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.

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 Got 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 uncertainty 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; Klučynski 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 lithologies to tectonically enhanced erosion. There are few lithological types seen today at the surface in the East Karko-
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,

Fig. 1. Geological sketch of the Intra-Sudetic Basin with location of samples.
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 Krkonoše1, 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; Dźdż & 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 (Zakowa, 1958, 1963; Teisseyre, 1975; Nemec et al., 1982; Dźdż & 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, Figłów 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 (Dźdż & Teisseyre, 1990). These four lowermost and outermost units were covered by the 1000–1500 m thick Stare Bogaczwowie 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; Dźdż & 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 (Goth) fauna (Zakowa, 1958, 1963). All the formations are characterized by the presence of upward fining cyclothemes (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

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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.
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 Dębno, 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, Denso- sporites cf. variabilis (Waltz) Potonie et Kremp, and Verruco- sporites 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. Denso- sporites 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-

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**Table 1**

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

<table>
<thead>
<tr>
<th>AGE Ma</th>
<th>STAGE</th>
<th>REGIONAL STAGE</th>
<th>MIOSPORE BIOZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>325</td>
<td>BRIGANTIAN</td>
<td>B. nitidus - R. carnosus NC (part)</td>
<td></td>
</tr>
<tr>
<td>330</td>
<td>VISEAN</td>
<td>T. vetustus - R. fracta VF</td>
<td></td>
</tr>
<tr>
<td>335</td>
<td>ASBIA</td>
<td>R. nigra - T. marginatus NM</td>
<td></td>
</tr>
<tr>
<td>340</td>
<td>HOLKERIAN</td>
<td>P. feissellatus - S. campyloptera (TC)</td>
<td></td>
</tr>
<tr>
<td>345</td>
<td>ARUNDIAN</td>
<td>K. triradiatus - K. stephanephorus TS</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td>CHADIAN</td>
<td>L. pusilla Pu</td>
<td></td>
</tr>
<tr>
<td>355</td>
<td>TOURNAIAN</td>
<td>L.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>COURCEYAN</td>
<td>S. pretiosus - R. clavata PC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. balticus - R. polypticha BP</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>K. hibernicus - U. distinctus HD</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V. verrucosus - R. incolatus VI</td>
<td></td>
</tr>
</tbody>
</table>

**Goniatis crenistria**
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 Perotritles tesellatus—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 (Zakowa, 1958, 1963; Table 1). This Zone spans the boundary between the Raistrickia nigra-Triquitrites marginatus (NM) and Triparites vetustus-Rotaspora fracta (VF) zones (Riley, 1993). Therefore, the rocks resting below the marine horizon are not younger than the NM Zone.

### 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 north-western 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 allochothonous 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 & Zelaźniewicz, 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
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/late Viséan; 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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