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Age, sedimentary environment and palaeogeographical position of the Late Silurian oolitic beds in the Holy Cross Mountains (Central Poland)

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ABSTRACT:

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A thin sandy-oolitic formation [Jadowniki Formation (JF)] is described from the Upper Silurian of the Łysogóry Unit, Holy Cross Mountains (Central Poland). Its numerous trilobites (e.g. *Homalonotus knighti, Acastella spinosa*) and position in the lithological column testify for the late Ludfordian age of this formation. The sedimentary environment of the Jadowniki Formation is interpreted as extremely shallow-barrier environments with episodes of emersion and subaerial early diagenesis and erosion. However, these shallows were not connected with the nearshore belt of Baltica land and were separated from them by a belt of deep basin sedimentation – the graptholitic shales. Silurian shallow marine sediments of the Łysogóry Unit were deposited on top of a clastic wedge, which in the Ludlovian infilled the offshore – deep basin of the SW margin of the East European Craton. The wedge was probably connected with the process of dockage of new terranes onto the south-west periphery of the East European Craton The second factor that led to the development of shallow marine environments was probably the uppermost Ludfordian regressive event.

Key words: Carbonate sedimentology, Oolites, Trilobites, Palaeogeography, Silurian eustacy, Holy Cross Mountains, Poland, Upper Silurian.

INTRODUCTION

The Silurian deposits on the south-western margin of the East European Craton (EEC) are developed as a relatively uniform succession of graptolitic shales (Llandovery – lower Ludlow) and a “greywacke – siltstones series” (lower Ludlow – Přídolí). The Silurian in the Holy Cross Mountains (HCM) is similarly bipartite in both parts of the region, i.e. in the southern – Małopolska Massif (MM) and in the northern – Łysogóry Unit (ŁU). In the upper part of the “greywacke series” of the ŁU, a thin oolitic-sandstone complex, named here the Jadowniki Sandstones and Oolite Formation (JF) have been found. This formation contains a rich trilobite fauna, indicative of a late Ludfordian age. Although the oolites were noted earlier from this part of the succession (CZARNOCKI 1957a), their palaeogeographical significance was underestimated and sometimes even ignored (e.g. MODLIŃSKI & SZYMAŃSKI 2001). Palaeontological and sedimentological investigations of this complex point to both shallow and extremely shallow depositional environments. In the author’s opinion, the Łysogóry Unit in the Late Silurian probably represented part of a shallow marine belt, developed on the greywacke wedge, parallel to the margin of the EEC and separated by a zone of graptolitic shales (deep shelf basin) from the nearshore carbonates of the Baltica landmass. The appearance of the Łysogóry shallow marine belt was probably connected with the process of dockage of new terranes onto the south-west periphery of the

EEC. Intense clastic (greywacke) sedimentation from the new sources (JAWOROWSKI 1971) caused the filling up of the south-western part of the Baltica shelf basin and development of the shallow marine environment. In the latest Ludlow, the sedimentation leading to the decrease of the accommodation space, probably overlapped with a regresion.

SILURIAN SUCCESSION OF THE HOLY CROSS MOUNTAINS

The area of the Palaeozoic deposits in the Holy Cross Mountains is subdivided palaeogeographically into the southern area, called the Kielce region (the northern part of Małopolska Massif), and the northern area, called the Łysogóry Unit (Text-fig. 1). The Palaeozoic successions in both areas differ generally in facies, depositional environment and completeness of record. However it is not significant in the Silurian succession (Text-fig. 2).

Silurian of Kielce region (Text-fig. 2). In the early Ludlow, a rapid change in the character and rate of sedimentation took place in this area (TOMCZYK 1970). The graptolitic shales of the *Saetograptus leintwardinensis* Zone were replaced by medium- and coarse-grained greywackes with intercalations of conglomerates (Niewachlów Beds of CZARNOCKI 1919). The thickness of these beds has not been unequivocally determined, and estimates range from 60 m (STUPNICKA *& al*. 1991) to 700 m (MALEC 1993). The thickness given by STUPNICKA *& al*. (1991) probably refers only to a part of the succession. On the other hand, the thickness given by MALEC (1993) is excessive, since it is based on the (erroneous) assumption that the strata are unaffected by tectonic repetitions, despite the fact that, on both the cross-sections and schematic geological maps he showed two anticlines and a syncline between them in the area of the Niewachlów fold.

Based on the geological map of FILONOWICZ (1971), the most probable thickness of the Niewachlów Beds is about 300 m, this thickness being consistent with earlier descriptions (TOMCZYK 1970).

A similar controversy regarding total thickness is found in the case of the Kielce Beds (MALEC 1993) which overlie the Niewachlów Beds and are composed of clay shales with sandstone intercalations. MALEC (1993, 2001) reported a thickness of 500 m, whereas, according to the map of FILONOWICZ (1971), the thickness does not exceed 200-300 m.

The Niewachlów Beds are characterised by the rare graptolite *Bohemograptus bohemicus* (TOMCZYK 1970), and the trilobites: *Baliozoma erraticum*, *Dalmanites nexilis*, *Richterarges kielcensis* (TOMCZYKOWA 1993; KOZŁOWSKI & TOMCZYKOWA 1999), indicating their early Ludlow age (TOMCZYK 1970; TOMCZYKOWA 1988). The Kielce Beds are of Ludfordian age, and their uppermost

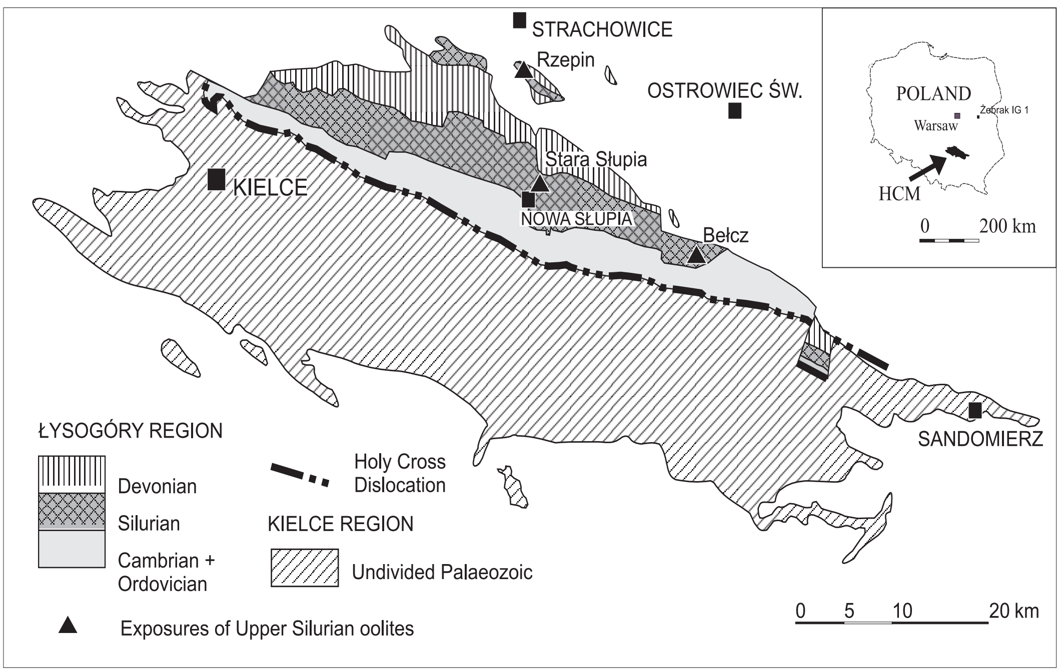

Fig. 1. A simplified geological sketch-map of the Palaeozoic core of the Holy Cross Mountains (after CZARNOCKI 1957b, TOMCZYKOWA & TOMCZYK 2000), with positions of discussed sections

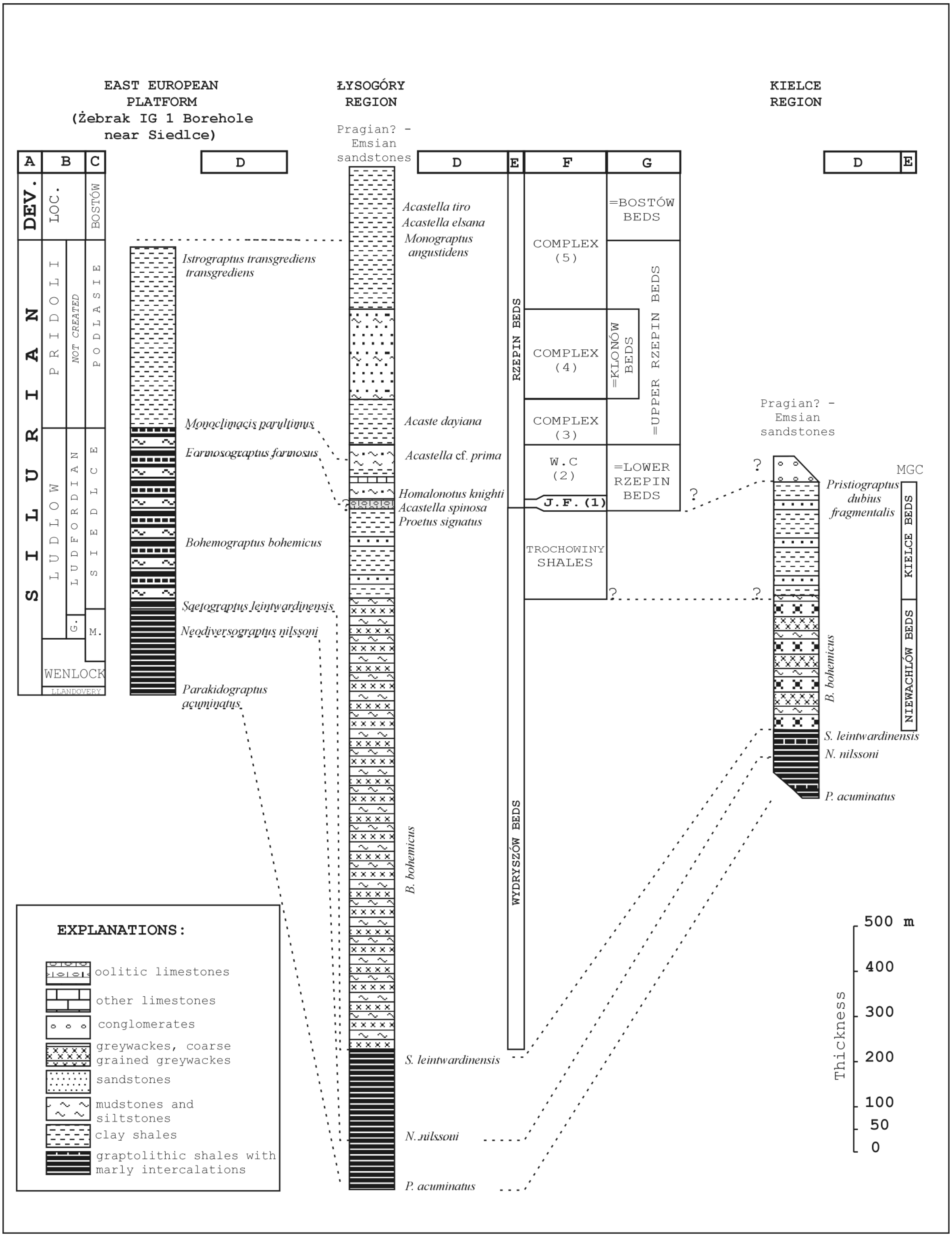

Fig. 2. Composite section of the Silurian in the Łysogóry Region, and its correlation with the Silurian of the Polish part of the East European Craton (EEC - Żebrak IG 1 Borehole near Siedlce – for positions of localities see figs 1 and 8) and the Kielce Region; A, B – Standard chronostratigraphy (Dev. - Devonian, Loc. – Lochkovian, G. – Gorstian), C – local stages on the EEP (M. – Mielnikian), D – selected graptolitic biozones, E – main, informal lithostratigraphical units in the Holy Cross Mountains, F – provisional lithostratigraphical units (W.C. – Winnica Complex) of the Upper Silurian rocks in the Łysogóry Region (see text), and position of the Jadowniki Formation (J.F), G – older equivalents of units

part contains a fauna indicative of the lower part of the *Formosograptus formosus* graptolite range Zone (MALEC 2001).

Both the Niewachlów and Kielce Beds were deposited in a relatively deep basin, with a significant contribution from turbidity currents (JAWOROWSKI 1971, KOZŁOWSKI & TOMCZYKOWA 1999, MALEC 2001).

The Late Silurian sedimentation was terminated by the Miedziana Góra Conglomerates, which are overlain by Emsian sandstones (MALEC 1993).

Łysogóry Unit (Text-fig. 2)**. A**s in the Kielce region, the change from the basinal graptolitic facies to the "greywacke series" took place in the early Ludlow. The lower part of the "greywacke series", named the Wydryszów Beds (CZARNOCKI 1936, 1957a), comprises greywackes, siltstones and shales over 1000 m thick (TOMCZYK 1970). The sedimentology of these deposits has not been studied in detail, but a depositional environment similar to that of the greywackes of the Niewachlów Beds is accepted herein (e.g. JAWOROWSKI 1971). The greywackes of the Wydryszów Beds are definitely more fine-grained than those of the Niewachlów Beds. In their upper part they resemble the Kielce Beds (Trochowiny Shales – Text-fig. 2). The appearance of the rare graptolite *Bohemograptus bohemicus* (TOMCZYK 1970, TOMCZYKOWA & TOMCZYK 2000) in the lower part of the Wydryszów Beds suggests the time equivalence of the sedimentation of the Wydryszów and Niewachlów Beds.

The uppermost part of the "greywacke series" is known as the Rzepin Beds (CZARNOCKI 1936). According to CZARNOCKI (1936, 1957a), the sequence is dominated by various olive-green to cherry-red coloured sediments comprising clay shales, greywackes, calcareous greywackes, oolitic greywackes and thin limestone lenses. The carbonate intercalations are characterised by a rich benthic fauna comprising tabulates (STASIŃSKA 1970), rugose corals (RÓŻKOWSKA 1962, 1990), bryozoans (DZIK & TOMCZYKOWA 1990), brachiopods (BIERNAT 1981), nautiloids (DZIK 1990), rostroconchs (KARCZEWSKI 1990), trilobites (TOMCZYKOWA 1962, 1975, 1990, 1991), bivalves (KARCZEWSKI 1990), crinoids (GŁUCHOWSKI 1990), as well as by gastropods, tentaculitids, ostracods and very rare graptolites (TOMCZYKOWA 1988). This assemblage indicates a shallow-water shelf environment (SAMSONOWICZ 1934; RÓŻKOWSKA 1962; STASIŃSKA 1970); probably also including lagoons, as suggested by KOZŁOWSKI (2000).

On the basis of the trilobites and sporadic graptolites (TOMCZYK 1970; TOMCZYKOWA 1988) the Rzepin Beds span the uppermost Ludlow and the Přídolí. The beds are covered by marine Lochkovian deposits (Bostów Beds).

LITHOSTRATIGRAPHY OF THE UPPERMOST SILURIAN IN THE ŁYSOGÓRY UNIT

The lithostratigraphical scheme of the Upper Silurian deposits of Łysogóry is burdened with an old tradition of informally established units. These units are devoid of precisely indicated boundaries and definitions, and they are based on a mixture of litho-, bio-, and chronostratigraphical criteria (comp. TOMCZYK 1970, TOMCZYKOWA 1988).

In view of this problem, the author decided to use a provisional lithostratigraphical subdivision of the upper part of the Silurian in the Łysogóry Unit, based on his own field observations.

The Rzepin Beds, which are treated herein as a major unit, are subdivided into five lithological complexes (Text-fig. 2F): (1) sandstones and oolites (Jadowniki Formation – see below), (2) clay shales, mudstones and siltstones with carbonate interbeds (lagoonal) – Winnica complex sensu KOZLOWSKI (2000), (3) green clay shales (open shelf), (4) red siltstones, sandstones and clay shales (fluvial), and (5) clay shales with grey and green sandstones (mostly open shelf). The relationship of these units to the older lithostratigraphic terms is shown in Text-fig. 2 (compare columns F and G).

The Rzepin Beds are underlain by the Wydryszów Beds, the topmost part of which is composed of green shales with intercalations of siltstones and thin-bedded sandstones, referred to here as the Trochowiny Shales (over 200 m thick). These deposits were included into the Rzepin Beds (e.g. FILONOWICZ 1969) but, according to the definition of CZARNOCKI (1936, 1957a) they constitute part of the Wydryszów Beds. The Trochowiny Shales can probably be treated as the time- and facies-equivalent of the Kielce Beds in the Kielce region.

Definition of the Jadowniki Sandstones and Oolites Formation (Polish name*: Formacja piaskowców i wapieni oolitowych z Jadownik*)

Derivation of name: From the village of Jadowniki Dolne, located near the stratotype.

Definition: The Jadowniki Formation is composed of sandstones, calcareous sandstones with ooids, sandy limestones and oolites (Text-fig. 3); grey or yellowish-grey in colour. The deposits are generally thick-bedded and hard. Locally they contain an abundant fauna, represented by brachiopods, crinoids, gastropods, trilobites, ostracods, bryozoans and sporadic tabulate corals. The proposed unit contrasts lithologically with the under- and overlying deposits (fine-grained clastics) and possibly also in geophysical logs.

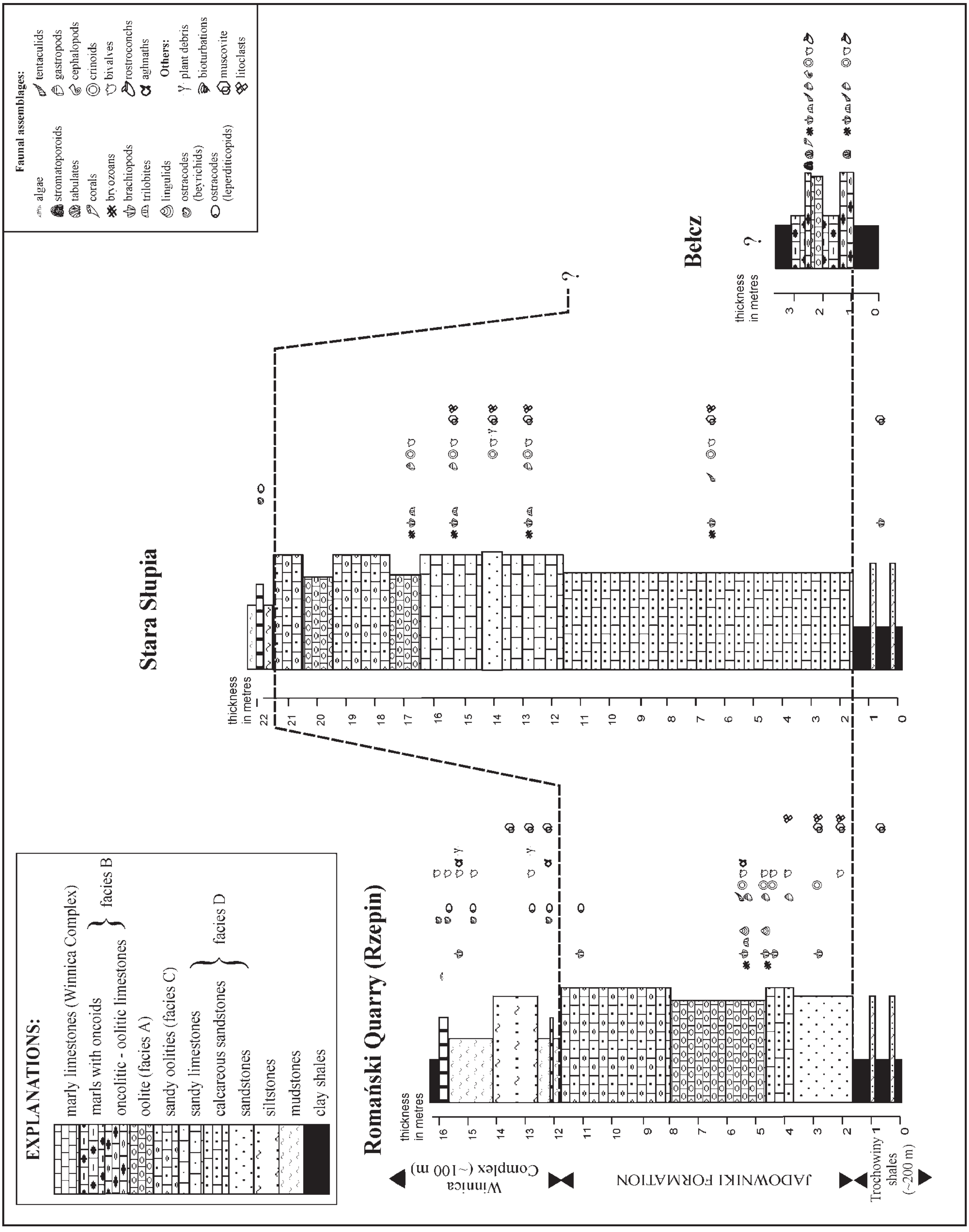

Fig. 3. Lithological correlation and the faunal - facies succession in the investigated sections

Synonymy: Lower Rzepin Beds (part) – CZARNOCKI 1957a; TOMCZYKOWA 1962; TOMCZYK 1970; TOMCZYKOWA & TOMCZYK 1981; Upper Rzepin Beds (part) – FILONOWICZ 1968; non Grzegorzowickie Beds (part) – SAMSONOWICZ 1936.

Stratotype: Romański Quarry - Rzepin (location – see Appendix).

Boundary stratotype: Romański Quarry

Boundaries and thickness: The lower boundary of the Jadowniki Formation was exposed in the southern slope of the Romański Quarry. The boundary between this formation and the underlying Trochowiny Shales lies at the base of the first sandstone bed (Text-fig. 3). The lithological change is rapid. The upper boundary was observed in the highest part of the Romański Quarry succession. The boundary between the Jadowniki Formation and the Winnica complex lies at the top of the last sandy-oolite limestone bed (Text-fig. 3). The thickness of the formation varies between 2 and 20 m.

Occurrence in the study area: Deposits of the Jadowniki Formation were observed in the central and eastern part of the Łysogóry Unit in the following sections: Romański Quarry, Stara Słupia, and Bełcz (Text-fig. 1 and Appendix). Deposits probably corresponding to this formation were described by CZARNOCKI (1957a) in the Łomno-Ostrostar 9 borehole (between 25.0 – 34.2 m), located ca. 3 km NW of Stara Słupia. The core revealed the presence of grey and black sandy limestones with ooids and calcareous greywackes.

Regional diversity and character of boundaries: In the eastern part of the Łysogóry Unit, the Jadowniki Formation corresponds to the lower "detrital" limestone complex in Bełcz (TOMCZYKOWA 1962; RÓŻKOWSKA 1962 – trench II; TOMCZYKOWA *in* ALBERTI *& al*. 1982, fig. 1; BIERNAT 1981, fig. 2), described herein as the oncolitic-oolitic limestones. Taking into account the much better preservation of fauna, finer fraction of the clastic material, its smaller thickness and the large admixture of oncoids it can be inferred that the Bełcz limestones represent the marginal parts of oolitic-sandy bodies of the Jadowniki Formation deposited in a slightly lower-energy sedimentary environment.

The base of Jadowniki Formation reflects probably a generally isochronous regional change in sedimentation. However its upper boundary is most probably diachronous. In the overlying Winnica complex, single beds of oolites and redeposited ooids were observed. It is assumed here that the Jadowniki Formation interfringes partly with the Winnica complex. Moreover, because of the small number of exposures, and the poor biostratigraphical resolution of the trilobites, it is now

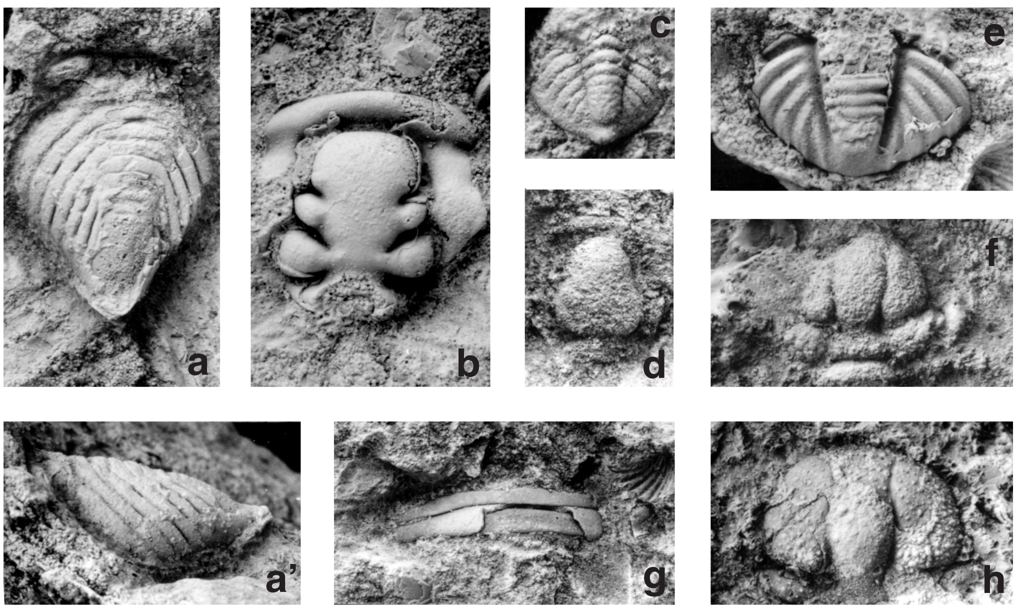

Fig. 4. Trilobite assemblage from the Jadowniki Formation: **a** - *Homalonotus knighti,* partly exfoliated pygidium (× 2): a – dorsal view; a' – lateral view, Rzepin; **b, e** - *Calymene beyeri*: b - exfoliated, almost complete cranidium (× 2), Rzepin; e – exfoliated pygidium (× 3.3), Stara Słupia; **c** - *Acastella spinosa*: pygidium (× 4.5), Stara Słupia; **d** - *Proetus signatus*: internal mould of almost complete cranidium (× 3.3), Stara Słupia; **f, h** - *Richterarges convexus*: f - cranidium (× 3.5), Stara Słupia; h – part of cranidium (× 3.3), Rzepin; **g** – *Homalonotus* sp.: partly exfoliated segment of thorax (× 1.5), Stara Słupia; **all specimens**: Uppermost Ludlow, Holy Cross Mountains, Poland

impossible to state whether the Jadowniki Formation contains single, expanded oolitic lithosome (e.g. oolitic barrier) or represent randomly distributed small oolitic-sandy bodies.

THE AGE OF THE JADOWNIKI FORMATION

The stratigraphical position of the Jadowniki Formation, as presented herein, is based on relatively numerous trilobites (Text-fig. 4,5) that have been found in each exposure. Because of the problems with precise location of specimens from older collections, only those collected by the author were taken into consideration.

Homalonotus knighti KÖNIG, 1825 – According to THOMAS & *al*. (1984), the genus *Homalonotus* is a good indicator of the Ludlow. In Great Britain the range of the species encompasses the Upper Gorstian and Ludfordian, interpreted as the shallowest ecofacies of the British Ludlow and representing a nearshore environment (MIKULIC & WATKINS 1981). *H. knighti* forms there characteristic association with *Acastella spinosa* and the brachiopod *Protochonetes ludloviensis*. *H. knighti* was also noted (MCLEARN 1924) in shallow marine deposits (DOUGLAS 1979) of the McAdam and Moydart formations (Ludfordian) in the vicinity of Arisaig in Nova Scotia.

ALBERTI & *al*. (1982) reported *H. knighti* from the upper Ludfordian of Gotland, where it occurs in shallow marine deposits of the Burgsvik Beds (STEL & DE COO 1977).

In NE Poland, the species was noted in the Gołdap IG 1 borehole (depth 1161-62 m), in the lower part of the *Formosograptus formosus* graptolite range Zone (TOMCZYKOWA 1975).

The total range of *H. knighti* is thus upper Gorstian through upper Ludfordian.

Acastella spinosa (SALTER, 1864) – This species is characteristic of the Upper Ludlow (Ludfordian) in Britain (THOMAS & *al*. 1984); it is also noted, however, in the basal parts of the Přídolí (SHERGOLD 1967). According to MIKULIC & WATKINS (1981), the taxon is facies-dependent as in the case of *Homalonotus knighti*. In the HCM however, it occurs in a much greater variety of deposits than *H. knighti*. *A. spinosa* is also known from the upper Ludfordian of the Potok IG 1 borehole (eastwards of the HCM) and in the Gołdap IG 1 borehole in NE Poland (TOMCZYKOWA 1982, 1991), where it was found in the *Formosograptus formosus* graptolite range Zone (upper Ludfordian). Its total range is Ludfordian to lowermost Přídolí.

Proetus signatus LINDSTRÖM, 1885 – This is a widely distributed taxon in Baltica, known from Gotland, the Baltic countries, and numerous boreholes in NE Poland (eg. Lębork IG 1, Gołdap IG 1, and Mielnik IG 1), as well as in the Potok IG 1 borehole. *P. signatus* spans the *Formosograptus formosus* to *Monoclimacis ultimus* graptolite range zones (uupper Ludfordian – lowermost Přídolí), for discusion - see ALBERTI & *al*. (1982).

Calymene beyeri RICHTER & RICHTER, 1954 – This long-ranging taxon is known from the Polish part of the EEC

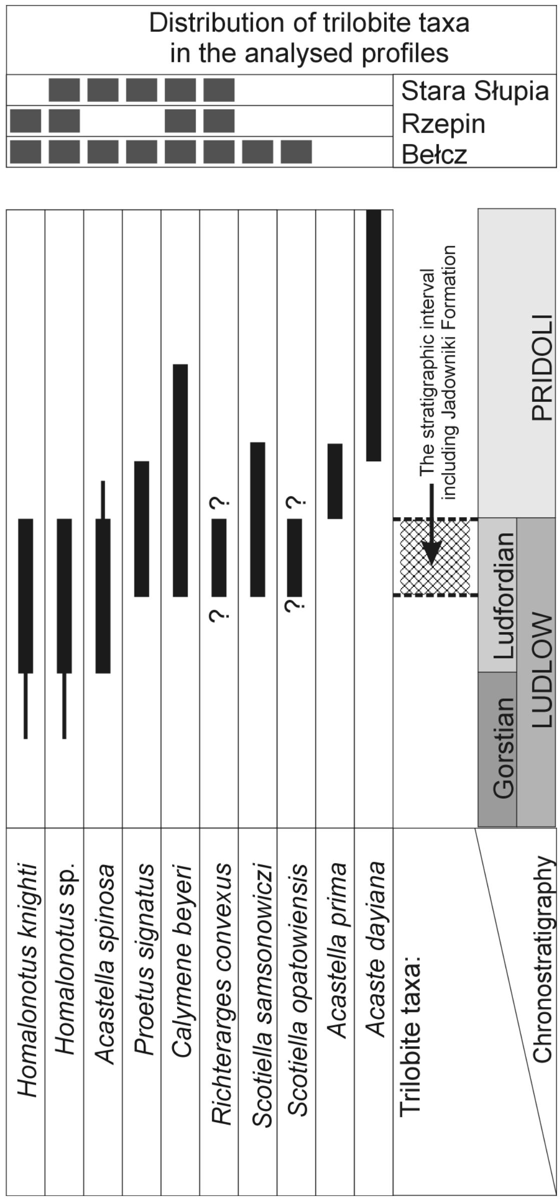

Fig. 5. The age of the Jadowniki Formation in the discussed sections interpreted from the stratigraphical ranges (discussed in text), and distribution of the trilobite taxa

(e.g. Mielnik IG 1, Lębork IG 1 and Łeba boreholes) and from the Potok IG 1 borehole (TOMCZYKOWA 1982, 1991). Its range in Poland encompasses the upper Ludfordian and lower Přídolí (TOMCZYKOWA 1991). According to ABUSHIK & *al*. (1985), it occurs in the entire Skała Stage in Podolia (Přídolí). It also occurs in the Kaugatuma Stage (lower Přídolí) in Estonia (MANNIL 1982, fig. 2) and co-occurs with *Acaste dayiana* in Germany (Rheinisches Schiefergebirge) (RICHTER & RICHTER 1954). The taxon was also noted in the beyrichid limestones within Scandinavian erratic boulders (SCHRANK 1970b).

The total range of *C. beyeri* may be estimated as the upper Ludfordian to lower Přídolían.

Scotiella samsonowiczi TOMCZYKOWA, 1962 – Besides the HCM, where *S. samsonowiczi* was first described (TOMCZYKOWA 1962), the species was also noted (SCHRANK 1970a) in the Upper Ludlow of the Łeba Borehole (East European Craton – northern Poland) and in erratic boulders (SCHRANK 1972). According to TOMCZYKOWA (1990), its range corresponds to the upper Ludfordian and lowermost Přídolían.

Richterarges convexus and TOMCZYKOWA, 1991 and ***Scotiella opatowiensis*** TOMCZYKOWA, 1962 are noted only from the Rzepin Beds of the HCM (TOMCZYKOWA 1991).

As shown in Text-fig. 5 trilobite assemblages from all of the exposures of the Jadowniki Formation are indicative of the late Ludfordian. The fauna typical of early Pridoli (*Acastella* cf. *prima* and *Acaste dayiana*) appear higher, in the Winnica Complex (complex 2) and still higher in complex 3 (Text-fig. 2). This estimation corresponds well to the previous stratigraphical dating of rocks considered here as belonging to the Jadowniki Formation, regarded then as a part of the Lower Rzepin Beds, by TOMCZYKOWA (1988). Based on the trilobite assemblage found in a single horizons in Bełcz she referred them to the *Formosograptus formosus* graptolite Zone of the upper Ludfordian.

It must be realised that the appearance of the trilobite fauna in the studied region was, most probably, largely facies-controlled. In view of the generally very large thickness of Upper Silurian Rocks in Łysogóry (about 2000 m), the Jadowniki Formation (10-20 m) must represent a very short period of time, probably shorter than the stratigraphical range of the trilobite taxa under discussion. On the other hand, the appearance of this shallow water assemblage in the HCM, northern Poland and in Gotland is assumed to be highly isochronous. In the author's interpretation, the appearance of this shallow water assemblage was the result of an eustatic event, possibly corresponding to the regressive pulse noted in the upper part of the *Formosograptus formosus* graptolite Zone (JOHNSON & *al*. 1998). The other effect of this event might have been the termination of marine sedimentation in the Kielce region and the beginning of deposition of the Miedziana Góra Conglomerates, a possible time equivalent of the Jadowniki Formation.

LITHOFACIES OF THE JADOWNIKI FORMATION AND THEIR ENVIRONMENTAL INTERPRETATION

The main criteria for distinguishing the various lithofacies were grain composition and fossil content in all of the rock types. The sedimentary structures, with a few exceptions, are poorly preserved or not readily discernible because of the poor conditions of the exposures and their small size. The environmental interpretation of Jadowniki Formation has been based on the fauna and microfacies, as well as on the succession of lithofacies (Text-fig. 3).

In the Jadowniki Formation four lithofacies has been distinguished:

Lithofacies A: Bioclastic-oolitic grainstones (Pl. 1, Fig. 1).

Grey, yellowish-grey or pink-coloured bioclastic-oolitic grainstones (sporadically packstones), with lenticular or cross-bedding. The numerous macrofossils are represented by: brachiopods, trilobites, bryozoans, bivalves, gastropods, and crinoids. Bioclasts (usually less than 20%) are crushed and well rounded, sometimes coated by a thin ooidal cortex (superficial ooids). Detrital quartz is rather common (up to 10%) and large (average 0.3 mm in diameter). A few oncoids and small oolite debris are also present. Flat clay-silty pebbles, up to several millimetres in size frequently contain an admixture of quartz grains and ooids, often completely micritized (Pl. 1, Fig. 12).

Ooids (usually 50-70%) 0.2-0.5 mm in diameter, are well preserved. Ooid cores are composed of quartz grains, peloids or bioclasts. However, the most common cores are older, micritized (Pl. 1, Fig. 5), abraded or partly dissolved ooids (Pl. 1, Figs 6-8) and small oolite debris comprising 1-3 ooids cemented with sparite (Pl. 1, Fig. 11) or weald by a stylolite seam (Pl. 1, Fig. 10). Such ooids with oolitic cores and 1-3 laminae of well preserved banded radial cortex are interpreted here as reworked ooids.

Interpretation: The facies contains two microfacies (Standard Microfacies 11– grainstones with coated bioclasts; and Standard Microfacies 15 – cross-bedded oolitic grainstones) characteristic of 6th facies belt in the model of Wilson (1975), which is interpreted as oolitic shoals above the wave base. The trilobite assemblage (*Homalonotus knighti* and *Acastella spinosa*) recognised in this facies, together with an abundant brachiopods (with numerous *Protochonetes ludloviensis*) and bivalves (*Pteronitella* sp.) resembles the *Protochonetes ludloviensis* ecological assemblage, typical of the shallowest open marine environment of the British Ludlow (Watkins 1978, Mikulic & Watkins 1981). In a general sense this association is included in the Homalonotid Community Group of Thomas & Lane (1999), which characterises the shallowest, high-energy part of the shelf (BA1 of Boucot 1975). Similar associations, indicative of this environment, are known in several localities in the world (Thomas & Lane 1999). The lack of build-up makers (tabulates, stromatoporoids, corals, etc.) in lithofacies A, may suggest considerable mobility of the sediment. The clay shale lithoclasts and reworked ooids suggest the erosion and supply of early lithified deposits into the shallow sea. It is probable that this process was connected with the emersion of the adjoining parts of the basin. The intense micritization and dissolution of some grains may also point to temporary exposure of the oolitic deposit to the action of fresh or meteoritic waters prior to redeposition in the marine environment.

Lithofacies B : Oncolitic-oolitic grainstones and marls with large oncoids (Pl. 1, Fig. 3).

Marly bioclastic oncolite-oolite, pink in colour, containing abundant brachiopods, trilobites, bryozoans, rostroconchs, crinoids, tentaculitids, gastropods, bivalves, ostracods, and rare tabulate and rugose corals. Some of the bioclasts are intensely crushed but very well preserved specimens of, for example, rostroconchs with finely ornamented and perforated shells, also occur. The grainstones are poorly graded and intercalated with marls with large oncoids (up to 3 cm). The limestones contain up to 60% of ooids: spherical normal ones (~0.3 mm in diameter) and large (up to 5 mm), rod-shaped ooids (Pl. 1, Fig. 4), formed typically around large bioclasts. The oncoids (up to 60%) are present in limestones and marls. Their envelopes comprise poorly visible micritic layers, with rarely preserved relicts of algal *Girvanella*-type tubes. The micritic layers and interstices contain numerous quartz grain, rarely ooids. The cores of the oncoids comprise bioclasts, rarely lithoclasts (also oolite debris) and large ooids. The diameter of the oncoids varies from 1 to 40 mm. The thickness and composition of particular laminae in the oncoid envelopes are variable, which indicates an irregular and multistage development of the grains. Oval oncoids (which are dominant) are randomly orientated in the rock (Pl. 1, Fig. 3). The limestones contain up to 10% quartz (0.1 to 0.3 mm in diameter) and few small oolite intraclasts.

Interpretation: The different state of preservation of the various groups of fossils, together with the bimodal character of the deposits (the occurrence of large oncoids as well as numerous small ooids), the chaotic rock texture (randomly orientated allochems) and the presence of numerous lithoclasts may indicate the significant role of redeposition in the limestone beds. However, the character of the autochthonous deposits – marls with oncoids – indicates a shallow shelf environment. It was probably a quiet part of the shelf, deeper than the area where the oncolite-oolitic material was produced. The oncoids and ooids were formed in these same or adjoining sedimentary environments because of presence of ooids and small oolite debris inside the oncoids. This material was transported down the slope in large amounts in a short time over probably small distances – most likely during strong storms. During the less dynamic intervals the thin, parallel-bedded oolites and marls with oncoids were deposited. In conclusion, lithofacies B was deposited in the marginal parts of oolitic-sand shoals, interpreted here as lithofacies A.

Lithofacies C: Oolitic grainstone with few bioclasts (Pl. 2, Figs 1-3, 5, 6).

Oolites and sandy oolites, grey-coloured, hard, with fossils confined to single beds. Deposits of this facies comprise ooids (up to 70%), quartz (15-30 %) and intraclasts. The sporadic bioclasts are very small and usually comprise fragments of shelly fauna. However, in single horizons large, well preserved leperditicopid ostracods and sporadic brachiopods occur. The rocks contain trace fossils belonging to the ichnogenus *Scolithos*

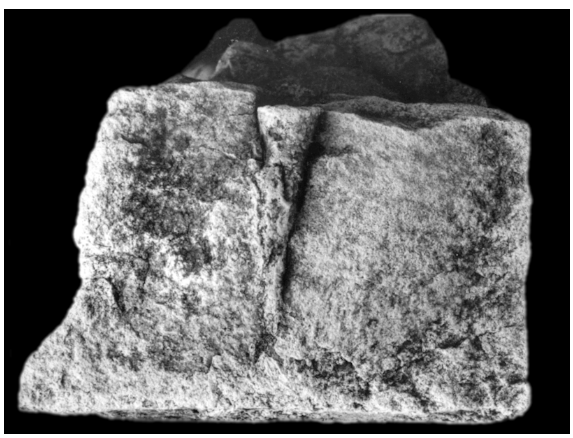

Fig. 6. *Scolithos* isp. in sandstone with ooids with few bioclasts

(Text-fig. 6). The ooids are often surrounded by isopachous or irregular (gravitational?) cement (Pl. 2, Fig. 3). In oolites of this facies a specific, "fenestral" structures occur (Text-fig. 7). These structures are developed as irregular vugs (1 to 5 mm in diameter) filled with sparite (Pl. 2, Figs 5-6). Their irregular shape and invariably subcircular cross-sections testifies to the inorganic character of these structures. The grain components are not sheared at the vug edge and there is also a lack of dissolution traces. In some of these cavities the walls are bent inside (Pl. 2, Fig. 6) and, in some cases, ooids were observed within the structures. Places of sediment "loosening", where there is a very low degree of allochem packing are extreme examples (Pl. 2, Fig. 5). The structures were developed prior to early diagenesis of the sediment, because the surrounding allochems are cemented by fringe cements, which are not cutting inside caverns. These structures are interpreted here as keystone vugs (cf. INDEN & MOORE 1983 - Fig. 7 b-d).

The occurrence of peculiar erosional surfaces is an important feature of the lithofacies. On these surfaces the hard elements, usually ooids or bioclasts, protrude upwards, while the softer matrix or cements are eroded; in other cases, both elements are erosionally truncated (Pl. 2, Figs 1-2). Sometimes the laminae with erosional surfaces are cracked and composed of fragments similar to elongated lithoclasts (Pl. 2, Fig. 1).

Interpretation: The crucial factor in the interpretation of the sedimentary environment of lithofacies C is the interfingering of deposits from two different environments. The first environment, represented by horizons with leperditicopid ostracods and/or early cemented oolitic layers, was relatively quiet and, in some respect, restricted (comp. remarks of VANNIER & *al.* 2001 on the ecological stress). In contrast, the second environment was more dynamic, with episodes of deposition of oolitic material or synsedimentary erosion. The co-occurrence of the intense micritization and leaching (?) of ooids, keystone vugs, *Scolithos* ichnofossils and irregular (gravitational?) cements may indicate the periodical emersions of the sediment. In this episodes the oolitic material was cemented during early diagenesis and subsequent erosion and transport into area of facies A, B, C and D [compare oolite intraclasts in these facies (Pl. 1, Fig. 9; Pl. 2, Fig 1,4) with general view of facies C (Pl. 2, Figs 1-3, 5, 6)].

Fig. 7. Fenestral structures in oolite – keystone vugs(?), Rzepin, Jadowniki Formation, Upper Silurian, Holy Cross Mts

Lithofacies C may represent the areas behind, or within, the oolitic-sand barriers, with possible episodes of subaerial exposition from one side, and incursions of more lagoonal, shallow but restricted waters (leperditid ostracodes) from the other side. This interpretation is confirmed by the facies succession and the direct transition of lithofacies C into the Winnica complex – lagoonal, represented possibly by brackish facies.

Lithofacies D: Fine-grained, tabular, quartz sandstones, calcareous quartz sandstones, and sandy limestones (Pl. 1, Fig. 2; Pl. 2, Fig. 4). The facies contain various clastic and carbonate deposits lying typically at the base of the Jadowniki Formation. In the lower part of the succession, yellow sandstones with sporadic bivalve moulds and crinoids are present. Abundant fragments of fossil plants were found in a single bed. In the upper part, hard calcareous sandstones or sandy limestones predominate.

The calcareous sandstones contain single large gastropods and bivalves. They also contain clayey lithoclasts, as well as sporadic ooids and oncoids.

The sandy limestones grey, bluish-grey, yellowish-grey or pink in colour are parallel-bedded, and split into plates. They are highly fossiliferous with bivalves, trilobites, brachiopods, gastropods, crinoids, bryozoans, tentaculitids and ostracods. Some bedding planes are characterised by an abundance of muscovite, mass occurrence of the large bivalve *Pteronitella* or by horizontally orientated clay-silty, flat lithoclasts (up to 2 cm in size). The bioclasts are usually of large size (typically 2 to 5 mm). The diameter of the detrital quartz varies from 0.1 to 0.15 mm. The infrequent ooids (0.15 and 0.2 mm in diameter) are typically strongly abraded and broken. The presence of numerous, well preserved ooids under larger bioclasts (Pl. 1, Fig. 2), as well as the presence of intraclasts of oolites, are characteristic features. Most of the intraclasts (Pl. 2, Fig. 4) are very similar to the rocks of lithofacies C.

Interpretation: The numerous fossil plant fragments and the abundant clastic material show that the land areas were located nearby. The succession of facies may indicate that the sandstones formed a background for oolitic sedimentation and, by analogy with the Burgsvik Beds of Gotland, may be interpreted as sandbanks (LONG 1993).

The fossil assemblage in the sandy limestones indicates a shallow marine environment similar to that of lithofacies A. In view of the large clastic material content, the ooids were probably not formed in the place of deposition, but were originally transported in larger quantities, as inside sediment under large bioclasts. Most of the ooids were abraded or washed out by multiple reworking of sediment. The sandy limestones could have formed in a shallow, high-energy environment, most probably above the wave base, close to the sedimentary environment of lithofacies A.

The Jadowniki Formation is represented by autochtonous facies of the shallowest shelf. The presence of redeposited ooids in the limestones of the overlying Winnica complex (complex 2) – interpreted as lagoonal deposits – may indicate partial lateral facies interfingering of the upper part of the Jadowniki Formation and the Winnica complex. The sandy-oolitic deposits of the Jadowniki Formation could have formed shallows that acted as barriers between the lagoons and the open sea. Within such shallows, small coastal-island areas could exist occasionally.

The Jadowniki Formation is very similar in terms of lithology, palaeoecology and age to the Late Silurian Burgsvik Beds of Gotland. These strata were deposited within near-shore and beach environments (STEL & DE COO 1977) and, as recently interpreted, as storm-dominated sandbanks or a sand-wave complex (LONG 1993). The rich (particularly in the upper part) fauna comprises i.a. *Homalonotus knighti*, *Acastella* sp. and numerous bivalves (*Pteronitella* sp.). There are also numerous facies similarities between the two areas. Clastic deposits lying at the base of the Burgsvik Beds are represented by sandstones and calcareous sandstones with ooids, numerous lenses and lithoclasts of clayey shales. These clastic deposits are overlain by carbonate deposits, represented mainly by sandy oolites, as well as oolitic-oncolitic limestones.

REMARKS ON THE LATE SILURIAN PALAEOGEOGRAPHY IN THE BALTIC REGION

The occurrence of the carbonate facies in the Upper Silurian of the Łysogóry Unit enables reconstruction of final phase of the evolution of the deep basin that characterised this zone since the Ordovician. It is also relevant to the discussion of the role of the regional factors controlling sedimentation, namely subsidence and eustatic movements.

The palaeogeographical position of the Łysogóry Unit during the early Palaeozoic is controversial, but the greatest controversy (Baltic or Gondwanan provenance of the block) concerns the Cambrian time (see comprehensive descriptions *in* BELKA & *al.* 2000, 2002). In the Late Silurian the Łysogóry Unit was most probably part of the vast, south-western shelf of Baltica (TOMCZYK 1988). The main arguments for this interpretation are as follows (see also DADLEZ & *al*. 1994):

1. The Małopolska Massif, fringing the Łysogóry Unit to the south, was already in its present-day position in the Late Silurian in relation to Baltica (NAWROCKI 1999).
2. The Silurian successions of Łysogóry and in the SW part of the East Baltic Basin are very similar.
3. The Upper Silurian rocks of Łysogóry include fossils characteristic of Baltica, with strong similarities to those of Gotland and Podolia (compare: RÓŻKOWSKA 1962, STASIŃSKA 1970, ALBERTI & *al.* 1981, BIERNAT 1981, TOMCZYKOWA 1990).

According to the reconstruction of facies distribution in the East Baltic Basin (EINASTO & *al*. 1986; BAARLI & *al*. 2003), the nearshore part of the basin in the Late Silurian was occupied by a shallow sea with carbonate sedimentation, extending from Gotland, Estonia, Latvia, Lithuania, eastern Poland and Belarus, as far as Podolia. The area of carbonate sediments in Łysogóry was not connected with this zone (Text-fig. 8); it was separated by a relatively deeper basin dominated by deposition of graptolitic clays, as documented in several boreholes (e.g. Żebrak IG1 – Text-fig. 2, 8a-f) in N and E Poland (TOMCZYKOWA 1988). This introduces the problem of explaining the causes of the appearance of shallow water carbonate sedimentation off the Baltic littoral zone. The answer has to take into consideration a comparison of the rate of sedimentation and subsidence during sedimentation of the two large Silurian complexes along the edge of Baltica. The pelagic graptolitic shales, which dominated from the Ordovician to the Early Ludlow, represent relatively deep-water facies of the outer shelf near the continental margin (Text-fig. 9a), as documented by the appearance of lydites, graptolites, lack of benthic fauna, etc. (for discussion see BAARLI & *al*. 2003). The regional occurrence of greywacke sediments at the beginning of the Ludlow dramatically changed the bathymetry of the basin. The distribution of the greywacke facies, and its decreasing thickness north-eastwards, suggest transport, probably by turbidity currents flowing mainly from the south-west (JAWOROWSKI 1971, 2000). The supply of large quantities of detrital material (deposition rate > 400 m/Ma) stopped the sedimentation of graptolitic clays and gradually filled the basin (Text-fig. 9b), making the environment appropriate for shallow water deposition. Another consequence of the fast rate of sedimentation was the development of loading subsidence. This is testified by the high rate of sedimentation of the Rzepin Beds (average deposition rate > 200 m/Ma), developing in a constantly small accommodation space (shallow marine/lagoonal/fluvial deposits – KOWALCZEWSKI & *al.* 1998, KOZŁOWSKI 2000). The clastic wedge that developed along the south-western margin of the Baltica shelf became the basement for shallow marine (i.e. oolitic) sedimentation not only in Łysogóry (Text-fig. 9c), but also in other analogous areas, as recorded in well-cores located NW of the Holy Cross Mts (TOMCZYK 1987).

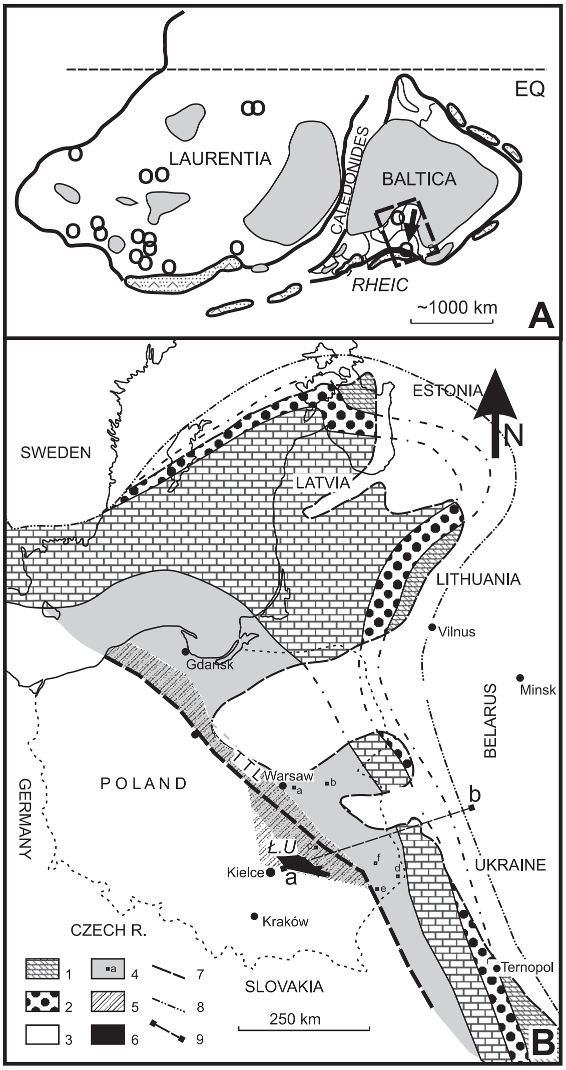

Fig. 8. **A:** Interpreted palaeogeography of the Late Silurian Baltica and Laurentia (modified after WITZKE 1990) with location of discussed area. Continental margins and distribution of land areas – shaded area, o – carbonate oolites, ^. – mountainous terrains, EQ – probable position of palaeoequator. **B:** Palaeogeographical map of the Baltic Region in late Silurian time (Base maps: BASSETT & *al.* 1989; JAWOROWSKI 1971; TOMCZYKOWA 1988): 1 - lagoon zone ; 2 – barrier zone ; 3 – shallow shelf zone ; 4 - deep shelf zone, a-f – main boreholes with Ludfordian graptolitic shales: a – Okuniew IG1, b – Żebrak IG1, c - Ciepielów IG1, d - Terebin IG5, e - Narol IG1, f - Łopiennik IG1 ; 5 – distribution area of greywacke facies in Ludlow (clastic wedge); 6 – probable distribution of shallow marine facies in the distal part of the Baltica Shelf - distribution area of the Jadowniki Formation – arrowed; 7 – present erosional boundaries of the Silurian sediments; 8 – coastal line of Baltica in Late Silurian, 9 – line of the transect in Text-fig. 9; ŁU – Łysogóry Unit

The massive deposition of the greywackes was not the only factor leading to the formation of shallow marine environments in Łysogóry. The predominance of reworked ooids, abundant lithoclasts of oolites and green shales (similar to the underlying deposits of the Trochowiny Shales) and abundant fossil plant detritus, may indicate that parts of the basin underwent subaerial exposure. However, the intense subsidence regime would not have favoured such processes but, on the contrary, would have caused rapid burial of the deposited sediments. An alternative explanation is that the filling up of the Łysogóry basin was followed by a decrease in the accommodation space as a result of eustatic factors. In fact, JOHNSON & *al*. (1998) locate a distinct regressive event in the upper part of the *Formosograptus formosus* Zone. The combination of both factors (eustatic and sedimentary) could have lead not only to shallowing of the basin, but also to the formation of small land areas on top of the clastic wedge. This is also testified by the abundant plant macrofossils in the Winnica complex (KOZŁOWSKI 2000; BODZIOCH & *al*, *in press*)

These arguments supply an important palaeobathymetric correction in modelling the peripheral parts of the Silurian shelf basin of SW Baltica (compare with POPRAWA & PACZEŚNA 2002). The extreme thickness of the greywacke deposits can not be treated as a direct measure of tectonic subsidence. It resulted from deposition of large quantities of clastic material, filling up the whole of the accomodation space of the basin and, at the same time, causing an increase of subsidence rate.

CONCLUSIONS

1. In the Łysogóry Unit (Holy Cross Mountains) sedimentation of the greywackes of the Wydryszów Beds was terminated by uppermost Ludfordian oolitic deposits of the Jadowniki Formation (JF).
2. The rocks of the JF are autochthonous and were deposited in extremely shallow – barrier - environments.
3. The Upper Silurian oolite deposits of the Łysogóry Unit do not belong to the nearshore shallow marine carbonates of Baltica; they are separated

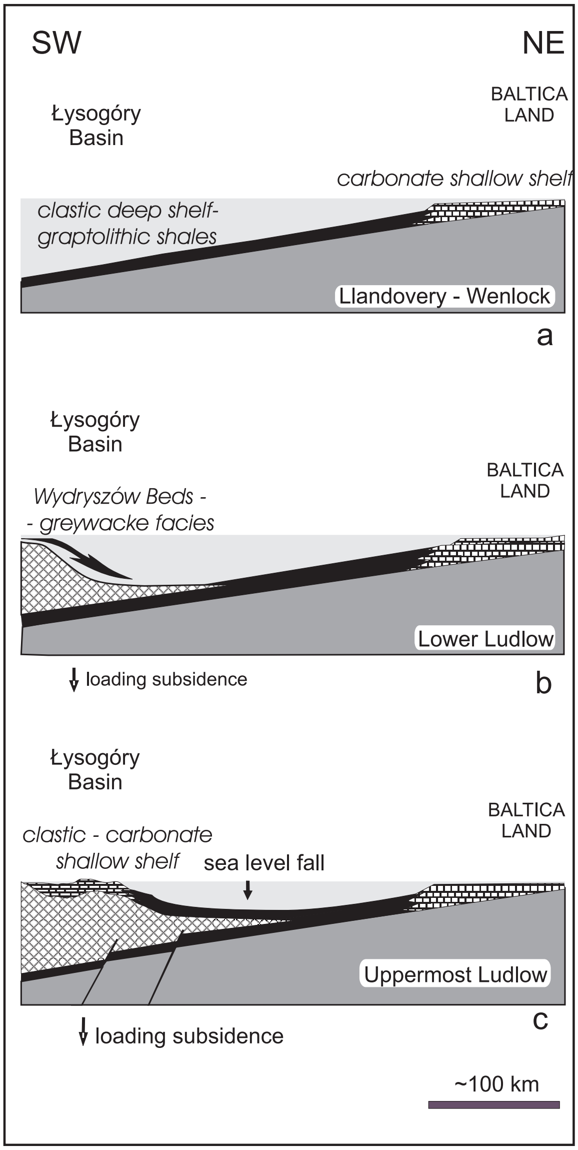

Fig. 9. Cartoon history of the development of the SW Baltica Shelf margin in the Silurian (a-b line on Fig. 7), and palaeogeographical position of the Jadowniki Formation in Silurian succession of Baltica Shelf Basin

from them by a belt of graptolitic shales. The oolites of the JF were probably connected with the margins of islands that formed along the SW edge of the Baltica shelf (JAWOROWSKI 1971, 2000).

4. The crucial factor leading to the development of shallow water sedimentation in the Łysogóry Unit was the intense sedimentation of greywackes, which caused infilling of the 'graptolitic basin' and the formation of a clastic wedge. The loading of the peripheral part of the Baltica shelf resulted in increased subsidence.
5. In the latest Ludlow, the sedimentary factor leading to the decrease of the accommodation space, probably overlapped with an eustatic regresion. This would have lead to the subaerial exposure of the oolitic (and also older) deposits and the formation of small land areas on top of the clastic wedge, which was located in an intense subsidence regime. The regression in question may correspond to the regressive event noted by JOHNSON & *al*. (1998) in the upper part of the *Formosograptus formosus* graptolite Zone.

Acknowledgments

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APPENDIX

Description of exposures of the Jadowniki Formation

The older publications on the Upper Silurian rocks in Łysogóry concentrated on the occurrences of fossils and their stratigraphical value. Because these papers provide only limited details about exposures (location, lithology and facies succession), the author decided to present short descriptions of the exposures, including their precise location (see also Text-figs 1 and 3).

Stara Słupia: The exposure is situated *ca.* 1.4 km NE of Nowa Słupia, on the southern side of the road passing through the hamlet of Winnica towards the valley. The Upper Silurian deposits were noted on the fields and in a in the right bank of the Słupianka valley.

In the southern (older) part of the succession comprises a complex of olive-coloured clay shales with intercalations of thin-bedded siltstones with numerous muscovite flakes. Sporadic beds of brown sandstones with crushed fossils have also been found. The complex, referred to here as the Trochowiny Shales, is more than 25 m thick.

The overlying Jadowniki Formation comprises (in stratigraphical order):

1. Brownish-grey sandstones, locally calcareous, with numerous bryozoans, brachiopods, tentaculitids, crinoids and bivalves, numerous lithoclasts of green shales and muscovite flakes (thickness: 10 m).
2. Grey sandy limestones with numerous fossils comprising bryozoans, brachiopods, trilobites, gastropods, crinoids and bivalves. The rocks contain muscovite and numerous lithoclasts of green shales, concentrated at some horizons. Thin beds of yellow sandstones with abundant plant debris, large fragments of crinoid arms and bivalves are also present (thickness: 5 m).
3. Thin-bedded oolites with crushed fossils comprising bryozoans, brachiopods, trilobites, gastropods, crinoids and bivalves. In the upper part occur intercalations of oolitic-sandy limestones that are generally devoid of fauna apart from *Scolithos* isp (thickness: 5 m).

The sandy-oolitic complex (~20 m) is overlain by red and olive-green bioturbated clay shales with plant debris as well as abundant muscovite and leperditicopid ostracods. In the lowermost part of the shales there are intercalations of thin beds of red limestones with numerous leperditicopid ostracods. These shales with limestone intercalations are considered to be the lowermost part of the Winnica complex - up to 100 m thick, and better exposed in the Winnica section (KOZŁOWSKI 2000) about 50 m north-westwards.

Romański Quarry (Rzepin): The exposure is located *ca.* 1.7 km westwards of the bridge over the Świślina River on the Starachowice – Kielce road. On the right-hand side of the ravine of the right-hand, unnamed tributary of the Świślina, which flows southwards parallel to the houses of the village of Jadowniki Dolne, there is an abandoned quarry. In the 1950s, hard, thick-bedded, almost vertical beds of calcareous sandstones were quarried here for road grit for local purposes. These rocks were included by SAMSONOWICZ (1936) in the Middle Devonian, by CZARNOCKI (1957a, p. 46, Fig. 8) in the Lower Rzepin Beds, and by FILONOWICZ (1968) in the Upper Rzepin Beds.

In the lowermost part of the exposure occur olive-green clay shales with muscovite, intercalated with rare beds of brown sandstones with fragments of fossils (Trochowiny Shales). They are overlain by the Jadowniki Formation (10 m), comprising (in stratigraphical order):

1. Yellow sandstones, with abundant muscovite and internal moulds of bivalves (thickness: 2 m).
2. Grey calcareous sandstones, with numerous large gastropods and bivalves in the lowermost part, and bryozoans, brachiopods and crinoids towards the top. Lithoclasts of green shales are abundant (thickness: 1 m).
3. Grey oolites with abundant, partly crushed fauna comprising bryozoans, brachiopods, trilobites, tentaculitids, gastropods, crinoids, inarticulate brachiopods, bivalves and remains of agnathans. The rocks contain numerous lithoclasts of green shales concentrated at some levels (thickness: 3.25 m).
4. Oolitic-sandy limestones, generally devoid of fauna, with numerous fenestral structures filled with sparite, locally interbedded with oolites containing crushed fossils. Single planes contain leperditicopid ostracods and brachiopods (thickness: 3.75 m).

The Jadowniki Formation is overlain by the Winnica complex - ca. 90 m thick fine clastics with leperditicopid and beyrichid ostracods, bivalves, eurypterids, agnathan remains, and plant debris. The carbonate intercalations contain ostracods, bivalves, gastropods and *Girvanella* nodules; rarely brachiopods, stromatoporoids, crinoids and tabulates. In the upperrmost part, c*a.* 85 m above the base, Winnica complex contain a 40 cm thick bed of oolites, in the upper part cross-bedded, with numerous brachiopods, crinoids, bryozoans and trilobites.

Bełcz: The exposure lies *ca.* 250 m eastwards of dwellings of the Bełcz vilage, *ca.* 7 km NW of Opatów, in the right bank of the Opatówka river. The lithological succession is as follows:

1. Cherry-coloured, locally olive-green clay shales, interbedded with grey sandstones with muscovite (thickness: 0.7 m).
2. Pink marly oncolitic-oolitic limestones with abundant fossils (thickness: 0.5 m).
3. Pink marls with numerous large oncoids (thickness: 0.4 m).
4. Pink oncolitic-oolitic limestones (thickness: 0.2 m).
5. Pink oncolitic-oolitic marls (thickness: 0.1 m).
6. Oolites, thinly bedded, with crushed fossils (thickness: 0.5 m).
7. Olive-green marls interbedded with pink, thin-bedded oncolitic-oolitic limestones (thickness: 0.3 m).
8. Olive-green clay-marly shales (thickness: 0.4 m).

This succession is covered by the complex of red shales with green mudstones and sandstone intercalations red shales with green mudstone and sandstone intercalations (more than 10 m).

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Plate 1

1 – General view of facies A – oolite with bioclasts, Rzepin, sample: R1a, × 20

2 – General view of facies D – calcareous quartz sandstone with ooids, note numerous ooids under brachiopod valve, Stara Słupia, sample: Sł 2, × 20.

3 – General view of facies B – oolitic oncolite, note different size and random orientation of allochems, Bełcz, sample: B1, × 12.

4 – Large, rod-shaped ooid, facies B, Bełcz, sample: B1, × 20.

5, 6, 7, 8 – Reworked ooids in facies A: 5 – micritized ooid (compare with ooid in lithoclast in Pl 1/12) with three laminae of new cortex; 6-8 – dissolved ooids with new thin cortex, note displaced ooid nuclei (quartz grains); 5 – Rzepin, sample: R1b, × 40; 6,7,8 - Stara Słupia, sample: Sł3, × 40.

9 – Small oolite intraclast. Facies A, Stara Słupia, sample: Sł3, × 40.

10 – Oolite fragment with a new thin lamine of the cortex, note stylolitic seam between two ooids in nucleus, facies A, Stara Słupia, sample: Sł3, × 40.

11 – Small oolite fragments as ooid nuclei, note irregular (gravitational ?) cement inside ooid, facies A, Stara Słupia, sample: Sł3, × 40.

12 – Mudstone lithoclasts with micritized ooid, facies A, Stara Słupia, sample: Sł3, × 40.

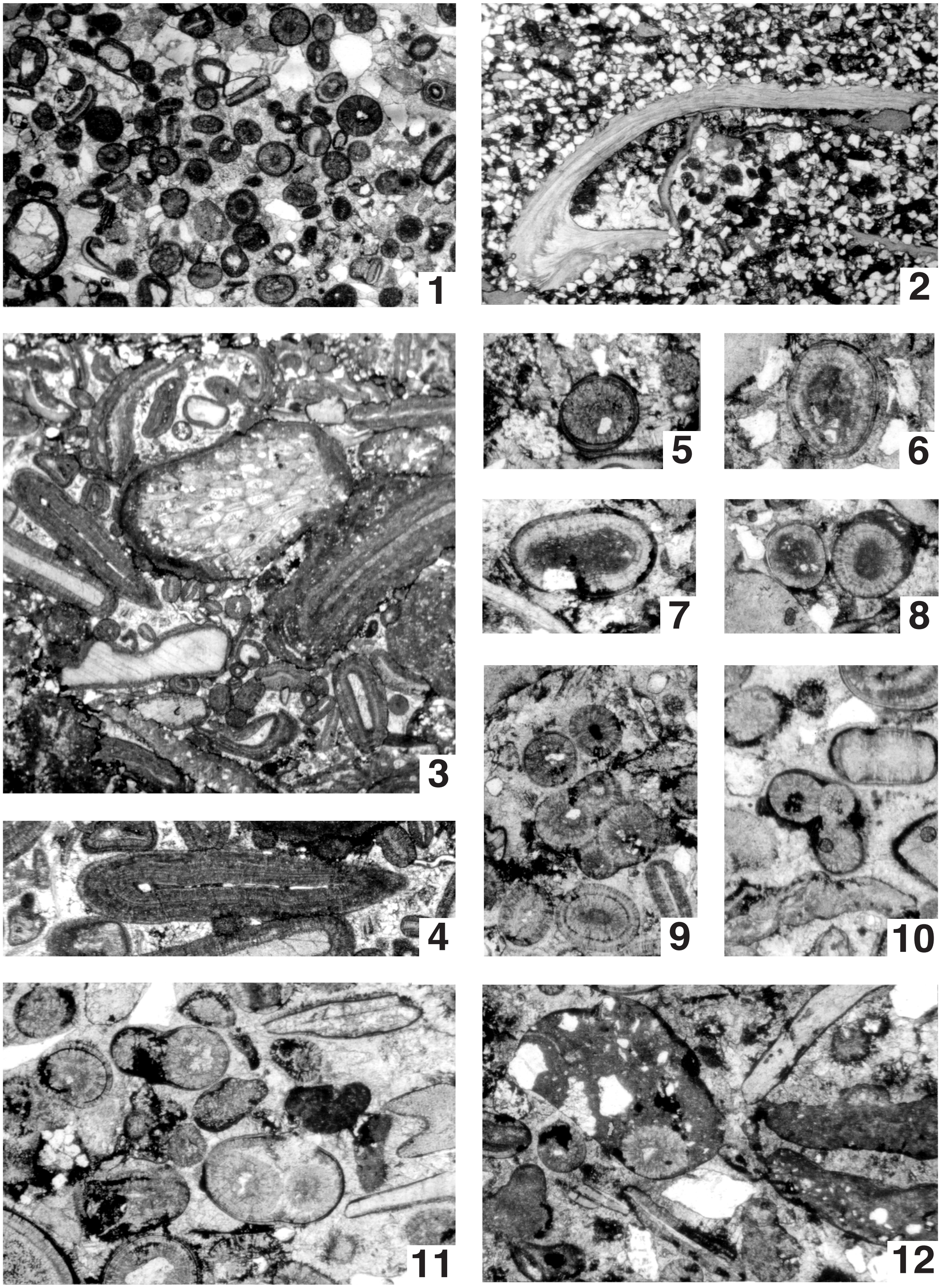
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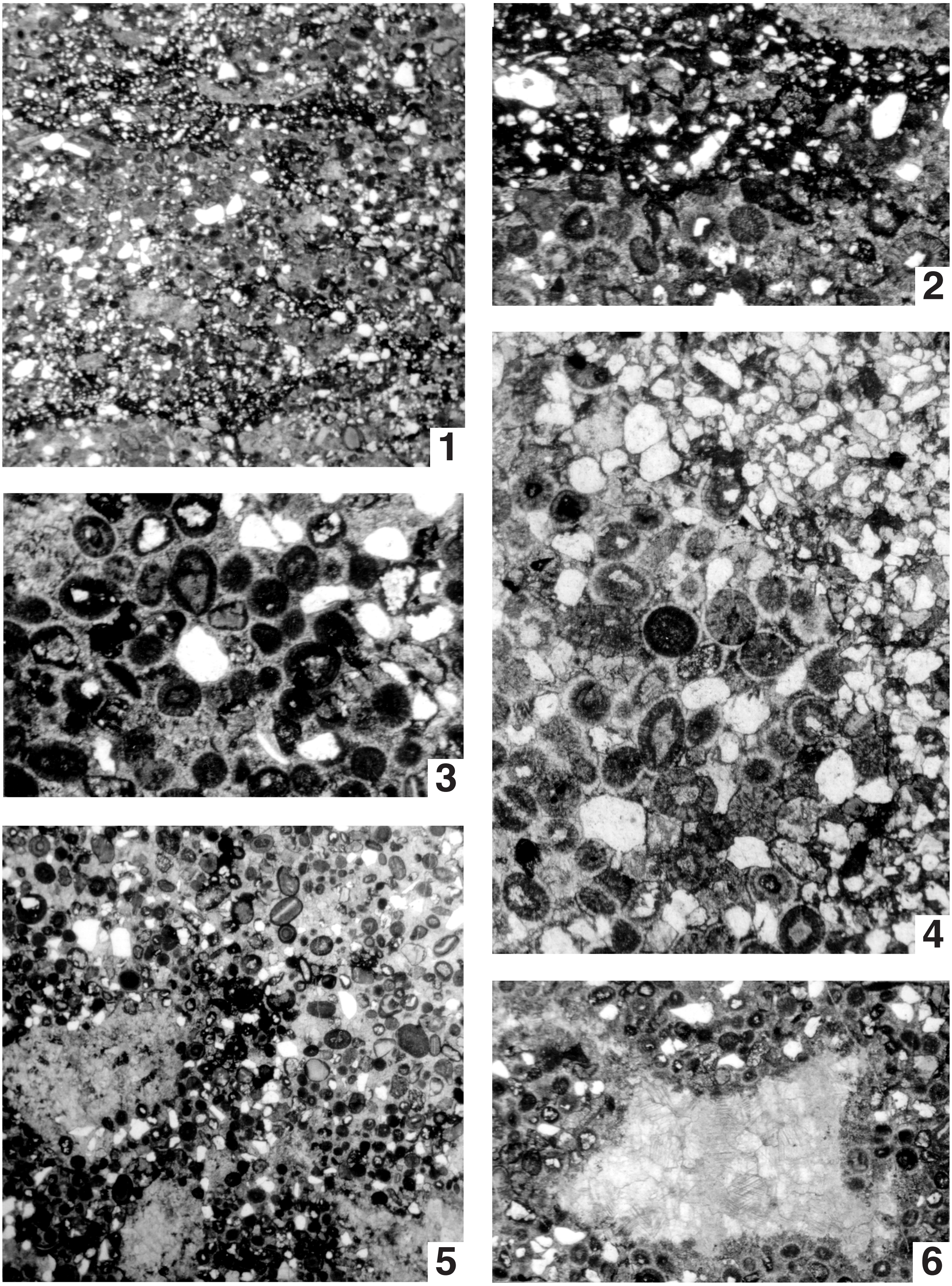
Plate 2

1 – View of limestone texture with "in situ lithoclasts", facies C, Rzepin, sample: R4, × 12.
2 – Truncated ooid with cement on the edge of oolite "in situ lithoclast", facies C, Rzepin, sample: R4, × 40.
3 – Isopachous and irregular (gravitational ?) rim cements around ooids, facies C, Rzepin, sample: R4a, × 40.
4 – Lithoclast of oolite without bioclasts (facies C) in facies D, note truncated ooids and cements, Stara Słupia, sample Sł3, × 40.
5 – Variable packing of allochems in oolites of facies C: k – keystone vug (?), g – grain-supported structure, m – "matrix-supported" structure, Rzepin, sample: R4a, × 20.
6 – Fenestral structure in oolite – keystone vug (?), facies C, Rzepin, sample: R4a, × 40.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