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Petrologic and isotope evidence for crustal source of ore-bearing Suwałki Anorthosites, Poland

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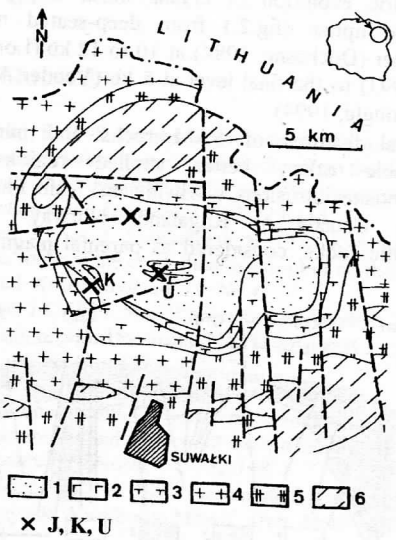
ABSTRACT: The magmatic Fe-Ti-V deposit in the Suwałki Anorthosite Massif (SAM), discovered in early 60-ties, is the largest deposit of iron and titanium in Poland. The SAM belongs to bigger W-E trending Proterozoic magmatic terrane called Mazury Complex. Ilmenite and magnetite are widespread ore-minerals with subordinate quantities (1-3% of vol.) of Fe, Cu, Ni, Co sulfides in SAM rocks. Ore minerals form large ore bodies in Krzemianka, Udryń, Jeleniewo and Jezioro Okrągłe ore fields with total documented reserves of abount 1.5 bilion tons of titanomagnetite ores grading (in wt %) 27% Fe, 7% TiO_2 and 0,3% V_2O_5. Petrographic and geochemical study of main, trace, ultratrace elements and isotopic characteristics (E_{Nd}, I_{Sr}, γ_{Os} and $\delta\ ^{18}O$) of SAM rocks points towards the lower, mafic crust, close to mantle/crust boundary as the most probable source of the rocks. The Re-Os ages on magnetite and sulfides have yielded 1559±37 Ma for Krzemianka and Jezioro Okrągłe and 1556±94 Ma for Udryń deposit.

1.INTRODUCTION

Large Fe-Ti-V ore deposits are associated with most of Proterozoic massif-type anorthosites of AMCG (anorthosite-mangerite-charnockite-granite) suite, eg. Rogaland (Norway), Allard Lake (Canada), Adirondack (USA). Suwalki Anorthosite Massif (fig.1.) and its titanomagnetite ores belong to this type of occurrences. The crystalline Proterozoic basement of the Suwalki area is covered by 800-1000 m of Phanerozoic sedimentary rocks. Ore deposits have been found by magneto-gravimetric surveys and evaluated down to the depth of 2300 m by over 100 boreholes yielding of about 1.5 bilion tons of economic reserves.

The composition of ore mineralization, its evolution, paragenetic assambleges and mineral succession have been studied in previous years by Kubicki and Siemiątkowski, (1979), Speczik et al.(1998), Kozłowska and Wiszniewska, (1989) and Wiszniewska, (1998).

Magmatic origin for the Suwałki ores and host rocks have been proposed by Kubicki and Siemiątkowski (1979). It has been considered that pseudostratiform layers of ore bodies originated due to emplacement of oxide-silicate melt alongside fault zones inside anorthosite-norite intrusion. Speczik et al. (1988) have discussed two separate processes responsible for poor ores accumulated in distinct ore-bodies like: vein, dispersed mineralization and for rich, massif s, pseudolayers, beds, nests and schlieren. They have suggested that



1.anorthosites, 2.gabbronorites, 3.dioritoids, 4. granites, 5.granitogneisses, 6.gneisses. **X** - **J**-Jezioro Okrągłe ,**K**-Krzemianka, **U**-Udryń –ore fields

Fig.1.Geological map of the Suwałki anorthosite intrusion (after Kubicki & Ryka, 1982, modified)

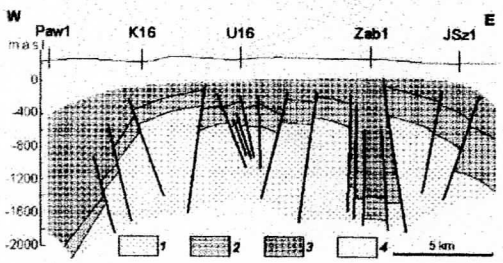
dispersed ore-minerals are genetically related to the anorthosite evolution and should be classified as a segregation type of mineralization. The massive-type titanomagnetite ores crystallized in different p-T-fO_2 conditions and should be classified as accumulation-type stimulated by "filter-press" and "squeezing out" of interstitial oxide melt. Basic petrographic study of all types of host rocks have been summarized by Juskowiak (1998). Only a few geochronological data by K-Ar method (Depciuch et al 1975, Jarmołowicz -Szulc, 1990) and by Rb-Sr (Bachliński, 1998) have been reported for SAM rocks. They show resetting or cooling ages of the rocks.

Trace and REE characteristics of the host rock minerals and main ore minerals; Re-Os age and Os/Os ratio combined with isotopic ratios of strontium *versus* neodymium and $\delta\ ^{18}O$ values of selected oxides and silicates are presented in this study

2 GEOLOGY OF ORE DEPOSITS

The SAM is composed mainly of plagioclase cumulus crystals with local enrichment in iridescent plagiclase megacrysts (ca.An55) with high Sr (800-900 ppm), high Fe (0.5-1.0% Fe_2O_{3t}) and Ti (0.04-0.1% TiO_2) and large megacrysts of aluminous orthopyroxene, considered to be the evidence of polybaric evolution of crystal mush emplaced as diapiric uprise (fig.2.) from deep-seated magma chamber (Duchesne, 1984) at 10 to 12 kb (Longhi et al., 1993) to the final level at 5 kb (Vander Auwera and Longhi, 1994).

Several features of SAM rocks and minerals resemble other, better studied regions of anorthosite intrusions worlwide eg. Nain Plutonic Suite, Canada or Rogaland, Norway. Thus, jotunitic rocks, considered as parental magma for



1.anorthosites,2.gabbronorites,3.dioritoids,4.sedimentary cover. Paw1, K16, U16 ect. boreholes.

Fig.2 Cross-section W-E through the SAM after Juskowiak, 1998, modified).

anorthosites (Vander Auwera and Longhi, 1994, Duchesne, 1999) from Rogaland have been compared with jotunites from Suwalki and Sejny intrusions .

Mineral composition of ferrolites (ore bodies) in the SAM; Krzemianka, Udryn, Jeleniewo and Jezioro Okrągłe are almost identical. Two solid solution series; magnetite-ulvöspinel and ilmenite-hematite, dependent on p-T and oxidation condition (fO_2), exist in ferrolites and host, basic rocks.

3 RE-OS AGE DETERMINATION

Anorthosite is a difficult rock for dating because of its monomineralic composition, exceeding 90% of plagioclase. Very rare zircon or baddeleyite crystals, used for U-Pb dating of massif-anorthosites are difficult to extract from small volume drill-cores.

Therefore, the Re-Os method has been applied for the first time to this type of rocks comprising dispersed Fe-Cu-Ni-Co sulfide minerals in titanomagnetite ores and host rocks (Stein et al 1998). Re and Os abundances and Os isotopic compositions were measured for nine sulfide and four titanomagnetite samples from the Suwałki Fe-Ti-V ores located in three different ore fields: Udryń, Krzemianka and Jezioro Okrągłe. Renium and osmium content in titanomagnetites are very low as compared to the co-existing sulfides. Pyrrhotite, pyrite and chalcopyrite contain Re (0.4-1.5 ppb) and Os (0.036-0.144 ppb) and (30-55 ppb) and (1-6 ppb) respectively. The age of 1559±37 Ma with the initial $^{187}Os/^{188}Os$ of 1.16±0.06 for the Jezioro Okrągłe and Krzemianka deposits is essentially identical to the age of 1556±94 (n=3) for the Udryń deposit (Morgan et al, 2000).

4 RADIOGENIC AND STABLE ISOTOPES

Initial Sr and Nd isotope ratios of the SAM anorthosites and gabbronorites have been obtained from ten selected samples. The results were recalculated to 1.5 Ga , and considered as identical to the age of the whole SAM dated by Re-Os method. The $^{87}Sr/^{86}Sr$ ratios range from 0.70458 to 0.70548 and $^{143}Nd/^{144}Nd$ from 0.51037 to 0.51078. The corresponding I_{Sr} and ε_{Nd} values for anorthosites are 26.2 to 39.6 and -6.3 to 1.56 respectively (Wiszniewska et al, 1999, Wiszniewska, 2000). The mostly negative ε_{Nd} values obtained give the evidence of potential

crustal derivation of the SAM rocks. The low initial Sr isotope ratios can be explained by the Rb-depletion of mafic lower crustal rocks rather then by the mantle signature of strontium ratio. On the other hand, the very high initial $^{187}Os/^{188}Os$ ratios, exceeding 1.16 ± 0.06 for Krzemianka and 0.87 ± 0.20 for Udryń, indicate that the source material was crustal and significantly older for the Suwałki ores and associated host anorthosites. (Stein et al. 1998, Morgan et al. 2000).

The $\delta\ ^{18}O$ values of feldspars from five boreholes of SAM vary within a relatively small range from 6.4‰ to 7.4‰. The average $\delta\ ^{18}O$ value for three whole rock jotunitic samples from the Udryń 18 borehole yielded from 2.8‰ to 3.7‰ and for magnetites from Jeleniewo, Łopuchowo, Krzemianka and Sejny the values range from 3.0‰ to 5.5‰. These ranges are consistent with Taylor`s (1969) determinations measurements for "normal" unmetamorfosed, magmatic anorthosites and related rocks. The plagioclase-magnetite oxygen isotope pair from Jeleniewo and Suwałki show similar temperature of about 870°C. This temperature of crystallisation consist rather the lowermost than highermost range for the plagioclase-magnetite pair studied (Jędrysek, M.O. and Sachanbiński,M. 1994). Experimental works carried out by Longhi et al.(1999) and Vander Auwera et al (1994, 1998) , show that parent melt was highly aluminous which plots on thermal highs in the respective phase diagrams, where opx + cpx are in equilibrium with plagioclase at 11.5 kb and 1300°C. This means that such liquids cannot be generated by fractionation of mantle derived basaltic magmas. The only possible source are (dry) mafic lower crustal rocks. Chilled jotunitic rocks from Suwałki and Sejny closely resemble jotunitic rocks from Hidra, Tjorn and Tellnes bodies in Rogaland (Norway), and thus could have similar origin (Fig.4).

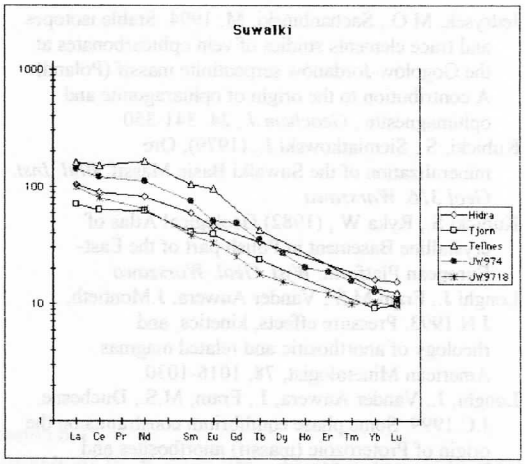


Fig.4 Chondrite normalizedREE pattern for jotunites from SAM and Sejny comparing to Rogaland (Norway)

5. CONCLUSIONS

The Suwałki rocks could be classifid to the typical AMCG suite of within-plate, anorogenic magmatic complex. The presence of high-Al megopx and megacrysts of iridescent plagioclase indicate polybaric evolution of the massif.

Mineral deformations (granulation, polygenization) during diapiric emplacement of partly crystallized crystal mush are also typical features of anorthosite massifs worldwide. Direct melting of high-Al gabbroic or gabbrodioritic (jotunitic) lower crustal rocks could be considered as a source material for the Suwałki ore-bearing anorthosite massif. High initial $^{187}Os/^{188}Os$ ratios and ε_{Nd} values support the concept of crustal origin of the Suwałki anorthosites.

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