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The presumed Teplá-Barrandian/Moldanubian terrane boundary in the Orlica Mountains (Sudetes, Bohemian Massif): structural and petrological characteristics

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Abstract

The Sudetes in southwestern Poland and northern Bohemia expose a Palaeozoic collage of the northeastermost extremity of the Variscan belt. One of presumed terrane boundaries occurs in the Orlica Mts, along the contact between the phyllite-amphibolite complex (Neoproterozoic?) of the Nové Město unit of probable Teplá-Barrandian affinities in the SW and the orthogneiss (Early Ordovician protolith) and mica-schist (Neoproterozoic?) complexes of the Orlica-Śnieżnik unit in the NE, most likely representing the Moldanubian terrane. The synmetamorphic structural evolution of both adjacent units comprised four deformation events. The Nové Město rocks have recorded an early stage of ductile, top-to-the SE thrusting (D_1), which must have resulted in an early juxtaposition of the both terranes within a nappe pile. The original overthrust contact was subsequently modified by a dextral shear-dominated event (D_2), which produced a 1–2 km wide shear zone at the boundary of both units, in which earlier fabric elements were overprinted and mostly obliterated. This deformation brought the lower-grade Nové Město rocks into present-day strike-slip contact with those of the regionally uplifted, higher-grade Orlica-Śnieżnik unit. Postdating this juxtaposition are E–W trending folds F_3, which affect both the adjacent units. The contact shear zone also contains record of a late, top-to-the SW, semi-brittle, normal-slip displacement (D_4), downthrowing the Nové Město unit. The peak, amphibolite facies metamorphic conditions were attained in the Orlica-Śnieżnik unit and in the contact shear zone prior to the D_2 event. They corresponded to maximum temperatures and pressures of ca. 600 °C and 10 kbar, respectively. The D_1 thrusting event in the phyllites of the Nové Město unit took place under greenschist facies conditions (ca. 350 °C and 4.5 kbar) and its effects mostly survived the later amphibolite-facies metamorphism. These structural relationships are equivalent to those observed elsewhere in the Bohemian Massif on the Teplá-Barrandian/Moldanubian terrane boundary. The characteristic features of this boundary are a high metamorphic gradient but lack of metamorphic inversion; the occurrence of mid-Carboniferous stitching plutons; and the importance of mid-Carboniferous deformation that resulted in significant downwards movement of the low-grade Teplá-Barrandian terrane relative to the uplifted high-grade and hot lower to middle crust of the Moldanubian terrane. The downthrow of the Teplá-Barrandian occurred on ductile shear zones showing either down-dip-slip kinematics or that of transfer strike-slip, as was the case with the Orlica Mts., both kinematics being associated within the same, regional-scale, linked shear zone

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extensional system. The extensional crustal collapse must have been preceded by a SE-directed crustal stacking achieved through overthrust emplacement of the Teplá-Barrandian on top of the Moldanubian terrane.

Keywords: Variscan belt; Tectonics; Shear zones; Extensional collapse; Metamorphism; Palaeozoic

1. Introduction

Recognition and analysis of major tectonic boundaries, in particular those showing features of suture zones, are of importance when distinguishing tectonostratigraphic terranes and setting up regional tectonic models. Since 1990 several terrane models have been proposed for the northeastern Bohemian Massif (e.g. Matte et al., 1990; Cymerman et al., 1997; Franke and Żelaźniewicz, 2000; Aleksandrowski and Mazur, 2002). Of these models, the best fitting to the factual geological relationships appears to be the hypothesis of Matte et al. (1990; see also Matte, 1991, 1998), recently updated and modified by Aleksandrowski and Mazur (2002) in its Sudetic part. This hypothesis assumes the Bohemian Massif to be composed of a few large terranes mostly corresponding to the older subdivisions of the Variscan belt made by Kossmat (1927) and Suess (1926), though in the Sudetes these terranes are of markedly different areal extent than the similarly named tectonostratigraphic units of these early authors (Fig. 1). Matte et al.'s (1990) model, followed by those of Cymerman et al. (1997) and of Aleksandrowski and Mazur (2002), proposes that the Sudetes, in their central part, contain the northern continuation of the Moldanubian and Teplá-Barrandian (Matte et al.'s 1990, Barrandian) terranes. The extension of the latter terrane into the Sudetes has also been postulated in recent papers of Franke and Żelaźniewicz (2000, 2002), who apply to it a more general name of Bohemicum (Malkovský, 1979; Chaloupský et al., 1995).

The Teplá-Barrandian terrane has been interpreted to continue beyond the central Bohemian Massif, extending across the Elbe fault zone into the basement of the North Bohemian Permian-Cretaceous basin and, further northward, into the substratum of the Intra-Sudetic basin (Mísař et al., 1983; Chaloupský, 1989; Pin et al., 1988; Matte et al., 1990; Mazur and Aleksandrowski, 2001a; Aleksandrowski and Mazur, 2002). It is widely believed, though not proved, that Teplá-Barrandian rocks crop out in the Železné hory hills and, also, in the Orlica Mountains of the Central Sudetes as the Nové Město and Zábřeh units (Fig. 1; e.g. Mísař et al., 1983; Cháb et al., 1995). The Nové Město unit merges to the NE with the Orlica-Śnieżnik unit, proposed by Matte et al. (1990), Cymerman et al. (1997) and Aleksandrowski and Mazur (2002) to represent the northern extension of the Moldanubian terrane, the basis for this conclusion being close similarities in lithostratigraphy and timing of successive tectonometamorphic events (cf. Turniak et al., 2000). The contact zone between the Nové Město and the Orlica-Śnieżnik unit is characterized by occurrence of mafic rocks of MORB-type geochemistry (Opletal et al., 1990; Floyd et al., 1996) and seems to represent the boundary between the Moldanubian and Teplá-Barrandian terranes, possibly being a tectonic suture (Mazur and Aleksandrowski, 2001b; Aleksandrowski et al., 2003).

The aim of this paper is to present new structural and petrological data from this suspected suture zone and to examine the mutual tectonic position of the two major terranes of the Bohemian Massif supposedly juxtaposed across it. The data were collected in ca. 60 outcrops, located mostly in the Czech part of the Orlica Mts., between Nové Město nad Metují, Olešnice v Orlických horách and Rychnov nad Kněžnou and, to a smaller degree, in the northern, Polish part of the Orlica Mts. The structural relationships encountered in the Orlica Mts. are compared to those known from the Moldanubian/Teplá-Barrandian boundary exposed elsewhere in the Bohemian Massif, to find out that, in spite of local geometrical differences, they are, in general, compatible with the model of a significant, regional-scale downthrow of the Teplá/Barrandian relative to the Moldanubian terrane during mid-Carboniferous times (Pitra et al., 1994;

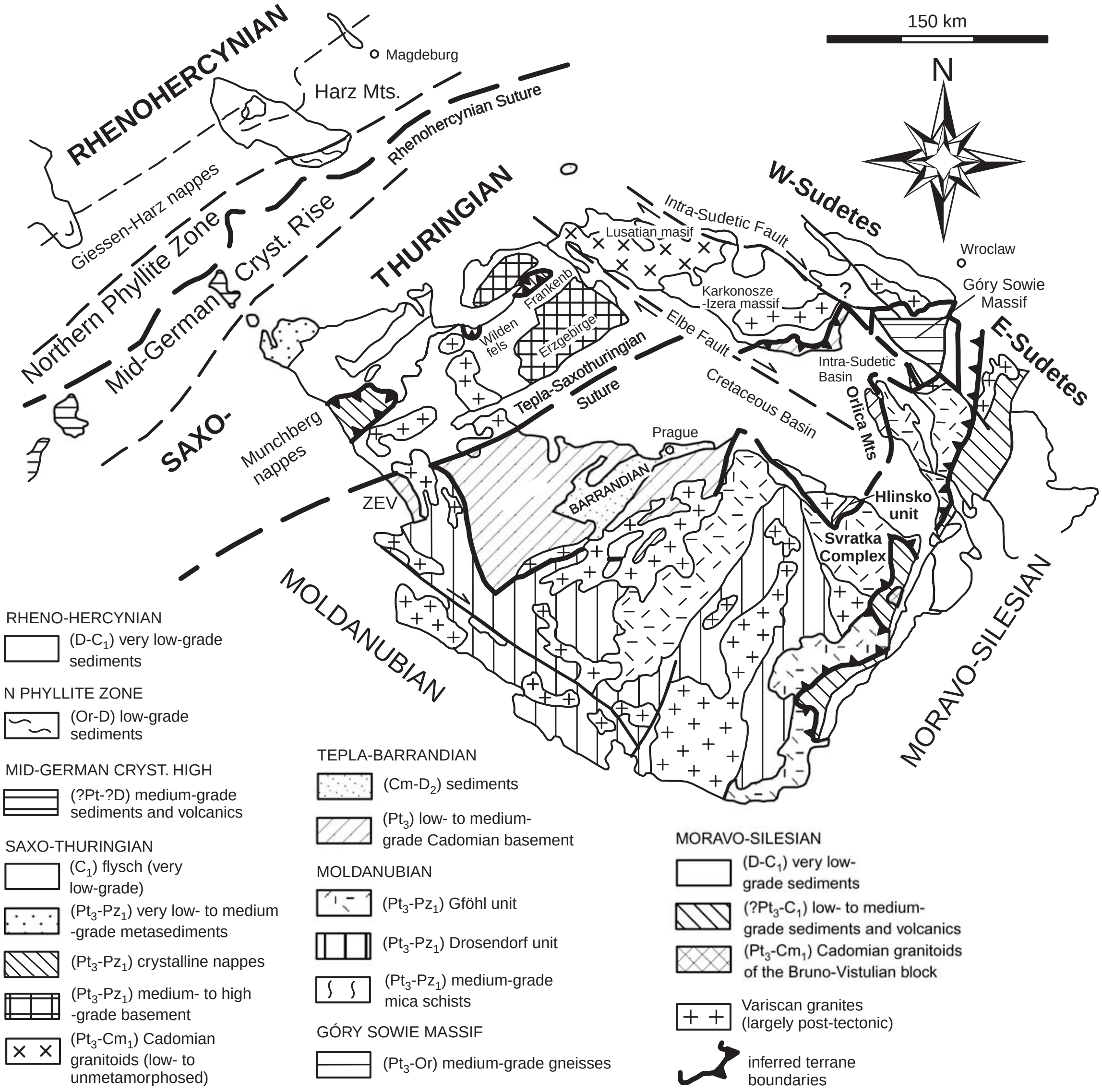

Fig. 1. Terranes of the Bohemian Massif (modified from Matte et al., 1990). Age assignments: Pt—Proterozoic; Pz—Palaeozoic; Cm—Cambrian; Or—Ordovician; D—Devonian; C—Carboniferous; 1—early; 2—middle; 3—late.

Zulauf, 1997; Scheuvens and Zulauf, 2000; Zulauf et al., 2002a,b; Bues et al., 2002).

2. Outline geology

The Nové Město, Zábřeh and Staré Město metamorphic units (Fig. 2) are believed to either represent an original mantle of the gneiss dome which exposes the Orlica-Śnieżnik crystalline rocks in its core (Svoboda, 1966), or to represent tectonic elements overthrust by the latter rocks (Mísař et al., 1983). The Orlica-Śnieżnik unit is composed mainly of amphibolite-facies orthogneisses whose protolith was emplaced at ca. 500 Ma (van Breemen et al., 1982; Oliver et al., 1993; Turniak et al., 2000; Kröner et al., 2001). Eclogite and granulite lenses are known to occur locally within the orthogneisses (e.g. Don et al.,

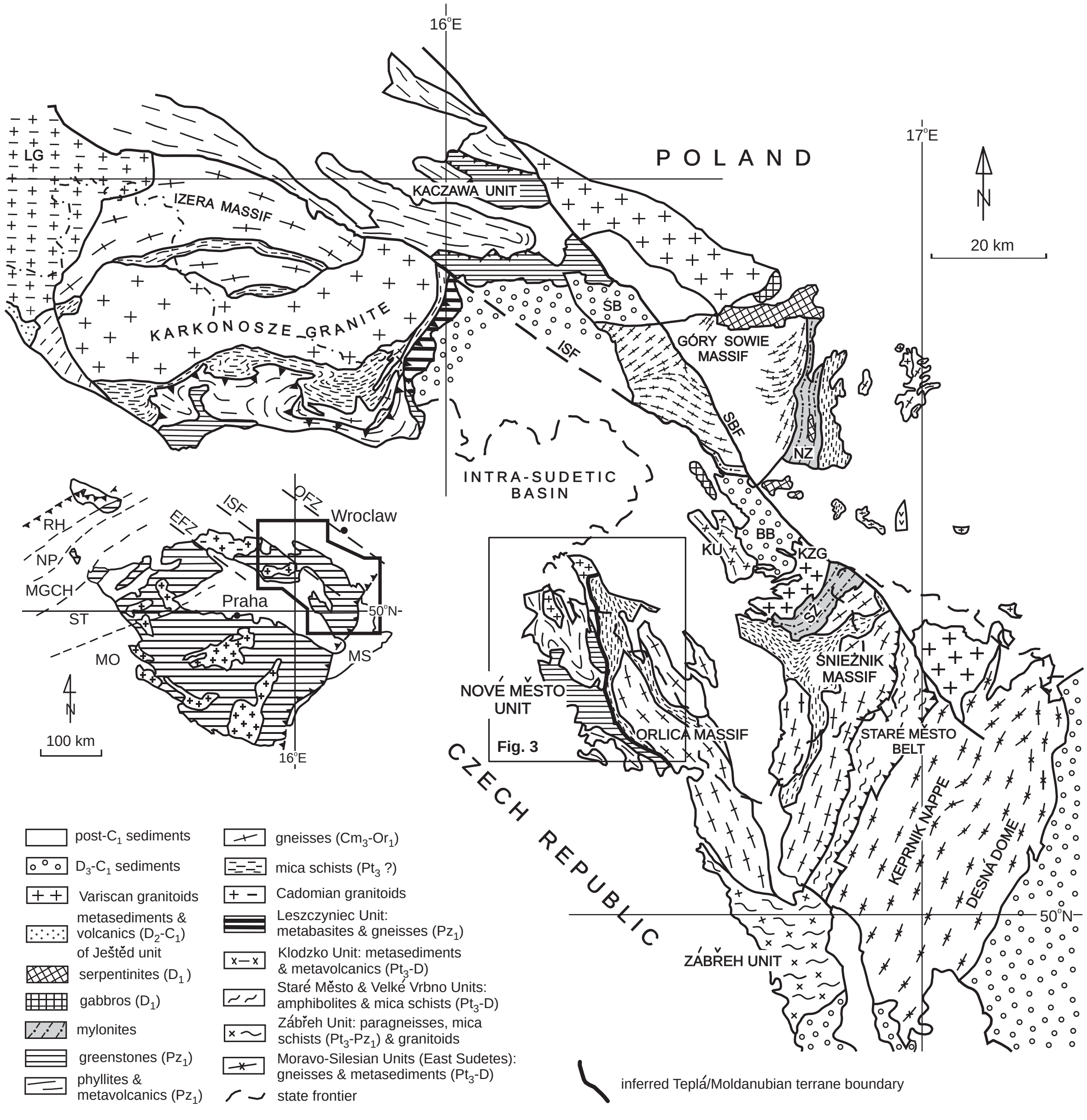

Fig. 2. Geological sketch map of the Sudetes. BB—Bardo basin; EFZ—Elbe fault zone; ISF—Intra—Sudetic fault; KU—Kłodzko metamorphic unit; KZG—Kłodzko-Złoty Stok granitoid massif; LG—Lusatian granitoid massif; MGCH—Mid-German Crystalline high; MO—Moldanubian zone; NP—Northern Phyllite zone; NZ—Niemcza shear zone; OFZ—Odra fault zone; RH—Rhenohercynian zone; ŚB—Świebodzice basin; SBF—Sudetic boundary fault; ST—Saxothuringian zone; SZ—Skrzynka shear zone. Age assignments as in Fig. 1.

1990). They are usually enveloped by mica schists of presumably Neoproterozoic to Lower Cambrian protoliths (Kröner et al., 2001). The Orlica-Śnieżnik complex was affected by high-grade metamorphism and intense synmetamorphic deformation, accompanied by exhumation of granulitic and eclogitic rocks. HP-HT granulite facies metamorphism was dated at ca. 360–369 Ma, using the U–Pb method on zircons (Klemd and Bröcker, 1999). At the same time, Sm–Nd whole rock ages for eclogites range between 350 and 330 Ma (Brueckner et al., 1991). The age of a later HT-MP/LP phase of metamorphism, which resulted in partial migmatisation of the Orlica-Śnieżnik rock complex, has been determined at ca. 342 Ma by SHRIMP dating of metamorphic rims on zircons extracted from the orthogneisses (Turniak et

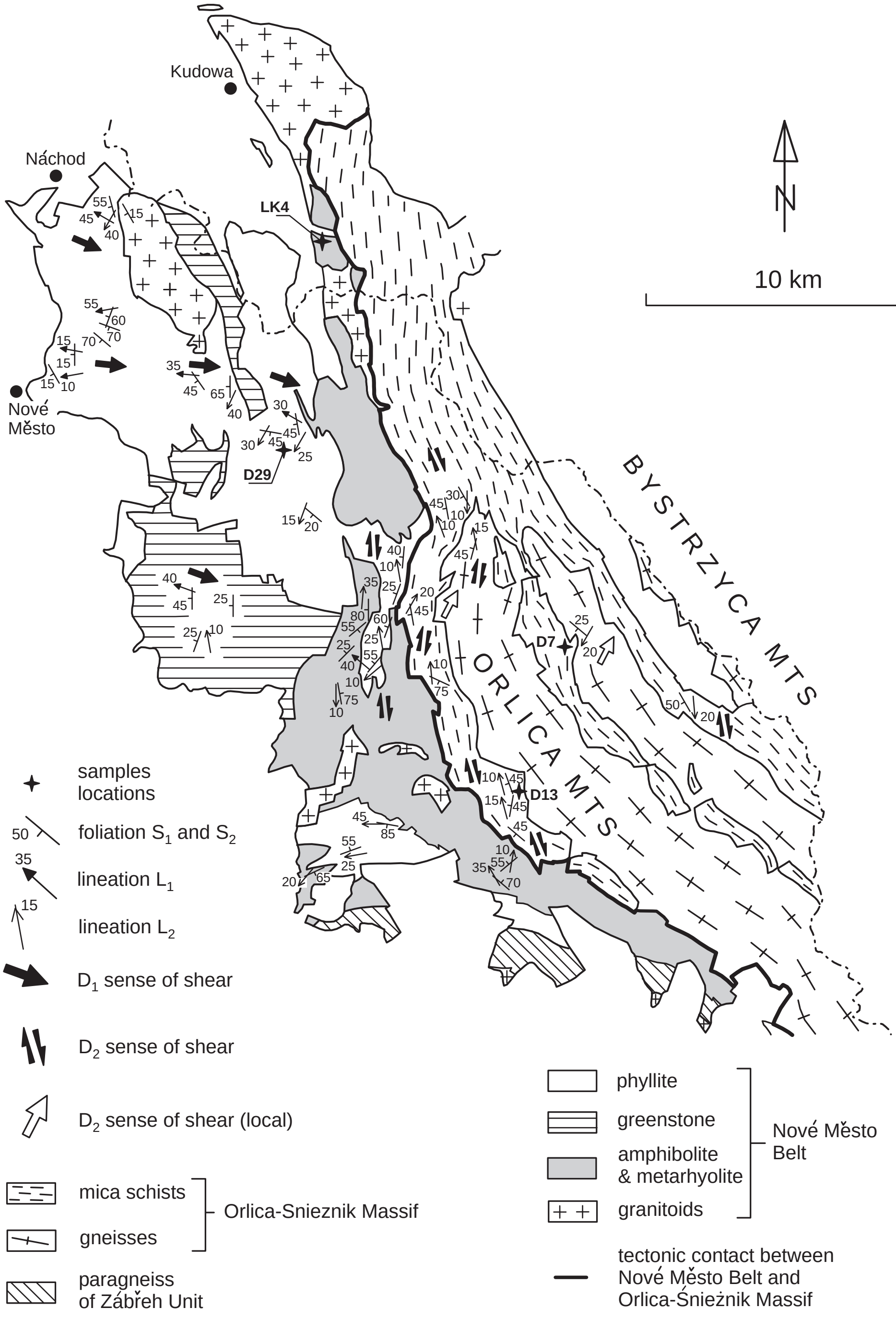

Fig. 3. Schematic tectonic map of Nové Město unit and westernmost part of Orlica-Śnieżnik unit.

al., 2000). ^{40}Ar–^{39}Ar cooling ages for the Orlica-Śnieżnik unit are in the range of 340–330 Ma (Steltenpohl et al., 1993; Maluski et al., 1995; Marheine et al., 2002). They are in good agreement with ^{87}Rb–^{86}Sr phengite- and biotite-whole rock ages of the orthogneisses, which provide a minimum age of ca. 340–325 Ma for the ductile shearing and final migmatization (Lange et al., 2002).

Since the Orlica-Śnieżnik unit displays prominent effects of Early Carboniferous collision-related medium- to high-grade HP-HT and HT-MP to LP metamorphism and deformation, analogous to those known from the Moldanubian terrane of the Bohemian Massif, it is recently more and more often ascribed to this terrane and excluded from the Saxothuringian domain of the Variscides (e.g. Matte et al., 1990; Cymerman et al., 1997; Aleksandrowski and Mazur, 2002). Further evidence supporting the affinities of the Orlica-Śnieżnik unit to the Moldanubian terrane was provided by zircon SHRIMP dating of gneisses from the Orlica-Śnieżnik and from the Gföhl unit of the Moldanubian domain (Friedl et al., 2000; Turniak et al., 2000). In these both areas the gneissic protoliths show nearly identical ages of ca. 500 Ma, and they underwent HT-MP to LP metamorphism, leading to migmatisation, at ca. 340 Ma. Furthermore, the presence of ca. 350 Ma HP rocks (eclogites and granulites) in the Orlica-Śnieżnik unit is not typical of the Saxothuringian domain proper, but fits well with the Moldanubian domain. In the Saxothuringian domain, the occurrences of HP rocks and intense 340 Ma L-MP/HT metamorphism are restricted to the Saxonian Granulite massif and the Münchberg, Wildenfels and Frankenberg massifs—the three latter units otherwise interpreted as 'exotic metamorphic nappes' by Franke et al. (1995), and also to the Erzgebirge area, which is recently also considered as a nappe pile resulting from long-distance westward thrusting (Konopásek et al., 2001) and, therefore, not representing the Saxothuringian proper. Nevertheless, due to scarcity of conclusive data, the affiliation of the Orlica-Śnieżnik unit is still a matter of debate, its Saxothuringian affinities being recently defended by Franke and Żelaźniewicz (2002), following their earlier concepts (Franke et al., 1993; Franke and Żelaźniewicz, 2000).

The Nové Město unit comprises mostly phyllites, greenstones and amphibolites (Fig. 3). In contrast to fairly well explored Orlica-Śnieżnik rocks, the age of those in the Nové Město unit remains unknown, being traditionally assumed to be Late Proterozoic (e.g. Opletal et al., 1980), by analogy to metamorphic rock complexes of the Teplá-Barrandian domain in the central Bohemian Massif.

The contact of the Nové Město and the Orlica-Śnieżnik units is traced by a roughly continuous zone of amphibolites of MORB-type affinities (Opletal et al., 1990; Floyd et al., 1996) on the Nové Město side and by an up to 2-km-wide mica schists belt of the Stronie formation on the Orlica-Śnieżnik side. The late-orogenic Kudowa-Olešnice granitoid pluton is emplaced directly into the contact zone (Domečka and Opletal, 1971a; Żelaźniewicz, 1977; Opletal et al., 1980). The outcrop zone of another pluton, the Nový Hrádek granodiorite massif, is entirely surrounded by phyllites. The metamorphic grade in the Nové Město unit increases from the greenschist facies in the west, to the amphibolite facies along the boundary with the Orlica-Śnieżnik rocks, the metamorphic isograds extending roughly parallel to this boundary and to the local contacts with the granitoid intrusions (Opletal et al., 1980; Opletal and Domečka, 1983).

3. Structural characteristics

The metamorphic complexes of the Orlica Mts. have been the subject of structural investigations since the 1960s. Successive descriptions and interpretations of deformation sequences present in the crystalline rocks of the Orlica-Śnieżnik and Nové Město units were published by Dumicz (1964, 1998), Opletal and Domečka (e.g. Domečka and Opletal, 1971b; Opletal and Domečka, 1976, 1983; Opletal et al., 1980), Żelaźniewicz (e.g. 1972, 1976, 1978) and Fajst (1976) and are summarized in Table 1. Those studies provided comprehensive information on the orientation of successive generations of structures; they did not supply, however, up-to-date kinematic data. Similarly, the earlier papers were either focused on only relatively small fragments of the Orlica Mts. (e.g. Żelaźniewicz, 1972, 1976, 1978; Dumicz, 1998), or offered only scarce information on the sequence of successive structural events and on the superposition of their

Table 1
Deformation events recognized in crystalline complexes of the Orlica Mts. by various authors and correlation with the sequence proposed in this paper

Proposed in this paper	Fajst (1976)	Żelaźniewicz (1976, 1978)	Opletal et al. (1980)	Dumicz (1998)
D1. Top-to-the SE oblique-slip ductile thrusting of NMU over OSU. Foliation S1 and NW-plunging lineation L1 together with intrafolial folds F1 develop, to be later almost totally obliterated in OSU by deformation D2.	D2. The main ductile deformation in NMU, resulting in NW–SE-trending structures.	D1 and D2. Formation of intrafolial F1 and tight to isoclinal folds F2, with generally N–S (NW–SE to NE–SW) trending axes, under metamorphism progressing from greenschist (D1 event) to lower amphibolite facies (D2 event). The main foliation and lineation developed during D2. Formation of E-vergent F2 folds and D2 thrusting. Żelaźniewicz's D1 and D2 do not directly correspond to this paper's D1 and D2. Local NE-vergent F3 folds of open geometry and axes parallel to F2. Pre-D4 granitoid emplacement.		D1–D2. Intrafolial to tight folding, with development of S2 axial planar foliation. D3. Further development of foliation parallel to S2 and NE–SW to NW–SE lineation.
D2. Ductile dextral shearing along the contact zone of NMU and OSU; pervasive deformation in OSU and the adjacent part of NMU resulting in formation of S2 foliation and NNW–SSE to N–S-trending lineation L2 and tight, E vergent folds F2. Granitoid emplacement and uplift of OSU relative to NMU during final stages of D2 deformation. High metamorphic gradient occurs between the amphibolite facies in OSU and greenschist facies in NMU.	D1. The main ductile deformation in OSU, producing N–S trending folds. (Fajst's sequence of D1 and D2 events is reverse to that recognized in this paper).		Formation of folds with N–S trending axes in OSU and N–S to NNW–SSE (also NE–SW) axes near the contact zone in NMU.	Dumicz's D1 through D3 do not directly correspond to this paper's D1 and D2.
D3. Folding due to N–S compression under conditions of waning metamorphism. Open to tight S- or N-vergent folds F3 of E–W-trending axes.	D3. Formation of E–W trending, S-vergent folds of subhorizontal axes.	D4. Formation of E–W trending N- or NE-vergent folds F4 under waning stages of metamorphism.	Formation of younger folds with axes trending E–W to NW–SE.	D4. Formation of open folds F4 of E–W axial trend.
D4. Localized normal-slip displacements along ductile–brittle shear zones throwing to SW.		Two systems of contractional kink structures: F5 striking NE–SW and F6 striking NW–SE.		D5. Oblique-slip, normal-sinistral displacement on Olešnice-Uhřinow fault in transtensional, semi-brittle regime, downthrowing NMU relative to OSU.

The kinematics are considered in present-day coordinates. NMU—Nové Město unit; OSU—Orlica-Śnieżnik unit.

effects (e.g. Opletal and Domečka, 1976; Opletal et al., 1980).

The most complete structural analysis of the Orlica Mts. rock complexes was presented by Fajst (1976), who inferred an occurrence of important structural discontinuity between the Nové Město and Orlica-Śnieżnik units, separating areas with different structural patterns. The Orlica-Śnieżnik rocks were found by this author to be characterized by an approximately N–S-trending, dominant mineral lineation and by folds representing a generation older than that of the NW–SE-trending tectonic structures which prevail in the Nové Město rocks. These two structural patterns were, nevertheless, interpreted to interfere locally, near to the contact zone, and to be uniformly overprinted by younger, E–W trending folds.

Our observations show that the synmetamorphic structural evolution of the Nové Město and Orlica-Śnieżnik complexes was accomplished roughly in four deformation events, D_1 through D_4, which affected both the adjacent units, though their effects vary significantly in space. In general, the strain intensity increases gradually from the west to east in the studied area, from the relatively low-strained western Nové Město unit to its higher strained eastern part and, across the tectonic contact zone, into the high-strained Orlica-Śnieżnik unit.

In the western part of the Nové Město unit, composed mostly of phyllitic rocks, the predominant tectonic structure is foliation S_1, mostly defined by parallel alignment of micas and by alternation of quartz and mica laminae. The S_1 dips mostly to the west and southwest at a moderate angle and bears stretching lineation L_1, which uniformly plunges to the WNW (Fig. 4). The L_1 is defined by elongation of mica aggregates and quartz rods. L_1-parallel pressure shadows around plagioclase porphyroclasts (Fig. 5a) show a top-to-the ESE sense of shear. According to the microstructural data of Żelaźniewicz (1976, 1978), the early deformation event, D_1, must have taken place under prograde greenschist facies metamorphism.

During deformation D_2, the S_1 foliation in the Nové Město unit was deformed by roughly NNW–SSE to NNE–SSW-trending F_2 folds (Fig. 6), which (together with later folds F_3) resulted in the dispersion of the attitude of S_1 along segments of great-cricle girdles on stereoplots (Fig. 4). The F_2 folds are, usually, upright, east-vergent (due to shorter eastern limbs on the westerly dipping foliation) and, in general, they become progressively tighter eastwards, from relatively open folds in the western part of the Nové Město unit, through tight in its eastern part, to nearly isoclinal folds in the Stronie formation mica schists at the border zone of the Orlica-Śnieżnik unit. In higher strained domains of the eastern Nové Město unit, the F_2 folds develop axial-planar crenulation cleavage S_2 in their hinges and shorter limbs (Fig. 5b). Locally, in the phyllites of the central and eastern parts of the Nové Město

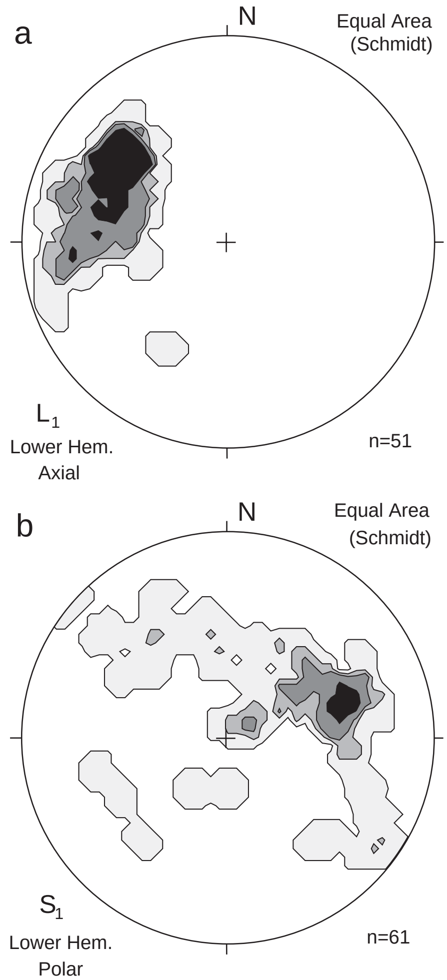

Fig. 4. Attitude of stretching lineation L_1 (a) and foliation S_1 (b) in Nové Město unit. Lower hemisphere equal-area projection (1%, 4%, 6% and 10% contour lines per 1% area).

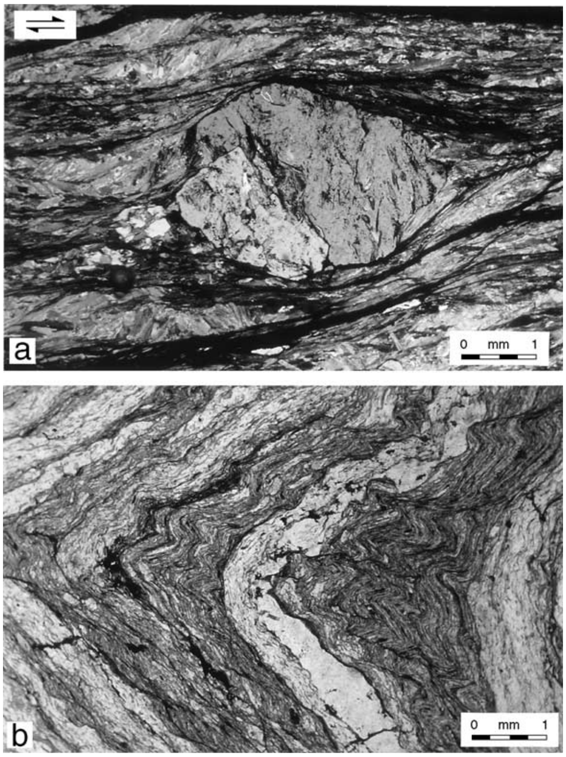

Fig. 5. (a) Asymmetric pressure shadows around plagioclase crystal in Nové Město phyllite, indicating D_1 top-to-SE sense of shear (road-cut east of Dobrošov). Section parallel to lineation L_1 (trend/plunge: 290/50) on foliation S_1 (dip azimuth/dip angle: 250/55); (b) Crenulations associated with axial-plane cleavage S_2 (orientation: 220/70) within F_2 fold (axis attitude: 250/15) in Nové Město phyllite (ravine Peklo, NE of Nové Město).

unit, a progressive flattening of the F_2 folds transformed the S_2 crenulation cleavage into a penetrative foliation composed of alternating mica and quartz laminae parallel to the axial planes of the crenulations (Fig. 7a). Crosscutting of the S_1 and S_2 foliations produced intersection lineation L_2, usually trending NNE–SSW to N–S and obliquely overprinting the older lineation L_1 on the S_1 surfaces (Fig. 7b). Small crenulations F_2 on the S_1 surfaces have their hinges parallel to the intersection lineation L_2. A gradually increasing asymmetry of the D_2 fabric towards the eastern margin of the Nové Město unit indicates an increase in strain intensity towards the Nové Město/Orlica-Śnieżnik boundary, along which a localised dextral shear zone developed. In places the L_2 lineation is defined by parallel alignment of mica flakes, probably formed due non-coaxial D_2 shear, and is, thus, a stretching lineation. The asymmetric D_2 fabric in the boundary shear zone, although clearly related to a rotational shear strain, was originally initiated as an axial cleavage of the F_2 folds, whose formation seems to have slightly preceded the onset of the localised dextral strike-slip shearing in the rock domain subjected to the highest D_2 strain. Both types of deformation, the F_2 folding and D_2 strike-slip shearing, are nevertheless kinematically linked to each other and can be regarded as produced in one event.

In the sheared Nové Město amphibolite belt, directly adjacent to the Orlica-Śnieżnik unit, the D_1 fabric is mostly obliterated by the superimposed D_2 strain. Relics of foliation S_1 defined by thin plagioclase laminae are preserved as hinges of intrafolial folds. The limbs of these folds have been mostly transposed into foliation S_2, due to rotational shear. The asymmetric D_2 fabric includes mostly subhor-

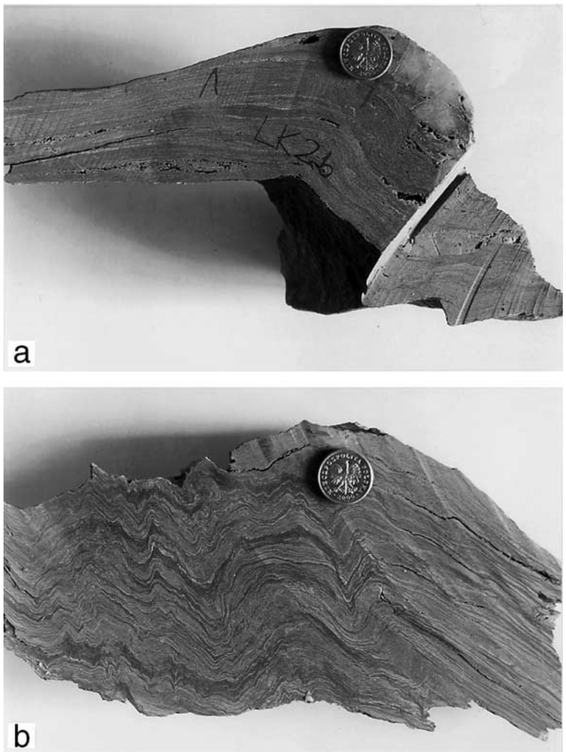

Fig. 6. F_2 mesoscopic folds in Nové Město phyllite. (a) Asymmetric ESE-vergent fold (exposure SW of Taszów, Poland). (b) Minor E-vergent folds with crenulation axial-plane cleavage in hinge zones (road-cut 1.5 km south of Nový Hrádek).

izontal L_2 stretching lineation of amphibole prisms on foliation S_2, the latter commonly represented by alternating plagioclase and amphibole laminae. The L_2 lineation parallels the map-view trace of the Nové Město/Orlica-Śnieżnik tectonic boundary line. The D_2 event resulted, as well, in the formation of shear bands along the S_2 surfaces and biotite-filled asymmetric pressure shadows around garnet porphyroclasts with dextral sense of shear (Fig. 8).

Immediately east of the contact zone, in the mica schist belt of the Stronie formation within the Orlica-Śnieżnik unit, the D_2 strain has almost entirely

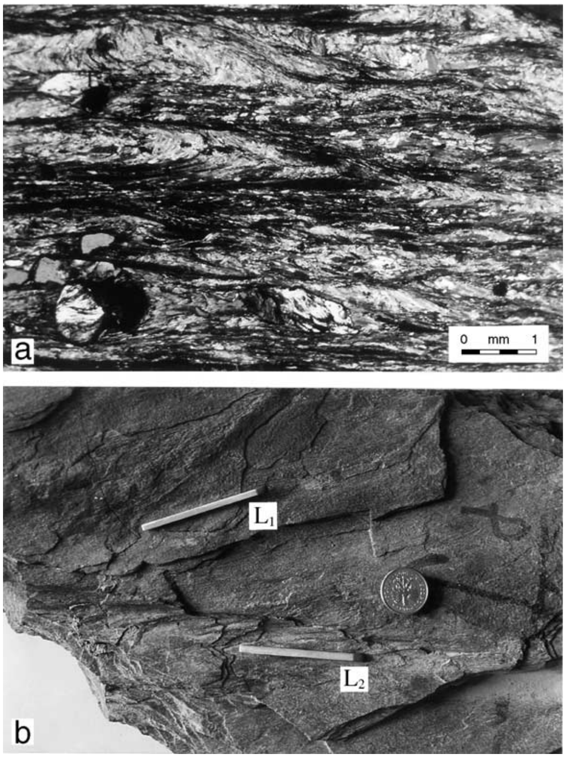

Fig. 7. (a) Microscopic crenulations of foliation S_1 preserved in microlithons between zones of dominant S_2 foliation (attitude: 205/70) in mica schist of Stronie complex, Orlica-Śnieżnik unit, 250 m east of contact with amphibolites of Nové Město unit (road-cut east of Uhřínov). (b) Superimposed lineations L_1 and L_2 on foliation S_1 in Nové Město phyllite (ravine Peklo, NE of Nové Město). Orientation of structures: L_1—290/15, L_2—250/15, S_1—260/20.

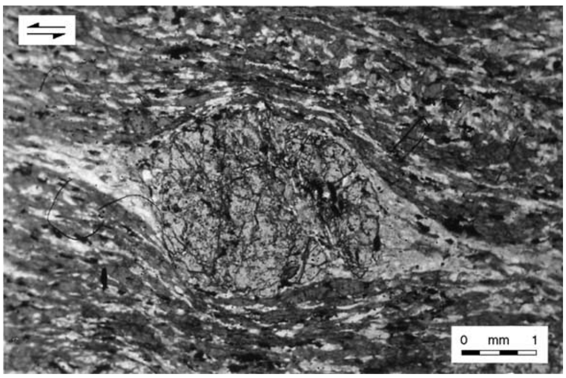

Fig. 8. Asymmetric pressure shadows around garnet crystal in amphibolite of Nové Město unit indicating dextral (in map view) sense of shear on foliation S_2 (attitude: 290/60) during deformation event D_2 (abandoned quarry north of Kocioł, Poland).

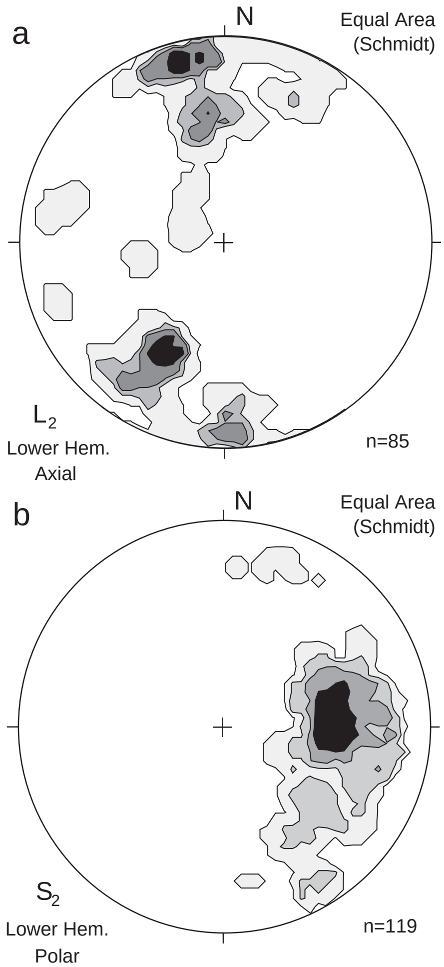

Fig. 9. Attitude of lineation L_2 (a) and foliation S_2 (b) in Nové Město unit and adjacent part of Orlica-Śnieżnik unit. Lower hemisphere equal-area projection (1%, 4%, 6% and 10% contour lines per 1% area).

obliterated S_1 and L_1 structures. The S_2 transposition foliation dips there to the WSW at a moderately steep angle; the L_2 stretching lineation usually plunges to the NNW or to the N at a very shallow angle (Fig. 9). The strike of foliation and trend of lineation are thus parallel to the contact. Mica schists are mylonitized to various degrees and contain conspicuous kinematic indicators, such as micro- and mesoscale S–C fabric and asymmetric tails and pressure shadows on feldspar porphyroclasts, documenting dextral sense of the shear (Fig. 10). Further east, at a distance from the contact, the dip of the S_2 foliation in the mica schists and orthogneisses decreases, whereas the L_2 lineation retains its direction from the contact zone and the Nové Město unit. As a result, the kinematics of the D_2 structures change from the dextral strike-slip close to the contact, to that of the top-to-the NNE in the interior of the Orlica-Śnieżnik unit (Fig. 14).

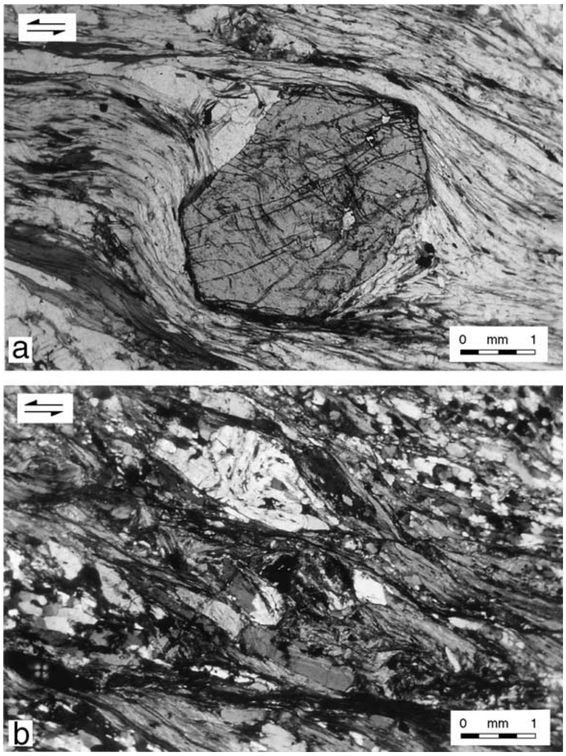

Fig. 10. (a) Asymmetric pressure shadows around garnet crystal in mica schist of Stronie formation, Orlica-Śnieżnik unit, indicating dextral (in map view) sense of shear along lineation L_2 oriented 180/25 on foliation S_2 (attitude: 220/30) during deformation event D_2 (road-cut NE of Čertův Důl). (b) Microscopic asymmetric fabric in mica schist of Stronie formation, Orlica-Śnieżnik unit, indicating dextral (in map view) sense of shear during D_2 deformation event (road-cut north of Deštné Zákouti). C planes are parallel to the main foliation S_2, oriented 260/50.

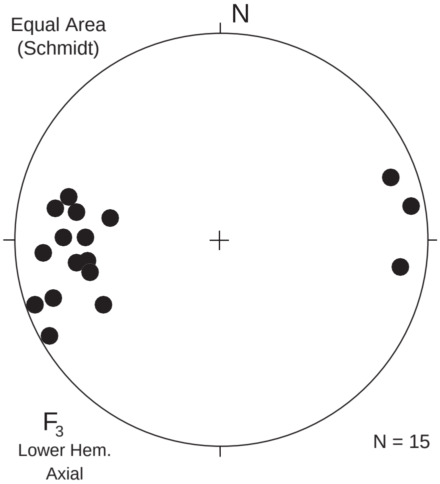

Fig. 11. Attitude of F_3 fold axes in the Nové Město unit. Lower hemisphere equal-area projection.

Within the entire study area, the S_1 and S_2 foliations are refolded by the E–W trending, south or north vergent, generally open F_3 folds (Fig. 11), resulting in great circle girdle scatter of both foliations on stereoplots (Figs. 4 and 9) and in local variations (sometimes considerable) in strikes of foliation and trends of lineation. Mesoscopic F_3 folds have rounded or, more often, sharp hinges and show concentric to chevron styles. Their axial planes are often occupied by fractures and quartz or chlorite veins.

The final, D_4 deformation, of semi-brittle characteristics, is confined to a few observed W-dipping normal-displacement shear zones within the phyllites and in rocks immediately adjacent to the Nové Město/Orlica-Śnieżnik boundary. They probably reflect the activity of the so called Olešnice-Uhřinov fault, interpreted by Opletal et al. (1980) and by Dumicz (1998) to occur along the eastern boundary of the Nové Město unit. The SE-ward continuation of this fault was recently described by Franke and Żelaźniewicz (2002) to occur between the Zabřeh and the Orlica-Śnieżnik units and, further on, to extend as the Bušin normal fault, throwing its SW side. The Olešnice-Uhřinov fault seems, thus, to be a localised, semi-brittle regime reactivation of the older, ductile structural discontinuity, which previously, during stage D_2, acted as a ductile dextral strike-slip shear zone at the Nové Město/Orlica-Śnieżnik contact. The sense of D_4 displacement is indicated by shear bands coexisting with the local L_4 lineation, defined by alignment of white mica flakes and by semiductile slickenlines. The non-penetrative D_4 shear bands suggest a top-to-the SSW sense of shear along the W-dipping S_2 foliation. As a result, the Olešnice-Uhřinov semi-brittle shear zone shows an oblique-slip kinematics, combining a normal down-dip displacement and some sinistral component (cf. Dumicz, 1998).

The results of our structural investigations are comparable, though not perfectly concordant, with the data provided by previous studies (Table 1). There is no difference between the regional patterns of foliations and lineations reported by e.g. Fajst (1976) and Opletal et al. (1980) and those found by us, although the superposition of L_1 and L_2 structures reported here (Fig. 7) has not been so far known from the Nové Město Unit. The formation of the relic foliation S_1 of Żelaźniewicz (1976, 1978) and Dumicz (1998) can be correlated with our D_1 event, as the data of the latter authors come mostly from the areas recognized by us to be intensely affected by the later strain D_2. The D_2 event probably corresponds, in turn, to deformation D_2 of Żelaźniewicz (1976, 1978) and Dumicz (1998), although the lack of kinematic data in the earlier contributions reduces the reliability of such a correlation. For the same reason and due to a rather small extent of the areas studied by Żelaźniewicz (1976, 1978) and Dumicz (1998), the distinction between the D_1 and D_2 structural patterns of these authors remains somewhat unclear. The reverse chronology of deformation events (D_1 vs. D_2) in the work of Fajst (1976), as compared to our interpretation, is the result of an assumption, common in the Sudetic geology during the 1970s, that the rocks of higher grade must have suffered earlier deformation. A common element shared by all the structural interpretations summarized in Table 1, is the development of late, E–W trending folds (our and Fajst's F_3, Żelaźniewicz's and Dumicz's F_4) under conditions of waning metamorphism. The subsequent ductile-to-brittle regime normal-slip displacements reported in the present paper correspond to those earlier recognized by Dumicz (1998). The timing of this event is poorly constrained and, thus, this deformation may well have postdated the development of two systems of kink-bands described by Żelaźniewicz (1976, 1978).

4. Aims and methods of petrological study

A petrological study complemented our field observations and the previously published data concerning an eastward increase in metamorphic grade and strain intensity from the western Nové Město to the Orlica-Śnieżnik unit. The P–T conditions were studied on four samples, two of which represent the highly deformed mica schists from the western contact zone of the Orlica-Śnieżnik unit (D7, D13). The other two are the phyllites (D29) and amphibolites (LK4) from the Nové Město unit. The amphibolites come from the eastern, sheared margin of the Nové Město unit, whereas the phyllites represent the western, weaker deformed part of this unit. Microprobe analyses were carried out at Warsaw University, using CAMECA CAMEBAX SM 100 facility and applying the standard conditions of 15 kV, 10 nA and 20s. For standardization, natural and synthetic minerals were used. The raw data were corrected by ZAF procedure by use of PAP software provided by Cameca.

5. Petrography

5.1. SampleD7 (Orlica-Śnieżnik unit)

This is a medium-grained mica schist composed of quartz, muscovite, biotite, plagioclase and garnet, with numerous garnet and plagioclase porphyroclasts up to 2 mm in diameter. Common accessories are apatite, tourmaline and iron oxides. Due to a relatively high plagioclase content of ca. 10%, the rock represents a lithological variety transitional towards a paragneiss. Retrograde reactions had only minor influence on the mineral composition and are manifested by chloritization of biotite and local decomposition of oligoclase into sericite and albite.

The rock fabric is defined by recurrent quartz and mica laminae anastomosing around large porphyroblasts. Both garnet and plagioclase crystals contain rectilinear inclusion trails variably oriented with respect to the foliation S_2. Inclusions in the plagioclase comprise quartz, muscovite, biotite and opaque minerals, whereas the garnets contain only quartz and opaque phases. The geometry of the inclusion trails suggest relics of foliation S_1, preserved within pre-D_2 porphyroclasts.

5.2. Sample D13 (Orlica-Śnieżnik unit)

The fine-grained mica schist is composed of quartz, muscovite, biotite, plagioclase and garnet. Accessories consist of tourmaline, apatite, allanite and opaque minerals. Plagioclase grains are partly sericitised along their rims and biotite is locally replaced by chlorite. The planar fabric of the mica schist is defined by mutually alternating mica laminae and quartz ribbons. Garnet porphyroclasts do not usually exceed 0.5 mm across and are often elongated parallel to the foliation. Scarce inclusion trails in the garnet, formed by muscovite intergrowths, are roughly parallel to S planes of the S-C fabric.

5.3. Sample D29 (Nové Město unit)

This is a very fine-grained phyllite composed of quartz, plagioclase, muscovite, biotite and chlorite, accompanied by accessory tourmaline and opaque minerals. Plagioclase grains demonstrate advanced sericitization, whereas biotite is almost entirely replaced by chlorite. The rock is differentiated into thin laminae characterised by various proportions of quartz and muscovite. Plagioclase porphyroblasts reach 0.5 mm in size and are randomly scattered in the rock.

5.4. Sample LK4 (Nové Město unit)

The fine-grained amphibolite contains garnet porphyroclasts up to 2 mm in size. The main constituents of the rock are amphibole, plagioclase, garnet, quartz and ilmenite. Amphibole prisms with pale green to olive green pleochroism reach 1.5 mm in length. Plagioclase grains are often elongated parallel to the foliation. The garnets contain randomly scattered inclusions of quartz and opaque minerals. The planar fabric of the rock is defined by parallel alignment of amphibole prisms and elongated plagioclase aggregates. The foliation is distinctly deflected around garnet porphyroclasts. Retrograde reactions seem to

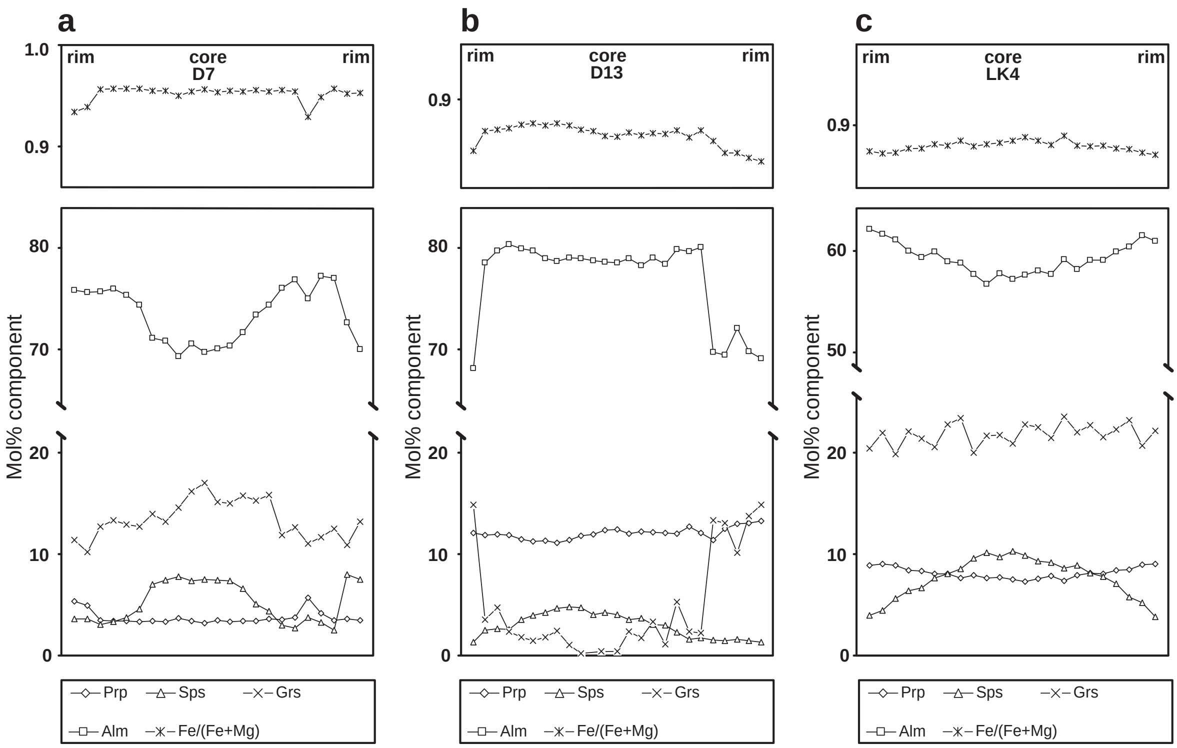

Fig. 12. Representative profiles of chemical zoning across garnet crystals from samples of mica schists D7 (a), D13 (b) and amphibolite LK4 (c). Prp—pyrope, Sps—spessartine, Grs—grossular, Alm—almandine.

have been insignificant, being manifested by growth of secondary chlorite at the expense of amphibole and garnet.

6. Mineral chemistry

6.1. Garnet

Garnet from the mica schist (sample D7) is mainly composed of almandine with only minor pyrope, grossular and spessartine components (Fig. 12a). Its grains display normal compositional zoning defined by increase in almandine content and decrease in that of spessartine and in Fe/(Fe+Mg) ratio from the core to rim of crystals (Fig. 12a). The profile of Fe/(Fe+Mg) ratio is flat in the inner part of the crystals and is declining at the rims. The inner parts of garnet grains show an average composition of $Alm_{64–76}Sps_{3–9}Prp_{3–4}$ $Grs_{14–23}Adr_{1–4}$, which gradually changes outwards to $Alm_{76–79}Sps_{2–3}$ Prp $_{5–8}Grs_{6–15}Adr_{1–5}$ (Table 2). The zonation scheme revealed by garnets from sample D7 is indicative of prograde metamorphism. However, the outer parts of the analysed crystal profiles are flat or document a drop of the almandine content and an increase in the spessartine and grossular concentrations towards the rims of the garnets. Such an inversion of compositional trends probably reflects a thermal episode driven by exhumation-related decompression. This conclusion is consistent with structural evidence suggesting growth of garnet porphyroblast before the D_2 event. Consequently, the composition of

Table 2
Composition and structural formula (O^{2-}=24) of garnet from mica schists of Orlica-Śnieżnik unit and amphibolite of Nové Město unit

Sample	d7	d7	d7	d7	d7	d7	d13	d13	d13	d13	d13	d13	LK4	LK4	LK4	LK4	LK4	LK4
Analysis	15	16	19	20	52	53	6	7	12	13	21	22	116	132	133	144	316	317
c/r	c	r	c	r	c	r	c	r	c	r	c	r					c	r
SiO_2	36.57	37.09	36.87	36.86	36.85	36.85	36.79	37.27	37.06	36.99	36.95	37.51	37.28	37.47	37.23	37.30	37.26	37.62
TiO_2	0.14	0.08	0.14	0.03	0.14	0.08	0.06	0.04	0.06	0.04	0.05	0.03	0.18	0.37	0.14	0.15	0.18	0.11
Al_2O_3	20.90	21.10	20.86	21.17	20.79	21.16	21.03	21.09	21.03	21.11	21.02	21.48	21.07	21.19	21.23	21.08	21.14	21.42
Cr_2O_3	0.00	0.03	0.02	0.04	0.05	0.03	0.04	0.02	0.00	0.02	0.03	0.00	0.04	0.03	0.03	0.02	0.03	0.00
FeO	32.32	34.11	31.68	35.15	34.72	34.52	35.98	36.26	35.15	35.51	35.91	32.07	26.19	28.50	29.13	26.82	26.88	29.27
MnO	3.34	1.29	2.04	1.18	1.45	1.02	1.12	0.80	1.67	1.93	0.94	0.71	5.31	1.92	1.75	4.55	5.28	1.90
MgO	0.88	1.23	0.89	1.54	0.81	1.36	3.10	3.16	3.01	2.81	3.11	3.20	1.76	2.23	2.24	1.88	1.85	2.35
CaO	5.70	5.53	7.82	4.77	6.04	5.56	2.27	1.88	2.17	1.98	2.06	5.47	8.80	9.19	8.69	8.73	8.63	8.33
Total	99.85	100.45	100.32	100.74	100.84	100.57	100.39	100.51	100.13	100.38	100.06	100.47	100.64	100.89	100.42	100.54	101.26	100.99
Si^{4+}	5.95	5.97	5.95	5.93	5.95	5.94	5.93	5.98	5.97	5.96	5.96	5.96	5.94	5.93	5.93	5.94	5.92	5.95
Ti^{4+}	0.02	0.01	0.02	0.00	0.02	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.04	0.02	0.02	0.02	0.01
AlIV	0.05	0.03	0.05	0.07	0.05	0.06	0.07	0.02	0.03	0.04	0.04	0.04	0.06	0.07	0.07	0.06	0.08	0.05
AlVI	3.95	3.98	3.91	3.95	3.91	3.95	3.92	3.97	3.96	3.97	3.95	3.98	3.90	3.88	3.91	3.91	3.87	3.94
Cr^{3+}	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.10	0.04	0.15	0.15	0.16	0.13	0.20	0.07	0.08	0.10	0.11	0.08	0.17	0.14	0.18	0.16	0.25	0.13
Fe^{2+}	4.30	4.56	4.12	4.58	4.53	4.52	4.64	4.80	4.65	4.68	4.73	4.18	3.32	3.63	3.70	3.41	3.32	3.74
Mn^{2+}	0.46	0.18	0.28	0.16	0.20	0.14	0.15	0.11	0.23	0.26	0.13	0.09	0.72	0.26	0.24	0.61	0.71	0.25
Mg^{2+}	0.21	0.29	0.21	0.37	0.19	0.33	0.75	0.75	0.72	0.67	0.75	0.76	0.42	0.53	0.53	0.45	0.44	0.55
Ca^{2+}	0.99	0.95	1.35	0.82	1.04	0.96	0.39	0.32	0.37	0.34	0.36	0.93	1.50	1.56	1.48	1.49	1.47	1.41
Sum	16.03	16.02	16.05	16.05	16.05	16.05	16.08	16.03	16.03	16.04	16.04	16.03	16.06	16.05	16.06	16.05	16.08	16.04
Py	0.04	0.05	0.04	0.06	0.03	0.05	0.13	0.13	0.12	0.11	0.13	0.13	0.07	0.09	0.09	0.07	0.07	0.09
Alm	0.72	0.76	0.69	0.77	0.76	0.76	0.78	0.80	0.78	0.79	0.79	0.70	0.56	0.61	0.62	0.57	0.56	0.63
Sp	0.08	0.03	0.05	0.03	0.03	0.02	0.03	0.02	0.04	0.04	0.02	0.02	0.12	0.04	0.04	0.10	0.12	0.04
And	0.02	0.01	0.04	0.04	0.04	0.03	0.05	0.02	0.02	0.02	0.03	0.02	0.04	0.03	0.04	0.04	0.06	0.03
Uv	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gro	0.14	0.15	0.19	0.10	0.14	0.13	0.02	0.04	0.04	0.03	0.03	0.14	0.21	0.23	0.20	0.21	0.19	0.21

Fe^{3+} calculated by charge balance according to Droop (1987).

Table 3
Composition and structural formula of muscovite (O^{2-}=24; O, OH) from mica schists (D7, D13) of Orlica-Śnieżnik unit and phyllite (D29) of Nové Město unit

Sample	D7	D7	D7	D7	D7	D7	D7	D7	D7	D7	D7	D7	D13	D13	D13	D13	D13	D13	D29	D29	D29	D29	D29	D29
Analysis	5	6	23	24	37	62	11	12	13	14	17	18	14	15	19	20	27	28	26	27	30	31	37	38
c/r	c	r	c	r	c	c	c	r	c	r	c	r	c	r	c	r	c	r	c	r	c	r	c	r
Variety	1	1	1	1	1	1	2	2	2	2	2	2												
SiO_2	51.62	51.98	50.22	51.37	50.22	47.29	50.62	48.31	51.56	48.22	51.43	49.82	49.81	48.36	51.47	47.97	52.39	49.05	48.84	47.84	48.47	48.37	47.85	49.03
TiO_2	0.55	0.23	0.37	0.42	0.55	0.40	0.47	0.38	0.34	0.38	0.38	0.48	0.23	0.57	0.21	0.44	0.23	0.41	0.42	0.41	0.35	0.35	0.36	0.32
Al_2O_3	29.3	28.46	28.27	28.55	29.57	30.99	29.49	34.11	28.00	33.29	29.07	29.51	31.1	32.45	27.74	33.19	27.72	32.43	32.67	31.79	33.68	32.99	33.39	32.69
FeO	2.67	2.61	3.36	3.57	2.6	3.60	2.57	1.97	3.52	2.17	2.8	3.34	2.63	2.07	2.37	2.08	2.97	2.00	2.49	2.28	2.39	2.53	2.34	2.66
MnO	0.00	0.08	0.00	0.04	0.00	0.02	0.00	0.00	0.08	0.00	0.05	0.03	0.06	0.1	0.00	0.02	0.02	0.07	0.00	0.02	0.01	0.02	0.00	0.00
MgO	2.68	2.75	2.61	2.67	2.55	2.29	2.58	1.27	2.69	1.46	2.67	2.5	2.39	1.8	3.14	1.66	3.17	2.00	1.62	1.37	1.38	1.46	1.27	1.61
CaO	0.00	0.00	0.00	0.00	0.06	0.04	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.02	0.00	0.03	0.03	0.01	0.00	0.00
Na_2O	0.15	0.11	0.2	0.2	0.16	0.12	0.15	0.49	0.16	0.35	0.17	0.22	0.29	0.37	0.17	0.37	0.17	0.33	0.21	0.65	0.31	0.31	0.26	0.19
K_2O	9.85	9.79	9.86	9.43	9.51	10.24	9.93	9.22	9.57	9.53	9.81	9.49	9.43	9.4	9.44	9.35	9.11	9.06	9.74	9.87	9.4	9.7	9.79	9.89
H_2O	4.59	4.56	4.48	4.55	4.52	4.45	4.54	4.56	4.54	4.53	4.57	4.51	4.55	4.52	4.5	4.52	4.56	4.55	4.55	4.45	4.56	4.54	4.51	4.56
Total	101.42	100.57	99.37	100.78	99.73	99.44	100.36	100.3	100.48	99.92	100.95	99.89	100.49	99.64	99.03	99.59	100.36	99.9	100.55	98.71	100.56	100.28	99.76	100.96
Si^{4+}	6.74	6.83	6.73	6.77	6.66	6.38	6.69	6.35	6.82	6.38	6.75	6.63	6.56	6.42	6.86	6.36	6.89	6.47	6.43	6.44	6.37	6.4	6.36	6.44
Ti^{4+}	0.05	0.02	0.04	0.04	0.05	0.04	0.05	0.04	0.03	0.04	0.04	0.05	0.02	0.06	0.02	0.04	0.02	0.04	0.04	0.04	0.03	0.03	0.04	0.03
Al^{IV}	1.26	1.17	1.27	1.23	1.34	1.62	1.31	1.65	1.18	1.62	1.25	1.37	1.44	1.58	1.14	1.64	1.11	1.53	1.57	1.56	1.63	1.6	1.64	1.56
Al^{VI}	3.25	3.24	3.2	3.2	3.28	3.31	3.28	3.63	3.18	3.57	3.25	3.26	3.39	3.49	3.21	3.55	3.18	3.51	3.5	3.48	3.59	3.54	3.59	3.5
Fe^{2+}	0.29	0.29	0.38	0.39	0.29	0.31	0.28	0.22	0.39	0.24	0.31	0.37	0.29	0.23	0.26	0.23	0.33	0.22	0.27	0.26	0.26	0.28	0.26	0.29
Mn^{2+}	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Mg^{2+}	0.52	0.54	0.52	0.52	0.50	0.46	0.51	0.25	0.53	0.29	0.52	0.50	0.47	0.36	0.62	0.33	0.62	0.39	0.32	0.27	0.27	0.29	0.25	0.32
Ca	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na^+	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.13	0.04	0.09	0.04	0.06	0.07	0.1	0.04	0.09	0.04	0.08	0.05	0.17	0.08	0.08	0.07	0.05
K^+	1.64	1.64	1.69	1.58	1.61	1.76	1.67	1.55	1.61	1.61	1.64	1.61	1.58	1.59	1.6	1.58	1.53	1.52	1.64	1.7	1.58	1.64	1.66	1.66
OH^-	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Sum	17.79	17.77	17.88	17.78	17.78	18.01	17.83	17.82	17.79	17.84	17.81	17.85	17.83	17.84	17.75	17.82	17.72	17.77	17.82	17.92	17.81	17.86	17.87	17.85

Based on all Fe as FeO.

garnets rims represents the eventual stage of prograde metamorphism in the mica schist that occurred during the D_2 event.

The garnets from sample D13 are characterised by high almandine content, which is different from that found in sample D7 (Fig. 12b). The composition in the centre of the crystals is $Alm_{78–80}Sps_{2–5}$ $Prp_{8–13}Grs_{1–4}Adr_{2–5}$ and it changes outwards into $Alm_{67–70}Sps_{2–7}$ $Prp_{10–13}Grs_{1–14}Adr_{1–5}$ (Table 2). The profiles of element concentrations (Fig. 12b) are relatively flat in the inner parts of the garnets, whereas they record a drop of almandine and increase in grossular near the rims. Towards the rims, the chemical composition gradually changes into $Alm_{67–70}Sps_{2–7}$ Prp $_{10–13}Grs_{1–14}Adr_{1–5}$, probably due to the same reasons as in the case of sample D7.

The garnet from the amphibolite in LK4 is composed of almandine with very minor amount of grossular, spessartine and pyrope (Fig. 12c). Its crystals display normal compositional zoning, defined by increase in almandine and decrease in spessartine content towards the rims. A slight drop of Fe/(Fe+Mg) ratio in the same direction can be observed as well. The centres of garnets are composed of $Alm_{55–61}Sps_{5–13}Prp_{7–9}Grs_{19–21}Adr_{3–6}$, whereas the rims consist of $Alm_{61–63}Sps_{2–6}Prp_{9–11}Grs_{20–24}Adr_{2–5}$ (Table 2). Such a zonation scheme is usually considered indicative of garnet growth during prograde metamorphism.

6.2. Muscovite

Sample D7 of a mica schist contains two varieties of muscovite of different chemical compositions. The first variety forms intergrowths in plagioclase porphyroblasts and, much less frequently, occurs within the rock matrix. It is characterised by a relatively high phengite content (Si^{4+}=6.66±0.19 and Fe+Mg=0.82±0.23; O^{2-}=24) and a minor paragonite admixture (Na/(Na+K)=0.01–0.05). Muscovite plates display an increase in Si^{4+} from core to rim in the range

Table 4
Composition and structural formula of biotite (O^{2-}=24; O, OH) from mica schists (D7, D13) of Orlica-Śnieżnik unit

Sample	d7	d7	d7	d7	d7	d7	d13	d13	d13	d13	d13	d13
Analysis	9	10	21	22	34	35	23	24	29	30	76	77
c/r	c	r	c	r	r	c	c	r	c	r	c	r
SiO_2	37.08	36.36	36.02	37.15	35.85	35.79	36.30	36.88	35.67	35.25	36.19	62.34
TiO_2	1.72	2.41	1.70	1.57	1.47	1.83	1.77	2.17	1.42	1.53	1.59	0.00
Al_2O_3	19.01	18.41	18.80	18.18	19.52	18.47	18.53	20.29	18.86	18.96	19.45	23.61
FeO*	18.76	18.61	20.20	20.00	20.28	21.48	19.14	17.54	18.91	19.76	18.59	0.43
MnO	0.09	0.06	0.00	0.03	0.08	0.02	0.08	0.13	0.09	0.12	0.04	0.00
MgO	10.04	9.88	9.97	9.99	9.74	9.36	10.83	9.93	10.59	10.59	10.51	0.17
Na_2O	0.12	0.12	0.11	0.14	0.20	0.09	0.05	0.28	0.11	0.09	0.15	8.97
K_2O	9.12	9.33	7.99	8.80	9.20	8.49	8.46	8.94	8.92	7.88	8.83	0.20
H_2O	4.01	3.96	3.95	3.99	3.98	3.94	3.97	4.05	3.94	3.92	3.99	4.79
Total	99.94	99.13	98.72	99.85	100.30	99.45	99.11	100.21	98.50	98.10	99.32	100.52
Si^{4+}	5.55	5.51	5.47	5.59	5.40	5.45	5.48	5.47	5.44	5.39	5.45	7.80
Ti^{4+}	0.19	0.27	0.19	0.18	0.17	0.21	0.20	0.24	0.16	0.18	0.18	0.00
Al^{IV}	2.45	2.49	2.53	2.41	2.60	2.55	2.52	2.53	2.56	2.61	2.55	0.20
Al^{VI}	0.90	0.79	0.84	0.81	0.87	0.77	0.78	1.01	0.83	0.81	0.90	3.28
Fe^{2+}	2.35	2.36	2.57	2.52	2.56	2.74	2.42	2.17	2.41	2.53	2.34	0.05
Mn^{2+}	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.02	0.01	0.02	0.01	0.00
Mg^{2+}	2.24	2.23	2.26	2.24	2.19	2.13	2.44	2.19	2.41	2.41	2.36	0.03
Na^+	0.04	0.03	0.03	0.04	0.06	0.03	0.01	0.08	0.03	0.03	0.04	2.18
K^+	1.74	1.80	1.55	1.69	1.77	1.65	1.63	1.69	1.74	1.54	1.70	0.03
OH^-	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Fe/(Fe+Mg)	0.51	0.51	0.53	0.53	0.54	0.56	0.50	0.50	0.50	0.51	0.50	0.59

Based on all Fe as FeO.

Table 5

Composition and structural formula of plagioclase (O^{2-}=8) from mica schists (D7, D13) of Orlica-Śnieżnik unit and phyllite (D29) and amphibolite (LK4) of Nové Město unit

Sample	D7	D7	D7	D7	D7	D7	D13	D13	D13	D13	D13	D13	D29	D29	D29	D29	D29	D29	LK4	LK4	LK4	LK4	LK4	LK4
Analysis	1	3	49	51	58	60	1	2	25	26	72	73	54	55	58	59	39	40	87	88	237	236	274	275
c/r	c	r	c	r	c	r	c	r	c	r	c	r	c	r	c	r	c	r	c	r	c	r	c	r
SiO_2	69.03	64.10	68.76	60.75	68.50	61.97	67.96	61.14	68.46	62.59	68.62	62.49	68.71	64.78	68.28	65.96	67.92	65.63	62.21	63.89	62.32	63.06	66.16	63.58
Al_2O_3	19.38	22.43	19.52	24.67	19.60	23.52	19.26	24.33	19.59	23.42	19.45	23.26	19.90	22.49	19.94	21.54	19.96	21.67	23.77	22.73	20.99	23.89	21.52	23.18
CaO	0.07	3.42	0.14	6.08	0.13	4.85	0.25	5.44	0.07	4.52	0.10	4.65	0.24	3.35	0.31	2.20	0.46	2.29	4.88	3.58	0.81	3.92	0.93	3.98
Na_2O	11.92	9.73	11.82	8.20	11.82	9.05	11.62	8.61	11.63	9.20	11.51	9.04	11.78	10.26	11.90	10.49	11.68	10.70	9.13	10.08	9.30	9.67	10.78	9.57
K_2O	0.06	0.13	0.09	0.13	0.11	0.12	0.06	0.08	0.05	0.09	0.08	0.10	0.03	0.05	0.07	0.10	0.06	0.04	0.19	0.04	0.89	0.24	0.80	0.09
Total	100.54	100.00	100.39	99.91	100.16	99.56	99.17	99.72	99.89	99.99	99.76	99.56	100.66	100.93	100.50	100.29	100.08	100.34	100.18	100.31	94.31	100.78	100.19	100.40
Si^{4+}	3.00	2.83	2.99	2.70	2.99	2.76	2.99	2.72	2.99	2.77	3.00	2.78	2.98	2.83	2.97	2.89	2.97	2.88	2.75	2.81	2.90	2.77	2.90	2.80
Al^{3+}	0.99	1.17	1.00	1.29	1.01	1.23	1.00	1.28	1.01	1.22	1.00	1.22	1.02	1.16	1.02	1.11	1.03	1.12	1.24	1.18	1.15	1.24	1.11	1.20
Ca^{2+}	0.00	0.16	0.01	0.29	0.01	0.23	0.01	0.26	0.00	0.21	0.00	0.22	0.01	0.16	0.01	0.10	0.02	0.11	0.23	0.17	0.04	0.18	0.04	0.19
Na^{+}	1.00	0.83	1.00	0.71	1.00	0.78	0.99	0.74	0.99	0.79	0.98	0.78	0.99	0.87	1.00	0.89	0.99	0.91	0.78	0.86	0.84	0.82	0.92	0.82
K^{+}	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.05	0.01	0.04	0.01
Sum	5.01	5.01	5.01	5.01	5.01	5.02	5.00	5.01	5.00	5.01	4.99	5.00	5.00	5.02	5.02	5.00	5.01	5.02	5.02	5.03	4.98	5.03	5.02	5.01
Ab	0.99	0.83	0.99	0.70	0.99	0.77	0.99	0.74	0.99	0.78	0.99	0.77	0.99	0.84	0.98	0.89	0.98	0.89	0.76	0.83	0.90	0.81	0.91	0.81
An	0.00	0.16	0.01	0.29	0.01	0.23	0.01	0.26	0.00	0.21	0.00	0.22	0.01	0.15	0.01	0.10	0.02	0.11	0.23	0.16	0.04	0.18	0.04	0.19
Or	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.06	0.01	0.04	0.01

of 6.34–6.84 cations per structural formula unit (Table 3). The second muscovite variety is more common in the mica schist and occurs as numerous mica plates which define foliation S_2. It shows lower phengite concentration (Si^{4+}=6.59±0.18; Fe+Mg=0.76±0.20; O^{2-}=24), compared to that in the first variety of mica and a similarly low content of paragonite (Na/(Na+K)=0.02–0.07). A distinctive feature of the second type of muscovite is the decrease in Si^{4+} concentration from core to rim of the mica plates ranging from 6.82 to 6.35 p.f.u. (Table 3).

Sample D13 contains only one muscovite generation, with crystals aligned parallel to the foliation. The chemical composition is characterised by a relatively high phengite content (Si^{4+}=6.64±0.23 and Fe+Mg=0.76±0.19; O^{2-}=24) and a low concentration of paragonite (Na/(Na+K)=0.02–0.06). Muscovite plates display decrease of Si^{4+} concentration from core to rim, ranging from 6.90 to 6.29 p.f.u. (Table 3).

In the phyllite from sample D29 only one generation of white mica is documented, whose crystals define the main foliation. This muscovite is characterised by a relatively low phengite content (Si^{4+}=6.41±0.04 and Fe+Mg=0.57±0.06; O^{2-}=24) and a minor paragonite content (Na/(Na+K)=0.01–0.13). The Si^{4+} concentration increases from core to rim, ranging from 6.35 to 6.50 p.f.u. (Table 3).

6.3. Biotite

The composition of biotite is similar in all the analysed samples, yielding Fe/(Fe+Mg) ratio between 0.58 and 0.29 and a Ti^{4+} concentration in the range of 0.12–0.27 p.f.u. (Table 4).

Table 6
Composition and structural formula of amphiboles (O^{2-}=23) from amphibolite (LK4) of Nové Město unit

Sample	LK4	LK4	LK4	LK4	LK4	LK4	LK4	LK4	LK4	LK4	LK4	LK4
Analysis	85	86	276	277	320	321	322	323	327	328	329	330
c/r	c	r	c	r	c	r	c	r	c	r	c	r
SiO_2	42.98	42.89	43.16	43.69	43.42	43.94	42.46	42.75	42.94	43.95	42.32	43.40
TiO_2	0.53	0.48	0.42	0.36	0.48	0.39	0.61	0.37	0.49	0.38	0.52	0.38
Al_2O_3	15.72	15.59	15.15	13.77	15.14	14.46	16.31	15.16	15.42	14.35	16.18	14.95
FeO	15.33	15.91	16.21	17.05	15.83	16.70	15.57	16.61	15.62	16.38	15.92	16.01
MnO	0.00	0.21	0.31	0.26	0.09	0.12	0.15	0.20	0.09	0.21	0.26	0.17
MgO	9.41	9.14	8.77	9.05	9.36	9.18	9.13	8.62	9.38	9.45	8.75	9.03
CaO	10.66	10.83	11.31	11.31	11.12	11.43	10.34	11.36	10.85	10.79	10.92	11.17
Na_2O	2.14	1.82	1.58	1.48	1.76	1.29	2.35	1.55	1.95	1.69	1.95	1.59
K_2O	0.37	0.37	0.34	0.45	0.36	0.28	0.42	0.41	0.35	0.31	0.45	0.32
Total	97.13	97.24	97.24	97.41	97.56	97.79	97.33	97.03	97.09	97.50	97.28	97.02
Si	6.30	6.28	6.36	6.44	6.35	6.42	6.21	6.33	6.30	6.41	6.23	6.39
Al^{IV}	1.70	1.72	1.64	1.56	1.65	1.58	1.79	1.67	1.70	1.59	1.77	1.61
Al^{VI}	1.01	0.98	0.99	0.84	0.96	0.90	1.02	0.97	0.97	0.88	1.03	0.98
Fe^{3+}	0.56	0.65	0.47	0.56	0.54	0.60	0.65	0.49	0.60	0.72	0.54	0.50
Ti	0.06	0.05	0.05	0.04	0.05	0.04	0.07	0.04	0.05	0.04	0.06	0.04
Fe^{2+}	1.32	1.30	1.53	1.54	1.40	1.44	1.25	1.57	1.32	1.28	1.42	1.47
Mn	0.00	0.03	0.04	0.03	0.01	0.01	0.02	0.03	0.01	0.03	0.03	0.02
Mg	2.06	2.00	1.93	1.99	2.04	2.00	1.99	1.90	2.05	2.05	1.92	1.98
Ca	1.67	1.70	1.79	1.79	1.74	1.79	1.62	1.80	1.70	1.69	1.72	1.76
Na	0.61	0.52	0.45	0.42	0.50	0.36	0.67	0.44	0.55	0.48	0.56	0.45
K	0.07	0.07	0.06	0.08	0.07	0.05	0.08	0.08	0.07	0.06	0.08	0.06
Total	15.35	15.29	15.30	15.29	15.31	15.20	15.37	15.32	15.32	15.22	15.36	15.28
$Mg/(Mg+Fe^{2+})$	0.61	0.61	0.56	0.56	0.59	0.58	0.61	0.55	0.61	0.62	0.58	0.57
(Na+K)A	0.35	0.29	0.30	0.29	0.31	0.20	0.37	0.32	0.32	0.22	0.36	0.28

Formulas of amphiboles calculated according to procedure of Robinson et al. (1982).

6.4. Plagioclase

Plagioclase crystals from the mica schist samples D7 and D13 are characterised by increase in the anorthite content from 0.7% in the core to 28.8% at the rim. A similar, but weaker trend (1–15.5% An) is also recorded in plagioclase from the phyllite sample D29. Generally, more anorthite-rich is the plagioclase from amphibolite sample LK4, where the An-content ranges between 14% in the cores to 27% at the rims of crystals. The plagioclase from all the analysed samples displays a uniformly low Or-admixture (below 0.8%; Table 5).

6.5. Amphibole

Sample LK4 contains calcium amphiboles with Ca_B ranging from 1.61 to 1.81. The value of $(Na+K)_A$ is in the range between 0.21 and 0.37. Therefore, the analysed amphiboles plot on the Si–Mg/(Mg+Fe) diagram (Leake et al., 1997) mainly in the field of tschermakite (Table 6).

7. Geothermobarometry

The temperatures of peak metamorphism in the mica schists (samples D7 and D13) were estimated using geothermometers based on exchange reactions of Fe and Mg between garnet and biotite (Holdaway, 2000), as well as between garnet and muscovite (Green and Hellman, 1982). The garnet-free phyllite sample D29 was analysed using exchange reaction of Na and K between plagioclase and muscovite (Green and Udansky, 1986). The peak pressures for samples D7 and D13 were calculated using the grt-ms-bt-pl geobarometer (Powell and Holland, 1988). Accordingly, two net-transfer reactions were applied to the analysed samples (mineral abbreviations after Kretz, 1983, symbols in brackets refer to lines shown in PT diagrams of Fig. 13):

$$\mathrm{Grs + Prp + Ms = 3An + Phl(GPMB - Mg)}$$

$$\mathrm{Grs + Alm + Ms = 3An + Ann(GPMB - Fe)}$$

The pressure recorded by the phyllite (sample D29) was estimated using the phengite geobarometer (Massone and Schreyer, 1987), calibrated for the assemblage including phlogopite, quartz and K-feldspar. Although the K-feldspar is missing in sample D29, the obtained results can be interpreted as minimum pressure conditions (Massone and Schreyer, 1987). Results of all the *P*–*T* calculations are shown in Fig. 13.

The temperature calculations for the garnet–biotite and garnet–muscovite pairs were based on the rim compositions of garnet grains and of the mica plates adjacent to the garnet or defining the foliation. However, the profiles across the entire garnet grains from samples D7 and D13 proved the chemical composition of crystal rims to have been controlled by a late thermal event. Consequently, it seems likely that the temperatures estimated for these samples may have not corresponded to the peak metamorphism conditions, but to those related to the D_2 deformation event. The temperatures obtained using the garnet–biotite thermometer are similar for all the particular mineral pairs considered and equal 546±24 °C for sample D7 and 632±23 °C for sample D13. The garnet–muscovite thermometer yielded temperatures of 535±10 °C and 614±29 °C for D7 and D13, respectively. The pressures estimated with the grt-pl-ms-bt geobarometer for the mineral rim compositions, are in the range of 8.6±0.8–6.9±1.0 kbar for sample D7 and 9.6±1.7–7.5±1.6 kbar for D13. Slightly lower pressures were determined using the phengite geobarometer: 7.7±1.3 kbar for sample D7 and 8.7±2.4 kbar for D13 (Fig. 13a, b).

The plagioclase porphyroblasts from sample D7 contain muscovite inclusions which allow an approximate determination to be made of the *P*–*T* conditions during the early stage of metamorphism. The plagioclase–muscovite geothermometer applied to them yielded temperatures of 290–300 °C for the core of the plagioclase porphyroblasts and the muscovite inclusions in them. The pressures estimated with the phengite geobarometer for the same pl-ms pair are between 3.0 and 5.5 kbar (Fig. 13a). In contrast, the temperature calculated for the rim compositions of the plagioclase porphyroblasts and muscovite intergrowths is equal to 485±10 °C.

The temperatures of peak metamorphism in the amphibolite sample LK4 were estimated using the hornblende-plagioclase geothermometer, based on the exchange reactions of $(NaAl)(Si)_{-1}$ and

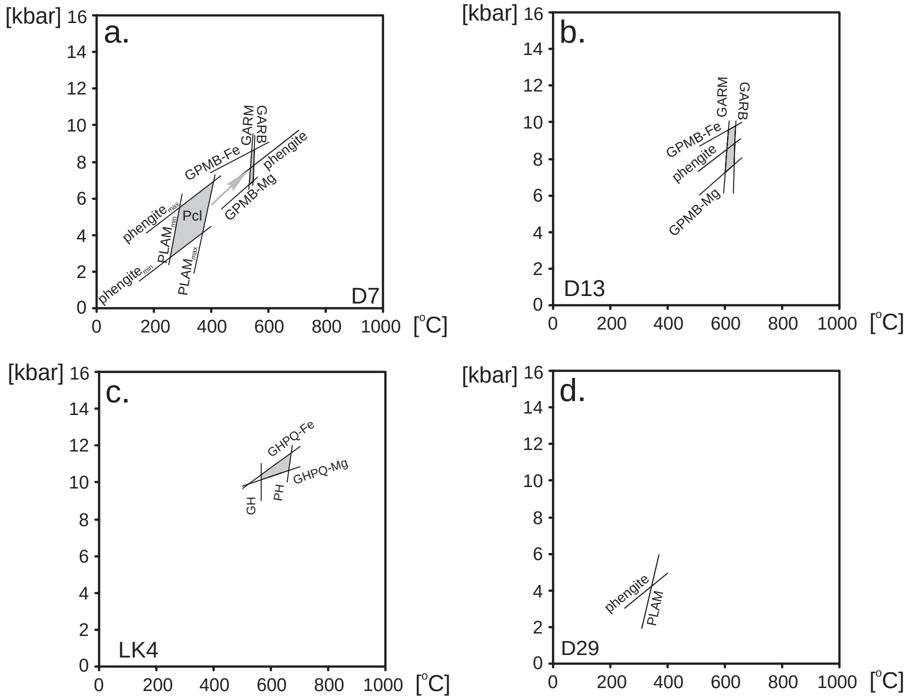

Fig. 13. Results of thermobarometric calculations for samples of mica schists D7 (a), D13 (b), amphibolite LK4 (c) and phyllite D29 (d). Pcl in diagram (a) results for muscovite inclusions in plagioclase porphyroclasts. GARB—garnet-biotite geothermometer, GARM—garnet-muscovite geothermometer, PLAM—plagioclase-muscovite geothermometer, Grt-hbl-garnet-hornblende geothermometer, Hbl-pl-hornblende-plagioclase geothermometer, GPMB—garnet-plagioclase-muscovite-biotite geobarometer, Phengite—phengite geobarometer, Grt-hbl-pl-q—garnet-hornblende-plagioclase-quartz geobarometer.

$MgSi(Al)_{-1}$ between individual hornblende components and of $(NaSi)(CaAl)_{-1}$ between plagioclase and hornblende (Holland and Blundy, 1994). From among two calibrated reactions, the silica saturated equilibrium was used in this study:

$$Ed + 4Q = Tr + Ab(PH)$$

Additionally, applied was also the garnet–hornblende geothermometer of Graham and Powell (1984), based on the Fe and Mg exchange reaction:

$$^1/_4 Fe - Prg + {}^1/_3 Prp = {}^1/_4 Prg + {}^1/_3 Alm(GH)$$

The peak pressures of metamorphism for the LK4 amphibolite were estimated using the grt-hbl-pl-qtz geobarometer in the calibration of Kohn and Spear (1990). It is based on the reaction of garnet, plagioclase, quartz and the Tschermak exchange in amphibole (hornblende). Two reactions originally calibrated by these authors were applied:

$$6An + 3Tr = 2Grs + Prp + 3Tsch + 6Q(GHPQ - Mg)$$

$$6An + 3Fe - Act = 2Grs + Alm + 3Fe - Tsch$$
$$+18Q(GHPQ - Fe)$$

The temperatures of peak metamorphism calculated for the LK4 amphibolite using the hornblende–plagioclase and garnet–hornblende thermometers are fairly similar and equal to 633±6 °C and 565±23 °C, respectively. For the same sample, the grt-hbl-pl-qtz geobarometer yielded pressure of 10.3±1.2 kbar (Fig. 13c).

The phyllite sample D29 comprises a relatively poor mineral assemblage. Therefore, calculations of the *P–T* conditions were based exclusively on the plagioclase–

muscovite geothermometer and phengite geobarometer. The temperature and pressure estimated for the mineral rim compositions are equal to 340±38 °C and 4.3±0.5 kbar, respectively (Fig. 13d). The solution models applied for garnet, biotite, plagioclase and amphiboles were identical to those used in the original calibrations of geothermobarometers applied.

8. Discussion

The *P–T* estimates for the mica schists (samples D7, D13) and amphibolite (D4), collected from the contact zone between the Nové Město and the Orlica-Śnieżnik units, provide evidence for the metamorphic conditions of these rocks in the range of the amphibolite facies. The mica schists from the western margin of the Orlica-Śnieżnik unit recorded temperatures and pressures between 535–623+23/−10 °C and 6.9–.9.6+1.7/−1.0 kbar. The amphibolite from the eastern edge of the Nové Město unit experienced the peak metamorphism under temperature of 565–633+6/−23 °C and pressure of 10.3±1.2 kbar. At least in the case of the mica schists, it is likely that the calculated *P–T* conditions refer to the D_2 deformation event that succeeded the peak metamorphism. The somewhat lower temperatures obtained for the mica schists (D7) can be explained by their location outside the boundary shear zone injected by several granitoid intrusions (Fig. 3). The westward trend of the slight increase in temperature within the Orlica-Śnieżnik unit has been recently confirmed by *P–T* data of Szczepański (2003) from the adjacent, more internal part of this unit (the area of Góry Bystrzyckie Mts.). The phyllite (D29), collected in the Nové Město unit far from its contact with the Orlica-Śnieżnik rocks, recorded significantly lower temperature and pressure compared to those obtained for the mica schists and amphibolite. The peak metamorphism conditions for the phyllites were characterised by temperatures and pressures of 340±38 °C and 4.3±0.5 kbars, respectively. The microstructural relatioships show that these peak conditions were associated with the D_1 deformation event. They are comparable to the conditions of an early metamorphic stage in the mica schists (sample D7) that were roughly estimated at 290–300 °C and 3.0–5.5 kbars.

The observed eastward increase in strain intensity and metamorphic grade from the western Nové Město to the Orlica-Śnieżnik unit, with a particularly high gradient near the boundary zone between the two units, apparently resulted from the tectonic juxtaposition of two different crustal domains, coming from different depths and characterized by unlike thermal conditions—interpreted here to represent the Teplá-Barrandian and Moldanubian terranes of the Bohemian Massif because of their characteristic features (Table 7) and on the basis of regional considerations. Their initial juxtaposition is ascribed here to the oldest deformation event, D_1, whose effects are observed in the Nové Město unit and point to a top-to-the ESE shearing under greenschist facies conditions. Since the top metamorphic conditions recorded in the mica schists from the western margin of the Orlica-Śnieżnik unit pre-date the D_2 event, the important metamorphic gradient at the Orlica-Śnieżnik/Nové Město boundary must have been achieved either during the D_1 deformation or in the time interval between the D_1 and D_2. The peak

Table 7
Comparison of features characteristic of the Teplá-Barrandian and Moldanubian terranes

	Teplá-Barrandian terrane	Moldanubian terrane
sedimentation	Neoproterozoic and Early Palaeozoic to Middle Devonian	Proterozoic and poorly constrained Early Palaeozoic; in the Orlica-Śnieżnik unit — pre-Ordovician
plutonism	Cambrian; Carboniferous at the contact with Moldanubian terrane	Ordovician, Carboniferous
metamorphic age	close to the Proterozoic/Cambrian boundary, Early Carboniferous overprint at the contact with the Moldanubian terrane	intense Early Carboniferous HT/M-LP overprint
HP metamorphism	lacking	bodies of eclogites and granulites ranging in age from 360 to 330 Ma
metamorphic grade	low-grade to unmetamorphosed	medium- to high-grade
uplift/exhumation	Late Devonian	Early Carboniferous

conditions of this pre-D_2 metamorphic event can be roughly estimated by the P–T data from the amphibolite belt at the eastern edge of the Nové Město unit. It is hypothesized here that the D_1 structures were produced by an SE-directed thrusting of the Teplá-Barrandian terrane on top of the Moldanubian terrane, as found in other areas of the Bohemian Massif (Pitra et al., 1994; Scheuvens and Zulauf, 2000; Bues et al., 2002). Similarly, the D_1 thrusting seems to be responsible for an early juxtaposition of the phyllite and amphibolite complexes within the Nové Město unit that are characterized by contrasting metamorphic paths. An equivalent structural evidence for the early SE-directed ductile thrusting, though not found by us in the investigated part of the Orlica-Śnieżnik unit, intensely affected by the later D_2 shearing, has been recently provided by Szczepański (2003) from an adjacent, more internal part of this unit. Furthermore, a deformation sequence similar to that described above, including an early W–E fabric overprinted by effects of a dominant top-to-the N shear was described by Přikryl et al. (1996) from the part of the Orlica Mts. located in the interior of the Orlica-Śnieżnik unit.

The direct juxtaposition of the high-grade Orlica-Śnieżnik and mostly low-grade Nové Město rocks must have occurred during the D_2 event along the predominantly dextral strike-slip, ductile shear zone located between these two rock units, which partly included the marginal amphibolite complex of the Nové Město unit and the Stronie formation mica schists of the Orlica-Śnieżnik unit. The D_2 deformation must have obliterated the original thrust contacts between the two units, and brought about the main features of the current structural pattern, which formed under the D_2-related metamorphism constrained by the P–T data from the mica schists. The structurally higher position of the Nové Město unit with respect to that of the Orlica-Śnieżnik is indicated by the map-scale relationships between the rock complexes of the two units and by the regionally stable eastward vergence of folds F_2 developed on the generally W-dipping foliation (Fig. 14). The formation of the asymmetric F_2 folds, probably roughly synchronous with the significant, localised dextral displacement on the Orlica Mts. terrane boundary, suggests a regional-scale strain partitioning into the strike-slip non-coaxial shearing and coaxial shortening components. The D_2 tectonic

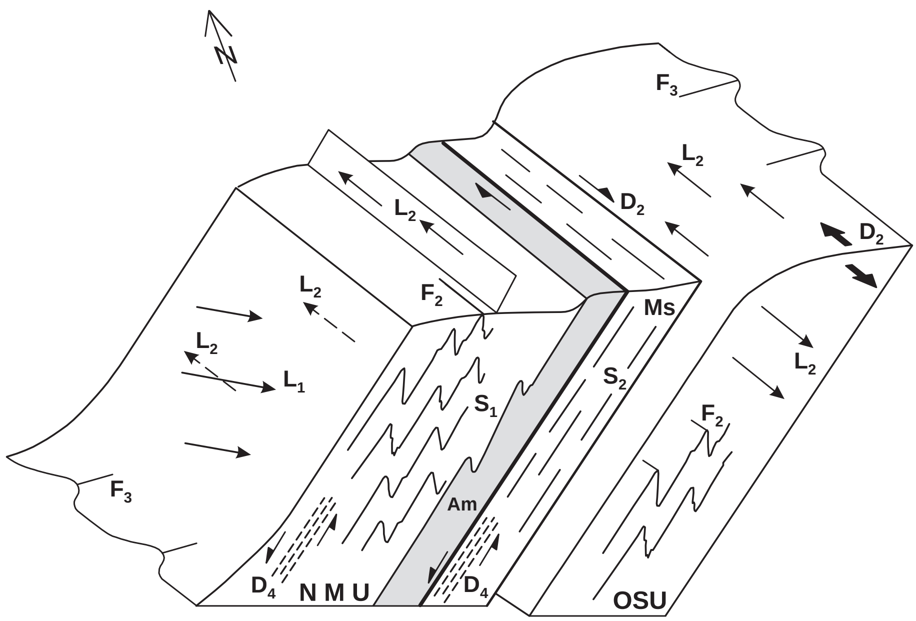

Fig. 14. Schematic map-scale block diagram showing typical attitude of structures and kinematics of successive deformation events near the contact between Nové Město (NMU) and Orlica-Śnieżnik (OSU) unit. Am—amphibolites; Ms—mica schists.

juxtaposition of the middle crust, hot Orlica-Śnieżnik rocks with the supracrustal, much colder Nové Město complexes, apparently did not destroy the original metamorphic contrast that had formed prior to the D_2. This is inferred from the fact that the original D_1 greenschist facies mineral assemblages in most part of the Nové Město phyllites were not subsequently overprinted. Consequently, the considerable geothermal and strain gradients occur now across the ca. 2 km wide transition zone between the two units/ terranes. The width of this zone is by far not large enough to account for the nearly 300 °C difference in temperature between its both sides achieved during the D_2 event and, thus, the Nové Město and Orlica-Śnieżnik units must have been juxtaposed tectonically. A very rough estimation based on the contrasting P–T conditions calculated for the Nové Město and Orlica-Śnieżnik units points to a maximum mutual vertical displacement of the order of ca. 8 km. The geochronological data from the Orlica-Śnieżnik unit, combined with the geological relationships at its boundary with the Nové Město unit, indicate that the final juxtaposition of both units, and hence, the deformation D_2, could not have been earlier than late Visean (340–330 Ma; cf. Steltenpohl et al., 1993; Maluski et al., 1995; Marheine et al., 2002). The Rb–Sr whole rock age of the late-kinematic Kudowa-Olešnice pluton dated at 331±11Ma (Bachliński, 2000) constrains an age of the pervasive D_2 deformation. The timing of this event corresponds well to the determined age of displacements along the major West and North Bohemian shear zones, which was limited to the period of 350–320 Ma with a culmination at ca. 340 Ma (cf. Zulauf et al., 2002a,b).

At a later stage, during the deformation D_4, the contact between the Nové Město and Orlica-Śnieżnik units was affected by a top-to-the-SSW-directed extensional collapse that occurred in semi-brittle conditions and whose effects mostly concentrated along the Olešnice-Uhřinov shear zone (fault). The extensional phase of displacement on this shear zone resulted in the downthrowing of its western, Nové Město, side and was probably, at least partly, related to the subsidence of the basement to the North Bohemian basin. The late, semi-brittle downthrow of the Nové Město with respect to the Orlica-Śnieżnik unit at the deformation stage D_4, can be hypothesised to have occurred in Late Carboniferous and/or Early Permian times, with some possible posterior effects due to the end Cretaceous "Laramide" tectonism widespread in central Europe.

The structure and kinematics of the Teplá-Barrandian/ Moldanubian contact exposed in the Orlica Mts. are compatible and complementary with the model presented by Pitra et al. (1994) for the SE boundary of the Hlinsko unit that is tectonically juxtaposed against the Svratka crystalline complex (Fig. 1). The latter is commonly ascribed to the Moldanubian domain (e.g. Mísař et al., 1983; Franke and Żelaźniewicz, 2002) and also reveals affinities to the Orlica-Śnieżnik unit (Melichar, 1995). Similarly, the Hlinsko unit is sometimes considered to represent fragment of the Teplá-Barrandian terrane, with SW–NE trending Hlinsko-Rychnov normal fault tectonically separating it from the Moldanubian domain to the SE (e.g. Franke and Żelaźniewicz, 2002).

A hypothetical, original thrust contact (resulting from a top-to-the SE thrusting) was extensively modified in the Hlinsko area by a top-to-the NW, normal-slip displacement on a moderately NW-dipping ductile shear zone (Pitra et al., 1994). The orientation of the stretching lineation related to this extensional shearing is basically the same as that of the L_2 in the Orlica Mountains. The normal-slip displacement along the NW-dipping Hlinsko shear zone brings the low-grade metamorphosed sediments and volcanics of the Hlinsko unit into contact with the high-grade Moldanubian rocks in their footwall. This extensional displacement seems to be transferred into the predominantly dextral strike-slip displacement on the NW–SE to NNW–SSE-trending segment of the Orlica Mts. terrane boundary (Fig. 15).

The compatibility of the structural relationships at the boundaries of both the Nové Město and Hlinsko units is significant, despite the possibility that the SE contact of the latter unit with the Svratka crystalline complex may not directly correspond to the boundary of the Moldanubian with the Teplá-Barrandian terrane proper. According to Pitra (personal communication, 2003), this boundary can, alternatively, be situated further to the NW, below the Carboniferous Nasavrky pluton, which separates the Hlinsko unit from the Palaeozoic succession of the Železné hory hills. Paszkowski and Wajsprych (pers. comm. 2003)

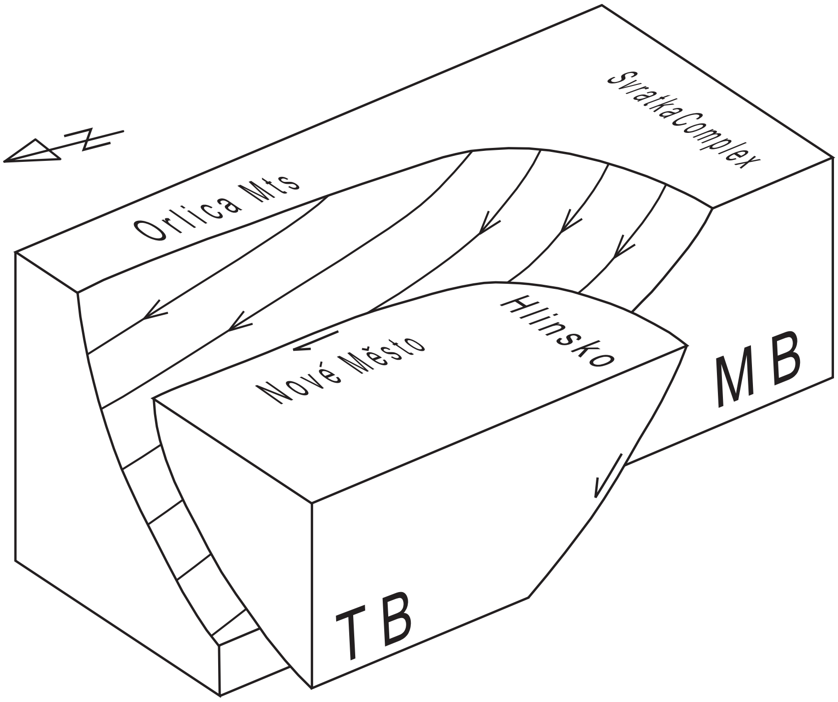

Fig. 15. Schematic diagram showing suggested kinematic link between the normal-slip contact of the Teplá-Barrandian (TB) and Moldanubian (MB) terranes established in the Železné hory hills (Pitra et al., 1994) and the dextral strike-slip contact in the Orlica Mts. reported in this paper. Not to scale.

postulate that the Hlinsko unit, together with that of Kłodzko in the Central Sudetes (Fig. 2), constitute a composite terrane accreted to the Teplá-Barrandian margin at the turn of the Middle and Late Devonian. This hypothesis is in accord with the recent terrane model proposed by Aleksandrowski and Mazur (2002), who distinguished the Góry Sowie-Kłodzko terrane in the Central Sudetes, distinct from the Teplá-Barrandian proper. Regardless of the details of terrane interpretations, it seems very likely that the Teplá-Barrandian terrane was already amalgamated with the Kłodzko and Hlinsko units at the beginning of Carboniferous times. Hence, while investigating the Early Carboniferous geodynamics of the tectonic boundary between the high-grade Moldanubian terrane and the metamorphically contrasting lower grade complexes, we can consider the latter, i.e. the the Nové Město and Hlinsko units as parts of the same composite terrane, whose core is represented by the Teplá-Barrandian proper. In this context, the Teplá-Barrandian composite terrane, as understood in this paper, is a Mid-Palaeozoic assemblage of several units amalgamated and exhumed due to the Middle Devonian collision.

A structural geometry and evolution comparable to those found by us in the Orlica Mts. have been described along the WSW–ENE trending Central Bohemian shear zone segment of the Teplá-Barrandian/Moldanubian terrane boundary in the SW Bohemian Massif (Scheuvens and Zulauf, 2000). This steeply dipping shear zone juxtaposes the HT-metamorphosed Moldanubian against the low grade Teplá-Barrandian rocks. The displacements along the Central Bohemian shear zone were explained by gravitational collapse of a collisionally overthickened Variscan crust (Zulauf, 1997). The collapse is believed to have been preceded by a Late Devonian SE-directed overthrusting of the Teplá-Barrandian onto the Moldanubian units dated at ca 370 Ma (Zulauf, 1997 and references therein). The latter event was probably echoed by an exhumation of low-grade schists of uncertain, Lower Palaeozoic(?) age that were later transgressively onlapped by unmetamorphosed Fammenian to Lower Carboniferous succession in boreholes east of Hradec Králové (Chlupáč and Zikmundová, 1976; Čech et al., 1988). This early basement exhumation in the part of the North Bohemian Cretaceous Basin that is adjacent from the west to the Orlica Mts., is in clear contrast to the Early Carboniferous intense metamorphism of the Orlica-Śnieżnik unit to the east (e.g. Brueckner et al., 1991; Turniak et al., 2000; Marheine et al., 2002).

9. Conclusion

The structural and geological relationships recognized in the Orlica Mts., Central Sudetes, corroborate the hypothesis assuming an occurrence of the Teplá-Barrandian/Moldanubian terrane boundary in this area (Matte et al., 1990). The supposed terrane boundary in the Orlica Mts. is characterized by a high metamorphic gradient, but not metamorphic inversion, and the occurrence of stitching granitoid plutons of mid-Carboniferous age, similarly as are all the other recently studied segments of the Teplá-Barrandian/Moldanubian boundary elsewhere in the Bohemian Massif: in the Železné hory hills and along the Central and West Bohemian shear zones. The sequence and kinematics of the successive deformation events in the Orlica Mts. are similar to or compatible with those established in all other segments of the Teplá-Barrandian/Moldanubian boundary. All these studied segments seem to be dominated by effects of a relatively late (mid-Carboniferous) significant downthrow of the low-grade Teplá-Barrandian terrane relative to the uplifted high-grade, hot, lower to middle crust of the Moldanubian terrane (cf. Zulauf, 2002, "elevator-style tectonics"). This downthrow occurred on ductile shear zones defining terrane boundaries, which showed either down-dip-slip kinematics or that of transfer strike-slip (as in the case of the Orlica Mts.), compatible and complementary with the former type of displacements, occurring together within the same regional-scale kinematically linked shear zone extensional system (Fig. 15). Similarly as in the Orlica Mts, in all other studied fragments of the Teplá-Barrandian/Moldanubian terrane boundary, the late extensional crustal collapse was probably preceded by a SE-directed crustal stacking, which involved an overthrust-emplacement of the Teplá-Barrandian on top of the Moldanubian terrane.

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