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Middle to early late Viséan onset of late orogenic sedimentation in the Intra-Sudetic Basin, West Sudetes: miospore evidence and tectonic implication

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Abstract The Early Carboniferous fluvial and deltaic sequence of the Intra-Sudetic Basin remained undated until recently, except for a Late Viséan ammonoid fauna in its upper part. Current miospore data indicate that the oldest part of the sequence is not older than the mid Viséan *Knoxisporites triradiatus–Knoxisporites stephanephorus* biozone of the west European miospore division. This palynological age determination is consistent with the recently obtained Ar–Ar cooling ages of white micas from sheared metamorphic rocks at the NW margin of the basin. This suggests that the rapid late orogenic denudation of the northern and western flanks of the Intra-Sudetic Basin must have started at or shortly after c. 335 Ma.

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INTRODUCTION

The Intra-Sudetic Basin, situated in the central part of the Variscan West Sudetes, contains Early Carboniferous through to lower Triassic deposits, overlain by Late Cretaceous strata. The overall thickness exceeds 10 km (Fig. 1). During the Early Carboniferous (Dinantian), fluvial and deltaic cyclic sedimentation accumulated a sequence of conglomerates and sedimentary breccias with subordinate sandstones and shales, which locally attain a thickness of 6.5 km (Teisseyre, 1975; Dziedzic & Teisseyre, 1990). These sediments were laid down in a narrow, NW-trending, mostly fault-bounded intramontane basin of c. 65 km length and 25 km width. Drainage was directed toward the sea in the SE. Intercalations of marine shales and conglomerates with Goα fauna near the top of the sequence in the NE part of the basin document NW-ward ingressions of the sea in late Viséan times. The underlying, main part of the sequence was hitherto undated. The lower part of the sequence has tentatively been assigned to the late Tournaisian or early Viséan (Teisseyre, 1975; Mastalerz & Prouza, 1995). This uncertainity has hampered tectonic reconstructions of the West Sudetes during the time of the Variscan collision. We have, therefore, sampled fine-grained siltstone/greywacke interbeds in the coarse-grained lower Carboniferous sequence for palynological dating.

GEOLOGICAL SETTING

The oldest part of the fluvial sequence is exposed in the NW part of the Intra-Sudetic Basin, where it is flanked by metamorphic units of the East Karkonosze, Góry Kaczawskie, and Góry Sowie Block (Fig. 1), and mostly separated from the crystalline basement by brittle normal fault contacts (Teisseyre, 1975). Provenance studies show that clastic material in the fining-upward cyclothems was persistently derived from the metamorphic units in the NW (Żakowa, 1963; Teisseyre, 1975; Felicka, 2000; Kulczyński *et al.*, 2001). Almost all the lithological types now exposed in the source areas are recognizable within the clast spectrum, although their contents change laterally and vertically. The outcrop pattern in the source areas varied with time, as did the availability of given litholo- - gies to tectonically enhanced erosion. There are few lithological types seen today at the surface in the East Karko-

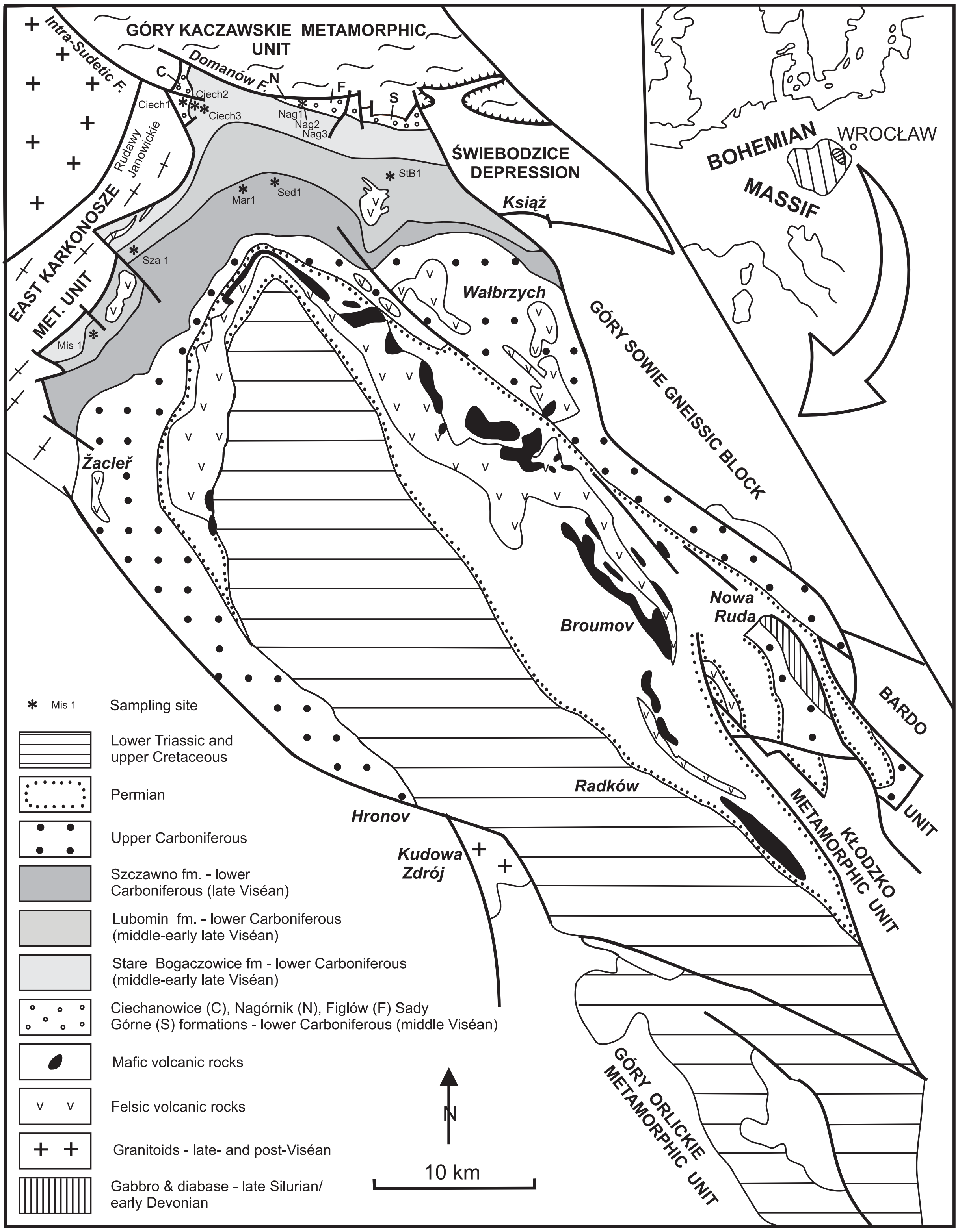

Fig. 1. Geological sketch of the Intra-Sudetic Basin with location of samples.

nosze which are not represented among the clasts in the palaeofans deposited at their ancient foothill, and indeed some are known only from pebbles. Normal faults partly separating the metamorphic basement from the overstep sediments were repeatedly rejuvenated, and were active at the time of their deposition and afterwards. In the NW part of the Intra-Sudetic Basin, the bedding planes of these sediments dip toward the centre of the basin where the strata are thickest. The Intra-Sudetic Basin has been interpreted as an intramontane depression bounded by normal faults and connected with a Carboniferous–Permian volcanic centre which developed underneath it (Teisseyre, 1975; Dziedzic & Teisseyre, 1990; Awdankiewicz, 2000). A pull-apart origin of the basin has also been proposed, linking its origin with dextral strike-slip activity and expected yet unconstrained large-scale displacements on the Intra-Sudetic Fault (Aleksandrowski, 1995; Aleksandrowski *et al.*, 1997; Franke & Żelaźniewicz, 2000).

In the South Krkonoše[1], Ar-Ar studies dated the end of blueschist metamorphism and the widespread greenschist overprint at c. 360 Ma and 340 Ma, respectively (Maluski & Patočka, 1997). Based on the extensive Ar-Ar studies, Marheine *et al.* (2002) concluded that the regional greenschist metamorphism and associated shearing occurred in the Izera–Karkonosze block, and indeed in the whole West Sudetes, between 344 and 333 Ma. In the East Karkonosze adjacent to the Intra-Sudetic Basin (Fig. 1), the sheared quartzite and metaporphyroid samples yielded Ar-Ar ages of 336±6 Ma and 334±6 Ma. Because biotite and muscovite ages are similar in these rocks, the relatively rapid cooling is inferred (Marheine *et al.*, 2002).

The isotopic data imply that the base of the extensive fluvial sequence in the Intra-Sudetic Basin is not older than 335 Ma, which translates into late middle Viséan times (according to the time-scale of Menning *et al.*, 2000). This inference is consistent with the map analysis and the results of provenance studies, which indicate that the orogenic stacking of tectonic units in the West Sudetes into the presently observed architecture preceded the onset of clastic sedimentation in the Intra-Sudetic Basin. In view of these facts, the hitherto assumed supposition (Teisseyre, 1975; Dziedzic & Teisseyre, 1990) of the Tournaisian or early Viséan onset of the extensive fluvial sedimentation in the basin seems to need correction.

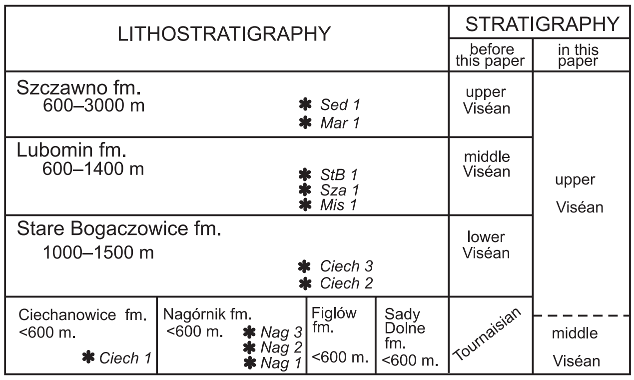

Fig. 2. Lithostratigraphic column of the lower Carboniferous deposits in the Intra-Sudetic Basin (after Teisseyre, 1975; Dziedzic & Teisseyre, 1990), with location of samples and stratigraphy revised according to the results of this study.

LITHOSTRATIGRAPHY

The lithostratigraphic scheme of the lower Carboniferous portion of the fluvial sequence was based on lithological and palaeogeographic criteria (Żakowa, 1958, 1963; Teisseyre, 1975; Nemec *et al.*, 1982; Dziedzic & Teisseyre, 1990; Mastalerz & Prouza, 1995). The base of the sequence is exposed (Fig. 1, 2) along the northern boundary fault of the Intra-Sudetic Basin against the Góry Kaczawskie Mts., with the oldest sediments located in the western part of the basin at the junction with the East Karkonosze (Rudawy Janowickie Mts.). They were deposited in a narrow (c. 3–4 km wide) graben bounded by W- to NW-trending normal faults. From the west to the east, the Ciechanowice, Nagórnik, Figlów and Sady Górne formations were discerned as lateral equivalents, each up to 600 m thick (Fig. 1, 2). The clastic material to fanglomerates of the three western formations was transported over a short but unestimated distance, while that of the eastern Sady Górne fm. covered a longer distance, estimated at c. 10–20 km (Dziedzic & Teisseyre, 1990). These four lowermost and outermost units were covered by the 1000–1500 m thick Stare Bogaczowice formation of sedimentary breccias, conglomerates, subgreywackes and mudstones; it was deposited in fans coalescent toward the centre of the basin (located to the S and SE). These fans, overgrown with forest (*Lepidodendron, Asterocalamites*), were disposed along the northern and western margins of the Intra-Sudetic Basin which underwent uplift with respect to the subsiding basin floor in the centre of the basin (Teisseyre, 1975; Dziedzic & Teisseyre, 1990). The overlying Lubomin formation is composed of 600–1400 m thick succession of conglomerates and sandstones to mudstones, whereas the uppermost Szczawno formation developed as 600–3000 m thick conglomerates, sandstones, mudstones and siltstones with marine interbeds containing late Viséan goniatite (Goα) fauna (Żakowa, 1958, 1963). All the formations are characterized by the presence of upward fining cyclothems (more than 20) controlled by both episodic normal faulting and climatic factors (Teisseyre, 1975).

MIOSPORE STRATIGRAPHY

MATERIAL EXAMINED

We have collected and examined nine samples from all pre-Namurian formations, and at seven locations in the NW part of the Intra-Sudetic Basin. The sample positions in the region and in the stratigraphic section are indicated in Figures 1 and 2. All the samples were taken from thin intercalations of fine-grained sandstones, mudstones and

1 The Karkonosze Mts. are shared between Czech Republic and Poland. The Czech spelling of the range's name is Krkonoše, whereas the Polish spelling is Karkonosze.

Table 1

Chronostratigraphy and miospore stratigraphy of the Lower Carboniferous of the British Isles; the position of the *Goniatites crenistria* ammonoid Zone is also shown (after Riley, 1993). Isotopic ages after Menning *et al.* (2000)

AGE Ma	STAGE	REGIONAL STAGE	MIOSPORE BIOZONE
325	VISÉAN	BRIGANTIAN	*B. nitidus - R. carnosus* NC (part)
	VISÉAN	BRIGANTIAN	*T. vetustus - R. fracta* VF
			(*Goniatites crenistria*)
330	VISÉAN	ASBIAN	*R. nigra - T. marginatus* NM
	VISÉAN	ASBIAN	*P. tessellatus - S. campyloptera* (TC)
335	VISÉAN	HOLKERIAN	*K. triradiatus - K. stephanephorus* TS
	VISÉAN	ARUNDIAN	*L. pusilla* Pu
340	VISÉAN	CHADIAN U.	*L. pusilla* Pu
	TOURNAISIAN	CHADIAN L.	*S. claviger - A. macra* CM
345	TOURNAISIAN	COURCEYAN	*S. claviger - A. macra* CM
350	TOURNAISIAN	COURCEYAN	*S. pretiosus - R. clavata* PC
	TOURNAISIAN	COURCEYAN	*S. balteatus - R. polyptycha* BP
	TOURNAISIAN	COURCEYAN	*K. hibernicus - U. distinctus* HD
355	TOURNAISIAN	COURCEYAN	*V. verrucosus - R. incohatus* VI

Grey band: *Goniatites crenistria*

siltstones occurring within thick beds of coarse clastic rocks. The Ciechanowice formation was sampled (Ciech 1, mudstone) at the railway cutting in the village of Ciechanowice. Samples Nag 1 (mudstone), Nag 2 (mudstone) and Nag 3 (fine-grained sandstone) came from the Nagórnik formation, exposed at a creek-bed in the village of Nagórnik. The Stare Bogaczowice formation was sampled 500 m SE of Ciechanowice (Ciech 2, siltstone) at the railway bridge, and 400 m further to SE at the cliff along the rail track (Ciech 3, mudstone). The Lubomin formation was sampled at the forested cliff 500 m NW of the church in the village of Miszkowice (Mis 1, fine-grained sandstone of a shadow bar wedge behind boulders in a coarse debris flow), at a road-cutting on the W slope of the Mrowica Hill 2 km S of the village of Stare Bogaczowice (StB 1, sandy mudstone), and at an old railway cutting 200 m N of the village of Szarocin (Sza 1, fine-grained sandstone). Two samples were collected from the Szczawno formation. These are: sample Mar 1 (sandy mudstone), taken at a guarded railway crossing along the road from Marciszów to Dębrznik, and sample Sed 1, collected from mudstone in an old quarry N of the village of Sędzisław on the road to Zimna Woda.

Samples were processed by standard techniques (Wood et al., 1996). Three of the samples (Ciech 1, Ciech 2 and Nag 1) did not contain any recognizable palynomorphs. The miospore assemblages obtained from the remaining six samples were closely examined, although they were extremely poor in specimens and taxa, and the palynomorphs were strongly corroded. Some determinations are tentative, and in a few cases, only generic assignments were possible.

MIOSPORE ZONATION

The Tournaisian and Viséan miospore successions are best documented in the British Isles. The zonal scheme for this region was created by Neves *et al.* (1972, 1973) and subsequently refined by the studies of Clayton, 1985; Higgs *et al.*, 1988a. It now comprises eleven zones. The scheme is keyed to the British Isles Carboniferous stages (Higgs *et al.*, 1988b; Riley, 1993) (Table 1).

The knowledge of the contemporaneous miospore successions from Poland is less detailed. The Tournaisian and early to middle Viséan assemblages are almost exclusively known from western Pomerania (Turnau, 1979; Matyja *et al.*, 2000), and the latest Viséan ones have been recorded from various parts of Poland (see the review by Kmiecik, 1995). Tournaisian and Viséan assemblages have been also described from western Europe, the Czech Republic and Romania. In spite of the more fragmentary evidence in the continental sections, the composition of the spore assemblages and the sequence of first appearance are the same as in the British Isles. Therefore, the British miospore zonal scheme can be applied to sections in western and central Europe.

AGE OF THE MIOSPORE ASSEMBLAGES

The distribution of taxa in the examined samples is shown in Table 2, and the stratigraphically important ones are illustrated in Figure 3.

The richest sample was Nag 2. It contained, among other taxa, *Vallatisporites ciliaris* (Luber) Sullivan, *Densosporites* cf. *variabilis* (Waltz) Potonie et Kremp, and *Verrucosisporites nitidus* Playford. In the British Isles, *V. ciliaris* first appears in the upper part of the (old) *Lycospora pusilla* (Pu) Zone (Neves *et al.*, 1973; Clayton *et al.*, 1977), subsequently defined as the *Knoxisporites triradiatus—Knoxisporites stephanephorus* (TS) Zone (Clayton, 1985). It is only in Scotland, that Mahdi & Butterworth (1994) have recorded this species from the (new) Pu Zone. *Densosporites* is also one of the taxa which in the British Isles appear for the first time in the TS Zone (Turnau *et al.*, 1997). *Verruco-*

sisporites nitidus is an important latest Famennian and Tournaisian species which ranges into the Viséan, to the top of the TS Zone (Neves *et al.*, 1972).

Other samples (Fig. 3) contained *Microreticulatisporites* sp. and *Waltzispora* sp. *Microreticulatisporites*, represented by several species, is common in the latest Viséan (Clayton *et al.*, 1977), and is not rare in the *Perotrilites tessellatus—Schulzospora campyloptera* (TC) Zone (Sullivan, 1964), but its range has not been precisely established. *Waltzispora* is first noted in the TS Zone (Carson & Clayton, 1997).

Only five samples (Table 1) contained *Lycospora pusilla* (confidently determined only in two samples). Traditionally, the base of the *Lycospora pusilla* (Pu) Zone, defined by the first appearance of this species, has been used to recognize the base of the Viséan in many parts of the world (Turnau *et al.*, 1997). Within its lowermost stratigraphical range, *L. pusilla* is rare but in most higher Viséan assemblages this species together with *L. noctuina* Butterworth et Williams are common or very common. So, the poor representation of *Lycospora* in the discussed assemblages may seem surprising but explanation of this fact is simple enough. As was mentioned earlier in this paper (see the section 'Material examined') the preservation of the assemblages studied is very poor, and *Lycospora* is a thin-walled miospore displaying a bizonate flange with a most delicate outer part. When this part is destroyed, neither specific nor generic assignment of the specimens is possible.

It may be thus supposed that the miospore assemblages discussed above, with the exception of those from Nag 3, Mar 1 and Ciech 2, which do not contain confidently identified taxa of stratigraphic importance, are not older than the TS Zone of Holkerian age. The palynological data do not permit a confident determination of the upper age limit, because the taxa discussed above range up into the Serpukhovian and even Pennsylvanian. Only *V. nitidus* is known not to extend above the TS Zone (Neves *et al.*, 1972), but only one specimen of this species was found in Nag 2, and a conclusion based on such evidence is not particularly sound. Marine ingressions in the lower part of the Szczawno Formation are dated on goniatites as belonging to the *Goniatites crenistria* Zone (Żakowa, 1958, 1963; Table 1). This Zone spans the boundary between the *Raistrickia nigra-Triquitrites marginatus* (NM) and *Tripartites vetustus-Rotaspora fracta* (VF) zones (Riley, 1993). Therefore, the rocks resting below the marine horizon are not younger than the NM Zone.

Table 2

Distribution of miospore taxa in the studied samples

Species \ Sample	Mis 1	Sed 1	Mar 1	Nag 2	Nag 3	StB 1	Sza 1	Ciech 2
Neoraistrickia sp.	+	+	+					
Leiotriletes sp.	+	+		+	+	+		
Lycospora pusilla	+	?	?			+		?
Waltzispora sp.	+	+			+	+	+	
Stenozonotriletes sp.	+							
Microreticulatisporites sp.		+		+	+	+		
Granulatisporites sp.		+				+		
Vallatisporites ciliaris				+				
Densosporites cf. *variabilis*				+				
Verrucosisporites nitidus				+				
Raistrickia sp.					+			
Verrucosisporites sp.					+	+		
Anaplanisporites baccatus						+		
Densosporites sp.						+		
Acanthotriletes sp.				+				

DISCUSSION OF REGIONAL IMPLICATIONS

Our new miospore data show that the sedimentation of the Carboniferous extensive fluvial sequence in the Intra-Sudetic Basin started in mid or early-late Viséan times, i.e. in the Holkerian at 336–333 Ma or in the Asbian at 333–330 Ma (see Table 1; isotopic ages after Menning *et al.*, 2000). The palynological age determination is consistent with the Ar-Ar isotopic mica datings from the northwestern flanks of the basin. Both suggest that the rapid uplift and extensive erosion at the source areas must have been younger than c. 335 Ma, which is consistent with the Ar-Ar data of Marheine *et al.* (2002) indicating that the regional greenschist facies metamorphism related to nappe thrusting occurred in the whole Izera–Karko- nosze Block within the interval of 344–333 Ma and was followed by the localized uplift-related shearing and faulting at 324–320 Ma. More detailed control on the relationship between metamorphism, subsidence and sedimentation is to be obtained by further datings of rocks from both the clasts in the basin and the identified source.

The combined isotopic and miospore data indicate that the main collisional activity and tectonic stacking in the West Sudetes terminated during the middle Viséan and was followed by the rapid late orogenic denudation in late Viséan times. The mid/early late Viséan fluvial deposits of the late orogenic Intra-Sudetic Basin overstepped the Sudetic allochthonous units that had been accreted to the Bohemian terrane before the end of the Devonian, and subsequently became metamorphosed and thrust NW-wards onto the Saxothuringian foreland (Franke & Żelaźniewicz, 2000; Mazur & Aleksandrowski, 2001) during early to middle Viséan times.

The miospore age data do not solve the question of the origin of the Intra-Sudetic Basin. Combined with the isotopic ages, however, they add to the tectonic, sedimentological, petrological and isotopic data used to discuss whether the Viséan extensive clastic fluvial sequence started to be deposited in an intramontane depression controlled by the normal faulting at its margins and coeval volcanic activity, or in an expanding pull-apart basin controlled by the regional major strike-slip faulting on the

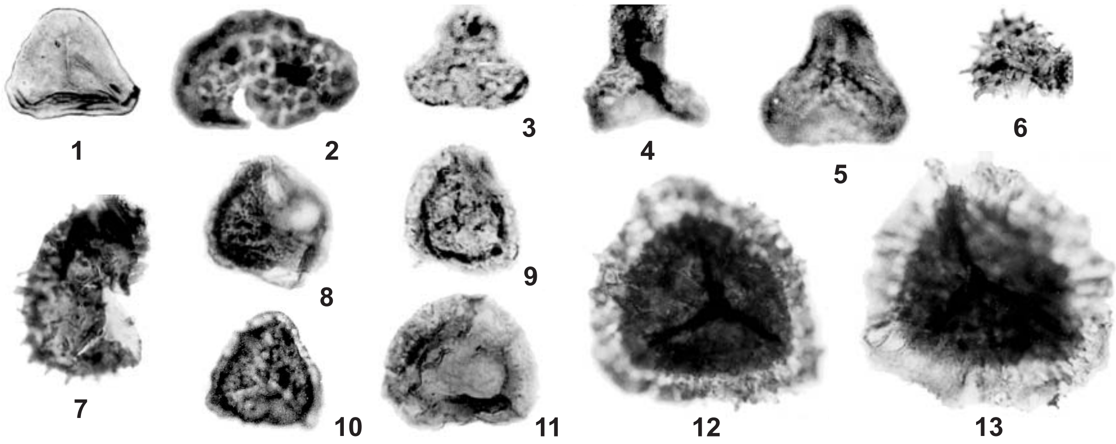

Fig. 3. Viséan miospores from the Nagórnik, Lubomin and Szczawno formations. 1 – *Leiotriletes* sp. in sample Nag 2; 2 – *Verrucosisporites nitidus* Playford in sample Nag 2; 3 – *Waltzispora* sp. in sample StB 1; 4 – *Waltzispora* sp. in sample Sed 1; 5 –*Microreticulatisporites* sp. in sample Nag 2; 6 – *Acanthotriletes* sp. in sample Nag 2; 7 – *Raistrickia* sp. in sample Mis 1; 8 – *Lycospora pusilla* Ibrahim in sample Mis 1; 9 – *Lycospora pusilla* Ibrahim in sample StB 1; 10 – *Lycospora pusilla* Ibrahim in sample Mis 1; 11 – *Densosporites variabilis* (Waltz) Potonie et Kremp in sample Nag 2; 12 and 13 – *Vallatisporites ciliaris* (Luber) Sullivan in sample Nag 2.

Intra-Sudetic Fault (Teisseyre, 1975; Dziedzic & Teisseyre, 1990; Aleksandrowski, 1995; Aleksandrowski *et al.*, 1997; Awdankiewicz, 2000; Felicka, 2000; Franke & Żelaźniewicz, 2000; Kulczyński *et al.*, 2001). It is to be emphasized that the faults bounding the basin to the north and west are only normal. The brittle deformation which started on the normal Domanów Fault zone (Fig. 1) in Holkerian–Asbian (mid/lateViséan; Table 1) times (< 333 Ma) corresponded neither temporally nor structurally to the medium-T ductile dextral shearing at 339 ± 3 Ma along the Intra-Sudetic Fault (Marheine *et al.*, 2002). The four lowermost formations of the Viséan fluvial sequence, arranged in a line along the Domanów Fault zone, are stratigraphically lateral equivalents deposited at the footwall in a normal fault regime. They are not an array of sequentially developing alluvial fans in response to the displacement of the basin margin along a strike-slip fault, which is consistent with the lack of evidence for any change in the relative position of the source areas in the Góry Kaczawskie with respect to the accumulation centres in the basin (Aleksandrowski, 1995; Aleksandrowski *et al.*, 1997). The continued activity on the Domanów Fault zone in times younger than Holkerian–Asbian was coeval with further movements on the Intra-Sudetic Fault zone matched by Ar-Ar ages of 335–328 and 326–324 Ma on micas from mylonites (Marheine *et al.*, 2002) with polyphase dextral strike-slip followed by sinistral kinematics (Aleksandrowski, 1995; Aleksandrowski *et al.*, 1997). The lack of evidence for strike-slip displacements along the Domanów Fault zone seems to testify to different regimes in which the two features may have developed. This may explain why the termination of the activity on the Intra-Sudetic fault prior to the emplacement of the Karkonosze granite in late Viséan and Namurian times (328–312 Ma) had no legible consequences for the ongoing sedimentation in the Intra-Sudetic Basin and continued normal faulting on the N, W and NE margins of the north-western Intra-Sudetic Basin.

CONCLUSIONS

1. The early Carboniferous extensive fluvial sequence in the Intra-Sudetic Basin is not older than the TS Zone of the west European miospore zonation representing the Holkerian Stage of the middle Viséan (i. e. not older than 336 Ma, time scale of Menning *et al.*, 2000). No evidence of possible local occurrences of still older alluvial fans was found.

2. The lowermost Nagórnik formation, which provided the richest miospore sample (Nag 2) was probably entirely deposited during the Holkerian. The overlying formations (Stare Bogaczowice, Lubomin, Szczawno) were deposited during the Asbian (late Viséan: 333–330 Ma) and continued into the Brigantian (Szczawno fm. < 330 Ma).

3. The miospore age of the onset of extensive sedimentation of the Carboniferous fluvial sequence in the Intra-Sudetic Basin is consistent with the Ar-Ar isotopic mica datings of metamorphic rocks from the western flank of the basin, suggesting that rapid uplift and denudation of the source areas in the west and north must be younger than c. 335 Ma (Marheine *et al.*, 2002).

4. The obtained miospore data do not provide critical arguments, but combined with other data, they are more consistent with an intramontane depression rather than a pull-apart model for the origin of the Intra-Sudetic Basin, which cannot, however, be excluded.

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