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## PRECAMBRIAN CRYSTALLINE BASEMENT OF NORTHEASTERN POLAND – NEW APPROACH

**Abstract:** The paper presents a discussion of few stages of a history of geological recognition of the Polish part of East European Craton. Moreover, it is shown how scientific concepts, ideas and models for basement geology have been changed during the last 20 years. The last ten years of scientific international collaborations, application of new geochronological methods, new geochemical technics and ideas resulted in developing modern view on geodynamic Precambrian evolution in that area. The updated genetic characteristics of the discussed rock complexes are presented.

**Keywords:** Precambrian, crystalline basement, U-Pb geochronology, NE Poland

### INTRODUCTION

The Precambrian crystalline basement of the Polish part of the East European Craton (EEC) is covered by thick sequences of non-metamorphosed Phanerozoic sedimentary and volcanogenic rocks belonging to Upper Precambrian to Carboniferous, Permo-Mezozoic and Cenozoic successions of variable thickness, ranging from *ca.* 0.5 km in the NE part to 5-8 km along the SW margin of the EEC (Ryka 1993). Recognition of the deep basement structures was possible through interpretation of the available geophysical data and from direct petrological studies of drill cores from about 250 deep boreholes, distributed unevenly throughout the area.

### PREVIOUS STUDIES

Systematic geophysical and geological studies of the Precambrian crystalline basement in NE Poland have been carried out since the 1950's. The observed EEC structure was believed to have resulted from the superimposition of multiple tectonic cycles, the number and the timing of which have been the subject of long-lasting discussions. The key element of this complex interpretation was a granitoid massif, situated in the centre of the Mazury-Suwałki elevation, mirrored at the surface by a coherent pattern of the potential field data. The long belts of strong, NE-SW oriented magnetic anomalies were interpreted to represent the trend of fold structures preserved in tectonic depressions. Subsequently, the zones of a weakly contrastive magnetic properties, occupying almost a half of the crystalline basement area, otherwise poorly penetrated by boreholes, were considered as granitoid massifs representing the oldest dome-shaped elements, comparable to central massifs in the Svecofenno-Karelian domain. They were believed to have experience a tectono-thermal overprint during the Svecofenno-Karelian cycle (Ryka 1984) and influenced the shape and style of the structures developed at that time. The successive lithostratigraphic scheme elaborated by Kubicki, Ryka (1982) and Ryka (1993), broadly accepted during the

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past two decades, distinguished six main lithostratigraphic units in the Precambrian basement of NE Poland:

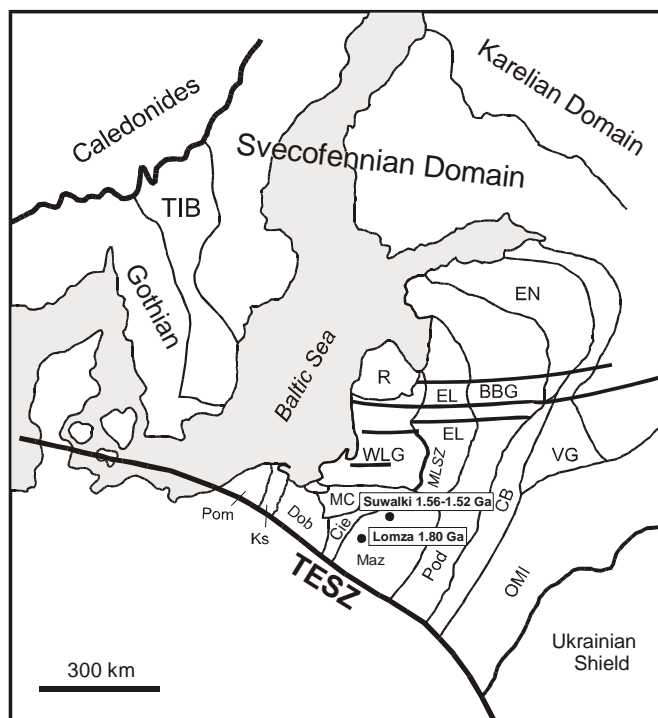
1. Pre-Karelian granitoids in the Mazovia, Dobrzyn and Pomerania massifs;
2. Pre-Karelian metamorphic fold zones: Podlasie complex, Lublin zone, Ciechanów complex (bifurcated into Warmia and Żuławy complexes) and Kaszuby complex;
3. Karelian metamorphic-magmatic Kampinos complex;
4. Gothian magmatic zone, represented by Mazury rapakivi granitoid complex, and by Suwałki and Kętrzyn anorthosite intrusions;
5. Quasi-platform sub-Jothnian Biebrza complex;
6. Palaeozoic sub-platform Elk, Tajno and Pisz intrusions.

Due to the lack of geochronological data, the mutual relationships between the pre-Karelian granitoid massifs and the metamorphic complexes remained mostly hypothetical. The first geochronological Ar-Ar data on biotite yielded the isotope age values of *ca.* 1600 Ma for the Krynki gneiss and 1382 to 1368 Ma for the Sokółka gneiss (Łaszkiwicz 1960). The available K-Ar isotope age determined on biotite and amphibole, usually pointing to Middle and Upper Proterozoic cooling, only reflected the time of final cessation of metamorphism (Kubicki *et al.* 1973). It was generally assumed that the granitoid massifs represented either relatively young domes emplaced into the earlier metamorphosed fold structures or fragments of the dismembered continental crust incorporated into a younger fold belt (Ryka 1993). A further modification of Precambrian lithostratigraphy (Ryka 1998) introduced distinguishing of the Palaeoproterozoic metamorphic Lublin, Podlasie, Ciechanów and Kaszuby complexes and Mazovia, Dobrzyn and Pomerania granitoid massifs, which replaced the earlier scheme of the “pre-Karelian” fold belts and granitoid domains. Rapakivi-like granitoids and anorthosite massifs were assigned to the Mezoproterozoic, including the Mazury igneous complex and Kampinos metamorphic complex. The Neoproterozoic assemblage consisted of the Biebrza complex with a quasi-platform metamorphosed cover.

## TECTONO-METAMORPHIC EVOLUTION

Last ten years of international scientific investigations resulted in developing new view on geodynamic evolution that area in Precambrian time. According to the results of these studies, East European Craton consists of three major elements named Fennoscandia, Sarmatia and Volga–Ural block, characterised by different structure and evolution, and formed from Archean to Paleoproterozoic (Bogdanowa 1999; Bogdanova *et al.* 2001). The palaeomagnetic data evidenced the separation of Fennoscandia and Sarmatia about 1.85 Ga ago, *i.e.* before the time of their accretion to the Baltica palaeocontinent. The crystalline basement of NE Poland represents an integral part of Fennoscandia. It is assumed, that Fennoscandia comprises a mosaic of several Archean blocks surrounded by accreted crust rocks, generally the younger, the farther westwards, *i.e.* in the direction of the Transeuropean Suture Zone (TESZ; *cf.* Gaal, Gorbatshev 1987) they occur. The Precambrian basement of NE Poland is spatially and petrogenetically a member of the Baltic-Belarus area. The major feature of this area is an occurrence of lentoid zones of high-grade rocks yielding the Palaeoproterozoic age (Bibikova *et al.* 1995; Bogdanova *et al.* 2001; Skridlaite, Motuza 2001, Krzemińska *et al.* 2005). The Belarus-Podlasie granulite belt (BPG or Pod-BBG), 100–200 km wide, extends in the SW – NE direction on a distance exceeding 600 km, from SE Poland to western Belarus (Fig. 1). In the gravimetric and magnetic images, it is visible as a linear zone of magnetic highs. The belt consists of small lentoid granulite bodies, separated by steep faults and blastomylonitic zones. These rocks

were subjected to variable tectonic and thermal evolution lasting from 1.89 to 1.50 Ga. The metamagmatic granulites, with geochemical characteristic of matured island arc tholeiites are located only in marginal parts of the BPG. Their protolith was emplaced due to subduction-related magmatism at 1.9–1.85 Ga. Further metamorphism in the granulite facies conditions took place at temperatures of 750–760°C (garnet–biotite geothermometer) and under pressures of 7.5–8.5 kbar (Taran *et al.* 2001), and was related to emplacement of bimodal (gabbro, enderbite, charnockite) intrusions at *ca.* 1,79 Ga (Bibikowa *et al.* 1996).



Explanations: R – rapakivi-like granites and related rocks, TIB – Transscandinavian igneous belt, BGG – Baltic – Belarus granulite belt, EL – East Lithuanian belt, WLG – West Lithuanian granulite belt, EN – North Estonian belt, CB – Central Belarus belt, VG – Vitebsk granulite domain, OMI – Osnitsk – Mikashevichi igneous belt; granulite massifs: Maz – Mazow-sze, Dob – Dobrzyń; Pom – Pomorze; metamorphic complexes: Lub – Lublin; Pod – Podlasie; Cie – Ciechanów; Ks – Kaszuby, Mesoproterozoic structures: MC – Mazury Complex with rapakivi-like granitoids and anorthosite massifs.

Fig.1. Tectonic outline of the western part of East European Craton after Bogdanowa (1999) with the structural units after Kubicki, Ryka (1982).

A continuation of the main crustal domains imaged on Eurobridge'95 seismic profile (Eurobridge '95 Working Group 2001) in Lithuania can be also expected in NE Poland. East Lithuanian block (EL) and West Lithuanian block (WL) are the major structures, separated by the Middle Lithuanian Suture Zone (MLSZ; *cf.* Motuza 2005). Model age values  $TDM_{Nd}$  (1.99–2.09 Ga) for the main tectonic-structural units of NE Poland, such as granite massifs and metamorphic complexes, are similar to those obtained for the Svecofennian massifs in Scandinavia and Lithuania (Claesson, Ryka 1999).

The presently conducted geophysical and petrological comparative studies of rocks from Łomża and Mońki and Lithuanian MLSZ and WL rocks shown continuation of MLSZ into NE Poland, just into the Łomża-Mońki area. The geochemical data suggest that the metavolcanic (including metavolcaniclastic) gneisses from Mońki and metavolcanic rocks from MLSZ reflect the same Paleoproterozoic (1.83–1.85 Ga) arc-related volcanic activity (Wiszniewska *et al.* 2005). Isotope age determinations of volcanic

and intrusive arc-related rocks vary between 1.85 and 1.80 Ga, and could indicate arc evolution in Paleoproterozoic. Moreover, the main phase of deformation and metamorphism of the Polish part of the EEC is ascribed to the Svecofennian orogeny (Claesson *et al.* 1996, Valverde-Vaquero *et al.* 2000).

#### MESOPROTEROZOIC POSTCOLLISIONAL MAGMATISM IN MAZURY COMPLEX

The Paleoproterozoic domains of NE Poland were affected by post-collisional, anorogenic magmatism of bimodal, felsic and basic composition. The E-W trending shear zones control the occurrence of these magmatic units that build the Mazury complex (Duchesne *et al.* 1998; Wiszniewska *et al.* 1999). This multiple pluton is composed of anorthosite-norite intrusions *e.g.* Kętrzyn massif, Suwałki massif and Sejny intrusion (Wiszniewska *et al.* 2002, Gawęda, Wiszniewska 2005) and A-type granitoids (Skridlaite *et al.* 2003; Bagiński *et al.* 2001). Granitoids of similar age, but with I-type geochemical features, have been found in Lithuania (*e.g.* in Kabeliai and Gardasiai) and in Belarus. The Kabeliai complex was dated at 1505±11 Ma (Skridlaite, Motuza 2001) and is probably an eastward extension of the Mazury complex. Geochronologically, the Mazury complex well correlates with the Ragunda rapakivi-like complex (NE Sweden) and with several smaller complexes in central Sweden which yielded dates between 1530 and 1470 Ma (Persson 1997) as well as the 1547–1530 Ma Salmi rapakivi granite-anorthosite complex in Russia (Amelin *et al.* 1997). The belt-shaped Mazury complex comprises the Suwałki anorthosite-norite intrusion with ferrolite ores (Fe-Ti-V-bearing) and variously composed felsic and intermediate rocks, such as leucogranite, quartz-monzonite, monzonite, granodiorite, and monzodiorite (Bagiński *et al.* 2001).

The best recognized Suwałki anorthosite massif (SAM) and associated rocks belong to the widespread, magmatic AMCG suite (anorthosite-mangerite-charnockite-granite of “rapakivi” type) and they are connected with Proterozoic deep crustal structures. The Re-Os method of direct age determinations of sulfides and ore oxides was applied for dating anorthosites in the Suwałki intrusion and the related Fe-Ti-V ores (Stein *et al.* 1998). This radiometric method resulted in the precise age determination for ferrolite ores and Fe-Cu-Co-Ni sulfide mineralization, indirectly indicating the age of the Suwałki massif. The isochrone age of the Krzemianka and Jezioro Okrągłe ores is 1559±37 Ma and the Udryń ores yielded 1556±94 Ma (Wiszniewska *et al.* 1999). The U-Pb age determinations, performed on single zircon crystals and on titanite fractions yielded age values of 1525±4 Ma (Krasnopol), 1522±2 Ma (Bartoszyce), 1512±1.1 Ma (Boksze) as well as 1499±4 Ma and 1502±2 Ma for two other quartz monzonites (Dörr *et al.* 2001) which imply an about 25 Ma long emplacement period for the felsic and intermediate rocks of the Mazury AMCG complex. No regularities were found that would link the age values and the geochemical and petrographic compositions of the granitoids. The *ca.* 1425 Ma Ar-Ar date from the Boksze and Krasnopol rocks refers to the age of cooling of the intrusion. The time interval between zircon crystallization at 900 °C and the calculated biotite Ar-Ar age values is *ca.* 100 Ma. The obtained initial isotope Os/Os ratios (which yielded 1.16±0.06 Ma for Krzemianka and 0.87±0.20 Ma for Udryń) and  $\epsilon_{Nd}$  (-1.56 to -6.3) indicate a lower crustal source of the parental Suwałki anorthosite magma (Morgan *et al.* 2000). Rocks of the gabbro-norite composition, remelted at a depth interval corresponding to a pressure of 10–13 kbars and temperature of *ca.* 1300 °C, are believed to be the most probable protolith of anorthosites. Fe-Ti-V ore mineralization was concentrated in the marginal parts of the massif (Krzemianka, Jezioro Okrągłe and Jeleniewo ore fields), as a result of granulation and polygenization processes of anorthosites, as well as filter-pressing and squeezing out

the ore-mineral mush into tectonic cracks and faults (Wiszniewska *et al.* 2001). The  $\delta^{34}\text{S}$  and  $\delta^{13}\text{C}$  values confirm the magmatic origin of pyrrhotite, pentlandite, chalcopyrite in ores and the same sulfides and graphite dispersed in anorthosite. On the contrary, pyrite is a typical secondary mineral of the hydrothermal provenance. The low  $\delta^{18}\text{O}$  value for the whole rock samples, and for the magnetite and plagioclase fractions provides an evidence for the normal magmatic origin and absence of the metamorphic overprints in the Suwałki intrusion (Wiszniewska, Jedrysek 1998).

Table 1. Results of geochronological studies from crystalline basement of Poland, Lithuania and Belarus.

<b>NEOPROTEROZOIC - PALAEOZOIC</b>			
327 Ma	K-Ar: feldspar	cooling of the Tajno massif (Poland)	Depciuch <i>et al.</i> (1976)
318-293 Ma	K-Ar: biotite	cooling of the Elk syenite massif (Poland)	Depciuch <i>et al.</i> (1976)
551 Ma	U-Pb: zircon	CFB magmatic activity (Poland)	Compston <i>et al.</i> (1995)
<b>MESOPROTEROZOIC</b>			
1436-1425 Ma	Ar-Ar: biotite	cooling of Bartoszyce and Krasnopol granitoids (Poland)	Dörr <i>et al.</i> (2001)
1513-1559 Ma	U-Pb: zircon	Mazury-Kabelai AMCG suite (Poland-Lithuania)	Dörr <i>et al.</i> (2001)
1519-1548 Ma	U-Pb: zircon	Sejny jotunite (Poland)	Dörr <i>et al.</i> (2001)
1559-1556 Ma	Re-Os: sulfides	Suwałki anorthosite and ores (Poland)	Wiszniewska, Stein (2000)
<b>PALAEOPROTEROZOIC</b>			
1660-1710 Ma	Ar-Ar: amphibole	NNE shearing, reheating, retrogressive metamorphism in BBG (Belarus)	Bogdanova <i>et al.</i> (2001)
1800 Ma	U-Pb: zircon, monazite	Ivije gneiss protolith (Belarus)	Taran <i>et al.</i> (2001)
1800 Ma	U-Pb: zircon	Slonim enderbites (Belarus)	Taran <i>et al.</i> (2001)
		Okuniew orthogneiss (Poland)	Valverde-Vaquero <i>et al.</i> (2000)
1802 Ma	U-Pb: zircon	Łomża igneous suite (Poland)	Krzemińska <i>et al.</i> (2005)
1830 Ma	U-Pb: zircon	Zeimiai granite (Lithuania)	Motuza (2005)
1836 Ma	U-Pb: zircon	Zeimiai granite (Lithuania)	Motuza (2005)
1850 Ma	CHIME: monazite	Łanowicze charnockite (Poland)	Bagiński, Krzemińska (2005)
1884 Ma	U-Pb: zircon	Shchuchin enderbite in BBG (Belarus)	Taran <i>et al.</i> (2001)

The studied granitoid rocks of the Mazury complex represent the following petrographical types: monzodiorite and granodiorite from the Krasnopol and Boksze area (in the southern part of the Suwałki anorthosite massif) and quartz monzonite from the Gołdap locality (in the central part of the MC). In Bartoszyce, situated in the western side of the Kętrzyn anorthosite massif, there occurs coarse-grained, porphyritic quartz monzonite which is petrographically and geochemically similar to the Fennoscandian rapakivi granites. These rocks commonly contain K-feldspar megacrysts (microcline and microcline microperthite), often mantled by plagioclase (Skridlaite *et al.* 2003). The above mentioned rocks show clearly defined geochemical characteristics, typical of rapakivi

granites, with low MgO, CaO, Al<sub>2</sub>O<sub>3</sub> and Sr amounts, but high contents of K<sub>2</sub>O (4–7,5 wt. %), Rb (64–192 ppm), Zr (412–1316 ppm), Hf, Th, U and REEs (Rämö, Haapala 1995). All the rocks of the Mazury complex are subalkaline. In the agpaitic index versus 10000\*Ga/Al diagram, they generally plot in the field of A-type granites and partly overlap the field of the typical Finnish rapakivi granites. A comparison of the recently obtained U-Pb data for the Mazury complex to several occurrences of anorogenic magmatism in Fennoscandia linked the Mazury complex to the Riga-Aland and Salmi subprovinces, but also to the Swedish magmatic complexes in Ragunda and Nordingra (Persson 1997; Dörr *et al.* 2001).

#### NEOPROTEROZOIC VOLCANIC ACTIVITY

In the uppermost part of the non-metamorphosed Precambrian suite of the Polish part East European Craton the basalts and related volcanoclastic rocks have been observed. The effusive rocks has been widespread in the East European Craton from Polish-Belarus border area to the Volhyn in the western slope of the Ukrainian Shield. The Late Neoproterozoic reactivation remains of continental flood basalts in SE part of the rifting zones: the Orsha–Volhyn aulacogen and the Trans-European Suture Zone (Bakun-Czubarow *et al.* 2000). An age of 551±4 Ma from uppermost tuff horizons in the Lublin region by SHRIMP technique was obtained by Compston *et al.* (1995). The Neoproterozoic volcanic activity in the western part of the East European Craton was probably caused by a rise of a mantle plume and formation of continental rifts during latest stages of the breakup of the Rodinia supercontinent (Białowolska *et al.* 2002). Summary of the main documented magmatic and metamorphic events and comparison of the geochronological results for different tectonic units described above are presented in Table1.

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