Petrology and geochemistry of rapakivi-type granites from the crystalline basement of NE Poland

Bogusław BAGIŃSKI, Jean-Clair DUCHESNE, Jacqueline VANDER AUWERA, Hervé MARTIN and Janina WISZNIEWSKA

Bogusław Bagiński, Institute of Geochemistry, Mineralogy and Petrography, Warsaw University, Zwórk 1, Wyszyński 93, PL-02-089 Warsaw, Poland, e-mail: boguslaw.wigaszewski.pl, Jean-Clair Duchesne, Jacqueline Vander Auwer A, A. Geologie, Pétrologie, Géochimie Université de Liège (Bat. 820) B-4000 Solvay, Belgium, Hervé Martin, Laboratoire Magnésia et Volcans, Université Paul Verlaine, 5 rue de la Place, 59038 Clermont-Ferrand, France, Janina Wiszniewska, Polish Geological Institute, Rakowska 4, PL-00-975 Warsaw, Poland, e-mail: just@pgi.waw.pl (received: October 27, 2006; accepted: December 20, 2006).

Key words: Mazury complex, rapakivi-type granites, jatlanite, granite modelling.

INTRODUCTION

The Mazury complex, situated in NE Poland, is part of the East European Craton (EEC) that forms the northeastern part of Europe (Fig. 1). The western, Polish part of the EEC is covered by Phanerzoic platform sediments. The thickness of this cover varies from 400 m in the east, to 6500 m along the TTA (Tessseiy-Tornquist Zone) (Fig. 2), as the crystalline basement dips to the SW.

The crystalline rocks of the Mazury complex have also been studied recently by Claeson et al. (1995b), Claesson and Ryka (1999), Lorenc and Wiszniewska (1999), Cymery and Wiszniewska (1999), Bagiński et al. (1999, 2000) and Skrdlaitie et al. (2000). The main aim of the present study was to check new geochemical data on various rock types coming from different area (different massif?) of the Mazury complex in respect of their evolution from co-genetic magma batches by similar processes though variable in degrees of pressure, temperature, contamination and level of emplacement.

GEOLOGICAL SETTING

The Polish part of the EEC consists of three large granitoid massifs (Mazovian, Dobrzyńsk and Pomeranian) separated by granulite-gneiss belts (Podlasie, Ciechanów, Kaszuby) with a complex Precambrian history (Fig. 2). The granitoids were thought by Kubicki and Ryka (1982) and by Znosko (1998) to be Archaean, based on sparse K-Ar age determinations of 2.65 Ga (Depcic et al., 1975). Recently, a new approach, based on combined geochronological and petrological studies (Claesson and Ryka, 1999), confines the Archaean domain to the northeastern part of the Baltic Shield (Karelia and Kola Peninsula) and to the eastern part of EEC (Ukraine), excluding Archaean rocks from Poland (Kubicki and Ryka, 1982). Indeed, new Nd model ages obtained at the Swedish Museum Isotopic Laboratory in Stockholm (Claesson and Ryka, 1999) on rocks from the main units of the crystalline basement of Poland were all Palaeoproterozoic. These rocks have been metamorphosed under amphibolite facies conditions and the main phase of deformation and metamorphism of the Polish part of the EEC is now...
considered as Svecofennian in age (Claesson et al., 1995b). Two zircon fractions extracted from the granites of Mazury complex gave an U-Pb age of about 1.5 Ga (Claesson et al., 1995a). Similar rapakivi-type intrusions from Lithuania, the Kabeliai complex (Skirdaité et al., 2000), yielded a zircon U-Pb age of 1505±11 Ma (Sandblad et al., 1994). On another hand, Mazury acidic rocks gave depleted mantle Nd model ages T(Nd) of 2.1 to 2.2 Ga (Claesson et al., 1995b), while the Suwałki anorthosite-gabbro-norite complex yielded Nd model ages of 1.7 to 2.3 Ga (Wiszniowska et al., 1999). Titanomagnetite and sulphide ores from the Suwałki massif dated by the Re-Os method have given isochron ages of 1559±37 and 1556±94 Ma (Stein et al., 1998; Morgan et al., 2000; Wiszniewska and Stein, 2000).

The tectonic setting of Mesoproterozoic magmatism in the Mazury complex has been considered (Kubicki and Ryka, 1982) as linked to a E–W trending zone of post-collisional origin or caused by rejuvenation of an older lineament. Several intrusions of anorogenic character and bimodal composition, mostly rapakivi-type granites and anorthosite-norite intrusions (Suwałki, Sejny, Kętrzyn), have been described within this area. Integrated geophysical approaches have been used to try to determine the shape, structure and extension of the magmatic belt (Wiszniowska et al., 2000). On the magnetic image map, the Mazury complex does not show any specific features, and generally comprises in a mosaic of positive anomalies. On a Bouguer map the anomaly is moderate in comparison to the gravity high on the northern rim of the Mazovian massif and the gravity low of the Dobrzyń domain in the west. The rapakivi-like granitoids show a variable densities, with values mostly higher than those of the anorthosite-norite massifs. In the vector image of the fractional vertical derivative, the gravity
1. Charnockite; main rock components: hypersthene (right center), biotite, quartz, plagioclase; crossed polars, x 28, Lanowicz 10, depth 1162.5 m. 2. Charnockite; hypersthene with numerous inclusions of quartz, ilmenite, biotite and zircon (polikliti texture); crossed polars, x 28, Lanowicz 10, depth 1162.5 m. 3. Leucogranite; visible microcline and albite crystals, quartz and minute biotite; crossed polars, x 28, Olezy 1, depth 2764.0 m. 4. Advanced albisation and sericitisation of plagioclase with small epidote crystals and xenomorphic quartz crystals; crossed polars, x 28, Olezy 4, depth 2780.5 m.
1. Porphyritic texture with large pink K-feldspar in charnockite from the Lasowice drill-core; depth 1111.8 m. 2. Large plagioclase in quartz monzodiorite from the Filipów drill-core; depth 1553.0 m. 3. Porphyritic texture with large plagioclase crystals in quartz monzonic from the Kętrzyn drill-core; depth 1540.5 m; diameter of the coin is 1.5 cm on all photos.
1. Porphyritic texture with large pink K-feldspar in the Golden granite; depth 1648.5 m.
2. Quartz monzodiorite from the Bartoszyce drill-core; depth 2141.5 m.
3. Porphyritic texture with large pink K-feldspar in the Pawłówka drill-core; depth 1907.0 m.
1. Quartz monzonite; clinoptyroxene alteration to hornblende (central left); evidence of deformation in quartz and biotite (upper right); typical structure of titanite growing on ilmenite (black, lower left); crossed polars, x 28, Goldap 4, depth 1648.0 m. 2. Granodiorite; titanite growing on ilmenite (black); numerous biotite slightly altered to chlorite; plane polarized light, x 28, Goldap 2, depth 1636.5 m. 3. Quartz monzonite; large K-feldspars and plagioclase, smaller clinoptyroxene altered to hornblende (center); plane polarized light, x 28, Bartoszyce 3, depth 2130.5 m. 4. Granodiorite; myrmekite zone; crossed polars, x 70, Bartoszyce 1A, depth 2141.5 m.
1. Quartz monzodiorite; altered clinopyroxene crystals within quartz (in the middle); quartz/biotite clinopyroxene symplectite (upper right); numerous small apatites; crossed polars, ×28, Kielno 1, depth 1782.0 m. 2. Quartz monzodiorite; relics of plagioclase within K-feldspar; alteration of clinopyroxene (upper left); crossed polars, ×28, Kielno 2, depth 1785.0 m. 3. Quartz monzonite; typical texture of the rock (not deformed); the main minerals visible: plagioclase; quartz, K-feldspar, biotite and amphibibolized pyroxene; crossed polars, ×28, Filipów 7, depth 1351.5 m. 4. Quartz monzonite; part of rock with clinopyroxene (centre part), biotite and hornblende (right middle), long needle-like inclusion of apatite within epid; crossed polars, ×28, Filipów 11, depth 1491.5 m.
lineaments, marking density contrasts, are enhanced (Wiszniowska et al. 1998, 2000). We suppose that rapakivi-like granite plutons are probably multiple intrusions, emplaced at relatively shallow levels.

**PETROLOGY**

Eight drill-cores from Olsztyn, Lanowice, Goldap, Bartoszyce, Pawłowka, Filipów, Krętyn, and Klenowo, were investigated geochemically (Fig. 1). Their composition ranges from diorites and monzodiorites (Klenowo) to leucogranites (Olsztyn, Lanowice). Eighty samples were chosen for geochemical and petrological investigation.

The Olsztyn leucogranite is a medium-grained rock characterized by abundant, oriented xenomorphic quartz crystals. The ground-mass is composed of quartz, microcline, plagioclase (An<sub>35</sub> - normative), minor biotite, and accessory minerals (apatite, zircon, rutile and opaques) (Pl. I, Fig. 3). The rock is commonly abraded (Pl. I, Fig. 4) and partly chloritized and shows various degrees of chloritisation and sericitisation. Some myrmekites are also present.

The Lanowice drill-core has yielded more than 500 m of crystalline rocks. It consists of several rock types:

1. **Charnockite.** This is a medium-grained rock, in which biotite can locally define a linear fabric. Its modal composition consists of quartz, plagioclase (An<sub>35</sub> - normative), K-feldspar, biotite, hypersthene and accessory minerals (apatite, zircon, magnetite, ilmenite and monazite) (Pl. II, Fig. 1). Garnet appears in meta-charnockite rocks as well as hypersthene, which breaks down to bowingite-like material. Rocks display a porphyritic texture with cm-sized K-feldspar and plagioclase crystals (Pl. II, Fig. 1). A poikilitic texture is also present with hypersthene, quartz, biotite and opaques (Pl. I, Fig. 2).
2. Granodiorites and granites. These are less abundant than charnockites from which they differ only by a lack of hypersthene and differences in plagioclase and K-feldspar abundances.

3. Leucogranites. These are similar to granodiorite, but are usually albitionised with biotite, altered to chlorite.

Metamorphosed rocks with a granitic composition have been also found in the Lomowice drill-core. They form layers several metres thick within charnockites, granodiorites and granites. The relationships between these rock types suggest that they could have been generated in two magmatic episodes, the first one linked to the last metamorphic event, dated in the Belarusian part of the BBG (Baltic-Belarusian Granulite) zone at 1.76 Ga (Bogdanova et al., 1996), and the second one connected with rapakivi magmatism at ca. 1.5 Ga (Claesson et al., 1995). This view is supported by the different textures of the charnockites: the “older” display metamorphic textures with linear biotite and deformed quartz and feldspars, while the “younger” ones display a texture similar to granodiorites. More isoche data are needed to better detail their evolution.

The Goldap porphyritic granodiorites and quartz monzodiorites are medium- and coarse-grained massive rocks with 3–5 cm-sized plagioclase (An90 — normative) and K-feldspar megacrysts (Pl. III, Fig. 1). The groundmass of the rock is made up of plagioclase, K-feldspar, quartz, biotite, minor hornblende, numerous titanite crystals, apatite, zircon and opaques (Pl. IV, Fig. 2). Myrmekites and quartz-biotite symplectites are also present. Changes in the plagioclase/K-feldspar ratio resulted in a magmatic suite from granodiorite (samples 1–3) to quartz monzonite and granite (samples 4–7). The rocks were slightly altered by sericitisation (plagioclases) and amphibolitisation (clinopyroxenes) pro-
<table>
<thead>
<tr>
<th>Sample</th>
<th>La</th>
<th>Ce</th>
<th>Pr</th>
<th>Nd</th>
<th>Sm</th>
<th>Eu</th>
<th>Gd</th>
<th>Tb</th>
<th>Dy</th>
<th>Ho</th>
<th>Er</th>
<th>Tm</th>
<th>Yb</th>
<th>Lu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lilwan 1</td>
<td>28.26</td>
<td>47.23</td>
<td>4.84</td>
<td>13.24</td>
<td>2.65</td>
<td>1.83</td>
<td>2.07</td>
<td>0.39</td>
<td>0.98</td>
<td>0.13</td>
<td>0.57</td>
<td>0.13</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Lilwan 4</td>
<td>44.57</td>
<td>82.26</td>
<td>4.84</td>
<td>13.24</td>
<td>2.65</td>
<td>1.83</td>
<td>2.07</td>
<td>0.39</td>
<td>0.98</td>
<td>0.13</td>
<td>0.57</td>
<td>0.13</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Lilwan 7</td>
<td>32.21</td>
<td>85.85</td>
<td>4.84</td>
<td>13.24</td>
<td>2.65</td>
<td>1.83</td>
<td>2.07</td>
<td>0.39</td>
<td>0.98</td>
<td>0.13</td>
<td>0.57</td>
<td>0.13</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Lilwan 11</td>
<td>72.66</td>
<td>153.62</td>
<td>17.24</td>
<td>62.59</td>
<td>11.02</td>
<td>2.12</td>
<td>16.64</td>
<td>1.41</td>
<td>6.81</td>
<td>1.57</td>
<td>3.27</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lilwan 15</td>
<td>73.66</td>
<td>154.62</td>
<td>17.24</td>
<td>62.59</td>
<td>11.02</td>
<td>2.12</td>
<td>16.64</td>
<td>1.41</td>
<td>6.81</td>
<td>1.57</td>
<td>3.27</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lilwan 24</td>
<td>78.19</td>
<td>169.16</td>
<td>18.80</td>
<td>69.59</td>
<td>12.40</td>
<td>2.52</td>
<td>9.54</td>
<td>1.10</td>
<td>4.80</td>
<td>1.34</td>
<td>3.39</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galap 2</td>
<td>104.59</td>
<td>224.40</td>
<td>25.50</td>
<td>98.90</td>
<td>16.60</td>
<td>3.08</td>
<td>11.30</td>
<td>1.90</td>
<td>3.20</td>
<td>0.78</td>
<td>2.96</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galap 3</td>
<td>104.06</td>
<td>224.40</td>
<td>25.50</td>
<td>98.90</td>
<td>16.60</td>
<td>3.08</td>
<td>11.30</td>
<td>1.90</td>
<td>3.20</td>
<td>0.78</td>
<td>2.96</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galap 5</td>
<td>115.68</td>
<td>238.68</td>
<td>27.80</td>
<td>102.00</td>
<td>18.19</td>
<td>3.27</td>
<td>12.01</td>
<td>1.32</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galap 6</td>
<td>114.08</td>
<td>234.40</td>
<td>25.50</td>
<td>101.00</td>
<td>17.20</td>
<td>2.76</td>
<td>11.04</td>
<td>1.74</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bhatnagar 1</td>
<td>119.43</td>
<td>207.43</td>
<td>25.50</td>
<td>101.00</td>
<td>17.20</td>
<td>2.76</td>
<td>11.04</td>
<td>1.74</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bhatnagar 3</td>
<td>130.00</td>
<td>227.43</td>
<td>25.50</td>
<td>101.00</td>
<td>17.20</td>
<td>2.76</td>
<td>11.04</td>
<td>1.74</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filippov 1</td>
<td>115.00</td>
<td>207.43</td>
<td>25.50</td>
<td>101.00</td>
<td>17.20</td>
<td>2.76</td>
<td>11.04</td>
<td>1.74</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filippov 3</td>
<td>130.00</td>
<td>227.43</td>
<td>25.50</td>
<td>101.00</td>
<td>17.20</td>
<td>2.76</td>
<td>11.04</td>
<td>1.74</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filippov 5</td>
<td>138.56</td>
<td>243.56</td>
<td>25.50</td>
<td>101.00</td>
<td>17.20</td>
<td>2.76</td>
<td>11.04</td>
<td>1.74</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filippov 7</td>
<td>154.16</td>
<td>259.16</td>
<td>25.50</td>
<td>101.00</td>
<td>17.20</td>
<td>2.76</td>
<td>11.04</td>
<td>1.74</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filippov 9</td>
<td>170.16</td>
<td>275.16</td>
<td>25.50</td>
<td>101.00</td>
<td>17.20</td>
<td>2.76</td>
<td>11.04</td>
<td>1.74</td>
<td>4.97</td>
<td>1.67</td>
<td>4.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ND — no determined
Petrology and geochemistry of rapakivi-type granites from the crystalline basement of NE Poland

Fig. 3. Peaceck index (CaO/(Na₂O + K₂O) vs SiO₂) after Brown (1981)
1 — Lanowice, 2 — Filipów, 3 — Goldap, 4 — Bartoszyce, 5 — Olsztyn, 6 — Klewno, 7 — Kętrzyn, 8 — Pawłówka

ceses (Pl. IV, Fig. 1). Minor prehnite and calcite result from late alteration (samples 4 and 5).
Quartz monzonites and granodiorites with subordinate quartz syenites and quartz monzodiorites occur in the Bartoszyce core. They are composed of K-feldspar, plagioclase (An₄₃ — normative), quartz, biotite, hornblende, clinopyroxene, apatite, zircon and opaques. The rock is characterised by a porphyritic texture (Pl. III, Fig. 2), with large plagioclase and K-feldspar phenocrysts (Pl. IV, Fig. 3). Myrmekites are widespread (Pl. IV, Fig. 4).

Pawłówka rocks consist in granodiorites made of quartz, plagioclase (An₄₃ — normative), K-feldspar, biotite, minor hornblende and clinopyroxene, apatite, zircon and opaques, and rare titanite (usually associated with hornblende). A porphyritic texture (Pl. III, Fig. 3), with 5 cm-sized plagioclases and K-feldspar phenocrysts, is typical. Sericitisation and chloritisation are conspicuous.

Quartz monzonite and minor quartz monzonodiorite have been described from the Filipów drill-core. They are made up of plagioclase (An₄₃ — normative), quartz, K-feldspar, biotite, clinopyroxene, hornblende, titanite, apatite, minor zircon and opaques (Pl. V, Figs. 3 and 4). They display a porphyritic texture (Pl. II, Fig. 2) with plagioclase and K-feldspar crystals up to 5 cm. The rock is commonly deformed and partly mylonitised.

Quartz monzodiorites to mafic diorites occur in Klewno. The rocks are medium- to coarse-grained and have a massive, ophitic texture. Plagioclase (up to 40 vol% — An₄₃ — normative) and biotite are the main component of the rocks. Large euhedral plagioclase crystals, biotite, clinopyroxene or hornblende resulting from clinopyroxene alteration (Pl. V, Fig. 1) were distinguished. The porphyritic texture is present in samples from Klewno where megacrysts (up to 3 cm) of plagioclases are visible. Large K-feldspar (Pl. V, Fig. 2) and quartz are also basic constituents. The accessories are titanite,
Fig. 5. $K_2O$ vs $SiO_2$ (the dividers are after Rickwood, 1989)
For explanations see Fig. 3.

Fig. 6. $Q = (Si/3) - [K+Na+2(Ca/3)]$ against $P = K$ (Na+Ca) diagram of Debon and Le Fort (1988)
Symbols have following meanings: to — tonalite, gd — granodiorite, ad — adamellite, gr — granite, qmad — quartz monzodiorite, qmz — quartz monzonite; CALK — line, shown trends of calc-alkaline rocks; SALK — trend lines are also shown.
Fig. 3. Major elements content (%) vs SiO₂ (Harbor diagrams), additional samples from Andery (C-type granite trend) (Kilpatrick and Ellis, 1992) are included.

For explanations see Fig. 3.
apatite, zircon and opaques. Myrmekites and biotite-quartz
symplectites are also abundant.

The Kętyn samples are quartz monzodiorites composed
of plagioclase (An$_{46}$ — normative), K-feldspar, quartz, biotite,
hornblende, titanite, apatite, zircon and opaques. They display
course, porphyritic textures with large plagioclase and
K-feldspar crystals (Pl. II, Fig. 3).

Most rocks display clear porphyritic textures similar to
those observed in repakivi granite (the only exception are the
samples from the Olsztyn drill-core). Typical K-feldspar
rinned by plagioclase have, however, not been observed.
Fig. 8. Sr, Co and V content (ppm) vs SiO₂
For explanations see Fig. 3
GEOCHEMISTRY

Major and trace elements on 80 samples have been analysed by XRF with a Philips PW 2400 Rig spectrometer at the Polish Geological Institute following the standard boron melting method, while REE and some ultratrace elements were analysed in 40 samples by the ICP-MS method with a VG elemental PQ2 Plus spectrometer at the University of Liège (Belgium) following the method described by Vander Auwera et al. (1998a). The results are presented in Tables 1 and 2.

The SiO₂ contents range from 46 to 76%. Rock types vary from diorite (Klesno) to leucogranite (Olszyn) comprising also quartz monzodiorite, quartz monzonite and granodiorite. The more differentiated rock suite is the Lanowicze massif in which SiO₂ ranges from 60 to 76%, other drill-holes giving less differentiated suites.

MAGMA TYPES

In the Peacock diagram (Fig. 3), Lanowicze and Olszyn are calc-alkaline, and the other massifs lie ambiguously close to the limit between alkali-calcic and alkaline series. None of the rocks has an aquatic index > 0.8 (except one albite-feldspar sample from Lanowicze — Fig. 4), and thus they are not alkaline. The K₂O-SiO₂ diagram (Fig. 5) shows that rocks from Lanowicze are high K calc-alkaline, whereas the rest of the rocks plot into the very high K domain. Since their calc-alkaline character is absent, they cannot be considered as shoshonites. They rather belong to the subalkaline potassic suite (sense Debon and Le Fort, 1988) (Fig. 6).

MAJOR ELEMENTS

Harker diagrams for major elements show that the rocks plot along a grossly defined jututitic line of descent (Duchêne and Wilmart, 1997; Vander Auwera et al., 1998a), which is close to the C-type granite trend (Fig. 7) (Kilpatrick and Ellis, 1992) and is typical of the AMCG suite (amphibole, mangerite, charnockite [rapakivi] granite). The magma terms of the suite are TiO₂-, FeO₂+, and P₂O₅-rich (4, 18 and 3% respectively), which is a typical feature of jututitics (Fe-Ti-P-rich hypersthene monzodiorites). FeO₂+, MgO and CaO are positively correlated with SiO₂. The Fe/Mg ratio for the Mazowie complex is intermediate in most massifs compared to the higher values in the evolved jututitics from Norway (Duchêne and Wilmart, 1997; Vander Auwera et al., 1998a).

TRACE ELEMENTS

Harker diagrams for trace elements do not display unique differentiation trends as regards major elements, each group...
having its own specificity. The most striking variation is observed in the Sr vs SiO₂ diagram (Fig. 8). Each group of rocks has distinct Sr contents which remain nearly constant with differentiation (slightly positive or negative slopes). This horizontal evolution is probably due to a partition coefficient of Sr between plagioclase and melt close to 2 and a liquids mineral assemblage containing ca. 50% plagioclase (the main bearer of Sr), thus giving a bulk partition coefficient close to 1. Zn, V and Co show a systematic decrease with SiO₂ (Figs. 8, 9) at the scale of the various drill-cores and within each core. This is
Fig. 11. Chondrite normalized REE distribution in the studied rocks from the Mazury complex.
mostly due to a constant subtraction of mafic minerals in the fractional crystallization process or to mixing with a leucogranitic melt.

**REE EARTH ELEMENTS**

Each group of rocks show similar REE distributions and ORG-normalized spidergrams (Fig. 10), which corroborates their consanguinity, as inferred by Lorenc and Wiszniewska (1999). Each group of rocks has, however, its own signature when considering REE amounts and spidergrams (Fig. 11). Moreover, the small range of variation in REE and other incompatible elements in each massif confirms that fractional crystallisation has only played a subordinate role in internal differentiation (except for Lanowicze). More or less pronounced Nb and Zr anomalies can be observed in all the massifs. The Nb anomaly is classically interpreted as reflecting a crustal input or influence, but this can also result from Nb-rich mineral fractionation. The Zr negative anomaly is probably due to zircon fractionation.

**SUGGESTIONS FOR FURTHER RESEARCH**

These new data support our working hypothesis which proposes that the different massifs represent different cogenetic magma batches, each of them having slightly evolved by differentiation in magma chambers at the level of final emplacement. As the parental magmas grossly define a liquid line of descent and because most of their geochemical characteristics are similar (for instance parallel REE patterns and spidergrams), we also put forward the working hypothesis that they were generated by different degrees of partial melting of a unique source. If it is accepted that the liquid line of descent reproduces the position of a cotectic line in a phase diagram at the P, T, fO2 conditions of melting, it would be interesting to investigate whether the variation from batch to batch results from variation of position of the cotectic line with pressure and some other intensive variables (fO2, etc.). Mixing with anatetic liquids must also be taken into consideration. The source rocks should have a relatively homogeneous modal composition resulting in a monotonous REE distribution. Similarities with the Rogaland jutulites (Norway) point to a source made up of a series of deep crustal rocks of basic composition, either mafic or amphibolite.

The problems that we have just outlined here require further investigation. Isotope geochemistry, modelling of partial melting process and calculation of mineral assemblages responsible for the fractionation in each batch should help in deciphering the genetic processes and the nature of the source.

**Acknowledgements.** This work was supported partly by the National Committee for Scientific Research, grant no. 620.9316.00.0 for Dr. Janina Wiszniewska and grant no. 6P04D02714 for Dr. Bogusław Bagiński and Dr. Janina Wiszniewska. Dr. Bogusław Bagiński has benefited from a Belgian CGRI grant to support a period of work at the University of Liège. The analyses were done at the Polish Geological Institute by I. Iwaszka-Budzyk and at the “Collectif Interinstitutionnel de Géochimie Instrumentale” (University of Liège) by G. Bologna.

**REFERENCES**


