EVIDENCE OF WILDFIRES DURING DEPOSITION OF THE UPPER SILESIAN KEUPER SUCCESSION, SOUTHERN POLAND

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Abstract: Charcoals from the Upper Triassic vertebrate-bearing clays of the Zawiercie area (Upper Silesia, S-Poland) were analyzed using petrographic methods, to reconstruct burning temperatures as well as taphonomic processes. SEM and reflected light microscopy show excellent preservation of charcoals most probable connected with early diagenetic permineralization by calcite. The charcoal was assigned to three morphotypes, probably corresponding to three different fossil taxa. Fusinite reflectance data suggest, that the highest temperature reached above 600 °C (fusinite reflectance of 3.59%), what counterparts to the lower limit crown fire temperature. The values for most of the samples are lower (ca. 1% to 2.5%) what is typical for surface fires. In many cases fusinite reflectance values depends on the measured zone within the sample. Such zonation formed due to charring temperature differences. In zones remote from the potential fire source, reflectance values gradually decreases. It implies that calculation of fire temperatures based on average fusinite reflectance values might be too far-reaching simplification. Occurrence of fungal hyphae within the charcoal supports the interpretation of a predomination of surface fire, consuming dead twigs and stems.

The low content of micro-charcoals in charcoal-bearing rocks as well as rounded to sub-rounded shapes of large specimens indicates that they were transported after burning, deposited away from the burning area, and finally early diagenetic mineralization.

Key words: Charcoals, wildfire, fusinite reflectance, taphonomy, Upper Triassic, Poland.

INTRODUCTION

Charcoals are frequently used as proxies for palaeo-wildfires (Scott, 2000), occurring often in both terrestrial and marine sedimentary rocks (e.g., Scott, 2010; Uhl and Kerp, 2003; Marynowski and Filipiak, 2007; Marynowski and Simoneit, 2009; Shen *et al*., 2012), including deeper parts of shelf basin facies (Marynowski *et al*., 2010, 2012). They are frequently used to reconstruct the concentration of atmospheric oxygen during the Phanerozoic (Chaloner, 1989; Belcher and McElwain, 2008; Glasspool and Scott, 2010) and wildfire type as well as burning temperature (e.g. Jones and Lim, 2000; Scott, 2000; 2010; Marynowski *et al*., 2011a). While evidences of Lower to Middle Triassic wildfires are rather scarce (Abu Hamad *et al*., 2012 and references therein), with only a few undoubted records through the Middle Triassic (Belcher and McElwain, 2008; Uhl *et al*., 2010, 2014; Abu Hamad *et al*., 2012; see also Diessel, 2010), their documentation increased in the Upper Triassic. The first report about Upper Triassic charred flora from South Wales was presented by Harris (1958). More recently, Jones *et al*. (2002) described Late Triassic, sub-rounded to rounded, up to 5 cm large charcoals from the Petrified Forest National Park in Arizona. Later, Zeigler *et al*. (2005) reported the co-occurrence of charcoals and vertebrate fossils from the Upper Triassic deposits of Snyder quarry (Chinle Group), New Mexico. Tanner *et al*. (2006) characterized fusain record from Carnian to Norian Chinle and Fundy Group of New Mexico, USA as well as Nova Scotia and New Brunswick, Canada. The next reports about wildfires activity during Upper Triassic based on charcoal evidences appeared in a last few years, are from Hägnach
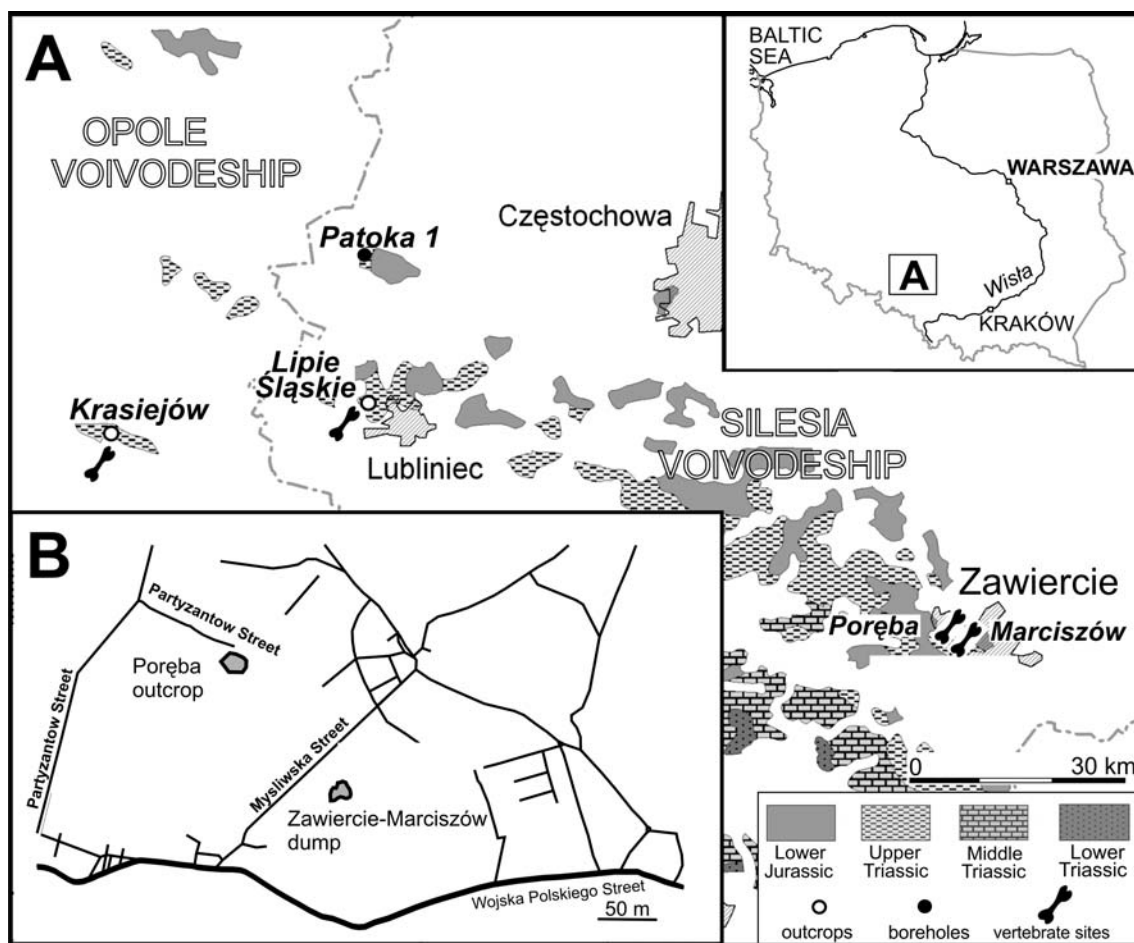
Fig. 1. Simplified geological map of the Upper Silesian region (**A**) with location of the Poręba and Zawiercie Marciszów sites, and other important Keuper localities (see Szulc *et al.*, 2015, fig. 1), and location sketch of the outcrops in the Poręba–Zawiercie area (**B**).

quarry (upper Keuper), SW Germany (Uhl and Montenari, 2011), Lipie Śląskie (Keuper), S Poland (Marynowski and Simoneit, 2009), the Triassic–Jurassic boundary, East Greenland (Belcher *et al*., 2010) and the Carnian of Jordan (Abu Hamad *et al*., 2014). All these data suggest increased wildfires activity in the Late Triassic connected with elevation of CO_2 concentration and temperatures (Belcher *et al.*, 2010; Steinthorsdottir *et al*., 2011) and/or better preservation of charcoal related to climate humidity (Abu Hamad *et al*., 2012; see also Jones *et al*., 2002). Here, we present for the first time the occurrence of large, permineralized charcoals from the Upper Triassic of Zawiercie area (Upper Silesia, S Poland), their state of preservation, taphonomy and implications connected with temperatures of burning.

MATERIALS AND METHODS

Samples

About 50 large (above 2–3 cm in diameter) charcoal fragments were collected from two sites of the Zawiercie area: Poręba (POR) and Zawiercie–Marciszów (ZAW) (Fig. 1). Generally, charcoals are usually rounded and have a particle size of less than 1 cm up to 10–15 cm in diameter.

They are permineralized by calcite and much less by pyrite, marcasite, clay minerals and rarely barite. Eight charcoal samples, characterized by large size (Fig. 2) were chosen for the detailed petrographic and geochemical analysis. In addition five samples of surrounding clays or mudstones and conglomerates were taken from Poręba site for charcoal micro-remain estimation.

All charcoal samples come from the Norian Patoka Marly Mudstone–Sandstone Member, which belongs to the recently redefined Grabowa Formation (Szulc and Racki 2015; Szulc *et al.*, 2015). The maximal thickness of the Patoka Member reached 300 m and represents fluvial and pedogenic facies described by Szulc *et al*. (2006). Investigated charcoals co-occurred with upper bone-bearing level (Lisowice horizon), and are present in all sites (Lipie Śląskie – see Marynowski and Simoneit, 2009; Poręba and Zawiercie Marciszów – this work) as large rounded and permineralized fragments present directly in clays or within carbonate concretions. In contrast, charcoals are absent in the lower bone breccias (Krasiejów horizon). More details about geology and stratigraphy of the vertebrate-bearing middle Keuper mudstones and clays of Upper Silesia region can be found in Szulc *et al*. (2006, 2015), Szulc and Racki (2015) and Konieczna *et al.* (2014).
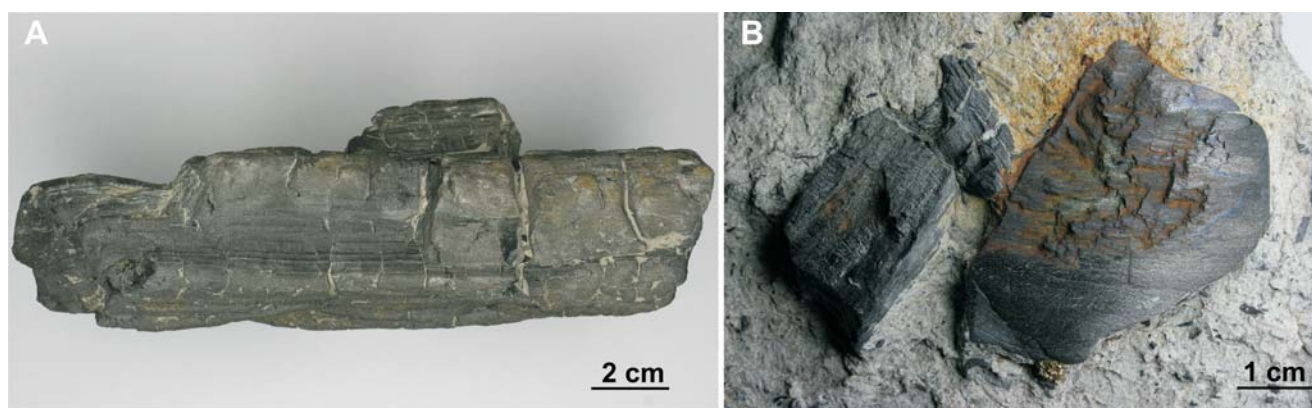
Fig. 2.   Macroscopic images of the typical, large charcoal (PORHC) from the Poręba site (**A**) and charcoals within the greenish clay (**B**).

Demineralization of rocks and micro-charcoals counting

Green clays (3 samples) and conglomerates (2 samples) were collected from the Poręba location to count the contents of micro-charcoals (e.g. Belcher *et al*., 2010). The host rocks were demineralized using hydrochloric acid (48 hours) and hydrofluoric acid (48 hours). Residuum was washed with distilled water and sieved through a sieve of 125 μm. The residue on the sieve was dried. The number of micro-charcoals was counted using a stereoscopic microscope.

Preparation of charcoal for taphonomic analysis

From seven specimens of charcoal which were permineralized with carbonate three approximately 2 mm thick, oriented slices were cut with a rock saw to exhibit transverse surfaces, radial longitudinal surfaces and tangential longitudinal surfaces. These slices were mounted on Standard SEM-stubs with LeitC (Plano GmbH, Wetzlar Germany). To remove carbonates, the surfaces to be examined by SEM were subsequently etched with acetic acid (25%) for 10–15 min. After repeated washing with water and drying, samples were gold-coated and examined with the aid of a JEOL JSM 6490 LV SEM (JEOL, Tokyo, Japan; at 20 kV) at the Senckenberg Forschungsinstitut und Naturmuseum Frankfurt.

Observation of charcoal using scanning electron microscopy (SEM)

Scanning electron microscope (Phillips XL30 ESEM model/TMP housed at University of Silesia, Sosnowiec) has been used for analysis of seven samples (six from Poręba and one from Zawiercie). Photographs made by using this microscope were performed on samples of both composition: intact and pre-treated by hydrochloric acid, which was used to remove crystals of calcite that filled intercellular spaces of tested charcoal.

In addition, four samples from Poręba were analyzed with a Quanta 650 FEG microscope, using 15 kV tension and high vacuum, housed at Wrocław Research Centre EIT + Ltd.

Reflected light and oil immersion microscopy

Microscopic examination of the samples in reflected light and immersion oil included five freshly polished charcoal samples. Random fusinite reflectance was measured with an AXIOPLAN II microscope using 156 nm light and immersion oil of refractive index 1.546 at a total magnification of 500x. The standards used were: 0.898, 1.42, 1.71 and 3.02% reflectance (Ro). Reflectance measurement was performed on the surface of charcoal, free from scratches and shiny points near the intersection of the cross.

Determination of total organic carbon, total sulfur, and the percentage of carbonates

Amounts of total carbon (TC) and total inorganic carbon (TIC) were determined by using an Eltra CS-500 IR-analyzer with TIC module at the Faculty of Earth Sciences, University of Silesia. Total organic carbon (TOC) was calculated as the difference between TC and TIC. Infrared cell detector of CO_2 gas has been used to measure the content of TC and TIC, which was evolved by combustion under an oxygen atmosphere for TC, and was obtained from reaction with 10% hydrochloric acid for TIC. Eltra standards were used for the calibration. Calcium carbonate content was calculated as $CaCO_3 = 8.333 \times TIC$, assuming that all carbonate is present as calcite. Analytical precision and accuracy were better than ±2% for TC and ±3% for TIC.

Extraction and fractionation

Cleaned and powdered samples were extracted in a Soxhlet apparatus using dichloromethane:methanol (80:20) as solvent. After the collection of extracts, the extractable organic matter (EOM) was separated by TLC using pre-washed plates coated with silica gel (Merck, Kieselgel 60 F254 10×20 cm). Prior to separation, the TLC plates were activated at 120 °C for 1 h. Plates were then loaded with the dichloromethane soluble fraction and developed with *n*-hexane as a mobile phase. The following fractions were collected: Aliphatic (Rf 0.6–1.0), aromatic (Rf 0.05–0.6), and polar (Rf 0.0–0.05).
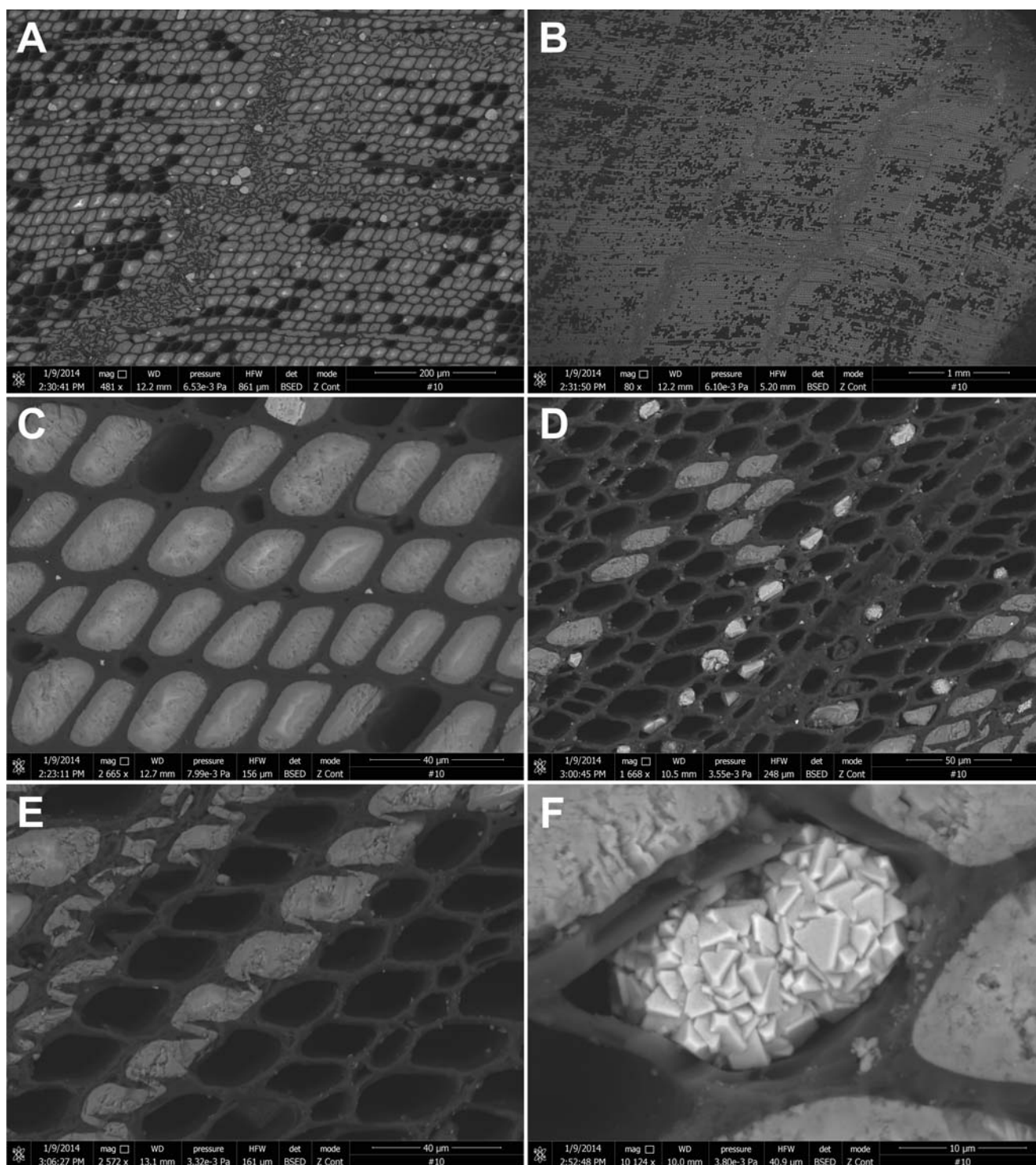
Fig. 3. Cut and polished charcoal (PORHA) from the Poręba site under SEM. **A.** Wood filled with calcite, exhibiting a tangentially oriented zones of compressed cells. **B.** Wood filled with calcite, exhibiting tangentially oriented zones of compressed cells. **C.** Tracheids filled with calcite in close up. **D.** Mixture of empty tracheids and tracheids filled with calcite and pyrite. **E.** Zipper-like structure, cell lumina filled with calcite. **F.** Close up of tracheid cell filled with recrystalized pyrite framboid.

RESULTS

Characteristics of charcoal using scanning electron microscopy (SEM)

Observations of all charcoal fragments under scanning electron microscope showed their regular cellular structure, best revealed in the excellently preserved PORHA and ZAWHA samples. All woods exhibit a homoxylic/pycnoxylic structure and show excellent preservation of anatomical details (e.g. Figs 3, 4). The charcoal can be assigned to three different morphotypes (all belonging to gymnosperms), probably corresponding to three different fossil taxa. A detailed
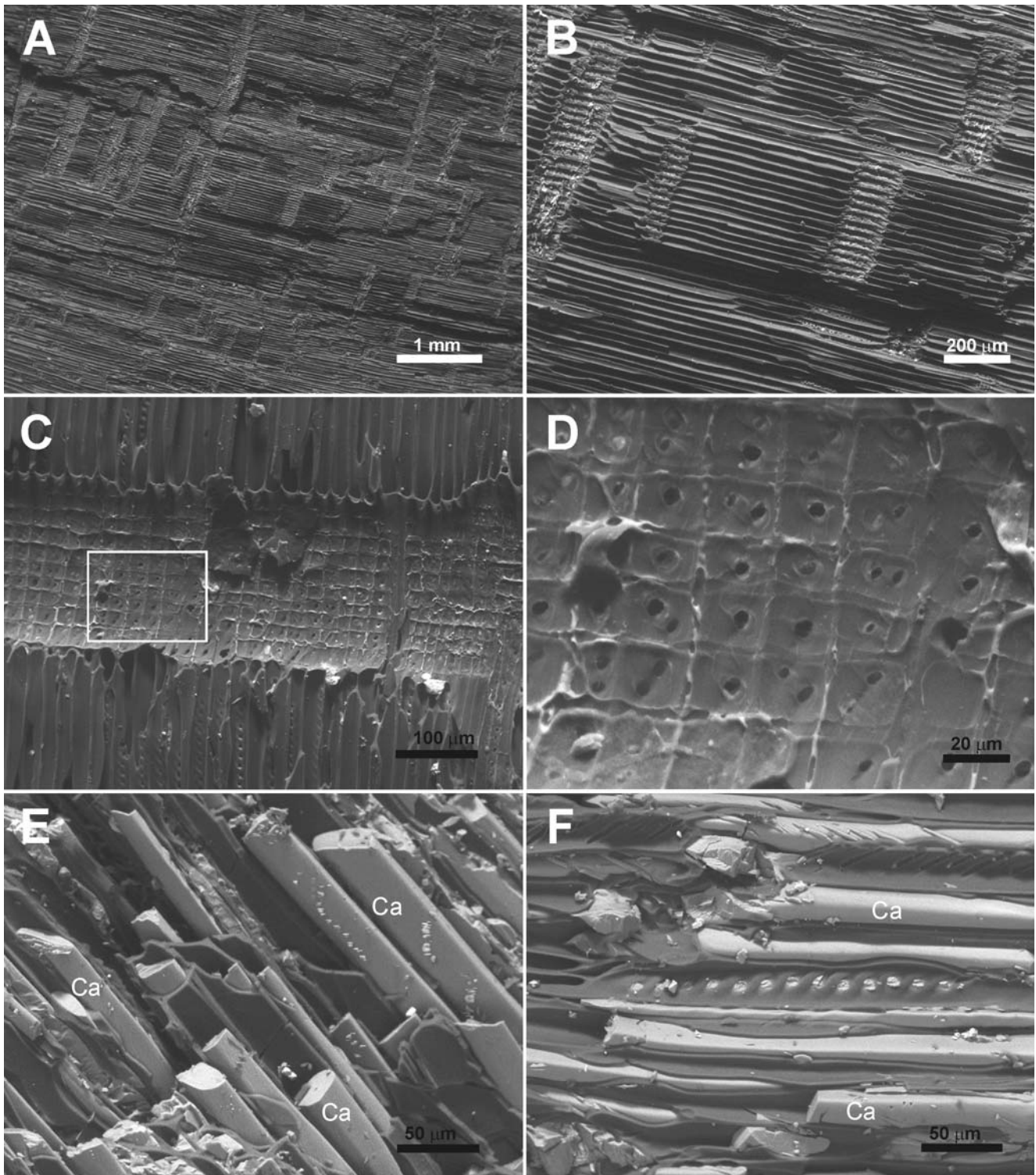
Fig. 4. Broken surfaces of charcoal (ZAWHA) from the Zawiercie area under SEM. **A.** Wood in radial view showing several wood rays. **B.** Detail of A. **C.** Wood ray in radial view. **D.** Detail of C showing araucarioid/cupressoid cross-field pitting. **E.** Tracheids in tangential view, partly filled with calcite (Ca). **F.** Tracheids in radial view exhibiting uniseriate, contiguous pitting, tracheids partly filled with calcite (Ca).

taxonomic analysis of the charred wood remains is currently in preparation and will be published elsewhere.

In some specimens (e.g., PORHA, PORHF) charred fungal hyphae are present within tracheids (Fig. 5A, B), indicating that biologically mediated decay of the wood started prior to charring. Other specimens (e.g., PORHA, PORHB, PORHC,

PORHD) exhibit checking of cells walls (Fig. 5C, D), indicating that the wood dried out prior to charring (Jones, 1993).

Only a few specimens show evidences of compaction, which most likely occurred after deposition, but prior to early diagenetic permineralization. In one specimens (PORHF) zones with compacted cells (with broken cell walls) are more
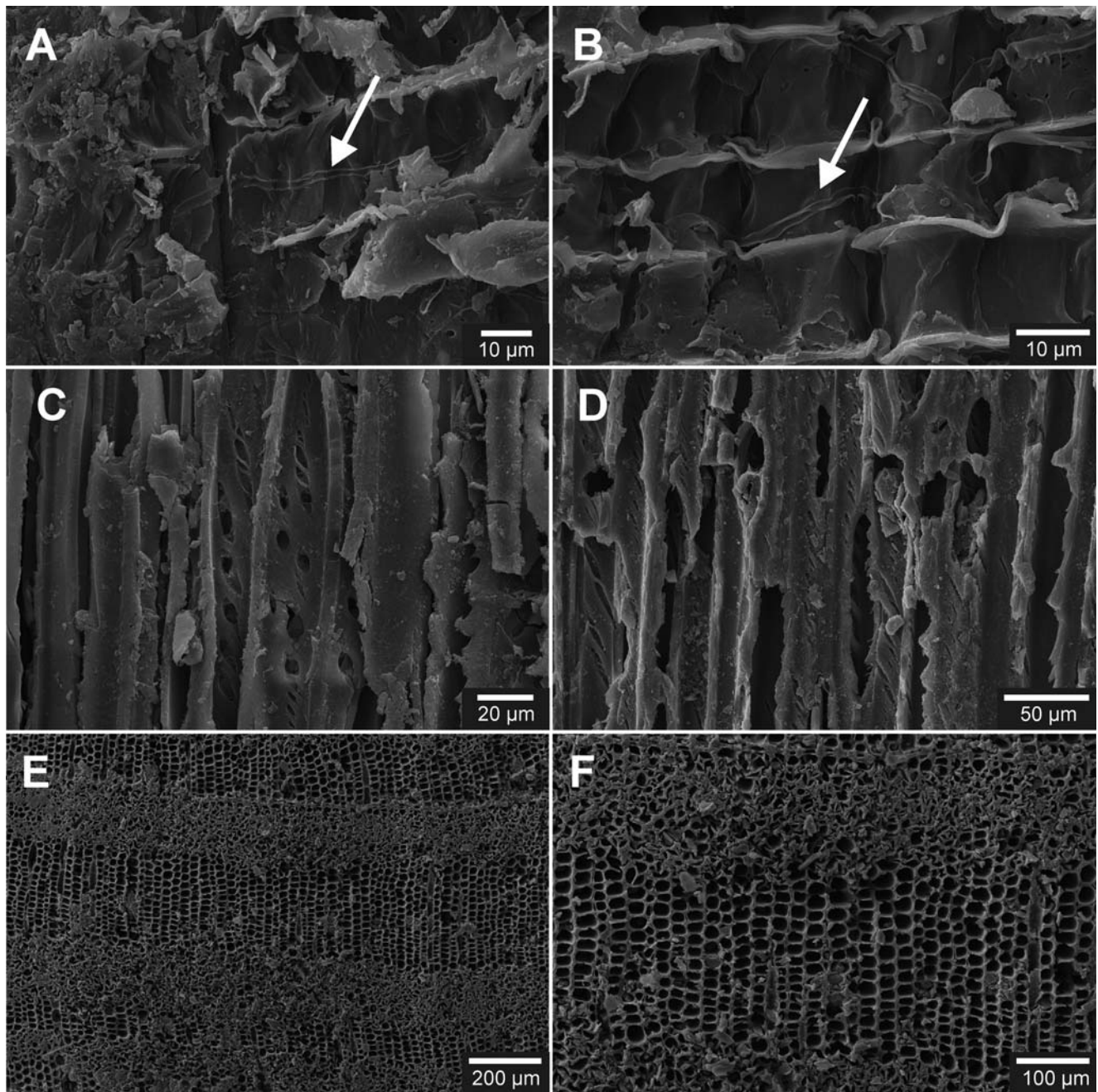
Fig. 5.   Cut and etched charcoal from the Poręba site under SEM. **A.** Ray cells in radial view with charred fungal hyphae (arrow) (PORHA). **B.** Ray cells in radial view with charred fungal hyphae (arrow) (PORHA). **C.** Checked tracheid walls in radial view (PORHC). **D.** Checked tracheid walls and wood rays in tangential view (PORHD). **E.** Cross-section of charcoal with tangentially orientated areas with compacted cells with broken cell walls (PORHF). **F.** Detail of E.

or less tangentially oriented (Figs 3A, B, 5E, F), whereas in other specimens (e.g., PORHC, PORHE) zones with compacted cells (with broken cell walls) are less regular orientated (Figs 6C, D, 7). These zones show some interesting features that may be relevant for the general understanding of the mechanical breakdown of charcoal. In some areas, with mostly undamaged cells zipper-like structures can be observed were just a single row of cell walls has been broken (Figs 3E, 7E, F). Sometimes adjacent to almost undisturbed areas are places with large nests or streaks (more or less parallel to wood cell files) of damaged cells with bro-

ken cell walls occur next to streaks of more or less undamaged wood (Fig. 7B). Large areas of totally compressed cells (with broken cell walls) show distinct borders to these areas (Figs 6C, 7A) and in some cases small nests of undamaged cells can be seen in such areas which consist otherwise purely of cells with shattered cell walls (Fig. 7C).

In a few places with otherwise undamaged cells, cracks can be seen in cross-sections (Fig. 6A, B). Such cracks are probably the result of charring of fresh, relatively wet wood as in such material water is expelled forcefully in form of water vapor due to high temperatures during charring (Sch-
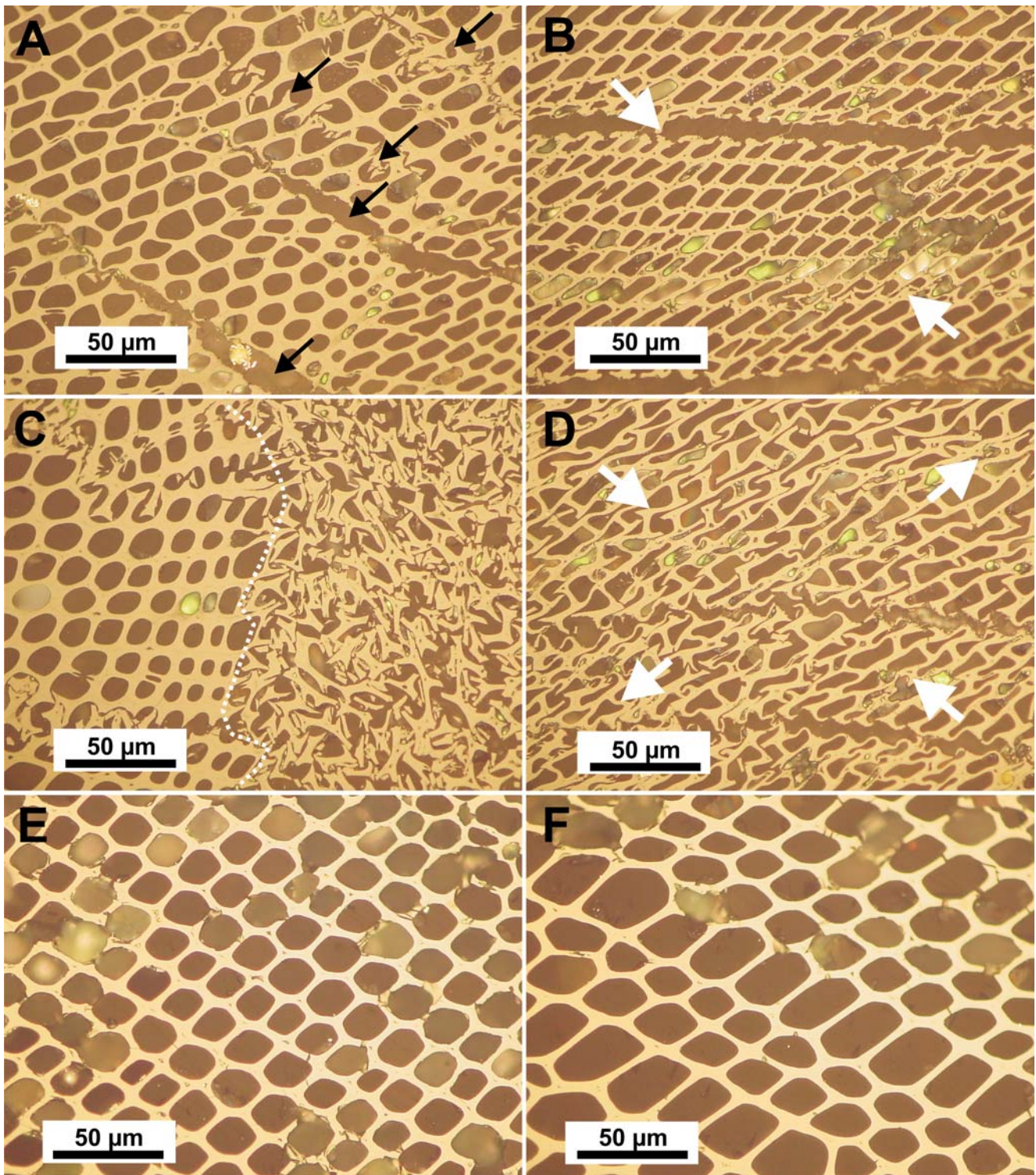
Fig. 6. Cut and polished charcoal from the Poręba and Zawiercie Marciszów sites in cross-section (reflected light); **A.** Area exhibiting cracks and a few broken cell walls (arrows) (PORHC). **B.** Area with large crack (PORHC), arrows shows compaction directions. **C.** Close up of boundary (dotted line) between an area with totally compacted/shattered cells (left) and partly shattered cells (right) (PORHC). **D.** Area with shattered cell walls, as well as wavy cell walls (PORHC). Arrows shows compaction directions. **E.** Tracheids with very homogenuous shapes, resulting in regular cellular structure (ZAWHA). **F.** Tracheids with in homogenuous shapes, resulting in more irregular cellular structure (ZAWHA).

weingruber, 2001). Some areas with compressed cells show unbroken, "wavy" cell walls (Fig. 5D) maybe indicating compression of slightly decayed wood prior to charring or compression of incompletely charred wood.

The presence of framboidal pyrite filling some of the cells is connected to the total sulfur results of these charcoals (PORHA, PORHB). The diameters of framboidal pyrites occurring in these samples are larger than 5 μm, which
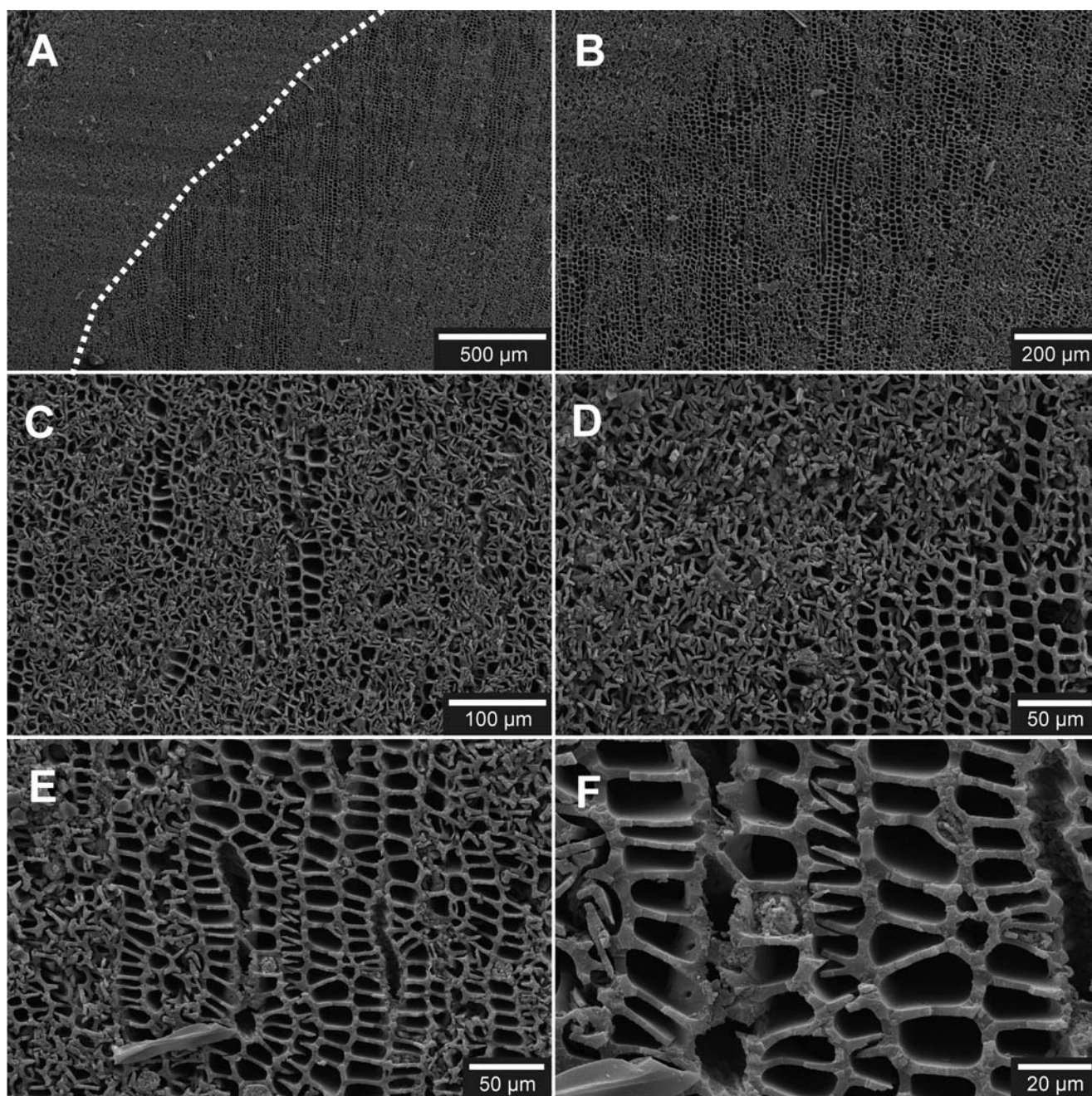
Fig. 7. Cut and etched charcoal from the Poręba site in cross-section (PORHE) under SEM. **A.** Boundary (dotted line) between an area with totally compacted/shattered cells (left) and partly shattered cells (right). **B.** Detail of A showing areas with compacted and uncompacted cells which are orientated more or less parallel to cell-files. **C.** small areas of uncompacted cells within an area of compacted cells. **D.** Detailed view of the boundary between an area with totally compacted/shattered cells (left) and partly shattered cells (right). **E.** Small areas of uncompacted cells within an area of compacted cells showing a zipper-like structure in the center. **F.** Detail of zipper-like structure.

indicates that pyrite is of early diagenetic origin (e.g. Wignall and Newton, 1998).

Bulk geochemical results

Total organic carbon (TOC) values of the tested samples, summarized in Table 1, are characterized by low diversity, ranging from 18.55% to 29.77%, with the lowest value of the sample from Zawiercie-Marciszów location, which may be caused by the partial oxidation. Other samples show little differences in the content of TOC (21.17–29.77%).

The percentage of carbonates in charcoals (Table 1) is in a narrow range from 43.96% to 57.11% $CaCO_3$ for the Poręba material. The exception is the Zawiercie-Marciszów sample, characterized by elevated carbonate content, reaching above 77%. It explains a generally lower TOC concentration of the mentioned sample.

The values of total sulphur (TS) oscillate between the wide range of 0.16% to 9.44% and exhibit no correlation with other data, such as TOC or the carbonate content, which indicates a non-organic sulfur origin in charcoal, what should be expected in case of terrestrial OM. Presum-

Table 1

Bulk geochemical data for charcoals from Zawiercie region

Sample	TIC [%]	TC [%]	TS [%]	TOC [%]	Carbonates [%]	EOKM mg/gTOC	Fractions		
							Al [%]	Ar [%]	Pol [%]
PORHA	5.28	29.15	9.44	23.87	43.96	10.5	4	29	67
PORHB	6.07	27.24	9.33	21.17	50.6	2	26	23	51
PORHC	6.08	35.86	1.1	29.77	50.69	11.1	9	21	70
PORHD	6.85	32.23	1.33	25.38	57.11	0.9	27	22	51
PORHE	6.42	34.8	0.99	28.39	53.47	2.2	19	21	60
PORHF	5.54	32.25	0.16	26.71	46.16	4.5	10	25	65
PORHG	6.13	28.76	4.79	22.63	51.08	1.3	23	10	67
ZAWHA	9.27	27.82	0.59	18.55	77.24	1.1	25	17	58

TIC = total inorganic carbon, TC = total carbon, TS = total sulfur, TOC = total organic carbon, EOM = extractable organic matter, Al = aliphatic fraction, Ar = aromatic fraction and Pol = polar fraction

ably, the main source are the sulphides: pyrite and marca-site. In case of five samples – the value of the total sulfur is very low (0.16%–1.33%), which may be related to their partial oxidation (see Marynowski *et al*., 2011b) or less extensive pyrite mineralization.

In all samples polar fraction dominates (Table 1), what is more typical of samples with lower thermal maturation and is surprising in case of charcoals. Presumably, the extracts are mixture of pyrolytic compounds and primary, much better solved and non-burned wood. In fact, some charcoal sections characterized by macroscopically visible partially gelified, jet-like structure, interpreted here as non burned wood fragments. The highest obtained extraction yields (highest EOM – see Table 1) are correlate with lowest aliphatic fraction and highest polar fraction content, what confirmed the assumption that greater part of the extract is derived from the dissolution of gelified, non-burned organic matter.

Fusinite reflectance

According to previous reports (Jones and Lim, 2000; Scott, 2000, 2010; see also O'Keefe *et al*., 2013) the fusinite (inertinite) reflectance values are strictly connected with the presumed temperature during charring, as is to some degree the mode of homogenization of the cell walls.

Almost the only maceral in the investigated charcoal samples was excellently preserved fusinite (and when reflectance values were low – semifusinite). Some of the samples (POR-HA, PORHB, PORHD), are characterized by lighter and darker zones, someplace connected with type of the section (longitudinal or transverse) with respect to the cell walls (Table 2). In case of PORHA sample differences between reflectance of light and dark zones are small, while in case of PORHB sample they are very significant (Table 2). Such observation in one sample suggests, that temperature influences the individ-

Table 2

Values of fusinite reflectance and their relationship to temperature of fire

Sample	Fusinite reflectance [%]					Temperature (°C)*		
	Avg	SD	Min	Max	n	Avg	Min	Max
PORHA	0.91	0.05	0.78	1.05	100	291	276	308
PORHA longitudinal (dark zone)	1.02	0.04	0.94	1.12	100	304	295	316
PORHA transverse (light zone)	1.48	0.15	1.03	1.76	100	359	306	392
PORHB	1.76	0.13	1.4	1.99	100	392	349	419
PORHB longitudinal (light zone)	3.59	0.43	3.74	4.51	100	608	625	716
PORHB longitudinal (dark zone)	1.34	0.22	0.68	1.63	100	342	264	376
PORHB transverse (light zone)	2.8	0.41	1.84	3.64	100	514	401	614
PORHB transverse (dark zone)	0.94	0.25	0.61	1.65	100	295	256	379
PORHC	1.62	0.31	0.77	2.3	101	375	275	455
PORHD transverse (dark zone)	0.98	0.09	0.79	1.22	100	300	277	328
PORHD longitudinal (light zone)	2.34	0.17	1.97	2.8	100	460	416	514
ZAWHA	1.8	0.33	0.95	2.48	100	396	296	477

Avg – average value, SD – standard deviation, Min – minimum value, Max – maximum value, n – number of measurements. * Calculation of combustion temperature (°C) = 184 + 118·X, where X is value of fusinite reflectance (based on Jones and Lim, 2000)

Table 3

The content of micro-charcoals in the host rocks
from Poręba site

Sample	Number of micro-charcoals in 100 g of the sample	Micro-charcoals / 1 g of the sample
Clay1	487	4.87
Clay2	994	9.94
Clay3	1882	18.82
Conglomerate 1	237	2.37
Conglomerate 2	0	0

ual parts of the wood varies significantly. Based on the results, it was found that the highest calculated temperature of charcoal formation are above 600°C, corresponding to an average reflectance of 3.59% (light zone of PORHB sample in transversal section – Table 2), which may indicate lower limit temperature of crown fires (e.g. Scott, 2000). The values for the other samples indicate surface fires, what is characteristic for temperatures of 300– 600°C (generally 400°C) (Scott, 2000).

Micro-charcoals occurrence in clays and conglomerates

The content of micro-charcoals counted under the binocular after prior demineralization of clays and conglomerates is presented in Table 3.

The results show a relatively low level of micro-charcoal abundance in host-rocks. The highest value were obtained for Clay3 sample, reaching 19 micro-charcoals per 1g of the sample, which is after all a very low amount, comparing the data obtained from other charcoal-bearing sedimentary rocks. For example, sandstones and claystones of the Middle Jurassic of Argentina, characterized by occurrence of micro-charcoals fluctuated from 207 to 4899 particles per gram (ppg) of the rock (Marynowski *et al.*, 2011a). On the other hand, the amount of micro-charcoals strictly at the Triassic–Jurassic boundary in Greenland reached 618 ppg (Belcher *et al.*, 2010). However, in most of the samples below and above the Triassic–Jurassic boundary the concentration of micro-charcoals were similar or only slightly higher than those counted in Poręba.

DISCUSSION

Burning of the Triassic fuel

Measured fusinite reflectance values for charcoal samples are diverse (Table 2). In many charcoal samples fusinite reflectance depend on tested cross-section and zone within one sufficiently large charcoal sample. It suggests that in the outermost zone directly exposed to the fire, temperatures were higher, what is reflected by elevated values of fusinite reflectance. In fields farther away from the potential source of fire, reflectance values gradually decreasing. Such observations reduce the value of fusinite reflectance as an indicator of fire type. However, most of the measured temperatures are

between 300 and 400°C, what corresponds, according to the classification of Keiluweit *et al.*, (2010), to the transition char and first phase of amorphous char formation. Because in transition char all precursor materials (lignin, cellulose and hemicellulose) can still survive, in some parts of charcoals we observe jet-like OM, formed by gelification of non-burned wood components.

Taphonomy

Occurrence of fungal hyphae within the charcoal (Fig. 5A, B), as well as checking of cell walls (Fig. 5C, D) supports the interpretation of a surface fire, consuming litter and dead twigs and/or stems, as a potential source of the charcoal.

Of considerable interest are the compaction patterns that can be observed in this material. These compaction patterns probably represent parts of a time series of mechanical shattering, which has been conserved due to early diagenetic permineralization. The zipper-like structures described above (Figs 3E, 7E, F), probably represent the first stage in this mechanical breakdown due to pressure from overlying sediment and compaction of sediments. Starting from such weak points shattering of cell walls continues probably following weak zones parallel (Fig. 7) or perpendicular (Fig. 5E, F) to individual wood cell files. This shattering ultimately leads to completely shattered cell walls (Fig. 7A), but during intermediate stages areas with undamaged cell walls can still occur next to more or less large areas with damaged cell walls (Fig. 7B–D).

These observations and interpretations may help to understand the processes occurring during mechanical breakdown of charcoal which complicates the anatomical investigation of charred woods in many localities (e.g. Uhl *et al.*, 2010, 2012a; Uhl and Montenari, 2011; Abu Hamad *et al.*, 2014). It also emphasizes the significance of early diagenetic permineralisation, e.g. by carbonates, for the three-dimensional preservation of charcoal. As shown previously, such charcoals may exhibit excellent anatomical details under the SEM (e.g., Uhl and Kerp, 2003; Uhl *et al.*, 2012a, b) in some cases even enabling a more or less specific determination of the charred woods (e.g. Uhl *et al.*, 2012b). Our data also indicate that careful etching of such permineralized specimens *in situ* (after cutting the charcoal still within the sediment) may produce better results (larger charcoal fragments that can be investigated by SEM) than bulk etching of sediment samples which contain permineralized charcoal (e.g. Uhl and Kerp, 2003). In the latter case partly compacted charcoal remains will most certainly fragment further after complete removal of the permineralization agent (in our case carbonates) that holds together the damaged and undamaged areas within a partly compacted charcoal specimen. Totally compacted specimens may even fragment completely, leaving only isolated remains of cell walls (i.e. tracheids), which would usually be regarded as micro-charcoal after bulk-maceration of sediments.

Transportation and mineralization of charcoals

Because of the rather low concentration of micro-charcoals in green clays and very low or nil concentrations in conglomerates (Table 3), it is suggested that relatively frequent large charcoals from the Upper Silesian Keuper

succession are allochthonous and were transported from unknown source area. In addition, a small amount of microcharcoals implies that wildfires were far from their depositional basin, and that large charcoals come a long distance from their parent source. The post-burning transportation of charred wood fragments is confirmed by their rounded to sub-rounded shapes. After deposition they were mineralized by early diagenetic and/or less possible hydrothermal processes (Środoń *et al.*, 2014; see also Słowakiewicz, 2003). The early diagenetic mineralization provides a very good state of preservation, without evidences of shattering caused by compaction (Jones, 1994) in most specimens investigated. The alternative scenario is transportation of large charcoals after mineralization, but it should be excluded because they were deposited in fine-grained mudstones/clays where energy of transportation was low.

CONCLUSIONS

Upper Triassic charcoals from Zawiercie region are excellently preserved and indicate the variations of the cell structure and intensity of mineralization.

Based on fusinite reflectance measurements, it has been found that the highest temperature for one Poręba sample reached above 600°C, corresponding to average reflectance of 3.59%. Comparable to the lower limit temperature of crown fires. The values for the other samples correspond to surface fires.

In many cases fusinite reflectance values are depending on the measured zone within one sample. We conclude that such zonations formed due to temperature differences during charring. In zones farther away from the potential fire source, reflectance values gradually decrease. This observation suggests that using average fusinite reflectance values for the calculation of temperatures could be too far-reaching simplification.

The insignificant content of micro-charcoals in green clays and conglomerates as well as rounded to sub-rounded shapes of large charcoals indicates that they were probably transported after burning, deposited in green clays and than mineralized.

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