Timing of ductile shearing within the Drūkšiai–Polotsk Deformation Zone, Lithuania: a U–Pb titanite age

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Abstract. A U–Pb dating of titanite from an augen granitoid mylonite in the Drūkšiai–Polotsk Deformation Zone has yielded a concordant age of 1534 ± 9 Ma. This light brown titanite follows the foliation in the host rock and was obviously formed during retrogression from amphibolite to epidote-amphibolite facies and coeval mylonitization. Shear zones of the same age are known in southern and central Sweden and in NE Poland. These E–W trending deformation zones accommodate both mafic and granitoid intrusions and are probably related to an extensional period in the Mesoproterozoic evolution in the western part of the East European Craton prior to the 1.50–1.45 Ga Danopolonian orogeny.

Key words: U–Pb geochronology, titanite, ductile shearing, East European Craton.

INTRODUCTION

Ductile shear zones and brittle faults are important structural elements of the crust and their structure and evolution. They are required for reconstruction of regional tectonic processes. Combining microstructural, metamorphic and isotopic information is a tool constraining the time of deformation and metamorphism in shear zones. Considerable progress has been achieved with the use of this approach in the neighbouring areas in Sweden and Finland (e.g. Johansson & Johansson 1993; Högdahl 2000; Högdahl & Sjöström 2001; Bergman et al. 2006; Hermansson et al. 2007; Torvela et al. 2008). These authors have shown that titanite is one of the minerals growing during deformation and thus can date deformational events.

The knowledge of shear zones in the crystalline basement of Lithuania is mostly based on geophysical and drill core studies. Their correlation with coeval deformation zones of the Baltic Shield in Sweden, also in Belarus, Latvia and Poland, can help to reveal the regional structure of the East European Craton around the Baltic Sea. Also, the Precambrian fault zones, bounding blocks of the crystalline basement, influence the formation of the sedimentary cover and neotectonic events. The knowledge of the Drūkšiai–Polotsk Deformation Zone (DPDZ) structure and composition might help to assess the recent tectonic activity in the Ignalina Nuclear Power Plant area, which is situated within the DPDZ.

In this paper we report U–Pb age data on titanite from an augen granitoid mylonite in the eastern part of the DPDZ. This zone is one of the major E–W shear zones in Lithuania.

GEOLOGICAL SETTING

The crystalline crust of Lithuania was formed between ca 1.9 and 1.8 Ga during the Svecofennian orogeny in broad terms (Skridlaitė & Motuza 2001; Motuza 2005). According to different structural and geophysical patterns, composition and crustal evolution, the crystalline basement of Lithuania is subdivided into several tectonic units. The major units are the West Lithuanian Granulite Domain (WLGD) and the East Lithuanian Domain (ELD), which are juxtaposed along the Mid-Lithuanian Suture Zone (MLSZ). The Belarus–Podlasie Granulite Belt (BPGB) features southeastern Lithuania (Skridlaitė & Motuza 2001). The understanding of the structure and tectonic evolution of the Lithuanian lithosphere has improved considerably due to seismic profiling: Sovetsk–Kohtla-Järve (Ankudinov et al. 1994) and EUROBRIDGE’95 (EUROBRIDGE’95 2001). The modelling of the magnetic and gravity fields (Korabliova & Sliaupa 2006) has revealed numerous E–W trending fault zones cutting the Palaeoproterozoic, mostly N–S, N–E and N–NW striking structures (Fig. 1). Some structures indicate lateral displacements.

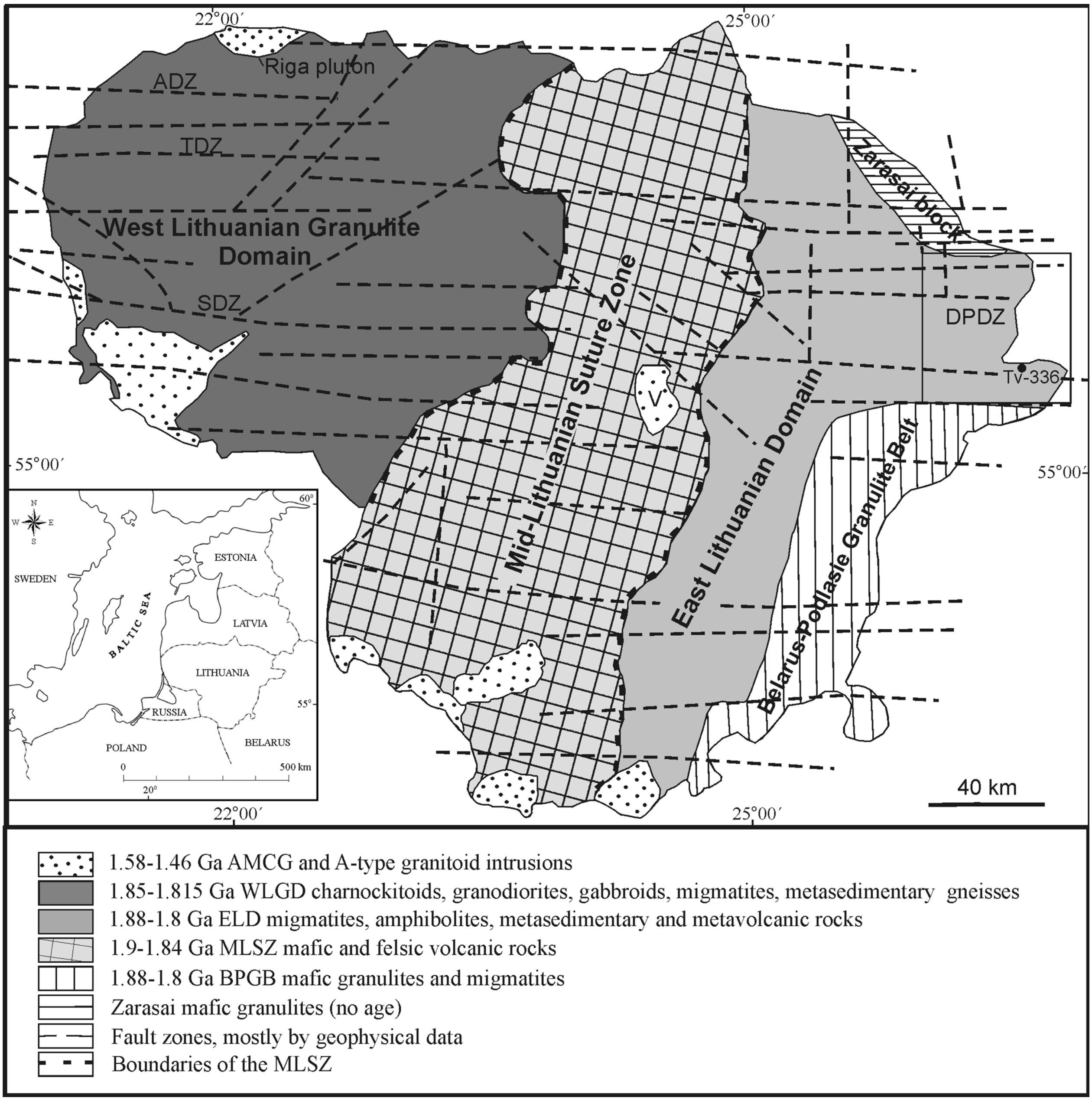

Fig. 1. Geological map of the Precambrian basement in Lithuania (modified after Motuza 2005). Abbreviations: ADZ, Akmene Deformation Zone; DPDZ, Drūkšiai–Polotsk Deformation Zone; SDZ, Silute Deformation Zone; TDZ, Telsiai Deformation Zone; Tv-336, Tverečius-336 borehole; V, Vepriai gabbro intrusion. The square shows the study area.

The studied DPDZ represents the southern margin of the major Polotsk–Kurzeme zone of faulting in the Baltic–Belarus region, transecting the ELD. The ELD has a 52–55 km thick crust, including the upper (15–20 km), middle (10–15 km) and lower (25–28 km) crust (Motuza 2005). The supracrustal, migmatitic and plutonic rocks of the ELD were formed between 1915 (G. Skridlaite, pers. comm. 2010) and 1837 Ma (Rimsa et al. 2001). The Veisėjai and Kabeliai granitoids intruded at 1.53–1.50 Ga (Skridlaite et al. 2003) and at ca 1500 Ma (Sundblad et al. 1994), respectively. The Mesoproterozoic events between 1570 and 1430 Ma have also been dated by $^{40}Ar/^{39}Ar$ ages of amphibole from several gabbroic rocks (Bogdanova et al. 2001; Skridlaitė et al. 2006; Skridlaite et al. 2007).

The DPDZ is situated in eastern Lithuania close to the Belarus border. It is 35–40 km wide, E–W trending and well marked by linear gravity and magnetic anomalies. According to gravity field modelling, the DPDZ may penetrate to 10–20 km depth (Šliaupa & Popov 1998). The crystalline rocks within the DPDZ are granulites, biotite granites and migmatites, the latter consisting of amphibole-plagioclase palaeo- and mesosomes, and plagioclase-quartz-biotite ± microcline ± amphibole neosomes. Because of ductile shearing gneisses, augen mylonites, mylonites and ultramylonites were produced in the DPDZ, while tectonic breccias and pseudotachyllite were formed by later brittle deformation.

The information on the structure and composition of the DPDZ has been enhanced due to geological, hydrogeological and engineering–geological mapping (scale 1 : 50 000) of the Drūkšiai object in the years 1988–95 (Marcinkevičius & Laškovas 2007). The deep wells reaching the crystalline basement, gravimetric and magnetic (Korabliova & Sliaupa 2006), and seismic works (Pačėsa et al. 2005) and neotectonic studies (Šliaupa 1998) define the fault location. All these studies were particularly carried out for understanding a possible relation of the Precambrian structure of the crystalline basement with the sedimentary cover. Geophysical data and the surface morphology of the crystalline basement have revealed a horst-graben structure along the DPDZ (Marcinkevičius & Laškovas 2007). The graben is filled with Vendian, Cambrian, Ordovician, Silurian and Devonian deposits.

SAMPLE DESCRIPTION

The selected sample (TV-336) is an augen granitoid mylonite from the Tverečius-336 drill core, located in the eastern part of the DPDZ close to the Belarus border (Fig. 1). The rock is rich in titanite, which has been used for isotopic analysis. The augen mylonite consists mainly of plagioclase, biotite, quartz, amphibole, epidote, titanite, magnetite and apatite. This rock (Fig. 2) is light grey, with pinkish augen plagioclase of 1 cm size (Fig. 2C, D). The foliation in this drill core dips from vertical to 75°. Ultramylonite zones are also found within this augen mylonite. In the upper part of the drill core the augen mylonite was brecciated due to brittle deformation and

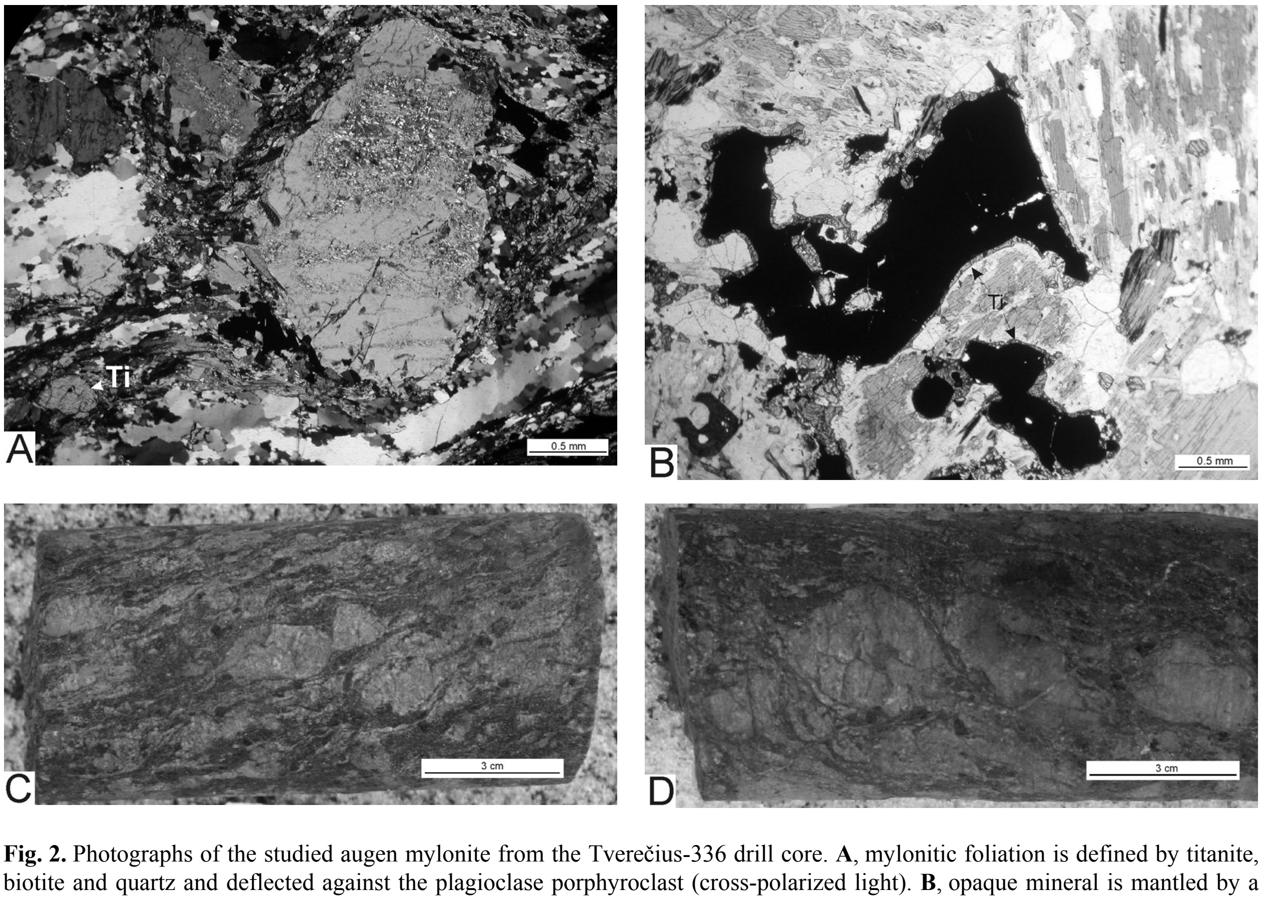

Fig. 2. Photographs of the studied augen mylonite from the Tverečius-336 drill core. **A**, mylonitic foliation is defined by titanite, biotite and quartz and deflected against the plagioclase porphyroclast (cross-polarized light). **B**, opaque mineral is mantled by a thin reaction rim of titanite (plane-polarized light). **C**, mylonitization of the granitoid. **D**, brecciated augen mylonite.

consists of the augen mylonite and mineral clasts (Fig. 2C). The plagioclase (andesine) porphyroclasts are fractured and some are split into several individual grains, which are separated by fine-grained recrystallized matrix (Fig. 2A–D). The porphyroclasts show evidence of much less plastic deformation, extensive fracturing and fragmentation. The mylonitic foliation, which is defined by biotite, quartz, titanite and epidote, is deflected around the porphyroclasts. Biotite is deformed plastically into elongated lenses and also recrystallized to fine-grained aggregates along foliation. Quartz and amphibole form polygonal grain aggregates. Amphibole is partly replaced by biotite along fractures. Some quartz grains are very thin, finely recrystallized ribbons.

The light brown titanite occurs as euhedral crystals up to 0.2 mm size, subhedral grains and as a mantle around opaque minerals (Fig. 2A, B).

ANALYTICAL PROCEDURE

The U–Pb analyses were carried out at the Institute of Precambrian Geology and Geochronology (IPGG) in St Petersburg, using a Finnigan MAT 261 mass spectrometer in static mode. Titanite was extracted from crushed rock samples, using standard heavy liquid and magnetic separation techniques. Only minerals free of inclusions were used. Titanite was washed in warm de-ionized water to remove surface contamination and a $^{202}Pb/^{235}U$ tracer was added before digestion in concentrated HF–HNO_3 in Krogh type PTFE dissolution vessels (Krogh 1973). Pb was separated using standard HCl–HBr chemistry and U was separated using EICHROM® resin. Total blanks were 0.01–0.05 ng Pb and 0.001 ng U. The PbDAT and ISOPLOT programs of Ludwig (1991, 1999) were used for calculation of the uncertainties, correlations of U/Pb ratios and the concordia age. All errors are reported at the 2σ level. The decay constants of Steiger & Jäger (1976) were used for age calculation, and corrections for common Pb were made using the values of Stacey & Kramers (1975).

RESULTS

Two fractions of brown to yellow titanite were analysed. The results of the two analyses (1 and 2) are listed in Table 1 and plotted in Fig. 3. Both analyses show uranium contents from 86.3 to 87.3 ppm and lead contents from 35.4 to 38.6 ppm. They yield the concordant data points (Table 1, Fig. 3) and the age of 1534±9 Ma (MSWD of concordance = 1.4, probability of concordance = 0.24).

Table 1. U–Pb isotopic data for the titanite from sample TV-336

No.	Sample weight, mg	Concentrations, ppm		$^{206}Pb/^{204}Pb$ [a]	Isotopic ratios corrected for blank and common Pb [b]				Rho [c]	Age, Ma		
		Pb	U		$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$		$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
1	1.11	35.4	86.3	778	0.0953±1	0.5953±1	3.5198±70	0.2678±5	0.95	1532±3	1530±3	1534±1
2	1.05	38.6	87.3	713	0.0956±1	0.7171±1	3.5403±71	0.2687±5	0.95	1536±3	1534±3	1539±1

Notes: [a] measured ratio; [b] uncertainties (95% confidence level) refer to the last digits of the corresponding ratios; [c] correlation coefficients of $^{207}Pb/^{235}U$ vs $^{206}Pb/^{238}U$ ratios.

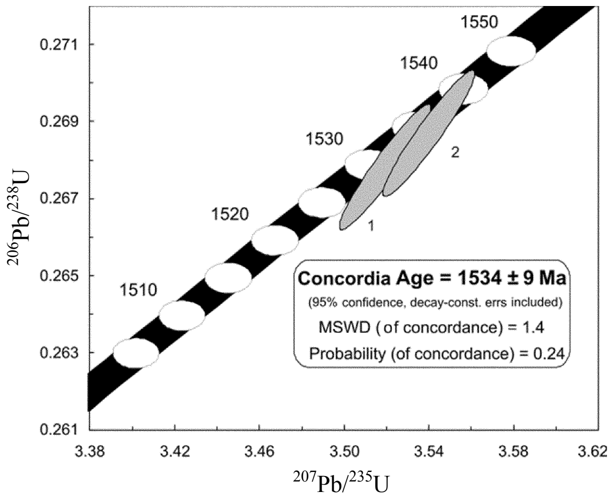

Fig. 3. Concordia diagram displaying the U–Pb TIMS data (analyses 1 and 2) on titanite from sample TV-336. Error ellipses are drawn at 2σ.

DISCUSSION AND CONCLUDING REMARKS

The U–Pb titanite age obtained for the augen mylonite (TV-336) in the DPDZ demonstrates that shearing and formation of this zone occurred at 1534 ± 9 Ma.

A similar $^{40}Ar/^{39}Ar$ amphibole age of 1534 ± 11 Ma was obtained from a sheared gabbro in the Vepriai borehole No. 22 nearby the DPDZ (Skridlaitė et al. 2006). Both ages indicate that strong deformation accompanied the DPDZ faulting. Since the crystallization age of the studied granitoid and the Vepriai gabbro is unknown, the question remains whether the emplacement of both intrusions was syntectonic to the DPDZ shearing or the DPDZ deformation superimposed older magmatic rocks. Skridlaitė et al. (2006) considered 1.85–1.82 Ga gabbro-tonalitic intrusions along the MLSZ as possible relatives to the Vepriai gabbro and thus the mylonitized plagioclase-bearing granitoid in our study can be of similar age as well.

The DPDZ steep shearing, occurring during the retrograde stage of metamorphism, indicates an extensional kinematics of the mylonitization, i.e. the development of the DPDZ and the whole Polotsk–Kurzeme zone of faulting due to a regional extension of the crust at ca 1.53–1.50 Ga. Numerous AMCG (anorthosite–mangerite–charnockite–granite suites) and A-type granitoid intrusions were emplaced into the crust in Fennoscandia at the same time, such as the Mazury complex in NE Poland and in Lithuania (Sundblad et al. 1994; Wiszniewska et al. 2002; Skridlaite et al. 2003), the Salmi AMCG intrusion in Karelia (Amelin et al. 1997) and several intrusions in Central Sweden (Andersson et al. 2002). Characteristically, they are accommodated mostly within E–W faulting zones.

The extension of the crust might have occurred with some lateral strike-slip movements as noted on geophysical grounds (Garetsky et al. 1990, 2002). The dextral lateral displacement along the Polotsk–Kurzeme Deformation Zone is obviously marked by the deflection of the BPGB and the Zarasai structures as recorded by linear magnetic anomalies (Fig. 1). Some displacements of the MLSZ boundaries along the E–W deformation zones may be a cause of their embayed outlines.

The E–W trending zones in Lithuania like in southern Sweden and on Bornholm became superimposed by the Danopolonian compressional deformation and metamorphism at 1.47–1.44 Ga, which was attended by granitoid magmatism (Bogdanova 2008). The detailed $^{40}Ar/^{39}Ar$ geochronological studies in the Oskarshamn area in southern Sweden on the opposite side of the Baltic Sea do have recognized two subsequent tectonothermal events at 1.51–1.47 and 1.43–1.42 Ga, which can be related to the Danopolonian orogeny (Söderlund et al. 2008).

At the end of the Precambrian the DPDZ was reactivated several times, as indicated by brecciated mylonite and pseudotachyllite. In the Palaeozoic the vertical movement of blocks along this zone affected the sedimentary cover (Zakarevičius & Stanionis 2005; Šliaupa et al. 2006; Marcinkevičius & Laškovas 2007). The study of the DPDZ by GIS-methods has revealed a rather high activity of the recent geodynamic processes, e.g. three major blocks in the sedimentary cover move differentially as fast as 10 mm per year (Šliaupa et al. 2006).

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Plastiliste nihkeliikumiste vanus titaniidi U-Pb isotoopsüsteemi alusel Drūkšiai-Polotski deformatsioonivööndis Leedus

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Drūkšiai-Polotski tektoonilise vööndi müloniitides sisalduva titaniidi U-Pb isotoopmäärangud on andnud titaniitide konkordantseks vanuseks 1534 ± 9 miljonit aastat. Titaniit on tekkinud ilmselt retrograadse metamorfismi käigus, kus kivim läks amfiboliitsest faatsiesest üle epidoot-amfiboliitsesse faatsiesse, ja on samaaegne müloniidistumisega. Sarnase vanusega nihkeliikumise vööndid on teada Lõuna- ja Kesk-Rootsist ning Kirde-Poolast. Nimetatud ida-läänesuunalised tektoonilised vööndid sisaldavad nii aluselisi kui happelisi intrusioone ja on ilmselt seotud laiali-venituspingetega Ida-Euroopa kratooni mesoproterosoilise arengu faasis.