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Pre-Ordovician polyphase tectonics of the Cambrian sequences in the Kielce Unit, Holy Cross Mts. (Central Poland)

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On a basis of tectonic mesostructures, the pre-late Tremadocian tectonic event (Sandomirian "phase"), believed to account for deformation of the Cambrian system in the Kielce Unit (Holy Cross Mts., Central Poland), has been subdivided into 3 successive tectonic episodes of different kinematics. During the first stage (D_1), flat, westerly vergent thrusts originated, giving rise to gravitational sliding. Subsequently, during D_2, the entire sequence was imbricated by the northerly vergent thrusts. In the terminal phase (D_3), map-scale folds developed, changing inclinations of previously formed structures. Mode of deformation during the D_2 stage is typical for thrust and fold belts. Absolute dating of these events remains speculative, but the pre-late Tremadocian age of the D_1 and D_2 phases is evident. The D_3 is considered as a continuation of the D_2, but alternative concepts are also acceptable in the light of the presented data.

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Key words: Holy Cross Mts., Cambrian, tectonic phases, mesostructures, thrust and fold belt.

INTRODUCTION

Because of its peculiar location in the tectonic framework of the pre-Permian Europe, in particular its location within the Trans-European Suture Zone (Berthelsen, 1992), geology of the Palaeozoic core of the Holy Cross Mts. (HCM) has been of notable interest to geologists over the last decades. Recent erosional extent of Palaeozoic exposures reflects Late Cretaceous-Early Paleogene faulting and uplift (Stupnicka, 1970) and it does not coincide with limits of older tectonic or stratigraphic units. The Palaeozoic core, divided after Czarnocki (1936) into northern (Łysogóry) and southern (Kielce) units, comprises various sedimentary and, occasionally, igneous rocks of Early Cambrian to Viséan age. As the outcrops are often delimited by tectonic zones, a complete profile is difficult to restore. Cambrian rocks play a prominent structural role in the HCM. They occupy almost entire eastern and southern part of the Kielce Unit, as well as the areas to the north of the Holy Cross Fault Zone, separating Kielce and Łysogóry units (Fig. 1). The latter unit is beyond the scope of this contribution.

This paper proposes a new model for kinematics and timing of deformation of the Cambrian rocks in the Kielce Unit. It is based on the results of extensive field studies carried during 2002–2004, supported by drill core data. Need for detailed structural studies, focused on deciphering possible superposition patterns, has emerged in view of increasing amount of other kinds of geological data, including palaeomagnetical (Nawrocki, 1999; Grabowski and Nawrocki, 2001), sedimentological (Kozłowski, 2003) and palaeontological information (Szczepanik, 1997; Żylińska, 2002), all having strong influence upon palaeogeographical interpretations. New structural data are virtually lacking (paper by Lamarche *et al.*, 1999, is a notable exception), and no new data on tectonics of the Cambrian in the Kielce Unit have been reported during the last years. This paper intends to fill this gap.

The size of study area (Fig. 1) was influenced by a scarcity of good exposures. Only the vast area could provide sufficient number of satisfactory outcrops. Despite of this only a few exposures, located mostly in eastern and central part, provided enough structural data to distinguish particular stages of deformation, determine style, geometry and kinematics of structures, as well as to constrain relative timing of the identified phases.

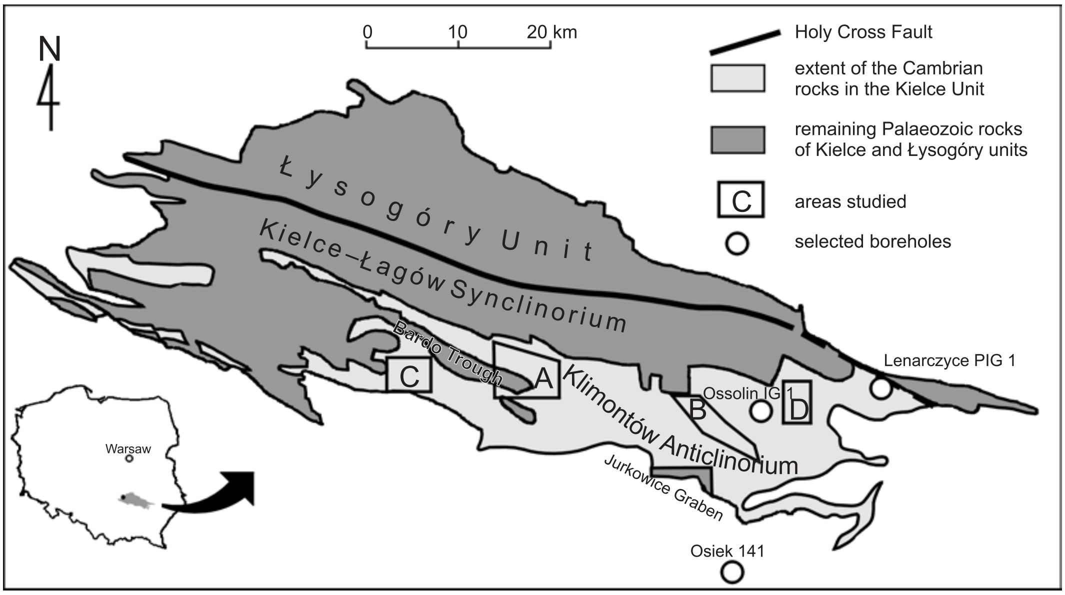

Fig. 1. Simplified geological map of the Palaeozoic core of the Holy Cross Mts. with investigated areas contoured

Areas of particular interest: A — environs of Łagów, B — environs of Klimontów, C — environs of Ocieseki, D — Jugoszów-Usarzów section

In particular, groups of exposures to the south of Łagów town and to the west of Klimontów town were taken into account (A and B areas in Figs. 1 and 2).

REGIONAL SETTING

The HCM are situated in the junction of three main tectono-stratigraphic units of Central Europe: East European Platform, Małopolska Block and the thrust and fold belt of the Variscan Orogen. The Kielce Unit is considered as the northernmost periphery of the Małopolska Block (Pożaryski and Tomczyk, 1968; Tomczykowa and Tomczyk, 2000). HCM are the only outcropping part of the tectonic zone (TESZ — Berthelsen, 1992), fringing the East European Platform from the south-west. Contacts with the surrounding units are hidden under post-Carboniferous cover. The basement of the Małopolska Block and obviously the platform basement dis-

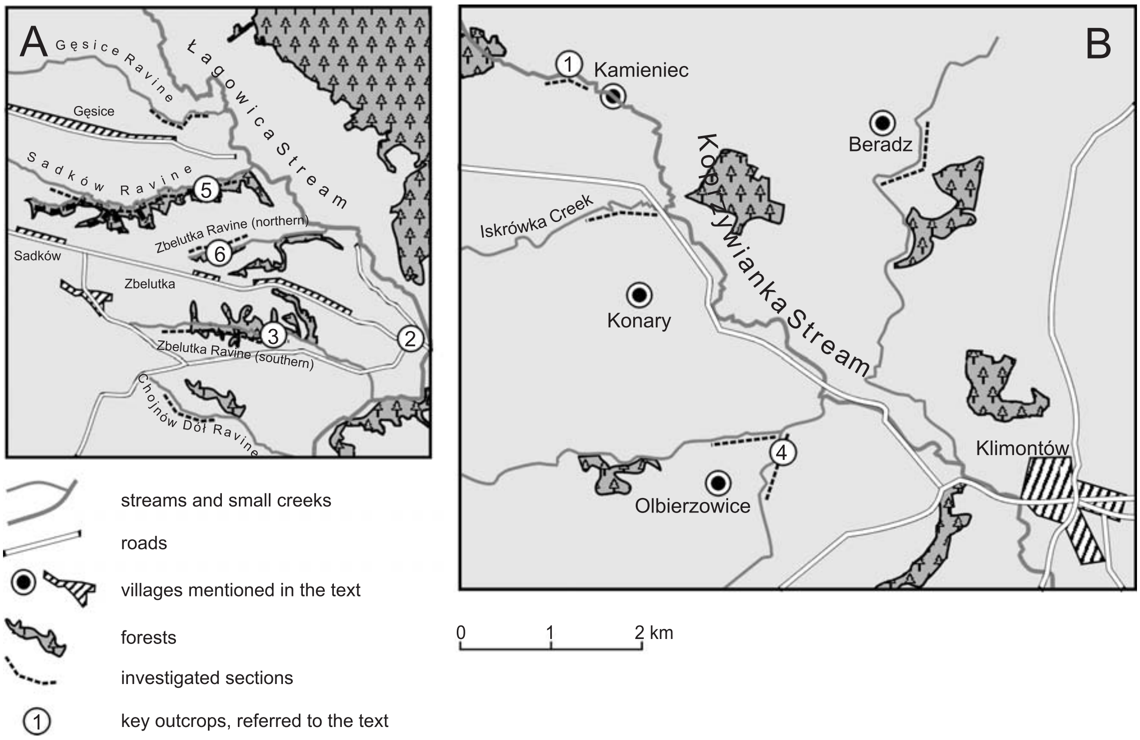

Fig. 2. Sketches of the areas A and B from the Figure 1 with locations of the investigated sections and key exposures

play pre-Cambrian metamorphism. However, they can not be treated as a framework, within which deformation of Cambrian sequences of the HCM took place, because of the speculative nature of contacts with adjoining units. The latter contacts are believed to have been rebuilt in a strike-slip regime in Caledonian (Dadlez *et al*., 1994) and/or Variscan times (Dadlez, 1994; M. Jarosiński, pers. comm.).

On a local scale, the Kielce Unit is separated from the Łysogóry Unit by a long-lived Holy Cross Fault. The Middle and Upper Cambrian sequences to the north of this fault show a polyphase deformation (Salwa, 2002) and a strong thermal alteration (Szczepanik, 1997). The southern extent of the Kielce Unit is defined by a shallow subsurface occurrence of very low grade Vendian and Lower Cambrian rocks of the Małopolska Block (Kowalski, 1983; Kowalczewski, 1993).

Lithology of Cambrian sequences in the Kielce Unit has been extensively described in published reports (e.g. Czarnocki, 1919; Orłowski, 1964*a*, *b*, 1975, 1992; Kowalczewski, 1995). The lithostratigraphic divisions of the Cambrian are still a matter of debate (Kowalczewski, 1995, 1997; Orłowski, 1997). In this paper the subdivision by Kowalczewski (1995) is used because it addresses most of the existing uncertainties. Generally, the sequence comprises siliciclastic rocks. They represent *Holmia* and *Protolenus* trilobite zones of the Lower Cambrian (Orłowski, 1975). In a few areas, however, also isolated exposures of the Middle Cambrian have been encountered (Orłowski, 1964*a*, *b*, 1985*b*; Orłowski and Mizerski, 1995). Recently the Upper Cambrian deposits, unconformably overlying palaeontologically barren Lower/Middle(?) Cambrian interval, have been identified in the Lenarczyce PIG 1 borehole (Szczepanik *et al*., 2004). As a rule, Middle Cambrian sediments are more sandy than underlying finer-grained Lower Cambrian. Acritarch thermal alteration studies of the Cambrian in the Kielce Unit point to low maximum temperatures, hardly approaching 100°C (Szczepanik, 1997). This evidence is strongly contrasting with much higher degree of thermal alteration of the Cambrian and Vendian rocks in the adjoining units.

The studied rocks belong mostly to the Lower Cambrian Kamieniec Shales. Co-eval Ociesęki Sandstones, as well as Middle Cambrian Słowiec and Usarzów Sandstones, provided only small amount of data, because of a limited number of outcrops. Spectacular exposures of the Middle Cambrian rocks in the Góry Pieprzowe Mts.were not taken into account in this paper because the latest studies (Szczepanik, 1997) indicate, that they belong to the Łysogóry rather than to the Kielce Unit.

PREVIOUS RESEARCH

Most of the past research involving Cambrian of the Kielce Unit focused on stratigraphy and palaeontology (Czarnocki, 1919; Samsonowicz, 1934; Orłowski, 1964*a*, *b*, 1974, 1975, 1985*a*, *b*, 1988*a*, *b*, 1992; Żakowa and Jagielska, 1970; Kowalczewski, 1995 and others). After pioneering and still valuable works by Czarnocki (1919), only a few papers on structural geology have been published. These include reports by Mizerski and Orłowski (1993), Mizerski (1994, 1995, 1998), Znosko (1996) and Mizerski and Skurek-Skurczyńska (1999). Other papers addressing tectonic aspect, along with stratigraphy and sedimentology, include Mizerski *et al*. (1986, 1991), Orłowski and Mizerski (1995, 1996). Most of the previous studies (except for Mizerski and Skurek-Skurczyńska, 1999) were based on map image and statistical analyses of data gathered over vast areas, the approach considered as invalid by the present author in this particular case (see below).

Structural evolution of the Cambrian system in the Kielce Unit has been hitherto interpreted within a framework of the traditional tectonic scheme developed over decades of geological studies in the HCM. Such approach assumes successive superposition of deformations related to the Sandomirian (local phase in the early Tremadocian), Caledonian (around the Silurian/Devonian boundary), Variscan (latest Viséan to late Westphalian) and Alpine (Cretaceous/Paleogene) tectonic events. The influence of these events on deformation of Cambrian rocks has been variously estimated. Mizerski *et al*. (1991) and Mizerski and Skurek-Skurczyńska (1999) suggested dominant role of Variscan folding for the tectonics of the Cambrian shales in the eastern part of the Klimontów Anticlinorium, with subsidiary role of Sandomirian event. Mizerski (1994), in turn, claimed the latter to be the most prominent tectonic episode. On the basis of archival data, Znosko favours the role of Caledonian Orogeny, assigning a minor role to the Sandomirian Phase (Znosko, 1996), or neglecting it at all (Znosko, 2001). Equally numerous discrepancies arose regarding tectonic style, kinematics and dynamics of deformation. Mizerski *et al*. (1991) report dominant southern vergence of folds in the Cambrian rocks of the eastern part of the HCM, but illustrate it with a series of upright folds in the cross-sections, while Mizerski (1994, 1995), and Mizerski and Skurek-Skurczyńska (1999) advocate northern vergence. Diapiric structural style of the "Cambro-Silurian" was postulated by Znosko (1996, 2001). Detailed results of the previous surveys are discussed further in the text when necessary.

METHODS

Unlike most of the previous tectonic research in the Cambrian of the HCM (Mizerski *et al*., 1986, 1991; Mizerski and Orłowski, 1993; Mizerski, 1995), the proposed interpretation is built upon detailed tectonic restoration performed for particular exposures rather than on statistical analysis of data from groups of exposures and map interpretation. The first method is inappropriate when a number of outcrops is limited and they are grouped in clusters far one from another. Data from one, big exposure may introduce bias to an overall pattern. This is also the shortest way to "erase" effects of polyphase deformation, because older structures, variably trending and inclined due to younger rebuilding, disappear on stereoplots; especially if density levels are set high. The second approach fails in poorly exposed sequences with partly uncertain stratigraphy, as is in the case of the Cambrian in the Kielce Unit. Moreover, due to the low temperatures experienced by the rocks and lack of carbonates, unfortunately the microstructural studies were of a limited value. Therefore, the presented model is based almost exclusively on structural relationships observed directly in exposures and in hand specimens.

Equal area stereographic plots (lower hemisphere) were used for data presentation. Selected outcrops were cleaned in order to archive better understanding of geometry and spatial relationships of tectonic structures.

PHASES OF DEFORMATION

In the following chapters the phases of the inferred pre-late Tremadocian deformation are presented. It should be stressed that the vergences, trends of structures *etc.* do not necessarily reflect the primary tectonic directions, as significant lateral displacements with possible rotations could have occurred during younger episodes of deformation including Variscan event in particular. In the author's opinion, however, the latter tectonic episode did not significantly modify internal structure of the Cambrian complex. The Devonian rocks, flanking the Klimontów Anticlinorium from the north, or preserved within this unit as erosional remnants (e.g. in the Jurkowice Graben or Bardo Trough), are merely weakly deformed, apart from narrow strike-slip zones. Therefore, the pre-Variscan basement of the blocks between them may be considered as much less affected. Moreover, the Variscan deformation of Cambrian rocks, if present, is pronounced as strike-slip faults and associated brittle structures easy to distinguish due to their rusty colouring. In these cases, Cambrian shales and mudstones are altered to soft clay. Basing on these facts, the supposed pre-late Tremadocian structural pattern of the Cambrian series is assumed to be unchanged, thus enabling studies of mutual geometrical relationships of different groups of structures.

D_1 — THRUSTING FROM THE EAST

Tectonic structures not corresponding to the previous structural models, both in direction and geometry, are abundant in a significant number of exposures. The latter include those regarded as type sections of the formal lithostratigraphic units (Orłowski, 1975), and their omitting in the previous research is confusing. It was only Mizerski *et al.* (1991), who mentioned the "pencil-shape cleavage" (probably pencil structures) dipping northward, but assigned it to the Variscan episode. Mizerski and Skurek-Skurczyńska (1999) noted a presence of single slickensided surface pointing to E–W direction of $_1$.

PATTERN AND KINEMATICS

Because the tectonic architecture created during the first phase of deformation was modified by younger tectonic episodes, the structures are strongly tilted with respect to their original position. This tilt is best pronounced in fold axes and structures parallel to them, such as rodding (*cf.* Ramsay and Huber, 1987). As a rule they dip north or south, at angles approaching bedding inclinations, thus perpendicularly to the long-known east-west trending map-scale folds. If such linear features occur individually, this relationship can be easily observed in a particular outcrop. In the wider zones, with the structures extensively developed, it can be determined by comparison with the adjacent, but not disturbed parts of the section.

The D_1 deformation involved mostly low-angle (often bedding-parallel) thrusts with subordinate folds, related mostly to the ramp segments of the thrusts. Duplex structures of varying scales are also common.

The most striking examples of deformation patterns, created before the overall north-south bedding tilting, were encountered in the eastern part of the Klimontów Anticlinorium, in the well-known outcrops close to Kamieniec village (Fig. 2B, outcrop no. 1). Here, the structure is dominated by bedding-parallel thrusts with numerous subordinate, highly inclined reverse faults (Figs. 3A and 4C). These often coincide down- and up-dip with low-angle faults, thus may be considered as ramps joining sole and roof thrusts of duplexes. Numerous drag folds are present, providing good indication of thrusting direction. As shown in Figure 4A, their axes plunge north, at angles approaching bedding inclination. Assuming their primary horizontal position, tilting of the faulted/folded sequence is related to younger tectonic episodes. The original direction may be restored by applying the relevant rotation. The most appropriate for this purpose are dip and strike angles of bedding in the nearest, not disturbed parts of a section, usually being roofwalls of the low-angle thrusts. As a result of this procedure a clear pattern of the westerly vergent thrusts and thrust-related north-south trending folds emerge (Fig. 4B and D).

Other, less impressive but much easier accessible examples of structures related to the westerly thrusting were encountered in a rural quarry near the Zbelutka village (Fig. 2A, outcrop no. 2). Structural features are here similar to those observed in the outcrop near Kamieniec. The main difference, crucial for interpretation, is southerly dip of bedding and of axes of minor folds. It is opposite to dips recorded near Kamieniec. The structure comprises flat, often bedding-parallel thrusts, occasionally tapering into ramps with related drag folds (Fig. 3B and C). Relationships of bedding orientation and minor folds axes (Fig. 4E and F) correspond almost exactly to that described above (Fig. 4A and B), despite the difference in a plunge direction. After rotating with respect to the bedding, the resultant fold axes trends indicate WSW–ENE direction of a tectonic component of compression. Top to the west direction of thrusting was determined by ramps geometries (Fig. 3C) and drag folds.

Structures with a typical D_1 orientation, but of a very peculiar geometry, were observed in deep ravines of Łagowica Stream tributaries near Zbelutka, Sadków and Gęsice villages, as well as in Iskrówka Valley near Konary village, west of the town of Klimontów. There, the tectonic fabric comprises bedding-parallel faults and subordinate drag folds, with axes parallel to the bedding (Fig. 5 except of E and F). After applying the rotation procedure mentioned before, the restored pattern becomes essentially the same as previously described and is interpreted in the same way. In this case, however, also rodding was taken into account. It is expressed as fine bedding corrugations, forming small ridges, up to 1 cm high, covering anisotropy surfaces. Their spacing is approximately proportional to height. These structures appear on every bedding-parallel splitting surface and therefore may be considered as fully penetra-

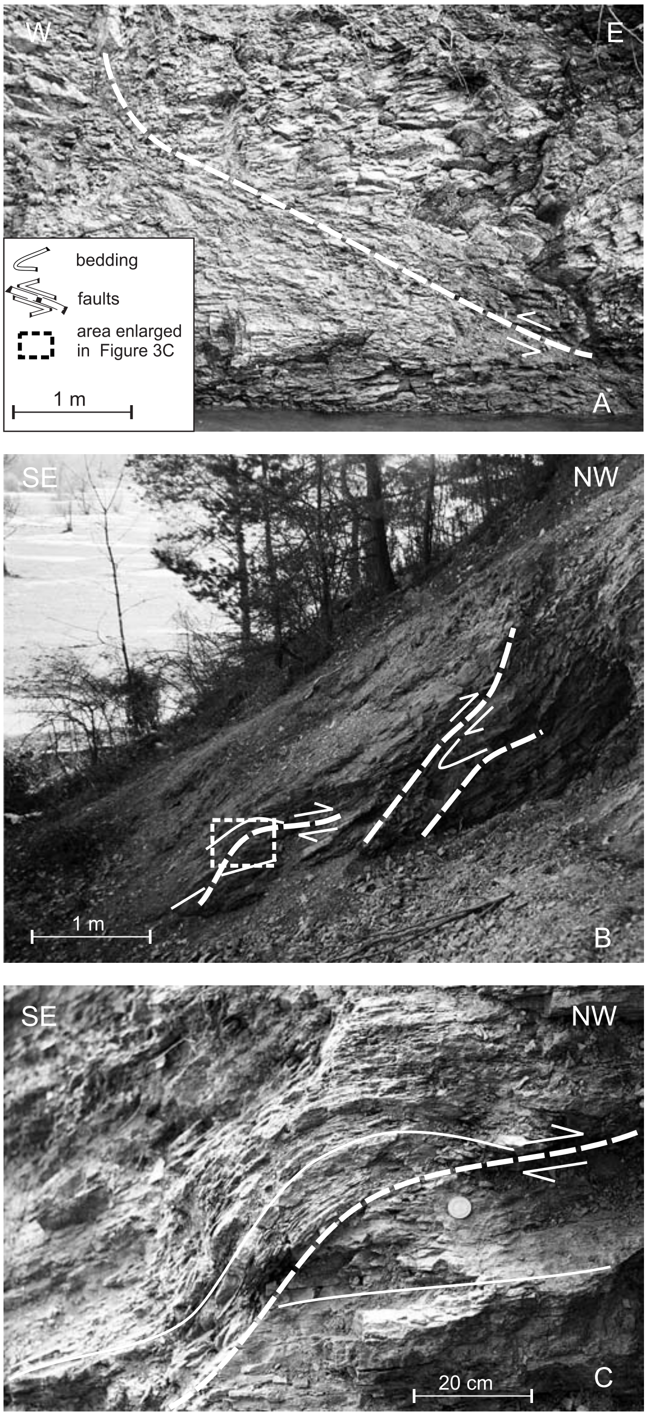

Fig. 3. Structures related to the first compressional phase; western vergence clearly discernible

A — reverse fault with intensely developed cleavage, Kamieniec near Klimontów; **B** — flat thrusts with drag folds, rural quarry near Zbelutka; **C** — details of the tapered (ramp) part of the bedding parallel thrust, the same location as B

tive. In most cases the ridges are less than 2 mm high and resemble crenulation in metamorphic rocks. Geometrically, as observed in outcrops near Zbelutka, the rodding is parallel to the D_1 fold axes and provides a reliable kinematic indicator of a B-type lineation. In some cases, corrugated beds are associated with zones of partial liquefaction of the sediment.

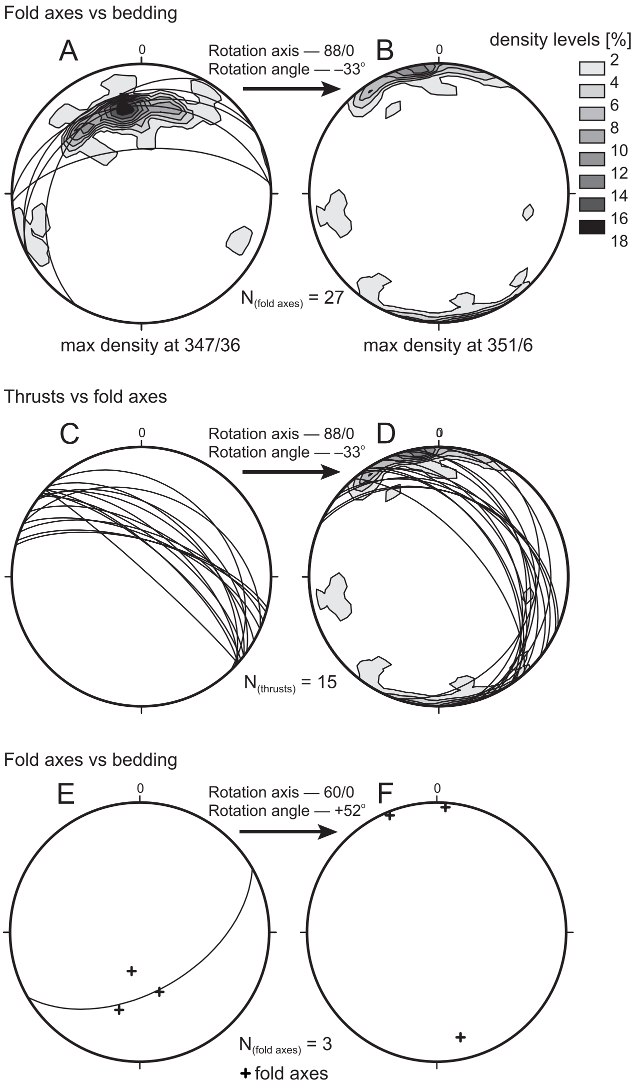

Fig. 4. Stereographic projections of D_1 structures from selected localities

Rotation with respect to bedding restores primary structural pattern with westerly vergent thrusts and north-south trending folds related to the E–W direction of tectonic compression, variably inclined during younger tectonic episodes; **A**–**D** — Kamieniec near Klimontów; **E**–**F** — Zbelutka near Łagów; **A**, **C**, **E** — before and **B**, **D**, **F** — after bedding correction

Although stretched silty laminae "float" within the clayey matrix, they are highly ordered and parallel to the shearing direction inferred from adjacent folds. In the extreme cases (i.e. in the Iskrówka Creek escarpments near Konary), the sediments become internally homogeneous, without regular fissility. An example of such a case is given in Figure 6. It is not clear whether these structures and folds are of a purely tectonic origin, or if this deformation was gravitationally induced. Without an exception, the tightly folded and corrugated beds are overlain by undisturbed beds. It is unlikely, however, that this resulted from the surface sediment slumping, succeeded by a quiet deposition upon earlier formed folds. Several observations do not support such interpretation:

1. Sandstone layers embedded in a liquefied matrix display jointing, thus they were already lithified and strained before the considered processes commenced. The jointing could not have been established later (i.e. due to mechanical differences be-

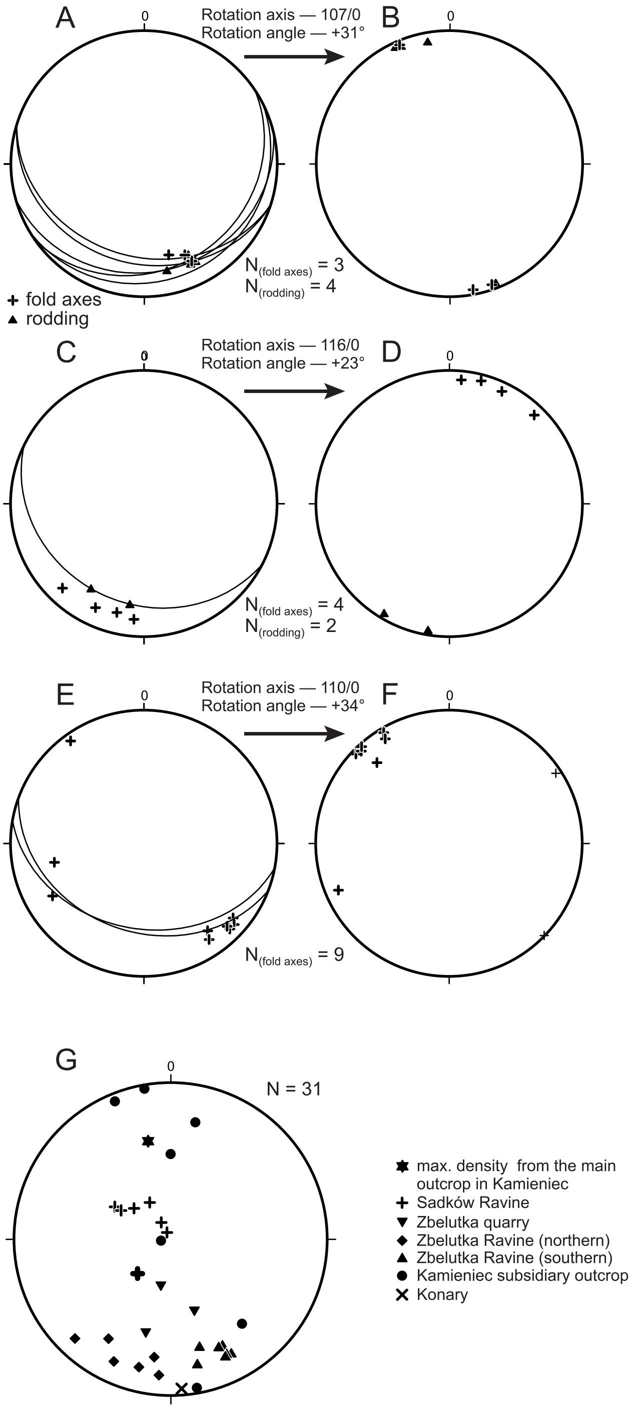

Fig. 5. Stereographic projections of drag folds and rodding vs. bedding

A–**F** — selected outcrops from Zbelutka Ravines near Łagów; structures plotted in E and F were rebuilt during D_2; **G** — composite stereoplot of D_1 linear structures, fold axes and rodding

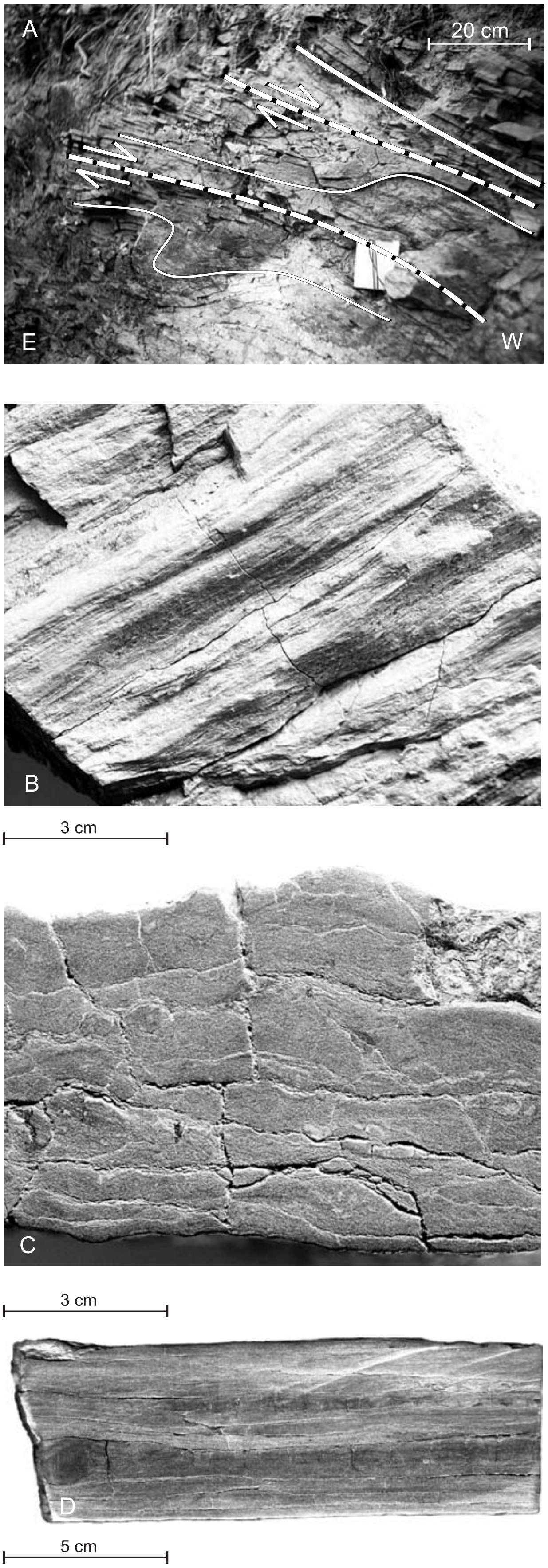

Fig. 6. Examples of structures related to partial liquefaction of sediments

A — typical appearance of a deformed zone, Zbelutka Ravine (southern), exposure no. 3 in Figure 2A; **B** — corrugated bed surface, Sadków Ravine, exposure no. 5 in Figure 2A; **C** — rodding, section perpendicular to corrugations, isometrical cross-sections of fold axes parallel sandstone rods visible, sample from exposure presented in Figure 6A; **D** — rodding, section parallel to corrugations, cross-sections of elongated sandstone rods visible, the same sample as in Figure 6C; explanations as on Figure 3 tween sandstones and clayey matrix), because the sandstone layers are sometimes torn apart along these joints. An example of early diagenetic, displaced and sealed joints is given in Figure 7A. Even in lithologically uniform, but homogenized series, relics of not liquefied, jointed mudstones/claystones may be found.

2. The initial form of rodding resembles boudins, implying at least partial rock lithification, so that it could sustain some amount of differential stress necessary for a regular jointing. In some cases, even incipient chocolate tablet pattern develops.

3. Highly consistent orientation across exposures of the Kamieniec Shales is unlikely in structures resulting from the surface sliding.

4. High regularity is observed in rodding development — even a few millimetres high ridges may be traced laterally for several tens of centimetres.

5. There are clear lithological differences between apparently undisturbed “cover” and the deformed sediments underneath. The overlying beds are devoid of trace fossils and thin layers of sandy material typical of the Kamieniec Shales. This can be explained by mixing and homogenization of the sediment due to intense shearing. Recent fissility (though often quite rough), defined by fine muscovite flakes, may reflect either shear planes, or be the result of later compaction.

The described structures could originate under a sedimentary cover resulting from a large scale sliding of internally coherent packages. The question whether the sliding was induced tectonically or by gravity remains open. In the author’s opinion, separating effects of both factors acting upon partly lithified and not completely dewatered sediments is rather difficult. Deformed zones with eastern vergence (opposite to clearly tectonic structures; i.e. near Kamieniec) could be gravity-induced in contrast with the westerly vergent structures, where contribution of tectonic stress is likely.

An early, syndiagenetic deformation of the Cambrian rocks of the Kielce Unit was postulated by Mizerski (1994). It was based, however, on observations by Mastella and Mizerski (1981) from the Middle Cambrian Góry Pieprzowe Shales, belonging to the Łysogóry Unit (Szczepanik, 1997), thus not necessarily corresponding to the phenomena described above.

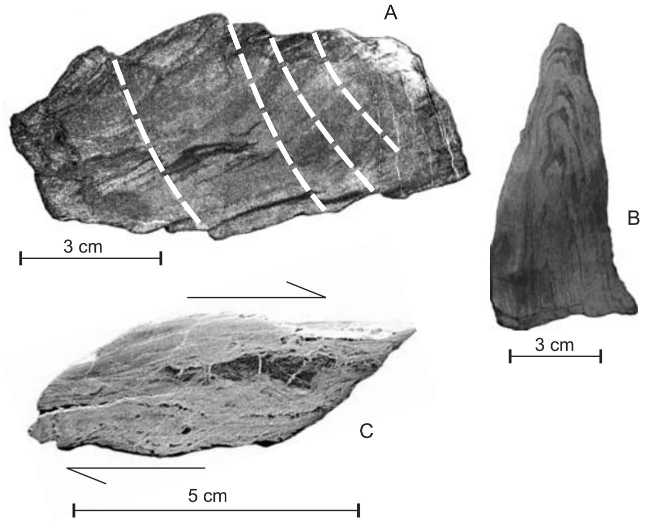

Fig. 7. Examples of the syndiagenetic tectonic structures

A — early joints slightly displaced and sealed, sample from Zbelutka Ravine (northern); **B** — small fold within liquefied sediment, sample from Zbelutka Ravine (northern); **C** — splitting pattern of a sheared and corrugated bed, sample from Sadków Ravine; explanations as on Figure 3

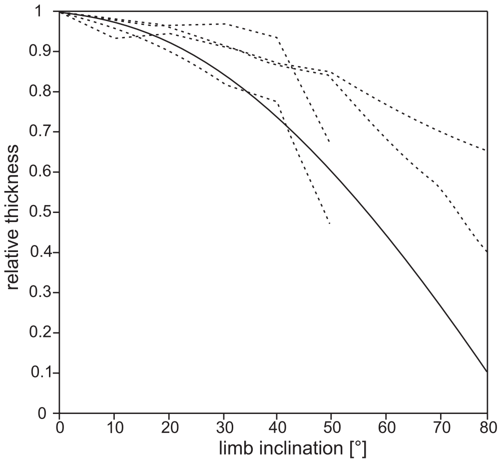

Fig. 8. Layer thickness patterns (striped lines) for some of the D_1 folds; limbs thinned with respect to hinges, implying material transfer during folding or passive amplification

Having established the geometrical relationships determining spatial arrangement of structures created during the episode of east-west compression one may with a great caution summarize data collected over the entire study area. Fold axes and rodding structures, meeting the above criteria, form a girdle (Fig. 5G) on a stereographic projection. It indicates presence of an older folding direction, refolded around east-west trending axis. Since the girdle coincides approximately with a great circle, the difference in folding directions approaches 90°.

As shown in Figure 8, minor folds fall into class 1C, 2 and 3 (Ramsay and Huber, 1987), which implies material transfer from limbs to hinge zones, but later uniform compactional (axial surfaces are often almost parallel to bedding) passive amplification is also likely. Contribution of this factor, cannot be quantified, because the primary fold geometries are not known.

CONDITIONS OF DEFORMATION

Rocks strained during D_1 show a wide spectrum of behaviours. Brittle structures, like thrusts and buckle folds, coexist with structures indicating ductile deformation.

Good proof of a ductile behaviour is the presence of deformation affecting the entire rock volume. Its best expression is rodding, sometimes confined to a single bed, but often widely developed throughout sections several metres thick. It results from penetrative ductile shearing. The appearance of rods suggests a significant displacement. No damaged surfaces were observed, indicating fully penetrative nature of this process, at least on a hand specimen scale. Locally, tight, small-scale folds were developed (Fig. 7B). Because of straight limbs, covered by numerous rodding-related B-lineation structures, such folds are interpreted as a product of intense shearing. With an increase of a total strain the rodding disappears and the rock becomes homogeneous even in thin sections. Nonetheless, the splitting pattern (Fig. 7C) clearly resembles shear structures. In the author’s opinion the above described structures result from a deformation of a cohesive, tixotropic material due to sudden strength drop, when a critical value of differential stress is exceeded. Assuming tixotropic behaviour, further ductile shearing could proceed at descending level of differential stress.

The above phenomena imply that the early stages of deformation took place shortly after deposition, with water still present, and with a contribution of gravitational sliding. Zones of deformation without penetrative shearing (i.e. outcrops near Kamieniec) originated under differential stress below the liquefaction threshold, or comprised horizons devoid of water.

D_2 — THRUSTING FROM THE SOUTH

Presence of numerous structures, pointing to the north-south compression, has been widely recognized and is well-documented (e.g. Czarnocki, 1919; Mizerski *et al.*, 1991; Mizerski, 1995, 1998; Znosko, 1996; Mizerski and Skurek-Skurczyńska, 1999, and others). Until now, all such structures were considered as subordinate with respect to the big-scale folds, inferred from the map. Two problems are discussed in details below: vergence of the structures and relation of this deformation phase to the general folding of the Cambrian rocks.

PATTERN AND KINEMATICS

The overall deformation pattern is of a thrust and fold type, thus similar to that developed during the D_1. Similarly, the major faults are of low angles, while subsidiary structures often display listric geometry with upward decaying displacement and/or turning into drape folds. Important for the interpretation is the fact that thrusts' inclinations vary strongly, but remain fairly constant with respect to the bedding.

The well known, though equivocally interpreted Lower Cambrian sections near the Olbierzowice village (Fig. 2B, outcrop no. 4) provide an insight into structures developed during this deformation. The most readily discernible feature is interlacing of wide, severely deformed zones with almost undisturbed sections. Direct contact between them is exposed in the spectacular outcrops to the east of the village. It is expressed as an almost horizontal thrust surface occasionally slickensided, with tens of centimetres thick layer of a very fine-grained, lithified fault gauge. Below the thrust, the rocks remain undisturbed, but the roofwall is truncated by numerous north-vergent thrusts (Fig. 9A). The geometrical relationships are shown on Figure 9B. Rotation with respect to bedding in the footwall of

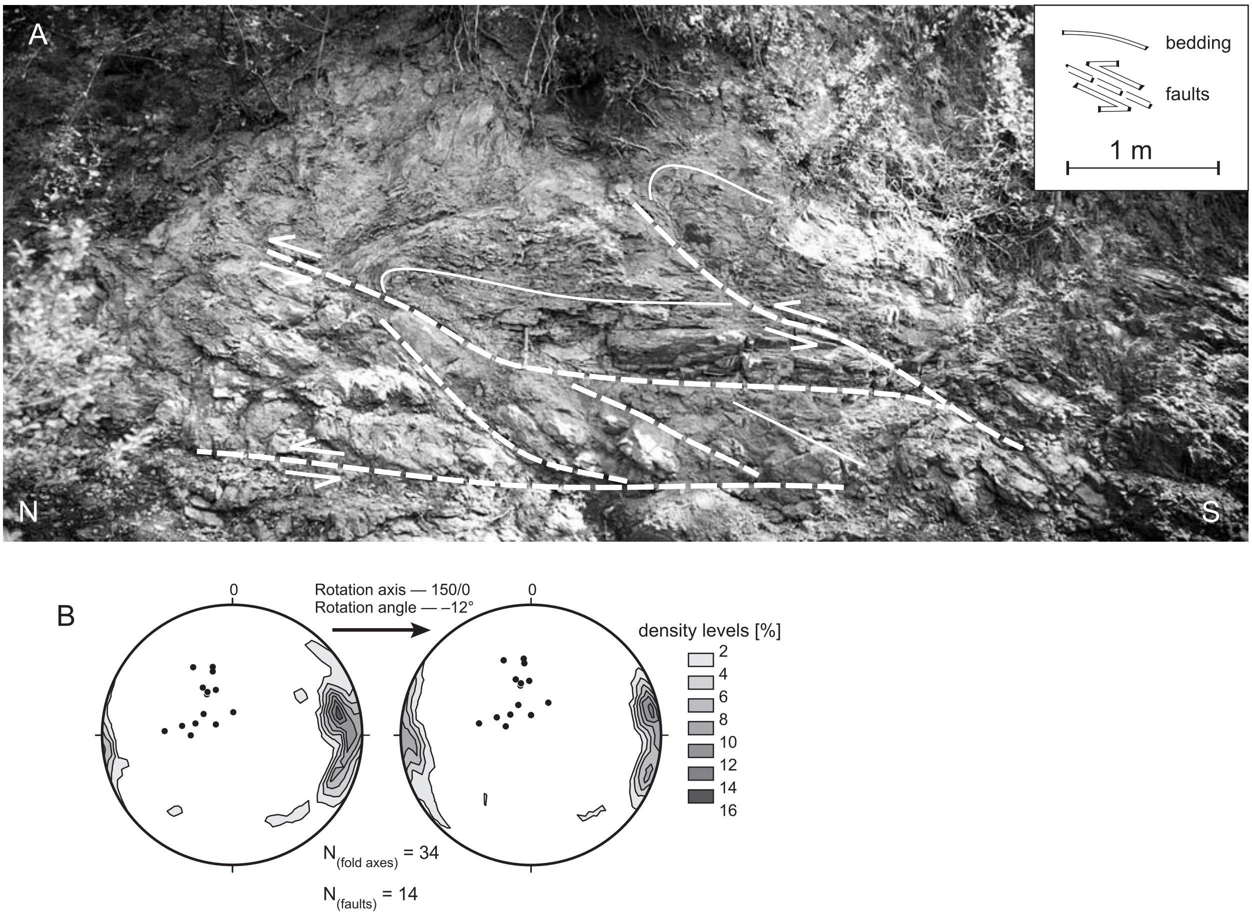

Fig. 9. Northerly vergent thrust zone with well-developed drag folds, Olbierzowice near Klimontów

A — overall view of the deformed series; **B** — stereoplots of normals to the thrust surfaces (dots) and drag folds axes from these localities, left — before and right — after bedding correction

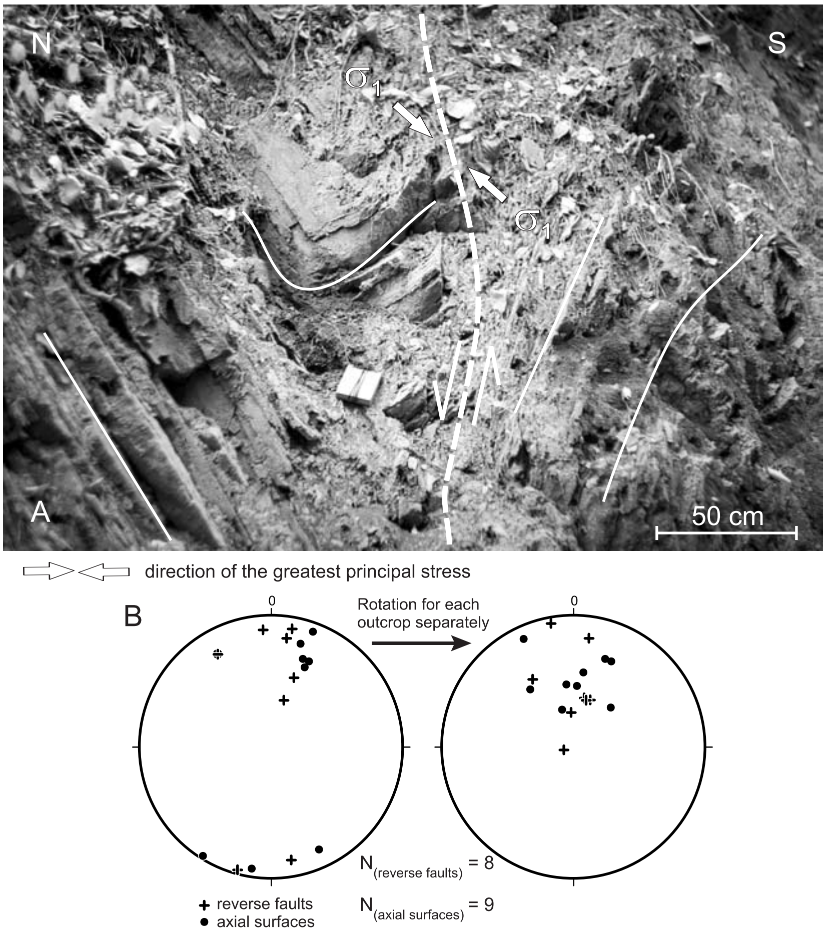

Fig. 10. A — vertical fault cutting through steeply inclined (70°) beds, probably early, low-angle thrust, oversteepened during younger phases of deformation; B — composite stereoplot of D_2 planar structures — thrust surfaces and fold axial surfaces (plotted as poles), rotation with respect to bedding reduces scatter and restores primary northern vergence; Zbelutka, Gęsice and Sadków ravines; location see Figure 2A, exposure no. 5; other explanations as on Figure 3

the main thrust reduces inclination of the drag folds axes and restores primary vergence of subsidiary thrusts from measured northwestern to northern after correction. Large data dispersion (thrusts with western vergence) indicates more than a single phase, as discussed below. Despite this restriction, the entire fault-zone was formed probably during the northerly thrusting. Such interpretation supports earlier conclusions of Mizerski and Skurek-Skurczyńska (1999), but contradicts results of Mizerski *et al*. (1991), who mentioned dominant southern vergences from the same outcrops. Total displacement is difficult to estimate, because the southern (upper) boundary of the thrust zone is not exposed. Judging from the observations of the long exposure (over 120 metres) it is very likely that the displacement is on the order of at least a few hundred metres.

Relatively good outcrops of the Kamieniec Shales are stretching along right tributaries of Łagowica Stream to the south-west of Łagów. Unfortunately, the exposures are in most cases strike-parallel, which significantly reduces amount of available data. In contrast to the previously described section they are characterized by variable, but usually steep dip of bedding. Whereas in the Olbierzowice section, the reverse faults were approximately of the same orientation, in the described exposures their tilt angle changes, but remains fairly constant with respect to bedding (Fig. 10A). After rotation of thrusts and fold axial surfaces, with respect to the bedding in each outcrop, the scatter significantly decreases (Fig. 10B), and the thrusts approach their theoretically predicted inclination of 30°. If the reverse faults are at their original positions, then a highly inhomogeneous stress field, with $_1$ often steeply inclined, can be assumed (*cf.* Fig. 10A).

Variable inclination of the east-west striking faults and fold axial surfaces is a peculiarity of this tectonic episode (*cf.* Czarnocki, 1919). This pattern could have been developed by flexural slip. In such a case, the vergence of minor thrusts and folds, regarded as parasitic structures with respect to major folds, is always up-dip. Assuming that the regional folds trend east-west, the direction of thrusting should be top to the north in the limbs dipping southward, and top to the south in the limbs dipping northward. However, in the studied sections, directions of thrust-

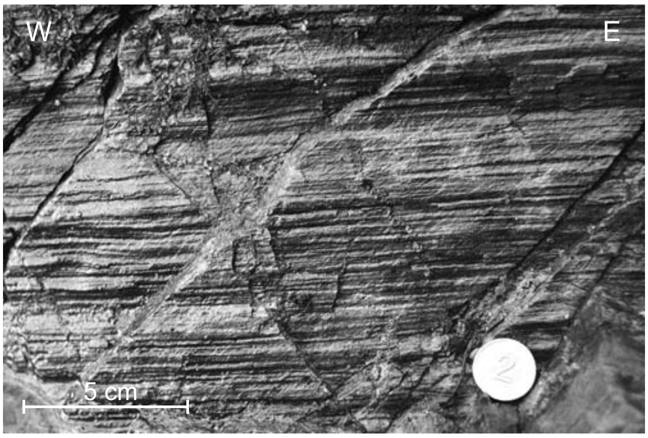

Fig. 11. Well pronounced B-lineation, originated during the D_2 episode; Sadków Ravine

ing are almost always top to the north, irrespective of dips of the bedding. As a result the thrusts have appearance of normal faults in the strata dipping northwards. Similar situations were reported by Mizerski (1994, 1998), and Mizerski and Skurek-Skurczyńska (1999) from the exposures near Klimontów, but were interpreted as submarine slumping. In the author's opinion, it is an evidence of a major thrusting episode, pre-dating overall folding of the Cambrian in the Kielce Unit.

D_2 folds cannot be geometrically classified, because their wavelengths exceed thickness of folded layers by an order of magnitude, preventing reliable measurements of bed thickness. Qualitatively, the folded multilayers display geometry intermediate between parallel and similar folds. It results, however, from different behaviour of sandy/silty and clayey beds.

CONDITIONS OF DEFORMATION

In a contrast to D_1, the D_2 stage did not produce structures indicating a high ductility of the deformation. Fold geometries are intermediate between parallel and similar but with mostly parallel geometry of single sandstone layers. This points to buckling as the main folding mechanism and therefore the deformation cannot be considered as ductile in the strict sense. In the single outcrop near Gęsice village, several metres thick corrugated section was encountered (Fig. 11) with B-lineation parallel to the dominant strike of D_2 folds. Despite appearance similar to D_1 structures, in this case we are dealing with purely tectonic phenomena as the deformed rock shows much higher degree of lithification than its direct neighbourhood and is overlain by strongly sheared claystones with dense cleavage developed. Mechanical explanation is similar to that of analogous D_1 structures, but the strength reduction, subsequent homogenization and ductile creep was initiated exclusively by tectonic factors.

Structural features of the D_2 episode are typical for thin-skinned tectonics of thrust and fold belts.

D_3 — REGIONAL-SCALE FOLDING

Presence of map-scale folds (or rather — prevailing steep bedding inclination) is a well-known feature of the Cambrian sequences in the Kielce Unit (e.g. Czarnocki, 1919; Mizerski *et al*., 1991; Mizerski, 1994, 1995). Due to the poor stratigraphical resolution it is extremely difficult to trace big scale structures. It may be achieved upon a stratigraphical basis only in a very restricted area around Ocieseki village. Bedding dip interpolation across a given profile also fails. Although fold geometry can be established using small-scale folds, presence of numerous east-west striking faults of varying age, especially the Variscan strike-slip faults, makes it difficult. Common difficulty with establishing way-up directions is another problem. In spite of the above difficulties, tight folding of the Cambrian sequences has never been questioned and is believed to postdate the D_2 episode. However, taking into account concordance between D_2 thrusting and D_3 folding directions, the latter may represent a final stage of the D_2, related to locking of the thrusting process, e.g. due to dewatering which increased internal friction.

SUPERPOSITION PATTERNS

A valid interpretation of multiple deformation phases should be based on analysis of interference patterns. It is particularly important in interpreting D_1 and D_2 structures, because they often have similar geometry, thus may be alternatively interpreted as formed during the same episode and later differently rotated during i.e. Variscan tectonic events. Because of small size of most of the exposures, and concentration of deformation in confined (though often wide) zones, finding interfering structures of the outcrop size is difficult. Several such structures were, however, located (Fig. 12A and B). The structure presented in Figure 12A sheds light on the dispersion of fold axes and fault orientations in the Olbierzowice section (compare description presented above and Fig. 9B). It may indicate rejuvenation of an older (D_1) deformation zone during the D_2 episode. It is still unclear, however, whether the observed pattern developed during progressive change of thrusting direction, or if it results from reactivation of previously "locked" deformation zone. This interpretation partly coincides with that of Mizerski and Skurek-Skurczyńska (1999). Much more common, both, in outcrops and in drill cores, is superposition of two sets of B-lineation, originated during D_1 and D_2 (Fig. 12C).

TIMING OF DEFORMATION

Whereas the relative timing of particular deformation phases was constrained by geometrical relationships, the absolute age has to be supported by stratigraphical and sedimentological evidence gathered during decades of stratigraphic studies.

The Sandomirian (early Tremadocian) tectonics are widely accepted for most of the folding in the Cambrian of the Kielce Unit (Mizerski *et al*., 1986, 1991; Mizerski, 1994, 1995, 1998; Orłowski and Mizerski, 1995; Mizerski and Skurek-Skurczyńska, 1999). The possibility of earlier, Cambrian, tectonic events was not discussed by the cited authors. There is a strong evidence suggesting that the D_1 and D_2 occurred before late Tremadocian. Erosional unconformities between strongly folded (D_2) Kamieniec Shales and Ordovician sedi-

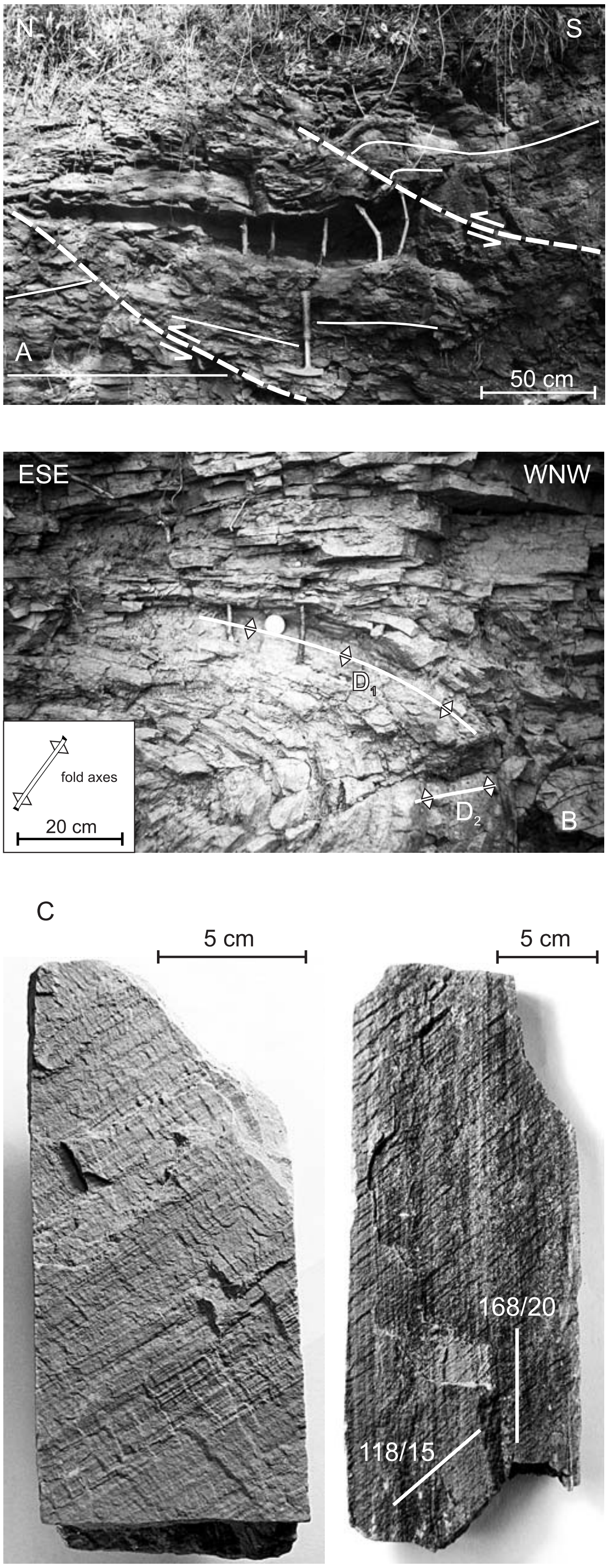

Fig. 12. Superposition patterns of the D_1 and D_2 phases

A — N–S trending fold truncated by northerly vergent thrust, Olbierzowice village near Klimontów; **B** — fold of the D_1 phase refolded in a limb of a bigger D_2 fold, Zbelutka Ravine (northern), location see Figure 2A, outcrop no. 6; **C** — superposition of two sets of corrugations: left — Ossolin IG 1 borehole, depth — 45 m, right — Zbelutka Ravine (northern); other explanations as on Figure 3

ments were reported from the Bardo Trough region (Czarnocki, 1919, 1939; Walczowski, 1968). It is not clear, however, whether the D_1 and D_2 represent two stages of a single, complex tectonic episode, or if they represent two separate and genetically independent tectonic phases. Although the available information does not allow clear answer to this question, a model based on a circumstantial evidence can be proposed.

The D_1, due to its kinematical and mechanical features, could be considered as genetically separate from D_2. The conclusions on intra-Cambrian deformation phase is supported by a long known, but never commonly accepted line of evidence of depositional discontinuities within the Cambrian of the Kielce Unit. Orłowski (1975) reported angular discordance between Kamieniec Shales and Usarzów Sandstones in Jugoszów village, but insisted on depositional continuity between Lower and Middle Cambrian arguing that this unconformity results from mechanical differences between two lithologies. Unfortunately the exposures discussed by Orłowski (*op. cit.*) are inaccessible now, and this interpretation can not be verified. Basing on topographical position of the Middle Cambrian Słowiec Sandstones, Kowalczewski (1995) interpreted this unit as unconformably overlying various levels of the Lower Cambrian. Contacts between Lower and Middle Cambrian are not exposed, but in some cases (e.g. in Konary and Beradz villages) they may be tectonic. An example of possible Lower/Middle Cambrian unconformity is a log of the Osiek 141 borehole (Kowalczewski, 1995). Its reliability is, however, limited by the fact that the age of the Osiek Sandstones, unconformably overlying *Holmia*/*Protolenus* (Kamieniec?) shales, is defined only by lithological similarities to the Słowiec Sandstones.

Absence of D_1 structures in the investigated Middle Cambrian (in particular in well-exposed sections in the Jugoszów and Beradz villages), and their inferred early diagenetic origin, suggest the timing of this phase at around the Early/Middle Cambrian boundary. Such interpretation is in concordance with the concepts of Czarnocki (1950) and Kowalczewski (1981, 1995) on the “Early Holy Cross Phase”.

The age of D_2 and D_3 deformations is difficult to determine. Both these deformations are usually attributed to an undivided early Tremadocian event (Mizerski *et al.*, 1986, 1991; Mizerski, 1994, 1995, 1998; Orłowski and Mizerski, 1995, 1996; Mizerski and Skurek-Skurczyńska, 1999). Taking into account only slight angular differences between tectonic components of compression during the D_2 and D_3 (Fig. 9B), these phases may be treated as genetically and temporarily related, but, as it has been proven, not contemporaneous. The pre-late Tremadocian cessation of D_3 in the Kielce Unit is likely, as the unconformity below Ordovician transgressive series reaches, in places, 90° (Chojnów Dół Ravine, southern Zbelutka Ravine).

In the Klimontów Anticlinorium, the sediments of late Middle Cambrian to the Early Ordovician are absent and there is no control on the timing of deformation. Therefore, the D_2 and D_3 age problem remains open until more evidence is provided, especially on the recently discovered (Szczepanik *et al.*, 2004), deformed Upper Cambrian in the Kielce Unit.

The interpreted pre-Ordovician tectonic development of the Cambrian in the Kielce Unit is presented in Figure 13.

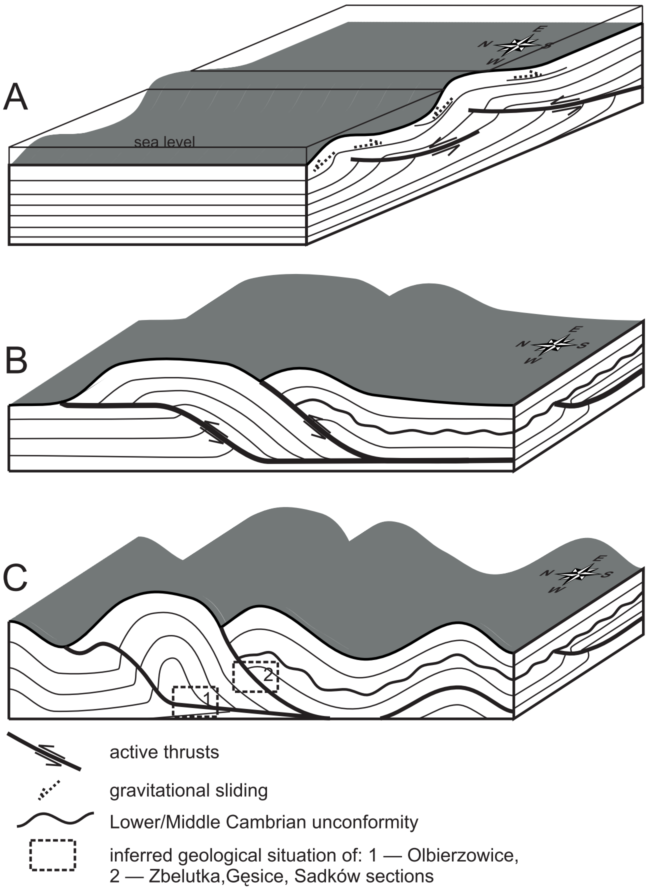

Fig. 13. Scheme of the inferred pre-Tremadocian tectonic development of the Kielce Unit

A — D_1, thrusting from the east associated with gravitational sliding, Lower/Middle Cambrian; **B** — D_2, thrusting from the south, before late Tremadocian; **C** — D_3, folding with steepening and passive amplification of older structures, before (?)late Tremadocian

DISCUSSION

In many aspects the proposed kinematics and time sequence of the inferred pre-late Tremadocian tectonic events depart from the previous interpretations of the early Caledonian (Sandomirian) tectonic phase in the HCM.

The structural model has three drawbacks: scarcity of field data, unclear nature of the D_1 episode and questionable position of the Ociesęki Sandstones. First problem is inherent in virtually any geological survey carried out in the Early Palaeozoic sequences of the HCM. The other two are related to the structural interpretation presented above.

In addition to limited amount of field data, caused by insufficient number of good exposures, the data themselves are often ambiguous and of poor quality. This problem arises from the fact, that dimensions of tectonic structures, especially those of D_2, exceed dimensions of most exposures. It makes determination of kinematics of inclined folds difficult, because limbs' lengths cannot be compared. In the author's opinion for this reason a great deal of uncertainty will remain as long as classical outcrop data are the sole base for tectonic interpretations. However, earlier concepts faced the same difficulties, thus it cannot be raised as an argument for sustaining a single-stage tectonic model.

An important problem is also the nature of the D_1 episode. As it has been pointed out, features of many of the structures described are similar to syn-sedimentary slumps. Earlier described evidence supporting their, at least partial, tectonic origin is only speculative and cannot be treated as ultimate. If, for example, future studies will reveal burrows cutting through the D_1 folds, the latter may appear as produced by submarine slumping. At this stage of investigations, however, tectonic factor is better evidenced.

Another issue to be solved is the behaviour and position of the Ociesęki Sandstones. This unit, more poorly exposed than the Kamieniec Shales, seems to record only the D_3 episode. If, as suggested by Orłowski (1975, 1988*a*, *b*, 1992), it is a lateral equivalent of the Kamieniec Shales, then the presence of D_1 tectonic event and separation of D_2 and D_3 may be questioned. Such a situation could be explained by mechanical differences between mudstone-dominated Kamieniec Shales and sandstone-dominated Ociesęki Sandstones. Until transitional facies are described, or tectonic contacts between these units are identified, this concept remains uncertain. Moreover, if the D_1 and D_2 structures are absent from the Ociesęki Sandstones, and the current extent of the Kamieniec Shales and Ociesęki Sandstones reflects their primary relations in the sedimentary basin, the conclusions on age of D_1 phase, based on its absence in the Middle Cambrian Usarzów Sandstones become doubtful. Lithologically, the Usarzów Sandstones resemble Ociesęki Sandstones and, if the latter did not record the phase in question due to mechanical differences, the same could be true for Usarzów Sandstones, thus the age of the D_1 would have to be reconsidered.

CONCLUSIONS

1. The pre-Tremadocian deformation of Cambrian in the HCM was polyphase and comprised tectonic processes of different kinematics.

2. The early D_1 event was associated with gravity-induced rock sliding on an uneven sea-floor, related to a development of westerly advancing thrusts.

3. The D_1 structures are confined to the Lower Cambrian Kamieniec Shales. Their lack in the Słowiec and Usarzów Sandstones constrains age of this tectonic event to the short interval around Early/Middle Cambrian boundary, which is in agreement with earlier postulated, but never directly evidenced early Holy Cross tectonic phase (Czarnocki, 1950; Kowalczewski, 1981, 1995).

4. The concept of the Lower/Middle Cambrian unconformity in the Kielce Unit is supported by tectonic evidence.

5. Structural features of the D_2 tectonic phase correspond well to a typical tectonics of thrust and fold belts.

6. The D_2 phase of the northerly vergent thrusts was succeeded by folding (D_3) caused by locking of the thrusting process.

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REFERENCES

BERTHELSEN A. (1992) — Mobile Europe. In: A Continent Revealed — the European Geotraverse: 11–32. Cambridge University Press.

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

CZARNOCKI J. (1936) — Przegląd stratygrafii i paleogeografii dewonu dolnego Gór Świętokrzyskich. Spraw. Państw. Inst. Geol., **8** (4): 129–200.

CZARNOCKI J. (1939) — Field work in the Święty Krzyż Mountains in 1938 (in Polish with English summary). Biul. Państw. Inst. Geol., **15**: 1–42.

CZARNOCKI J. (1950) — Geology of the Łysa Góra Region (Święty Krzyż Mountains) in connection with the problem of iron ores at Rudki (in Polish with English summary). Pr. Państw. Inst. Geol., **1**.

DADLEZ R. (1994) — Strike-slip movements in the Polish Lowlands. Geol. Quart., **38** (2): 307–318.

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

GRABOWSKI J. and NAWROCKI J. (2001) — Palaeomagnetism of some Devonian carbonates from the Holy Cross Mts. (Central Poland): large pre-Permian rotations or strain modified palaeomagnetic directions? Geol. Quart., **45** (2): 165–178.

KOWALCZEWSKI Z. (1981) — Key problems of the tectonics of the Palaeozoic core of the Holy Cross Mts. (in Polish with English summary). Prz. Geol., **29** (7): 334–340.

KOWALCZEWSKI Z. (1993) — Coarse-grained Cambrian deposits in Mid-Southern Poland. Biul. Państw. Inst. Geol., **366**: 5–37.

KOWALCZEWSKI Z. (1995) — Fundamental stratigraphic problems of the Cambrian in the Holy Cross Mts. Geol. Quart., **39** (4): 449–470.

KOWALCZEWSKI Z. (1997) — Fundamental stratigraphic problems of the Cambrian in the Holy Cross Mts. — reply. Geol. Quart., **41** (1): 81–83.

KOWALSKI W. R. (1983) — Stratigraphy of the Upper Precambrian and lowest Cambrian strata in southern Poland. Acta Geol. Pol., **33** (1–4): 183–218.

KOZŁOWSKI W. R. (2003) — Age, sedimentary environment and palaeogeographical position of the Late Silurian oolitic beds in the Holy Cross Mountains (Central Poland). Acta Geol. Pol., **53** (4): 341–357.

LAMARCHE J., MANSY J. L., BERGERAT F., AVERBUCH O., HAKENBERG M., LEWANDOWSKI M., STUPNICKA E., ŚWIDROWSKA J., WAJSPRYCH B. and WIECZOREK J. (1999) — Variscan tectonics in the Holy Cross Mountains (Poland) and role of the structural inheritance during the Alpine tectonics. Tectonophysics, **313**: 171–186.

MASTELLA L. and MIZERSKI W. (1981) — Deformation phases of the Middle Cambrian rocks it the Góry Pieprzowe (in Polish with English summary). Prz. Geol., **29** (7): 351–355.

MIZERSKI W. (1994) — Paleotectonic evolution of the Cambrian in the Holy Cross Mts. (in Polish with English summary). Prz. Geol., **42** (9): 721–727.

MIZERSKI W. (1995) — Geotectonic evolution of the Holy Cross Mts. in Central Europe. Biul. Państw. Inst. Geol., **372**.

MIZERSKI W. (1998) — Main problems of tectonics and tectogenesis of the Paleozoic in the Holy Cross Mts. (Central Poland) (in Polish with English summary). Prz. Geol., **46** (4): 337–342.

MIZERSKI W. and ORŁOWSKI S. (1993) — Main transversal faults and their importance for the tectonic of the Klimontów Anticlinorium (Holy Cross Mts.) (in Polish with English summary). Geol. Quart., **37** (1): 19–40.

MIZERSKI W. and SKUREK-SKURCZYŃSKA K. (1999) — Small tectonic structures of the Cambrian rocks in the middle part of the Klimontów Anticlinorium (Kielce block, Holy Cross Mts., Central Poland) (in Polish with English summary). Prz. Geol., **47** (3): 266–272.

MIZERSKI W., ORŁOWSKI S. and RÓŻYCKI A. (1986) — Tectonic of the Pasmo Ociesęckie and Pasmo Zamczyska ranges in the Góry Świętokrzyskie Mts. (in Polish with English summary). Kwart. Geol., **30** (2): 187–200.

MIZERSKI W., ORŁOWSKI S. and WAKSMUNDZKI B. (1991) — New data on geology of the Kamieniec Shale Formation (Lower Cambrian, Holy Cross Mts.). Geol. Quart., **35** (2): 149–160.

NAWROCKI J. (1999) — Prefolding remanent magnetization of diabase intrusion from the Bardo Syncline in the Holy Cross Mts. (Central Poland) (in Polish with English summary). Prz. Geol., **47** (1–2): 1101–1104.

ORŁOWSKI S. (1964*a*) — The Middle Cambrian in the Holy Cross Mts. (in Polish with English summary). Acta Geol. Pol., **14** (4): 547–556.

ORŁOWSKI S. (1964*b*) — Middle Cambrian and its fauna in the eastern part of the Holy Cross Mts. (in Polish with English summary). Stud. Geol. Pol., **16**.

ORŁOWSKI S. (1974) — Lower Cambrian biostratigraphy in the Holy Cross Mts., based on the trilobite family Olenellidae. Acta Geol. Pol., **24** (1): 1–16.

ORŁOWSKI S. (1975) — Cambrian and Upper Precambrian lithostratigraphic units in the Holy Cross Mts. (in Polish with English summary). Acta Geol. Pol., **25** (3): 431–448.

ORŁOWSKI S. (1985*a*) — Lower Cambrian and its trilobites in the Holy Cross Mts. Acta Geol. Pol., **35** (3–4): 231–250.

ORŁOWSKI S. (1985*b*) — New data on the Middle Cambrian trilobites and stratigraphy in the Holy Cross Mts. Acta Geol. Pol., **35** (3–4): 251–263.

ORŁOWSKI S. (1988*a*) — Stratigraphy of the Cambrian system in the Holy Cross Mts. Kwart. Geol., **32** (3–4): 525–530.

ORŁOWSKI S. (1988*b*) — The Cambrian in the Holy Cross Mts. (in Polish with English summary). Prz. Geol., **36** (1): 5–9.

ORŁOWSKI S. (1992) — Cambrian stratigraphy and stage subdivision in the Holy Cross Mountains, Poland. Geol. Mag., **129**: 471–474.

ORŁOWSKI S. (1997) — Fundamental stratigraphic problem of the Cambrian in the Holy Cross Mts. — discussion. Geol. Quart., **41** (1): 77–80.

ORŁOWSKI S. and MIZERSKI W. (1995) — New data on geology of the Middle Cambrian rocks in the Klimontów Anticlinorium (Holy Cross Mts.). Geol. Quart., **39** (3): 293–306.

ORŁOWSKI S. and MIZERSKI W. (1996) — The Cambrian rocks and their tectonic evolution in the Dyminy Anticline of the Holy Cross Mts. Geol. Quart., **40** (3): 353–366.

POŻARYSKI W. and TOMCZYK H. (1968) — Assyntian orogen in south-east Poland. Biul. Inst. Geol., **237**: 13–29.

RAMSAY J. G. and HUBER M. I. (1987) — The techniques of modern structural geology. Folds and Fractures, **2**. Acad. Press Inc. (London) Ltd.

SALWA S. (2002) — Deformacje tektoniczne skał staropaleozoicznych — zachodni odcinek jednostki łysogórskiej, Góry Świętokrzyskie. I Sesja Robocza Projektu Celowego — Zamawianego „Paleozoiczna Akrecja Polski”. Warszawa, 12–13.12.2002. Prz. Geol., **50** (12): 1221.

SAMSONOWICZ J. (1934) — Carte géologique générale de la Pologne 1:100 000, Feuille Opatów (in Polish and French). Państw. Inst. Geol. Warszawa.

STUPNICKA E. (1970) — Tectonics of Mesozoic rocks in the southern border of the Holy Cross Mts. (in Polish with English summary). Rocz. Pol. Tow. Geol., **40**: 393–409.

SZCZEPANIK Z. (1997) — Preliminary results of thermal alteration investigations of the Cambrian acritarchs in the Holy Cross Mts. Geol. Quart., **41** (3): 257–264.

SZCZEPANIK Z., TRELA W. and SALWA S. (2004) — Upper Cambrian in the Kielce Region of the Holy Cross Mts. — preliminary report. Prz. Geol., **52** (9): 895–898.

TOMCZYKOWA E. and TOMCZYK H. (2000) — The Lower Palaeozoic in the Daromin IG 1 borehole — confirmation of the concept of the terrane structure of the Łysogóry and Małopolska blocks (Góry Świętokrzyskie Mts.) (in Polish with English summary). Biul. Państw. Inst. Geol., **393**: 167–203.

WALCZOWSKI A. (1968) — Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1:50 000, ark. Łagów. Wyd. Geol. Warszawa.

ZNOSKO J. (1996) — Tectonic style of the Early Palaeozoic sequences in the Holy Cross Mountains. Geol. Quart., **40** (1): 1–22.

ZNOSKO J. (2001) — New data on Caledonian Alpine-style folding in the Holy Cross Mts., Poland. Geol. Quart., **45** (2): 155–163.

ŻAKOWA H. and JAGIELSKA L. (1970) — The oldest fossils of Lower Cambrian age in the Świętokrzyskie Mts. (in Polish with English summary). Kwart. Geol., **14** (1): 9–28.

ŻYLIŃSKA A. (2002) — Stratigraphic and biogeographic significance of Late Cambrian trilobites from Łysogóry (Holy Cross Mountains, central Poland). Acta Geol. Pol., **52** (2): 217–238.