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Palinologia osadów żywetu i franu południowo-wschodniej Polski

Rozprawa doktorska

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STRESZCZENIE

Przedłożona rozprawa doktorska dotyczy badań palinologicznych utworów żywetu i franu(?) południowo-wschodniej Polski. Składa się na nią treść czterech publikacji z lat 2021-2022. Analizy palinologiczne wykonano łącznie dla ośmiu profili: pięciu otworów wiertniczych (Kowala 1, Szwejki IG-3, Niesiołowice IG-1, Giełczew PIG 5, Krowie Bagno IG-1) oraz trzech profili z odsłonięć w Miłoszowie (M0, M1, M2). Tym samym prace objęły kielecką część Gór Świętokrzyskich, obszar basenu łysogórsko-radomskiego oraz basen lubelski.

Praca zawiera wyniki analiz palinostratygraficznych, które w oparciu o rozpoznane zespoły mikroflory lądowej wykonano dla każdego z analizowanych profili. Ponadto przeprowadzono analizę palinofacjalną, która obejmowała wszystkie profile za wyjątkiem otworu wiertniczego Kowala 1. Wyniki tej analizy posłużyły do próby zidentyfikowania palinologicznego zapisu globalnego zdarzenia Taghanic na obszarze Polski i porównania tego zapisu z dotychczasowymi danymi.

Istotnym elementem pracy jest także szczegółowa charakterystyka rzadkich palinomorf jakimi są organiczne tentakulity pochodzące z otworu wiertniczego Kowala 1.

W toku analiz opisano również nowy gatunek akritarchy rozpoznany w odsłonięciach z Miłoszowa: *Teleostomata rackii* oraz nowy gatunek miospory *Retusotriletes radomskii*.

Prezentowany zbiór artykułów omawia palinologię osadów żywetu i prawdopodobnie franu badanych regionów stanowiąc uzupełnienie wiedzy na temat palinostratygrafii tych obszarów oraz po raz pierwszy porusza zagadnienie palinofacji w regionie radomsko-lubelskim.

PUBLIKACJE WCHODZĄCE W SKŁAD ROZPRAWY

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1. WSTĘP

Materiał, który został wytypowany do badań pochodzi z obszarów o odmiennej historii geologicznej: kieleckiej części Gór Świętokrzyskich, basenu łysogórsko-radomskiego oraz basenu lubelskiego (Fig. 1). Pomimo, że dla utworów żywetu i wczesnego franu każdego z tych obszarów (poza regionem kieleckim Gór Świętokrzyskich) głównie Turnau wykonała pionierskie opracowania palinologiczne, to są to prace które kładły nacisk na aspekty palinostratygraficzne, tym samym pomijając zupełnie zagadnienia dotyczące palinofacji oraz analizy palinomorf innych niż mikroflora lądowa (np. Malec i Turnau, 1997; Turnau, 1985, 1986, 2011).

Badania palinologiczne dewonu na obszarze Gór Świętokrzyskich mają wieloletnią tradycję, jednak szczegółowość z jaką rozpoznane są poszczególne piętra znacznie się waha.

W części kieleckiej Gór Świętokrzyskich za najbardziej szczegółowo zbadane można uznać utwory górnego dewonu (np. Turnau, 1990; Filipiak, 2004, 2005; Marynowski i Filipiak, 2007; Marynowski et al., 2010), natomiast zdecydowanie słabiej rozpoznane są interwały dolno- oraz środkowodewońskie. Osady od pragu do eiflu zostały opisane przez Fijałkowską-Mader i Malca (2011) oraz Filipiaka (2011). Żywecki interwał części kieleckiej Gór Świętokrzyskich był dotychczas pomijany w badaniach palinologicznych, głównie z uwagi na litologię niesprzyjającą takim analizom (przede wszystkim wysoki stopień dolomityzacji, patrz: Narkiewicz, 1991; Bełka i Narkiewicz, 2008). Stąd też stratygrafia tego interwału oparta została głównie na konodontach, makrofaunie oraz litostratygrafii (np. Narkiewicz et al., 1990; Romanek i Rup, 1990; Racki, 1993; Szulczewski, 1995). Tym samym powstała znacząca luka obejmująca palinologiczne rozpoznanie osadów żywetu i franu w regionie kieleckim. Analiza utworów z otworu wiertniczego Kowala 1 była próbą uzupełnienia tej luki (Kondas i Filipiak, 2021).

Odmienna sytuacja rysuje się w północnej, łysogórskiej części Gór Świętokrzyskich. Palinologia osadów emsu i eiflu została rozpoznana przez Fijałkowską-Mader i Malca (2011) oraz Filipiaka (2011). Dodatkowo utwory emsu z kamieniołomu w Bukowej Górze zostały szczegółowo opisane pod kątem występowania zarówno mikro-jak i makroflory przez Filipiaka et al. (2021) oraz Filipiaka et al. (2022). Osady żywetu i franu (warstwy skalskie oraz nieczulickie) z odsłonięcia Grzegorzowice-Skały zostały rozpoznane przez Turnau (patrz: Malec i Turnau, 1997) i skorelowane z danymi konodontowymi. Natomiast ostatnie opracowanie osadów żywetu Synkliny Bodzentyńskiej z odsłonięcia Świętomarz-Śniadka obejmowało nie tylko palinostratygrafię, ale także analizę palinofacji (Turnau i Racki, 1999). Warto podkreślić, że istniejące opracowania nie są liczne, a z uwagi na specyfikę regionu analizy palinologiczne napotykają duże trudności. Do najczęściej występujących problemów należą zmiany termiczne materiału organicznego lub jego skorodowanie, co utrudnia lub uniemożliwia rozpoznanie palinomorf (Kondas i Filipiak, 2022a). Biorąc pod uwagę powyższe, każde nowe opracowanie palinologiczne ma duże znaczenie i istotnie zwiększa wiedzę odnośnie mikroflory, stratygrafii i środowiska depozycji osadów w tym regionie.

Radomska część basenu łysogórsko-radomskiego znana jest głównie z opracowań głębokich otworów wiertniczych (Miłaczewski i Żelichowski, 1970; Niemczycka, 1975; Żakowa et al., 1986; Malec et al., 1996; Narkiewicz et al., 2011). Osady dewonu tego obszaru były przedmiotem szczegółowych analiz przeprowadzonych przez Narkiewicza (2011a) oraz Narkiewicza et al. (2011), którzy opisali litostratygrafię tych osadów oraz rozwój sedymentacji w tej części basenu łysogórsko-radomskiego. Dla tego obszaru wykonano także liczne badania konodontowe przeprowadzone przez Narkiewicza i Narkiewicz (1998), Narkiewicz i Bultyncka (2007) oraz Narkiewicz (2011). Ponadto, otwór Szwejki IG-3 był analizowany pod kątem obecności konodontów oraz małżoraczków przez Malca et al. (1996), w otworze udokumentowano również obecność koralowców (Fedorowski, 1990).

W kontraście do badań faunistycznych, opracowania palinologiczne dewonu tego regionu są skromniejsze. Stratygrafia utworów dolnego dewonu z otworów Pionki 1 oraz Pionki 4 została rozpoznana przez Turnau (1985, 1986), a utworów z otworu Ciepielów IG-1 przez Turnau i Jakubowską (1989). Przeprowadzona obecnie analiza palinologiczna profili Szwejki IG-3 oraz Niesiołowice IG-1 stanowi wkład w rozpoznanie stratygrafii oraz warunków depozycji osadów żywetu i franu(?) tego regionu.

Osady dewonu basenu lubelskiego były badane od lat 60. XX wieku, głównie w związku z poszukiwaniem węglowodorów. Pierwsze rezultaty opublikowane były w pracach Żelichowskiego (1961, 1964). Co istotne, otwór Krowie Bagno IG-1 będący przedmiotem analizy w niniejszej pracy został szczegółowo opracowany pod kątem litologicznym przez Miłaczewskiego (1975). Dane stratygraficzne podsumowane zostały w pracach Miłaczewskiego (1981) oraz Miłaczewskiego et al. (1983). Szczegółowe opracowanie dotyczące rozwoju sedymentacji na obszarze basenu lubelskiego zostało wykonane przez Narkiewicza (2011b) oraz Narkiewicza et al. (2011). Biostratygrafia tego obszaru została dobrze rozpoznana faunistycznie, głównie dzięki badaniom konodontowym przeprowadzonym między innymi przez Szulczewskiego (1972), Matyję i Żbikowską (1985), Narkiewicza i Narkiewicz (1998), Nehring-Lefeld et al. (2003), Narkiewicz i Bultyncka (2007), Narkiewicza i Narkiewicz (2008) oraz Turnau i Narkiewicz (2011). W obrębie tego regionu przeprowadzono także pionierskie prace palinostratygraficzne. Aluwialne oraz płytkomorskie osady z otworu Terebin IG-5 były opracowane przez Turnau et al. (2005). Osady żywetu z otworów Terebin IG 1, Terebin IG-5, Giełczew PIG 5 oraz Giełczew PIG 6 były przedmiotem analizy przeprowadzonej przez Turnau (2011).

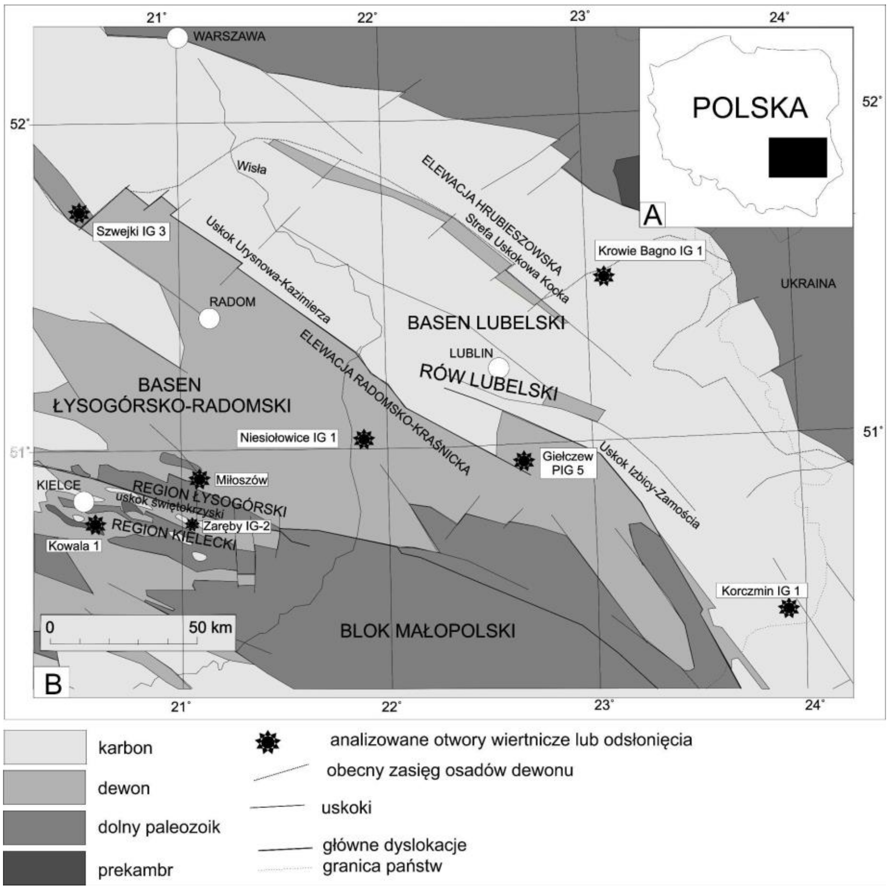

Fig. 1. A. Lokalizacja obszaru badań na tle Polski. B. Lokalizacja badanych otworów wiertniczych i odsłonięć na tle wybranych elementów budowy geologicznej (wzięte z: Narkiewicz et al., 2011, zmienione).

Badany obszar Polski jest także niezwykle interesujący z punktu widzenia zapisu globalnych zdarzeń biotycznych (Racki, 2006). Zdarzenia te najszczegółowiej opracowane zostały w przypadku osadów górnego dewonu Gór Świętokrzyskich (np. Racki et al., 2002; Racki et al., 2004; Marynowski i Filipiak, 2007). Analizowany w niniejszej pracy interwał stratygraficzny pozwolił na podjęcie próby scharakteryzowania palinologicznego zapisu zdarzenia Taghanic, które obejmuje zony konodontowe od *ansatus* po *hermanni* odpowiadające późnemu żywetowi (House, 2002). To globalne zdarzenie związane jest ze zmianami poziomu mórz i w konsekwencji epizodem wymierania obejmujących zarówno świat zwierzęcy jak i roślinny. Dotychczas palinologiczny zapis tego zdarzenia najszczegółowiej udokumentowany został na obszarze Szkocji (Marshall et al., 2011) oraz północnej i centralnej Polski (Turnau, 2014). W niniejszej pracy podjęta została próba scharakteryzowania palinologicznego zapisu zdarzenia Taghanic na obszarze radomsko-lubelskim (Kondas i Filipiak, 2022b).

1.1 Cele pracy

Zasadniczymi celami pracy są interpretacja wieku i środowiska depozycji utworów żywetu i dolnego franu(?) centralnej i południowo-wschodniej Polski w oparciu o badania palinologiczne. Przeprowadzona analiza mikroflorystyczna obejmowała trzy aspekty: (1) wyznaczenie względnego wieku badanych osadów w oparciu o rozpoznanie mikroflory lądowej (wyznaczenie zon miosporowych), (2) interpretację palinofacji oraz (3) palinologiczne rozpoznanie zdarzenia Taghanic (*sensu* Marshall et al., 2011).

Przy okazji przeprowadzonych badań rozszerzono charakterystykę rzadko występujących mikroskamieniałości jakimi są organiczne tentakulity, a także udokumentowano wystąpienia nowego rodzaju i gatunku akritarchy *Teleostomata rackii* oraz nowego gatunku miospory *Retusotriletes radomskii*.

Badania przedstawione w pracy realizowane były w ramach grantu Narodowego Centrum Nauki pt. „Zmiany paleośrodowiskowe w osadach żywetu i franu w świetle badań palinologicznych oraz geochemii izotopowej” (2017/27/N/ST10/01699), na podstawie którego uzyskano pozwolenia na pobór materiału skalnego. Publikacje naukowe w których zamieszczono wyniki badań wchodzą w skład niniejszej rozprawy. Wkład procentowy autorki rozprawy w poszczególne publikacje określony i potwierdzony został przez załączone do pracy oświadczenia współautorów.

2. ZARYS GEOLOGII OBSZARU BADAŃ ORAZ CHARAKTERYSTYKA ANALIZOWANYCH PROFILI

Materiał badawczy w postaci próbek skalnych pobrano z siedmiu rdzeni wiertniczych oraz trzech odsłonięć. Otwory wiertnicze Kowala 1 (50°48’04, 52”N, 20°33’35, 97”E) oraz Zaręby IG-2 (50°47′02,79″N, 21°02′47,23″E) ulokowane są w kieleckiej części Gór Świętokrzyskich, z kolei w obrębie basenu łysogórsko-radomskiego znajdują się otwory Szwejki IG-3 (51°42′45,00″N, 20°32′33,53″E), Niesiołowice IG-1 (51°01′51,71″N, 21°50′06,01″E), a także trzy odsłonięcia z Miłoszowa (M0 o lokalizacji 50°54,07’N, 21°07,18′E, M1 znajdujące się około 25 m od odsłonięcia M0, 50°54,150’N 21°7,271′E oraz M2 będące krótkim rowem przekopanym prostopadle do warstw ulokowanych w 50°54,139’N 21°7,213′E). Pozostałe otwory: Giełczew PIG 5 (50°56′39,08″N, 22°40′34,68″E), Krowie Bagno IG-1 (51°30′03,44″N, 23°09′06,34″E) oraz Korczmin 1 (50°43′03,77″N, 24°01′00,12″E) znajdują się na obszarze basenu lubelskiego (Fig. 1). Tak rozlokowana sieć profili pozwoliła na uzyskanie kompleksowych danych palinologicznych dla tego regionu. Z pięciu rdzeni wiertniczych (Szwejki IG-3, Niesiołowice IG-1, Giełczew PIG 5 i Krowie Bagno IG-1) oraz z odsłonięć w Miłoszowie (profile M0, M1, M2) uzyskano próbki zawierające palinomorfy. Profile Zaręby IG-2 i Korczmin 1 dostarczyły próbek, które nie zawierały żadnych palinomorf. Z profilu Zaręby IG-2 przemacerowano 50 próbek, z profilu Korczmin 1 maceracji poddano 10 próbek.

2.1 Obszar kielecki, Góry Świętokrzyskie (otwór wiertniczy Kowala 1)

Otwór wiertniczy Kowala 1 odwiercony został w latach 1981-82, w pobliżu północnej ściany kamieniołomu Kowala znajdującego się w południowej (kieleckiej) części Gór Świętokrzyskich (Romanek i Rup, 1990). Analizowany interwał (głębokość 633-535 m; Kondas i Filipiak, 2021; Fig. 2) znajduje się w obrębie płytkomorskiej formacji z Kowali reprezentującej sukcesję platformy węglanowej (= kompleksu ławicowo-rafowego w ujęciu Rackiego, 1993), której depozycja miała miejsce wzdłuż południowo-wschodniego brzegu paleokontynentu Laurussi (Narkiewicz et al., 1990, Bełka i Narkiewicz, 2008). Warstwy stringocefalowe, będące spągową częścią żywetu formacji z Kowali (od głębokości 846 m) reprezentowane są przez dolomity oraz wyżej ległe facje karolowcowo-stromatoporoidowe (Romanek i Rup, 1990). W efekcie transgresji morskiej, która miała miejsce w późnym żywecie, nastąpiła depozycja warstw o charakterze mikrytycznych wapieni marglistych (ogniwo z Jaźwicy, głębokość 633,2-616,3 m; patrz fig. 14 w Racki, 1993, Narkiewicz et al., 1990, Romanek i Rup, 1990). Osady o charakterze węglanowym przykryte zostały przez warstwy sitkówczańskie będące głównie biostromami koralowcowo-stromatoporoidowymi, których wiek sięga franu (Bełka i Narkiewicz, 2008). Stropowa część formacji z Kowali lokowana jest na głębokości 412 m (Narkiewicz et al., 1990).

2.2 Basen łysogórsko-radomski, część łysogórska (odsłonięcie w Miłoszowie)

Odsłonięcia zlokalizowane są w pobliżu osady Miłoszów, nieopodal wsi Nieczulice. Obszar ten należy do północnej (łysogórskiej) części Gór Świętokrzyskich. Próbki pobrano z warstw skalskich, reprezentowanych przez wapienie, margle oraz pakiety łupków (Malec i Turnau, 1997; Halamski, 2004, Kondas i Filipiak, 2022a), poniżej których znajdują się warstwy wojciechowickie, a nad którymi zalegają warstwy świętomarskie. Sukcesja ta jest zapisem depozycji węglanowej i silikoklastycznej (deltowej) w warunkach płytkiego szelfu (Skompski i Szulczewski, 1994; Halamski i Racki, 2005; Malec 2012). Osady będące przedmiotem analiz były deponowane w wewnątrz-szelfowej części basenu związanej z transgresją morską zdarzenia Kačak zapoczątkowaną w późnym eiflu (Racki, 1993; Skompski i Szulczewski, 1994; Szulczewski 1995).

2.3 Basen łysogórsko-radomski, część radomska (otwory wiertnicze Szwejki IG-3 oraz Niesiołowice IG-1)

Radomska część basenu łysogórsko-radomskiego od SW graniczy z blokiem małopolskim, z kolei od NE z elewacją radomsko-kraśnicką (Narkiewicz i Dadlez, 2008). W pracy przyjęto schemat litostratygraficzny zaproponowany przez Narkiewicza et al. (2011), stąd analizowane interwały obejmują kilka jednostek litostratygraficznych: silkoklastyczno-węglanową formację z Bąkowej (wraz z ogniwem z Łazisk), która w analizowanym interwale profilu Szwejki IG-3 znajduje się na głębokości 4983-4551 m, a w otworze Niesiołowice IG-1 na głębokości 1517-1338,6 m. Węglanowa formacja ze Szwejków w otworze Szwejki IG-3 występuje na głębokości 4551-4352 m, a w Niesiołowicach IG-1 na głębokości 1338,6-1330 m. W przypadku otworu Szwejki IG-3 analizowany interwał obejmuje także formację z Iłżanki (głębokość 4352-4300,4 m), składającą się głównie z iłowców i zmiennej ilości węglanów. Stropowa próbka z otworu Szwejki IG-3 (4299 m) reprezentuje serię dolomitów i wapieni, która zalega bezpośrednio na osadach formacji z Iłżanki (Kondas i Filipiak, 2022b).

2.4 Basen lubelski (otwory wiertnicze Giełczew PIG 5 oraz Krowie Bagno IG-1)

Basen lubelski od SW graniczy z basenem łysogórsko-radomskim, natomiast na wschodzie jego zasięg ograniczony jest w sztuczny sposób przez granice państwowe (Narkiewicz, 2011b). Również w tym przypadku przyjęty został schemat litostratygraficzny zaproponowany przez Narkiewicza et al. (2011). Według Narkiewicza (2011b) osady środkowego dewonu oraz wczesnego franu zostały zdeponowane w wyniku siedmiu cykli transgresywno-regresywnych. Analizowany interwał obejmuje formację telatyńską (ogniwo giełczewskie) oraz zalegającą na niej formację modryńską. Formacja telatyńska wykazuje znaczące różnice w sposobie wykształcenia: dolna część jest reprezentowana głównie przez piaskowce, mułowce oraz iłowce, z kolei górna część przez osady węglanowe (Narkiewicz, 2011b). Ogniwo giełczewskie, podobnie jak zalegająca powyżej niego formacja modryńska, w analizowanych interwałach mają charakter osadów głównie węglanowych (Narkiewicz et al., 2011).

3. MATERIAŁ I METODY

Wszystkie pobrane próbki zostały opisane, ponumerowane i zabezpieczone za pomocą foliowych torebek. Dla próbek pobranych z rdzeni wiertniczych odnotowano głębokość z jakiej dana próbka została pobrana oraz numer skrzynki w której znajdował się rdzeń. Próbki pobrane z profilu M0 w Miłoszowie opisane zostały numerem warstwy z której pochodziły. Próbki z profili M1 oraz M2 w Miłoszowie zostały dostarczone przez dr hab. Adama Halamskiego (Polska Akademia Nauk w Warszawie).

W celu pozbycia się części mineralnych wszystkie pozyskane próbki poddane zostały procesowi standardowej maceracji z użyciem kwasu solnego oraz kwasu fluorowodorowego (Wood et al., 1996; Riding, 2021). Węglany usunięte zostały przy pomocy kwasu solnego o stężeniu 30 %. Następnie każda z próbek w celu usunięcia krzemianów poddana została działaniu 40 % kwasu fluorowodorowego. Próbki w których stwierdzono obecność pozostałości węglanów powtórnie poddano działaniu kwasu solnego. Uzyskane w ten sposób organiczne residuum zdekantowano przy użyciu wody destylowanej, a następnie przesiano na sicie o gęstości oczek 10 µm. Jeżeli w próbce stwierdzono taką ilość amorficznej substancji organicznej (AOM), która uniemożliwiała obserwację palinomorf, dla próbki przygotowywano dwa rodzaje preparatów: pierwszy z zachowaną w całości AOM oraz drugi z usuniętą AOM. Do usunięcia AOM stosowano 100 % dymny kwas azotowy, przy czym minimalny czas oddziaływania kwasu na próbkę to 30 minut. Dla wszystkich czynności w procesie maceracji użyto naczyń jednorazowego użytku. Z maceratów wykonano po dwa standardowe preparaty mikroskopowe dla każdej pobranej próbki, która nie zawierała AOM oraz trzy preparaty dla każdej próbki zawierającej AOM. Do obserwacji preparatów wykorzystane zostały mikroskopy do światła przechodzącego Nikon Eclipse 50i oraz Optika B-510BF z oprogramowania NIS-Elements D oraz kamerą NIK-Cam Pro-1. Wybrane próbki, zawierające szczególnie interesujące palinomorfy, poddane zostały obserwacji z użyciem elektronowego środowiskowego mikroskopu skanningowego (ESEM) Philips XL30. Na podstawie literatury obserwowane palinomorfy zostały przypisane do właściwych im jednostek taksonomicznych, co stanowiło punkt wyjścia do dalszych analiz: palinostratygraficznej oraz palinofacjalnej.

Na potrzeby analiz palinostratygraficznych wykorzystano zonację zaproponowaną przez Richardsona i McGregora (1986) dla kontynentu Old Redu oraz obszarów do niego przylegających, Streela et al. (1987) dla obszaru Ardenów i Reńskich Gór Łupkowych, Avkhimovitch et al. (1993) odnoszącą się do Europy wschodniej oraz lokalne schematy sporowe zaproponowane przez Turnau (1996, 2007, 2011) dla Pomorza Zachodniego i obszaru radomsko-lubelskiego .

Dla wszystkich badanych profili za wyjątkiem profilu Kowala 1 wykonano analizę palinofacjalną. W każdym preparacie, w którym liczba palinomorf przekroczyła 500, odliczono 500 kolejnych okazów, które podzielone zostały według ich pochodzenia na lądowe oraz morskie. Poszczególne kategorie palinomorf wyznaczane były w zależności od tego jakie zespoły były obserwowane w danym profilu (szczegóły patrz Kondas i Filipiak, 2022a, 2022b). Następnie prześledzono zmiany w ilości materiału pochodzenia lądowego i morskiego. Wykorzystane do przeprowadzania analiz preparaty, maceraty oraz świadki, znajdują się w Instytucie Nauk o Ziemi Wydziału Nauk Przyrodniczych Uniwersytetu Śląskiego.

3.1 Szczegóły opróbowania w poszczególnych stanowiskach i charakterystyka występujących zespołów mikroflorystycznych

Z uwagi na niesprzyjającą analizom palinologicznym wapienną litologię, celowo z rdzenia wiertniczego Kowala 1 pobrano podwyższoną ilość próbek, tak by możliwie najbardziej zwiększyć prawdopodobieństwo uzyskania palinomorf. Spośród 60 pozyskanych próbek pobranych z głębokości 633,3-340,10 m jedynie cztery pobrane z głębokości 633-535 m zawierały rozpoznawalne palinomorfy (Fig. 2). Stan zachowania palinomorf był różny - od złego po bardzo dobry. W próbkach odnotowano obecność miospor, megaspor, tetrad miosporowych, organicznych tentakulitów oraz nielicznych skolekodontów, prazynofitów i akritarch. Miospory istotne z punktu widzenia palinostratygrafii oraz organiczne tentakulity pokazane są na planszach 1-4 (patrz: Kondas i Filipiak, 2021).

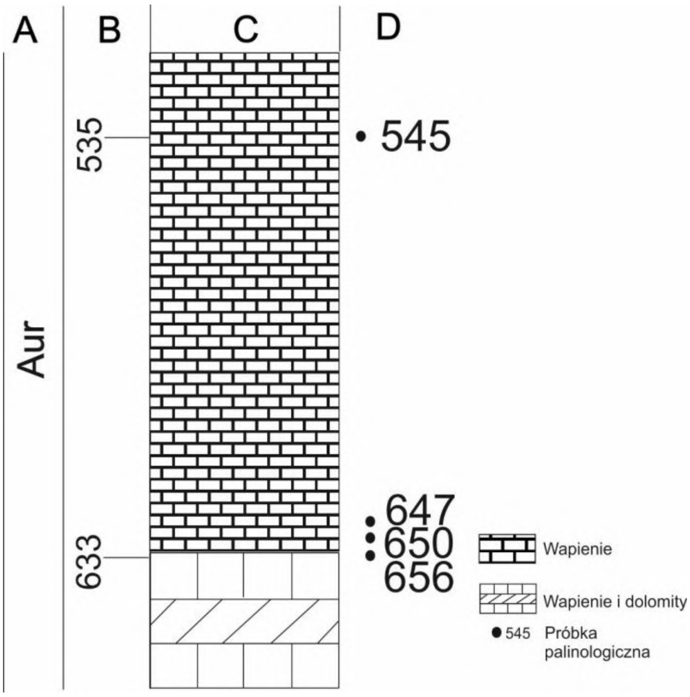

Fig. 2. Profil badanego interwału w otworze wiertniczym Kowala 1. A-wyznaczony poziom miosporowy, B-głębokość w m, C-litologia, D-numer pozytywnej próbki palinologicznej (wzięte z: Kondas i Filipiak, 2021, zmienione).

Z obszaru basenu łysogórsko-radomskiego próbki pobrane zostały z trzech profili z odsłonięć w Miłoszowie oraz z dwóch rdzeni wiertniczych: Szwejki IG-3 oraz Niesiołowice IG-1 (Fig. 1). Odsłonięcia w Miłoszowie dostarczyły łącznie 36 próbek, przy czym z profilu M0 pobrano 18 pozytywnych próbek, z profilu M1 zbadano 12 próbek (pięć zawierało palinomorfy), a z profilu M2 sześć próbek (cztery zawierały palinomorfy; Fig. 3). Stan zachowania palinomorf pozyskanych z profilu M0 był różny - palinomorfy pozyskane z łupków określić można jako zachowane dobrze lub średnio, natomiast te pozyskane z wapieni były źle zachowane. Próbki z profili M1 oraz M2 zawierały źle zachowane pozostałości organiczne. Palinomorfy były silnie zmienione termiczne, a także z widocznymi śladami utleniania (patrz: Kondas i Filipiak, 2022a; plansze II i III). Wszystkie pobrane próbki pochodzą z warstw skalskich.

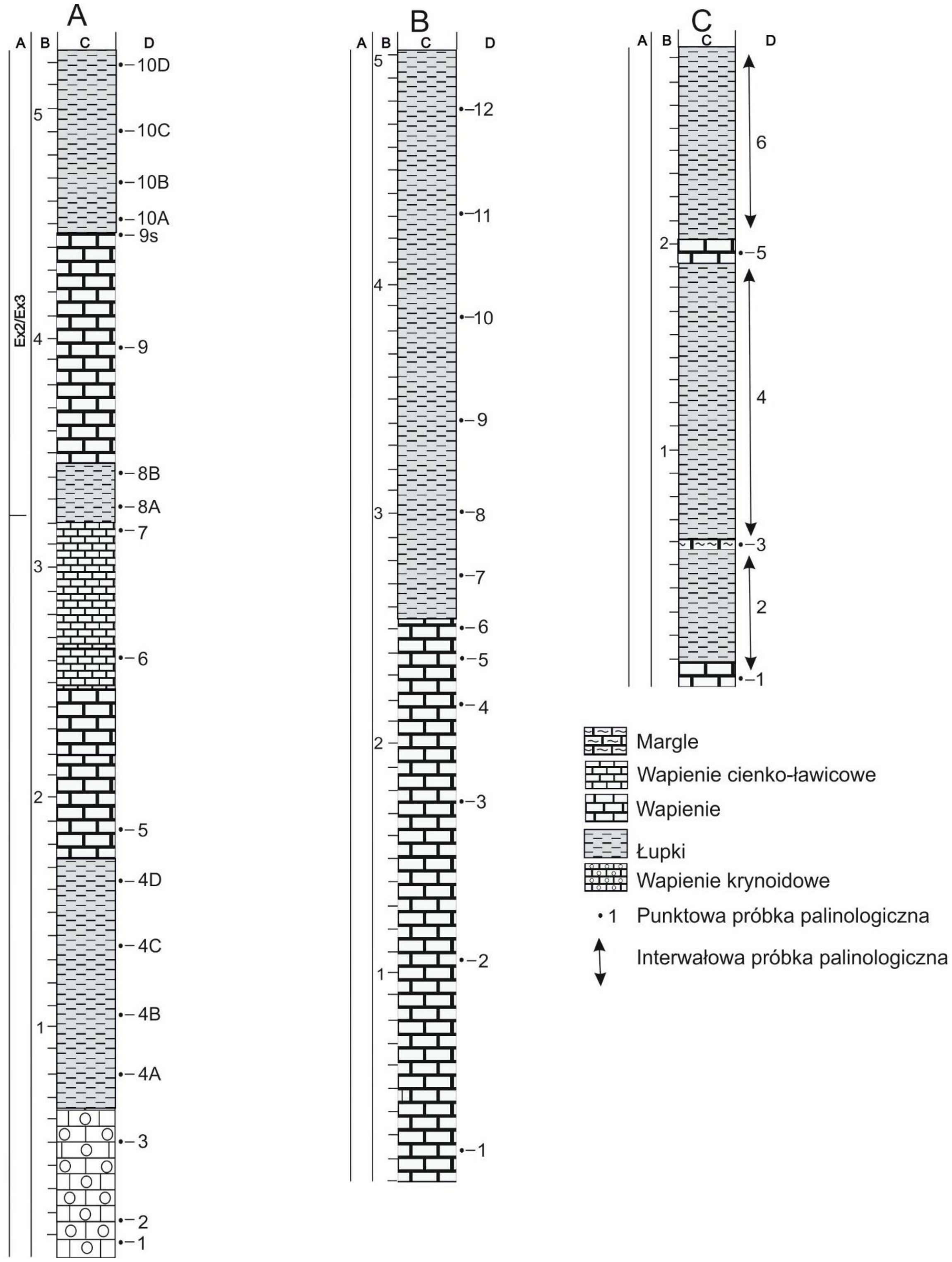

Fig. 3. Profile M0, M1 i M2 z odsłonięć w Miłoszowie. A-wyznaczony poziom miosporowy, B-wysokość w m nad spągiem, C-litologia, D-numer próbki palinologicznej. (wzięte z: Kondas i Filipiak, 2022a, zmienione).

Otwór wiertniczy Szwejki IG-3 (Fig. 4) dostarczył 39 próbek (23 próbki pobrano w obrębie formacji z Bąkowej, w tym 7 pochodziło z ogniwa z Łazisk, 9 próbek z formacji ze Szwejków, 6 z formacji z Iłżanki oraz jedną z serii dolomitów i wapieni, wszystkie zawierające palinomorfy o bardzo dobrym stanie zachowania.

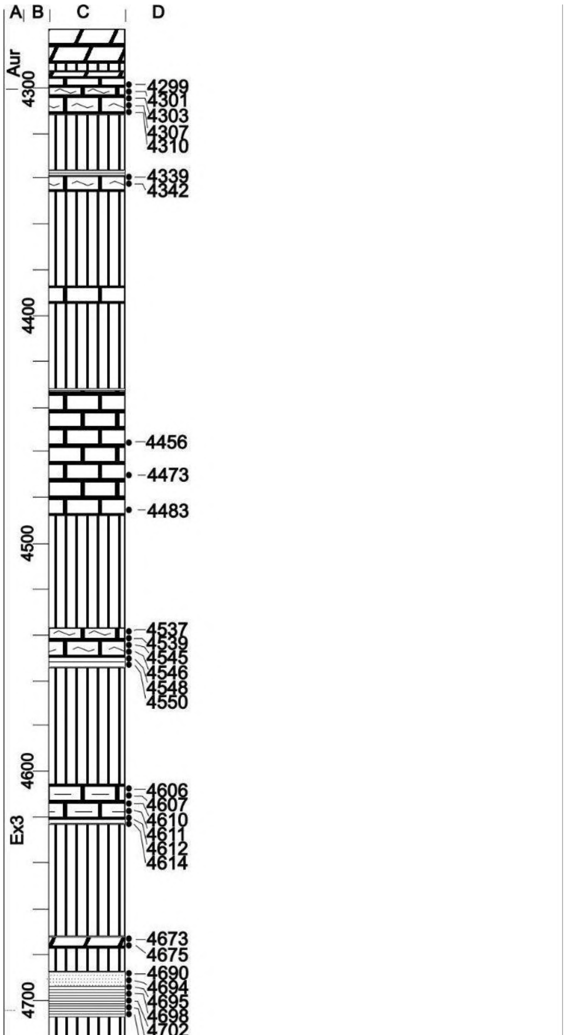

Fig. 4. Profil badanego interwału w otworze wiertniczym Szwejki IG-3. A-wyznaczony poziom miosporowy, B-głębokość w m, C-litologia, D-numer próbki palinologicznej (wzięte z: Kondas i Filipiak, 2022b, zmienione).

Nieco gorszy, jednak wciąż dobry stan zachowania prezentowały palinomorfy otrzymane z 27 próbek uzyskanych z otworu Niesiołowice IG-1 (24 próbki pozyskano z formacji z Bąkowej, w tym 20 z ogniwa z Łazisk, trzy próbki pobrane zostały z formacji ze Szwejków; Fig. 5).

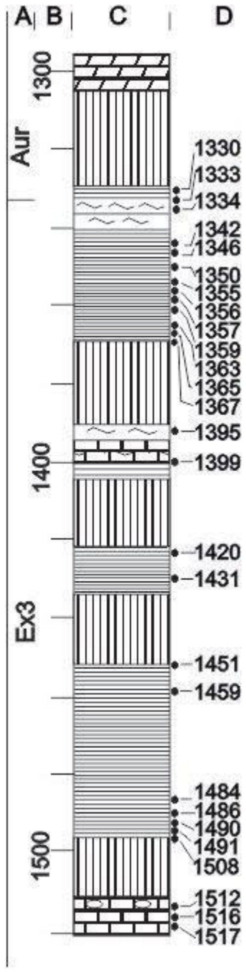

Fig. 5. Profil badanego interwału w otworze wiertniczym Niesiołowice IG-1. A-wyznaczony poziom miosporowy, B-głębokość w m, C-litologia, D-numer próbki palinologicznej. Objaśnienia litologiczne znajdują się pod Fig. 4 (wzięte z: Kondas i Filipiak, 2022b, zmienione).

W próbkach z basenu łysogórsko-radomskiego odnotowano obecność licznych bioklastów o niejasnym pochodzeniu biologicznym, miospor, pojedynczych megaspor oraz tetrad, niewielkich ilości prazynofitów, skolekodontów, chitinozoa oraz akritarch. Z obszaru basenu lubelskiego analizie poddano dwa profile: Giełczew PIG 5 oraz Krowie Bagno IG-1 (Fig. 1). Z otworu wiertniczego Giełczew PIG 5 pobrano 29 próbek (28 pochodziło z ogniwa giełczewskiego formacji telatyńskiej, jedna pobrana została z formacji modryńskiej; Fig. 6).

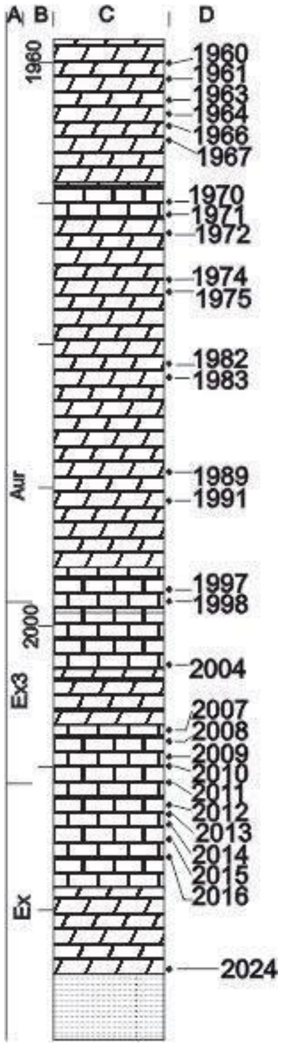

Fig. 6**.** Profil badanego interwału w otworze wiertniczym Giełczew PIG 5. A-wyznaczony poziom miosporowy, B-głębokość w m, C-litologia, D-numer próbki palinologicznej. Objaśnienia litologiczne znajdują się pod Fig. 4 (wzięte z: Kondas i Filipiak, 2022b, zmienione).

Z otworu Krowie Bagno IG-1 pobrano 13 próbek (cztery z ogniwa giełczewskiego formacji telatyńskiej i dziewięć z formacji modryńskiej; Fig. 7).

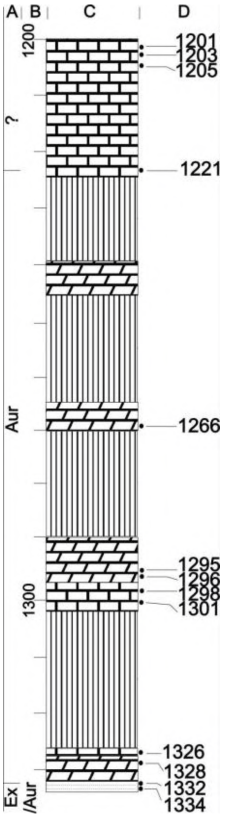

Fig. 7. Profil badanego interwału w otworze wiertniczym Krowie Bagno IG-1. A-wyznaczony poziom miosporowy, B-głębokość w m, C-litologia, D-numer próbki palinologicznej. Objaśnienia litologiczne znajdują się pod Fig. 4 (wzięte z: Kondas i Filipiak, 2022b, zmienione).

Profil Giełczew PIG 5 dostarczył próbki w których palinomorfy były bardzo dobrze zachowane. Udokumentowano wystąpienie znaczących ilości miospor oraz bioklastów, pojedynczych tetrad, nielicznych fitoklastów, skolekodontów, chitinozoa oraz sporadycznie pojawiających się akritarch i prazynofitów. Próbki palinologiczne z profilu Krowie Bagno IG-1, które zaliczono do wieku dewońskiego zawierały słabo zachowane, jednak oznaczalne taksonomicznie palinomorfy. Pośród nich udokumentowano miospory, fitoklasty, pojedyncze prazynofity, skolekodonty i akritarchy oraz bioklasty o niejasnej przynależności biologicznej.

4. PALINOSTRATYGRAFIA

4.1. Zarys problematyki

Palinostratygrafia jest metodą badań biostratygraficznych, której celem jest ustalenie wieku, najczęściej na podstawie występujących w osadzie zespołów miospor lub innych palinomorf. Metoda ta ma szczególne znaczenie dla osadów lądowych pozbawionych innych markerów stratygraficznych.

Zasadniczym celem analiz palinostratygraficznych jest ustalenie wieku badanych osadów w oparciu o ustalone schematy (zonacje) mikroflorystyczne. W zależności od idei danej zonacji może ona być oparta na występowaniu pojedynczych, wskaźnikowych gatunków lub na ilościowo-jakościowych relacjach obserwowanych w całym zespole miospor. Stąd zonacje mogą być konstruowane w oparciu o jeden bądź kilka rodzajów biozon, np. poziomy rozkwitu, poziomy współwystępowania, poziomy zasięgu czy poziomy częściowego zasięgu (patrz: Playford i Dettmann, 1996; Wrzołek, 2006). Poziomy zespołowe, które definiowane są w oparciu o występujące zespoły gatunków są bardziej przydatne niż poziomy wyznaczane na podstawie wystąpień pojedynczych gatunków (Playford i Dettmann, 1996). Zasięg lateralny jaki osiągają miospory zależy od ich cech morfologicznych, stąd wynika ich podatność na zmiany środowiskowe. Tym samym jeżeli do wyznaczenia zony użyty będzie pojedynczy gatunek, może się okazać że jego zasięg przestrzenny jest ograniczony i nie reprezentuje wszystkich środowisk w danym obszarze depozycji (Playford i Dettmann, 1996).

Palinostratygrafia osadów dewonu w Europie i Ameryce Północnej najczęściej oparta jest na zonacji Richardsona i McGregora (1986) skonstruowanej dla paleokontynentu Old Redu i sąsiadujących z nim regionów, zonacji Streela et al. (1987) dla Ardenów i Reńskich Gór Łupkowych oraz zonacji Avkhimovitch et al. (1993) dla Europy wschodniej. Często zdarza się jednak, że konkretne obszary posiadają swoją odrębność mikroflorystyczną i różnią się od typowych regionów dla których powstały schematy standardowe. Z tego powodu w pracy użyto lokalnych schematów dla obszaru Pomorza Zachodniego zaproponowanych przez Turnau (1996, 2007, 2008). Z uwagi na podobny skład zespołów mikroflorystycznych oraz kolejność pierwszych wystąpień dwóch charakterystycznych taksonów: *Chelinospora concinna* i *Samarisporites triangulatus*, które są takie same w Europie wschodniej i na obszarze Pomorza Zachodniego, Turnau (1996) za najbardziej użyteczny dla dewonu środkowego obszaru Polski uznała schemat z platformy wschodnioeuropejskiej zaproponowany przez Avkhimovitch et al. (1993). Problem jednak stanowiły pozostałe taksony wskazane w tym schemacie jako kluczowe do wyznaczenia zon, ponieważ w osadach z Polski pojawiały się rzadko lub w ogóle nie występowały. Tym samym zaproponowana została modyfikacja obejmująca zonę *Extensa*. Lokalna zona *“Geminospora” extensa* (Ex) obejmuje trzy podpoziomy: Ex1, Ex2 oraz najmłodszy Ex3. Dolna granica zony wyznaczona jest przez pierwsze pojawienie się gatunku *Geminospora lemurata*. Zdarzenie to w przybliżeniu odpowiada granicy eifel-żywet i na obszarze gór Eifel udokumentowane jest w obrębie poziomu konodonotowego *hemiansatus* (Łoboziak et al., 1991; Matyja i Turnau, 2008). Dolna granica podpoziomu Ex2 zdefiniowana jest przez pierwsze pojawienie się gatunku *Chelinospora concinna*. W obrębie tego poziomu zanikają gatunki *Cristatisporites collaris* var. *kalugianus* oraz *Hystricosporites setigerus* (Turnau, 2011). Pierwsze pojawienie się gatunku *Samarisporites triangulatus* wyznacza dolną granicę podpoziomu Ex3, natomiast za gatunki charakterystyczne Turnau (2011) uznała *Kraeuselisporites spinutissimus* oraz *Geminospora decora*. W obrębie tego podpoziomu zanika ważny takson *Lanatisporites bislimbatus*. Granica podpoziomów Ex2 oraz Ex3 zawiera się w poziomie konodontowym *ansatus* (Turnau, 2011). Poziom *Geminospora aurita* (Aur) jest lokalnym poziomem ustanowionym przez Turnau (2007, 2008) dla Pomorza Zachodniego wyznaczającym późny żywet oraz najwcześniejszy fran. Dolna granica poziomu wyznaczona jest przez zanik gatunku *Aneurospora extensa*, zaś cechą charakterystyczną całego poziomu jest niskie zróżnicowanie gatunkowe miospor (Turnau, 2007, 2008). Granica poziomów Ex/Aur przebiega w obrębie nierozdzielonych zon konodonotowych *ansatus-hermanni* (Turnau i Narkiewicz, 2011).

Jednoznaczne określenie pozycji górnej granicy poziomu Aur jest trudne. Według Turnau (2007; tab. 1, 2008) na obszarze Pomorza Zachodniego granica ta pokrywa się w przybliżeniu z granicą pięter żywetu i franu, jednak na obszarze lubelskim górna granica poziomu Aur przebiega w interwale reprezentującym prawdopodobnie zony konodontowe MN1 oraz MN2/3 (górny *falsiovalis*), tym samym obejmując najniższy fran (Turnau, 2011; fig. 3; Turnau i Narkiewicz, 2011; fig. 4).

4.2. Wyniki analizy palinostratygraficznej

Na podstawie:

Kondas, M., Filipiak, P. 2021. Organic tentaculitoids from the Kowala Formation (Devonian) of the Holy Cross Mountains, Poland. Palynology. 45(4): 657–668.

Kondas, M., Filipiak, P. 2022a. Middle Devonian (Givetian) palynology of the northern Holy Cross-Mountains (Miłoszów, south-central Poland). Review of Palaeobotany and Palynology. 301: 104629.

Kondas, M., Filipiak, P. 2022b. The palynology of the Middle-Upper Devonian (Givetian-Frasnian) in the Łysogóry-Radom and Lublin basins, south-central Poland. Palynology. https://doi.org/10.1080/01916122.2022.2140457.

Rozdział przedstawia streszczenie wyników analiz palinostratygraficznych, które szczegółowo opisane zostały w powyższych pracach i które wykonano dla wszystkich badanych profili. Rozpoznane poziomy obejmują żywet oraz prawdopodobnie wczesny fran (podpoziom Ex1 poziomu Ex-poziom Aur; Fig. 8). Wyniki zaprezentowano w kolejności od osadów najstarszych po najmłodsze.

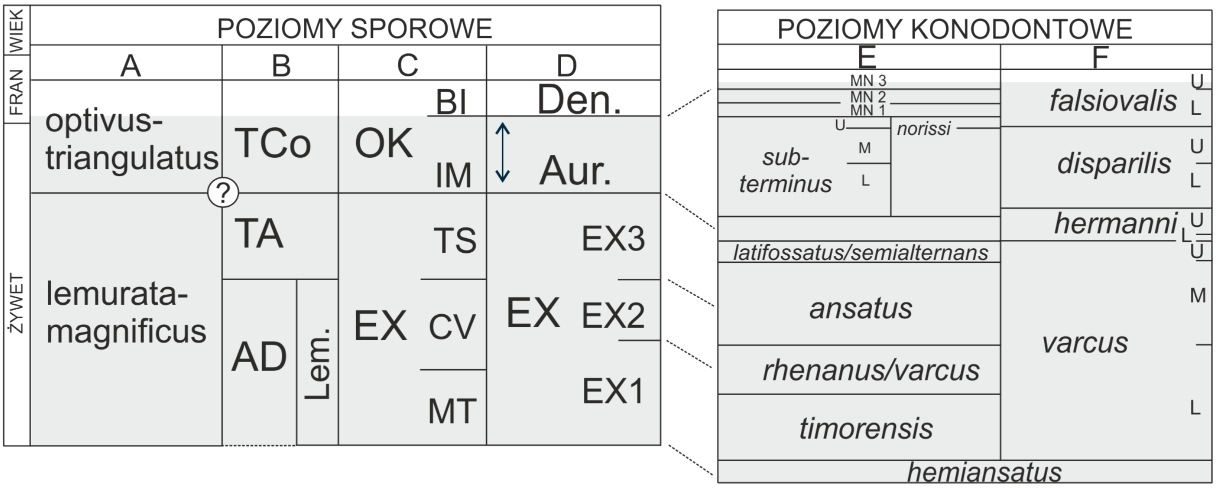

Fig. 8. Zonacje miosporowe orientacyjnie skorelowane z podziałami konodontowymi. Poziomy sporowe rozpoznane w analizowanych profilach zaznaczone są szarym kolorem. L - późny, M - środkowy, E - wczesny (dotyczy zonacji konodontowej). A - Richardson i McGregor (1986), B - Streel et al. (1987), C - Avkhimovitch et al. (1993), D - Turnau (1996, 2008, 2011), E – zonacja konodontowa dla środowisk płytkich basenów, F - zonacja konodontowa dla środowisk głębokich basenów. Przerywane linie wskazują przybliżoną korelację poziomów sporowych i konodontowych. Poziom Aur jest odpowiednikiem większej części podpoziomu IM (zaznaczone podwójną strzałką). Zonacje konodontowe podano za Klapper (1988); Clausen et al. (1993); Narkiewicz i Bultynck (2010), Narkiewicz et al. (2011), zmienione.

Korelacja profili w których rozpoznano pewne poziomy sporowe nie starsze niż Ex3 przedstawiona jest na Fig. 9.

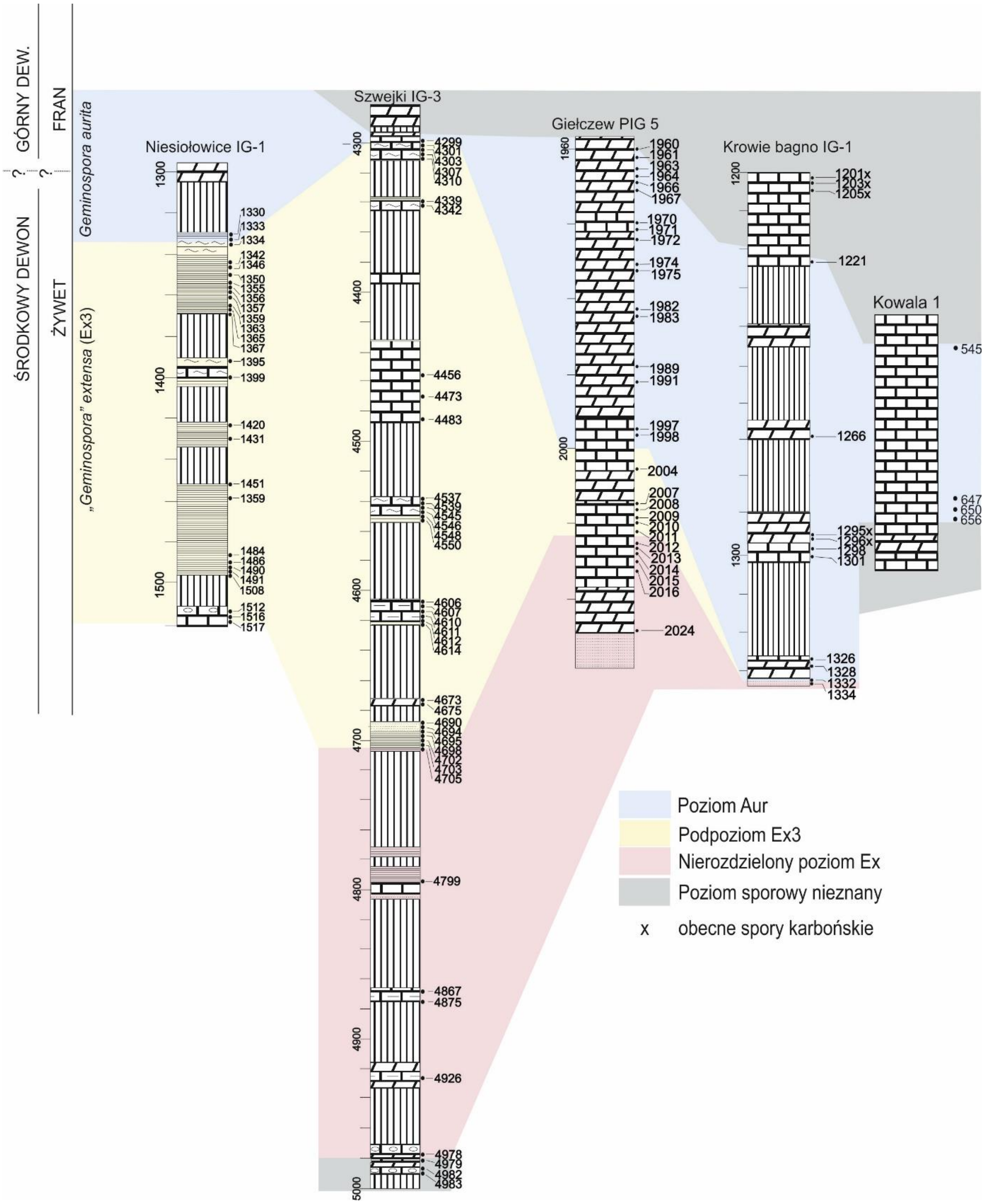

Fig. 9. Korelacja profili basenu łysogórsko-radomskiego, basenu lubelskiego oraz profilu Kowala 1. Z uwagi na to, że wiek najmłodszych osadów z odsłonięcia w Miłoszowie ustalony został na podpoziom Ex2, nie są one ujęte na powyższej figurze.

4.2.1. Basen łysogórsko-radomski (odsłonięcia w Miłoszowie; profile M0, M1, M2)

W oparciu o zespół mikroflory lądowej w profilu M0 z Miłoszowa udokumentowano poziom Ex (Kondas i Filipiak, 2022a). Miospory oznaczone w próbkach numer 1, 2 oraz 3 prawdopodobnie reprezentują podpoziom Ex1. Ponieważ w próbce numer 3 odnotowano obecność gatunku *Geminospora lemurata*, stąd próbki 1 oraz 2 nie mogą być młodsze. Jednak z uwagi na zły stan zachowania miospor wynik traktować należy z przybliżeniem. Niepewne datowania dotyczą także próbki 4A, w której nie znaleziono taksonów indeksowych dla żadnego z podpoziomów, w związku z czym została ona zaliczona do nierozdzielonego interwału Ex1-Ex2 (Kondas i Filipiak, 2022a). W próbce 4B odnotowano obecność gatunku *Chelinospora concinna*, który pozwolił wydatować ją na podpoziom Ex2. Z uwagi na to, że w próbkach 4C oraz 4D udokumentowano pojawienie się miospor takich jak np. *Aneurospora extensa*, *Rhabdosporites langii* czy *R. streelii*, próbki te również zaliczono do podpoziomu Ex2. Materiał uzyskany z próbek 5, 6 oraz 7 był źle zachowany ale ponieważ odnotowano pojawienie się *C. concinna* w próbkach 4B i następnie 10A, próbki 5, 6 i 7 nie mogą być młodsze lub starsze niż podpoziom Ex2 (Kondas i Filipiak, 2022a). Problematyczny interwał stanowiły próbki 8A-10D. W próbkach 8A, 8B, 10B, 10C i 10D udokumentowano obecność miospor zbliżonych pod względem morfologii do *Samarisporites triangulatus* jednak stan zachowania mikroflory uniemożliwiał jednoznaczne stwierdzenie obecności tego taksonu. Tym samym problematyczne próbki zaliczone zostały do nierozdzielonego interwału Ex2-Ex3 (Kondas i Filipiak, 2022a).

W profilu M1 udokumentowano obecność gatunków *Aneurospora extensa* oraz *Geminospora lemurata*, przy czym nie stwierdzono obecności gatunku *Chelinospora concinna*. W związku z tym wiek próbek pozyskanych z profilu M1 ustalony został w przybliżeniu na podpoziom Ex1. Niepewność datowania wynika z nienajlepszego stanu zachowania organiki (Kondas i Filipiak, 2022a).

Podobnie w profilu M2 na podstawie obecności *A. extensa* oraz *G. lemurata* i braku *C. concinna* wiek określono jako prawdopodobny podpoziom Ex1. Zły stan zachowania materiału obarczył ten wynik niepewnością (Kondas i Filipiak, 2022a).

4.2.2. Basen łysogórsko-radomski (otwory wiertnicze Szwejki IG-3 oraz Niesiołowice IG-1)

Zespoły miospor z próbek uzyskanych z otworów wiertniczych Szwejki IG-3 oraz Niesiołowice IG-1 wskazują na obecność utworów młodszych niż te pozyskane z odsłonięć w Miłoszowie (Kondas i Filipiak, 2022b).

W profilu Szwejki IG-3 (Fig. 9) próbki z głębokości 4983, 4982 oraz 4979 m zawierały niewielkie ilości mikroflory lądowej, nie odnotowano obecności indeksowych taksonów stąd wiek tych osadów jest niepewny poziom Ex (lub starsze). Wyżej legły interwał skalny z głębokości 4978-4705 m zaliczony został do nierozdzielonego poziomu Ex. Udokumentowano występowanie gatunku *Aneurospora extensa* na głębokościach 4978, 4867, 4799 oraz 4705 m jednak z uwagi na brak drugiego indeksowego taksonu nie było możliwym określenie podpoziomu. Skład zespołu wskazuje na możliwy podpoziom Ex2 lub Ex3 (Kondas i Filipiak, 2022b). Interwał skalny pomiędzy głębokościami 4703 do 4301 m zaliczony został do podpoziomu Ex3. Udokumentowano wystąpienie obu ważnych dla wyznaczenia podpoziomu taksonów: *A. extensa* oraz *Samarisporites triangulatus* (Kondas i Filipiak, 2022b). Ponieważ w próbce z głębokości 4299 m nie stwierdzono obecności gatunku *A. extensa*, natomiast odnotowano pojawienie się miospor *Geminospora aurita* i *G. notata*, stąd próbka ta zaliczona została do lokalnego poziomu Aur (Kondas i Filipiak, 2022b).

W profilu Niesiołowice IG-1 (Fig.9) rozpoznano dwa poziomy sporowe. W próbkach z głębokości 1517-1334 m stwierdzono obecność gatunków *A. extensa* oraz *S. triangulatus* co jednoznacznie wskazuje na podpoziom Ex3 zony Ex. W dwóch próbkach z głębokości 1333 oraz 1330 m nie zaobserwowano obecności *A. extensa*, w związku z czym włączono je do zony Aur. Co istotne, w obu próbkach pojawiły się *G. aurita*, *G. micromanifesta* i *G. notata*, które potwierdziły datowanie tych osadów (Kondas i Filipiak, 2022b).

4.2.3. Basen lubelski (otwory wiertnicze Giełczew PIG 5 oraz Krowie Bagno IG-1)

Szczegółowe analizy palinostratygraficzne dla profilu Giełczew PIG 5 zostały wykonane przez Turnau (2011), a uzyskane aktualne wyniki są z nimi zbieżne (Fig. 9). Próbki pochodzące z interwału 2024-2012 m zaliczyć można do zony Ex, w żadnej z nich nie zaobserwowano obecności *C. concinna* oraz *S. triangulatus* (Kondas i Filipiak, 2022b). Oba indeksowe gatunki *A. extensa* oraz *S. triangulatus* pojawiły się w próbkach pobranych z głębokości 2011-2004 m, co pozwoliło określić wiek tych osadów jako podpoziom Ex3 zony Ex (Kondas i Filipiak, 2022b). Nie zaobserwowano gatunku *A. extensa* w próbkach pobranych z głębokości 1998 do 1960 m, a jednocześnie w tym interwale odnotowano obecność gatunków *Convolutispora subtilis*, *G. aurita*, *G. micromanifesta* i *G. notata* tym samym zaliczając ten interwał do poziomu Aur (Kondas i Filipiak, 2022b).

Znacznym problemem okazało się ustalenie wieku osadów z profilu Krowie Bagno IG-1. Z uwagi na brak gatunków indeksowych nie było możliwe jednoznaczne określenie wieku osadów z próbki pochodzącej z głębokości 1334 m, może ona należeć zarówno do poziomu Ex jak i Aur. W próbkach z głębokości 1326 m oraz 1221 m nie odnotowano obecności *A. extensa*, pojawiła się *G. aurita*, a także inne taksony charakterystyczne dla poziomu Aur np. *Geminospora micromanifesta* (1332 m, 1328 m), *Geminospora notata* (1326 m) czy *Spelaeotriletes krestovnikovii* (1326 m). W próbkach pochodzących z głębokości 1301, 1298 i 1266 m z uwagi na brak jakichkolwiek palinomorf przydatnych do datowania nie było możliwe określenie poziomu sporowego (Kondas i Filipiak, 2022b). Szczególnie interesujące okazały się być próbki pozyskane z głębokości 1296, 1295, 1205, 1203 i 1201 m. Każda z nich zawierała karboński zespół miospor, udokumentowano w nich taksony takie jak np. *Cingulizonates* spp., *Cirratriradites saturni*, *Densosporites* spp., *Florinites* spp., *Lycospora pusilla*, *Raistrickia fulva*, czy *Tripartites vetustus* (Kondas i Filipiak, 2022b; Fig. 9). Zjawisko to najprawdopodobniej związane jest z położeniem otworu w strefie intensywnej erozji i tym samym infiltracją karbońskich osadów zalegających nad formacją modryńską w osady dewonu (patrz np. Narkiewicz, 2005; Narkiewicz et al., 2011).

4.2.4. Góry Świętokrzyskie (część kielecka, otwór wiertniczy Kowala 1)

Próbki z profilu Kowala 1 zawierały nieliczny zespół mikroflory lądowej. W zespole odnotowano obecność takich gatunków jak *Geminospora aurita*, *G. micromanifesta*, *G. notata* czy *Samarisporites triangulatus*. Jednocześnie nie zaobserwowano występowania gatunku *Aneurospora extensa*, co pozwoliło włączyć analizowany interwał do poziomu Aur (Kondas i Filipiak, 2021). Obecność gatunku *Ancyrospora incisa* współwystępującego z *G. micromanifesta* wskazuje na podpoziom *Ancyrospora incisa–Geminospora micromanifesta* zony *Contagisporites optivus–Spelaeotriletes krestovnikovii* (Avkhimovitch et al., 1993) korespondującej z lokalnym poziomem Aur (Turnau, 2008, 2011).

5. ANALIZA PALINOFACJALNA

5.1. Zarys problematyki

Materia organiczna znajdująca się w skałach osadowych jest nośnikiem wielu informacji dotyczących środowiska depozycji tych osadów. Analiza palinofacji jest metodą pozwalającą na pozyskanie informacji środowiskowych w oparciu o szczegółowe rozpoznanie szczątków organicznych uzyskanych w palinologicznym procesie maceracji skały. Po raz pierwszy pojęcie palinofacji zostało wprowadzone do literatury przez Combaza (1964). Termin ten określał całkowitą zawartość kwasoodpornej materii organicznej, którą można otrzymać ze skały w procesie palinologicznych metod maceracji i która możliwa jest do obserwacji w mikroskopie świetlnym. Na wieloznaczność tego terminu zwrócili uwagę Powell et al. (1990). Zaproponowali oni zmodyfikowaną definicję palinofacji jako zespołu palinoklastów, którego skład odzwierciedla konkretne środowisko depozycji. Trudno mówić o jednomyślności w interpretacji tego terminu, przez wielu autorów stosowany był on z dużą swobodą i jego rozumienie uzależnione było od intencji autora oraz celów w jakich stosował analizę palinofacji (patrz: dyskusja w Batten, 1996).

W związku z rozwojem analizy palinofacjalnej do literatury wprowadzony został termin materii palinologicznej. W literaturze funkcjonuje szereg klasyfikacji materii palinologicznej (patrz np. Burgess, 1974; van Bergen et al., 1990; Tyson, 1995). Jednym z najczęściej przytaczanych jest podział zaproponowany przez Battena (1996). W tej klasyfikacji materia palinologiczna składa się z trzech rodzajów pozostałości organicznych: palinomorf, strukturalnej materii organicznej (SOM) oraz bezstrukturalnej materii organicznej (USTOM). W pierwszej grupie znajdują się wszystkie wyodrębnione, kwaso-odporne mikroskamieniałości, które mogą znajdować się w preparatach palinologicznych. Niektórzy autorzy termin palinomorfy stosują w przypadku wyłącznie tych szczątków, które można sklasyfikować taksonomicznie (Słodkowska, 2003). Wszystkie organiczne pozostałości, które nie są palinomorfami, a posiadają widoczną strukturę włączane są do kategorii SOM. Szczątki te mają widoczną strukturę komórkową lub wykazują inne cechy dzięki którym można je powiązać ze światem roślin (fitoklasty) lub zwierząt (zooklasty). Pozostałą część materii organicznej stanowi materia organiczna pozbawiona widocznej struktury.

Co istotne, w analizie palinofacjalnej badaniom podlega całość materii organicznej, nie tylko palinomorfy. Ustalenie proporcji pomiędzy składnikami pochodzenia lądowego (sporomorfy, zoomorfy, słodkowodny fitoplankton, fitoklasty, zooklasty) i morskiego (morski fitoplankton, akritarchy, zoomorfy) pozwala na określenie warunków depozycji osadów oraz warunków paleośrodowiskowych. Ponieważ zespoły palinomorf obserwowane w osadzie charakteryzują różne środowiska depozycji, ustalenie względnych oraz rzeczywistych relacji pomiędzy tymi grupami pozwala na szereg interpretacji dotyczących środowiska depozycji takich jak: wahania poziomu morza, zmiany dynamiki wód, szacowanie wielkości produkcji pierwotnej oraz na ocenę warunków natlenienia (Tyson, 1995).

Obecność spor oraz ziaren pyłków w osadzie uzależniona jest od szeregu czynników m.in. ich wielkości, morfologii, warunków klimatycznych czy produktywności roślin macierzystych (Tyson, 1995). Ich występowanie związane jest z istotnymi czynnikami środowiskowymi np. odległością od brzegu zbiornika czy dynamiką wód zbiornika, są więc znaczącym wskaźnikiem paleośrodowiska (Tyson, 1995). Fitoplankton stanowi liczną i różnorodną grupę palinomorf, przy czym w analizowanych osadach reprezentowany był przez akritarchy oraz prazynofity.

Szczegółową analizę akritarch jako wskaźników paleośrodowiskowych przeprowadził Dorning (1981) wskazując na relację pomiędzy środowiskiem depozycji, a zróżnicowaniem taksonomicznym zespołów oraz dominującymi w zespole cechami morfologicznymi. Podobnie jak sporomorfy, akritarchy można zatem uznać za ważne narzędzie w ocenie odległości paleobrzegu oraz energii środowiska (Tyson, 1995). Prazynofity są grupą, która pojawiać się może zarówno w osadach słodkowodnych, jak i morskich. Ich obecność oraz ilość wskazuje na odległość od brzegu, mogą być również użytecznym wskaźnikiem oceny wielkości produkcji pierwotnej oraz natlenienia zbiornika (Tyson, 1995). Zoomorfy stanowią zróżnicowaną grupę, która w analizowanych osadach reprezentowana była głównie przez chitinozoa, skolekodonty oraz organiczne pozostałości tentakulitów. Zoomorfy są wskaźnikiem warunków tlenowych, ich ilość wskazuje także na typ środowiska depozycji (Tyson, 1995). Palinoklasty (fitoklasty, zooklasty oraz AOM) pozwalają na interpretację dotyczące długości transportu materii organicznej, określenia środowiska depozycji oraz odległości od brzegu (Tyson, 1995).

Warto zwrócić uwagę także na ograniczenia jakie pojawiają się podczas analizy palinofacji. Najczęściej związane są one ze stanem zachowania organiki. Na zły stan zachowania, a w konsekwencji brak możliwości lub znaczne trudności w rozpoznaniu palinomorf wpływ mogą mieć zmiany termiczne organiki oraz procesy wietrzenia. Im bardziej zmieniona termicznie lub zwietrzała jest materia organiczna, tym mniej czytelny staje się obraz palinofacji (Tyson, 1995). Szczególne znaczenie ma także proces transportu, który wpływa na stopień wysortowania materii organicznej oraz często związany jest ze stopniem utlenienia organiki (Batten, 1996). Znacząca część materii organicznej w środowisku tlenowym ulega degradacji już na etapie transportu lub opadania w kolumnie wody co związane jest między innymi z fizycznym rozpadem szczątków oraz aktywnością bakterii czy grzybów (Batten, 1996). Tym samym korzystniejsze warunki dla zachowania materii organicznej obecne są w środowiskach ubogich w tlen lub beztlenowych (Batten, 1996).

5.2. Wyniki analizy palinofacji

Na podstawie:

Kondas, M., Filipiak, P. 2022a. Middle Devonian (Givetian) palynology of the northern Holy Cross-Mountains (Miłoszów, south-central Poland). Review of Palaeobotany and Palynology. 301: 104629.

Kondas, M., Filipiak, P. 2022b. The palynology of the Middle-Upper Devonian (Givetian-Frasnian) in the Łysogóry-Radom and Lublin basins, south-central Poland. Palynology. https://doi.org/10.1080/01916122.2022.2140457.

Analiza palinofacji wykonana została dla wszystkich badanych profili z wyjątkiem profilu Kowala 1, co wynikało z niewielkiej ilości pozytywnych próbek pozyskanej z tego rdzenia. Rozdział przedstawia streszczenie wyników, które szczegółowo omówione zostały w składających się na tę rozprawę artykułach (Kondas i Filipiak, 2022a; Kondas i Filipiak, 2022b).

5.2.1. Basen łysogórsko-radomski (odsłonięcie w Miłoszowie; profile M0, M1, M2)

W profilach M0, M1 oraz M2 najważniejszym ograniczeniem dla wykonywanej analizy palinofacji był stan zachowania materii organicznej (Kondas i Filipiak, 2022a). W profilach M0 i M1 dominowały palinomorfy pochodzenia lądowego (Fig. 10). Zespół miospor był liczny i zróżnicowany taksonomicznie, przy czym dominującymi rodzajami były *Ancyrospora*, *Aneurospora*, *Geminospora* oraz *Rhabdosporites*. Tym samym flora okolic Miłoszowa reprezentowana była głównie przez aneurofity (w tym przedstawicieli *Aneurophyton* i *Archeopteris*) oraz widłaki (Allen, 1980; Gensel, 1980; Wellman, 2002, 2009). Fitoklasty (tkanki przewodzące oraz kutikule) były nieliczne. Morskie palinomorfy stanowiły mniejszość i reprezentowane były głównie przez akritarchy (*Gorgonisphaeridium*, *Micrhystridium*, *Navifusa*, *Stellinium*), prazynofity (*Cymatiosphaera*, *Dictyotidium*, *Muraticavea*, *Leiosphaeridia*, *Polyedrixium*) oraz skolekodonty. Profil M2 znacznie odbiegał od tego schematu, w próbkach najliczniejszymi palinomorfami były prazynofity, reprezentowane głównie przez *Leiosphaeridia* (Fig. 10). W próbce 4 z profilu M2 odnotowano także obecność chitinozoa.

Pomimo nienajlepszego stanu zachowania, w oparciu o wzajemną relację ilościową miospor i akritarch, w profilu M0 możliwym było wyznaczenie dwóch typów palinofacji (Kondas i Filipiak, 2022a). Próbki 1-8A zawierały mniej komponentów morskich, podobne zjawisko widoczne jest w próbkach 7-12 w profilu M1. Ilość akritarch wyraźnie wzrastała w próbkach 8B-10D, tym samym sugerując nieznaczny epizod o charakterze transgresywnym (Kondas i Filipiak, 2022a). Wzajemna relacja pomiędzy palinomorfami o pochodzeniu lądowym i morskim wskazuje na depozycję badanych osadów w środowisku niezbyt głębokiego szelfu w obrębie którego duże znaczenie miała dostawa materiału lądowego. Akritarchy obserwowane w badanych profilach potwierdzają to rozstrzygnięcie, są to głównie formy sferyczne, o krótkich i prostych wyrostkach (Dorning, 1981; Tyson, 1995; Kondas i Filipiak, 2022a). Odmienność profilu M2, zdominowanego przez prazynofity, w którym odnotowano także występowanie chitinozoa, może sugerować że profil ten jest starszą częścią warstw skalskich, reprezentującą środowisko o innych, bardziej sprzyjających prazynofitom warunkach troficznych niż profile M0 i M1 (Kondas i Filipiak, 2022a). Obecnie sformalizowana formacja skalska jest wiązana z rozwojem rampy węglanowej (Racki et al., w druku).

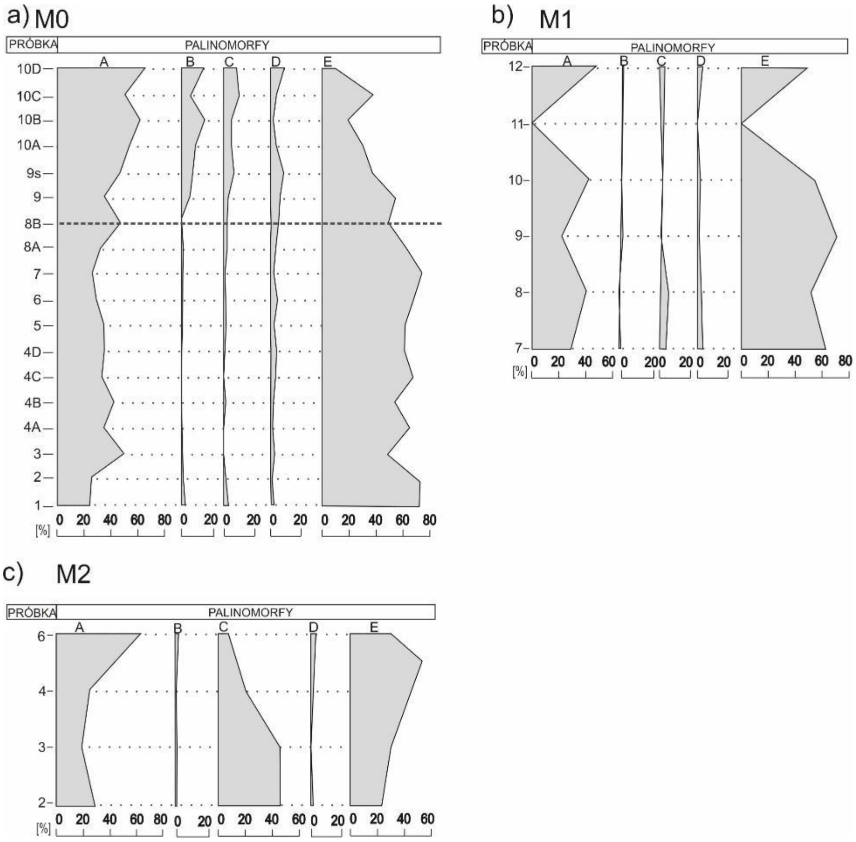

Fig. 10. Zestawienie relatywnej frekwencji materii organicznej dla profilów M0, M1 i M2 z odsłonięć w Miłoszowie. A-miospory, B-akritarchy, C-prazynofity, D-skolekodonty, E-ciemne bioklasty (szersze informacje w: Kondas i Filipiak, 2022a, zmienione).

5.2.2. Basen łysogórsko-radomski (otwory wiertnicze Szwejki IG-3 oraz Niesiołowice IG-1)

Zarówno profil Szwejki IG-3 jak i Niesiołowice IG-1 dostarczyły próbek zawierających palinomorfy lądowe oraz morskie. Palinomorfy lądowe reprezentowane były przez miospory oraz szczątki roślinne (tkanki przewodzące i kutikule). Zespół sporomorf był zróżnicowany taksonomicznie, przy czym rodzajami dominującymi były *Ancyrospora*, *Aneurospora* oraz *Geminospora* wskazując na dominację makroflory przez aneurofity (Gensel, 1980).

Dodatkowo w obrębie zespołu odnotowano obecność megaspor i tetrad sporowych. Szczątki roślinne były nieliczne, jednak stanowiły zróżnicowany zespół; od kutikul z zachowanymi aparatami szparkowymi po tracheidy. W próbkach odnotowano także obecność pojedynczych szczątków grzybów, nematofitów (*Cosmochlaina*) oraz zooklastów. Morskie palinomorfy reprezentowane były głównie przez słonowodne prazynofity oraz skolekodonty. Akritarchy (głównie *Micrhystridium*, *Multiplicisphaeridium*, *Veryhachium*) oraz chitinozoa (*Angochitina*, *Lagenochitina*, *Ramochitina*) pojawiały się w bardzo ograniczonej liczbie. W obu profilach dominującą grupę palinomorf stanowiły bioklasty o niejasnej przynależności biologicznej.

W oparciu o zaobserwowany zespół palinomorf środowisko depozycji badanych osadów określić można jako szelfowe ze znacznym dopływem materiału organicznego z lądu. W profilu Szwejki IG-3 wyróżniono cztery rodzaje palinofacji (Fig. 11). Dwa typy wyróżnione zostały w obrębie formacji z Bąkowej. Najbardziej spągowa palinofacja SZI (interwał 4979-4702 m) charakteryzuje się względnie stabilną ilością miospor. Z kolei palinofacja SZII obejmująca także ogniwo z Łazisk sygnalizuje spłycenie zbiornika w interwale 4702 do 4614 m, gdzie ilość miospor wzrasta, a następnie jego pogłębienie (4612-4606 m) zaznaczające się spadkiem ilości mikroflory lądowej (Kondas i Filipiak, 2022b). Fluktuacja zawartości komponentów lądowych widoczna jest w palinofacji SZIII, która koresponduje w dużym stopniu z utworami platformy węglanowej formacji ze Szwejków. Stropowa część profilu w której wyróżniono palinofację SZIV (za wyjątkiem próbki 4299) wskazuje na niewielką zmianę o charakterze transgresywnym (Kondas i Filipiak, 2022b).

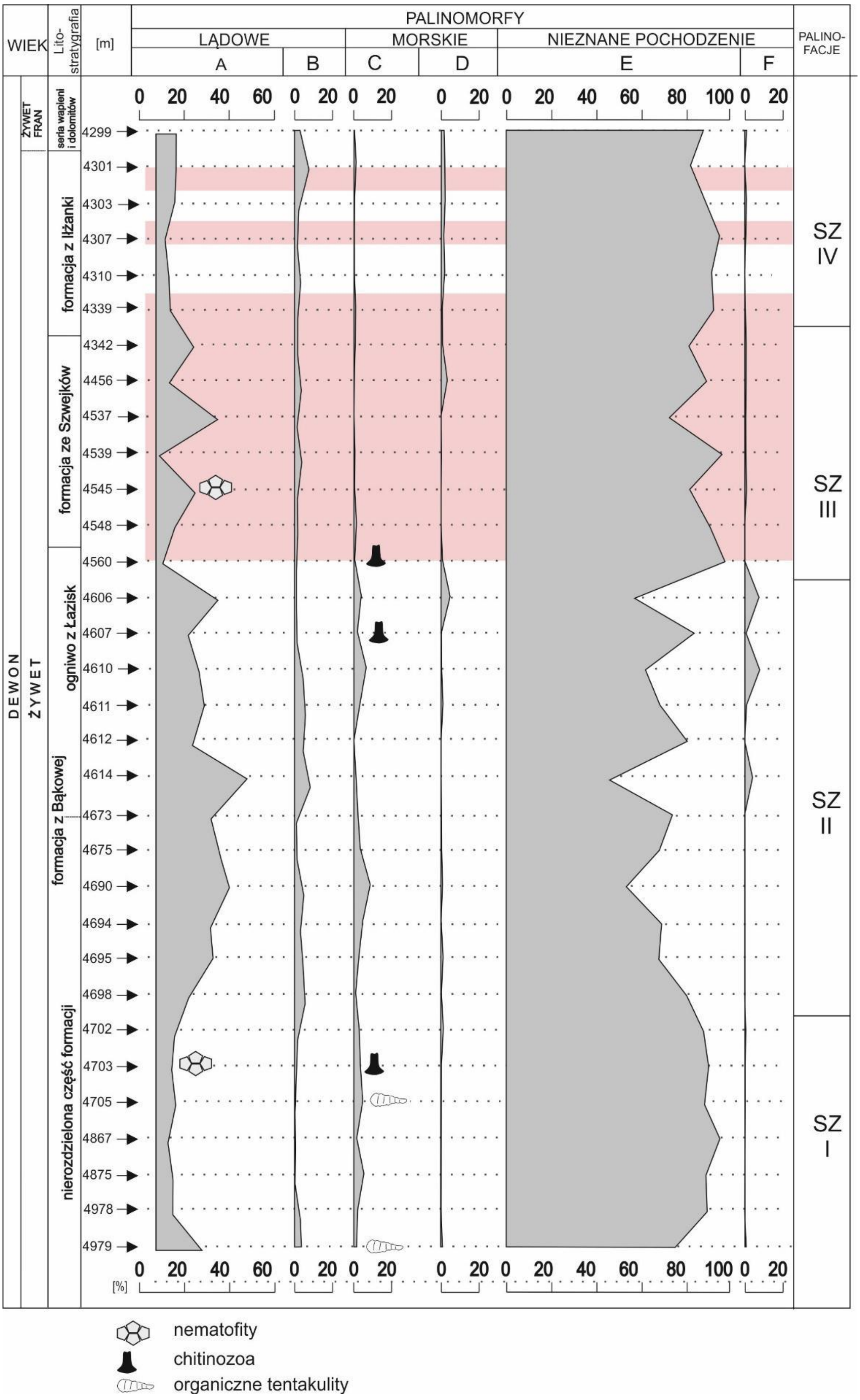

Fig. 11. Zestawienie palinofacji na tle relatywnej frekwencji składowych MO dla profilu Szwejki IG-3. A-miospory, B-fitoklasty, C-prazynofity, D-skolekodonty, E-bioklasty, F-inne, interwał zubożony taksonomicznie w miospory zaznaczony został czerwonym kolorem (szersze informacje w: Kondas i Filipiak, 2022b, zmienione).

Podobny zapis palinofacjalny zaobserwowany został w profilu Niesiołowice IG-1 (Fig. 12). W profilu wyróżniono dwa typy palinofacji. Palinofacja NI wskazuje na regresywny charakter środowiska, co podkreśla wzrost zawartości mikroflory lądowej w próbkach z głębokości 1491-1484 m, natomiast powyżej tego interwału, w obrębie palinofacji NII skład palinofacji wskazuje na pogłębianie się zbiornika.

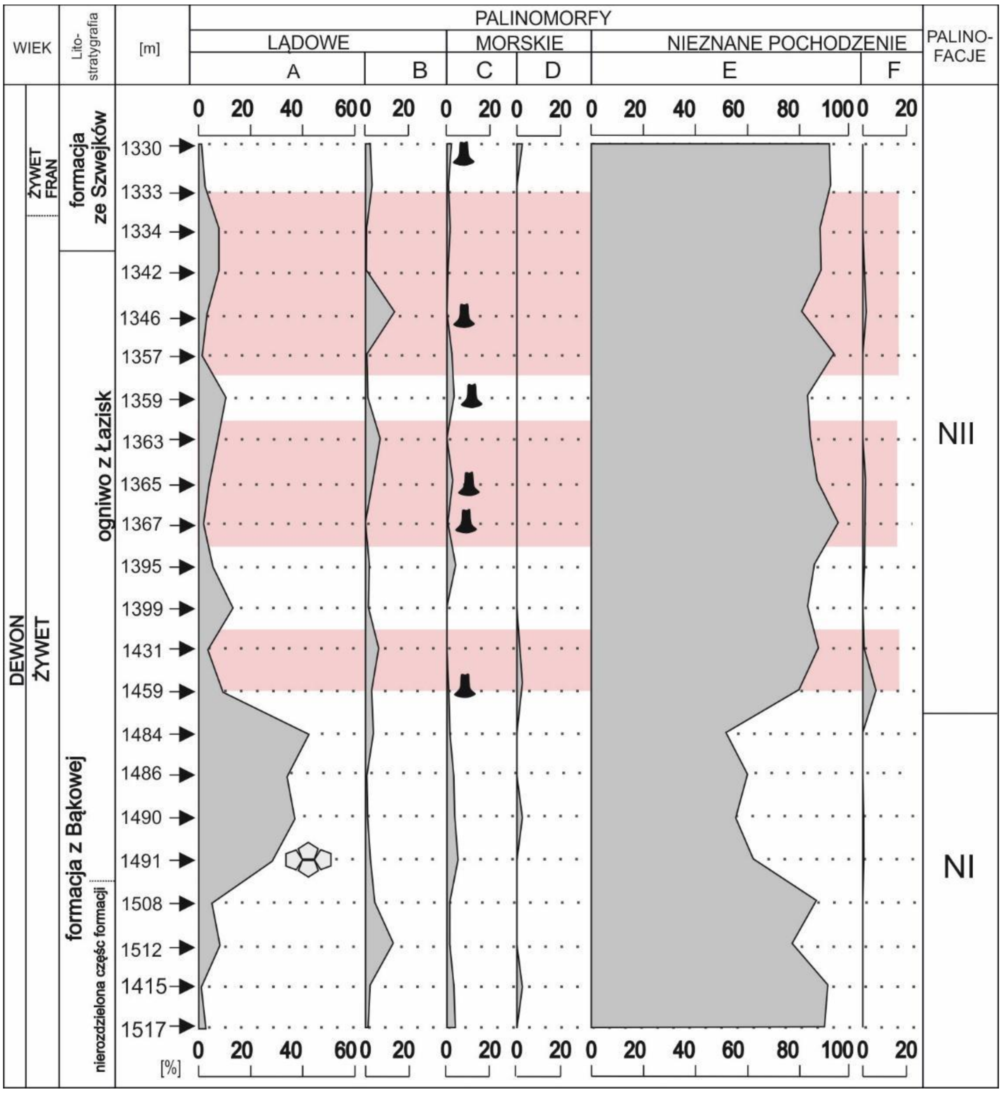

Fig. 12. Zestawienie palinofacji na tle relatywnej frekwencji składowych MO dla profilu Niesiołowice IG-1. A-miospory, B-fitoklasty, C-prazynofity, D-skolekodonty, E-bioklasty, F-inne, interwał zubożony taksonomicznie w miospory zaznaczony został czerwonym kolorem (szersze informacje w: Kondas i Filipiak, 2022b, zmienione).

5.2.3. Basen lubelski (otwory wiertnicze Giełczew PIG 5 oraz Krowie Bagno IG-1)

Profile Giełczew PIG 5 oraz Krowie Bagno IG-1 dostarczyły próbek zawierających podobne zespoły palinomorf jak profile Szwejki IG-3 oraz Niesiołowice IG-1 (Figs, 11-13). Palinomorfy lądowe reprezentowane były przez miospory przy czym dominującymi rodzajami były *Ancyrospora*, *Aneurospora* oraz *Geminospora*, które produkowane były przez aneurofity (Allen, 1980; Gensel, 1980). Co istotne, wśród mikroflory lądowej udokumentowano obecność tetrad sporowych oraz megaspor. Fitoklasty pojawiały się w niewielkiej ilości, reprezentowane były przez kutikule oraz tkanki przewodzące. Pojedyncze próbki zawierały nieliczne szczątki grzybów, nematofity (*Cosmochlaina*) oraz zooklasty. Palinomorfy pochodzenia morskiego reprezentowane były przez skolekodonty, słonowodne prazynofity oraz pojedyncze akritarchy (głównie *Micrhystridium, Multiplicisphaeridium, Veryhachium*), a także chitinozoa (*Fungochitina*). Dominującą grupę stanowiły bioklasty o nieznanym pochodzeniu biologicznym. W profilu Giełczew PIG 5 istotnym elementem składowym były także czarne, nieprzeświecające cząstki, które podobnie jak bioklasty, nie mają jasnej przynależności biologicznej.

Na podstawie zespołów palinomorf z profili basenu lubelskiego środowisko depozycji określić można jako płytkomorskie/szelfowe ale ze znacznym dopływem składników pochodzenia lądowego (Kondas i Filipiak, 2022b). W profilu Giełczew PIG 5 wyodrębniono pięć typów palinofacji, które wskazywały na zróżnicowaną sytuację paleośrodowiskową (Fig. 13). Palinofacja GI charakteryzowała się stabilną zawartością komponentów lądowych, z kolei wyżej legła palinofacja GII (interwał 2012-2007 m) zubożona była w mikroflorę lądową, dając tym samym sygnał zdarzenia o transgresywnym charakterze. Znaczący wzrost ilości lądowych palinomorf widoczny jest w palinofacji GIII (2004-1975 m). Tym samym palinofacje GI-GIII można zinterpretować jako jeden cykl transgresywno-regresywny (T-R). W obrębie palinofacji GIV zawartość miospor znacząco spada i ponownie wzrasta w obrębie palinofacji GV co odczytać można jako kolejny cykl T-R (interwał 1974-1960 m).

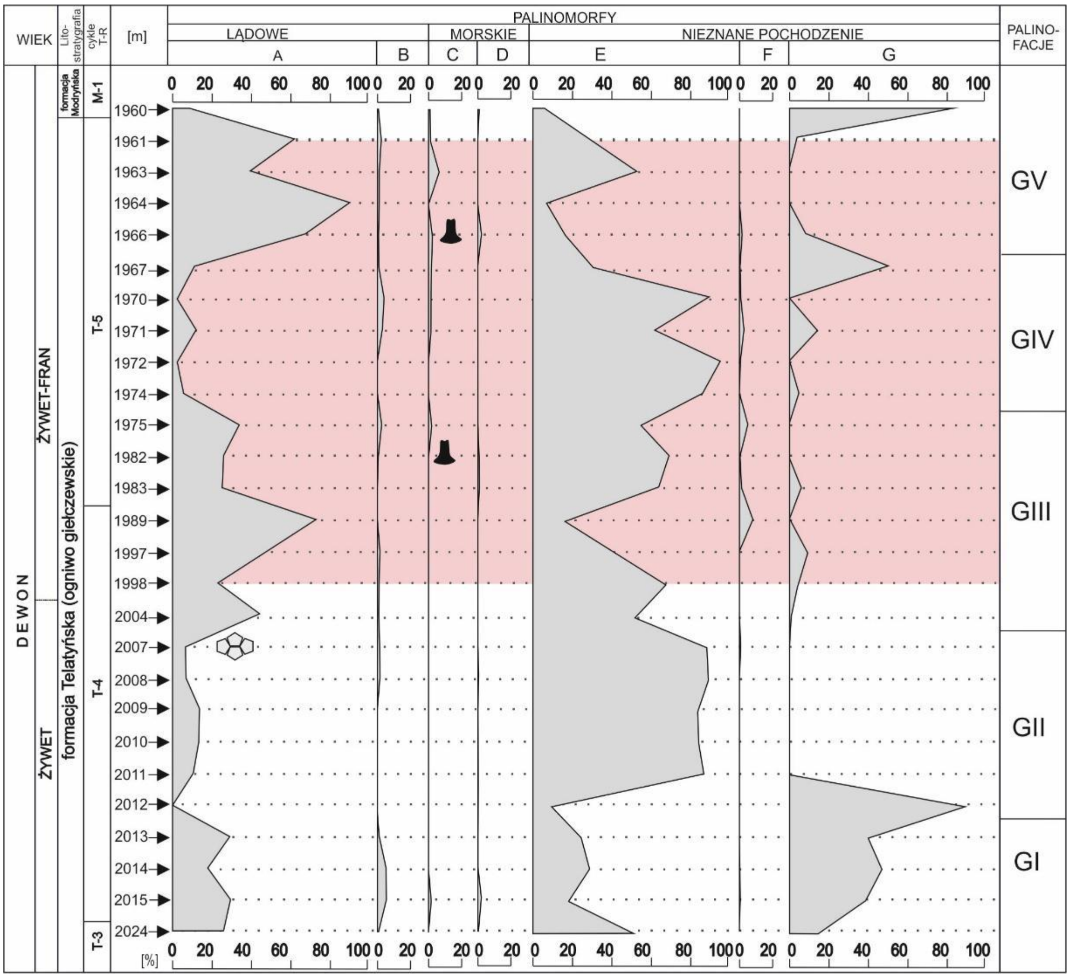

Fig. 13. Zestawienie palinofacji na tle relatywnej frekwencji składowych MO dla profilu Giełczew PIG 5. A-miospory, B-fitoklasty, C-prazynofity, D-skolekodonty, E-bioklasty, F-inne, G-nieprzeświecające cząstki, interwał zubożony taksonomicznie w miospory zaznaczony został czerwonym kolorem (szersze informacje w: Kondas i Filipiak, 2022b, zmienione).

Z uwagi na mniejszą ilość próbek przebadanych w profilu Krowie Bagno IG-1 uzyskany wynik traktować należy jako orientacyjny. Dynamiczne zmiany ilości mikroflory lądowej widoczne są w obrębie palinofacji KBI, wskazują one na epizod spłycenia zbiornika (głębokość 1328 m). Znaczący spadek zawartości miospor w interwale 1301-1221 m sugeruje z kolei możliwe pogłębianie się zbiornika w którym deponowane były osady (Kondas i Filipiak, 2022b; fig. 12).

6. PALINOLOGICZNY ZAPIS ZDARZENIA TAGHANIC NA OBSZARZE POLSKI

Na podstawie:

Kondas, M., Filipiak, P. 2022b. The palynology of the Middle-Upper Devonian (Givetian-Frasnian) in the Łysogóry-Radom and Lublin basins, south-central Poland. Palynology. https://doi.org/10.1080/01916122.2022.2140457.

Z uwagi na fakt że zdarzenie Taghanic przypada na poziomy miosporowe Ex3 oraz Aur, które rozpoznano w kilku analizowanych otworach i odsłonięciach, podjęto próbę palinologicznego scharakteryzowania tego zdarzenia na obszarze Polski południowo-wschodniej. Zdarzenie to obejmuje zony konodontowe od *ansatus* po *hermanni* (House, 2022), co w zonacji konodontowej odpowiada poziomom sporowym Ex oraz Aur (Turnau, 2011). Jest ono związane z serią zmian poziomu mórz (w pierwszej kolejności wielką transgresją), które w konsekwencji doprowadziły do wymierania fauny i flory oraz m. in. wielkoskalowych migracji w basenach morskich (House, 2022). Palinologiczny zapis tego kryzysu został do pewnego stopnia rozpoznany na obszarze NE Szkocji przez Marshalla et al. (2011) oraz przez Turnau na obszarze Polski (2014). Za kluczową cechę pozwalającą rozpoznać interwał Taghanic uznano znaczący spadek zróżnicowania mikroflory lądowej. Turnau (2014) za ważny parametr uznała także wzajemną relację pomiędzy ilością spor z gatunków *A. extensa* (wzrost frekwencji) i *Rhabdosporites langii* (spadek frekwencji).

W profilach z obszaru radomsko-lubelskiego we wszystkich przypadkach odnotowano interwały w których spada zróżnicowanie taksonomiczne miospor. Dla każdego z profili zmiany poziomu morza opisane przez Narkiewicza et al. (2011) poprzedzały spadek zróżnicowania gatunkowego mikroflory lądowej widoczny na granicy poziomów Ex/Aur. Nie jest jednak możliwym by powiązać to zjawisko jednoznacznie ze wzrostem lub spadkiem poziomu mórz. W przypadku profilu Giełczew PIG 5 spadek zróżnicowania poprzedzony jest epizodem transgresywnym, z kolei w przypadku profili Szwejki IG-3 oraz Niesiołowice IG-1 regresywnym. Interesującym jest także, że w przypadku profilu Giełczew PIG 5 interwał o mniejszym zróżnicowaniu taksonomicznym jest jednocześnie interwałem o zwiększonej ilości mikroflory lądowej. Tym samym trudno mówić o jednoznacznej korelacji pomiędzy lokalnymi zjawiskami eustatycznymi oraz spadkiem różnorodności gatunkowej w obserwowanym zespole mikroflory.

Z analiz tych wyłączono profile z Miłoszowa z uwagi na to, że wiek tych utworów określony został jako podpoziomy Ex1 i Ex2. Tym samym te utwory obejmują interwał czasowy starszy niż zdarzenie Taghanic.

7. ORGANICZNE TENTAKULITY Z OTWORU WIERTNICZEGO KOWALA 1

Na podstawie:

Kondas, M., Filipiak, P. 2021. Organic tentaculitoids from the Kowala Formation (Devonian) of the Holy Cross Mountains, Poland. Palynology. 45(4): 657–668.

W publikacji udokumentowano najstarsze wystąpienie organicznych tentakulitów. Po raz pierwszy opisano te palinomorfy z granicy pięter żywetu i franu oraz co istotne, po raz pierwszy powiązano organiczne pozostałości ze szczątkami mineralnymi tych zwierząt współwystępujące w tych samych próbach. Na podstawie cech morfologicznych takich jak kształt komory embrionalnej, kształt muszli oraz ułożenie żeber wszystkie zaobserwowane okazy rozpoznano jako przedstawicieli rzędu Nowakiidae. Charakterystyczną ich cechą jest komora embrionalna o bulwiastym kształcie, której średnica wahała się od 4,5 do 22 µm. Całkowita długość okazów wynosiła od 170 do 600 µm. Każdy z okazów posiadał widoczne na powierzchni skorupki żebrowanie.

Prawdopodobnie organiczne pozostałości stanowiły swego rodzaju wewnętrzną warstwę wyścielającą muszlę zwierzęcia. Takie rozwiązanie sugeruje po raz pierwszy udokumentowany okaz składający się z mineralnej skorupki połączonej bezpośrednio z organiczną pozostałością (Plansza 3, figs. 1a-1c; Kondas i Filipiak, 2021). Problematyczna jest również kwestia niewielkiej ilości stwierdzonych wystąpień tych mikroskamieniałości. Do tej pory występowanie organicznych tentakulitów odnotowano jedynie w czterech lokalizacjach w obrębie Laurussi oraz ostatnio na obszarze Michigan (USA) podczas gdy skamieniałości mineralne są bardzo powszechne w profilach całego świata (Wood et al., 2004; Filipiak i Jarzynka, 2009, Marshall i Telnova, 2012, 2017; Meehan i Boyle, 2022). Nie jest wykluczone, że znaczenie ma proces maceracji, a szczególnie czas w jakim próbki skalne poddawane są działaniu stężonych kwasów. Z pewnością organiczne tentakulity to grupa palinomorf wymagająca dalszych badań.

8. CZĘŚĆ TAKSONOMICZNA

Na podstawie:

Kondas, M., Filipiak, P., Breuer, P. 2022. Teleostomata rackii gen. et sp. nov.: an acritarch from the Devonian (Givetian) of south-central Poland. Palynology. 46(2): 1–8.

Kondas, M., Filipiak, P. 2022b. The palynology of the Middle-Upper Devonian (Givetian-Frasnian) in the Łysogóry-Radom and Lublin basins, south-central Poland. Palynology. https://doi.org/10.1080/01916122.2022.2140457.

8.1 Teleostomata rackii Kondas, Filipiak, Breuer 2022

W pracy Kondas et al. (2022) omówiono pozycję systematyczną oraz cechy morfologiczne nowego rodzaju i gatunku akritarchy udokumentowanego w warstwach skalskich w profilach M0 oraz M2 z Miłoszowa. W obrębie tej lokalizacji zasięg stratygraficzny tej akritarchy jest ograniczony wyłącznie do poziomu *“Geminospora” extensa* (zony konodontowe *hemiansatus-varcus*). Podobny takson opisywany był z osadów eiflu Gondwany (Tunezja). Podstawą do wykreowania nowego rodzaju i gatunku akritarchy jest odrębność morfologiczna okazów względem innych akritarch. *T. rackii* charakteryzuje się tetrahedralnym kształtem ciałka centralnego zaopatrzonego w szerokie wyrostki. Kąt pomiędzy dwoma sąsiadującymi ze sobą wyrostkami wynosi od 120° do 220°. Każdy z wyrostków znajduje się na krawędzi ciałka, posiada cylindryczny lub stożkowy kształt i zaopatrzony jest w marszczony kołnierz (wysokość 3–5 µm) okalający porowate otwarcie znajdujące się na czubku wyrostka (średnica otwarcia to 8–15 µm). Grubość ścianki ciałka wynosi 1 µm.

8.2 Retusotriletes radomskii Kondas i Filipiak 2022

Nowy gatunek miospory *Retusotriletes radomskii* został udokumentowany w profilu M0 z odsłonięcia w Miłoszowie oraz w profilach Szwejki IG-3 i Niesiołowice IG-1 (Kondas i Filipiak, 2022a; 2022b). Nowy gatunek spor posiada wyraźnie zarysowany znak zrostowy sięgający brzegu spory, który ograniczony jest przez labra o wysokości 1.25 µm i szerokości 1.6-6.2 µm. Powierzchnia spory jest gładka lub bardzo drobno punktowana. Średnica waha się od 70 do 122 µm (~96 µm, w oparciu o 12 okazów). Zasięg stratygraficzny nowego taksonu ograniczony jest do poziomu *"Geminospora" extensa* (podpoziom Ex3), co odpowiada zonom konodontowym od środkowego *varcus* do *hermanni*. Z uwagi na wąski interwał czasowy w którym udokumentowano pojawienie się tego taksonu oraz jego charakterystyczną morfologię może on mieć znaczenie w przyszłości jako lokalny marker stratygraficzny.

PODSUMOWANIE

Wyniki przeprowadzonych analiz palinologicznych opisują zróżnicowanie zespołów palinomorf uzyskanych z osadów pogranicza żywetu i franu południowo-wschodniej Polski. Przeprowadzone prace, w oparciu o rozpoznane zespoły mikroflory lądowej pozwoliły na rozpoznanie poziomu sporowego Ex w profilach z Miłoszowa oraz w profilach Szwejki IG-3, Niesiołowice IG-1 i Giełczew PIG 5. Poziom sporowy Aur rozpoznany został w profilu Kowala 1, Szwejki IG-3, Niesiołowice IG-1, Giełczew PIG 5 oraz Krowie Bagno IG-1. Na podstawie analizy palinofacji środowisko depozycji utworów z odsłonięcia w Miłoszowie zostało określone jako niezbyt głęboki szelf w obrębie którego duże znaczenie miała dostawa materiału lądowego. W profilach Szwejki IG-3 oraz Niesiołowice IG-1 analiza palinofacji wskazywała na depozycję w środowisku szelfu o znacznym dopływie materiału z lądu. Zbliżone, płytkomorskie warunki rozpoznane zostały w profilach Giełczew PIG 5 oraz Krowie Bagno IG-1. Wykorzystanie analizy palinofacjalnej pozwoliło na interpretacje dotyczące środowiska depozycji osadów oraz prześledzenie lokalnych zmian eustatycznych, a także stanowiło podstawę do rozpoznania palinologicznego zapisu globalnego zdarzenia Taghanic. Uzyskane wyniki wskakują na obecność tego zdarzenia w zapisie palinologicznym jednak nie zaznacza się ono tak wyraźnie jak wskazują na to opisy literaturowe. Ponadto, w profilu Kowala 1 stwierdzono obecność organicznych tentakulitów, które powiązano z mineralnymi pozostałościami tych zwierząt. Przeprowadzone prace pozwoliły także na opisanie nowego rodzaju i gatunku akritarchy *Teleostomata rackii* oraz nowego gatunku miospory *Retusotriletes radomskii*.

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Organic tentaculitoids from the Kowala Formation (Devonian) of the Holy Cross Mountains, Poland

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ABSTRACT
A palynological investigation was carried out on samples obtained from the Givetian/Frasnian interval in the formation comprising stromatoporoid-coral dolomites and limestones from the Kowala 1 borehole (south-central Poland). These carbonate bank to reef deposits have not previously been subjected to palynological studies. The analysed samples revealed the presence of organic tentaculitoids, which are particularly uncommon. According to their morphological features all observed forms were classified into the subclass Dacryoconarida, of which only representatives from the order Nowakiida were recognised. An organic tentaculite with an associated partially preserved mineral shell was found for the first time. Palynological investigation allowed the palynostratigraphy of this interval to be established as *Cristatisporites optivus–Spelaeotriletes krestovnikovii*, from the East European Miospore zonation (late *varcus* up to *transitans* conodont zones).

KEYWORDS
tentaculitoids; Nowakiidae; Dacryoconarida; zoomorphs; palynomorphs

1. Introduction

Palynological research has recently been carried out using Givetian samples from the Kowala 1 borehole in the Holy Cross Mountains (HCM) of south-central Poland. It has revealed the presence of a large population of organic tentaculites, demonstrating the unique character of the stromatoporoid-coral dolomites and limestones in Kowala (Kowala Formation). The existence of these organic microfossils, which have so far only been recorded from the palaeocontinent of Laurussia, has been acknowledged for several years. Forms with mineral shells are better known and were recognised much earlier (e.g. Dewitz 1883).

In general, mineralised tentaculitoids were small marine organisms that became distributed worldwide over the period from the Ordovician to the Late Devonian. They are characterised by their conical shells, which are often accompanied by characteristic rings or annular banding (Fisher 1962; Schindler 2012; Wei et al. 2012). Tentaculitoids had thin outer and inner organic layers as well as the main mineral shell (e.g. Larsson 1979). They were stenotopic organisms that initially occurred only in tropical latitudes, but their geographical range expanded rapidly in the Early Devonian and decreased thereafter, during the Middle and Late Devonian (Marshall and Telnova 2012; Wei et al. 2012). The reason for their extinction is still under discussion. They disappeared shortly after the Frasnian/Famennian (F/F) boundary and their disappearance is considered a result of the F/F crisis. The youngest population of organic tentaculitoids found was described by Marshall and Tel'nova (2017). They obtained samples from the Lower Famennian deposits in Russia. Wei et al. (2012) observed a negative correlation between sea level and the generic diversity of tentaculitoids, in which sea level rise was related to a decline in the generic diversity of those organisms. Natural processes such as the invasion of other species are proposed as another reason for the disappearance of the tentaculitoids (Wei et al. 2012).

The taxonomical status of tentaculitoids also remains unclear. Several authors have classified them as an independent class related to the Mollusca (Bouček 1964; Blind 1969; Blind and Stürmer 1977; Farsan 1994), while others consider them microconchids (Weedon 1990, 1991; Vinn and Taylor 2007; Vinn et al. 2008; Vinn and Taylor 2009; Vinn 2010). In this study, organic tentaculitoids were treated as palynomorphs (zoomorphs) and the division presented in Farsan (2005) was applied.

Although mineral forms from the Early and Mid-Palaeozoic have frequently been recorded, few occurrences of organic tentaculitoids have been reported. Wood et al. (2004) were the first to describe Frasnian remains of Dacryoconarida in the Giełczew PIG-5 borehole in the Radom-Lublin area of Poland. A similar assemblage was reported in the Frasnian deposits of Western Pomerania (Poland) by Filipiak and Jarzynka (2009). Marshall and Telnova (2012) and Marshall and Tel'nova (2017) documented a particularly abundant assemblage of Early Famennian tentaculitoids from Komi Republic in Russia (Figure 1), which had many atypical and malformed forms that had probably been affected by mutation. Currently, the Kowala 1 borehole reveals the first palynological record of these organisms from the transitional Givetian/Frasnian interval in the HCM. This is the oldest documented organic tentaculitoid assemblage found so far. Moreover, the associated

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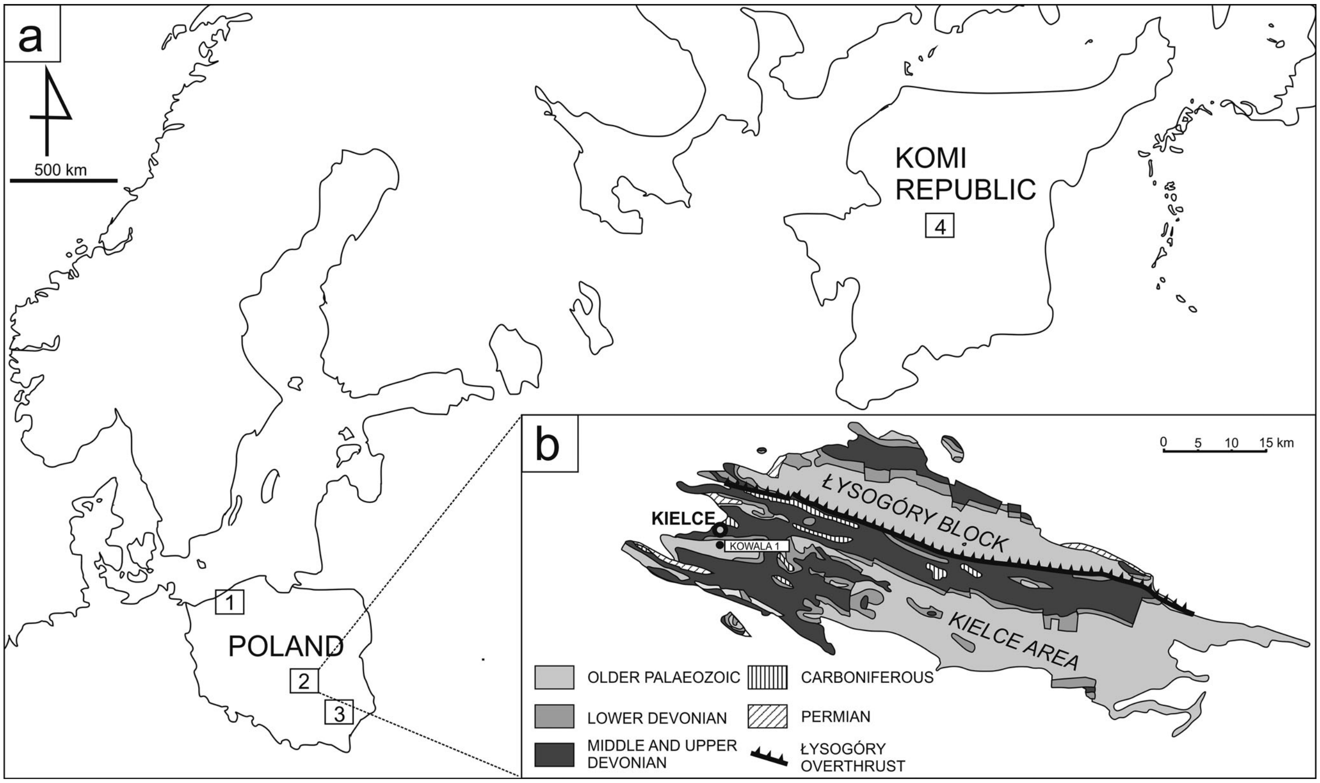


Figure 1. The research area and other regions in which organic tentaculitoids have been described so far. (a) Occurrence of tentaculitoids preserved as palynomorphs. Location 1: Dobrzyca 2 borehole (Western Pomerania, Poland); location 2: Kowala 1 borehole (Holy Cross Mountains, Poland); location 3: Giełczew PIG-5 borehole (Radom-Lublin area, Poland); location 4: Sosnovka 1 borehole and Sirachoi quarry (Komi Republic, Russia). Source: Author

fragments of mineral shells in combination with the inorganic layer is the first evidence that directly connects these two groups.

The palynostratigraphical recognition of the Devonian deposits in the HCM is not comprehensive for each stage. Deposits from the Middle Devonian were only studied in the northern part of the HCM (Łysogóry area); the palynostratigraphy of the Givetian Skały and Nieczulice beds was previously discussed by Malec and Turnau (1997). The latest biostratigraphical studies of the Givetian deposits from the Bodzentym Syncline were performed by Turnau and Racki (1999). However, the Givetian interval of the southern HCM (Kielce area) has never been investigated in terms of palynology, and despite the fact that this area of the HCM has been a subject of intense geological investigations in the past, stratigraphical data concerning the time interval discussed in this paper are mainly investigations of conodonts, macrofauna, and lithology (e.g. Narkiewicz et al. 1990; Romanek and Rup 1990; Racki 1993; Szulczewski 1995).

Mineralised tentaculitoids were first reported from the Devonian deposits of the Kielce area by Filonowicz (1973) and Hajłasz (1993); Styliolinida, Nowakiida, and representatives of the class Tentaculitoidea were documented. Mineralised Styliolinida have also been recorded in the Famennian strata of the Kowala 1 section (Żakowa and Radlicz 1990). The order Microconchida was also documented in the Late Emsian–Late Givetian of the Grzegorzowice-Skały, Jaźwica, and Posłowice by Zatoń and Krawczyński (2011); however, these fossils were significantly different morphologically from the tentaculitoids described in this paper.

The principal aim of this study is to provide palynological data from the transitional Givetian/Frasnian interval of the Kowala 1 borehole with a focus on two aspects: the occurrence of organic tentaculitoids and a discussion concerning their relationship with the mineral forms, and a determination of the age of these fossils based on the palynology.

2. Geological setting

The Kowala 1 borehole was drilled in the Kielce area of the HCM during the period 1981–1982 (south-central Poland, 50°48′04.52″N, 20°33′35.97″E, Figure 1; see also Romanek and Rup 1990), close to the northern wall of the well-known Kowala Quarry. The analysed interval (depth 633 to 535 m) belongs mainly to the biostromal Kowala Formation, which was deposited along the south-western margin of Laurussia as shallow-marine carbonate platform facies (Narkiewicz et al. 1990; Pisarzowska et al. 2006; Bełka and Narkiewicz 2008) within a carbonate bank-to-reef complex (Racki 1993). Any biostratigraphical division of this area is difficult because of its widespread secondary dolomitisation (Narkiewicz 1991; Bełka and Narkiewicz 2008). The basal Givetian layer of the Kowala Formation (stringocephalus beds from 846 m; Narkiewicz et al. 1990, fig. 3) consists of dolomites overlain with coral/stromatoporoid facies (Romanek and Rup 1990; Figure 2). The Late Givetian transgression caused the development of micritic and marly limestone (Jaźwica Member, depth from 633.2 to 616.3 m; see fig. 14 in Racki 1993; see also Narkiewicz et al. 1990; Romanek and Rup 1990; Figure 2). All these carbonate deposits are overlain by biostromal coral/stromatoporoid Sitkówka beds, which range up to the Frasnian (Bełka and Narkiewicz 2008). The uppermost part of the Kowala Formation occurs at a depth of 412 m, as indicated by Narkiewicz et al. (1990) (see also Romanek and Rup 1990).

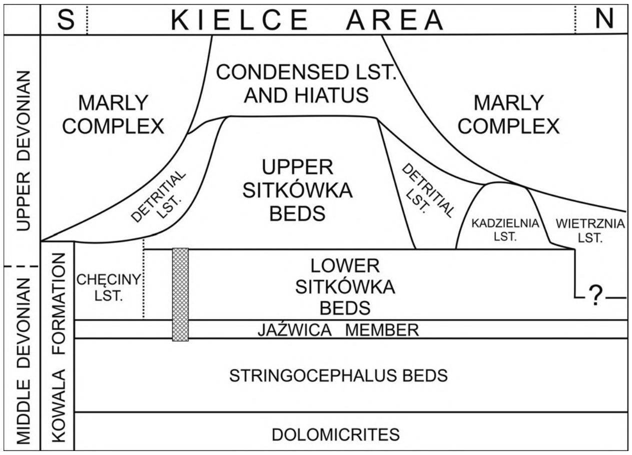


Figure 2. Simplified, schematic lithostratigraphical division of the southern area of the Holy Cross Mountains. The investigated section is marked by the grey rectangle (modified after Narkiewicz et al. 1990).

3. Material and methods

Sixty palynological samples were taken directly from the drill core at Kowala 1 (at a depth of 633.3 to 340.1 m). Only four of the samples contained palynomorphs, from the Jaźwica Member and the lower Sitkówka Beds which are at depths of 633 to 535 m (Figure 3). All obtained samples were chemically processed using standard procedures with a combination of hydrochloric and hydrofluoric acids (HCl-HF-HCl) (Wood et al. 1996). Due to the strong concentration of amorphous organic matter (AOM) in the positive samples, two types of macerates were prepared. In the first, the AOM was removed and the organic residuum was treated for 30 minutes with 100% fuming nitric acid (HNO_3). In the second the preserved AOM was retained. Two slides were prepared with each type of residue. The organic state of preservation varied from bad to very good.

The organic remains of tentaculitoids were found in all positive samples (Figure 3), and they were the second most common palynomorphs after miospores. Tetrads of miospores and some single fragments of megaspores were also noticed. Only single specimens of scolecodonts, prasinophytes, and

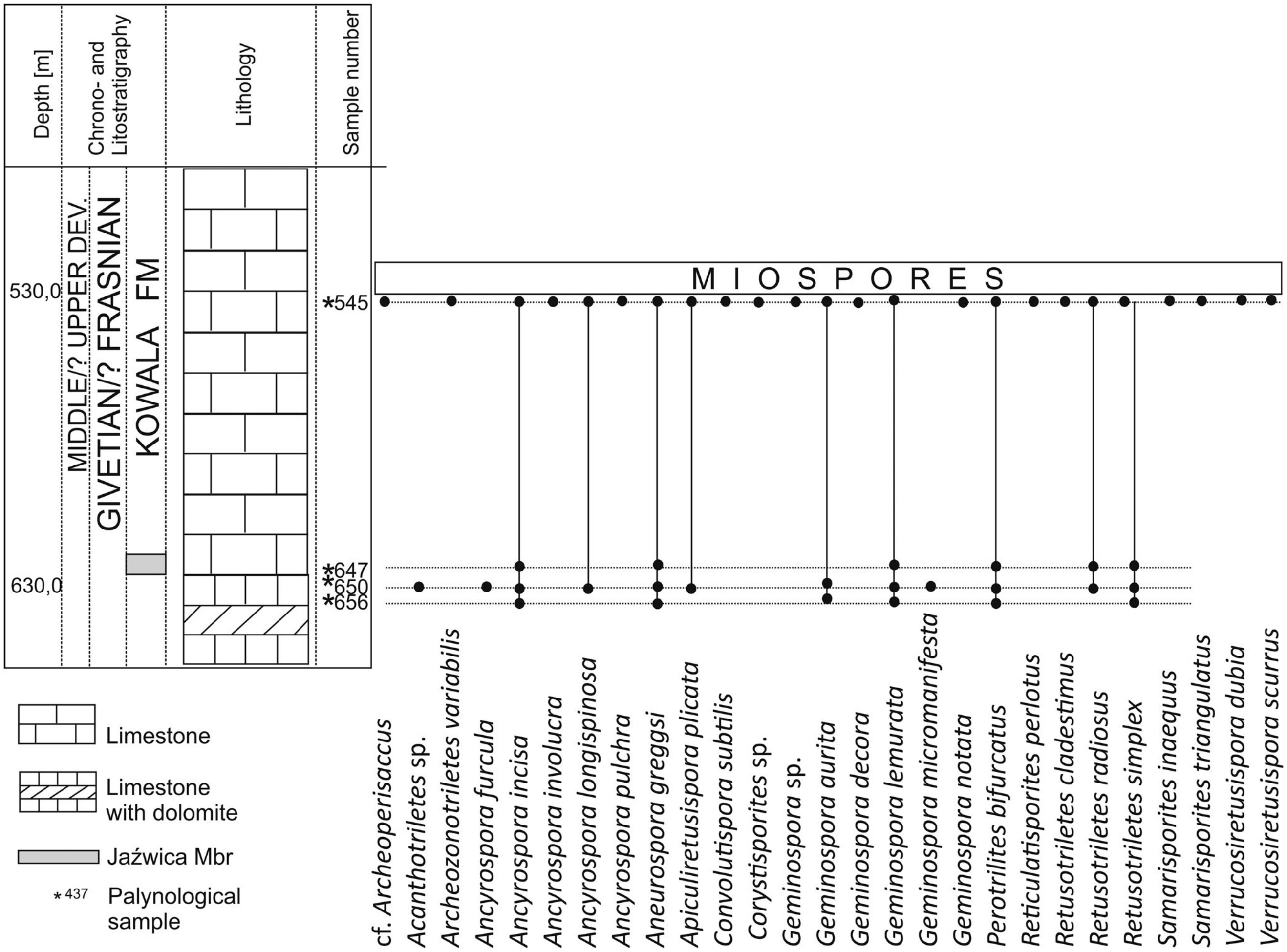


Figure 3. The analysed Kowala 1 section showing the location of the samples containing palynomorphs and the miospore taxa distribution.

acritarchs were documented. It should be noted that samples prepared without HNO_3 contained high numbers of organic tentaculitoids while those that were treated with HNO_3 were slightly depleted in terms of this palynomorph. The miospore taxa, which are important in terms of palynostratigraphy, and the organic tentaculitoids are shown in Plates 1–4. All images were produced using Optika B-510BF and Nikon Eclipse 50*i* transmitted light microscopes with the software NIS Elements-

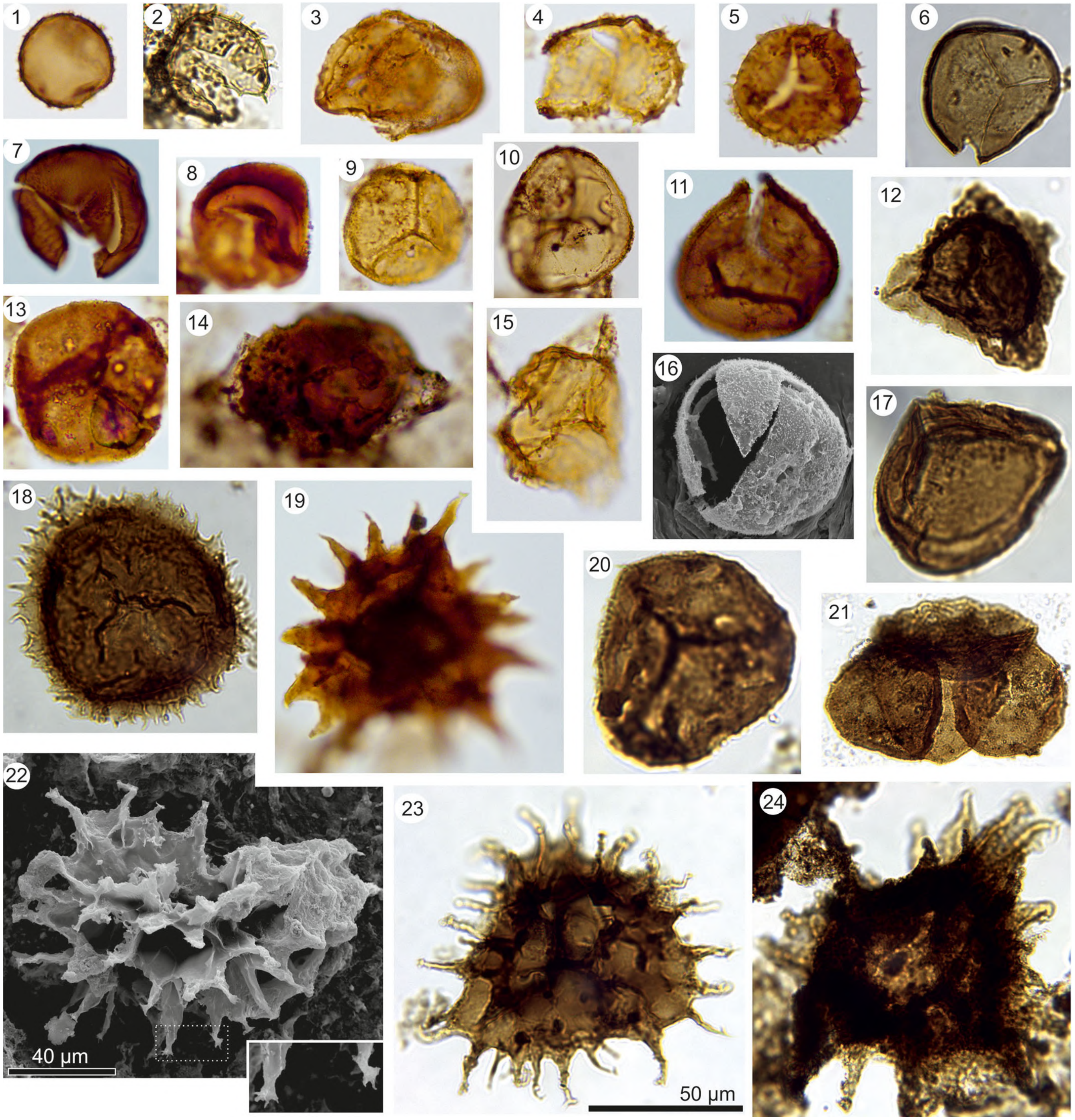
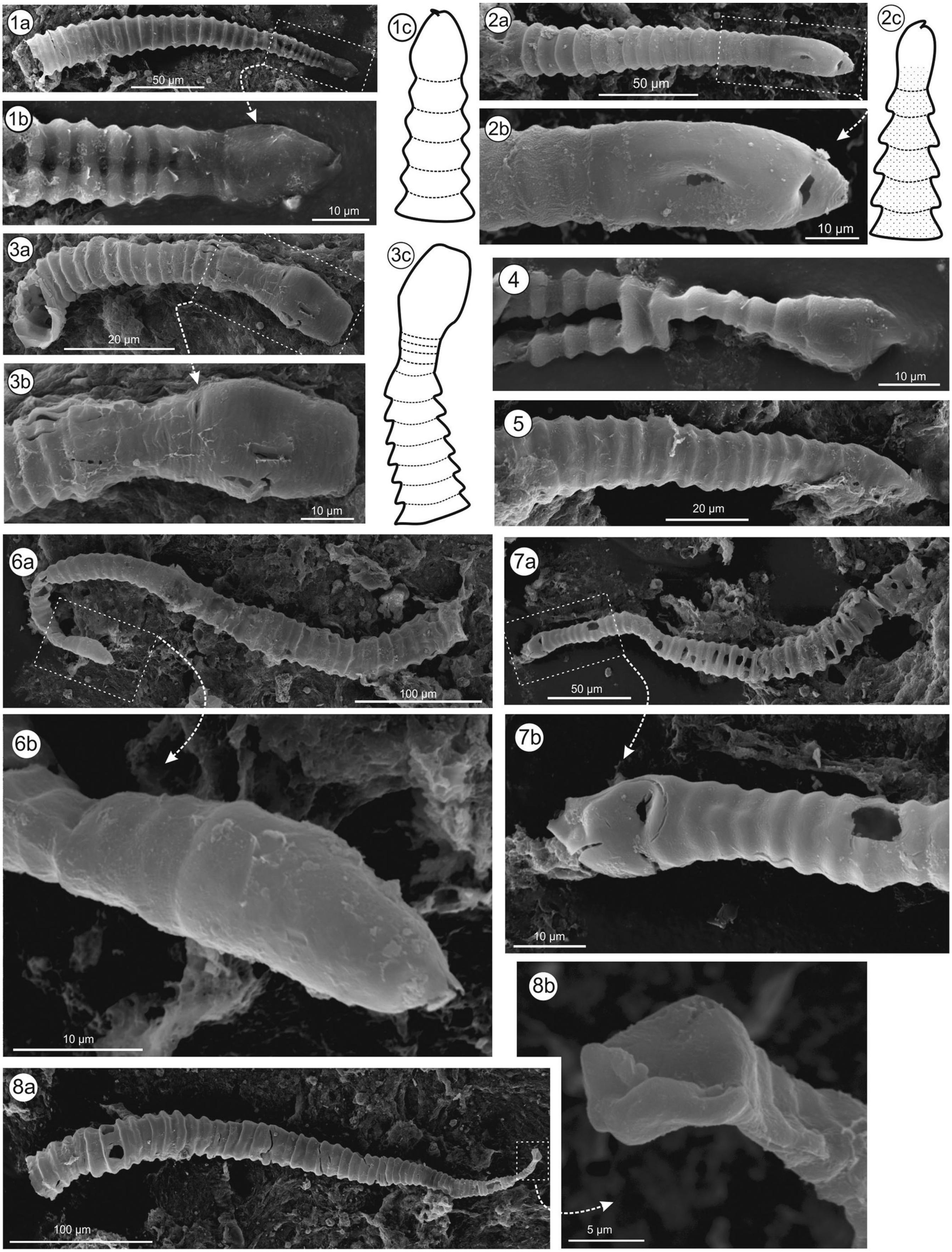


Plate 1. Spores and phytoplankton from the Kowala 1 borehole. All photographs are to the same scale except figure 22. 1. *Gorgonisphaeridium* sp., sample 650, depth: 626.00–627.00 m, EF (27U3). 2. *Gorgonisphaeridium granatum*, sample 545, depth: 534.00–535.00 m, EF (11Q4). 3. *Geminospora micromanifesta*, sample 650, depth: 626.00–627.00 m, EF (18O). 4. *Corystisporites* sp., sample 545, depth: 534.00–535.00 m, EF (29O). 5. *Acanthotriletes* sp., sample 650, depth: 626.00–627.00 m, EF (14G2). 6. *Geminospora* sp., sample 545, depth: 534.00–535.00 m, EF (23N1). 7. *Retusotriletes radiosus*, sample 545, depth: 534.00–535.00 m, EF (17T2). 8. *Archeozonotriletes variabilis*, sample 545, depth: 534.00–535.00 m, EF (26P1). 9. *Apiculiretusispora plicata*, sample 545, depth: 534.00–535.00 m, EF (33B2). 10. *Geminospora micromanifesta*, sample 650, depth: 626.00–627.00 m, EF (35T2). 11. *Aneurospora greggsi*, sample 650, depth: 626.00–627.00 m, EF (22N4). 12. *Samarisporites triangulatus*, sample 545, depth: 534.00–535.00 m, EF (19V3). 13. *Aneurospora greggsi*, sample 650, depth: 626.00–627.00 m, EF (22N4). 14. cf. *Archeoperisaccus*, sample 545, depth: 534.00–535.00 m, EF (35S2). 15. *Samarisporites triangulatus*, sample 545, depth: 534.00–535.00 m, EF (14Y). 16. *Geminospora micromanifesta*, sample 545, depth: 534.00–535.00 m. 17. *Geminospora micromanifesta*, sample 545, depth: 534.00–535.00 m, EF (22F2). 18. *Perotrilites bifurcatus*, sample 545, depth: 534.00–535.00 m, EF (26E1). 19. *Ancyrospora incisa,* sample 545, depth: 534.00–535.00 m, EF (13K2). 20. *Geminospora aurita*, sample 650, depth: 626.00–627.00 m, EF (D141). 21. The tetrad of *Geminospora* sp., sample 545, depth: 534.00–535.00 m, EF (19F3). 22. *Ancyrospora pulchra* with magnified part showing multifurcate spine, sample 545, depth: 534.00–535.00 m. 22. *Ancyrospora furcula*, sample 650, depth: 626.00–627.00 m, EF (18U3). 23. *Ancyrospora longispinosa*, sample 545, depth: 534.00–535.00 m, EF (24W4).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D and the NIK-Cam Pro-1 camera. The SEM (Scanning Electron Microscope) observations and pictures were produced using a Phillips XL30 Environmental Scanning Electron Microscope (ESEM). England Finder coordinates were used to locate the specimens on the palynological slides. All microscope slides and residues are housed at the Faculty of Natural Sciences in Sosnowiec, Poland.

4. Age of the investigated samples

Because of similarities in the composition of the miospores and the succession of the first appearances of stratigraphically important species, the zonal scheme from Avkhimovitch et al. (1993) for eastern Europe was considered the most useful in the HCM area (Figure 4).

The analysed samples contained recognisable miospore assemblages, which were dominated by small-sculptured camerate spores, and mostly comprised the two genera *Ancyrospora* and *Geminospora* (see the full list of taxa in Appendix). Despite the limitations in the number of miospores present, taxa such as *Ancyrospora incisa*, *A. involucra*, *Geminospora micromanifesta*, and *G. notata* were documented, which are important in terms of palynostratigraphy (Plate 1). The occurrence of *A. incisa* together with *G. micromanifesta* indicates that the analysed assemblage is part of the *Ancyrospora incisa–Geminospora micromanifesta* (IM) Subzone in the Contagisporites *optivus–Spelaeotriletes krestovnikovii* (OK) Miospore Zone from Avkhimovitch et al. (1993). Other taxa that were classified as typical for this subzone by Turnau (2011), such as *Aneurospora greggsi*, *Geminospora lemurata*, and *Samarisporites triangulatus*, were also documented.

The upper boundary of the Eastern European *C. optivus–S. krestovnikovii* Zone is the stratigraphical equivalent of the upper boundary of the *Contagisporites optivus* var. *optivus–Cristatisporites triangulatus* Miospore Zone from Richardson and McGregor (1986, fig. 4). Although the former index taxa were absent, the general composition of the analysed assemblage – dominated by anchor-spined spores with conical bifurcate spines – remains consistent with the schemes proposed by Richardson and McGregor (1986). Of the miospores considered stratigraphically important by Streel et al. (1987) for the corresponding *Samarisporites triangulatus–Chelinospora concinna* (TCo) Zone, only *S. triangulatus* was documented.

The presence of *Geminospora aurita* also leads to recognition of the local *G. aurita* Zone from Turnau (2007, 2008; Figure 4). This local zone corresponds to most of the IM Subzone from Avkhimovitch et al. (1993) and is therefore part of the *Contagisporites optivus* var. *optivus–Cristatisporites triangulatus* Zone of Richardson and McGregor (1986) and the lower part of the TCo Zone of Streel et al. (1987). The lower boundary of the *G. aurita* Zone is equivalent to the boundary between the *varcus* and *hermanni* conodont zones, which have a narrower stratigraphical range than the OK Miospore Zone (Avkhimovitch et al. 1993; Turnau 2008). The lower boundary of the following local miospore zone *Tholisporites densus* tentatively corresponds with the late *falsiovalis*; however, this miospore zone was not recognised. The same established local miospore zone tentatively involves conodont zones from *hermanni* to *falsiovalis* that correspond to the late Givetian/early Frasnian (Turnau 2007, 2008; Narkiewicz et al. 2011; Figure 4).

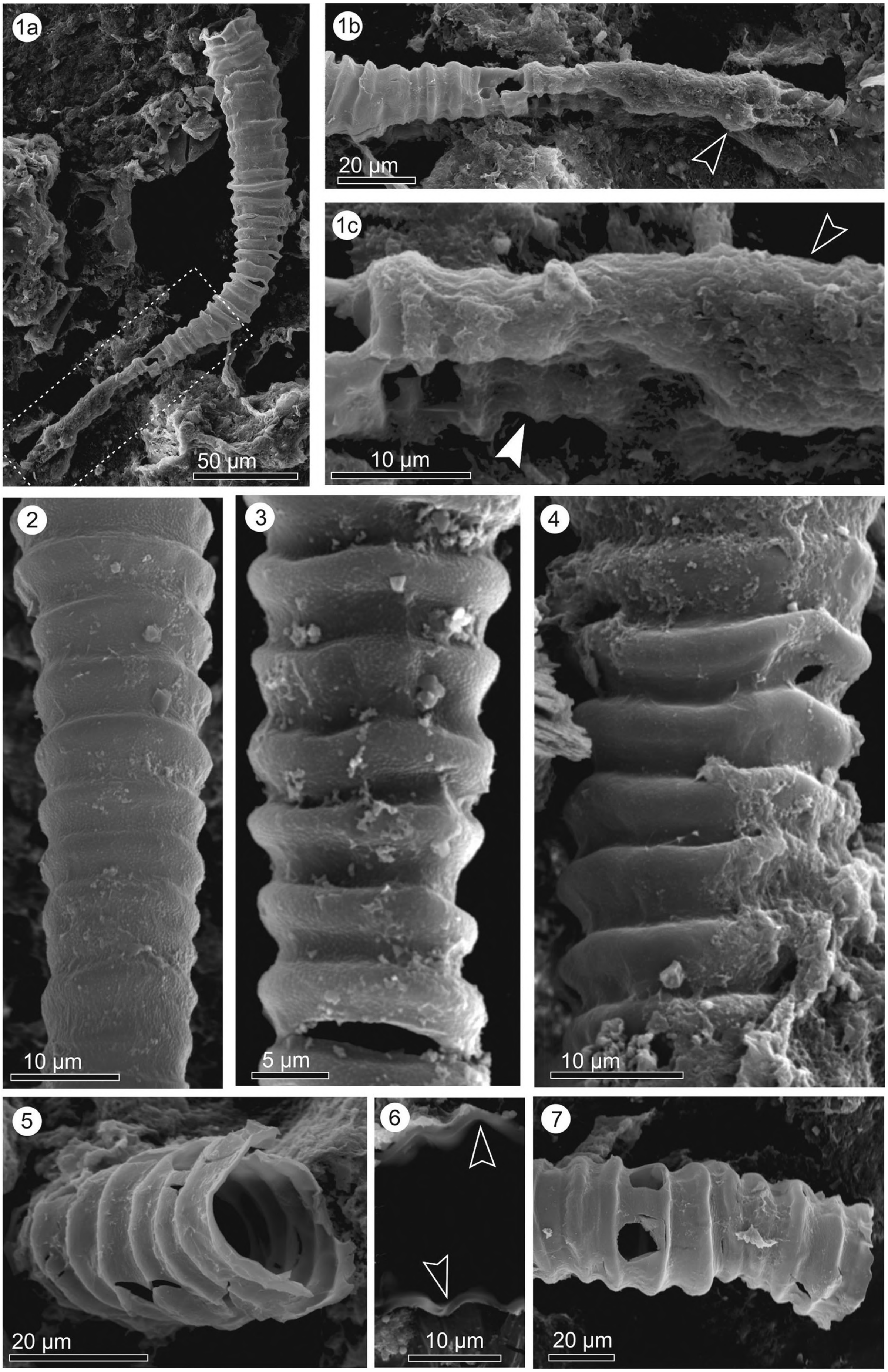
According to Turnau (2007, 2011), Turnau and Racki (1999), and Obukhovskaya (2000), typical features that are observed in this zone include a decrease in the taxonomical diversification and the disappearance of *Aneurospora extensa*. As the number of palynologically positive samples was very limited it was not possible to observe the former phenomenon; however, no *A. extensa* were found within the samples, reinforcing the established diagnosis.

Racki (1993) indicated that the uppermost part of the Kowala Formation is mostly early Frasnian in age (*punctata* Conodont Zone). The Jaźwica Member, which is located at a depth of 633.2 to 616.3 m, represents the latest part of the Givetian (the early *falsiovalis* Conodont Zone) but it is possible that its basal part might be older (*varcus* Conodont Zone; Narkiewicz et al. 1990). Using the shallow–deeper water zonation by Narkiewicz and Bultynck (2010), the Jaźwica Member is recognised as being part of the Early and Middle *subterminus* conodont zone. All those considerations remain in agreement with the palynological results obtained in this study.

Despite the quantitative predominance of the miospores, a few acritarch and prasinophyte taxa were also noted in the organic assemblage. Prasinophytes were represented by *Leiosphaeridia* sp. only. The acritarchs *Gorgonisphaeridium granatum* and *Gorgonisphaeridium* sp. were also documented (Plate 1, figures 1 and 2). Miospore tetrads and fragments of megaspores were also noticed.

The palynomorph assemblage must have been deposited from a proximal source as megaspores and tetrads cannot be transported over long distances (e.g. Tyson 1995). It is worth noting that mineral tentaculitoids were not observed within the samples.

Plate 2. SEM images of three tentaculitoid morphotypes A, B, and C. All specimens were obtained from sample 545 (depth: 534.00–535.00 m). 1a. Tentaculitoid form A with sigmoidal shell and an embryonic chamber with single caudal process. 1b. Image of the same specimen at higher magnification shows the smooth wall of the shell. 1c. A simplified scheme showing the crucial features of form A. 2a. Tentaculitoid form B with funnel-shaped ribs and small granular ornamentation. 2b. Magnification demonstrating the fine granular surface texture covering the shell and the elongated, oval embryonic chamber. 2c. A simplified scheme showing the crucial features describing form B. 3a. Tentaculitoid form C. The overall shape of the embryonic chamber differs from the forms A, B, and D. It has parallel walls and a shape that is more rectangular than bulbous, sample 545 (depth: 534.00–535.00 m). 3b. Magnified part of embryonic chamber with the characteristic flat base. 3c. Simplified scheme showing the parallel-sided shape of the embryonic chamber and funnel-shaped ribs. 4. Specimen representing form B1 with fine granular surface texture covering the shell, funnel-shaped ribs, and a single caudal process. 5. Specimen representing form A with a smooth sigmoidal shell. 6a. Specimen representing form A with a sigmoidal shell, an elongated embryonic chamber, and a with single caudal process. 6b. Magnified part showing the embryonic chamber. 7a. The badly preserved specimen representing form A with a sigmoidal shell, an elongated embryonic chamber, and a single caudal process. 7b. Magnified part showing the smooth surface of the shell and details of an embryonic chamber with a distorted caudal process. 8a. Specimen representing form B2 with funnel-shaped ribs and a small embryonic chamber. 8b. Magnified embryonic chamber with visible damage.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5. The organic tentaculitoids

Farsan (2005) indicated six of the most important morphological features that can be used for taxonomical recognition of mineral tentaculitoids; however, only the morphology of the shell, the shape of the embryonic chamber, and the arrangement of the ribs are applicable for palynological analysis (Marshall and Tel'nova 2017). Consequently, as most of the features required for tentaculitoid classification at more detailed taxonomical levels are lacking here, it was not possible to discern particular species. It was possible to assign documented organic tentaculitoids into the subclass Dacryoconarida based on the results of Fisher (1962) and Farsan (1994, 2005), as these specimens show bulbous embryonic chambers (Plates 2–4) that vary from 4.5 to 22 μm in diameter. The total lengths of the documented tentaculitoids ranged from 170 to 600 μm. All specimens have annular rings next to the embryonic chamber (Plate 2, figures 1a–3c). According to Farsan (2005) the presence of radial ribs in this form is typical of the order Nowakiidae, whereas other Dacryoconarida lack these features; they instead have shells that are either smooth or feature a striated, longitudinal external sculpture (Farsan 2005; Wei et al. 2012; Marshall and Tel'nova 2017). The second feature typical of Nowakiidae is the angle of growth from the bulb; however, this characteristic is not applicable for the classification of organic forms (Marshall and Tel'nova 2017).

Based on the abovementioned features, the observed organic tentaculitoids were placed in the order Nowakiidae. Consideration of the morphological details led to the classification of the tentaculitoids into three categories. One specimen deserves special attention as the main part of the organic shell is inserted into the relict preserved mineral shell (Plate 3, figures 1a–1c). This association indicates a direct relationship between the organic forms recognised in this study and their mineral counterparts.

Subclass DACRYOCONARIDA Fisher, 1962
Order NOWAKIIDAE Lyashenko, 1955

5.1. Form A (Plate 2, figures 1a–1c, 5–7b, Plate 4, figures 6 and 11)

The total length of this form varies from approximately 170 to 600 μm, with the adult part of the shell forming a tapering conical shape. The number of ribs per unit varies (usually 5 ribs per 10 μm within the juvenile part of the shell). The striation formed by the ribs shows a regular sigmoidal pattern (Plate 2, figure 1a). The embryonic chamber is bulbous to oval in shape, with an apex that demonstrates a characteristic single caudal process (Plate 2, figure 1b). The size of the chamber varies between approximately 4.5 and 22 μm. The wall that forms the chamber is smooth and thick.

This form strongly resembles that of the tentaculitoids described by Wood et al. (2004) and Filipiak and Jarzynka (2009; figs 5, A, E?, F–H?, L?, M), and the forms reported by Marshall and Tel'nova (2017; fig. 9, pl. 2). A total of 245 specimens of this kind were documented, and this form was found within all positive samples.

5.2. Form B (Plate 2, figures 2a–2c, 4, 8a–8b, Plate 3, figures 1–4, Plate 4, figures 1–5, 7–10, 12–13)

This type includes two forms (B1 and B2), both of which demonstrate a thick wall and an overall shape that is noticeably different from that of form A. The total length of the shell varies between approximately 150 and 300 μm. The shell is conical with funnel-shaped segments that are sequentially combined (Plate 2, figure 2a). All specimens show annular ribs (generally 3–4 ribs per 10 μm). SEM analysis reveals that the specimens may be ornamented with small grana (less than 0.5 μm in size). The embryonic chamber of form B1 shows no ornamentation and is bulbous to oval in shape (average length and width of approximately 20 μm × 10 μm) with a thickened caudal process that is similar to that of form A (Plate 2, figures 2b, 4). Only three specimens of this kind were observed in the analysed samples. Form B2 shows a much smaller embryonic chamber (approximately 5 μm). A very characteristic narrowing of the shell next to the embryonic chamber occurs over a length of approximately 10–50 μm (Plate 2, figures 8a–8b; Plate 3, figures 1a–1c; Plate 4, figures 3 and 5). A total of 20 specimens of this kind were documented in the analysed section.

Considering the presence of the ornamentation, a similar form was presented by Marshall and Tel'nova (2017, see pl. 4, figs 3–5).

5.3. Form C (Plate 2, figures 3a–3c)

The preserved part of the shell is similar to form B, with the same funnel shape; however, the shape of the embryonic chamber differs. The embryonic chamber has a flat base (approximately 17 μm in width) and parallel sides (30 μm in length; Plate 2, figure 3a). The wall of the shell is thick and smooth and generally shows 5 ribs per 10 μm. Due to its poor preservation, the total length of this specimen remains unknown.

Samples of this taxon strongly resemble the forms described by Marshall and Tel'nova (2017, pl. 3, figs 16, 17, 22, 23) and the morphotype was represented by only one incomplete specimen.

Plate 3. SEM pictures showing the specimen with partly preserved mineral cover and magnification of different details. All specimens are from sample 545 (depth: 534.00–535.00 m). 1a. Specimen of the form B2 with partially preserved mineral shell (marked by dashed line). 1b. Magnification of the dashed frame; the arrow indicates the part that includes the mineral embryonic chamber. 1c. Higher magnification of specimen showing both the organic shell (white arrow) and its mineral cover (black arrow). 2. Different types of organic layer ornamentation. Very fine dotted shell from form B. 3. Different types of organic layer ornamentation. Fine grana covering the organic layer of form B. 4. Different types of organic layer ornamentation. Sparsely distributed grana are visible on tentaculitoid form B. 5. Specimen showing very smooth inner part of the shell. 6. The broken shell; arrows indicate the thickness of the organic layer (approximately 0.5 μm). 7. Magnified part of specimen in Plate 2; figure 6a shows details of the living chamber.

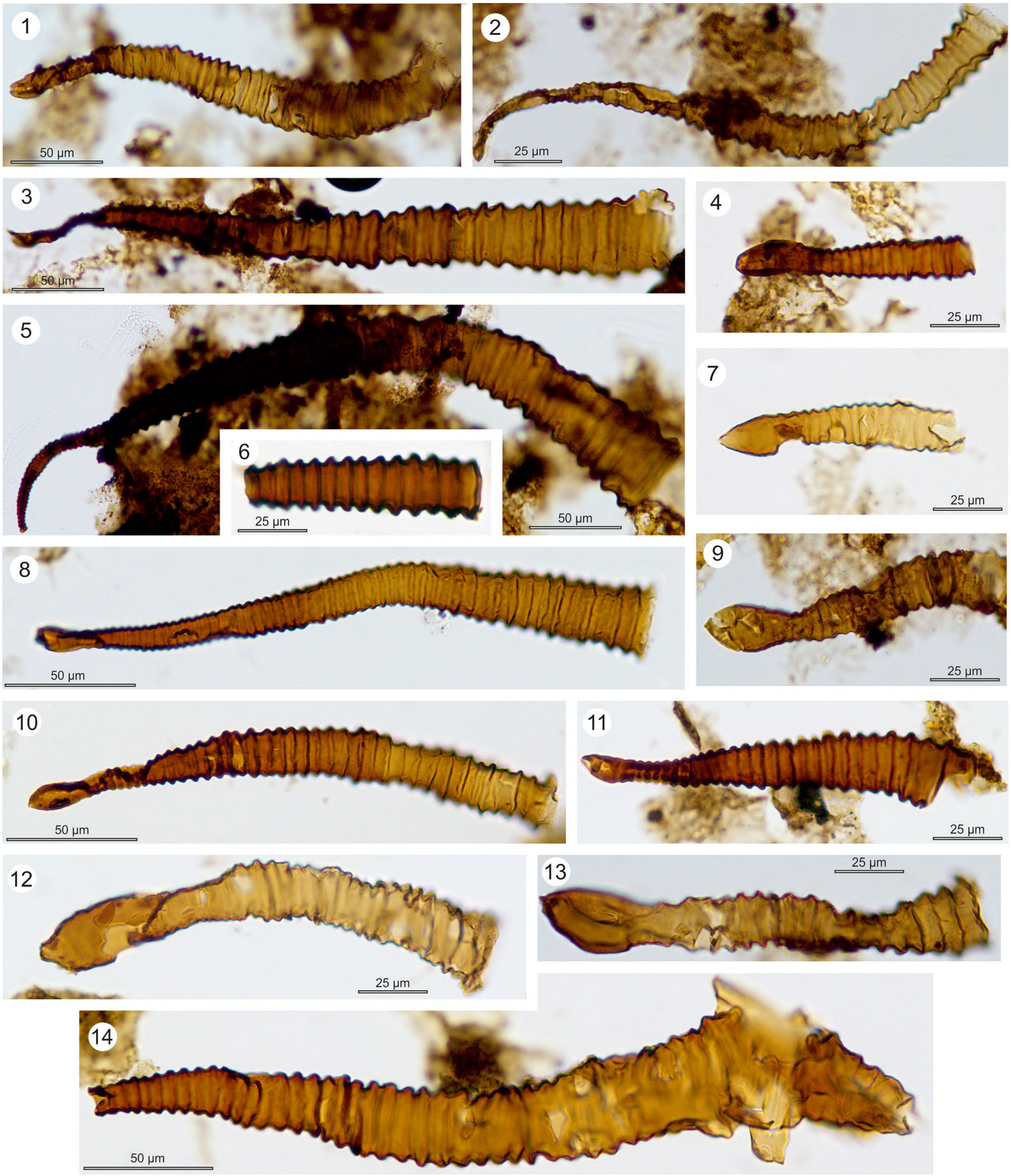

Plate 4. The organic tentaculitoids in transmitted light. All specimens are from sample 545 (depth: 534.00–535.00 m). The delicate ornamentation is imperceptible in transmitted light, from which only the shape of the shell and the size and shape of the embryonic chamber can be discerned. Based on this, tentaculitoids were tentatively divided into two forms: form A: 6, 11; and form B: 1–5, 7–10, 12–13.

6. Discussion

Organic tentaculitoids were described for the first time by Wood et al. (2004), who obtained samples from the Frasnian deposits in the Giełczew PIG-5 borehole from the Lublin-Radom area of Poland. All these forms had small bulbous embryonic chambers, often with a caudal process, and were very similar to form A described in this paper. The shape, total length of the shell, and sigmoidal rib patterns are approximate. Wood et al. (2004) assigned their specimens into the subclass Dacryoconarida, and the morphology of the specimens in this study suggests that the same classification

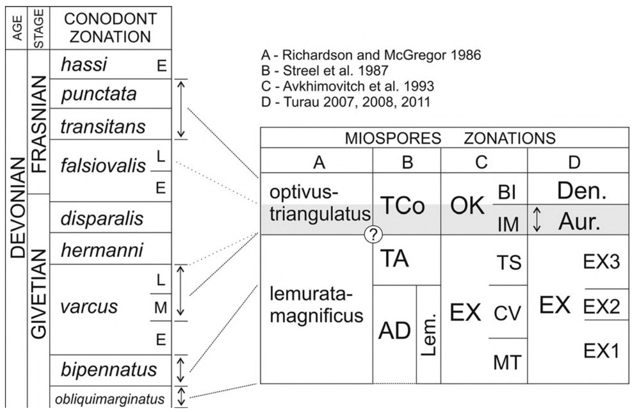

Figure 4. Miospore zonation combined with a standard conodont zonation. The miospore zones recognised within the analysed Kowala 1 section are marked in grey. L – Late, M – middle, E –Early (for conodont zonation). The dashed lines indicating the tentative correlation between the miospore zones and the conodont zones exclude the local *Geminospora aurita* Miospore Zone as it has a narrower stratigraphical range; it is marked with a dotted line (Turnau 2008, 2011). The Aurita Zone is equivalent to most of the *Ancyrospora incisa-Geminospora micromanifesta* (IM) Subzone (see the dark blue double-ended arrow). Conodont zonation modified after Klapper and Ziegler (1979); Weddige (1984); Ziegler and Sandberg (1990).

is appropriate for the forms in the Kowala 1 borehole. Similar microfossils were described by Filipiak and Jarzynka (2009). Their specimens were also considered to belong the subclass Dacryoconarida; however, the two orders Nowakiida and Styliolinida were distinguished. The sizes of the adult part and the embryonic chamber of Nowakiida indicated by Filipiak and Jarzynka (2009) are approximate to the form A specimens from Kowala 1.

Until now, the most differentiated and abundant assemblage of tentaculitoids was documented in early Famennian deposits from Russia (Marshall and Telnova 2012; Marshall and Tel’nova 2017), in which four different forms of Nowakiids were distinguished (excluding aberrant tentaculitoids). This assemblage was similar to the one in the Kowala 1 borehole and was dominated by forms resembling form B (for comparison see plate 3 in Marshall and Tel’nova 2017). According to Marshall and Tel’nova (2017) the preservation of tentaculitoids as palynomorphs is related to the environmental conditions. The hostile shallow-water environment of the Frasnian carbonate lagoon might trigger the tentaculitoids to change the chemical composition their shell from carbonate to organic matter or may cause the problem of maintaining a carbonate shell. The assemblage from Russia was strongly associated with the F/F extinction event; thus, the assemblage from Kowala 1 is not fully comparable. However, the idea that there were environmental problems with the preservation of tentaculitoids cannot be excluded.

So far, there have been problems in interpreting organic tentaculitoids that are combined with mineral fossils. The multi-laminated calcitic and organic composition of the mineral fossils was recognised for the first time by Dewitz (1883). The same observation was made by Bouček (1964). Blind (1969) indicated that the tentaculitoid shell is composed of three layers: outer organic, calcitic micro-lamellar, and inner organic. This was confirmed by Larsson (1979), who estimated that the outer layer reached approximately 1 µm in thickness and the inner layer was 0.1–0.3 µm thick. The organic wall was measured at 0.5 µm thick by Marshall and Tel’nova (2017), and the same result was obtained from the Kowala 1 tentaculitoids (Plate 3, figures 5–7).

It is notable that the tentaculitoids described by Larsson (1979) were much older (Silurian). Those tentaculitoids only had sculptural rings on the external surface of the shell, and the inner wall was smooth and had the associated septa (e.g. Larsson 1979, figs 8a and 8d). Based on this morphological feature, Wood et al. (2004) interpreted the organic tentaculitoids as an outer organic layer. However, it is worth noting that the Devonian mineral tentaculites show similar inner ornamentation (ridged surface) on the outer surface (see e.g. Flügel 2004, fig. 1046b). Filipiak and Jarzynka (2009) suggested that the differences in the size of the adult part and the shape of the embryonic chamber might represent different organic layers. Tentaculitoids with larger embryonic chambers and visible ribs might be the remains of tentaculitoids with an external organic layer, while those with no embryonic chamber, a wrinkled surface, and a smaller size may represent the remains of tentaculitoids with an inner organic layer. An attempt to find both organic and mineral remains of the tentaculitoids was therefore conducted by Marshall and Tel’nova (2017) from sediments that are exceptionally rich in these taxa. They separated many calcareous microfossils with elongated shapes, but none included organic layers (for details see Marshall and Tel’nova 2017). However, the idea that organic tentaculitoids might reflect a similar nature to microforaminifera tests is not excluded. The internal microforaminifera tests are 5–40% smaller than the host tests (Cohen and Guber 1968; Stancliffe and Matsuoka 1991), with a similar pattern noticed by Marshall and Tel’nova (2017), and the mineral fossils in the tentaculitoid assemblage from Russia were approximately three times larger than the organic remains. Stancliffe (1996) indicated that microforaminiferal linings in the tests of different genera might have identical morphology, rendering taxonomical classification impossible if the mineral host test is excluded. Similar difficulties cannot be excluded in the case of tentaculitoids.

Based only on palynology, there is no possible means by which clear conclusions can be obtained concerning the role of the organic tentaculitoids. Their comparison with the microforaminifera linings only provides an idea of how organic and mineral remains can be combined. There is currently only one documented specimen from the Kowala 1 borehole in which the organic and mineral layers appear together; the specimen tentatively demonstrates how the organic lamina is covered with partly degraded mineral shell. This specimen is the first to allow comparison of the mineral and organic remains of tentaculitoids and their consideration as one fossil (Plate 3, figures 1a–1c). Unfortunately, the outer mineral layer seems to be heavily etched with acid and therefore does not reflect the original ornamentation or shape.

It is also interesting that the tentaculitoids from Kowala 1 reveal unusual preservation, with the spatially preserved shells providing details about both the inner and the outer wall of the organic layer. For comparison, the SEM images of the specimens that were obtained by Marshall and Tel’nova (2017) appeared rather flat. Electron microscopic observations of the taxa comprising form B reveal a fine ornamentation (granular surface) on the outer surface and a smooth inner surface. This may indicate that the organic layers within the organically preserved tentaculitoids constituted the inner lining of the mineral shell. Importantly, the granular surface is only noticeable in the SEM photos, while this feature is not visible under transmitted light and is therefore unhelpful for taxonomy.

The reason for the enhanced preservation of these microfossils remains unclear. So far, organic tentaculitoids have been documented in only four localities within Laurussia, while mineral fossils have been observed worldwide (e.g. Wei et al. 2012). Therefore, another questionable issue is the chemical procedure that is used in palynology to dissolve mineral samples. Larsson (1979) indicated that the organic layers of the tentaculitoid shells were very fragile and were easily destroyed during maceration. Based on the maceration of the Kowala 1 samples, it is apparent that fuming nitric acid only affects the shells slightly. However, the extent of the damage caused by the combination of HCl-HF-HCl is unknown. The acid residence time of the organics may also be an important factor. The present research clearly reveals that some of the softer parts of organic tentaculitoids are preferentially degraded (Plate 3, figures 5 and 7; Plate 4, figures 7, 12, and 13). So far, the richest assemblage (with many hundreds of thousands of specimens per sample) was recovered by Marshal and Tel'nova (2017) in relatively weakly compacted rocks. More research is therefore required to clarify this issue.

7. Summary

1. Based on palynology, the transitional Givetian/Frasnian (at a depth of 633 to 535 m) interval in the Kowala Formation was established as *Cristatisporites optivus–Spelaeotriletes krestovnikovii* in the East European miospore zonation and is thus classified as a local *Geminospora aurita* Zone (late *varcus* to *transitans* conodont zones).
2. The assemblage of tentaculitoids that was preserved as palynomorphs was reported for the first time in the shallow-water Devonian deposits of the Kielce area (Holy Cross Mountains, Poland).
3. Based on the documented morphological features, the three morphotypes of tentaculitoids observed were classified in the subclass Dacryoconarida (Nowakiids).
4. For the first time, an organic tentaculitoid was found in association with a partially preserved mineral shell. This may indicate a strict taxonomical relationship between these groups, which were previously treated separately.

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Disclosure statement

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Appendix

List of miospore taxa:
Acanthotriletes sp., Naumova, 1939 ex 1949
Ancyrospora furcula Owens, 1971
Ancyrospora incisa (Naumova) M. Raskatova & Obukhovskaya, in Avkhimovitch et al. (1993).
Ancyrospora involucra Owens, 1971
Ancyrospora longispinosa Richardson, 1962
Ancyrospora pulchra Owens, 1971
Aneurospora greggsi (McGregor) Streel, in Becker et al., 1974
Apiculiretusispora plicata Allen, 1965
Archaeozonotriletes variabilis Naumova, 1953
Convolutispora subtilis Owens, 1971
Corystisporites sp. Richardson, 1965
Geminospora sp. Balme, 1962
Geminospora aurita Arkhangelskaya, 1987
Geminospora decora (Naumova) emend. Arkhangelskaya, 1985
Geminospora lemurata Balme emend. Playford, 1983
Geminospora micromanifesta (Naumova) emend. Arkhangelskaya, 1985
Geminospora notata (Naumova) Obukhovskaya, 1993
Perotrilites bifurcatus Richardson, 1962
Reticulatisporites perlotus (Naumova) Obukhovskaya, 1993
Retusotriletes cladestimus Tchibrikova, 1972
Retusotriletes radiosus Raskatova
Retusotriletes simplex Naumova, 1953
Samarisporites inaequus (McGregor) Owens, 1971
Samarisporites triangulatus Allen, 1965
Verrucosiretusispora dubia Richardson & Rasul, 1978
Verrucosisporites scurrus (Naumova) McGregor & Camfield, 1982
cf. *Archeoperisaccus* McGregor & Owens, 1966
List of phytoplankton taxa:
Gorgonisphaeridium sp. Staplin, Jansonius & Pocock, 1965
Gorgonisphaeridium granatum Playford, 1977
Leiosphaeridium sp. (Eisenack) Downie & Sarjeant, 1963

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Middle Devonian (Givetian) palynology of the northern Holy Cross-Mountains (Miłoszów, south-central Poland)

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ABSTRACT

Givetian samples from Miłoszów (Holy Cross Mountains, Poland) are characterized by a disparity of palynomorph assemblages including miospores, acritarchs, prasinophytes and chitinozoans. Based on the miospores, the age of the investigated deposits was tentatively established as Givetian. The *Geminospora extensa* Zone (MT and CV subzones) was documented, which corresponds with the local palynostratigraphical division ("*Geminospora*" *extensa* Zone, Ex1 and Ex2 subzones). This involves conodont zones from *hemiansatus* to Middle *varcus*. Also, due to the differences of understanding the definition of the important taxon *Samarisporites triangulatus* its morphological features are taken under discussion. Palynofacies analysis indicates intrashelf, deep-marine depositional environment with slight signal of transgression in the uppermost part of succession.

1. Introduction

The area of the Holy Cross Mountains (HCM; central Poland) reveals a great opportunity to investigate the palynology of the diversified Devonian deposits. The whole area of the HCM is divided into two parts: northern Łysogóry Region and southern Kielce Area separated by Holy Cross Fault (Fig. 1). Each part has a different geological setting; the Middle and Late Devonian marine deposits from the Łysogóry Region originated in deep-intrashelf basin, and Kielce Area represents shallow marine carbonate platform (Racki, 1993; Szulczewski, 1995).

While the Late Devonian sediments from southern part of the Holy Cross Mountains were palynologically intensively studied (e.g., Turnau, 1990; Filipiak, 2004, 2005; Marynowski and Filipiak, 2007; Marynowski et al., 2010), the published data on the Middle Devonian intervals are scarce. The palynology of the Lower to Middle Devonian (Pragian-Eifelian) deposits were documented by Fijałkowska-Mader and Malec (2011) and Filipiak (2011). The most detailed palynostratigraphy of the Givetian of the Łysogóry Region (Skały and Nieczulice beds) was made by Malec and Turnau (1997). The latest investigation, including the palynofacies analysis, in this area was focalized on the Givetian deposits of Bodzentyn Syncline (Turnau and Racki, 1999). The synthetic work concerning the regional aspect of the Givetian Taghanic Crisis (sensu Marshall et al., 2011) was performed by Turnau (2014) as well. The organic material analyzed in this study was gathered from the Skały beds and it is undoubtedly Givetian in age (see Halamski, 2004).

The current palynological investigation carried out on three new sections from Miłoszów wood (Fig. 1) provided more details of this time interval from the Łysogóry Region. The main objectives in this report are: (1) to provide new data on palynostratigraphy and (2) and to use palynofacies analysis for establishing palaeoenvironmental conditions.

2. Geological setting

All of the three sampled sections are located in the vicinity of Miłoszów settlement close to the Nieczulice village (Fig. 1). This area belongs to the northern part of the HCM (Łysogóry Region, Bodzentyn Syncline). The Łysogóry Region is bounded from the south by the Holy Cross Fault and from the north it follows the Teisseyre-Tornquist Zone (Mazur et al., 2018; Golonka et al., 2019). According to the previous investigations these deposits represent the intrashelf basin that was formed during the late Eifelian transgression (Racki, 1993; Skompski and Szulczewski, 1994; Szulczewski, 1995).

The analyzed Middle Devonian deposits belong to the mixed limestone and shale fossiliferous Skały beds (Malec and Turnau, 1997; Halamski, 2004; Halamski, 2009; Zatoń and Wrzołek, 2020; Fig. 2). This lithostratigraphic unit is underlain by Wojciechowice beds (Skompski and Szulczewski, 1994; Halamski and Racki, 2005; Narkiewicz and Narkiewicz, 2010) and is overlain by the Świętomarz beds composed of shales and fine grained sandstone deposited within the shallow-water shelf (Halamski, 2005; Malec, 2012).

Investigated palynological samples come from three sections. Section M0 (50°54.07′N, 21°07.18′E) is a 5.3-m thick part of the western

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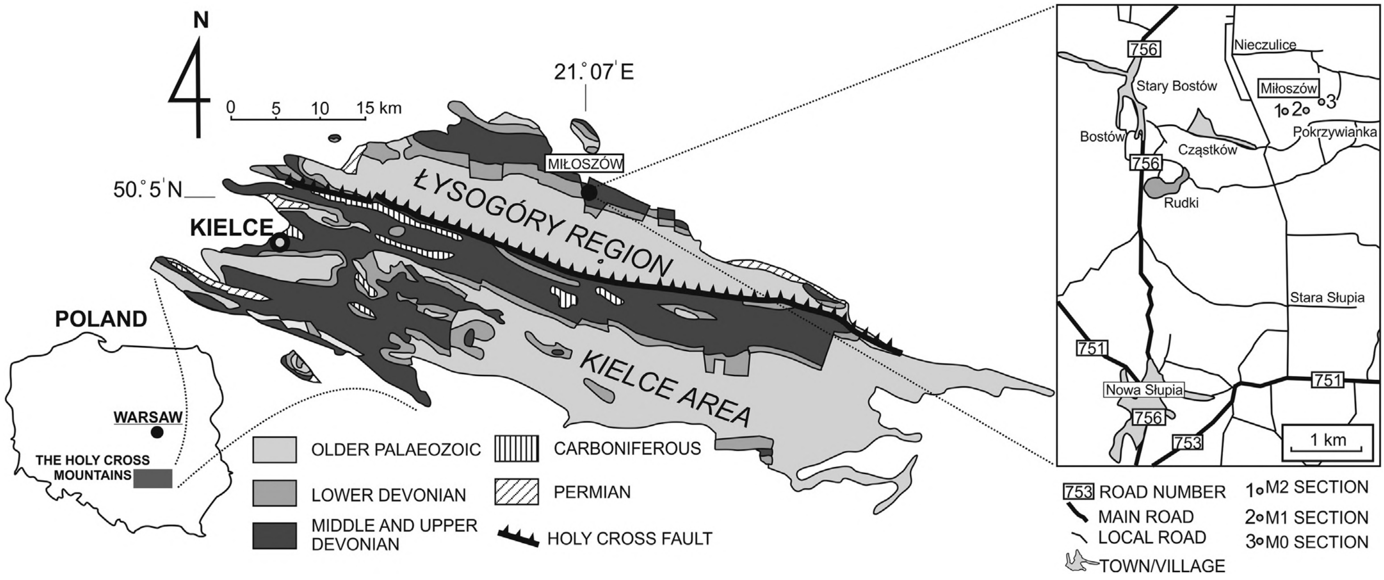

Fig. 1. Locations of the studied outcrops on a tectono-stratigraphic map. The detailed map of the investigation shows the exact location of the Miłoszów outcrops.

quarry wall consisting of limestone interbedded with dark shales (Fig. 3a). The 5-m thick section M1 is located ~25 m SWW from section M0 (50°54.150'N 21°7.271′E). This section is made of limestone set overlain by shales (Fig. 3b). The third M2 section was a short ~2-m trench dug perpendicularly to the layers at 50°54.139'N 21°7.213′E. It was a shale sequence limited from the bottom and from the top by limestone, with one thin marls layer separating the shales (Fig. 3c).

3. Material and methods

The total amount of 36 samples obtained from three sections were investigated for palynology (Fig. 3). The section M0 provided 18 samples and all of them contained palynomorphs. Section M1 provided 12 samples but only five contained organic remains. Six samples were taken from the M2 section and only four contained palynomorphs (Fig. 3). All samples were processed using the standard procedure with the combination of HCl-HF-HCl acids applied (Wood et al., 1996; Riding, 2021). For shales containing amorphous organic matter (AOM) 100% fumic nitric acid was also applied. All collected samples contained palynomorphs but their preservation varied. The palynomorphs obtained from the shale from M0 section showed good or medium state of preservation while the ones obtained from the limestone were mostly corroded. Sections M1 and M2 generally purveyed worse preserved palynomorphs. Within the short section M2 the samples 3 and 6 contained the poorest preserved material. Better yet not the perfect state of preservation of the organic components was shown by samples 2 and 4. Although the preservation was not satisfying, it allowed conducting the palynofacies analysis. All samples revealed material thermally altered and affected by oxidation and within the Łysogóry Block this is common phenomenon (Bełka, 1990; Marynowski, 1999; compare with Dubicka et al., 2021, and references therein). The spore color index (SCI) varied from 8.0 up to 9.5 (see: Fischer et al., 1981; Suáraz-Ruiz et al., 2012).

For each sample the following five categories of palynomorphs were established: miospores, acritarchs, prasinophytes, scolecodonts and dark bioclasts (including plant remains e.g., tracheids). The fifth category of dark bioclasts was created due to the thermal alternation of the organic matter and it was used to define all dark brown and black particles that were not possible to classify into any of the categories mentioned above. The AOM occurred in all analyzed samples but it was excluded from the statistic as the part of it was lost during the maceration process. For each sample palynomorphs were counted up to 500 specimens, which allowed to establish the relative percentage abundance for each of the groups. Additionally, the mutual ratio of the spores of *Aneurospora extensa* and *Rhabdosporites langii* was counted for every sample of section M0 only. This method was applied by Turnau (2014) as the one indicating floral changes during the Taghanic Event. In the case of section M1 and M2 the organic material was so poorly preserved that this analysis was not feasible.

All analyses were prosecuted using Optika B-510BF and Nikon Eclipse 50*i* transmitted light microscopes with NIS Elements-D software and NIK-Cam Pro-1 camera. Petropoxy 154, the mounting agent, was used in order to prepare the microscopic slides whereas organic clumping was avoided by the Cellosize dispersal agent. England-Finder coordinates were used to locate the specimens on the palynological slides. For each macerate two slides were prepared. All microscope slides and residues are housed at the Faculty of Natural Sciences in Sosnowiec, Poland. Selected, stratigraphically and environmentally important palynoflora species are illustrated in Plates I, II and III.

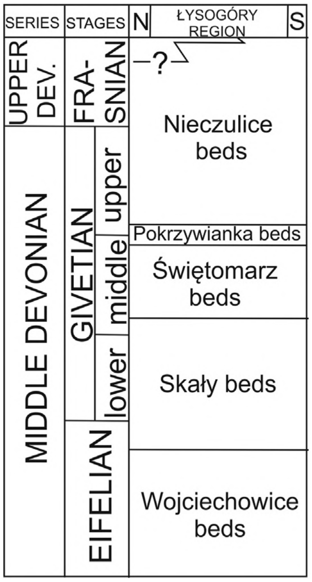

Fig. 2. Simplified, lithostratigraphical division of the northern area of the Holy Cross Mountains (based on Malec and Turnau, 1997).

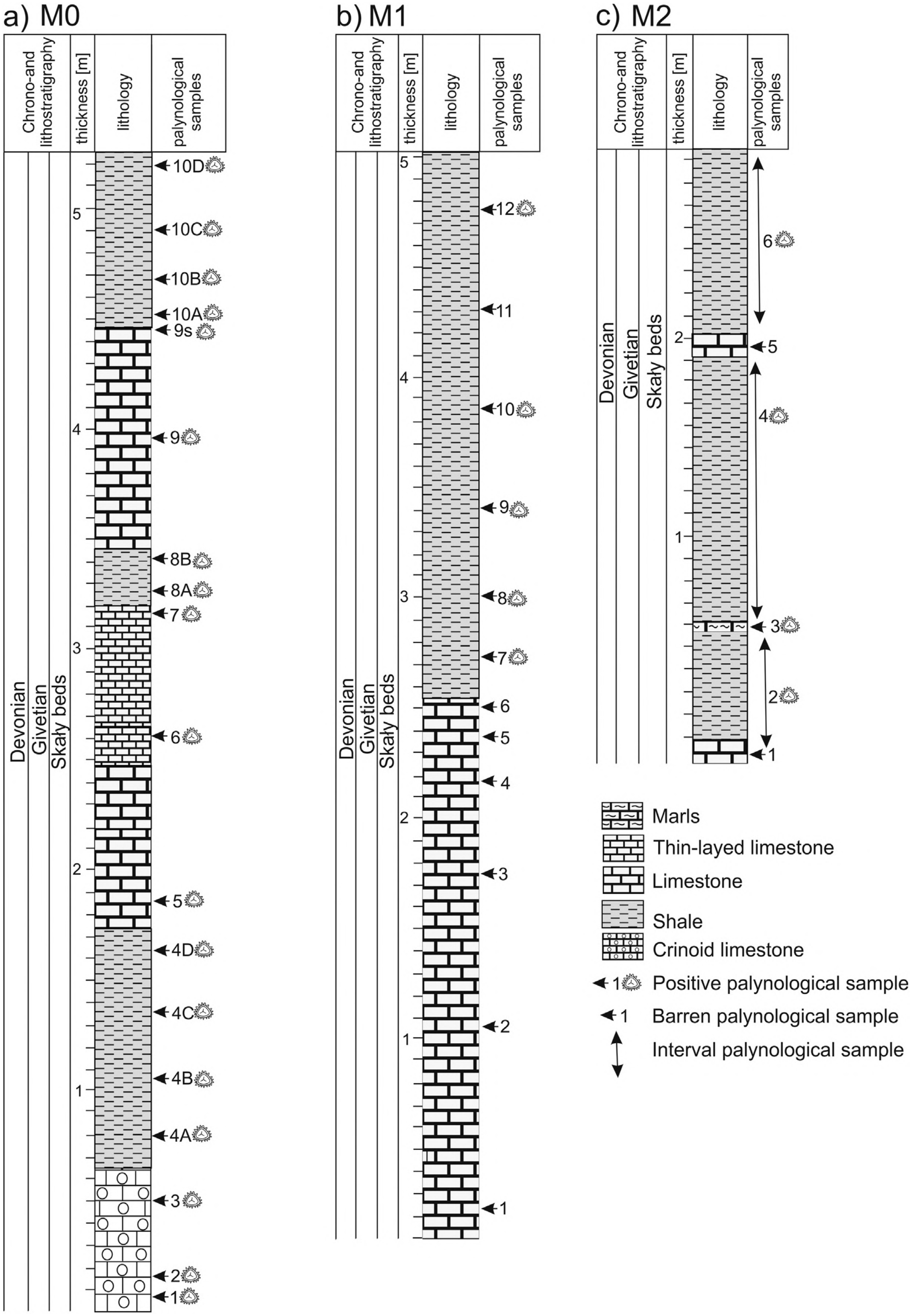

Fig. 3. The analyzed sections. a. section M0, b. section M1, c. section M2 (based on the information provided by A. Halamski and A. Pisarzowska). Note that for levels in the M0 and M1 section the present authors used the same convention as Halamski and Pisarzowska, whereas for M2 they introduced their own level notation different from that used by Halamski and Pisarzowska.

4. Palynostratigraphy

The microflora documented in all sections from Miłoszów shows significant similarities to the palynoflora of Eastern Europe. As previous investigations shown, the miospore zonation proposed by Avkhimovitch et al. (1993) was useful for the investigations of the Middle Devonian deposits in the HCM, Radom-Lublin area and Western Pomerania (e.g., Turnau, 1996, 2007, 2008, 2011; Malec and Turnau, 1997; Turnau and Racki, 1999). Thus, the same zonation, with the version modified by Turnau (2007, 2008), was applied for palynostratigraphical

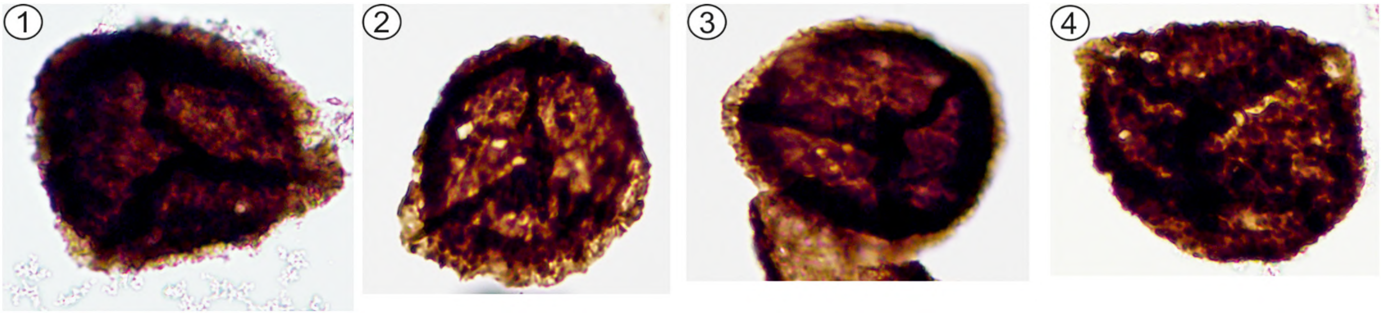

Plate I. Different morphological variants of the *Samarisporites* that resemble *S. triangulatus*. 1-3. *Samarisporites triangulatus* sp. 1, sample 10C (EF for 1: 17J, for 2: 37V3, for 3: 41X2), section M0, (compare with Turnau and Racki, 1999; pl. II, fig. 5) 4. *Samarisporites triangulatus* sp. 1, sample 10D (EF 13X4), section M0, (compare with Turnau and Racki, 1999; pl. II, fig. 5)

investigation of the material from Miłoszów (Fig. 4). The lower and the upper boundary for the Ex ("*Geminospora" extensa*) Miospore Zone by Avkhimovitch et al. (1993) and by Turnau (e.g., 2008) are stratigraphical equivalents, thereby the modifications introduced by Turnau (2008; see Fig. 4) are related to the divisions of the Ex Zone into subzones.

According to the local division, the Ex Zone is divided into three subzones: Ex1, Ex2 and Ex3 (e.g., Turnau, 2008; see Fig. 4). The lower boundary of the Ex1 Subzone is determined by the first appearance of *Geminospora lemurata*, which approximately allows to indicate the Eifelian-Givetian boundary. According to Turnau (1996) the basal part of the Ex2 Subzone is based on the first appearance of *Chelinospora concinna* and within this subzone *Cristatisporites collaris* var. *kalugianus* and *Hystricosporites setigerus* disappear completely (Byvsheva et al., 1985; Avkhimovitch et al., 1993; Turnau, 2011). The first appearance of *Samarisporites triangulatus* determines the lower boundary of the Ex3 Subzone. The typical miospores of this subzone are *Geminospora decora* and *Krauselisporites spinutissimus* (Turnau, 1996). This local zonation is also comparable with miospore zonations by Richardson and McGregor (1986) and Streel et al. (1987; see Fig. 4). The miospore zone Ex includes the conodont zones of *hemiansatus, timorensis*, *rhenanus/varcus*, *ansatus* and *latifossatus-semialternans* (see Narkiewicz et al., 2011; Fig. 4). In terms of the chronostratigraphy it indicates early and middle Givetian interval.

4.1. Palynostratigraphy of the M0 section

Based on the miospore assemblage the age of the deposits obtained from the M0 section was established as the Ex Miospore Zone by Turnau (1996, 2007, 2008). The miospores from the samples 1, 2, and 3 tentatively represent the Ex1 Subzone (Table 1). The occurrence of the *Geminospora lemurata*, the important index taxa for the Ex1 Subzone, was observed in sample 3, therefore the samples 1 and 2 are not younger than Ex1. However, due to the poor preservation of taxa this result is approximate. Beside the *G. lemurata*, the common specimens of *Lanatisporites bislimbatus* and *Rhabdosporites langii* were also documented in samples 1, 2 and 3 and at the same time *Chelinospora concinna*, according to Turnau (2011) the taxon characteristic for the Ex2 Subzone was not observed. It was not possible to include the sample 4A into Ex1 or Ex2 Subzone due to the lack of index taxa, thus it belongs to the undivided Ex1/Ex2 interval (Table 1). The assemblages from the samples 4B, 4C and 4D were assigned to the Ex2 Subzone. *C. concinna* was documented in sample 4B and moreover, samples 4B-4D contained following miospores considered by Turnau (1996, 2007, 2008) as typical for this zone: *Aneurospora extensa*, *Rhabdosporites langii*, *R. streelii* and numerous spores of genus *Ancyrospora* (Table 1). The microflora in the samples 5, 6 and 7 was so poorly preserved that they were not included into any of the subzones with the full certainty, but taking into account the presence of *C. concinna* in sample 4B and 10A, samples 5, 6 and 7 are not older or younger than Ex 2 (Table 1). The problematic assemblages determined as Ex2/Ex3 were recognized in samples 8A, 8B, 9, 9s, 10A, 10B, 10C and 10D, which contained taxa characteristic for Ex Zone: *Aneurospora extensa*, *Geminospora decora*, *G. micromanifesta*, *G. tuberculata*, *G. tenuispinosa*, *Lanatisporites bislimbatus*, *Rhabdosporites langii*, and *Verrucosisporites scurrus*. Additionally, some miospores strongly resembling the specimen of *Samarisporites triangulatus*, which is an index taxa for Ex3 Subzone, were also documented from samples 8A, 8B, 10B, 10C and 10D (Plate I; Table 1, see discussion below). What is also important, *C. concinna* might be consider as late Givetian in age (Streel et al., 2021)

The Ex Miospore Zone established by Turnau (2008) corresponds with the *Extensa* Zone of Eastern Europe by Avkhimovitch et al. (1993). The taxa indicated by Avkhimovitch et al. (1993) as the most typical for this zone, such as *Aneurospora extensa*, *Geminospora tuberculata*, *G. micromanifesta* are present in samples from the M0 section. The recognized Ex Zone corresponds to the *Geminospora lemurata* - *Cymbosporites magnificus* Zone of Richardson and McGregor (1986) as well (Fig. 4). The miospores considered by Richardson and McGregor (1986) as stratigraphically important, such as *Aneurospora goensis, A. greggsi, Coristisporites serratus* together with the index taxa *Geminospora lemurata* were also reported from the investigated samples. The subzones Ex1 and Ex2 correlate with the AD (*Acinosporites acanthomammillatus–Densosporites devonicus*; Subzone Lem.) of Streel et al. (1987) for the Ardenne–Rhenish area. None of the index taxa for this zone was found in the analyzed section but the general miospore assemblage containing the taxa mentioned above does not exclude using this zone. According to conodont analysis the age of the section M0 ranges from the upper *rhenanus/varcus* to lower *ansatus* zones (= Lower to Middle *varcus* zones in conodont zonation by Klapper (1988) and Clausen et al. (1993) and it does not exclude the results obtained from palynology (K. Narkiewicz, personal information, see Fig. 4). However, this result must be treated with caution. The presence of *C. concinna*, and the miospore that resembles *S. triangulatus* might suggest the late Givetian age, but this would be inconsistent with the current results of conodont analysis.

4.2. Palynostratigraphy of the M1 section

The miospore assemblage contained not only the wide-stratigraphical range taxa but also several taxa considered by Turnau (1996, 2007, 2008) as important for the palynostratigraphy: *Aneurospora extensa*, *A. greggsi*, *Archeozonotriletes variabilis*, *Geminospora lemurata* and *Rhabdosporites langii* (see Table 1). Using local zonation of Turnau (2007, 2008) and basing on the presence of *G. lemurata* and *A. extensa* and the lack of the *C. concinna*, the age of the investigated interval might be tentatively established as Ex1? Subzone. This result is consistent with the biostratigraphy based on the conodonts. According to the conodont analysis (K. Narkiewicz, personal information) the samples from 1 to 6 are undivided *timorensis* - lower *rhenanus/varcus* zonal interval (= Lower *varcus* zone in scheme by Klapper, 1988) in age and that corresponds


1
2
3
25 µm
4
5
6
7
8
9
10
11
12
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with Ex1 Subzone (see Fig. 4). The same, samples from 7 up to 12 must be younger or the same in age.

4.3. Palynostratigraphy of the M2 section

Based on the miospore succession, the age of the deposits from three investigated samples was also established as the Ex Miospore Zone (e.g., Turnau, 2008). The age of the deposits from M2 section was tentatively determined as Ex1? Subzone, due to the presence of *A. extensa* occurring together with *G. lemurata,* and lack of the *C. concinna* (Table 1). Beside this stratigraphic important spores, samples from M2 section contained specimens described by Turnau (2007, 2008) as typical for the Ex Zone such as: *Ancyrospora longispinosa, Aneurospora greggsi, Apiculiretusispora plicata, Geminospora notata, Grandispora echiniformis, Retusotriletes clandestinus, Rhabdosporites langii*, and *R. streelii*. It is worth mentioning that some documented miospores resemble *Samarisporites triangulatus* (see Plate I; Table 1). Conodonts data (K. Narkiewicz, personal information) indicate the *rhenanus*/*varcus* to *ansatus* zones (Lower and Middle *varcus* Conodont zones in zonation by Klapper (1988) and Clausen et al. (1993), and this corresponds with the obtained palynological results (see Fig. 4).

4.4. Discussion

Based on the lithostratigraphy all three sections belong to the Skały beds (Fig. 2). The detailed analysis of the Givetian deposits of this unit was performed by Malec and Turnau (1997). Using the division by Pajchlowa (1957) they investigated Skały beds divided into 13 lithological units (from XIII to XXV, see Malec and Turnau, 1997, figs. 3 and 5) and the Miospore Zone Ex1 was recovered from the units XX, XXI, XXIV and the lower part of XXV. The specimen of *Corystisporites collaris* var. *kalugianus* indicated by Malec and Turnau (1997) as a characteristic taxon that disappeared in the Ex2 was documented in samples 4C, 5, 8A and 10A of the section M0 (Plate I; Table 1). This indicates the Ex2 Subzone as the youngest possible for these samples. What is important, the problematic specimen strongly resemble typical for Ex3 Subzone spore of *Samarisporites triangulatus* occurred in samples 8A, 8B, 10B, 10C and 10D of section M0 and also in samples 2 and 4 of section M2 (Table 1). According to Turnau and Racki (1999) the first appearance of this taxon in the HCM should be located within the basal strata of the Nieczulice beds, dated as the late Givetian (see Fig. 2). The worldwide distribution of *S. triangulatus* shows that this taxon may co-exists with *Chelinospora concinna* and in Canada it appears presumably in the Late *varcus* Zone, while in Boulonnais (France) this spore is documented for the first time in the Middle *varcus* Zone (Loboziak and Streel, 1980; Fig. 4). Specimens documented from Poland that are morphologically similar to the problematic spores from Miłoszów were marked by Turnau and Racki (1999) and Turnau (2007) as unquestionable *S. triangulatus* (see Turnau and Racki, 1999; plate II, fig. 5; Turnau, 2007; fig. 17G), while there is no certainty that these miospores truly belong to the *S. triangulatus* species. This spore differs from typical *S. triangulatus* by possessing noticeably ornamented zona (Turnau, 2011). Another different way of understanding this species was shown by Stempień-Sałek (2002). The specimens from Western Pomerania differ from *S. triangulatus* Allen, 1965 in possessing less elongated apices, less convex sides and it is slightly larger (see Stempień-Sałek, 2002, fig. 9E). This shows the wide range of understanding of this palynostratigraphically important taxon. Similar taxonomic problem with *S. triangulatus* was recently marked by Streel et al. (2021). They indicated that poorly preserved *S. triangulatus* may strongly resemble *Auroraspora pseudocrista* that ranges from the uppermost Frasnian to Famennian (Streel et al., 2021). Some different problematic forms that strongly resemble the specimen from Miłoszów is documented on Plate I, Figs. 1–4. Because of this uncertainty the samples 8A-10D of section M0 and 2–4 of section M2 cannot be clearly included into Ex3 Subzone. Moreover, Streel et al. (1987) indicate the lack of the *R. langii* within the TA (equivalent of Ex3 Subzone; Fig. 4) zone, while this taxon occurred in all analyzed samples. In fact Turnau (2011, 2014) documented *R. langii* ranging from Eifelian up to the Givetian–Frasnian (G–F) boundary but with the noticeable decrease in number upward the G–F boundary. This phenomenon was not observed in any of the investigated samples from Miłoszów. All these stratigraphical considerations allow us to suspect that the miospores from Miłoszów only resemble *S. triangulatus.* Those taxa are, probably, the other species of *Samarisprites*.

5. Palynofacies analysis

Within the recognizable palynomorph assemblage in sections M0 and M1 palynomorphs of terrestrial origin were the most numerous. Marine components were limited in number and represented mainly by prasinophytes, acritarchs and scolecodonts. Section M2 shown different palynomorph assemblage, with a noticeable high number of prasinophytes. What is important, sample 4 from section M2 contained chitinozoans, which were not reported from any of the remaining investigated samples in all three sections. Chitinozoans are represented by two families: Desmochitinidae and Lagenochitinidae (personal

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Plate II. Important miospores from Miłoszów sections. 1. *Chelinospora concinna*, sample 10B, section M0 (EF: 16V4)
2. *Ancyrospora ancyrea* var. *brevispinosa*, sample 8B, section M0 (EF 22W2)
3. *Aneurospora extensa*, sample 10C, section M0 (EF: 22V1)
4. *Aneurospora gregssi*, sample 10C, section M0 (EF: 17R)
5. *Archeoperisaccus variabilis*, sample 10C, section M0 (EF: 28T1)
6. *Lanatisporites bislimbatus*, sample 10C, section M0 (EF: 37Q3)
7. *Aneurospora goensis*, sample 8B, section M0 (EF: 45T4)
8. *Corystisporites collaris* var. *kalugianus*, sample 10A, section M0 (EF: 31E2)
9. *Perotrilites granuleticonatus*, sample 10C, section M0 (EF: 46E2)
10. *Grandispora echiniformis*, sample 10C, section M0 (EF: 48X1)
11. *Rhabdosporites langii*, sample 10C, section M0 (EF: 53K3)
12. *Aneurospora extensa*, sample 10, section M1 (EF: L26)
13. *Samarisporites arcadensis*, sample 10C, section M0 (EF: 16Y2)
14. *Corystisporites collaris* var. *kalugianus*, sample 10A, section M0 (EF: 16S2)
15. *Rhabdosporites streelii*, sample 10C, section M0 (EF: 36P3)
16. *Geminospora tuberculata*, sample 10D, section M0 (EF: 49P1)
17. *Samarisporites arcadensis*, sample 10C, section M0 (EF: 34M1)
18. *Geminospora lemurata*, sample 10C, section M0 (EF: 42J1)
19. *Retusotriletes clandestinus*, sample 10D, section M0 (EF: 43G1)
20. *Dibolisporites echinaceus*, sample 10D, section M0 (EF: 9N1)
21. *Rhabdosporites langii*, sample 10C, section M0 (EF: 16V1)
22. *Geminospora micromanifesta*, sample 5, section M0 (EF: 45U1)
23. *Geminospora lemurata*, sample 10C, section M0 (EF: 38O1)
24. *Verrucosisporites scurrus*, sample 10C, section M0 (EF: 32C)
25. *Aneurospora extensa*, sample 10C, section M0 (EF: 35H3)

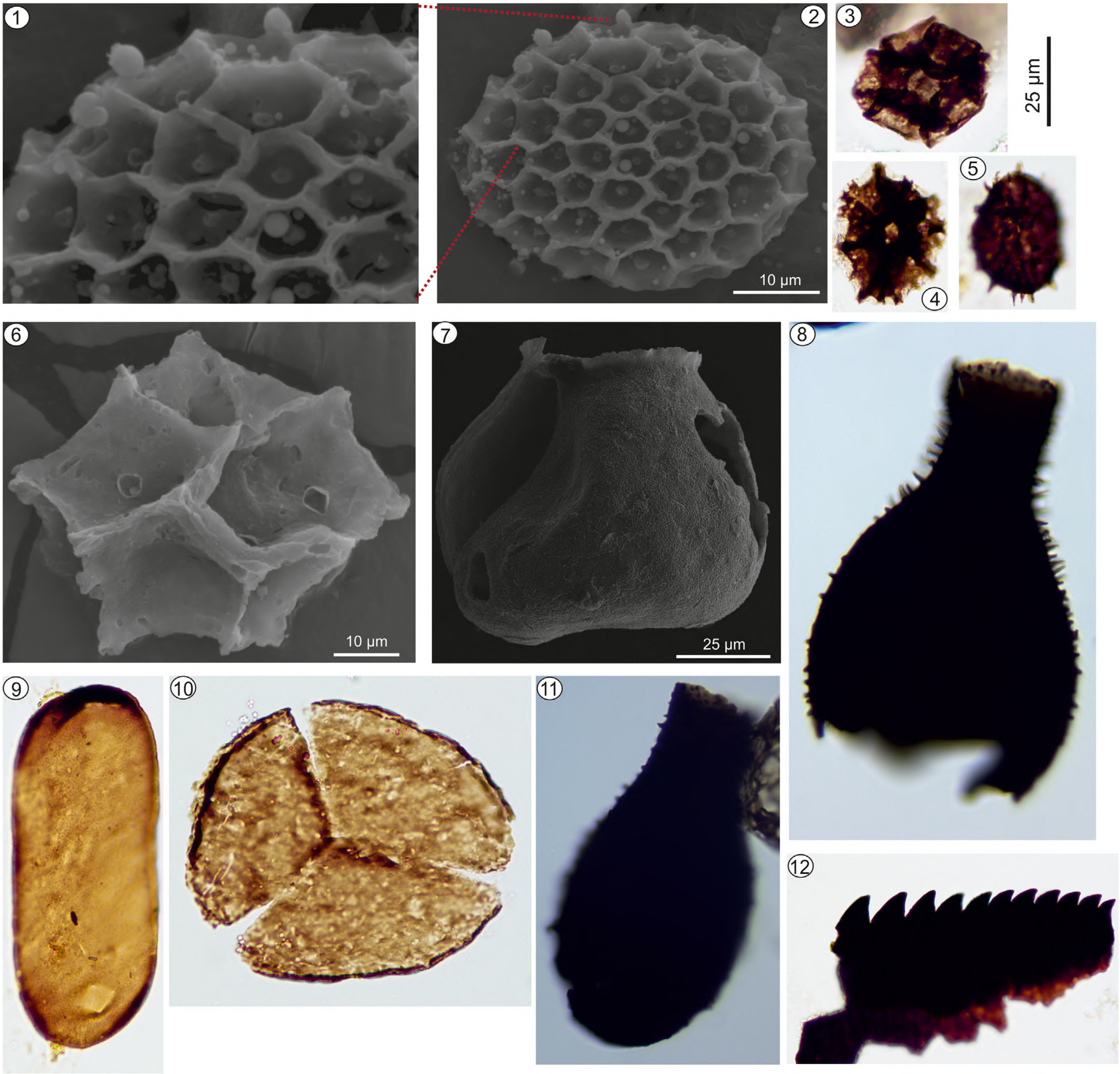

Plate III. Marine and terrestrial palynomorphs from Miłoszów. 1. *Dictyotidum* sp., sample 10C, section M0, the magnification of picture 2
2. *Dictyotidum* sp., sample 10C, section M0
3. *Polyedrixium skalensis*, sample 10B, section M0 (EF: 45V3)
4. *Polyedrixium evolutum*, sample 10D, section M0 (EF: 33X3)
5. *Gorgonisphaeridium* sp., sample 10C, section M0 (EF: H193)
6. *Polyedrixium skalensis*, sample 10A, section M0
7. Chitinozoa, sample 4, section M2
8. Chitinozoa, sample 4, section M2 (EF: 5R2)
9. *Navifusa bacilla*, sample 8A, sectiom M0 (EF: 17V4)
10. Spore, sample 10C, section M0 (EF: 17M2)
11. Chitinozoa, sample 4, section M2 (EF: 34S4)
12. Scolecodont, sample 10C, section M0 (EF: 16N3)

information from S.C. Camina; Fig. 3c). In both sections land microflora was abundant, represented by taxonomically differentiated assemblage of miospores characteristic for the Givetian of central and east Europe. The genera: *Ancyrospora*, *Aneurospora*, *Geminospora* and *Rhabdosporites* were the most common (Table 1). Plant cuticles and tracheids were restricted in number. Within the prasinophytes assemblage different sized *Leiosphaeridia* were the most abundant. Beside them only single specimens of *Cymatiosphaera*, *Dictyotidum*, *Muraticavea* and *Polyedrixium* were documented. The acritarchs showed poorly differentiated assemblage with the species of *Gorgonisphaeridium*, *Micrhystridium*, *Navifusa*

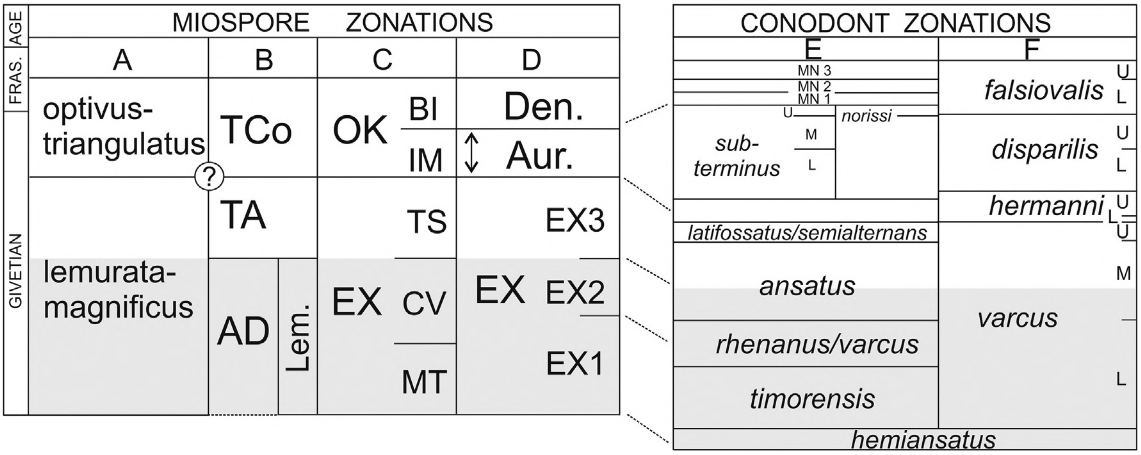

Fig. 4. Miospore zonation combined with conodont zonation. The miospore zones recognized within the Miłoszów sections are marked with gray color. L-Late, M-Middle, E-Early (for conodont zonation). A-Richardson and McGregor (1986), B-Streel et al. (1987), C-Avkhimovitch et al. (1993), D-Turnau (2007, 2008, 2011), E-alternative conodont zonation, F-"standard" deep-water zonation. Dashed lines indicate the tentative correlation between miospore zones and conodont zones excluding the local *Geminospora Aurita* Miospore Zone as it has narrower stratigraphic range and it is marked with dotted line (Turnau, 2008, 2011). The *Aurita* Zone is equivalent to most of the IM Subzone (see the dark-blue two-ended arrow). Conodont zonation after Klapper (1988); Clausen et al. (1993); Narkiewicz and Bultynck (2010), Narkiewicz et al. (2011), modified.

and *Stellinium* occurring the most frequently (Table 2). A new specimen of acritarcha *Teleostomata rackii* was documented in previous report (see Kondas et al., 2021).

Due to the poor preservation of the organic matter, the palynofacies analysis results should be treated approximately. However, the M0 section shows small variation within the analyzed assemblages. Two different types of palynofacies can be observed in the studied material (Fig. 5a). They were distinguished in accordance with the differences in the presence and proportions of miospores and acritarchs. Sections M1 and M2 provided fewer samples and they contained poorly preserved material thus it was no possibility to observe any significant fluctuations (see Fig. 5b and c; Table 3).

5.1. Palynofacies of M0 section

5.1.1. The Miospore Palynofacies (samples 1-8B)

Within these palynofacies, beside the dark bioclasts, the miospores were the most numerous group. Sample 3 was the richest (49.2%) and sample 1 contained the lower number of land microflora (22.4%; Fig. 5a). Acritarchs were very limited in number with their maximum in sample 1 (1.7%; Fig. 5a). In samples 4A, 4B, 4C, 4D, 6 and 8B the acritarchs were so few that they were not included in the statistics. Similar pattern was observed within the prasinophytes assemblages. Sample 1 contained the maximum (2%, Fig. 5a) and in samples 4A, 4C and 4D prasinophytes constituted a negligible percentage of the whole palynomorph assemblage thus they were not included into statistics. Each sample contained scolecodonts, with the maximum in sample 8B (5.8%; Fig. 5a). Their number increased noticeably upward the section (Fig. 5a). Due to the high number of the palynomorphs included into the dark bioclasts category, the *Miospore Palynofacies* gives only an approximate view of the environmental changes that occurred during the deposition.

5.1.2. The Miospore-Acritarchs Palynofacies (samples 9-10D)

Similarly, like in *Miospore Palynofacies* the miospores were the most numerous components (Fig. 5a). Their relative percentage amount varied from 36% (sample 9) up to 63% (sample 10D). The number of acritarchs significantly increased when compared to the samples 1-8B. Sample 9 contained the fewest of them (3.8%) and the sample 10B was the richest (15%; Fig. 5a). In a similar way, the content of prasinophytes increased upward the section with the minimum of 2% in sample 9 and the maximum of 13.2% in sample 10C (Fig. 5a). The percentage amount of the scolecodonts varied from 1.2% (sample 10B) up to 8% (sample 10D). The organic matter of the *Miospore-Acritarchs Palynofacies* was much better preserved than in the case of the *Miospore Palynofacies*. The highest content of undivided organic matter was in sample 9 (53%) and the lowest was in sample 10D (9%; Fig. 5a).

5.2. Palynofacies of M1 section

Miospores were the most numerous with their maximum in sample 12 (45.6%, Fig. 5b). Except the samples 8 and 10 acritarchs were in statistics of each sample and they reached the maximum of 1% in sample 9. The number of prasinophytes varied from 0.8% (sample10) up to 3.4% (sample 8). Every sample contained scolecodonts, with their maximum in sample 12 (3.6%) and their minimum in sample 9 (0.4%; Fig. 5b). Up to 73.6% of organic remains were included into the category of the dark bioclasts as the material was thermally altered.

5.3. Palynofacies of M2 section

The very short section M2 is more a supplement of the previous two sections because it reveals different palynofacies pattern. Prasinophytes, especially *Leiosphaeridia* sp. were the most common palynomorphs, reaching the maximum of 47.6% in sample 2 and minimum of 5.6% in sample 6 (Fig. 5c). The number of miospores varied from 18% in sample 3 up to 61.6% in sample 6. Acritarchs were very uncommon, up to 1.6% in sample 6 and the percentage amount of scolecodonts fluctuated from 0% in sample 6 up to 2.6% in sample 4 (Fig. 5c).

5.4. Discussion of palynofacies

Based on the mutual proportion of the terrestrial derived and marine components, one can estimate the relative distance from the palaeoshoreline (Tyson, 1995; Batten, 1996). Generally, the number of spores declines offshore (Tyson, 1995). However, the abundance of the land derived palynomorphs may differ not only because of changes of the shoreline proximity but also because of terrigenous material input changes caused by climatic changes or tectonic events (Tyson, 1995). Also the number of marine palynomorphs is related to a great variety of factors like the circulation of the surface waters or water chemistry and fertility and these features are not a simple derivation of the distance from the shoreline (Tyson, 1995).

Changes within the phytoplankton and especially acritarchs assemblages related to the bathymetry of the basins were examined by

Table 1
Givetian miospores from Miłoszów, the Ex Miospore Zone.

Litho-and chronostratigraphy	Skały beds (Givetian)																										
Section	M0																		M1					M2			
Sample	1	2	3	4A	4B	4C	4D	5	6	7	8A	8B	9	9 s	10A	10B	10C	10D	7	8	9	10	12	2	3	4	6
Miospore Zone	“Geminospora” extensa																										
Miospore sub-Zone	Ex1?			Ex1/Ex2	Ex2						Ex2/Ex3?								Ex1?					Ex1?			
Ancyrospora ampulla					x																						
Ancyrospora ancyrea var. *brevispinosa*										x	x	x															
Ancyrospora furcula				x	x			x						x											x		
Ancyrospora involucra			x				x	x			x																
Ancyrospora longispinosa																									x		
Ancyrospora melvillensis															x												
Ancyrospora nettersheimensis			x																								
Ancyrospora pulchra			x		x		x		x	x	x			x				x									
Ancyrospora simplex															x					x							
Ancyrospora voronensis				x																							
Aneurospora extensa			x	x	x	x	x	x		x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x
Aneurospora goensis											x	x															
Aneurospora greggsi			x	x	x	x						x			x		x	x						x	x	x	
Apiculiretusispora plicata																											
Archeoperissacus opiparus																	x										
Archeozonotriletes variabilis																	x						x				
Chelinospora concinna					x										x	x		x									
Contagisporites subnotatus																				x							
Convolutispora subtilis												x															
Corystisporites collaris var. *kalugianus*						x		x			x				x												
Corystisporites multispinosus												x															
Corystisporites serratus										x																	
Cymbosporites magnificus																		x		x							
Dibolisporites echinaceus				x	x	x	x	x	x	x	x			x				x					x	x			
Dibolisporites gibberosus			x																								
Geminospora aurita																		x									
Geminospora compta										x																	
Geminospora decora												x					x		x	x		x					
Geminospora lemurata			x				x					x			x		x	x		x	x	x		x	x	x	x
Geminospora micromanifesta								x											x	x			x		x		
Geminospora notata																				x	x	x		x	x		
Geminospora obtuispinosa																						x					
Geminospora teniuspinosa							x						x		x												
Geminospora tuberculata																x		x									
Grandispora echiniformis			x		x	x			x				x		x		x			x			x		x	x	x
Krauselisporites acerosus																	x										
Krauselisporites pomeranius										x					x												
Lanatisporites bislimbatus	x	x	x		x			x	x		x	x					x	x		x				x			
Lophozonotriletes scurrus																	x										
Perotrilites bifurcatus																									x	x	
Perotrilites granuleticonatus																	x										
Retusotriletes clandestinus			x	x	x	x	x	x			x	x	x	x	x			x		x	x	x	x	x		x	x
Retusotriletes distinctus																	x										
Retusotriletes simplex				x			x				x						x										
Rhabdosporites langii	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Rhabdosporites streeli			x		x	x	x	x		x	x	x	x				x			x				x	x		
Samarisporites orcadensis				x	x	x											x										
Samarisporites concinnus						x																					
Samarisporites inaequus					x	x																					
Samarisporites tozeri																			x				x				
Samarisporites aff. *triangulatus*																	x										
Samarisporites sp. 1											x	x				x	x	x						x	x		
Spinozonotriletes cassideus					x																						
aff. *Vallatisporites celeber*																		x									
Verrucosisporites flexibilis							x							x													
Verrucospisrites premnus				x																							
Verrucosisporites scurrus				x	x	x							x	x			x							x			

many authors (e.g., Dorning, 1981; Richardson, 1984; Tyson, 1995; Molyneux et al., 1996). The suggested models show the distribution of phytoplankton as follows: (1) proximal, nearshore assemblages: dominance of simple, thin-walled, short-spines taxa; (2) off-shore shelf assemblages: increase in number of long-spined taxa, less thin walled acritarchs, netromorph forms; (3) deep-open marine basin: low taxonomical diversity, thick walled, short-spined taxa.

The acritarch assemblage from Miłoszów was poorly differentiated and dominated by the spherical forms possessing short and solid processes (e.g., *Gorgonisphaeridium inflatum*, *Stellinium micropolygonale, Micrhystridium stellatum*) and this corresponds with the assemblages described by Turnau and Racki (1999). This kind of acritarch forms are characteristic for the proximal, shallow-water environments (e.g., Dorning, 1981; Tyson, 1995). Only the section M2 showed the dominance of prasinophytes (Fig. 5c, Table 3). The reason for their abundant occurrence in the M2 section is not clear. Usually the abundance of prasinophytes is related to the surface water eutrophication (Tappan, 1980). In Miłoszów taking into account the palynofacies compositions of sections M0 and M1 and their close localities, this situation is rather unlikely and may be explained by the occurrence of the local faults (Narkiewicz et al., 2006; Narkiewicz et al., 2011). The same, the presence of chitinozoans remains unclear and it may indicate section M2 as the oldest part of the Skały beds showing different type of eutrophic biotop than section M0 and M1 (G. Racki, personal information).

The similarity between Łysogóry Basin and Radom Basin may explain this situation to some extent. According to Żakowa et al. (1986), Malec et al. (1996) and Narkiewicz et al. (2011) there are some important common features for those two basins for Middle Devonian deposits (1) the dominance of marly carbonates with marine fauna, (2) similar thicknesses of the deposits, (3) the presence of the terrigenous complex in the middle of the succession, (4) topmost part of the succession shows the transition from the marly to the carbonate deposits. Based on those similarities both regions can be considered as one open marine basin, with the Radom part being more proximal (Narkiewicz et al., 2011). According to Narkiewicz et al. (2011) the sedimentation in the whole basin is affected by synsedimentary tectonics and this may partially explain the local palaeoenvironmental differences occurring between sections, even though they are located nearby.

Taking into account the relative percentage amount of the terrestrial derived and marine organic matter, the land origin material prevailed in the analyzed sections (except section M2). The high number of terrestrial derived material may be related to periodically intensified input of terrigenous material. Another common feature was low content of the AOM and the also sparse scolecodonts and acritarchs. All these premises indicate not a very deep but intrashelf marine depositional environment. Additionally, the upper part of section M0 reveals a weak signal of transgression. The relative percentage amount of acritarchs, prasinophytes and scolecodonts increases upward the section (samples 8B-10D; Fig. 5a). Samples 1-8A contain a noticeable less amount of the marine palynomorphs and this corresponds with samples 7–12 from section M1. This indicates the similarity especially between the samples dated as Ex1? Subzone from both: M0 and M1 sections.

The Givetian deposits of the Łysogóry Region were palynologically analyzed by Turnau in Malec and Turnau (1997), Turnau and Racki (1999) and Turnau (2014) but the palynofacies were discussed in only one paper by Turnau and Racki (1999). Within the analyzed deposits belonging to the Ex3 and OK Miospore Zone (*Contagisporites optivus-Speleaotriletes krestovnikovii* Miospore Zone; Skały, Świętomarz and Nieczulice beds; Fig. 2) Turnau distinguished four different palynofacies: *Spore Palynofacies*, *Leiosphere/spore Palynofacies*, *Spore/acritarch Palynofacies* and *Hemiruptia Palynofacies*. Both of the important for Turnau and Racki (1999) prasinophytes were present in Miłoszów but in limited number. The other algae species that occurred frequently in Miłoszów were: *Cymatiosphaera chelina, C. perimembrana, Polyedrixium evolutum, P. skalensis* and they were also documented from the Świętomarz-Śniadka and Skały-Włochy sections (Turnau and Racki, 1999). According to Skompski and Szulczewski (1994) and Malec and Turnau (1997) the onset of the Skały beds deposition coincides with the deepening of the basin and this is proved by current palynofacies analysis (see Fig. 5a).

The miospore assemblage was taxonomically differentiated. Previously, similar in taxonomic composition Givetian assemblages were described from Russia (Avkhimovitch et al., 1993; Telnova, 2007, Telnova, 2008, Poland Malec and Turnau, 1997; Turnau and Racki, 1999; Turnau, 2011, 2014), Estonia (Mark-Kurik et al., 1999), Belarus (Obukhovskaya, 2000), France (Brice et al., 1979), Scotland and Spitsbergen (Marshall et al., 2011) and Wyoming (di Pasquo et al., 2022) Due to the stratigraphical difficulties and uncertainty concerning the Ex3 Subzone it is impossible to refer to Turnau's observation about decreasing taxonomical diversification within the microflora occurring on the Ex2/Ex3 boundary (Turnau, 2014). No such a phenomenon was observed in samples from Miłoszów and this is important indication for establishing the age of the Miłoszów sections as Ex2 and Ex1 subzones. The same the specimens of *Samarisporites* sp. 1 are not the specimens of *Samarisporites triangulatus* Allen, 1965. The mutual relation between the common miospores *Aneurospora extensa* and *Rhabdosporites langii* was indicated as an important factor from environmental point of view which can show the changes in climate aridity and palaeoshorelines proximity (Marshall et al., 2011; Turnau, 2014). Turnau (2014) noticed the decrease in the number *R. langii* and proliferation of the *A. extensa*, however this was observed as a phenomenon typical for the Ex3 Subzone. In section M0 the percentage amount of the *R. langii* decreased in sample 8A and remains noticeably lower upward the section (Fig. 6) but considering the age and the uncertainty in *Samarisporites* specimens diagnosis, the pattern of this relation indicated by Turnau (2014) is not applicable to samples from Miłoszów.

Table 2
Occurrence of the phytoplankton taxa from Miłoszów.

Litho-and chronostratigraphy	Skały beds (Givetian)																										
Section	M0																		M1					M2			
Sample	1	2	3	4A	4B	4C	4D	5	6	7	8A	8B	9	9 s	10A	10B	10C	10D	7	8	9	10	12	2	3	4	6
Cymatiosphaera chelina								x			x		x		x		x										
Cymatiosphaera perimembrana													x														
Dictyotidum sp.																	x										
Gorgonisphaeridium disparatum								x					x		x												
Gorgonisphaeridium granatum										x	x		x														
Gorgonisphaeridium inflatum																	x	x									
Gorgonisphaeridium sp.																	x										
Hemiruptia sp.												x			x												
Leiosphaeridia sp.					x	x		x	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x
Micrhystridium stellatum			x	x				x	x			x		x													
Multiplicisphaeridium ampliatum																x											
Multiplicisphaeridium ramusculosum									x	x				x													
Muraticavea sp.																	x										
Navifusa bacilla					x			x			x	x			x			x	x								
Polyedrixium decorum												x					x										
Polyedrixium embudum														x													
Polyedrixium evolutum			x													x	x	x									
Polyedrixium pharaonis																	x	x						x	x		x
Polyedrixium skalensis														x	x	x											
Stellinium micropolygonale								x		x		x	x	x				x									
Teleostomata rackii	x		x								x					x	x	x						x	x	x	x

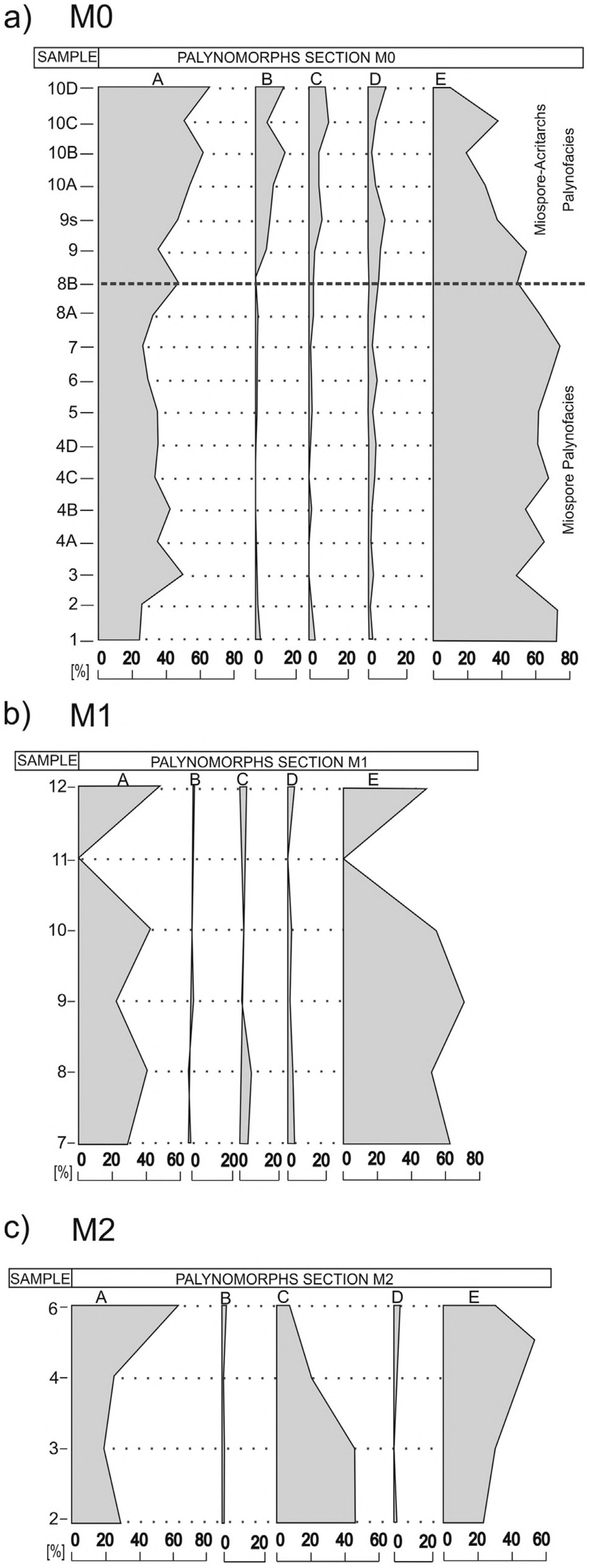

Fig. 5. Distribution of the organic components in the Miłoszów sections. A-miospores, B-acritarchs, C-prasinophytes, D-scolecodonts, E-dark bioclasts. Gray, dashed line indicates two types of palynofacies.

Table 3
The percentage content of each group of the palynomorphs from the Miłoszów sections.

Palynomorphs [%]																											
Section	M0																		M1					M2			
Sample	1	2	3	4A	4B	4C	4D	5	6	7	8A	8B	9	9 s	10A	10B	10C	10D	7	8	9	10	12	2	3	4	6
Miospores	22.4	24	49.2	36.4	41.8	31.8	36.2	35.2	27.8	24.2	32.6	44	36	45.6	54.6	61.6	49.8	63	31.8	42	23.8	41.8	45.6	26.8	18	22.6	61.6
Acritarchs	1.7	1	0.2	0	0	0	0	0.2	0	0.2	0.6	0	3.8	4.6	7.8	15	4.6	13.6	0.4	0	1	0	0.2	1	0	0.2	1.6
Prasinophytes	2	1.2	0.2	0	1.2	0	0	1.6	1	0.6	1	1	2	4.4	3	3	13.2	6.4	2.6	3.4	1.2	0.8	1.6	47.6	46.6	20.4	5.6
Scolecodonts	1	0.4	1.2	0.6	0.8	1.4	1.8	1	4	1	3.6	5.8	5.2	6.6	3.2	1.2	3	8	2.6	2.2	0.4	1.8	3.6	1.6	0.2	2.6	0
Bioclasts	72.9	73.4	49.2	63	56.2	66.8	62	62	67.2	74	62.2	49.2	53	38.8	31.4	19.2	29.4	9	62.6	52.4	73.6	55.6	49	23	35.2	54.2	31.2

6. Conclusions

1. According to the palynostratigraphy the age established for the sample investigated from the M0 section is Ex1 and Ex2/Ex3. It corresponds with *hemiansatus* to Middle *varcus* Conodont Zones. Due to the poor preservation of the organic matter the age of the sections M1and M2 was determined only with question as Ex1 Subzone (*hemiansatus* to Lower *varcus* Conodont Zones). This confirms lithostratigraphic assignment to Skały beds (compare with Zatoń and Wrzołek, 2020; Dubicka et al., 2021). However, it is not excluded that the deposits from the M0 section are younger but this consideration must be treated with a great precaution.
2. Current observations of the taxon *Samarisporites triangulatus* when confronted with literature data, indicate a relatively high variability of forms classified as certain *S. triangulatus*. Meanwhile, some of the historical markings seem to be incorrect. The presence of these forms in older subzones (e.g., Ex2) shows that increased vigilance in defining this very important index taxon is required.
3. Due to palynofacies analysis results Skały beds were deposited in a relatively deep intrashelf marine environment with high input of the land-derived material. Moreover, section M0 revealed upward a weak signal of transgression. Possibly lowermost part of the Miłoszów succession (M2) represents another set of Skały beds, characterized by more eutrophic habitat.

6.1. Taxonomic remarks

Genus: **Samarisporites** Allen, 1965
Samarisporites sp. 1 (Plate I, Figs. 1-4)
Synonymy: compare with Turnau and Racki, 1999; plate II, fig. 5

Description: Zonate spores with subtriangular to rounded amb, 40–57 μm in diameter, zona up to 4 μm interradially and maximum 10 μm in width at apices. Apices broadly rounded, trilete rays extending to the margin of zona, accompanied by lips ~2 μm in width. Central body is thick and dark. Body and zona ornamented by spinose or grana-like processes.

Remarks: This specimen differs from *S. triangulatus* because of the presence of distinctly ornamented zona, rounded outline and short apices.

List of taxa:

Miospores:
Ancyrospora ampulla Owens, 1971
Ancyrospora ancyrea var. *brevispinosa* (Eisenack) Richardson, 1962
Ancyrospora furcula Owens, 1971
Ancyrospora involucra Owens, 1971
Ancyrospora longispinosa Richardson, 1962
Ancyrospora melvillensis Owens, 1971
Ancyrospora nettersheimensis Riegel, 1973
Ancyrospora pulchra Owens, 1971
Ancyrospora simplex Guennel, 1973
Ancyrospora voronensis Arkhangelskaya, 1985
Aneurospora extensa (Naumova) Turnau, 1986
Aneurospora goensis Streel, 1964
Aneurospora greggsi (McGregor) Streel, in Becker eta al., 1974
Apiculiretusispora plicata Allen, 1965
Archeoperissacus opiparus Owens, 1971
Archeozonotriletes variabilis Naumova, 1953
Chelinospora concinna Allen, 1965
Contagisporites subnotatus Owens, 1971
Convolutispora subtilis Owens, 1971
Corystisporites collaris var. *kalugianus* Arkhangelskaya, 1985
Corystisporites multispinosus Richardson, 1965
Corystisporites serratus (Naumova) McGregor and Camfield, 1982
Cymbosporites magnificus (McGregor) McGregor and Camfield, 1982
Dibolisporites echinaceus (Eisenack) Richardson, 1965
Dibolisporites gibberosus (Naumova) Richardson, 1965
Geminospora aurita Arkhangelskaya, 1987
Geminospora compta (Naumova) Arkhangelskaya, 1985
Geminospora decora (Naumova) emend. Arkhangelskaya, 1985
Geminospora lemurata Balme emend. Playford, 1983
Geminospora micromanifesta (Naumova) Arkhangelskaya, 1985
Geminospora notata (naumova) Obukhovskaya, 1993
Geminospora obtuispinosa Turnau, 1999
Geminospora teniuspinosa (Kedo) Turnau, 2011
Geminospora tuberculata (Kedo) Allen, 1965
Grandispora echiniformis Kedo, 1955
Krauselisporites acerosus (Arkhangelskaya) McGregor and Camfield, 1982
Krauselisporites pomeranius (Stempień-Sałek) Turnau, 2011
Lanatisporites bislimbatus (Tchibrikova) Arkhangelskaya, 1985
Lophozonotriletes scurrus Naumova, 1953
Perotrilites bifurcatus Richardson, 1952
Perotrilites granuleticonatus Turnau, 1999
Retusotriletes clandestinus Tchibrikova, 1972
Retusotriletes distinctus Richardson, 1965
Retusotriletes simplex Naumova, 1953
Rhabdosporites langii (Eisenack) Richardson, 1960
Rhabdosporites streelii Marshall, 1996
Samarisporites orcadensis Richardson, 1965
Samarisporites concinnus Owens, 1971
Samarisporites inaequus (McGregor) Owens, 1971
Samarisporites tozeri Owens, 1971
*Samarisporites*sp. aff. *triangulatus*
Samarisporites sp. 1
Spinozonotriletes cassideus Owens, 1971
aff. *Vallatisporites celeber*
Verrucosisporites flexibilis Turnau, 1996
Verrucosipisrites premnus Richardson, 1965
Verrucosisporites scurrus (Naumova) McGregor and Camfield, 1982

Phytoplankton:
Cymatiosphaera chelina Wicander and Loeblich, 1977
Cymatiosphaera perimembrana Staplin, 1961
Dictyiotidum sp.
Gorgonisphaeridium sp.
Gorgonisphaeridium disparatum Playford, 1977
Gorgonisphaeridium granatum Playford, 1977
Gorgonisphaeridium inflatum Wicander and Wood, 1981
Hemiruptia sp.
Leiosphaeridia sp.
Micrhystridium stellatum Deflandre, 1945
Multiplicisphaeridium ampliatum Playford, 1977
Multiplicisphaeridium ramusculosum (Deflandre), emend. Lister, 1970
Muraticavea sp.
Navifusa bacilla (Deunff) Playford, 1977
Polyedrixium decorum Deunff, 1955
Polyedrixium embudum Cramer, 1964
Polyedrixium evolutum Deunff, 1955
Polyedrixium pharaonis Deunff, 1961
Polyedrixium skalensis Turnau, 1999
Stellinium micropolygonale (Stockmans and Willière) Playford, 1977
Teleostomata rackii Kondas et al., 2021

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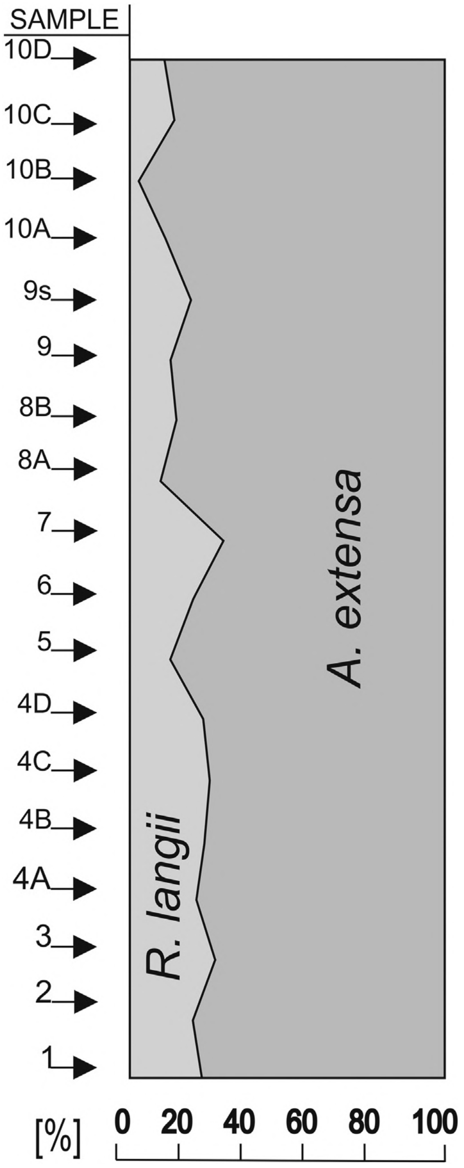

Fig. 6. Distribution of the *R. langii* and *A. extensa* miospores in section M0.

Declaration of Competing Interest

All authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The palynology of the Middle-Upper Devonian (Givetian-Frasnian) in the Łysogóry-Radom and Lublin basins, south-central Poland.

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Abstract

The Middle and Upper Devonian (Givetian and Frasnian) deposits of the Łysogóry-Radom and Lublin Basins (south-central Poland) provided diversified palynomorph assemblage. Numerous miospore taxa were documented and also contained well-preserved and various plant remains, scolecodonts, acritarchs, chitinozoans, organic tentaculitoids, and bioclasts of uncertain biological affinity. *Aneurospora extensa*, *Geminospora aurita*, *Samarisporites triangulatus* as well as other documented taxa allowed to establish two local miospore zones: Givetian "*Geminospora" extensa* zone and Givetian-Frasnian *Geminospora aurita*. This interval is described as the time of the impoverishment in taxonomic diversity of microflora related to the rapid climate changes that are associated with the global Taghanic Event. The palynofacies analysis indicated a shallow-shelf environment with significant terrestrial input that was controlled by transgressive-regressive impulses, which confirmed the dynamic palaeoenvironmental changes. The new miospore taxon *Retusotriletes radomskii* was described.

key words: Taghanic, palynofacies, Givetian/Frasnian boundary, Middle-Upper Devonian, taxonomic diversification, Poland

1. Introduction

The Middle and Upper Devonian (Givetian and Frasnian) deposits of the south-central Poland (Łysogóry-Radom and Lublin areas; Figure 1) document the noticeable and important palaeoenvironmental changes. A detailed analysis that was performed by Narkiewicz et al. (2011) indicated that this region during late Givetian was affected by sea-level changes that significantly influenced marine biota. This critical interval named the Taghanic Crisis (Aboussalam 2003) or Taghanic Event (House 1985) was well recorded worldwide and it was related not only to the series of sea-level changes but also to the marine and terrestrial flora and fauna perturbations during the Middle to Upper *varcus* conodont zones (e.g. Aboussalam 2003; Aboussalam and Becker 2011; Marshall et al. 2011; Turnau 2014; see Figure 2). This interval was also the subject of palynological investigations made by Turnau (2014) for the area of Poland, Marshall et al. (2011) for the Eday Marl Formation in Scotland and di Pasquo et al. (2022) who described this event from Wyoming (USA). However the significant part of the Givetian palynological studies

was not focused on this interval as being the record of the palaeoenvironmental crisis.
The current samples come from two different basins: the Radom-Łysogóry and the Lublin Basins.

The Łysogóry-Radom Basin has been investigated for many years but mostly with focus on the Łysogóry Block part (e.g. Narkiewicz et al. 1998a, 1998b) and with particular emphasis on the Łysogóry Region of the Holy Cross Mountains (Czarnocki 1950; Szulczewski 1995; Narkiewicz et al. 2006; Malec and Turnau 1997; Halamski 2009; Fijałkowska-Mader and Malec 2011; Filipiak 2011; Malec 2012; Zatoń and Wrzołek 2020). The Radom Area of the Łysogóry-Radom Basin is known for only few boreholes and despite the relative low number of these boreholes, they were drilled to the considerable thickness and they provided valuable lithostratigraphical and biostratigraphical data (e.g. Miłaczewski and Żelichowski 1970; Niemczycka 1975; Żakowa et al. 1986; Malec et al. 1996; Narkiewicz et al. 2011). The detailed lithostratigraphical schemes for this area were proposed by Narkiewicz et al. (2011) and these schemes are used in this paper. Moreover, there are noticeable similarities between the succession of deposits in the Radom Area and the Łysogóry Region. Thus, the palynological investigation may be an important correlative feature for both areas considered by Malec et al. (1996) and Narkiewicz et al. (2011) as one basin. Palynological studies of the Radom Area are scarce. Lower Devonian Pionki 1 and Pionki 4 sections from Łysogóry-Radom Basin were studied by Turnau (1985, 1986), and the deposits from the Ciepielów IG 1 borehole of the same area and age were investigated by Turnau and Jakubowska (1989).
The palynological analysis of the two sections: Szwejki IG-3 and Niesiołowice IG-1 is an important contribution for the studies of Middle and Upper Devonian deposits in central Poland. Both two sections were the objects of the detailed analysis performed by Narkiewicz M. (2011a), Narkiewicz K. (2011) and Narkiewicz et al. (2011) with the description of the lithostratigraphy, depositional systems, transgressive-regressive cycles and biostratigraphy based on conodonts. Moreover, the drill core Szwejki IG-3 was examined for conodonts and ostracods by Malec et al. (1996).

The Devonian deposits of the Lublin Basin were intensively studied since the 60` of the XXth century, mostly due to the hydrocarbon investigations. The stratigraphical data were summarised by Miłaczewski (1981) and Miłaczewski et al. (1983). The biostratigraphy of this area is well-known from the conodonts analysis made by e.g. Szulczewski (1972), Matyja and Żbikowa (1985), Narkiewicz and Narkiewicz (1998), Nehring-Lefeld et al. (2003), Narkiewicz K. (2006), Narkiewicz and Bultynck (2007), Narkiewicz and Narkiewicz (2008). Turnau and Narkiewicz (2011) published a biostratigraphy based on conodonts and palynology. Alluvial and marginal marine Lower Devonian deposits from sections Giełczew PIG 5 and Terebin IG-5 were investigated by Turnau et al. (2005). Turnau (2011) also conducted further investigation of the Giełczew PIG 5, Giełczew PIG 6, Terebiń IG 1 and Terebiń IG 5 sections. Krowie Bagno IG-1 section was an object of detailed lithological studies performed by Miłaczewski (1975, 1981). Because Giełczew PIG 5 was previously studied only for palynostratigraphy (Turnau 2011), thus this research is focused mostly on palynofacies analysis.

The main objectives of this paper are: (1) to establish palynostratigraphy for Szwejki IG-3, Niesiołowice IG-1 and Krowie Bagno IG-1 sections, (2) to describe palaeoenvironmental depositional conditions and (3) to discuss the Taghanic Crisis based on its palynological record. Moreover, new spore taxa is described.

2. Geological setting

2.1 Łysogóry-Radom Basin

Middle and Upper Devonian deposits of the Łysogóry-Radom Basin represent the part of the large Devonian epicontinental sedimentation area of southern Poland (Narkiewicz 1985; Narkiewicz et al. 2011). According to the Variscan tectonic (?) this area belongs to the Łysogóry Block and it is limited from the SW by Małopolska Block and from NE by Radom-Kraśnik Elevation being a part of the Eastern-European Platform (Narkiewicz and Dadlez 2008; Żelaźniewicz et al., 2011) while the Łysogóry Block is considered to be a proximal, Caledonian terran (Narkiewicz et al. 2011; Figure 1). The investigated sections involve a few lithostratigraphical units. Lowermost unit is Bąkowa Formation (including the Łaziska Member) which is Givetian in age and represents diversified siliciclastic-carbonate rock interval. Then Givetian/Frasnian fully carbonate Szwejki Formation and overlain Iłżanka Formation that contains mostly siltstones with variable carbonate content (Figure 3). The section Szwejki IG-3 provides also a small piece of information about dolomitic and carbonates series that overlain the Iłżanka Formation. The formal lithostratigraphy scheme is followed by the one proposed by Narkiewicz et al (2011).

2.2 Lublin Basin

During the Devonian, the Lublin Basin was the western part of the epicontinental basins system located on the south margin of Laurussia, where the Neoproterozoic-early Palaeozoic deposits of the eastern-Europe platform developed (Narkiewicz et al. 2011). The Lublin Basin is limited from the west and south by the Radom-Kraśnik Elevation and from the SE the boundary is determined by the country border and it becomes the Lviv Basin (Narkiewicz et al. 2011, Żelaźniewicz et al. 2011). The Middle Devonian and basal Frasnian sediments were deposited during seven transgressional-regressional cycles (T-R cycles) revealing a significant variability of environmental successions showing the greatest extent of the basin (Narkiewicz et al. 2011). The analysed Giełczew PIG 5 section is located within the Lublin Trench, and Krowie Bagno IG-1 represents Hrubieszów Elevation (Figure 1). Investigated interval involves the Telatyń Formation, which ranges from the Emsian to the Frasnian and overlain Modrzyń Formation that is Frasnian in age (Narkiewicz M. 2011b). The Telatyń Formation shows noticeable duality: the lower part is represented by gray sandstones, mudstones and siltstone and the upper part consists mostly of carbonates (Narkiewicz et al. 2011). Within the investigated sections the Telatyń Formation is developed as Giełczew Member that is Emsian/Eifelian to Frasnian in age (Narkiewicz M. 2011b). It is represented in the lower part by marly dolomites, breccias and sandstones and in the upper part by limestones (Narkiewicz et al. 2011). These deposits are related to the environment of the carbonate platform and shallow, restricted shelf (T-R cycles 2-5; Narkiewicz et al. 2011). The Modrzyń Formation shows mostly carbonate deposits being a result of the deposition in the environment of the carbonate platform (Narkiewicz et al. 2011).

3. Material and methods

118 samples from five drill cores were investigated for palynology. 111 of them contained recognizable palynomorphs. From the 720-metres section Szwejki IG-3, 39 contained palynomorphs (Figure 4). The 220-metres Niesiołowice IG-1 section provided 27 samples and each of them contained microflora (Figure 5). The drill core Giełczew PIG 5 (~70 metres long) provided 29 positive samples and the most incomplete section Krowie Bagno IG-1 (130-metres long) provided 13 samples (Figures 6 and 7). 10 samples were macerated from the drill core Korczmin IG-1 but they contained no palynomorphs. All sections provided well-preserved palynomorphs with the exception of the Krowie Bagno IG-1 section, where the preservation varied-from good preserved specimens to the bad state of preservation. All samples were treated by the standard combination of acids (Wood et al. 1996; Riding 2021). HCl was used in order to remove carbonates, then HF was applied for dissolving the silicates and then again HCl was applied to eliminate the remains of carbonates. For samples containing a noticeable amount of amorphous organic matter (AOM) 100 % fumic nitric acid was applied. Obtained organic residuum was sieved using a 10 μm nylon screen. The palynomorphs obtained from the samples were well-preserved, contained diversified microflora, large amount of bioclasts of uncertain biological affinity, phytoclasts, scolecodonts, fungi, single acritarchs, chitinozoans, tentaculitoids and nematophytes. All samples were examined for palynostratigraphy and selected ones for palynofacies. In order to conduct palynofacies analysis all palynomorphs were divided into the six categories: miospores, phytoclasts, prasinophytes, scolecodonts, bioclasts and *others*. Only for the Giełczew PIG 5 section an additional category of opaque particles was established. The category bioclasts contains all objects that are organic particles but their biological or taxonomic affinity remains unclear. *Others* contain all palynomorphs that were very restricted in number and as the single categories would not be included into the statistic. Due to the better understanding of the palynofacies composition this category is discussed in detail for each section. Small amount of AOM was also present but it was excluded from the statistics as the main part of it was removed during the maceration process. For each sample palynomorphs were counted up to 500 specimens in order to establish the relative percentage amounts for each palynomorph group.

Analyses were conducted using Optika B-510BF and Nikon Eclipse 50*i* transmitted light microscopes with NIS Elements-D software and NIK-Cam Pro-1 camera. For each sample two microscope slides were prepared and Petropoxy 154 was used as the mounting agent and Cellosize was applied as dispersal agent that helped to avoid organic clumping. In order to estimate the location of the specimens on the slides, each specimen was tagged with England-Finder coordinates. Slides and residues are housed as a part of the geological collection at the Faculty of Natural Sciences in Sosnowiec, Poland. Drill cores are housed at PIG Drill core storage in Hołowno, Poland. Specimens important for stratigraphy and environmental analysis are illustrated in Plates I, II and interesting phytoplankton taxa together with other organic remains are illustrated in Plates III and IV.

4. Palynostratigraphy

The microflora obtained from analyzed sections show some similarities to the microfloral zonation from Eastern Europe thus the most accurate standard zonation for palynostratigraphy of the investigated area is the one established by Avkhimovitch et al. (1993). However, the local microflora assemblages show distinctiveness and Turnau (1996, 2008) proposed the modified version of the Avkhimovitch`s scheme adapted to the area of Poland. This local zonation was previously used for studies of the deposits from Holy Cross Mountains, Radom-Lublin Area and Western Pomerania (e.g. Turnau 1996, 2007, 2008, 2011; Malec and Turnau 1997; Turnau and Racki 1999).

The lower and upper boundary of the „*Geminospora” extensa* Miospore Zone (Ex) proposed by Avkhimovitch et al. (1993) and Turnau (e.g. 2008) are equivalents but the differences proposed by Turnau (1996, 2008) are related to the division of this zone into the subzones (see Figure 2). The local Ex Zone is divided into three subzones: Ex1, Ex2 and Ex3 (Turnau 1996). The base of the Ex1 subzone is determined by the first appearance of *Geminospora lemurata* and that is also the approximate position of the Eifelian/Givetian boundary, however this event was also recorded from the Eifelian deposits of Eifel region (Loboziak et al. 1990). The first appearance of the *Chelinospora concinna* indicates the lower boundary of the Ex2 subzone. The disappearance of the *Cristatisporites collaris* var. *kalugianus* and *Hystricosporites setigerus*, the taxa known from Eifelian deposits of eastern Europe, is also typical for this subzone (Byvscheva et al. 1985; Avkhimovitch et al. 1993; Turnau 2011). The first appearance of *Samarisporites triangulatus* is an indicator for the basal boundary of the Ex3 subzone. Other characteristic taxa are *Kraeuselisporites spinutissimus* and *Geminospora decora* (Turnau 2007, 2008, 2011). The boundary between Ex2 and Ex3 subzones is placed within the *ansatus* Conodont Zone (Turnau and Narkiewicz 2011). *Geminospora aurita* Miospore Zone (Aur) is a local zone established by Turnau (2007, 2008) for Western Pomerania. The lower boundary is indicated by the last appearance of *Aneurospora extensa*. According to Turnau (2008) other important taxa that disappear on this boundary are: *Chelinospora concinna*, *Densosporites devonicus*, *Geminospora decora*, *G. tuberculata*, *Lanatisporites bislimbatus*, *Kraeuselisporites spinutissimus* and *Rhabdosporites langii*. Current conodont data allow establishment of the Ex/Aur boundary within the *ansatus-hermanni* Conodont Zone (Turnau and Narkiewicz 2011). The upper boundary of the Aur zone is problematic. In Western Pomerania this boundary is approximately consistent with the boundary of Givetian and Frasnian (Turnau 2007). In the Lublin area the upper boundary of Aur zone is located within the interval that belongs more likely in MN1 and MN2/3 conodont zones (Upper *falsiovalis*) and the same it involves basal Frasnian (Turnau 2011; Turnau and Narkiewicz). For miospore zonation details see Figure 2.

Palynostratigraphy analysis involved sections Szwejki IG-3 and Niesiołowice IG-1 from Radom Basin and sections Giełczew PIG 5 and Krowie Bagno IG-1 from Lublin Basin.

4.1 Section Szwejki IG-3

Samples from the depths 4983, 4982 and 4979 m showed the presence of the very few miospores e.g. *Ancyrospora pulchra*, *Geminospora lemurata*, *G. notata*, *Grandispora echiniformis* and *Rhabdosporites langii*. Thus, their stratigraphical position remains unclear, their age may be Ex or older (Figure 4). The age of the upper-located rock interval from depths 4978-4705 metres was tentatively recognised as an undivided Ex zone (Figure 4). *Aneurospora extensa* was present in samples from 4978, 4867, 4799 and 4705 m and *G. lemurata* occurred on depths 4978, 4799 and 4705 m. This assemblage contains spores that may occur in Ex1 to Ex3 subzones (e.g. *Geminospora decora*, *Grandispora echiniformis*, and *Rhabdosporites langii*). The interval from 4703 to 4301 metres is included into Ex3 subzone sensu Turnau (2007, 2008, 2011), as it contains both index taxa: *Aneurospora extensa* and *Samarisporites triangulatus* (Figure 4). The miospores that according to Turnau (2007, 2008) are common for this subzone: *Aneurospora greggsii*, *Dibolisporites echninaceus*, *Geminospora decora*, *G. notata*, *Grandispora echiniformis*, *Lanatisporites bislimbatus*, *Rhabdosporites langii*, *R. streeli* or *Verrucosisporites scurrus* were also documented from these deposits. Due to the lack of the *Aneurospora extensa*, and the occurrence of *G. aurita* and *G. notata* the interval from the depth 4299 m may belong to the Aur Miospore Zone by Turnau (2007, 2008, 2011; Figure 4).

Unfortunately, the conodont stratigraphy does not solve the problem of uncertain age for samples from 4983-4705 interval. The interval from 5039.4 to 4691.8 was included into *costatus-ansatus* zones (Narkiewicz K. 2011). These zones range from Eifelian (AP Miospore Zone *sensu* Streel et al. 1987) up to the Givetian (Ex3 subzone) and this does not provide more details than obtained from palynological results, especially when one considers that index taxon *G. lemurata* may occur in Eifelian (Loboziak et al. 1990). The interval dated as Ex3 Subzone matches the results of conodont analysis, where *ansatus-hermanni* conodont zones were recognised at the depth of 4546.4-4542 m (Narkiewicz K. 2011). *Hermanni/norrisi* Conodont Zone was documented at the depth of 4343.8 m and *hermanni/transitans* Conodont Zone at the depth of 4343 m (Narkiewicz K. 2011). The *hermanni* zone to some extent corresponds with the Ex3 subzone thus the palynological and conodont analysis results are consistent.

4.2 Section Niesiołowice IG-1

Two miospore zones were recognised within this section. Due to the presence of *A. extensa* together with *S. triangulatus* at the depth 1517 to 1334 m, the age of this interval is established as Ex3 subzone of Ex Miospore Zone by Turnau (2007, 2008, 2011; Figure 5). The poorly preserved specimen that resembles *Contagisporites optivus* was documented at depths 1484 and 1399 m (Figure 5). The stratigraphical range of this miospore according to Avkhimovitch et al. (1993) ranges from Frasnian up to Early Famennian. The deposits from the depth 1333 to 1330 metres were included into the Aur Miospore Zone. These two samples did not contain *A. extensa* and disappearance of this taxon is a characteristic palynological event that marks the upper range of the Ex Miospore Zone (Figure 5). Moreover, samples from 1333 m and 1330 m contain *Geminospora aurita*, *G. notata* a taxa important for local stratigraphy.

Conodont analysis revealed the presence of the *rhenanus/varcus-ansatus* zones (1512.1-1481.3 metres), Lower *subterminus* Zone (1358.5 m) and the interval of Upper *subterminus* Zone (1337.8 m; see Narkiewicz and Bultynck 2007). The palynostratigraphy of the interval from 1517 to 1359 m (Ex3 subzone) interferes with the conodonts. Because the Lower and Upper *subterminus* conodont zones correspond with the Aur Miospore Zone the interval from 1357 to 1334 according to conodont analysis suggests age younger than Ex3 subzone indicated by palynostratigraphy. For the samples from the depth 1333 and 1330 metres there is consistency for the miospore and conodont zones.

4.3 Section Giełczew PIG 5

The detailed palynostratigraphy for this drill core was provided by Turnau (2011). Here, the previous results are confirmed. Due to the presence of *A. extensa* and *G. lemurata* the interval 2024-2012 metres is considered to be tentatively Ex Zone (Figure 6). *Samarisporites triangulatus* occurs from the depth 2011 m upward to the 1960 m. Combining it with the occurrence of the *A. extensa* the interval from 2011 m to 2004 might be dated undoubtedly as Ex3 subzone (Figure 6). The interval from 1998 to 1960 metres was included into the Aur Miospore Zone, as none of the investigated samples contain *Aneurospora extensa* and the following local taxa, which are according to Tunaru (2008) important for stratigraphy occurred: *Convolutispora subtilis, G. aurita*, *G. micromanifesta* and *G. notata* (Figure 6).

This result remains in agreement with the conodonts. The *ansatus* Conodont Zone was recognised at the depth 2017.9-2002.5 metres, corresponds with the Ex3 and Ex2 subzones of the Ex Miospore Zone, thus despite the occurrence of *A. extensa* and *G. lemurata*, the Ex1 subzone was not established (Narkiewicz et al. 2011, see Figure 2). Conodonts from the depth of 1970.2 indicated *subterminus* zone and the Lower *falsiovalis* Conodont Zone was documented at the depth of 1969.7-1967.1 metres (Narkiewicz and Bultynck 2007). These zones are consistent with most of the Aur Miospore Zone. Turnau (2011) indicated Ex2? Subzone for the sample from the depth 2018.87 and the interval from 2014.7 to 2004.31 metres according to Turnau is undoubtedly Ex3 in age. This remains consistent with current data, however there are no premises for indicating Ex2 subzone in our samples. Aur Miospore Zone was established for the interval of 1967.83 m to 2004.31 metres (Turnau 2011) and this remains in agreement with the result presented in this paper. The uppermost interval (depth 1965.45 to 1960.65 m) according to Turnau (2011) is Aur/Den in age, while the results from the current palynological investigation indicate the Aur Miospore Zone.

4.4 Krowie Bagno IG-1 section

Only five samples (1334-1221 m) from this section contained recognizable miospores (Figure 7). Due to the lack of the specimens unambiguous for stratigraphy the lowermost sample from depth 1334 m might belong to both Aur or Ex miospore zones. Samples from interval 1332 to 1221 m showed no presence of *Aneurospora extensa*, thus they might be included tentatively into the local Aur Miospore Zone (Figure 7). Due to the low number of samples and poor preservation of the organic matter, the obtained result must be treated approximately and it is not excluded that these deposits may be younger as *G. aurita* disappeared in late Frasnian (Obukhovskaya 2000). The Aur Miospore Zone is to some extent an equivalent of the IM subzone of the OK Miospore Zone by Avkhimovitch et al. (1993; see Figure 2). Sample from 1326 m contains all these index taxa except the *Spelaeotriletes krestovnikovii* and what is important, *Geminospora micromanifesta* occurred also at depths 1332 and 1328 m. This suggests that the interval from 1332 m up to 1221 m might be included into the OK Miospore Zone and the same into the local Aur zone. Also, the *Geminospora notata* that occurs at depth 1334 and 1326 m, is the taxon that commonly occurs within this zone (Avkhimovitch et al. 1993).

The conodont analysis at the depth of 1333 to 1332.2 m indicates the *subterminus* Zone (Narkiewicz K. 2011). This zone corresponds with the *Geminospora aurita* Miospore Zone. The uncertain *falsiovalis* Conodont Zone was documented from the depth 1298 m to 1297.8 m (Narkiewicz K. 2011) and it may be correlated with the uppermost part of the Aur zone or younger *Tholisporites densus* Miospore Zone by Turnau (2008, 2011). MN 3 up to Lower *hassi* conodont zones were recognised from the depth of 1292.8 and this indicates the analyzed interval younger than the tentatively established Aur Miospore Zone (see Narkiewicz K. 2011).

Samples taken from depths 1301, 1298 and 1266 m contained no microflora or any other palynomorphs useful for stratigraphy. Samples from depths 1296, 1295, 1205, 1203 and 1201 m contained only Carboniferous miospores: *Cingulizonates* spp., *Cirratriradites saturni*, *Densosporites* spp., *Florinites* spp., *Lycospora pusilla*, *Raistrickia fulva*, *Tripartites vetustus* and others (see Plate V). The Modryń Formation is overlain by Carboniferous deposits as this section is located within the area of intensive erosion (Narkiewicz M. 2011b; Narkiewicz et al. 2011). Thus the Carboniferous deposits might infiltrate into the Devonian deposits, using the fissures caused by erosion (see Narkiewicz M. 2005).

The stratigraphical correlations for all sections are summarised in Figure 8.

5. Palynofacies analysis

The detailed palynofacies analysis revealed an opportunity to show a noticeable pattern of changes in the depositional environment (Tyson 1995). Each section contained both types of palynomorphs: marine and terrestrial and the ones that may be included into any of aforementioned categories. Land derived palynomorphs were divided into miospores and phytoclasts (cuticles and tracheids were not distinguished). Miospores were the most prominent group of palynomorphs that allowed for distinguishing the different palynofacies types. This group was taxonomic differentiated but with the significant dominance of the *Ancyrospora*, *Aneurospora* and *Geminospora* genera. The numerous presence of this group and as well as the presence of the tetrads and the occurrence of the large miospores (~200 µm) is suggested for a proximal environment of deposition (Tyson 1995). Plant remains were considered as supportive components for the palynofacies diagnosis as they were not as numerous as miospores. Plant particles included different types of remains: the fragile cuticles with preserved stomatas but also high resistant tracheids. Marine and transitional components were represented by prasinophytes and scolecodonts as the most numerous of this origin. Prasinophytes were represented mostly by leiospheres that can be fresh-water but also marine in origin. Scolecodonts are thought to represent the shallow-marine polychaetes and they were the most noticeable from the other zooclasts. The majority of the organic matter was categorised as palynomorphs of uncertain origin and in this group three categories were established: bioclasts, *others* and opaque particles. Bioclasts are the category of all particles of cuticle-like morphology, usually yellow to dark brown sheets of different shapes. *Others* are a wide category with acritarchs, nematophytes, zooclasts, chitinozoans and fungi. They are different in origin but they were so strongly limited in number that as a separate category none of them would be included into the statistic. Acritarchs were represented mostly by *Micrhystridium*, *Multiplicisphaeridium* and *Veryhachium*. Their low number as well as low taxonomic diversification is a feature of shallow-marine environments (Dorning 1981; Tyson 1995; Li et al. 2004) but the opposite trend was indicated by Molyneux (2009). Nematophytes were rare and represented mostly by *Cosmochlaina*. Nematophytes may be interpreted as fungi and together with them they suggest the shallow-water, proximal depositional conditions (Tyson 1995; Wellman and Ball 2021). Chitinozoans were present in each section, these marine organisms occur mostly within the shelf area (Tyson 1995). The detailed documentation of the non-pollen palynomorphs is beyond the scope of this study, thus here they are only mentioned in the context of palynofacies. Opaque particles were documented only from the section Giełczew PIG 5. Each section showed the dominance of the palynomorphs of unknown origin (bioclasts). Beside this feature, the land origin palynomorphs prevailed over the marine components.

5.1 Radom Basin

Within the Radom Basin two sections provided material for palynofacies analysis: Szwejki IG-3 and Niesiołowice IG-1 (Figure 1). Interval analyzed in Szwejki IG-3 section shows four types of palynofacies. Two lowermost samples from 4983 m and 4982 m contained only a few palynomorphs, thus they were excluded from the statistics. Samples from the depth 4979-4702 belong to the first type of palynofacies (SZI). These palynofacies were characterised by a stable number of miospores, the dominance of bioclasts, low but stable amount of phytoclasts and low numbers of prasinophytes and scolecodonts (Figure 9). *Other* palynomorphs occurred as single components up to 0.6 % (4979 m; Figure 9). This category was differentiated and contained acritarchs (4705-4703 m), chitinozoans, nematophytes, fungal hyphae, animal remains (4703 m) and organic tentaculitoids (depths 4705 m and 4979 m; Table I).

Palynofacies SZII involved interval 4698-4606 m and were dominated by bioclasts as well. The content of miospores increased to the depth of 4614 m and then decreased. Phytoclasts were present in all samples but limited in number. The amount of prasinophytes was the highest in the whole section and the number of scolecodonts was limited (Figure 9). In these palynofacies, *others* palynomorphs reached the maximum of 8.2 % in sample 4610 (Figure 9). This category contained mostly animal remains and fungal hyphae, sample from 4610 m contained also acritarchs and at the depth 4607 m chitinozoans occurred (Table I).

Third palynofacies (SZIII, depth 4548-4342 m) were characterised by the changing number of

miospores and the dominance of the bioclast. Phytoclasts were limited the same as the prasinophytes and scolecodonts (Figure 9). *Other* palynomorphs were less than 1 % (0.8 %, depth 4545 m; Figure 9). They were animal remains, fungal hyphae, nematophytes (4545 m) and chitinozoans (depth 4548 m; Table I).
The uppermost palynofacies (SZIV) contained interval 4339-4299 m. These palynofacies were distinguishable because of the stable content of miospores, low number of phytoclasts and prasinophytes and the content of scolecodonts higher than other palynofacies and the dominance of bioclasts (Figure 9). *Other* palynomorphs were limited with the maximum of 1 % at the depth 4299 m (Figure 9). The category *others* was represented by animal remains, fungal hyphae and acritarchs that were documented only from depth 4339 m (Table I).

Niesiołowice IG-1 section was divided into two types of palynofacies. First type of palynofacies NI contained interval from 1517 to 1484 m. They show the dominance of bioclasts and the noticeable increase in the number of miospores upward the section. Phytoclasts provided a reverse pattern. The number of prasinophytes was limited the same as scolecodonts. *Other* palynomorphs were present only in samples from depths 1491m and 1490 m (0.4 %; Figure 10). They were represented by acritarchs, nematophytes, fungal hyphae and animal remains (Table II).
Palynofacies NII involved samples from interval 1359 to 1330 m (Figure 10). They were dominated by bioclasts and they contained fewer terrestrial palynomorphs than palynofacies NI, with a fluctuating number of miospores. The number of phytoclasts varied from their lack at depth 1357 m up to 12.4 % at depth 1346 m. Prasinophytes and scolecodonts were limited in number. *Other* palynomorphs were in the minority with the peak at depth 1459 m (4.4 %; Figure 10). This category provided acritarchs, numerous chitinozoans, fungal hyphae and animal remains (Table II).

5.2 Lublin Basin

Two sections from Lublin Basin were analyzed: Giełczew PIG 5 and Krowie Bagno IG-1. Giełczew PIG 5, shows complex palynofacies record. Palynofacies GI involved interval from 2024 to 2013 m (Figure 11). The whole palynofacies GI showed an increase in the number of miospores upward the section with varying amounts of bioclasts and opaque particles. Prasinophytes occurred only at depth 2015 m, and scolecodonts were limited in number. The category *others* was represented for this palynofacies by animal remains and fungal hyphae that occurred only at depths 2015 m and 2013 m (Table III). GII palynofacies involved samples from interval 2012 to 2007 m (Figure 11). These palynofacies contained less miospores and phytoclasts than palynofacies GI. There were no prasinophytes in this interval and scolecodonts were limited. Opaque particles were present reaching the maximum in 2012 m and each depth but 2012 m was dominated by bioclasts (Figure 11). Nematophytes occurred at depth 2007 m (Table III). Samples from the interval 2004-1975 m (palynofacies GIII) were characterised by the dominance of bioclasts and contained increasing relative amounts of miospores and restricted number of phytoclasts. Prasinophytes occurred only at depth 1975 m. Opaque particles were also limited (Figure 11). The *other* palynomorphs were chitinozoans (depth 1982 m), fungal hyphae and animal remains (Table III). Upward the section, the number of miospores decreased (interval 1974-1967 m; palynofacies GIV; Figure 11). Phytoclasts were restricted in number, similar to prasinophytes. These palynofacie were also distinctive because of the variable number of bioclasts and opaque particles (Figure 11). The category of *others* was represented by fungal hyphae, animal remains and tubes of unknown origin (Table III). The uppermost palynofacies (GV) involved samples from 1966 to 1961 m. It showed a significant increase in the relative amount of miospores and variable content of bioclasts and opaque particles. Phytoclasts and prasinophytes were rare. The assemblage of *other* palynomorphs contained acritarchs and chitinozoans (sample 520), fungal hyphae and animal remains (Table III). The uppermost sample from depth 1960 m showed different palynomorph assemblages with the high content of opaque particles, low number of miospores, phytoclasts, prasinophytes, scolecodonts and bioclasts. (Figure 11).

Based on the relative percentage amounts of the selected palynomorph groups, two separate stages were documented in Krowie Bagno IG-1 (Figure 12). Due to the low number of samples and varied preservation this result is approximate. Sample from 1334 m contained only single particles; they were so limited in number that it was not included in the statistics. Palynofacies KBI involved an interval 1332-1326 m. Bioclasts were the dominant category and miospores were the second most numerous group. These palynofacies contained no phytoclasts except the depth 1326 m and low number of scolecodonts (Figure 12). *Others* were represented by single specimens of fungal hyphae and acritarchs (maximum of 0.4 % in sample from 1328 m). Palynofacies KBII involved an interval from 1301 to 1298 m. Sample from the depth 1266 m was barren. They were distinguishable due to the very low number of miospores and high content of bioclasts. These palynofacies were also the one containing tubular components with uncertain affinity (see Plate III). Sample from depth 1221 m showed different palynomorph assemblages. It was dominated by bioclasts but miospores were also present (Figure 12). The category *others* was represented in this palynofacies by fungal hyphae, animal remains and tubes of unknown affinity (Table IV).

6. Palaeoenvironment interpretation

Based on the palynomorph assemblages the depositional environment in the Radom Basin can be described as a marine shelf with the significant terrigenous input. Moreover, the Szwejki IG-3 section gives the northernmost record of the Devonian Polish shelf area (Narkiewicz 1985). Taking into account the palynomorphs that were possible to classify according to their biological affinity, the palynofacies of Szwejki IG-3 section were dominated by terrestrial components (Figure 9). Additionally, the presence of animal remains, fungi and chitinozoans indicates the proximal shelf or shallow-water basin. Within the Bąkowa Fm (samples from depth 4979-4560 m) two palynofacies were distinguishable (Figure 9). Palynofacies SZI (interval 4979-4702 m) are parallel to the middle part of the formation. They show stable content of the terrigenous material upward the section (Figure 9). Palynofacies SZII correspond not only with the undivided Bąkowa Fm but also with Łaziska Member being the uppermost part of this formation. They may

be interpreted as a weak signal of shallowing the basin followed by deepening, as the number of miospores from the depth 4702 to 4614 m increased and from 4612 m to 4606 decreased (Figure 9).
Bąkowa Fm (4979-4560 m) is mixed carbonate-siltstone/mudstone formation with the presence of crinoids, brachiopods, corals, stromatoporoids and with the occurrence of the plant debris (Narkiewicz M. 2011a). The part of the formation from 5036 to 4807 m was considered to be a result of deposition in the cyclic marine shelf/carbonate-siltstone ramp succession (Narkiewicz M. 2011a). This diagnosis may be confirmed by palynofacies record in Szwejki IG-3 section, especially by fluctuating number of miospores and phytoclasts (Figure 9). Above this interval, the formation is represented by a proximal carbonate-clastics platform with variable terrestrial supply (Narkiewicz M. 2011a). According to palynofacies (depths 4705-4675 m) this interval was also an episode of the increased terrestrial input. Łaziska Mbr (4673-4560 m) is different, palynofacies showed decrease in number of miospores upward the section but they are still an important and numerous component (Figure 9). Narkiewicz et al. (2011) interpreted this interval as shallow marine silestone-mudstone shelf. This does not exclude the palynofacies results. The overlain Szwejki Fm (4548-4456 m) varies and it shows more marine type of deposits with the amount of the terrestrial components lower than it was in Bąkowa Fm, however, in terms of palynofacies, this change is not significant (Figure 9). According to Narkiewicz M. (2011a) this interval was deposited as a broad carbonate platform with small siltstone inputs and was limited from the open basin. This diagnosis does not conflict with the palynofacies. Only in section Szwejki IG-3 it was possible to follow the palynofacies for Iłżanka Formation (4342-4301 m). They had a very stable record of the number of terrestrial components and it also corresponds with the diagnosis of M. Narkiewicz (2011) describing this unit as siltstones and carbonate-marls deposits being the result of the weak transgressive pulse. Variable types of fauna were documented from Szwejki IG-3 section. Malec et al. (1996) described the occurrence of the ostracodes. Corals were documented by Fedorowski (1990) and the occurrence of crinoids and brachiopods was mentioned by Narkiewicz et al. (2011). This fauna assemblages may correspond with the environment of a proximal marine shelf that was indicated by palynofacies. Similar interpretation is noticeable in Niesiołowicce. Interval 1517 m to 1342 m represent the Bąkowa Fm. The lower interval of the section (1517-1508 m) is correlative with the undivided part of the Bąkowa Fm. These samples showed a noticeable regressive pulse upward the section. Upper located interval (1491-1342 m) is included into the Łaziska Mbr and similarly like in section Szwejki IG-3, it shows deepening of the basin but in Niesiołowice IG-1 this interval in its lower part is significantly enriched in terrestrial components. The deepening trend continues upward the section and includes all samples, together with interval 1334-1330 m that represent Szwejki Fm. The full characteristic of the Szwejki Fm in Niesiołowice IG-1 section is not possible due to the limited number of samples. In general, the characteristic made by Narkiewicz M. (2011a) is consistent with the palynofacies results.

The Lublin Basin shows a more complex record of the palynofacies. Considering it, the depositional environment may be described as shelf/shallow-marine with noticeable terrestrial input. In section Giełczew PIG 5 all samples except the uppermost sample from 1960 m represent the Telatyń Formation (Giełczew Mbr). Palynofacies GI indicated the stable amount of terrestrial components but upward section the palynofacies GII show their amount to be slightly decreased (Figure 11). Significant regression signal was documented in the interval 2004 to 1975 m (palynofacies GIII; Figure 11). Palynofacies GIV revealed a second noticeable decrease in the number of miospores and the same indicated on the transgressional peak. Similar to the lower part of the section, the palynofacies GV that follow palynofacies GIV, showed the regression pattern with the noticeable higher microflora content (Figure 11). This interval according to Narkiewicz et al. (2011) is divided into the two transgressive-regressive cycles: T-4 and T-5, only sample from the depth 2024 m belongs to the T-3 cycle. The cycle T-4 involves an interval 2015-1989 m and according to palynofacies the noticeable lower amount of the terrestrial material is documented from the lowermost located sample up to the depth 2007 m and then, the pulse of regressive character is clearly seen (Figure 11).This interval in Krowie Bagno is documented at depth 1334 m but this sample was not analyzed in terms of palynofacies. The changes in palynofacies are also recorded in lithology as according to Narkiewicz et al. (2011) the cycle T-4 in Giełczew PIG 5 represents the carbonate platform deposits that evolve into marly dolomite deposits. The characteristic feature of cycle T-5 (depth 1983-1961 m) in the central part of the Lublin Basin according to Narkiewicz et al. (2011) is a high terrestrial input. The transgressive part of the cycle is represented mostly by carbonates and the upper regressive part of the cycle is, in turn, deposited as dolomicrite and dolomitic marls (Narkiewicz et al. 2011). It is confirmed by palynofacies, interval 1983-1967 m indicates noticeable transgressive pulse and upper located samples (1966-1961 m) with the high content of land-derived material are clearly regressive (Figure 11).

Because only six samples were examined in Krowie Bagno IG-1 section, the reliable palynofacies analysis is unlikely to carry out. The pieces of information suggest shelf/shallow-marine depositional conditions similar to the section Giełczew PIG 5 (compare Figure 11 and Figure 12). Fauna documented from the Lublin Basin confirm shelf environment; it is represented mostly by brachiopods, ostracods (Miłaczewski 1981) and tabulata corals (Stasińska and Nowiński 1976).

To sum up, the investigated deposits from the Radom Basin were deposited in shelf/shallow-water marine environment with variable terrestrial influx and regression signal occurring (most of the SZII palynofacies, depth 4698-4606 m in Szwejki IG-3 and NI palynofacies, 1491-1484 m in Niesiołowice IG-1). Narkiewicz et al. (2011) described the depositional environment for this interval as carbonate-terrigenous open marine shelf ones with no legible cyclicity and this is consistent with the results obtained from palynofacies analysis.

The deposits from the Lublin Basin represent visible cyclicity and the palynofacies indicate also the shelf/shallow-marine environment. In line with that diagnosis, Narkiewicz et al. (2011) interpreted the depositional conditions as the shallow, restricted carbonate shelf/carbonate platform. This difference may be explained by the more proximal setting of the Radom Basin to a continental eroded area in the north and the south caused by the synsedimentary activity of the Holy Cross Mountains Fault (Narkiewicz et al. 2011). This diagnosis is confirmed by the assemblage of the non-pollen palynomorphs: low number of acritarchs, rarely occurring chitinozoans, frequently appearing fungal hyphae and animal remains.

7. The palynological record of the Taghanic Event

The Taghanic interval (*sensu* Abousalam and Becker 2011) ranges from *ansatus* up to the *hermanni* conodont zones (House 2002). The same it involves the Ex3 and Aur miospore zones that were recognised in analyzed sections. This global event is also known as the Taghanic Unconformity, Taghanic Crisis or Taghanic Onlap (Aboussalam 2003; Aboussalam and Becker 2011) and it is related to the series of sea-level changes and extinctions of fauna and flora. This event is widely recognised within the marine realm but the record of changes that took place in the terrestrial environment are scarce (Marshall et al. 2011; Turnau 2014). The Łysogóry-Radom and Lublin Basins during the Devonian formed a part of a wide tropical belt of a shelf margin of the Laurussia continent and that gives an opportunity to look into the interval of noticeable palaeoenvironmental changes related to the eustatics (Narkiewicz 2007; Narkiewicz et al. 2011). The microfloristic aspects of the Taghanic Event were recognised to some extent by Marshall et al. (2011) and Turnau (2014). According to Marshall et al. (2011) and Turnau (2014) the most prominent feature of the palynological Taghanic record was noticeable decrease in miospores taxonomic diversity. Marshall et al. (2011) described the miospore assemblage from NE Scotland, Orkney and Shetland being dominated by *Rhabdosposrites langii* and *R. streeli*. Other significant miospores were *Archaeozonotriletes variabilis*, *Chelinospora concinna*, *C. ligurata*, *Kraeuselisporites violabilis*, *Verrucosisporites scurrus* and *V. premnus*. All these taxa with the exception of *C. ligurata* and *K. violabilis* were present in samples from the investigated area but they were not the most numerous ones. Turnau (2014) on the area of northern and central Poland indicated the dominance of the *Geminospora* genera, and the same trend is noticeable in currently analyzed samples. The miospore assemblage from the investigated area contains 76 taxa and this number changes within the section (for full list of taxa see the supplementary data). Three of the four sections show the same pattern with significant decrease in new taxa appearances (see Figures 9, 10 and 11). In section Giełczew PIG 5 samples from the interval 1998 m to 1961 m provided no new taxa appearances (Figure 11). Samples from the interval 1459 m to 1333 m from Niesiołowice also show the lack of the new taxa (exceptions are samples from the depths 1399 m, 1395 m, 1359 m, Figure 10). In the Szwejki IG-3 section this interval involves samples from depths 4548 m to 4301 m (with the exception of samples from 4545 m, 4537 m, 4310 m and 4303 m; Figure 9). Due to the low number of samples this phenomenon was not possible to observe in the Krowie Bagno IG-1 section. In Giełczew PIG 5 and Niesiołowice IG-1 sections this taxonomic decrease corresponds with the occurrence of chitinozoans. In section Szwejki IG-3 chitinozoans occur below this interval (Figure 9). The taxonomic decrease in the sections Szwejki IG-3 and Niesiołowice IG-1 is consistent with the general less number of terrestrial palynomorphs and with the signals of transgression (Figures 9 and 10). In Giełczew PIG 5 section there the Ex/Aur boundary is marked with the taxonomic diversification decrease, but there is the general increase in total miospore number (Figure 11).

For each section the sea-level changes indicated by Narkiewicz et al. (2011) as being related to the Taghanic Event preceded the decrease in taxonomic diversification. Turnau (2014) indicated that Ex3 subzone corresponds with the Taghanic Event or most of it but the taxonomic diversification decrease occurs only on the Ex/Aur boundary, where the disappearance of nine species was documented. The low diversity included archaeopterids, filicopsids, rhyniophytes, zosterophylls, trimerophytes, cladoxyls, trimerophyte-cladoxylalean intermediates and lycopsids (Turnau 2014). The special attention was put on the disappearance of the *A. extensa* and *R. langii* producers (Turnau 2014). In the investigated material, *A. extensa* also disappears on the upper boundary of the Ex Miospore Zone but *R. langii* ranges upward the section into the local Aur Miospore Zone (Figures 4 and 6). The low miospore taxonomic diversity in this time interval was documented from the other parts of the world as well. The miospore assemblages from Belarus (Obukhovskaya 2000), central and Volga-Ural regions of European Russia (Avkhimovitch et al. 1993) from this time interval presented impoverished palynoflora that was dominated by finely sculptured *Geminospora* genera. Avkhimovitch et al. (1993) documented the disappearance of *Aneurospora extensa*, *Geminospora tuberculata*, *G. decora*, *Lanatisporis bislimbatus* and *Verrucosisporites scurrus*. Obukhovskaya (2000) also noticed the disappearance of the *Kraeuselisporites spinutissimus*. In the currently analyzed section *A. extensa*, *G. decora*, *L. bislimbatus* disappear within the Ex3 subzone as well.

The changes in the microflora composition, and as a consequence, the macrofloral changes were observed in different parts of the world. There are signals of taxonomic decrease also from Estonia (Mark-Kurik et al. 1990) and Timan-Pechora Province (Russia; Telnova 2007, 2008) but with no details. Diversity reduction was documented also from Boullonais (France) with the *Aneurospora goensis*, *Ancyrospora ancyrea* var. *brevispinosa*, *Auroraspora macromanifesta* and some other species disappearing within the member H of the Blacourt Formation (Brice et al. 1979). In NE Scotland and Shetlands the spore assemblage from the Ex3 subzone contained 28 species and the one from the IM subzone only 14 (Marshall et al. 2011). Marshall and Allen (1982) described the assemblage from the same subzone that also shows a reduction in diversity and contains the specimens like *Ancyrospora ancyrea* var. *brevispinosa*, *Densosporites devonicus*, *Grandispora* (al. *Calyptosporites*) *velata*, *G. protea*, *Geminospora tuberculata*, and *R. langii*. Different records were observed in North America. McGregor (1964) described the assemblage of 13 miospores from Alberta dominated by *A. greggsii* but with no abrupt decrease in diversity (McGregor 1964). Chi and Hills (1976) showed no impoverishment within the Givetian megaspore succession in eastern USA. Di Pasquo et al. (2022) documented microflora from Wyoming (USA) that did not reveal any significant taxonomic decrease in miospore assemblage. Moreover, some of the species that disappear in eastern Europe on Ex/Aur boundary are still present in Frasnian in Canadian sections e.g. *Calyptosporites velatus*, *Lanatisporites bislimbatus*, *Verrucosisporites scurrus* (McGregor 1981; McGregor and Playford 1992). *R. langii* was documented from Frasnian from the arctic Canada (Whitaley 1980). Consequently, the taxonomic decrease is the most prominent feature of this time interval in the area of central Europe and Russia and it has a slight impact in North America. In the currently investigated sections the observation made by Turnau (2014) concerning the taxonomic impoverishment on the Ex/Aur boundary seems to be applicable. As it was mentioned in the palynofacies section, the palaeoenvironmental conditions shown by analyzed sections were complex. Giełczew PIG 5 section in the T-4 cycle interval showed a considerable variability of the sea level (Narkiewicz et al. 2011). Similar conditions were mentioned by Marshall et al (2011) as the possible reason for the decline of taxa number. The Eday Marl Formation in Scotland shows a record of a rapid alternation of cool and arid, and hotter pluvial events that controlled the eustatic sea level changes. The unstable climate was indicated as the major cause of the faunal changes (Marshall et al. 2011). The palynofacies in Giełczew PIG 5 section indicate that despite the regressional regime the taxonomic diversity remained lower than before the Taghanic interval (Figures 6 and 11). Niesiołowice IG-1 and Szwejki IG-3 sections show the opposite pattern with the transgressional regime that co-occurred with the decrease of the taxonomical diversification (Figures 4, 5, 9, 10). Turnau (2014) indicated that shoreline shifts were one of the causes of the floral changes. DiMichele and Hook (1992) suggested that flood disturbance was the major modifier of the Middle Devonian ecosystem and it may cause the changes in evolution strategy of the particular plant species as some of the plants have lost their habitats (Turnau 2014). Taxonomic diversification is a complex problem with several possible causes. Wellman et al. (2022) considered the taxonomic biodiversity as the result of palaeocontinental configuration, environmental stress and specific pattern of land plant evolution. Despite the fact that these considerations are related to the Lower Devonian it is plausible they may explain to some extent the taxonomic impoverishment of the late Givetian microlora.

8. Systematic palaeontology

Anteturma **SPORITES** H. Potonié 1893

Turma **TRILETES** (Reinsch 1953) Dettmann 1963

Subturma **AZONOTRILETES** (Luber 1955) Dettmann 1963

Infraturma **LAEVIGATI** (Bennie & Kidston 1954) R. Potonié 1956

Genus ***Retusotriletes*** Naumova 1953 emend. Streel 1964

Type. *Retusotriletes simplex* Naumova 1953

Retusotriletes radomskii sp . nov.

Plate VI, figures 1-9

Holotype. Plate VI, figure 5.

Type locality. Niesiołowice IG-1 borehole, Rybitwy village, central Poland (N51°01′51,71″, S21°50′06,01″).
Stratigraphical range. Devonian, Givetian, "*Geminospora" extensa* Miospore Zone, Ex3 subzone.

Diagnosis. Trilete spore of rounded outline. The trilete mark is distinctive, bordered by elevated labra 1.25 µm high and 1.6-6.2 µm width. Trilete mark reaches the spore margin and it is clearly distinctive. Exospore thin, laevigate or scabrate.

Dimensions. Minimum: 70 µm, maximum: 122 µm (mean: 96 µm). Based on the 12 specimens.

Remarks. The specimens documented from south-central Poland often show only the proximal side preserved and lack of the marginal parts of the spore and the same lack of the curvaturae. The fragmentary preserved spores with marginal areas are shown in figures 4 and 5 (Plate VI) and thus these specimens are included into the *Retusotriletes* genus. *Retusotriletes radomskii* differs from other spores of this genus by its larger size, thin exospore and massive labra. *R. loboziakii* Rooney et al. 2013 is similar in size but thicker and its trilete mark reaches ⅘ of the spore diameter. *R. distinctus* Richardson 1964 poses darker triangular areas within the contact areas. *Retusotriletes radomskii* differs from *Retusotrilestes* sp. Steemans et al. (2011) by larger size and lack of punctation on the surface. *R. avonensis* Playford 1964 strongly resembles *R. radomskii* but is smaller (mean diameter 79 µm) than currently described specimen. Moreover, *R. avonensis* shows equatorial regions thicker than contact areas, while this feature is not typical for *R. radomskii*.
The specimens of *Retusotriletes radomskii* were also documented from the Western Pomerania from the same time interval (Ex3 subzone; unpublished data). Due to the characteristic morphology and narrow stratigraphical range this taxon may be useful for local stratigraphy. Further recognition of *Retusotriletes radomskii* occurrence is required in the future.

Derivation of name. Name comes from the Radom part of the Łysogóry-Radom Basin, where it was found.

The slides containing the holotype are housed at the Faculty of Natural Sciences in Sosnowiec, Poland.

9. Summary

Based on the microflora assemblage, the interval that might be Ex3 Subzone or older in age was established in Szwejki IG-3 section at the depth 4705 m downward the section and in Giełczew PIG 5 from the depth 2024 m to 20212 m. The Ex3 subzone was documented from the section Szwejki IG-3 at the depth 4703-4301 m, in the section Niesiołowice IG-1 at the depth 1517-1334 m, in section Giełczew PIG 5 at the depth 2011-2004 m. Undivided zone Ex/Aur was indicated in Krowie Bagno IG-1 at the depth 1334 m. The Aur Miospore Zone was recognised at the depth 4299 m in section Szwejki IG-3, on 1333-1330 in section Niesiołowice IG-1,1998-1960 m in

Giełczew PIG 5 and 1332-1221 m in the Krowie Bagno IG-1 section but the last result should be treated approximately.

Palynofacies analysis showed that the depositional environment for two basins slightly differs, both may be described as shelf/shallow-water marine. Despite the fact that the palynofacies record seems to be similar, the Lublin Basin shows visible cyclicity in terrigenous material input. In the Radom Basin the depositional conditions may be described as a more open marine shelf, while in the Lublin Basin the environment of deposition was a shallow, restricted shelf.

A decrease in taxonomic diversification occurs close to the Ex/Aur zones boundary and the same close to the Givetian/Frasnian boundary. This may be related to the climatic changes that affected plant habitats during the Taghanic interval. This microfloristic event is noticeable, however it is difficult to connect it with the particular pattern of the environmental changes. Thus, this time interval requires more palynological studies in the future, preferably supported by geochemistry.

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Figure 1. The locality of the investigated boreholes against selected geological structures in Łysogóry-Radom and Lublin Basins area. A-the simplified map of Poland showing the investigated area, B-the investigated area in detail (from Narkiewicz et al. 2011 and references therein, modified).

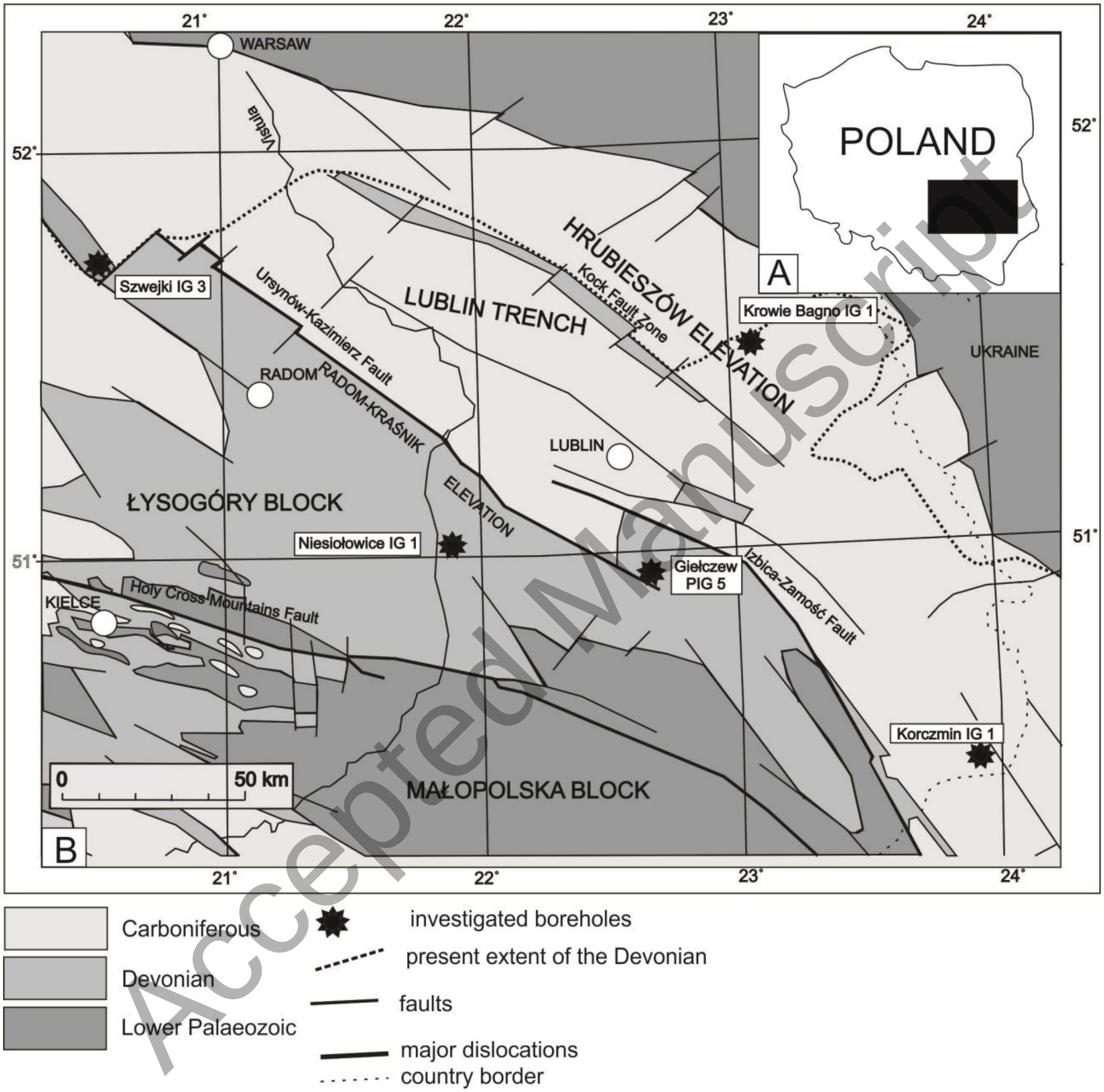


Figure 2. Miospore zonations combined with the "standard" conodont zonation. The miospore zones documented within the analysed sections are marked in grey. L-Lower, M-Middle, U-Upper for conodont zones. A-Richardson and McGregor (1986), B-Streel et al. (1987), C-Avkhimovitch et al. (1993), D-Turnau (2007, 2008, 2011), E-shallow marine conodont zonation, F-standard conodont zonation. The tentative correlations between conodont and miospore zones are marked with dashed lines (except the Aur Miospore Zones as its stratigraphical range is narrower, see the double-ended arrow). Conodont zonations modified after Klapper and Ziegler (1979), Weddige (1984) and Ziegler and Sandberg (1990). From Kondas and Filipiak (2021), modified.

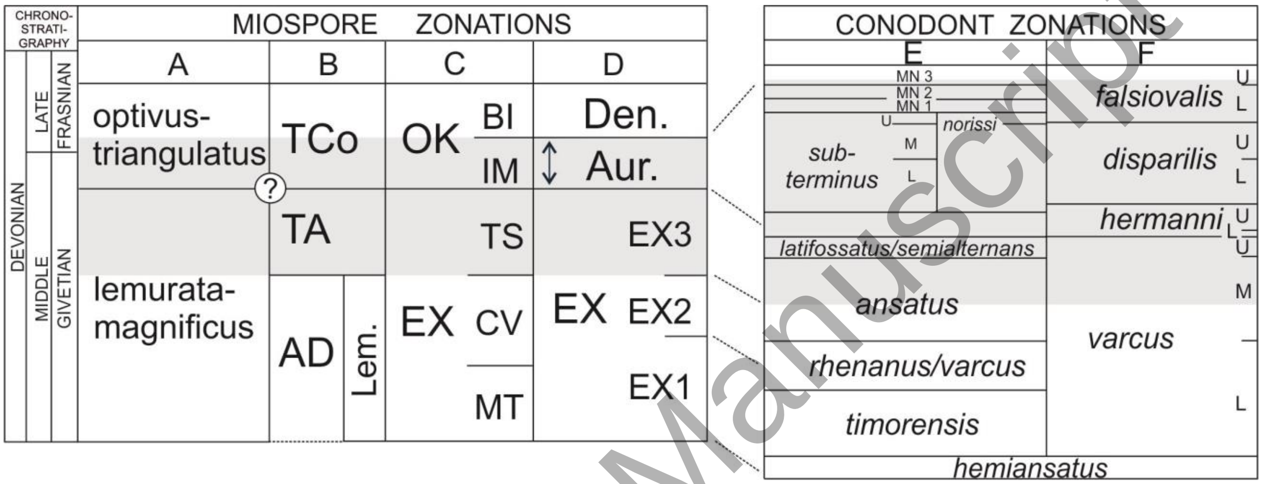


Figure 3. Lithostratigraphical diagram of the Givetian-Frasnian deposits in the Łysogóry-Radom and Lublin Basin area. PB-Pokrzywianka beds, DLU-Dolomitic Limestone Unit, for conodont zonation: U-Upper, L-Lower (after Narkiewicz et al. 2011, modified).

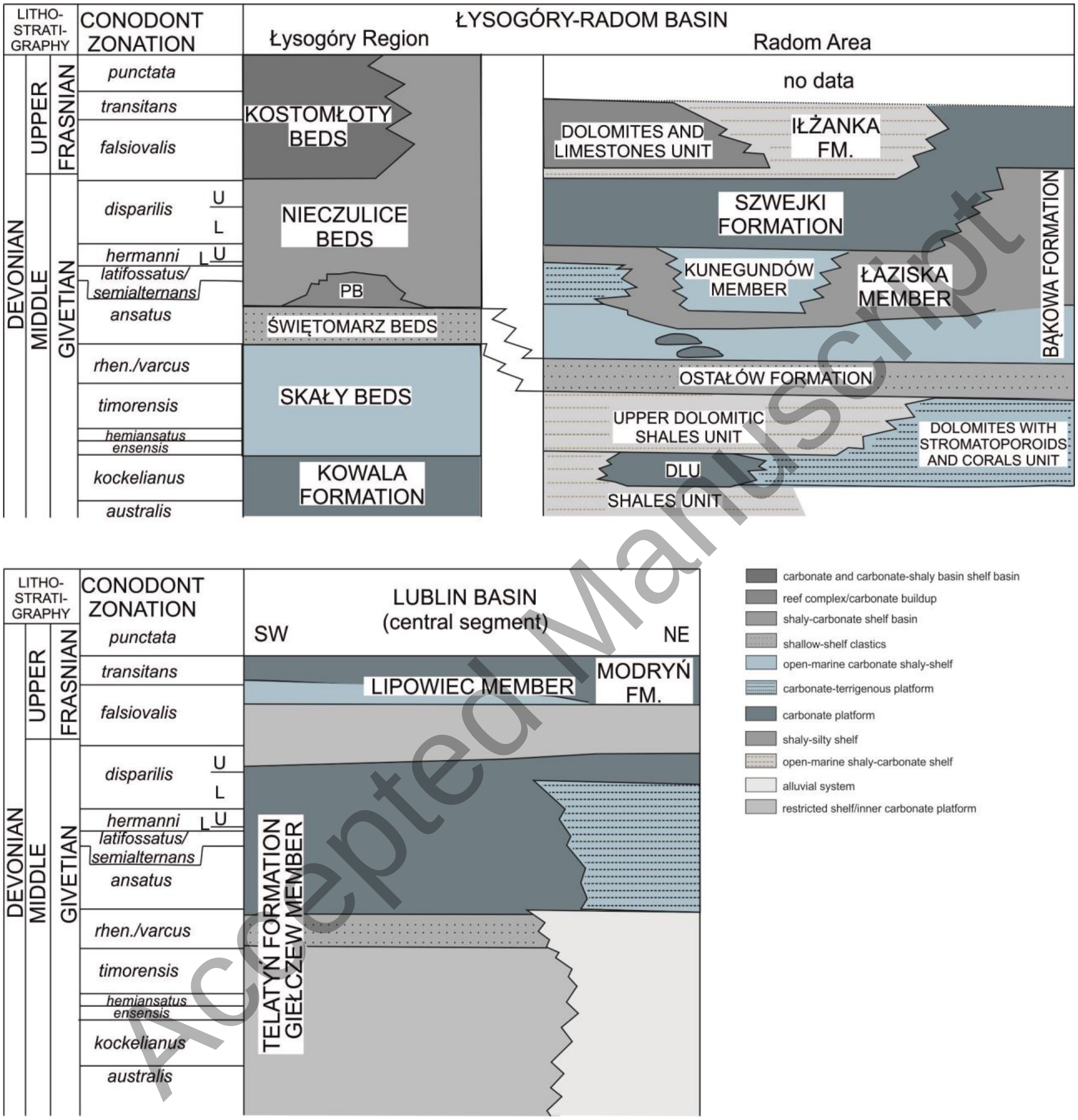


Figure 4. Drill core section Szwejki IG-3 with important and common miospore taxa ranges. A-age, B-miospore zone, C-depth, D-lithology, E-palynological samples, F-taxa important for stratigraphy.

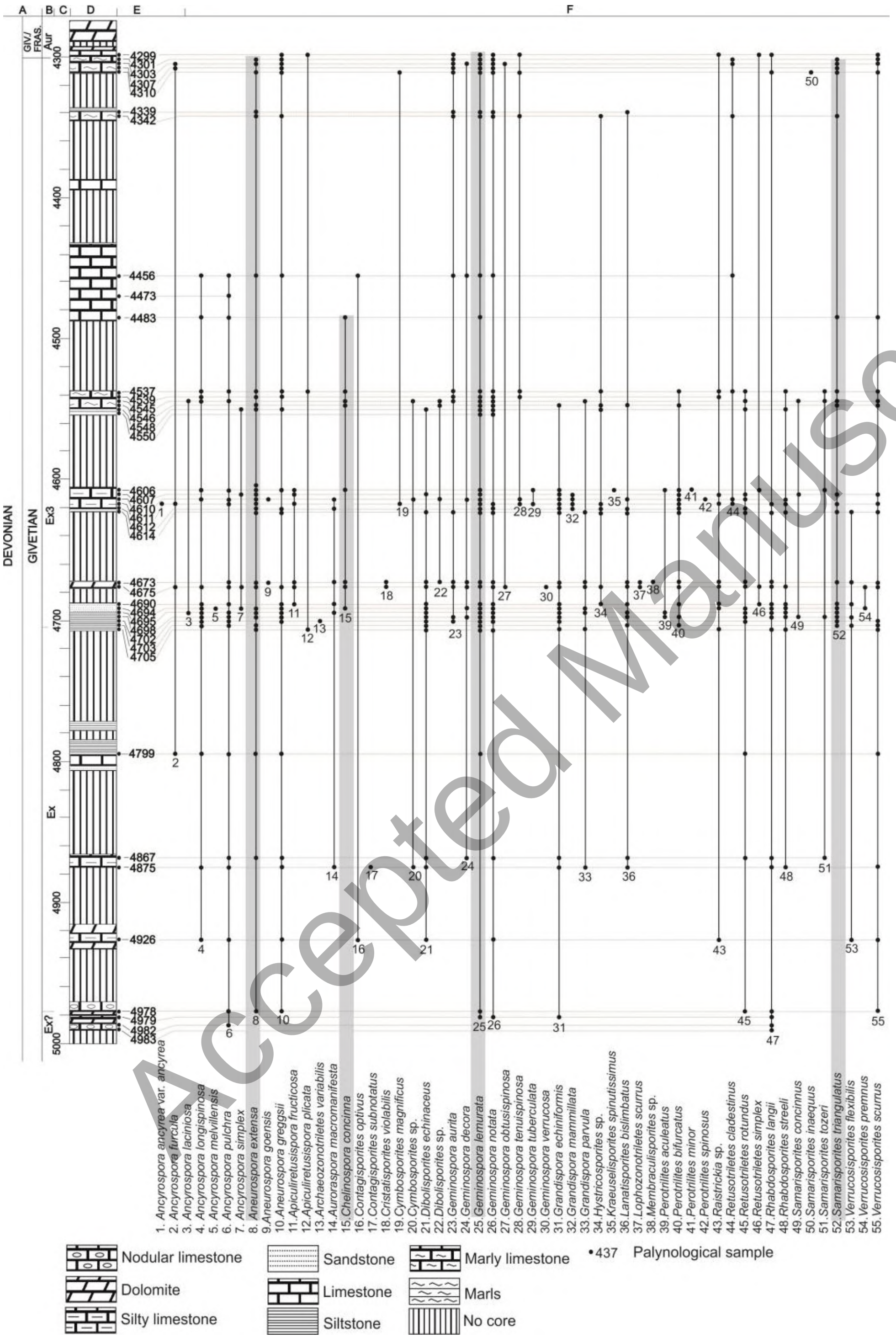


Figure 5. Drill core section Niesiołowice IG-1 with important and common miospore taxa ranges. For explanation see Figure 4.

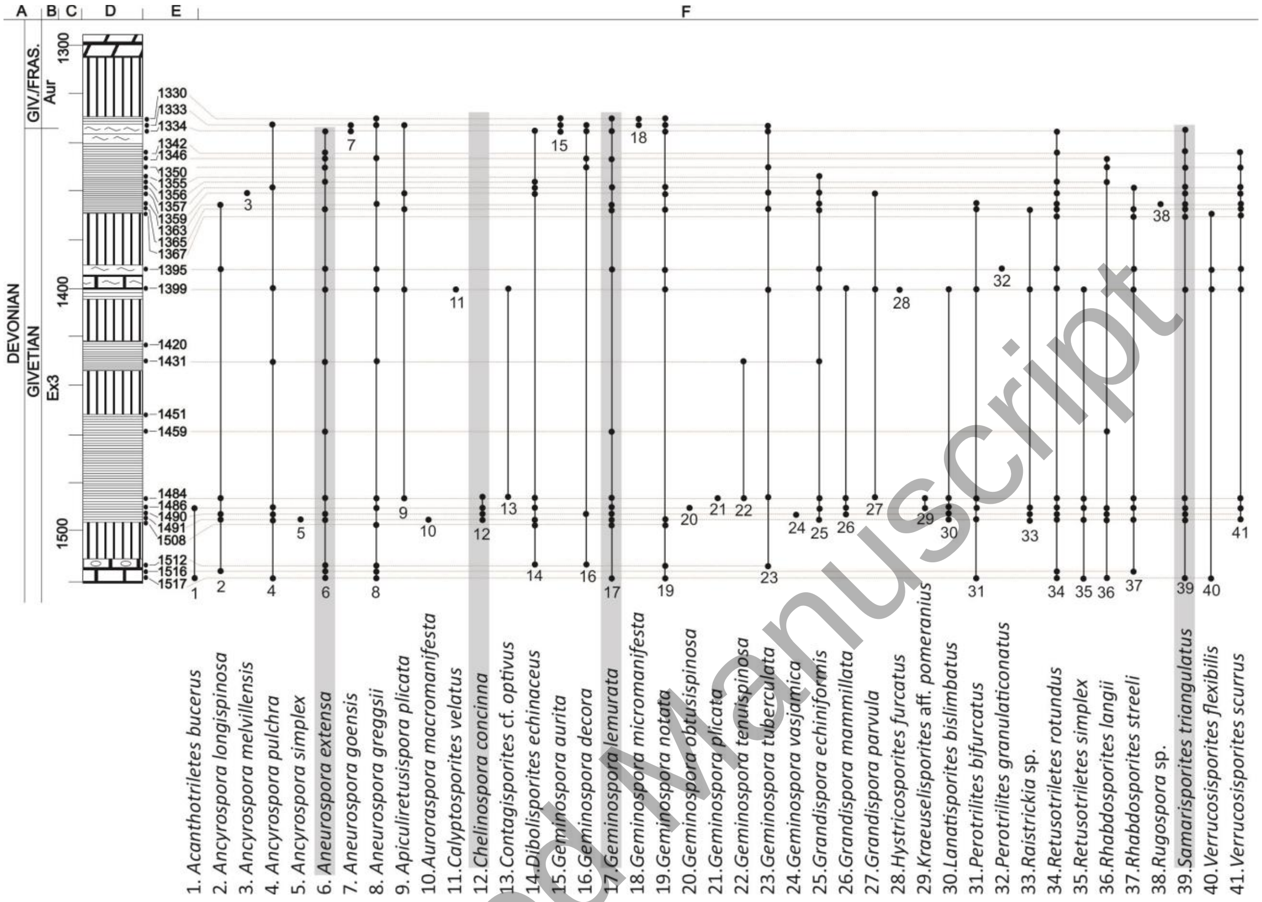


Figure 6. Drill core section Giełczew PIG 5 with important and common miospore taxa ranges. For explanation see Figure 4.

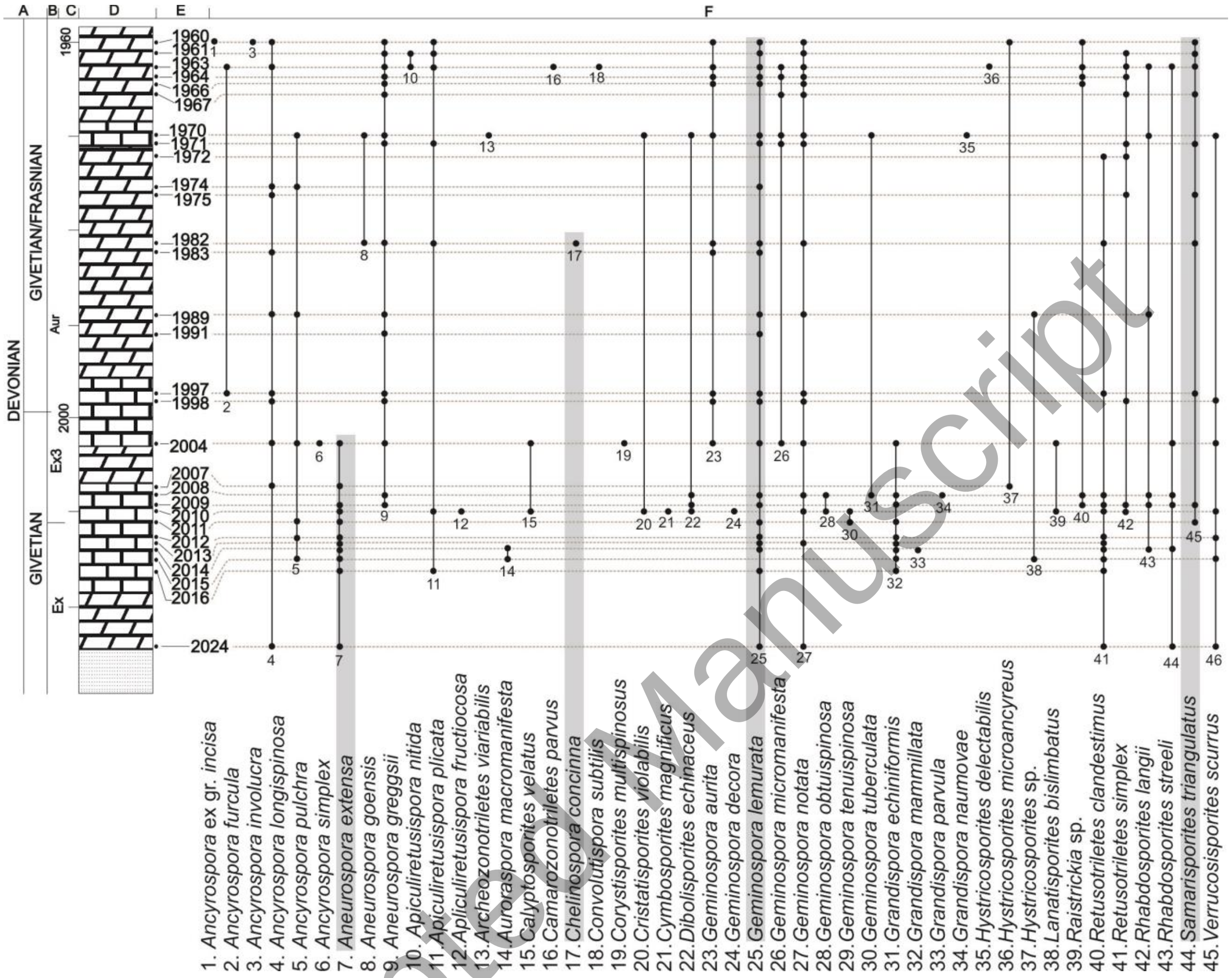


Figure 7. Drill core section Krowie Bagno IG-1 with important and common miospore taxa ranges. For explanation see Figure 4.

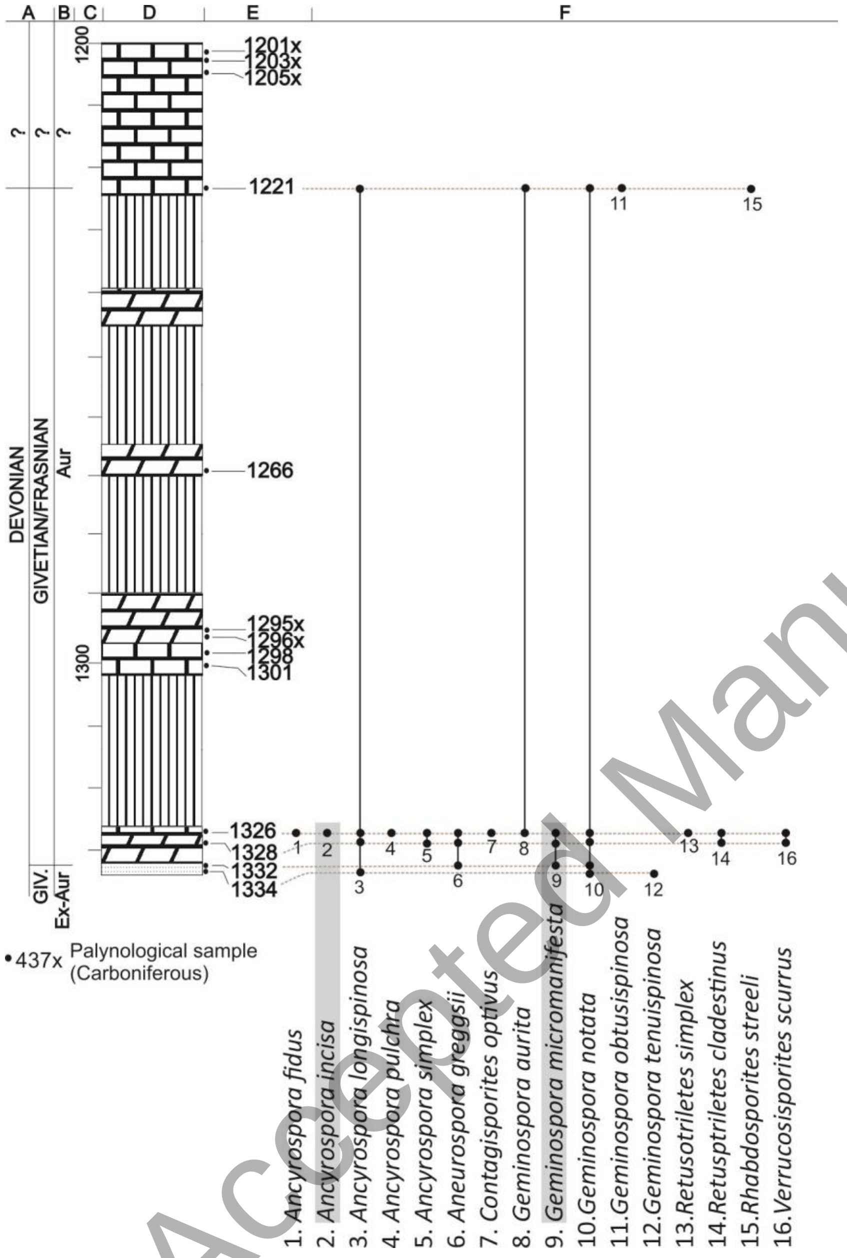


Figure 8. Palynostratigraphical correlations between sections Szwejki IG-3, Niesiołowice IG-1 (Łysogóry-Radom Basin) and Giełczew PIG 5, Krowie Bagno IG-1 (Lublin Basin).

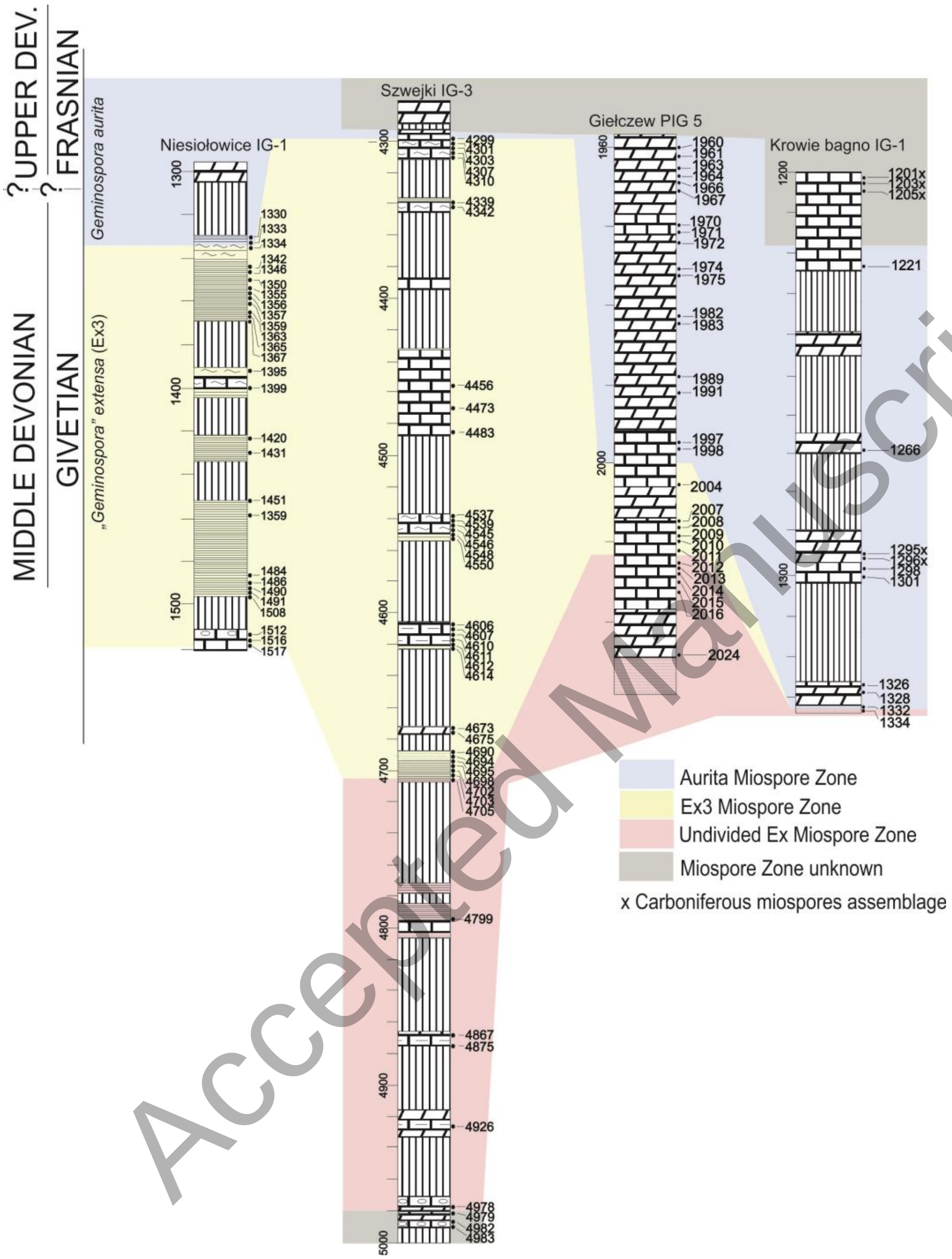


Figure 9. The relative percentage of the palynomorphs in the Szwejki IG-3 section. A-miospores, B-phytoclasts, C-prasinophytes, D-scolecodonts, E-bioclasts, F-opaque particles. The interval with samples showing no new taxa appearances is marked with red colour. Lithostratigraphy is based on the scheme from Narkiewicz et al. (2011)

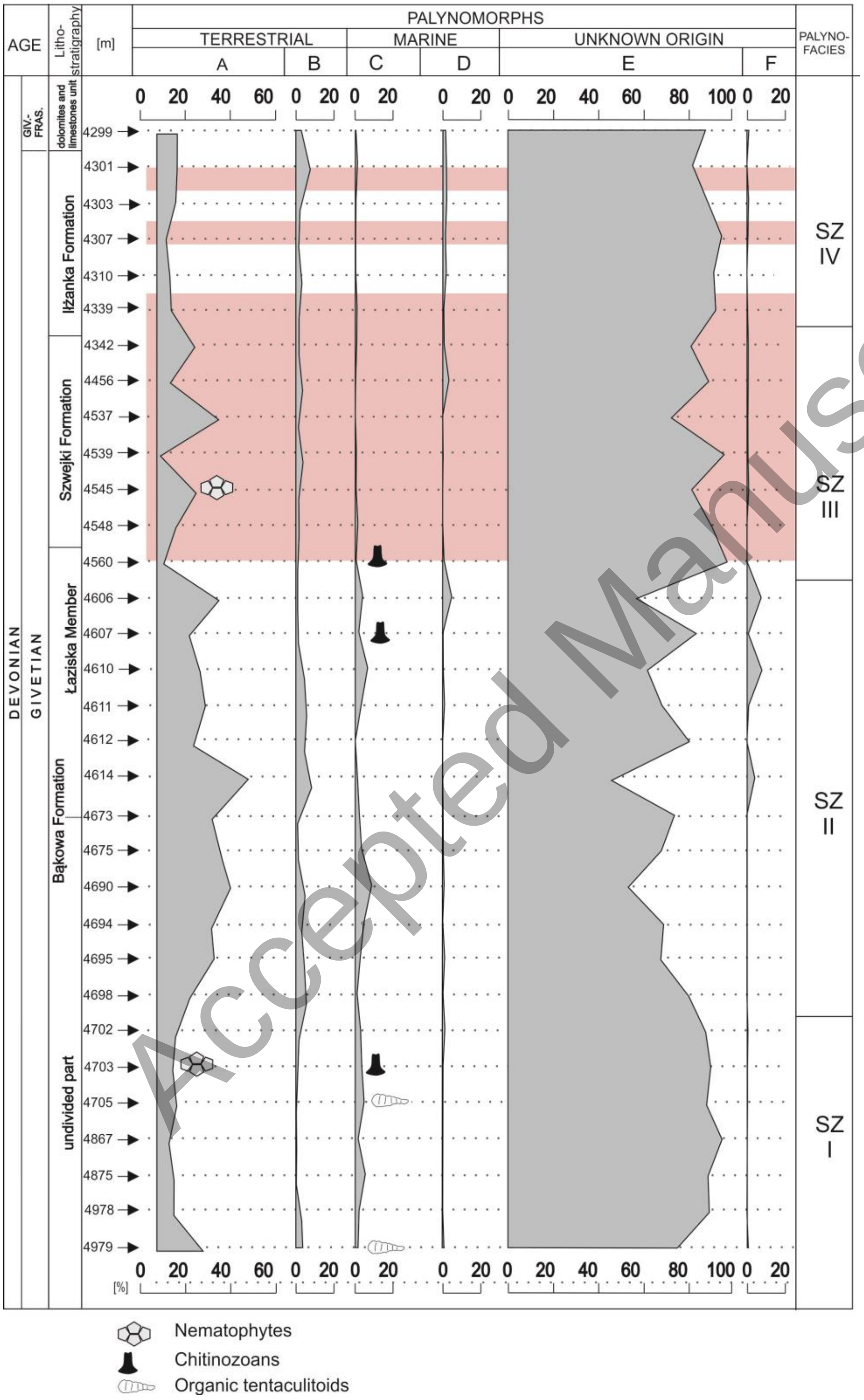


Figure 10. The relative percentage of the palynomorphs in the Niesiołowice IG-1 section. For explanations see Figure 9.

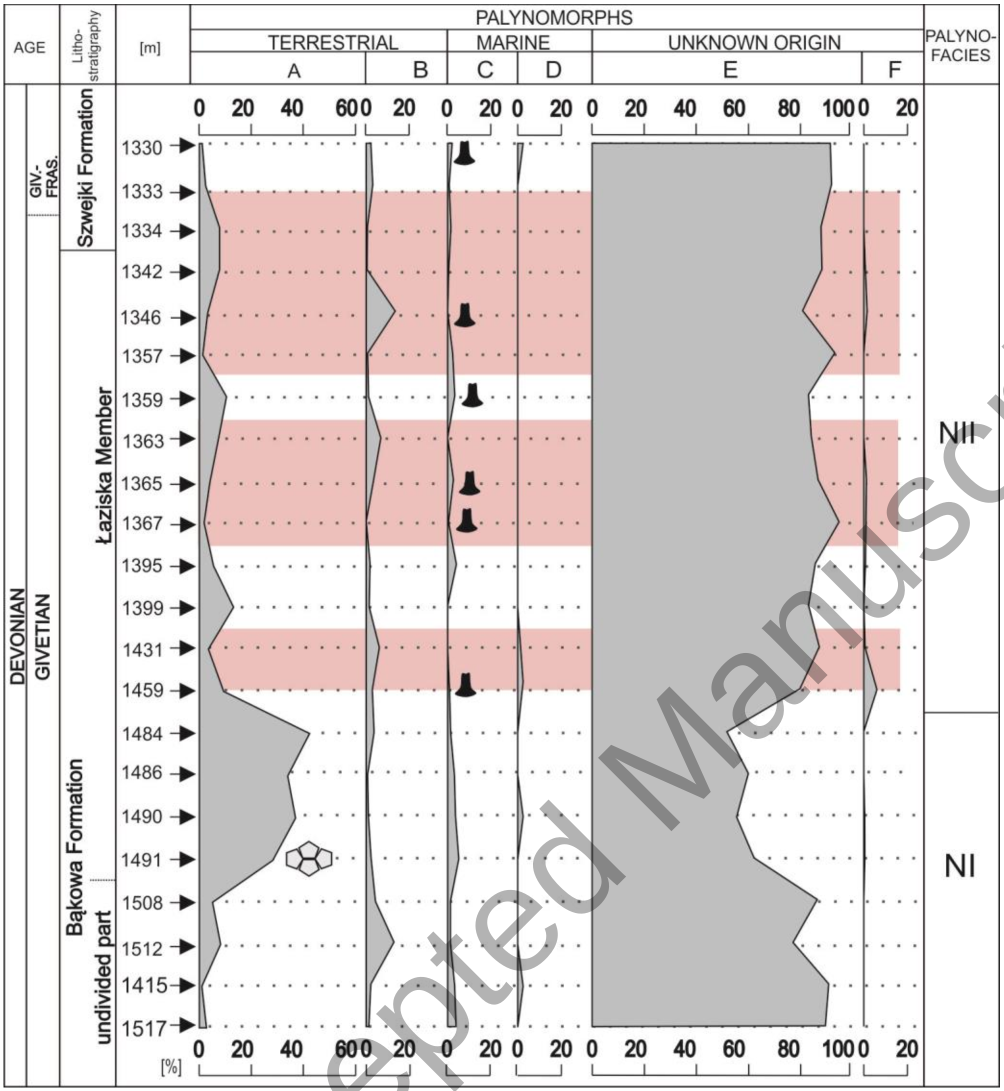


Figure 11. The relative percentage of the palynomorphs in the Giełczew PIG 5 section. For explanations see Figure 9. T-R cycles positions based on the Narkiewicz et al. (2011).

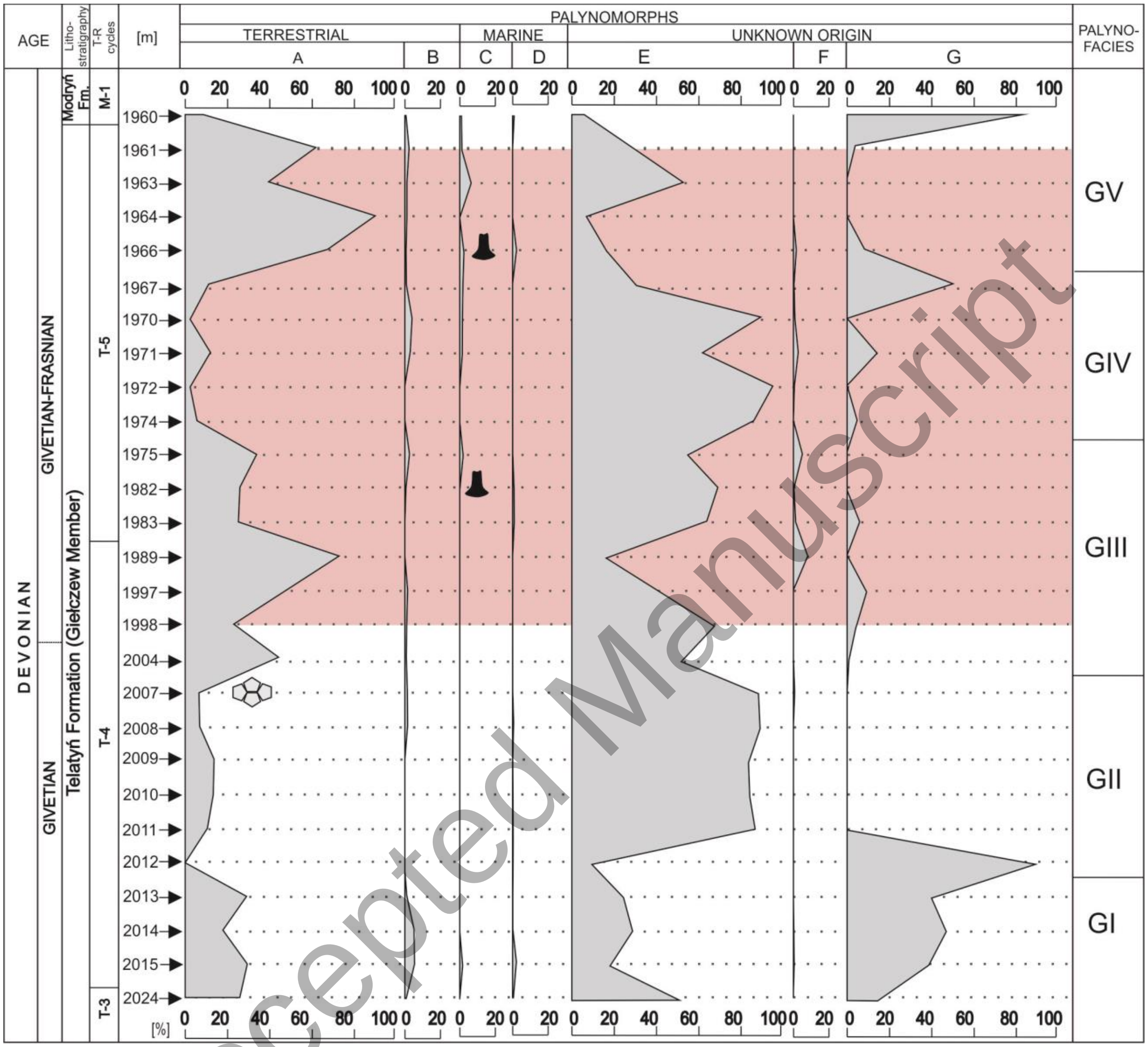
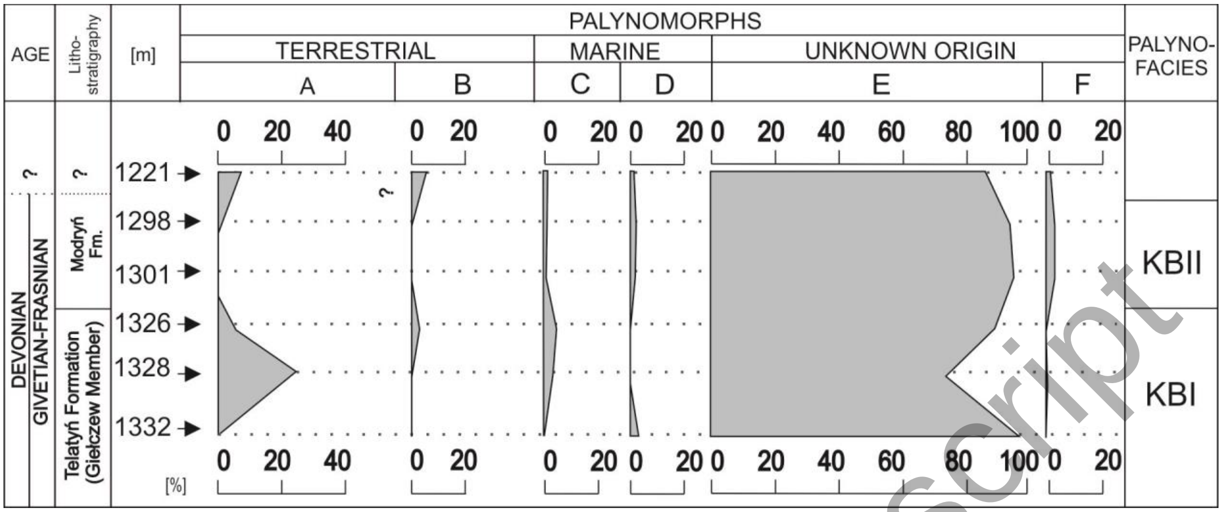


Figure 12. The relative percentage of the palynomorphs in the Krowie Bagno IG-1 section. For explanations see Figure 9.



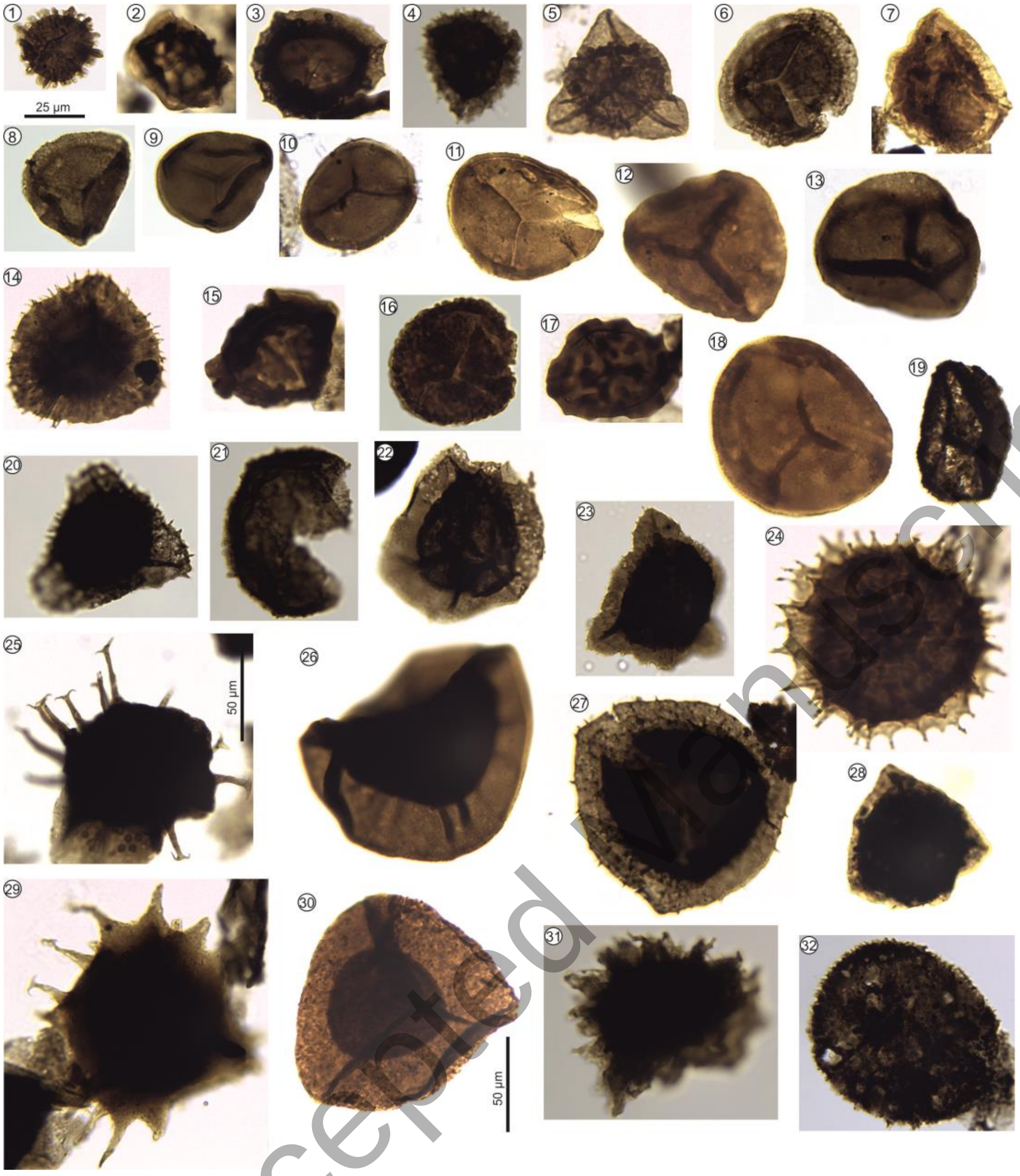


Plate 1. Miospores obtained from the Szwejki IG-3 section. The scale bar is 25 µm except for photographs with a scale bar next to the specimen.

1. *Raistrickia* sp., depth 4926 m, EF:27X
2. *Chelinospora concinna*, sample 438, EF:15V1
3. Unrecognised miospore, sample 325, EF:12U2
4. *Samarisporites concinnus*, depth 4606 m, EF:21T
5. *Samarisporites triangulatus*, depth 4342 m, EF:24T2
6. *Lanatisporites bislimbatus*, depth 4875 m, EF:23R2
7. aff. *Samarisporites triangulatus*, depth 4339 m, EF:11Q2
8. *Geminospora obtusispinosa*, depth 4675 m, EF:12P1
9. *Aneurospora extensa*, depth 4342 m, EF:26M3

10. *Aneurospora greggsii*, depth 4978 m, EF:23S2
11. *Geminospora lemurata*, depth 4483 m, EF:42P2
12. *Geminospora aurita*, depth 4299 m, EF:30S
13. *Geminospora notata*, depth 4799 m, EF:33L2
14. *Grandispora* sp., depth 4867 m, EF:49O2
15. *Verrucosisporites scurrus*, depth 4875 m, EF:33Y2
16. aff. *Cymbosporites magnificus*, depth 4703 m, EF:45T2
17. *Lophozonotriletes scurrus*, depth 4675 m, EF:31J
18. *Aneurospora greggsii*, depth 4456 m, EF:7M3
19. *Geminospora tuberculata*, depth 4606 m, EF:12P4
20. Unrecognised miospore, depth 4606 m, EF:50D136S1
21. *Perotrilites aculeatus*, depth 4606 m, EF:24Q4
22. Unrecognised miospore, depth 4606 m, EF: 22W3
23. *Samarisporites triangulatus*, depth 4537 m, EF:38V3
24. *Perotrilites bifurcatus*, depth 4675 m, EF:34O2
25. *Hystricosporites* sp., depth 4611 m, EF:36S1
26. *Rhabdosporites langii*, depth 4705 m, EF:30T2
27. *Grandispora echiniformis*, depth 4610 m, EF:32Q4
28. cf. *Samarisporites triangulatus*, depth 4695 m, EF:36H
29. *Ancyrospora longispinosa*, depth 4675 m, EF:43U3
30. *Auroraspora macromanifesta*, depth 4690 m, EF:31T1
31. *Ancyrospora laciniosa*, depth 4695 m, EF:39S1
32. Unrecognised miospore, depth 4698 m, EF:48R

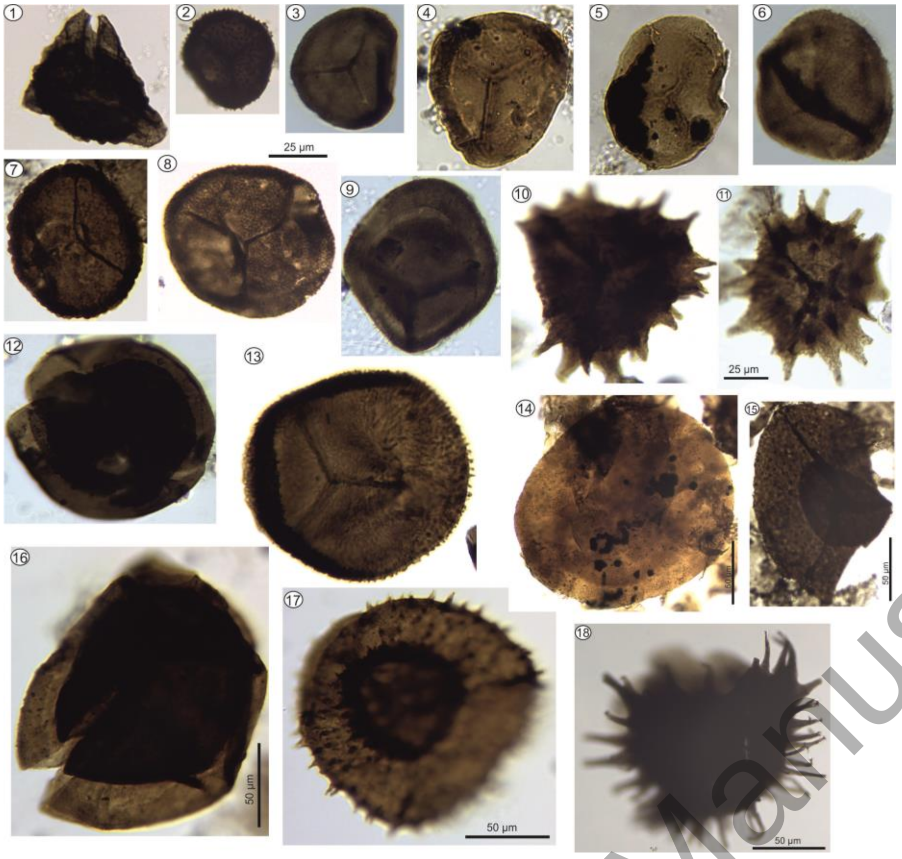


Plate 2. Miospore taxa important for stratigraphy obtained from sections Niesiołowice IG-1, Giełczew PIG 5 and Krowie Bagno-IG-1. The scale bar is 25 µm except for photographs with a scale bar next to the specimen.

1. *Samarisporites triangulatus*, section Niesiołowice IG-1, depth 1346 m, EF:53Y1
2. *Aneurospora extensa*, section Niesiołowice IG-1, depth 1512 m, EF:56U1
3. *Aneurospora greggsii*, section Giełczew PIG 5, depth 2008 m, EF:36Q
4. *Geminospora micromanifesta,* section Krowie Bagno IG-1, depth 1326 m, EF:35K2
5. *Geminospora aurita*, section Krowie Bagno IG-1, depth 1326 m, EF:36J2
6. *Geminospora notata*, section Giełczew PIG 5, depth 1989 m, EF:14D1
7. *Geminospora tuberculata*, section Giełczew PIG 5, depth 2008 m, EF:12W3
8. *Geminospora lemurata*, section Giełczew PIG 5, depth 1960 m, EF:24W3
9. *Geminospora aurita*, section Giełczew PIG 5, depth 1998 m, EF:20V1
10. *Ancyrospora simplex*, section Giełczew PIG 5, depth 1998 m, EF:56M1
11. *Ancyrospora pulchra*, section Giełczew PIG 5, depth 1997 m, EF:45W4
12. *Rhabdosporites streeli*, section Giełczew PIG 5, depth 2024 m, EF:13Q1
13. *Dibolisporites echinaceus*, Giełczew PIG 5, depth 1970 m, EF:40T2
14. *Contagisporites optivus,* section Krowie Bagno IG-1, depth 1326 m, EF:22Q2
15. *Calyptosporites velatus*, section Niesiołowice IG-1, depth 1399 m, EF:27R4
16. *Rhabdosporites langii*, section Giełczew PIG 5, depth 1970 m, EF:18R

17. *Grandispora mammillata*, section Giełczew PIG 5, depth 2014 m, EF:14R2
18. *Ancyrospora longispinosa*, section Niesiołowice IG-1, depth 1484 m, EF:5H2

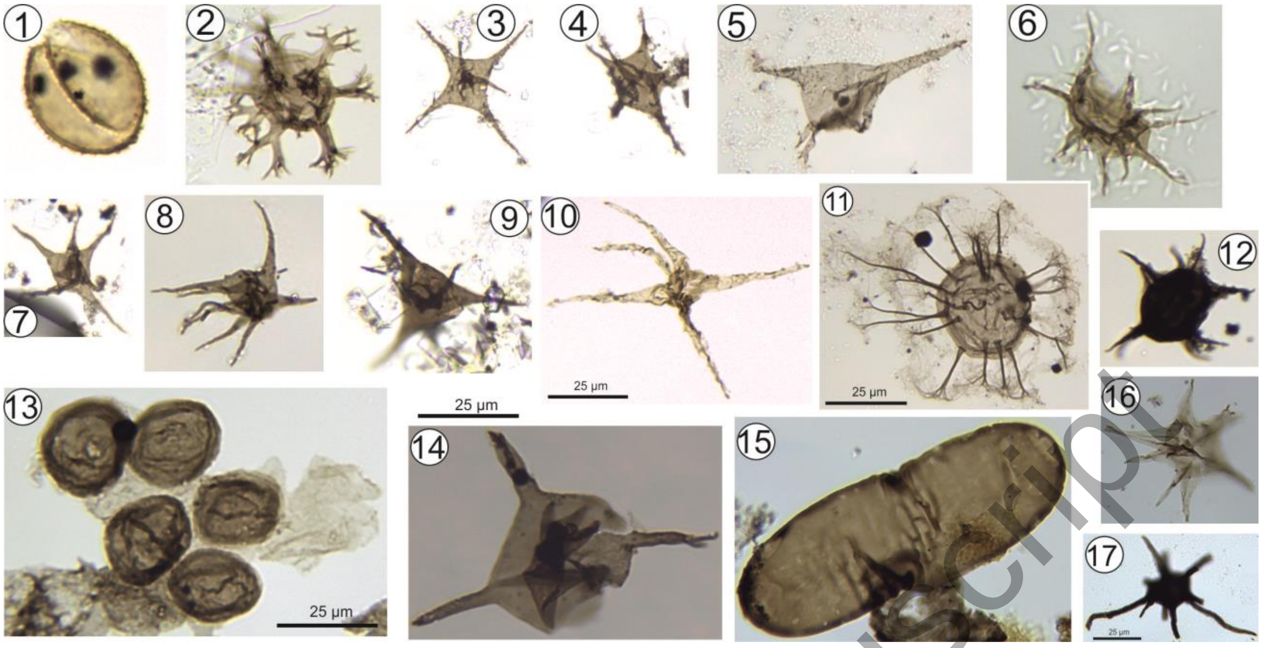


Plate 3. Phytoplankton taxa documented from the sections Szwejki IG-3, Niesiołowice IG-1, Giełczew PIG 5 and Krowie Bagno IG-1. The scale bar is 25 µm except for photographs with a scale bar next to the specimen.

1. *Gorgonispaheridium* sp., section Krowie Bagno IG-1, depth 1328 m, EF:18O3
2. *Multiplicisphaeridium ramusculosum*, section Giełczew PIG 5, depth 1966 m, EF:31K2
3. *Polyedrixium* sp., section Niesiołowice IG-1, depth 1330 m, EF:15F2
4. *Stellinium octoaster*, section Niesiołowice IG-1, depth 1330, EF:25N
5. *Veryhachium* sp., section Szwejki IG-3, depth 4339 m, EF:21M
6. *Micrhystridium stellatum*, section Szwejki IG-3, depth 4339 m, EF:29O2
7. *Stellinium* sp., section Niesiołowice IG-1, depth 1491 m, EF:30R3
8. *Stellinium* sp., section Niesiołowice IG-1, depth 1490 m, EF:31Q2
9. *Veryhachium trispinosum*, section Niesiołowice IG-1, depth 1490 m, EF:16U2
10. Acritarcha, section Szwejki IG-3, depth 4703 m, EF:24C2
11. Acritarcha, section Niesiołowice IG-1, depth 1490 m, EF:19K3
12. *Micrhystridium* sp., section Niesiołowice IG-1, depth 1330 m, EF:37S1

13. *Leiosphaeridia* sp., section Niesiołowice IG-1, depth 1490 m, EF:17W3
14. Acritarcha, section Niesiołowice IG-1, depth 1490 m, EF:14T3
15. *Navifusa baccilla*, section Niesiołowice IG-1, depth 1490 m, EF:18T1

16. *Stellinium micropolygonale*, section Giełczew PIG 5, depth 1966 m, EF:28L2

17. Acritarcha, section Giełczew PIG 5, depth 1966 m, EF:30K3

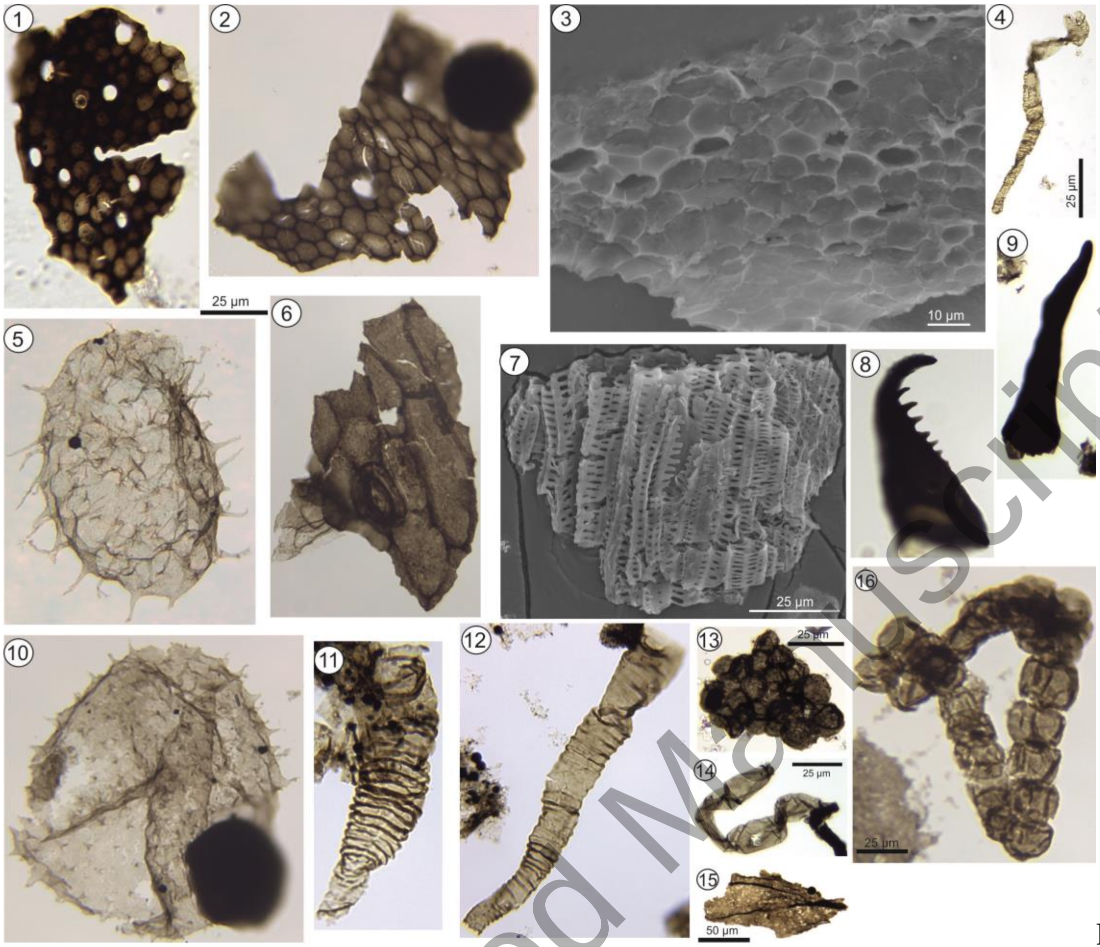


Plate 4.

Other palynomorphs and palynoclasts obtained from the section Szwejki IG-3, Niesiołowice IG-1 and Giełczew PIG 5. The scale bar is 25 µm except for photographs with a scale bar next to the specimen.

1. *Cosmochlaina*, section Giełczew PIG 5, depth 2007 m, EF:21S3
2. *Cosmochlaina*, section Niesiołowice IG-1, depth 1491 m, EF:39V
3. *Cosmochlaina*, section Niesiołowice IG-1, depth 1491 m, EF:33Z2
4. Tentaculitoids, section Szwejki IG-3, depth 4979 m, EF:41W2
5. Acritarcha, section Niesiołowice IG-1, depth 1491 m, EF:31R4
6. Plant cuticle, section Niesiołowice IG-1, depth 1359 m, EF:43S
7. Plant tracheid, section Niesiołowice IG-1, depth 1365 m, EF:25R2
8. Scolecodont, section Giełczew PIG 5, depth 2008 m, EF:36T2
9. Spine (?), section Niesiołowice IG-1, depth 1367 m, EF:32S4
10. Acritarcha, section Niesiołowice IG-1, depth 1491 m, EF:23R4
11. Tentaculitoid, section Szwejki IG-3, depth 4979 m, EF:15R2
12. Tentaculitoid, section Szwejki IG-3, depth 4979 m, EF:19S3
13. aff. *Synsphaeridium* sp., section Niesiołowice IG-1, depth 1490 m, EF:36S1

14. Bioclast, section Niesiołowice IG-1, depth 1490 m, EF:21R3
15. Bioclast, section Szwejki IG-3, depth 4979 m, EF:41RR3
16. Unidentified small, spherical objects arranged in line, section Niesiołowice IF-1, depth 1490 m, EF:26S2

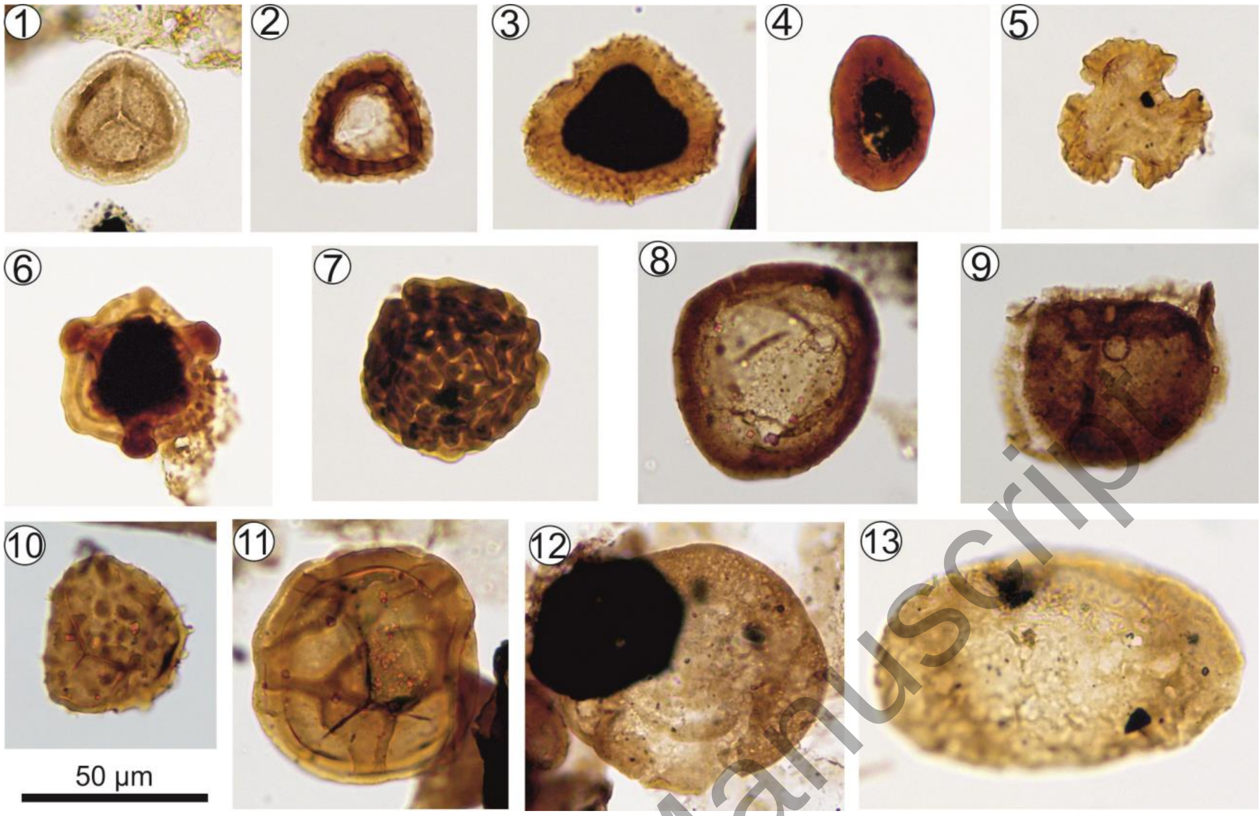


Plate 5. The Carboniferous miospores documented from the Krowie Bagno IG-1 section.

1. *Lycospora pusilla*, depth 1295 m, EF:S17
2. *Cingulizonates* sp., depth 1201 m, EF:53Q4
3. *Cristatisporites* sp., depth 1201 m, EF:46R3
4. *Densosporites* sp., depth 1201 m, EF:H16
5. *Tripartites vetustus*, depth 1295 m, EF:10V4
6. *Knoxisporites triradiatus*, depth 1201 m, EF:45N4
7. *Convolutispora* sp., depth 1201 m, EF:35T2
8. *Crassispora kosankei*, depth 1296 m, EF:M13
9. *Cirratriradites saturni*, depth 1296 m, EF:19I4
10. *Raistrickia fulva*, depth 1296 m, EF:S26
11. *Reticulatisporites reticulatus*, depth 1296 m, EF:J23
12. *Florinites* sp., depth 1296 m, EF:19M4
13. *Schulzospora* sp., depth 1295 m, EF:44R4

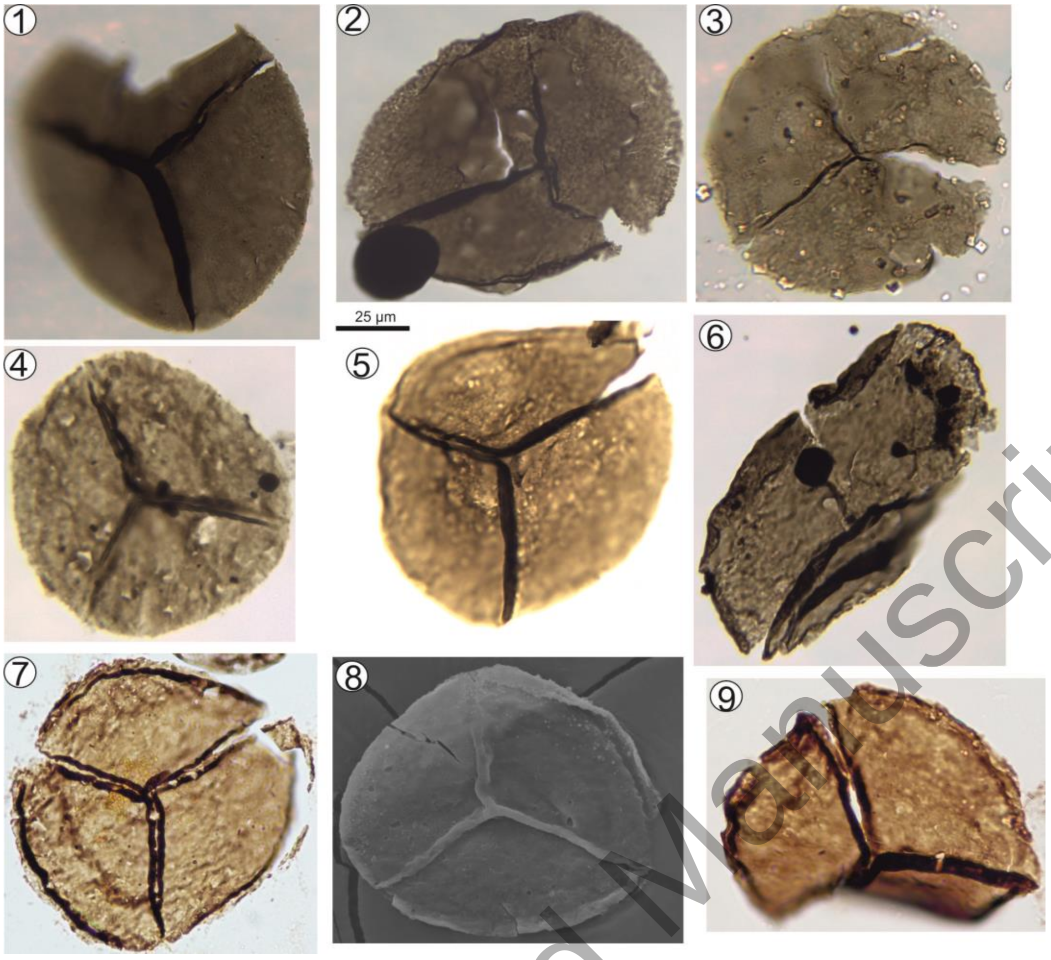


Plate 6. 1-6. *Retusitriletes radomskii* sp . nov.

1. Section Szwejki IG-3, depth 4607 m, EF:6X2
2. Section Szwejki IG-3, depth 4611 m, EF:15F2
3. Section Szwejki IG-3, depth 4703 m, EF:11H2
4. Section Niesiołowice IG-1, depth 1395 m, EF:16Q1, paratype
5. Section Niesiołowice IG-1, depth 1399 m, EF:23R3, holotype
6. Section Niesiołowice IG-1, depth 1484 m, EF:30Q1, paratype

7. Section M0, Miłoszów, sample 10C, EF: 20M3. For more details of this locality see: Kondas and Filipiak 2022.

8. Section M0, Miłoszów, sample 10C, SEM picture

9. Section M0, Miłoszów, sample 10C, EF:32L2

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Teleostomata rackii gen. et sp. nov.: an acritarch from the Devonian (Givetian) of south-central Poland

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ABSTRACT
The acritarch *Teleostomata rackii* gen. et sp. nov. is described and illustrated from the Middle Devonian Skały Beds that outcrop at Miłoszów, Holy Cross Mountains, Poland. At the type locality, its stratigraphical range is within the '*Geminospora*' *extensa* (Ex) Miospore Zone (= *hemiansatus–varcus* Conodont Zones), which correspond to the early and middle Givetian. The same acritarch has been illustrated from the Eifelian strata of the Gondwanan shelf in Tunisia, but it was unnamed at the time. This acritarch from Miłoszów can be distinguished from other phytoplankton genera of tetrahedral shape because of its broad processes with distal pore-like openings.

KEYWORDS
acritarchs; Devonian; phytoplankton; Holy Cross Mountains; taxonomy; Poland

1. Introduction

Palynological investigations carried out on two Lower–Middle Devonian outcrops from Miłoszów, Holy Cross Mountains, Łysogóry Block, Poland revealed the presence of mixed terrestrial and marine palynomorphs. One of these acritarchs is morphologically distinctive and is herein described as *Teleostomata rackii* gen. et sp. nov. This acritarch has not been described previously, although it resembles the acritarch *Tyligmasoma* or some *Estiastra* species. The same acritarch was briefly documented from Tunisia but was not named (Breuer 2007). The main objective of the present study is to provide a detailed taxonomic diagnosis of *Teleostomata rackii* gen. et sp. nov.

Published data on Devonian palynomorphs from the Łysogóry Block are scarce. The presence of Frasnian miospores was reported from a brickyard in the vicinity of Bodzentyn (Jachowicz in Filonowicz 1968). The miospore, conodont, and ostracod stratigraphy of the Givetian Skały and Nieczulice Beds was discussed by Malec and Turnau (1997). Turnau and Racki (1999) carried out further investigations of the Givetian Świętomarz and Nieczulice beds. The palynostratigraphy and palynofacies of Pragian–Eifelian deposits were examined from many localities by Filipiak (2011) and Fijałkowska-Mader and Malec (2011, 2018). Two new Givetian sections from Miłoszów complement the palynological investigations of the Łysogóry Block.

2. Geological setting

The outcrops are located in the Miłoszów settlement near Nieczulice village in the vicinity of Nowa Słupia town. Geologically, this site is located within the Bodzentyn Syncline in the northern Łysogóry Block of the Holy Cross Mountains, south-central Poland (Figure 1). The area of the Holy Cross Mountains is divided into two parts: a southern part (Kielce Area) with Devonian deposits of a shallower depositional regime; and a northern part (Łysogóry Block) where the Devonian deposits represent a deeper, intrashelf environment (e.g. Racki 1993; Szulczewski 1995; Narkiewicz et al. 2006). The sampled limestone and shale intervals belong to the Eifelian–Givetian Skały Beds, which are underlain by the dolomitic Wojciechowice Formation (Skompski and Szulczewski 1994; Halamski 2005; Halamski and Racki 2005; Narkiewicz and Narkiewicz 2010) and are overlain by the clastic Świętomarz Beds (Malec and Turnau 1997; Turnau and Racki 1999; Malec 2012). The material used for palynological analysis was obtained from the Skały Beds at two outcrops. The first section (M0; 50°54′07″N, 21°07′18″E; Figure 2a) is part of a gorge wall. It consists of limestone interbedded with dark shale. The second section, M2, was a trench dug perpendicular to the outcrop located at 50°54.139″N, 21°7.213″E. This section consists of shales and marls bounded at the bottom and top of the limestone (Figure 2b). Based on the palynology, these deposits were assigned to the '*Geminospora*' *extensa* Miospore Zone, local Ex1 and Ex2 Subzones (Avkhimovitch et al. 1993; Turnau 2007, 2008). This zone correlates with the *acanthomammillatus–devonicus* miospore zone of Streel et al. (1987) or the *lemurata–magnificus* Miospore Zone of Richardson and McGregor (1986). These miospore zones correspond to the *hemiansatus*–middle *varcus* Conodont Zones (Klapper 1988; Clausen et al. 1979), which are equivalent to the *hemiansatus–ansatus* Conodont Zones of Narkiewicz and Bultynck (2010). In terms

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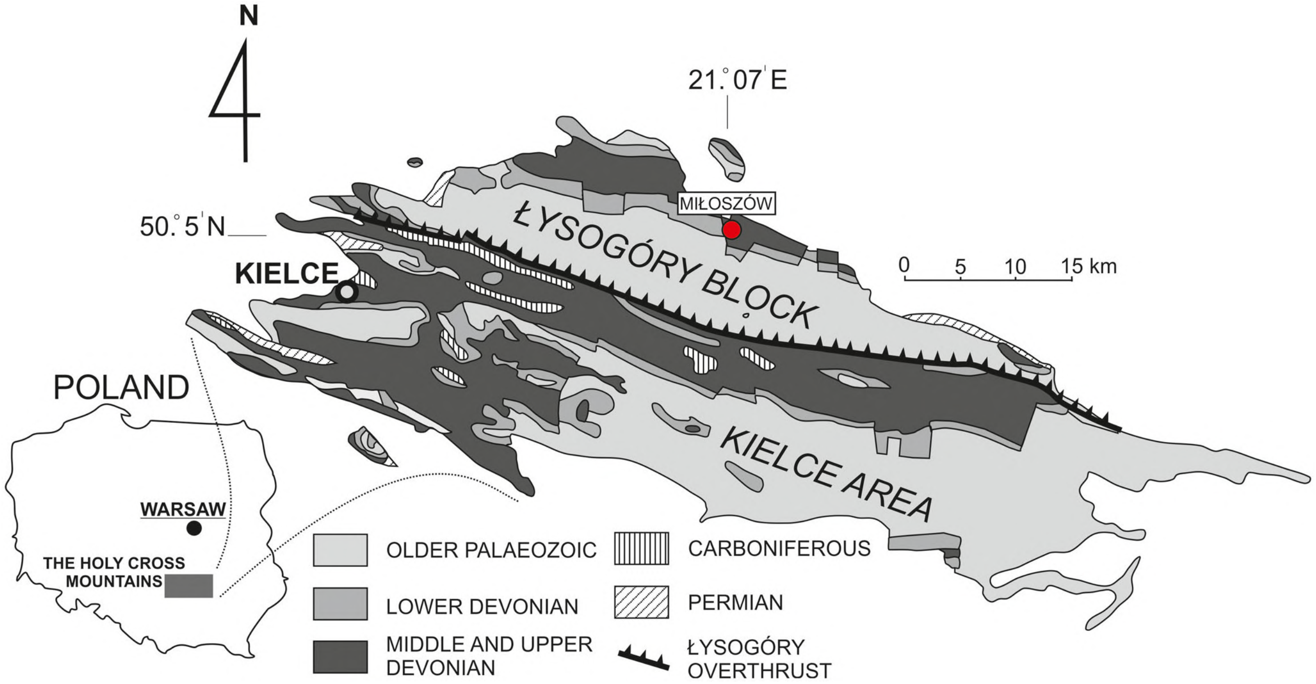

Figure 1. Simplified geological map of the Holy Cross Mountains showing the location of the Miłoszów site. Source: Author.

of chronostratigraphy, these zones indicate the early and middle Givetian (Figure 3).

3. Material and methods

Palynological samples were collected from two outcrops located in Miłoszów, Holy Cross Mountains, Poland (Figure 1). The first section, M0, provided 18 samples, six of which contained the new acritarch. Only three productive palynological samples were obtained from the second section, M2, and all of them contained *Teleostomata rackii* gen. et sp. nov. (Figure 2a and b). All samples were processed using a standard palynological procedure with a combination of hydrochloric and hydrofluoric acids (HCl-HF-HCl; Wood et al. 1996). The organic residue was sieved using 18-μm nylon mesh. Each of the samples contained recognisable palynomorphs: miospores, plant remains, and phytoplankton. Owing to the variable (good to poor) preservation, specimens were studied using both optical and environmental scanning electron microscopes (SEMs). Additionally, a well-preserved specimen from Tunisia that shows all taxonomically important features is illustrated (Plate 1, figure 12). Slides were prepared with Cellosize as the dispersal agent and Petropoxy 154 resin as the mounting agent. Palynological analyses were carried out using a transmitted light microscope with 40× and 60× lenses, and SEM investigations were carried out using an environmental SEM. England Finder coordinates (EFC) were used to mark the specimen localities on the palynological slides. All slides (collection M0 and M2) are housed at the Institute of Earth Sciences, University of Silesia in Katowice, Poland.

4. Systematic palaeontology

Group ACRITARCHA Evitt 1963

Subgroup ACANTHOMORPHITAE Downie et al. 1963

Genus *Teleostomata* gen. nov.

Etymology. The name is derived from two Greek words: *teleos*, which means *end*, and *stomata*, which means *pores*.

Holotype. Plate 1, figure 6, slide 10D, EFC: J13/3, sample 10D, section M0.

Synonymy. 2007 Unidentified acritarchs; Breuer, pl. 125, fig. 17.

Type locality. Skały Beds, Miłoszów outcrops, Miłoszów, Holy Cross Mountains, Poland.

Type stratigraphical range. Early and middle Givetian, Ex Miospore Zone of Avkhimovitch et al. (1993); Ex1 and Ex2 Subzones of Turnau (2007, 2008) = *hemiansatus*–middle *varcus* Conodont Zones.

Diagnosis. Single-layered vesicle. The overall shape is tetrahedral with almost straight sides. The most distinctive feature is the presence of broad processes arising from the common centre, one at each apex of the vesicle. Usually, the processes are sub-cylindrical/conical in shape and display a wrinkled flange that surrounds a pore-like distal opening-like structure.

Remarks and comparisons. *Teleostomata* gen. nov. has a similar overall morphology to that of *Estiastra*. However, the two genera can be readily distinguished based on the shape of the processes. *Teleostomata* gen. nov. has characteristic flanges that occur at the process tips (Figure 4). *Estiastra* processes are conical/phalloid in shape; distally, they may be acuminate with a nipple-like prominence or briefly bifurcate, but they are never blunt and have no flanges. The present specimens are also similar to *Tyligmasoma* Playford 1977 in

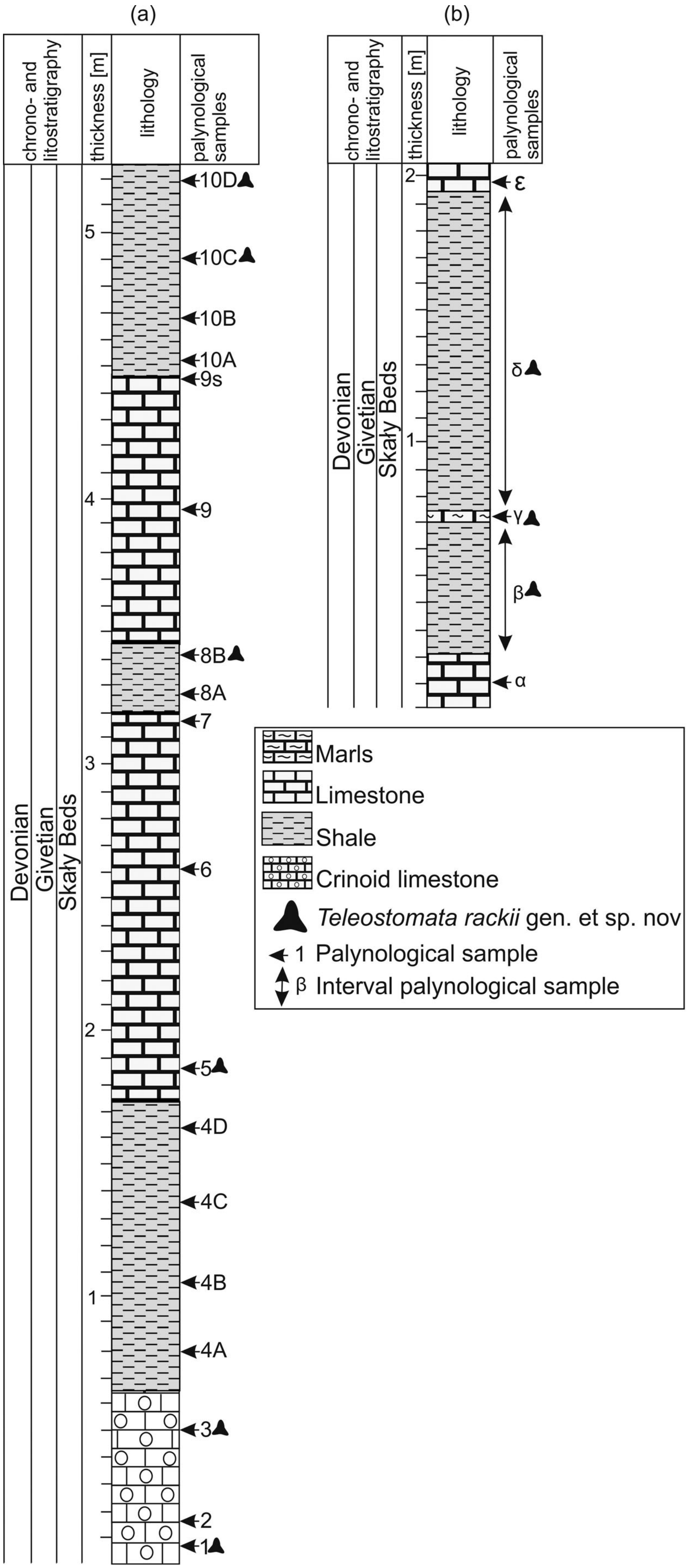

Figure 2. Lithological section of the Givetian deposits that outcrop in Miłoszów (based on the information obtained from A. Halamski and A. Pisarzowska). Sections M0 (a) and M2 (b) are marked, with the positions of samples that have yielded *Teleostomata rackii* gen. et sp. nov.

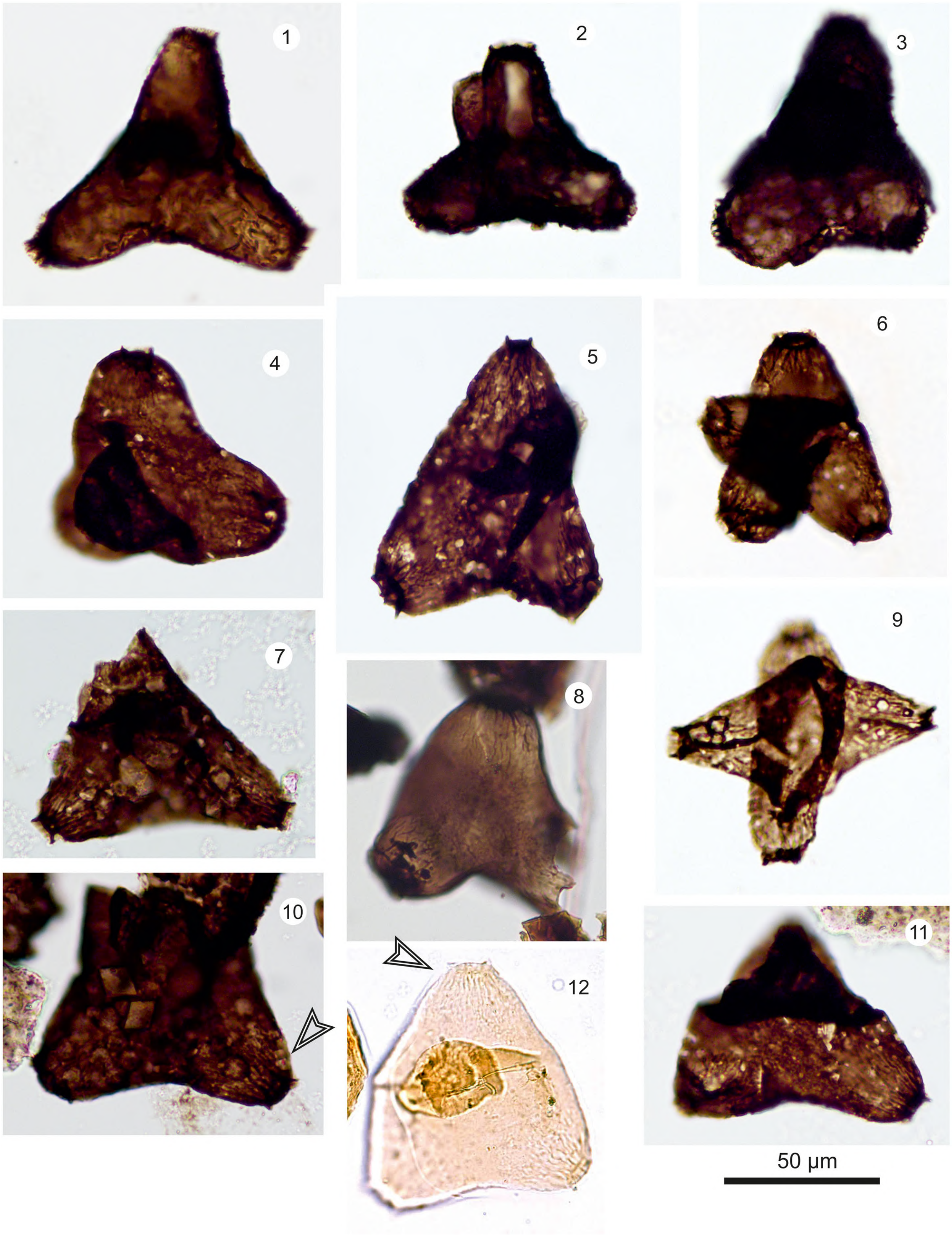

Plate 1. *Teleostomata rackii* gen. et sp. nov. Specimens 1–11 are from the Givetian of the Holy Cross Mountains (Poland), and specimen 12 is from the Eifelian of Tunisia. Arrows in 10 and 12 indicate the flange and wrinkled surfaces. The scale bar of 50 µm applies to all specimens. 1. Section M0, sample: 10D, EFC: F22/4. 2. Section M2, sample: γ, EFC:W29/4. 3. Section M2, sample: γ, EFC:Q16/1. 4. Section M0, sample:10C, EFC:H19/3. 5. Section M0, sample:10C, EFC:H31. 6. Section M0, sample:10D, EFC:J13/3. 7. Section M0, sample:10D, EFC:K42/2. 8. Section M2, sample: β, EFC:X39/3. 9. Section M0, sample:10C, EFC:C32/1. *Teleostomata* cf. *rackii*. 10. Section M0, sample:10D, EFC:E44/3. The arrow points to the wrinkled flange surface. 11. Section M0, sample:10D, EFC:K39/3. 12. Well: MG-1, depth: 2483 m, slide #: 62803, EFC: U41/2. The arrow points to the wrinkled flange surface.

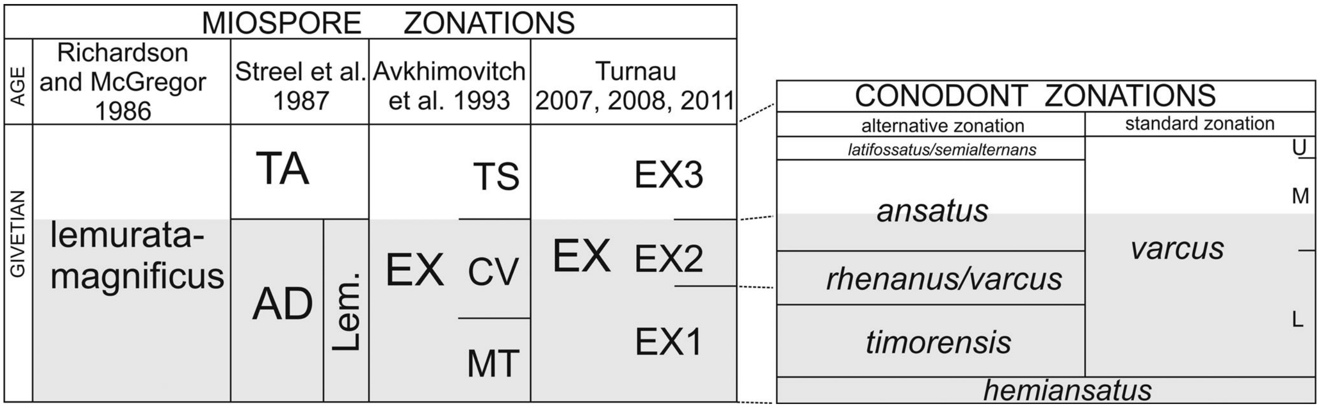

Figure 3. Miospore zonation combined with standard conodont zonation. The miospore zones recognised within the Miłoszów sections are marked in grey. L, Late; M, middle; E, Early (for conodont zonation). Dashed lines indicate the tentative correlation between miospore zones and conodont zones. Conodont zonation modified from Klapper (1988), Clausen et al. (1979), Narkiewicz and Bultynck (2010) and Narkiewicz et al. (2011).

shape and size. However, *Tyligmasoma* exhibits a two-layered vesicle. The outer layer is extended to form prominent, hollow, subcylindrical, or spine-shaped processes, clearly distinct from the rest of the vesicle. None of the specimens observed here have this kind of process, and it is unlikely that they were lost or damaged during maceration or as a result of taphonomic processes (for comparison see Brito 1967, pl. 2, figs 8 and 9; Cramer et al. 1976, pl. 5, figs 59 and 61; Playford 1977, pl. 19, figs 1–6; Wicander and Wright 1983, fig. 6.3; Moreau-Benoit 1984, pl. 3, fig. 3; Huysken et al. 1992, pl. 1, fig. 3; van der Meer and Wicander 2008, fig. 2Q; Zhu et al. 2008, pl. 4, fig. 2; Mendlowicz et al. 2009, pl. 3, fig. M; Grahn et al. 2010, fig. 12M; Troth et al. 2010, fig. 6G; Filipiak et al. 2012, fig. 7K; Wicander and Playford 2017, pl. 4, fig. 14). The seemingly similar genus *Triangulina* Cramer 1964 (see le Hérissé et al. 1997, pl. 1, fig. 8) also has a two-layered vesicle, but it too can be distinguished from *Teleostomata* gen. nov. *Schizocystia* Jardiné et al. 1972 has a similar morphology to *Teleostomata* gen. nov., but the key feature of *Schizocystia* is the division of the central vesicle along the straight line into two approximately equal halves. *Teleostomata* gen. nov. does not exhibit this kind of symmetry. *Onondagella* Cramer 1966 strongly resembles *Teleostomata* gen. nov., but it always has three processes (see Cramer et al. 1976, pl. 2, figs 17–19; Playford 1977, pl. 12, figs 13–16; pl. 13, figs 10, 11; Mendlowicz et al. 2009, pl. 3, fig. I), where two of them are tapering and the third is stout and has a circular opening. *Teleostomata* gen. nov. may be compared to *Pulvinosphaeridium* Eisenack 1954, emend. Sarjeant & Stancliffe 1994, but *Pulvinosphaeridium* has a different type of distal process termination with no pore-like opening structure. *Chalaziosphaeridium* Sarjeant & Stancliffe 1994 is highly similar to *Teleostomata* gen. nov., but it differs in its characteristic opening structure that is not present in *Teleostomata* gen. nov. For morphological details of *Teleostomata* gen. nov., see Figure 4.

Type species. *Teleostomata rackii* sp. nov. Plate 1, figures 1–12, Plate 2, figures 1–8

Teleostomata rackii sp. nov.

Plate 1, figures 1–11; Plate 2, figures 1–8

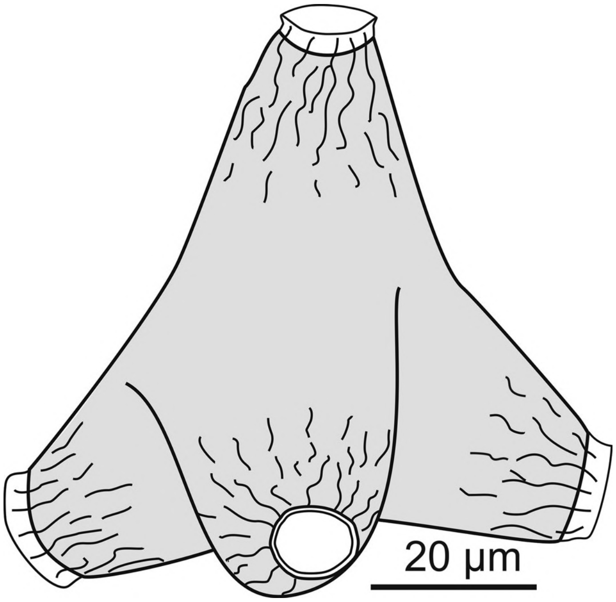

Figure 4. Diagrammatic representation of *Teleostomata rackii* gen. et sp. nov. showing morphological characters.

The type locality and stratigraphical range are the same for the genus and species.

Holotype. Plate 1, figure 6, slide 10D, EFC: J13/3, sample 10D, section M0.

Diagnosis. Hollow vesicle of tetrahedral shape and almost straight sides. The vesicle wall thickness is approximately 1 µm. Four processes arise in two perpendicular planes. Usually, the processes are sub-cylindrical or conical in shape with blunted tips possessing a wrinkled flange (3–5 µm height) that surrounds a distal pore-like structure (8–15 µm in diameter). The angle between two adjacent processes varies from 120° to 220°. The processes exhibit smooth/scabrate/psilate surfaces and randomly occurring compression folds.

Measurements. (15 specimens). The length from the centre of the vesicle to the top of the process is 35–55 µm (mean 45). The width of the processes at the base is 20–35 µm (mean 27).

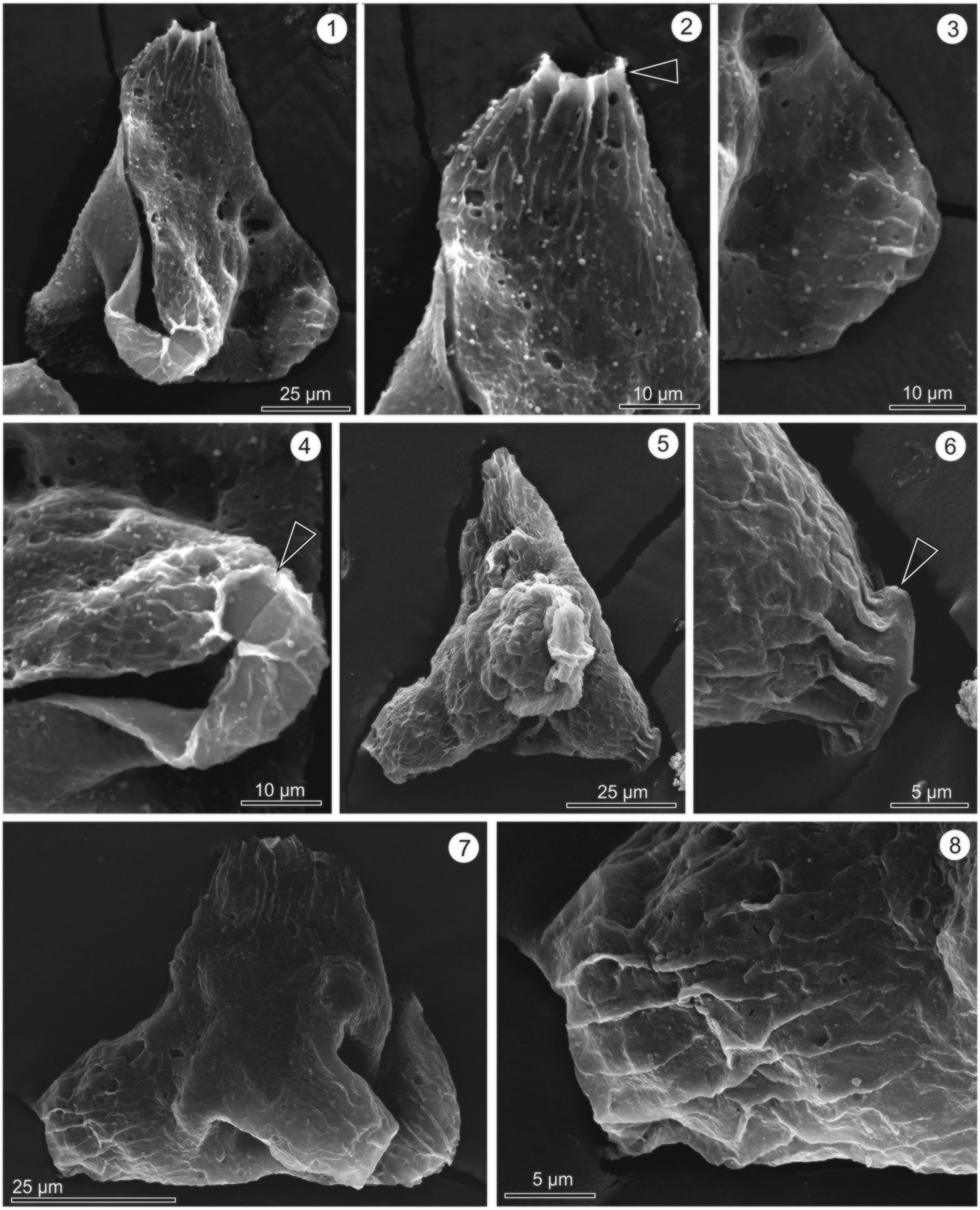

Plate 2. Scanning electron microscope documentation of *Teleostomata rackii* gen. et sp. nov. 1–8. *Teleostomata rackii* gen. et sp. nov., section M0, sample 10C. 2–4. Magnified parts of 1. Arrows on 2 and 4 indicate the flange and wrinkled surfaces. 6. Magnified part of 5. Arrow points to well-preserved flange. 8. Magnified part of 7 with wrinkled surface.

Etymology. This new species is named in honour of Professor Grzegorz Racki for his important contributions to the study of the Devonian of the Holy Cross Mountains.

Previous records. *Teleostomata rackii* sp. nov. has only been reported previously as an unidentified acritarch from the upper Eifelian of Tunisia (Breuer 2007), where it occurs in the

Awaynat Wanin I Formation. This acritarch occurs in strata correlated to the lower part of the *Grandispora incognita* Miospore Subzone of Breuer and Steemans (2013), which is broadly coeval to the *Rhabdosporites langii* Miospore Zone of Avkhimovitch et al. (1993).

5. Conclusions

A previously undescribed acritarch is described as the new genus and species *Teleostomata rackii*. The geographical distribution of this species encompasses the northern part of the Holy Cross Mountains and the palaeocontinent of Gondwana (Tunisia). To date, stratigraphically, this taxon has only been recognised from the Givetian (Ex Miospore Zone in Poland), but taking the Gondwana occurrence into account, its global stratigraphical range should be extended down to the Eifelian.

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No potential conflict of interest was reported by the authors.

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Statement of the co-author of the work included in the doctoral dissertation

here I state that in the publication entitled „**Teleostomata rackii gen. et sp. nov.: an acritarch from the Devonian (Givetian) of south-central Poland**", published in 2022 in *Palynology,* the contribution of first author Marcelina Kondas is **70 %.**

The PhD student Marcelina Kondas contributed by collecting the rock samples, carrying out the palynological analyses (including maceration processes), describing the idea of the new taxon, preparing the figures, plates and the main part of the manuscript.

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