POLSKA AKADEMIA NAUK · KOMITET NAUK GEOLOGICZNYCH

PAŃSTWOWE WYDAWNICTWO NAUKOWE . WARSZAWA

acta geologica polonica

Vol. 36, No. 1-3 Warszawa 1986

STANISŁAW SPECZIK, CZESŁAW SKOWRONEK,
GÜNTHER FRIEDRICH, RALF DIEDEL,
CLAUS SCHUMACHER & FRANZ-PETER SCHMIDT

The environment of generation of some base metal Zechstein occurrences in Central Europe

ABSTRACT: The observed differences in the petrographical, mineralogical and geochemical character of base metal Zechstein occurrences in Central Europe resulted from different geological environment of generation. The main processes, leading to the ultimate ore deposits formation, including preconcentration of base metals during the Late Variscan, transport in oxidized solution, and precipitation at the interface with euxinic environment, were generally the same. Different ore composition in particular occurrences corresponds to other geochemical characteristics of intimately associated basement. At least two provenance sources of metal, with other tenor and geochemical composition were active during the Lower Zechstein time. The first source is due to the metallogenic evolution of Caledono-Variscan basement, the second is related to prolonged oxidation and leaching of base metals from red Rotliegendes molasse.

INTRODUCTION

The Kupferschiefer occurrences of Central Europe are generally thought to be of the same origin. However, individual authors principally emphasize other aspects of their origin basing on their own experiences from limited areas. Therefore, several different theories have been proposed to explain the origin of Kupferschiefer mineralization despite the numerous similarities between them. All those genetic theories are extensively contrasted and elaborated by RYDZEWSKI (1976), NIŚKIEWICZ (1980), and RENTZSCH (1981). Up till now, only several comparative studies concerning the Kupferschiefer occurrences of Central Europe have been published. The Central European Kupferschiefer and

African copperbelt deposits are contrasted and discussed by GARLIC (1961) and RENTZSCH (1974), while the similarities and differences between Polish and U.S. Midcontinent stratiform occurrences are studied by BERENDSEN & SPECZIK (1986). Yet, no one comparative study has been presented with respect to European occurrences themselves.

GEOLOGICAL OVERVIEW

The geological data collected so far, were gathered in regions known to have high metal concentrations or to be intimately associated with operating mines. Information concerning the entire Kupferschiefer horizon, sub-economic or low metal concentrations, is relatively scarce. Geological exploration and related studies recently conducted in BRD by the Federal Institue for Geosciences and Natural Resources, the St. Joe Explorations, Hannover, and the Institut für Mineralogie and Lagerstättenlehre, RWTH Aachen, helped to fill, to some extent at least, the mentioned gap in our knowledge about Kupferschiefer mineralization and allowed to present this study.

Based upon generalized representative profiles of nine occurrences, their main similarities and differences will be discussed. The profiles are situated along the southern rim of the Zechstein basin, that spatially limits the base metal mineralization. The known economic occurrences are resting exclusively above the boundary between the Saxothuringian and Rhenohercynian Zones of the Variscan externides (Text-fig. 1). They appear to be confined to those areas that are bounded by large positive paleomasses, shear zones, strongly tectonically disturbed basement and sea paleohighs. The Kupferschiefer occurrences lie above the Variscan basement and are additionally spatially bounded by areas having an anomalously high paleogeothermal gradient (SPECZIK 1985b). The most important local factor controlling the occurrences of mineralization is the border area with the oxidized horizon, called the "Rote Fäule" facies.

The mineralization is intimately associated with bituminous marly layer, the "Kupferschiefer", that appears at the base of Zechstein sediments. This unit extends over the entire area of the Zechstein basin with facies changes restricted to rims and schwellen. In places mineralization moves up and down in stratigraphic sequence, embracing the underlying Weissliegendes sandstones, the Kupferschiefer, and the overlying carbonates of *Z1*. The Kupferschiefer contains elements like Fe, Co, Ni, V, Cr, and organic carbon in concentrations found commonly in black shales. In all occurrences a well defined vertical and horizontal zonation pattern of metals and minerals is observed. This paragenetic sequence conforms to the known solubilities of metals, with some small variations, resulting from diagenetic processes. The prominent rôle of

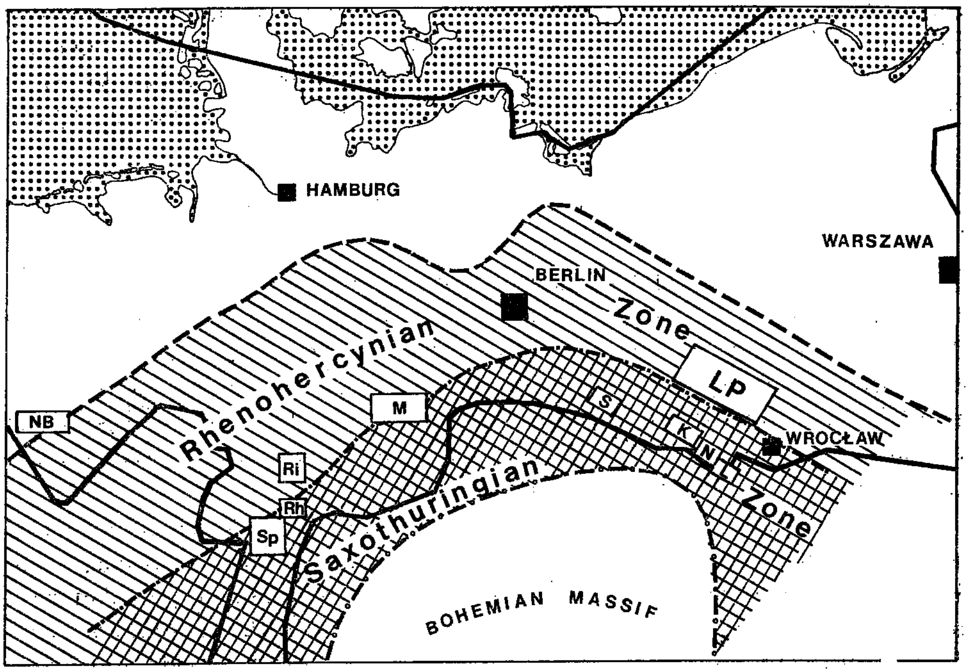

Fig. 1. Kupferschiefer occurrences in the Zechstein basin of Central Europe

L — Lena, N — Nowy Kościół, K — Konrad, L-P — Lublin — Polkowice, Ri — Richelsdorf, Rh — Rhön, Sp — Spessart, NB — Niederrheinische Bucht, M — Mansfeld (not investigated), S — Spremberg — Weisswaser (not investigated)

The extent of the Zechstein basin is indicated by a heavy line

organic material in the ultimate process of sulphate sulphur reduction and consequent metal fixation seems to be justified.

The main differences between the individual occurrences concern lithologic column and the local facies devolopment. Other principal distinctions are: the tenor and bulk richness of mineralization, the mineralogical and geochemical composition of the ore, correlations between the lithologic column and mineralogical and geochemical characteristics of the ore, the geology and petrography of basement rocks, and the type of association with the Rote Fäule facies. The latter topics are the main subject of presented studies.

GEOLOGIC AND METALLOGENIC CHARACTERISTICS OF DISCUSSED OCCURRENCES

The consideration starts from occurrences that are situated most southerly, near the Zechstein shoreline, and are resting exclusively above the Saxothuringian Zone of the Central European Variscides.

Later it proceeds to those that are located farther north, the sedimentological environment of which was controlled by sandbars, lagoonal barriers and other sea-paleohighs. Those occurrences overlay to some part the basement of the Saxothuringian and Rhenohercynian Zones.

NORTH-SUDETIC SYNCLINORIUM

The three of the elaborated profiles (Text-figs 2-4) are situated on the eastern flank of the North-Sudetic Synclinorium, which is cut by the Jerzmanice fault that separates the Bolesławiec syncline (Konrad mine) from the Leszczyny syncline (Lena and Nowy Kościół mines). The basement of the North-Sudetic Synclinorium is thought to be composed of similar rock types as the Kaczawa Mountains, that rise west of Synclinorium Permo-Mesozoic outcrops.

The Kaczawa block is composed of Cambrian, Ordovician, Silurian, and minor Devonian and Carboniferous rocks that are variously altered up to greenschist facies. The sedimentary-metamorphic section consists of dolomitic limestones, marbles, phyllitic schists, quartzites, sericite phyllites, black lydites interbedded with radiolarian beds and argillaceous phyllites.

The Lower Paleozoic volcanic rocks have been counted as belonging mainly to the Middle and Upper Cambrian, the Ordovician, and rarely to the Silurian. Among these basic rocks spillites and spillitic tuffs dominate over diabases, and minor keratophyres. The amygdaloidal spillitic lavas of the Kaczawa Mountains are particularly rich in calcite (about 9%). The keratophyres on the other hand are noted for their high alkali content (the sum of the oxides of K and Na, up to 12%). These rocks become transformed to a greater or lesser extent, and are described in the literature as greenstones and greenschists. The Middle and Upper Cambrian Greenstone Formation of the Kaczawa Mountains reaches up to 1000 m in thickness.

During the Devonian and Lower Carboniferous the North Sudetic Synclinorium was a landmass. Upper Carboniferous (Westphalian *B*) clastic sediments lie discordantly on folded and metamorphosed basement. They were deposited only in the southern part of the Synclinorium and consist of red colored breccias, claystones, conglomerates, and tuffs up to 120 m thick. At the surface as well as in the subsurface the copper bearing areas of the Bolesławiec and Leszczyny synclines are intimately associated with quartz-sericite and sericite schists. Polymetallic hydrothermal veins, characterized by a high copper content, are common in the Paleozoic rocks of the Kaczawa Mountains (*e.g.* Stara Góra, Chełmiec, Męcinka, Wleń, etc.).

LENA

The Upper Rotliegendes formation in the vicinity of Lena has an average thickness of only 10.5 m. The lower part consists of very poorly sorted red-gray conglomerates, composed predominantly of cobbles and boulders of quartzite and schist. Toward the top the conglomerate becomes finegrained and changes to a poorly sorted sandstone. The upper part of Rotliegendes is partly bleached and in places contains conglomeratic quartzose sandstone with a carbonate-clayey cement. It contains sporadically a *Z1* fauna, and is considered to represent the basal conglomerate of the Zechstein. The conglomerate is overlain by a persistent, thin (2 to 20 cm), bed of gray-green or red-stained shale. A beige, thinly laminated, basal limestone contains irregular lens-type intercalations of gray-green shale. A characteristic feature of basal limestone is its low magnesium content (2%).

The Marly Series, resting on top of the basal limestone, is composed of thin alternating beds of marly limestone (argillaceous limestone) and marl (calcareous shale). This unit shows a characteristic lateral as well as vertical zonation pattern. It consists of dolomitic limestone in the SE part of the Leszczyny Syncline, and become more marly towards the NW, where thin marly layers appear, that slowly increases in thickness and dominate the section. Respectively, at the bottom of the Marly Series marls prevail over the limestone, grading upwards content of MgO and CaO increases and the Marly Series passes gradually into a Dolomitic Series. Towards the SE, in the marginal part of the syncline, sandy material and organic matter are commonly intercalated or intermixed with the rocks of Marly Series. The average thickness of the Marly Series, overlying dolomitic limestones and dolomites of the Dolomitic Series reaches up to 19 m, and increases slightly in the western part of the syncline. The overlying regressive sediments of the Stassfurt Cyclothem are composed of finegrained red arkosic sandstones intermixed with shale and dolomitic limestone. These are overlain by shales interbedded with dolomitic sandstones and capped by a sandy-shale unit.

Copper mineralization occurs in the middle part of the Marly Series (Text-fig. 2), and towards the NW it occurs in progressively (parallelly to the Marly Series displacement) younger, stratigraphically higher beds. It is accompanied by successive replacement of the overlying dolomitic limestones and dolomites by marls and marly limestones. Above and below the mineralized unit red spots (Rote Fäule) are observed, that migrate with the mineralization (from SE to NW) from older to younger strata. The main ore minerals are chalcocite, bornite, chalcopyrite and pyrite, with minor galena, sphalerite, wurtzite, hematite, idaite, tetrahedrite, tenorite, cuprite, malachite, native copper and silver. They occur in minute xenomorphic and hypautomorphic grains. The native

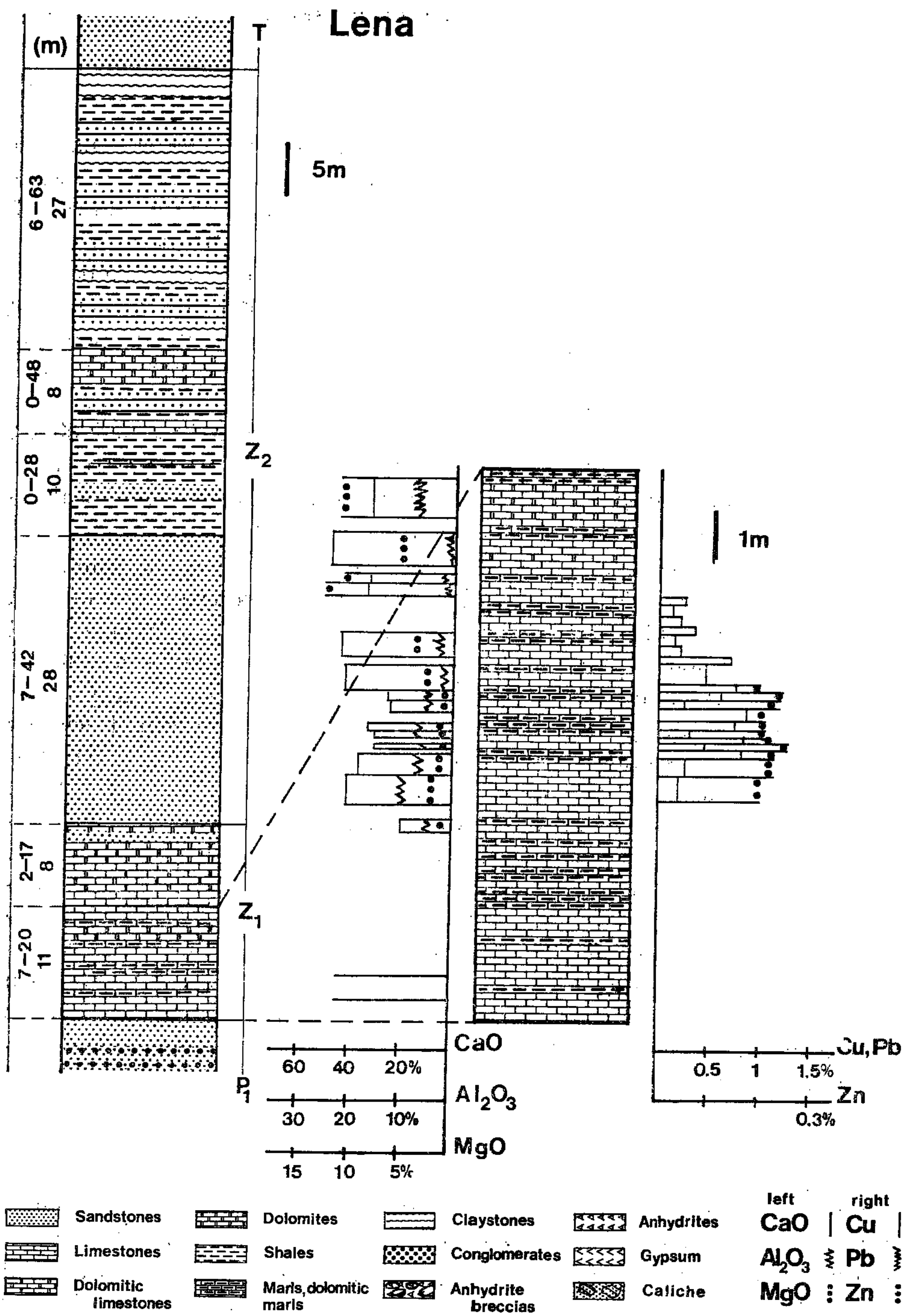

Fig. 2. Geological profile at the Lena mine

Lithology and metal content are given for Text-figs 2—10

Stratigraphy (also for Text-figs 2—10): Pl — Paleozoic older than Carboniferous; C_2 — Upper Carboniferous; P_1 — Lower Permian, in general; W — Lower Permian, Weissliegendes; Z_{1-4} — Upper Permian, Zechstein (successive cyclothems); T — Triassic silver occurs mostly as intergrowths in chalcocite. The marly laminae are relatively enriched in copper (0.5 to 2% Cu), compared to the carbonate ones (0.4 to 1% Cu). The progressive shift of the optimally mineralized units in a northwesterly direction from stratigraphically lower to higher beds in the marly dolomitic sequence amounts to about 100 m in Lena.

NOWY KOŚCIÓŁ

The Rotliegendes formation at Nowy Kościół (150 m) is built up of coarse, red-brown, friable sandstones with a clay-carbonate matrix. Throughout the unit, but more abundant near the base, is a quartz pebble and cobble conglomerate. Higher in the section the sandstone is bleached and overlain by 1 to 4 m of Werra basal conglomerate, which contains predominately dobbles and pebbels of quartz, carbonates and schists. A bed of green-gray, plastic, sandy clay or shale overlies most of the basal conglomerate. The thickness of the overlying basal limestone the southern part of the deposits is about 4 m, to the north it diminishes to a few centimeters. That finecrystalline, aphanitic, thinly laminated limestone contains irregular vanishing beds of sandy limestone and shale.

The Marly Series is composed of dark-gray marly beds alternating with thinner limestone laminae. Similar to the Lena profile the Marly Series grades upwards into the Dolomitic Series. The Marly Series is divided into three units at Nowy Kościół. The bottom unit of the "Stained Marls", is recognized by hematite stains and speckles; it has a high CaO content and is characterized by an abundant fauna. The middle unit has an appreciable copper content (Kupfermergel); its upper part shows an increased lead content, up to 1% (Bleimergel). The overlying Dolomitic Series consists of yellow, dark-gray finecrystalline limestone interbedded with thin beds of dolomite. The Dolomitic Series contains an increasing amount of detrital sandy material and passes fairly gradually into the overlying sandstones of the Stassfurt cyclothem. The fine- to medium-grained, red-brown thinly laminated Stassfurt basal sandstone is irregularly intercalated or interbedded with marls, limestones and shales, and passes gradually into shale containing high admixture of sandy material. Higher in the section, comparable to the Lena area, two limestone and dolomitic limestone layers appear, capped by a light gray sandstone and shale. The Stassfurt age of the latter sediments has been confirmed recently by MILEWICZ (1981). The average thickness of the Zechstein is similar to that in Lena (92 m). The Triassic Buntsandstein formation unconformably overlies the Zechstein sediments.

The mineralization occurs in the middle part of the Marly Series (Text-fig. 3). In contrast to the Lena area, the Rote Fäule occurs only below the mineralized horizon, but again, both the Rote Fäule and the mineralization migrate upwards in the section towards the younger Dolomitic Series in a northwesterly direction. The average copper content of the 2 m thick minable bed ranges from 0.5 to 0.6%; it is 0.7 to 0.9% in the marly beds, and 0.4 to 0.5% in the marly limestone, respectively.

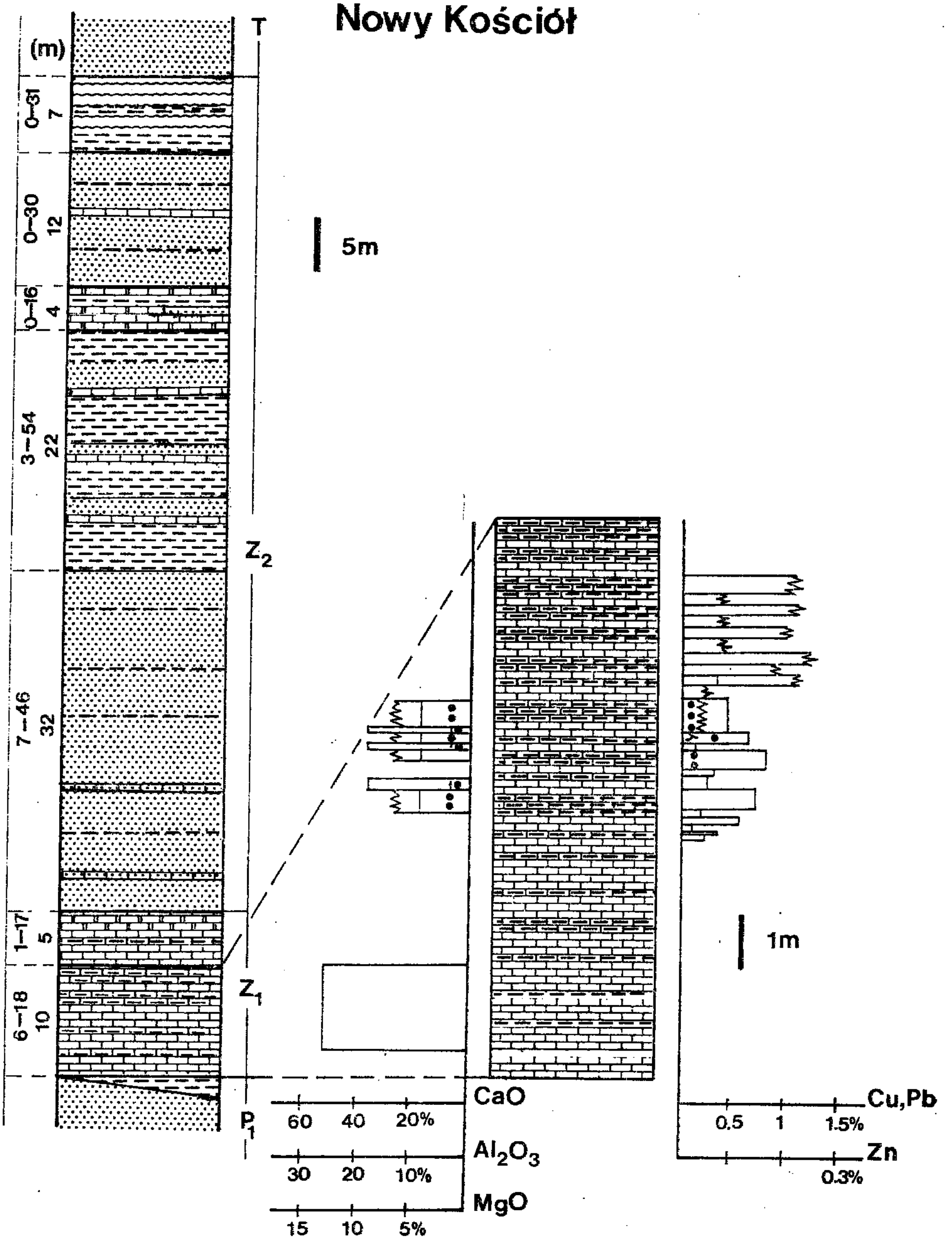

Fig. 3. Geological profile at the Nowy Kościół mine
Explanations the same as for Text-fig. 2

The mineral composition and paragenetic sequence are comparable to the Lena, with higher galena (Bleimergel) and lower silver content. In both occurrences, malachite, azurite, tenorite, cuprite, native copper and silver and occasionally gold were preferentially noticed in Permian outcrops or concentrated along microfractures.

KONRAD

The lower half of the Rotliegendes formation (550 m) in the Bolesławiec syncline consists of red and reddish-brown quartz-feldspar arenites and wackes with clay-carbonate matrix. Gypsum lenses and seams commonly occur throughout the section. Higher up, the detrital material becomes more coarsegrained and the rock changes to a sandy conglomerate and conglomerate intermixed with sandstones. The pebbles and cobbles consist mainly of quartz, lydite, granite, volcanic rock and schist. In the uppermost part of the section fragments of volcanics (melaphyres and porphyries) dominate. Light gray, finegrained and laminated quartzose sandstones at the top of the Rotliegendes are believed to represent the first sediment of the ingressing sea. A thin lamina (2 to 10 mm) of gray clay or gypsum separates the sandstone from overlaying basal limestone, that is variously argillaceous in places, about 1 m thick, and contains 2 to 3 thin marly laminae. The Marly Series has an average thickness of 17.9 m, and could be divided into a lower marl and an upper limestone (marl-limestone) unit. The Marl unit (about 2.5 m thick) is interbedded with several very thin limestone laminae, one of which, referred to as the "middle limestone", is persistent over the entire deposit. The 15 m thick limestone unit is composed of interbedded 20 cm thick limestone beds and slightly thinner marly beds. The transition zone from the Marly into Dolomitic Series is similar to that in other parts of the Synclinorium. Higher in the section, the Dolomitic Series again contains a considerable amount of sandy material. The Stassfurt cyclothem starts with red and gray sandstone intermixed with shale, overlain by dark shale containing thin intercalations of fibrous, white or pink gypsum. Grading upward, shale bed intercalated with anhydrite is overlain by dolomitic limestone capped by a dark-red shale intermixed with sandstone. The younger member is represented by the Triassic Buntsandstein Formation.

The mineralized horizon moves in the lithologic column (Text-fig. 4) between the basal limestone, marl, and limestone units, but it always occurs a few centimeters above the distinctive red stain. Generally, the ore occurs in the middle part of marls, and embraces from 1 to 1.5 m of the unit. When mineralization occurs in the basal limestone, its thickness as well as the tenor increases. In marls, the richest ore is limited to the bottom part of the horizon and intimately associated with the Rote

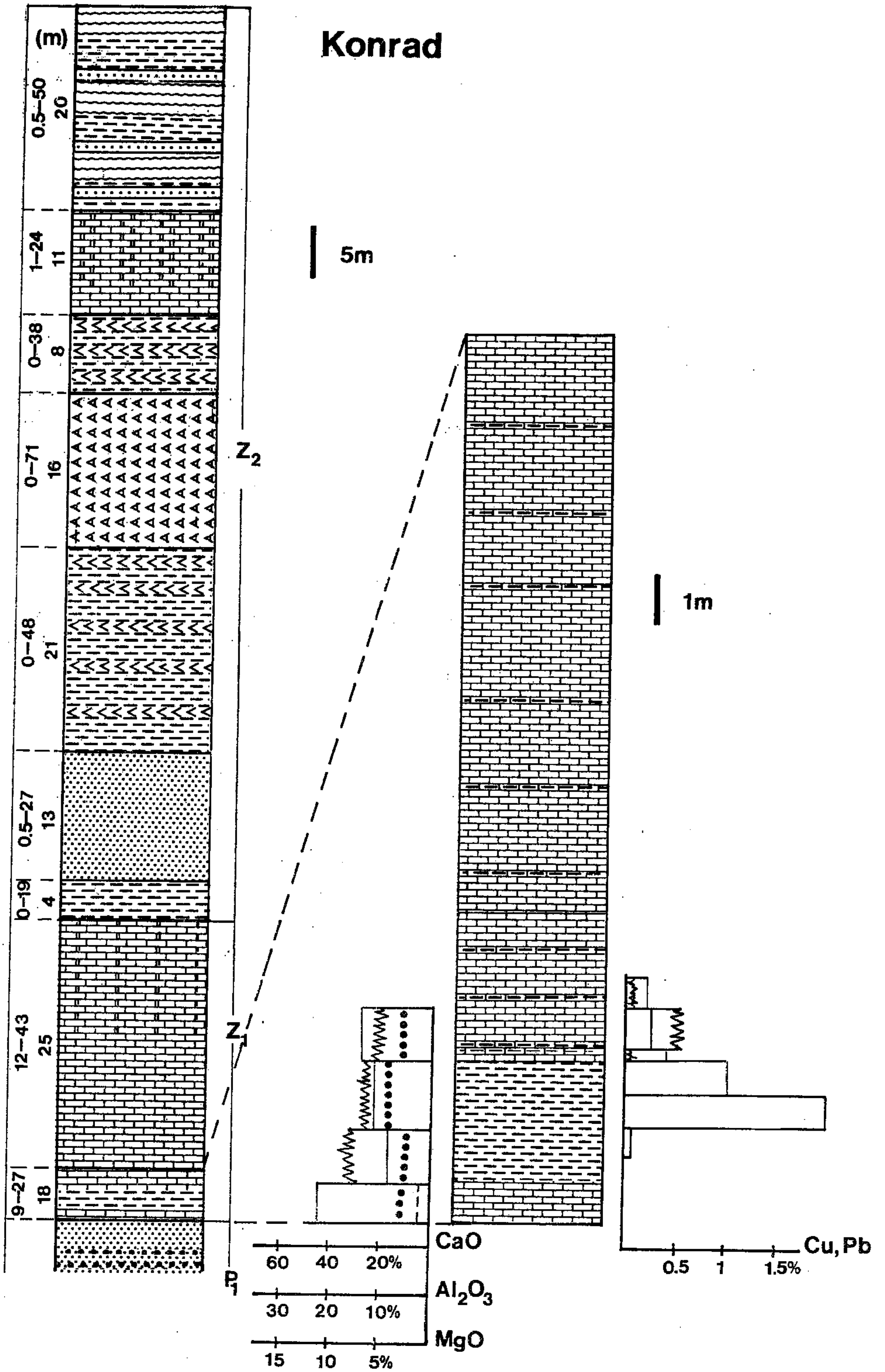

Fig. 4. Geological profile at the Konrad mine
Explanations the same as for Text-fig. 2

Fäule. Above the copper mineralization a zone of up to 1 m thick having an increased lead content (1.4% max), is recognized. The lead content in the copper zone is about 0.1%. The amount of zinc in the entire mineralized horizon is below 0.03%. Silver (30 to 70 ppm) shows a positive corrrelation with zones of the increased copper content. Other metals that show interesting concentrations are: As = 0.025%, Cr = 0.016%, Ni = 0.05%, Mo = 0.003%, and Pt+Pd > 1 ppm. The main components of ore paragenese are: chalcocite (white and light blue varieties), bornite, chalcopyrite and pyrite, accompanied by minor tetrahedrite, covellite, tenorite, malachite, azurite, galena, sphalerite, arsenopyrite, native silver, and organometallic complexes of V, Ni, Cr, Au, Mo, and Pt/Pd group.

NIEDERRHEINISCHE BUCHT

The Niederrheinische Bucht constitutes the southern part of striking from NNW to SSE vast geological structure situated near the border of the Westphalian and Rhenohercynian zones of Variscan externides. This area of virtual Variscan subsidence that stretches along the southern shorebelt of Zechstein sea, is currently continually subsidizing. The extension of Niederrheinische Bucht is bordered in the east by Münsterländer Cretaceous Plateau, and on the south and southeast by the Rheinisches Schiefergebirge.

The geological structure of the Niederrheinische Bucht can be conviniently discussed in terms of the folded and faulted Carboniferous basement, and gently northward dipping (from 2 to 5°) Permian, Mesozoic and Cenozoic sedimentary cover. The basement is exposed at the northern rim of the Rheinisches Schiefergebirge. Older formations of Devonian and Ordovician age, similar to those of the Stavelot-Venn anticline of the Rheinisches Schiefergebirge are commonly thought to compose the deeper parts of the Niederrheinische Bucht basement. The latter assumption has not however been confirmed by consequent drillings. The southern part of the Niederrheinische Bucht exhibits anomalously high paleogeothermal field. The rank of vitrinite in the Upper Carboniferous rocks, up to 4% R_{oil}, corresponds with a locally increased coalification of the Kupferschiefer horizon. The anomaly is caused by the basic pluton of the Krefelder Gewölbe, believed to be intruded at about 3.5 km below the Upper Carboniferous rocks. Geophysical modelling suggests that the pluton may be basic. Abundant basalt-olivin veins, that cut Carboniferous formations constitute additional evidence. Up to several thousand meters thick Lower and Upper Carboniferous formations consists of: limestones, quartzites, sandstones (graywackes), shales and schists, with countless minable coal seams, more in the upper part of the section (Westphalian *A* and *B*). After Westphalian *C*, the Carboniferous strata have been folded. The intensity of folding increases to the south.

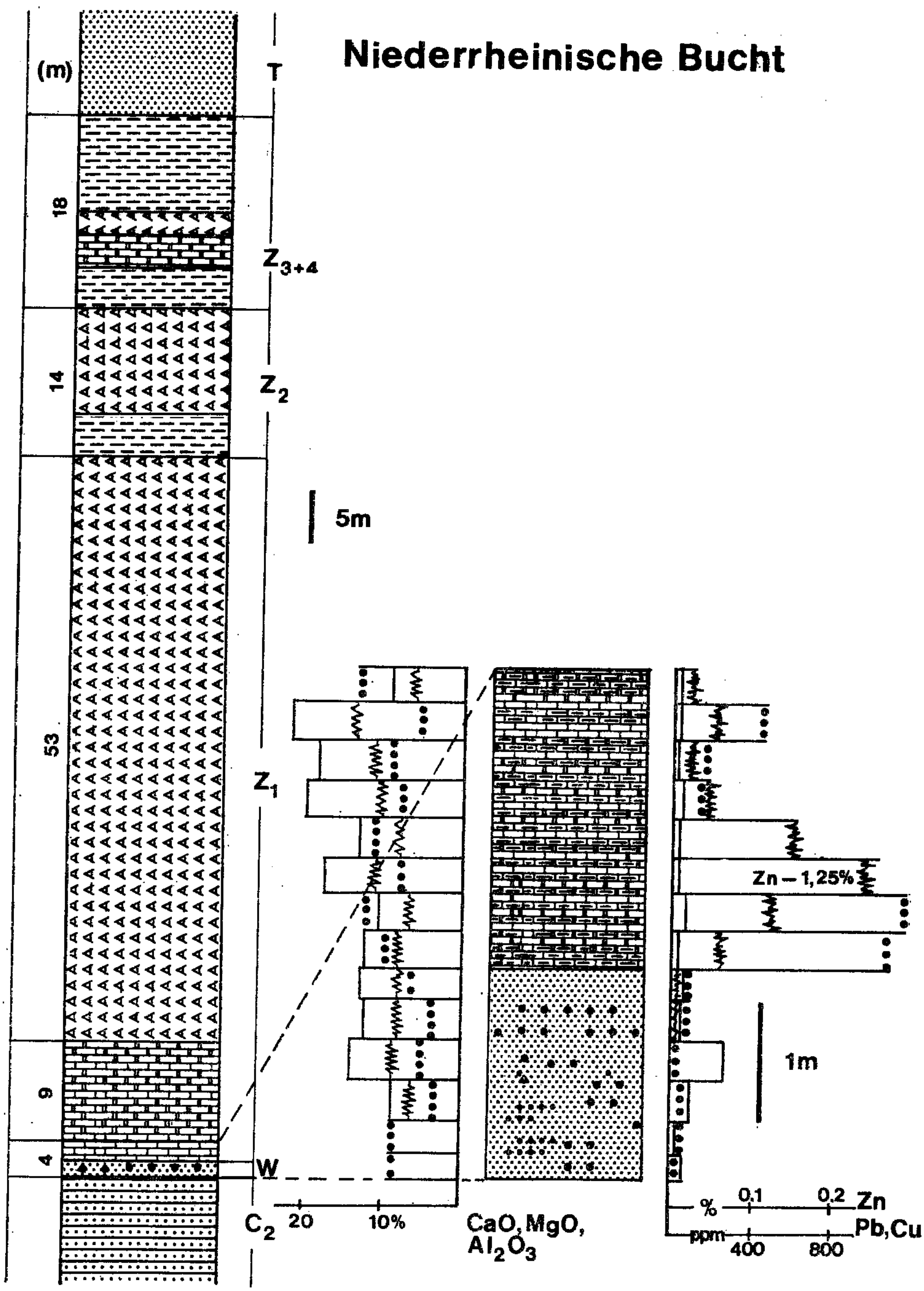

Fig. 5. Geological profile in the Niederrheinische Bucht

Explanations the same as for Text-fig. 2

Parallelly to this, the distance between the axis of NE to SW trending anticlines and synclines increases. The folding system is accompanied by perpendicular system of NW to SE striking faults, that have either downthrown or uplifted some elements of the structure, up to 400 m. Renewed movement in post-Variscan time, resulted in typical horst and graben morphology.

The Rotliegendes sediments were not deposited over the entire area of Niederrheinische Bucht. A thin, 25 cm to 1 m, bed of conglomerate or fine- to coarsegrained sandstone represents the first sediment of the transgressing sea. Pebbles and cobbles are mostly poorly rounded and sorted fragments of Carboniferous limestones, sandstones, and schists, rarely of Upper and Middle Devonian limestones. Similar Middle Devonian limestones make up the main body of the Velberter Sattel, situated about 20 km southeast from Niederrheinische Bucht. The cement consists mainly of calcite, dolomite, ankerite. anhydrite, gypsum and barite. In places it has increased amount of argillaceous material and shows symptoms of silification. Barite occurs also in a form of veinlets and nodules up to 3 cm thick. In places the Zn content in the basal conglomerate reaches 0.7%.

A thin, 2 to 5 cm, irregular patchy bed of basal dolomitic limestone sometimes separates the Kupferschiefer from the underlying basal conglomerate. The Kupferschiefer is developed here as a dark-gray, bituminous, and laminated marly limestone, from 0.5 to 380 cm thick (Text-fig. 5). It contains in places large amounts of argillaceous and sandy material and towards the presumed shorebelt the MgO content increases. In places it is intercalated with thin clayey laminae, that pinch out near minor sea paleohighs. The overlying Zechstein sediments (*Z1* to *Z4* cyclothems) show a facies thickness, development and distribution typical of marginal basins. They are overlain by about 300 m Bundsandstein followed by 300 m of Paleocene, Oligocene and Miocene sediments.

The Kupferschiefer shows a remarkable barium distribution pattern. When it overlies the Westphalian *C* formation it has a relatively low barium content, about 200 ppm. When it overlies the Westphalian *A* and *B* strata barium content increases to an average several of thousand ppm, up to a maximum 5% (DIEDEL & FRIEDRICH 1986). The Kupferschiefer horizon is slightly mineralized with zinc (max. 1.25%) and lead (max. 0.2%), and the richest mineralization is confined to its basal part. The copper content is comparable to that of normal black shales ($<$ 300 ppm). The areas of increased mineralization show spatial correlation with the Carboniferous basement lead-zinc-barium (hydrothermal vein type) mineralization of the Erzprovinz Ruhrgebiet. An increased metal content can also be correlated with the high paleogeothermal field of the Krefelder Gewölbe (Zn+Pb+Cu = 0.5%/m). The observed vertical metal zonation is Zn — Pb — Ba. The ore paragenesis consists of pyrite, marcasite, sphalerite with minor galena, chalcopyrite, covellite and malachite.

SPESSART-RHÖN

The basement rocks of the Spessart-Rhön (Spessart-Rhön Schwelle) belong to the Saxothuringian Zone of the Central European Variscides (mid-European crystalline rise). They are principally of Early Paleozoic age (Cambro-Ordovician) and have been metamorphosed by the Variscan orogeny. Several types of orthogneisses, paragneisses, micaschists, amphibolite and marbles occur, which additionally contain intrusive rocks in some places. During the Rotliegendes the Werra-Fulda Basin was gradually filled by fluviatile and sabkha-type desposits. The sediments consist of conglomerates and sandstones; they are cyclic red-beds, representing fining-upwards sequences. The sabkha sediments occur in the northwestern part of the Rhön block. They are dominantly red colored and consist mainly of clay- and siltstones with sandy intercalations. Characteristic features are nodules of carbonates and anhydrite. Two facies types of Weissliegendes, sandbars and conglomeratic sandstone layers, both of fluviatile origin, were recognized. The stratiform occurrence of carbonate nodules enables the establishment of an A-, B-, and C-zonation (SCHUMACHER 1985). The sandbars can form huge mega-crosslaminated structures more than 50 m in thickness. They appear in the area surrounding the Rhön high. The Kupferschiefer as well as the Zechsteinkalk are developed in two facies types.

The "Hessische Facies" which surrounds the Rhön high, shows an average Kupferschiefer thickness of 0.5 to 1 m, and occurs as a dark gray, thinly laminated, bituminous shale, with various amount of carbonates. The darker layers contain more organic material, whereas the lighter ones are characterized by a higher $CaCO_3$ content. The thickness of the Zechsteinkalk ranges between 10 to 12 m, with marls predominating in the section.

The "Spessart Facies" occurs in the area of the Spessart high. The Kupferschiefer ranges between 0.3 to 4.4 m in thickness. The difference in thickness results from slumping and intercalations of marls and limestones. The highest content of organic carbon is concentrated at the bottom of the Kupferschiefer. The Zechsteinkalk is composed of siltstones, marls, limestones, sideritic and hematitic layers. Its maximal thickness is about 120 m. Within the Zechsteinkalk several stratiform red layers occur, which have been formed under oxidizing conditions. These red colors never crosscut the Kupferschiefer and have no obvious influence on the spatial distribution of the mineralization.

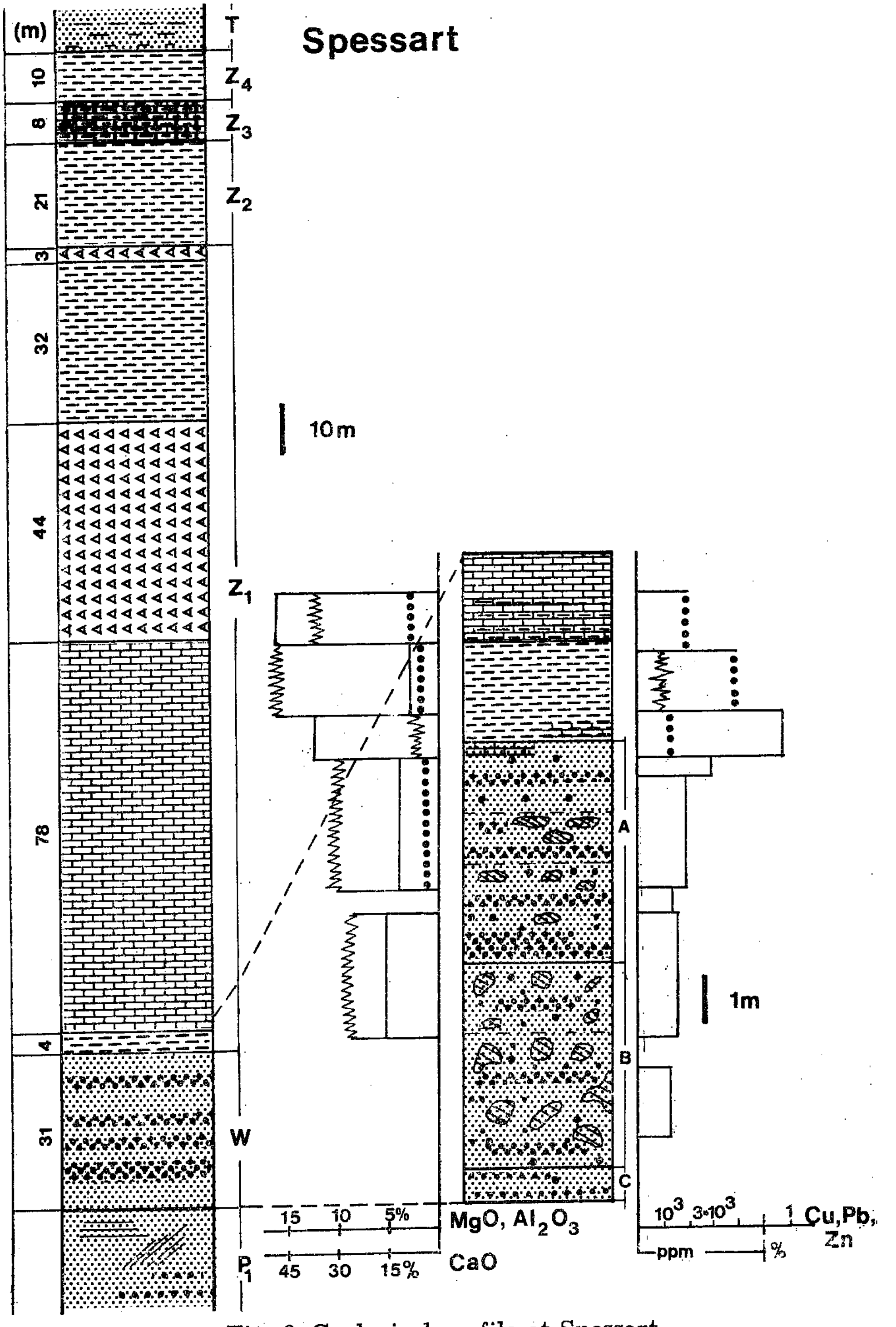

Fig. 6. Geological profile at Spessart
Explanations the same as for Text-fig. 2

The mineralization shows a vertical upwards Cu — Pb — Zn or Cu — Zn — Pb zonation. The metals are preferentially concentrated in the basal part of the Kupferschiefer (Text-figs 6—7). Dominant ore minerals are Cu-As-sulphides (tennantite, enargite) and arsenides (loellingite, arsenopyrite), which replaced former generated sulphides (chal-

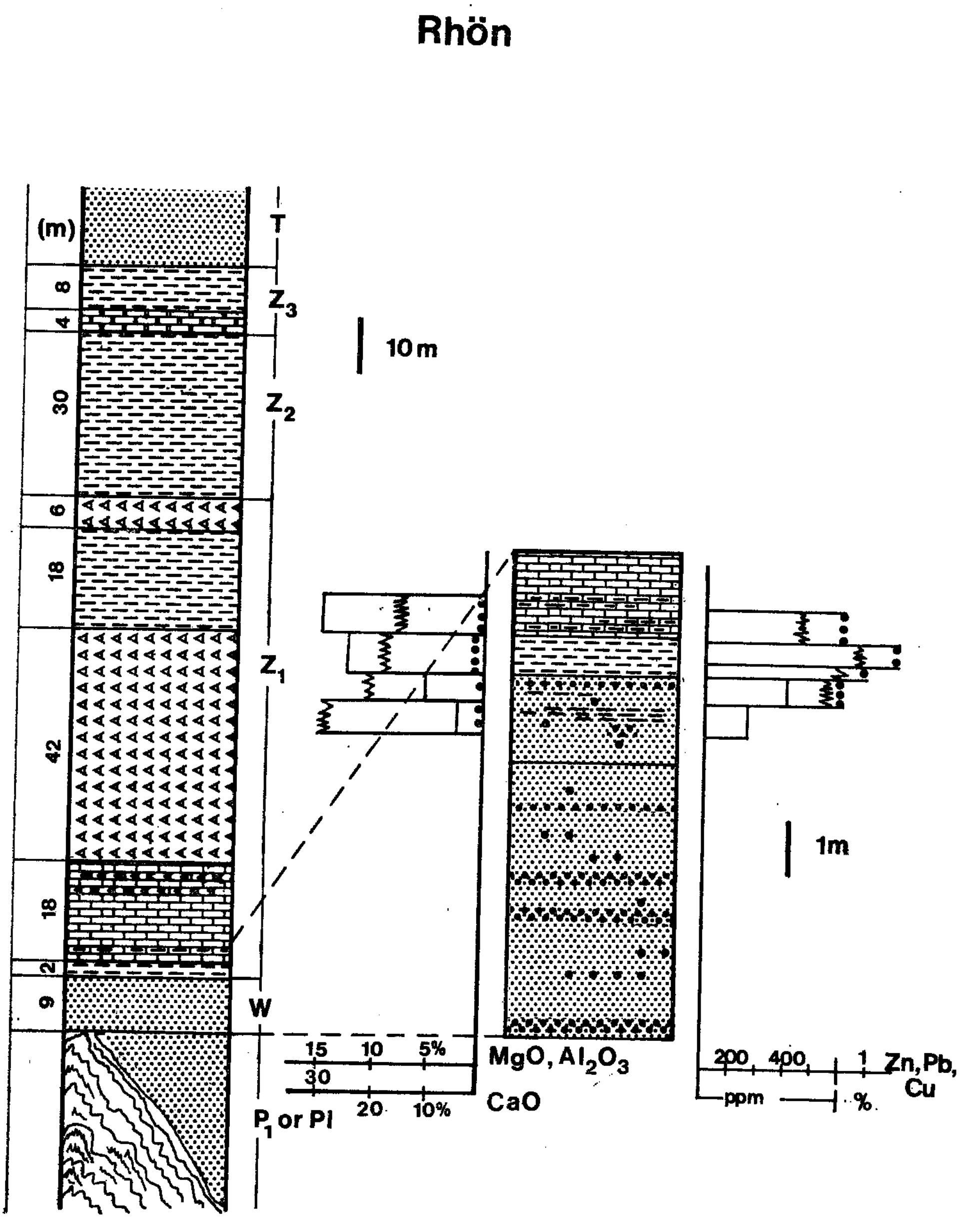

Fig. 7. Geological profile at Rhön
Explanations the same as for Text-fig. 2

cocite, bornite and chalcopyrite). Whether the generation of the earlier formed and now replaced copper-rich sulphides refers to a "Rote Fäule" process is not clear at present. The most common copper sulphide in the zone of lead-zinc mineralization is chalcopyrite. The copper-arsenic mineralization also has been found within the basement rocks, where several NW-SE striking vein structures occur, that are related to Saxonian tectonism.

RICHELSDORF

In the Richelsdorf area the basement is formed by the Hunsrück--Oberharz-Taunus Schwelle and the Baumbacher Querschwelle, which are parts of the phyllite zone that marks the transition between the mid-European crystalline rise in the south and the Rheinisches Schiefergebirge in the north. The basement rocks belong to the Rhenohercynian Zone of the Central European Variscides. They are of Carboniferous and Devonian age and have been altered and folded due to the Variscan orogeny. The rocks are represented by phyllites, strongly folded mica--bearing sand-siltstones and graywackes. The Rotliegendes sediments are more than 1000 m in thickness. In the northern Richelsdorf syncline they comprise alluvial fans. The southern area is characterized by fining upwards sequences of red-colored sandstones and conglomeratic intercalations.

Among the Weissliegendes sediments both the A-, B-, and C-zons as well as the two facies types of cross-laminated sandbars and conglomeratic channel sediments are developed. The sandbar of Ronshausen crops out around the edges of the Rotliegendes through the area of Sontra and Bebra, whereas the conglomeratic channels occupy the central part of the basin. The Kupferschiefer consists of a black, thinly laminated, bituminous shale, which contains a high proportion of quartz, more in its basal part. Its thickness ranges between 0.15 to 2 m. The Zechstein limestone has an average thickness of 10 m and it contains increasing amounts of marls towards the top of the sequence.

The mineralization is hosted in the upper part of the Weissliegendes as well as in the Kupferschiefer and the lower part of the Zechsteinkalk (Text-fig. 8). In the southern part of the Richelsdorf area red-colored rocks in the basal Zechstein rock sequence occur, referred to as "Rote Fäule". In relation to the "Rote Fäule" the following metal- and mineral zonation is developed: Rote Fäule facies → copperfacies → lead-zinc facies, and hematite-chalcocite-bornite-chalcopyrite-galena-sphalerite-pyrite, respectively (SCHMIDT 1985). The vertical separation of the copper, lead-, and zinc maxima, designeted as "spacing" was found to be a significant indication of the influence of "Rote Fäule". Apart from the Rote Fäule-type of mineralization, also vein-type Co-Ni-As-Ba mineralization occurs in the northern part of the Richelsdorf area. This type of mineralization, which was formed as a result of Saxonian tectonism, is crosscutting the basal Zechstein strata, and it secondarily enriched the Kupferschiefer mineralization by the generation of Co-Ni minerals. Only

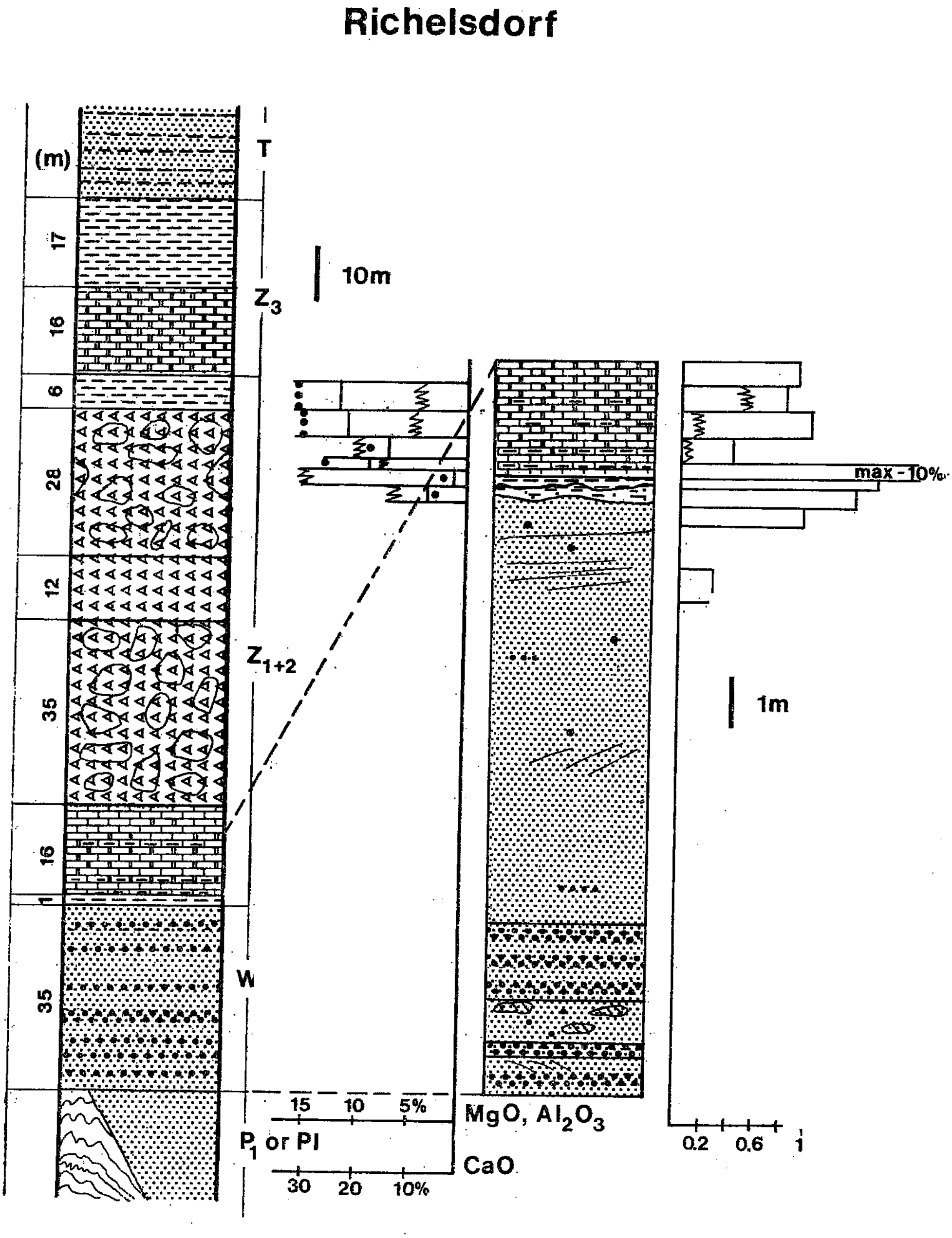

Fig. 8. Geological profile at Richelsdorf
Explanations the same as for Text-fig. 2

the Werra cycle of the Zechstein is completely developed. The following Zechstein cycles are regressive and their total thickness does not even equal that of the basal Werra cycle. Up to 650 m of Bundsandstein overlies the Zechstein, and is succeeded in places by different strata of the Lower Triassic.

FORE-SUDETIC MONOCLINE

The Sieroszowice-Lubin deposit is situated in the southernmost part of the Fore-Sudetic Monocline associated with the Middle Odra step-like system of dislocations separating the Monocline from the Fore-Sudetic Block. The geological structure of the Fore-Sudetic Monocline is composed of two main structural stages. The first stage is the basement of Monocline which comprises a thick body (up to 2000 m) of Lower and Upper Carboniferous, as well as minor Precambrian and Paleozoic rocks variously diagenesed, metamorphosed, folded and faulted. The second stage is made up of Permo-Mesozoic-Cenozoic sedimentary rocks that rest discordantly upon the basement and gently dip (1 to 2°) to the northeast. Precambrian and Early Paleozoic rocks occur in the inner parts of four anticlinal zones trending from SE to NW parallelly to the Middle Odra fault (OBERC 1978). At least two of those zones the Middle Odra Crystalline Zone and the Krotoszyn-Wolsztyn Uplift are thought to represent paleohighs that were active during the Zechstein. Numerous types of Precambrian and Early Paleozoic rocks are recognized: granites, gneisses, schists, hornfelses, variously altered sericite-chlorite phyllites, and slightly metamorphosed Upper Devonian graywackes, sandstones and mudstones.

The Carboniferous series are composed of sandstones (graywackes, lithic wackes, arenites, tuffites and quartz arenites) interbedded and intermixed with siltstones, black shales and minor intercalations of conglomerates. They are cut by the network of epigenetic veinlets related to the Variscan microtectonics of the Erzgebirge and Asthurian phase. The dominant component of the Lower Carboniferous lithoclasts are fragments of basic volcanics. During the Carboniferous, due to subfluence of oceanic plates with locally welded Paleozoic zones beneath the Central European continent, a long chain of Variscan granitoid intrusions trending parallelly to the Sudetes has been formed. Some of them, as for example the Strzelin and Strzegom intrusions, occur in the Fore-Sudetic Block, others are associated with the Middle Odra Crystalline Zone. The basement rocks that underlay the Sieroszowice-Lubin deposits consist of phyllites, amphibolites, biotite schists and quartzites. Similar rocks are known from the neighboring Fore-Sudetic Block and Kaczawa Mountains, where they are thought to represent metamorphosed volcano-sedimentary rocks of Cambro-Carboniferous age.

The presented profiles (Text-figs 9—10) comprise only a small part of all possible variability of geological profiles in highly differentiated geological environment of Sieroszowice-Lubin. At least, five principal types of lithological profiles were recognized by HARAŃCZYK (1971).

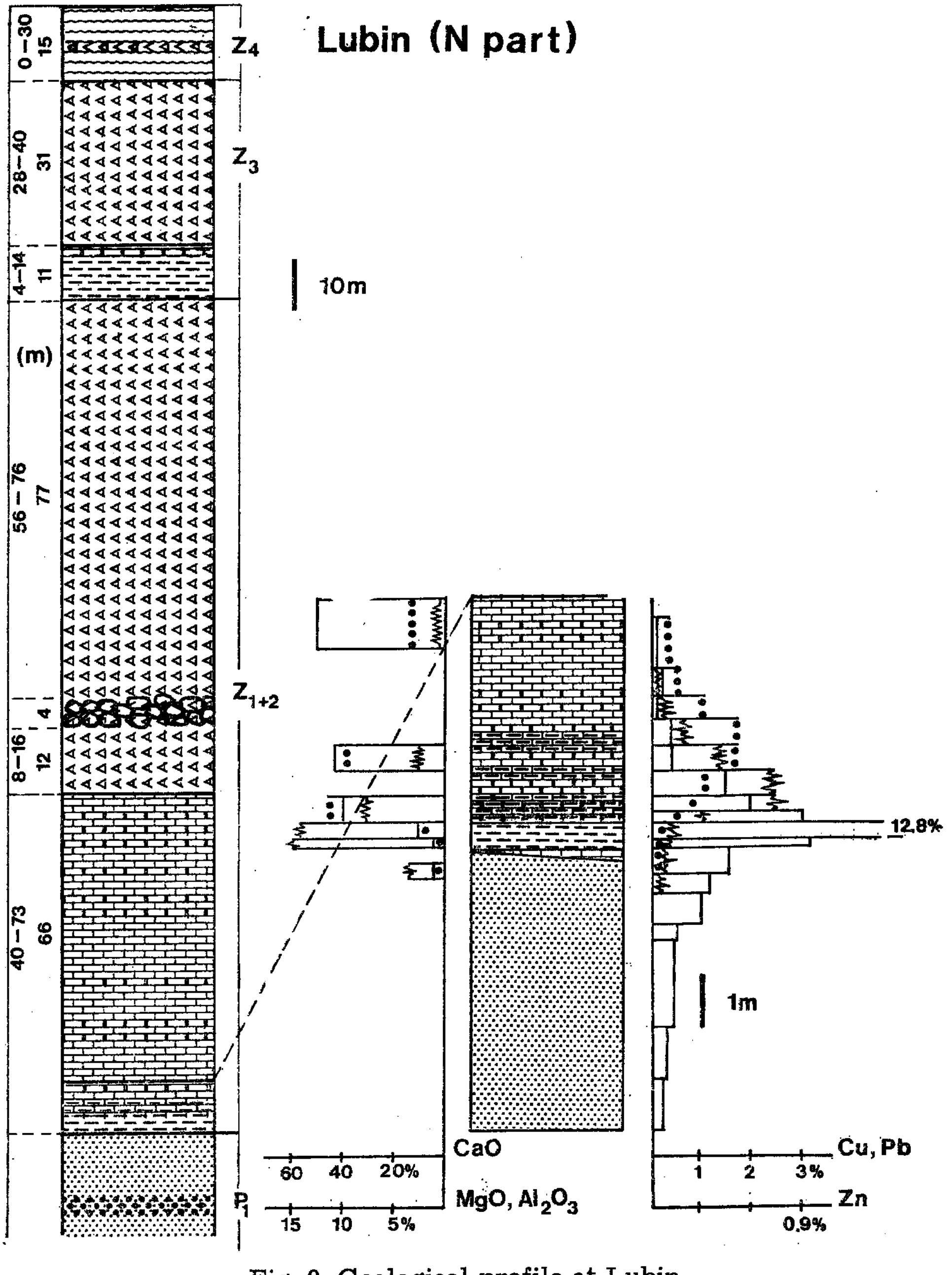

Fig. 9. Geological profile at Lubin
Explanations the same as for Text-fig. 2

The profile Lubin is representative for an area situated north from the town of Lubin, while the Polkowice profile is representative for an area located northeast of the town of Polkowice.

The Rotliegendes in the Sieroszowice-Lubin area is about 300 m thick. It consists of melaphyres and dacites with pyroclastic material near the bottom. It grades upward to red sandstones with subordinate lenses of red and gray mudstones, and is overlain by conglomerates with an irregular bed of light-gray, white sandstone at the top of the section (Weissliegendes). In the Lubin mine, Rotliegendes sediments were to greater extent bleached than in the remaining Sieroszowice-Lubin area. The thickness of Weissliegendes ranges from some tens of centimeters to about 60 m. It is represented by finegrained quartzose arenites, with various amount of rock fragments (quartzite, granite, schists) and feldspar grains. In the lower part of Weissliegendes large scale cross-stratification is common, while the upper Weissliegendes consists of (0 to 16 m) finer-grained massive sandstones. In the uppermost part of the section bioturbations are common and scarce Zechstein fauna occurs. Thin siltstone laminae often showing soft-sediment deformation textures occur throughout the Weissliegendes.

The thickness of the Zechstein marine sediments increases gradually in a northeasterly direction from 140 m in the southern part of Lubin mine to about 300 m, with four Zechstein cyclothems being more completely developed (TOMASZEWSKI 1962). Finely crystalline, bituminous, and marly basal dolomite is about 10 to 30 cm thick and is somewhat patchy in its character and it is forming persistent beds only in the SE part of the deposit. The copper-bearing shale rests in places on the basal dolomite or lies directly on Weissliegendes sandstones. It is characterized throughout the deposit by being irregularly distributed and variably developed. A typical Kupferschiefer is a black, foliated, bituminous, highly mineralized shale. It is fissile in the upper part, due to alternating more clayey and limy laminae. To the southeast and west from Lubin a facies change occurs and the rock consists of argillaceous limestone, marls or marly dolomites. Moreover, in some areas, the *Z1* limestone bed rests directly on the Weissliegendes sandstone. It is suggested, that these areas represent local barriers separating basinal and lagoonal facies (HARAŃCZYK 1971). The facies equivalent of the Kupferschiefer in the zone of oxidation are red shale, red stained argillaceous limestone and calcareous shale. The thickness of the Kupferschiefer varies from 0 to about 2 m (average 0.3 m to 0.5 m).

The lead-bearing shale has been found in a zone trending WNW to ESE, and located north of the Lubin and Polkowice mines. It is black, bituminous, highly mineralized, partly fissile shale composed mainly of interlayered montmorillonite-illite group minerals, in contrast to Kupferschiefer which consists predominantly of illite group minerals (HA-

RAŃCZYK 1985). The lead-bearing shale is mostly underlain by thin laminae of copper bearing-shale and upwards near the schwellen it vanishes.

The thickness of the overlying dolomite-limestone series of *Z1* increases in the southerly direction from about 10 m in the northern part of the deposit to about 60 m, occasionally 120 m, at the boundary with the Fore-Sudetic Block. The bottom part of the *Z1* key limestone is dolomitic, marly and bituminous, with abrupt onset of bioturbations. Grading upwards the amount of clay material and magnesium generally diminishes. In areas where Kupferschiefer has not been deposited, the bottom part of *Z1* limestone bed is composed of light-gray, beige, organo-detrital biohermal dolomite with countless nodules of gypsum and anhydrite. The thickness of the *Z1* anhydrite key bed increases in a northeasterly direction. Likewise, the salt bed of *Z1* is observed only in the northwestern and northeastern offshore parts of the basin. The bottom key dolomite bed of *Z2* (Hauptdolomite) has been deposited in only small area of the Sieroszowice-Lubin deposit. Thus the *Z1* cyclothem is followed by the *Z2* anhydrite bed and is overlain by gray claystone of *Z3* with dolomite lenses at the top, and capped by up to 40 m thick bed of *Z3* anhydrites. The *Z4* cyclothem consists of lower and upper red claystone interbedded with irregular anhydrite and gypsum layers and lenses. Permian rocks are overlain by over 250 m of Triassic sandstones, that are succeded discordantly by Neogene (300 m) and Quaternary deposits (80 m).

The mineralized horizon includes Weissliegendes sandstone, basal dolomite, Kupferschiefer and the bottom part of the *Z1* carbonates. The mineralization shows irregular distribution throughout this horizon, with Weissliegendes mineralization extending only over 25 to 30% of the entire deposit area. Additionally, it varies greatly both in thickness and tenor from centimeters to tens of meters, and from 0.1% to tens of procent, respectively. The most persistent and richest ore body in the Weissliegendes occurs near the base of a lagoonal barrier. Both the basal dolomite (when present) and copper-bearing shale are generally highly mineralized, with the richest mineralization in the lower portion of the section. However, several places have been found with bituminous Kupferschiefer only slightly mineralized. The mineralization in *Z1* carbonates is more regularly distributed as in the Weissliegendes. It is closely associated with the contact zone of Kupferschiefer and diminishes quickly up in the section. Northeast from Polkowice profile, the mineralization in the *Z1* carbonates vanishes, forming the richest and most persistent ore bodies in the area of Sieroszowice mine.

The problems of mineral composition, paragenetic sequence and mineral succession in the Sieroszowice-Lubin deposit have their excellent coverage in the works by HARAŃCZYK (1971) and NIŚKIEWICZ (1980).

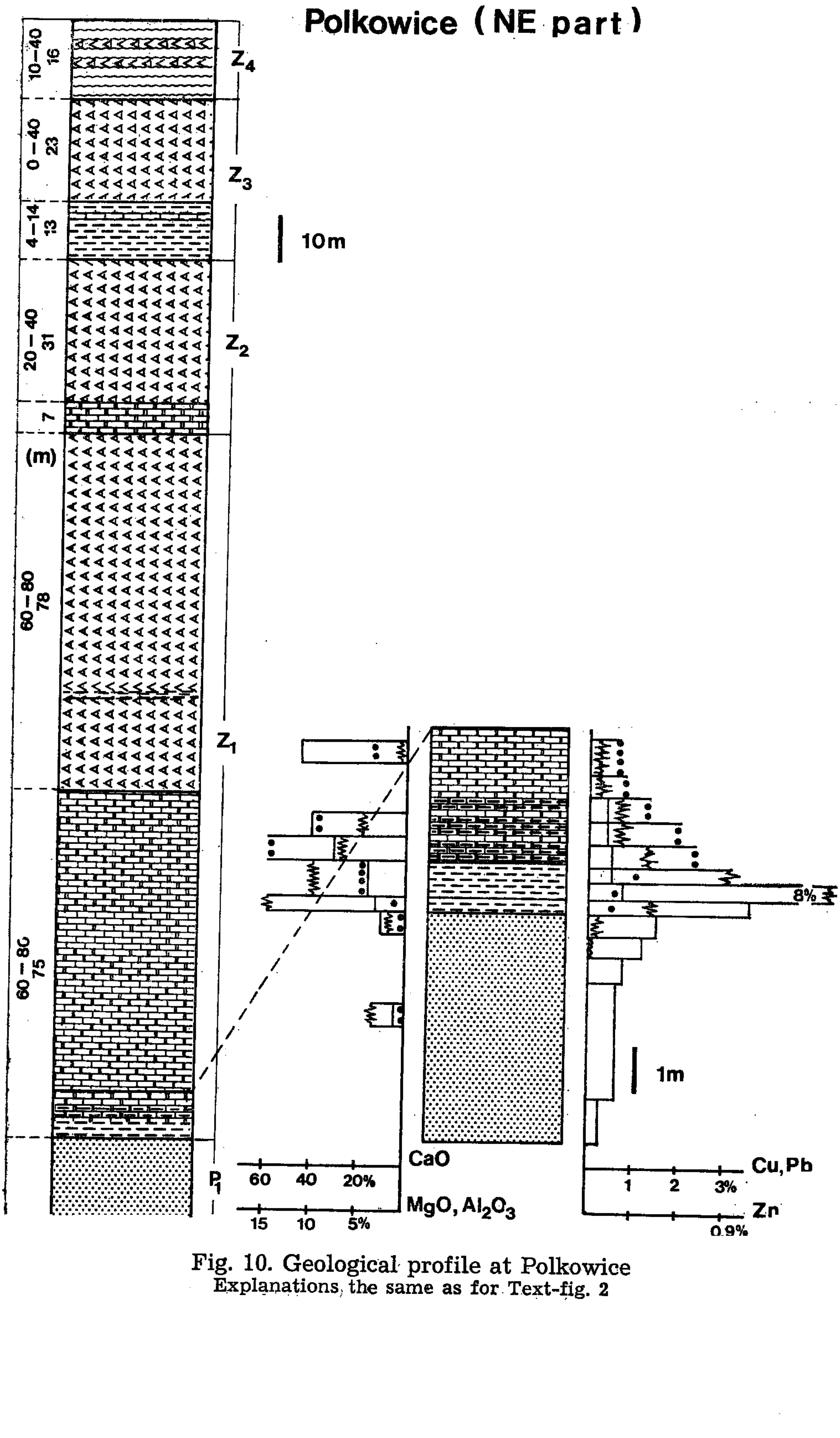

Fig. 10. Geological profile at Polkowice
Explanations, the same as for Text-fig. 2

The ore minerals occur mostly as minute grains disseminated nearly equal throughout the host rocks. Major ore minerals are chalcocite (white and light blue variety) bornite, chalcopyrite, digenite, pyrite, galena, sphalerite, marcasite, enargite, stromeyerite, native silver, and cobalt and nickel arsenides. The mineral paragenesis of the Kupferschiefer and mineralized carbonates of *Z1* is quite similar, with chalcocite being the major copper mineral. In lead-bearing shale galena occurs in association with sphalerite, pyrite and minor copper minerals. Digenite, bornite, marcasite, covellite, tetrahedrite, tennantite and cobalt-nickel arsenides tend to be concentrated in the Weissliegendes. A similar paragenesis is found in diagenetic and syndiagenetic barite-rich veinlets observed sporadically in the area.

Metal and mineral associations vary both vertically and laterally throughout the deposit. Chalcocite mineralization predominates in the major part of the deposit, but is separated from the chalcopyrite mineralization farther east by a thin rim of bornite. Vertically, copper and chalcocite tend to be concentrated in the bottom of the mineralized horizon, whereas when grading upwards, bornite, chalcopyrite, lead and zinc mineralization dominate. The greatest copper values in the Kupferschiefer occur at the contact with the oxidized Rote Fäule horizon. Towards the northeast the area with predominant copper mineralization is succeeded by lead- and zinc-rich areas. The positive correlations between organic carbon and sulphide sulphur, and the sum of base metals as well as the low content of the heavy sulphur isotope ^{34}S, have been discussed by HARAŃCZYK (1971). Beside Cu, Ag, Pb, Zn, many other elements such as: Co, Ni, Mo, V, As, Sn, Re, Se, Au, Cd, Bi, Pt and Pd show interesting concentrations in the Sieroszowice-Lubin deposit.

ENVIRONMENTAL CONSIDERATIONS

The Rotliegendes basin of Central Europe shows basin architecture and sedimentary facies patterns from alluvial fans, braided rivers to meandering rivers, saline lakes, sabkhas, longitudinal river to eolian dunes, typical of a foreland rift basin (JOWETT 1984). Moreover, the bimodal character and composition of the Autunian volcanics coupled with deuteritic alteration processes are characteristic for extensional movements (SPECZIK 1985a). Assumed rifting resulted in continuous subsidence of the Permian basin floor, the rate of which was highly different in individual sedimentary sub-basins. The change of climate from relatively humid in early Autunian to semiarid and arid in late Saxonian, as evidenced by eolian sedimentation in the central parts of the Rotliegendes basin, was suggested by MROCZKOWSKI (1981). Eolian deposition caused selective redeposition and redistribution of the Rotliegendes, but no overall increase of sediments thickness in the steadily subsiding basin. The shortage of water as a transporting medium and as a consequence a decrease in the supply of clastic material to the sedimentary basin, together with the continuing subsidence, led to the formation of extensive depressions, promptly invaded by the Zechstein sea (SMITH 1980). The tectonic processes that led to the inundation of the Zechstein basin are evidenced by the large influx of clastics in the northern part of the basin, whereas in the southern part no increase in the rate of clastic sedimentation or signs of rapid subsidence are observed.

The transgressing sea reworked some of the Upper Rotliegendes deposits, slightly when transgressing over basinal (depressed areas), to greater extent in low-relief plains, schwellen, and tidal high-energy environments. These processes were especially significant expressed in weakly consolidated or unconsolidated eolian deposits (GLENNIE & BULLER 1983). Redeposited Rotliegendes sediments laid down in shallow water display bioturbations, burrows, admixtures of clay material, and increased amounts of carbonate matrix. In some areas (Lena, Nowy Kościół) Upper Weissliegendes grades continuously into a thin bed (20 cm) of clay material corresponding to calm sedimentation after the period of turbulent ingression. The Zechstein sea, invading from the north, flooded a basin characterized by a variable paleomorphology of preformed schwellen, paleohighs and sub-basins. Therefore, local factors strongly influenced the type of sedimentation in the investigated southern part of the basin. However, major regressions and transgressions were approximately synchronous throughout the basin.

Shortly after transgression, characterized by oxygenating conditions, a system of stratified water was established. Due to small supply of fresh water, low activity of currents and waving, the Kupferschiefer depositional environment was dominated, in prevailing part of the basin, by euxinic sapropelitic facies. The Kupferschiefer deposited on the basin floor (Lubin, Richelsdorf) is a thin (0.3 to 0.5 m) bituminous marly shale that extends nearly uniformly over the entire Zechstein sea, and was deposited isochronously troughout the basin (SMITH 1980). Facies changes are restricted to rims and schwellen and depend mainly on presumed shoreline, pre-Zechstein relief and the chemocline. The studied sections of North-Sudetic Synclinorium, Spessart-Rhön and Richelsdorf indicate a continuously transgressing sea in early Kupferschiefer time. The equivalent of the basal part of Kupferschiefer on schwellen or deeper shoals in a tidal environment is a generally fossiliferous basal limestone (Lena, Nowy Kościół), dolomite (Sieroszowice-Lubin), or Mutterflöz (Hessische Senke). It suggests, that the schwellen have been partially above the level of the chemocline during the deposition of the basal limestone. The low content of MgO in the basal limestone of Leszczyny syncline may be explained by low salinity at the initial stages of transgression.

It is plausible, that the sea reached its maximal extent shortly after transgression into the southeastern part of the Zechstein basin, which is marked by the deposition of marls in the entire area of the North--Sudetic Synclinorium. The small thickness and composition of the Rotliegendes and Weissliegendes formations, and the common admixture of sandy and organic material in Marly Series, which is mainly a carbonate sequence, indicates a marginal, nearshore depositional environment for the Lena and Nowy Kościół deposits (Text-fig. 11). The neighboring landmass (Kaczawa Block) probably showed considerable relief, as indicated by the fairly abrupt facies changes from sandy dolomites to dolomitic limestones to lime-marls and marls, north from the presumed shoreline. The area of the Leszczyny syncline was probably a land--locked embayment, partly separated from the open sea, with conditions favorable for the development of carbonate sedimentation, which predominated here for a long time. The alteration of carbonate-rich and shaly layers are interpreted to result from small oscillations of the sea level and parallel long term fluctuations in plankton productivity. The consequent movement of the marly unit and mineralized horizon from older (SE) to younger (N) layers are assigned to a very slow, and variable, but continuous regression of the Zechstein sea. A similar regression pattern of the Kupferschiefer sea is suggested by HARAŃCZYK (1986) for the Sieroszowice-Lubin deposit.

The marginal basin of the Niederrheinische Bucht was similar to that of the Leszczyny syncline, in that it formed a bay at the rim of Zechstein sea. But in contrast, the sea flooded here a relatively flat plain covered by a thin bed of residual and fluviatile sediments. The finer grained materials were probably earlier effectively removed as a result of wind action and redeposited and incorporated in dunes in the central part of the Rotliegendes basin. Hence, the thin conglomerate bed underlying the Kupferschiefer is coeval with the Weissliegendes sandstone. The flat, strongly peneplained land was prior (or at the same time) to transgression subject to strong subsidence that laid the large part of the landmass well below contemporary sea level. Therefore, the sea was here relatively deep, which resulted in uniform deposition of a more basinal facies of the Kupferschiefer over the entire Niederrheinische Bucht area. In contrast to a typical basinal facies, the Kupferschiefer is here generally thicker (1.5 m) and towards the presumed shoreline its thickness, content of detrital material, and carbonates slightly increases.

The depositional environment illustrated by the Konrad profile was situated somewhat farther from the shoreline than the Niederrheinische Bucht and Lena — Nowy Kościół areas although within a rather shallow water environment. As the Fore-Sudetic Block was submerged during the *Z1* deposition, the Konrad sea probably had a connection with the predominantly basinal environment of the Sieroszowice-Lubin deposit, throughout the so-called Sieroszowice Depression (PERYT 1981). The Szprotawa elevation zone situated NW from Konrad and the Kaczawa Mountains in the east, markedly influenced the Zechstein sedimentation in Konrad. The marly bed overlying the basal limestone in Konrad is thought to be the facies equivalent of the Marly Series in the Leszczyny syncline and the Kupferschiefer in the Lubin area. The regressive character of the sea is marked by marls grading upwards into a limestone-marly unit, which is a facies equivalent of the Marly Series section of the Nowy Kościół area. It is plausible, that the lower portion of this section may correspond (to some degree) to the upper part of the Kupferschiefer and the Marly Series. The incomplete sandy-clayey development of *Z1* and *Z2* cyclothems in the entire area of the North-Sudetic Synclinorium may be evidence of the near-shore, land-locked character of this sub-basin of the Zechstein sea.

The paleohighs and barriers in a relatively deep sea controlled the distribution of the Spessart-Rhön, Richelsdorf, and Sieroszowice-Lubin facies. Those elevations were at least for some time and to some extent emerged above the water table. In the Richelsdorf-Ronshausen area, the Baumbacher Schwelle is intimately associated with littoral sandbars composed of a thick body of Weissliegendes sandstones. Thus the basinal facies in Richelsdorf in direction to sandbars show rapid changes in thickness depending on the development of these sandbars. In several instances the Kupferschiefer pinches out at the flanks of the sandbars. The "sandy" type of Kupferschiefer (SCHUMACHER 1985) is composed of bituminous shale containing lenses of sandy material; or shale intermixed, even regularily interbedded with thin sandstone laminae. The amount of sandy material is evidently higher in the basal part of the section. The different paleogeographical setting of the Rhön and Spessart Schwellen during Kupferschiefer time is reflected in development of two distinct facies associated with the "Hessische"- and "Spessart"-facies, respectively. The most elevated parts of the Spessart-Rhön highs formed isolated islands about 100 km east from the west coast of Zechstein sea (Rheinisches Schiefergebirge). The smaller Rhön high, because of its steep and abrupt slopes is surrounded mostly by a basinal facies of the Kupferschiefer, and is additionaly characterized by a small thickness of *Z1* key limestone (10 to 12 m). In contrast, the larger Spessart Schwelle built up a flat and vast mobile shelf with a somewhat steep slope. Hence, the basinal facies shows remarkable changes in thickness when approaching the Spessart high. It is caused both by slumping and an increased content of carbonates and detrital material. The slumping facies of the Kupferschiefer is characterized by unordered or disturbed laminations and in places by shellbeds, that are explained as tempestites

(PAUL 1982). The mobile type of the Spessart Schwelle is exemplified by a large thickness (about 120 m) and common marly interlayers in the *Z1* limestone.

Shortly after transgression the sea extended probably some tens, to 100 km west and south from the Sieroszowice-Lubin deposit. The paleomorphology of the sea bottom was highly diversified by sandbars having a subaqeuous origin, that trend E-W parallel to the presumed shoreline (KONSTANTYNOWICZ 1965). On top of some sandbars carbonate reefs have started to develop. Barrier reefs are chiefly developed in the English Zechstein (SMITH 1981). They are scattered in the Harz area and are persistent around the Thuringian Basin. The retreat of the Zechstein sea in Kupferschiefer time, observed in entire southeastern Poland, increased the existing heterogeneity in the sea bottom morphology. As was shown by HARAŃCZYK (1986), the facies development and composition of the mineralized horizon are dependent upon these very morphologies. As a result of regression, erosion and redeposition of copper-bearing shale present on steep seaward slopes as well as in high energy environment, a slump-tempestite facies (*flats ore*, HARAŃCZYK 1986) of the Kupferschiefer, were formed. The continuous retreat of the sea, and strong stratification of shallow water brines led to the formation of lead- and zinc-bearing shales on the internal slopes of existing schwellen (Polkowice profile). Simultaneously, in more basinal facies (Lubin profile) the coeval formation of highly mineralized copper bearing shale took place.

METAL SOURCES

The above sedimentological considerations may well explain the differences in facies development, petrographic and to some degree the mineralogic composition of the mineralized horizon in particular sub-basins of the Zechstein sea. However, they are completely insufficient to explain the discrepancies in metal and mineral assemblages, richness of the ore as well as a patchy irregular distribution of the ore bodies.

It is to envisage, that the controlling processes governing the ultimate occurrence of base metal deposits, although generally were the same, they display final differences dependent upon the regional geotectonical development, and the discrepant composition of primary source of base metals. A patchy occurrence of the Kupferschiefer mineralization above the border of Saxothuringian and Rhenohercynian Zones implies a genetic link between the occurrences and the tectonic development of the basement (SPECZIK 1979, 1985a; RENTZSCH 1981). The subfluencing and later rifting caused that the NE European plate was divided by transform faults into several sub-plates. As a consequence of deviations in particular sub-plates movement, the favorable tectonic conditions for the base metal generation were established in these particular areas, which were related to major zones of subfluence and rifting. Studies of the St. Joe Explorations in Richelsdorf and Spessart-Rhön regions show that small areas having high grade mineralization and varying composition can occur spatially separated and not far from each other. From these observations and studies of the presented profiles it is conceivable that the Kupferschiefer horizon was fed by different composition brines from regionally separated sources. It is believed that two processes leading to a gradual base metal preconcentration in Late Variscan time, resulted in a two-sourced, composite character of the discussed mineralization.

The first source for more uniform deposition and wide-ranging composition is connected with red-bed deposition in the Variscan intramontane throughs. The geochemical composition of this source depends upon the petrography of the bedrock and the regional processes of weathering and oxidation. It is presumed that detrital and volcanic material of the Rotliegendes formation was continuously leached of their metal content by water enriched in chlorides of mostly meteoritic origin. This process took place simultaneously with deposition, and its effectiveness is shown by the very low content of base metals in the entire Rotliegendes formation (SPECZIK 1985a). The second source is characterized by abrupt variations in composition and tenor and reflects the different composition and development of the spatially associated Variscan basement. Intraformational processes stimulated by a high paleogeothermal field of the Variscan externides evolved high saline brines enriched in metals that were successively introduced into and mixed with subsurface waters of Rotliegendes age. As a consequence of strong diagenesis and anchimetamorphism of Carboniferous rocks these brines probably had an appreciable content of bituminous material (hydrocarbons) which may have acted as an important complexing agent.

It was suggested, that prior to the marine transgression, the brines enriched in metal were contained in some kind of underground aquifers (RYDZEWSKI 1976). It is also conceivable, that during the leaching and oxidation of the Rotliegendes, parts of the metals were redeposited in more reduced parts of the Rotliegendes section. Later migration of subsurface waters was responsible for the introduction of the metals into the Kupferschiefer horizon (BERENDSEN & SPECZIK 1986). In a similar fashion, a stratiform clayey ore body of the Mansfeld type is recognized on the top of red-bed sediments containing countless mineralized horizons of Dzhezkazgan in Kazachstan, Soviet Union. A widely varying metal assemblage is found in the deposits discussed here, and has already been documented by KAUTZSCH & *al.* (1964), WEDEPOHL & *al.* (1978), and KUCHA (1983). The observations presented by these authors may be convincing evidence for the suggested existence of two different sources of metal.

The most probably form of metal supply was likely similar to that suggested by BROWN (1978) and LURYE (1986), with the Kupferschiefer acting as a geochemical hydrogen-sulphide barrier. The ore-bearing solutions have emerged within the epigenetic Rote Fäule horizon in areas closely associated with Variscan paleohighs. The discharge was restricted to those areas where hydraulic communication between subsurface waters and the Kupferschiefer horizon existed. The first source of metals suggested was probably more important at the time of transgression and resulted in a background geochemical composition throughout in the basin. The source suggested second predominated during Kupferschiefer sedimentation and continued throughout early diagenesis when subsurface water was introduced. The possibility of the latter processes is confirmed by studies of deposits preserved in old tailing ponds at the Lena and Konrad mines (SKOWRONEK, *observations in* 1985); they revealed, that apparently consolidated mining tails are still liquid in the center, and show a noticeable process of remnant metals redistribution because of the action of surface and subsurface waters.

REGIONAL METALLOGENIC PATTERN

Two major metallogenic zones are distinguished along the southern rim of Zechstein basin. The first is spatially associated with the Saxothuringian Zone of the Variscan externides and embrace the Lena, Nowy Kościół, Konrad and Spessart-Rhön occurrences. It is characterized by relatively low tenor and fairly simple mineral composition. The occurrences are situated close to the shoreline, and are apparently tectonically controlled. The old basement in this zone was strongly metamorphosed prior to the Variscan orogeny. Moreover, the Carboniferous strata are here relatively thin and irregularily distributed. Hence, the basement of the Saxothuringian Zone is not considered to be a good source for Late Variscan intraformational processes (source *2*). The principal sources of primary metals in this zone are the Cadomian and Caledonian basic volcanics and associated tuffs (greenstone formation). To some extent other Precambrian and Paleozoic country rocks that compose together with Lower Permian volcanics the main bulk of the Rotliegendes formation, are also source rocks. The observed tiny deviations in richness and mineral composition of separate occurrences in this zone are related to variable thickness and volume of Rotliegendes rocks that were depleted of their metal content; and probably to variations in associated basement composition. An increased content of Pt and Pd in the Kupferschiefer of the North-Sudetic Synclinorium may confirm to some degree an important role of basic volcanics in copper provenance in the area.

The base metal occurrences of the second metallogenic zone rest above the Rhenohercynian Zone of the Variscan externides. They are situated fairly far, up to 100 km from the seashore, in areas of widely varying sea bottom morphology. These occurrences are characterized by a intricated metal assemblage and mineral composition, well pronounced zonation patterns and a tenor varying from relatively low (Richelsdorf) to immense high (Sieroszowice-Lubin). The mostly late Paleozoic basement of the zone, includes large bodies of Devonian and Carboniferous rocks of different composition (sedimentary, volcanic and igneous). They subjected to alteration processes, that varied greatly in intensity, and related to the Late Variscan subfluence and rifting. Prior to and probably during these processes, the basement rocks were variously mineralized (Meggen, Rammelsberg, Fore-Sudetic Monocline). In some areas associated with paleohighs, deep-seated-fault high paleogeothermal fields occur. Due to tectonic stress and heat flow, brines enriched in base metals, hydrocarbons and chlorides moved up along these faults and introduced into the younger geochemical cycles. However, the leaching of red Rotliegendes molasse remains the main source of metals later incorporated in the copper-bearing shale. Principally larger influx of mineralized brines derived from the basement only accentuate differences in metal composition and richness in the Kuperschiefer of this zone. Volcanic and sedimentary basement rocks and Autunian volcanics serve as the main source for copper, while acid intrusives of Late Carboniferous seem to be responsible for enormous lead content in some occurrences (SACHANBIŃSKI 1980).

The basement of the North-Sudetic Synclinorium and Spessart-Rhön areas contains large share of strongly metamorphosed Caledonian rocks of limited metallogenic potential. This is evidenced by the actually observed relatively low tenor of mineralization. Very thin beds of Weissliegendes conglomerate, and the lack of Rotliegendes rocks in the Niederrheinische Bucht area precludes the possibility of occurrence of base metal mineralization in the entire area of Niederrheinische Bucht according to the above concept. Elsewhere in the Permian of Central Europe where Rotliegendes thin outs, the ore mineralization vanishes. The closest area to the Niederrheinische Bucht where virtual Rotliegendes deposition occurs (Norddeutschen Becken) is around 100 km away. To transport mineralized solutions through a merely 1 m thick horizon over that distance seems to be highly improbable. It is conceivable that mineralized fluids may have contact with Zechstein sediments of Niederrheinische Bucht only during the transgression. The metallogenc specialization of the basement, characterized by common Pb-Zn vein type hydrothermal mineralization in Carboniferous rocks (Erzprovinz Ruhrgebiet) is reflected by a larger content of those elements in the Kupferschiefer horizon of the Niederrheinische Bucht.

Some inessential polarieties in the present day composition and structure of the disscused occurrences are attributed to later epigenetic processes of different origin (Richelsdorf, Spessart Rhön, Lubin), or oxygeneted meteoritic water activity (Lena, Nowy Kościół).

CONCLUSIONS

The presented distinctions in geological characteristics between Zechstein base metal occurrences in Central Europe are attributed to different geological environments of their generation. The regional position of particular Zechstein sub-basins with respect to shoreline, paleohighs, barriers and sandbars is reflected in various facies developments as well as geological structure. The development and metallogenic composition of the associated basement are responsible for variations of petrographical, mineralogical, geochemical characteristics and richness in individual occurrences. Some additional small variations and polarieties in the final composition of individual deposits resulted from later diagenetic, tectonic, epigenetic and hypogene processes. In spite of this, the deposits are closely related, demonstrating affinities in their major genetic specifications. Hence, the authors believe that the major processes governing the formation of Zechstein base metal occurrences in Central Europa were principally the same.

The occurrence of mineralization in the Kupferschiefer horizon required a definite sequence of events. A positive correlation between Variscan anomalous high paleogeothermal field at the southern rim of the Zechstein basin and known base metal occurrences implies that the decisive factor providing the control for the mineralization is the availability of energy. Heat flow and stress connected with Late Variscan plate motion propelled the processes leading to base metal preconcentration. Two provenance sources of different importance, supplying metals to separate areas are recognized. The first is related to intraformational processes that affected the Caledono-Variscan basement of the Zechstein basin, the second promoted by a gradual depletion of base metals from Rotliegendes sediments, due to prolonged oxidation. The mutual inter-reaction of both sources governed the geochemical characteristics and bulk richness of the ore in particular occurrences. A definite paleohydrological regime, facilitating the flow of mineralized solutions into the interface with the Kupferschiefer horizon, was required. It is likely that the ore-bearing solutions emerged both in the areas of oxidized and reduced environments. In reduced environments base metals were precipitated as a consequence of reactions between metal-bearing solutions with hydrogen sulphide (HS^-) produced by sulphate reducing bacteria. When approaching an oxidized horizon the vertical flow of fluids changed to a lateral. The latter is manifested both by an envelope of enormously rich ore at the contact of oxidized and reduced facies, and the observed lateral zonation pattern.

Acknowledgements

The most sincere and cordial thanks are expressed to Professor P. BERENDSEN (University of Kansas) and Professor A. RADWAŃSKI (University of Warsaw) who kindly read an early draft of this paper, and offered many helpful comments. S. SPECZIK, wishes to acknowledge the Alexander-von-Humboldt Foundation, Bonn, for supporting this study at the RWTH Aachen.

Institute of Geology of the University of Warsaw, Al. Żwirki i Wigury 93, 02-089 Warszawa, Poland

(S. Speczik)

Konrad Mine, ul. Górnicza 29a m. 7, 59-500 Złotoryja, Poland

(C. Skowronek)

Institut für Mineralogie und Lagerstättenlehre RWTH Aachen, Wüllnerstrasse 2, 5100 Aachen, BRD

(G. Friedrich & R. Diedel)

St. Joe Explorations GMBH, Georgstrasse 50, 3000 Hannover, BRD

(C. Schumacher & F.-P. Schmidt)

REFERENCES

ANDERSON, T. A. 1975. Carboniferous subduction complex in the Harz Mountains, Germany. *Geol. Soc. Amer. Bull.*, **86**, 77—82. Boulder.

BANAŚ, M., SALOMON, W., PIESTRZYŃSKI, A. & MAYER, W. 1982. Replacement phenomena of terrigenous minerals by sulphides in copper-bearing Permian sandstones in Poland. *In:* Ore Genesis, pp. 3—9. *The State of the Art. Springer Verlag;* Berlin — Heidelberg.

BEHR, H. J. 1978. Subfluenz-Prozesse im Grundgebirgs-Stockwerk Mitteleuropas. *Z. Dt. Geol. Ges.*, **129**, 283—318. Hannover.

BERENDSEN, P. & SPECZIK, S. 1986. A comparison of Polish and U. S. Midcontinent stratiform copper occurrences. *Arch. Miner.*, **40** (2), Warszawa.

BROWN, A. C. 1978. Stratiform copper deposits — Evidence for their post-sedimentary origin. *Minerals Sci. Engng.*, **10**, 172—181. Johannesburg.

DIEDEL, R. & FRIEDRICH, G. 1986. Buntmetall- und Schwerspatmineralisation in der Niederrheinischen Bucht. *Fortschr. Geol. Rheinld. u. Westf.* (in press). Krefeld.

GARLIC, W. G. 1961. The syngenetic theory, *In:* F. MENDELSON *(Ed.), The geology of the northern Rhodesian copperbelt,* pp. 146—162; *Mc Donald and Co., Ltd.* London.

GLENNIE, K. W. & BULLER, A. T. 1983. The Permian Weissliegendes of NW Europe: the partial deformation of eolian dune sands caused by the Zechstein transgression. *Sedimentary Geology,* **35**, 43—81. Amsterdam.

HARAŃCZYK, C. 1971. Ore mineralization in the Lower Zechstein euxinic sediments of the Fore-Sudetic Monocline. *Arch. Miner.*, **30** (1/2), 13—173. Warszawa.

— 1986. Zechstein copper-bearing shales in Poland, lagoonal environments and the Sapropel Model of genesis. *In:* G. FRIEDRICH *(Ed.), SGA Special Publ.*, **4**. Berlin — Heidelberg.

JOWETT, E. C. 1984. The Rotliegendes in Central Europe: basin development controlled by plate tectonics. *Przeg. Geol.*, **4**, 196—201. Warszawa.

KAUTZSCH, E. 1964. Über die Bestimmung von Pb-Isotopenhaüfigkeiten an Bleierzen der DDR. *Abh. Dtsch. Akad. Wiss., Kl. Chem. Geol. u. Biol.*, **7**, p. 86! Berlin.

KONSTANTYNOWICZ, E. 1965. Signs of mineralization in the Zechstein of the North Sudetic Syncline. *Prace Geol.*, **28**, 7—99. Warszawa.

KUCHA, H. 1983. Precious metal bearing shale from Zechstein copper deposits, Lower Silesia, Poland. *Trans. Inst. Min. Metall. (Sect. B, Appl. Earth Sci.)*, **92**, 72—79. Edinburgh.

LUR'YE, A. M. 1986. Formation conditions of copper sandstone and shale type deposits. *In:* G. FRIEDRICH *(Ed.)*, *SGA Special Publ.*, **4**. Berlin—Heidelberg.

MILEWICZ, J. 1981. Some remarks on cyclic subdivision of the Zechstein in the North-Sudetic Synclinorium. *Kwart. Geol.*, **25** (1), 67—73. Warszawa.

MROCZKOWSKI, J. 1982. On the role of climatic factor in Zechstein marine transgression. *Bull. Acad. Polon. Sci., Sér. Sci. de la Terre*, **29** (4), 303—310. Warszawa.

NIŚKIEWICZ, J. 1980. Metasomatic phenomena in the Zechstein copper ore deposits of Lower Silesia. *Geol. Sudetica*, **15** (2), 7—80. Wrocław.

OBERC, J. & SERKIES, J. 1968. Evolution of the Fore-Sudetian copper deposit. *Econ. Geology*, **63** (2), 372—379. New-Haven — Lancaster.

OBERC, J. 1978. Rozwój formacji i tektonika Ziemi Lubuskiej i Legnicko-Głogowskiego Okręgu Miedziowego ze szczególnym uwzględnieniem utworów przedpermskich. *Przewodnik* **50** *Zjazdu Pol. Tow. Geol.*, 11—41. Warszawa.

PAUL, J. 1982. Types of stratification in the Kupferschiefer *In:* G. EINSELE & A. SELACHER *(Eds)*, *Cyclic and event stratification*, pp. 476—481; *Springer Verlag*. Berlin — Heidelberg.

PERYT, T. 1981. The Zechstein in the neighbourhood of the Fore-Sudetic Block. *Kwart. Geol.*, **25** (1), 75—91. Warszawa.

RENTZSCH, J. 1974. The Kupferschiefer in comparison with the deposits of the Zambian Copperbelt. *Cent. Soc. Geol. Belg.*, 395—413. Liège.

— 1981. Mineralogical-geochemical prospection methods in the Central European Copper Belt. *Erzmetall*, **34** (9), 492—495. Weinheim.

RYDZEWSKI, A. 1976. Geneza dolnocechsztyńskiej polimetalicznej mineralizacji kruszcowej. *Przegl. Geol.*, 4, 176—181. Warszawa.

SCHMIDT, F. P. 1985. Erzkontrolle im Kupferschiefer Osthessens. *Dissertation, Min. Inst. RWTH.*, 1—158. Aachen.

SCHUMACHER, C. 1985. Die Kupfervererzung des basalen Zechsteins im Rahmen der sedimentären Entwicklung des Werra-Fulda-Beckens. *Dissertation, Freie Universität Berlin*, 1—142. Berlin.

SMITH, D. B. 1980. The evolution of English Zechstein basin. *Contr. Sedimentology*, **9**, 7—34. Stuttgart.

— 1981. The Magnesian Limestone (Upper Permian) reef complex of northeastern England. *In:* D. F. TOOMEY *(Ed.)*, European Fossil Reef Models. *Soc. Econ. Pal. Miner. Spec. Publ.*, **30**, 161—186. Lancaster.

SPECZIK, S. 1979. Ore mineralization in the basement Carboniferous rocks of the Fore-Sudetic Monocline (SW Poland). *Geol. Sudetica*, **14** (1), 77—122. Wrocław.

— 1985a. Metallogeny of Pre-Zechstein basement of the Fore-Sudetic Monocline (SW Poland). *Geol. Sudetica*, **20** (1), 37—112. Wrocław.

— 1985b. Relation of Permian base metal occurrences to Variscan paleogeothermal field of the Fore-Sudetic Monocline; Results of fluid inclusion studies and vitrinite rank determinations. *Fort. der Mineralogie*, **63**, p. 122. Stuttgart.

TOMASZEWSKI, J. B. 1981. Development of Zechstein deposits in the vicinity of Lubin — Sieroszowice. *Inter. Symp. Central European Permian, Materials*, pp. 341—355. Warszawa.

WEDEPOHL, K. H., DELEVAUX, M. H. & DOE, B. R. 1978. The potential source of lead in the Permian Kupferschiefer Bed of Europe and some selected Paleozoic mineral deposits in the Federal Republic of Germany. *Contrib. Mineral. Petr.*, **65**, 273—281. Berlin — Heidelberg.

S. SPECZIK, C. SKOWRONEK, G. FRIEDRICH, R. DIEDEL,
C. SCHUMACHER i F.-P. SCHMIDT

ŚRODOWISKO POWSTAWANIA CECHSZTYŃSKICH ZŁÓŻ I WYSTĄPIEŃ METALI CIĘŻKICH NA OBSZARZE CENTRALNEJ EUROPY

(Streszczenie)

Obserwowane różnice w petrograficznym, mineralogicznym i geochemicznym charakterze cechsztyńskich warstwowych złóż metali ciężkich Centralnej Europy, wynikają z ich odmiennego środowiska powstawania. Wykazano, że główne procesy prowadzące do powstania tych złóż, tj.: późnowaryscyjska prekoncentracja metali ciężkich, transport metali w utlenionych solankach oraz ich precypitacja na kontakcie ze środowiskiem euksynicznym, były zasadniczo takie same. Regionalna pozycja poszczególnych złóż i wystąpień metali w stosunku do linii brzegowej, barier oraz innych paleowzniesień znajduje swoje odzwierciedlenie w odmiennym wykształceniu asocjujących z mineralizacją facji i formacji skalnych (*patrz* fig. 1—11).

Przestrzenne rozmieszczenie kruszców miedzi, ołowiu, cynku i srebra w obrębie tzw. łuku miedzionośnego Centralnej Europy, jak również skład geochemiczny indywidualnych wystąpień metali ciężkich powiązano z innym charakterem geochemicznym sąsiadującego podłoża. Głównym czynnikiem kontrolującym możliwość zaistnienia mineralizacji była dostępność energii. Strumień ciepła i stress, związane z waryscyjskim ruchem płyt, stymulowały procesy prowadzące do stopniowej prekoncentracji metali. Przyjęto dwa różniące się genetycznie źródła metali ciężkich, o odmiennym znaczeniu dla poszczególnych obszarów. Pierwszym z nich były procesy intraformacyjne, jakim podlegały skały kaledono-waryscyjskiego podłoża w okresie od górnego karbonu po czerwony spągowiec. Drugim źródłem metali ciężkich były procesy oksydacji i stopniowego ługowania kontynentalnych formacji czerwonego spągowca przez utlenione solanki typu śródwarstwowego.