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The ilmenite-magnetite ore deposit Krzemianka in northeastern Poland: brief history of discovery and exploration

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The Krzemianka deposit hosted in anorthosites of the East European Precambrian Craton was discovered in 1962 owing to exploration concept and planning of a drilling project by professor Jerzy Znosko. Since then, the ores have been extensively studied by several authors, both from petrological and genetic, as well as from economic point of view. The early ideas of establishing an industrial complex in the Suwałki area were abandoned in favour of the environmental protection of the scenic area.

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The discovery of the Krzemianka ore deposit is related to geophysical and geological research of the crystalline basement of the East European Craton in northeastern Poland conducted by the Polish Geological Institute. The investigations were planned by Jerzy Znosko in 1956 and 1957 (J. Znosko, 1956, 1957). The case history and more important results of the research works were published by the cited author in *Przegląd Geologiczny* issued on the occasion of the 64th Congress of the Polish Geological Association that was held in the Suwałki area on September 9–12, 1993 (J. Znosko, 1993*b*).

The unquestionable key to discovery of the ore deposit was a 1 m-thick bed of siltstones with angular clasts of goethites, overlying anorthosites — the host rocks of the ores, drilled in borehole Suwałki IG 1 (also called Szlinokiemie) at a depth of 725 m (J. Znosko, 1958). The next and most important stage in discovering iron, titanium and vanadium ores was the analysis of the negative gravity anomaly (and positive magnetic anomalies within it) with a simultaneous abandonment of a hypothesis of occurrence in NW Poland of iron-bearing Krivoy Rog-type quartzites. This analysis gave rise to the Krzemianka 1 and Udryń 1 boreholes project (J. Znosko, 1961). This project was undertaken and, after the sedimentary cover had been pierced through, a weathered martite ore was encountered on August 1, 1962, at a depth of 855 m. After the 6 m thick weathering zone was been drilled the primary ilmenite-magnetite ore was found.

This fact gave rise to a new stage of exploration, resulting in documentation of the Krzemianka deposit. The first geological documentation was prepared in 1971 by a team of scientists from the Polish Geological Institute, and "The geological documentation of iron, titanium and vanadium ores Krzemianka in category C_2", was accepted by the President of the Central Geological Office on December 31, 1971 (M. Subieta *et al.*, 1971).

The ore deposit has been investigated by the teams of geologists from the Polish Geological Institute and Geological Enterprise in Warsaw for 28 years. A brief history of these efforts was presented by Antoni Parecki during the 64th Congress of the Polish Geological Association. As a result of the investigations, 726 mln t of ore in category C_1, has been documented (214 mln t of Fe, 53 mln t of TiO_2 and 2.3 mln t of V_2O_5). The ore deposit is composed of 111 lenticular bodies, dipping 45°W, and ranging from a few up to 145 m in thickness, and up to 1100 m long, up to 320 m wide. It is worth noting that 72% of resources is contained within 7 bodies located in the SW part of the ore deposit, and the body No. 277 contains 56% of its resources. Basing upon the content of TiO_2 in magnetite, the ores have been subdivided into four types:

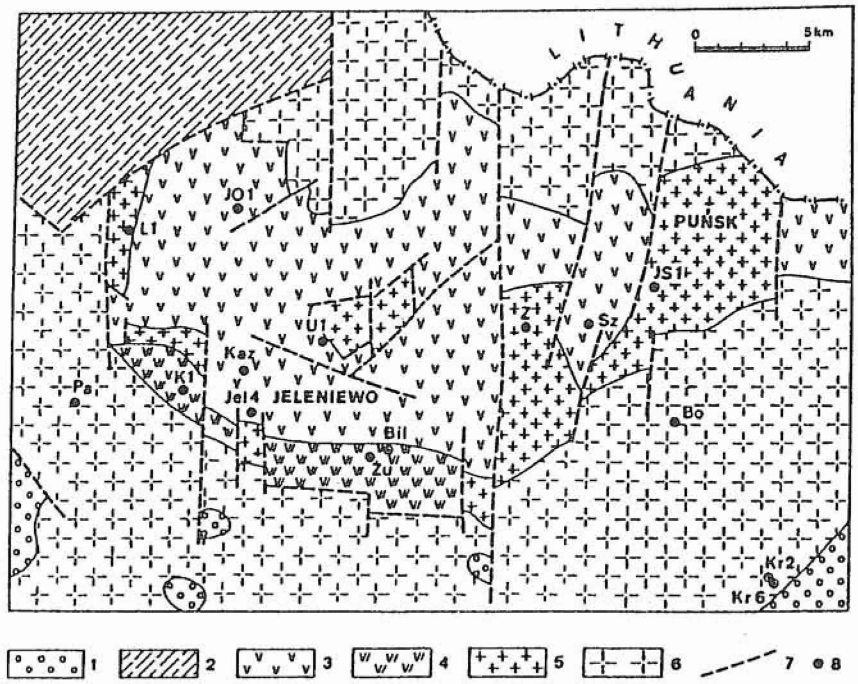

Fig. 1. Geological map of the Suwałki Anorthosite Massif with major boreholes (after O. Juskowiak, 1998)
1 — metamorphic rocks of the granulitic facies, 2 — metamorphic rocks of the amphibolitic facies, 3 — anorthosites and norites, 4 — gabbronorites, 5 — dioritoids, 6 — granitoids rapakivi-like, 7 — faults, 8 — boreholes: Pa — Pawłówka PIG 1, L1 — Łopuchowo PIG 1, JO1 — Jezioro Okrągłe IG 1, K1 — Krzemianka IG 1, Kaz — Kazimierówka IG 1, Jel4 — Jeleniowo IG 4, U1 — Udryń IG 1, Żu — Żubryń IG 1, Bil — Bilwinowo PIG 1, Z — Zaboryszki IG 1, Sz — Szlinokiemie IG 1 (Suwałki IG 1), JS1 — Jezioro Szlinokiemskie PIG 1, Bo — Boksze PIG 1, Kr2 — Krasnopol IG 2, Kr6 — Krasnopol PIG 6

Mapa geologiczna podłoża suwalskiego masywu anortozytowego z głównymi otworami wiertniczymi (według O. Juskowiaka, 1998)
1 — skały metamorficzne facji granulitowej, 2 — skały metamorficzne facji amfibolitowej, 3 — anortozyty i noryty, 4 — gabronoryty, 5 — diorytoidy, 6 — granitoidy rapakiwipodobne, 7 — uskoki, 8 — otwory wiertnicze (objaśnienia symboli otworów wiertniczych — patrz podpis angielski)

— type I contains < 2.5% (0.9–2.5%) TiO_2 and 17–25% Fe (3% of total resources);

— type II contains 2.5–5.0% (2.7–4.7%) TiO_2 and 29–35% Fe (29% of total resources);

— type III contains 5.0–7.5% (5.3–6.5%) TiO_2 and 30–40% Fe (60% of total resources);

— type IV contains > 7.5% (8.0–9.0%) TiO_2 and 42–45% Fe (8% of total resources) (A. Parecki, 1993).

Mineralogical and petrographical investigations of the ores, leading to assessment of their technologic properties and to the recognition of their origin, have also their own history. In the beginning, the ore deposit was merely mentioned in papers concerning related subjects. The first paper on its mineralization was entitled "The basic massifs of south Siberia" (published as a classified paper) (M. Subieta, 1966), the second one — "The metamorphosed iron ore deposits in the Sudetes against the background of other deposits of this type" (E. Zimnoch, 1967). In 1970 the first significant account on the ore deposit was published in *Przegląd Geologiczny* in a column: Geology abroad (R. Osika *et al.*, 1970). All those papers did not use the name Krzemianka, speaking generally of northeastern Poland or Suwałki area, only. The first information in literature on the occurrence of the ilmenite-magnetite ore deposit was published in a paper by Roman Osika, the Director General of the Polish Geological Institute, entitled "The accomplishments of the Geological Institute in the field of the recognition of geological structure in Poland" (R. Osika, 1967, p. 889).

In the later published, more detailed petrographical and mineralogical papers concerning the Krzemianka ore deposit (O. Juskowiak, 1971; S. Kubicki, J. Siemiątkowski, 1973), the described rocks were precisely located, but the ores were called ilmenite-magnetite rocks or ferrolites. The first published paper discussing various aspects of the Krzemianka ore deposit, and showing its location, was entitled "The results of geophysical-geological surveys of the Suwałki region". This paper has given a description of the ilmenite-magnetite ores from the Suwałki Massif (H. Kurbiel *et al.*, 1979). Many petrographical, mineralogical and geochemical papers on the Krzemianka ore deposit and its origin also started to be published in 1979 (S. Kubicki, J. Siemiątkowski, 1979). The first paper on the ores of Suwałki area, published in an international journal appeared in *Mineralium Deposita*, and was co-authored by S. Speczik *et al.* (1988). The earlier investigations on the ilmenite-magnetite ore deposits occurring within the Suwałki anorthosites, with particular regard to their origin, were summarized in a monograph entitled "Geology of the Suwałki Anorthosite Massif (Northeastern Poland)", published in *Prace Państwowego Instytutu Geologicznego* (vol. CLXI, 1998) under scientific editorship of W. Ryka and M. Podemski (1998).

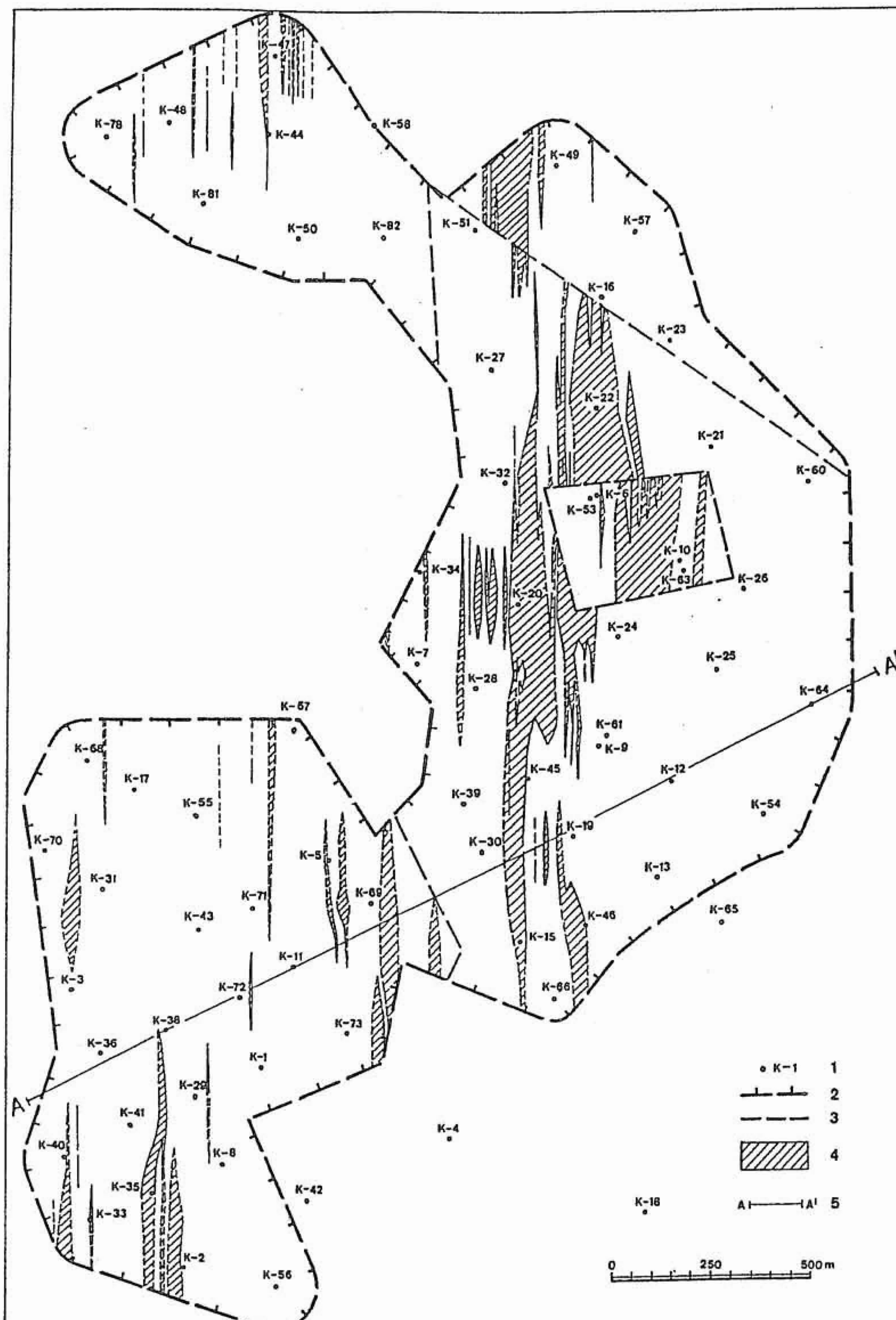

Fig. 2. Schematic map of the magnetite-ilmenite ores appearance in the Krzemianka deposits, at the –1450 m (after A. Parecki, 1998)
1 — boreholes, 2 — the approximate limit of the deposit, 3 — faults, 4 — magnetite-ilmenite ores, 5 — location of the geological cross-section

Schematyczna mapa występowania rud magnetytowo-ilmenitowych w złożu Krzemianka, głęb. 1450 m (według A. Pareckiego, 1998)
1 — otwory wiertnicze, 2 — przybliżona granica złoża, 3 — uskoki, 4 — złoże ilmenitowo-magnetytowe, 5 — lokalizacja przekroju geologicznego

The Krzemianka ore deposit, located within the south-western marginal zone of the massif near a gabbronorite and diorite belt (E. Cieśla *et al.*, 1998), is strictly connected with anorthosites (Fig. 1). Regardless of different views on the origin of the anorthosites themselves: magmatic, anatectic-rheomorphic, metamorphic-rheomorphic or metamorphic, rock complexes were enriched in ore minerals owing to a discrete process of a regional rock metasomatosis (W. Ryka,

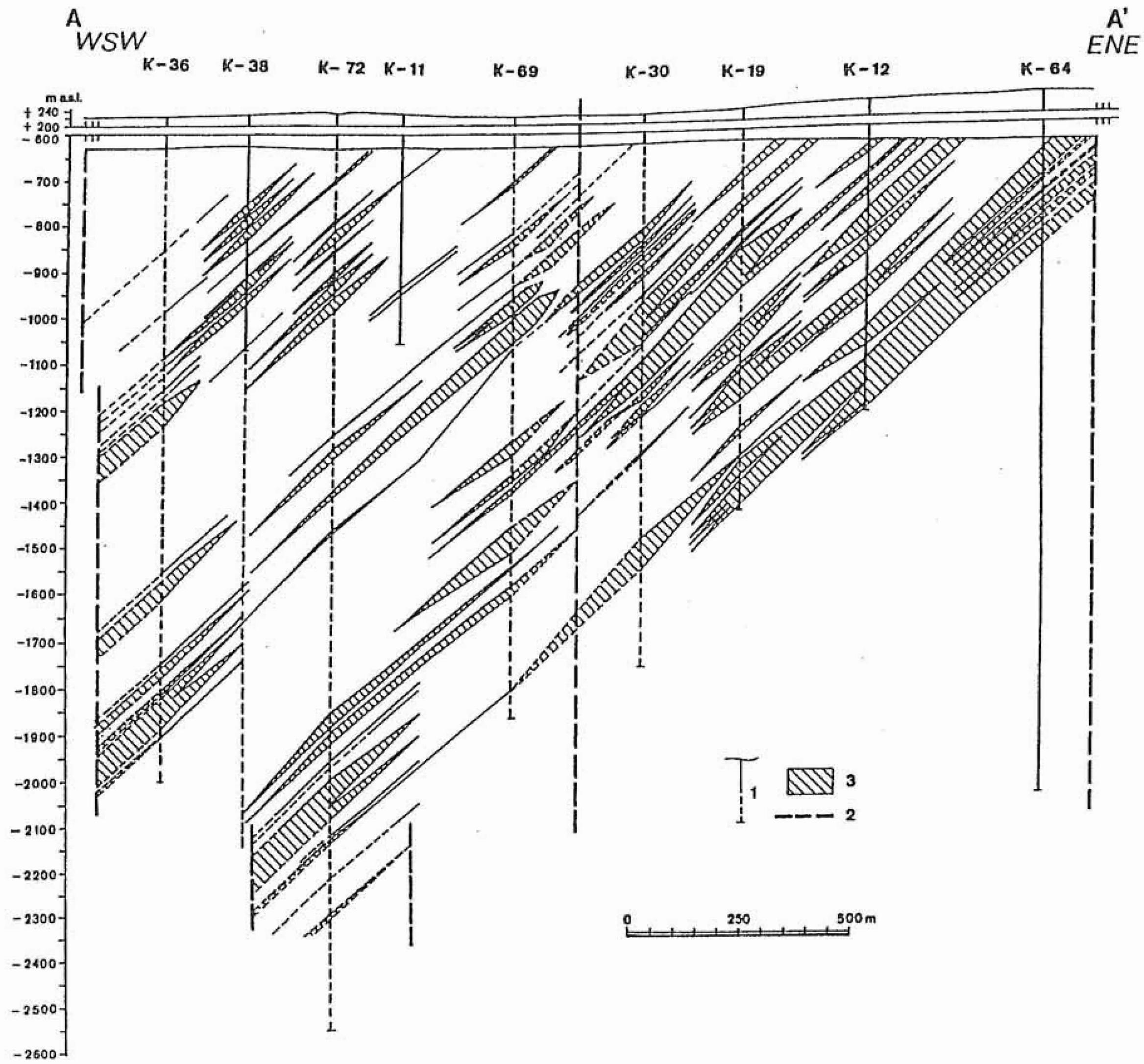

Fig. 3. Geological section A–A' across the Krzemianka deposit (after A. Parecki, 1998)
1 — boreholes, 2 — faults, 3 — magnetite-ilmenite ores

Przekrój geologiczny A–A' przez złoże Krzemianka (według A. Pareckiego, 1998)
1 — otwory wiertnicze, 2 — uskoki, 3 — złoże magnetytowo-ilmenitowe

1998). The ore complex being hosted by the anorthosite is composed of ore bodies alternating with norites and anorthosites of similar shapes and sizes (H. Kurbiel *et al.*, 1979, figs. 1–3; S. Kubicki, J. Siemiątkowski, 1979, figs. 5 and 6; A. Parecki, 1998, figs. 2 and 3). This structure is shown in Figures 2–5.

Norites are characterized by oriented structure, traces of cataclasis and later blastesis. These features gave rise to suggestions that this complex was formed either due to convection currents in an anorthosite magma chamber (S. Kubicki, J. Siemiątkowski, 1979; J. Siemiątkowski, 1993), or it attained its present-day position, owing to tectonic uplift, after it had been deposited on the bottom of a magma reservoir (S. Speczik *et al.*, 1988).

Some authors explain the origin of the ores as being due to metamorphic processes. One hypothesis assumes that the ore top was separated from rocks being subjected to anatectic processes, and rheomorphicaly squeezed out into the present-day position (W. Ryka, 1979). The other hypothesis assumes the existence of a norite protomylonitic zone which was formed due to disintegration of gabbronorites and anorthosites. These processes resulted in a high heat emission that gave rise to formation of an alloy of ferrolitic rocks, which was displaced due to continuous tectonic movements.

The anorthosite itself shows no stratification, and it is largely composed of plagioclase of a constant content of 45.3–55% An (O. Juskowiak, 1993, 1998). Thus, this is an andesine anorthosite with a small admixture of other minerals.

Ore bodies can be distinguished macroscopically with the distinct although not very sharp boundary with norites, in particular with anorthosite. There are no gradual transitions as it is in the case of stratified ore deposits. Individual ore bodies can be arranged throughout the whole deposit into a continuous range: from low-grade into high-grade ores. This

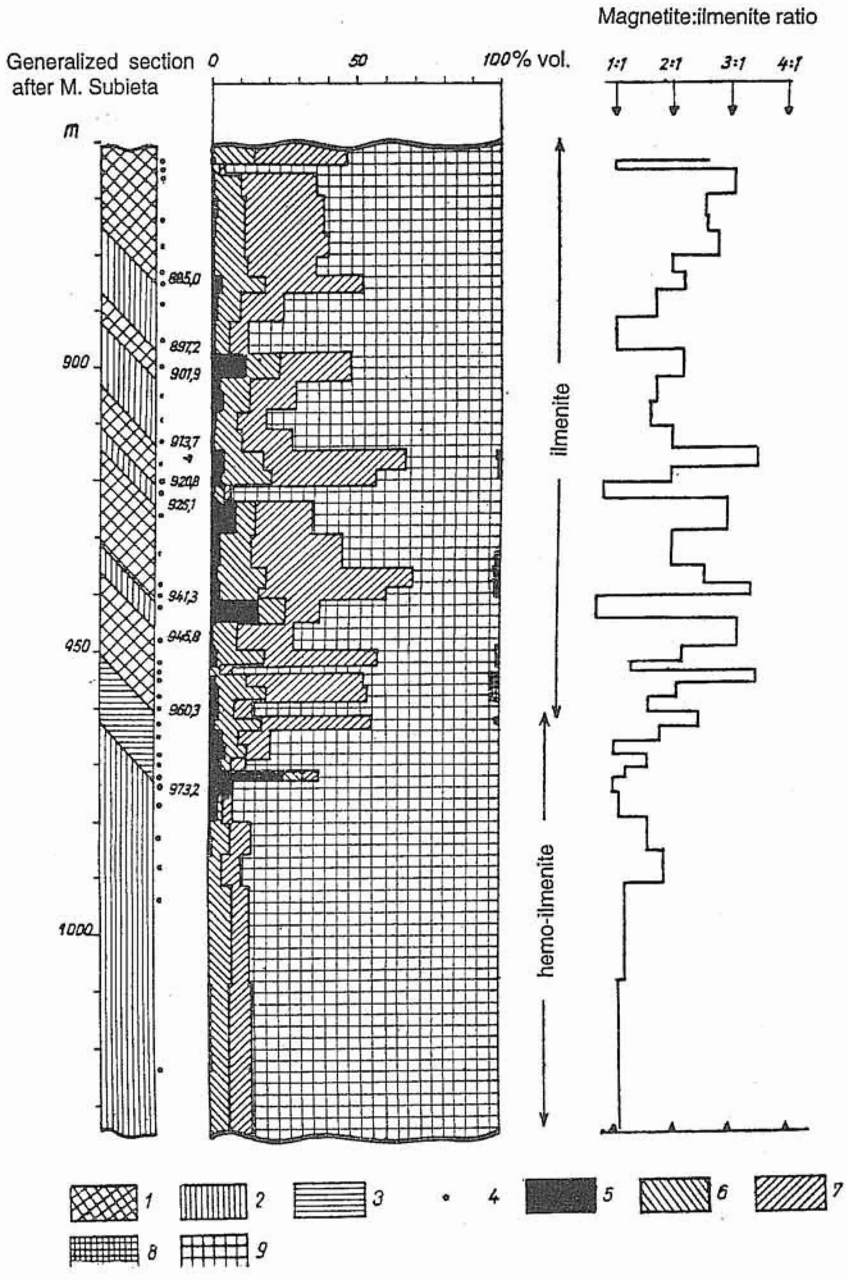

Fig. 4. Mineral composition of rocks and ores of the Suwałki massif exemplified by a fragment of drilling core K1 (after S. Kubicki and J. Siemiątkowski, 1979)
1 — ores and ore-bearing norites, 2 — norites, 3 — anorthosites, 4 — sampling sites, 5 — sulphides, 6 — ilmenite, 7 — magnetite, 8 — aluminium spinel, 9 — silicates

Skład mineralny skał i rud masywu suwalskiego na przykładzie fragmentu rdzenia wiertniczego K1 (według S. Kubickiego i J. Siemiątkowskiego, 1979)
1 — rudy i noryty rudne, 2 — noryty, 3 — anortozyty, 4 — miejsca pobrania próbek, 5 — siarczki, 6 — ilmenit, 7 — magnetyt, 8 — spinel glinowy, 9 — krzemiany

is confirmed by planimetric and chemical analyses. An important feature is also a constant Fe_C/TiO_2 ratio, in spite of both an increase in contents of Ti and Fe, and different ilmenite/magnetite ratios ranging from 1:1 to 1:10 (S. Kubicki, J. Siemiątkowski, 1979, fig. 8; A. Parecki, 1993). This is a result of the occurrence, within high-grade ores, of high amounts of titanium not only in ilmenite but also in magnetites (so-called titanomagnetites) in a form of small inclusions of ulvite and ilmenite. This is one of the factors limiting economic value of the ores as a raw mineral for metallic iron production. Ore dressing processes and yielding of ore concentrates are hindered by the presence of Fe, Ni, Co and Cu sulphides in ores.

Along with the geological documentation of the ore deposit, the research on utilization technologies of the ores, co-ordinated by the Institute for Metallurgy of the Ferrous Metals in Gliwice (*fide* A. Parecki, 1993), was conducted. Basing upon mineralogical and technological studies, four

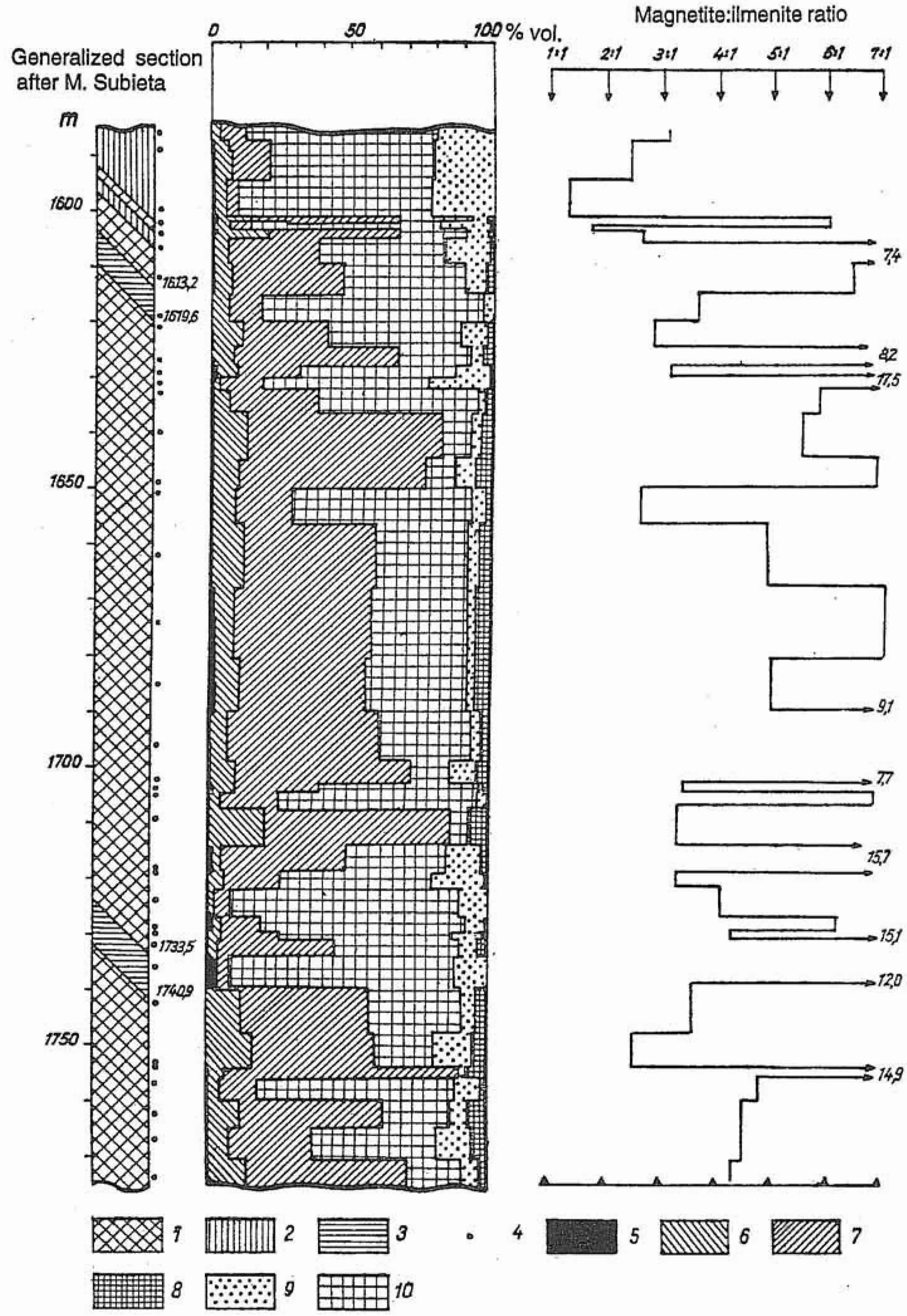

Fig. 5. Mineral composition of rocks and ores of the Suwałki massif exemplified by a fragment of drilling core K22 (after S. Kubicki and J. Siemiątkowski, 1979)

1 — ores and ore-bearing anorthosites, 2 — norites and leuconorites, 3 — anorthosites, 4 — sampling sites, 5 — sulphides, 6 — ilmenite, 7 — magnetite, 8 — aluminium spinel, 9 — pyroxenes, 10 — plagioclases

Skład mineralny skał i rud masywu suwalskiego na przykładzie fragmentu rdzenia wiertniczego K22 (według S. Kubickiego i J. Siemiątkowskiego, 1979)

1 — rudy i anotrozyty rudne, 2 — noryty i leukonoryty, 3 — anortozyty, 4 — miejsca pobrania próbek, 5 — siarczki, 6 — ilmenit, 7 — magnetyt, 8 — spinel glinowy, 9 — pirokseny, 10 — plagioklazy

types of ores have been distinguished according to a content of TiO_2 in magnetite concentrate.

Most of resources belong to type II ores which yield magnetite concentrates containing 62–65% Fe, 2.7–4.7% TiO_2, 2.1–2.9% SiO_2 and 0.5–0.55% V, as well as type III ores containing in ore concentrates 62–63% Fe, 5.3–6.5% TiO_2, 1.1–2.3% SiO_2 and 0.5–0.55% V. The most valuable component of the ores — vanadium, may be obtained by means of a hydrochemical method from magnetite concentrates.

The discovery of the Krzemianka ore deposit and the similar Udryń one (J. Wiszniewska, 1993) influenced the site planning of the Suwałki area. It was changing through time from a concept of an industrial district to an idea of the "green lungs of Poland" (S. Kozłowski, 1993). After the discovery, the site planning was completed, involving a construction of an iron-ore mine, processing works and smelting works. Ecologists' protests gave rise to an idea to locate the processing works underground abandoning the construction of the smelting works and simultaneously suggesting the exploitation of rocks hosting the ore deposit as non-metallic raw materials. The economic crisis in Poland, presumed difficult geological conditions of exploitation and complex technology of ore dressing resulted in abandoning the plan to construct a mine and other objects in 1982. Instead, the idea of the "green lungs of Poland" and even of Europe (S. Kozłowski, 1993) appeared in 1992 in the site planning concepts of the Suwałki area.

The question put by Jerzy Znosko: "How to get both the ore and the Suwałki area" (J. Znosko, 1993*a*), was solved by the economy in favour of the Suwałki area protection (A. Bolewski *et al.*, 1998). The Krzemianka ore deposit lies deep under the surface, it is overlain by water-bearing layers, and the processes of recovering metals from the ore, in particular of titanium and iron, are difficult and expensive.

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ZŁOŻE RUD ILMENITOWO-MAGNETYTOWYCH KRZEMIANKA W PÓŁNOCNO-WSCHODNIEJ POLSCE: ZARYS HISTORII ODKRYCIA I ROZPOZNANIA

Streszczenie

Odkrycie w 1962 r. złoża rud ilmenitowo-magmetytowego Krzemianka zawierających wanad wiąże się z badaniami formacji krystalicznych podłoża północno-wschodniej Polski. Badania te zaprojektował J. Znosko (1956, 1957).

Po 28 latach prac udokumentowano 726 mln t rudy zawierającej 214 mln t Fe, 53 mln t TiO_2 i 2,3 mln t V_2O_5. Złoże składa się ze 111 ciał zbliżonych kształtem do soczewek o upadzie 45° na zachód, miąższości od kilku centymetrów do 145 m, długości do 1100 m i szerokości do 320 m. Rudy ze względu na zawartość TiO_2 (od 0,9 do 9%) w magnetycie podzielono na cztery grupy. Przeprowadzono studia nad planami zagospodarowania przestrzennego Suwalszczyzny i stworzono wizję okręgu przemysłowego. Po protestach ekologów oraz wprowadzeniu bardziej realistycznej polityki ekonomicznej zaniechano budowy kopalni, stworzono wizję „zielonych płuc" Polski, a następnie Europy.