Geological Quarterly, 2004, **48** (2): 135–146

Geological setting of the Milejowice-Janowice diabase intrusion: insights into post-Caledonian magmatism in the Holy Cross Mts., Poland

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Kowalczewski Z. (2004) — Geological setting of the Milejowice-Janowice diabase intrusion: insights into post-Caledonian magmatism in the Holy Cross Mts., Poland. Geol. Quart., **48** (2): 135–146. Warszawa.

Near Milejowice and Janowice in the eastern part of the Łysogóry Unit of the Holy Cross Mts., Poland, a SW–NE trending diabase has been identified intruding Lower Palaeozoic strata. This intrusion causes a magnetic anomaly, with ΔT values of 48–112 γ. It is orientated perpendicular to the regional strike. Boreholes encountered one to three component dykes 2.0 to more than 10.0 m thick inclined at 75–90°, generally towards the east. They are hydrothermally altered and affected by surface weathering. The intrusion is located along two independent transverse faults, "skipping" from one to another irrespective of their strike. The intrusive zone is strongly tectonically disturbed, S-curved and disrupted by faults into segments and sub-segments. Most of the diabases are slicken-sided, and locally cataclased and mylonitized. The Milejowice-Janowice diabases probably formed in the Early Devonian, i.e. late Lochkovian–early Pragian, as post-tectonic igneous rocks belonging to within-plate, continental basalts according to Krzemiński (2004). Their origin may be referred to magmatism triggered by the extension of the Baltica passive margin during the final Late Silurian–Early Devonian phase of its collision with eastern Avalonia. A complex and at least two-phase development of magmatism in the Holy Cross Mts. is envisaged.

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Key words: Holy Cross Mts., Łysogóry Unit, Early Devonian, magnetic anomaly, diabase intrusion.

INTRODUCTION

Small igneous bodies intruded sedimentary rocks of the Kielce and Łysogóry regions of the Holy Cross Mts. during the Palaeozoic. Diabase and lamprophyre dykes and sills have been identified in the Kielce (southern) region, but only diabase dykes in the Łysogóry (northern) region (Fig. 1). In both the areas these igneous bodies have been traced primarily in the Lower Palaeozoic rocks. The lamprophyres of the southern region and the diabases of the northern region have also intruded into Lower Devonian and lower Middle Devonian (Eifelian) rocks (Kowalczewski, 1974).

The diabases of the Kielce region, especially from the Bardo Syncline, have been more studied than those from the Łysogóry region. The origin and age of the latter intrusions have not been fully determined. We still do not know whether they formed in one or several phases of tectonic activity. Moreover, it is not clear what the relationships (especially the tectonic and genetic ones) between the Kielce and Łysogóry diabases are. Did they originate from the same magma chamber? Why are the Kielce diabases linked on a structural plan only to longitudinal faults, and the Łysogóry ones only to transverse faults? Why did igneous rocks not intrude into the main zone of the Holy Cross Mts. Fault separating both regions?

The conclusions derived from the studies of igneous rocks are also essential to constrain the age of the tectonic deformation responsible for formation and consolidation of the Holy Cross Mts. area, which consists of the two different tectonic units discussed above. They also influence views on the structural position of this area, located close to the margin of the East European Craton and at the same time near the Variscan Front of southwestern Poland.

In order to better understand the igneous rocks of the Łysogóry Unit, magnetic surveys were conducted during 1973–1976 near major transverse fault zones, being potential sites for diabase intrusions. Near the villages of Milejowice and Janowice, a magnetic anomaly of 30–112 γ was discovered in 8 profiling lines (Karaczun and Karaczun, 1976). Subsequently, this area was mapped in detail. Due to insufficient exposure of the diabase-bearing Palaeozoic bedrock, mapping was supplemented by geoelectrical and magnetic surreys (Tracz and Wągrowska, 1975). After interpretion of the geo-

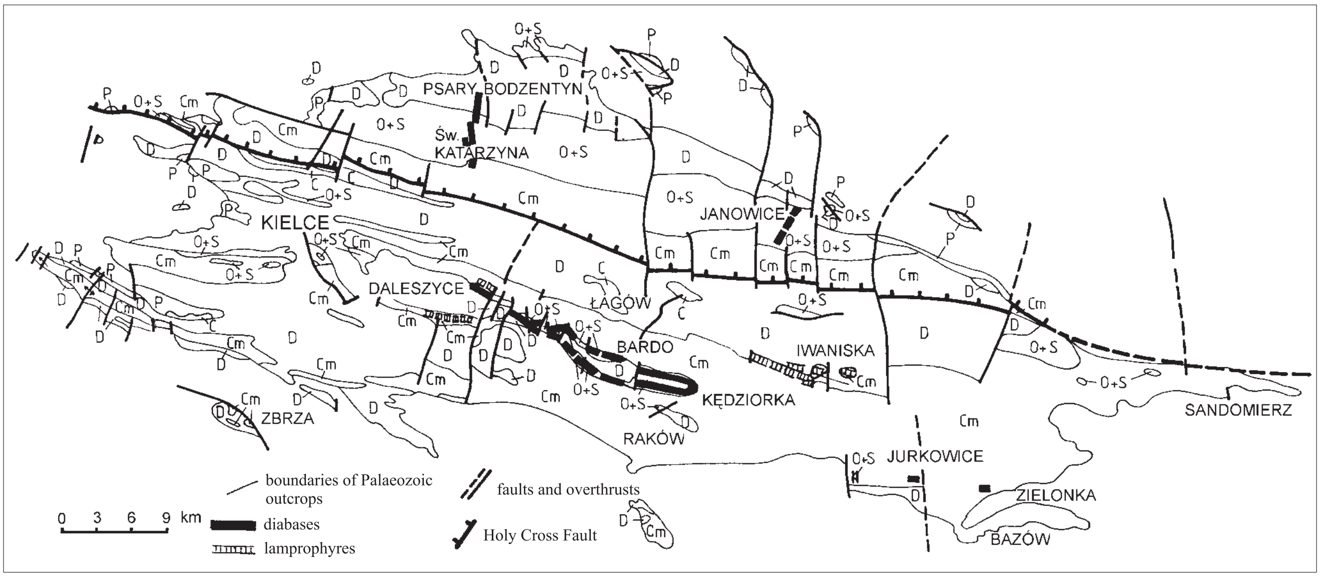

Fig. 1. Geological sketch map of Palaeozoic rocks in the Holy Cross Mts.

Stratigraphy: Cm — Cambrian, O + S — Ordovician and Silurian, D — Devonian, C — Lower Carboniferous, P — Permian

physical and geologic data obtained, 4 prospecting boreholes, i.e. Milejowice 1 (depth 150 m), Milejowice 2 (150 m), Janowice 1 (144 m) and Janowice 2 (130 m), were drilled. They were designed to explain the origin of magnetic anomalies, as well as to identify in more detail the geologic setting of the adjacent area. These boreholes achieved their objectives; the intrusive rocks and adjacent Ordovician and Silurian beds were penetrated and studied. In addition to macroscopic examination of the cores, petrographic and geochemical (Krystkiewicz and Ryka, 1976) as well as biostratigrafic investigations (Tomczykowa and Tomczyk, 1976) were performed on the samples collected. The results of these studies, which, I designed and conducted, were given in an unpublished report (Kowalczewski, 1976).

Near the contact zones, diabases and surrounding rocks are mineralized by metal sulfides, primarily pyrite (Wróblewski, 1976). This relationship was examined by geochemical methods by Lenartowicz (2000). New petrographic and geochemical studies of the Milejowice-Janowice diabases have been relently conducted by Krzemiński (2004).

The views expressed in this paper are backed up by basic and interpreted geological and geophysical results derived from the investigations performed during 1971–1976. They have been supplemented by conclusions drawn from my subsequent studies and those of Lenartowicz (2000), and particularly of Krzemiński (2004). Attention is focused on the diabase intrusion itself, and not on the associated sedimentary rocks and the geological setting of the area. The latter will be discussed in a separate report.

OUTLINE OF GEOLOGICAL SETTING

The study area is located in central part of the eastern (Jeleniów-Opatów) segment of the Łysogóry Unit of the Holy Cross Mts. (Fig. 1). Quaternary deposits cover a bedrock composed of Middle and Upper Cambrian rocks (Jeleniów Range) and of Ordovician, Silurian and Devonian rocks (Opatów Upland). These rocks are overlain in the north by the Upper Permian and Lower Triassic (Fig. 2). The thickness of various Quaternary deposits exceeds 40 m in the neighborhood of Milejowice.

Cambrian. The poorly exposed Cambrian outcrops were delineated by geoelectrical methods. The stratigraphic position of the lithologically diversified successions can be determined only indirectly by comparisons with comparable deposits in adjacent areas. There are few precise constraints on the age and tectonic history of the Cambrian rocks, and thus the successions labeled in Figure 2 are only tentatively identified.

The clayey-silty unit $\in_{2} + \in_{3}$? is represented by shaly claystones with subordinate siltstone and sandstone interbeds, showing an impedance of 35–120 ohms and a mean of 60–70 ohms. These deposits were informally classified as the "Jurkowice Beds" (Kowalczewski *et al.*, 1975) and compared to the Góry Pieprzowe Formation; they are most probably of Middle and Upper Cambrian age (Szczepanik, 2001).

The sandstone-siltstone unit $\in_{3-1}$a? consists of quartzitic sandstones, quartz sandstones and siltstones with muscovite, ferric siltstones and claystones, with black shaly silty claystone interbeds. The impedance is in the range of 120–180 ohms with mean values of 150–180 ohms.

The sandstone unit $\in_{3-1}$b? consists entirely of quartzitic sandstones, primarily thick-bedded, gray; they contain less siltstone and claystone interbeds then the former unit. The impedance locally reaches 500 ohms with mean values of 150–200 ohms.

Two of the units described above were assigned to the informal "Gołoszyce Beds" (Kowalczewski *et al.*, 1975), namely to their lower (sandstone-siltstone unit $\in_{3-1}$a?) and their upper part (sandstone unit $\in_{3-1}$b?). Their lithological similarity to the Wiśniówka Formation (Orłowski, 1968, 1975) suggests that these units are coeval and were formed in the early Late Cambrian (Salwa and Szczepanik, 2002).

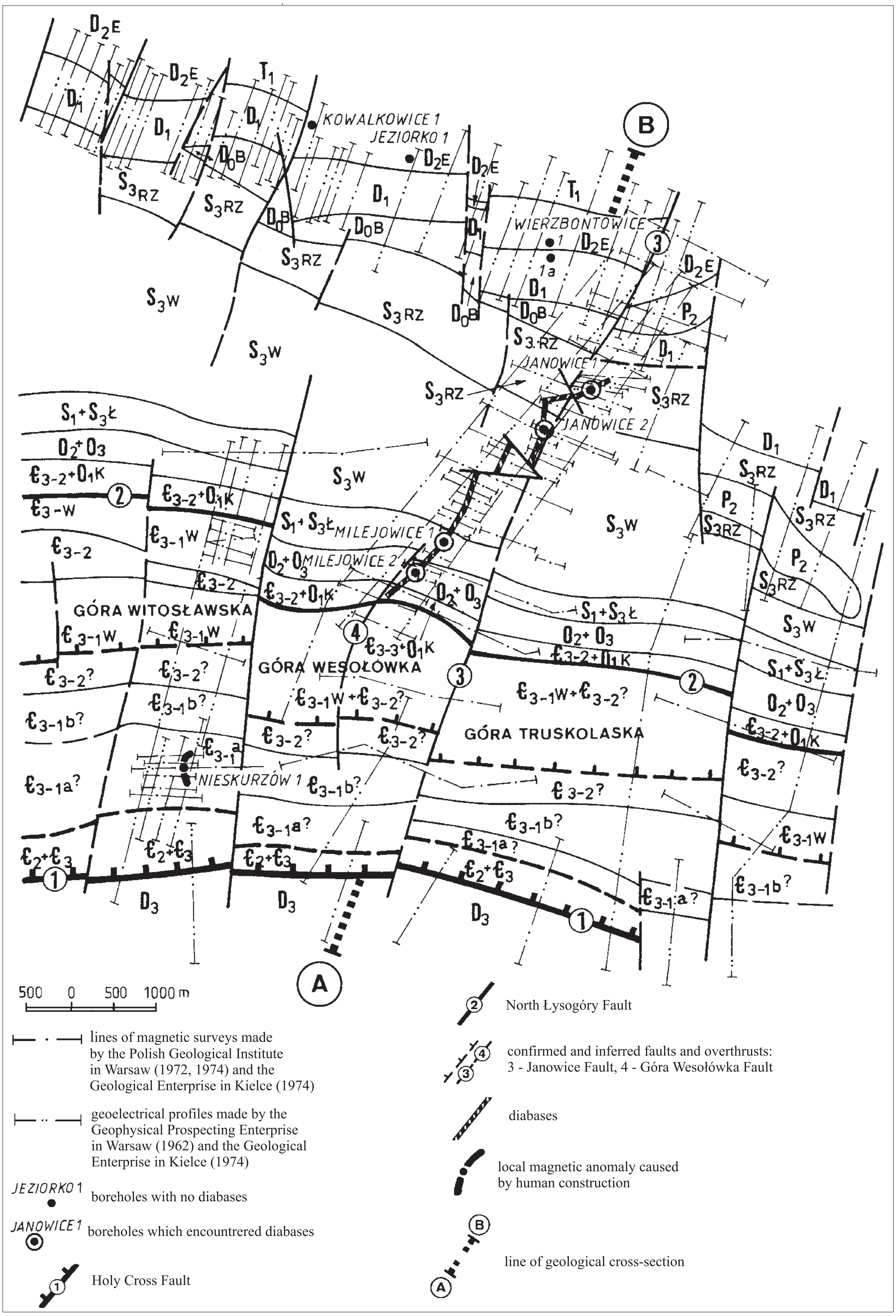

Fig. 2. Solid geological map of the Milejowice–Janowice area

Stratigraphy: $\in_2 + \in_3$ — Middle and Upper Cambrian, Jurkowice Beds; $\in_{3-1}$a? — inferred lower Upper Cambrian, Lower Gołoszyce Beds; $\in_{3-1}$b? — inferred lower Upper Cambrian, Upper Gołoszyce Beds; $\in_{3-2}$? — inferred uppermost Cambrian, Marcinkowice Beds; $\in_{3-1W}$? — lower Upper Cambrian, Wiśniówka Formation; $\in_{3-2}$ + O_1K — uppermost Cambrian and Lower Ordovician (Tremadocian), Klonówka Formation; $\in_{3-1}$W + $\in_{3-2}$? — lower Upper Cambrian, Wiśniówka Formation and inferred uppermost Cambrian, undivided; $O_2 + O_3$ — Middle and Upper Ordovician; S_{1+3}Ł — Lower and Upper Silurian (Llandovery, Wenlock and lower Ludlow), graptolite shales; S_3W — Upper Silurian (upper Ludlow), Wydryszów Formation; S_3RZ — Upper Silurian (Pridoli), Rzepin Formation; D_oB — lowermost Devonian (lower Lochkovian), Bostów Formation; D_1 — Lower Devonian (upper Pragian and Emsian), Barcza and Zagórze Formation; D_2E — Middle Devonian, Grzegorzowice Formation; D_3 — Upper Devonian (Frasnian and Famennian undivided); P_2 — Upper Permian (Zechstein); T_1 — Lower Triassic (lower Buntsandstein)

The siltstone-claystone unit $\in_{3-2}$? consists of shaly siltstones and claystones with subordinate quartz and quartzitic sandstones. The impedance ranges from 60 to 250 ohms, primarily from 70 to 120 ohms. This unit, informally distinguished as the "Marcinkowice Beds" (Kowalczewski *et al*., 1975) may represent the middle Late Cambrian, i.e. lower lithostratigraphic members of the Klonówka Formation (Salwa and Szczepanik, 2002).

The Wiśniówka Formation $\in_{3-1}$W of early Late Cambrian age (Żylińska and Szczepanik, 2002), consists mainly of thick-bedded quartzitic sandstones with shaly siltstone and claystone, and in places, with sedimentary breccia interbeds. The impedance increases towards the west exceeding 1000 ohms with mean values of about 500 ohms.

The rocks of $\in_{3-1}$W and $\in_{3-2}$? are folded together in a crest zone of the Jeleniów Range. In some places these units cannot be reliably separated, therefore a joint $\in_{3-1}$W and $\in_{3-2}$? subdivision was introduced in the geological map (Fig. 2).

The Klonówka Formation $\in_{3-2}$W + O_1K consists of dark gray shaly siltstones and claystones interbedded with sandstone (quartzitic sandstones primarily at the base). These rocks are characterised by an impedance of 70–300 ohms. Their age is between Late Cambrian and early Tremadocian (Orłowski, 1968, 1975, 1992; Tomczykowa, 1968; Kowalczewski, 1971; Żylińska and Szczepanik, 2002).

Ordovician. The Bukowiany, Jeleniów and Wólka Formations, O_2 + O_3 (Bednarczyk, 1981; Modliński and Szymański, 2001*a*) were identified near the study area in the boreholes Bukowiany 1 and Jeleniów 1, and were also penetrated in the Milejowice 2 borehole.

The upper Llanvirn Bukowiany Formation consists of detrital and organodetrital limestones containing oolites, and chamosites, and with marly claystone interbeds with siderites and bentonite clays. Their thickness does not exceed 20 m.

The Jeleniów Formation of Llandeilo and Caradoc age is developed as a black graptolite shale facies with bentonite interbeds (in borehole Milejowice 2), with a thickness of 90–130 m.

The Wólka Formation of Ashgill age is represented by graptolitic shaly claystones the base, passing upward into marls and calcareous-dolomitic siltstones with thin limestone interbeds. These rocks are about 80–100 m thick.

Silurian. The Graptolite Formation S_1 + S_3Ł of Llandovery to Ludlow age spans the *Parakidograptus acuminatus* to *Saetograptus leintwardinensis* Zones (Kozłowski, 2003). According to Tomczyk's informal subdivision (1962, 1968), the unit encompasses the "Ciekoty Shales", the "Dębniak Beds" and the lower portion of the "Wilków Shales". This formation was penetrated by Milejowice 1 borehole (*Gothograptus nassa– Neodiversograptus nilssoni* Zones) and its thickness is between 250 and 350 m.

Geoelectrical surveys are not sufficient to subdivide the graptolite shales into lower (Ordovician) and upper (Silurian) parts. The impedance of these rocks is low, varying from 35 to 90 ohms.

The Wydryszów Formation S_3W encompasses upper Ludlow and probably lower Pridoli strata (Teller, 1997; Modliński and Szymański, 2001*b*; Kozłowski, 2003). In the Jaronowice 2 borehole these deposits consist of shaly claystones, in place variegated, with subordinate graywacke siltstone and sandstone interbeds. Their impedance is the lowest among the Ordovician–Silurian succession, of some 30–70 ohms. The thickness has not been recorded reliably; I consider that it has been overestimated by previous authors (Tomczyk 1962, 1970) due to tectonic repetition. The true thickness may be as low as 500–600 m rather than the 1500–2000 m previously estimated (Tomczyk, 1962, 1968).

The Rzepin Formation S_3RZ includes strata of Pridoli and Lochkovian age from near the Silurian–Devonian boundary (Teller, 1997; Modliński and Szymański 2001*b*). Tomczyk (1962, 1968) assigned them to the informal "Lower Rzepin Beds" and "Upper Rzepin Beds". According to Tomczykowa and Tomczyk (1976), in the Janowice 1 borehole the former were drilled at a depth of 88.20–130.00 m, whereas the "Upper Rzepin Beds" were found at a depth of 19.30–53.00 m. These deposits reach about 500 m in thickness, and at the bottom consist of shaly claystones and marly siltstones with sandstone and organodetrital limestone interbeds, passing upward into claystones and siltstones with siderite nodules and calcareous sandstone interbeds with fauna, in some places with subordinate graywacke sandstones, topped by arkosic sandstones. The impedance averages 60–70 ohms. The rocks of the upper member show a higher magnetic susceptibility than any other Silurian rocks studied.

Devonian. The Bostów Formation D_oB of Lochkovian age was studied in the neighbouring area (Tomczykowa, 1969). This formation consists of variegated shaly claystones, with oxidised sandstones at the bottom, and with gray marly limestones at the top. Its thickness amounts to about 300 m while the impedances averages 40–80 ohms.

The Barcza and Zagórze Formations D_1 span rocks of the late Pragian to lower Emsian, known from exposures and the Wierzbontowice 1, Wierzbontowice 1a and Jeziorko 1 boreholes (Wróblewski, 1969). These are gray quartz sandstones, fine-grained, locally micaceous and massive quartzitic sandstones with variegated siltstone and claystone interbeds. The impedance is in the range of 80–300 ohms (Pilarska, 1962; Tracz and Wągrowska, 1975).

The Grzegorzowice Formation D_2E of late Emsian and early Eifelian age was identified in the Kowalkowice 1, Jeziorko 1 and Wierzbontowice 1 boreholes (Malec, 2002). In the west this formation includes at its base black dolomitic siltstones passing upward into shaly claystones. To the east the siltstones are replaced by marly limestones and marls overlain by dolomites. The lower members of this formation are bituminous and enriched in metal sulfides, primarily pyrite.

Permian. In NE part of the study area Zechstein conglomerates (Pz) occur; they include clasts representing Middle and Upper Devonian limestones and dolomites, as well as Lower Devonian and Upper Cambrian sandstones and siltstones. The pebbles are variably rounded, reaching 5 cm in diameter. They are bound by a silty-calcareous-ferric cement. At top of these conglomerates, ferric sandstone interbeds appear.

Triassic. The Lower Triassic (Bunter) T_1 consists of various sandstone types, variegated, ferric, in places micaceous, with a clayey or clayey-silty cement, non-calcareous, thin- to thick-bedded. The sandstones also contain brown claystones, and conglomerates with yellow or white gray crystalline quartz.

SELECTED TECTONIC PROBLEMS

Both the solid geological map (Fig. 2) and cross-section (Fig. 3) reveal the major patterns of multi-stage tectonics of the study area. As in the entire Holy Cross Mts., the Lower Palaeozoic (especially Cambrian) successions of the study area are most strongly affected by ductile and brittle deformation; the Devonian successions are less, and the Permian–Triassic ones the least deformed.

Cambrian rocks make up a tectonic block of complex inner structure, strongly uplifted and framed by major longitudinal faults — from the south by the major Holy Cross Fault (HCF) and from the north by the North Łysogóry Fault (NŁF) (Fig. 2). Along the HCF Cambrian strata were overthrown towards the south. The normal NŁF shows a southern wall uplifted by hundreds of metres; north of this fault, the Palaeozoic beds of the downthrown block were strongly deformed (Fig. 3).

The strikes of folds and longitudinal faults in the Cambrian approximate a E–W direction (Fig. 2), the "Sandomierz direction". The Cambrian tectonics are not directly relevant to the diabase intrusion, but the tectonic pattern of recognised deformations is similar to that in the Łysogóry Range (Kowalczewski and Kowalski, 2000).

The tectonics of Ordovician and Silurian rocks has not been sufficiently studied. Their structural pattern in the south, near the uplifted Cambrian block, differs from that in the north, near the Lower Devonian sandstone outcrops. In the former area the graptolite shale complexes (O_2 + O_3 and S_1+S_3Ł — Figs. 2 and 3) adjust their strike to the "Sandomierz direction" of the Cambrian outcrops and at the same time to the strike of NŁF. In the north, however, the exposures of the Rzepin and Bostów formations (S_3RZ and D_OB in Figs. 2 and 3) follow the ESE–WNW structural Holy Cross Mts. direction. The azimuths of beds (and fold axes), typical of this direction, are 110–115° here.

The dips of the Wydryszów Formation (S_2W in Fig. 2) vary from 30 to 65° in the Janowice 1 borehole (Fig. 7). We infer that these are older folded beds.

Tectonic relationships between selected rock units. The direct contact between the upper Llanvirn and lower Tremadoc rocks in the southern part of the study area conceals a large stratigraphic gap and an unconformity with an angularity of several degrees (Kowalczewski, 1971). The Early Ordovician Sandomierz tectonic movements in the eastern part of the Łysogóry region did not cause Alpine-type deformation of the Cambrian-Tremadoc rocks. They caused uplift of this area before a subsequent marine transgression, which took place as late as in late Llanvirn time.

The solid geological map (Fig. 2) shows that the Devonian beds of the Barcza and Zagórze Formations are characterised by a nearly parallel (E–W) Sandomierz strike (coinciding with the strike of Cambrian beds in the Jeleniów Range), whereas the Lochkovian Bostów Beds (DoB) follow the Holy Cross Mts. (ESE–WNW) direction. In places these rocks differ in strike by at least 10–15°. Towards NW of the study area, approaching the Lower Palaeozoic lateral elevation of regional scale, the Barcza Beds lie over successively older rocks of the Pridolian-Lochkovian basement. An angular unconformity at the contact of these formations has not yet been proved, but one would be expected. Late Caledonian movements of unknown extent in the late Lochkovian and early Pragian also affected the Milejowice–Janowice deposits.

The Zechstein and Lower Triassic sediments unconformably overlie older Palaeozoic rocks. Near Zwola, Permian conglomerates cover the Silurian Rzepin Formation, and near Kowalkowice, Jeziorko and Wierzbontowice Lower Triassic sandstones overlie Middle Devonian dolomites and limestones. The dips of the Devonian beds vary from 35 to 50°, whereas those of the Triassic beds only exceptionally exceed 10°. The discordance at the contact discussed often exceeds 25°. The study area was strongly affected by Variscan movements and weakly by the subsequent Alpine movements.

Faults. The study area is transected by longitudinal and transverse faults (Figs. 2 and 3). The regionally most important longitudinal faults are the HCF and NŁF noted above, trending ESE–WNW to E–W. The remaining faults usually affect the southern limbs of folds. These mostly normal and normal-wrench transverse faults develop along NNE–SSW and N–S directions. Their amplitude reaches 1.0 km.

Of the transverse faults, the most interesting are those located near the intrusion (Fig. 2). The regional scale Janowice Fault is situated near Baćkowice–Garbacz. It cuts the northern flank of the Kielce-Łagów synclinorium, the Łysogóry Unit and the Permian–Triassic cover of the Holy Cross Mts. (Fig. 2). It probably comprises a broad, complex fault zone with a long history involving different type of fault motion. In the south (Jeleniów Range and adjacent area) this is a shear fault, with its eastern wall inclined northwards. Near Janowice village it is a normal — wrench fault whose eastern wall is downthrown and pushed southwards. In its central part, crossing the Wydryszów Formation — S_3W, this fault is normal with an eastern hanging wall. The fault zone seems to have formed in the Early Palaeozoic during the Caledonian movements, then was reactivated after the Devonian during the Variscan movements, and eventually rejuvenated after the Triassic during the Alpine movements. Near Janowice the diabase intrusion is present along this zone; however, the extent of the main fault differs somewhat from the extent of the igneous body, the latter being deformed in a different manner to the fault (Fig. 2). The intrusion seems to be older than the fault over this interval.

The inferred subordinate Góra Wesołówka Fault (Fig. 2) displays arc-shaped course from S to N and then to the NE, weakly affecting Cambrian, Ordovician and Lower Silurian beds. In the vicinity of Milejowice the intrusion cuts Ordovician-Silurian beds near the inferred fault.

The central part of the diabase intrusion reveals no tectonic relationship with the Janowice Fault or with the Góra Wesołówka Fault (Fig. 2).

The tholeiite magma that intruded through deep fractures of the lithosphere towards the surface locally “skipped” from one fault into another. Where faults were absent, it pierced the sedimentary cover in tectonically lowered areas of relatively thin lithosphere.

When tracing the intrusion between Janowice and Milejowice, we observe that in the south it neither crosses the longitudinal North Łysogóry Fault, nor pierces the Upper Cambrian sandstones of the Wiśniówka Formation. In the north the

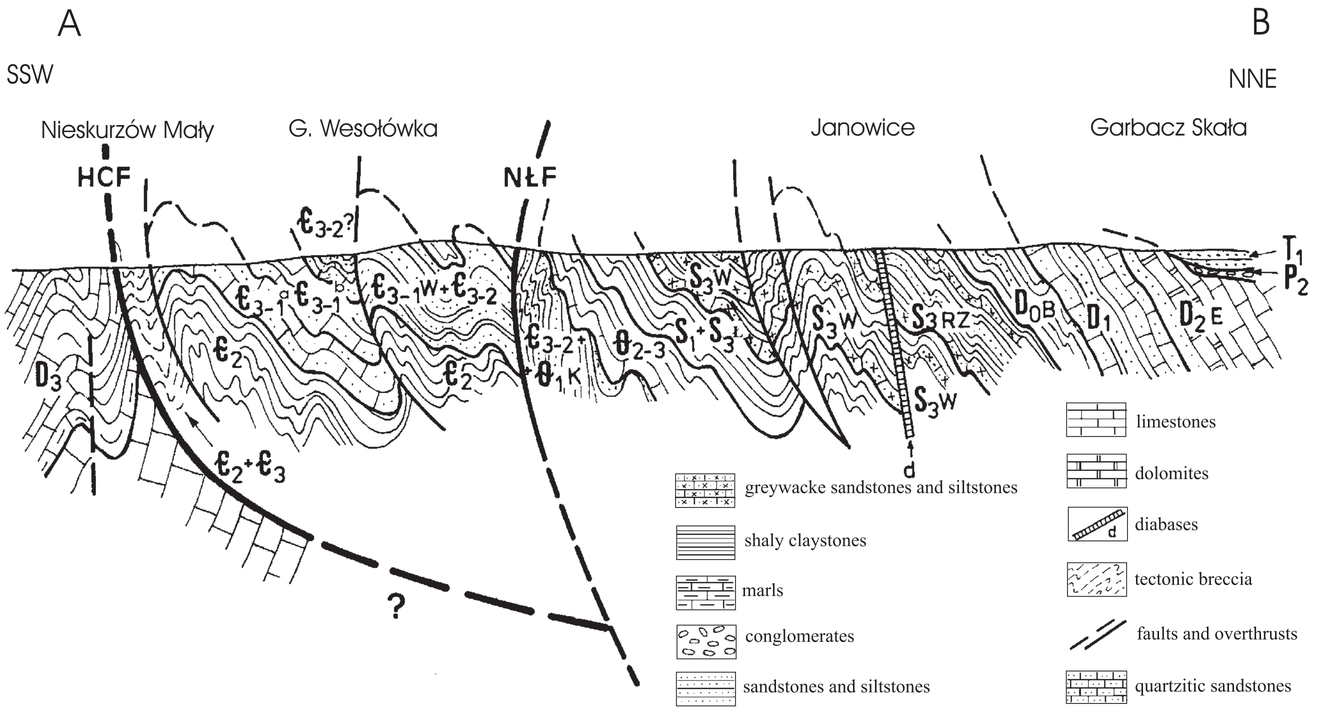

Fig. 3. Geological cross-section through the eastern part of the Łysogóry Unit

HCF — Holy Cross Fault, NŁF — North Łysogóry Fault; for explanations see Figure 2

intrusion ends in the Rzepin Formation and does not penetrate the Lower Devonian Barcza Formation (Fig. 2).

The Cambrian basement of the Jeleniów Range. Analysis of the 1:200 000 scale gravimetric maps (Królikowski and Petecki, 1995) shows that the zone of positive residual anomalies, related to carbonate rocks of greater density in eastern part of the Kielce-Łagów synclinorium, extends northwards across the HCF, framing the Cambrian outcrops of the Jeleniów Range from the south. The axis of this anomaly runs approximately along the HCF zone. Its northern boundary is marked by an axis of maximum horizontal gradient visible on the residual anomaly map in the northern part of the Jeleniów Range. It seems to be controlled by the NŁF bounding the uplifted Cambrian block.

An integrated analysis of geophysical and geological results enables us to conclude that in the basement of the Jeleniów and Łysogóry Ranges carbonate rocks, identical to those in the Kielce-Łagów synclinorium, occur. These rocks were overridden by the Łysogóry Cambrian masses. However, the scale of the horizontal overthrust is relatively small, not exceeding 2.5–3.0 km. The diabase intrusion was apparently unable to pierce through the lithosphere, whose thickness increased markedly near the HCF overthrust.

GENERAL CHARACTERISTICS OF THE DIABASES

The diabases were drilled in four boreholes (Figs. 2, 5–8). The petrographic and geochemical studies indicate that these rocks are genetically homogeneous and formed during the same Palaeozoic intrusive process (Krystkiewicz and Ryka, 1976; Krzemiński, 2004). The diabases form dykes of different thickness and geometries. Some of these dykes, especially their heads located near the surface, are weathered. The diabases, both at top and bottom of the dykes, are hydrothemally altered. The marginal, (near contact) altered dyke zones yield a fine-grained structure, whereas those placed inside are usually medium-grained. The marginal rocks are usually dark and light green, whereas the internal ones reveal a variable color — from pale gray to black. In the central portions an ophitic, in places, porphyritic texture is prevalent, whereas the hydrothermally altered marginal zones show a subophitic and subordinate apointersertal texture (Krystkiewicz and Ryka, 1976). The unaltered diabases are hard and massive, and show a disordered texture. Individual dykes usually show evidence of asymmetrical alteration: as for example the upper dike in the Milejowice 1 borehole where only the upper contact is altered. In other examples, unaltered diabases predominate and marginal zones are not developed, as for example, in the middle and lower dykes of Milejowice 1. The thickest (about 28 m) and entirely hydrothermally altered dike is the lower near contact zone in Janowice 1.

The diabase consists principally of plagioclase and pyroxene (Krystkiewicz and Ryka, 1976). The pyroxene is represented by diopsidic augite. Subordinate are tiny biotite flakes and needle-shaped apatite; amphibole is scarce. Fe and Ti oxides are quite common.

In one of the diabase samples from borehole Milejowice 2 (depth 116.2 m), scarce xenomorphic grains of fresh olivine, with a composition typical of continental tholeiitic basalts, were recorded. In the diabase of borehole Janowice 2 (depth 53.2 m) a resorbed peridotite xenolith was observed (Krzemiński, 2004).

Relics of amorphous palagonite, corresponding to quartz tholeiites with a large amount of hypersthene, were also found (Krzemiński, 2004).

In the marginal dyke zones the primary minerals underwent alteration. In the lower dyke of borehole Milejowice 2, albite with chlorite has replaced plagioclase, while amphibole has replaced pyroxene (Krystkiewicz and Ryka, 1976).

The common secondary minerals include sericite, saponite, chlorite, calcite and illite-montmorillonite. Many of the diabases contain cracks coated or infilled with carbonates (calcite), carbonates and chlorites, or only chlorites. Some of the carbonate veins are enriched in sulfides, primarily pyrite.

The Milejowice-Janowice diabases are strongly tectonically deformed. The drilling cores are strongly fractured at angles that vary from 20 to 90°; in addition, most of them are slicken-sided, and locally brecciated (for example in the Milejowice 1 borehole) or even cataclased (Janowice 2 at depths of 62.5–66.0 and 68.5–72.0 m), i.e. "...ground to fragments of several millimetres in size, bound in the upper part by mylonitic breccia, whereas in the lower part by a hydrothermal material..." (Krystkiewicz and Ryka, 1976). The coating by "hydrothermal material" 1 cm thick was also observed on slickensides, for example, in the Janowice 1 borehole. Hydrothermal processes occurred here at least twice in subsequent stages of the tectonic development of the area studied.

The diabase intrusion is associated with abundant sulfide mineralization, mostly pyrite at near-contact zones with the surrounding rocks. A study of trace element distribution (Lenartowicz, 2000) indicates that the unaltered diabases yield relatively high concentrations of Cu and all elements of the iron group. Their concentrations decrease in the marginal zones of hydrothermal and hypergene alteration. Conversely, the contents of Zn and Pb, and to a lesser extent of Ag, Br and Sr, is generally higher in diabases which were subjected to secondary alteration.

The highest levels of Cu, Pb and Zn are recorded in Milejowice in black graptolite shales that are altered at the contact, especially at the bottom of the intrusion and in vein-separating rock fragments. Such zones of 0.3–1.7 m in thickness yield higher concentrations of these metals compared to regional background values, for example, Zn is increased 2 to 11 times, Cu 4–8 times, and Pb 3–4 times more (Lenartowicz, 2000).

In the Janowice 1 and Janowice 2 boreholes, siltstones and sandstones of the Wydryszów and Rzepin Formations contain fissures with hematite efflorescences. No pyrite mineralization was observed in the near-contact zones.

These observations indicate that in the Holy Cross Mts. mafic volcanism could have been a source of copper mineralization in the Palaeozoic rocks, whereas post-magmatic hydrothermal fluids are responsible for Pb and Zn — enriched mineralization. According to Wróblewski (1976), the latter process was due to secondary mobilization of heavy metals from black, somewhat bituminous graptolite shales, and their relative concentration in the near-contact zones with the diabases.

INTRUSIVE BODIES AND THEIR MODE OF OCCURRENCE

The diabases with their high magnetic susceptibility cause the Milejowice-Janowice magnetic anomaly. Karaczun and Karaczun (1976) and Tracz and Wągrowska (1975) were able to trace a narrow and long zone of their occurrence on their maps of magnetic anomalies T (Fig. 4). The subcrop of the igneous body is also shown on the solid geological map (Fig. 2). These maps show that the intrusion forms a transverse dyke generally developed in a SSW–NNE direction, perpendicular to the strike of the Ordovician-Silurian strata. After having penetrated Palaeozoic rocks, this intrusion was squeezed and then S-deformed in "vices" of tectonic blocks situated in the south and north-east. The faults divided it into several segments (Fig. 2).

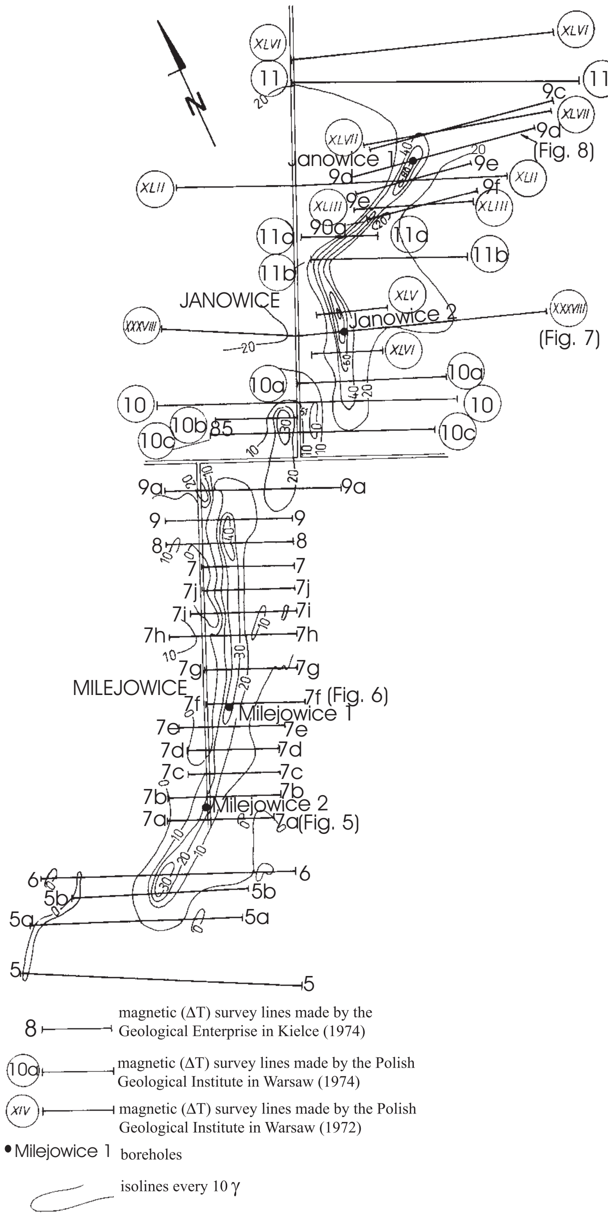

Fig. 4. Magnetic anomaly (ΔT) map in the Milejowice–Janowice area (Karaczun and Tracz in: Kowalczewski, 1976)

The diabases intruded only into Lower Palaeozoic deposits along distance of about 3.5 km (Fig. 2). The dykes have been found in rocks spanning the interval from the Klonów Formation (Cambrian-Tremadocian boundary) to upper members of the Upper Silurian Rzepin Formation (Fig. 2). The diabases were drilled within Upper Ordovician graptolite shales in the

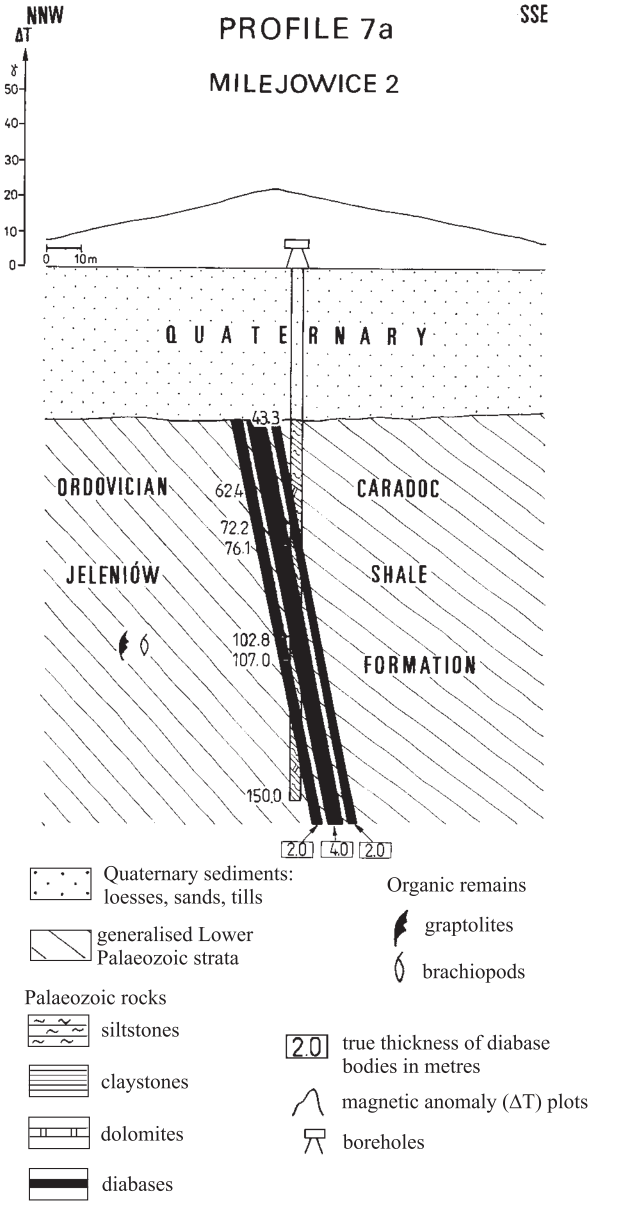

Fig. 5. Simplified geological cross-section through the diabase intrusion zone near the Milejowice 2 borehole

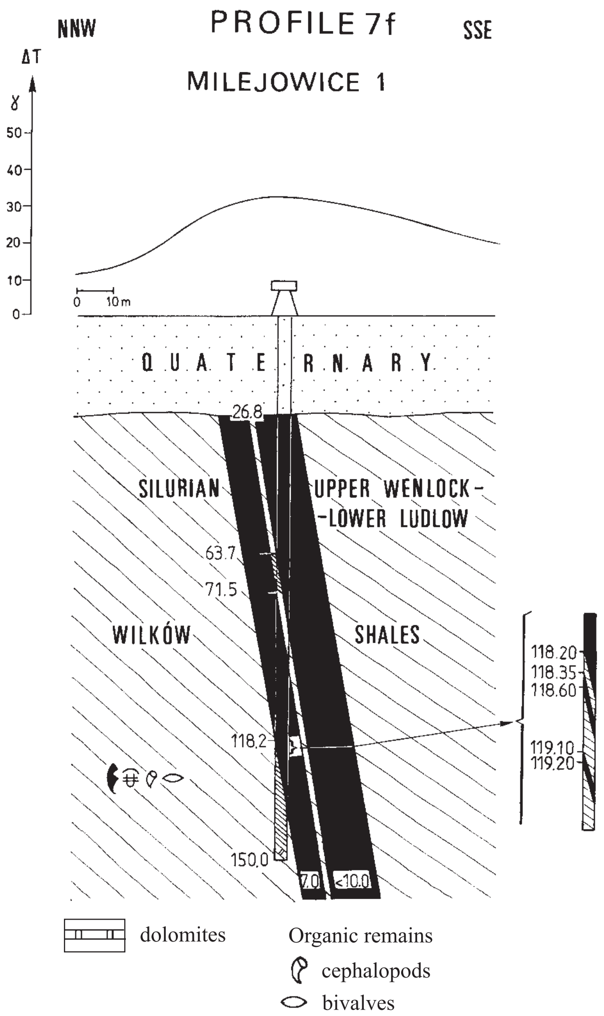

Fig. 6. Simplified geological cross-section through the diabase intrusion zone near the Milejowice 1 borehole

For other explanations see Figure 5

Milejowice 2 borehole (Fig. 5), Silurian graptolite shales in Milejowice 1 (Fig. 6), Upper Silurian shales and greywackes of the Wydryszów Formation in Janowice 2 (Fig. 7), and uppermost Silurian shales and sandstones of the Rzepin Formation in Janowice 1 (Fig. 8).

The intrusion is split into two segments, i.e. the Milejowice (southern) and Janowice (northern) ones (Figs. 2 and 4). The former is uniform and 1.8 km long, whereas the latter, dismembered into two subsegments, is 1.7 km long. The extent and dip of the igneous bodies differ in individual segments and subsegments. In the southern segment the maximum ΔT values reach 48 γ (Karaczun and Karaczun, 1976). The intrusion extends from the SSW to the NE and then to the NNW, forming a gentle curve with its concavity facing eastwards (Figs. 2 and 4). Near Janowice, where three anomalous zones are marked, the maximum ΔT values reach 112 γ (Fig. 4). Negative anomalies observed in profiles 10 and 10c are linked to man-made constructions. The longest fragment of the northern segment is also arch-shaped in plan view, but its concavity is faces westward (Figs. 2 and 4).

The ΔT profiles reveal asymmetry related to inclinationof the dikes. It appears that the igneous bodies are always very steep (75–90°). Most of them are inclined eastwards at an angle of about 80° (at least in the neighborhood of boreholes); in places, they are vertical. The intrusion heads are shallower near Janowice (19.0–20.0 m) than near Milejowice (26.5–44.0 m). The thickness of the Quaternary cover influences the clarity of the magnetic anomaly image (Figs. 2 and 4).

The complex shape of magnetic anomaly plots (ΔT) on some of the measured lines (for example Figure 8) may suggest the presence of several igneous bodies. Boreholes confirmed that we are dealing with complex intrusive zone with numerous igneous bodies. In each of the boreholes different numbers of diabase dykes were recorded: one — in the Janowice 2 borehole (Fig. 7), two — in the Janowice 1 borehole (Fig. 8), two with additional thin apophyses in the Milejowice 1 borehole (Fig. 6) and three such in the Milejowice 2 borehole (Fig. 5). The true thickness of these dykes varies from 2.0 to more than 10.0 m. They are sepa-

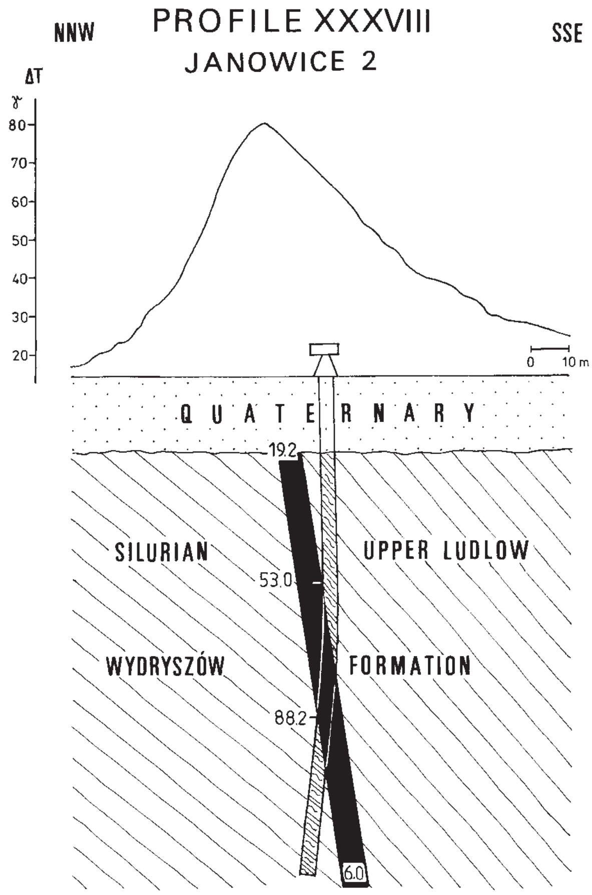

Fig. 7. Simplified geological cross-section through the diabase intrusion zone near the Janowice 2 borehole

For explanations see Figure 5

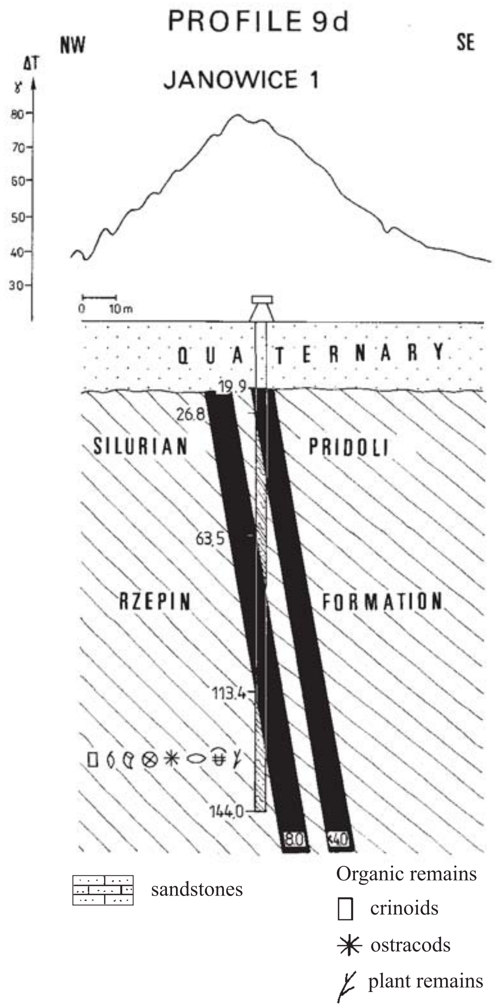

Fig. 8. Simplified geological cross-section through the diabase intrusion zone near the Janowice 1 borehole

For explanation see Figure 5

rated by host rock zones ranging from 1.0 to 7.0 m in thickness. The full "thickness" of the intrusive zone, i.e. the total thickness of the diabase dykes and intervening host rock may locally exceed 20.0 m (Milejowice 1 and Janowice 1 boreholes).

STRUCTURAL POSITION OF THE MILEJOWICE–JANOWICE INTRUSION — A DISCUSSION

Until recently the view dominated that small intrusions of diabases and lamprophyres belong to a co-magmatic mafic association of the Holy Cross Mts. (Kardymowicz, 1967; Rubinowski, 1967; Kowalczewski, 1974; Ryka, 1966). The diabases could have been linked to a relatively shallow mafic magma chamber (Kardymowicz, 1967). Ryka (1974*a*, *b*) regarded the Bardo diabases as differentiated products of tholeiitic magma formed after partial melting of pyrolite. In his opinion, plagioclase-pyroxene tholeiites formed during the main intrusion phase, whereas quartz tholeiites formed in the final phase. The process of differentiation of magma, which was contaminated by lithospheric melts during orogenic movements, occurred in the Palaeozoic over a long time. The ESE–WNW trending deep fault zones in the Kielce Unit and the SSW–NNE ones in the Łysogóry Unit were used several times by variously differentiated intruding magmas. The only evidence of a Variscan age of these intrusions, except for general tectonic premises, was indicated by the discovery of an intrusion in the Psary–Święta Katarzyna Zone of the Łysogóry region (Pawłowski, 1947; Czarnocki, 1947). This intrusion was linked to the Psary transversal fault that penetrated also Eifelian rocks (Kowalczewski *et al*., 1989). The Psary diabases of greenstone nature are at least partly similar to those from Kędziorka in the Bardo Syncline of the Kielce region (Ryka, 1966, 1974*a*; Kardymowicz, 1967).

Znosko (1965) linked the diabases of the Kielce region to late-orogenic or post-tectonic Caledonian magmatism. This view was later supported by boreholes drilled in the vicinity of Prągowiec near Bardo (Kowalczewski, 1974). The diabases found there form two varieties, notably:

— normal (older) intrusions, predominant in the Bardo Syncline,

— microlitic (younger), subordinate intrusions making up thin veins that cut across the main body (Łabęcki, 1969, 1970; Kowalczewski and Lisik, 1974).

According to these researchers, the normal variety of the plagioclase-pyroxene diabases formed after the Ludlow and before the Emsian, whereas the microlitic and greenstone varieties originated later, apparently during the broadly understood Variscan orogeny (Late Devonian–Late Carboniferous). Based on K-Ar and Ar-Ar radiometric dating, Migaszewski (2002) confirmed a multi-stage process of formation for Bardo Syncline diabases. However, he did not exclude "rejuvenation" of older diabase varieties during microlitic diabase injections in the Permian time.

Based on palaeomagnetic investigations of the Bardo diabases, Nawrocki (1999, 2000) claims that these rocks formed before late Caledonian deformation, more likely in the late Ludlow than in the Pridoli or Lochkow. This view is based on the convergence of the palaeomagnetic pole, determined in the diabases, to a Ludlow interval of the reference curve for Baltica. However, the cited author does not exclude the possibility of small post-Silurian rotation of the rocks examined, that could have brought this pole onto the Late Silurian interval of the reference curve.

Krystkiewicz and Ryka (1976) stressed that the mineral composition of the Milejowice and Janowice diabases and their texture and structure are similar to the normal diabase variety of the Bardo Syncline. The former intrusive bodies lack typical spilite diabases that occur in the Bardo intrusions at the contacts with sedimentary rocks. This scarcity is "compensated" in the Łysogóry area, both in the Milejowice–Janowice and the Psary zones, by a high degree of hydrothermal alterations. According to Krystkiewicz and Ryka (1976, p. 25). "If the diabase dykes had become enriched in alkaline constituents with time, the Milejowice-Janowice diabases would be the oldest in the Holy Cross Mts., whereas the Kędziorka diabases the youngest". Following this line of thinking, it has been concluded that in the Łysogóry and Kielce regions igneous rocks formed diachronously: the Milejowice-Janowice diabases in the Early Devonian after the Pridoli and before the late Pragian, whereas the Psary diabases formed after the Eifelian, perhaps by analogy with those at Kędziorka, in the Carboniferous or Early Permian (Kowalczewski, 1974).

Current knowledge of the geology of the Holy Cross Mts. allows some constraints on the views discussed above.

The study performed by Krzemiński (2004) supported the previous opinions of Ryka (1974*a*, *b*) that the Holy Cross Mts. diabases, including those from Milejowice and Janowice, are relatively evolved subalkaline olivine — normative tholeiites. The Prągowiec diabases also reveal a partly normative composition corresponding to quartz tholeiites. According to Ryka (1974*a*), the quartz tholeiites are transitional to the greenstone variety of pyroxene-depleted diabases from Kędziorka.

The view that the Holy Cross Mts. diabases and lamprophyres are co-magmatic can be questioned. The Milejowice-Janowice and Bardo diabases most probably were not derived from the same primary magma. These rocks originated from various primary melts of picritic composition formed in somewhat different degrees of partial melting of the mantle sources represented by subcontinental lithosphere and asthenosphere. The primary melts underwent more or less advanced gabbro fractionation in the shallow zones of lithosphere. The primary melt of the Milejowice-Janowice diabase was generated by a lower degree of melting, and is slightly less evolved (Krzemiński, 2004).

The partial melting must have occurred under the thermal influence of a raising asthenospheric mantle plume. The continental lithosphere of the Holy Cross Mts. (including the Łysogóry region) that enriched the primary melt was relatively thick at that time, and the influence of the plume was not so strong as, for example, in Upper Silesia (Krzemiński, 2004). Its activity may have faded towards the margin of the magma province, encompassing the area of the subsequent Central European Variscides. The influence of the plume also led to extension, and fracturing of the crust, e.g. in the Holy Cross Mts., thus channelling the intruding magma.

Both the Milejowice-Janowice and the Bardo diabases are anorogenic and post-tectonic igneous rocks formed under an extensional regime. These diabases probably belong to the within -plate type of continental basalts (Krzemiński, 2004).

The nature of the continental plateau basalts should be further examined, following the results of investigations carried out on the Pridoli-lower Lochkovian rocks of the Klonów Formations in the western part of the Holy Cross Mts. (Kowalczewski *et al*., 1998). These results indicate that the sedimentary basin was supplied with pyroclastic material linked to rhyolitic or rhyolitic-dacitic volcanism; however, we do not know where its source was located. Assuming that it was active in the Holy Cross Mts. area at the turn of the Silurian, acidic (rhyolitic, synorogenic) volcanism could have been followed by mafic (basalt, post-tectonic) volcanism. In this context, the problem of the origin and age of lamprophyres, the rocks of complex origin known only from the Kielce region, becomes particularly important. Let us recall that the old lamprophyre variety linked to the young Caledonian orogeny may have been formed before the late Siegenian–early Emsian (Tarnowska, 1966, 1969; Łabęcki, 1970; Kowalczewski, 1974). Were they really formed after the diabases had originated?

Relating magmatic processes, including the Milejowice-Janowice and Bardo intrusions, to defined stages of tectonic evolution of the Holy Cross Mts. is difficult. Comprehensive study of this issue is beyond the scope of this paper. The view expressed by Krzemiński (2004), though, is in agreement with the overall structural concept of Dadlez *et al*. (1994). According to Dadlez *et al*. (1994), the Łysogóry Unit is not a terrane. It was formed at the stable passive Baltica margin on which, in a final phase of collision of eastern Avalonia with Baltica, a foredeep depression developed in the Late Silurian (Narkiewicz, 2002). The Kielce Unit, along with the Małopolska Block, could have been displaced from the SE into the NW and docked as a proximal terrane against the Łysogóry Unit. This occurred in the Early Devonian at the latest. The time of welding of these two component tectonic units, i.e. the Łysogóry and the Kielce of the Holy Cross Mts., is very important. In the Janowice area the diabases intruded into the Rzepin Formation rocks of Pridoli age. We do not know if the diabases penetrated the Bostów Formation deposits of early Lochkovian age. They were not found with certainty in the Barcza Formation sandstones and claystones of late Pragian–early Emsian age. The Milejowice-Janowice diabases intruded after the mutual position of the Kielce and Łysogóry tectonic units had been fixed. This occurred after deposition of the Kielce Formation in the Kielce region and the Rzepin Formation in the Łysogóry region, but before deposition of the Miedziana Góra conglomerates (?) and the Barcza Formation, developed on both sides of the main Holy Cross Fault (Kowalczewski *et al*., 1998). The welding probably occurred during Pridoli–Lochkovian, or at least before late Pragian–early Emsian time, i.e. before the onset of the Barcza Formation deposition (Kowalczewski *et al*., 1998). The Milejowice-Janowice diabases may have intruded in the late Lochkovian–early Pragian at the earliest.

However, the age of the intrusion requires further studies because at Psary (Łysogóry Unit), the diabases also intruded into the Emsian Barcza and Zagórze Formations and the lower Eifelian Grzegorzowice Formation (Kowalczewski *et al*., 1989). Thus they may have originated after the Eifelian or even after the Devonian. The temporal relationship between the Milejowice-Janowice and Psary diabases, and also the Bardo intrusion, remains an open question.

Further studies should examine whether the fine-grained Prągowiec diabases and the Milejowice-Janowice diabases, linked genetically to olivine tholeiites, are not older than the medium-grained Prągowiec diabases showing normative composition that correspond to quartz tholeiites (Krzemiński, 2004). Ryka (1974) referred the Kędziorka greenstone diabases in the Bardo Syncline to the residual magma of quartz tholeiite type. The Psary diabases were ascribed completely (Kardymowicz, 1967) or partly (Ryka, 1966) to the same greenstone variety. The hypothesis of releasing variously differentiated tholeiitic magma portions from deep sub-crystal sources still remains to be proven.

The diabase intrusions both in Święta Katarzyna–Psary and in Milejowice is constrained from the south by the North Łysogóry Fault. It did not pierce the rocks thrust over the apparent Devonian basement. The tholeiitic magma also was not able to pierce the thickened lithosphere of the Łysogóry Unit.

CONCLUSIONS

The following conclusions can be drawn from the results of investigations performed on the Milejowice-Janowice intrusion:

1. The diabase dykes near Milejowice generate magnetic anomalies of ΔT values reaching 48 and 112 γ near Janowice.

2. The Milejowice-Janowice diabases intruded over a distance of about 3.5 km only into Lower Palaeozoic rocks that occupy an area between the longitudinal North Łysogóry Fault and the Lower Devonian Barcza Formation outcrops.

3. In the northern segment of its extent, the igneous intrusion follows a regional transverse Janowice Fault, whereas in the south it follows the subordinate, inferred Witosławska Góra Fault. The intrusion is not restricted to these tectonic zones, in places penetrating the host rocks away from faults.

4. In the vicinity of Milejowice-Janowice one to three igneous bodies locally penetrated sedimentary rocks of the Cambrian/Ordovician Klonów Formation through to the Upper Silurian Rzepin Formation. The thicknesses of these dykes vary from 2.0 to more than 10.0 m. The transverse intrusive zone consists of numerous individual dykes inclined steeply at an angle of 75–90° and generally dipping eastwards; some of them are vertical.

5. The diabase dykes are strongly hydrothermally altered, and their heads are additionally affected by weathering. The products of hydrothermal alteration "coincide" locally with previously brecciated rocks and older slickensides.

6. The SSW–NNE extending intrusive zone is strongly tectonically deformed and S-curved. Disrupted by perpendicular faults, this zone is split into component segments and subsegments. In addition, it is commonly slicken-sided, and locally cataclased and mylonitized.

7. The Milejowice-Janowice diabases, which must have intruded in the late Lochkovian–early Pragian, are post-tectonic igneous rocks (Krzemiński, 2004). The emplacement was controlled by the extension which must have occurred after displacement of the Małopolska Block (along with the Kielce Unit) from the SE to the NW and its docking, perhaps as a proximal terrane, against the Łysogóry Unit during Pridoli–Lochkovian time.

8. The author supports the idea of complex, at least two-stage, development of magmatic and hydrothermal processes both in the Kielce and the Łysogóry region of the Holy Cross Mts.

Acknowledgments. The author extends his warmest thanks to Professor Marek Narkiewicz for his critical review of this publication and inspiring discussions.

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