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Preliminary results of thermal alteration investigations of the Cambrian acritarchs in the Holy Cross Mts.

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Analyses comparing thermal alteration degree between main tectonic units of the Holy Cross Mts. were performed. Results indicate a distinctive heating increase of the Cambrian organic matter from the south to the north. The Lower Cambrian acritarch assemblages from the Dyminy–Klimontów Anticlinorium indicate the temperatures not exceeding 80°C. The maximum temperature influencing the Cambrian deposits of the Kielce–Łagów Synclinorium varies from less than 80°C to significantly exceeding 100°C. In the Łysogóry area a significant thermal alteration of the Cambrian acritarchs suggests that the maximum temperature significantly exceeded 100°C, locally even 300°C.

INDRODUCTION

A high degree of colour alteration is observed in the Cambrian acritarchs in the Holy Cross Mts. The specimens vary from transparent, yellow, orange, various tints of brown to entirely black. The colour differentiation results from thermal alteration of the Cambrian organic matter in the geological history. Organic matter darkens when it is relatively enriched in carbon in consequence of thermal energy influx. This process was experimentally proved, it commonly occurs, is irreversible and the carbonification degree is directly dependent on the maximum temperature reached by palynomorph bearing deposits. In consequence, acritarch wall colour observations may be used to estimate the maximum temperature which influenced organic matter, and thereby the surrounding rock. The temperatures corresponding with particular phases of thermal alteration were estimated experimentally and served to elaborate the Thermal Alteration Index (TAI), calibrated in degrees centigrade (AMOCO, 1992 — unpublished materials). The scale was prepared mainly for the usage petroleum industry where it serves to estimate the possibilities of hydrocarbon generation and to find preferable migration paths. The palaeothermal investigations of organic matter may be also useful, for example, for structural, tectonic and palaeothickness reconstructions or for detecting an intensive heat flow zones.

The Thermal Alteration Index is a subjective scale and bases on comparison of palynomorphs found with a standard. This way of colour estimation is not very precise and may lead to mistakes, especially because the published scale is restricted to a certain number of morphological types of palynomorphs which are not always present in the investigated sample. Specimens of acritarch assemblages occurring in the some sample or even fragments of specimens may differ from each other in colour. This is caused by many factors. The thickness of walls and processes is very important. When it gets thicker the colour observed in transmitted light darkens. Relief of wall surface, tucks, overlaps of wall layers cause a distinctive darkening of the observed specimen. The quality and thickness of palynological slide, transparence of resin and finally the quality and intensity of microscopical light play also an important role. In addition, some differences in acritarch colour may be caused by maceration techniques — strong oxidizer make specimen significantly brighter what restricts the palaeothermal observations. The quality of the TAI standard and own specimen copies are important when photographs are compared.

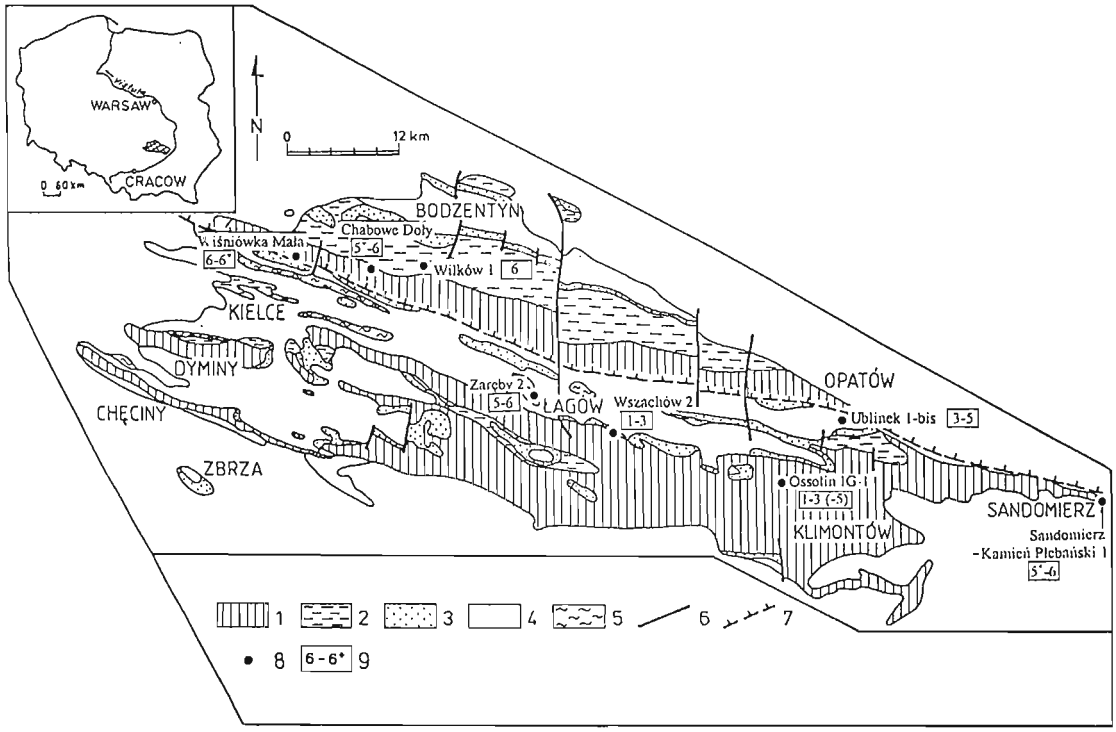

Fig. 1. Locality map and sketch of the Palaeozoic geology of the Holy Cross Mts.

1 — Cambrian; 2 — Ordovician and Silurian; 3 — Lower Devonian; 4 — Middle and Upper Devonian; 5 — Carboniferous; 6 — main faults; 7 — Main Holy Cross Fault; 8 — investigated boreholes and outcrops; 9 — Thermal Alteration Index

Lokalizacja badań na tle szkicu budowy geologicznej paleozoiku Gór Świętokrzyskich

1 — kambr; 2 — ordowik; 3 — dewon dolny; 4 — dewon środkowy i górny; 5 — karbon; 6 — główne uskoki; 7 — główny uskok świętokrzyski; 8 — badane otwory wiertnicze i odsłonięcia; 9 — stopień przeobrażeń termicznych (TAI)

Lately, palaeothermal investigations of colour alteration of organic remains gain in importance, because they are the most simple and cheapest methods of estimation of the maximum temperature which influenced the deposit. Such research are mainly performed on conodonts (CAI) and palynomorphs (TAI). Contrary to conodont fauna, the palynomorphs occur commonly in various facies, they are not restricted by time — they may be found in deposits representing various geological periods. In the Cambrian deposits only acritarchs may be used to estimate the degree of thermal alteration. Conodonts are not suitable there, bacause of their specific internal structure (K. Narkiewicz, M. Nehring-Lefeld, 1993).

The TAI scale after modification by the AMOCO (1992 — unpublished material) is precise in the temperatures varying from < 50 to 90°C. Above this range the scale is more generalized and temperatures may be estimated less accurately.

HISTORY OF RESEARCH

M. Moczydłowska (1988) was the first in Poland to perform palaeothermal investigations based on acritarch colour alteration. She focused on the Vendian and Lower Cambrian microflora assemblage from the Lublin Slope of the East European Platform. Her results univocally indicated that colour of acritarch darkens together with the increasing depth of burial (increasing temperature). She also showed that Vendian acritarchs are disproportionately high thermally alterated in comparison to their depth of burial. It proves that heat flow was higher during the Vendian than Cambrian. M. Moczydłowska's general conclusions are still up-to-date, though her paper was published when the different TAI scale was being used. Results of palaeothermal observations of the Cambrian (mainly from the Lublin area) this author recapitulated later (M. Moczydłowska, 1989). Other papers dealing with palynological problems (mainly stratigraphical) often contain some casual informations on specimen colours, however, they rarely have any essential remarks (M. Moczydłowska, G. Vidal, 1986; W. Brochwicz-Lewiński *et al.*, 1986; Z. Kowalczewski *et al.*, 1986; Z. Szczepanik, 1988, 1996).

Composite palaeothermal investigations of acritarch colour alteration in the Holy Cross Mts. have not been carried out yet. Z. Bełka (1990) presented preliminary results of his research on thermal alteration of the Palaeozoic and Triassic conodonts in this area.

METHODS

Samples collected during the last few years were used in this palaeothermal studies of the Cambrian organic matter. Process of sample preparation was similar in every case and included all phases of standard palynological maceration, i.e. crushing, etching in strong acid, including the nitric acid and floatation. The nitric acid may cause some trouble to obtain real picture of thermal alteration. In this case the weaker 65% nitric acid was used and the whole piece of rock was treated, not the enriched sample. A series of controlling macerations were performed to examine the acid influence on the obtained results. Samples were divided into two parts. First group was treated with acid and second was not. Later, acritarchs recovered from these two groups of samples were compared. No distinct differences of their wall colour were noticed. However, controlling analyses were not performed from the entire material and it was possible that some samples might be secondary lightened.

To standardize all observations the previously obtained results of colour analyses based on photographs were ignored and were done once again in microscope, where no filters were used, light had the same intensity, diaphragm and condenser position were the same. To restrict influence of the background colour and to eliminate colour changes caused by photographical techniques the author decided to transmit directly the microscopical picture to the computer using the video camera. Through this method the background colour could be unified and simultaneous observation of many specimens on the screen was possible. It served to minimize an effect of subjective colour estimation and to establish the range of colour variability of specimens representing one taxon and occurring in one slide.

The analysed Cambrian deposits of the Holy Cross Mts. vary in age from the Lower Cambrian *Holmia* Superzone to the boundary between Upper Cambrian and Tremadoc. In such a long period the acritarch microflora was changing very rapidly and the analysed assemblages were often not comparable taxonomically. Common taxa with longlasting stratigraphical range (*Leiosphaeridia*) are characterized by a high variability of wall thickness and therefore they are not very useful for palaeothermal observations. Comparison of specimens representing various genera was necessary, however, only specimens with similar wall thickness, preferably with a delicate periphragm and distinctive processes were chosen for analyses.

Samples were taken from selected boreholes and outcrops from the entire area of the Holy Cross Mts. From the Dyminy–Klimontów Anticlinorium area the Lower Cambrian (*Holmia* Superzone) deposits were investigated in the Wszachów 2 and Ossolin IG 1 boreholes. From the basement of the Kielce–Łagów Synclinorium samples were taken from the Zaręby 2 (*Protolenus* Zone) and Ublinek 1-bis (Cambrian/Tremadoc boundary) boreholes. The Sandomierz–Kamień Plebański 1 (Middle–?Upper Cambrian) borehole was analysed in the Góry Pieprzowe Mountains (Pepper Mountains) area and in the Łysogóry Unit: Wilków 1 borehole, outcrop in Chabowe Doły (upper part of the Upper Cambrian) and outcrop in Wiśniówka Mała (no possibilities of precise dating) (Fig. 1).

Generally, most of the specimens recovered show a high degree of colour diversity. None of the sample can be precisely related to a particular degree in the TAI scale, but always represent a certain range including a few stages of thermal alteration. This feature is significant in samples coming from the Dyminy–Klimontów Anticlinorium area, where the investigated acritarchs vary from light yellow to brownish in colour (stages 1 to 5). However, it is not surprising, because this range of colours falls within 50 to 80°C temperature interval.

RESULTS FROM THE PARTICULAR AREAS

DYMINY–KLIMONTÓW ANTICLINORIUM

Ossolin IG 1 borehole. The acritarch assemblage recognized in the Cambrian shales is dominated by specimens of the genera: *Leiosphaeridia*, *Asteridium*, *Heliosphaeridium* and *Skiagia*. This is a typical Lower Cambrian acritarch assemblage. Single specimens of *Globosphaeridium cerinum* (Volkova) Moczydłowska (Pl. I, Fig. 1) indicate here the *Heliosphaeridium–Skiagia* Acritarch Zone (M. Moczydłowska, 1991), correlated with the upper part of the *Holmia* Superzone. The specimens are relatively well preserved but not very frequent. Most of acritarchs are light yellow and sometimes brownish in colour what corresponds with the 1 to 3 stages of the AMOCO 1992 TAI scale related to the lower part of the 50 to 80°C temperature interval (Pl. I, Figs. 1, 2). Single acritarchs slightly darker in colour were also noticed here.

Wszachów 2 borehole. This section was selected because of its lamprophyre intrusion occurring at the top of the Cambrian section. It gave an opportunity to analyse how the palynomorph colour changes as the distance from the intru-

sion increases and to establish how far is the extent its thermal influence on the surrounding rocks.

The Cambrian is represented here by shales and silty shales with rare sandy intercalations. Acritarchs are relatively abundant and are dominated by the genera: *Leiosphaeridia*, *Lophosphaeridium*, *Asteridium*, *Heliosphaeridium* and *Skiagia*. Cooccurrence of *Skiagia ciliosa* (Volkova), *Lophosphaeridium tentativum* Volkova and *L. dubium* (Volkova) suggests that the acritarch assemblage corresponds with the *Heliosphaeridium–Skiagia* Zone (M. Moczydłowska, 1991), related to the upper part of the *Holmia* Superzone. In spite of numerous specimens their state of preservation is rather poor — processes are often broken into fragments, walls — damaged by mechanical erosion and crystallization of pyrite. Acritarchs are light in colour — from yellow to orange. The brightest (transparent to light yellow) specimens are represented by the genus *Asteridium*. Representatives of the thick-walled genus *Alumiella* are the darkest. Only some limited conclusions on the intrusion influence could be made. The Cambrian deposits occurring directly below the intrusion do not contain any acritarchs. It is hard to explain this feature. Maybe intensive thermal modification on the intrusion contact lead to total degradation of organic matter composing the palynomorph integument or the fault zone used by intruding lava is responsible for it. Down the section, further away from the intrusion acritarchs become abundant. The orange to brownish specimens (Pl. I, Fig. 5) pass through yellow to frequent, light yellow ones. The colour alteration indicate that thermal influence of the intrusion on the surrounding rocks took place, however, in case of the Wszachów 2 borehole (strong tectonics, deviated drilling) it is hard to estimate precisely its extent. Certainly this influence did not exceed a few metres. The zone of intensive thermal alteration is 2–3 m thick. Slightly further than 3 m the acritarch colours indicate 80°C at most (3 to 5 stage in the AMOCO TAI scale). 4 to 6 m from the intrusion the colours represent 1 to 3 stages and correspond with the lower part of the 50 to 80°C temperature interval (Pl. I, Figs. 3, 4). These lower temperatures seem to be typical for the thermal background of the Dyminy–Klimontów Anticlinorium area.

KIELCE–ŁAGÓW SYNCLINORIUM

Ublinek 1-bis borehole. Shales, occurring at the boundary between Cambrian and Tremadoc, were drilled here. They contain a rich and perfectly preserved acritarch assemblage represented by the genera: *Acanthodiacrodium*, *Cymatiogalea*, *Stelliferidium*, *Veryhachium*, *Polygonium*, *Vulcanisphaera* and others. The acritarch assemblage composition is very similar to the Upper Cambrian–Lower Tremadoc assemblages of the East European Platform (N. A. Volkova, 1990). The occurrence of *Calyxiella izohoriensis* Golub et Volkova indicate the WK4B Zone (N. A. Volkova, 1990) and *Corollasphaeridium* cf. *vilcoxianum* Martin is typical for the American AU2 Zone (F. Martin, 1992) — both occurring at the Cambrian/Tremadoc boundary. Specimens are light yellow to orange in colour and indicate that the maximum temperature which influenced deposits did not exceed 80°C (AMOCO 3–5 TAI stages) (Pl. I, Figs. 6–9). Thus, these temperatures are very close to those which influenced the Lower Cambrian organic matter in the Dyminy–Klimontów Anticlinorium area.

Zaręby 2 borehole. The Lower Cambrian silty-sandy deposits, unusually poor in acritarch microflora occur at the base of this section. Among a dozen or so analysed samples only three contain poor assemblages of palynomorphs. A few specimens of *Volkovia dentifera* (Volkova) Downie (Pl. I, Fig. 11) were recognized. This is a typical acritarch for the *Volkovia–Liepaina* Zone (M. Moczydłowska, 1991) — equivalent of the Lower Cambrian *Protolenus* Zone. This dating is consistent with stratigraphy of the Zaręby 2 borehole section based on trilobites (W. Bednarczyk *et al.*, 1965). Because of a little diversity of fauna and occurrence of thin-walled specimens only the thermal interpretation is very hard here. Very thin organic integuments do not react on the temperature in such a way as more massive morphological features of acritarchs. Darkening dependent on the temperature increase is not easy to notice in such cases and rather a process of decolourization of the integument is observed here. Brown patches occurring in places where integument tucks or gets thicker are the only traces of thermal alteration. This feature would not be easy to observe in an ordinary microscope. Computer techniques which permitted a significant enlargement of specimens were helpful here. The standard TAI scale do not deals with such types of organic remains, therefore its univocal comparison with investigated material is very hard. Taking into account that the genus *Leiosphaeridia* is represented here by brown specimens, it is possible to say, with certain approximation, that thermal alterations of acritarchs correspond with the 5–6 stages, therefore the temperature of an order of 100°C. This is a rather significant increase in comparison to the deposits from Ublinek or the Dyminy–Klimontów Anticlinorium. Maybe it is related with the Upper Palaeozoic cover, 1000 m thick, developed above the Cambrian deposits in Zaręby.

The Góry Pieprzowe Mountains. The Sandomierz–Kamień Plebański 1 borehole reached intensively tectonised, black shales containing the first Cambrian acritarchs found in the Góry Pieprzowe Mts. However, their assemblage is poor, damaged and stratigraphically problematic. Typical taxa for the lower part of the Middle Cambrian and single Upper Cambrian specimens occur here. Strong tectonic disturbances are probably responsible for mixing of the older deposits with rock fragments containing Upper Cambrian acritarchs. Irrespective of stratigraphical problems the thermal state of acritarch preservation is considerably different than in the Cambrian deposits of the southern part of the Holy Cross Mts. The preserved acritarch specimens are dark, intensively brown in colour (Pl. I, Figs. 12–14) and correspond with the AMOCO 5+ to 6 TAI stages (temperatures from 100 to 200°C). Thus, the results are identical with those of the Cambrian deposits of the Łysogóry area.

ŁYSOGÓRY AREA

Wilków 1 borehole. The Upper Cambrian shales, drilled at the base of the Wilków 1 borehole, contain abundant and well preserved Cambrian acritarch assemblage. It is dominated by specimens representing the diacriodal symmetry (*Acanthodiacrodium*, *Dasydiacrodium*) and also the genera *Polygonium* and *Cymatiogalea* proving the uppermost Cambrian age of the rock. The occurrence of *Goniosphaeridium uncinatum* (Downie) Kjellstrom and *Vulcanisphaera africana* Deunff indicate here the WK4B–WK5 Zones (N. A. Volkova, 1990). Therefore, based on acritarchs, the age of deposits is determined here on the upper part of the *Peltura* or *Acerocare* standard Scandinavian Trilobite Zone. It is more or less consistent with trilobite dating (E. Tomczykowa, 1968). Acritarchs recognized here are generally dark, sometimes very dark in colour. A high degree of colour variability results from very rich spectrum of specimens found here and their variable wall thickness (Pl. I, Figs. 19, 20). However, most likely, the TAI is 6, corresponding with the temperatures varying from 200 to 300°C.

Chabowe Doły. Very rich in specimens and various taxa acritarch assemblage was recognized in the Cambrian shales of the Chabowe Doły outcrop. Its composition, stratigraphical position and thermal alteration degree is very similar to the assemblage from Wilków. Because of numerous palynomorphs it seems to be that there are more light brown than black specimens, but in fact this is a subjective impression. Without doubt deposits reached here the AMOCO 5+ to 6 TAI stages, therefore the temperatures significantly exceeded 150°C.

Wiśniówka Mała. This outcrop was chosen, because of the highest degree of acritarch thermal alteration. The assemblage is poor and damaged by high temperatures. Specimens are dark brown to black in colour (Pl. I, Figs. 21, 22). Some specimens only partly resemble an acritarch and elsewhere the specimens do not differ from amorphous kerogen. Precise determination of acritarchs is precluded by poor stage of their preservation. Most of them resemble the genus *Timofeeva*, common in other quarries in Wiśniówka. Therefore they may represent, like in other sites in this area, the SK2–WK1 Zones of the East European Platform. (N. A. Volkova, 1990) or the lower part of the A2 Zone of Newfoundland (F. Martin, W. T. Dean, 1981, 1988) — the upper part of the Middle and the lower part of the Upper Cambrian. The single specimen of *Raphesphaera* sp. found in the Podwiśniówka quarry, evidences a possibility of the WK1 Zone occurrence. The TAI is 6 to 6+ here, thus the temperature exceeded 300°C.

CONCLUSIONS

The results clearly show that the maximum temperatures increase northwards. The Dyminy–Klimontów Anticlinorium area is characterized by the temperatures varying from 50 to 80°C, in the Łysogóry area they are much higher and reach 100 to 300°C and more. The Kielce–Łagów Synclinorium Cambrian basement is characterized by transitional TAI values corresponding with the temperatures varying from 50 to 100°C. However, the data from the Kielce–Łagów Synclinorium are restricted to two Cambrian deposit occurrences only — in Zaręby and Ublinek. It is hard to draw conclusions from such a poor material, however, it is striking that the TAI values are so different in the both boreholes. It may suggest a high degree of tectonical differentiation of the poorly known Lower Palaeozoic basement of the Kielce–Łagów Synclinorium.

Variable heating of the Cambrian rocks in the particular structures of the Holy Cross Mts. is regional and probably caused by tectonics. Significant is the conclusion that the Cambrian sequence of the Góry Pieprzowe Mts. in its palaeothermal pattern, is more similar to the Łysogóry than to the Kielce Unit. Consequently, the extension of the Holy Cross Fault could be presumed to the south of the River Vistula escarpment in Sandomierz. Maybe it is caused by occurrence of a major transversal strike-slip, running between Opatów and Sandomierz, analogous to the Rudki Fault.

In the geological literature thermal alteration of rocks is often concerned as burial temperature — function of the cover thickness and geothermal gradient. Assuming that the geothermal gradient was similar (2.0 to 2.5°C/100 m, typical for the East European Platform — J. Majorowicz, 1982) in both main tectonic units of the Holy Cross Mts., significant differences between the interpreted maximum temperatures (exceeding 150°C) would not be easy to explain. The difference in the thickness of the cover above the Cambrian sequence should reach 6000 m then, what seems to be unlikely. It is interesting that the southern region which underwent diastrophic processes three times in the Palaeozoic (Sandomierz phase, late Caledonian and Variscan) show very weak thermal alteration values. On the contrary, in the Łysogóry area, which — according to some authors — represents platform tectogenesis, the values are very high.

Low TAI values in the Cambrian of the Dyminy–Klimontów Anticlinorium speak for the assumption of a geoanticlinal character of this area which, from the Cambrian to Carboniferous, revealed a constant tendency to be elevated. It caused the thickness reduction of the Palaeozoic cover. Therefore, though this area underwent many times diastrophic processes it was not connected with a high geothermal gradient. It seems that position within an orogen plays the most important role in thermal alteration intensity. Some zones are especially predisposed for intensification of the heat flow and some not, though they are significantly tectonically deformed.

In the light of these results the point that the northern part of the Holy Cross Mts. has a platform structure cannot be maintained. Comparison with palaeothermal investigations on the Cambrian of the Lublin Slope of the East European

Platform (M. Moczydłowska, 1988), univocally indicates that the significantly higher degree of thermal alteration is in the Łysogóry Unit. Assuming the same geothermal gradient as in the platform areas the cover, for example in Wiśniówka Mała had to be 10 000 m thick and in Wilków more than 7000 m thick. A relatively high variability in the TAI values, noticed in the geographically close Łysogóry Cambrian sections is also significant and hard to explain assuming the platform structural development. The Łysogóry Unit seems to lie within a marked, high heat flow zone connected with a tectonically predisposed area (for example deep faults in the basement or deep folding and the like).

Results of palaeothermal investigation could be more useful if significantly more samples would be analysed. Thermal alteration should be recognized within particular stratigraphical sequences with special emphasis put on the boundaries structural stages. Evaluation of the influence of folds, faults as well as within various tectonic structures and volcanic intrusions on thermal alteration is also important. Such research would help to better understanding of the geological history of the Holy Cross Mts., especially if studies on diagenetic transformations of clay minerals could be additionally performed. In the younger deposits the TAI results could be confirmed by vitrinite reflectance measurements. To explain the problems with the correlation between the TAI and CAI results which have been mentioned by Z. Bełka (1993), a comparable study of these two indices in the Holy Cross Mts. seems to be important.

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WSTĘPNE WYNIKI BADAŃ NAD ZMIANAMI TERMICZNYMI KAMBRYJSKICH AKRYTARCHÓW W GÓRACH ŚWIĘTOKRZYSKICH

Streszczenie

Proces geologiczny wzbogacania w węgiel powłok organicznych akrytarchów, zachodzący w skałach wskutek ich przeobrażeń termicznych i manifestujący się zmianami kolorystycznymi (ciemnieniem), jest powszechny i nieodwracalny. Udokumentowano go także doświadczalnie. Obserwacje

i analiza zmienności barw materii organicznej stanowi stosunkowo prosty i tani sposób wyznaczania maksymalnej temperatury, jaka oddziaływała na skałę w jej historii geologicznej. Uzyskane tą drogą informacje dostarczają nowych danych dla rekonstrukcji paleomiąższościowych i tektonicznych. Metoda ta jest szczególnie przydatna w geologii naftowej, gdzie służy do określania możliwości generowania złóż węglowodorów i wskazywania potencjalnych kierunków ich migracji.

Analizę taką przeprowadza się poprzez porównanie barw znalezionych okazów z cechowanymi wzorcami (skala TAI). Ten sposób prowadzenia badań oparty jest w dużej mierze na subiektywnej ocenie barwy, co niesie ze sobą ryzyko pewnych niejednoznaczności w określaniu stopnia zmian termicznych. Biorąc także pod uwagę fakt, że zespoły mikroflory rozpoznawane w preparatach palinologicznych cechują się często zróżnicowaniem kolorystycznym i reprezentują raczej spektrum zmian, niż precyzyjnie dające się ulokować na skali przemian termicznych ich stadium, oraz fakt, że technika obserwacji mikroskopowej i porównań z kopiami wzorca niesie za sobą niebezpieczeństwo zaburzeń stabilności warunków prowadzonych badań, wyniki te należy traktować z pewną ostrożnością. Niemniej jednak, przy analizie materiału z dużej ilości próbek, można zauważyć ewidentne różnice stopnia zmian termicznych poszczególnych zespołów akrytarchowych i wychwycić prawidłowości rysujące się w przestrzennym obrazie paleotermiki badanego obszaru.

W przeprowadzonych badaniach obserwowano stopień zmian termicznych kambryjskich akrytarchów w głównych jednostkach tektonicznych Gór Świętokrzyskich: antyklinorium dymińsko-klimontowskim, synklinorium kielecko-łagowskim i skibie łysogórskiej. Akrytarchy z antyklinorium kielecko-łagowskiego (z otworów wiertniczych Ossolin IG 1 i Wszachów 2) charakteryzują się stosunkowo niskim stopniem przeobrażeń termicznych. Są to formy jasne, często bardzo jasne, których barwa sugeruje, że maksymalne temperatury jakie oddziaływały na skałę nie przekraczały 80°C. W otworze Wszachów 2 analizowano zasięg oddziaływania termicznego występującej tam intruzji lamprofirowej na otaczające skały. Stwierdzono, że wpływ ten ogranicza się jedynie do skał odległych nie dalej niż 2–3 m od intruzji.

W synklinorium kielecko-łagowskim można zaobserwować znaczne różnice stopnia uwęglenia materii organicznej między skałami z poszczególnych badanych otworów wiertniczych. Maksymalne temperatury jakie oddziaływały na kambryjską materię organiczną wahają się od niespełna 80°C, na jaką wskazują barwy akrytarchów z wiercenia Ublinek 1-bis, poprzez zbliżone do 100°C w kambrze otworu Zaręby 2, do znacznie przekraczających tę wartość w Górach Pieprzowych (otwór Sandomierz–Kamień Plebański 1).

W osadach kambru regionu łysogórskiego ciemne, często prawie czarne barwy akrytarchów wskazują na temperatury 150–200°C. Stwierdzono to w otworze Wilków 1 i odsłonięciach w Chabowych Dołach. Bardzo wysoki stopień degradacji termicznej mikroflory z kamieniołomu Wiśniówka Mała przemawia za ogrzaniem sięgającym, a być może, przekraczającym 300°C.

W obrazie regionalnym zmian termicznych wyraźnie widoczna jest tendencja do wzrostu maksymalnych temperatur oddziaływujących na kambryjską materię organiczną z południa ku północy. Szczególnie istotne różnice występują między południową częścią Gór Świętokrzyskich (antyklinorium dymińsko-klimontowskim) a regionem łysogórskim. Obszar synklinorium kielecko-łagowskiego zdaje się zajmować pozycję przejściową, przy czym charakteryzuje się znacznym zróżnicowaniem wewnętrznym. Stopień ogrzania kambryjskiej materii organicznej Gór Pieprzowych wskazuje na paleotemperatury typowo łysogórskie, co może sugerować inną niż przyjmowana pozycję tektoniczną tego obszaru.

Na obecnym etapie badań trudno jednoznacznie powiązać przestrzenny rozkład intensywności zmian termicznych skał kambru z konkretnymi przyczynami. Mało prawdopodobne wydaje się być tłumaczenie tak znacznego zróżnicowania tylko miąższościami serii okrywających. Wydaje się, że decydującą przyczyną mogą być tutaj znacząco inne wartości natężenia strumienia cieplnego w obu głównych jednostkach tektonicznych Gór Świetokrzyskich.

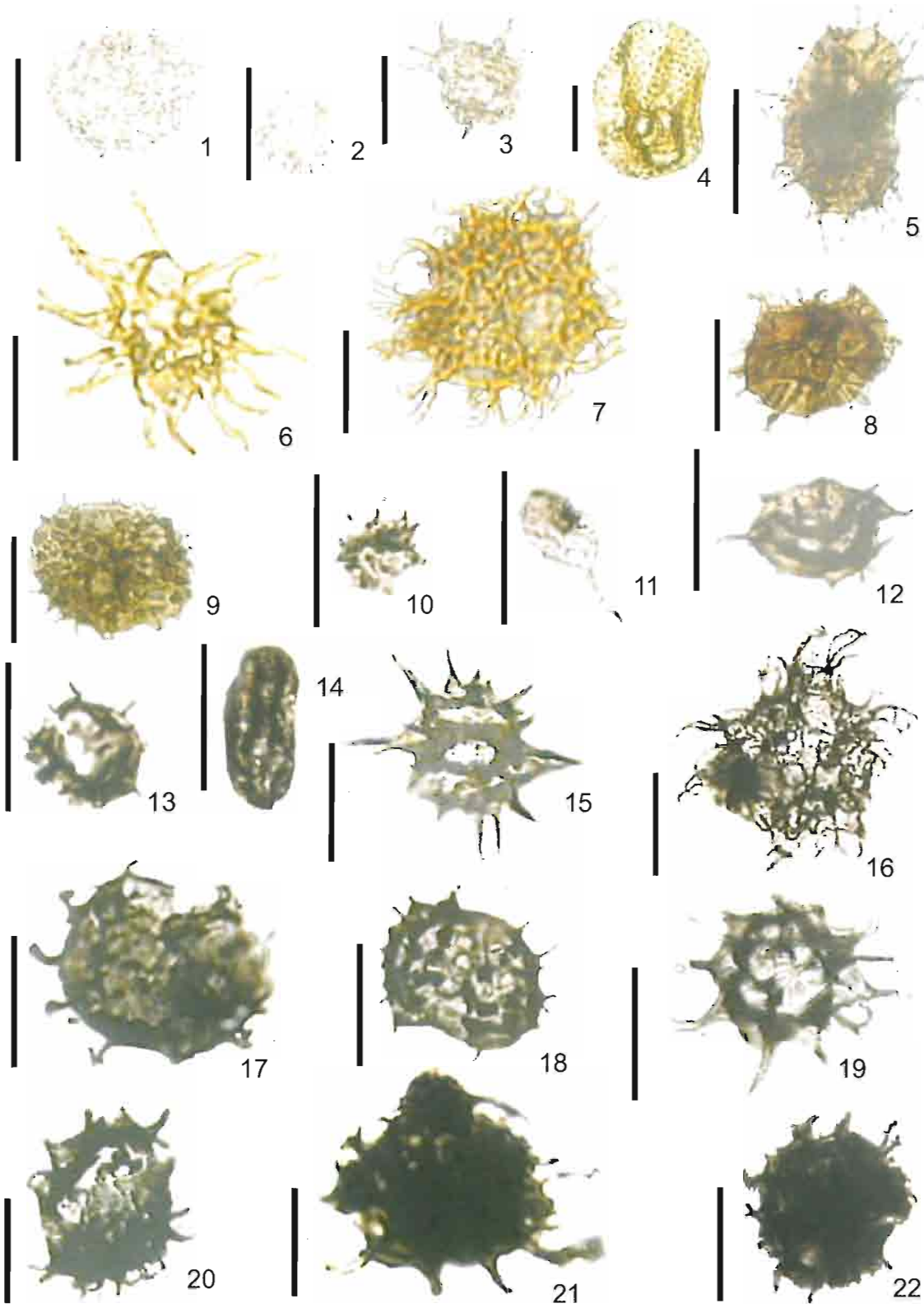
Zastanawia, że w obszarze południowym, który w paleozoiku trzykrotnie był dotknięty procesami górotwórczymi (sandomierskimi, młodokaledońskimi i waryscyjskimi), stopień zmian termicznych kambru jest niski, podczas gdy w obszarze łysogórskim, któremu część badaczy przypisuje genezę platformową, odwrotnie — jest bardzo wysoki.

EXPLANATIONS OF PLATE

PLATE I

Fig. 1. *Globosphaeridium cerinum* (Volkova) Moczydłowska
Ossolin IG 1 borehole
Fig. 2. *Asteridium lanatum* (Volkova) Moczydłowska
Ossolin IG 1 borehole
Fig. 3. *Goniosphaeridium* sp.
Wszachów 2 borehole
Fig. 4. *Lophosphaeridium tentativum* Volkova
Wszachów 2 borehole
Fig. 5. *Skiagia ciliosa* (Volkova) Downie
Wszachów 2 borehole
Fig. 6. *Goniosphaeridium uncinatum* (Downie) Kjellstrom
Ublinek 1-bis borehole
Fig. 7. *Vulcanisphaera africana* Deunff
Ublinek 1-bis borehole
Fig. 8. *Cymatiogalea* cf. *colummelifera* (Deunff) Deunff, Górka et Rauscher
Ublinek 1-bis borehole
Fig. 9. *Acanthodiacrodium timofeevi* Golub et Volkova
Ublinek 1-bis borehole
Fig. 10. *Heliosphaeridium cf. lubomlense* (Kirjanov) Moczydłowska
Zaręby 2 borehole
Fig. 11. *Volkovia dentifera* (Volkova) Downie
Zaręby 2 borehole
Fig. 12. *?Goniosphaeridium* sp.
Sandomierz–Kamień Plebański 1 borehole
Fig. 13. *Impluviculus* sp.
Sandomierz–Kamień Plebański 1 borehole
Fig. 14. *Eliasum* sp.
Sandomierz–Kamień Plebański 1 borehole
Fig. 15. *Goniosphaeridium uncinatum* (Downie) Kjellstrom
Chabowe Doły outcrop
Fig. 16. *Vulcanisphaera africana* Deunff
Chabowe Doły outcrop
Fig. 17. *Cymatiogalea* sp.
Chabowe Doły outcrop
Fig. 18. *Acanthodiacrodium* cf. *timofeevi* Golub et Volkova
Chabowe Doły outcrop
Fig. 19. *Goniosphaeridium uncinatum* (Downie) Kjellstrom
Wilków 1 borehole
Fig. 20. *Arbusculidium* sp.
Wilków 1 borehole
Figs. 21, 22. *Acritarcha* gen. et sp. ind.
Wiśniówka Mała outcrop

Scale bar — 30 μm



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