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Pre-Late Devonian unconformity in the Kłodzko area excavated: a record of Eo-Variscan metamorphism and exhumation in the Sudetes

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Abstract The results of excavation works aimed at exposing the pre-Late Devonian unconformity in the vicinity of Kłodzko (Middle Sudetes, NE Bohemian Massif) are reported. The unconformity, first described by Bederke in 1924, provides important constraints on the timing of the exhumation of metamorphic complexes in the Sudetes. However, despite its importance, the unconformity is nowhere exposed at present (with the possible exception of the gabbro blocks at one locality - Mt.Wapnica in Dzikowiec), and has been inaccessible for direct observation for decades. Therefore, new excavation works were conceived and done to confirm the unconformity's existence and to describe details of the contact between the metamorphic basement and the Devonian sedimentary cover.

Two localities, at Łączna and Gologłowy, were selected for the excavation, based on detailed mapping and an EM31 conductivity survey. In both localities, four trenches, 2.5–3 m deep and up to 24 m long, were dug across the expected contact zone. Along the trenches in both sites the unconformity was excavated. At each site, the metamorphic rocks are in primary, sedimentary contact with the overlying basal sedimentary breccias and conglomerates. There is no evidence of tectonic disturbance at the contact. This angular unconformity must have formed during a relatively narrow time interval of c. 10–15 Ma, between the early Givetian and late Frasnian or Famennian. This timing is constrained by the late Frasnian?– to Famennian age of the limestones directly overlying the basal conglomerates and by the recently revised early Givetian age of a coralline fauna from the metamorphosed limestones of the Klodzko Metamorphic Unit at Mały Bożków. The existence of this unconformity implies that at the turn of the Middle and Late Devonian times, freshly deformed and metamorphosed rocks were exhumed and onlapped by sediments of the Bardo sequence, which, eventually, became folded during latest Visean/Namurian times.

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INTRODUCTION

The discovery by Bederke (1924) of a pre-Late Devonian angular unconformity in the vicinity of Klodzko (Figs. 1 & 2) was a challenge to the then generally accepted view that the Sudetes formed part of the Variscan orogenic belt (Suess, 1888). The discovery was soon extrapolated over the entire area of the Sudetes and became the cornerstone of a hypothesis which proposed that the main influence on Sudetic tectonics was Caledonian. This hypothesis, assuming only relatively minor Variscan reworking, became generally accepted (e.g. Kodym & Svoboda, 1948; Stille, 1949; Teisseyre, 1956); subsequently, however, in view of new research results, it was gradually abandoned and replaced by the opinion that the tectonic fabric of the Sudetes was mainly the result of Late Devonian and Carboniferous, i.e. Variscan tectonothermal activity (e.g. Teisseyre, 1976, 1980; Urbanek, 1978; Baranowski *et al.*, 1990; Żelaźniewicz *et al.*, 1995). However, Ordovician to Late Devonian/Early Carboniferous successions, showing apparently continuous basinal sedimentation were reported to be juxtaposed with metamorphic complexes overlain unconformably by non-metamorphosed Upper Devonian strata and these relationships were considered the most important evidence in favour of a Caledonian age of major folding and metamorphism in the Sudetes (e.g. Don, 1984; Chaloupsky, 1988; Oliver *et al.*, 1993; Johnston *et al.*, 1994). Nevertheless, it became obvious to many geologists that the earlier supposed, regional, pre-Late Devonian unconformity in the Sudetes was non-existent, or at best doubtful, in almost all of the Sudetic units (e.g. Baranowski *et al.*, 1990; Chlupač & Hladil, 1992; Aleksandrowski *et al.*, 1999). Even at its *'locus typicus'*, in the Kłodzko area, the angular unconformity of

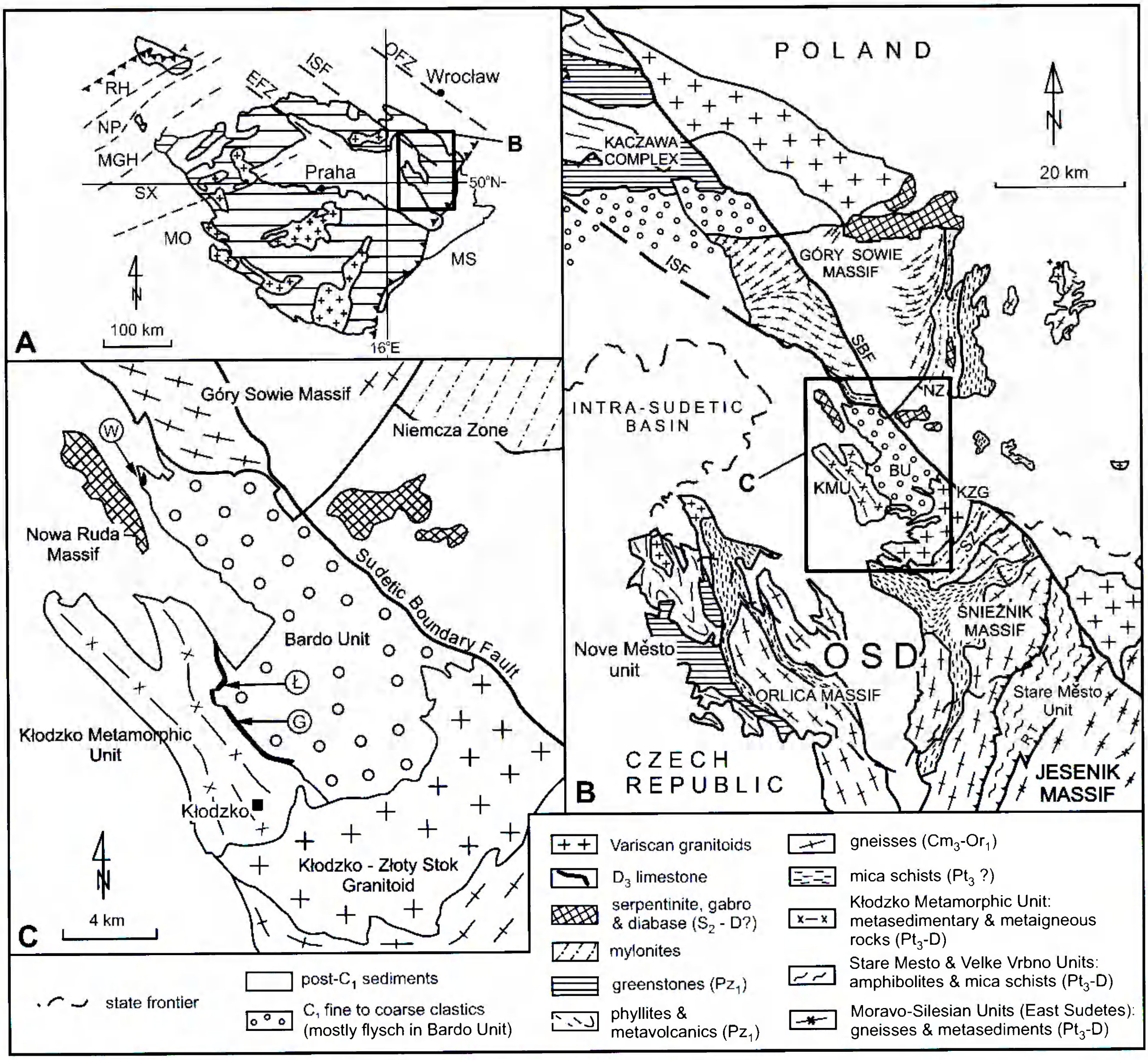

Fig. 1. Geological position of the Klodzko Metamorphic Unit and Bardo Unit (map C) in the Sudetes (map B) and Bohemian Massif (map A). Inset map A: EFZ – Elbe Fault Zone, ISF – Intra-Sudetic Fault, MGH – Mid-German Crystalline High, MO – Moldanubian Zone, MS – Moravo-Silesian Zone, NP – Northern Phyllite Zone, OFZ – Odra Fault Zone, RH – Rhenohercynian Zone, SX – Saxothuringian Zone. Map B: BU – Bardo Unit, ISF – Intra-Sudetic Fault, KMU – Klodzko Metamorphic Unit, KZG – Klodzko–Zloty Stok Granitoid, NZ – Niemcza Shear Zone, OSD – Orlica-Śnieżnik Dome, RT – Ramzova Thrust, SBF – Sudetic Boundary Fault, SZ – Skrzynka Shear Zone. Map C: G – Gologlowy, Ł – Łączna, W – Wapnica. Abbreviations in the legend: C_1 – Lower Carboniferous, Cm_3 – Upper Cambrian, D – Devonian, D_3 – Upper Devonian, Or_1 – Lower Ordovician, Pt_3 –Upper Proterozoic, Pz_1 – Lower Palaeozoic, S_2 – Upper Silurian.

Bederke (1924) has not been exposed for decades (c.f. Oberc, 1957), nor accessible for direct inspection (with the possible exception of the gabbro blocks at the base of the Wapnica section (Gürich, 1900; Bederke, 1924)). Therefore, in order to verify the existence and character of the contact between the metamorphic basement and the sedimentary cover in the vicinity of Kłodzko, excavation works were planned and performed in November 1998, within research project 6 P04D 023 12, supervised by R. Kryza. This paper reports on the results of the new field and excavation works and discusses their geological implications within the context of new geological data acquired in this part of the Sudetes, including palaeontological and radiometric dating.

GEOLOGICAL SETTING

The type locality of the pre-Late Devonian unconformity is at the boundary between the Klodzko Metamorphic Unit (KMU) and the Bardo Unit (BU; Fig. 1c). The Klodzko Metamorphic Unit consists of low- to medium-grade metasedimentary and metaigneous rocks of early- to mid-Palaeozoic age. Wojciechowska (1966, 1990) interpreted these rocks as forming a single 1500–2000 m thick volcano-sedimentary succession. However, Mazur & Kryza (1999) argue that the KMU consists of a number of tectonostratigraphic elements. The latter opinion follows earlier ideas of Bederke (1929) and Finck *et al.* (1942), based on a difference in the lithological composition and metamorphic grade between the NE and SW parts of the area. According to Mazur & Kryza (1999), the NE part of the KMU exposes two metasedimentary successions, with a minimum thickness of c. 600 m each (Fig. 3). The lower sequence (Bożków Formation) of siltstones/mudstones, now metamorphosed to sericite phyllites, grades upward into metaconglomerates, metasandstones and metamudstones with lenticular intercalations of dark, fossil-bearing crystalline limestones previously assigned to the Ludlovian (Gunia & Wojciechowska, 1971) and recently reinterpreted as lower Givetian (Hladil *et al.*, 1999). This sequence is overlain by the upper sedimentary succession (Łączna Formation) outcropping further to the south and composed of chlorite schists, sedimentary breccias and lenses (olistoliths) of carbonate rocks, all recently interpreted by Mazur as a metamorphosed sedimentary mélange (Mazur & Kryza, 1999). Both successions are separated by a tectonic contact, possibly a thrust fault (op. cit.). The poorly exposed SW part of the KMU, consisting of mostly metagabbros, orthogneisses and mylonites with subordinate metasedimentary rocks, most probably forms a separate tectonic unit (or units). This part of the KMU displays a higher grade of metamorphism, up to amphibolite facies conditions, with distinct thermal influence along the contact with the Klodzko–Zloty Stok Variscan granitoid intrusion to the SE (Fig. 1).

The metamorphic basement rocks of the KMU were described by Bederke (1924; Fig. 2) to be in sedimentary contact with c. 60 m thick, unmetamorphosed, Upper Devonian and Tournaisian sediments, including thin basal conglomerates, calcareous breccias and limestones. The most complete profile of the Upper Devonian succession is exposed at Mt. Wapnica in Dzikowiec near Nowa Ruda (W in Fig. 1). It starts with a calcareous sedimentary breccia containing large boulders of gabbro (Gürich, 1900; Chorowska, 1979; Mazur, 1987; Wajsprych, 1979). Since the works of Gürich (1900, 1902) and Dathe (1900), these blocks have been supposed to represent the crystalline basement of the Nowa Ruda gabbro massif. The age of the breccia was provisionally estimated as upper Frasnian, based on problematic macrofauna (Gürich, 1902; Bederke, 1929). The size and quantity of the gabbro pebbles rapidly

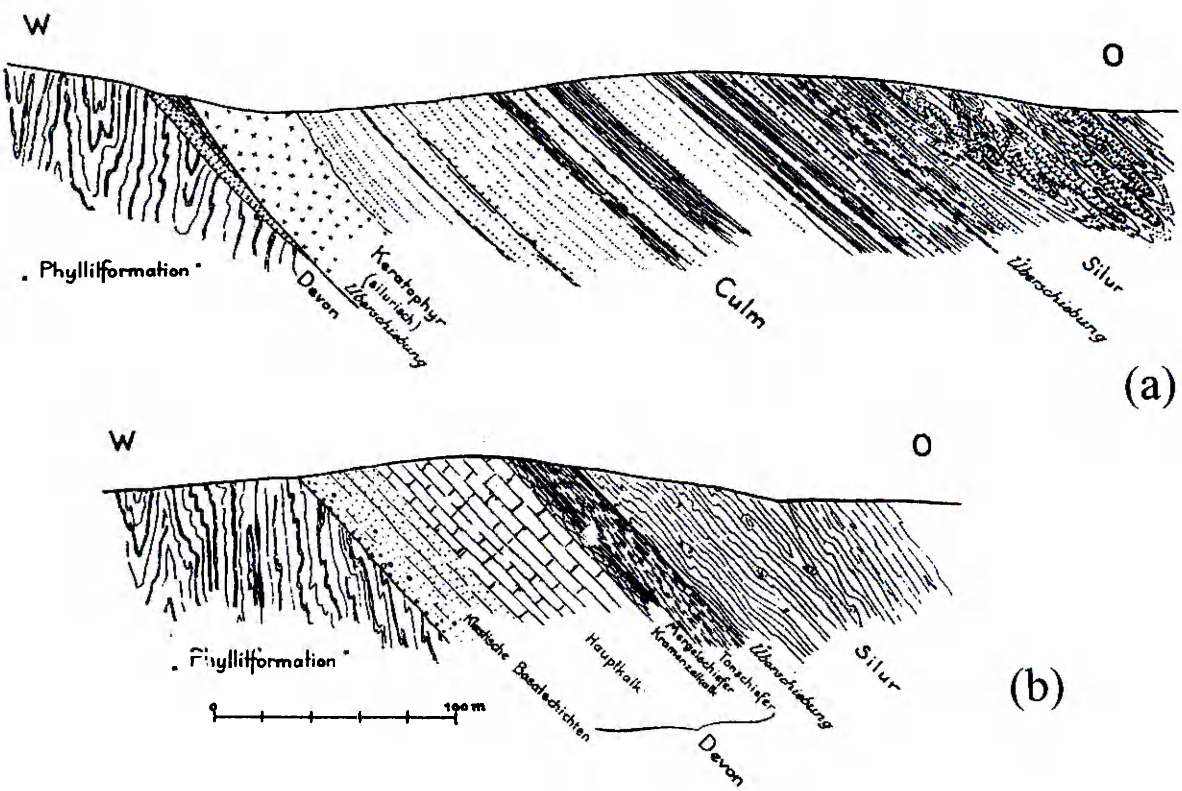

Fig. 2. Pre-Late Devonian unconformity in the vicinity of Kłodzko (from Bederke, 1924): (a) Ścinawica, (b) Gołogłowy.

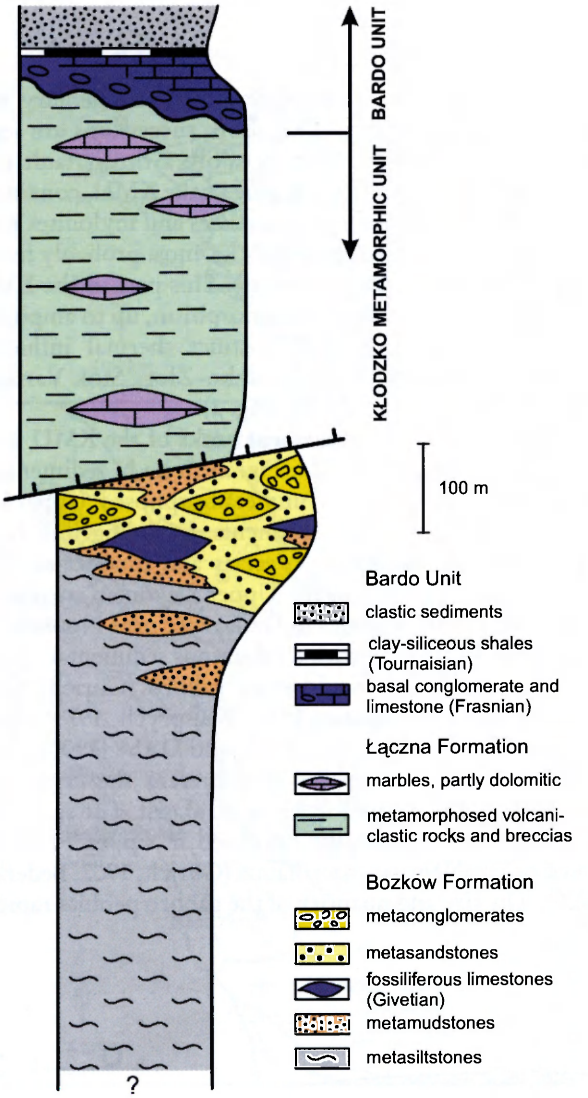

Fig. 3. Lithostratigraphic log of the NE part of the Kłodzko Metamorphic Unit and the position of the Upper Devonian basal conglomerates and limestones (partly based on Hladil *et al.*, 1998).

decreases up the succession as the sedimentary breccia grades into basal limestone and, then, into a partly nodular main limestone (Mazur, 1987; Haydukiewicz, 1990). The age of the latter is palaeontologically well documented by conodont fauna as Famennian, *marginifera* and *styriacus* zones (Freyer, 1968; Chorowska, 1974). The main limestone continuously passes upwards into the upper Famennian Clymenia limestone related to the *costatus* conodont zone (Weyer, 1965; Freyer, 1968; Chorowska, 1974). According to the recent conodont zonation (Ziegler & Sandberg, 1984), the *marginifera* and *styriacus* zones are equivalent to the *marginifera* and Lower *expansa* zones respectively, while the *costatus* zone corresponds to Middle *expansa* – Lower *praesulcata*. The uppermost part of the calcareous succession forms the Lower Tournaisian limestone representing the Gattendorfia crassa ammonoid zone (Schindewolf, 1937; Weyer, 1965), in agreement with the identified conodont fauna (Freyer, 1968; Chorowska, 1974; Dzik 1997). The limestones are, in the most part, discordantly overlain by a thick sequence of Culm sandstones (Dathe, 1900; Bederke, 1924) which are considered as latest Tournaisian in age (Głuszak & Tomaś, 1993). This contact was alternatively interpreted as a major thrust (the Kłodzko thrust of Bederke, 1924) or local erosional discordance (Mazur, 1987). The base of the sandstones is usually marked by a thin layer of black shales, equivalent to those at Gołogłowy, which are dated by conodont fauna as Tournaisian (Haydukiewicz, 1981). The other outcrops of Upper Devonian strata at the boundary of the KMU and BU (Fig. 1) show fragments of a succession similar to that best exposed at Dzikowiec (Bederke, 1924; Gunia, 1977). The specific feature of the Dzikowiec profile is the unconformable contact of the Upper Devonian rocks with the gabbros of the Nowa Ruda massif whereas in all other localities they adjoin the metamorphic basement of the Kłodzko Unit.

The rest of the Bardo Unit, adjacent to the east, is formed of various sedimentary rocks, ranging in age from Ordovician to Carboniferous, and displaying complex structural relationships (Oberc, 1957, 1987; Wajsprych, 1978, 1986; Haydukiewicz, 1990). Wajsprych (1978, 1986, 1995) interprets the BU as Upper Devonian to Lower Carboniferous successions, mostly of flysch and wildflysch characteristics, with large olistoliths containing fragments of Ordovician to Devonian sequences. The base of this succession is represented by the described Upper Devonian conglomerates and limestones found along the boundary of the Bardo Unit with the Nowa Ruda massif and Kłodzko Unit (Wajsprych, 1986). However, as mentioned, the contact has been inaccessible for direct observation for several decades (Oberc, 1957).

SITES DESCRIPTION AND RESULTS

Bederke (1924) described eight localities of Devonian sedimentary rocks along the western edge of the Bardo Unit. These included the quarry at Mt. Wapnica in Dzikowiec (Bederke's no. 1) and the locality at Bożków Mały, or Bożkówek (no. 2), where the limestone later appeared to belong to the metamorphic basement of the KMU (Gunia & Wojciechowska, 1971). The remaining six localities in the close vicinity of Kłodzko, from N to S, are: (3) Łączna, (4) Ścinawica, (5) Gołogłowy, (6) Kłodzko - ul. Półwiejska (*Półwiejska street*), (7) Kłodzko - Owcza Góra, and (8) Kłodzko - Dolina Jodłownika (*Jodłownik Valley*). After detailed field inspection and an EM31 conductivity survey (for a description of this technique, see Mathers & Zalasiewicz, 1985), two localities, at Łączna and Gołogłowy, were selected for the excavation works.

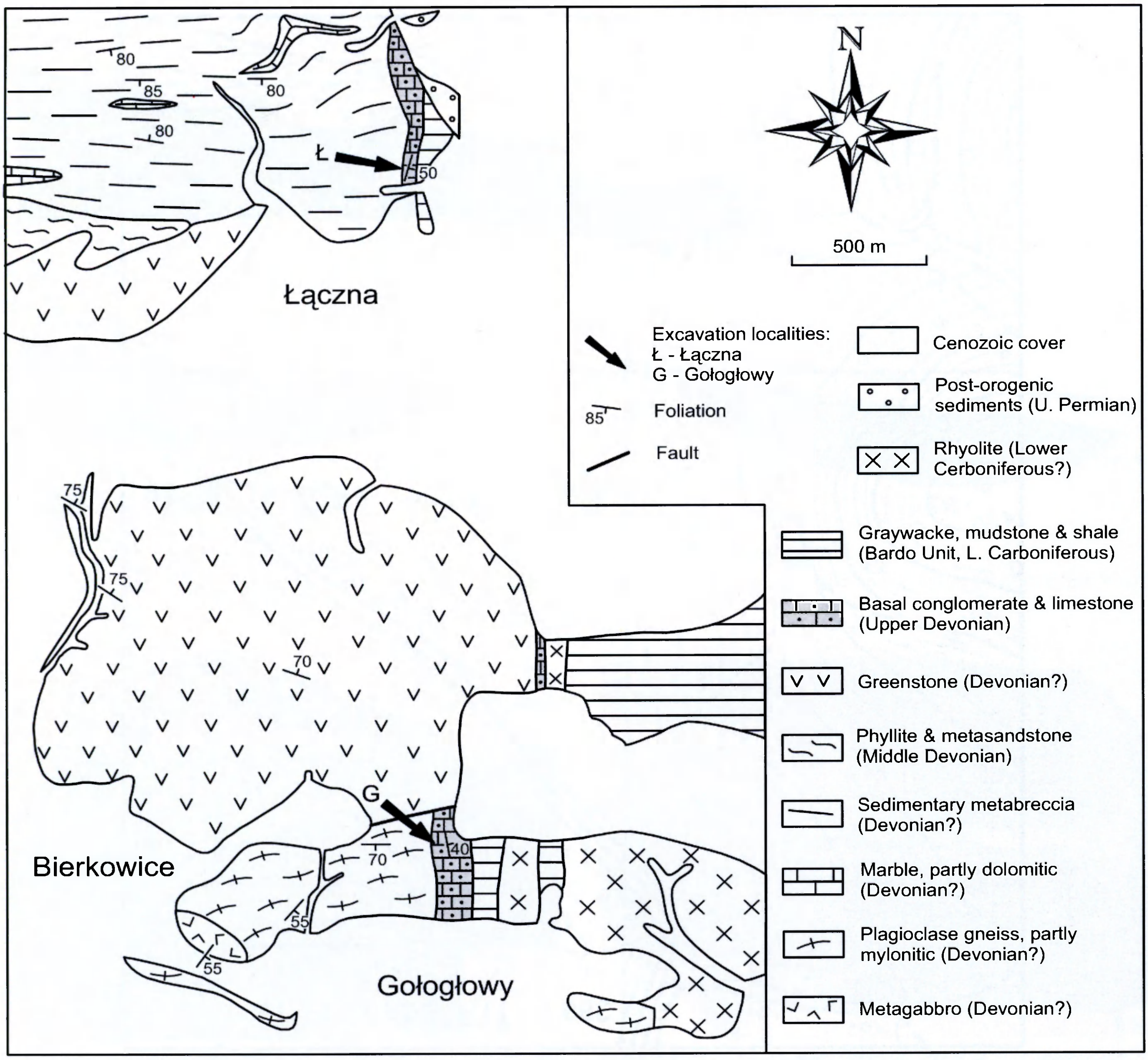

Fig. 4. Geological map of the Gołogłowy – Łączna area, north of Kłodzko (based on Emerle-Tubielewicz, 1979), showing the location of the excavation sites.

ŁĄCZNA

According to the 1 : 25 000 geological map, "Kłodzko" sheet (Emerle-Tubielewicz, 1979, 1981, see Fig. 4), the Devonian limestones form a N–S aligned outcrop, c. 60 m wide, a few hundred metres north of the village of Łączna. To the west, the limestones adjoin "chlorite schists" (assigned by Wojciechowska, 1966, and Emerle-Tubielewicz, 1979, 1981, to the Silurian–Devonian), while to the east, they are in contact with Visean mudstones, and covered by thick delluvial sediments. The limestones are exposed in an old, small quarry, 80 m east of the summit of an unnamed hill (c. 475 m a.s.l.), and some lower part of the sequence (calcareous sandstones) can be traced in a very poor exposure along a local W–E trending road, 300 m north of Łączna. The whole profile represents the lower part of the Upper Devonian succession, comprising the basal limestone and the lowermost part of the main limestone (Chorowska, 1979). The unconformity is nowhere accessible.

The EM31 conductivity survey in the area around the old quarry revealed a sharp decrease in conductivity values going westwards, from more than 20 to less than 10 millimhos, just to the east of the quarry (Fig. 5). This feature follows the base of a morphological step, trending 350°, in significant contrast with the elongation of the outcrop indicated on the map (strike of c. 10°). After a field inspection, three trenches were dug within 20 to 50 metres west of the quarry (Fig. 6).

At the Łączna locality, the metamorphic basement rocks are represented by strongly foliated amphibole schists and dark grey and greenish phyllites (Fig. 7a). The

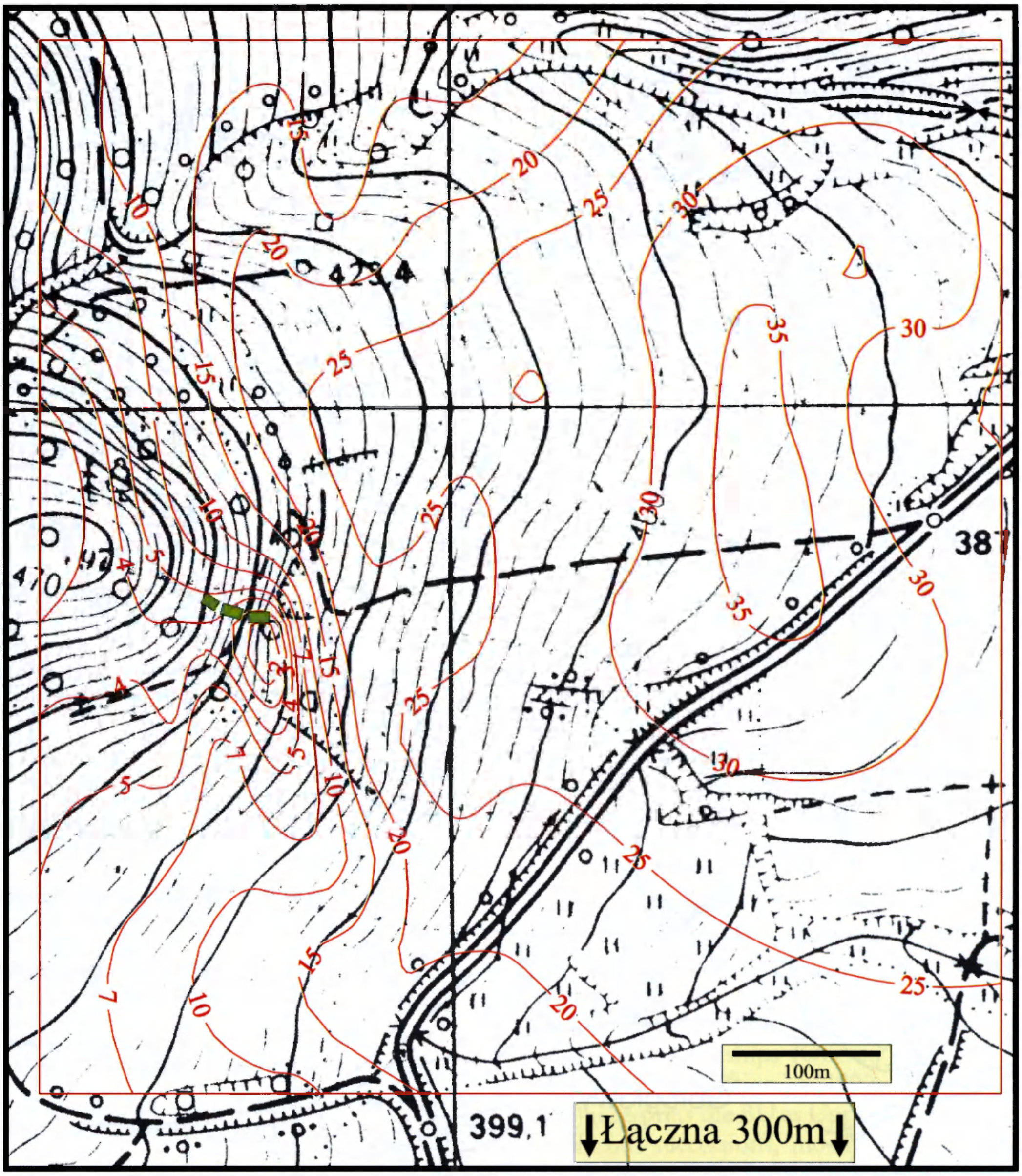

Fig. 5. Łączna: conductivity map based on the EM31 survey showing the location of the excavation works (small green boxes to the left of the centre). Conductivity (red lines) in millimhos.

foliation dips steeply to the N (average 15°/80°) and the mineral lineation plunges moderately to the E (90°/45°). The contact here is a primary angular unconformity, with no evidence of tectonic disturbance. Breccias at the base of the succession are massive and rich in subrounded pebbles of various size, up to 40 cm in diameter. The pebbles are represented by fragments of calcareous breccias (intraformational breccias) and lithologies found in the metamorphic basement of the KMU: phyllites, greenstones, gneisses, deformed quartz, mylonites, quartzites and marbles, as well as fragments of unmetamorphosed, fossiliferous limestones (Fig. 7b–d). The breccias grade upwards into finer-grained conglomerates and calcareous sandstones. The thickness of the basal breccias, calcareous conglomerates and sandstones, up to the base of the quarried limestones, is around 15–18 m. In the quarry, the dark grey detrital limestone is fine-grained, rather massive, with indistinct bedding (dip direction: 100°/45°).

GOŁOGŁOWY

The outcrop of the Devonian conglomerates and limestones on a hill north of the village of Gołogłowy is the southward continuation of the outcrop zone at Łączna, having a similar N–S direction and a width of c. 120–150 m. To the west, these rocks adjoin gneisses of the Kłodzko Unit, supposedly separated by an angular unconformity (Bederke, 1924). Towards the east, they are in sedimentary contact with Lower Carboniferous shales (Haydukiewicz, 1981), considered earlier by Bederke (1924; Fig. 2) as Silurian. In the north, a WSW–ENE trending fault cuts the described outcrop, bringing it into

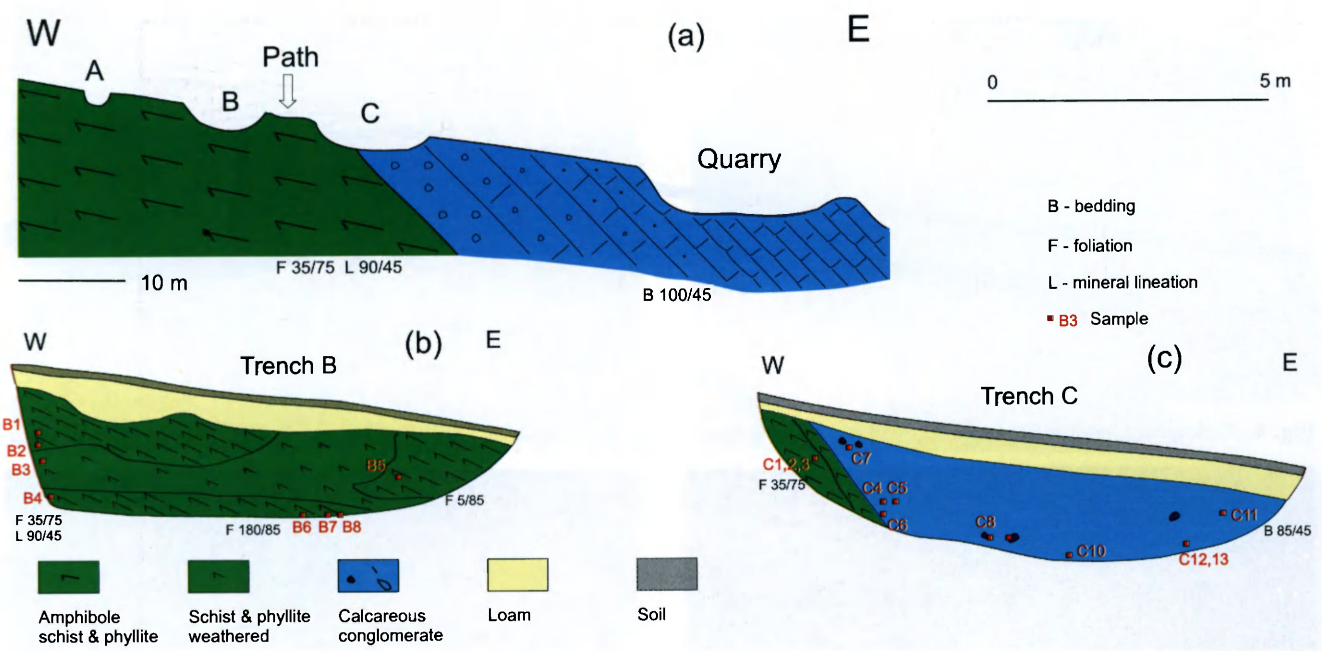

Fig. 6. (**a**) – Location of trenches A, B and C west of the abandoned limestone quarry at Łączna. (**b**) and (**c**) – profiles of trenches B and C.

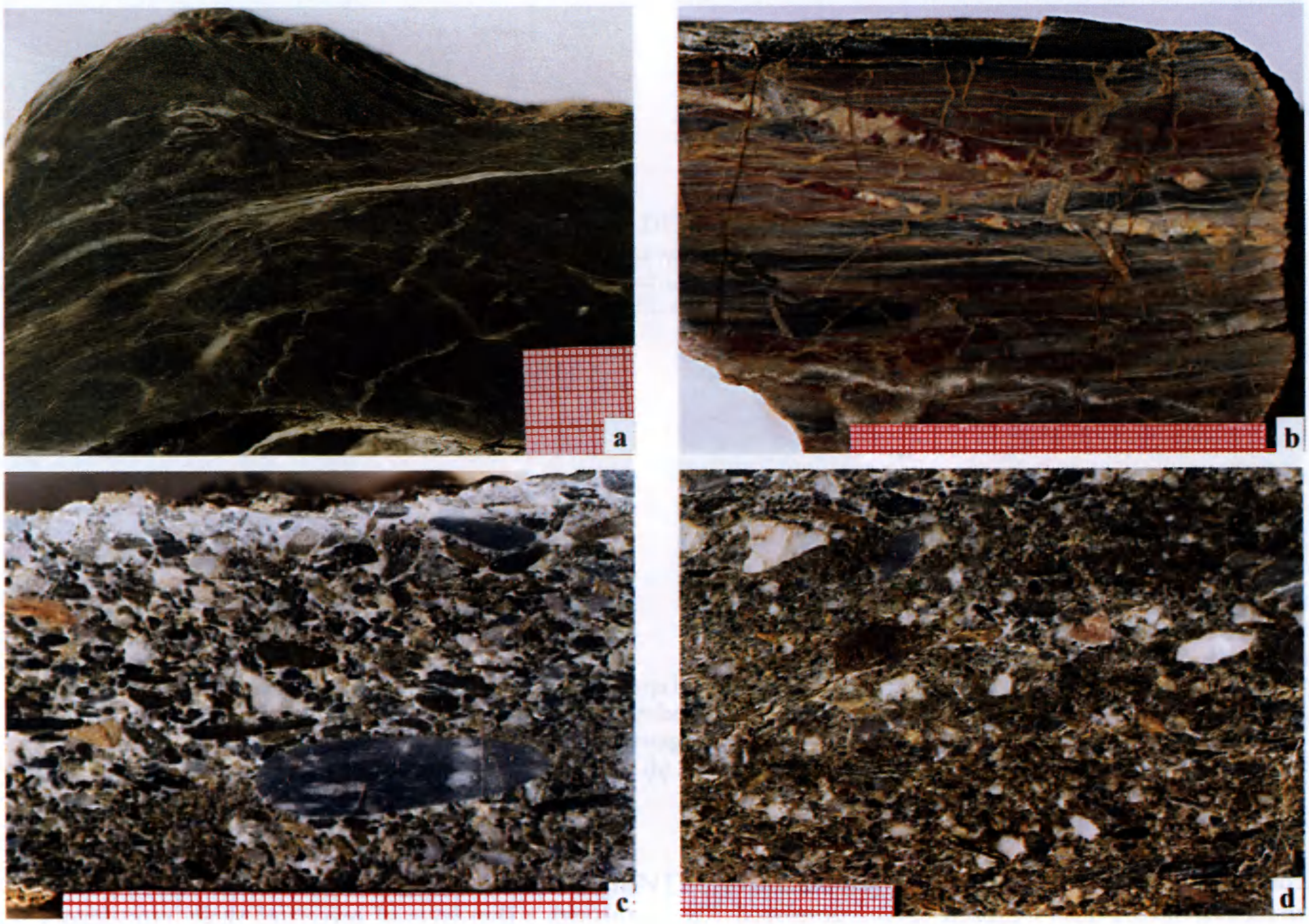

Fig. 7. (**a**). Łączna: Strongly foliated calcite-tremolite-muscovite schist (phyllite). Sample B8, c. 10 m below the unconformity. (**b**). Strongly foliated marble = subrounded block, 9x13x15 cm in size (sample C8), within massive basal conglomerate, 1.5 m above the unconformity. (**c**). Calcareous conglomerate, rich in well rounded - to - subangular, flattened clasts of phyllite, quartzite, metamudstone, marble, gneiss, quartz and limestone. Sample C10, 2.5 m above the unconformity. (**d**). Calcareous conglomerate, sample C11, 5 m above the unconformity.

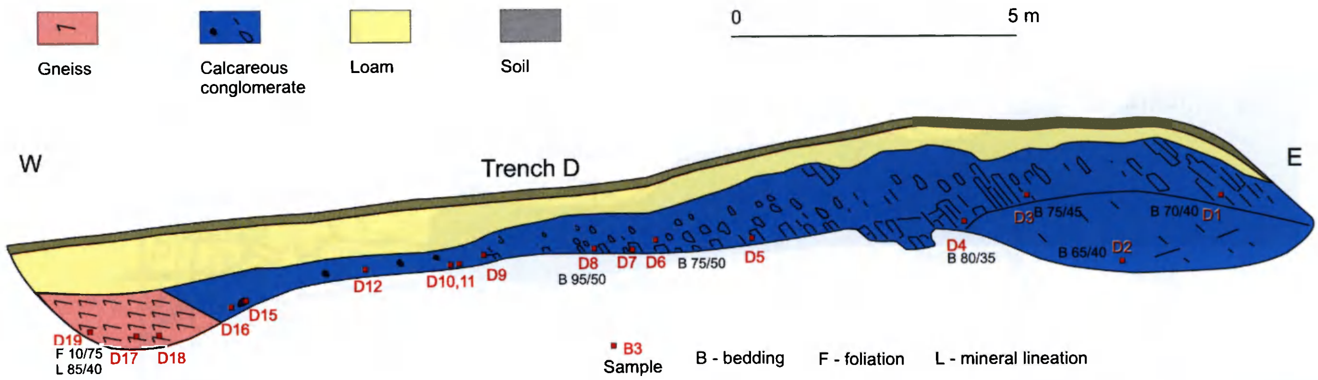

Fig. 8. Gologłowy: profile of trench D, west of the little quarry near the summit of a hill 396.48 m a.s.l., north of the village.

Fig. 9. (**a**). Gołogłowy: trench D (compare Fig. 8), 24 m long and up to 2.5 m deep. (**b**). Mylonitized gneiss at the western end of trench D (marker is 14 cm long). Site of sample D19 (see Fig. 8), c. 1.5 m below the unconformity. Foliation 10/75, mineral lineation 85/40. (**c**). Massive basal conglomerate, rich in subangular and rounded fragments of metamorphic rocks and limestones (largest limestone fragment = sample D15, see Fig. 8), c. 0.5 m above the unconformity. (**d**). Bedded calcareous sandstones at the eastern end of tench D = site of sample D1. Bedding 70/40.

contact with a relatively large body of greenstones, while to the NE and S, a thick Cenozoic cover is developed. The limestones outcrop in two abandoned quarries on the hill, although the basal unconformity is nowhere exposed. The profile starts with the basal limestone containing an important admixture of a siliciclastic material. The basal beds grade upward into the thinly bedded main limestone, nodular in its upper part. The uppermost layer consists of nodules enveloped by muddy shale, grading upward through a thin layer of brecciated shale into siltstone of Tournaisian age (Haydukiewicz, 1981).

Based on the EM31 conductivity survey combined with morphological observations, a 24 m long and up to 3 m deep trench (trench D, Fig. 8) was dug to the west of the little quarry, c. 50 m west of the top of the hill 396.48 m a.s.l. (Fig. 4).

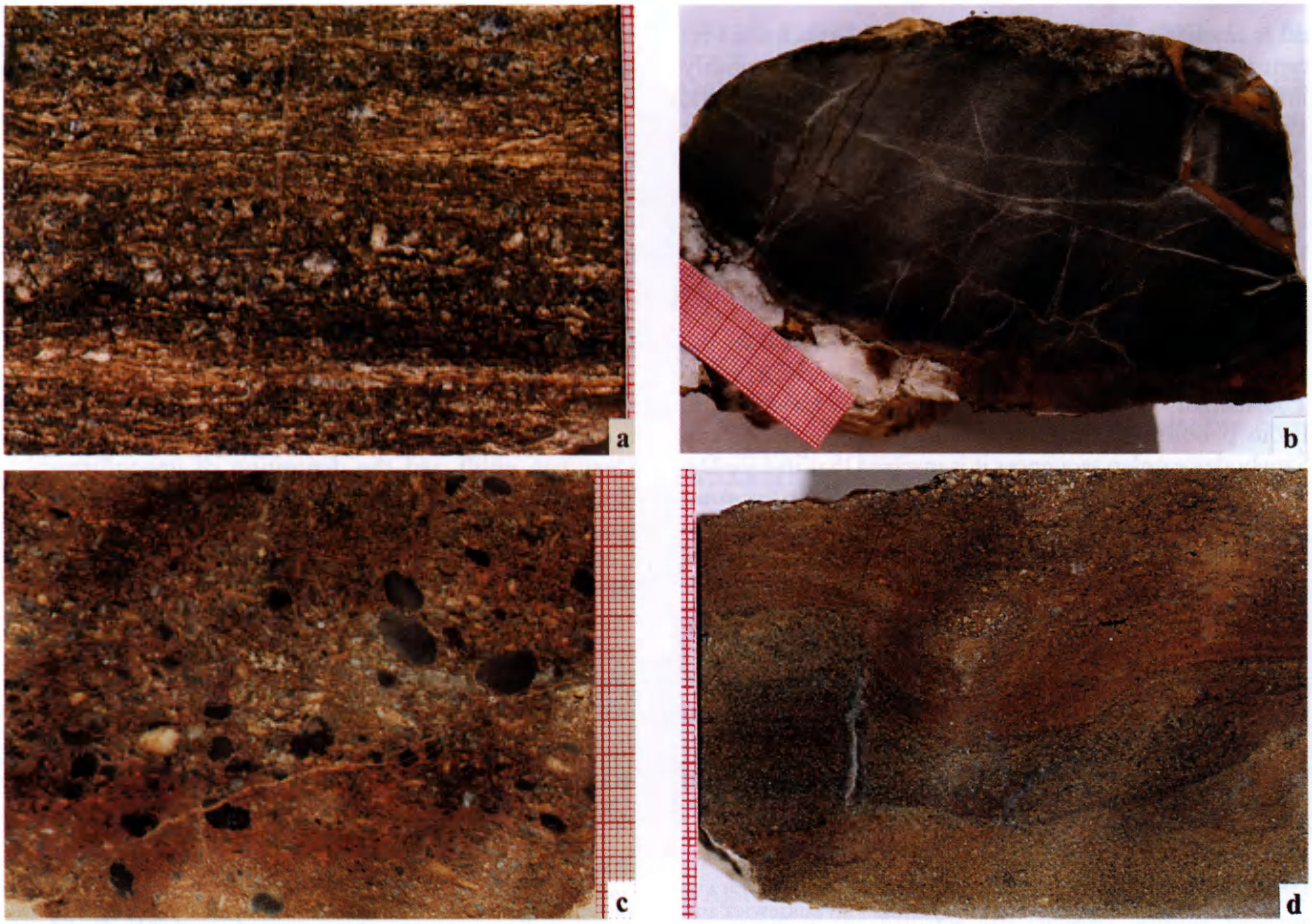

Fig. 10. (**a**). Gologlowy: mylonitized two-mica gneiss. Sample D19, western end of trench D, 1.5 m below the unconformity. (**b**). Large rounded block of unmetamorphosed, dark, bluish-grey, fine-grained limestone within massive basal conglomerate. Sample D15, 0.5 m above the unconformity. (**c**). Calcareous conglomerate, rich in dark-grey pebbles of fossiliferous (stromatoporoid?) limestone. Sample D7, c. 5 m above the unconformity. (**d**). Convolute stratification in calcareous sandstone. Sample D4, c. 10 m above the unconformity.

The section exposed in trench D is shown in Figs. 8 & 9. The metamorphic basement rocks are represented by fine- to medium-grained, moderately- to strongly-foliated, greyish gneiss (Fig. 10a). The foliation dips steeply to the N (10°/75°) and the mineral lineation at a moderate angle to the E (85°/40°). The gneiss here is also in primary, sedimentary contact with the overlying basal sedimentary breccias and conglomerates. There is no evidence of tectonic disturbance at the contact. The overlying sedimentary rocks are strongly weathered, but they look rather massive near the contact, where they contain a large amount of mostly subrounded pebbles of various sizes, up to 40 cm across. The pebbles are mostly fragments of unmetamorphosed, light-coloured or bluish-grey, massive limestones (Fig. 9c). Further up the sequence, the amount and size of pebbles decrease and the rock becomes calcareous conglomerate and sandstone (Fig. 10c & d). Locally, it contains a large amount of fossiliferous (stromatoporoids?) limestone pebbles (Fig. 10c). Around 8–15 m above the contact, the rock becomes distinctly bedded (Fig. 9d). The bedding is roughly perpendicular to the foliation in the gneiss and it dips at a moderate angle to ENE (75°/45°), indicating a considerable rotation after the deposition of the sediments.

DISCUSSION AND CONCLUSION

The described excavation works confirmed the existence of a sedimentary contact between the unmetamorphosed Upper Devonian conglomerates and limestones and the metamorphic rocks of the Kłodzko Metamorphic Unit. This angular unconformity must have formed during a relatively narrow time interval of c. 10 Ma between the early Givetian and late Frasnian. This timing is constrained by the late Frasnian age of the limestones directly overlying the basal conglomerates (Gürich, 1902; Bederke, 1929; Gunia, 1977) and by the early Givetian age of a coralline fauna from the metamorphosed limestones of the basement rocks of the KMU at Mały Bożków (Hladil *et al.*, 1999). The latter, lower limit follows from a recent revision of a faunal assemblage which was previously interpreted as Late Silurian (Gunia & Wojciechowska, 1971). The existence of this unconformity implies that at the turn of the Middle and Late Devonian, freshly deformed and metamorphosed rocks were exposed and onlapped by sediments of the Bardo sequence, which, eventually, became folded during latest Visean/Namurian times (Oberc, 1972).

Apparently equivalent Middle/Late Devonian overstepping of sedimentary rocks may be represented by the presumed basal unconformity of the late Frasnian–early Tournaisian clastic sequence of the Świebodzice Basin. From pebbles in conglomerates in both the Bardo and Świebodzice onlap sequences it is inferred that in Late Devonian times a number of metamorphic/igneous complexes in the Sudetes (in particular the Góry Sowie gneisses) or in the neighbouring areas were already exhumed and undergoing erosion.

However, at roughly the same time in other areas, e.g. in the Kaczawa Unit to the north, apparently continuous basinal sedimentation lasted at least till the end of the Devonian (Baranowski *et al.* 1990). Thus, the discussed unconformity reflects the first exhumation of a Variscan nappe pile during late Devonian times, contemporaneous with continuous metamorphism at lower crustal levels and uninterrupted sedimentation in adjacent synorogenic basins (c.f. Oberc, 1980; Aleksandrowski *et al.*, 1999).

Effects of pre-Late Devonian and Middle-Late Devonian tectonism and exhumation, similar to those recorded in the Sudetic units adjacent to the Góry Sowie Massif, are known from many places in the Variscan Belt. For example, the Middle/Late Devonian exhumation of the KMU was contemporaneous with the cessation of sedimentation in the Barrandian Basin, and the earliest known supply of the Saxothuringian flysch, reflecting the exhumation of the Münchberg crystalline nappes (e.g. Franke, 1998). A record of middle Palaeozoic, i.e. Silurian–Early Devonian high-pressure metamorphism, followed by Early to Late Devonian uplift and the deposition of unconformably-based Middle to Late Devonian overstepping sequences, has also been reported from the Vosges, the north Massif Central and the south Armorican Massif (e.g. Pin, 1990; Faure *et al.*, 1997).

All these phenomena are interpreted as reflecting early to mid Palaeozoic, Eo-Variscan convergence (see e.g. Franke, 1998) which was due to subduction and which may have involved microcontinent/microcontinent or arc/microcontinent collisions (Aleksandrowski *et al.*, 1999).

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