Geological Quarterly, 2001, **45** (2): 131–142

Sedimentological record of changing hydrodynamic conditions in the upper Tremadoc deposits of the Holy Cross Mountains, Poland

Wiesław TRELA

Trela W. (2001) — Sedimentological record of changing hydrodynamic conditions in the upper Tremadoc deposits of the Holy Cross Mountains, Poland. Geol. Quart., **45** (2): 131–142. Warszawa.

In the upper Tremadoc, in the Kielce region of the Holy Cross Mountains, siltstones and fine-grained sandstones are interbedded with chalcedonites and claystones. The deposits were probably laid down when the late Tremadoc transgression reached its maximum. Storm currents influenced deposition at times while, during calm periods, sedimentation of chalcedonites, clayey cherts and clays took place. Weak bottom currents affected the deposition of siliceous layers. The deposits accumulated on a distal shelf.

Wiesław Trela, Holy Cross Mts. Branch, Polish Geological Institute, Zgoda 21, PL-25-953 Kielce, e-mail: trela@pgi.kielce.pl *(received: January 20, 1999; accepted: August 30, 2000).*

Key words: Holy Cross Mts.,Ordovician, Late Tremadoc, chalcedonites, transgression, storm deposits.

INTRODUCTION

In the Late Tremadoc, after the Sandomierz tectonic movements (Tomczyk, 1971; Bednarczyk, 1971; Znosko and Chlebowski, 1976), a marine transgression developed in the Kielce region of the Holy Cross Mountains, recorded by the deposition of detrital and siliceous rocks. The character of the deposits suggest changing energy levels in the environment. This paper considers the sedimentology of the deposits, and discusses the sources of the silica within the chalcedonites and clayey cherts.

The data comes from sections at Zalesie Nowe and Kędziorka (Chojnów-Dół gorge) near Łagów (Fig. 1) in the southern part of the Bardo Syncline, where the best exposed profiles of these deposits occur, and also from the Szumsko Kol. 2 borehole (Fig. 1). Macroscopic observations were augmented by study of 60 thin sections.

HISTORY OF RESEARCH

Chalcedonites from the Holy Cross Mountains were first mentioned by Czarnocki (1919, 1928) and Samsonowicz (1948). Their petrology was studied by Turnau-Morawska (1958), and Chlebowski (1971, 1976). Palaeontological and stratigraphical studies were carried by Kozłowski (1948), Górka (1969), Bednarczyk (1962, 1964, 1966*a*, *b*, 1971, 1981, 1988, 1996), Bednarczyk and Biernat (1978) and Szaniawski (1980).

Czarnocki (1919) explained the formation of the chalcedonites as the results of “advanced diagenetic changes”. Samsonowicz (1948) suggested that the silica formed syngenetically on the sea bottom, where it was delivered from land. Turnau-Morawska (1958) suggested that changes in basin bathymetry took place during the deposition of the siltstones and chalcedonites. The siltstones formed in a relatively shallow environment, sourced from erosion on land, while deposition of chalcedonites took place during deepening episodes. The role played by bottom currents during the deposition of upper Tremadoc siltstones and chalcedonites was first mentioned by Chlebowski (1971).

GEOLOGICAL SETTING

The study area, located south from the Holy Cross Fault, lies in the Kielce region of the Holy Cross Mountains (Fig. 1). The region forms the northern, exposed part of the Małopolska Block (Pożaryski, 1990; Dadlez *et al.*, 1994), which during the Ordovician was located between Baltica and Gondwana (Dzik

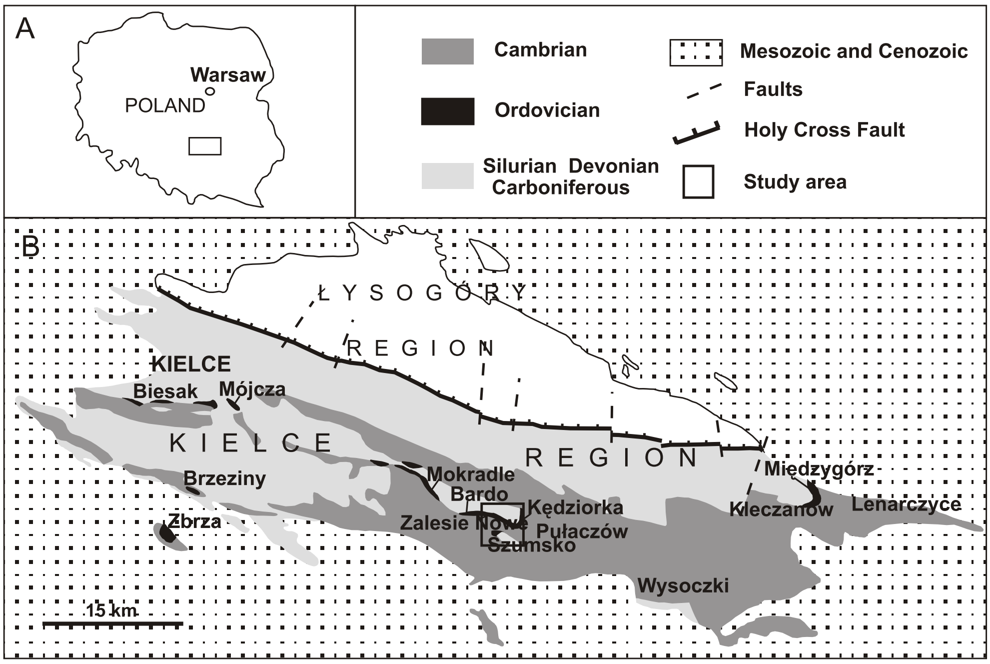


Fig. 1. Distribution of Ordovician deposits in the Holy Cross Mountains (Tomczykowa, 1968; Bednarczyk, 1971)

and Pisera, 1994). In the Arenig it was close to a latitude of 60° south (Lewandowski, 1987).

The upper Tremadoc strata in the Kielce region of the Holy Cross Mountains have been termed the Zbilutka Siltstone and Chalcedonite Member (Fig. 2) (Bednarczyk, 1981, 1996), while Dzik and Pisera (1994) lifted them to the rank of formation (Wysoczki Chalcedonite Formation) (Fig. 2).

In the Bardo Syncline, Tremadocian siltstones and chalcedonites rest on almost vertically lying Lower Cambrian rocks (Czarnocki, 1939; Samsonowicz, 1948; Kowalczewski, 1964, 1965; Bednarczyk, 1971; Chlebowski, 1971). At Kędziorka they are about 33 m thick (Fig. 3), at Zalesie Nowe they are about 7 m thick (Figs. 3, 4) and in the Szumsko Kol. 2 borehole they are 10 m thick (Fig. 3).

The late Tremadoc age of this unit is documented by brachiopods (Bednarczyk, 1971, 1981, 1988, 1996; Bednarczyk and Biernat, 1978), graptolites (Kozłowski, 1948) and conodonts of the *Drepanoistodus deltifer prostinus* Subzone (Bednarczyk and Biernat, 1978; Szaniawski, 1980; Bednarczyk, 1981, 1988, 1996, 1998; Dzik and Pisera, 1994). Bednarczyk (1996) placed the upper part of the unit in the lowermost Arenig, based on the occurrence of the brachiopods *Celdobolus mirandus* (Barrande) and *Eosiphonotreta acrotretomorpha* (Goryansky).

Tremadocian rocks have been also recorded in excavations and boreholes in Wysoczki, around Pułaczów and in the western part of the Bardo Syncline (Koziel, Mokradle) (Fig. 1) (Samsonowicz, 1948; Turnau-Morawska, 1958; Bednarczyk, 1962; Chlebowski, 1971).

In the eastern part of the Kielce region (Międzygórz), as well as around Brzeziny, Zbrza and Kielce (Fig. 1), upper Tremadoc to lower Arenig grey-green glauconitic sandstones are present (Samsonowicz, 1928; Tomczyk, 1954; Turnau-Morawska, 1960; Tomczyk and Turnau-Morawska, 1964; Deczkowski and Tomczyk, 1969; Bednarczyk, 1971, 1981, 1996). Their stratigraphic position is documented by the brachiopods *Thysanotos siluricus* (Eichwald), *Celdobolus mirandus* (Barrande) and *Rosobolus* cf. *robertinus* (Havliček) and conodonts of the *Drepanoistodus deltifer deltifer* Subzone (Bednarczyk, 1981, 1996). In the Zbrza region these deposits are interbedded with a few chalcedonite layers. Their thickness varies from 5 m around Zbrza and Brzeziny to 20 m at Międzygórz.

GENERAL LITHOLOGICAL CHARACTERISTICS

The Lower Ordovician profile in the Bardo Syncline begins with a thin layer of sandy conglomerate (currently unexposed) 10–15 cm thick, composed of pebbles of Cambrian rocks and quartz (Czarnocki, 1928, 1939; Chlebowski, 1971).

Above this conglomerate lie siltstones and fine-grained sandstones interbedded with chalcedonites and claystones (Figs. 3, 4). Siltstone and sandstone beds both range between 3 and 20 cm thick. Claystone layers are mostly 2 to 4 cm thick, sporadically reaching 30 cm. Bed boundaries are sharp, and numerous load structures can be found. Mudstones and fine-grained sandstones reveal a distinct green colour, while chalcedonites are grey and bluish. Locally, thin interlayers and laminae of coarse sand and fine gravel occur within individual siltstone-sandstone layers.

PETROGRAPHIC CHARACTERS

The overall petrographic characters, mineral composition and textural attributes of the main lithological types are given here. Detailed petrographic analyses of the Tremadoc deposits from Wysoczki and Bardo Syncline can be found in Turnau-Morawska (1958) and Chlebowski (1971, 1976).

DETRITIC ROCKS

The detrital rocks comprise mainly quartz grains with a diameter of 0.02–0.06 mm, locally between 0.06–0.1 mm (Pl. I, Fig. 3), making them siltstones and fine-grained sandstones. Quartz grains are angular to slightly rounded, some having regeneration rims. Glauconite is abundant, forming grass-green aggregates with diameters of 0.02–0.6 mm. Faint green flakes of glauconitised biotites are also present, as well as other micas and feldspars. The matrix and cement are formed by clay minerals and silica (amorphous and fine-crystalline). Opaque iron oxides and hydroxides are also present. Chlebowski (1971) noted occurrence of volcanic material (quartz, fresh feldspars and micas) in the detrital rocks. Both siltstones and sandstones contain fine gravel, represented by phosphatic grains, claystone rock pebbles, quartzitic siltstones, coarse-grained quartz and fragments of siliceous rocks.

SILICEOUS ROCKS

Siliceous rocks are composed of chalcedonite, usually developed in the form of fan-shaped spherulites (0.1–0.5 mm) (Pl. I, Fig. 2). Very well preserved sponge spicules, without any traces of mechanical or chemical erosion, and fragments of phosphatic brachiopod shells can be seen in the chalcedonite matrix (Pl. I, Fig. 2). Organic remains and detrital grains form the nuclei of the chalcedonite spherules. Glauconite, detrital quartz, feldspars, micas and phosphates also form a small proportion of the rock.

Clayey cherts also occur (Turnau-Morawska, 1958; Chlebowski, 1971), being a mixture of silica, clay minerals, detrital quartz, feldspars, phosphates, glauconite and ferruginous compounds (Pl. I. Fig. 4). As in the chalcedonites, sponge spicules are present. In the clayey cherts of the Szumsko Kol. 2 borehole, calcite carbonate locally occurs (Pl. I, Fig. 4), some forms of which resemble organic remains. Less abundantly, calcium carbonate occurs also in the siliceous deposits of Zalesie Nowe and Kędziorka. Its presence was mentioned by Turnau-Morawska (1958) and Chlebowski (1971).

SEDIMENTOLOGY

SILTSTONES AND SANDSTONES

A characteristic feature of the upper Tremadoc profiles exposed in Kędziorka and Zalesie Nowe is a rhythmic occurrence of siltstones/sandstones, chalcedonites and claystones (Figs. 3, 4; Pl. I, Fig. 1). Sedimentological structures analysed in this section refer mainly to siltstones and sandstones. The claystones are usually massive or bioturbated, or in some cases horizontally laminated.

Basal surfaces of the siltstone-sandstone layers are usually sharp, erosional and in most cases covered by coarse sand and fine gravel (Pl. II, Fig. 5; Pl. III, Fig. 1). Larger pebbles here reach a maximum diameter of 1 cm, and comprise well-rounded intraclasts of green claystone and fragments of chalcedonites and clayey chert. Groove marks on these basal surfaces reach a dozen or so centimetres in lenght, 1–5 mm in width, and 1–2 mm in depth. Longitudinal ridges moulds are also present (Pl. IV, Fig. 4).

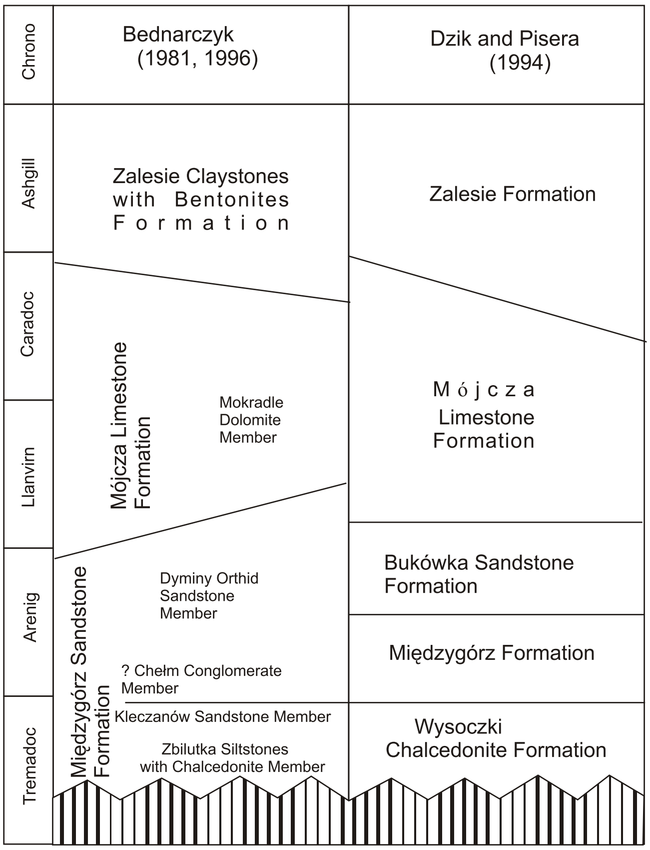


Fig. 2. Lithostratigraphy of the Ordovician deposits in the Kielce region of the Holy Cross Mountains

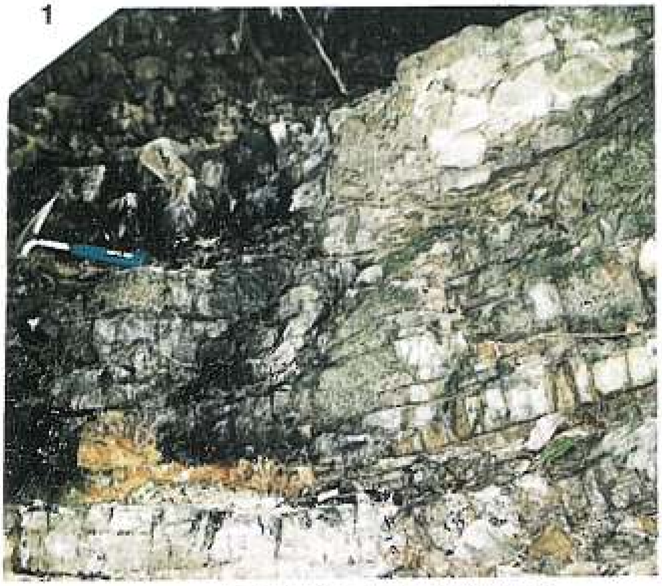
The siltstone-sandstone layers contain horizontal lamination or low-angle cross-bedding (Pl. II, Fig. 3; Pl. III, Figs. 2, 3). Flaser bedding and ripple cross-lamination also occur (Pl. I, Fig. 5; Pl. II, Fig. 2). Surfaces of the siltstone-sandstone layers are commonly irregular, deformed and loaded (Pl. II, Fig. 1). In few cases hummocky cross-stratification (Pl. III, Fig. 4) and wavy lamination occur. Upper surfaces of some of the claystone and siltstone layers are developed in the form of low hummocks, with a diameter of about 10 cm and the height of about 2 cm, separated by depressions of similar dimensions.

Graded-bedding within the layers comprises passages from coarse sands and fine gravels into siltstones (Pl. II, Fig. 5). Commonly, layers are graded in their lower parts and horizontally laminated in their upper parts, and this may pass up into low-angle cross-bedding or ripple bedding (Pl. I, Fig. 5; Pl. II, Fig. 2). Current ripples may occur on top surfaces, with an amplitude not exceeding 1 cm, and usually around 0.5 cm (Pl. I, Fig. 6).

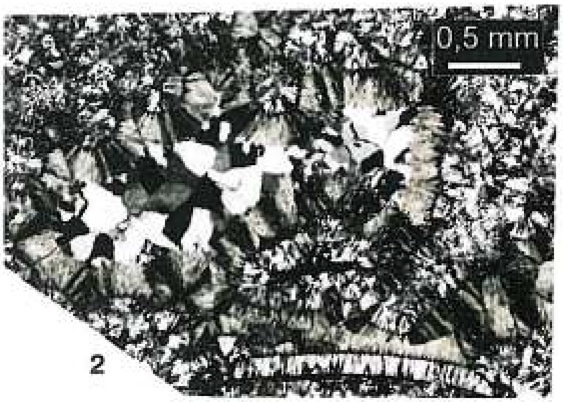
Wash-out structures commonly occur at the base of siltstone-sandstone layers, as small flute marks and erosional

PLATE I

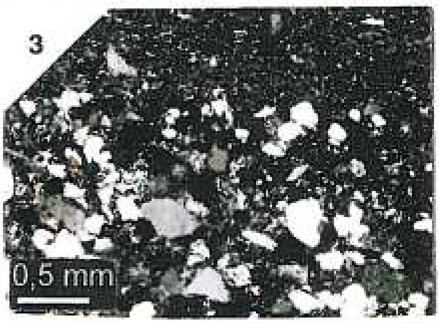
1



2



3



4

5

6

1. Exposure of the Zbilutka Siltstone and Chalcedonite Member in the Kędziorka (Chojnów-Dół gorge); alternation of siltstone-sandstone and chalcedonite layers is visible. ***2***. Chalcedonite spherulites around detritic quartz and on the surface of a phosphatised brachiopod shell fragment (lower part of the picture); crossed polars; Kędziorka. ***3***. Horizontal lamination of fine-grained sandstones seen under the microscope; crossed polars; Zalesie Nowe. ***4***. Contact of clay chert, containing an admixture of carbonates, with siltstone (upper-right corner of the picture); crossed polars; Szumsko Kol. 2. ***5***. Horizontally laminated siltstone; ripple lamination and fodinichnias filled with siltstone-chalcedonite material on a bedding surface; Kędziorka; scale bar — 1 cm. ***6***. Current ripples on the surface of a siltstone layer; Kędziorka

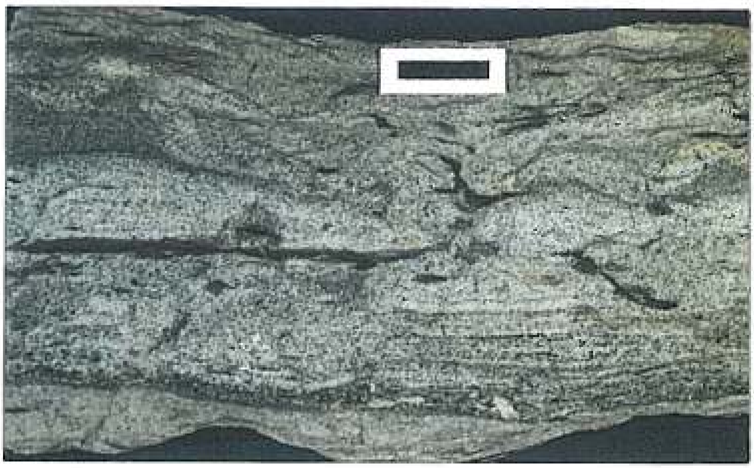
PLATE II

1

2

3

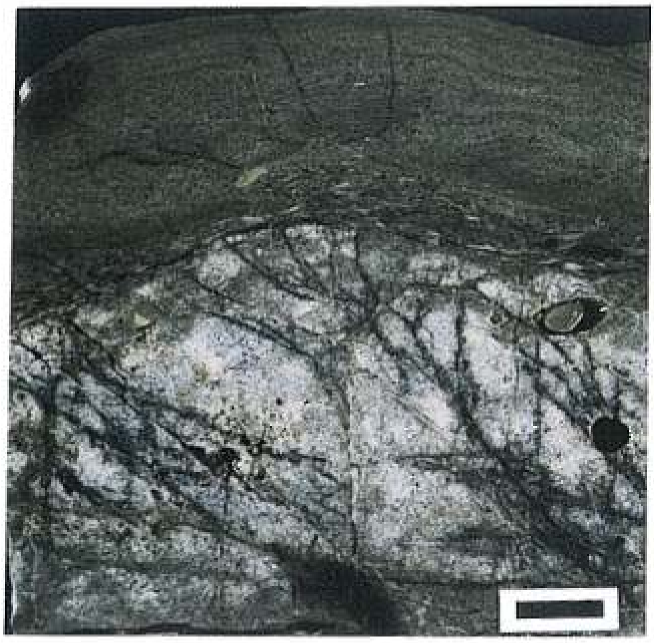
4



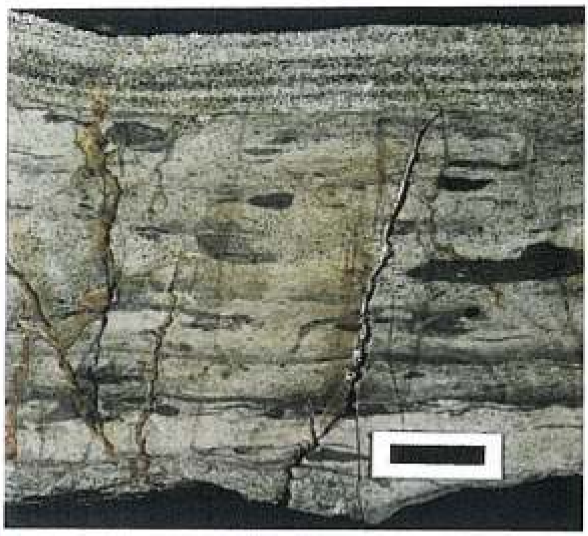
5

1. Siltstone with interrupted horizontal lamination; bending of the lamination at the contact with the chalcedonite is visible (middle part of the picture); oval fragments of clayey cherts (lower part of the picture); Zalesie Nowe. ***2***. Siltstone-siliceous heterolithic deposit; at the bottom of a layer the interrupted internal structure of the deposit is visible, with horizontal and ripple lamination at the top; Zalesie Nowe. ***3***. Contact of chalcedonite with a horizontally laminated siltstone; in its lower part the chalcedonite contains an admixture of detrital material, emphasizing the horizontal lamination; Kędziorka. ***4***. Bed with an interrupted internal structure, composed of redeposited fragments of siliceous rocks and of a sany and gravel; in the lower part of the picture a thin layer of horizontally laminated siltstone is visible; Kędziorka. ***5***. In the lower part of the picture — an erosion surface capped by a thin sandstone layer with small pebbles; higher — a horizontally laminated siltstone; at the top — a claystone with bioturbation traces (dark stripes) and an admixture of siltstone; Zalesie Nowe. Scale bar — 1 cm

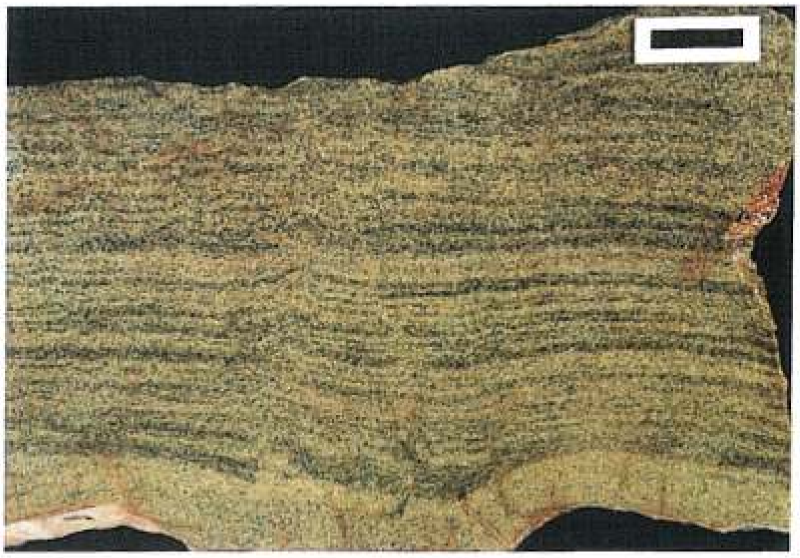
PLATE III



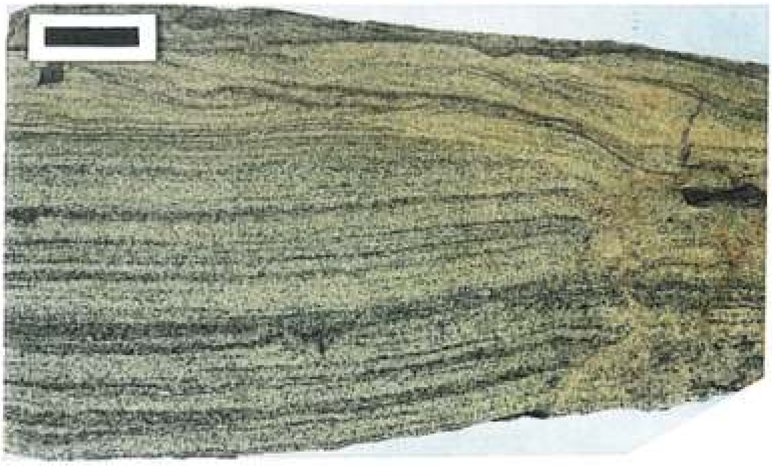
1



2



3

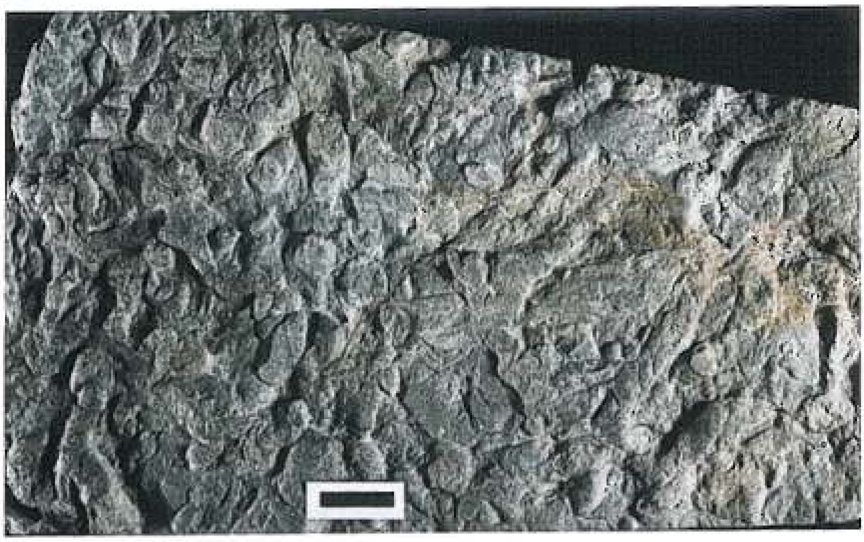


4

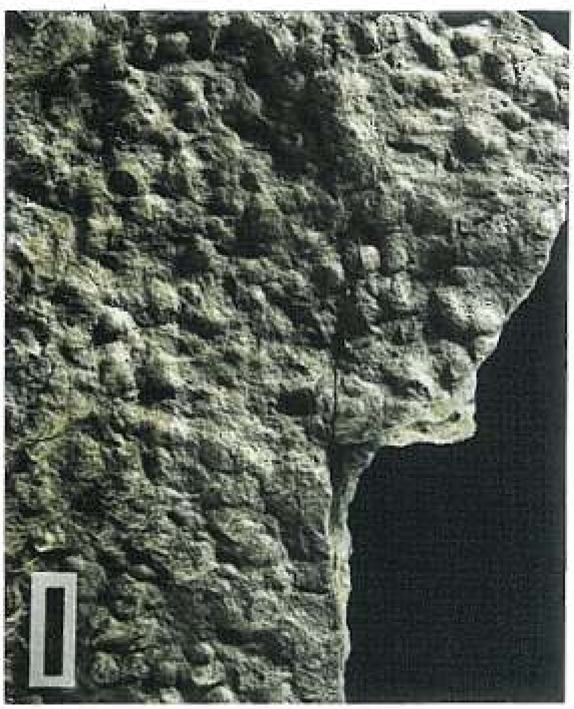
1. Chalcedonite-siltstone contact; a thin layer of coarse-grained sandstone with small pebbles is visible at the bottom of the siltstone layer, capped by horizontal and ripple lamination; chalcedonite with an admixture of terrigenic material; Kędziorka. ***2***. A sharp boundary between a bioturbated siltstone and overlying horizontally laminated siltstone; Zalesie Nowe. ***3***. Horizontally laminated fine-grained sandstone with escape structures; Zalesie Nowe. ***4***. Hummocky cross-stratification (HCS), with an escape structure (right side of the picture); Kędziorka. Scale bar — 1 cm

PLATE IV

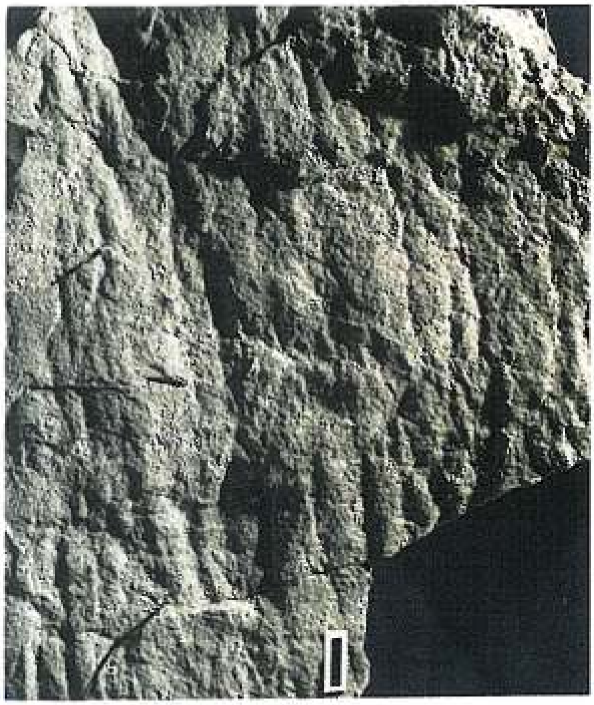
1



2



3



4

1. Bioturbated siltstone; Kędziorka. ***2, 3***. Oval and circular animal traces, preserved on the bottom surface of a bed of fine-grained sandstone; Kędziorka. ***4***. Moulds of longitudinal ridges on the lower surface of a fine-grained sandstone bed; Zalesie Nowe. Scale bar — 1 cm

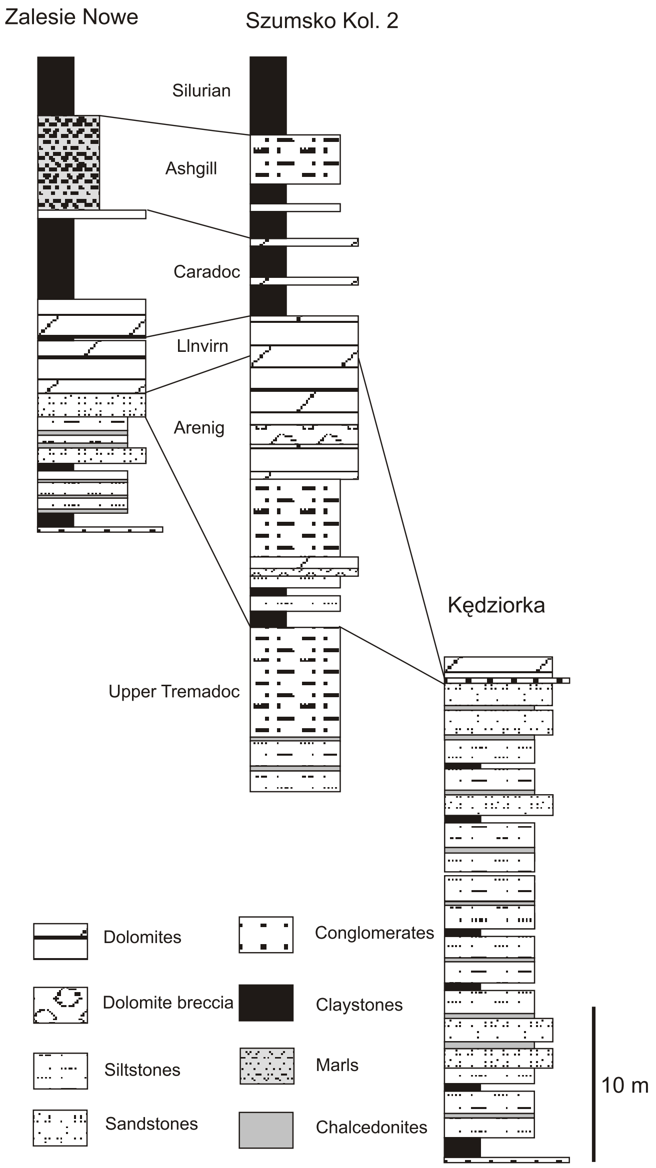


Fig. 3. Lithological profiles of the Ordovician deposits in the area studied (Czarnocki, 1939; Chlebowski, 1971; Bednarczyk, 1971, 1996; Dzik, 1996)

channels, with widths reaching 3–5 cm, and the depths of 1–3 cm, cut into the underlying claystone. These are filled with sand or fine gravel and intraclasts of chalcedonites, which are sometimes rounded.

Individual, lenticular, elongated or oval chalcedonite fragments with a thickness of few or up to a dozen or so millimetres locally occur. They resemble clay balls, and are commonly torn apart and folded (Pl. II, Fig. 1).

In some cases, thin laminae of siltstone, chalcedonites and clayey chert alternate, forming heterolithic layers.

Internally deformed layers commonly occur and comprise torn-apart fragments of claystone, chalcedonites and clayey cherts, with sandy-gravel material squeezed in between them (Pl. II, Figs. 2, 4). Sand and fine gravel form irregular lenses to 1 cm thick, and laminae up to 0.5 cm thick and 3 cm long. These deformed packets are associated with more coherent strata, the whole being probably due to instability as a result of density stratification (Dżułyński, 1966; Anketell *et al.*, 1970).

Lenses, intraclasts and grains of sand occur within some claystone layers, and these usually have gradational boundaries.

Bioturbation comprises mainly endichnias within thin, grey-green claystones and fine-grained siltstones, arranged parallel to the bedding planes (Pl. II, Figs. 2, 5) and outlined by dark organic matter. In many cases, primary sedimentary structures have been destroyed by intense bioturbation (Pl. IV, Fig. 1). Locally bioturbation traces are preserved as hypichnia on bottom surfaces of the siltstone-sandstone layers. They form short, oval forms, up to 1–2 cm long and about 0.5 cm wide (Pl. IV, Fig. 2), and oval traces of diameter 0.5 cm (Pl. I, Fig. 3), and straight forms with a maximum length of 2 cm and widths of 0.3 cm, resembling *Planolites* sp. These traces are built of material from the overlying layers. Sporadically, in the top parts of the siltstone layers, traces of raindrop-shaped borings, up to 2 cm long, and 1 cm across occur (Pl. I, Fig. 5). They cut the original sedimentary structures and are filled by fine-grained, sometimes chalcedonite sediment. They resemble *Glossifungites* (Frey and Pemberton, 1984; Ekdale *et al.*, 1984). Individual escape structures are also found within the siltstone-sandstone layers (Pl. III, Figs. 3, 4), filled with fine-grained homogeneous siltstone. Adjacent to these forms the lamination of the deposits is deformed.

CHALCEDONITES

Rocks built of chalcedonite spherulites usually form continuous layers, easy to trace in the exposures. Lenses, concretions, and clay balls are also present within siltstones and sandstones (Pl. I, Fig. 1). Most commonly they are flat or discoidal and reach dimensions of 1.5 x 3 x 4 cm. Some are load-shaped, or form discontinuous thin laminae, with a maximum length of a few centimetres and widths up to 0.5 cm. In some chalcedonite layers traces of horizontal lamination, marked by the fine detritus can be observed occur (Pl. III, Fig. 3). Concentrations and clay balls of clayey cherts, as well as fine glauconite and quartz grains also occur in the chalcedonite matrix.

Clayey cherts usually form irregular concentrations, lenses or disrupted irregular layers, or they adopt oval shapes (Pl. II, Fig. 1). They are characterised by gradual boundaries and are replaced by chalcedonites and siltstones. Their thickness is variable, averaging about 3 cm. Some laminated and oval clayey cherts with a higher silica content have more distinct boundaries with the surrounding siltstone-sandstone rocks, or occur as load structures in a chalcedonite or siltstone-sandstone matrix (Chlebowski, 1971). In a few cases traces of lamination are preserved within the bedded cherts.

DISCUSSION

SOURCE OF SILICA

Samsonowicz (1948) suggested a syngenetic origin for the silica on the sea bottom, where it was derived from the land. Turnau-Morawska (1958) thought that the silica source was "...disintegration of mineral pelite suspensed in the sea water for a long time during a period of brake of erosional processes on the neighbouring land...". According to Chlebowski (1971, 1976) and Kowalczewski (1974), large quantities of silica were supplied to the basin by volcanic activity.

Durakiewicz *et al.* (1998) suggested that the silica in the Kielce region of the Holy Cross Mountains was of hydrothermal origin possibly connected with the activity of undersea springs. In case of the Tremadoc chalcedonites, though, there is no obvious source of heat. But, as in the early Precambrian of Newfoundland (Simonson, 1985), cooling igneous intrusions may have sourced thermal waters bringing silica into the basin. There is no evidence of intrusions in the late Tremadoc in the Holy Cross Mountains. These could occur on greater depths, as the products of nearby volcanic activity reached the Kielce region of the Holy Cross Mountains. Chlebowski (1971) suggested that the volcanism bringing pyroclastic material into the Holy Cross region occured south of the Holy Cross Mountains, at the distance of 30 km or closer. According to Kowalczewski and Wróblewski (1971, 1974) common examples of post-volcanic mineralisation are connected with nearby active volcanic zones.

Hydrothermal solutions and undersea volcanic exhalations, possibly connected with nearby volcanism, seem to be the most probable sources of silica in the Kielce region of the Holy Cross Mountains in the late Tremadoc. Higher temperature is one of the favouring silica dissolution (Siever, 1962; Simonson, 1985). The bottom sediment of the late Tremadoc sedimentary basin in the Kielce region was weakly reducing, because of organic matter decay. Organic matter influences the precipitation of silica, as it causes a drop of the solution's pH and forms protecting colloids, and therefore prevents silica dissolution (Siever, 1962; Kasiński *et al.*, 1981). These conditions, also determining the Fe^{3+}/Fe^{2+} ratio (Harder, 1989), additionally favoured glauconite formation. Bottom waters in the late Tremadoc sedimentary basin became oversaturated with respect to silica, and this precipitated where the slightly alkaline bottom waters mixed with the slightly acidic pore waters. According to Krauskopf (1959) a rapid increase of the silica precipitation rate takes place in such conditions. Precipitation of silica in oversaturated solutions is enhanced in the presence of electrolytes in the seawater.

It cannot be excluded that the hydrothermal solutions migrated along fault zones. The Ordovician basin of the Holy Cross Mountains was tectonically active (Kowalczewski, 1964, 1965, 1994; Tomczyk, 1964; Kowalczewski and Wróblewski, 1971, 1974). In Kędziorka and Zbrza, local tectonics and eustatic sea level changes caused local emergence during the Arenig and Llanvirn (Figs. 1, 3). In Zalesie Nowe, Middle Ordovician dolomites, showing traces of hydrothermal alteration, overlie the Lower Ordovician siltstones, chalcedonites and sandstones (Fig. 3). Hydrothermal activity in the Middle Ordovician might have taken place along fault zones which were active already in the Tremadoc.

INTERPRETATION OF SEDIMENTARY CONDITIONS

The sedimentological record of the upper Tremadoc profiles in Kędziorka, Zalesie Nowe and Szumsko Kol. 2 indicates rapid changes in the energy of the depositional environment. Siltstone-sandstone layers contain sedimentary structures suggesting energetic deposition. Sharp, erosive basal bed surfaces indicate a rapid accumulation that was preceded by erosion of underlying sediments, with the formation of small intraclasts. Such graded beds are typically left by waning currents (Dott and Bourgeois, 1982; Walker, 1984; Aigner, 1984, 1985). Water escape structures also indicate rapid accumulation.

Wave-generated structures are rare in the deposits studied, what suggests deposition on distal shelves, below normal wave base (Aigner, 1984, 1985; Leckie and Krystinik, 1989; Jannette and Pryor, 1993). The replacement of graded-bedding by horizontal lamination, or of horizontal lamination by cross-bedding and ripple-bedding observed record weakening storm currents (Bhattacharyya *et al.*, 1980; Dott and Bourgeois, 1982; Aigner, 1984, 1985; Walker, 1984; Simpson and Eriksson, 1990; Tucker, 1995). Hummocky cross-stratification (HCS) and wavy lamination are diagnostic features of storm deposits, indicating rapid deposition of the material from suspension in waning flow conditions as wave action is modified by unidirectional currents (Bourgeois, 1980; Dott and Bourgeois, 1982; Harms *et al.*, 1982; Walker, 1984; Duke *et al.*, 1991; Jannette and Pryor, 1993; Galloway and Hobday, 1996). Hummocky cross stratification is present, though rare in the deposits analysed.

The occurrence of graded-bedding, horizontal lamination, low-angle cross-bedding and common erosional surfaces, as well as the presence of small-scale hummocky cross-stratification and wavy lamination, indicate storm-generated bottom currents, during deposition of the siltstones and sandstones.

The load structures and internally deformed layers observed indicate rapid sand deposition on a water-saturated clay substrate, or on a soft and plastic layer of siliceous gel. Dense currents flowing on the soft substrate tore and deformed existing layers, the interbedding of sediments with different densities encouraging deformation (Dżułyński and Radomski, 1966). According to Chlebowski (1971), apart from current flow, tectonically induced mass movements were an important factor in the formation of load structures and clay-ball structures. Indeed, some of the bottom currents might have been generated by tectonic activity.

During calm episodes the surface of siltstone-sandstone layers was penetrated by organisms. Fodinichnias, drilled in firm, semi-consolidated deposits, provided shelter against erosion and bottom currents (Frey and Pemberton, 1984; Ekdale *et al.*, 1984). Rapid deposition locally preserved burrows as moulds on the undersides of beds.

A rise in wave base led to deposition of siliceous strata and sedimentation of fine detrital material from suspension. A low deposition rate and calm sedimentary conditions favoured the bioturbation observed in claystone and siltstone layers, locally causing homogenisation of the deposit. Individual chalcedonite and claystone layers show the influence of weak currents marked by thin layers of sand-gravel or of chert/clay balls in the chalcedonite matrix. The chalcedonite, as a semi-plastic, sediment was locally eroded and redeposited by currents. Mixed with silt, introduced by weak currents, it formed clayey cherts.

Traces of calcium carbonate occur within the clayey cherts, suggesting incorporation of this component into the original sediment, which, according to Turnau-Morawska (1958), could originally have been calcareous and then been replaced by silica. Concentrations of calcium carbonate resembling organic remains suggest at least a partly organic origin. Such calcareous bioclasts were probably current-derived from a shallower part of the basin. pH and Eh conditions probably favoured partial dissolution of calcareous skeletons, and calcium ions made precipitation of siliceous gel easier (Turnau-Morawska, 1958; Kastner, 1979). Some of the irregular calcareous concentrations may, though, be of diagenetic or, as Chlebowski (1971) suggests, of hydrothermal origin.

The deposits resemble those formed on a deep shelf or ramp (Aigner and Reineck, 1982; Harms *et al.,* 1982; Brett, 1983; Walker, 1984; Aigner, 1984, 1985). Siltstone-sandstone layers represent distal current activity, perhaps generated by storms, interrupting calm clay-siliceous sedimentation. High amplitude storm-generated waves can influence bottom sediment to depths exceeding 200 m (Galloway and Hobday, 1996; Collins, 1988). It can not be excuded that some of the bottom currents was generated by tectonic activity.

CONCLUSIONS

1. The upper Tremadoc profile in the Kielce region of the Holy Cross Mountains comprises thin- and medium-bedded siltstones, sandstones, chalcedonites and clays, deposited in the final phase of the late Tremadoc transgression.

2. The sediments record rapid fluctuations in energy. Sandstones and siltstones were deposited in turbulent conditions under the influence of storm currents. Graded-bedding and horizontal lamination is succeeded by small scale cross-bedding and ripple cross-lamination within individual beds. Hummocky cross-stratification and wavy lamination are locally present. Bed boundaries are sharp and common loading of clastic rocks into chalcedonites.

3. During calm intervals sedimentation of chalcedonites and claystones occurred. Low deposition rates favoured bioturbation. During periods of increased current activity some of the chalcedonites and clayey cherts were reworked.

4. Hydrothermal solutions and volcanic exhalations associated with nearby volcanic activity were the source of the silica in the cherts.

5. Sedimentation took place on a distal shelf, under the influence of waning storm or tectonically-genetated currents.

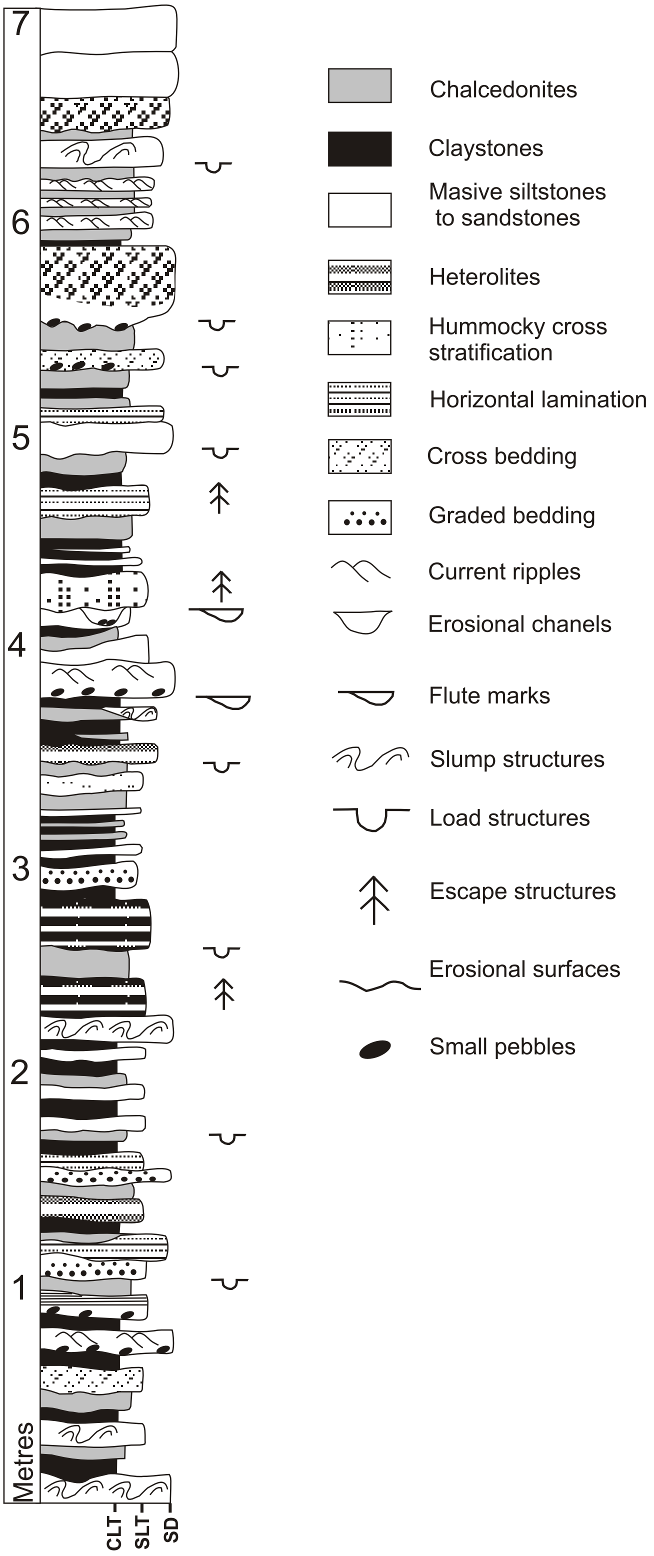


Fig. 4. Sedimentological profile of the upper Tremadoc deposits in Zalesie Nowe

REFERENCES

AIGNER T. (1984) — Dynamic stratigraphy of epicontinental carbonates, Upper Muschelkalk (Middle Triass), South German basin. N. Jb. Geol. Paläont. Abh., **169**: 127–159.

AIGNER T. (1985) — Storm depositional systems. Lect. Not. Earth Sc., **3**: 174. Springer-Verlag. Berlin.

AIGNER T. and REINECK H. (1982) — Proximality trends in modern sands from Helgoland Bight (North Sea) and their implications for basin analysis. Senckenberg. Maritima, **14**: 183–215.

ANKETELL J. M., CEGŁA J. and DŻUŁYŃSKI S. (1970) — On the deformational structures in systems with reversed density gradients. Rocz. Pol. Tow. Geol., **40** (1): 3–30.

BEDNARCZYK W. (1962) — Dolny ordowik okolic wsi Koziel w Górach Świętokrzyskich. In: Księga Pamiątkowa ku czci Profesora Jana Samsonowicza (ed. E. Passendorfer): 149–170. Wyd. Geol. Warszawa.

BEDNARCZYK W. (1964) — The stratigraphy and fauna of the Tremadocian and Arenigian (Ölandian) in the Kielce region of the Holy Cross Mountains (in Polish with English summary). Biul. Geol. Wydz. Geol. UW, **4**: 3–127, 188–197.

BEDNARCZYK W. (1966*a*) — Lower Ordovician palaeogeography of the Kielce region in the Holy Cross Mts. (in Polish with English summary). Acta Geol. Pol., **16** (1): 91–106.

BEDNARCZYK W. (1966*b*) — Lithology of the lower Ordovician (Oelandian) in the Kielce region of the Holy Cross Mts. (in Polish with English summary). Biul. Geol. Wydz. Geol. UW, **8**: 4–53.

BEDNARCZYK W. (1971) — Stratygraphy and paleogeography of the Ordovician in the Holy Cross Mts. Acta Geol. Pol., **21** (4): 574–616.

BEDNARCZYK W. (1981) — Stratygrafia ordowiku Gór Świętokrzyskich. Przew. 53 Zjazdu Pol. Tow. Geol., Kielce: 35–41.

BEDNARCZYK W. (1988) — The role of brachiopods in stratigraphy of the lowest Ordovician of the Holy Cross Mts (in Polish with English summary). Prz. Geol., **36** (1): 17–23.

BEDNARCZYK W. (1996) — Międzygórz quarry. Zalesie. In: Sixth European Conodont Symposium ECOS VI, June 30–July 3. Excursion Guide (eds. M. Szulczewski and S. Skompski): 12–21. Warszawa.

BEDNARCZYK W. (1998) — Stratigraphic position of acritarchs from the lowermost Ordovician of the Holy Cross Mts. in the light of conodonts studies. Bull. Pol. Acad. Sc., Earth Sc., **46**: 1–8.

BEDNARCZYK W. and BIERNAT G. (1978) — Inarticulate brachiopods from the Lower Ordovician in the Holy Cross Mts., Poland. Acta Palaeont. Pol., **23** (3): 293–316.

BHATTACHARYYA A., SARKAR S. and CHANDA S. K. (1980) — Storm deposits in the Late Proterozoic lower Bhander sandstone of Vindhyan Supergroup around Maihar, Satna district, Madhaya Pradesh, India. J. Sed. Petrol., **50**: 1327–1335.

BOURGEOIS J. (1980) — A transgressive shelf sequence exhibiting hummocky stratification: the Cape Sebastian Sandstone (Upper Cretaceous), southwestern Oregon. J. Sed. Petrol., **50**: 681–702.

BRETT C. E. (1983) — Sedimentology, facies and depositional environments of the Rochester Shale (Silurian; Wenlockian) in western New York and Ontario. J. Sed. Petrol., **53**: 947–971.

CHLEBOWSKI R. (1971) — Petrography of the Ordovician deposits of the Bardo syncline in the southern part of the Świętokrzyskie Mts (in Polish with English summary). Arch. Miner., **29** (1/2): 193–304.

CHLEBOWSKI R. (1976) — Studium petrograficzne skał tufogenicznych starszego paleozoiku Gór Świętokrzyskich. Arch. Miner., **34**: 69–134.

COLLINS L. B. (1988) — Sediments and history of the Rottest Shelf, southwest Australia: a swell-dominated, non-tropical carbonate margin. Sed. Geol., **60**: 15–50.

CZARNOCKI J. (1919) — Stratygrafia i tektonika staropaleozoicznych utworów Gór Świętokrzyskich. (Kambr, sylur, dewon dolny). Pr. Tow. Nauk. Warsz., **28**.

CZARNOCKI J. (1928) — Le profil de l'Ordovicien inférieur et supérieur á Zalesie prés Łagów comparé á celui des autres régions de la partie centrale du massif de S-te Croix (in Polish with French summary). Spraw. Państw. Inst. Geol., **4** (3/4): 555–581.

CZARNOCKI J. (1939) — Field work in the Święty Krzyż Mountains in 1938 (in Polish with English summary). Biul. Państw. Inst. Geol., **15**: 1–41.

DADLEZ R., KOWALCZEWSKI Z. and ZNOSKO J. (1994) — Some key problems of the pre-Permian tectonics of Poland. Geol. Quart., **38** (2): 169–190.

DECZKOWKI Z. and TOMCZYK H. (1969) — Geological structure of the Zbrza anticline in the south-western part of the Góry Świętokrzyskie (in Polish with English summary). Biul. Inst. Geol., **236**: 143–175.

DOTT R. H. and Jr. BOURGEOIS J. (1982) — Hummocky stratification: significance of its variable bedding sequence. Geol. Soc. Amer. Bull., **93**: 663–680.

DUKE W. L., ARNOTT R. W. C. and CHEEL R. J. (1991) — Shelf sandstones and hummocky cross-stratification: New insights on a storm debate. Geology, **19**: 625–628.

DURAKIEWICZ T., MIGASZEWSKI Z. and HAŁAS S. (1998) — Oxygene isotope determinations in quartz group minerals (in Polish with English summary). Prz. Geol., **46** (2): 167–170.

DZIK J. (1996) — Mójcza quarry. In: Sixth European Conodont Symposium ECOS VI, June 30–July 3. Excursion Guide (eds. M. Szulczewski and S. Skompski): 22–26. Warszawa.

DZIK J. and PISERA A. (1994) — Sedimentation and fossils of the Mójcza Limestone. Palaeont. Pol., **53**: 5–41.

DŻUŁYŃSKI S. (1966) — Sedimentary structures resulting from convection-like pattern of motion (in Polish with English summary). Rocz. Pol. Tow. Geol., **36** (1): 3–21.

DŻUŁYŃSKI S. and RADOMSKI A. (1966) — Experiments on bedding disturbances produced by the impact of heavy suspensions upon horizontal sedimentary layers. Bull. Acad. Pol. Sc., Ser. Sc. Geol. Geogr., **14** (4): 227–230.

EKDALE A. A., BROMLEY R. G. and PEMBERTON S. G. (1984) — Ichnology — the use of trace fossils in sedimentology and stratigraphy. Soc. Econ. Paleont. Miner., Short Course, **15**: 316.

FREY R. W. and PEMBERTON S. G. (1984) — Trace fossil facies model. In: Facies Models. Geoscience Canada (ed. R. G. Walker): 189–207.

GALLOWAY W. E. and HOBDAY D. K. (1996) — Terrigenous clastic depositional systems. Springer-Verlag. Berlin, Heidelberg.

GÓRKA H. (1969) — Mikroorganismes de l'Ordovicien de Pologne. Palaeont. Pol., **22**.

HARDER H. (1989) — Mineral genesis in ironstones: a model based upon laboratory experiments and petrographic observations. In: Phanerozoik Ironstones (eds. T. P. Young and W. E. G. Taylor). Geol. Soc., Spec. Publ., **46**: 7–18.

HARMS J. C., SOUTHARD J. B. and WALKER R. G. (1982) — Structures and sequences in clastic rocks. Soc. Econ. Paleont. Miner., Short Course, **9**: 251.

JANNETTE D. C. and PRYOR W. A. (1993) — Cyclic alternation of proximal and distal storm facies: Kope and Fairview Formations (Upper Ordovician), Ohio and Kentucky. J. Sed. Petrol., **63**: 183–203.

KASIŃSKI J. R., PIEŃKOWSKI G. and PISERA A. (1981) — Lithologic-microfacial characteristics of the Branisko and Czorsztyn Successions along the road from Krośnica to Kąty, Pieniny Klippen Belt, Carpathians (in Polish with English summary). Stud. Geol. Pol., **70**: 73–94.

KASTNER M. (1979) — Silica polymorphs. In: Marine Minerals (ed. R. G. Burns). Miner. Soc. Amer., Short Course Notes, **6**: 99–110.

KOWALCZEWSKI Z. (1964) — Wstępne wyniki badań nad kaledonikiem świętokrzyskim w rejonie Dymin i Barda. Kwart. Geol., **8** (2): 463–464.

KOWALCZEWSKI Z. (1965) — Wyniki badań nad tektoniką synkliny bardziańskiej w Górach Świętokrzyskich. Kwat. Geol., **9** (2): 463–464.

KOWALCZEWSKI Z (1974) — Geological and structural aspects of magmatism in the Góry Świętokrzyskie Mts. Against the back-ground of recent research (in Polish with English summary). Biul. Inst. Geol., **275**: 11–62.

KOWALCZEWSKI Z. (1994) — The Holy Cross Mts. in the early Paleozoic. In: Europrobe. Trans-European Suture Zone Workshop. Excursion Guidebook the Holy Cross Mountains (eds. Z. Kowalczewski, M. Szulczewski, Z. Migaszewski and K. Janecka-Styrcz): 1–18. Kielce.

KOWALCZEWSKI Z. and WRÓBLEWSKI T. (1971) — Wybrane problemy magmatyzmu i mineralizacji w Górach Świętokrzyskich. Kwart. Geol., **15** (4): 1046–1047.

KOWALCZEWSKI Z. and WRÓBLEWSKI T. (1974) — Problem of ore contents in sediments in the light of diastrophism and volcanism of the Świętokrzyskie Mts (in Polish with English summary). Kwart. Geol., **18** (3): 535–563.

KOZŁOWSKI R. (1948) — Les graptolithes et quelques nouveaux Groupes d'animaux du Tremadoc de la Pologne. Palaeont. Pol., **3**.

KRAUSKOPF K. B. (1959) — The geochemistry of silica in sedimentary environments. In: Silica in Sediments (ed. H. A. Ireland). Soc. Econ. Paleont. Miner., Spec. Publ., **7**: 4–19.

LECKIE D. A. and KRYSTINIK L. F. (1989) — Is there evidence for geostrophic currents preserved in the sedimentary record in inner to middle-shelf deposits? J. Sed. Petrol., **59**: 862–870.

LEWANDOWSKI M. (1987) — Results of the preliminary paleomagnetic investigations of some Lower Paleozoic rocks from the Holy Cross Mts. (Poland). Kwart. Geol., **31** (4): 543–556.

POŻARYSKI W. (1990) — The Middle Europe Caledonides — wrenching orogen composed of terranes (in Polish with English summary). Prz. Geol., **38** (1): 1–9.

SAMSONOWICZ J. (1928) — Sprawozdanie z badań geologicznych, wykonanych w 1927 r. w okolicach Międzygórza na arkuszu Sandomierz mapy 1:100 000. Posiedz. Nauk. Państw. Inst. Geol., **19/20**: 25–27.

SAMSONOWICZ J. (1948) — Characteristique geologique du tremedoc de Wysoczki. Palaeont. Pol., **3**.

SIEVER R. (1962) — Silica solubility, 0–200°, and the diagenesis of siliceous sediments. J. Geol., **70**: 127–150.

SIMONSON B. M. (1985) — Sedimentology of cherts in the Early Proterozoic Wishart Formation, Quebec — Newfoundland, Canada. Sedimentology, **32**: 23–40.

SIMPSON E. L. and ERIKSSON K. A. (1990) — Early Cambrian progradational and transgressive sedimentation patterns in Virginia: an example of the early history of a passive margin. J. Sed. Petrol., **60**: 84–100.

SZANIAWSKI H. (1980) — Conodonts from the Tremadocian chalcedony beds, Holy Cross Mountains (Poland). Acta Geol. Pol., **25** (1): 101–121.

TOMCZYK H. (1954) — Stratigraphy of the Gothlandian of the Międzygórz basin — Święty Krzyż Mts on the basis of the fauna from graptolitic shales (in Polish with English summary). Biul. Inst. Geol., **93**.

TOMCZYK H. (1964) — New data on stratigraphy and tectogenesis of the Older Paleozoic in Poland (in Polish with English summary). Prz. Geol., **12** (6): 262–267.

TOMCZYK H. (1971) — The Arenigian transgression in Poland and its relation to earlier formations. Mem. Bur. Rech. Geol. Miner., **73**: 421–430.

TOMCZYK H. and TURNAU-MORAWSKA M. (1964) — Stratigraphy and petrography of the Ordovician in Brzeziny near Morawica (Holy Cross Mts., Central Poland) (in Polish with England summary). Acta Geol. Pol., **14** (4): 501–546.

TOMCZYKOWA E. (1968) — Stratigraphy of the uppermost Cambrian deposits in the Świętokrzyskie Mountains (in Polish with English summary). Pr. Inst. Geol., **54**.

TUCKER M. E. (1995) — Sedimentary Petrology. Blackwell Scientific Publications.

TURNAU-MORAWSKA M. (1958) — Chalcedonites and associated rocks of the Tremadoc in the Holy Cross Mountains (Central Poland). A petrographic study (in Polish with English summary). Rocz. Pol. Tow. Geol., **27** (1–4): 169–191.

TURNAU-MORAWSKA M. (1960) — A glauconitic conglomerate from the Lower Ordovician in Międzygórz, Holy Cross Mountains, Central Poland. Acta Geol. Pol., **10** (2): 123–145.

WALKER R. G. (ed.) (1984) — Facies Models. Geoscience Canada. Toronto.

ZNOSKO J. and CHLEBOWSKI R. (1976) — Revision of the Lower Ordovician stratigraphy in the Holy Cross Mts (Central Poland) (in Polish with English summary). Rocz. Pol. Tow. Geol., **46** (1/2): 135–157.