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Large-scale erosional channels in the Lower Cambrian sandstones, Gieraszowice environs (Kielce Block, Holy Cross Mts.)

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Unique erosional channels of meridional strike have been recognized in the Lower Cambrian sandstones (Ocieseki Sandstone Formation) at Gieraszowice village within the Klimontów Anticlinorium (Kielce Block). These channels have been interpreted as "storm-cut cross-shelf channels" related to the undertow induced by strong storm waves (waves generated by a series of submarine seismic shocks) during deposition of the Cambrian sediments within a shelf zone. It is highly probable that earthquakes occurring in short time intervals generated the current which eroded the channels. After the deepest channel had been formed the earthquakes led to a sliding of partly consolidated sediments onto its floor.

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Key words: Holy Cross Mts., Lower Cambrian, erosion, erosional channels, turbidity currents, debris flow.

INTRODUCTION

In the southeastern part of the Klimontów Anticlinorium at Gieraszowice village (Fig. 1) there are outcrops of rocks which were already recognized by J. Samsonowicz (1918) to represent the Lower Cambrian. He was the first who found trilobites in fine-grained sandstones, among others *Holmia kjerulfi* (Linnarsson), a guide fossil for the *Holmia* Zone of the Baltic Province. In a lithostratigraphic division of the Holy Cross Cambrian these rocks have been named the Ocieseki Sandstone Formation (S. Orłowski, 1975) and, basing upon trilobites, assigned to the Lower Cambrian *Holmia* Zone. This stratigraphic position was maintained when Lower Cambrian trilobite fauna was revised (S. Orłowski, 1985) and when a spatial model for Cambrian lithostratigraphic units in the Holy Cross area was reconstructed (S. Orłowski, 1987). The latter paper has evidenced that the Ocieseki Sandstone Formation located east of the Łagowica River is considerably thinner than it had been supposed before. At Gieraszowice and Rybnica these sandstones compose a distinct range of hills and their thickness decreases down to about 100 m.

Sandstones composing the Ocieseki Formation are mostly thin- and medium-bedded, occasionally regularly bedded, laminated, frequently with bioturbation visible on bed surfaces. Little is known about sedimentary conditions under which these rocks were deposited because detailed sedimentological investigations have not been made for this formation. We know that the rocks were deposited within a neritic zone and within the *Cruziana* ichnofacies (S. Orłowski, 1992). Sedimentary conditions for this formation were interpreted by M. Studencki (1988) basing on three borehole sections. He expressed the opinion that the Ocieseki Formation sandstones were deposited within a shelf zone under relatively calm sedimentary conditions. Basing upon studies conducted over modern and ancient marine basins (R. Anderton, 1976; N. Kumar, J. E. Sanders, 1976; H. E. Reineck, J. B. Singh, 1973), M. Studencki (1988) considers the sediments to have been deposited in a transitional zone between littoral sands and shelf clays, in a shallow sea, at a moderate sedimentation rate.

In the Gieraszowice environs, large-scale erosional channels occur within the Ocieseki Sandstone Formation evidencing erosional processes that continued during sedimentation.

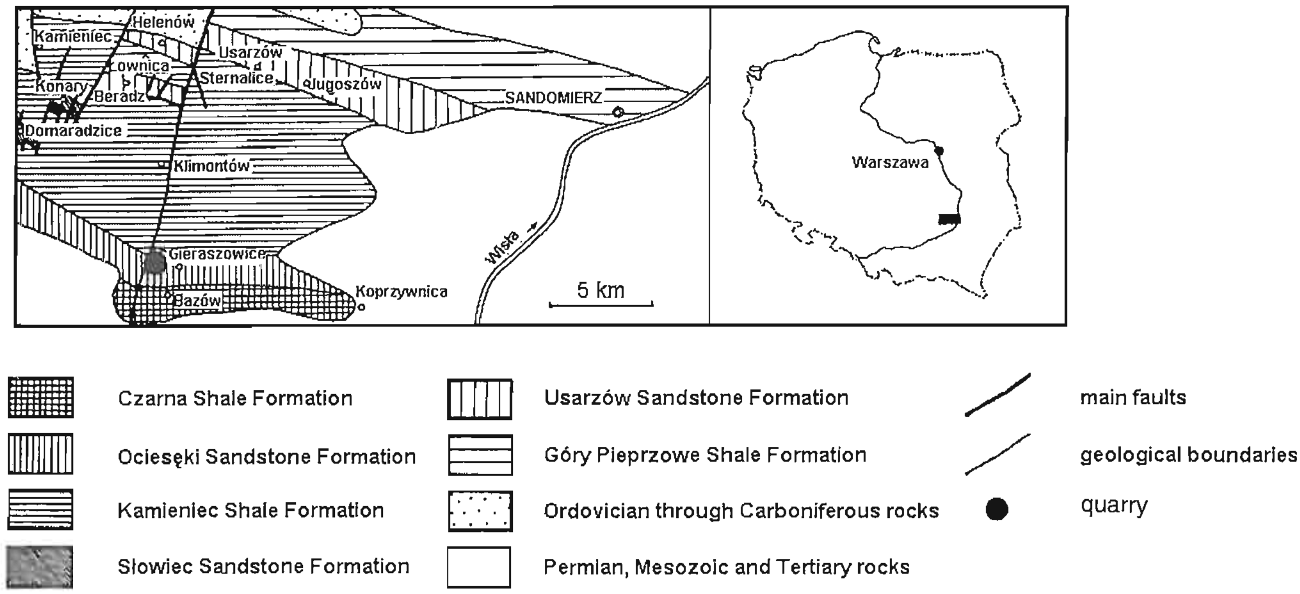

Fig. 1. Location of the area studied against the eastern part of the Klimontów Anticlinorium; on the right — location of the area in Poland (after S. Orłowski, W. Mizerski, 1995)

These channels have not been described so far and are the subject of the present paper.

EXPOSURE DESCRIPTION

LITHOLOGY AND STRATIGRAPHY

An old and largely bush-grown quarry in which the above-mentioned structures were found is located on the eastern bank of the Koprzywianka River (Fig. 1) flowing south through Klimontów and Nawodzice villages. It is about 1 km far from Gieraszowice village. Dark grey, rarely light grey, fine-grained sandstones and siltstones regularly bedded, usually with about 10–20 cm-thick beds sporadically up to 1 m, occur in this quarry and in neighbouring areas. They have yielded trilobites: *Holmia kjerulfi* (Linnarsson) in Gieraszowice village (J. Samsonowicz, 1918) and *Holmia* sp., *Comluella igrzycznae* (S. Orłowski, 1985) immediately close to the quarry. Moreover, these rocks contain very abundant organic traces locally occurring in a mass (this mainly refers to elongated, oval in diameter burrows, assigned to the ichnofacies *Planolites*). The complete list of the organic traces is as follows: **trilobite traces**: *Cruziana dispar* Linnarson, 1871 (4 specimens), *C. rusoformis* Orłowski, Radwański et Roniewicz, 1970 (9 specimens), *Rusophycus* sp. (3 specimens), *Dimorphichnus obliquus* Seilacher, 1955 (2 specimens), *Monomorphichnus lineatus* Crimes, 1977 (2 specimens), *M. multilineatus* Alpert, 1976 (1 specimen); **other traces**: *Planolites beverleyensis* (Billings, 1862) (a few tens of specimens), *P. montanus* Richter, 1937 (a few tens of specimens), *P. annularis* Walcott, 1890 (1 specimen), *Monocraterion tentaculatum* Torell, 1870 (3 specimens), *Phycodes palmatum* (Hall, 1852) (2 specimens), *Teichichnus rectus* Seilacher, 1855 (2 specimens), *Gordia* sp. (1 specimen).

Rocks, fossils and organic traces (Pl. I) occurring within the range of hills near Gieraszowice and Rybnica villages are easy for a stratigraphic interpretation. Lithological features allow to assign them to the Ociesęki Sandstone Formation. This is supported by the presence of abundant and characteristic organic traces, same as in the stratotype area of this formation (S. Orłowski, 1989, 1992). Trilobites found at Gieraszowice (J. Samsonowicz, 1918) and Rybnica (S. Orłowski, 1985) suggest the correlation of the sandstones and siltstones with the Lower Cambrian *Holmia-Schmidtiellus* Zone (Fig. 2).

TECTONICS

A quarry wall, stretching at an azimuth of about 70°, reveals two sequences: the lower and upper one. In the lower part of the wall there are three erosional channels of different sizes, stretching along a N–S axis. The channels cut rocks lying at 80–90/30–35S, slightly different from those of the upper sequence. The upper part is undeformed (Fig. 3), and mean dip and strike of strata are of 110–120/20–25S. In both parts, however, there are two similar assemblages of joint forming one system: 0/90 and 120/25N, as well as cleavage 120/40S.

Strata of deposits infilling the channels are obliquely inclined to bedding planes of surrounding rocks (Fig. 3), and contact with the surface separating both these sequences at an angle of up to 30° (Pl. II). Organic hieroglyphs are often visible on bottom surfaces of laminae of deposits infilling the channels. At the eastern slope of the greatest channel, some of beds are shattered and warped. In the two remaining channels, the infilling deposits are homocentric in relation to the channel floor.

A boundary between these two members shows an erosional character. There is no evidence suggesting possible displacements of rocks along this boundary. There are also no signs of weathering at the top surface of the lower sequence.

It may be concluded from all these observations (Fig. 3) that all the rocks exposed in the quarry wall were simultaneously subjected to tectonic movements taking place as late as after the upper sequence had been deposited.

SEDIMENTOLOGY

The rocks composing the quarry wall were sampled, and 4 thin sections were prepared (Pl. III). The first sample was collected from the lower sequence in which the channels are cut. Next two samples — from the infills of the large and small channels. The fourth sample was collected from the upper sequence.

DESCRIPTION OF THIN SECTIONS

I. Fine-grained quartz sandstone with patches of slightly coarser-grained material, well packed grains, contact-pore cement, poorly rounded detrital grains. Quartz is dominant (*ca.* 70%), potassium feldspars (mainly microcline) are fairly abundant, single persilic plagioclases are well preserved, abundant mica (mainly muscovite), crystals are strongly degraded, only few are fresh. Very abundant heavy minerals: zircon, tourmaline (brown-reddish in colour), epidote, glauconite, rutile, few opaque minerals.

II. Variously grained quartz sandstone, poorly rounded detrital grains. Locally clay cement, more strongly silicified patches are also visible; contact, siliceous (quartzitic) cement. Quartz is a dominant component (*ca.* 50–60%), mica is more abundant than in thin section and includes mainly muscovite and degraded biotite in lesser amounts. Clay minerals are concentrated within thin laminae, occasionally irregular and disturbed. Large amount of feldspars (like in thin section I) are characteristic features, but they are more strongly altered. The amount of heavy minerals is also similar: zircon (two generations: rounded and euhedral authigenic), rutile, glauconite, tourmaline (rounded). Opaque minerals and lithic clasts of claystones occur accessorily.

III. Muddy-sandy rock with a clay fraction as a groundmass, very poor sorting, poor roundness. Mostly clay cement but locally even with patches of quartzitic cement. Disturbed clay laminae and graded zones are visible. The content of quartz is *ca.* 40%, clay minerals are also abundant. Similar amount of feldspars as in thin sections I and II, but they are most strongly altered here. Abundant elongated mica flakes highly degraded muscovite and biotite. Heavy minerals: zircon, rutile, titanite. Distinct lamination and parting, enrichments in ferruginous material.

IV. Quartz sandstone with a slightly variable grain size, poor roundness and sorting. Abundant irregular and warped, fanwise arranged clay laminae, strongly ferruginized. Lenses and nests of coarser-grained material between laminae. Contact-pore cement, partly quartzitic, locally with zones of ferruginous-clay cement. Quartz is a dominant component (*ca.* 50–60%), mica (muscovite and biotite) also occurs but in smaller amounts than in thin sections II and III. Feldspars occur in proportions similar to those from other samples (microcline, other potassium feldspars and persilic plagioclases of albite-oligoclase series). Decrease in heavy minerals content is visible. They are represented by glauconite, zircon, epidote, rutile, tourmaline (greenish-brownish) occasionally authigenic, chlorites are also present.

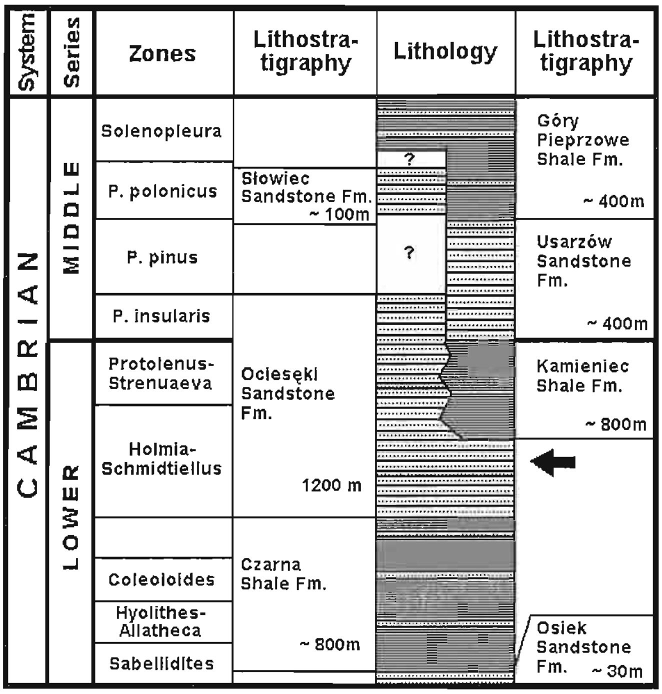

Fig. 2. Lower and Middle Cambrian subdivision in the Holy Cross Mts. (after S. Orłowski, 1988); the stratigraphic position of the discussed outcrop is arrowed

INTERPRETATION

The three erosional channels (Pl. I and IV) are incised into moderately bedded fine-grained sandstone with scarce intercalations of clayey-silty shales (thin section I). The channels are developed along one surface and their formation may be related to a single event. This might have been a heavy storm, submarine earthquake-induced waves or erosion caused by a turbidity current. Top part of the section (thin section IV) is characterized by increasing contribution of clay and silt fraction, and the deposits display features of rhythmical sedimentation. The upper sequence shows a slight deepening of the sea.

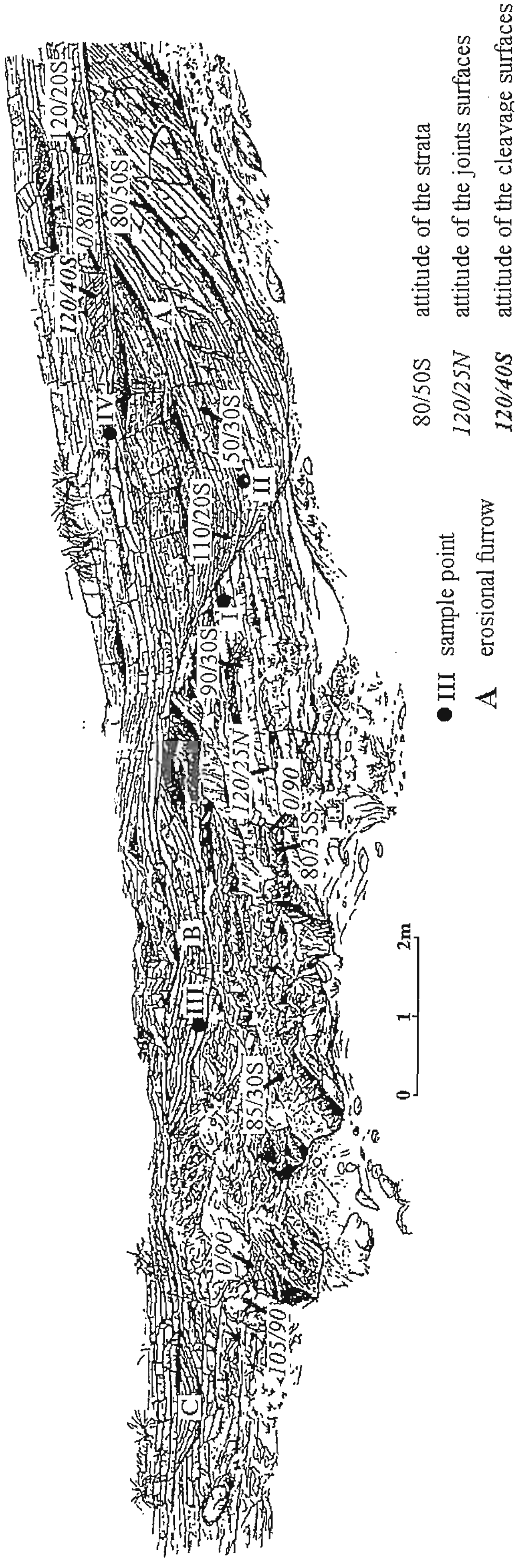

Fig. 3. Sketch of the quarry wall at Gieraszowice (by K. Skurek-Skurczyńska)

The strike of the erosional channels is indicative of a general southerly material transport in this part of the Cambrian basin. Material was probably trasported from the south towards north because outcrops of the Kamieniec Shale Formation, which was deposited in a deeper marine environment, extend north of the area occupied by of the Ocieseki Sandstone Formation (S. Orłowski, 1985; M. Studencki, 1988; W. Mizerski *et al.*, 1991). However, this fragmentary section does not allow to infer transport directions throughout the whole Cambrian basin. Sedimentary conditions for these deposits cannot be determined firmly due to insufficient investigations (K. Jaworowski, 1997; M. Juskowiakowa, 1978; Z. Kowalczewski, 1993; P. Dziadzio, M. Jachowicz, 1996; P. Dziadzio, J. Probulski, 1997). The rocks exposed in the quarry correspond to sandy-silty facies representing a marine environment in a middle shelf zone, with deposition shifting towards an outer shelf with turbidite sedimentation in the upper part of the section (thin section IV). The erosional channels are filled with sediments developed similarly as underlying and overlying deposits. The largest, western channel is filled with material related to a from synsedimentary debris flow (thin section II) running to the east. A consolidated but still plastic sediment in its frontal part was subjected to a folding due to a collision with the channel wall (Pl. IV). Depositional conditions of already deposited material may be inferred from a distinct bedding within the channel infill with strongly deformed beds at the front of the slide. Abundant bioturbation can be observed on bottom surfaces in most of sandy beds. The sliding resulted in a cloud of sediment which, being deposited, filled the middle and eastern part of the channel with sandy-muddy material (thin section III) showing a distinctly deformed structure of clay beds and graded zones.

The essential problem is to explain a mechanism of formation of such erosional channels and the reason why partly consolidated material was transported into the largest of them. It seems that measurements of orientation of both underlying and overlying beds may play a decisive role in solving this problem. Positions of beds within both these sequences differ slightly (Fig. 3), but the contact between them shows a sedimentary nature.

Taking into account the uniqueness of this feature in the Holy Cross Cambrian, it may be suggested that a single, i.e. untypical geological event, was responsible for the current which eroded these channels. It is highly probable that those were very strong storm waves (waves generated by a series of submarine seismic shocks) which resulted in:

— a head of water in a coastal zone and undertow of such a high energy to be able to erode in the sea floor a channel reaching 5 m in depth and perpendicular to the coast line; these forms may presumably be assigned to "storm-cut cross-shelf channels" (W. L. Duke *et al.*, 1991);

— stability disturbance of sediments close to the deepest channel causing a rapid slide of partly consolidated material onto the channel floor and its infill, and inducing a cloud of sediment which, being deposited, filled the remaining troughs of the floor; the sliding was directed towards the east from the area located west of the channel;

— a slight rotation of a marine floor block after which, as the channels were already infilled, sedimentation generally returned to its earlier state, however, causing deposits of the upper sequence to show slightly different orientation compared with those of the lower sequence in which the channels were eroded.

After the channels had been infilled, the basin slightly deepened and sedimentation of the analogous deposits with similar organic traces assemblage resumed.

The recognized discordance suggests a more complex origin of these structures. A storm-type event with waves generated by weather conditions does not usually result in an angular disconformity between depositional complexes. Therefore the authors suppose that several processes controlled the origin of the channels. The discordance may be related with a series of submarine seismic shocks. Such events generated strong waves which may have induced both a head of water in a coastal zone and undertow as an erosional factor. A turbidity current can be considered another possible effect of submarine earthquakes. In its initial phase it can cause erosion.

The above proposed interpretation seems even more probable as signs of a tectonic activity which induced submarine slumps have been recorded in Cambrian deposits from other regions of the Holy Cross area (L. Mastella, W. Mizerski, 1981; W. Mizerski, 1995). Probability of such an interpretation is also confirmed when the described features are compared with sediment deformations caused by a current activity. The latter features are well visible in Upper Cambrian sandstones exposed in the Wiśniówka Mt. quarry. Erosional scours in the floor have shapes of irregular pans and troughs there, not exceeding 0.5 m in depth. There are also occasional water-drainage channels, but they are short and less than 0.2 m in depth (S. Dżułyński, C. Żak, 1960; A. Radwański, P. Roniewicz, 1960, 1962; S. Orłowski, 1968). M. Studencki (1988) was also of the opinion that sedimentation changes in the Lower Cambrian may be related to tectonic factors. Tectonic activity during sedimentation might have had a much greater extent. Syndepositional deformations of a debris flow character in the Lower Cambrian deposits of an outer shelf zone have also been described from the southern part of the Małopolska Massif, from the basement of NE part of the Carpathian Foredeep (P. Dziadzio, M. Jachowicz, 1996; P. Dziadzio, J. Probulski, 1997; S. Dżułyński, A. Ślączka, 1959).

CONCLUSIONS

1. Unique erosional channels of meridional strike occur at Gieraszowice village within the Klimontów Anticlinorium (Kielce Block) in the Lower Cambrian sandstones (*Holmia-Schmidtiellus* Zone) belonging to the Ociesęki Sandstone Formation

2. The erosional channels are developed along one surface.

3. Beds infilling the channels are obliquely inclined in relation to the rock bedding within which they are cut.

4. The channels are interpreted as undertow-related "storm-cut cross-shelf channels".

5. The current which eroded the channels was most probably induced by a series of submarine seismic shocks.

6. The largest channel was filled by shimping partly consolidated sediment.

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WIELKOSKALOWE RYNNY EROZYJNE W PIASKOWCACH KAMBRU DOLNEGO W OKOLICACH GIERASZOWIC (BLOK KIELECKI, GÓRY ŚWIĘTOKRZYSKIE)

Streszczenie

W okolicach Gieraszowic (fig. 1) w antyklinorium klimontowskim (blok kielecki), w formacji piaskowców z Ociesęk, udokumentowanej tu trylobitami i śladami organicznymi (fig. 2, tabl. I), stwierdzono unikatowe rynny erozyjne (fig. 3) o rozciągłości południkowej. Warstwy osadów wypełniających rynny są nachylone skośnie do powierzchni uławicenia, w której są wycięte, i dochodzą pod kątem około 40° (tabl. II) do powierzchni rozdzielającej sekwencję dolną, w której wycięte są rynny, z przykrywającą ją sekwencją górną. Na spągowych powierzchniach warstw wypełniających rynny stwierdzono ślady organiczne.

Na podstawie badań płytek cienkich pobranych z różnych miejsc odsłonięcia (tabl. II), a także na podstawie obserwacji terenowych (tabl. II, IV), rynny te zinterpretowano jako utworzone w wyniku działania powrotnego prądu przydennego lub rozrywającego powstałego na skutek silnego falowania sztormowego (falowania wywołanego serią podmorskich wstrząsów tektonicznych) w trakcie sedymentacji utworów kambryjskich w strefie szelfu. Jest wielce prawdopodobne, iż przyczyną powstania prądu, który wyerodował rynny, była seria wstrząsów tektonicznych, występujących w krótkich odstępach czasu, powodujących:

— spiętrzenie wód w strefie brzegu i powstanie powrotnego prądu przydennego lub rozrywającego o tak dużej energii, że wyerodował na powierzchni dna rynny o głębokości dochodzącej do 5 m i przebiegu prostopadłym do linii brzegowej; omawiane formy można prawdopodobnie zaliczyć do *storm-cut cross-shelf channels* (W. L. Duke i in., 1991);

— naruszenie stateczności osadów w sąsiedztwie najgłębszej rynny, powodujące szybki zsuw materiału częściowo skonsolidowanego na dno rynny i jej wypełnienie oraz wzburzenie chmury osadu, która opadając zapełniła pozostałe zagłębienia dna; zsuw ten odbył się ku wschodowi z obszaru na W od rynny;

— niewielką rotację bloku dna morskiego, po której, po wypełnieniu rynien, sedymentacja wróciła w zasadzie do pierwotnego planu sprawiając jednak, że osady sekwencji górnej mają nieco inne położenie warstw w porównaniu do sekwencji dolnej, w której wyerodowane są rynny.

Po wypełnieniu rynien zbiornik nieznacznie się pogłębił i kontynuowała się sedymentacja analogicznych utworów z podobnym zespołem śladów organicznych, do zsunięcia się częściowo skonsolidowanych osadów na jej dno.

EXPLANATIONS OF PLATES

PLATE I

Organic traces in Lower Cambrian deposits in the vicinity of Gieraszowice (phot. by S. Ulatowski)

Fig. 1: a — *Planolites beverleyensis* (Billings, 1862), b — *Planolites annularis* Walcott, 1890, c — *Monomorphichnus lineatus* Crimes, 1977

Fig. 2. *Monomorphichnus multilineatus* Alpert, 1976

Figs. 3, 7. *Cruziana rusoformis* Orlowski, Radwański et Roniewicz, 1970

Fig. 4. *Phycodes palmatum* (Hall, 1852)

Fig. 5: a — *Planolites beverleyensis* (Billings, 1862), b — *Planolites montanus* Richter, 1937

Fig. 6. *Dimorphichnus obliquus* Seilacher, 1955

PLATE II

Figs. 1, 2. Contact between rocks infilling the largest erosional channel (in Fig. 3 — channel A) and overlying sequence (phot. by W. Mizerski)

PLATE III

Photos of thin sections prepared from rocks occurring in the quarry (sampled sites shown in Fig. 3) (phot. by M. Krzyżanowski)

Fig. 1. Fine-grained quartz sandstone with feldspars. Light-coloured concentrations are characterized by stronger silification and coarser fraction, locally bounded by strongly deformed clay-ferruginous laminae

Fig. 2. Variously grained quartz sandstone with feldspars. Dark flasers contain clay cement enriched in ferruginous matter

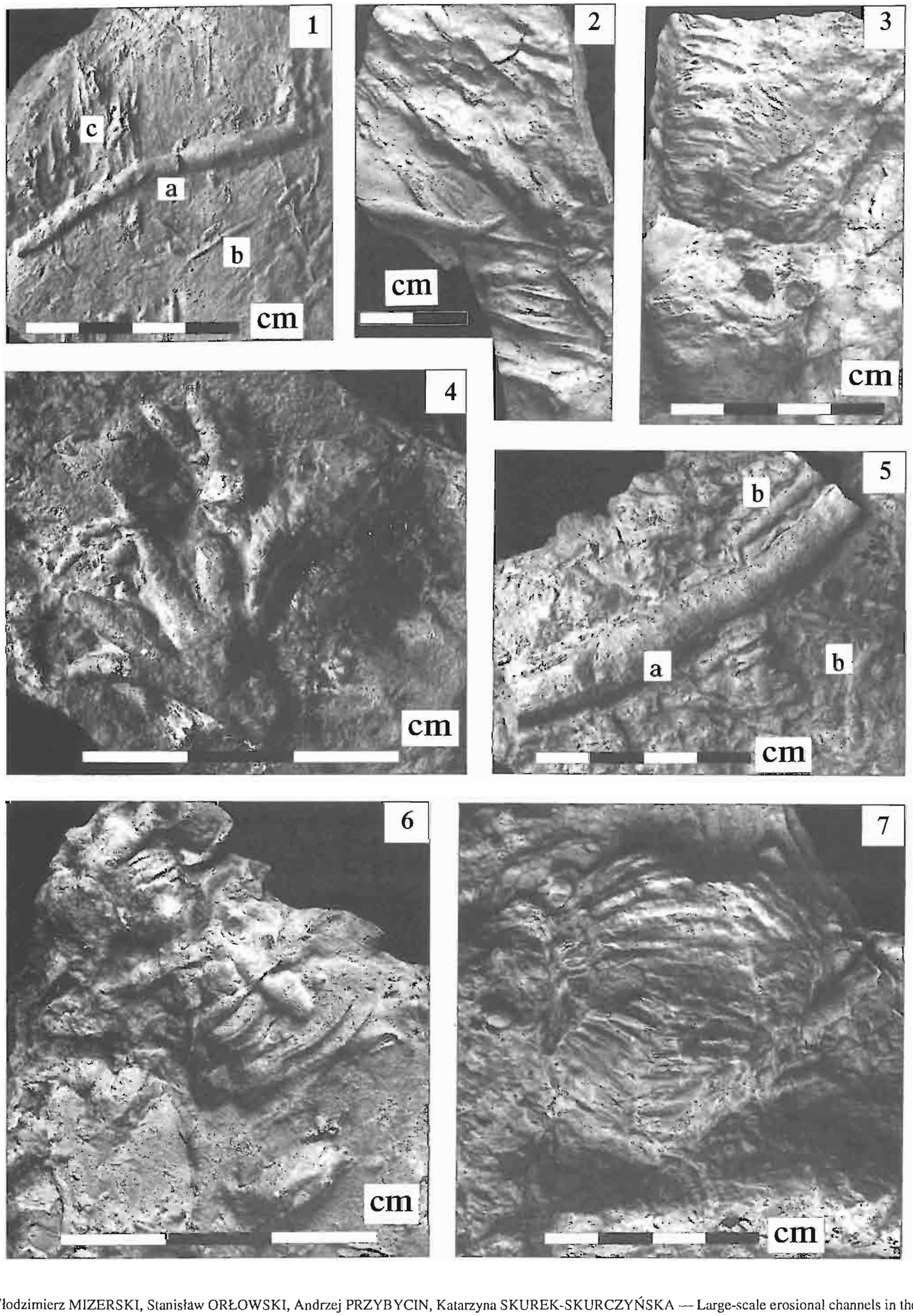
Fig. 3. Muddy-sandy rock with lenticular concentrations of sandy material and quartzitic cement, graded in lower part

Fig. 4. Quartz sandstone with feldspars. Abundant irregular and warped clay laminae fanwise arranged; nests and lenses of coarser material between laminae

PLATE IV

Figs. 1, 2. Warped and shattered (due to collision with eastern wall of the channel — channel A in Fig. 3) sandstone beds infilling the largest erosional channel (top — phot. by W. Mizerski, bottom — phot. by A. Przybycin)

 Geol. Quart., 1999, **43** (3)



Włodzimierz MIZERSKI, Stanisław ORŁOWSKI, Andrzej PRZYBYCIN, Katarzyna SKUREK-SKURCZYŃSKA — Large-scale erosional channels in the Lower Cambrian sandstones, Gieraszowice environs (Kielce Block, Holy Cross Mts.)

Fig. 1

Fig. 2

Włodzimierz MIZERSKI, Stanisław ORŁOWSKI, Andrzej PRZYBYCIN, Katarzyna SKUREK-SKURCZYŃSKA — Large-scale erosional channels in the Lower Cambrian sandstones, Gieraszowice environs (Kielce Block, Holy Cross Mts.)

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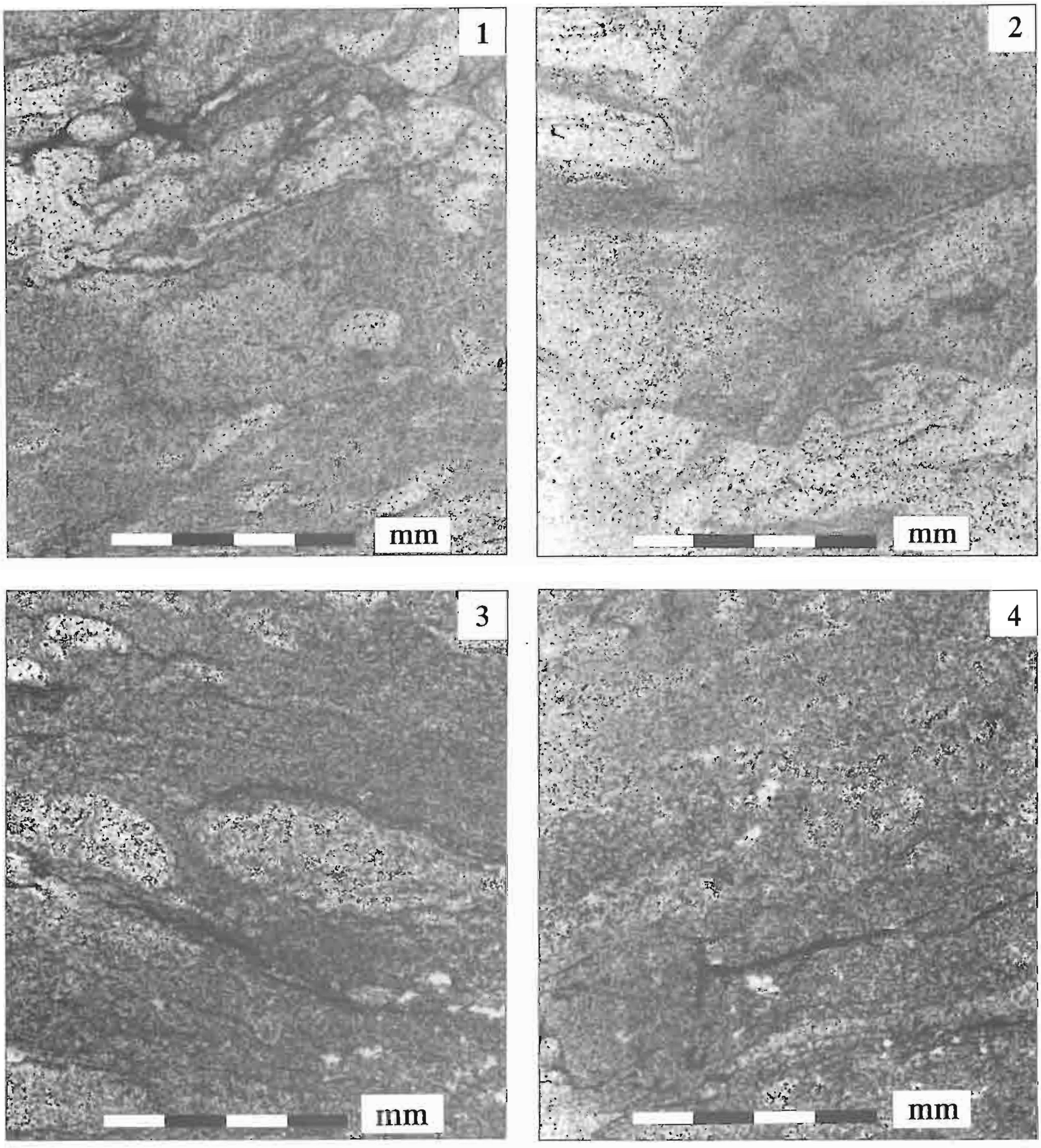

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Fig. 1

Fig. 2

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