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Comparison of palaeomagnetic data from three Late Caledonian magmatic intrusions piercing the Upper Silesian and Małopolska tectonic blocks (S Poland), and its palaeotectonic significance

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ABSTRACT:

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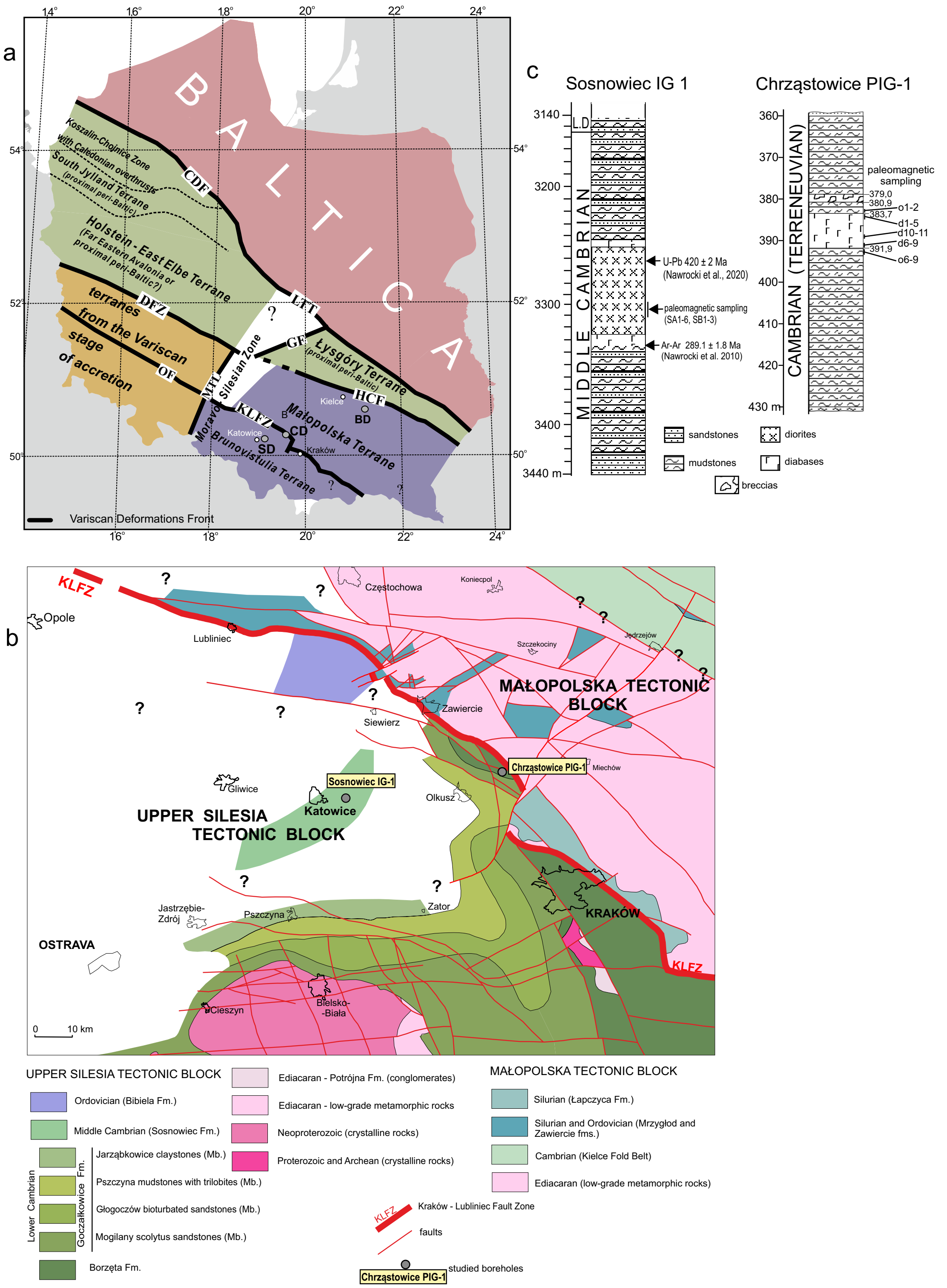
The dioritic part of the latest Silurian intrusion drilled in the Sosnowiec IG-1 borehole and the diabase from the newly drilled Chrząstowice PIG-1 borehole, both in the Upper Silesia Tectonic Block, were palaeomagnetically studied. The palaeoinclinations of the same polarity primary component "A" are similar in the studied intrusions. They correspond well with the latest Silurian/earliest Devonian palaeoinclination obtained from the Bardo diabase (Holy Cross Mts.), and with those calculated from the Apparent Polar Wander Path for palaeocontinent Baltica. All compared intrusions represent the late Caledonian magmatic event that can be linked with the back-arc extension in the marginal part of the Old Red Continent. The angle between declinations of the latest Silurian/earliest Devonian normal polarity component "A" and the latest Carboniferous/earliest Permian secondary reversed polarity component "B", both isolated from the Chrząstowice diabase, indicate the lack of palaeomagnetically detectable clockwise tectonic rotations of the Upper Silesia Tectonic Block with respect to stable Europe at least after the Silurian. However, a slight (up to a dozen or so degrees) anti-clockwise rotation of local sense cannot be excluded after the earliest Permian. The distribution of magnetic fabric points to the sill form of both studied intrusions.

Key words: Palaeomagnetism; Magmatic intrusions; Latest Silurian; Upper Silesia.

INTRODUCTION

The Trans-European Suture Zone (TESZ) of central and south-eastern Europe separates a set of Phanerozoic terranes from the Precambrian East European Craton (Berthelsen 1993; Franke 1995). Some authors have proposed large scale strike-slip movements of terranes on the SW edge of the East European Craton (Text-fig. 1a) even during the Variscan orogenic cycle. A significant Variscan right-lateral displacement along the TESZ has been postulated by Pegrum (1984) and Lewandowski (1993). Tectonic motions of the Hercynide zone of the same sense along the TESZ and other parallel shear zones have also been presented by other authors (e.g. Neugebauer 1989; Matte *et al.* 1990). Badham (1982) presented a strike-slip model for the Western European Hercynides. In this interpre-



Text-fig. 1. (a) The location of Chrząstowice PIG-1 and Sosnowiec IG-1 sampling sites for palaeomagnetic study on the map of terranes in Poland (see Nawrocki 2015) (CDF – Caledonian Deformation Front, LTT – Teisseyre-Tornquist tectonic line, GF – Grójec Fault, DFZ – Dolsk Fault Zone, OF – Odra Fault, KLFZ – Kraków-Lubliniec Fault Zone, MTL – Moravian Tectonic Line, HCF – Holy Cross Fault, SD – Sosnowiec IG1 borehole with diorite intrusion, BD – Bardo diabase, CD – Chrząstowice diabase). (b) Simplified geological map of the contact zone between the Małopolska and Upper Silesia tectonic blocks (after Buła and Habryn 2015), with studied boreholes marked. (c) Simplified lithological columns of Middle Cambrian rocks cut by magmatic intrusions drilled in the Sosnowiec IG-1 and Chrząstowice PIG-1 boreholes. Location of samples for palaeomagnetism and isotope age estimations are marked.

tation the so-called 'Tornquist line' and Kraków-Lubliniec Fault Zone (KLFZ) were of fundamental importance for the Variscan strike-slip processes (see also Aleksandrowski and Mazur 2002; Mazur *et al.* 2006). The KLFZ separates the Brunovistulia and Małopolska terranes of southern Poland (Żaba 1999; Buła 2000; Malinowski *et al.* 2005; Żelaźniewicz *et al.* 2009; Habryn *et al.* 2014; Buła *et al.* 2015). A large-scale tectonic transport of these units along the above-mentioned discontinuity could cause their rotation to be detectable by the palaeomagnetic method. Palaeomagnetic data from the southern region of the Holy Cross Mts. (northern part of the Małopolska Terrane) indicate their stable position with respect to Baltica at least since the Ordovician (Schätz *et al.* 2006; Nawrocki 2000). However, the problem of the tectonic transport scale of the Brunovistulia Terrane along the KLFZ during the Variscan orogenic cycle remains unsolved because the potential field data may indicate that the KLFZ does not continue to the NW (Mazur *et al.* 2020). The palaeomagnetic data obtained from the Brno Massif (Nawrocki *et al.* 2021) can indicate that the Brunovistulian Terrane was included into the peri-Baltic part of the Cadomian orogenic belt and, at least since the mid-Ediacaran, it had a common drift history with Baltica, but a local post-Silurian tectonic clockwise rotation of its Moravian part is probable. The Palaeozoic rocks of the KLFZ were disturbed by strike-slip motions at the end of the Silurian (sinistral transpression) and during the late Carboniferous (dextral transpression and transtension) (Żaba 1999). Carboniferous tectonic rotation of the basement of the Upper-Silesian Coal Basin has been postulated by Bogacz and Krokowski (1981).

It is not possible to verify this hypothesis using Devonian palaeomagnetic data because the geomagnetic field during this period appears to have been so weak, and in part non-dipolar, that obtaining reliable primary palaeomagnetic data from Devonian rocks is challenging (van der Boon *et al.* 2022). This observation can justify the occurrence of strongly rotated Devonian palaeomagnetic directions in the Devonian sedimentary rocks from the Holy Cross Mts. (Lewandowski 1993, Grabowski and Nawrocki 2001) and Moravia (Krs and Pruner 1995). One way to overcome this difficulty is study of the palaeomagnetic record from some older rocks like the Bardo diabase intrusion in the Holy Cross Mts. (424–416 Ma, Nawrocki *et al.* 2013), which has provided a good quality palaeomagnetic pole (Nawrocki 2000).

Along the KLFZ, several late Carboniferous–early Permian magmatic bodies have been penetrated by boreholes (e.g. Buła 2000; Żelaźniewicz *et al.* 2008; Nawrocki *et al.* 2010; Słaby *et al.* 2010). Mafic intrusions have also been drilled in the area of the Brunovistulia Terrane about 50 km from the KLFZ. A diabase – diorite polycyclic intrusion of about 90 m in thickness, drilled here in the Sosnowiec IG-1 borehole, cuts Middle Cambrian clastic rocks. Samples from the dioritic parts of this polycyclic intrusion gave an ^{40}Ar-^{39}Ar plateau age of 399.4 ± 1.8 Ma, obtained on an amphibole concentrate, but the whole rock ^{40}Ar-^{39}Ar dating of the diabase part of the same intrusion revealed a plateau age of 289.1 ± 1.8 Ma (Nawrocki *et al.* 2010). The new U-Pb age of the dioritic part of the Sosnowiec intrusion (420 ± 2 Ma; Nawrocki *et al.* 2020) is comparable with the combined Ar-Ar/magnetostratigraphic age of the Bardo diabase intrusion from the northern part of the Małopolska Terrane (Nawrocki *et al.* 2013). The Sosnowiec diorite and Bardo diabase have the same distinct signature of anorogenic magmatics, typical of continental extensional settings (Krzemiński 2004).

The aim of this paper is to provide reliable palaeomagnetic data from the Sosnowiec diorite and the newly drilled diabase intrusion from the Brunovistulia part of KLFZ in the Chrząstowice PIG-1 borehole (Text-fig. 1b). The next aim is to ascertain if both the intrusion from the Brunovistulia Terrane and the Bardo diabase intrusion from the Holy Cross Mts. were emplaced during approximately the same extensional event at the turn of the Silurian and Devonian. Even though the studied samples of magmatic rocks were not oriented geographically with respect to the north, the possibility of the occurrence of the secondary post-Variscan component of magnetization could have created an opportunity for such an orientation and the detection of eventual tectonic rotations.

MATERIAL AND METHODS

Eleven pieces of the diabase were derived for palaeomagnetic investigations from the Chrząstowice PIG-1 borehole at depths of 383.7–391.9 m (Text-fig. 1c). They were cut into 24 cubic specimens one inch in diameter and 22 mm long. The diabase is characterized by fine- to medium-grained, subophitic to ophitic texture. Six pieces of Cambrian mudstones from the contact zones were also taken for palaeomagnetic studies from this borehole. They were cut into 10 cubic specimens. Nine fragments of diorite (13 specimens) were derived from the Sosnowiec IG 1 borehole located c.a. 47 km west of the Chrząstowice PIG 1 borehole (Text-fig. 1c). Sampling was performed at depths of 3298.2–3312.4 m (Text-fig. 1b).

The natural remanent magnetization (NRM) was measured using a JR-6A spinner magnetometer (AGICO Brno). Most samples (41) were demagnetized by means of the alternating field method (AF) using a Molspin device. For comparison purposes, a few samples (6) were subjected to a stepwise thermal demagnetization in the non-magnetic MMTD1 furnace (Magnetic Measurements). The NRM measurements and demagnetizations were carried out in the MMLFC cage of Magnetic Measurements. The demagnetization results were analysed using orthogonal vector plots (Zijderveld 1967), and the directions of linear segments were calculated using principal component analysis (Kirschvink 1980). For the calculations and for preparing the diagrams with the results, the REMASOFT software from AGICO Brno has been used. The magnetic susceptibility and its anisotropy were measured for 32 samples by means of a MKF1-FB bridge (AGICO Brno). Measurements with statistical parameters e12 <22.5° and $F12$ >4 were regarded as recording statistically significant magnetic lineations and statistically significant magnetic foliation was defined in the samples with $F23$ > 10 and e23< 30° (see Lagroix and Banerjee 2004). Isothermal remanent magnetization (IRM) was obtained using a Magnetic Measurements Pulse Magnetizer (MMPM10). Magnetic mineralogy was determined based on IRM and thermomagnetic analyses (Lowrie 1990) for five samples. Paleomagnetic and rock magnetic studies were conducted at the Paleomagnetic Laboratory of the Polish Geological Institute – NRI in Warsaw.

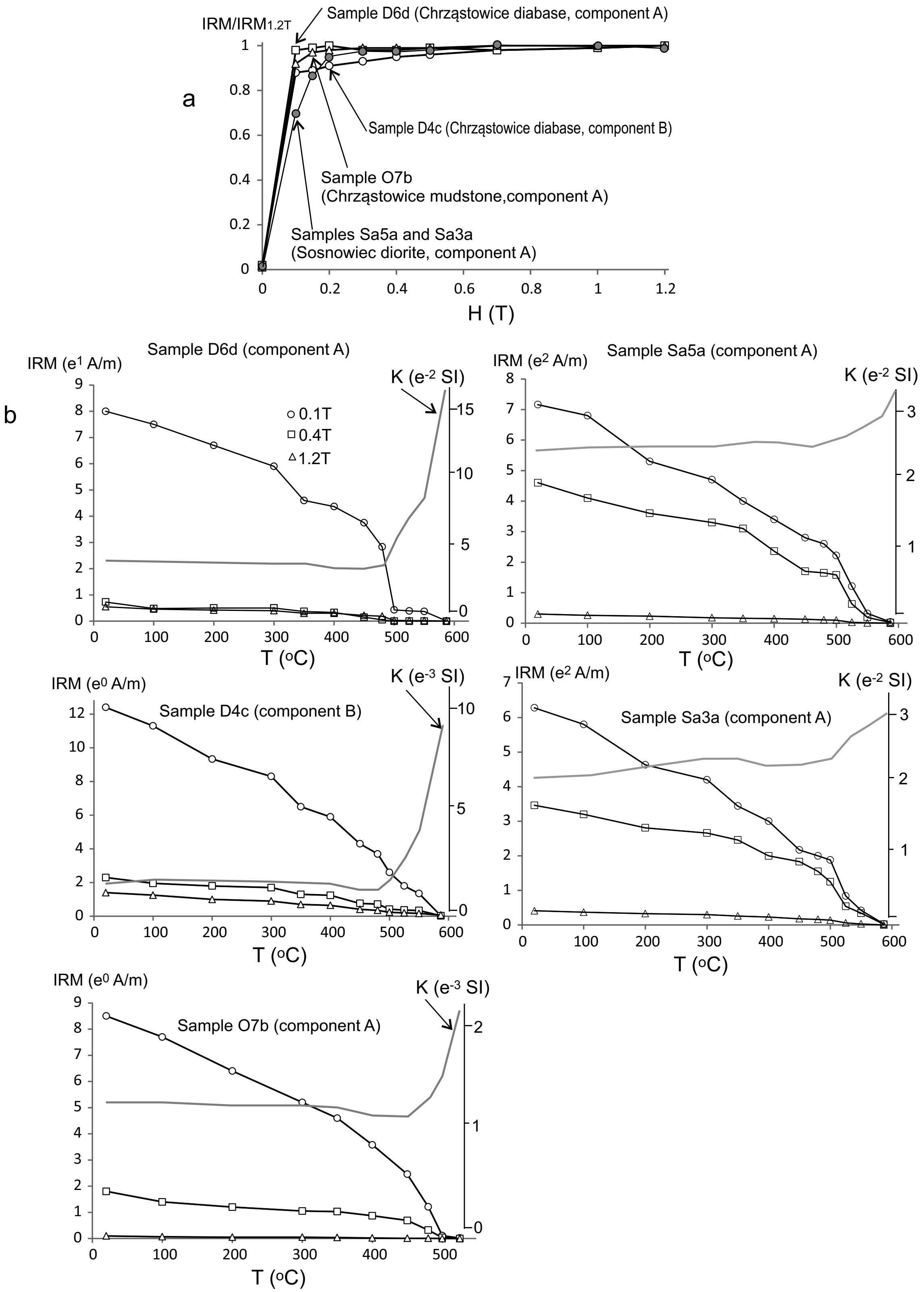
All samples were oriented top-bottom only, but the spatial orientation of the magmatic rocks along the core was the same because fragments of cores were matched sequentially according to fracture surfaces The tectonic correction was not introduced in the case of diorite from the Sosnowiec IG-1 drillcore because the surrounding Cambrian sedimentary rocks are inclined at merely 2–4°. The same low angle was noted for the deviation of the borehole from the vertical. According to the acoustic scanner data obtained from sedimentary rocks underlying the Chrząstowice diabase, they dip ca. 22° towards the SSE with the mean dip azimuth of 168°. These values were used for the tectonic correction of palaeomagnetic directions isolated from the diabase and underlying sedimentary rocks. It should be stressed, however, that in the contact zone of diabase and sedimentary rocks, acoustic scanner data are not interpretable, most probably because of disturbance of the strata during the intrusion emplacement, and consequently the diabase cannot be geographically oriented using the acoustic scanner image. This problem was solved thanks to isolation of the primary component of NRM enabling geographic orientation of samples according to its most likely value of declination checked by the declination of secondary component also isolated from the Chrząstowice diabase.

RESULTS

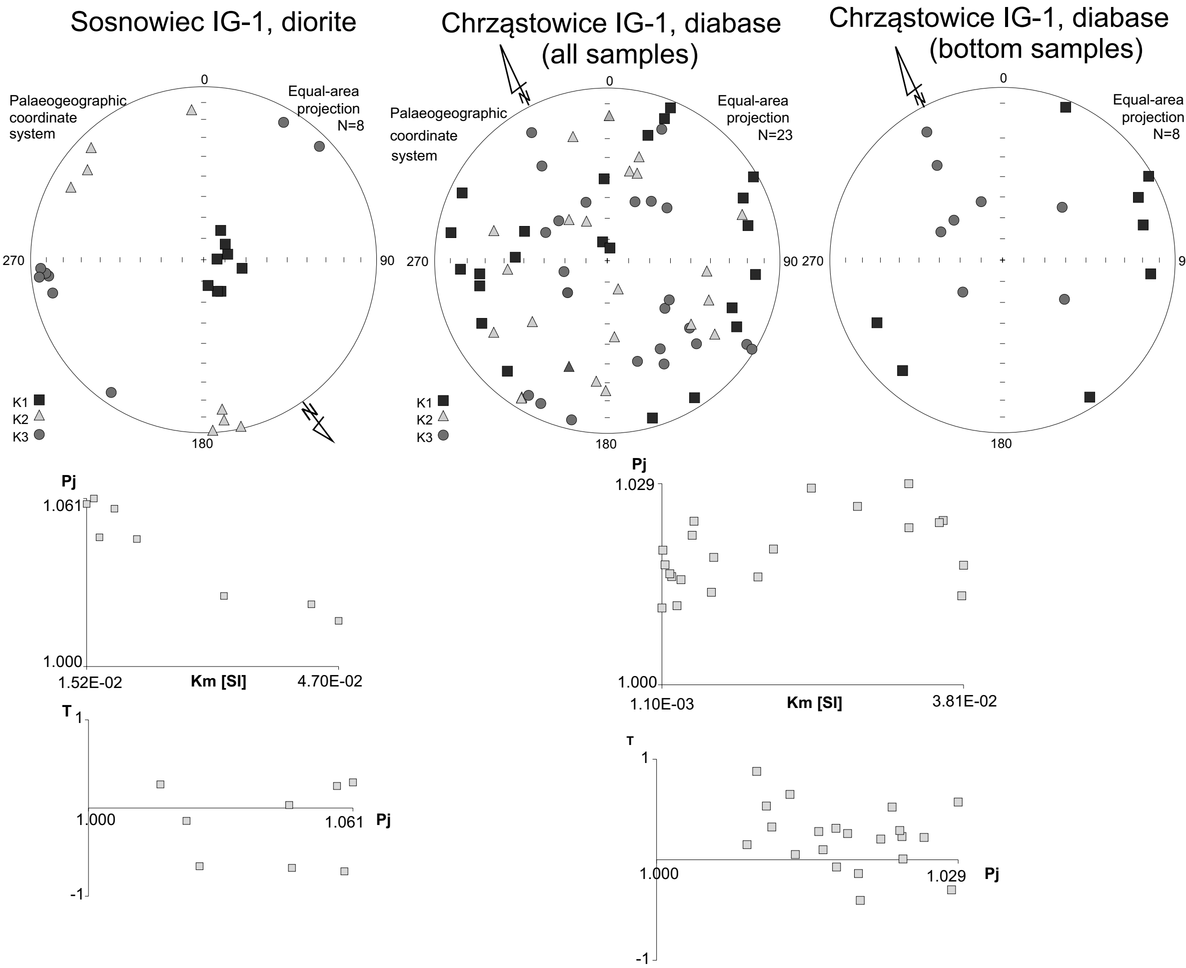
The IRM diagrams indicate that low to medium coercivity magnetic carriers occur in the studied rocks (Text-fig. 2a). The medium coercivity carrier occurs in the diorite samples and in the diabase sample with component "B" of NRM). Two drops of IRM intensity of the low coercivity component are observed in thermomagnetic curves at temperatures of c. 500–550°C for the diabase and near 585°C for the diorite (Text-fig. 2b). This indicates most probably the presence of titanomagnetite and magnetite, respectively (e.g., Dunlop and Özdemir 1997). A slight decrease in the value of IRM after ca. 350°C and the subsequent decrease of magnetic susceptibility at temperatures between 400 and 500°C may indicate a certain amount of maghemite. An increase in magnetic susceptibility at temperatures higher than 500°C is observed in all studied samples. The volume magnetic susceptibility fluctuates between approximately 1.1×10^{-3} SI units and 3.81×10^{-2} SI units in the diabase (Text-fig. 3). The values of this parameter are comparable in the diorite being enclosed between 1.52×10^{-2} SI units and 4.7×10^{-2} SI units.

The experiment of AF demagnetization revealed a very simple structure of NRM of the Sosnowiec diorite because only one stable NRM component (labelled "A") occurs in almost all samples. The NRM was unstable during demagnetization in one sample only. The component "A" was demagnetized at 70 mT or higher fields (Text-fig. 4). The inclination of this component is negative and relatively shallow with a mean value of -34.9°. Its statistical parameters are very good (Table 1).

Two distinct components of NRM were isolated from the Chrząstowice diabase. Five samples contained an unstable NRM record during demagnetisation. The "A" component with the mean inclination after tectonic correction of -38.8° (Table 1) isolated in 11 samples was demagnetized at c. 70 mT and temperatures of 500–580°C. Another component "B" was identified in the samples containing component "A" (two samples) and without it (8 samples). It was demagnetized in the field up to 50mT. Results of thermal demagnetization of one sample containing both



Text-fig. 2. Results of magnetic mineralogy studies. (a) Isothermal remanence (IRM) acquisition curves prepared for the studied diabase (samples D4c, D6d), diorite (samples S3a, Sa5a), and sedimentary rocks (O7b) drilled in the Chrząstowice PIG-1 and Sosnowiec IG-1 boreholes. (b) Thermal demagnetization of orthogonal-axes IRM curves (Lowrie 1990) obtained for the same samples.

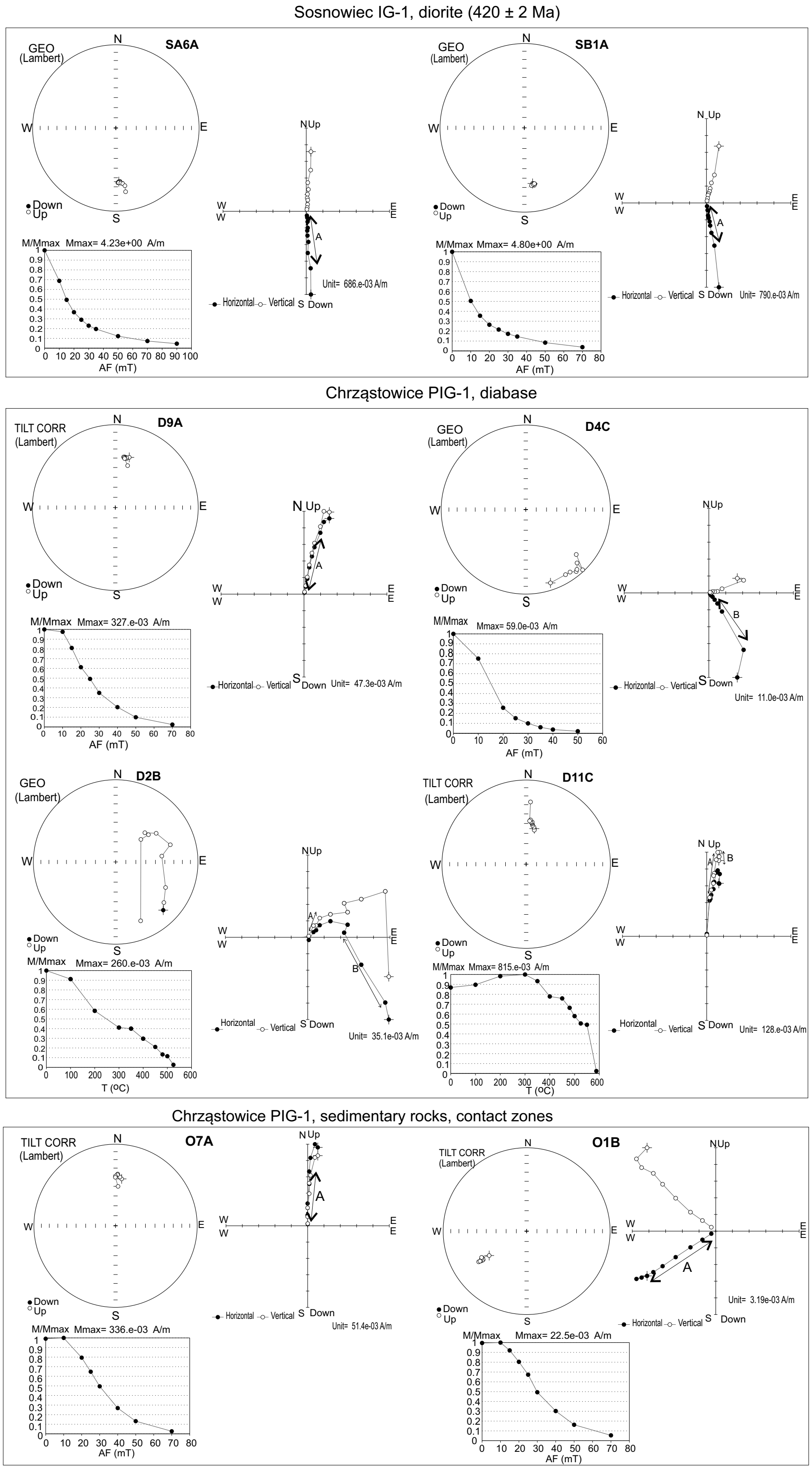


Text-fig. 3. The anisotropy of magnetic susceptibility stereoplots with the distribution of principal susceptibility axes determined for specimens from the studied magmatic intrusions from the Upper Silesia Tectonic Block. The Km versus Pj and Pj versus T graphs are also shown (Km – magnetic susceptibility, Pj – corrected anisotropy factor, T – shape parameter). The direction of north on the stereoplots is shown according to the assumption that the declination of the primary component of NRM is c. 40° i.e. the AMS data are plotted in paleogeographic coordinates with a plane of 40° (see text). Also, data from the lower contact zone of the diabase are presented separately because the flow-oriented fabric could occur mainly in this zone.

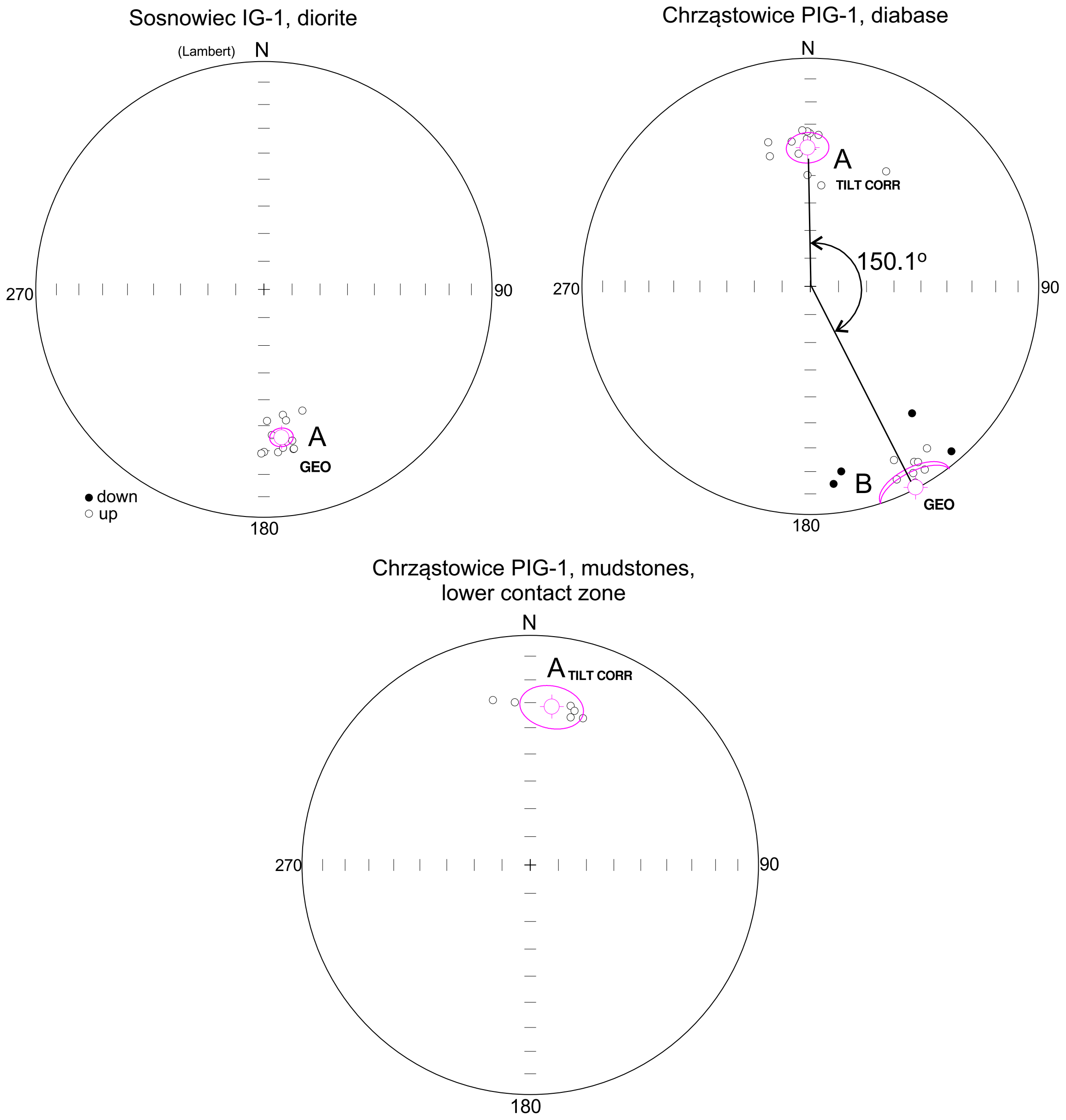
Borehole	Rock	Component	N	D	I	Alpha95	K	Plat/Plong*	dp	dm
Sosnowiec IG-1	diorite	A[1]	12	173.2	-34.9	3.7	124.8	12.1S/341E	2.4	4.3
Chrząstowice PIG-1	diabase	A[1]	11	1.2	-46.4	6.4	47.1	0S/343.8E	5.3	8.2
		A[2]	11	358.1	-38.8	6.4	47.1	9.7S/342.2E	4.5	7.6
	diabase	B[1]	1o	148.2	-4.5	8.7	32.0	41.3S/5.8E	4.4	8.7
		B[2]	10	149.4	-26.1	8.7	32.0	52.4S/1.4E	5.1	9.4
	mudstone	A[1]	6	17.7	-36.5	9.3	53.2	3.0S/326.6E	6.3	10.8
		A[2]	6	13.2	-30.2	9.3	53.2	8.4S/327.7E	5.7	10.3

Table 1. Palaeomagnetic directions and poles obtained from the Sosnowiec diorite and Chrząstowice diabase and mudstone. [1] data in geographic coordinates, [2] data after tectonic correction, Plat/Plong* – south palaeopole latitude and longitude calculated for the assumed declination (after tectonic correction) of component "A" of 41 degrees (see text), N – number of samples, D – declination, I – Inclination, Alpha95 – semi-angle of 95% confidence, K – precision parameter, dp – error of the distance between site and palaeopole; dm – palaeodeclination error.

these components of NRM can indicate an unblocking temperature for component "B" of c. 450°C (Text-fig. 4). The mean inclination of component "B" before tectonic correction is -4.5° (Table 1). The NRM of sedimentary rocks from the contact zone is not complex. These strongly magnetized rocks contain only



Text-fig. 4. Results of demagnetization (stereoplots of demagnetization directional tracks, intensity decay curves, orthogonal demagnetograms) of representative samples from the diabase and diorite drilled in the Chrząstowice PIG-1 and Sosnowiec IG-1 boreholes, respectively.



Text-fig. 5. Stereoplots with characteristic “A” and “B” directions of natural remanent magnetization isolated from the studied magmatic intrusions and sedimentary rocks from the contact zone. Mean directions (Table 1) are marked with bigger circles and surrounded by circles of confidence limit.

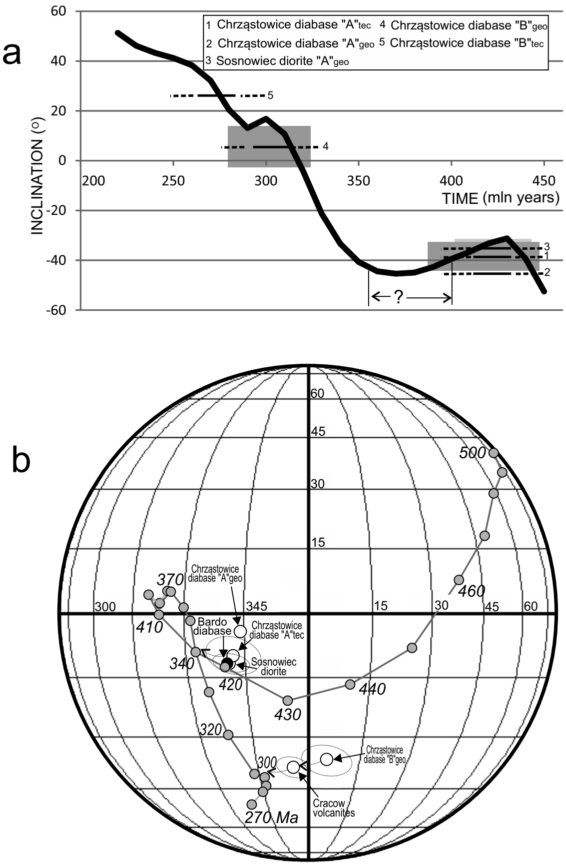
one component “A” with the mean inclination after tectonic correction of -30.2° (Table 1, Text-fig. 4). It was demagnetized at c. 70 mT. Its relative declination in the samples from the lower contact zone is the same as in the diabase (Text-fig. 5). In a few specimens from the upper contact zone, this parameter differs by a. 120°, most probably due to a wrong spatial linkage of sedimentary rocks and the diabase in this part of the section. Data from the upper contact zone has not been included in Table 1. The relative declinations of components “A” and “B” from the Chrząstowice diabase differ by ca. 150° (Text-fig. 5).

The degree of anisotropy of magnetic susceptibility (AMS) of the diabase is up to 3%, but it is higher (up to 6.1%) in the diorite samples (Text-fig. 3). The pattern of the AMS axes in the samples from both intrusions is different. The magnetic fabrics with vertical minimum susceptibility axes defined for the Sosnowiec diorite are evidently inversed. The inverse or intermediate fabrics occur usually when single-domain grains of magnetite are present (e.g. Moncinhatto *et al.* 2020). The oblate magnetic fabrics are predominant in the diabase intrusion. The magnetic fabrics defined for the diorite have a mixed shape (Text-fig. 3). They can be interpreted in terms of magma flow direction, but with a caution.

DISCUSSION

The nature and age of natural remanent magnetization components

The IRM and IRM (T) curves indicate that low- to medium coercivity ferromagnetic phases with blocking temperatures of ca. 500–550°C and near 585°C occur in the studied rocks. These magnetic properties are characteristic of titanium-poor titanomagnetite and magnetite (e.g. Dunlop and Özdemir 1997). The titanium-poor titanomagnetite is characteristic for the diabase with the component “A” of NRM. The same component of NRM isolated from the diorite is most probably carried by magnetite. The unblocking temperatures of c. 450°C and a drop in magnetic susceptibility between 350°C and 450°C observed in the samples containing component “B” indicate a substantial contribution of maghemite (e.g. Dunlop and Özdemir 1997) which indicates the secondary chemical origin of this component. On the other hand, the very strong magnetization of the diabase (mean intensity of NRM 40.2 × 10^{-2}A/m) and the surrounding sedimentary rocks (mean intensity of NRM 12.9 × 10^{-2}A/m) indicates the primary origin of component “A” isolated from the same diabase. It was most probably recorded during the magma emplacement. The mean intensity in the diabase samples containing only component “B” (24.6 × 10^{-2} A/m) is nearly twice as low as that noted in the diabase samples containing the component “A” of NRM. The highest values of NRM intensities with a mean of 43.8 × 10^{-1} A/m were noted in the Sosnowiec diorite.



Text-fig. 6. Palaeomagnetic inclinations and poles isolated from the Chrząstowice diabase and Sosnowiec diorite. (a) Inclinations of component “A” (with confidence limits in grey) isolated from the studied magmatic intrusions on the background of Ordovician to Triassic inclinations characteristic for palaeocontinent Baltica (after Torsvik et al., 2012, recalculated to geographic coordinates of the Chrząstowice PIG-1 borehole). Note that the reference data for the Devonian (part with the question mark) should be treated with caution because a persistent non-uniformitarian palaeomagnetic field is possible at that time (Van der Boon *et al.* 2022). (b) Palaeomagnetic poles calculated for components “A” and “B” (with ellipsoids of confidence) on the background of the latest Cambrian to mid-Permian segment of the Apparent Polar Wander Path characteristic for Baltica (Torsvik *et al.* 2012) when a declination of 40° for component “A” is assumed (see text). Palaeopoles isolated from the Bardo diabase (Nawrocki 2000) and Cracow volcanites (Nawrocki *et al.* 2008) are also presented.

To date, two phases of post-Ediacaran magmatic activity have been recognized in the Upper Silesia Tectonic Block and the Małopolska side of the KLFZ. The older late Caledonian phase was dated at ca. 420 Ma (Nawrocki *et al.* 2021) and the younger one at c. 310–290 Ma (Nawrocki *et al.* 2008, 2010, 2020; Żelaźniewicz *et al.* 2008; Mikulski *et al.* 2019). The Chrząstowice diabase has not been dated by isotopic methods yet. Thus the age of component “A” cannot be estimated directly. The mean inclination of this component after tectonic correction (-38.8° ± 6.4°) within analytical error is the same as that calculated for component “A” isolated from the Sosnowiec diorite (-34.9° ± 3.7°; Table 1) ca. 420 My old (Nawrocki *et al.* 2020). The mean inclination of the primary component of NRM isolated from the coeval Bardo diabase in the Holy Cross Mts. (Nawrocki *et al.* 2013) is also similar (-33.1° ± 3.4°; Nawrocki 2000). The palaeoinclinations of component "A" isolated from the Chrząstowice diabase could also possibly be of earliest Carboniferous age (Text-fig. 6), but until now magmatic intrusions of this age have not been recognized in the Upper Silesia and Małopolska tectonic blocks and therefore we exclude this solution.

The palaeoinclination obtained from the early Permian Cracow volcanites (-13°; Nawrocki *et al.* 2008) is c. 20–26° lower than that characteristic for component "A", but within analytical error is close to that characteristic for component "B" calculated in geographical coordinates (-4.5°; Table 1). Component "B" of secondary origin differs in relative declination of 150.1° from "A" and therefore must represent the opposite polarity with respect to component "A". Normal polarity of component "A" is the only acceptable solution because of the general palaeogeographic frames in which this part of Europe was located at the southern latitudes until the late Carboniferous (e.g. Torsvik *et al.* 2012). The reversed polarity component "B" was not recorded before the Variscan or older tectonic deformation of sedimentary rocks under- and overlying the Chrząstowice diabase because, before tectonic correction, it fits the Permian segment of the inclination curve characteristic for stable Europe (Text-fig. 6a). All this evidence points to the older, i.e. the latest Silurian/ earliest Devonian, age of the Chrząstowice diabase and component "A". Component "B" was recorded during the second phase of Paleozoic magmatic activity in the study area, i.e. at the turn of the Carboniferous and Permian.

Tectonic implications

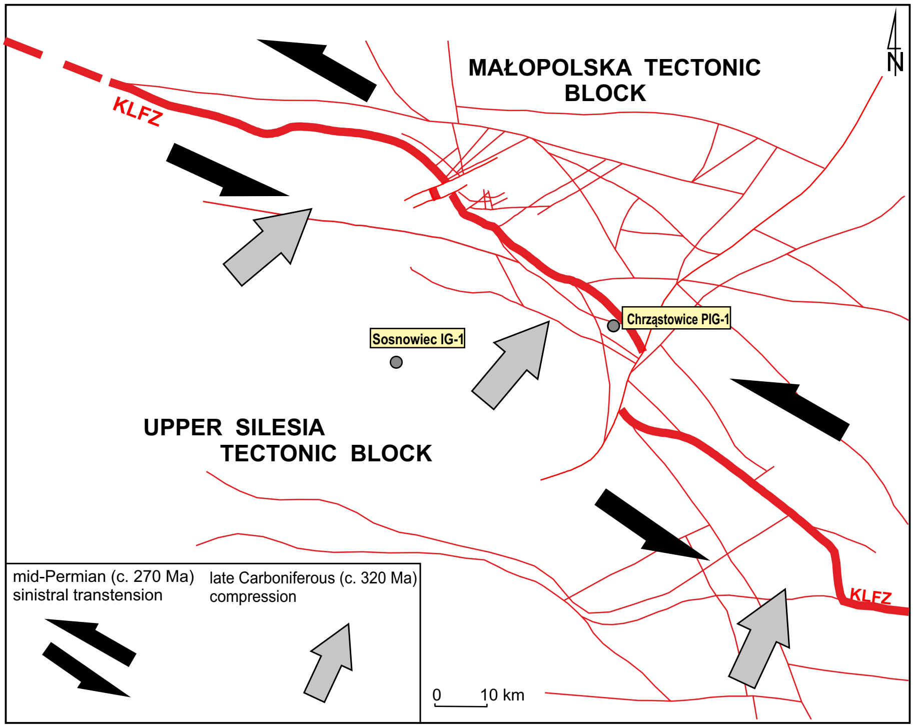
The difference between the relative declination of components "A" and "B" isolated from the Chrząstowice diabase (150.1°; Text-fig. 5) is within analytical errors the same as that between the declination of the primary latest Silurian palaeomagnetic direction characteristic for the Bardo diabase (Kielce Region of the Holy Cross Mts.) and the secondary late Carboniferous–early Permian palaeomagnetic directions isolated from the Devonian carbonates of the Holy Cross Mts. (Grabowski *et al.* 2006). The primary early Permian reversed polarity directions isolated from the early Permian Cracow volcanic rocks (Nawrocki *et al.* 2005, 2008) and the primary direction from the Bardo diabase differ in declination by ca.155°.

After the assumption that the real declination of component "A" is 41° (as recalculated from the Bardo diabase) and consequently that of component "B" is 191.1°, the palaeopoles obtained from these palaeodirections fit approximately to the latest Silurian and latest Carboniferous/early Permian segment of the reference APWP, respectively (Text-fig. 6). A certain departure of palaeopole "B" from the latest Carboniferous/earliest Permian palaeopoles obtained earlier (Nawrocki et. al. 2005, 2008; Grabowski et al., 2006) could result from inaccuracy of the reference APWP or/and from the slight anticlockwise rotations of the studied rocks, caused most probably by mid-Permian sinistral transtension in the KLFZ (Text-fig. 7) and other reactivated prominent SW-NE-trending faults of Central Europe (Nawrocki, 1998; Nawrocki et al., 2008). Before this, in the late Carboniferous, the SW-NE-directed tectonic compression led to the breaking of the KLFZ in some places. Theoretically it can be assumed that palaeopole "B" is fully convergent with the reference APWP and that palaeopole "A" is slightly clockwise rotated. However, as already mentioned above, these early Permian palaeopoles defined in adjacent areas depart a bit from the reference APWP. All these facts point to the lack of palaeomagnetically detectable clockwise tectonic rotation of the Upper Silesia Tectonic Block with respect to the Małopolska Tectonic Block and stable Europe at least after the Silurian.

Due to dextral translation of the Variscan Belt along the Moravian Line (e.g. Franke and Żelaźniewicz, 2000; Nawrocki *et al.* 2024), the KLFZ does not continue to the NW (see Mazur *et al.* 2020). The most likely latest Silurian/earliest Devonian palaeomagnetic age of the Chrząstowice intrusion indicates that the late Caledonian magmatic processes of this age in the Małopolska Terrane and Brunovistulia Terrane were more extensive, not being constrained to the Sosnowiec diorite and Bardo diabase only. This phase of magmatic activity is also supported by common occurrences of Silurian micas and monazites in the Carboniferous sedimentary sequences of the Upper Silesian Coal Basin (Kusiak *et al.* 2006). The above-mentioned intrusions cutting sedimentary covers of the BVT and MT point to extensional processes near the Silurian/Devonian boundary, common for both units which must have been situated close each other (Nawrocki *et al.* 2021). They could be linked with the back-arc extension ca. 425–410 Ma ago in the marginal (Avalonian) part of the Old Red Continent, forming the peripheral part of the Old Red Continent (see Franke *et al.* 2017).

The spatial form of the intrusions

The pattern of the AMS axes characteristic of the bottom part of the diabase intrusion probably at



Text-fig. 7. Tectonic regime in the Kraków-Lubliniec Fault Zone area in Late Carboniferous and mid-Permian times. The net of tectonic discontinuities is the same as in Text-fig. 1b.

least partly reflects an approximate W-E direction of magma migration and a sill-type intrusion with ca. horizontal maximum susceptibility axes (Text-fig. 3). This is the most common feature in magmatic rocks with normal fabric, which have the Kmax axes parallel to the magma flow plane (e.g. Knight and Walker 1988). The AMS data obtained from the Sosnowiec diorite can be also interpreted in terms of magma flow direction, but with a caution because of the inverse nature of the magnetic fabrics. They could indicate that this intrusion is also of sill type with the magma emplacement in an approximate W-E direction that was interpreted after spatial orientation of the core according to the directions of NRM components.

CONCLUSIONS

From the palaeomagnetic study of the latest Silurian Sosnowiec diorite, Chrząstowice diabase and sedimentary rocks, supported by previous palaeomagnetic data from the latest Silurian/earliest Devonian Bardo diabase, despite limited sample collection we can draw the following conclusions:

- The characteristic inclinations of primary palaeomagnetic directions are within analytical errors the same in all the studied and compared magmatic intrusions. They correspond very well with the latest Silurian palaeoinclination at the site of these investigations, derived from the stable European Apparent Polar Wander Path.
- All the compared intrusions most probably represent the same late Caledonian magmatic event linked with the back-arc extension in the marginal part of the Old Red Continent.
- The angle of 150.1° between the relative declinations of the latest Silurian normal polarity component “A” and the latest Carboniferous/earliest Permian reverse polarity component “B” isolated from the Chrząstowice diabase indicate the lack of palaeomagnetically detectable clockwise tectonic rotation of the Upper Silesia Tectonic Block with respect to stable Europe at least after the Silurian. However, a slight (up to a dozen or so degrees) anti-clockwise rotation of a local sense cannot be excluded after the earliest Permian.
- The anisotropy of the magnetic susceptibility data support a sill-type form of both studied intrusions. This conclusion should be however supported by further more extensive studies.

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