Acta Geologica Polonica, Vol. 52 (2002), No. 3, pp. 365-378

Depositional evolution of the Middle Jurassic carbonate sediments in the High-Tatric succession, Tatra Mountains, Western Carpathians, Poland

PIOTR ŁUCZYŃSKI

Institute of Geology, Warsaw University, Al. Żwirki i Wigury 93, PL-02-089 Warszawa, Poland.
E-mail: achmed@geo.uw.edu.pl

ABSTRACT:

ŁUCZYŃSKI, P. 2002. Depositional evolution of the Middle Jurassic carbonate sediments in the High-Tatric succession, Tatra Mountains, Western Carpathians, Poland. *Acta Geologica Polonica*, **52** (3), 365-378. Warszawa.

Facies development and tectonic history of the High-Tatric Middle Jurassic resembles that of other regions of the Jurassic Tethys (e.g. Southern Alps, Spain). The Triassic carbonate platform disintegrated and divided into a system of horsts and grabens. Syndepositional extensional movements controlled the deposition. During the Aalenian carbonate-clastic sedimentation took place. During the Bajocian crinoidal meadows developed over most of the High-Tatric area. The Bathonian deposits belong to three main lithofacies: crinoidal, ferruginous and nodular limestones. The crinoidal limestones formed by deposition of pelmatozoan material transported over the sea-bottom in the form of megaripples. The ferruginous limestones developed in zones of restricted sedimentation, which were located above the areas of crinoid deposition that surrounded elevated blocks supplying terrigenous material. The nodular limestones represent deeper facies that were deposited on a slope descending towards a deep-sea basin. The Callovian wavy-bedded limestones mark the onset of pelagic deposition, which continued during the Late Jurassic.

Key words: Middle Jurassic, Tatra Mountains, Western Carpathians, Carbonate deposition, Palaeogeography, Crinoidal limestones, Synsedimentary block-faulting.

INTRODUCTION

The aim of this work is to reconstruct the depositional history of the High-Tatric domain during Middle Jurassic time. It focuses on the Bajocian/Bathonian Dunajec Formation, but some attention is paid also to the Aalenian and Callovian deposits, which however were not a subject of detailed field analysis. The Middle Jurassic represents a distinct phase of the area's history, during which an extensive carbonate platform was subjected to disintegration into a system of horsts and grabens. A similar process is typical of many regions of Jurassic Tethys (e.g. Southern Alps, Spain). Comparing the depositional development of various regions may contribute to a better understanding of the Middle Jurassic palaeogeography of the Tethys, and therefore the author hopes that the presented results will be valuable both for readers interested in the geology of the Tatra Mts., and for those studying other regions.

GEOLOGICAL SETTING AND STRATIGRAPHIC FRAMEWORK

The Tatras are the northernmost of the so-called core mountains of the Central Western Carpathians. On its northern slopes the Variscan crystalline massif is covered by autochthonous and allochthonous Permo-Mesozoic sedimentary rocks. They represent two major successions (or series) that differ substantially in their

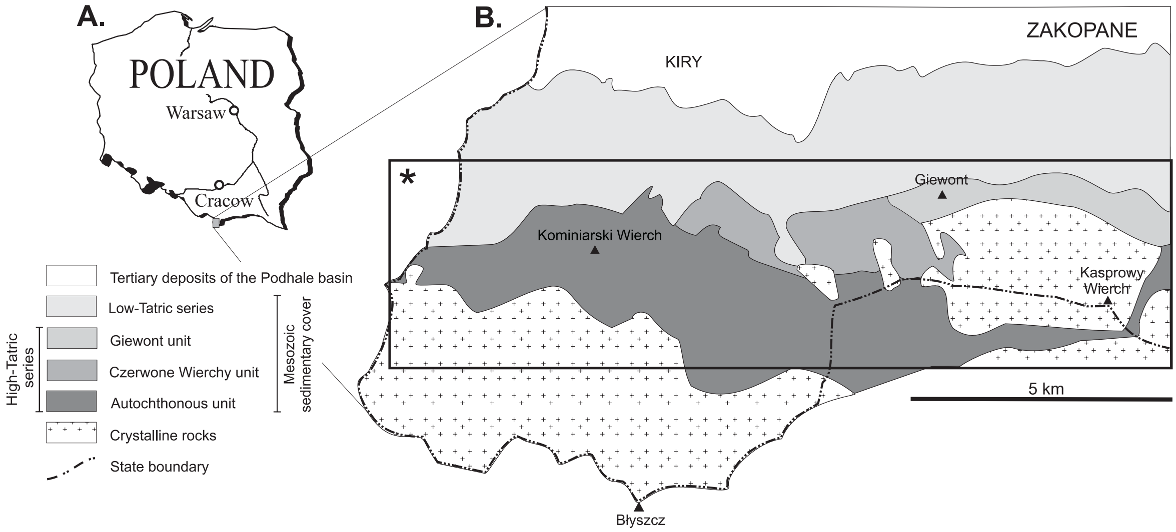


Fig. 1. Structural map of western part of the Polish section of the Tatra Massif (B), and its geographic location (A). Box (*) shows the area enlarged on Text-fig. 3

facies development. The High-Tatric succession, resting on the crystalline massif, is represented mainly by relatively shallow-water facies, with numerous hiatuses. The more continuous Sub-Tatric series, covering the High-Tatric succession, is composed of deeper facies and is stratigraphically more complete.

The High-Tatric series consists of both autochthonous and allochthonous rocks, which belong to three major tectonic units (Text-fig. 1): Kominy Tylkowe (autochthonous), Czerwone Wierchy and Giewont units (allochthonous or foldic). The Kominy Tylkowe unit is divided further into the autochthonous unit *sensu stricto*, with the sedimentary rocks lying in their original position in relation to the crystalline core, and the parautochthonous folds, where the rocks have been detached and moved for minor distances. The allochthonous units were detached from their basement and overthrust northwards during the Alpine orogeny. Palaeogeographically they represent areas situated south of the autochthonous series. The palaeogeographic domain of the High-Tatric series is commonly referred to as Tatricum (KOTAŃSKI 1979).

In the Kominy Tylkowe unit the stratigraphic succession is complete across the Triassic/Jurassic boundary and the Lower Jurassic is developed as sandy-carbonate deposits of the Dudziniec Formation (RABOWSKI 1954, KOTAŃSKI 1959, RADWAŃSKI 1959a, Z. WÓJCIK 1959 and K. WÓJCIK 1981). The chronostratigraphy of this formation is unclear. HORWITZ & RABOWSKI (1922) determined its age as Sinemurian through Bathonian, based on the belemnite and brachiopod fauna. However, based on the presumed Bajocian age of the overlying Smolegowa Formation, documented mainly in the Pieniny Klippen Belt (BIRKENMAJER 1977), the upper boundary of the

Stage(s)	Formation	Group
Callovian – Tithonian	Raptawicka Turnia	Kominy Tylkowe
Bathonian	Krupianka	Dunajec
Bajocian	Smolegowa	
Hettangian - Aalenian	Dudziniec	-

Table 1. Litostratigraphy of the High-Tatric Jurassic (after LEFELD & *al.* 1985)

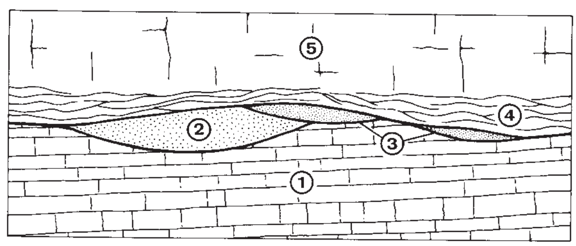


Fig. 2. Idealised spatial relations between the Middle Jurassic lithosomes in the High-Tatric foldic units; **1** – Middle Triassic limestones and dolomites, **2** – white coarse crinoidal limestones of the Smolegowa Formation (Bajocian), **3** – red ferruginous and crinoidal limestones of the Krupianka formation (Bathonian), **4** – Wavy-bedded limestones of the Raptawicka Turnia Formation (Callovian), **5** – Massive limestones of the Raptawicka Turnia Formation (Oxfordian)

Dudziniec Formation is here supposed to be of Bajocian age (Table 1).

In the Czerwone Wierchy and Giewont units a major stratigraphic gap occurs above the Middle Triassic (Anisian) limestones and dolomites, which are penacordantly covered by Middle Jurassic deposits of the Smolegowa, or overlain directly by the Krupianka and the Raptawicka Turnia formations (Text-fig. 2). The Smolegowa Formation, and particularly the Krupianka Formation are preserved as laterally discontinuous, lenticular bodies, with their thickness ranging from a few centimetres to about 2 m. In numerous places they are missing, or are limited to neptunian dykes only (ŁUCZYŃSKI 2001a). The same formations exposed in the autochthonous unit, where they occur in sedimentary continuity with the underlying Dudziniec Formation, are usually more continuous and are up to several metres thick.

The Smolegowa Formation is uniformly developed as massive, white, light grey and pinkish, coarse crinoidal limestones. The deposits have been referred to as *weisser Doggercrinoidenkalk* by UHLIG (1897) and "white Bajocian crinoidal limestones" by i.a. HORWITZ & RABOWSKI (1922), ANDRUSOV (1958-1965), RABOWSKI (1959), KOTAŃSKI (1959, 1961) and MIŠIK (1966). Their age was determined as Bajocian by HORWITZ & RABOWSKI (1922) on the basis of the brachiopod fauna (Table 1).

The Krupianka Formation occurs in three major lithofacies – crinoidal, ferruginous and nodular limestones with gradual transitions between them. Common features of all three lithofacies are: intensively red colour; occurrence of more or less rich pelmatozoan material; and a relatively abundant terrigenous content. The actual differences between them are mostly an effect of late diagenetic pressure solution and compaction (ŁUCZYŃSKI 2001b).

In spite of the lithological variety, all red limestones overlying the Smolegowa Formation, or resting directly on the Triassic, have been referred to as *rother Doggercrinoidenkalk* by UHLIG (1897) and "red Bathonian crinoidal limestones" by i.a. HORWITZ & RABOWSKI (1922), PASSENDORFER (1935, 1938), ANDRUSOW (1950), RABOWSKI (1959), KOTAŃSKI (1961) and SZULCZEWSKI (1963a, 1963b, 1965, 1968). They were assigned to the Middle Bathonian *Hecticoceras retrocostatum* Zone, based on the rich ammonite fauna from Wielka Świstówka (PASSENDORFER 1935, 1938). The Middle Bathonian age of the Krupianka Formation was recently confirmed by GALACZ & MATYJA (1999).

The basal, wavy-bedded part of the Raptawicka Turnia Formation (Table 1) yielded Callovian ammonites (HORWITZ & RABOWSKI 1922; PASSENDORFER 1935, 1938). However, the Callovian/Oxfordian boundary, which is traditionally placed at the transition to the overlying massive limestones (RABOWSKI 1959; KOTAŃSKI 1959, 1961), has no palaeontological basis.

BAJOCIAN AND BATHONIAN OF THE HIGH-TATRIC SERIES

Bajocian and Bathonian deposits occur in all tectonic units of the High-Tatric series. They crop out in three distinct, approximately latitudinal bands. The sections of the autochthonous series are accessible in the Chochołowska Valley (Pl. 1, Fig. 3), in the Kominy Tylkowe massif (Pl. 1, Fig. 2) and in the Kraków gorge (Text-fig. 3). The outcrops belonging to the parautochthonous folds are located at Rzędy pod Ciemniakiem (Pl. 1, Fig. 1; Text-fig. 3). The sections of the Czerwone Wierchy unit are accessible in the Kościeliska Valley, and in the Mała and Wielka Świstówka cirques (Pl. 1, Figs 4-5) in the Miętusia Valley (Text-fig. 3). In the Giewont unit the sections studied lie along the southern slopes of the Giewont and Zawrat Kasprowy crests (Text-fig. 3).

Smolegowa Formation

Development. The Smolegowa Formation of the High-Tatric series is uniformly developed as white, grey and pinkish, coarsely crystalline, massive crinoidal limestones. Faint and irregular bedding occurs only at Rzędy pod Ciemniakiem and in the Chochołowska Valley. Recrystallised pelmatozoan elements, locally accompanied by abundant debris of brachiopod shells, make up almost 100% of the rocks. The limestones are grain-supported - mostly crinoidal grainstones, built of syntaxial calcite crystals developed on individual pelmatozoan elements (Pl. 2, Fig. 2), only locally accompanied by crinoidal, crinoidal-brachiopod and brachiopod packstones (Pl. 2, Fig. 3). The micritic content is substantially higher in the western part of the autochthonous unit. In most localities the crinoidal material is accompanied by a sparce terrigenous component. At Rzędy pod Ciemniakiem the formation starts with a layer rich in ferruginous (hematite) encrustations, clasts and nodules. In other cases, the ferruginous compounds are limited to extraclasts and concentrations on pressure solution structures.

The Smolegowa Formation is poor in macrofauna other than pelmatozoan fragments (GŁUCHOWSKI 1987), which are locally accompanied by brachiopods (mainly rhynchonellids) and bivalves (HORWITZ &

RABOWSKI 1922). The micritic parts contain the so-called filaments, interpreted as scattered fragments of thin-shelled *Bositra* bivalves (OSCHMANN 1994, WIERZBOWSKI 1994), and rare foraminifers. The overwhelming majority of the pelmatozoan material consists of separated crinoid stem fragments. The individual elements are usually well preserved and retain their original circular or pentagonal shapes. Their sizes range from 0.5 up to 1.5 cm. Also present are unseparated fragments of crinoid stems and branches (GŁUCHOWSKI 1987).

Depositional environment. The Smolegowa crinoidal limestones reveal a lot of features indicating the autochthonous character of their deposition, in the immediate vicinity of crinoidal meadows.

The taxonomic diversity of the Smolegowa limestones crinoidal assemblage is relatively high (GŁUCHOWSKI 1986, 1987). The specimens are large, which, together with their mass occurrence, points to very favourable conditions for the development of crinoidal meadows (WENDT 1988). The very strong concentration of crinoid fragments in the deposits and their good state of preservation, preclude the possibility of longer transport (JENKYNS 1971a, MIŠIK & *al.* 1994). Light crinoids are very easily transported, and even moderate transport causes their disintegration into individual elements. Therefore, the occurrence of unseparated stems and branches is regarded as an indicator of *in situ* deposition (MIŠIK & *al.* 1994).

The occurrence of a scarce terrigenous component indicates that fine clastic material was delivered into the basin, which points to good water circulation and hence good oxidation and nutrient supply. On the other hand the terrigenous input was not strong enough to disturb crinoid deposition. The Smolegowa crinoidal limestones are unbedded and very uniformly developed, which probably indicates a high deposition rate. The fragmentary preservation of the deposits in the foldic units is probably an effect of differential post-Bajocian erosion, which removed the Smolegowa Formation from large areas.

The domain of crinoid deposition covered the whole area of the High-Tatric series. The sediments were deposited below wave base. Probably, however, they must have been affected by storms, during which the crinoid material was repeatedly removed, uncovering a solid substrate, necessary for the continuation of development of the crinoidal meadows. The limestones cropping out in the western part of the autochthonous unit are slightly different from their counterparts in other areas. The main attributes that distinguish them are lower content of crinoid material in favour of micrite, and its poorer state of preservation. These rocks represent a slightly deeper part of the basin, located below the storm wave base, into which the crinoids were winnowed.

Krupianka Formation

Crinoidal limestones

Development. The Krupianka Formation is developed as crinoidal limestones in the Giewont unit, in the parautochthonous folds and in part of the autochthonous unit *sensu stricto*, where they occur subordinately within the nodular limestones sequence. The rocks are composed mainly of fine pelmatozoan material, the content of which ranges between 30 and 80%, and contain a rich terrigenous component. They are commonly cut by erosion surfaces. The limestones are usually mud-supported, and are represented by crinoidal, crinoidal-brachiopod, crinoidal-filamentous (Pl. 2, Fig. 4) and filamentous (Pl. 2, Fig. 5) packstones and wackestones. Only locally the rock is grain-supported, and is developed as crinoidal and crinoidal-lithoclast grainstones.

A characteristic feature of the Krupianka crinoidal limestones is their intensely red colour caused by disseminated ferruginous compounds (Table 2). Its intensity of coloration is positively correlated with the abundance of the terrigenous component. Ferruginous (hematite) clasts and clasts with hematite envelopes are common. Nonetheless, the rocks are almost completely devoid of any evidence of *in situ* hydrogenic ferruginous mineralization. The only exceptions are encrustations on stromatolites.

The macrofauna is relatively rich but poorly preserved. Apart from pelmatozoans, the rocks contain common stromatolites, belemnites and brachiopods, accompanied by rare gastropods (PASSENDORFER 1935, 1938). Agglutinating foraminifers and filaments are common, accompanied sporadically by poorly preserved radiolarians and algal fragments. The skeletal elements of the pelmatozoans are strongly fragmented and abraded (rounded after separation). The original circular or pentagonal shapes of individual crinoid segments are usually not preserved. Most commonly the crinoids do not exceed 5 mm in diameter. Distinctly larger specimens occur only in the vicinity of the Wrótka Pass in the Giewont crest (Pl. 3, Fig. 1).

The Krupianka crinoidal limestones are variously developed across the High-Tatric series. At Zawrat Kasprowy they are characterised by the highest content of well preserved pelmatozoan elements, and by the

Type of ferruginous compounds concentration		Lithologic variety	
	Ferruginous limestones	**Crinoidal limestones**	**Nodular limestones**
Disperced in the micritic matrix	very strong	very strong	strong
Encrustations	common	only sporadic on stromatolites	no
Laminated nodules	common	no	no
Coatings on extraclasts	very common	very common	rare
Coatings and incrustations of macrofossils	very common	common	rare
Authigenic crystals of ferruginous minerals	very common	common	rare
Colloidal concentrations	common	no	no
Stromatolites with *Frutexites*	very common	common	no
***Frutexites* outside of stromatolites**	common	no	no
Incrustations of microfossils	very common	very common	very common
Concentration on pressure solution structures	very strong	very strong	very strong in the matrix

Table 2. Occurrence of ferruginous compounds in various lithofacies of the Krupianka Formation.

paucity of the terrigenous component and ferruginous compounds. Typical features of the exposures in the Giewont crest are stromatolites, a relatively rich terrigenous component and abundant belemnites and brachiopods. The sections of the autochthonous unit contain rich extraclasts and ferruginous compounds.

Depositional environment. The Krupianka crinoidal limestones show a lot of attributes pointing to the allochthonous character of their deposition.

Compared with that of the Smolegowa Formation the pelmatozoan assemblage of the Krupianka crinoidal limestones is relatively poor (GŁUCHOWSKI 1986, 1987), which, together with the small dimensions of the crinoids, indicates that the conditions were not particularly favourable for the development of crinoidal communities. The areas of crinoid deposition shrank substantially. Considerable fragmentation of the pelmatozoan fragments, together with their occurrence in a micritic matrix, point to winnowing of crinoids away from a high-energy environment. Transport of crinoids is very easy due to their low specific weight (JENKYNS 1971a, GŁUCHOWSKI 1987), and hence disaggregation of individual elements indicates long action of destructive processes (BLYTH CAIN 1968, WENDT & AIGNER 1985, MIŠIK & *al.* 1994). The crinoidal material content varies substantially within and between the sections, which was probably caused by variable intensity of wave action or variation in current direction. This, together with the relatively rich occurrence of brachiopods and belemnites, suggests deposition at substantial distances from the crinoid meadows, which were probably situated close to Zawrat Kasprowy crest, where the crinoid material is best preserved.

The abundant terrigenous component shows negative correlation with the state of preservation of the crinoidal material. The input of terrigenous material was probably so strong that it limited the development of the pelmatozoan communities. Moreover, the occurrence of common erosion surfaces points to an environment in which an undisturbed development of crinoidal meadows was impossible. In all of the exposures, the lithosomes of Krupianka crinoidal limestones show a characteristic lenticular shape, which have been interpreted as fossil "submarine dunes" (MIŠIK 1964, JENKYNS 1971a). Such a lithosome shape could, however, also be a result of differential post-Bathonian erosion, which removed the Bathonian sediments from most of the area, leaving it only in palaeodepressions.

In the opinion of GŁUCHOWSKI (1986) the Bathonian crinoidal limestones from both Pieniny and Tatry were deposited in zones below the crinoidal meadows, in deeper, low-energy environments. Some observations from the High-Tatric series contradict these conclusions. The pelmatozoan skeletons were probably not deposited in calm waters below the meadows, but rather were winnowed into shallow high-energy zones, as described in models presented i.a. by JENKYNS (1971a), RUHRMANN (1971) and WINTERER & *al.* (1991). The crinoid fragments became mixed with terrigenous material derived from the neighbouring elevated areas. Loose crinoid-lithoclast sand was transported over the sea bottom in the form of megaripples, which are probably reflected by the lenticular shape of the lithosomes. Large areas of the sea bottom either remained as omission surfaces, as is indicated by the long period separating the opening and filling of the neptunian dykes (ŁUCZYŃSKI 2001a), or they were covered by stromatolites. Winnowing of the fine material lead to the formation of lag deposits pack-filled with macrofauna – mainly belemnites. Migrating sandy material could cause local abrasion, reflected by flat erosional surfaces. Part of the area was probably also temporarily subjected to emersion, which is indicated by karstic phenomena observed in the neptunian dykes (ŁUCZYŃSKI 2001a).

Ferruginous limestones

Development. The Krupianka ferruginous limestones crop out only within the Czerwone Wierchy unit. The thickness of the Krupianka Formation developed in this microfacies does not exceed 1 m, and in Wielka Świstówka is limited to 10 cm. The ferruginous limestones form an internally variable group. They are developed as: detritic ferruginous limestone with crinoid debris (10%-30% of rock volume), a rich terrigenous component and common stromatolites (Mała Świstówka) resembling the crinoidal limestones of the Giewont unit; cephalopod ferruginous limestone ("Świstówka Passendorfera" section), where the rock is composed almost entirely of ammonites forming a 10-20 cm thick layer, capping the stromatolites; and ferruginous limestone, pervasively penetrated by pressure dissolution structures (Wielka Świstówka). The microfacies are represented mainly by crinoidal, crinoidal-lithoclast, crinoidal-filamentous and lithoclast wackestones, in places accompanied by crinoidal and crinoidal-lithoclast packstones.

Ferruginous limestones are the only variety of the Krupianka Formation that contains evidence of syndepositional, authigenic, *in situ* ferruginous mineralization (Table 2), such as: laminated ferruginous encrustations on erosion surfaces, stromatolites and ammonites; laminated nodules with a diameter of up to few centimetres (Pl. 4, Fig. 1) and authigenic hematite crystals (Pl. 4, Fig. 3). They are accompanied by ferruginous clasts (circa 40% of all extraclasts), envelopes on extraclasts (Pl. 4, Fig. 2) and bioclasts (Pl. 4, Fig. 4), and a red colour of the micritic matrix, which is known from other lithological varieties. The ferruginous compounds are concentrated in the rocks as a result of particularly intensive pressure dissolution (ŁUCZYŃSKI 2001b).

Ferruginous limestones are the most fossiliferous lithofacies of the Krupianka Formation. The ammonite-bearing exposure "Świstówka Passendorfera" is one of the most famous fossil localities in the Tatra Mountains. Also common are crinoids, belemnites, brachiopods (rhynchonellids) and thin-shelled bivalves (SZULCZEWSKI 1963a). The microfossil assemblage is very similar to that known from the crinoidal limestones and contains foraminifers, filaments and algal detritus.

Depositional environment. Extremely slow and discontinuous sedimentation of the Krupianka ferruginous limestones is indicated i.a. by common stromatolites (SZULCZEWSKI 1968, JENKYNS 1974, OGG 1981) and horizontally laminated ferruginous encrustations (JAANUSSON 1961, WINTERER & BOSSELINI 1981, JIMENEZ-ESPINOSA & *al.* 1997), as well as by ferruginous nodules, formed due to rolling over the sea bottom (WENDT 1974, ZYDOROWICZ & WIERZBOWSKI 1986), and encrustations on lithoclasts and bioclasts (TUCKER 1973, CRONAN & *al.* 1991). A low deposition rate is also confirmed by dissolution of the upper surfaces of ammonite shells (COMAS & *al.* 1981, CLARI & *al.* 1995), observed in Wielka Świstówka, and by their very rich concentration (WENDT 1973, 1988; WENDT & AIGNER 1985). Breaks in sedimentation are also indicated by ferruginous encrustations and calcite cements on the walls of neptunian dykes filled by Krupianka limestones (ŁUCZYŃSKI 2001a). The indications of slow deposition are found together, however, with an abundant terrigenous compounds, the input of which points to temporarily rapid sedimentation, possibly caused by seismic phenomena. After their deposition the clasts remained uncovered for a long time and were coated by ferruginous encrustations. Most of the clastic material of the Krupianka ferruginous limestones (limestone, dolomite and ferruginous clasts) may have come from two sources: erosion of the substrate within the Czerwone Wierchy unit in places of non-deposition, or from outside. Only the quartz grains must have been derived from outside the unit. The large dimensions and poor rounding of some of the extraclasts point to their short transport.

SZULCZEWSKI (1963a, 1963b, 1968) postulated the formation of the discussed deposits in very shallow zones, based mainly on the occurrence of stromatolites. However, nowadays it is known that the stromatolites formed in a wide spectrum of depths (i.a. HOFFMAN 1974, MONTY 1977, KENNARD & JAMES 1986, BÖHM & BRACKERT 1993, DROMART & *al.* 1994). Nonetheless, shallow-water deposition or even temporary emergence of the area are confirmed by the occurrence of erosion surfaces and by evidence of karstic phenomena in the neptunian dykes (ŁUCZYŃSKI 2001a). The character of accumulation of the echinoid material, and the microfaunal assemblage are similar to those in the contemporary crinoidal limestones, which are interpreted as having been deposited in a high-energy environment above the zone of crinoidal meadows. The area was, however, distant from the meadows, and therefore the inflow of crinoidal debris was reduced to a minimum.

Nodular limestones

Development. The Krupianka Formation is developed as nodular limestones only in the autochthonous unit. The limestones are mostly unbedded, attain the greatest thickness off all the Krupianka Formation lithofacies, and pass gradually into the under- and overlying deposits. They occur in two main varieties, passing continuously one into another.

The more common variety is limestone with lenticular nodules. The nodules have the form of horizontal lenses, usually 3-8 cm long and 1-2 cm high, and are composed of red and pink micritic limestone, sometimes with rich pelmatozoan and brachiopod debris. In some cases they are developed around ammonite shells that are usually partly dissolved. The nodules are densely packed, and the matrix thickness rarely exceeds 2 cm. The matrix is much richer in ferruginous compounds and in the terrigenous component, mainly quartz, than in the nodules; it is also more clayey and contains fewer microfossils. In addition, the concentration of pressure dissolution structures is different (ŁUCZYŃSKI 2001b): the nodules contain only scarce stylolites, while the matrix is densely penetrated by thick clay seams (Pl. 3, Fig. 4). The nodules are developed as crinoidal, crinoidal-brachiopod, crinoidal-lithoclast, crinoidal-filamentous and filamentous wackestones. The matrix can be treated as a pressure dissolution residuum, but where distinguishable, it occurs in the same microfacies as the nodules.

The second variety is limestone with sharp-edged nodules. Pink nodules of various sizes (circa 5 mm up to 10 cm) are randomly and relatively loosely spaced in the dark red matrix (Pl. 3, Figs 2, 3). The differences between the nodules and the matrix are smaller than in the lenticular variety. The matrix is slightly more clayey and richer in ferruginous compounds and pressure dissolution structures. Microfossils are equally frequent in the nodules and in the matrix. Both matrix and nodules are developed in the same microfacies, represented by filamentous, filamentous-peloidal, filamentous-crinoidal, crinoidal and crinoidal-lithoclast wackestones.

All of the ferruginous compounds in both varieties of the Krupianka nodular limestones are allochthonous (Table 2). Nonetheless, the rock exhibits an intense red coloration, which is caused by the presence of dispersed hematite, concentrated mainly in the matrix.

The faunal assemblage of the nodular limestones is similar to that of the other Krupianka Formation lithofacies. The content of pelmatozoan elements varies between 0 and 20%. Individual crinoids are small but well preserved, retaining their original pentagonal or circular shapes. In some sections unseparated fragments of stems and branches can be found. Ammonites and belemnites, preserved as nodules, are relatively common, as is a detritus of brachiopod (rhynchonellid) shells. In the lenticular variety the microfauna is almost entirely limited to the nodules. Common are filaments (in places up to 20-30% of the rock volume), and foraminifers accompanied by abundant radiolarians, which are absent in the other Krupianka Formation lithofacies. The matrix contains only very scarce microfauna, comprising single foraminifers and recrystallised filaments. The microfaunal assemblage of the limestone with sharp-edged nodules is similar to that in the lenticular variety; the microfossils, however, occur both in nodules and in the matrix, being richer in the former.

Depositional environment. The development of Krupianka nodular limestones is to a considerable extent the result of compaction and pressure dissolution processes (ŁUCZYŃSKI 2001b), which have largely obliterated the original texture of the sediment.

The nodular structure of the lenticular limestones formed without any transport factor, as is proved by the macrofossils (mainly belemnites) crossing the nodule/matrix boundaries, as well as by the uniform distribution, shapes and sizes of the nodules, and their dense packing. Among the depositional attributes mentioned as necessary for the formation of the nodular structure, the sediments were probably characterized by a suitable content of micrite and clay minerals (JENKYNS 1974), the occurrence of relatively abundant ammonites (WENDT & AIGNER 1985) and winnowing by bottom currents (SANTANTONIO 1993). Most probably the final factor causing precompactional heterogeneity of the deposits was a patchy distribution of early calcite cements. The sharp-edged nodules, on the other hand, show attributes indicating their syndepositional origin. The nodular structure formed by mechanical reworking of partly lithified sediments by bottom currents. Transport of individual nodules over limited distances is proved by a non-horizontal lamination within them (SZULCZEWSKI 1965). The original, postdepositional structure was overprinted by pressure dissolution (ŁUCZYŃSKI 2001b), which emphasised the lithological contrast between the nodules and the matrix.

The two varieties of nodular limestones were deposited in environments with different energies. This is indicated by a substantial difference in the terrigenous admixture component, which is rich in the sharp-edged variety and sparse in the stylonodular limestones, and by different preservation of the pelmatozoan material. The limestones with sharp-edged nodules represent a shallower depositional setting. They formed probably in the upper part of a submarine slope, in a zone with a rich input of terrigenous and crinoidal material that was subjected to intensive activity of bottom currents and possibly also to particularly strong storms. The lenticular variety formed in the deeper part of the slope. The occurrence of relatively abundant radiolarians and ammonites proves the proximity of, and good communication with an open deep-sea basin. Pelagic sedimentation was continuous and relatively fast. Small quantities of fine terrigenous material were supplied from shallower zones, together with much more abundant pelmatozoan fragments.

Stromatolites

Development. Bathonian stromatolites from the High-Tatric series were the subject of detailed studies by SZULCZEWSKI (1963b, 1968). In this paper only the basic attributes of their occurrence, development and relationship to other lithofacies of the Krupianka formation are discussed.

Stromatolites occur within the sections of crinoidal and ferruginous limestones in the allochthonous units and in the parautochthonous folds. Most commonly they form distinct polygonal layers, usually capping the Triassic or the Bajocian, or covering erosion surfaces within the Bathonian. Single domes are rare, and occur at definite horizons. The height of both the polygonal layers and individual domes does not exceed 10 cm, usually ranging between 3 and 7 cm. Stromatolites are commonly accompanied by oncolites. The polygonal layers have very distinct interstices (Pl. 3, Figs 5, 6), commonly infilled by abundant extraclasts (Pl. 3, Fig. 7). Rich terrigenous material occurs also in the deposits directly capping the stromatolites.

The laminae building the stromatolite domes contain abundant *Frutexites* – millimetre-size dendroidal concentrations of ferruginous oxides (Pl. 4, Fig. 5) of microbial affinity (MASŁOW 1960, SZULCZEWSKI 1968, WALTER & AWRAMIC 1979, BÖHM & BRACKERT 1993). Less commonly the *Frutexites* occur also outside the stromatolites, within the micritic material of the crinoidal and ferruginous limestones (Pl. 4, Fig. 6). Such concentrations of microbial structures devoid of lamination are referred to as trombolites (AITKEN 1967, PASZKOWSKI 1983, KENNARD & JAMES 1986). Single *Frutexites* are also found dispersed in the deposits and even in the fillings of the neptunian dykes (ŁUCZYŃSKI 2001a).

Depositional environment. The occurrence of stromatolitic layers covering large areas of the sea bottom indicate that during their growth a solid substrate was easily available. The same is confirmed by the fact that the stromatolites do not cover ammonite shells, large extraclasts etc. Exposure of solid substrate may result from restricted deposition, as well as from erosion and removal of non-lithified material. In places where the stromatolites cover ferruginous encrustations, the first possibility occurred, while elsewhere a solid substrate was exposed thanks to erosional processes. Suitable conditions did not, however, continue for a long time, but occurred only episodically, as indicated by their presence at particular horizons only. Changes in deposition rate were probably also responsible for the termination of stromatolite growth through burial. In the case of crinoidal limestones this could have been caused by megaripplemarks of crinoid sand migrating over the sea bottom, but the factor responsible for the process in the ferruginous limestones remains unclear.

MIDDLE JURASSIC PALAEOGEOGRAPHY OF THE HIGH-TATRIC AREA

Palaeogeographic reconstruction of the High-Tatric area during the Middle Jurassic is severely limited by a lack of precise stratigraphy.

Period before the deposition of the sediments of the Smolegowa Formation (Aalenian)

The oldest Middle Jurassic deposits of the High-Tatric series form the uppermost part of the Dudziniec Formation, exposed in the autochthonous unit (Table 1). The Formation consists of carbonate-clastic deposits, built of three main components in various proportions (WÓJCIK *in* LEFELD & *al.* 1985) – quartz and carbonate grains; pelmatozoan elements; and chal-

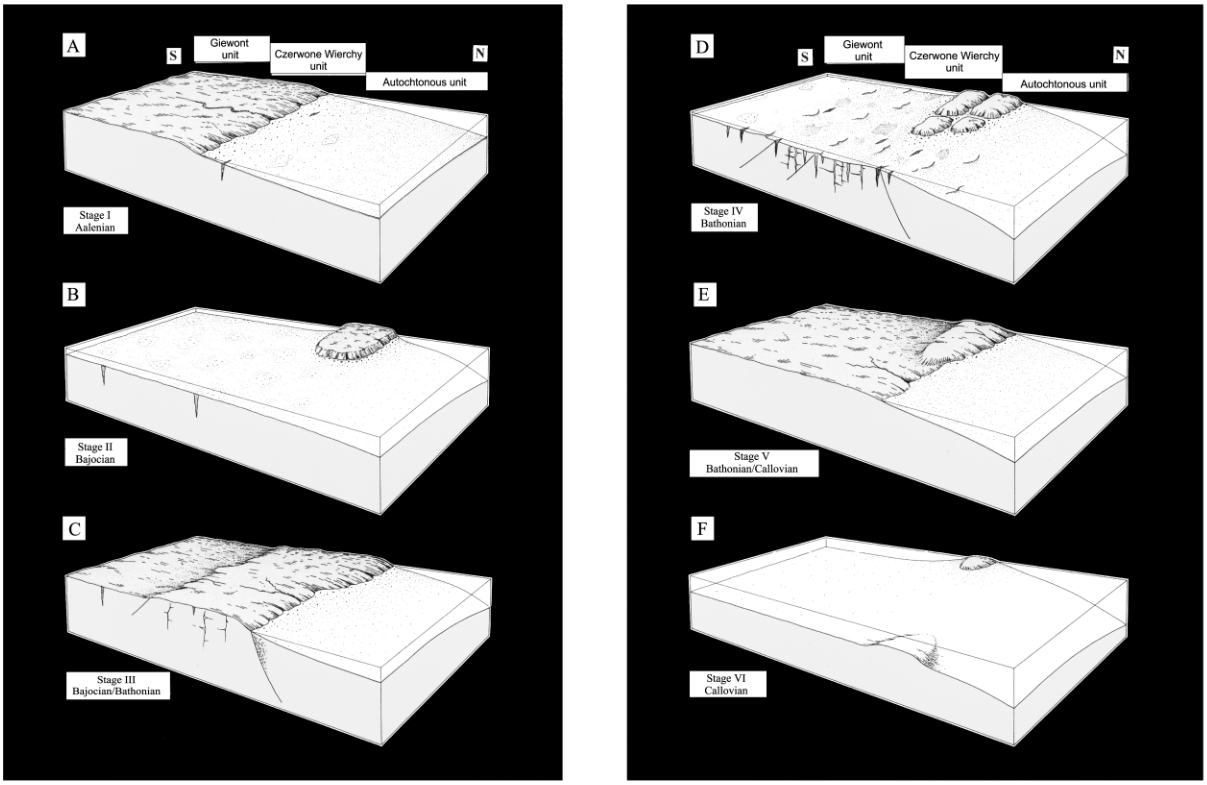


Fig. 4. Palaeogeographic history of the High-Tatric area during the Middle Jurasic

cedonite and sponge spicules. The deposits are developed in four major lithofacies (WÓJCIK 1981): sandy (Pl. 2, Fig. 1), sandy-crinoidal, sandy-crinoidal-peloidal and crinoidal. In its uppermost (Aalenian?) part the Dudziniec Formation is developed predominantly as massive, sandy and sandy-crinoidal limestones. The transition towards the overlying Smolegowa limestones is continuous.

During the Aalenian the palaeogeographic situation typical of the Early Jurassic continued. Deposition was probably restricted to the northern part of the High-Tatric domain (autochthonous unit). Due to erosion prior to the deposition of the Smolegowa limestones, it is impossible to tell if the sedimentation of the Dudziniec deposits took place also in the allochthonous units. It is most probable that these areas were elevated and eroded; however, the occurrence of scarce lithoclasts of the Dudziniec Formation rocks in the Smolegowa and Krupianka limestones of the allochthonous units (JAROSZEWSKI 1957, KOTAŃSKI 1961, SZULCZEWSKI 1963a) suggests that sandy-carbonate deposition took place at least temporarily in that area as well.

The proportions of the main components of the Dudziniec Formation were controlled by syndepositional block movements and intensity of erosion (WÓJCIK 1981). The sandy facies represents episodes of enhanced tectonic activity, while the crinoidal facies was deposited during calmer periods. The final phase of deposition of the clastic-carbonate deposits – the Aalenian – was relatively calm. The crinoidal meadows developed over relatively vast areas of the sea-bottom and the source areas of terrigenous material became more distant. An extensional regime is indicated i.a. by the occurrence of neptunian dykes filled with Dudziniec Formation deposits in the autochthonous unit (RADWAŃSKI 1959b).

The sandy material of the Dudziniec Formation is of local origin, i.e. it came from the erosion of the Tatricum domain (RADWAŃSKI 1959a). Its source area was located to the south of the present-day Tatra Mts. Shallow zones north of that area were covered by crinoidal meadows (Text-fig. 4a) that were destroyed during storms, yielding pelmatozoan material that became mixed with the extraclasts and deposited in deeper zones.

Period of deposition of the sediments of the Smolegowa Formation (Bajocian)

During the Bajocian, the extensional regime that started during the deposition of the Dudziniec Formation sediments, began to control the topography of the sea bottom and the depositional conditions. In the allochthonous units the Smolegowa Formation lies penacordantly on the Triassic, indicating that minor rotations of substrate blocks preceded its deposition. Only in the western part of the autochthonous unit was sedimentation continuous across the Early/Middle Jurassic boundary.

In spite of flooding of most of the High-Tatric area, some parts of it remained emerged and supplied extraclasts. The material is exclusively local, i.e. it came from erosion of the High-Tatric area. The occurrence of quartz grains in the terrigenous component, most probably redeposited from the Dudziniec Formation, points to emergence of some parts of the autochthonous unit (Text-fig. 4b). The source rocks of the limestone and dolomite clasts – the High-Tatric Triassic, could have been subjected to erosion in all of the tectonic units, but the distribution of the extraclasts shows that the areas being eroded were probably located within the autochthonous unit. The source of the ferruginous clasts remains unknown. It is probable that the deposition of the Smolegowa crinoidal limestones was locally preceded by sedimentation of ferruginous deposits.

Neptunian dykes filled with Smolegowa limestones show a lot of attributes indicating their tectonic origin (ŁUCZYŃSKI 2001a). Most of them were infilled by a process of hydrostatic injection (*sensu* LEHNER 1991) of loose sediments resting on the sea bottom into fissures that opened in the lithified Triassic substrate. Therefore, the first episode (episodes?) of dyke formation followed the deposition of a substantial part of the Smolegowa Formation sediments, but was prior to their lithification.

After the deposition of the Smolegowa limestones most of the Czerwone Wierchy unit (apart from the Kościeliska Valley region) remained elevated (Text-fig. 4c), resulting in total removal of the Smolegowa Formation from that area and in the development of numerous neptunian dykes of chemical origin that were subsequently infilled by red micrite (ŁUCZYŃSKI 2001a). Also in the Giewont unit, deposition of the Smolegowa and the Krupianka formations was separated by an episode of erosion, removing the Bajocian or substantially reducing its thickness. The only region where sedimentation was not interrupted at the Bathonian/Bajocian boundary was the western part of the autochthonous unit (Text-fig. 4c).

The history of the High-Tatric area during the deposition of the Smolegowa limestones can be divided into three stages. The first stage was transgression followed by the development of pelmatozoan communities, with only a few elevated areas supplying terrigenous material. The second stage was marked by intensification of the extensional movements and the formation of neptunian dykes infilled by loose sediments deposited on the sea bottom. It was followed by emergence of most of the High-Tatric area and erosion of the crinoidal limestones.

Period of deposition of the sediments of the Krupianka Formation (Bathonian)

During the Bathonian the sedimentation of crinoidal limestones was replaced over large areas by deposition of ferruginous and nodular limestones. The facial differentiation resulted from intensive extensional movements and the formation of a system of structural highs and basins.

The Bathonian zones of crinoidal meadows do not crop out, but probably were located mainly in the Giewont unit, or even south of it. The domains of crinoidal sedimentation surrounded the areas of deposition of ferruginous limestones of the Czerwone Wierchy unit, representing the shallowest facies of the Krupianka Formation. The ferruginous limestones were deposited around the elevated areas, which were the sources of the terrigenous component, to which the pelmatozoan material was supplied only in minor quantities (Text-fig. 4d). The crinoidal limestones were sedimented on flat areas located lower. The western part of the autochthonous unit represents the deepest depositional zone of the Bathonian, situated on a slope descending toward a deep-sea basin. This was the area of sedimentation of the nodular limestones.

The composition and distribution of the terrigenous component in the Krupianka Formation suggest that the eroded areas were located in the autochthonous and the Czerwone Wierchy units. The Dudziniec Formation of the autochthonous unit was the source of the quartz grains and the Triassic of the allochthonous units supplied the limestone and dolomite clasts. The ferruginous clasts could have come only from redeposition of Bajocian and/or Bathonian material.

Neptunian dykes filled with deposits of the Krupianka Formation (ŁUCZYŃSKI 2001a) show substantial geographical differentiation. In the Czerwone Wierchy unit, many of the fissures are of chemical origin. These dykes formed during emergence of the area. The eastern part of the autochthonous unit, on the other hand, was a place of internal breccias concentration, the formation of which was directly connected with tectonic phenomena and fissuring of the solid substrate in the immediate vicinity of fault-scarps. The dykes of the Giewont unit are also of tectonic origin.

The dykes filled with Bathonian deposits commonly have walls covered by ferruginous encrustations and calcite cements, indicating a time-span separating the opening of the fissures and infilling them with sediments. This feature is connected with the discontinuous character of deposition during the Bathonian. In the sedimentation area of the crinoidal limestones the fissures opening in the Triassic and/or Bajocian substrate remained unfilled until burial by a megaripple of crinoidal sand. The occurrence of dykes filled with Bathonian deposits in places where sediments of that age are absent from the normal stratigraphic succession, points to an episode of erosion following the deposition of the Krupianka Formation (Text-fig. 4e).

During the Bathonian, the central part of the High-Tatric domain was occupied by elevated and eroded areas, which were sources of terrigenous material. In their immediate vicinity deposition of ferruginous limestones took place. Areas situated lower, but still above storm wave base, were the domain of crinoidal limestone deposition. The sedimentation of these limestones had an allochthonous character, and migration of crinoidal-lithoclast sand waves caused abrasion of the sea-bottom. Nodular limestones were deposited in the western part of the autochthonous unit, on the slope descending to a deeper basin. Sedimentation of the Krupianka Formation was followed by uplift and erosion over almost the whole area of the High-Tatric series.

Period after the deposition of the deposits of the Krupianka Formation (Callovian)

The youngest Middle Jurassic deposits of the High-Tatric series form the lowermost part of the Raptawicka Turnia Formation (Table 1). The Formation embraces Callovian through Hauterivian deposits and is developed as massive limestones (Lefeld & *al.* 1985), wavy-bedded in their lowermost (Callovian?) part. The dark-grey and greenish Callovian deposits consist of limestone beds interbedded by clay-marly layers (Pl. 1, Fig. 6). They contain a sparse admixture of fine terrigenous material (mainly limestone lithoclasts with rare dolomites and ferruginous clasts). The clay-marly layers contain abundant belemnites. The microfossil assemblage is dominated by radiolarians (Pl. 2, Fig. 6), accompanied by foraminifers and strongly disintegrated crinoids.

A meaningful reconstruction of the Callovian palaeogeography of the High-Tatric area is almost impossible because of the lack of stratigraphic tools, which might enable the Callovian to be distinguished from the Oxfordian. However, based on the variable development of the basal part of the Raptawicka Turnia Formation, some conclusions can be drawn.

In the Callovian the syndepositional tectonics did not play an important role any more. Following a period of erosion, which removed the Bathonian in many places, the High-Tatric area became submerged in the Callovian, but the diversified palaeorelief of the sea bottom remained for some time (Text-fig. 4f). The deposition of wavy-bedded limestones took place in relatively calm waters, probably in the lower part of the photic zone, under the influence of bottom currents (SZULCZEWSKI 1963b). The abundance of radiolarians and the dominance of open-marine filamentous microfacies prove good communication with a deeper basin. However, some very restricted areas remained elevated and acted as sources of terrigenous material. The presence of the terrigenous component in the bottom part of the wavy-bedded limestones, points to the start of deposition of the Raptawicka Turnia Formation being diachronous. This diachroneity is additionally substantiated by a lack of wavy bedding in some of the sections. The remaining elevated areas became progressively submerged, with concomitant reduction and eventual disappearance of the terrigenous component upwards in the successions, together with the development of a unified facies as a result of burial of the Middle Jurassic palaeorelief.

FINAL REMARKS

Disintegration of the Triassic carbonate platforms into a system of horsts and grabens was a typical phenomenon in many segments of the Tethys. Similar facies arrays and tectonic phenomena as in the Tatra Mts. were described i.a. from the Early Jurassic of Hungary (CRONAN & *al.* 1991) and from the Late Jurassic of the Betic zone in Spain (COMAS & *al.* 1981, VERA & *al.* 1987) However, probably the closest analogue of the High-Tatric Middle Jurassic is the Early and the Middle Jurassic of the Southern Alps, described i.a. by WINTERER & BOSSELINI (1981), WINTERER & *al.* (1991) and MARTIRE (1996).

During the Middle Jurassic the Tatricum domain was located at the northern margin of the Central Western Carpathians continental plate, separated from the European Continent by the Vahic Ocean. According to PLAŠIENKA (1991, 1995; PLAŠIENKA & *al.* 1997), the oceanic crust of this ocean began to form at the Early and Middle Jurassic decline. After its formation, the Tatricum domain found itself on the passive edge of a continental plate. The High-Tatric area became an isolated elevation, surrounded by the Vahic Ocean to the north and by the

Fatricum domain to the south, with deep-marine sedimentation of the Sokolica radiolarites (LEFELD 1974). During the Bajocian the greater part of the High-Tatric area was submerged. During the Bathonian the High-Tatric domain was divided into smaller blocks, which is reflected in the variety of facies development. Early Cimmerian movements are marked in the High-Tatric series only by a penacordant contact of the Middle Jurassic on the Triassic. Comparison of the High-Tatric succession with eustatic curves for the Middle Jurassic (HAQ & *al.* 1988, HALLAM 1988) shows that only the Callovian transgression could have been caused by a global rise of the sea level. All of the other bathymetric changes are effects of tectonic block movements.

Acknowledgements

The paper comprises a major part of the authors Ph.D. thesis prepared at the Faculty of Geology, Warsaw University under the supervision of my tutor, Prof. Michał SZULCZEWSKI, to whom I wish to express my gratitude for all the help and advice. I also wish to thank Prof. LEFELD and Prof. BLENDINGER, the journal referees, who helped to improve the final version of this paper.

The studies were partly financed from a Polish state KBN grant No. 6 P04D 005 15. The financial support of the KOPIPOL Foundation is acknowledged.

REFERENCES

AITKEN, J.D. 1967. Classification and environmental significance of cryptalgal limestones and dolomites with illustration from the Cambrian and Ordovician of southwestern Alberta. *Journal of Sedimentary Petrology*, **37**, 1163-1178.

BIRKENMAJER, K. 1977. Jurassic and Cretaceous lithostratigraphic units in the Pieniny Klippen Belt, Carpathians, Poland. *Studia Geologica Polonica*, **45**, 1-158.

BLYTH CAIN J.D. 1968. Aspects of the depositional environment and palaeoecology of crinoidal limestones. *Scottish Journal of Geology,* **4**, (3), 191-208.

BÖHM, F. & BRACKERT, T.C. 1993. Deep-water stromatolites and *Frutexites* Maslow from the Early and Middle Jurassic of S. Germany and Austria. *Facies*, **28**, 145-168.

CLARI P.A., DE LA PIERRE, F. & MARTIRE, L. 1995. Discontinuities in carbonate successions: identification and classification of some Italian examples. *Sedimentary Geology*, **100**, 97-121.

COMAS, M.C., OLORIZ, F. & TAVERA, J.M. 1981. The red limestones (Ammonitico Rosso) and associated facies: a key for settling slope or swell areas in the Subbetic Upper Jurassic submarine topography (Southern Spain*). Rosso Ammonitico Symposium Proceedings*, pp. 113-135.

CRONAN, D., GALACZ, A., MINDSZENTY, A., MOORBY, S. & POLGARI, M. 1991. Tethyan ferromanganese oxide deposits from Jurassic rocks in Hungary. *Journal of the Geological Society*, **148**, 655-668.

DROMART, G., GAILLARD, C. & JANSA, L.F. 1994. Deep-marine microbial structures in the Upper Jurassic of Western Tethys. *In*: BERTRAND-SARFATI, J. & MONTY C. (*Eds*), Phanerozoic Stromatolites II, 295-318. Berlin – Heidelberg.

GALACZ, A. & MATYJA, B. 1999. Passendorfer's Middle Jurassic ammonites from the High Tatras. V International Symposium cephalopods – Present and Past, Vienna 6-9 September 1999, *Abstract Volume Berichte Geologische Bundesanstalt,* **46**, 40a. Vienna.

GŁUCHOWSKI, E. 1986. Jurassic and Lower Cretaceous articulate crinoids of the Pieniny Klippen Belt in Poland. *Przegląd Geologiczny*, **6**, 304-309. [*In Polish*].

— 1987. Jurassic and Early Cretaceous articulate Crinoidea from the Pieniny Klippen Belt and the Tatra Mountains. Poland. *Studia Geologica Polonica*, **94**, 1-102.

HALLAM, A. 1988. Re-evaluation of Jurassic eustacy in the light of new data and the revised Exxon curve. *In:* WILGUS, C.K., HASTINGS B.J. & POSAMMENTIER G. (*Eds*). Sea-level changes: an integrated approach. *Special Publications of the Society of Economic Paleontologists and Mineralogists*, **42**, 261-273.

HAQ, B.U., HARDENBOL, J., VAIL, P.R. & COLIN, P.J. 1988. Mesozoic and Cainozoic chronostratigraphy and cycles of sea-level change. *In:* WILGUS, C.K., HASTINGS, B.J. & POSAMMENTIER, G. (*Eds*). Sea-level changes: an integrated approach. *Special Publications of the Society of Economic Paleontologists and Mineralogists*, **42**, 214-261.

HOFFMAN, P. 1974. Shallow and deepwater stromatolites in Lower Proterozoic platform-to-basin facies change. Great Slave Lake. Canada. *American Association of Petroleum Geologists Memoirs*, **58** (5), 856-867.

HORWITZ, L. & RABOWSKI, F. 1922. O liasie i doggerze wierchowym w Tatrach. *Posiedzenia naukowe Państwowego Instytutu Geologicznego,* **3**, 15-18.

JAANUSSON, V. 1961. Discontinuity surfaces in limestones. *Bulletin of the Geological Institute, Uppsala*, **40**, 221-241.

JENKYNS, H.C. 1971a. Speculations on the genesis of crinoidal limestones in the Tethyan Jurrasic. *Geologische Rundschau*, **60**, 471-488.

— 1971b. The genesis of condensed sequences in the Tethyan Jurassic. *Lethaia*, **4** (3), 327-352.

— 1974. Origin of red nodular limestones. (Ammonitico Rosso, Knollenkalke) in the Mediterranean Jurassic: a diagenetic model. *In*: HSÜ K.J. & JENKYNS H.C. (*Eds*) Special Publications of the International Association of Sedimentologists 1, Pelagic sediments on Land and under the Sea, 149-271. Oxford – London – Edinburgh – Melbourne.

JIMENEZ-ESPINOSA, R., JIMENEZ-MILLAN, J. & NIETO, L. 1997. Factors controlling the genesis of Fe-Mn crusts in stratigraphic breaks of the eastern Betic Cordillera (SE Spain) deduced from numerical analysis of geological data. *Sedimentary Geology*, **114**, 97-107.

KENNARD, J.M. & JAMES, N.P. 1986. Thrombolites and stromatolites: two distinct types of microbial structures. *Palaios*, **1** (5), 492-503.

KOTAŃSKI, Z. 1959. Stratigraphic sections of the High-Tatric Series in the Polish Tatra Mts. *Biuletyn Instytutu Geologicznego,* **139**, 1-160. [*In Polish*]

— 1961.Tectogénèse et reconstitution de la paléogeographie de la zone hauttatrique dans les Tatra. *Acta Geologica Polonica*, **11** (2, 3), 187-413. [*In Polish*]

— 1979. The position of the Tatra Mts. in the Western Carpathians. *Przegląd Geologiczny*, **7**, 359-369. [*In Polish*]

LEFELD, J. 1974. Middle-Upper Jurassic and Lower Cretaceous biostratigraphy and sedimentology of the Sub-Tatric succession in the Tatra Mts (Western Carpathians). *Acta Geologica Polonica*, **24**, 277-364.

LEFELD, J. GAŹDZICKI, A. IWANOW, A. KRAJEWSKI, K. & WÓJCIK, K. 1985. Jurassic and Cretaceous lithostratigraphic units of the Tatra Mountains. *Studia Geologica Polonica,* **84**, 1-93.

LEHNER, B.L. 1991. Neptunian dykes along a drowned carbonate platform margin: an indication for recurrent extensional tectonic activity? *Terra Nova*, **3**, 593-602.

ŁUCZYŃSKI, P. 2001a. Development history of Middle Jurassic neptunian dykes in the High-Tatric series, Tatra Mountains, Poland. *Acta Geologica Polonica*, **51**, (3), 237-252.

— 2001b. Pressure solution and chemical compaction of condensed Middle Jurassic deposits, High-Tatric series, Tatra Mountains. *Geologica Carpathica*, **52** (2) 91-102.

MARTIRE, L. 1996. Stratigraphy, facies and synsedimentary tectonics in the Jurassic Rosso Ammonitico Veronese (Altopiano di Asiago, NE Italy). *Facies,* **35**, 209-236.

MASŁOW, V.P. 1960. Stromatolites. *Trudy Geologickiego Institutu Akademii Nauk S.S.S.R*. 41, 188 pp. Moscow. [*In Russian*]

MIŠIK, M. 1964. Lithofazielle Studien im Lias der Grossen Fatra und im westlischen Teil der Niederen Tatra. *Geologicky Sbornik*, **11** (2), 11-36.

MIŠIK, M. SYKORA, M. & AUBRECHT, R. 1994. Middle Jurassic scarp breccias with clefts filled by Oxfordian and Valanginian-Hauterivian sediments, Krasin near Dolna Suča (Pieniny Klippen Belt, Slovakia). *Geologica Carpathica*, **45** (6), 343-356.

MONTY, C.L.V. 1977. Evolving concepts on the nature and the ecological significance of stromatolites. *In*: FLÜGEL, E. (*Ed*.), Fossil Algae – Resent Results and Developments, 15-35. Berlin – Heidelberg.

OGG, J.G. 1981. Middle and Upper Jurassic sedimentation history of the Trento Plateau (Northern Italy). *Rosso Ammonitico Symposium Proceedings,* 471-503. Roma.

OSCHMANN, W. 1994. Adaptive pathways of benthic organisms in marine oxygen-controlled environments. *Neues Jahrbuch für Paläeontologie*, **191** (3), 393-444.

PASSENDORFER, E. 1935. Studien über die Stratigraphie und Paläontologie des hochtatrischen Jura in Tatry. I. *Annales de la Société géologique de Pologne*, **11**, 1-22. [*In Polish*]

— 1938. Étude sur la stratigraphie et paléontologie du Jurassique hauttatrique dans les Tatras. *Prace Towarzystwa Przyjaciół Nauk, Wilno,* **12**,165-173. [*In Polish*]

PASZKOWSKI, M. 1983. Algal biosedimentary structures in Dinantian limestones in the area of Krzeszowice near Cracow. *Przegląd Geologiczny,* **4**, 254-257. [*In Polish*]

PLAŠIENKA, D. 1991. Mesozoic tectonic evolution of the epi-Variscan continental crust of the Central Western Carpathians – a tentative model. *Mineralia Slovaca*, **23**, 447-457.

— 1995. Passive and active margin history of the northern Tatricum (Western Carpathians, Slovakia). *Geologishe Rundschau*, **84**, 748-760.

PLAŠIENKA, D., HAVRILA, M., MICHALIK, J., PUTIŠ, M. & REHAKOVA, D. 1997. Nappe structure of the Western Part of the Central Carpathians. *In*: PLAŠIENKA, D. HOK, J. VOZAR, J. & ELEČKO, M. (*Eds*). International Conference: Alpine Evolution of the Western Carpathians and Related Areas, Bratislava Abstracts & Introductory Articles to the Excursion, 139-161. Bratislava.

RABOWSKI , F. 1954. Recherches géologiques de la région de Kominy Tylkowe dans les Tatra, executées en 1938. *Biuletyn Instytutu Geologicznego*, **86**, 29-35. [*In Polish*].

— 1959. High-Tatric series in western Tatra. *Prace Instytutu Geologicznego*, **27**, 1-178. [*In Polish*].

RADWAŃSKI, A. 1959a. Researches on petrography of the High-Tatric Lias. *Przegląd Geologiczny*, **8**, 359-362. [*In Polish*]

— 1959b. Littoral structures (cliff, clastic dykes and veins, and borings of *Potamilla*) in the High-Tatric Lias. *Acta Geologica Polonica*, **9** (2), 31-280. [*In Polish*]

RUHRMANN, G. 1971. Riff-ferne Sedimentation der unterdevonischer Krinoidenkalke im Kantabrischen Gebirge (Spanien). *Neues Jahrbuch für Geologie und Paläontologie*, **138** (4), 30-58.

SANTANTONIO M. 1993 Facies associations and evolution of pelagic carbonate platform / basin systems: examples from the Italian Jurassic. *Sedimentology* **40**, 1039-1067.

SZULCZEWSKI, M., 1963a. The geology of Mała Świstówka in western Tatra. *Acta Geologica Polonica*, **13** (2), 199-222. [*In Polish*]

— 1963b. The Bathonian stromatolites in the Tatra Mts. *Acta Geologica Polonica*, **13** (1), 25-145. [*In Polish*]

— 1965. Observation sur la génèse des calcaires noduleux des Tatras. *Annales de la Société geologique de Pologne*, **35** (2), 243-257. [*In Polish*]

— 1968. Jurassic stromatolites of Poland. *Acta Geologica Polonica*, **18** (1), 1-99. [*In Polish*]

TUCKER, M.E. 1973. Ferromanganese nodules from the

Devonian of the Montagne Noire (S. France) and West Germany. *Geologische Rundschau*, **62**, 137-153.

UHLIG, V. 1897. Die Geologie des Tatra Gebirges. I. Einleitung und Stratigraphischer Theil. *Denkschreiben der Academie der Wissenschaften Wien. Mathematik – Naturwissenschaften,* **64**, 643-684.

VERA, J.A. RUIZ-ORTIZ, P.A., GARCIA-HERNANDEZ, M. & MOLINA, J.M. 1987. Paleokarst and related pelagic sediments in the Jurassic of the Subbetic Zone, Southern Spain. *In*: JAMES N.P. & CHOQUETTE P.W. (*Eds*), Paleokarst, 364-384. Berlin.

WALTER, M.R. & AWRAMIK, S.M. 1979. *Frutexites* from stromatolites of the Gunflint Iron Formation of Canada and its biological affinities. *Precambrian Research*, **9** (1/2), 23-34.

WENDT, J. 1973. Cephalopod accumulation in the Middle Triassic Hallstatt Limestone of Yugoslavia and Greece. *Neues Jahrbuch für Geologie und Paläontologie,* 325-344.

— 1974. Encrusting organisms in deep-sea manganese nodules – Special Publications of the International Association of Sedimentologists, **1**, 437-447. Oxford – London.

— 1988. Condensed carbonate sedimentation in the Late Devonian of the eastern Anti-Atlas (Marocco). *Eclogae Geologica Helvetica*, **81** (1), 155-173.

WENDT, J. & AIGNER, T. 1985. Facies patterns and depositional environment of Palaeozoic cephalopod limestones. *Sedimentary Geology*, **44**, 263-300.

WIERZBOWSKI, A. 1994. Late Middle Jurassic to earliest Cretaceous stratigraphy and microfacies of the Czorsztyn Succession in the Spisz area, Pieniny Klippen Belt, Poland. *Acta Geologica Polonica*, **44** (3-4), 223-249.

WIERZBOWSKI, A., JAWORSKA, M. & KROBICKI, M. 1999. Late Middle Jurassic Deposits (Upper Bajocian, Bathonian & Callovian) of the Ammonitico Rosso type in the Pieniny Klippen Belt, Carpathians. Stratigraphy, Microfacies, Fauna and Sedimentation. *Studia Geologica Polonica* **115,** 7-74.

WINTERER, E.L. & BOSSELINI, A. 1981. Subsidence and sedimentation of a Jurassic passive continental margin, Southern Alps. Italy. *American Association of Petroleum Geologists Bulletin*, **65** (3), 394-421.

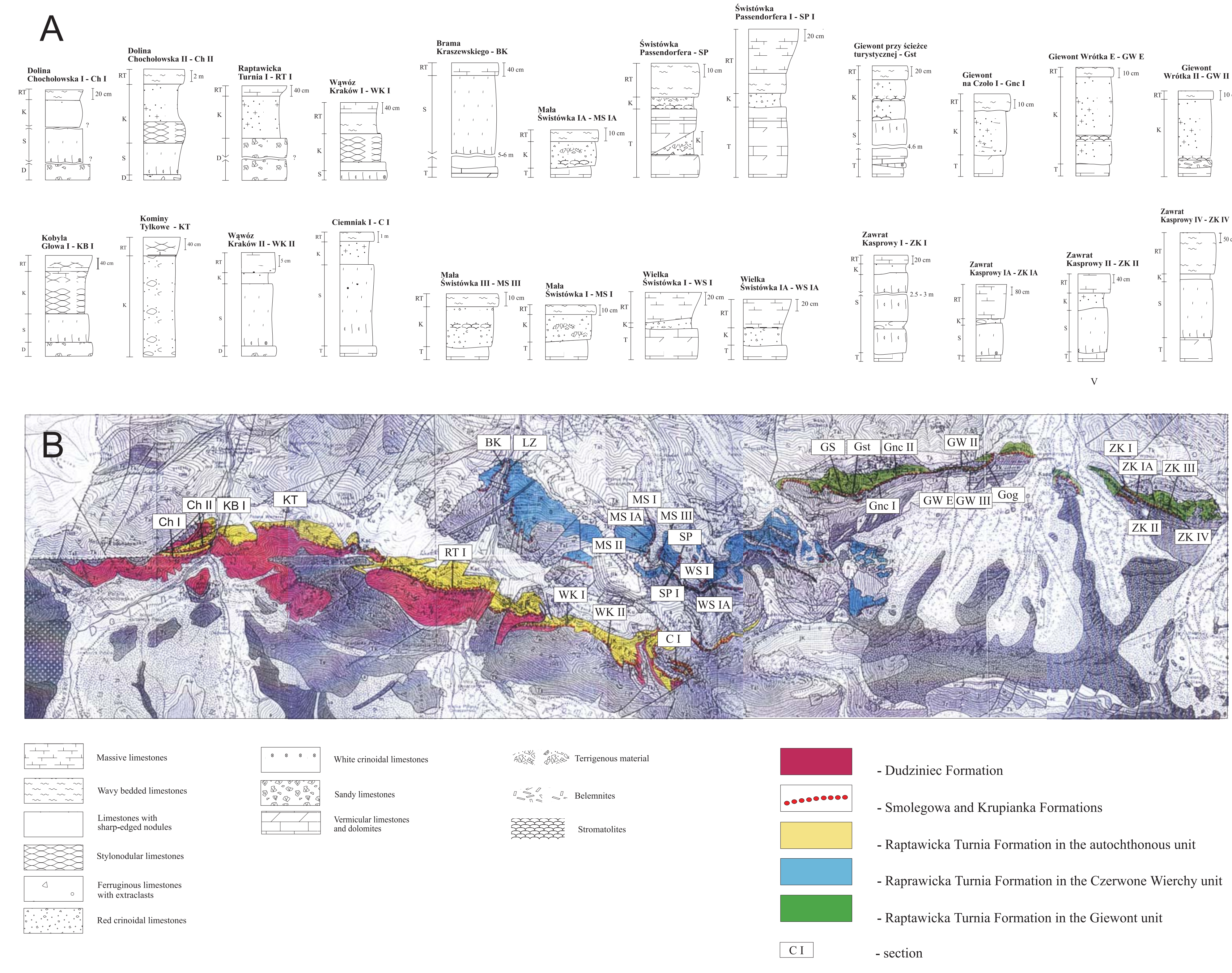
WINTERER, E.L., METZLER, C.V. & SARTI, M. 1991. Neptunian dykes and associated breccias (Southern Alps, Italy and Switzerland): role of gravity sliding in open and closed systems. *Sedimentology*, **38**, 381-404.

WÓJCIK, K. 1981. Facies development of the High-Tatric Lias in the vicinity of the Chochołowska Valley. *Przegląd Geologiczny*, **8**, 405-410. [*In Polish*]

WÓJCIK, Z. 1959. High-Tatric series in the south side of Mt. Bobrowiec (Western Tatra Mountains). *Acta Geologica Polonica*, **9** (2), 165-201. [*In Polish*]

ZYDOROWICZ T. & WIERZBOWSKI A., 1986. Ferromanganese concretions from the Jurassic of the Czorsztyn Succesion, Pieniny Klippen Belt, Carpathians. *Przegląd Geologiczny,* **6**, 324-327. [*In Polish*]

Manuscript submitted: 10th April 2001
Revised version accepted: 15th May 2002



Selected profiles of Middle Jurassic deposits of the High-Tatric series (A) and their location (B). B presents the area embraced in box (*) in Text-fig. 1. T – Triassic, D – Dudziniec Formation, S – Smolegowa Formation, K – Krupianka Formation, RT – Raptawicka Turnia Formation

PLATE 1

Selected sections of the High-Tatric Middle Jurassic

1 – *Ciemniak I* section, autochthonous unit; **A** – Smolegowa Formation, **B** – Krupianka Formation (overturned position)

2 – *Raptawicka Turnia I* section, autochthonous unit; **A** – Dudziniec Formation, **B** – Krupianka Formation, **C** – Raptawicka Turnia Formation

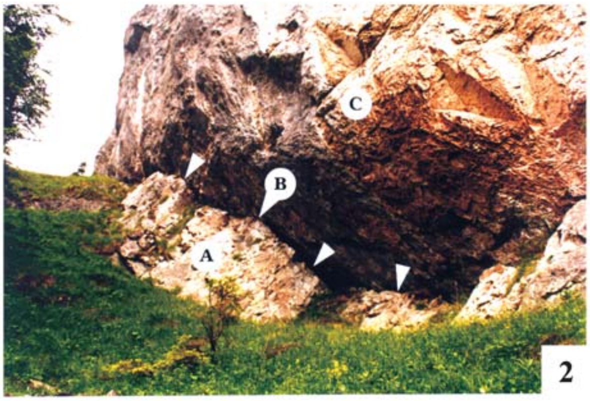
3 – *Kobyla Głowa I* section, autochthonous unit; **A** – Smolegowa Formation, **B** – Krupianka Formation

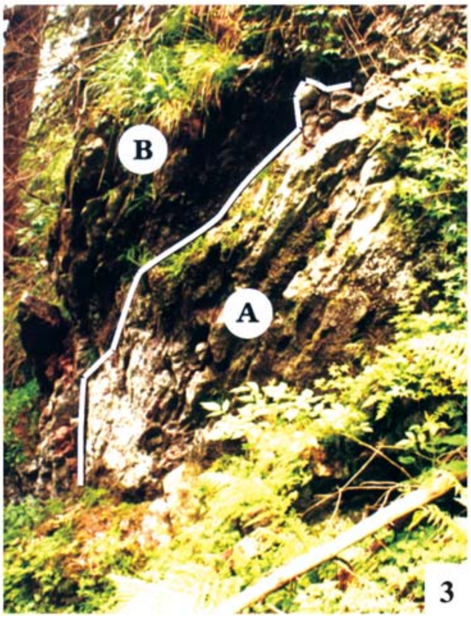
4 – Overall view of the "*Świstówka Passendorfera*" cirque, Czerwone Wierchy unit; **A** – line along which the Krupianka Formation crops out

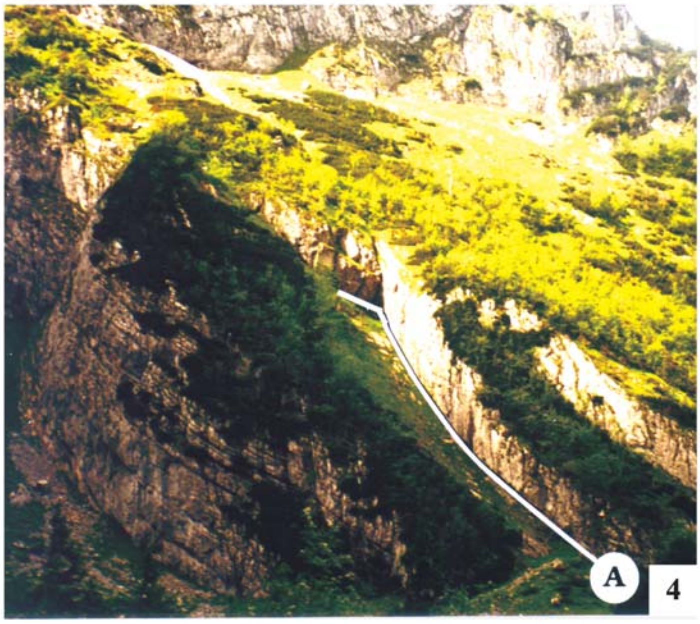
5 – Outcrop of Krupianka ferruginous limestones (**A**) in *Mała Świstówka* cirque, Czerwone Wierchy unit

6 – Outcrop of wavy-bedded limestones forming the basal part of the Raptawicka Turnia Formation in *Mała Świstówka* cirque, Czerwone Wierchy unit


A
B
1


C
B
A
2


B
A
3


A
4

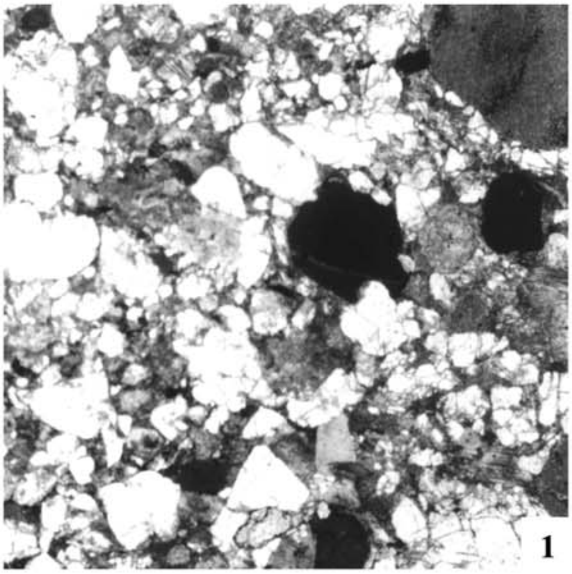

A
Nikon
5

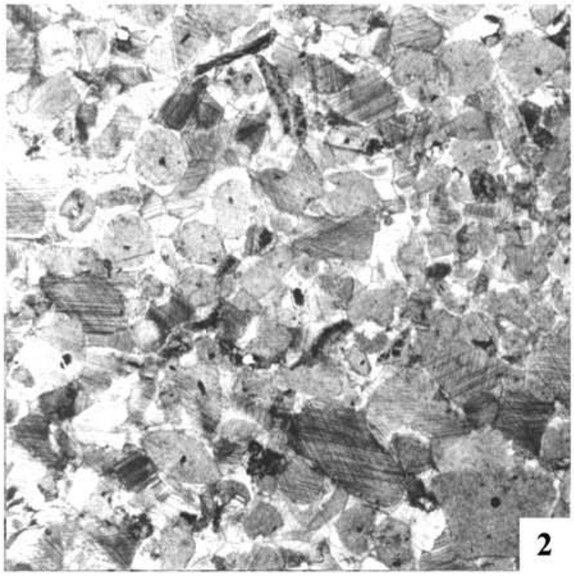

6

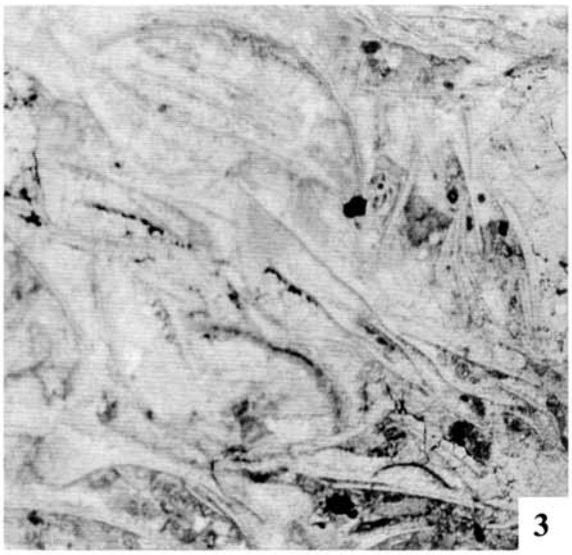
PLATE 2

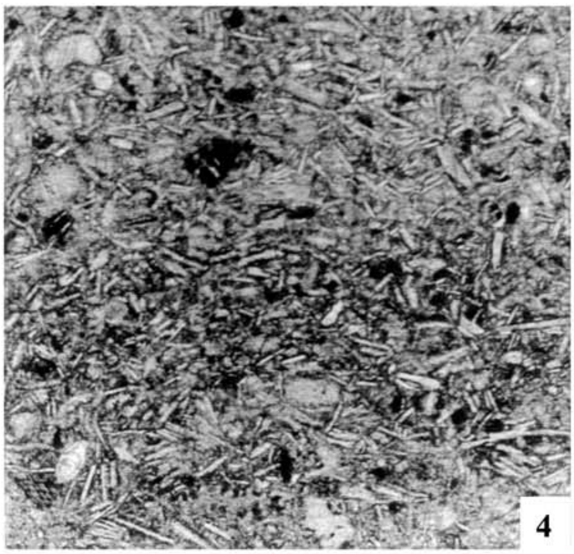
Thin plates - lithofacies of High-Tatric Middle Jurassic deposits

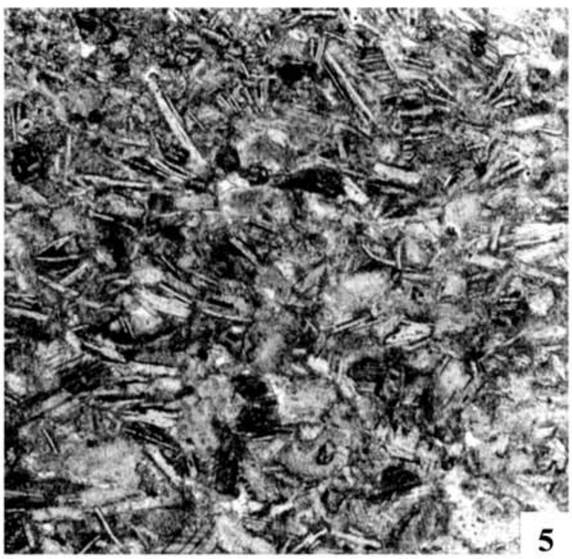
1 – Sandy limestones; uppermost part of the Dudziniec Formation, × 15
2 – Coarse-grained crinoidal limestones; Smolegowa Formation, × 15
3 – Brachiopod limestones; Smolegowa Formation, × 20
4 – Crinoidal – filamentous limestones; Krupianka Formation, × 40
5 – Filamentous limestones; Krupianka Formation, × 40
6 – Micritic limestones with radiolarians; bottom part of the Raptawicka Turnia Formation, × 50


1


2


3


4


5

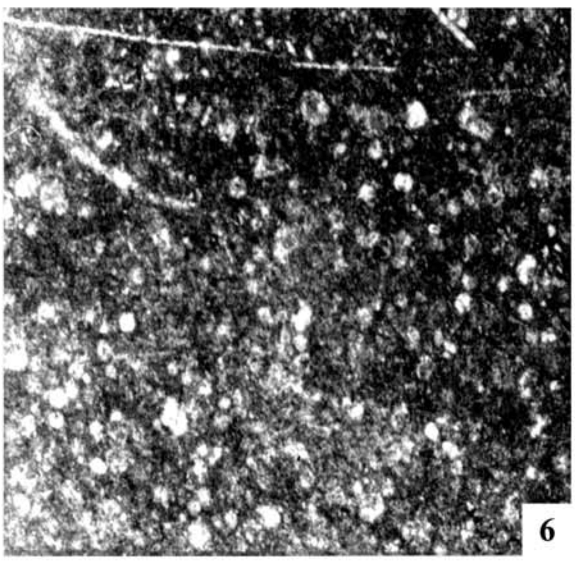

6

PLATE 3

Fossil accumulations, nodular limestones, stromatolites.

1 – Crinoidal limestones pack-filled with unseparated crinoid columns (**A**) and belemnites (**B**); Krupianka Formation, *Wrótka II* section

2 – Limestones with sharp-edged nodules; Krupianka Formation. Arrow points to stylolitic boundary between the nodules; *Kominy Tylkowe* section

3 – Matrix of stylonodular limestones with the character of a pressure solution residuum; Krupianka Formation, *Wąwóz Kraków* section, × 2

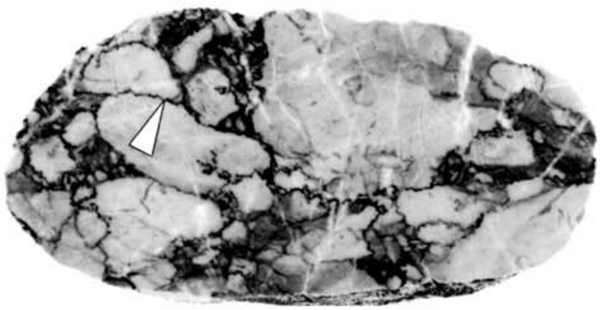
4 – Stylonodular limestones. **A** – concentration of numerous clay seams in the matrix, **B** – microstylolites penetrating the nodule-matrix boundary, **C** – stylolite cutting through the nodule; Krupianka Formation, *Kobyla Głowa I* section

5 – Stromatolite with terrigenous material (mainly ferruginous clasts) in the interstices: Krupianka Formation, *Giewont Wrótka E* section

6 – Stromatolite domes; Krupianka Formation, *Giewont ścieżka turystyczna* section

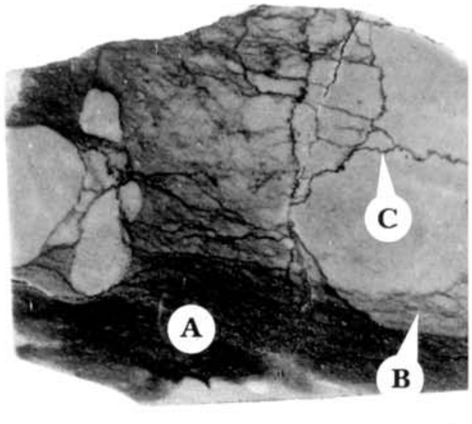
7 – Ferruginous clasts (arrows) in stromatolite interstice; Krupianka Formation, *Mała Świstówka I A* section, × 2

1



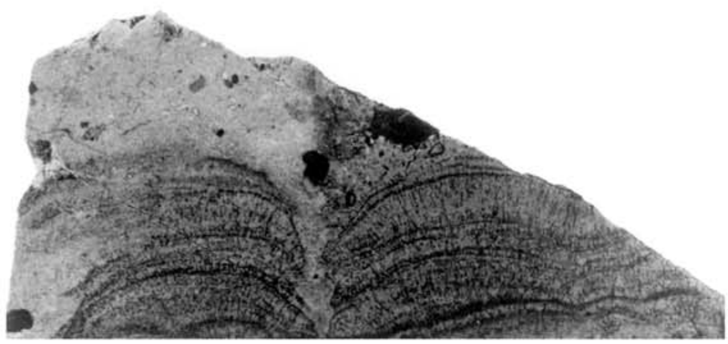
2

3

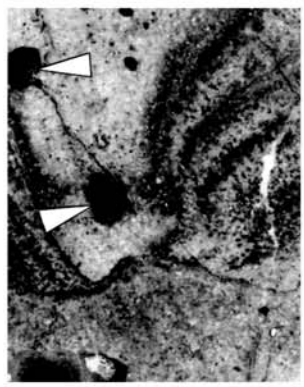


4

5



6

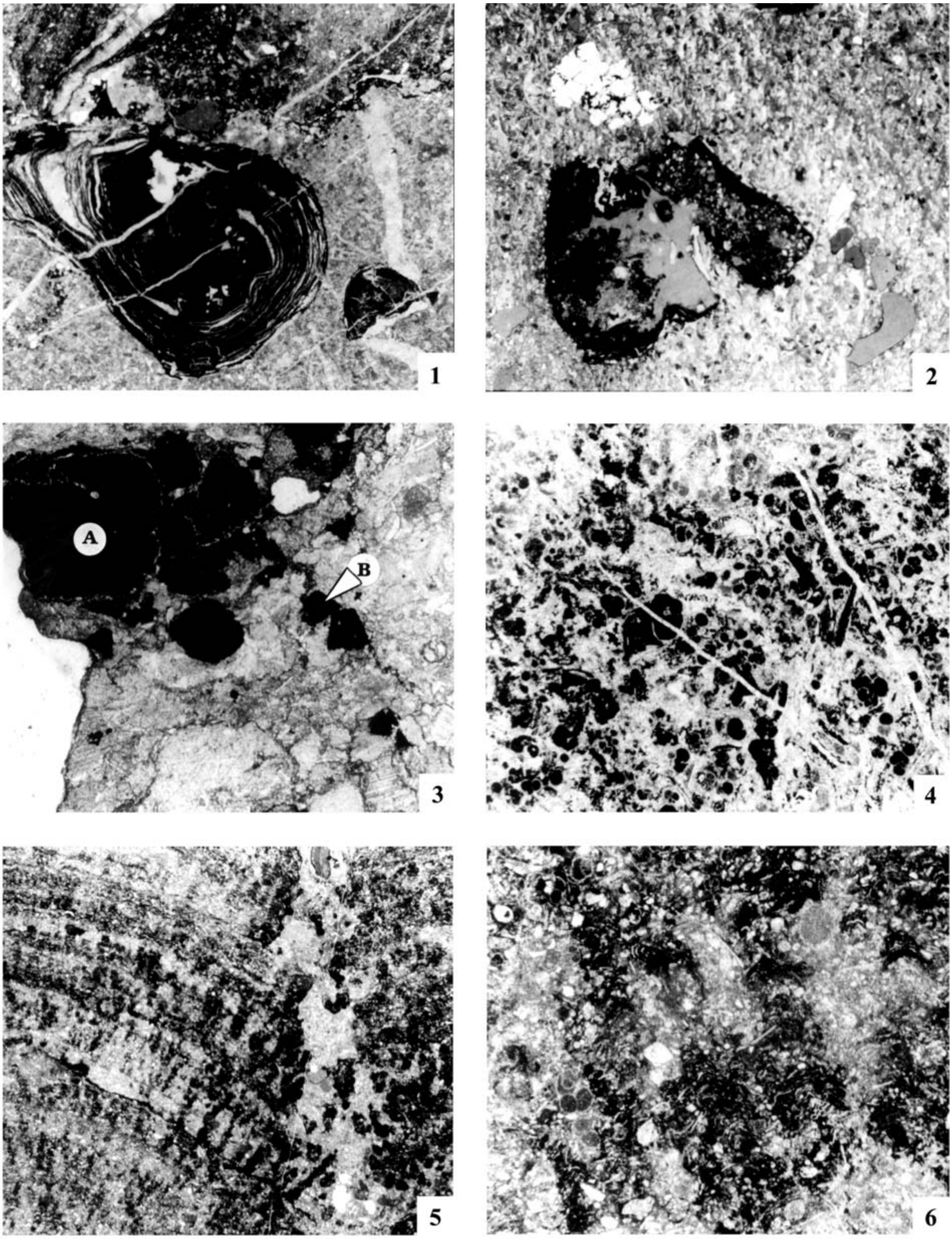


7

PLATE 4

Thin plates – ferruginous mineralization, stromatolites

1 – Laminated ferruginous nodule; Krupianka Formation, × 10
2 – Limestone extraclast encrusted by ferruginous compounds; Krupianka Formation, × 7
3 – Amorphous, non-transparent concentrations of ferruginous compounds (**A**) and authigenic hematite crystals (**B**); Krupianka Formation, × 25
4 – Foraminifers (globigerinids) encrusted by ferruginous compounds; Krupianka Formation, × 40
5 – Fragment of a stromatolite dome with numerous *Frutexites*; Krupianka Formation, × 7
6 – *Frutexites* penetrating micritic limestones outside a stromatolitic structure; Krupianka Formation, × 50


1
2
A
B
3
4
5
6