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A PETROLOGICAL-GEOCHEMICAL OVERVIEW OF THE TAJNO CARBONATITE COMPLEX (NE POLAND): A COMPARISON WITH THE KOLA CARBONATITE PROVINCE (RUSSIA)

Abstract: The Tajno massif is an alkaline-carbonatite body intruding the Proterozoic crystalline basement of NE Poland that belongs to the East European Craton. It is a plutonic-volcanic complex composed of the three classical lithological members found in the Kola province: ultramafic cumulates (mainly clinopyroxenites), alkaline silicate rocks (syenites) and several generations of carbonatite occurring as thin (<1m) veins that crosscut the other rocks and as cement of the central brecciated chimney zone of the body. By contrast with the Kola carbonatites, the Tajno carbonatites are poor in silicate minerals (except alkali feldspar) and in Nb-rich phases but they contain fluorite and sulfides. The paper reviews the main geochemical characteristics of the Tajno rocks and compare them to their equivalents in the Kola massifs.

Keywords: carbonatites, clinopyroxenites, geochemistry, Tajno massif, Kola Peninsula

INTRODUCTION

The Tajno massif was discovered in the 1950's by gravity method. It was drilled during the 1960's and the 1980's through the 600 m thick, Mesozoic to Caenozoic sedimentary cover. Twelve boreholes, down to about 1300 m, allow to delineate the approximate extent of the massif that covers about 5 km². A monograph with petrographical description and preliminary geochemical data has been published by the Polish Geological Institute and edited by Ryka (1992a). Since that time, the Tajno massif has not been extensively studied.

Together with the much bigger (400 km²) Ełk syenite intrusion and Pisz gabbrosyenite complex, the Tajno massif intruded the Proterozoic granites, gneisses and migmatites of the so-called Mazovian unit (Ryka 1998) south of the Mazury anorogenic magmatic complex of NE Poland (Dörr *et al.* 2002) that comprises the Suwalki anorthosite massif and related rocks (Wiszniewska 2002). The crystalline basement of NE Poland belongs to the East European Craton and more particularly to the Fennoscandian block (Fig. 1).

The Tajno massif has not been yet properly dated: field relations and preliminary K-Ar age estimates suggest a Palaeozoic age. A Rb-Sr whole rock isochron of the Ełk syenite intrusion points to the age of 355±4 Ma (Blusztajn 1994). If these ages are confirmed (work in progress), the Tajno and Ełk massifs could be contemporaneous with the large Kola alkaline and carbonatite province (KACP) of NW Russia and Karelia that was emplaced during a narrow time interval, 360-380 Ma (Kramm, Kogarko 1994).

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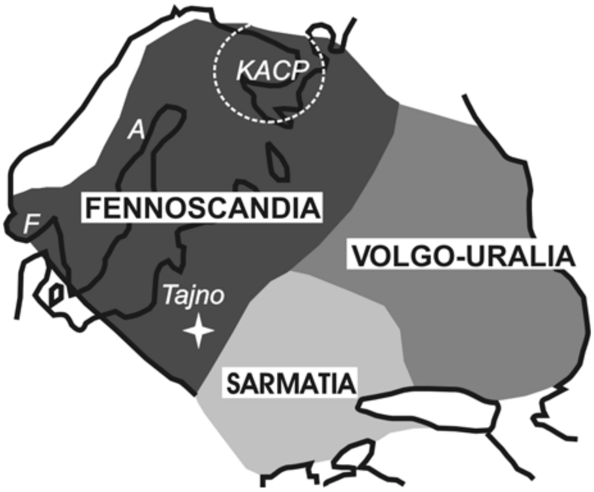

Fig. 1. Schematic map of the 3 blocks (Fennoscandia, Sarmatia and Volgo-Uralia) that form the East European craton. Localisation of the Tajno massif in NE Poland and of other carbonatite occurrences; KACP – Kola alkaline carbonatite province, A – Alnö massif, F – Fen massif (adapted from Gee and Zeyen 1996).

The Kola alkaline carbonatite province consists of more than 20 ultramafic, alkaline and carbonatite complexes, including the well-known agpaitic nepheline syenite complexes of Khibiny and Lovozero. Kukharenko *et al.* (1965) and Kogarko *et al.* (1995) provide an overview of the field relations and petrographical description of the various Kola intrusions. Downes *et al.* (2005) review the petrogenetic processes of the Kola magmatism.

THE TAJNO COMPLEX: FIELD RELATIONS AND PETROGRAPHIC FEATURES

Field relations are difficult to assess as the Tajno complex is only known from boreholes. Twelve boreholes have penetrated various magmatic lithologies down to a maximum depth of about 1300 m. It appears that the Tajno complex is a multiphase igneous body comprising both plutonic and volcanic rocks. The plutonic rocks are essentially clinopyroxenites and alkaline silicate rocks, mainly syenites. The central part of the intrusion consists of a diatreme breccia pipe (800 m in diameter) with pyroclastic material.

Subvolcanic rocks occur as dykes crosscutting the plutonic rocks; Krystkiewicz and Krzeminski (1992) described 3 series of rocks: ultrabasic foidites or nephelinites, phonolites-tephrites and tinguaites. According to Dziedzic and Ryka (1983), and Ryka (1992b), carbonatites occur either as thin (<10 cm; exceptionally up to 1 m) veins crosscutting the plutonic rocks or as cement of the central chimney breccia.

Clinopyroxenites (Fig. 2A) are essentially medium-grained cumulates of diopside + magnetite + titanite ± apatite with interstitial phlogopite, amphibole and alkali feldspar. Two kinds of clinopyroxene have been recognised in most pyroxenites: 1) large (>3 mm) zoned, inclusion-rich crystals (core: Mg# 0.86 to 0.75) that locally form clasts embedded in a finer-grained matrix and 2) elongated prismatic, unzoned and inclusion-free, crystals (Mg#: 0.78-0.61). Variations of grain size and of deformation texture (cataclasis) are observed from sample to sample.

Syenites are also quite variable. Two end-members are tentatively identified. 1) Syenites-melasyenites with miaskitic texture: they contain colourless, tabular and slightly zoned clinopyroxene (Mg#: 0.76-0.63 in the core; low Na_2O content: 0.75-1.22 wt%), titanite and apatite embedded in large poikilitic, perthitic alkali feldspar. In our view, these syenites could be associated to the clinopyroxenites and represent a slightly more evolved stage with a higher proportion of interstitial aggregate. 2) Nepheline syenites (Fig. 2B) are less common: they show typical agpaitic texture with large, twinned, microperthitic alkali feldspar laths and strongly zoned clinopyroxene with colorless augite core (Mg#: 0.76) and dark-green aegirine-augite to aegirine rim (Mg#: down to 0.23 and high Na_2O content, up to 4.35 wt%). They contain lamprophyllite, a typical mineral of the agpaitic nepheline syenite of the Lovozero intrusion.

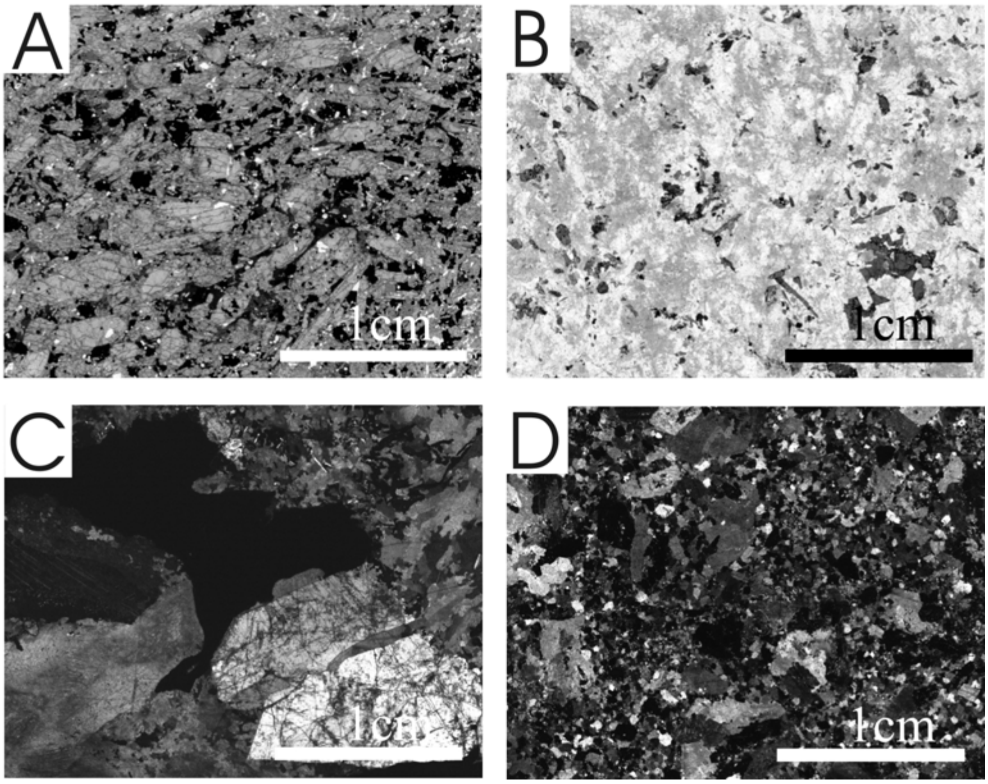

Fig. 2. Microphotographs of the main lithological units of the Tajno massif. A. Clinopyroxenite (sample 6-614.5; parallel nicols); B. Agpaitic nepheline syenite (sample 8-1254.6; parallel nicols); C. Carbonatite with subhedral alkali feldspar(sample 7-1128.6; crossed-nicols) and D. Albitite (sample 10-1091; crossed-nicols).

Carbonatite. Three stages of its emplacement were recognised by Ryka (1992b): 1) the early stage carbonatites have been only found as fragments in the central breccia; 2) the second stage carbonatites form the main stage (Fig. 2C): they occur as veins and as cement in the breccia; 3) the late-stage carbonatites could be related to late hydrothermal activity.

Grain size variations have been observed from borehole to borehole; most carbonatites are fine-grained (mm) but coarse varieties (calcite grains ≥ 1 cm) have been found locally.

Textures are variable as well: some carbonatites are granular, others display a porphyroclastic texture; others have a comb texture with elongated calcite grains (Katz, Keller 1981).

More than 70 minerals have been identified by Ryka (1992b). Calcite is the main mineral phase, hence the rocks are mainly calciocarbonatites (ferrocarbonatites and silicocarbonatites are uncommon). Calcite is often Sr-rich and locally contains strontianite inclusions. Other carbonates (dolomite, ankerite, burbankite and/or REE-bearing fluorocarbonates) have been identified.

Ryka (1992b) suggested that fluorite is the second major mineral phase in the carbonatites, with modal abundance generally < 10 vol%, but as high as 50% in some samples. In fact, fluorite is generally absent in the bulk carbonatites, it mainly occurs as cement in the central breccia. As fluorite is absent in the Kola carbonatites, the Tajno carbonatites resemble the Okorusu fluorite-bearing carbonatites of Namibia (Bühn *et al.* 2002) in which fluorite ores are associated to the fenitised zones.

Apatite is ubiquitous in Tajno carbonatites, but not very abundant (average: 0.4 vol%). Magnetite is present; sulfides (pyrrhotite, pyrite, chalcopyrite, sphalerite) are abundant; late-stage sulfates (barite, celestine) have been found.

Large (up to 1 cm) euhedral twinned alkali feldspar is the main silicate mineral, phlogopite and aegirine have been found in some samples. Nb-rich minerals (i.e. perovskite, pyrochlore) are virtually absent in the Tajno carbonatites, except in one sample. By contrast with the Kola carbonatites, phoscorites are absent in Tajno.

Carbonate-bearing albitites (Fig. 2D) have been recognised; they contain euhedral (50-200 µm) zircons closely associated to the calcite and dolomite grains.

Most subvolcanic rocks are deeply retrogressed and altered. Relics of porphyritic texture can be still recognised locally.

GEOCHEMICAL FEATURES

Major and trace element contents have been analysed in 25 whole rock samples (13 carbonatites, 5 clinopyroxenites, 3 syenites, 2 albitites and 2 volcanites).

The clinopyroxenites have rather low SiO_2-content (35-52 wt%) but quite high CaO (13.9 to 18 wt%), Fe_2O_3tot (8.6 to 21 wt%), TiO_2 (4.5 to 7 wt%) and P_2O_5 (0.6-1.6 wt%) contents. K_2O and CO_2 contents are also quite variable, 0.3 to 3 wt% and 0.3 to 1.6 wt% respectively. The REE patterns (Fig. 3A) are strictly parallel with LREE enrichment $(La/Yb)_N$: 21-30 and no Eu anomaly. The bulk REE content varies largely with La_N ~100 up to 700. These geochemical variations can be directly related to the degree of differentiation and to variation of modal proportions of the main cumulus phases (diopside, titanite, magnetite, apatite) on one hand and of the amount of trapped interstitial liquid on the other hand. It is typical of the studied samples that the rocks with low REE content also have generally low LILE content (Rb, Sr, Zr, U, Th, Nb) and clinopyroxene with rather high Mg# (0.78-0.82).

The syenites-melasyenites are SiO_2-poor rocks (45-47 wt%) with low Mg# (0.25) and significantly lower CaO (8-9 wt%), Fe_2O_{3tot} (11-13 wt%) and TiO_2 (3.4-3.9 wt%) contents than the clinopyroxenites. They are enriched in alkalis (Na_2O+K_2O: 7.5 to 9 wt%). The agpaitic nepheline syenites have still more evolved compositions with SiO_2=55 wt%, Na_2O+K_2O up to 14.5 wt% and very low Mg# (0.16).

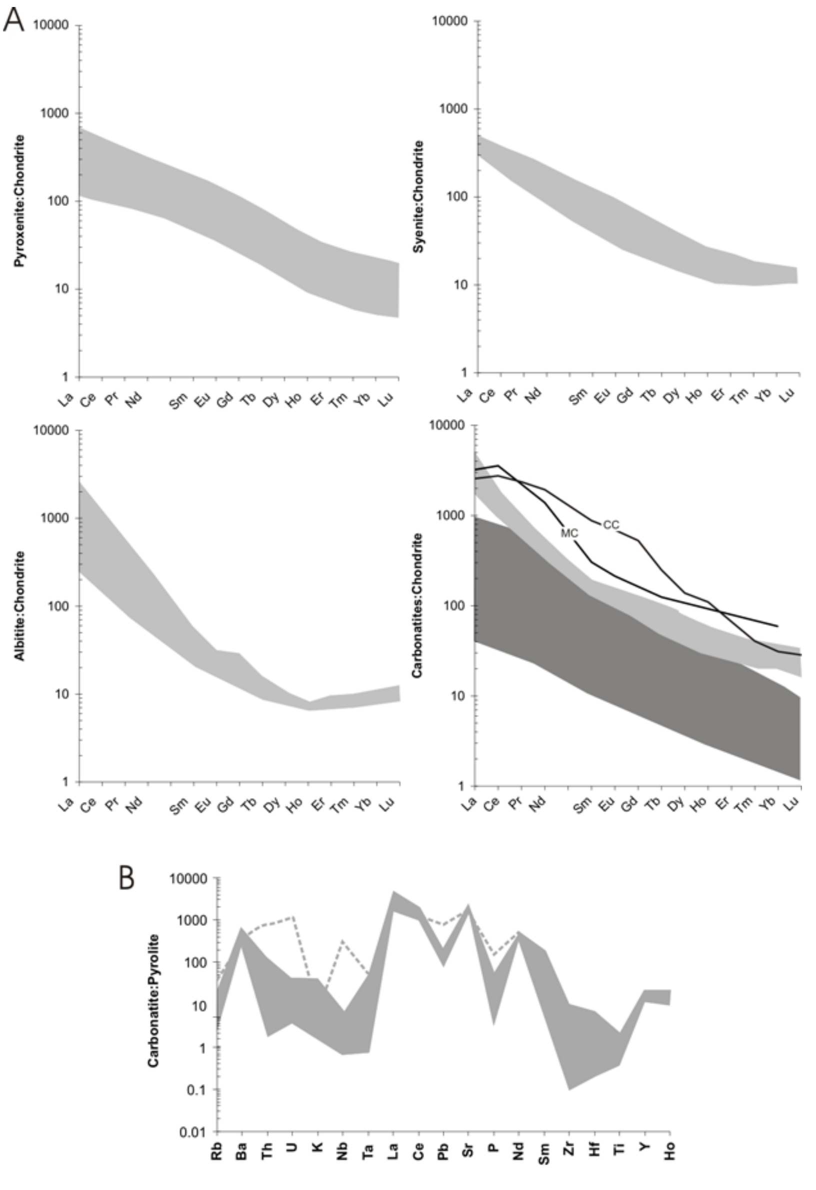

Fig. 3. A. REE chondrite normalised diagrams for clinopyroxenites (n=5), syenites (n=3), albitites (n=2) and carbonatites (n=13); B. Spidergram for carbonatites normalised to the pyrolite. Normalisation values from McDonough, Sun (1995). MC and CC: average magnesiocarbonatite and calciocarbonatite (Woolley, Kempe 1989).

The syenites-melasyenites have linearly decreasing REE patterns, from L- to HREE. These patterns are very similar to those of the clinopyroxenites; the REE content falls in the upper part of the clinopyroxenite range of values (Fig. 3A). By contrast, the agpaitic nepheline syenites have significantly lower REE content the syenites-melasyenites, with a slightly convex upwards normalised pattern (Fig. 3A). This could suggest that a REE-enriched mineral fractionated at that stage: titanite is suitable as it is a cumulate phase in the clinopyroxenites and is highly enriched in LREE with $Ce_N > La_N$, *cf.* recent work on titanite from Alnö alkaline intrusion by Hode Vuorinen and Hälenius (2005).

All the analysed carbonatites are calciocarbonatites; the Ca/Ca+Mg ratio is always higher than 0.98. The iron content can be quite high (up to 6 wt%) in relation with the high pyrrhotite modal contents. The silica content is variable but always rather low (0.5 to 8 wt% SiO_2). The common presence of euhedral to subhedral alkali feldspar explains the K_2O (up to 1.7 wt%) and Al_2O_3 (up to 2.5 wt%) contents. Despite their major element chemical variations, the carbonatites have very similar REE distribution patterns (Fig. 3A) with La_N in the narrow range from 1870 to 2650 (one sample at 5000); $(La/Yb)_N$: 60 to 220 and no Eu or Ce anomalies. Similarly to most Kola carbonatites, the Tajno carbonatites have globally lower REE contents than the average calciocarbonatites and magnesiocarbonatites (Woolley, Kempe 1989). In the Tajno complex Ryka (1992b) has observed REE-rich carbonatites with total REE_2O_3 in the range from 2 to 9 wt%. We did not analyse these REE-bearing carbonatites. In multielement diagrams (Fig. 3B), the carbonatites also appear quite homogeneous with high enrichment factors (500× to 5000× pyrolite values) for Ba, Sr, LREE, and moderate to low enrichments (2× to 50× pyrolite) for K, Rb and HFS elements (U, Th, Zr, Hf, Nb and Ta). The Tajno carbonatites are very unusual by their low Nb annd Ta contents; only one sample is strongly enriched in Nb and Ta (moreover in U, Th and Pb).

Two volcanic rocks of the trachyte-phonolite family have been analysed, their REE patterns are intermediate between those of the clinopyroxenites and the carbonatites: they presumably represent melt which was in equilibrium with the various cumulates (clinopyroxenites, syenites).

Few preliminary Sr and Nd isotopic data for carbonatite have been obtained, the initial ratios were recalculated assuming an age of 360 Ma (similar to carbonatites in the Kola province). The initial $^{87}Sr/^{86}Sr$ ratio (~0.7037) and $^{143}Nd/^{144}Nd$ (0.51220-0.51234), corresponding to εNd_{360Ma} of +0.69±3.45 suggest a slightly depleted time-integrated mantle source, comparable to the source of the Kola magma *see e.g.* Verhulst *et al.* (2000) for the Kovdor massif and Downes *et al.* (2005) for the isotope data of the Kola province.

DISCUSSION AND CONCLUSIONS

The Tajno intrusion is a differentiated plutonic-volcanic complex that associated typical cumulates (clinopyroxenites and syenites) with several generations of carbonatite and of subvolcanic rocks. In that respect, the Tajno massif is comparable to the ultramafic, alkaline and carbonatite complexes of the Kola province.

Nevertheless, the Tajno rocks have some mineralogical and geochemical peculiarities as compared to their Kola equivalents:

1) foids are much less abundant in the Tajno massif. In the carbonatites, foids are completely absent while alkali feldspar is common. Typical agpaitic nepheline syenites are rare in the Tajno complex.
2) Perovskite is absent in Tajno rocks while titanite appears as a cumulate phase in the clinopyroxenites. These observations point to a higher silica activity in the Tajno magma. Perovskite $CaTiO_3$ was probably not stable and reacted with silica to form titanite:

$$CaTiO_3 + SiO_2 \rightarrow CaTiSiO_5$$

3) The Tajno carbonatites do not contain the typical accessory minerals (pyrochlore, perovskite, zirconolite, baddeleyite) that are found in other carbonatites. This

explains the low average Nb content of the Tajno carbonatites. By contrast, fluorite and sulfides are abundant as cement of the carbonatite breccia.

If the late Paleozoic age of Tajno massif (and nearby Ełk syenite intrusion) is confirmed, Tajno massif would belong to the Kola-Karelia carbonatite province and would extent this province to the whole Fennoscandia block of the East European craton.

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