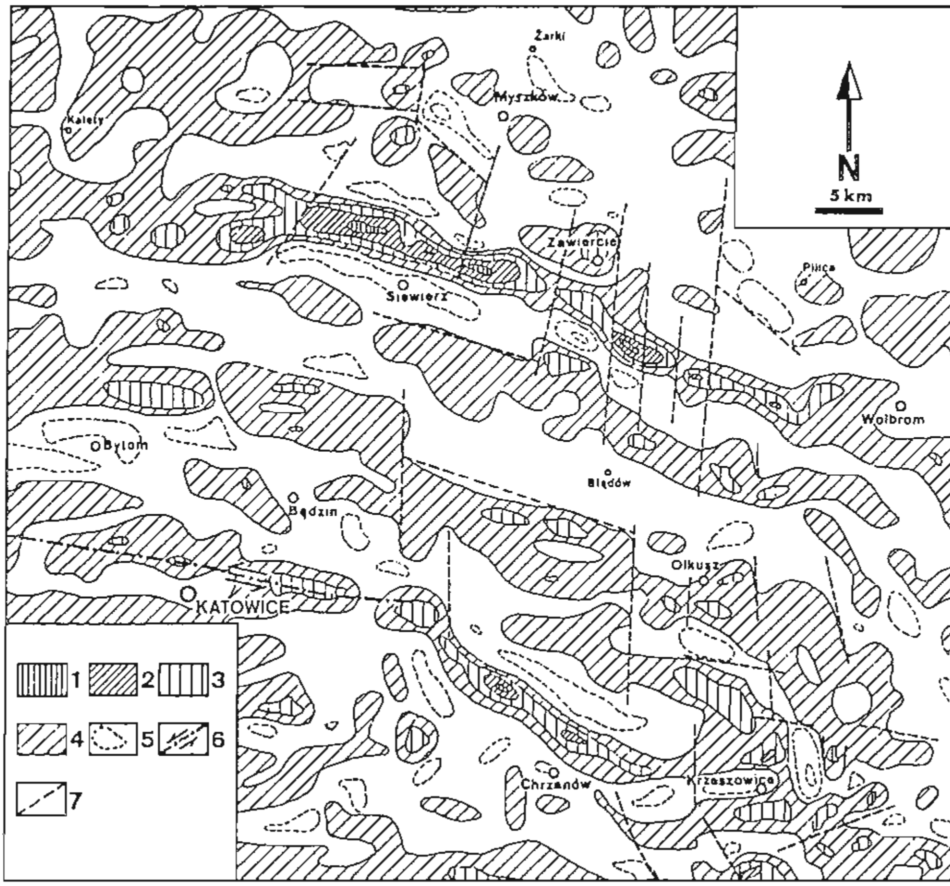

Fig. 7. Map of residual gravity anomalies (after H. Kurbiel, 1978; after J. Grzywacz's map)

Areas with values: 1 — 3-4 mGal, 2 — 2-3 mGal, 3 — 1-2 mGal, 4 — 0-1 mGal; 5 — areas with negative residual anomalies; 6 — Upper Silesian deep fracture (after E. Herbich, 1981); 7 — presumed dislocation zones (as interpreted by the author)

Mapa rezydualnych anomalii grawimetrycznych (według H. Kurbiela, 1978; na podstawie mapy J. Grzywacza)

Obszary o wartościach: 1 — 3-4 mGal, 2 — 2-3 mGal, 3 — 1-2 mGal, 4 — 0-1 mGal; 5 — obszary rezydualnych anomalii ujemnych; 6 — rozłam górnośląski (według E. Herbicb, 1981); 7 — przypuszczalne strefy dyslokacyjne (w interpretacji autorki)

basement of Triassic consists of Carboniferous and Permian clayey-sandstone and conglomerate sediments (Chrzanów and Bytom regions), as drawn in the Figs. 4-6, 9. The vertical extent of mineralization varies from several tens of eentimetres up to several tens of metres. Locally, where the ores occur also in the Paleozoic basement, the vertical extent of mineralization is even up to a few hundred metres, e.g. in the Olkusz region (E. Górecka, 1991).

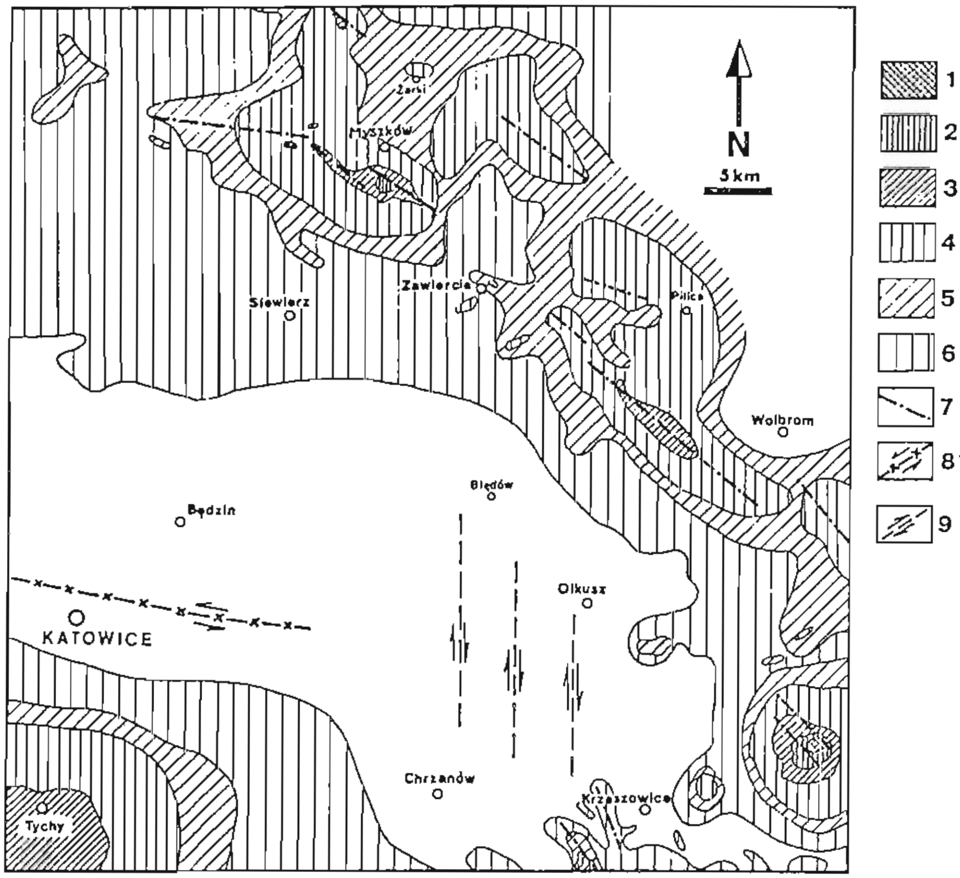

Fig. 8. Map of magnetic anomalies ΔZ (for epoch 1950,5) after H. Kurbiel (1978)

Areas with values: 1 — >400 gammas, 2 — 300-400 gammas, 3 — 200-300 gammas, 4 — 100-200 gammas, 5 — 60-100 gammas, 6 — 0-60 gammas; 7 — zones of maximum ΔZ values; 8 — Upper Silesian deep fracture (after E. Herbich, 1981); 9 — possible displacements in the strike-slip faults zone (as interpreted by the author)

Mapa anomalii magnetycznych ΔZ (dla epoki 1950,5) według H. Kurbiela (1978)

Obszary o wartościach: 1 —> 400 gamma, 2 — 300-400 gamma, 3 — 200-300 gamma, 4 — 100-200 gamma, 5 — 60-100 gamma, 6 — 0-60 gamma; 7 — strefy maksymalnych wartości ΔZ ; 8 — rozłam górnośląski (według E. Herbich, 1981); 9 — możliwe przemieszczenia w strefie uskoków przesuwczych (w interpretacji autorki)

Most of the Zn-Pb ores (about 92% of the ores, as estimated by T. Gałkiewicz, 1983) are hosted by carbonate rocks of the Lower Muschelkalk (lower Middle Triassic). The economically important ore regions are located in this unit. As a rule, considerable amounts of the ores are concentrated within the epigenetic dolomites, the so-called ore-bearing dolomites, which concentrate about 85% of the ores (*op. cit.*).

Besides the Zn–Pb deposits occur locally in the Roethian (uppermost Lower Triassic) dolomites (mined in the Bolesław mine), in Diplopora Dolomite of Middle Muschelkalk, and in the Middle to Late Paleozoic carbonates, mostly of the Devonian age (about 4% of the ores). Rarely Zn–Pb mineralization is found in the sediments of Upper Muschelkalk and Keuper (Upper Triassic), Jurassic, Permian and even in the Early Paleozoic rocks. However, in the Olkusz region, relatively large ore bodies, mainly FeS_2, were found and exploited in Upper Jurassic beds (Fig. 9; C. Kuźniar, 1925),

While generally similar, nevertheless different ore regions are characterized by their tectonics, spatial distribution of the ore-bearing dolomites, and ore mineralization, as well as by forms, macrostructures and mineral composition of the ores.

The forms of the ore bodies are very complicated. In the Mesozoic cover the deposits are tabular in shape. They consist of metasomatic, dispersed ores and cavity-filling (crusted, veiny, drusy and breccia) ores. The mineralized zones do not correspond to the stratigraphic levels. The rich ore bodies are generally located in the lower part of the ore-bearing dolomites. The epigenetic ore-bearing dolomites developed more or less horizontally over a large area where they replaced, partly or totally, Lower Muschelkalk rocks, mainly Gorażdże, Terebratula and Karchowice beds, represented originally by limestones and early diagenetic dolomites. The ore-bearing dolomites are crystalline, compact or microporous, often cavernous and cracked (e.g. K. Bogacz et al., 1975). This „stratoidal" deposit type of different thickness, from few metres to several tens of metres, discontinuously extend at the length of even several kilometres.

The scientists have been paying much attention to ore-bearing dolomite breccias with sulfide cement of karst origin and they accepted the view that hydrothermal karst processes were the main formation factor of the examined deposits (K. Bogacz et al., 1970; S. Dżułyński, M. Sass-Gustkiewicz, 1985; M. Sass-Gustkiewicz, 1985). According to these authors, the hydrothermal fluids penetrated through the rocks in several pulses. Underground karst deposits developed mainly in the contact zone of the ore-bearing dolomites with Gogolin Limestones (lowermost Lower Muschelkalk); they have the shapes of channels, cracks widened by karst, interlayer joints or residual clays. There are deposits accompanied by broad zones of breccia, formed as a result of collapse of karst chambers or by fissures created due a heterogeneous subsidence of rocks over collapsing chambers. The three types of sulfide deposits can be observed: the metasomatic ores, the initial karst deposits and the mature underground karst deposits. Each of them is characterized by specific ore structures (M. Sass-Gustkiewicz, 1985).

Other mineralization forms, such as different size ore stocks, nests, veins, are discordant to the lamination of rock complexes. The distribution of ore mineralization is controlled by joints. Ore bodies of this type were better recognized in mines where they occur both in Muschelkalk and in Roethian beds (e.g. M. Nieć, 1980).

Lately, the studies of mutual relations between tectonic effects and ore mineralization in the Mesozoic and Paleozoic beds have been observed (S. Kibitlewski, E. Górecka, 1988; E. Górecka, 1991; E. Górecka et al., 1991). Small-to-middle scale

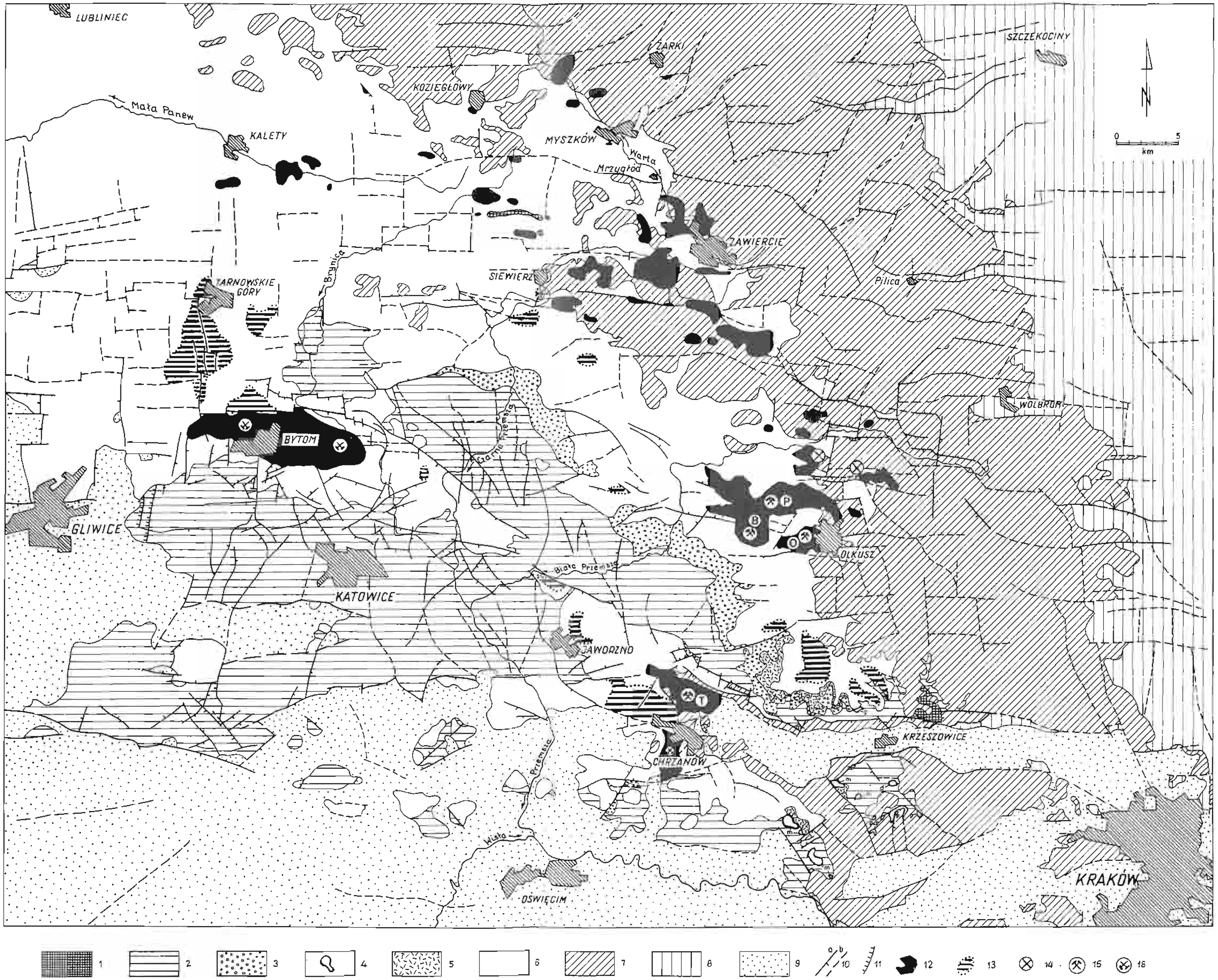

Fig. 9. Map of distribution of Zn–Pb deposits in the Silesian–Cracow area (geology after S. Kotlicki, 1977 and H. Kaziuk, 1978, completed on the basis of the map by J. Bednarek et al., 1985; Zn–Pb deposits by the author)

1 — Devonian; 2 — Carboniferous; 3–5 — Permian: 3 — conglomerates, 4 — volcanics (p — porphyries, d — diabases, m — melaphyres), 5 — tuffs; 6 — Triassic; 7 — Jurassic; 8 — Cretaceous; 9 — Tertiary; 10 — faults (a — found, b — inferred); 11 — overthrusts; 12 — Zn–Pb deposits (proved and mined); 13 — Zn–Pb deposits totally exhausted; 14 — ore deposits (mainly iron sulfides; exhausted) in the Jurassic rocks; 15, 16 — mines working and closed: P — Pomorzany, B — Bolesław, O — Olkusz, T — Trzebionka

Mapa rozmieszczenia złóż Zn–Pb w obszarze śląsko-krakowskim (geologia według S. Kotlickiego, 1977 i H. Kaziuk, 1978, uzupełniona na podstawie mapy J. Bednarka i in., 1985; złoża Zn–Pb według autorki)

1 — dewon; 2 — karbon; 3–5 perm: 3 — zlepieńce, 4 — skały wulkaniczne (p — porfiry, d — diabazy, m — melafiry), 5 — tufy; 6 — trias; 7 — jura; 8 — kreda; 9 — trzeciorzęd; 10 — uskoki (a — stwierdzone, b — przypuszczalne); 11 — nasunięcia; 12 — złoża Zn–Pb (udokumentowane i eksploatowane); 13 — złoża Zn–Pb całkowicie wyeksploatowane; 14 — złoża kruszcowe (głównie siarczki żelaza, wyeksploatowane) w skałach jurajskich; 15, 16 — kopalnie czynne i nieczynne: P — Pomorzany, B — Bolesław, O — Olkusz, T — Trzebionka

tectonic structures (i.e. small faults, flexures, joints, slickensides, minor folds) revealed the existence of block-faulting, deep-seated pattern as a main control factor of the deposit development. These problems are discussed in a number of papers included into this volume.

In the Upper Paleozoic carbonate sediments, the ore bodies are often located directly below the Triassic cover, sometimes building continuous ore bodies together with the ores from the Triassic cover (Fig. 5; E. Górecka, 1991). Several small and middle size ore bodies have been explored in the Olkusz — Zawiercie — Siewierz area (Fig. 6; S. Kurek, 1988, 1991). These ore „nests" are usually distinguished by a limited horizontal distribution and by relatively larger vertical one. The ore bodies are commonly associated with faults (S. Przeniosło, 1976; C. Harańczyk, 1979; E. Górecka, 1991). A connection between the morphology of the Paleozoic basement and occurrence of Zn-Pb ores in ore-bearing dolomites of Lower Muschelkalk, suggested by certain investigators (e.g. F. Ekiert, 1971; S. Kurek, 1988), was not currently confirmed. These occurrences have similar mineral parageneses to the ores in Mesozoic beds, and may represent conduits of the ore fluids migration.

FINAL REMARKS

Regional analysis of the geological setting of the Silesian-Cracow deposits of Zn-Pb ores may yield to several general conclusions:

1. Distribution of the Zn-Pb deposits subordinates to the Variscan (and older) and Alpine tectonic patterns of the discussed area. The richest Zn-Pb deposits occur within the regional deep-seated discontinuity zone, bordering the NE margin of the Upper Silesian Massif. The Permian graben structure, associated with magmatic phenomena, is a marker of this zone. On the both sides of this graben structure, in the Mesozoic cover, there are concentrated the richest Zn-Pb deposits. Thus, one may suppose that the above mentioned deep disjunctive zone was active to various degree during several tectonic cycles.

2. In the Mesozoic cover, the main dislocation zones of the generally meridional and parallel (changing their direction to NW) to latitude strike were the places of special preference to concentration of the ores; at least the first dislocations were faults of the strike-slip type, developed on the older tectonic foundations. The places of crossing of these zones are most preferred as Zn-Pb ore mineralization sites, e. g. the Olkusz ore district. The Zn-Pb deposits, occurring in Triassic sediment troughs (the Chrzanów, Jaworzno and Bytom ore districts), are located also in the immediate neighbourhood of the Cracow-Będzin main dislocation zone. One may observe that the largest vertical extent of ore mineralization, achieving Paleozoic beds, occurs closely to the deep dislocations rejuvenated several times in Alpine epoch. Accepting the idea of the hydrothermal (telethermal origin of the Silesian-Cracow Zn-Pb deposits, one should also accept that the Zn-Pb ores in Paleozoic host rocks are the root parts of these deposits. This may be evidenced by similarities in mineral parageneses compositions and spatial distribution of the deposits in the Mesozoic and Paleozoic beds.

3. The connection was found in the Mesozoic cover between intensity of the ore mineralization process at a given area and the intensity of tectonic phenomena, like small faults, cracks, cataclasis and breccias. The larger ore concentrations occur in the downthrown sides of faults and in graben structures. One may suppose that the development of the graben structures was connected with a network of ledge faults, active in the basement.

4. The above considerations lead to the conclusion that polyphase, pulsating development of the ore mineralization (mineral parageneses) was caused by a sequence of tectonic impulses. The important problem of the ore sequence should be considered on the background of all possible migration paths of the ore-forming solutions, including also tectonic conduits. A supposition appears that already during karst development, in connection with the ore-forming solutions activity and probably also during dolomitization, there existed regular fracture systems or their foundations, causing easier penetration of the rock massif by the mineralizing solutions. Direction or directions of the ore-forming solutions are not clear. One cannot exclude that these processes were conneeted with the forming of Carpathians. Studies of these problems have already begun and they will be subjects of separate elaborations.

5. The tectonic factor in the Zn–Pb deposits formation in the Silesian–Cracow area can be of practical importance for prospecting and for the further exploitation of ore.

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POZYCJA GEOLOGICZNA ŚLĄSKO-KRAKOWSKICH ZŁÓŻ Zn-Pb

Streszczenie

Rozmieszczenie złóż Zn-Pb przystosowuje się do waryscyjskiego (i starszego) oraz alpejskiego planu tektonicznego obszaru śląsko-krakowskiego. Najbogatsze złoża są zlokalizowane w obrębie regionalnej strefy rozłamowej, ograniczającej od NE masyw górnośląski (fig. 1, 2). Wyznacznikiem tej strefy, wśród struktur późnowaryscyjskich, jest permska struktura rowowa, której towarzyszą zjawiska magmowe (fig. 6). Po obu stronach tej struktury — w pokrywie mezozoicznej — występują najbogatsze złoża Zn-Pb (fig. 4, 9). Można więc domniemywać, iż wspomniana strefa rozłamu wgłębnego była aktywna w różnym stopniu przez kilka cykli tektonicznych.

W pokrywie mezozoicznej szczególnie uprzywilejowane dla koncentracji kruszców są walne strefy dyslokacyjne o ogólnym przebiegu południkowym (okołopołudnikowe) i równoleżnikowym (skręcające na NW), z których przynajmniej te pierwsze były przez dłuższy czas dyslokacjami typu przesuwczego, opartymi na starszych założeniach tektonicznych. Miejsca krzyżowania się tych stref są najbardziej uprzywilejowane dla koncentracji kruszców Zn-Pb. W pobliżu dyslokacji głębiej zakorzenionych i kilkakrotnie odmładzanych w epoce alpejskiej występuje największy pionowy zasięg okruszcowania, sięgający paleozoiku.

W świetle przeprowadzonej analizy regionalnej uzasadniony jest pogląd, reprezentowany przez większość badaczy, o wielofazowym (pulsacyjnym) rozwoju mineralizacji Zn-Pb w obszarze śląsko-krakowskim.