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Mesozoic remagnetization of Upper Devonian carbonates from the Česis and Skaistgirys quarries (Baltic states)

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The palaeomagnetic properties of Frasnian and Famennian dolomites from two quarries in Latvia and Lithuania respectively are compared. Famennian dolomites from Skaistgirys quarry (N Lithuania) revealed the presence of one distinct normal polarity component (D =14°, I = 53°, $_{95}$ = 4.2°, n = 28 specimens). The reversed polarity component predominates in Frasnian dolomites from Česis quarry (Central Latvia). Only one hand specimen from this locality contained a component with the opposite direction. The mean direction from Česis quarry (D = 198°, I = –53°, $_{95}$ = 4.4°, n = 22 specimens) is very close to that from Skaistgirys quarry and therefore was recorded most probably during the same event of remagnetisation but at a later stage. The remagnetizations of these dolomites were caused most probably by progressive oxidation of ferric sulphides to magnetite and finaly to hematite. A comparison of the palaeomagnetic poles obtained with the stable European APWP (Apparent Polar Wander Path) indicates a Late Jurassic/Early Cretaceous age for the remagnetization event. This estimation can be useful for chronostratigraphic linking of post-Palaeozoic tectonic activity and diagenetic events, so far very poorly recognized in this part of the European plate. Our data shows also that the Late Jurassic/Early Cretaceous part of the stable European APWP may still be inaccurate.

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INTRODUCTION

Remagnetization is a widespread phenomenon in Palaeozoic and Mesozoic carbonates of North America and Europe (e.g. Elmore *et al*., 1993; Molina Garza and Zijderveld, 1996; Katz *et al*., 1998; Grabowski, 2000; Zegers *et al*., 2003). It is widely accepted that most of these remagnetizations produce a chemical remanent magnetization. The formation of new magnetic minerals is linked to interaction between the rock and fluids, mineralizing fluids or hydrocarbons (McCabe and Elmore, 1989; Lewchuk and Symons, 1995; Brothers *et al*., 1996). Proposed mechanisms include the conversion of ferric sulphides to magnetite by oxidizing fluids (Suk *et al*., 1990) and the formation of magnetite as a byproduct of the conversion of smectite to illite (Katz *et al*., 1998).

Palaeomagnetic studies of Devonian carbonates from Central Europe (Holy Cross Mts., Cracow-Silesia Region) revealed the presence of Early Permian remagnetization (Nawrocki, 1993; Grabowski *et al*., 2002). The aim of our studies was to see if this Early Permian remagnetization had a wider extent and could be found also in the the Baltic states where Upper Devonian late diagenetic dolomites occur. Possible causes of remagnetization are also discussed.

MATERIAL AND METHODS

The Upper Devonian of the East Baltic area consists mainly of dolomitic rocks subdivided into 18 regional stages (Fig. 1). Samples for palaeomagnetic studies were taken from the Plavini and Žagarė regional stages. In Latvia and Estonia the Plavini regional stage is composed of marlstone and metasomatic cavernous dolomite with brachiopods, bivalves, gastropods, crinoids, stromotoporoids, tabulate and, rugose corals, and algae (Sorokin, 1981), and is up to 40 m thick. Dolomites of the Žagarė regional stage are distributed across northern Lithuania and southwestern Latvia. Metasomatic dolomites prevail in this formation that is up to 14 m thick

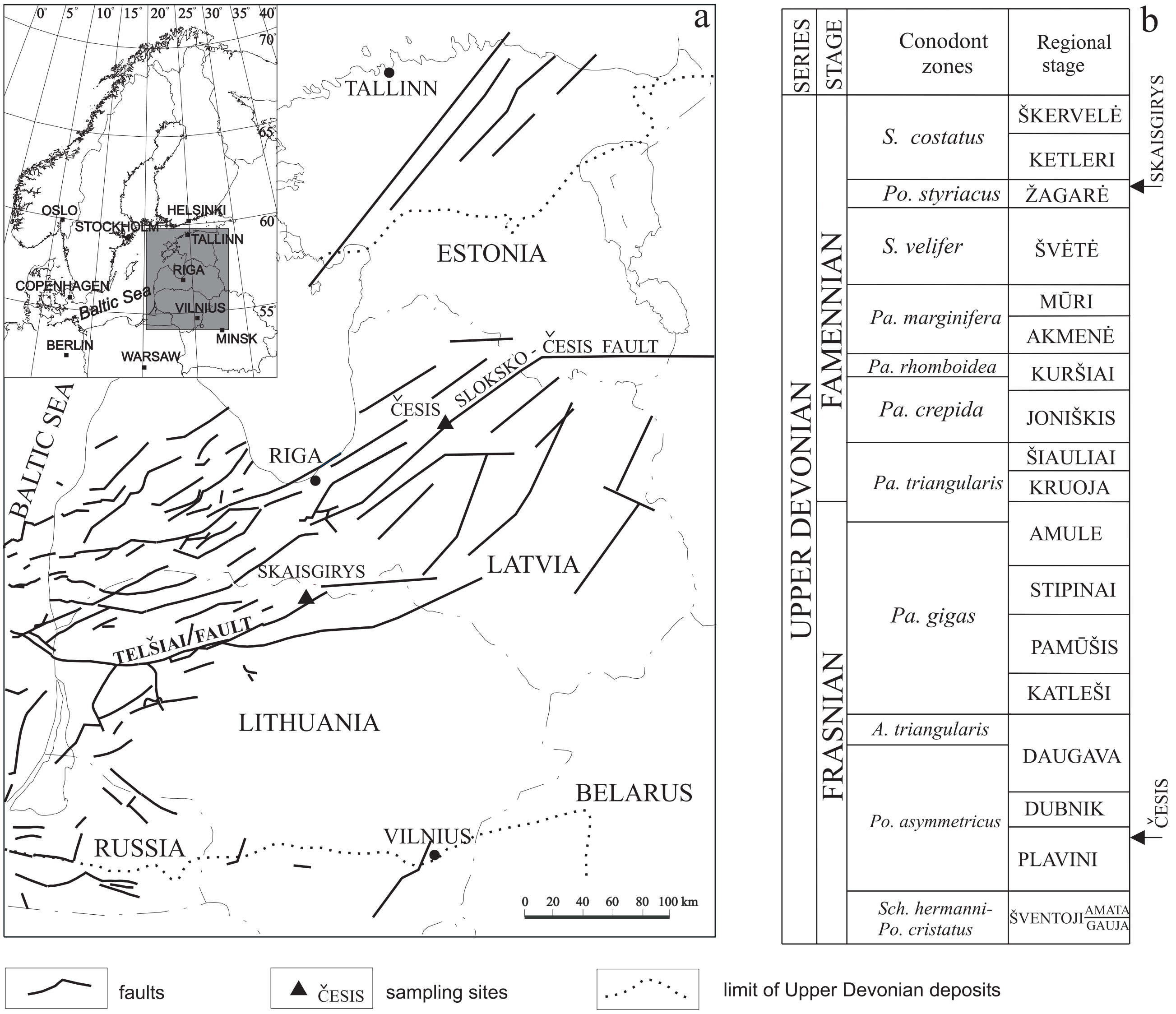


Fig. 1. a — Locations of sites studied sites plotted on the fault map of the Baltic states; b — Upper Devonian stratigraphic scheme of the Baltic states (Paškiewičius, 1997)

Locations of sampling sites are indicated by arrows

(Paškevičius, 1997); they have a "nucleus" structure indicating that dolomitization was polycyclic (Vodzinskas, 1966). In places, these nucleus structures were dissolved and filled by pyrite and calcite. The outcrops studied are located close to regional tectonic discontinuites — the Telšiai and Slokско–Česis faults (Fig. 1). Their maximum activity was connected to Caledonian and Hercynian tectonic movements (Stirpeika, 1999; Šliaupa, 2003).

13 hand oriented samples were taken from dolomites of the Žagarė regional stage cropping out in Skaistgirys quarry. Dolomites of the Plavinas Formation were sampled in Česis quarry (Fig. 1) where 8 hand samples were taken. Hand samples were cut into standard palaeomagnetic specimens of 2.5 cm diameter and 2.2 cm height. Usually 3 specimens were obtained from each hand sample. Natural remanent magnetization (NRM) was measured by means of a JR-5 spinner magnetometer while magnetic susceptibility during thermal demagnetization was monitored with a KLY-2 bridge. The rock specimens were thermally demagnetized with a MMTD non-magnetic oven. Demagnetization experiments and the NRM measurements were performed inside Helmholz coils that reduced the geomagnetic field by 95%. Characteristic directions were calculated using principal component analysis (Kirschvink, 1980). Palaeomagnetic poles were plotted using the *GMAP* for *Windows* package (Torsvik and Smethurst, 1994). Stepwise acquisition of the isothermal remanence magnetization (IRM) up to 1.4 T and thermal demagnetization of the

3 axes IRM acquired in fields of 0.1, 0.4 and 1.4 T (Lowrie, 1990) were applied to identify the magnetic minerals.

RESULTS OF THERMAL DEMAGNETIZATION

Seven samples from Česis quarry revealed only one high temperature NRM component removed by temperatures of about 650°C. This magnetization isolated as a straight-line segment directed towards the origin in orthogonal projection has negative inclination with a mean value of 52° on the sample level (Fig. 2, Table 1). One sample from this locality showed a different palaeomagnetic behaviour. A distinct component, removed by temperatures of about 550°C, with positive inclination (mean value 54° on the specimen level) was isolated. Similar palaeomagnetic properties were observed in the dolomites from Skaistgirys quarry. Samples from this locality contained a well clustered component removed most probably by temperatures of about 550°C that has positive inclination with mean value of 54° on the sample level (Fig. 3, Table 1). Precise definition of unblocking temperatures was impossible because of a substantial increase in magnetic susceptibility at temperatures higher than 550°C.

Table 1

Summary of statistics of palaeodirections isolated in the studied dolomites

Locality (coordinates)	N	n	D	I	α_{95}	*K*	*Plong.*	*Plat.*	*dp*	*dm*	*Lat.*
ČESIS		22	198°	–53°	4.4°	49.6	172°E	63°N	4°	6°	34°N
(25°15'0"E; 57°17'60"N)	8		199°	–52°	5.5°	101.5	170°E	63°N	5°	8°	33°N
SKAISTGIRYS		28	14°	53°	4.2°	43.4	174°E	66°N	4°	6°	34°N
(23°23'17"E; 56°18'27"N)	13		11°	54°	5.3°	61.8	179°E	67°N	5°	7°	34°N

N — number of samples, n — number of specimens, D — declination, I — inclination, α_{95}, *K* — Fisher (1953) statistics parameters, *Plong.* — longitude of north palaeomagnetic pole, *Plat.* — latitude of north palaeomagnetic pole, *dp* — error of the distance between site and palaeopole, *dm* — palaeodeclination error, *Lat.* — site palaeolatitude.

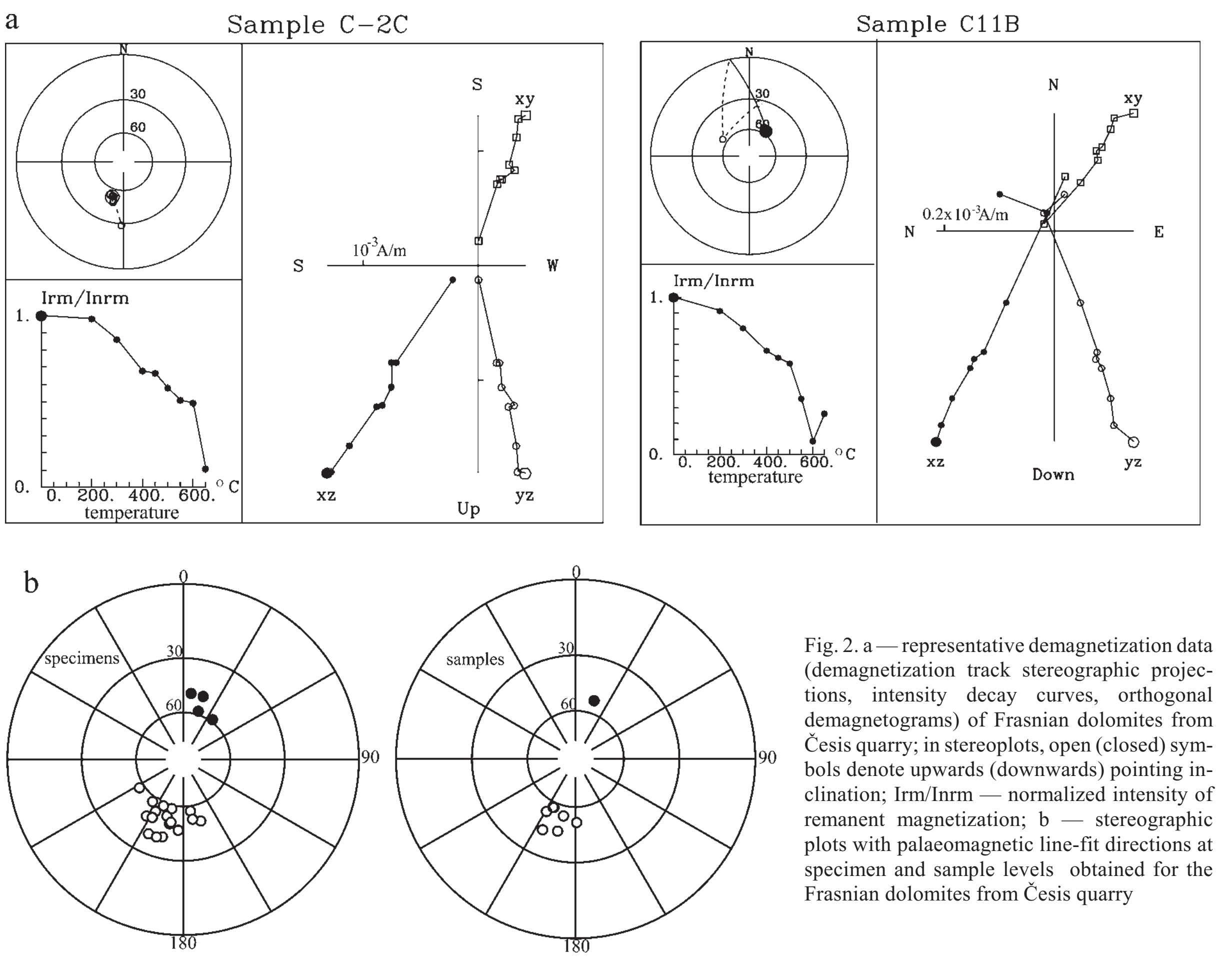
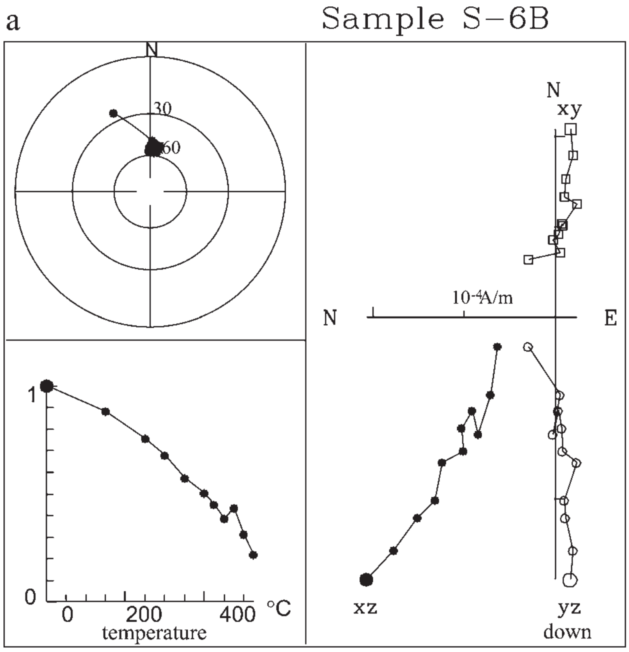


Fig. 2. a — representative demagnetization data (demagnetization track stereographic projections, intensity decay curves, orthogonal demagnetograms) of Frasnian dolomites from Česis quarry; in stereoplots, open (closed) symbols denote upwards (downwards) pointing inclination; Irm/Inrm — normalized intensity of remanent magnetization; b — stereographic plots with palaeomagnetic line-fit directions at specimen and sample levels obtained for the Frasnian dolomites from Česis quarry



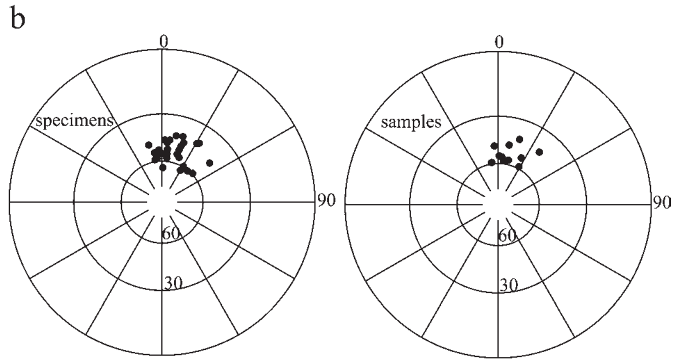


Fig. 3. a — representative demagnetization data of samples from Famennian dolomites from Skaistgirys quarry; b — stereographic plots with palaeomagnetic line-fit directions at specimen and sample levels obtained for the Famennian dolomites from Skaistgirys quarry

MAGNETIC CARRIERS

Subsequent thermal demagnetization of the 3-axis IRM acquired in fields of 0.1, 0.4 and 1.4T, and IRM acquisition experiments (Fig. 4) indicate the presence of a high coercivity mineral with unblocking temperatures higher than 600°C in the samples from Česis and Skaistgirys as well. These samples show also a significant contribution of a low (sample S11) and a medium (sample C-3) coercivity mineral with unblocking temperatures below 600°C. These results suggest that hematite is a main carrier of IRM in the samples from Česis. Magnetite and hematite are the main carriers of IRM in the samples from Skaistgirys. However, results of thermal demagnetization of the entire sample set suggest that the contribution of these carriers to the characteristic remanent magnetization is different than the contribution to the IRM. Apart from the sample with normal polarity, hematite is the main remanence carrier in the samples from Česis. The characteristic component from Skaistgirys is carried most probably by magnetite. All samples with normal polarity lose up to 95% of NRM intensity at temperatures below 600°C. A certain increase of magnetic suscep-

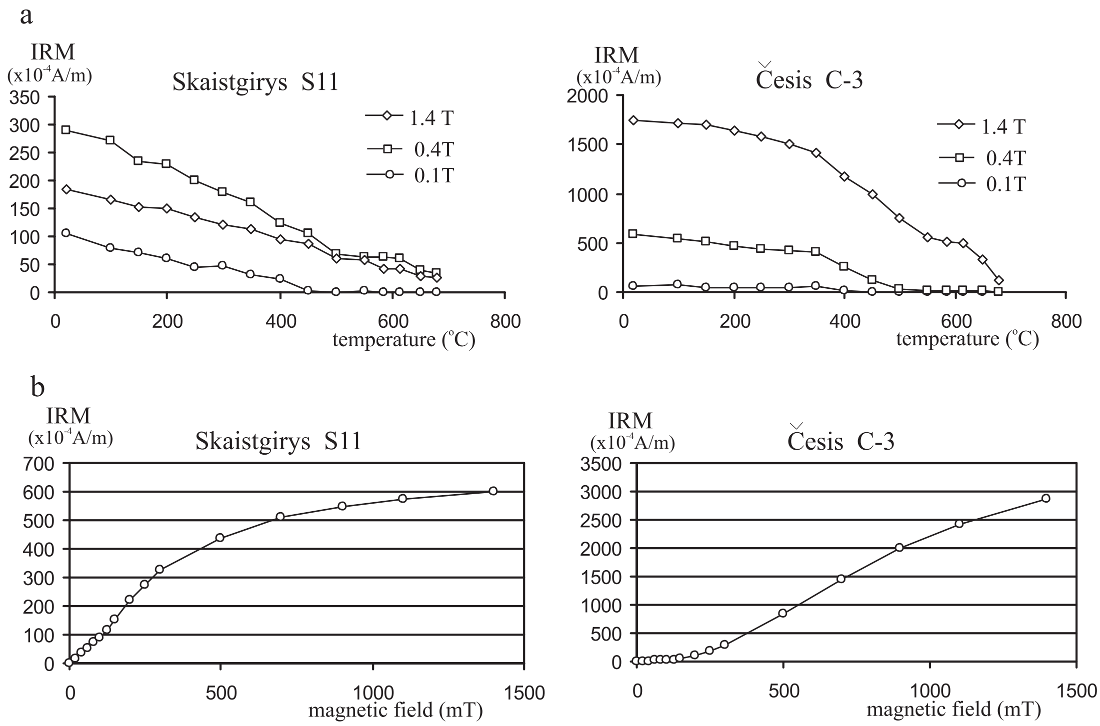


Fig. 4. a — thermal demagnetization of orthogonal-axis IRM curves of dolomites from the Česis and Skaistgirys quarries; b — IRM acquisition curves prepared from the same samples

tibility at temperatures higher than 400°C indicates that part of them contains ferric sulphides. The observations together indicate that carriers of characteristic components are polarity dependent. Magnetite is mainly connected with the normal polarity magnetization, while hematite is the main carrier of the reverse polarity characteristic component.

DISCUSSION AND CONCLUSIONS

The directions were converted to palaeomagnetic poles (Table 1) that were compared to the apparent polar wander path (APWP) for stable Europe. The palaeomagnetic pole from Česis as well as the palaeomagnetic pole from Skaistgirys correspond to the latest Jurassic–earliest Cretaceous European poles (140–150 Ma), although their small latitudinal departure from this APWP is visible (Fig. 5). An Early Permian remagnetization event known from Devonian carbonates in Poland (Nawrocki, 1993; Grabowski *et al*., 2002) does not occur in the dolomites from Skaistgirys and Česis, that were totally remagnetized in latest Jurassic–earliest Cretaceous time. This remagnetization event was long enough to record two polarities of a secondary component. Magnetite and hematite, defined as the carriers of characteristic remanence indicate that remagnetization took place due to progressive oxidation. Magnetite had been formed most probably during the first stage of the remagnetization event. It could have formed at the expense of sulphides (Vodzinskas, 1966). At this stage of our studies we have no arguments linking the observed remagnetization with the formation of diagenetic dolomite. This process was likely older than remagnetization, provided the magnetite was formed from sulphides of secondary dolomite.

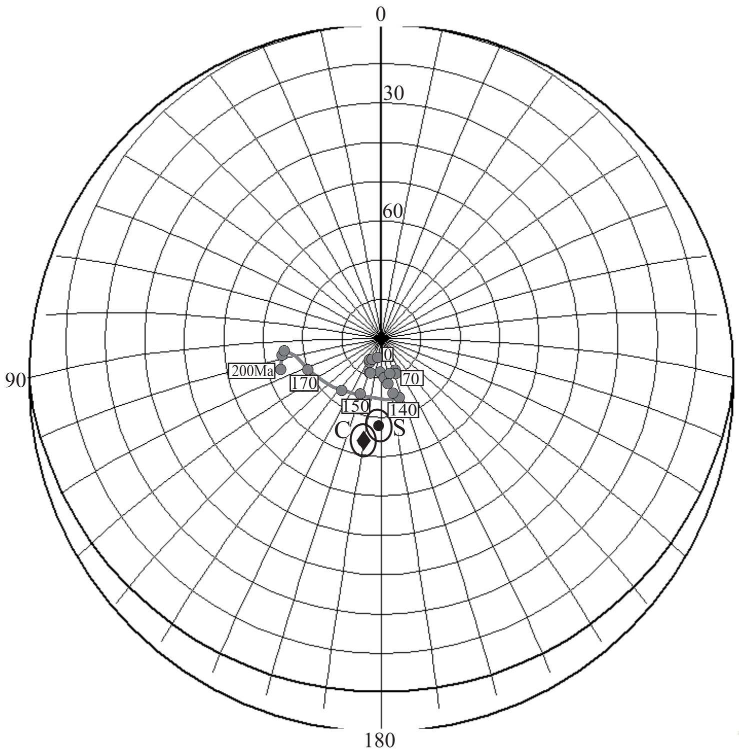


Fig. 5. Early Jurassic–Quaternary Apparent Polar Wander Path of the European Plate (Besse and Curtillot, 2003) and the palaeopoles from this study

C — palaeopole from Česis, S — palaeopole from Skaistgirys)

What was the cause of oxidation of the dolomites studied ? A correlation of sampling localities with the tectonic framework of the Baltic region indicates that the outcrops studied are located in proximity to regional tectonic discontinuites, i.e. the Telšiai and Slokško–Česis faults (Fig. 1). According to Šliaupa (2003) and Stirpeika (1999) their maximum activity was connected with the Caledonian and Hercynian tectonic movements. However, seismic studies of the Telšiai fault revealed fault activity during the Mesozoic as well (Šliaupa, 2003). The post-Palaeozoic thermal event was recorded by the thermal maturity of the organic matter in Western Lithuania (Šliaupa *et al*., 2002). It should be stressed that primary dolomites occur east of Skaisgirys quarry in areas not affected by fault tectonics. Sulfide mineralization of the Devonian rocks occurs close to the faulted zones (Liepins, 1963). Hence a relationship between diagenetic processes and tectonic activity is very possible. The Telšiai and Slokško–Česis faults provided path-ways for migration of oxidizing fluids that most probably remagnetized the dolomites. The results of our palaeomagnetic studies revealed the Late Jurassic/Early Cretaceous reactivation of the Telšiai and Slokško–Česis faults. Up till now the exact time of such reactivation had not been recognized using other methods.

A small departure of the obtained palaeomagnetic poles from the stable European APWP (Fig. 5) may indicate that the Late Jurassic–Early Cretaceous part of this path is still inaccurate. The secondary components of magnetization from dolomites should be free of inclination error and their aquisition was slow. They should reliably define the mean geomagnetic dipole at the time of aquisition. The imperfection of the Late Jurassic–Early Cretaceous part of the European APWP may result from lack of good quality primary palaeomagnetic poles of this age.

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