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Clastic Badenian deposits and sedimentary environments of the Roztocze Hills across the Polish-Ukrainian border

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ABSTRACT:

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The sedimentary conditions of the clastic Badenian deposits of the Roztocze Hills are reconstructed, in the territories of Poland and Ukraine. Detailed sedimentological analyses are performed for fourteen exposures. Four petrographic rock types: quartz arenites, quartz arenites with limeclasts, calcarenites with quartz and biocalcarenites have been distinguished. The lithology and microfacies of these rocks point to a high-energy, shallow-water, normal-marine environment connected with the shore zone. Moreover, diversified sets of sedimentological structures, including depositional, deformational and biogenic, are ascribed to the shallow-water high-energy environment. The characteristics of the Badenian succession allow an interpretation of the environment and its change during sedimentation. Deposition during the Badenian in the Roztocze area was connected with the evolution of the Carpathian Foredeep. Initially sedimentation was mainly dependent on hydrodynamic factors, however the influence of diastrophic factors gradually increased.

Key words: Clastic sedimentation, Sedimentary structures, Synsedimentary tectonic, Badenian, Carpathian Foredeep.

INTRODUCTION

The aim of this paper is to reconstruct the sedimentary conditions of the clastic Badenian deposits of the Roztocze Hills between Lviv (=Lwów, *in Polish*) and Zwierzyniec, across the Polish-Ukrainian border (Text-fig. 1). Studies of the Roztocze Hills in the territories of Poland and western Ukraine have allowed examination of a complete succession of the Badenian deposits.

The first geological studies of the Roztocze Hills area were carried out in the second half of the 18th century, and concentrated on the medicinal properties of the mineral waters (for a detailed review *see* HARASIMIUK & NOWAK 1998). Intensive studies were connected with works on the Geological Atlas of Galicja. The first half of the 19th, and the beginning of the 20th centuries, were periods of thorough mineralogical, palaeontological and cartographic studies that concerned both the Tertiary and Cretaceous rocks. The Tertiary was described by ŁOMNICKI (1874, 1897, 1898, 1900), TEISSEYRE (1900) and SIEMIRADZKI (1909), and in the period between the First World War and the Second World War their work was continued by KOWALEWSKI (1929) and CZARNOCKI (1935) among others. After the Second World War a new arrangement of state boundaries caused the part of the Roztocze Hills with the best Miocene sections to be situated outside the territory of Poland.

In Poland, the study area ranges between Zwierzyniec and the state boundary (Text-fig. 1). Existing papers concerning this region (*i.e.* BRZEZIŃSKA 1957, 1961; AREŃ 1959, 1962; NEY 1969, BIELECKA 1967, JAROSZEWSKI 1977, JAKUBOWSKI & MUSIAŁ 1979, SZCZECHURA 1982, PISERA 1985, MUSIAŁ 1987a, 1987b; ŁUCZKOWSKA-SCHILLER 1987, KURZAWA 1990, HEFLIK 1996, JASIONOWSKI & WYSOCKA 1997, RONIEWICZ & WYSOCKA 1997, BURACZYŃSKI 1997) were devoted mainly to stratigraphic aspects, and consequently did not examine the sedimentology in detail.

In Ukraine relatively few works were published after the Second World War for the region between Lviv and the state boundary. They were devoted mainly to biostratigraphy and tectonics (ŁAZARENKO 1958, UTROBIN 1958, GORECKI 1962, KUDRIN 1966, SIENKOWSKIJ 1977, BOGUCKI & *al*. 1998a, 1998b).

GEOLOGICAL SETTING AND STRATIGRAPHY

The Roztocze Hills area lies in a complex zone of deep basement structure, which is related to the boundary between the Precambrian East-European Platform and a younger Epi-Variscan Platform below the Mesozoic sedimentary cover (ŻELICHOWSKI 1974). The strongly folded and faulted Palaeozoic rocks are overlain by a slightly folded Mesozoic cover of Jurassic and Cretaceous age which forms vast, low-amplitude anticlines and synclines. The direct substratum of the Miocene deposits in the Roztocze Hills is formed of Upper Cretaceous rocks, mainly Maastrichtian, up to 1000 m thick, developed as sandy limestones (=gaizes) (CIEŚLIŃSKI & RZECHOWSKI 1993).

Throughout the Tertiary, block movements were taking place in the Roztocze Hills area causing reacti-

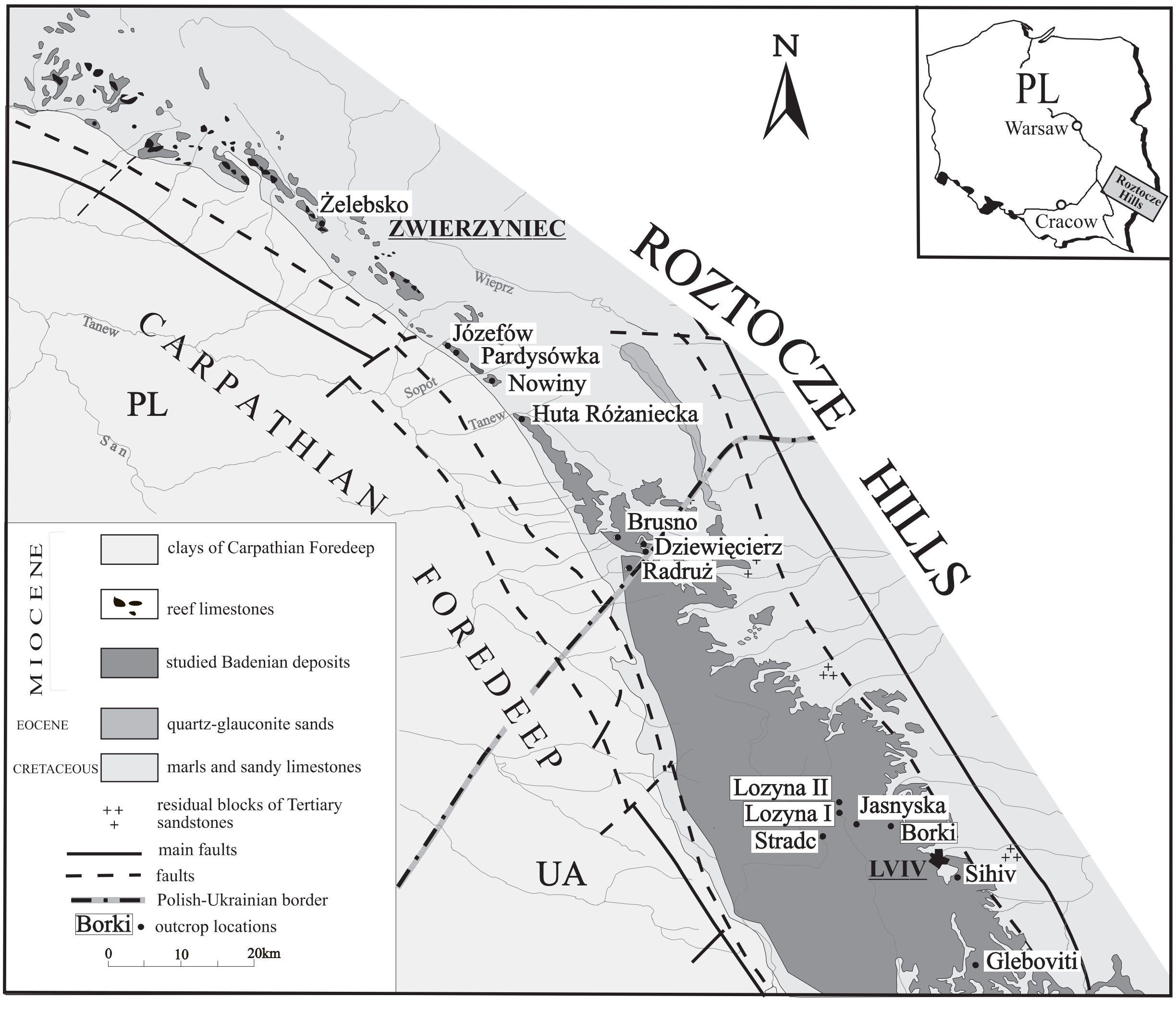

Fig. 1. Location of investigated area (geological map adopted from MUSIAŁ 1987a and BURACZYŃSKI 1997)

vation of older faults, and leading to uplift of the area (Ney 1969). The last episode of structural development of the Roztocze Hills area took place in the Neogene, and was connected with the tectonic reaction of this region to the Neo-Alpine orogenic movements in the Carpathians. At the beginning of the Miocene, a foredeep basin began to form due to the advance of the Carpathian nappes. This peripheral foredeep basin developed from the Eggenburgian until the Sarmatian (Oszczypko 1996), forming a northern part of the Paratethys Ocean. The study area lies in the northern, marginal part of the Carpathian Foredeep basin. At that time, the northern edge of the Carpathian Foredeep was divided into two facies zones, especially evident in deposits lying above the Evaporitic-Chemical Beds: an open-sea deep water zone and a shallow-water zone. Their formation was connected with the rejuvenation of older, Mesozoic discontinuities in the basement, as a result of the Carpathian Foreland plate subduction, and of the development of the Mid-Polish Swell (Krzywiec 1998). The deeper water zone located within the Carpathian Foreland plate was characterised by a high subsidence rate (Oszczypko 1996) and was filled with fine siliciclastic Middle Miocene deposits over 2000 m thick (Ney & *al*. 1974, Krzywiec 1998). The Roztocze Hills area was a part of the shallow-water zone, which was subjected to block movements. Organodetritic deposits, with thickness of dozen or so metres, predominate in this zone.

In the territories of both Poland and Ukraine the oldest deposits that filled the Carpathian Foredeep are included in the Karpatian. Northward shift of the basin limits in the Badenian resulted in transgression onto the Roztocze Hills area (Kudrin 1966, Ney & *al*. 1974, Musiał 1987a). The Miocene deposits that occur in this region are included in the Badenian and the Sarmatian. The Badenian is defined by the occurrence of nannoplanktonic zones NN5 and NN6, and the Sarmatian by zones NN7-NN8. These are stages distinguished for the Central Paratethys area (Steiniger & *al.* 1989) (Text-fig. 2). Unfortunately, no occurrence of diversified nannoplanktonic assemblages has been determined in rocks from the Roztocze Hills area (Musiał 1987a), which limits the biostratigraphy of these deposits.

Musiał (1987a) and Szczechura (1982) based the stratigraphy of the Miocene on foraminifera. The deposits yielding the foraminiferal assemblages index for the CPN 6-7 Zone they included into the Lower Badenian, assemblages of the CPN 8 Zone into the Middle Badenian, and assemblages of the CPN 9 Zone into the Upper Badenian. The Lower and Middle Sarmatian belong to zones CPN 10-11 and CPN 12 respectively. On the basis of these studies, Musiał (1987a, 1987b) included the Miocene deposits of the Polish part of the Roztocze Hills with the supra Evaporitic-Chemical Beds (Upper Badenian and Sarmatian). However, there are still many discussions on foraminiferal stratigraphy (*see* Łuczkowska-Schiller 1987, Olszewska, 1999) which cause many problems with stratigraphic correlations based on both foraminifera and nannoplankton. Moreover, the most recent nannoplanktonic studies have further complicated this situation. The deposits of the Evaporitic-Chemical Beds have been included into Zone NN6-NN7, that means into the Upper Badenian (Sarmatian) (Peryt & Peryt 1994), and not to the Middle Badenian, as before. The situation is complicated by a lack of the gypsum level (belonging to the Evaporitic-Chemical Beds) in the Polish part of the Roztocze Hills. Because of difficulties in the usage of biostratigraphy for the studied deposits, the authors working in this region have still used the lithostratigraphic units (Text-figs 3, 4).

Generally, the Miocene succession of the Roztocze Hills begins with transgressive quartz sands and sand-

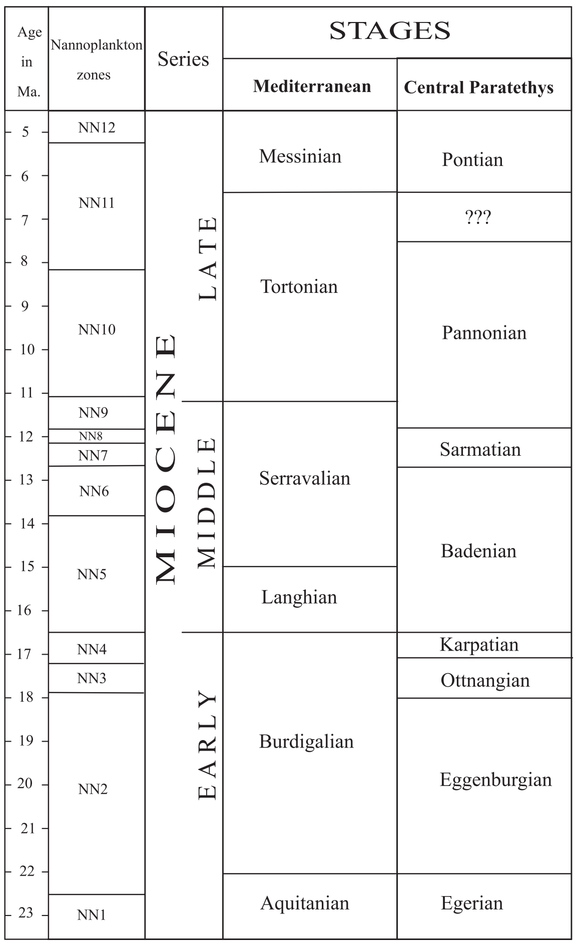

Fig. 2. Stratigraphic scheme of the Miocene (*after* Steininger & *al*. 1989)

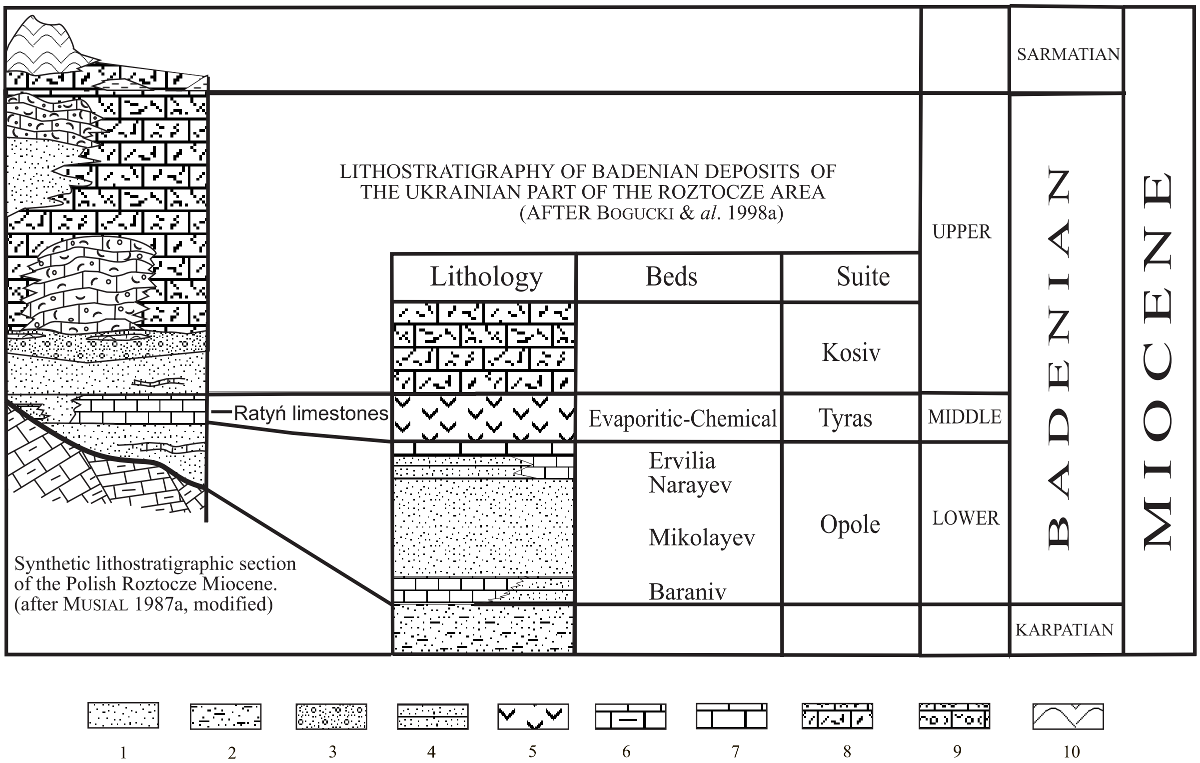

Fig. 3. Lithostratigraphic scheme of the Miocene deposits from the Polish and Ukrainian parts of the Roztocze area. Lithology: 1 – quartz sands, 2 – clayey quartz sands, 3 – quartz – rhodolith sands, 4 – quartz sandstones, 5 – gypsum, 6 – marls, 7 – micritic limestones, 8 – calcarenites, 9 – reef limestones, 10 – serpulid – microbial limestones

stones of Early Badenian age, possessing their greatest thickness and limits in Ukraine (BURACZYŃSKI 1997). Towards the top, the sands pass laterally into marls and *Lithothamnium* limestones (Text-fig. 3). Those deposits are overlain by a continuous level of gypsum and/or Ratyń Limestones (both included into the Evaporitic-Chemical Beds). In Poland, the Lower Badenian deposits have been identified only in the vicinity of Radruż (Text-fig. 1). Various shallow-water carbonate and terrigenous deposits of Late Badenian age overlie the Evaporitic-Chemical Beds (Text-fig. 3), in both Polish and Ukrainian territories. The terrigenous rocks are represented mainly by quartz sands and sandstones with an admixture of glauconite, siltstone and clay. The biogenic rocks are represented by various shell coquinas and reefal-type deposits.

The Miocene succession of the Roztocze Hills is terminated by deposits of Sarmatian age. These are represented by serpulid-vermetid reefs (PISERA 1985) and serpulid-microbial build-ups (JASIONOWSKI 1996, 1998), exposed in the westernmost part of the Roztocze Hills. The present-day northern limit of the Miocene deposits in and immediately north of the Roztocze Hills area reveal an erosional character, and thus determination of the original extent of the Miocene sea is difficult. The shoreline of this sea, determined by the occurrence of borings and coastal abrasion forms, has been described only north-east of the study area, on the southern slopes of the Holy Cross Mountains (RADWAŃSKI 1969).

METHODS

Detailed lithological sections were constructed for the studied exposures (Text-fig. 5). Palaeocurrent directions were measured in Huta Różaniecka (n=35), Stradc (Polish *Stradcz*) (n=100), Lozyna (Polish *Łozina*) (n=115) and Gleboviti (Polish *Chlebowice*) (n=75), mainly of the cross-stratifications (Text-fig. 4). The palaeocurrent rose diagrams were drawn and the mean vector magnitude was calculated for each distribution (GRADZIŃSKI & *al*. 1986).

Petrographic studies – 110 thin sections were prepared and studied, including 70 sections mounted on araldite. For the terrigenous rocks, in which quartz was the dominant component, a quantitative analysis was performed, which allowed classification of the deposits based on classification triangles (ZUFFA 1980, TUCKER & WRIGHT 1991). The following components were taken into account (33 sections): quartz (monomineral, consisting of a few crystals and polycrystals; with straight and wavy extinction), feldspars, glauconite, opaque and heavy minerals, intraclasts (lithoclasts, peloids, rhodoliths, algal intraclasts, skeletal elements of foraminifera, gastropods, bivalves, serpulids, bryozoans and pelmatozoans), carbonate cements (microspar, blocky spar, poikilotopic spar, syntaxial spar, micrite), non-carbonate cements and pores. For selected thin sections a cathodoluminescence analysis was performed, using an optical microscope with a countershaft for CL studies – 8200MK3, GH Gold Cathoda Luminescence, in conditions of accelerating voltage 15-20kV, and with a current intensity of 400mA.

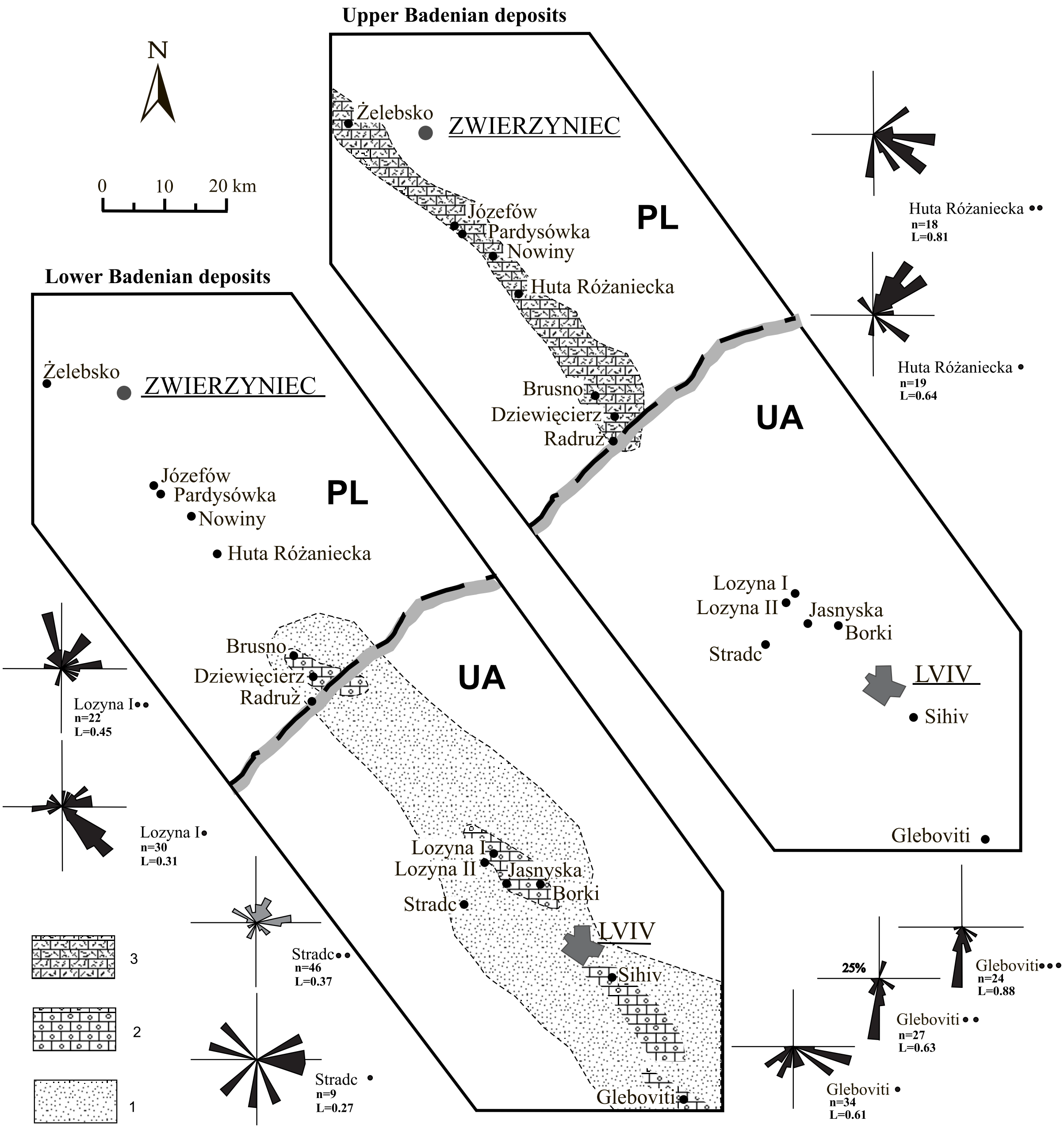

Fig. 4. Distribution maps of dominant lithofacies associations representing the Lower and Upper Badenian deposits. Lithology: 1 – sandy lithofacies, 2 – *Lithothamnium* limestones lithofacies, 3 – calcarenite lithofacies. Rose diagrams show palaeocurrent directions measured from cross-bedding (black) and flat clast imbrication (grey); n = number of readings, L = mean vector magnitude; for detail of location in sections *see* Text-fig. 5

In cases of organodetritic and organogenic rocks, standard microfacial studies of thin sections (70 sections) were performed, which allowed a unified classification of carbonates (DUNHAM 1962).

Geochemical studies were aimed at determining the contribution of secondary elements and selected trace elements in a few sandstone samples. The studies were made using an atomic absorption spectrometer Perkin Elmer type 400. For the component which was insoluble in hydrochloric acid, the Si content was determined (weight %), as well as the content of the following trace elements: Al, Ti, Fe, Mg and Mn (ppm). For the acid-soluble part, the Ca content was determined (weight %), and the content of trace elements such as: Mg, Fe, K, P, Mn, Sr, Al. and Ti (ppm). For all of the samples the content of sulphur and organic carbon was also determined. Sulphur was determined by the weight method, by oxidation of sulphur compounds contained in the sample, by melting them with the flux in oxidation conditions, and by determining the sulphur content after the precipitation and by weight determination of the sulphur in the form of barium sulphate. Organic carbon was determined by oxidation of carbon by potassium chromate in a strongly acidic environment.

LITHOFACIES

Lower Badenian

The Lower Badenian deposits, developed as the Opole suite (Text-fig. 3), were described in the Lviv region [Stradc, Lozyna I, Lozyna II, Jasnyska (Polish *Jaśniska*), Borki, Sihiv (Polish *Sichow*) and Gleboviti sections] and in the vicinity of Radruż (Text-figs 4, 5). These deposits rest here with a stratigraphic disconformity on an erosional surface of the Upper Cretaceous (in Poland); and of the Upper Cretaceous, Paleogene or Karpatian (in Ukraine). The Lower Badenian deposits form a continuous cover (Text-figs 1, 4) and they reach a maximum thickness of up to 80 metres in the area of the Roztocze Hills near Lviv. They represent a set of lithologically diversified rocks with a predominance of sandy, quartz and quartz-glauconite deposits, more rarely accompanied by calcarenites and *Lithothamnium* limestones. These deposits may pass laterally into each other, as well as occur several times within the sections.

The studied Lower Badenian succession starts with quartz and quartz-glauconite sands (Text-fig. 5) of various thickness. These deposits are overlain by marly or sandy *Lithothamnium* limestones (in the Lozina I, Jasnyska, Borki, Sihiv and Gleboviti sections), by strongly clayey quartz-glauconite sandstones with rhodoliths, *Lithothamnium* limestones with discontinuous interlayers of micritic limestones and quartz sandstones (Lozina II section), or directly by the Ratyń Limestones. Because of the high lithofacies diversification it is necessary to briefly describe the Lower Badenian succession in measured sections.

Stradc (Text-fig. 1): sandpit in the southern slope of the Stradecka Hill in the Wereszczyca river valley. An over 30 m thick section of Lower and Middle Badenian deposits - quartz sands, in some places slightly glauconitised, is exposed here (Text-fig. 5).

On the western slope of the Stradecka Hill, above the sands, a 4 metre thick complex of Ratyń Limestones crops out. These limestones are developed as cream-coloured, pelitic, cavernous, strongly weathered rock. According to ŁOMNICKI (1898), an important attribute of the Badenian deposits of the Stradc region is the presence of two levels of the Ratyń Limestones, separated by quartz sands. Unfortunately, these two separate levels cannot be found at present.

The Stradc section is extraordinary, as far as sedimentary structures are concerned. Synsedimentarily disturbed stratification and other deformational structures occur within the sands. The style of sediment deformation is very variable, and ranges from small convolute folds within the ca. 10 cm thick layers (Pl. 7, Fig. 2), to diapirs with heights of 3 m (Pl. 7, Fig. 1). The occurrence of dispersed disturbed stratification (Pl. 7, Fig. 3), pillar water escape structures (Pl. 7, Figs 4-6) and dish structures (Pl. 7, Fig. 4) has also been observed. The large-scale deformation forms are additionally associated with preferential cementation. The deformation styles have different scales, and commonly even lead to total homogenisation of the sediment. Large-scale channel-like forms (Pl. 6, Fig. 1) recur several times in this section. Convolute deformations of different scales occur on top of the channel-like forms (Pl. 6, Fig. 1). Measurements of palaeocurrent directions, performed in cross-laminated tabular sets from the uppermost part of the section, do not show any dominant direction (Text-fig. 4). Moreover, the arrangement of clasts in the flat-pebble fillings of the channel-like forms is random and also does not reveal any dominant direction. Measurement of the orientation of the channel axes and of the angle of the channel bottoms is not possible in this exposure. Based on the observations of cross-sections that cut the channels in the wall of the exposure, all that can be determined is that the channels are elongated perpendicularly to the wall. As the azimuth of the wall ranges between 120° and 160°, the long axis of the channels is probably between 30° and 70°.

Lozyna (Text-fig. 1): sandpit (Lozyna I section) and a natural scarp in the Stara Rzeka valley (Lozyna II section), 7 km north of Stradc. The Lozyna I and II sections are about 2 km from one another. In these localities the Ratyń Limestones are exposed at the top of the section; the bottom of this limestone unit serves as a level that enables correlation.

In the Lozyna I section (Text-fig. 5) the Lower Badenian deposits comprise, in ascending order, fine- and medium grained quartz sands; marly *Lithothamnium* limestones with abundant bivalve shells in their bottom parts; quartz sands with rhodoliths and *Lithothamnium* limestones in the top. These deposits are overlain by the Middle Badenian Ratyń Limestones.

A substantial variety of palaeocurrent directions within the quartz sands has been observed in the Lozyna I section. In its lowermost part (Text-fig. 5), sets up to 20 cm thick with tabular cross-laminations predominate, dipping towards the southeast. There are also subordinate W and ENE palaeocurrent directions (Text-fig. 4). Higher in the section, the SE direction disappears, no distinct dominant direction exists, and the azimuth array lies between 270 and 120°. In the uppermost part of the sands from this section, the primary stratification was subjected to substantial destruction by organism activity within the sediment.

In the Lozyna I section, marly or sandy *Lithothamnium* limestones (Text-fig. 5), overlie the quartz sands. The top of the quartz sandstones is flat throughout the exposure, with *Lithothamnium* deposits lying on top of it with a sharp basal contact. The section is terminated by the Ratyń Limestones.

In the Lozyna II section, (Text-fig. 5) quartz sandstones, marly *Lithothamnium* limestones with admixture of quartz and glauconite, strongly clayey quartz-glauconite sandstones with rhodoliths, *Lithothamnium* limestones with discontinuous interlayers of pelitic limestones and quartz limestones are exposed. They are overlain by the Ratyń Limestones.

A characteristic feature of the Lozyna II succession is the occurrence of thick sets (>3 m) of quartz sandstones above the *Lithothamnium* limestones. Assuming isochroneity of the bottom of the Ratyń Limestones, comparison of the sections from the Lozyna area indicates lateral facies variation within the Lower Badenian deposits. In the Lozyna I section, the quartz sandstones do not occur above the *Lithothamnium* limestones, and the boundary with the Ratyń Limestones occurs above the *Lithothamnium* limestones. In the Lozyna II section, the *Lithothamnium* limestones occur as a strongly sandy level with a thickness of almost 3 m within the quartz sandstones (Text-fig. 5). In the Lozyna II section, the transition between the sandstones and the Ratyń Limestones is gradual, devoid of a distinct boundary. Traces of sandstone dissolution and fracturing, marked by the occurrence of a rugged, discontinuous erosional surface, occur in the transitional zone. Modern karstic processes have developed between the quartz sandstones and the Ratyń Limestones.

Jasnyska (Text-fig. 1): a vast disused sandpit at the end of a mountain range, which continues towards Lozyna. It is a monotonous section: the greater lower part is formed of quartz sands with a thickness of 17 m.; above the sands lies a thin unit of sandy *Lithothamnium* limestones, which becomes more marly towards the top (Text-fig. 5).

Three complexes, with various sedimentary structures, can be distinguished within the quartz sands. The lower part of the section, over 10 m thick, is composed of varigrained cross-laminated quartz sands with single pebbles. It also includes portions of horizontally laminated sediments with clayey, strongly ferruginous interlayers containing dispersed organic matter. This part of the Jasnyska section forms a portion of the sediments that dip towards the southeast at an angle of 15°. Medium-grained, trough- and cross-stratified quartz sands, over 3 m thick, occur at higher levels. Cross-stratified sets form tabular cosets. Strongly bioturbated horizons, about 10 cm thick, are developed at the set boundaries. The highest part of the sandy deposits is represented by strongly bioturbated quartz sands. The bioturbation is so intense that the identification of stratification is impossible. The quartz sands are overlain by sandy *Lithothamnium* limestones, which pass into marly *Lithothamnium* limestones towards the top of the section.

Borki (Text-fig. 1): small sandpit in a scarp of the Młynkówka river valley. A 15 m thick section of Lower Badenian deposits is exposed here (Text-fig. 5). The lower part of the section consists of quartz and quartz-glauconite sands with rhythmically repeating portions of strongly bioturbated deposits with thick intercalations of non-bioturbated deposits. The bioturbated parts are composed of 10-25 cm thick horizons separated by preserved relicts of stratification. The occurrence of two portions, more than 2 m thick, of quartz sands devoid of bioturbation was also observed in the Borki profile. The sandy series ends with a 3 m thick horizon of massive quartz sandstones with single burrows. The Borki section is terminated by *Lithothamnium* limestones with an admixture of quartz and glauconite, marly *Lithothamnium* limestones and quartz sandstones crowded with bivalve shells.

Sihiv (Text-fig. 1): sandpit located near the Lviv ring road, close to the exit to Rogatyn. A poorly exposed, especially in its upper part, 20 m thick section of quartz sandstones occurs here (Text-fig. 5).

In the Sihiv exposure, quartz sands with a minor admixture of glauconite occur as part of a large-scale cross-stratified set that dips towards the southwest at an angle of 5-10^{o}. The cross-stratification occurs in the form of tabular cosets. Within them, as in the Borki section, numerous strongly bioturbated horizons occur. Channel-like structures, filled by massive deposits, have also been recognised in this section. In the highest part of the section the quartz sands pass continuously into marly *Lithothamnium* limestones.

Gleboviti (Text-fig. 1): a disused sandpit, with a section of Lower Badenian sandy and carbonate deposits. The Gleboviti section starts with tabular cross-stratified quartz sands (Text-fig. 5). At the base of these sands an *in situ* occurrence of silicified taxodiacean tree stumps has been noted (*see* RADWAŃSKI & WYSOCKA 2001). Above, there is a 3 m thick, distinctly bipartite section, with numerous bioturbated horizons. Cross-stratification analysis indicates a predominance of two palaeocurrent directions (Text-fig. 4), mainly towards the southeast, with a slightly smaller contribution towards the southwest. The upper part of this set is very strongly bioturbated, with the bioturbation horizons occurring within the cross-stratified quartz sands. The array of palaeocurrent directions (Text-fig. 4) within this set is characterised by a relatively high mean resultant (L=0.63), and points to a dominant transport direction towards the south. Above them, a large-scale, up to 2 m thick, cross-stratified set of sands occurs. The sandy part is terminated by sands with sets of tabular cross-stratification, each set being about 10 cm thick. Higher in the section, quartz-rhodolithic sandstones and marly *Lithothamnium* limestones with coquina-like horizons rest on the sands with a distinct erosional boundary.

Radruż (Text-fig. 1): a series of small outcrops in the slope of the Radrużka river valley. The section starts with cross-stratified quartz sands (Text-fig. 5), which gradually become more and more coherent and pass into pelitic, porous Ratyń Limestones with varying degrees of sandiness. The Lower Badenian quartz sands of this section are fine-grained and rather poorly sorted. The Ratyń Limestones are overlain by Upper Badenian cross-stratified quartz sands.

Middle Badenian

In the Polish part of the Roztocze Hills, Middle Badenian deposits have been observed only in the vicinity of Radruż (Text-figs 1, 5). In the Ukrainian part of the Roztocze Hills, in the Lviv region, they are developed as the Tyras suite (Text-fig. 3). The rocks of this suite lie on an erosional surface of the Lower Badenian or the Upper Cretaceous (BOGUCKI & *al*. 1998a). The Tyras suite contains a complex lithological set: sulphate deposits – gypsum and anhydrites, chemogenic pelitic limestones (so-called the Ratyń Limestones), and sandy deposits. The lithofacies pass laterally into each other. Gypsum and anhydrites occur only on the southeastern slopes of the Roztocze Hills, in the transitional zone with the Carpathian Foredeep, where their thickness rarely exceeds 10 m. By contrast, the Ratyń Limestones have a larger geographical extent. They crop out in the regions of Radruż, Stradc and Lozyna (Text-figs 1, 5)

Upper Badenian

In the Roztocze Hills area the Upper Badenian deposits occur as erosional relict patches (Text-fig. 1). In its eastern part, in the Radruż region, the Miocene succession starts with Lower Badenian sands and Middle Badenian Ratyń Limestones. Moving westwards, progressively younger deposits of the Upper Badenian and the Sarmatian appear in the sections (Text-fig. 5). The Upper Badenian deposits are composed mainly of calcarenites with a variable admixture of quartz.

Dziewięcierz (Text-fig. 1): two exposures near the road from Horyniec to Werchrata. The exposure on the western side of the road is a recultivated sandpit, in which the rocks are poorly exposed. A small sandpit on the eastern side of the road exposes a 5 m thick succession of Upper Badenian sandy deposits and limestones (Text-fig. 5).

The succession starts with medium-grained, well-sorted tabular cross-stratified quartz sands. Higher up, they pass into medium-grained cross- and ripple cross-stratified sands with single small quartz pebbles. The uppermost part of the sands is medium-grained and well sorted. In the upper part of the succession the quartz content gradually decreases. The quartz sands are overlain by quartz-rhodolithic sands with a thick-shelled oyster fauna. The section ends in massive sandy or marly *Lithothamnium* limestones with a framework composed of rhodoliths and algal detritus.

Brusno (Text-fig. 1): numerous exposures on the Brusno Hill, the best of which are in a series of vast disused quarries. The section begins with marly *Lithothamnium* limestones. They are overlain by a thick layer (>0.5 m) of quartz-glauconite sands, with an admixture of finer fractions, clay minerals and glauconite, and with an increase in the content of organodetritic material. Above it rests a lithologically monotonous, thick (>20 m) set of calcarenites. They are composed of fragments of calcareous algae, foraminifera and variously fractured shells of gastropods, bivalves, and rare fragments of pelmatozoans and polychaetes (RONIEWICZ & WYSOCKA 1999). Despite the monotonous lithology, these calcarenites exhibit a varied set of sedimentological structures, mainly stratification (RONIEWICZ & WYSOCKA 1997). Cross- and ripple cross-stratification predominates, accompanied by horizontal and trough cross-stratification. Due to the occurrence in the calcarenites of the index *Bolboforma badenenis* and *Velapertina* sp., these deposits were included in the Upper Badenian (SZCZECHURA 1998).

Huta Różaniecka (Text-fig. 1): numerous exposures on the southern side of a long elevation, elongated parallel to the southern edge of the Roztocze Hills. The section in Text-fig. 5 is a compilation of nine exposures. Due to a lack of marker horizons that could be used for correlation between the exposures, the composite section was constructed on the basis of the lithological succession and the relative altitude setting of the sets in the different exposures.

The section starts with poorly coherent, sandy-rhodolithic deposits, with rhodoliths of up to 4 cm diameter. They are cross and trough cross-stratified, and the north-eastern component predominates among the stratification dip directions (Text-fig. 4). Lithification of the quartz-rhodolithic deposits changes from unconsolidated sands to strongly cemented sandstone interlayers.

The lowermost part of the Huta Różaniecka section might correspond to the period of deposition of the Ratyń Limestones in the shore zone of the Carpathian Foredeep (MUSIAŁ 1987a), or may even be a counterpart of the Baranów Beds (JAKUBOWSKI & MUSIAŁ 1979). These opinions are, however, based solely on lithological premises, and are so far not substantiated biostratigraphically. Due to the similarity of the succession to the section in Brusno, and a lack of biostratigraphic control, the quartz-rhodolithic deposits from Huta Różaniecka were included in this work into the lower part of the Upper Badenian.

Above the quartz-rhodolithic deposits, an abundant accumulation having a form of a continuous layer of bivalve casts and shells, with a character of a coquina bed occurs. It is overlain by quartz and quartz-glauconite sands. The sands are alternately cross- and horizontally-stratified. Above them rests a thick complex (>10 m) of cross-stratified calcarenites (Text-fig. 5), with a variable degree of sandiness. Horizons with rich accumulations of bivalve casts and shells recur several times within this set. Characteristically beds of ripple and cross-stratified sands also occur repeatedly. In the uppermost part of the section the degree of sandiness of the deposits increases, and thick sets of cross-stratified sandy calcarenites start to occur. Based on the dip directions of the cross-stratification in the uppermost part of the section, transport of the material took place generally towards the south-east, varying in azimuth between 49° and 190° (Text-fig. 4). Due to the occurrence in the calcarenites of the index *Bolboforma badenenis* and *Velapertina* sp., these deposits were included in the Upper Badenian (SZCZECHURA 1998).

Nowiny (Text-fig. 1): disused quarry on the Krzyżowa Góra Mountain. A continuous succession of the Upper Badenian sandy calcarenites, with a thickness of ca. 15 m is exposed here. The calcarenites are underlain by quartz and quartz-glauconite sands, which are not exposed at present (MUSIAŁ 1987a).

The lower, less diversified part of the exposed succession (Text-fig. 5) consists of alternating, apparently massive layers of calcarenites and of horizontally-laminated, fine-grained calcarenites with an admixture of quartz and glauconite. In thicker, apparently massive layers, tabular cross-stratification is visible.

The upper, most diversified part of the section starts with a distinct erosional surface, above which rest characteristically stratified calcarenites. A medium-scale cross-stratified set is capped by a cover of ripple cross-lamination. In the consecutive layers of coarse-grained calcarenites, a succession from horizontal to ripple cross-stratification is observed, accompanied by a decrease in grain size towards the top. The highest part of the section consists of layers of variously cemented calcarenites.

In the western part of the quarry, about 100 m from the main wall, a distinctive set of sediments, up to 6 m thick, is visible over an area of about 200 m. It rests with a sharp, erosional boundary on the rocks of the described section. It is characterised by poor lithification and by poor sorting of the detritic material. It contains common oyster shells, quartz grains, fragments of black flints and clayey-marly intraclasts. The intraclasts have a diameter of up to 50 cm (*see* RONIEWICZ & WYSOCKA 1997).

Józefów (Text-fig. 1): two vast active quarries, Józefów and Pardysówka, in a range of hills elongated parallel to the southern edge of the Roztocze Hills. Calcarenites with a variable quartz grain content are exposed.

In the Józefów section (Text-fig. 5) there are a series of channel-like forms of different sizes (Pl. 6, Figs 3, 4), with a wide range of internal deposits (Pl. 6, Figs 5, 6) These forms are orientated N-S, and all dip southwards. In the exposures, the channel-like forms are visible in sections perpendicular to their elongation. Their widths range between 2 (Pl. 6, Fig. 4) and approximately 15 metres (Pl. 6, Fig. 3), and their depths between 1 and 10 m. Channel-like forms occur at various horizons within the ripple cross-stratified calcarenites. They are filled by deposits that contrast markedly with the underlying sediments. The fills consist of medium- and coarse-grained organodetritic material with numerous intraclasts. The intraclasts are clay and clay-marly patches, or large fragments of algal clasts.

The whole complex of the Badenian deposits from the Józefów region, observed in the Józefów and Pardysówka quarries, dips slightly southwards – towards the Carpathian Foredeep. Because most of the layer sets have a concave bottom, it seems that the observed small dips are of an original, sedimentary character.

Żelebsko (Text-fig. 1): active quarry, the westernmost of the described sections. A continuous Badenian/Sarmatian transition is visible here (RONIEWICZ & WYSOCKA 1999). The Badenian deposits are fine- and medium-grained, ripple cross-stratificated calcarenites (Text-fig. 5). The lowermost part of the section is built of wavy- and flaser-laminated marly calcarenites. Towards the top of the section, thickness of layers increase and the content of clay admixtures decreases. This part of the Żelebsko section is overlain, with a small angular unconformity, by a set of thick, massive calcarenites.

Above them lie a clay layer with thin intercalations of compact micritic limestones, and a few layers of calcarenites containing scarce, small fragments of serpulid-microbialitic limestones. Individual Sarmatian forms occur among the foraminiferal fauna of these layers (SZCZECHURA 1998). Therefore the Badenian/Sarmatian boundary in the Żelebsko section (Text-fig.5) is based on lithological-palaeontological premises placed within the deposits in which the foraminiferal fauna contains Sarmatian forms. The deposits included in the Sarmatian are calcarenites, with fragments of serpulids, and marly clays, with lenses of serpulid-microbialitic build-ups (JASIONOWSKI 1996; JASIONOWSKI & WYSOCKA 1997).

PETROGRAPHY

Petrographic analysis of thin sections indicated a substantial variety of frameworks and the occurrence of two groups of components (Tabs 1, 2): extraclasts and intraclasts. The extraclasts (NCE – non-carbonate extrabasinal grains, after ZUFFA 1980) were derived from a land area. They are represented mainly by quartz (Q) and feldspars (F), accompanied sporadically by grains of heavy minerals (HM) and non-transparent minerals (MNT).

Quartz content (Q_t) in the Lower Badenian deposits ranges widely, between 54.6% and 95.9%, with an average value of 84.8%. All the studied thin sections contain more than 50% quartz grains, and so they represent different types of sandstones. The quartz content of the Upper Badenian deposits (Tab. 2) ranges between 6.6% and 95.6%, with an average value of 49%. The samples that contain less than 25% of quartz grains were classified on the basis of microfacial criteria.

In order to identify the origin of the quartz, three types of quartz grains have been distinguished: the grains

LOCATION		FRAMEWORK COMPONENTS																								WHOLE SAMPLE				
		extraclasts (NCE)								intraclasts																	cements			
										NCI	carbonate (CI)																			
outcrop	sample	quartz					other		Σ NCE	glauconite	lithoclasts	pizoids	rhodoliths	algal clasts	foraminiferas	bryozoans	pelmatozoans	bivalves	gastropods	serplids	ditrups	peloids	other	Σ CI	framework	carbonate	noncarbonate	Σ	porosity
		Q_t	Q_m	Q_{2-3}	$Q_{>3}$	Qm/Q_p	F	MNT +HM																					
Lozyna	LVI(1)	95,6	92,9	3,9	3,2	13,1	3,4	0,4	99,4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,6	55,1	41,0	0,4	41,4	3,5
Lozyna	LVI(3)	95,6	90,8	7,1	2,1	9,8	3,4	0,3	99,3	-	100	-	-	-	-	-	-	-	-	-	-	-	-	0,7	50,0	34,6	10,6	45,2	4,8
Lozyna	LVI(5)	78,3	94,9	3,8	1,3	18,8	3,0	1,6	82,9	10,8	-	-	47,3	10,5	-	-	36,8	-	-	-	-	-	5,3	6,3	62,1	36,7	0,4	37,1	0.8
Lozyna	LVI(9)	90,3	92,0	2,9	5,1	11,5	0,5	1,0	91,8	7,7	-	-	-	-	-	-	-	-	-	-	-	-	100	0,5	39,9	41,7	12,7	54,4	5,7
Stradc	S4	83,6	92,1	4,8	3,1	11,8	1,8	2,5	87,9	9,5	-	-	-	-	42,9	-	-	-	-	-	-	42,9	14,2	2,6	56,7	33,3	6,1	39,4	3,9
Stradc	S5	93,3	95,4	2,3	2,3	20,8	3,7	0,9	97,9	2,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	61,8	37,1	-	37,1	1,1
Stradc	SIV(3)	90,6	95,5	2,7	1,8	21,1	6,6	1,6	98,8	1,2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51,9	15,7	19,6	35,3	12,8
Stradc	SIV(4)	90,9	91,7	4,3	4	11,0	4,6	-	95,4	1,8	11,1	-	-	-	-	-	-	22,2	-	-	-	-	66,6	2,7	54,6	30,6	10,2	40,8	4,6
Stradc	SIV(5)	95,9	93,1	3,9	3,0	13,4	2,5	0,4	98,1	0,4	-	-	-	50	-	-	50	-	-	-	-	-	-	0,8	51,7	18,9	20,8	39,7	8,6
Borki	B(14)	63,3	92,8	3,3	3,9	12,8	3,2	1,8	68,3	13,0	-	-	-	-	11,3	62,3	11,3	3,8	-	-	-	3,8	7,5	18,7	51,8	42,0	1,8	43,8	4,4
Radruż	RI(3)	93,4	92,9	3,4	3,7	13,0	3,5	1,0	97,9	1,4	-	-	-	-	-	-	-	-	-	-	-	100	-	0,7	59,5	34,1	1,2	35,3	5,2
Radruż	R3	94,7	94,3	3,5	2,2	16,6	2,9	0,4	98,0	-	-	-	-	-	-	-	-	-	-	-	-	100	-	2,0	40,3	54,3	0,3	54,6	5,1
Radruż	R(5)	73,7	96,4	2,9	0,7	26,4	16,7	-	90,4	1,6	-	-	-	-	-	-	-	-	-	-	-	100	-	8,0	34,7	60,1	0,7	60,8	4,5

Tab.1. Petrographic composition of the Lower Badenian terrigenous rocks. Q_t – quartz content, Q_m – monocrystalline quartz, Q_{2-3} – grains composed of max. 3 quartz crystals, $Q_{>3}$ – polycrystalline quartz. Qm/Q_p – monocrystalline/polycrystalline quartz ratio ($Q_p = Q_{2-3} + Q_{>3}$). F – feldspars, MNP+HM – non-transparent and heavy mineral grains. NCE – non-carbonate extrabasinal grains, NCI – non-carbonate intrabasinal grains, CI – carbonate intrabasinal grains

LOCATION		FRAMEWORK COMPONENTS																							WHOLE SAMPLE				
		extraclasts (NCE)								intraclasts																cements			
		quartz					other			NCI	carbonate (CI)																		
outcrop	sample	Q_t	Q_m	Q_{2-3}	$Q_{>3}$	Q_m/Q_p	F	MNT +HM	Σ NCE	glauconite	lithoclasts	pizoids	rhodoliths	algal clasts	foraminiferas	bryozoans	pelmatozoans	bivalves	gastropods	serpulids	ditrups	peloids	other	Σ CI	framework	carbonate	noncarbonate	Σ	porosity
Dziewięcierz	D14	29,4	93,5	3,2	3,3	14,5	1,3	0,6	31,3	-	-	-	64	5,0	6,9	14,4	2,8	4,1	-	-	-	0,5	2,3	68,7	86,2	8,7	0,5	9,2	4,6
Dziewięcierz	DII(25)	88,9	94,9	3,4	1,7	18,5	4,9	1,5	95,3	1,5	-	-	-	-	-	-	-	-	-	-	-	100	-	3,2	55,7	31,2	3,7	33,9	10,4
Brusno	Br(39)	6,8	100	-	-	-	0,3	0,3	7,4	3,2	-	-	-	68,9	10,5	12,1	2,0	1,3	-	-	-	-	5,2	89,4	93,6	-	-	-	6,6
Brusno	Br(51)	6,6	95,5	-	4,5	21	0,3	0,3	7,2	1,8	1,0	-	-	69,8	11,2	5,6	2,6	2,9	-	-	-	-	6,9	91,0	92,9	0,8	0,8	1,6	5,5
Brusno	Br60	94,2	94,9	4,1	1,0	18,6	3,5	1,9	99,6	-	-	-	-	-	-	-	-	-	-	-	-	100	-	0,4	94,4	41,1	-	4,1	1,5
Brusno	BrVIII	90,3	94,3	5,0	0,7	16,5	3,0	0,3	93,6	0,3	90	-	-	-	-	-	-	-	-	-	-	10	-	6,1	60,5	37,1	0,6	37,7	1,8
Huta Różaniecka	HR27	57,8	94,2	4,0	1,8	16,3	6,4	0,3	64,5	-	-	-	82,1	4,7	-	-	2,8	1,9	-	-	-	7,5	1,0	35,5	65,0	33,7	0,2	33,9	1,1
Huta Różaniecka	HR(72)	37,6	97,7	-	2,3	43,0	0,9	-	38,5	0,6	-	-	55,1	9,8	11,2	9,8	4,7	1,9	-	-	-	0,5	7,0	60,9	73,5	25,0	-	25,0	1,5
Huta Różaniecka	HR(81)	38,7	95,2	1,6	3,2	19,8	1,5	0,3	40,5	0,3	-	-	79,7	-	-	17,7	-	2,1	-	-	-	-	0,5	59,2	73,8	2,5	14,1	16,6	9,6
Nowiny	KN(21)	23,3	93,5	6,5	-	14,5	0,7	-	24,0	0,4	-	-	-	71,6	2,5	16,9	0,5	2,5	-	0,5	0,5	1,0	4,0	75,6	73,7	9,7	1,9	11,6	14,7
Nowiny	KN(84)	52,4	94,2	4,5	1,3	16,2	3,0	-	55,4	-	-	-	4,5	74,1	3,0	2,3	7,6	2,3	-	-	-	2,3	3,9	44,5	73,0	26,8	-	26,8	0,2
Józefów	BD31	13,8	93,5	4,8	1,7	14,5	1,6	0,4	15,8	0,2	-	-	15,1	70,8	2,7	5,6	1,6	1,1	0,5	-	-	1,1	1,5	84,0	75,9	19,1	0,3	20,2	3,9
Józefów	MT40	51,6	95,7	1,4	2,9	22,2	0,7	0,4	52,7	2,2	-	-	13,2	39,7	4,9	5,8	9,9	0,8	-	-	-	20,7	5,0	45,1	67,0	30,7	0,3	32,0	0,8
Józefów	FT(17)	18,1	94,8	5,2	-	18	0,3	-	18,4	0,3	25,4	-	66,1	2,3	-	-	2,3	3,9	-	-	-	-	-	81,3	73,6	25,2	-	25,2	1,2

Tab. 2. Petrographic composition of the Upper Badenian terrigenous and organodetritic-terrigenous rocks (for explanations – *see* Tab. 1)

composed of monocrystalline quartz (Q_m) grains; composed of max. 3 crystals (Q_{2-3}); and grains composed of more than 3 crystals ($Q_{>3}$). The type of light extinction – straight or wavy was also examined. The ratio of monocrystalline quartz (Q_m) versus polycrystalline quartz ($Q_p = Q_{2-3} + Q_{>3}$) is a good indicator of the origin of the quartz that builds the grains. Quartz grains that crystallised under deep conditions are monocrystalline and characterised by straight light extinction, while quartz grains of a metamorphic origin are dominated by polycrystalline grains with wavy light extinction (BASU & *al.* 1975). In all the samples, the Q_m/Q_p ratio is more than 10 (Tabs 1, 2), which indicates uniquivocally that the original source area of terrigenous material was composed of weathering plutonic rocks or reworked sediments. Additionally, in all the samples a minor admixture of feldspars has been found, with an absolute lack of lithic clasts (Tabs 1, 2). In all the samples, microspar-like calcareous cements, and blocky or poikilotopic spar accompany the framework. If the classification of the studied clastic deposits is based solely on the terrigenous material occurring in the framework, all the samples would be represented by quartz or subarcose arenites (PETTIJOHN & *al.* 1973). This indicates a petrographic maturity of the terrigenous material. As both Lower and Upper Badenian samples do not contain lithic clasts (Tabs 1, 2) in the terrigenous material, and the feldspar content is a maximum of 16.7% (average 3.3%), the source area of this material was located in the centre of a craton (DICKINSON & *al.* 1983). This conclusion is in agreement with the position of the Roztocze Hills in relation to the East European platform.

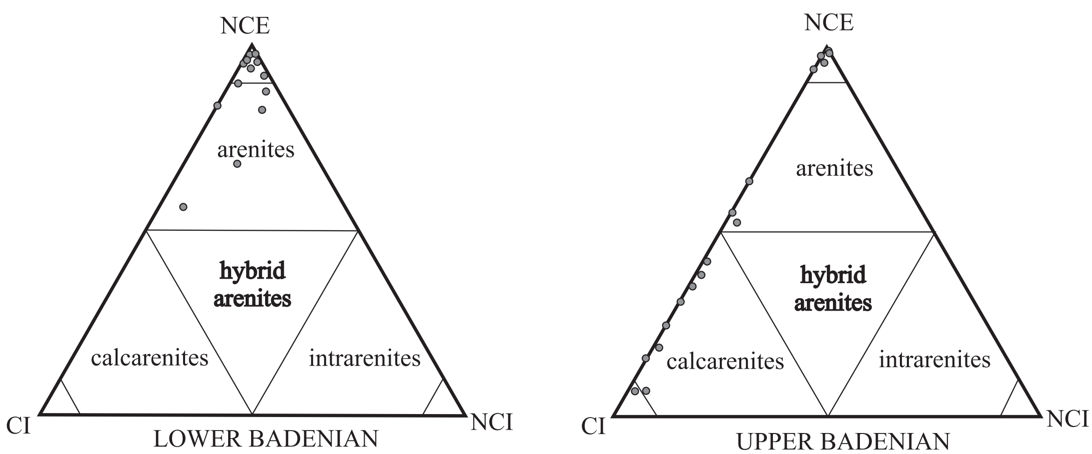

Fig. 6. NCE/NCI/CI diagram for arenites: NCE – non-carbonate extrabasinal grains; NCI – non-carbonate intrabasinal grains; CI – carbonate intrabasinal grains

Components %	arenites		calcarenites	
	quartz arenites	quartz arenites with limeclasts	calcarenites with quartz	biocalcarenites
noncarbonate extrabasinal grains (NCE)	**96,7** (90,4-99,6)	**70,0** (52,7-88,8)	**29,3** (18,4-40,5)	**7,3** (7,2-7,4)
carbonate intrabasinal grains (CI)	**1,9** (0,0-8,0)	**23,7** (2,6-44,5)	**70,3** (59,2-84,0)	**90,2** (89,4-91,0)
noncarbonate intrabasinal grains (NCI)	**1,2** (0,0-2,1)	**5,7** (0,0-13,0)	**0,4** (0,0-0,8)	**2,5** (1,8-3,2)

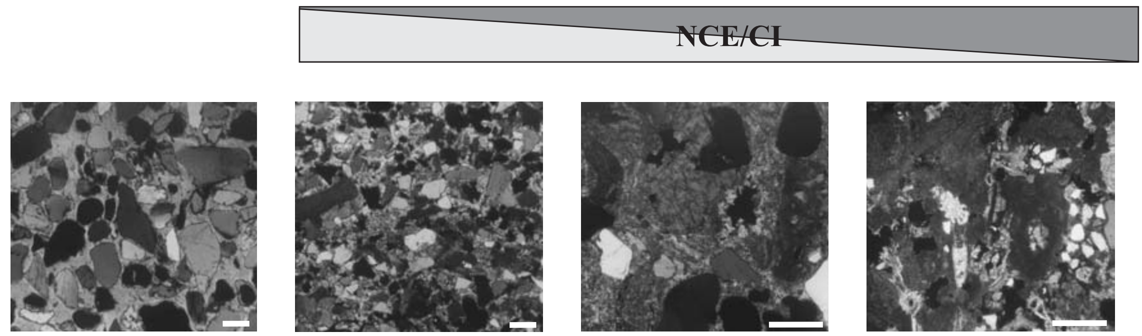

Fig. 7. Average petrographical composition and classification of the Badenian deposits (bar on photos = 0,5 mm)

Apart from terrigenous material, the Badenian deposits of the Roztocze Hills contain clasts formed directly in the basin during sedimentation, i.e. the intraclasts. Two groups of intraclasts have been distinguished. Non-carbonate intraclasts (NCI – noncarbonate intrabasinal grains, after ZUFFA 1980) – grains of glauconite or phosphates; and carbonate intraclasts (CI carbonate intrabasinal grains, after ZUFFA 1980): lithoclasts, ooids and grains formed by destruction of skeletal elements of organisms, or by destruction of organic build-ups. The following organodetritic grains were distinguished: rhodoliths, algal intraclasts, skeletal elements of various groups of invertebrates, and peloids. Carbonate intraclasts predominate, while non-carbonate intraclasts occur only in subordinate quantities (Tabs 1, 2). The variable content of intraclasts in the deposits points to a changing rate of terrigenous input and to changing rates of development and growth of the organisms that were the source of the organodetritic material.

As the clastic deposits of the Roztocze Hills are composed of terrigenous clasts and organodetritic intraclasts, the used criteria are based on the classification of terrigenous (PETTIJOHN & *al*. 1973), carbonate (FOLK 1962), and mixed rocks (ZUFFA 1980) (Text-figs 6, 7). Four petrographic rock types have been distinguished (Text-fig. 7): quartz arenites, quartz arenites with limeclasts, calcarenites with quartz, and biocalcarenites. The main component (>90%) of the framework of the quartz arenites (Text-fig. 7) is quartz. In subordinate quantities occur carbonate intraclasts: shells of foraminifera, skeletal elements of pelmatozoans, peloids, lithoclasts and glauconite. Quartz arenites have been observed in the Ukrainian sections of the Lower Badenian deposits (Text-figs 4, 5), in Lozyna and Stradc, and in Radruż in Poland. In the sections of Upper Badenian deposits (Text-figs 4, 5) they occur in Dziewięcierz and Brusno.

Quartz arenites with limeclasts (Text-fig. 7) represent rocks with a mixed framework composition, incorporating substantial admixtures of both carbonate and non-carbonate intraclasts. Among the carbonate intraclasts predominate algal intraclasts, rhodoliths, shells of foraminifera, bryozoan clasts and pelmatozoan skeletal elements. Glauconite is the main non-carbonate intraclast. In some samples its content exceeds 10%. Quartz-carbonate arenites occur mainly in the Lower Badenian deposits (Text-figs 4, 5) in Lozyna, Stradc and Borki. In the Upper Badenian deposits (Text-figs 4, 5) they occur in the regions of Huta Różaniecka, Józefów and Nowiny.

The calcarenites with quartz (Text-fig. 7) have a predominance of organodetritic, intrabasinal grains. Quartz occurs in smaller quantities and glauconite sporadically. The intraclasts are represented by rhodoliths, algal intraclasts, and skeletal elements of foraminifera, pelmatozoans, more rarely bivalves, gastropods, serpulids, and peloids. The calcarenites with quartz formed in an environment in which the intrabasinal organodetritic material was transported in the basin. Temporary, minor inputs of terrigenous material are recorded in the deposits as admixtures of quartz grains. Calcarenites with quartz are a characteristic petrographic type for the Upper Badenian deposits of the Polish Roztocze Hills (Text-figs 4, 5), in the region of Brusno, Huta Różaniecka, Nowiny and Józefów. Interlaying of quartz arenites and calcarenites with quartz has been observed in these sections (*see* RONIEWICZ & WYSOCKA 1997).

The biocalcarenites (Text-fig. 7) comprise rocks composed of intrabasinal grains, mainly of algal fragments. Using microfacies criteria they belong to the algal packstones type. They were formed by accumulation of intrabasinal material. Biocalcarenites occur in the sections of Upper Badenian deposits within the calcarenites with quartz, in the vicinity of Brusno, Nowiny and Józefów (Text-figs 4, 5).

CEMENT CHARACTERISTICS OF THE QUARTZ ARENITES AND QUARTZ ARENITES WITH LIMECLASTS, WITH SOME REMARKS ON DIAGENESIS

The quartz arenites and quartz arenites with limeclasts contain calcite cements, which sporadically are phosphatised and ferruginous. The porosity of the arenites is relatively low and ranges between 0.8 and 12.8%. In the arenites the cement is commonly developed as isometric calcite that sporadically forms isopachous envelopes around the quartz grains. More often the cement that fills the spaces between the grains is developed as blocky calcite (Pl. 1, Figs 1, 3). The blocky calcite filling the open spaces is characterised by a tendency of crystal growth towards the centre of the space (Pl. 1, Figs 3, 5). This type of calcite cement is typical of crystallisation from pore waters in a freshwater phreatic zone (HARRIS & *al.* 1985; JAMES & CHOQUETTE 1990) and is characterised by a rather monotonous composition, marked by a lack of distinct zones of luminescence (Pl. 1, Figs 2, 4).

Different features are typical of the blocky calcite that fills the spaces after dissolved bioclasts (Pl. 1, Figs 5, 6). A ghost of the original aragonite shell is indicated by the presence of a micritic envelope, while the calcite that fills the space is characterised by a distinct zonation of the luminescence. This zonation is a result of variations in the content of iron and manganese ions and of the changing proportions between them. It documents variations in pore-waters composition during calcite crystallisation. This kind of cement, filling the spaces after dissolved bioclasts, is characteristic of a freshwater vadose zone (JAMES & CHOQUETTE 1990).

In the quartz arenites an occurrence of poikilotopic calcite has also been observed (Pl. 2, Figs 1, 3). It is developed as large, single crystals, with diameters of 2 millimetres. This type of meteoric cement is associated with a slow rate of crystal growth that results from relatively low saturation of the pore waters versus $CaCO_3$ (TUCKER & WRIGHT 1991). In the Badenian deposits of the Roztocze Hills this type of cement occurs in the partly lithified Lower Badenian sandy deposits from Ukraine, and in the sandy deposits from the lower part of the Upper Badenian sediments from the regions of Brusno and Dziewięcierz. Crystallisation of poikilotopic cements must have taken place in a solution oversaturated with $CaCO_3$, but with a diversified content of iron and manganese ions. In the samples from the Ukraine sections the cements reveal distinct luminescence (Pl. 2, Fig. 2), while the samples from Poland do not show any luminescence (Pl. 2, Fig. 4).

	Components insoluble in HCl (1+1)							**Components soluble in HCl (1+1)**												**Whole sample**	
Sample	**Σ** %mas	**Si** %mas	**Mg** ppm	**Mn** ppm	**Fe** ppm	**Al.** ppm	**Ti** ppm	**Ca** %mas	**$CaCO_3$** %mas	**Mg** %mas	**$MgCO_3$** %mas	**Mn** ppm	**Fe** ppm	**Al** ppm	**Ti** ppm	**K** ppm	**P** ppm	**Sr** ppm	**S** %mas	**C** ppm
ŁVI(4)	69,39	32,32 3	4	9	590	221	330	12,11	30,24	0,076	0,27	85	310	38	42	150	108	85	0,20	440
D13	88,52	x	x	x	x	x	x	5,15	12,86	0,040	0,14	10	480	x	19	90	x	3	0,03	x
DII(25)	75,44	35,01	58	15	515	767	735	9,61	23,99	0,047	0,16	150	1330	350	50	300	62	-	0,14	65
DIII(33)	66,40	30,90	26 1	0	320	230	305	13,37	33,38	0,021	0,07	27	850	200	17	300	29	-	0,11	70
PŚIV(37)	79,60	37,11	25	5	370	337	109	8,09	20,21	0,016	0,06	40	550	33	4	150	68	-	0,09	80
Br60	61,27	x	x	x	x	x	x	16,32	40,75	0,11	0,38	37	590	x	12	120	x	10	0,02	x
KG43	76,8	x	x	x	x	x	x	9,9	24,72	0,09	0,31	68	305	x	17	125	x	24	0,03	x

- contents less than the limits of the method; x analysis not undertaken

Tab. 3. Geochemical composition of the quartz sandstones

In the sandy part of the Ratyń Limestones from Radruż (Text-fig. 5) an occurrence of microspar envelopes, micritic in their outer part, has been found on quartz grains. Their formation is linked with subaerial evaporation of marine pore waters, which precipitated as concentric calcite envelopes on quartz grains dispersed in the carbonates. Because this type of structure has been described in caliche levels (ESTEBAN & KLAPPA 1983), they are considered in the present work to be quartz pisoids (Pl. 2, Fig. 5). Their characteristic feature is distinct luminescence, which reflects by its intensity the outline of consecutive concentric envelopes on the quartz grains (Pl. 2, Fig. 6). The process of calcite crystallisation on the grains took place in the vadose zone, but it is difficult to determine the time of its formation. It would deal with a fossil caliche and with an early diagenetic precipitation of calcite envelopes on quartz grains from capilarilly oozing marine waters (WALLS & *al*. 1975; GRADZIŃSKI & *al*. 1986).

The studied quartz arenites are built of components that are soluble and insoluble in hydrochloric acid. The insoluble components account for more than 60% of the weight of the studied samples, with a maximum of 88.5% of the total weight (Tab. 3). The main component insoluble in HCl is silica, which occurs mainly in the form of quartz grains. The main component soluble in HCl is calcium (Tab. 3). It has been presumed that all the calcium is assimilated in the form of calcium carbonate, and that this is therefore the predominant component of the matrix soluble in the acid. This presumption is the probable cause of exceeding by about 1% the total of soluble and insoluble parts for the samples: D13, Br60, and KG43. It results from the possibility of Ca assimilation also in the form of phosphates.

Some elements soluble in HCl in the studied samples – magnesium, manganese, iron, aluminium, titanium, potassium, phosphorus and strontium, are present only in trace quantities (Tab. 3). The quantity of sodium is so small, that with the use of the selected method its occurrence has not been detected. The average content in the analysed samples equals less than 600 ppm of Mg, 17 ppm of Sr and non-determinable quantities of Na. The Sr/Mg and the Mg/Fe content ratios are also very low. The results are drastically different from those of modern marine cements (CARPENTER & LOHMANN 1992) and of marine cements of Sarmatian and Badenian limestones from the western part of the Roztocze Hills (JASIONOWSKI 1998). These quantities uniquivocally preclude the presence of marine cements in the studied samples. They indicate that the process of carbonate cementation of quartz arenites and quartz arenites with limeclasts took place under meteoric conditions (JAMES & CHOQUETTE 1990, MORSE & MACKENZIE 1990, SALLER & MOORE 1991), and was an epigenetic process, linked with partial dissolution of the aragonite bioclasts and with the crystallisation of low-manganese calcite. A very low strontium content indicates that no substantial quantities of Sr were removed as a result of the dissolution of aragonite and calcite bioclasts, which initially contained substantial quantities of this element. For comparison, modern red-algal clasts contain between 2100 to 2960 ppm of Sr (CARPENTER & LOHMANN 1992). Based on the obtained results, it can be stated that the system of meteoric diagenesis was open, because in a closed system there would have been an increase in the Sr concentration, and subsequently precipitation of calcite with a higher Sr content (SALLER & MOORE 1991).

MICROFACIES

The main framework components of the Badenian limestones of the Roztocze Hills are calcareous algae belonging to the order *Rhodophyta*, and the family *Corallinaceae*. PISERA (1985), analysing the construction of Badenian algal-vermetid reefs, described eight genera belonging to this family: *Lithothamnium* (*Lithothamnion* after BOSENCE 1991), *Lithophyllum*, *Mesophyllum, Dermatholithon (Titanoderma* after BOSENCE 1991), *Archaeolithothamnium, Paleothamnium, Melobesia* and *Jania*.

In the carbonate microfacies the algae occur both as bioclasts and as rhodoliths. In the grainstones and packstones the algal clasts occur commonly as bioclasts, constituting a predominant component of the framework (Text-fig. 8; Pl. 3, Figs 1-6). The algal bioclasts include fragments of several different corallinacean genera, of which the most common are: *Lithothamnion, Lithophyllum* and *Mesophyllum*.

The rhodoliths occur in foraminiferal – bioclastic wackestones with large rhodoliths and in rhodolithic boundstones (Text-fig. 8; Pl. 3, Fig. 8; Pl. 4, Figs 6-8). They adopt spheroidal shapes (BOSENCE 1983a), and are built from multispecific assemblages of algae (multispecific rhodoliths – *after* BOSENCE 1983a) that grow as encrustations or branches. Preliminary studies of the construction and composition of rhodoliths from the Badenian deposits of the Roztocze Hills were undertaken by Jasionowski (JASIONOWSKI & WYSOCKA 1997). He distinguished the following genera: *Lithothamnion, Mesophyllum, Titanoderma, Lithophyllum* and *Mastophoroideae*. The shape of the rhodoliths and the encrusting construction of their clasts suggest a high-energy environment for their formation. Rare rhodoliths with a dendroid construction indicate an

MICROFACIES		FRAMEWORK COMPONENTS														CEMENTS								PORE TYPE				
		quartz	glauconite	pizoids	rhodoliths	algal clasts	foraminiferas	bryozoans	pelmatozoans	bivalves	snails	serpulids	ditrups	peloids	other	micrite	matrix+micrite	blocky spar	syntaxial spar overgrowths	microspar	neomorphic spar	micrite around grains	calcite spar	interparticle	intercrystal	intraparticle	mouldic	vug
1	algal grainstone	•				⬤	•	○	○				•		○			⬤	○					○				
	quartz-rich algal grainstone	●				⬤	○	○	○	•			•					⬤	○		○			○				○
2	foraminiferal algal grainstone	•				⬤	⬤	●	○						○			⬤	•	•	○	•	○	●	●			●
3	algal packstone with bioclasts					⬤	○	○	•						•	•	○				○			●		●		⬤
	quartz-rich algal packstone with bioclasts	●				⬤	○	●	○	•	•		•				●			●	○			●				○
4	porous algal packstone with bioclasts	•				⬤	○	○	•				•		•	•			○		○		○	●		●		⬤
	quartz-rich porous algal packstone with bioclasts	●				⬤	○	○	•				•			•	•		•	•	○			●		●		⬤
5	foraminiferal algal packstone	•				⬤	⬤	○	•				•			•			○		●			⬤		●		○
	quartz-rich foraminiferal algal packstone	●	•			⬤	⬤	○	○				•		•	•			○	●	●			⬤		●		○
6	bryozoan algal packstone					⬤	●	⬤	•						•	•					●			⬤		⬤		○
	quartz-rich bryozoan algal packstone	⬤				⬤	●	⬤	•						•	•					●			⬤		⬤		○
7	quartz-rich bryozoan foraminiferal wackstone	●				○	●	⬤	○						•	●			○	●				●		●		
8	foraminiferal bioclastic wackstone with rhodoliths				⬤	○	●	○	○	•	•	•				●					●					○		○
9	quartz-rich wackstone with pisoliths	○		●		●								●		●		•		●		●						●
10	quartz-rich peloidal wackstone with gypsum pseudomorphoses	○				○								●	○	●				●		●			○			●
11	mudstone	•												○		⬤												○
	porous mudstone										•			●	•	⬤				○							○	⬤
12	rhodolithic boundstone	•			⬤					•	•			○	•	●	●	○					●		•	⬤		
	quartz-rich rhodolithic boundstone	○			⬤	○	○	○	○							●				●			●			●		●

⬤ (>25%) abundant ● (<25%) common ○ (<10%) rare • (<1%) trace

Fig. 8. Microfacies of the Badenian limestones from the Roztocze Hills

environment with a slightly lower energy (BOSENCE 1991).

The rhodoliths occurring in the Badenian limestones of the Roztocze Hills formed in a shallow-water, warm, high-energy environment, similar to the modern environments connected with reef-flats and back-reefs (see BOSENSE 1983b). No occurrence of typical reefal deposits has been observed. Large areas of the sea bottom must have been colonised by red algae, like a sea grass and by patch reefs. This may have taken place within sandy flats, which would account for the occurrence of very common admixtures of sandy material – quartz grains and numerous bioclasts. *Lithothamnium* limestones, sandy limestones and quartz-rhodolithic sands are examples of the deposits that formed in this type of environment. Additionally, apart from the rhodoliths, in the zones where the sediments were moved by the currents, destruction of red-algal clasts transported large quantities of algal bioclasts into the basin.

Foraminifera also constitute an important component of the limestones (Text-fig. 8; Pl. 3, Figs 5-8). Tests of benthic foraminifera – glassy and grainy calcareous, and more rarely agglutinating, predominate in most of the microfacies. As it is indicated in the unpublished work of SZCZECHURA (1998), the Badenian deposits are characterised by an abundant and diversified foraminiferal assemblage. An occurrence of foraminiferal assemblages characteristic of a shallow-water, offshore sea with a normal salinity, was observed for the deposits from the Brusno, Huta Różaniecka, Józefów, and Żelebsko sections (Text-fig. 5). These assemblages are dominated by benthic, sessile foraminifera connected with plant vegetation and with a dynamic environment, i.e. foraminifera of the genera *Cibicides, Sphaerogypsina, Cassidulina, Asterigerina, Bolivina* and *Elphidium*. Poorly preserved planktonic forms are also present, but are not common. Based on the occurrence of the index *Bolboforma badenenis* and *Velapertina* sp., the sections in Brusno, Huta Różaniecka and Józefów were included into the Upper Badenian.

Bryozoan clasts are the next most commonly occurring framework component of the limestones. In a few cases, they constitute the predominant component of the limestone framework e.g. in the bryozoan-algal and bryozoan-foraminiferal deposits (Text-fig. 8; Pl. 3, Figs 2-4). The bryozoans may occur as strongly fractured dendroid forms, and as forms encrusting the red-algal clasts. Occurrence of bryozoan colonies inside the rhodoliths has also been observed.

A separate group of limestones are the Ratyń Limestones, within which three microfacial types have been distinguished: wackestones with quartz pisoids (Text-fig. 8; Pl. 4, Fig. 1), peloidal wackestones with pseudomorphs after gypsum (Text-fig. 8; Pl. 4, Figs 2, 5) and mudstones (Text-fig. 8; Pl. 4, Figs 3, 4). The occurrence of wackestones with quartz pisoids was observed only in the Radruż section. The micritic and microspar matrix contains numerous micritic envelopes on individual grains (Pl. 4, Fig. 1). Their nuclei are formed of quartz grains and algal intraclasts that are covered by a continuous, multilayer micrite or microspar envelope.

Peloidal wackestones with pseudomorphs after gypsum (Pl. 4, Figs 1, 5) constitute another microfacies connected with the Ratyń Limestones – this microfacies was observed in the Radruż section. The micritic and microspar matrix contains numerous peloids and quartz grains. Its characteristic feature is the presence of intraclasts of the Ratyń Limestones. Observation of pseudomorphs after gypsum is possible in the parts of the deposits that are devoid of quartz admixtures (PERYT & PERYT 1994). The most typical microfacies of the Ratyń Limestones are mudstones. Apart from rare peloids and fragments of laminites, this microfacies does not contain any other framework components. It is composed of a micritic or microspar matrix (dismicrite *after* FOLK 1962). Sporadically, a disturbed lamination resulting from changes of porosity occurs within the limestones included in this microfacies.

SEDIMENTARY STRUCTURES

Depositional structures. Various sedimentary structures have been observed in all the studied sections of Badenian deposits from the Roztocze Hills. Among the small-scale structures horizontal and ripple cross-lamination have been observed. Horizontal lamination (Pl. 5, Fig. 1) is characteristic of the fine-grained sands, sandstones and calcarenites. The thickness of horizontally laminated sets rarely exceeds 10 cm. Another commonly occuring sedimentary structure is ripple cross-lamination (Pl. 5, Figs 2, 3). It dominates in many sections (e.g. in Józefów and Żelebsko). The heights of individual ripples range between 2 and 10 cm, most of them are symmetrical. Two types of climbing-ripple lamination (JOPLING & WALKER 1968) have been found in the deposits: ripple laminae-in-phase (Pl. 5, Fig. 2) and ripple laminae-in-drift (Pl. 5, Fig. 3). Wavy and flaser lamination (Pl. 5, Fig. 2) has also been distinguished.

Medium- and large-scale depositional structures are represented by trough cross-stratification and tabular cross-stratification. The set thickness of trough cross-stratification (Pl. 5, Fig. 4) varies between 10 and 50 cm. Tabular cross-stratification (Pl. 5, Figs 5, 6) in the studied sections occurs most commonly in the form of tabular cosets, bounded by parallel horizontal surfaces. The laminae reach the set boundary surfaces at different angles, allowing diagonal, tangential and sigmoidal stratification to be distinguished. The maximum thickness of a single set is about 4 m (Pl. 5, Fig. 6). The occurrence of tabular cross-stratification can be connected with the migration of bottom forms, such as dunes or bars (GRADZIŃSKI & *al*. 1986). All the depositional structures described above point to a high-energy environment, moreover the sets of structures distinguished for particular sections can be interpreted as connected with a shallow-water environment.

Another characteristic group comprises depositional structures connected with mass flow processes. The geometry, lithology of infilled deposits and relation to the deposits that they cut into allows slump scours and channels to be distinguished. Characteristic large-scale elongate scours have been observed in the Ukrainian part of the Roztocze Hills in fine-grained, well-sorted Lower Badenian quartz sands. Depths reach up to 10 m and widths range up to 20 m (Pl. 6, Figs 1, 2). The bottom surfaces of these forms have a concave shape, and are separated by a sharp boundary from the underlying deposits (Pl. 6, Figs 1, 2). Scours have been observed in the Stradc and Sihiv sections. In the Stradc section, the scours recur several times in the wall of the exposure and are filled with quartz sands with small admixtures of glauconite. Their basal parts are massive, and the sediment is homogenised (Pl. 6, Fig. 1). Their top parts show traces of lamination, and contain numerous diapir and fold deformations (Pl. 6, Fig. 1, Pl. 7, Figs 1, 2). Scours erode into large-scale cross-stratified sets and are infilled by massive quartz sands (Pl. 6, Fig. 2). As these scours are characterised by sharp boundaries, by homogenisation of the deposits that fill them, and in some cases, by the presence of convolute deformations in their topmost part, their formation might be linked with abrupt mass movement of the sediment down the slope of depositional forms. They therefore probably represent grain flow in the form of underwater slump-scours. The movement of sediments may be connected with overloading of the slopes of large depositional forms and/or by seismic shock. The scours were probably infilled very rapidly and their fills therefore were more likely to liquefy than the surrounding sediments.

Large-scale channel-like forms, with sharp concave lower boundaries and filled with massive or thick-bedded (Pl. 6, Figs 3, 4), coarse-grained organodetritic material with different clasts (Pl. 6, Figs 5, 6) and a variable quartz admixture were found in the Upper Badenian organodetritic deposits in the western part of the Roztocze Hills. Such forms were observed in the Józefów section and the Nowiny section.

In the Józefów section, the channel-like forms are elongated N-S and all dip southwards. In the exposures, they are visible in sections perpendicular to their elongation. Their width ranges between 2 (Pl. 6, Fig. 4) and 15 metres, and their depth between 1 and 10 metres. The bottom parts of these forms have a concave shape (Pl. 6, Fig. 3). The channel-like forms occur at various horizons within the ripple cross-stratified fine calcarenites and they are infilled by massive or thick stratified calcarenites. The deposits infilling the channel-like forms are identical to the deposits through which these channel-like forms cut, and therefore their origin might be the result of collapsed large-scale dunes. The channel-like forms would then probably represent slump-scours.

Beside the slump-scour structures, other types of channel-like forms are found in the Józefów section. In some there is a large contrast between the infills and the host deposits (Pl. 6, Fig. 4). In these cases, the infills consist of medium- and coarse-grained organodetritic material with numerous intraclasts. The intraclasts are clay and clay-marly elongate clasts (up to 1.5 m length) (Pl. 6, Fig. 6), or large fragments of rhodoliths and white organodetritic limestones (up to 10 cm in diameter) (Pl. 6, Fig. 5). In the basal parts of the infills a distinct bimodal distribution of grain size occurs (Pl. 6, Fig. 5), and the coarser grains disappear towards the top. A similar, single channel-like form occurs in the Nowiny section, where a characteristic set of sediments, up to 6 m thick, is visible over an area of about 200 m.

In those cases where the channel-like structures are filled by massive coarse-grained bimodal organodetritic material with normal grading at their bases, and contain a wide variety of large-size clasts that are not found in the immediately surrounding deposits, the mechanism of their formation might be linked with shear flow. Therefore the origin of those channel-like forms should be connected with the action of currents. There are many types of currents in shallow-water sea *e.g.* longshore current, rip currents, tidal currents and storm-generated currents (Reading 1979). Unfortunately, there is no evidence of the position of the Late Badenian shoreline in the Roztocze Hills area. Moreover, there is no evidence for tides in the Late Badenian sea that filled the Carpathian Foredeep. Therefore, it is difficult to connect the described channel-like structures with the action of longshore, rip or tidal currents. Consequently, they were probably cut by storm-generated currents. In such cases, the channel-like forms from Józefów and Nowiny should be classified as storm surge channels filled by storm lag deposits.

Deformational structures. Deformational structures have been observed only in the Lower Badenian quartz sands of the Stradc section. Folds, diapir, convolute bedding, disintegrated and disturbed bedding, water escape structures and dish structures have been distinguished.

The folds have the form of vertical anticlines and synclines. They occur in the highest parts of the slump-scour infills. In some places the folds exceed a height of 2 m (Pl. 6, Fig. 1). The diapirs have the form of detached, single inclined or overturned anticlines with a strongly deformed bend zone (Pl. 7, Fig. 1). According to Wojewoda (1987), folds of this kind are considered to be orthoseismites (seismites *sensu stricto*); that is structures formed in place, as a result of seismic shock. However, in the described sections they occur within deposits that were homogenised probably as a result of collapsed large-scale dunes, which excludes a direct tectonic origin. It is possible that they formed as a result of redeposition caused by tectonic shock, and may therefore be referred to as paraseismites (seismites *sensu lato*).

Convolute bedding (Pl. 7, Fig. 2) is an intralayer deformation in the form of small folds. The folds are underlain and overlain by non-deformed deposits. The anticlinal parts of the folds are steep and chevron-like, whereas the synclinal part are flat and blunt. The thickness of the layers with convolute bedding is about 30 cm. Convolute bedding can develop as a result of reversed density gradient, sediment liquefaction caused by overburden by the overlying deposits, seismic shock, or movement of liquefied sediment (REINECK & SINGH 1975).

Another type of deformational structure is disintegrated and disturbed bedding (Pl. 7, Fig. 3) that is caused by breaking and dispersion of deformed layers (DŻUŁYŃSKI 1963). The origin of this type of structure can be connected with gravity mass movement or deformational influence of currents (GRADZIŃSKI & *al.* 1986). These agents could result in dispersion of the sediment, producing chaotically placed, flat fragments of more coherent sediment of various sizes. In this particular situation, the disintegrated and disturbed bedding embrace the part of the deposits that originally contained substantial admixtures of fine-grained glauconite aggregates. The tops of the deformed portions of the sediment are flat and overlain by massive sands.

The pillar water-escape structures have the forms of vertical columns, filled by massive deposits. They cut the original lamination, and are commonly overlain by characteristically anticlinally bent layers (Pl. 7, Figs 4-6). They are limited to a single layer, and their maximum height is 10 cm, with a diameter not exceeding 2 cm. Most probably they are places of concentrated flow of pore water, which escaped from the sediment. The bending of the layers above the pillar water-escape structures is connected with unequal subsidence of variously fluidised sediments (OWEN 1987). In the Stradc section, the water-escape structures can be observed in the deposits lying directly beneath the slump-scours (Pl. 7, Fig. 6). The slumps-scours in this section were probably formed as a result of underwater grain flow in the form of landslides, weight of the moving flow caused pore water increase and fluid escape from the underlying deposits.

Dish structures are also connected with water escape from unlithified sediment. They occur sporadically in the studied deposits. Their presence has been observed in cross-stratified deposits. Individual "dishes" are almost completely flat or slightly concave (Pl. 7, Fig. 4), with a length not exceeding 5 cm.

The occurrence of various-scale plastic deformations in the Lower Badenian sandy deposits from the Stradc section is connected with underwater landslides. These deformations have been distinguished both inside deposits that filled slump-scours and outside

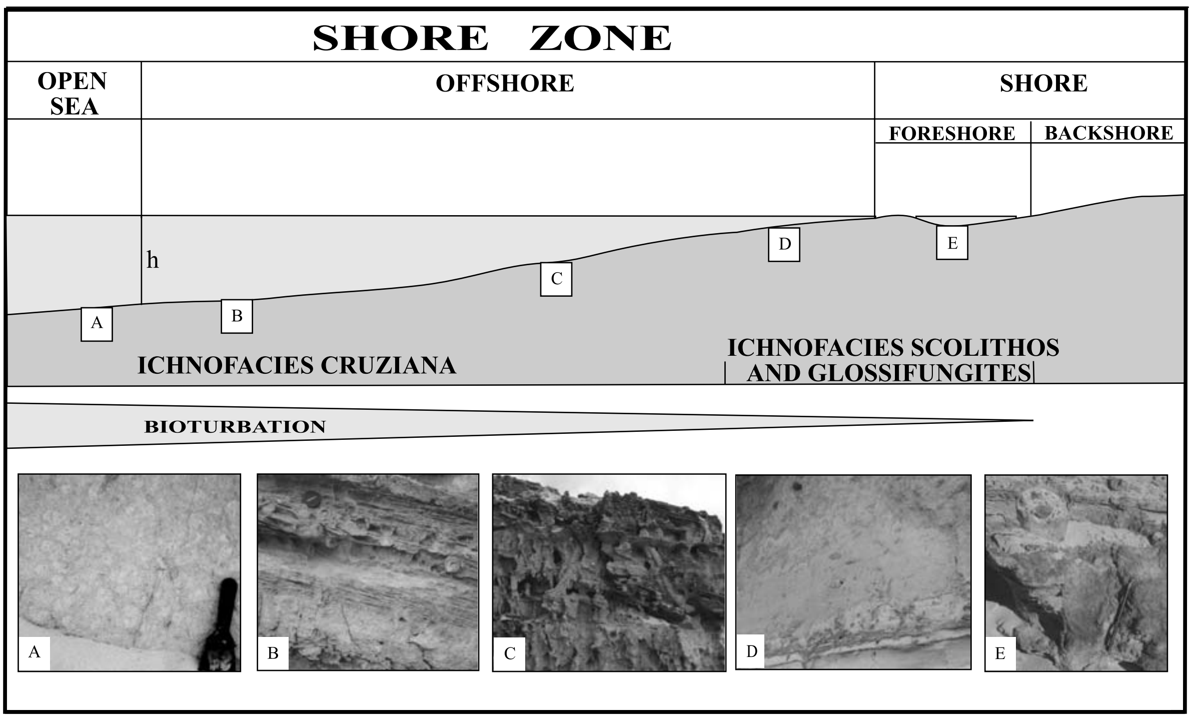

Fig. 9. Ichnofacies connected with the shore zone of the Early Badenian sea in the Roztocze Hills area (shore zone division after RUDOWSKI 1986; ichnofacies after SEILACHER 1967). A – primary sedimentary structures completely destroyed by echinoid burrows (Sihiv); B – interlayers of sands, strongly bioturbated by echinoids, in the tabular cross-stratified sands (Gleboviti); C – tabular cross-stratified sands with numerous burrows of callianassid decapods (Gleboviti); D – single burrows of callianassid decapods and polychaetes in sands (Jasnyska); E – burrows attributed to crabs (Gleboviti)

them. Erosional truncation of the deformations by overlying beds, the presence of deformation among non-deformed deposits and the large variability suggest their syn- or almost synsedimentary nature (GRADZIŃSKI & *al*. 1986). These types of deformations are connected with the movement of probably liquefied sediments and with water escape (COLLINSON 1994). It is difficult to point out a simple mechanism causing the sediment liquefaction and water escape. On a regional scale, it could have been seismic shock, whereas on a local scale they may have been triggered by rapid sedimentation, pressure changes connected with storm waves, as well as by movements of groundwaters (OWEN 1987).

Biogenic structures. The trace fossil assemblages were observed only in the Lower Badenian deposits from the Ukrainian part of the Roztocze Hills, (the Lozyna I, Jasnyska, Borki, Sihiv and Gleboviti sections). Pascichnia and fugichnia left by echinoids, polychaetes, crabs and bivalves predominate. In many sections, for example Gleboviti, Sihiv, Borki and Jasnyska, the rate of bioturbation is so high that it leads to total destruction of the primary sedimentary structures.

Trace fossil assemblages of the ***Cruziana*** **ichnofacies** (Text-fig. 9) are dominated mainly by traces of the activity of echinoids, lobsters, shrimps and bivalves. Traces connected with the activity of echinoids (Pl. 8, Figs 1-2; Pl. 9, Figs 2, 4) are the most common type of trace in the sandy deposits, especially in the Gleboviti section (*see* RADWAŃSKI & WYSOCKA 2001). These are traces of burrowing in soft sandy sediment, probably searching for food. These traces are most commonly observed in cross-section. They occur in large numbers in horizons within cross-bedded sands (Pl. 8, Fig. 1). These horizons crowded with traces of burrows show a substantial rate of sediment reworking with burrows left by a large number of specimens overprinting each other. An occurrence of strongly bioturbated portions of the sediment within cross-bedded sands points to rhythmic deposition (REINECK & SINGH 1975). The sedimentation consisted of short episodes of intensive, fast deposition that is reflected by the occurrence of cross-stratified sands lacking bioturbation. Episodes of slow or no deposition occurred between them. During these breaks, colonisation of the sea bottom by echinoids took place, which penetrated the sediment, causing bioturbation and destroying the primary structures. This situation was repeated several times.

Preserved surfaces covered by echinoid burrows made by *Echinocardium leopolitanum* (RADWAŃSKI & WYSOCKA 2001) are observed relatively rarely because of poor lithification of the deposits (Pl. 8, Fig. 2). The tests of these echinoids are preserved rarely, sporadically forming clusters and pavements (Pl. 8, Fig. 3). The echinoid tests from the Gleboviti section are exceptionally well preserved, commonly bearing an intact coat of spines. These echinoids, as well as their taphonomy and environmental (hydrodynamic) conditions of presumably lethal burial, were the subject of a separate paper (RADWAŃSKI & WYSOCKA 2001).

Traces connected with the activity of lobsters and shrimps occur more rarely than traces made by echinoids. They are, however, the second most common group of traces that are connected with the activity of benthic organisms within the sediment. They occur within quartz sands in the form of vertical or oblique burrows with slightly cemented, nodular outer walls, and penetrate the sediment to a depth of 60-80 cm, through the sedimentary structures and through highly bioturbated horizons (Pl. 8, Fig. 4). Burrows of this type are referred to the ichnogenus *Ophiomorpha*. Modern *Ophiomorpha* sp. are produced by the activity of the lobster *Callianassa major*. They are characteristic of a shallow-water high- to moderate energy environment (BOCKELIE 1991), as well as for the extremely shallow, intratidal zone (RADWAŃSKI & *al*. 1975).

Trace assemblages belonging to the ***Scolithos*** **and** ***Glossifungites*** **ichnofacies** are connected with the activity of polychaetes, sea-anemones and crabs. Traces connected with the activity of polychaetes accompany the surface, in which the *Ophiomorpha* are developed, and occur sporadically within the horizons strongly bioturbated by echinoids. They have straight, vertical tubes, with a diameter of 5 mm and a length of up to 10 cm. Present-day forms of this type are formed by polychaetes of the genera *Onuphis* and *Diopatra* (RADWAŃSKI & *al*. 1975) that live in offshore zones. Fossil traces of this type are referred to as the *Scolithos* ichnofacies (WETZEL & UCHMAN 1998).

Traces connected with the activity of bivalves occur in the form of fugichnia. They are filled with sandy deposits, with u-shaped lamination (Pl. 9, Fig. 2). The length of fugichnias can reach up to 40-50 cm, cutting both the bioturbated parts of the sediments and the sets of depositional structures. Present-day fugichnia of bivalves (e.g. *Mya* sp. and *Macoma* sp.) were observed on tidal flats and in an offshore zone (REINECK & SINGH 1975), while fossil examples have been described from the shallow-marine sandy Miocene Hagenør-Børup sequence of Denmark (RADWAŃSKI & *al*. 1975).

In the sets of cross- and horizontally-bedded sands there are also small vertical traces with a length of up to 15 cm and widths up to 8 cm. They have a u-shaped end, and are filled with u- or v-shaped laminated sediment in their lower parts (Pl. 9, Figs 1-2, 4), which is arranged conformably in the form of consecutive portions of the sediment – the so-called cone-in-cone structure (SHINN 1968). Most probably, these traces are connected with the sea anemones colonising the sea bottom, the upper parts of which protruded above the surface (RADWAŃSKI & *al*. 1975). This structure, resembling superimposed cones, is connected with escape from overburden. Present-day traces of this type are known from intertidal areas and from a shallow sub-littoral marine environment of warm climatic zones (SHINN 1968, FREY 1970).

Another type of sporadically occurring trace consist of broad, oval vertical forms of filled channels, with a diameter of up to 10 cm and lengths reaching 40 cm, and with a u-shaped (Pl. 9, Fig. 3) or v-shaped end. They are filled with sediment with very faint lamination. Their occurrence is connected with the top parts of strongly bioturbated horizons. Similar forms were described from the Middle Miocene deposits of Korytnica (RADWAŃSKI 1977), where they were referred to as traces of burrows made by the crab *Ocypode* sp. Modern burrows of *Ocypode* sp. are characteristic of extremely shallow marine environments and for supratidal environments of the lower shore zone (RADWAŃSKI 1977).

A problematic trace fossil, which has not been described so far in the Miocene deposits of Roztocze, has also been included into the *Scolithos* and *Glossifungites* ichnofacies. This fossil has the form of branching bush-like colonies with a diameter of about 5 cm. Individual branches of the "bushes" have diameters of 2-3 mm, are strongly battered and divide sporadically into two. The fossil has a radial shape, lateral branches run radially away from a small central channel (Pl. 8, Figs 5, 6). It is difficult to include this form in any of the known groups of trace fossils. Because of the lack of lithification, its preparation is impossible. The form is connected with the surfaces that point to a slower sedimentation rate. These forms occur in assemblages covering the sea bottom (Pl. 8, Fig. 5). They occur above erosional surfaces covered by a thin clayey layer, within strongly bioturbated quartz sands with numerous trace fossils of *Ophiomorpha* types. This ichnofossil is probably *Haentzechlinia ottoi* (formerly *Spongia ottoi*), (HÄNTZSCHEL 1975), a form known from shallow-water Mesozoic and Cainozoic deposits (UCHMAN – *personal communication*). It is a stationary – domichnia-pascichnia structure.

In the case of trace assemblages belonging to the *Scolithos* and *Glossifungites* ichnofacies, the sedimentary environment was much shallower than it was in the case of the trace assemblage representing the *Cruziana* ichnofacies. The most spectacular trace assemblages occur in the Lower Badenian sandy succession of the Gleboviti section. The changes in lithology, succession of depositional structures, and trace assemblages seen have reflect an upward-deepening sequence developed during the Lower Badenian transgression, which encroached upon a coastal swamp (RADWAŃSKI & WYSOCKA 2001). During a continuation of the transgression, deeper waters were established in the Gleboviti area. The increased depths were periodically above wind wave base, in the photic zone, allowing growth of the red algal *Lithothamnion*, and production of rhodoliths with concentric growth lamellae indicative of permanent transport by waves and/or currents. Diversified trace assemblages are also observed in the Sihiv and Borki sections, where sandy deposits with traces belonging to the *Cruziana* ichnofacies are overlain by sandy deposits with traces belonging to the *Scolithos* and *Glossifungites* ichnofacies. Trace assemblages from the Lower Badenian deposits point to a shore zone with depth ranges from a few centimetres up to 20 metres.

EVOLUTION OF THE SEDIMENTARY ENVIRONMENT THROUGH BADENIAN TIME IN THE ROZTOCZE HILLS AREA

Early Badenian. In the Early Badenian the eastern part of Roztocze was a zone of shallow-water clastic sedimentation, characterised by constant intensive input of terrigenous material. This material consists mainly of well-sorted sand-grade quartz grains. This indicates that the land located to the north and the northeast was a low-lying area, devoid of substantial topography and covered by sandy weathering products. The source area of the material lay in Podole, where weathered material from crystalline rocks was reworked on multiple occasions. These processes produced a high mineral and textural maturity. Quartz sands were delivered to the basin by rivers transporting substantial quantities of fine-grained material that probably formed deltas in the river mouths. The lower part of the Jasnyska section is an example of the fossil record of such a delta. In its lower part it contains deposits interpreted as part of an underwater delta slope prograding towards the southeast (Text-fig. 10). It is impossible today to directly reconstruct the Early Badenian shoreline because of erosion of Badenian deposits from the area north and northeast of the Roztocze Hills. Based on the succession of depositional and biogenic structures in the deposits from the Jasnyska, Sihiv and Gleboviti sections, the hypothetical Early Badenian shore line was situated in close proximity to the studied sections. In addition to the occurrence of the deltaic deposits, the ichnofacies succession observed in the sandy deposits also suggests that the shoreline was close to these sections (Text-fig. 9). There is evidence for a gradual marine transgression, and therefore for shoreline migration. The deposits from the Gleboviti section document a zone of deposition in the direct vicinity of the shoreline. In its lowermost part, an *in situ* occurrence of silicified stumps of taxodiaceans prove the continental conditions. The upper succession of biogenic structures reflects a gradual transition from the lower shore to progressively deeper offshore zones. It is expressed by the occurrence, in the lowermost part of the section, of traces of life activity of crabs, and higher in the section of numerous polychaetes and lobsters. These traces belong to the *Scolithos* and *Glossifungites* ichnofacies (Text-fig. 9). The deposits occurring in the uppermost part of the sandy succession from the Gleboviti section and the assemblage of lobster and echinoid traces, belonging to the *Cruziana* ichnofacies (Text-fig. 9), indicate the shallow-water conditions that are characteristic of the offshore areas.

In the Early Badenian, the shore zone was characterised by a high supply of terrigenous material. It was an area covered by bedforms of different scale. Fields of small wave ripples, dunes and sporadically coralline algae patches occurred (Text-fig. 10). The depth of the basin never exceeded wave base during the Early Badenian. In such an environment the sedimentation was controlled mainly by changes in hydrodynamic conditions. These changes were induced by wind-driven waves causing the formation of currents. Strengthening of the influence of these currents, and therefore intensification of the sediment transport, probably took place during the storms. Generally, the transport of the material in this zone took place in a southward direction.

During the Early Badenian, the bottom of the basin was relatively flat and gently inclined towards the south. Nonetheless, a few kilometres from the shore, in a shallow, open-sea zone, dunes have been formed (Text-fig. 10). On the southern slopes of these dunes, as a result of high rates of terrigenous deposition, mass movements in the form of slumps occurred repeatedly (Stradc section). Overloading of the slope by rapidly accreted sediments on top of it and/or by seismic shocks could have acted as mechanisms responsible for the origin of this phenomenon (WYSOCKA 1998). Synsedimentary tectonic movements of the substratum within the Wereszcza-Strawczan tectonic trough (PALIJENKO 1993) could have caused the seismic shocks.

The period of deposition of the chemogenic series was preceded in this basin by facies unification. In some sections (Lozina I, Borki, Jasnyska, Sihiv, Gleboviti), organogenic and organodetritic deposits overlie the terrigenous deposits. These are usually represented by sandy *Lithothamnium* limestones and marls. Their occurrence in the sections indicates a richer development of the red algae, probably connected with a decrease in the accumulation rate of the terrigenous material. These facies changes were connected with a lower energy of the environments, slight deepening and/or transition of the shore-

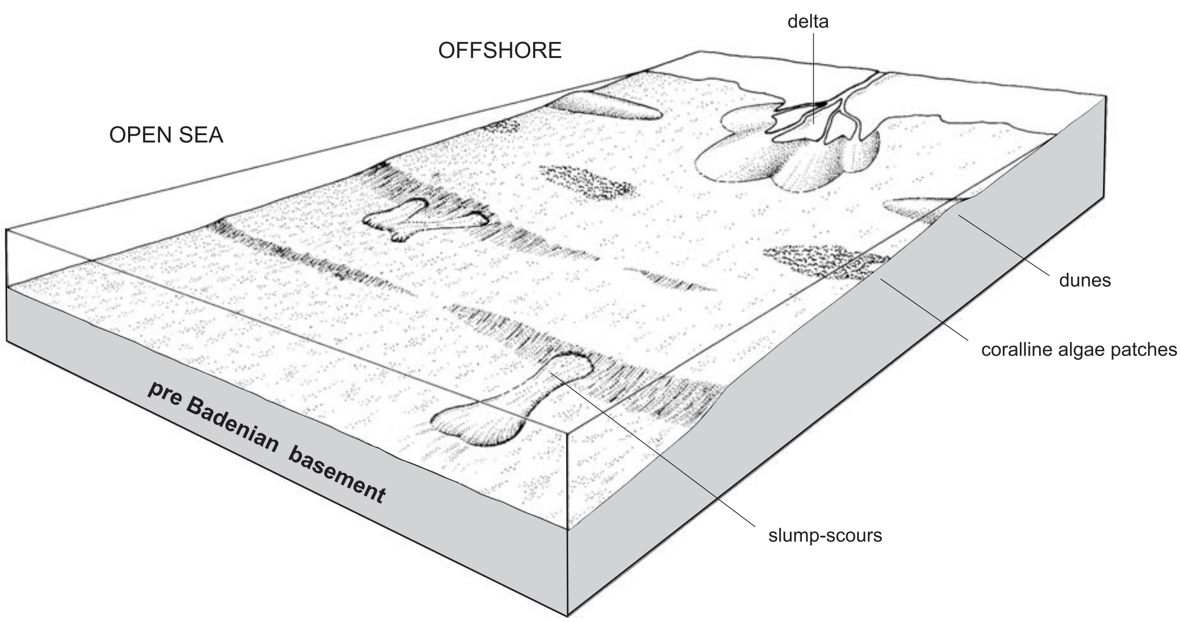

Fig. 10. Depositional forms of a shore zone of the Roztocze Hills area in the Early Badenian

line towards the north, and therefore with the shifting of the zone of intensive accumulation of terrigenous material in the same direction. Unfortunately, due to erosion of the Lower Badenian deposits from the area lying north of the Roztocze Hills, reconstruction of the shoreline changes during the development of the transgression in the Early Badenian is impossible.

Middle Badenian. The Middle Badenian deposits in the studied part of Roztocze are developed as the Ratyń Limestones. Their occurrence has been observed only in the sections in Radruż, Lozyna and Stradc. They have been well documented (KASPRZYK 1993, PERYT & PERYT 1994, PERYT 1996, BĄBEL 1996) and were not the subject of this work.

Late Badenian. Initially, after an episode of deposition of the chemogenic series, the Roztocze Hills area had the same sedimentary environment as in the Early Badenian. Sand deposits accumulated in a shallow-water shore zone (Radruż, Dziewięcierz and the lowermost parts of the Brusno and Huta Różaniecka sections). A large input of terrigenous material is distinctly marked there. Shoals, fields of small ripples and migrating dunes occurred on the sea bottom, with zones of rhodolith growth, which developed between them on a sandy bottom. There are no indicators of the shoreline position. The lack of biogenic structures probably resulted from an episode of a high deposition rate and/or of unfavourable conditions for colonisation of the sea bottom by benthic organisms. However, organodetritic sedimentation developed on the sea bottom in the zones with lower accumulation rates and energy. The bottom surface was inhabited by red algae, which functioned as specific carbonate build-ups of patch reefs (the Dziewięcierz and Brusno sections). In the higher energy zones, the bottom could have been inhabited by red algae in those places where movements of rhodoliths and quartz material over the sea bottom led to the formation of deposits of a mixed character, such as quartz-rhodolithic sands. Sandy rhodolithic waves (Huta Różaniecka section) were built from this material. The orientation of these forms changed with time, dependent on the current directions that were generated by the wave action and cyclically repeating storms.

Shallow-water, open-sea deposition of organodetritic material derived from the destruction of the organic build-ups, continued in this zone during the Late Badenian. A zone of high organism productivity was located outside the study area, and the Roztocze Hills area played only the role of a transit zone for the material that was transported by the currents in the form of sand waves and dunes (Text-fig. 11). The sediments deposited at that time are characterised by an abundance

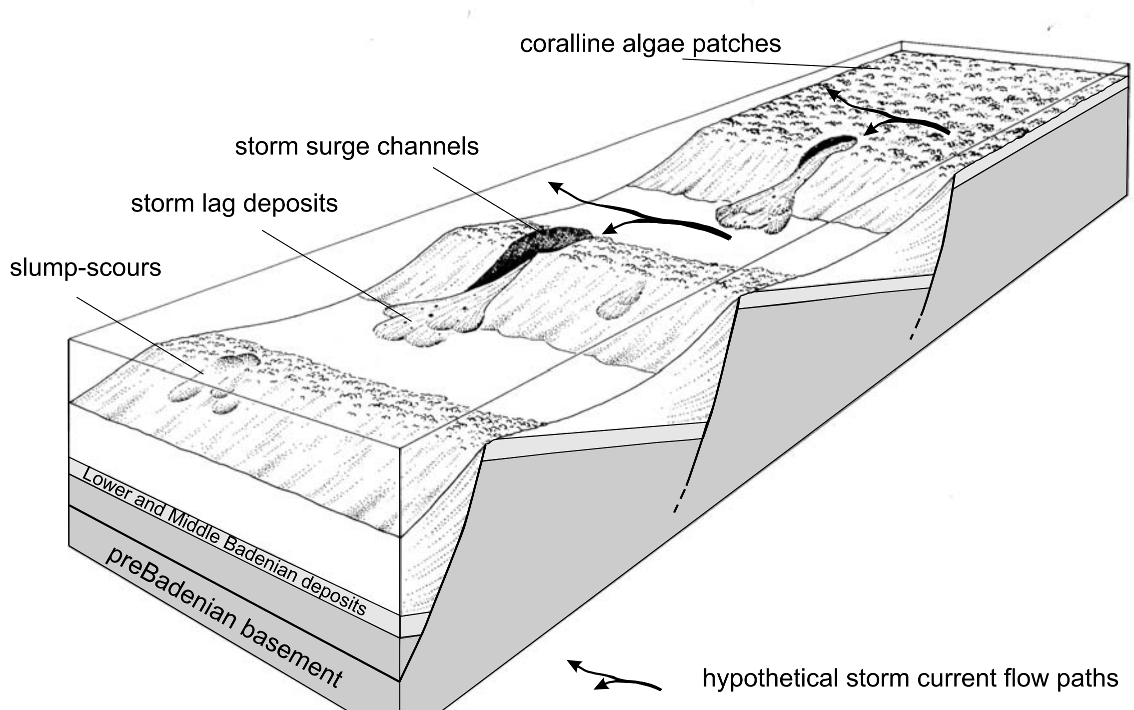

Fig. 11. Model for sedimentary environment of the Roztocze Hills area in the Late Badenian

of various-scale cross-stratification (*e.g.* Brusno, Huta Różaniecka, Józefów and Żelebsko sections). Temporarily, apart from the organodetritic material, terrigenous material was also delivered into the basin (Brusno, Huta Różaniecka and Nowiny sections). Over time, the amount of terrigenous material in the basin decreased in favour of intrabasinal organodetritic material. The area remained a zone of shallow-water deposition. A series of probable storm surge channels filled by storm lag deposits cut through the organodetritic deposits (Józefów and Nowiny sections). At this time, an array of bed forms, induced by the gradual development of synsedimentary faults in the substrate, began to form on the sea bottom (Text-fig. 11). During this period, an increase in tectonic activity took place, and a step-like array of normal faults began to develop, the footwall wings of which were subjected to antithetic rotation, as suggested by JAROSZEWSKI (1977).

In the uppermost part of the Upper Badenian succession of the Roztocze Hills, cross-stratified sets at a scale of dozen or so metres, prograding towards the south, can be observed, *e.g.* in the Józefów region and in the Żelebsko section. Similar large-scale bedforms are known from the Miocene of the southern slopes of the Holy Cross Mountains, from Szydłów and Smerdyna (RUTKOWSKI 1965, 1976; ŁAPTAŚ 1992, RONIEWICZ & WYSOCKA 2001). Large thickness of cross-stratified sets and uniform bedding dip directions suggest a series of parallel, straight-crested depositional forms (Text-fig. 11). These lines were induced by the formation of a system of synsedimentary step-faults in the substratum of a latitudinal direction, linked with intensification of tectonic movements within the Carpathian Foredeep (*see* Jaroszewski 1977, OSZCZYPKO 1996, KRZYWIEC 1998). The greatest deposit thickness was reached in the lowermost part of the rotated blocks (Nowiny and Józefów sections). Abundant mass-flow phenomena developed on the slopes of large depositional forms can also be interpreted as resulting from increased tectonic activity of the substratum. The source of large thickness of organodetritic material near-fault zones were areas of rich red algae development, located on the ridges that developed on the hanging wall of the substrate blocks (Text-fig. 11). Vast areas, characterised by a low deposition rate of fine-grained sediments occurred in the central parts of the blocks, between the fault zones (the Żelebsko section). Such a pattern of sedimentation zones, controlled by the occurrence of synsedimentarily active tectonic zones within the substrate, caused substantial facies and thickness diversity of the deposits. This model is also confirmed by the absence of greater quantities of organodetritic material in the zone of the Carpathian Foredeep south of the study area. Most of this material was trapped between the faulted substratum blocks, so it could not be transported towards the Carpathian Foredeep. Because of the lack of geophysical data and cores in this area, this model should be examined by future investigations, especially using seismic profiles.

Such a pattern of sedimentation zones within a shallow marine basin also occurred in the study area at the beginning of the Sarmatian. The transition between the Upper Badenian and the Sarmatian deposits is continuous, and the Badenian/Sarmatian boundary occurs within the shallow-water organodetritic deposits (the Żelebsko section). A change in sedimentary environment and structural setting of this part of the basin took place during the deposition of the Sarmatian deposits (*e.g.* JAROSZEWSKI 1977, JASIONOWSKI 1998).

CONCLUSIONS

Terrigenous and organodetritic deposition took place in the Roztocze Hills during the Badenian. The source of the terrigenous material was weathered crystalline rocks or reworked sediments of Podole. The following rock types have been distinguished, on the basis of the proportion of terrigenous and organodetritic grains: quartz arenites, quartz arenites with limeclasts, calcarenites with quartz and biocalcarenites.

The chemical composition of carbonate cements occurring in the quartz arenites and quartz arenites with limeclasts indicate that the diagenetic processes took place as a result of calcite crystallisation from meteoric waters, both in vadose and phreatic zones.

Microfacies analysis of the biocalcarenites and organogenic and chemogenic limestones allowed twelve microfacial varieties of the limestones to be distinguished. The biocalcarenites are represented by various types of grainstones, packstones and sporadically wackestones, with the predominance of algal bioclasts, rhodoliths and skeletal elements of foraminifera, bryozoans and pelmatozoans in the framework. Large quantities of algal bioclasts suggest that the sea bottom must have been overgrown by red algae, having the character of “sea grass”, and by patch reefs. Moreover, the foraminiferal assemblages in the Upper Badenian deposits are characteristic of a shallow-water, offshore sea with normal salinity.

Depositional, deformational and biogenic assemblages of sedimentary structures occur within the studied deposits. They are characteristic of several sedimentary zones in shallow-water high-energetic offshore and open sea environments.

Detailed analysis of sections allowed an interpretation of subenvironments and their changes during the Badenian. The Lower Badenian succession documents a shallow-water marine environment, within the shore zone. The following forms of sediment accumulation have been distinguished: delta slope, sand waves and fields of ripples. Gradual evolution during the Late Badenian of the shallow-water environment to an open-marine zone where sedimentation was strongly influenced by synsedimentary fault tectonics, has been inferred in the Upper Badenian sections.

In general, Badenian sedimentation was dependent mainly on hydrodynamic factors, however the influence of diastrophic factors gradually increased:

– during the Early Badenian, the eastern part of Roztocze was located within the northern shore zone of the basin that filled the Carpathian Foredeep. It remained under constant influence of the land and was a zone of accumulation of terrigenous material in a shallow sea, with the water depth not exceeding the wave base. Development of deposition was controlled by sediment supply from the land, as well as by intensity and orientation of the currents;

– during the Late Badenian, due to tectonics, the pattern of sedimentation zones varied both temporally and spatially. The sedimentary environment changed to a shallow, open sea. Most probably, the location and extent of the subenvironment zones of organodetritic and organogenic deposition were dependent on bathymetric factors, as a result of uplifted and subsided blocks of the substratum.

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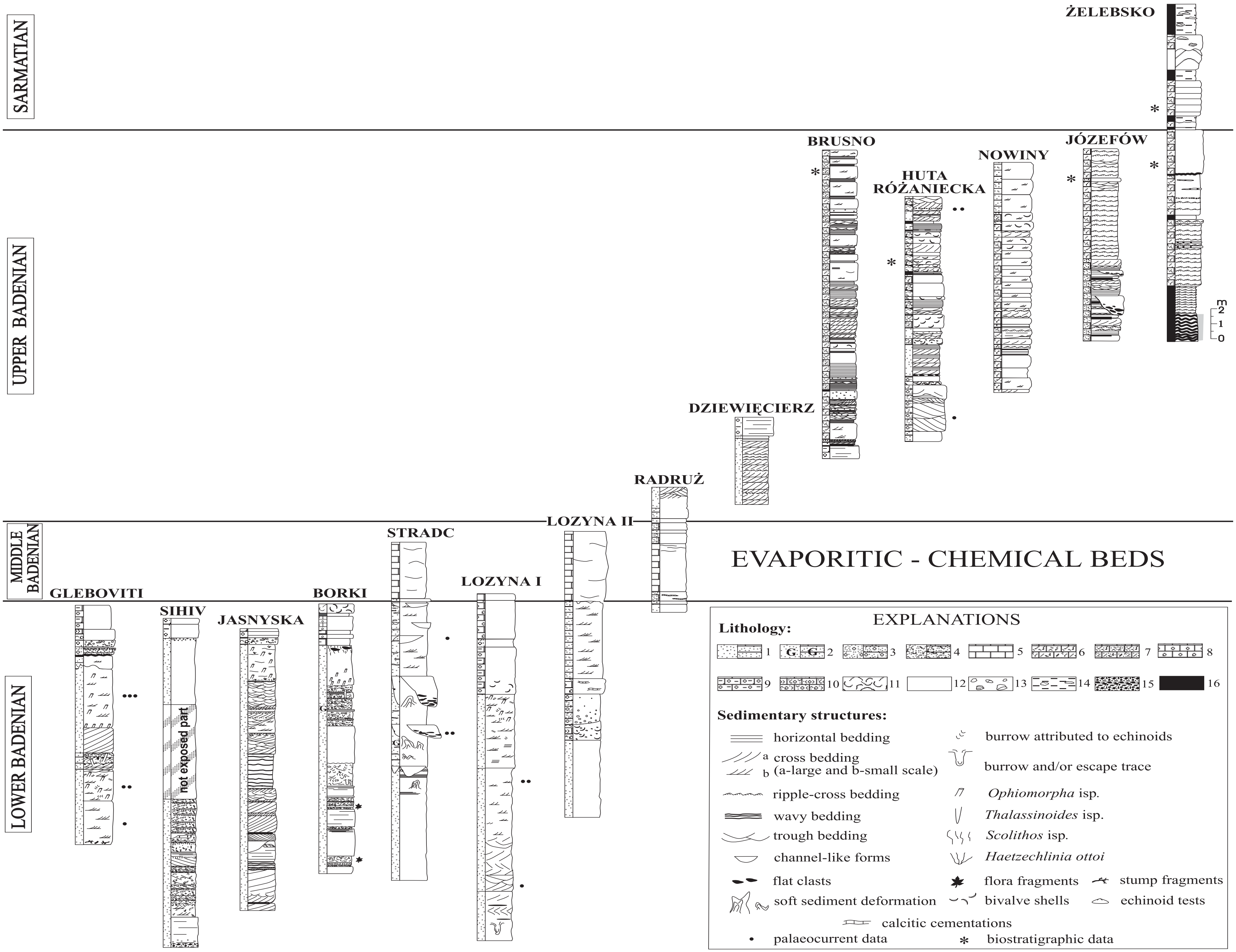


Fig. 5. Measured Badenian sections from the Roztocze Hills (arranged from southeast to northwest – for location *see* Fig. 1). Correlation based on position in relation to the Evaporitic-Chemical Beds, present-day hipsometry and rare biostratigraphic data. Lithology: 1 – quartz sands and sandstones, 2 – quartz-glauconite sands and sandstones, 3 – quartz-rhodolith sands and sandstones, 4 – quartz-organodetritic sands and sandstones, 5 – micritic limestones, 6 – calcarenites, 7 – sandy calcarenites, 8 – *Lithothamnium* limestones, 9 – marly *Lithothamnium* limestones, 10 – sandy *Lithothamnium* limestones, 11 – coquina beds, 12 – serpulid–microbial limestones, 13 – calcarenites with spheroidal bodies of serpulid–microbial limestones, 14 – clays with spheroidal bodies of serpulid–microbial limestones, 15 - sandy mudstones with organic matter, 16 – clayey marls

PLATE 1

Calcite cements in quartz arenites (x – crossed polars, CL – view under cathodoluminescence), scale bar is the same for all photos

1 – blocky spar mosaic between quartz grains (x) (Stradc)
2 – as in Fig. 1; lack of luminescent zonation in cement crystals (CL)
3 – blocky spar and microspar mosaic between quartz grains (x) (Lozyna II)
4 – as in Fig. 3, two types of luminescence are visible: bright luminescence is microspar and dull dark is blocky spar (CL).
5 – syntaxial calcite spar overgrowth on an echinoderm fragment (sc) and cavity, after dissolution of bioclast, infilled with blocky cement (bc) (x) (Huta Różaniecka)
6 – as in Fig. 5, luminescent zonation of blocky cement infilling dissolution cavity (CL)

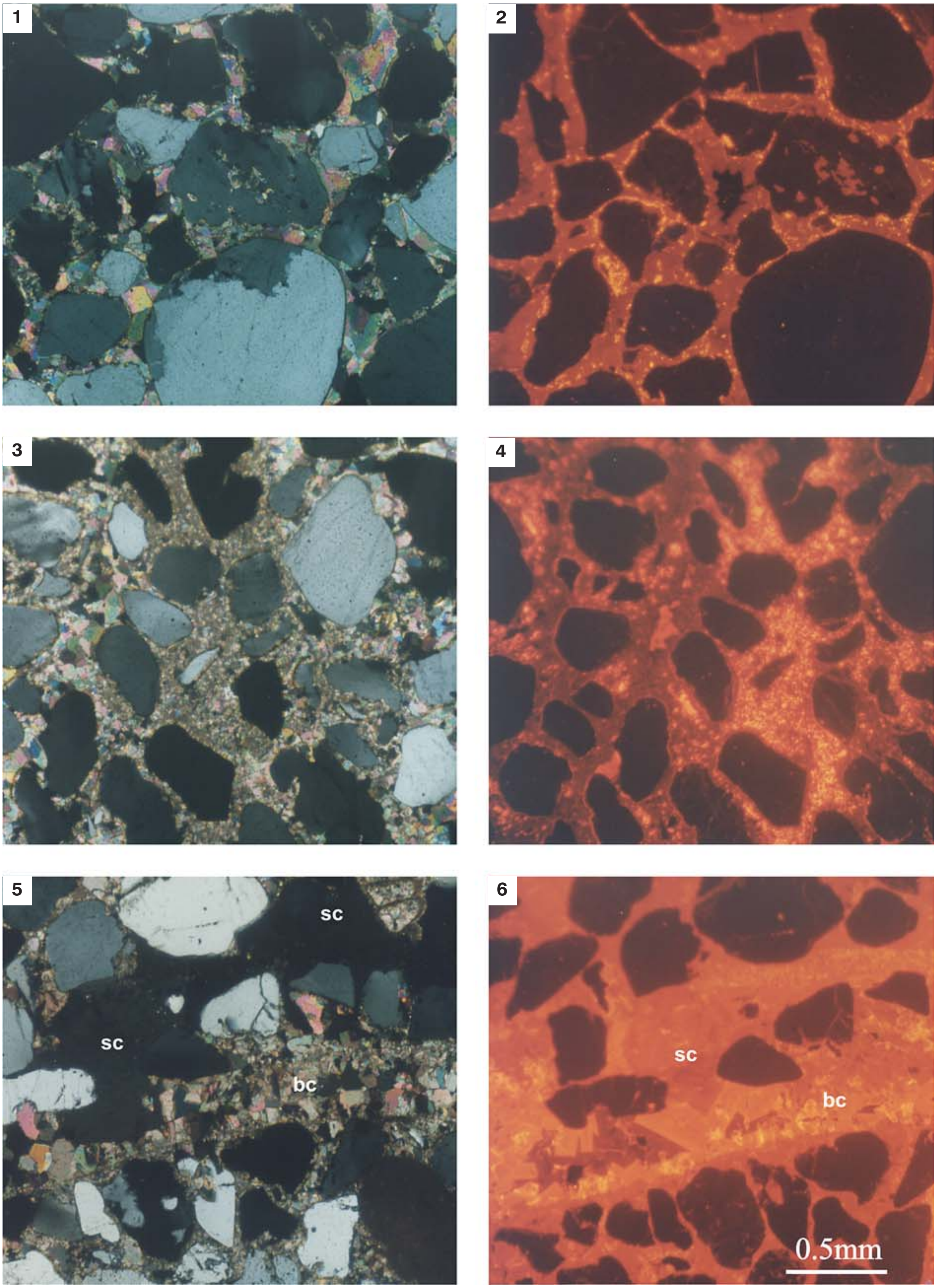

1
2
3
4
5
sc
sc
bc
6
sc
bc
0.5mm

PLATE 2

Calcite cements in quartz arenites (x – crossed polars, CL – view under cathodoluminescence), scale bar is the same for all photos

1 – poikilotopic calcite spar consists of large crystals including several quartz grains (x) (Lozyna II)
2 – as in Fig. 1, uniform luminescence of poikilotopic spar (CL)
3 – poikilotopic calcite spar consisting of large crystals including several quartz grains (x) (Dziewięcierz)
4 – as in Fig. 3, lack of luminescence of poikilotopic spar (CL)
5 – sandy part of Ratyń Limestones; numerous microspar and micrite fringes around quartz grains (x) (Radruż)
6 – as in Fig. 5, distinct and various luminescence of microspar and micrite fringes around quartz grains (CL)

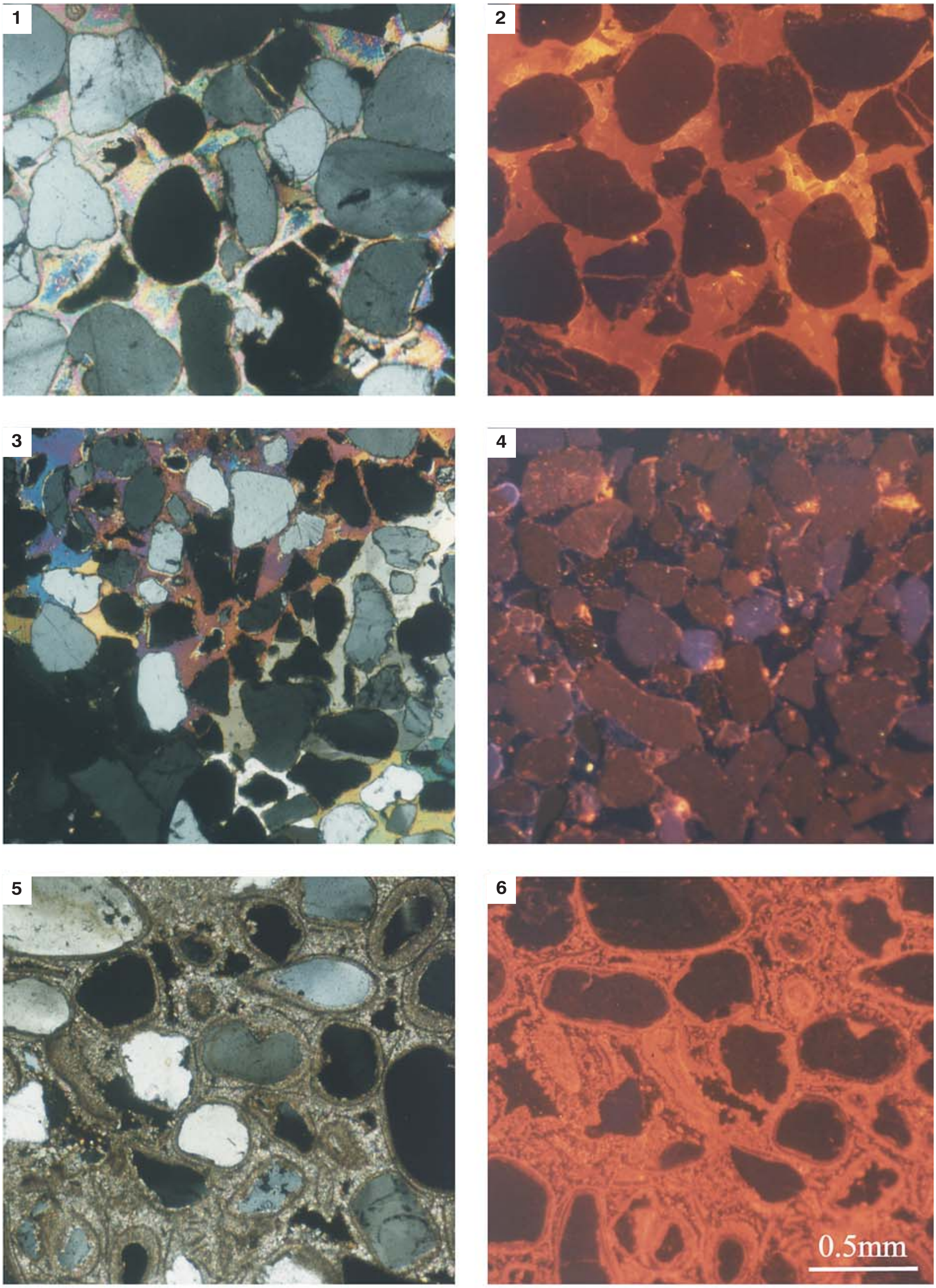

1
2
3
4
5
6
0.5mm

PLATE 3

Microfacies of sandy calcarenites and biocalcarenites

1 – red corallinacean grainstone composed of algal clasts, foraminiferal tests, bryozoan and echinoderm bioclasts (Józefów)
2 – foraminiferal algal grainstone composed of fine algal clasts and numerous foraminiferal tests (Józefów)
3 – algal packstone with bioclasts composed of oval algal clasts, single bioclasts of bryozoans (b), tubes of *Ditrupa* (d) and quartz grains (Q) (Brusno)
4 – porous algal packstone with bioclasts (the Brusno)
5 – foraminiferal algal packstone composed of fine algal clasts and numerous foraminiferal tests; directional textures connected with parallel bioclast arrangement (Brusno)
6 – porous bryozoan algal packstone, framework is composed of bryozoan and algal bioclasts with single foraminiferal tests (Brusno)
7 – bryozoan foraminiferal wackestone composed of bryozoan (b), foraminiferal (f), algal (a) and echinoderms bioclasts (e) with small admixture of fine quartz grains (Q) (Dziewięcierz)
8 – foraminiferal bioclastic wackestone with large rhodoliths (Brusno)

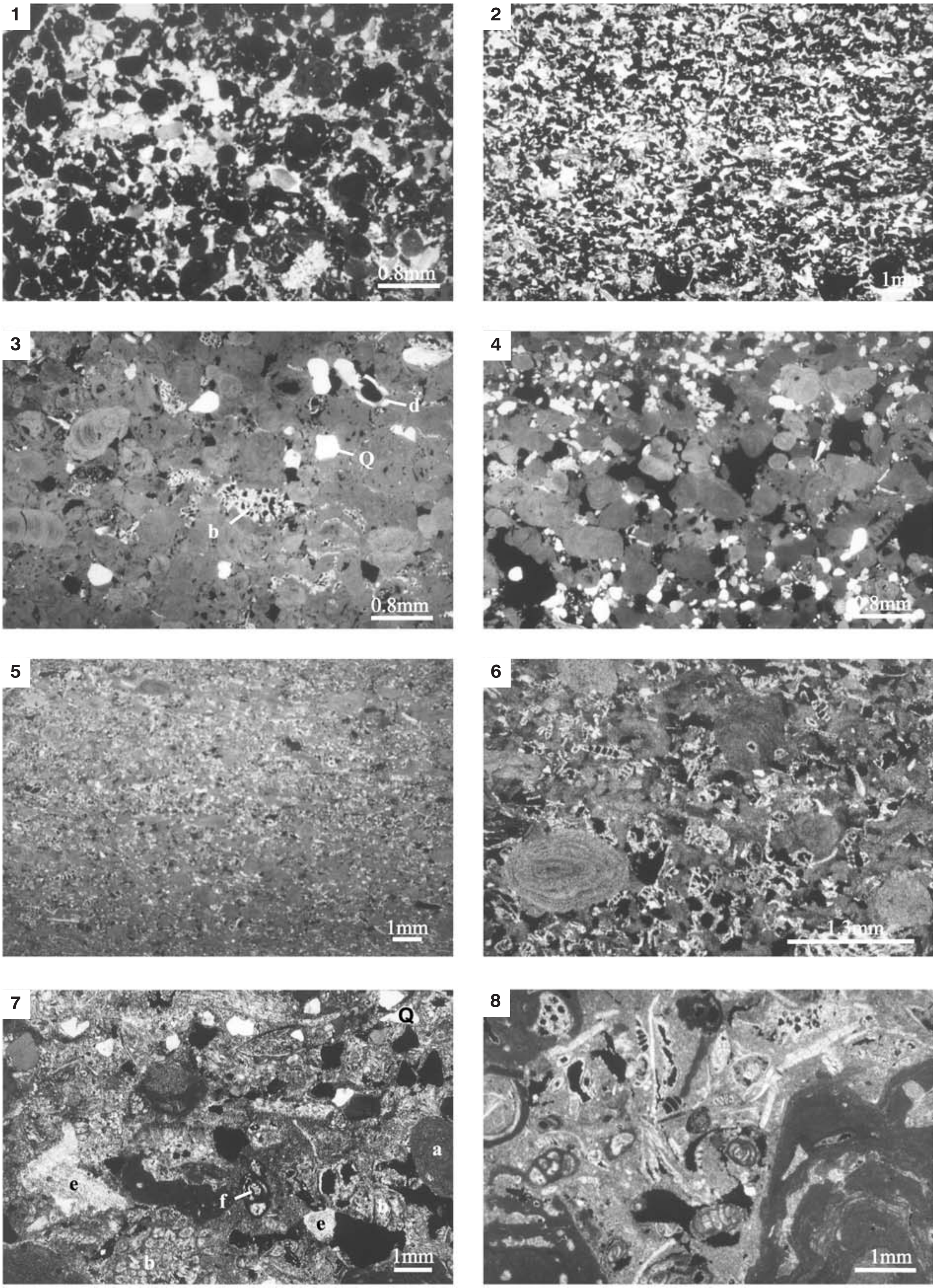

1
0.8mm
2
1mm
3
d
Q
b
0.8mm
4
0.8mm
5
1mm
6
1.3mm
7
Q
a
e
f
e
b
1mm
8
1mm

PLATE 4

Microfacies of sandy calcarenites and biocalcarenites

1 – quartz-rich wackestone with pisoliths, quartz grains (Q) surrounded by microspar fringes (Radruż) (*see also* Pl. 9, Figs 5, 6)
2 – quartz-rich peloidal wackestone with gypsum pseudomorphs (Radruż)
3 – mudstone, microfacies type without framework components, composed of microspar with disturbed lamination (Radruż)
4 – porous mudstone (Radruż)
5 – gypsum pseudomorphs in peloidal wackestone (Radruż)
6 – rhodolithic boundstone (Radruż)
7 – rhodolithic boundstone, cavity in the algal thalli filled up with internal peloid sediments (black arrow) and meteoric blocky cement (white arrow) (Radruż)
8 – rhodolithic boundstone with fine quartz grains in internal sediments (Dziewięcierz)

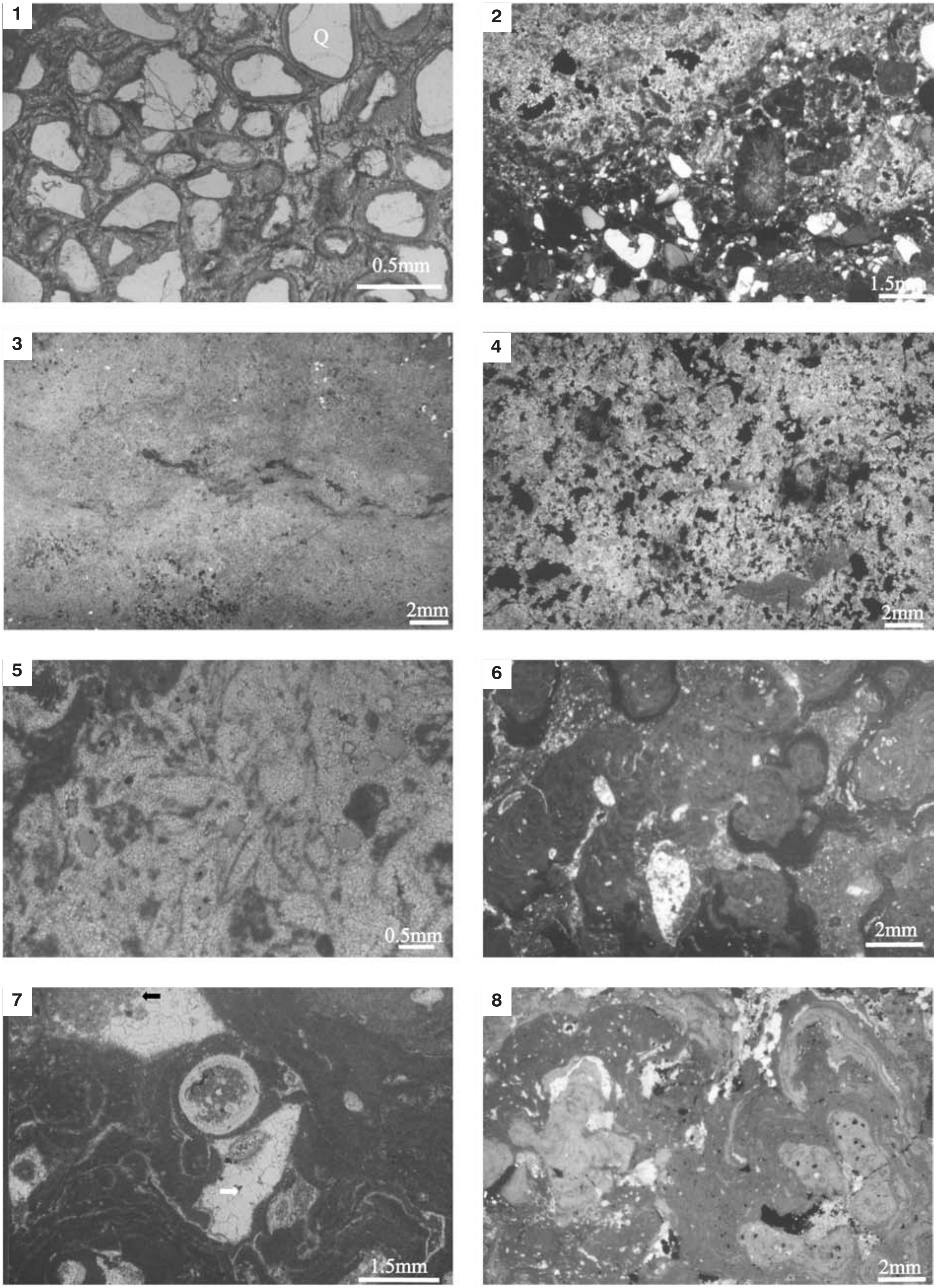

1
Q
0.5mm
2
1.5mm
3
2mm
4
2mm
5
0.5mm
6
2mm
7
1.5mm
8
2mm

PLATE 5

Various types of stratification (bars for Figs 1-4 = 10 cm, for Fig. 6 = 2 m)

1 – horizontally laminated quartz sands containing clayey ferruginous layers with dispersed organic matter (Jasnyska)
2 – flaser ripple cross-lamination in fine quartz-glauconite sands (Stradc)
3 – ripple cross-lamination in calcarenites above the quartz-glauconite sands (Brusno)
4 – trough cross-lamination in quartz sands (Jasnyska)
5 – cosets of tabular cross-stratified quartz sands (Lozyna I)
6 – giant-scale cross-stratification in quartz sands (Gleboviti)

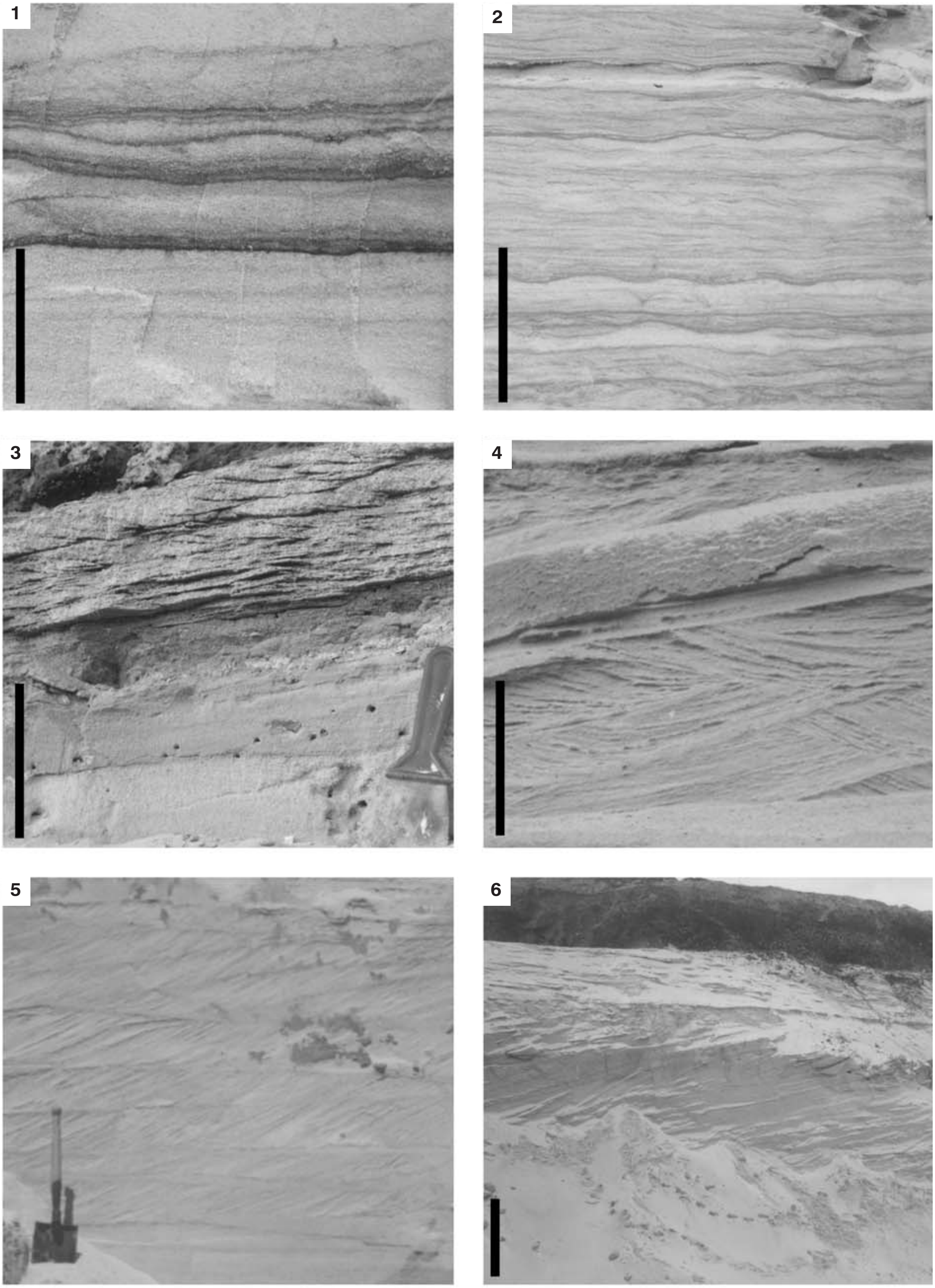
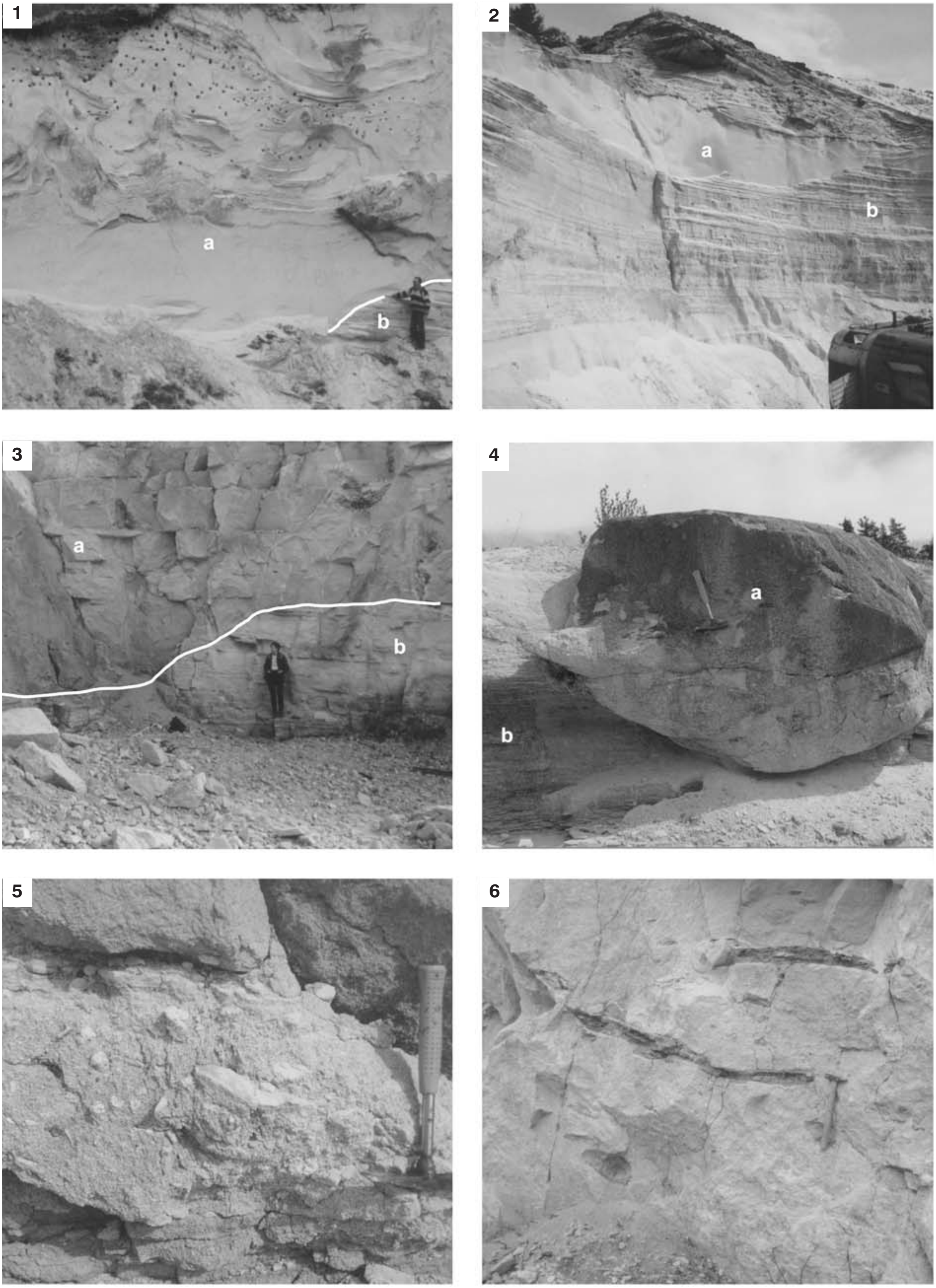

1
2
3
4
5
6

PLATE 6

Channel-like forms of different origin

1 – large-scale channel-like form (a) cut in ripple cross-laminated quartz-glauconite sands (b); note the massive structure in the lower part and soft sediment deformation in the upper part (Lower Badenian, Stradc)
2 – channel-like form (a) infilled by homogenous quartz sands. The scour cuts into tabular cross-stratified, slightly bioturbated quartz sands (b) (Lower Badenian, Sihiv)
3 – large-scale channel-like structure (a) infilled by massive calcarenites with flat, clayey clasts, cut in ripple cross-stratificated calcarenites (b) (Upper Badenian, Józefów)
4 – small scale channel-like structure (a) cut in coarse grained calcarenites (b) (Upper Badenian, Pardysówka Quarry)
5 – close up of Fig. 4. Coarse-grained, poorly sorted calcarenites with flat lime clast and rhodoliths which infilled the channel-like structures (Upper Badenian, Pardysówka Quarry)
6 – close up of Fig. 3. Massive calcarenites with elongated clayey clasts which infill the channel-like structures (Upper Badenian, Józefów)


1
a
b
2
a
b
3
a
b
4
a
b
5
6

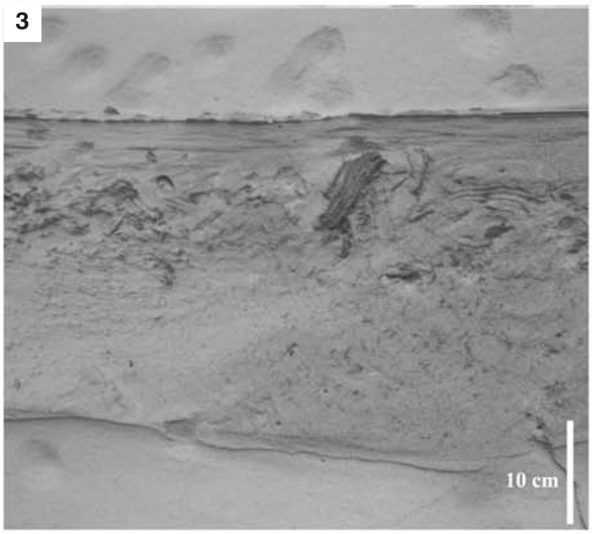
PLATTE 7

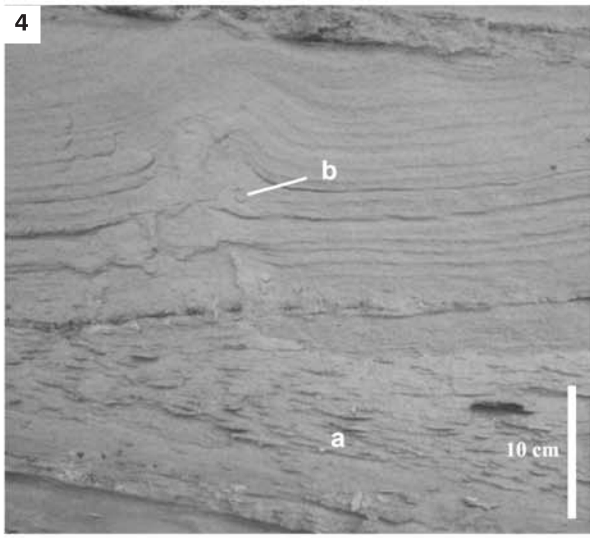
Synsedimentary soft-sediment deformations of the Lower Badenian deposits from the Stradc section

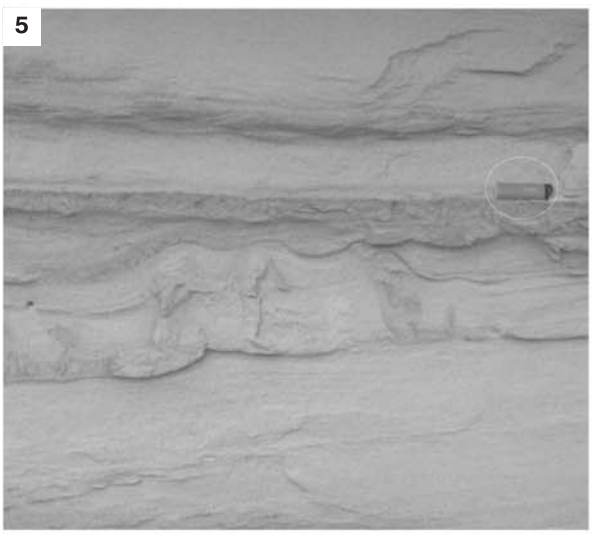
1 – large scale fold deformation of diapir-type, in partly homogenous quartz sands
2 – convolute bedding in quartz-glauconite sands
3 – disintegrated and disturbed stratification in quartz-glauconite sands; note sharp and flat top surface
4 – dish (a) and pillar (b) water-escape structures, note the anticlinal form of lamination above the water-escape structure
5 – pillar water-escape structures; note the anticlinal form of lamination in upper layers of sandy sediments (lighter as a scale)
6 – pillar water-escape structures (a) overlaid by partly homogenous sands which infilled channel-like structures (b) (lighter as a scale)


1


2


3
10 cm


4
b
a
10 cm


5

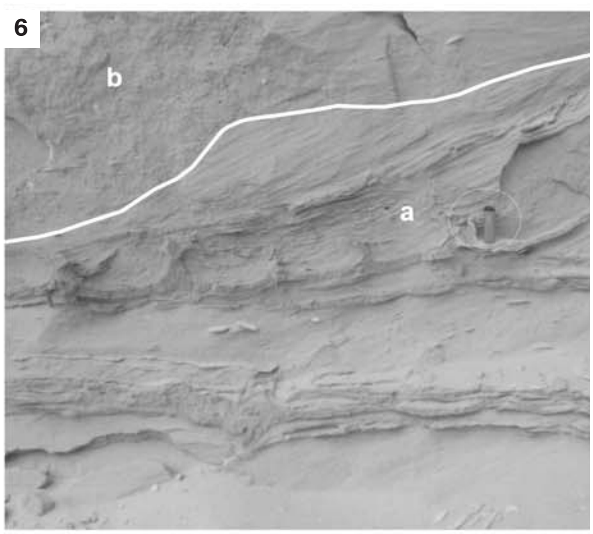

6
b
a

PLATE 8

Biogenic structures in the Lower Badenian deposits from the Ukrainian part of the Roztocze Hills

1 – tabular cross-stratified sands with strongly bioturbated sandy horizons (Gleboviti)
2 – sandstone surface with well preserved echinoid burrows (Gleboviti)
3 – size-segregated and current-orientated tests inside the cross-stratified quartz sands (Gleboviti)
4 – cross-stratified quartz sands with a trace fossils assemblage: echinoids bioturbation (a), callianassid decapod burrows (b) (Gleboviti) (bar = 10 cm)
5 – cross-stratified quartz sands (a) overlain by horizon (arrowed) with numerous problematic trace fossils (probably *Haentzechlinia* sp.); above lie strongly bioturbated sands (b) with numerous burrows of callianassid decapods (Jasnyska) (bar = 10 cm)
6 – problematic trace fossil, probably *Haentzechlinia* sp., (Jasnyska)

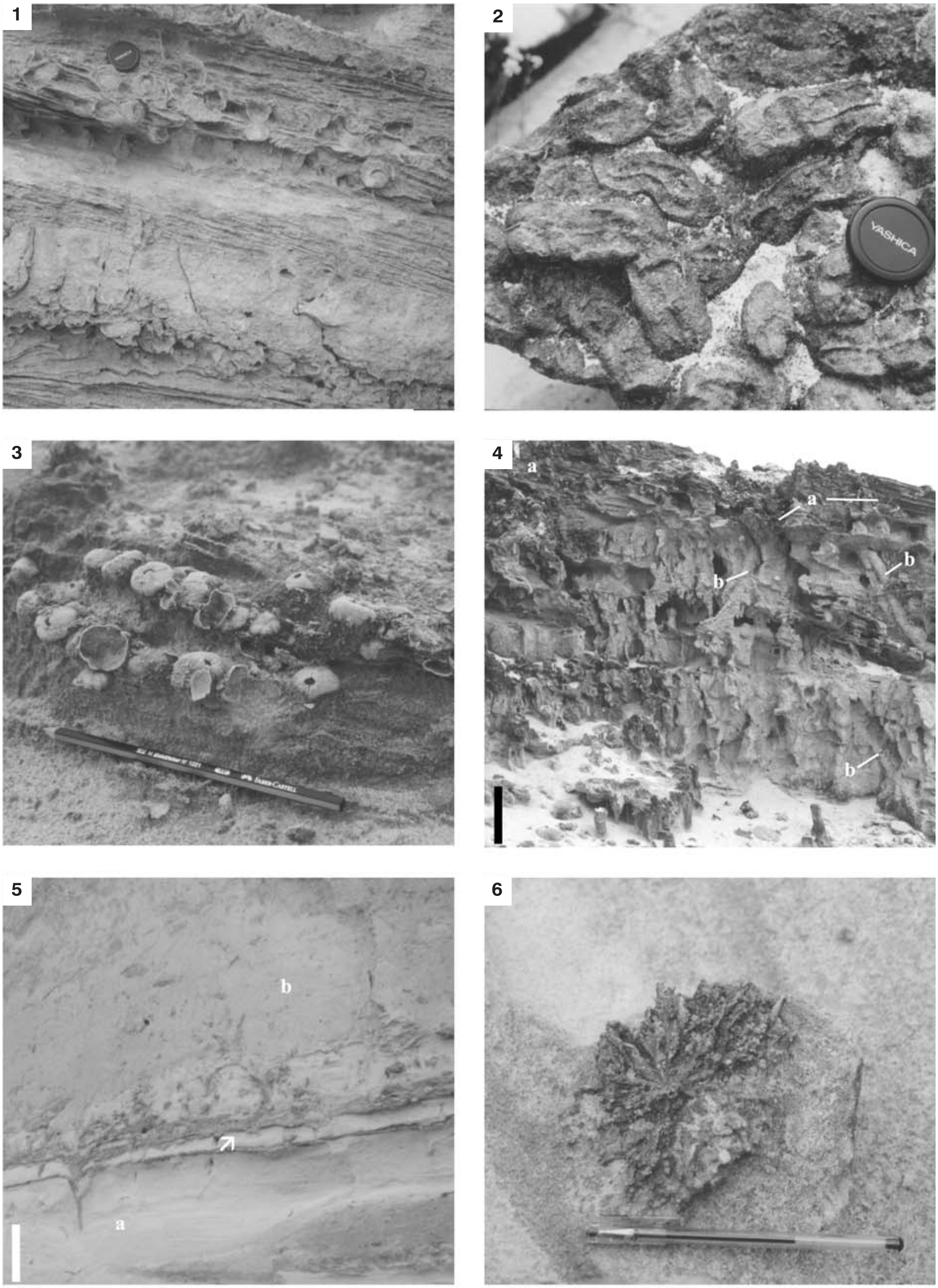
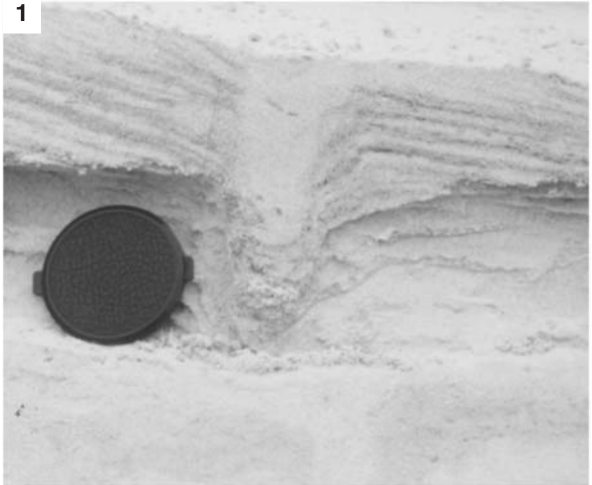
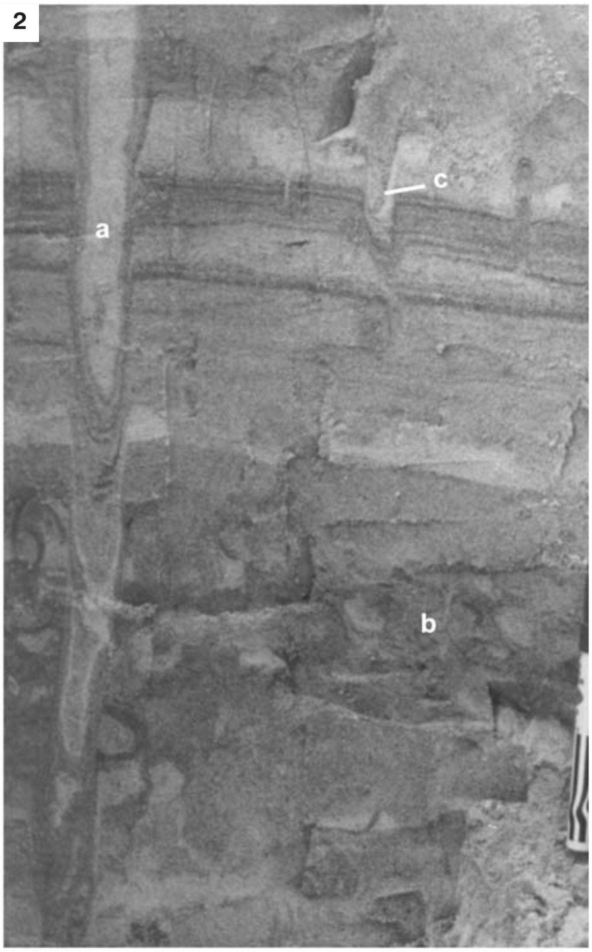

1
2
YASHICA
3
FABER-CASTELL
4
a
a
b
b
b
5
b
a
6

PLATE 9

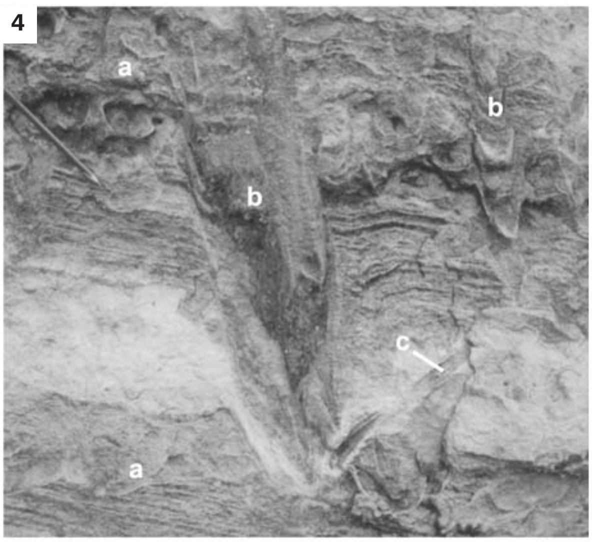
Biogenic structures in the Lower Badenian deposits from the Ukrainian part of the Roztocze Hills

1 – burrows of sea anemone in cross-laminated quartz sands (Borki).
2 – fugichnia caused by bivalve (a) in laminated quartz-glauconite sands, partly bioturbated by echinoids (b) and sea anemones (c) (Borki)
3 – burrow attributable to a crab in partly cemented sands (Gleboviti).
4 – tabular cross-stratified quartz sandstones, strongly bioturbated by echinoids (a), sea-anemones (b) and callianassid decapods (c) (Gleboviti)


1


2
c
a
b


3


4
a
b
b
c
a