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Famennian, thermally altered chert exotic clasts from the Jędrzychowice/Ludwigsdorf wildflysch (Sudetes) — stratigraphic and tectonic implications

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A wildflysch sequence recently recognized in the Görlitzer Schiefergebirge/western Kaczawskie Mts. boundary zone permits the characterization of the westernmost Kaczawa Unit as a chaotic complex. The cherts, many of which contain numerous radiolarians, occur as exotic clasts within the olistostrome deposits of the wildflysch. They are associated with allochthonous blocks of blueschist, andesite pillow lavas and pyroclastic rocks, flysch facies clastic rocks, mudstones (often of black shale lithology) and carbonates. The conodonts extracted from the grey-greenish radiolarite cherts indicate a mid-Famennian age (Early *rhomboidea* Zone to Early *marginifera* Zone). The conodont-bearing radiolarite clasts reveal no trace of a tectonometamorphic fabric. Their 4–4.5 conodont colour alteration index (CAI) indicates that the rock underwent low-temperature (250–285°C) thermal alteration. The lack of thermal overprint in the olistostrome matrix allows this alteration to be interpreted as a part of the tectonothermal, post-mid-Famennian evolution of the source area. A number of the exotic blocks of unmetamorphosed volcanic rocks associated with the chert exotics seems to indicate igneous (volcanic) activity as the reason for the chert alteration. The fact that exotic blocks of the Devonian chert have been found as clasts within deposits earlier believed to represent Upper Proterozoic (Cadomian) flysch suggests the need for reassessement of the extent of Cadomian rocks in the westernmost Sudetes.

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Key words: Western Sudetes, Viséan wildflysch, cherts, exotic blocks, Famennian conodonts, thermal alteration, tectonostratigraphy.

INTRODUCTION

The rock assemblage dealt with in this paper, described by Wajsprych and Achramowicz (2003) as the Jędrzychowice Unit, is situated in the westernmost part of the Kaczawskie Mts. region, in the Zgorzelec/Görlitz area of the Polish/German border zone. Geologically, the Jędrzychowice Unit is situated in the boundary zone between the Görlitzer Schiefergebirge (Görlitz Complex) and the western Kaczawa Complex (Fig. 1). Its general lithological composition, stratigraphy, low to very low grade metamorphic alteration, and weak penetrative deformation indicate that the Jędrzychowice Unit is part of the Görlitz Complex. However, there are some lithological, stratigraphic and structural similarities between the Jędrzychowice Unit and some parts of the western Kaczawa Complex. This could suggest that the tectonostratigraphic relationships between the Görlitz and western Kaczawa complexes must be more complicated than those thus far postulated (Milewicz *et al*., 1979/1989; Jerzmański, 1982, in Grocholski and Sawicki, 1982; Baranowski *et al*., 1990; Aleksandrowski and Mazur, 2002). Recently, the Jędrzychowice rock unit has been shown to be a wildflysch succession that includes radiolarite, andesite, ophiolite and blueschist material (Wajsprych and Achramowicz, 2003). Therefore, understanding the geology of this unit can contribute significantly to the interpretation of the tectonostratigraphic structure of the entire Lugo-Sudeticum Zone (as defined by Paszkowski *et al*., 1991) of the Central European Variscan Orogen.

Until now, the presence of Upper Devonian cherts in the Jędrzychowice Unit has been inferred from lithological comparisons with the cherts known from the Görlitzer Schiefergebirge, biostratigraphically dated as Upper Devonian (Freyer, 1968). The new data set presented in this paper is concerned with the degree and nature of the Famennian chert alter-

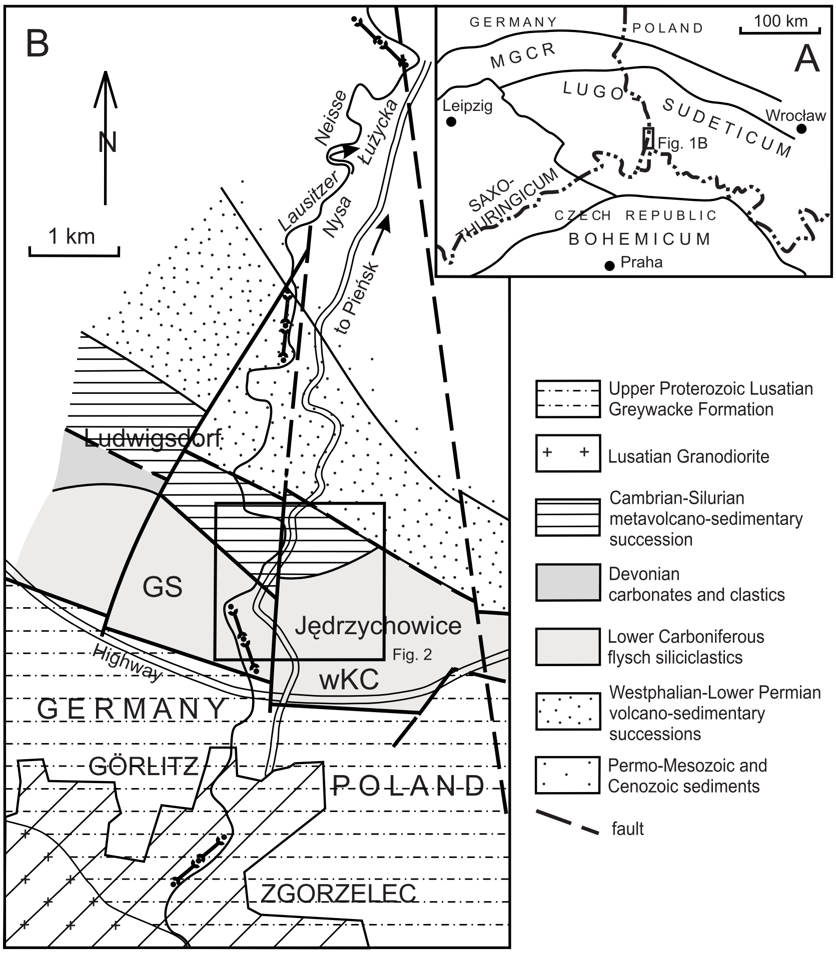

Fig. 1. Tectonic setting of the Jędrzychowice Unit against the tectonostratigraphic structure of the Central European Orogen (A) and detailed location in the West Sudetes region (B) (based on Kozdrój *et al.*, 2001)

GS — Görlitzer Schiefergebirge Complex; MGCR — Mid-German Crystalline Rise; wKC — western Kaczawa Complex

ation. All these data modify the interpretation of the tectonosedimentary and metamorphic evolutions of the Görlitz and western Kaczawa complexes.

Upper Devonian chert clasts have been found in pebble mudstone intercalations situated within siliciclastic turbidite deposits previously referred by Frydrychowicz and Frydrychowicz (1959) to the Upper Proterozoic Lusatian Greywacke Formation. This discovery shows that at least part of the Lusatian Greywacke Formation must be of Early Carboniferous age, and prompt reassessment of the extent of Upper Proterozoic deposits within the Lusatian Formation, and of the relationship between the Cadomian and Variscan orogenic complexes in the westernmost Sudetes.

GEOLOGICAL SETTING

The Jędrzychowice Unit is situated in the boundary zone between the Görlitzer Schiefergebirge and the western Kaczawa complexes. The tectonostratigraphic relationships between the two complexes still remain a subject of debate. Initially, the presence of biostratigraphically documented Upper Devonian shales and Lower Carboniferous flysch deposits within the Görlitz Complex was the main argument for separating the Görlitzer Schiefergebirge as a tectonostratigraphic unit independent from the Kaczawskie Mts. Unit (e.g. Brause and Hirschman, 1970; and references therein), where such rocks were unknown at that time. Therefore, the biostratigraphic (conodont) documentation of the Early Carboniferous (Viséan) age of limestones from the Lubań-Gryfów domain of the western Kaczawa Complex (Chorowska, 1978) and the interpretation of these limestones as olistoliths within the flysch matrix (Chorowska, 1978) have led to the Görlitz and western Kaczawa complexes being considered to be parts of one unit (for review, see Aleksandrowski and Mazur, 2002). On Kozdrój *et al.* (2001) "Geological Map of Lausitz-Jizera-Karkonosze", the Jędrzychowice Unit is a part of the continuous flysch belt that links the Görlitzer Schiefergebirge and western Kaczawa Complex into one litho-tectonostratigraphic unit. Thus, these authors (Kozdrój *et al.*, 2001) interpret this new unit as being composed of two, tectonically separated rock successions: (1) a Lower to Middle Cambrian succession, composed of carbonates (mostly dolomites) and clayey shales (of the Charlottenhof Formation) with basic volcanic and pyroclastic rocks; and (2) a Lower Carboniferous, undivided sequence of greywackes, sandstones, shales, limestones, and conglomerates. Linnemann and Schauer (1999), following some ideas of Thomas (1990), have suggested that the entire Görlitzer Schiefergebirge Unit is composed of a large-scale wildflysch deposits, in which the Cambrian, Ordovician, Silurian and Devonian rocks are allochthonous. However, this suggestion has only been shown on a schematic map (Linnemann and Schauer, 1999, fig. 16) and not documented fully (see also Linneman and Romer, 2002).

More recently, Göthel (2001) interpreted the Görlitzer Schifergebirge Complex as originating from the amalgamation of autochthonous Lower Carboniferous shelf sediments (Förstgen Formation) with an Ordovician to Lower Carboniferous accretionary wedge. He considered the Görlitz Syncline as the Lower Carboniferous mélange deposited in front of the Variscan accretionary wedge that collided with the Cadomian Lausitz Block that in turn was capped by autochthonous shelf sediments. Göthel (2001) suggested the Sproitz-Ludwigsdorf thrust fault system to be the suture between the shelf margin and the accretionary prism.

Wajsprych and Achramowicz (2003) proposed that the Jędrzychowice rock unit is a Lower Carboniferous, probably Lower Viséan, wildflysch-to-flysch succession. According to this concept, all the sedimentary and volcanic rocks older than

Lower Viséan are allochthonous and form olistoliths up to some hundred metres long incorporated into the olistostrome and/or flysch matrix. The results of preliminary studies have shown that the "Lower to Middle Cambrian volcanites and volcanoclastics" of the currently accepted lithostratigraphic scheme for the Görlitz Complex (for review, see Kozdrój *et al.*, 2001; Krentz, 2001), in reality represent a mélange comprising a wide spectrum of intermediate to basic, subaerial to submarine, unmetamorphosed through low-grade to blueschist facies metamorphosed volcanogenic rocks and various sedimentary rocks. Chromite grains found in some clasts of the mélange additionally indicate the presence of ophiolite ultrabasites within their source area. It means that these various lithologies are undoubtedly of different ages. The exotic sedimentary rocks are unmetamorphosed or display contact (as proposed in this paper) and regional, very low-grade to greenschist facies metamorphism. Consequently, volcanic and sedimentary successions of different ages and of different tectonic and geodynamic affinity must have been juxtaposed in the orogenic wedge which subsequently supplied the clastic material to the Jędrzychowice/Ludwigsdorf wildflysch to flysch succession. Accurate data on the age and on the degree and nature of the metamorphic alteration of the chert exotic blocks presented in this paper are of particular significance for tectonostratigraphic and geodynamic reconstructions in this poorly recognized region.

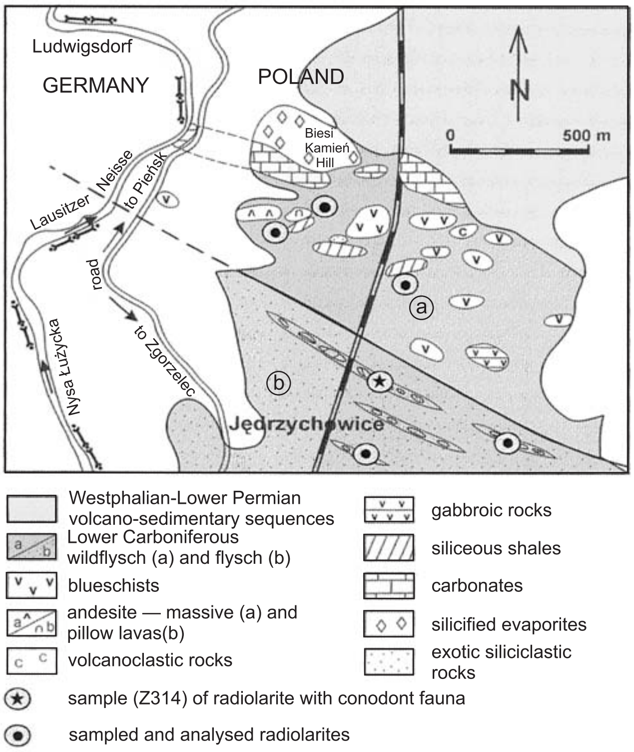

Fig. 2. Geological sketch map of the Jędrzychowie area (after Wajsprych and Achramowicz, 2003) showing sample location

LITHOLOGY AND STRUCTURE

The sedimentary succession described in this paper as the Jędrzychowice Unit (Fig. 2) was formerly considered in the regional geological literature as a stratigraphically coherent succession of weakly deformed and unmetamorphosed to slightly metamorphosed volcano-sedimentary deposits of Cambrian to Early Devonian (Frydrychowicz and Frydrychowicz, 1959) or Late Devonian age (as inferred from comparisons with lithologies of the Görlitzer Schiefergebirge: Berezowski and Chorowska, 1966). Generally, the Jędrzychowice Unit is composed of volcanic and sedimentary rock suites of very diverse lithological composition (Fig. 2). The volcanic rocks dominate in the northeastern part of the unit, where, together with shales and carbonates from the Biesi Kamień Hill, they have been described as the easternmost continuation of the Lower to Middle Cambrian Charlottenhoff Formation of the Görlitzer Schiefergebirge (Frydrychowicz and Frydrychowicz, 1959; Kozdrój *et al.*, 2001). The discovery of basalt clasts, metamorphosed to blueschist-facies, associated with low-grade to unmetamorphosed volcanic rocks (mostly of andesitic composition) and various chert and flysch-dominated sedimentary rocks (Wajsprych and Achramowicz, 2003) indicates a sedimentary mélange origin for this rock association, comprising as it does an assemblage of large allochthonous rock fragments. Its total thickness can be estimated at *ca.* 600 to 800 m.

In the central part of the Jędrzychowice Unit, the succession analysed is dominated by finer-grained olistostromes. The thickness of individual olistostrome layers here does not exceed some tens of metres. Olistoliths recognized within this part of the succession are several metres long and no more than 2–3 m thick. The number and thickness of the olistostrome intercalations decrease to the south, and the succession grades laterally to a purely turbiditic one, that shows a fining upwards trend. The olistostrome-bearing part of this succession is estimated to be at least 300–350 m thick.

Turbidite clastic deposits devoid of olistostrome intercalations form the southern part of Jędrzychowice Unit which is situated between the Jędrzychowice and the northern periphery of Zgorzelec (Fig. 1). These fine- to medium-grained greywackes display grading, often demonstrated by the gradual transition from fine-grained sandstone to siltstone and claystone (A, B to D/E Bouma's intervals). More detailed sedimentological descriptions of the turbiditic succession await, but it can be provisionally described as a fine- to medium-grained, siltstone-dominated flysch. There are no essential structural and petrographic differences between the parts of the flysch succession that do and do not contain olistostrome interbeds, indicating that the entire flysch sequence is one lithostratigraphic entity.

The small number of exposures leaves open the question of the stratigraphic relationships between the successions described above. Although the graded bedding shows that the strata are the right way up across the Jędrzychowice Unit, the presence of late small open folds prevents a full reconstruction of the succession. Generally, the Jędrzychowice/Ludwigsdorf succession can be interpreted as a fining-upwards, wildflysch-to-flysch succession (Wajsprych and Achramowicz, 2003).

LITHIC COMPOSITION

Individual allochthonous blocks with the mélange from the northern part of the Jędrzychowice Unit reach relatively large sizes (up to 350–400 m in length and some tens of metres of thick). One of the largest mapped blocks, exposed in a small, abandoned quarry, is composed of blueschist grade meta-basalt (Wajsprych and Achramowicz, 2003; Achramowicz and Wajsprych, 2004*a*). Detailed mapping indicates that some other lithologies, such as andesite pillow lavas, siliciclastic rocks of more or less arenitic/arkosic to greywacke composition, black shales, carbonates and various cherts, also form relatively large blocks or slabs within the described mélange (Fig. 2). Moreover, as mentioned above, the detrital chromite grains found within the siliciclastic sediments of the mélange matrix record the presence of ophiolite ultrabasites in the source area. The reinterpretation of a large-scale quartz vein (Śliwa, 1967) from the Biesi Kamień Hill as a totally silicified and thermally altered evaporite sequence, primarily composed mostly of selenite to salt deposits of unknown age (Wajsprych and Achramowicz, 2003, 2004; Achramowicz and Wajsprych, 2004*b*), suggests that evaporites are an additional lithic component of the described mélange, though this interpretation needs confirmation.

The olistostrome deposits of the central part of the Jędrzychowice Unit are dominated by exotic sedimentary rocks, as regards both the detrital material of their matrix and the olistoliths. The matrix is usually composed of dark grey to black, weakly laminated to massive mudstones (up to 60 vol.% and more) and very fine-grained, quartz-rich dark grey sandstones. In some clasts of the laminated black mudstone, radiolarians (probably of Silurian-Devonian age) were noted. Clasts of strongly altered, acid and more basic volcanic rocks are also present, although their content does not exceed a few percent of the total volume of the matrix. Dark grey and greenish-grey cherts were also found, but mostly as larger clasts (several centimetres to some tens of centimetres across). Field observations revealed some larger concentrations of chert clasts within the weathered cover, probably marking the presence of, two- to three-metre long, slab-like olistoliths of -greenish, probably Devonian cherts. A similar greater concentration of bioclastic limestone clasts suggests the presence of larger, slab-like limestone olistoliths. Recent field studies indicate the presence of a relatively large (50–60 m in diameter), weakly exposed blueschist basalt body as a slab-like olistolith, situated in the uppermost part of the olistostrome-dominated part of the succession.

BIOSTRATIGRAPHY

All the chert samples that provided biostratigraphic data were collected from the lager clasts or slabs. These were found within one of the thickest olistostrome beds, situated at the top of the turbidite-olistostrome sequence of the Jędrzychowice succession. The rock is a grey-greenish, thinly bedded, locally weakly laminated siliceous shale. Under a microscope, all the samples examingreyed of this rock display a fine-grained, microcrystalline texture. No traces of tectonic or metamorphic alteration were recognized, both at meso- and microscopic scale. Commonly observed radiolarians form perfectly spherical (undeformed) structures.

Conodonts were extracted from a greenish-grey radiolarian chert sample 0.15 kg in weight (sample Z 314). The chert sample was treated several times for 10 to 20 minutes in 40% HF. The conodonts obtained by this processing technique were poorly preserved. Only a few small specimens, less than 1 mm in size, could be identified, while larger, adult specimens were, as a rule, incomplete and usually visible on the rock surface.

For the biostratigraphic analysis, only platform elements were utilized (Fig. 3). Among them, fragments of long, slender platforms with the shagreen-like surface of *Palmatolepis* dominated. The platform features observed in the fragments are characteristic of the Upper Devonian (Famennian) *prima* group. The stratigraphic ranges of the taxa identified were determinated after Ziegler and Sandberg (1990) and Ji and Ziegler (1993).

The chert clasts analysed yielded specimens of:

Palmatolepis ex.gr. *glabra*
Palmatolepis glabra cf. *pectinata*
Palmatolepis cf. *rhomboidea*
Palmatolepis spp. indet.
Polygnathus spp. indet.

The conodont taxa listed above suggest an interval from the Early *rhomboidea* Zone to the Early *marginifera* Zone, which represents the middle part of the Famennian (Fig. 4). According to established conodont biofacies models (Sandberg, 1976; Sandberg *et al*., 1988), the dominance of *Palmatolepis* indicates a pelagic origin of the chert.

The conodonts found are housed at the Institute of Geological Sciences of the University of Wrocław under the sample collection No. ING/H. Z 314.

THERMAL ALTERATION

All the conodonts extracted from the samples analysed are black to dense black. According to the conodont alteration index (CAI) scale proposed by Rejebian *et al*. (1987) and Jones (1992), this represents a CAI value of about 4.5 to 5. However, the conodonts recovered from the cherts by use of HF have CAI values of about half a unit higher than those dissolved from carbonates with acetic acid (see Belka, 1993; Legal *et al*., 1982; Haydukiewicz, 2002). Thus, a CAI value of 4 to 4.5 seems to best represent the degree of transformation of the conondonts described in this paper.

This CAI suggests very low grade, either regional or contact, metamorphism as a possible cause of the thermal overprint. Temperatures had to be generally below 300°C or about 250 to 285°C, according to the temperature ranges proposed in the models of Epstein *et al*. (1977), Rejebian *et al*. (1987) and Jones (1992), respectively.

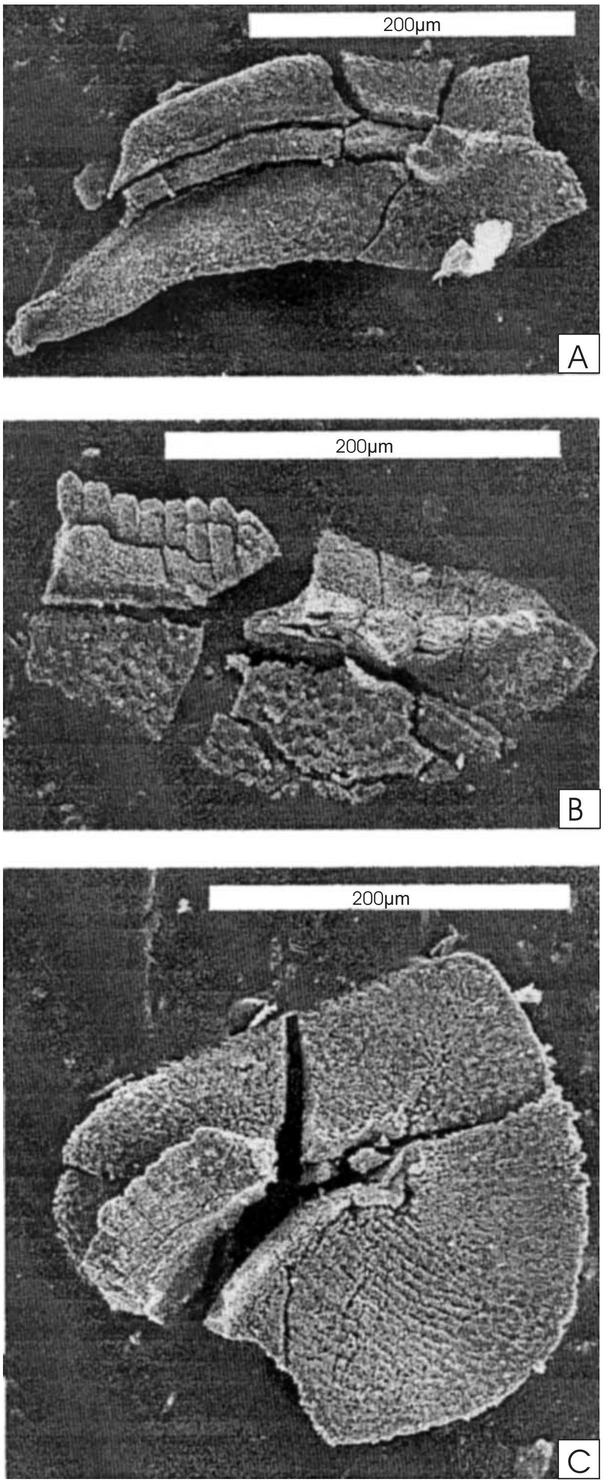

Fig. 3. Conodonts obtained from sample Z314

A — *Palmatolepis glabra* cf. *pectinata* Ziegler, 1962, **B** — *Palmatolepis* ex.gr. *glabra*, **C** — *Palmatolepis* cf. *rhomboidea* Sanneman, 1955

DISCUSSION

The lithic composition of the exotic rock material of the Jędrzychowice/Ludwigsdorf wildflysch to flysch succession is very diverse. The distribution of this detrital material shows some characteristic changes through the profile of the succession. In the wildflysch, olistostrome-dominated part of the succession, volcanic and sedimentary rocks are prevalent, while the flysch deposits are composed mostly of siliciclastic material.

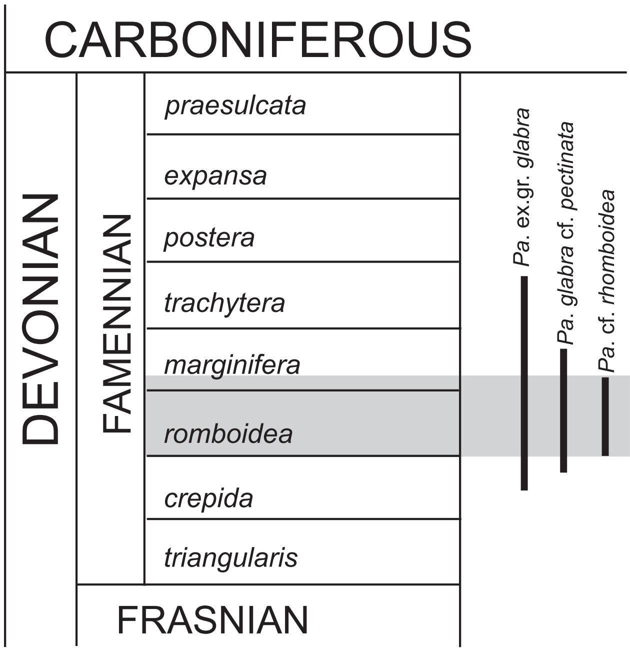

Fig. 4. Fammenian conodont zonation and the stratigraphic range of the identified taxa

Pa. — *Palmatolepis*

The sedimentary exotics in the Jędrzychowice wildflysch are essentially unmetamorphosed. However, the data presented in this paper indicate that the middle Famennian greenish-grey radiolarian cherts, found as allochthonous slabs, are thermally altered. The CAI, estimated here at 4–4.5, indicates low temperature (250–285°C) thermal alteration. Field observations and the preliminary results of petrographic studies show that the olistostrome and flysch matrix is generally devoid of such a thermal overprint (Wajsprych and Achramowicz, 2003). A significant number of clasts derived from volcanic rocks suggests that volcanic activity may have provided, besides regional metamorphism, the source of heat responsible for the chert alteration.

Besides the middle Famennian cherts discussed in this paper, the succession that supplied material to the olistostrome had to contain other sedimentary material, such as black shale and various, mostly quartz-rich clastics. The black shale lithologies are abundant in the clastic material of the olistostrome matrix. They are mainly represented by black mudstone and claystone as well as by some dark grey to black, fine-grained, quartz-rich siliciclastic rocks (Wajsprych and Achramowicz, 2003). The pelitic facies commonly contain radiolarians. The age of the black shale has not yet been biostratigraphically determined. However, the lithological composition and some characteristic features, such as the presence of radiolarians and Mn-Fe concretions, allow this black shale to be compared to the middle Tournaisian (Tn3a — according to Haydukiewicz, 1981; and Tn2c — according Chorowska *et al.*, 1992) Gołogłowy Formation of the Bardo Mts. rock succession the Central Sudetes (Wajsprych, 1986).

The abundance of radiolarians within all the chert and black shale exotic blocks examined suggests a deep water environment of their deposition. This conclusion is consistent with some biofacies features of the chert. As noted above, the conodonts of the middle Famennian cherts are dominated by palmatolepids, which, according to the conodont biofacies models of Sandberg (1976) and Sandberg *et al*., (1978), indicates deep water, pelagic depositional environments for these rocks.

The Famennian age of the chert exotics described confirms a generally Early Carboniferous age for the western Kaczawa wildflysch, as proposed earlier by many geologists working in this region (for review see Wajsprych and Achramowicz, 2003). There is, however, no data to correlate this wildflysch with the Upper Viséan wildflysch succession from Rząsiny in the central part of the western Kaczawa Unit (Chorowska, 1978). The clasts of black shale and fine-grained sandstone abundant in the Jędrzychowice wildflysch matrix probably represent the youngest exotic material (Wajsprych and Achramowicz, 2003). If so, the Tournaisian-Viséan boundary interval or the early Viséan is a possible time span for the wildflysch deposition. A similar tectonostratigraphic position has been proposed for the chaotic deposits recently identified at the base of the Lower Viséan Nowa Wieś Formation of the Bardo Mts. succession in the Central Sudetes (Wajsprych, 1997). This finding may help to guide future comparative studies of the tectonostratigraphic correlation of the chaotic deposits of Lugo-Sudeticum.

Another important aspect of the investigations reported in this paper concerns the large-scale tectonostratigraphic structure of the Lugian, western Kaczawa Complex, part of the Lugo-Sudeticum (according to a definition proposed by Paszkowski *et al.*, 1991). One of the characteristic, tectonostratigraphic features of the thus defined Lugian domain is the presence of two, Cadomian (Upper Proterozoic) and Variscan (Lower Carboniferous), flysch successions. The problem is how to discriminate between these two succession. The area of the Jędrzychowice Unit and its southern neighbourhood, the latter composed of the Precambrian Lusatian Granodiorite (Fig. 1) and the Izera Lower Ordovician Gneiss, typifies this problem. The conodont-proved Famennian age of the chert clasts from the flysch deposits is not consistent with the portrayal of these rocks on the geological map of Frydrychowicz and Frydrychowicz (1959) as the Upper Proterozoic Lusatian Flysch Formation. Kozdrój *et al*. (2001) shifted, on their map, the boundary between the Upper Proterozoic and Lower Carboniferous successions to the south, relative to the map of Frydrychowicz and Frydrychowicz (1959). The problem however is that the whole of the flysch succession cropping out in the Zgorzelec region is lithologically and petrographically (quartz-rich subgreywackes) uniform and seems to represent one sequence. Accordingly, the problem of discrimination between the two flysch successions and delineation of their boundary remains open. The biostratigraphic data, reported on in this paper, are a first step towards the solution of this problem.

CONCLUDING REMARKS

The data presented in this paper prove middle Famennian (*rhomboidea to* Early *marginifera* Zone) age for the thin-bedded, grey-green, radiolarian-rich chert, found as exotic sedimentary clasts in the Jędrzychowice/Ludwigsdorf wildflysch (Fig. 4). This suggests an Early Carboniferous age for the sedimentary rock succession (Jędrzychowice Unit) from the boundary zone between the Görlitzer Schiefergebirge and the western Kaczawa Complex.

The conodonts extracted from chert samples are thermally altered, though the rock does not bear any traces of a metamorphic fabric. The CAI has been estimated at 4.0–4.5, which records the low thermal alteration state of the rock (generally below 300°C or 250–285°C, according to models of Epstein *et al*., 1977; Rejebian *et al*., 1987; Jones, 1993, respectively).

The identification of the Famennian age of the chert exotics from the siliciclastic sequence formerly defined as the Upper Proterozoic, Cadomian flysch (the Lusatian Greywacke Formation) re-opens the question concerning the extent of the Cadomian succession in the West Sudetes (Wajsprych and Achramowicz, 2003).

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