Geological Quarterly, 2013, **57** (1): 175–180
DOI: http://dx.doi.org/10.7306/gq.1070

Tectonics of the Chęciny Anticline (Holy Cross Mts., central Poland) in the light of new cartographic data and calcite vein analysis (discussion)

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Mastella L., Konon A., Dwornik M., Ludwiniak M., Rybak-Ostrowska B. and Śmigielski M. (2013) Tectonics of the Chęciny Anticline (Holy Cross Mts., central Poland) in the light of new cartographic data and calcite vein analysis (discussion). Geological Quarterly, **57** (1): 175–180, doi: 10.7306/gq.1070

Jurewicz and Stępień (2012) discussed the geometric reconstruction of the Chęciny Anticline based on new map data. The two, newly found exposures of Cambrian rocks, not reported previously from the southern limb of the fold, and fracture analysis based on data from Rzepka Quarry, enabled these authors to propose different interpretations of structures mapped earlier by Czarnocki (1938, 1948), Filonowicz (1967) and Hakenberg (1973). Moreover, Jurewicz and Stępień (2012) provided new interpretations of the evolution of the Chęciny Anticline, on associated transverse faults and extensional fractures, as well as providing an estimate of the strain ratio in the Kielce fold zone.

Several of their interpretations are challenged in this discussion. Particularly, we consider that some of their arguments, i.e. concerning the presence of Cambrian rocks at the locations shown by the authors and regarding the geometry and formation of folds, components of movement across the fault planes, their model of development of the extensional fractures, the timing of the structure's formation, as well as their terminology are misleading and are in need of amendment.

Jurewicz and Stępień (2012) described "two new Cambrian outcrops" located near Chęciny: one located to the west, and the second to the east of Rzepka Hill. We have conducted geological mapping in both areas. At the first location, below a thin clay layer with fragments of quartzitic sandstone of probable Cambrian age, we have found red ferruginous and siliceous quartz sandstones representing the Buntsandstein facies referable to the Lower Triassic, as well as Middle Devonian dolomites (Fig. 1). At the second location, no fragments of quartzitic sandstones that could be assigned to the Cambrian have been found. Only regolith was found there, with fragments of white and yellow quartz sandstone, poorly cemented and free of iron oxides. The sandstone most probably belongs to the Lower Triassic Buntsandstein facies.

Based on data from those two outcrops, Jurewicz and Stępień (2012) discussed the geometry of the fold profile of the Chęciny Anticline in the Holy Cross Mountains fold belt. They considered that it formed due to diapiric-like movements, with a local detachment formed at the boundary of competent and incompetent rocks, and they have misinterpreted Konon (2006) in support of their interpretation. Konon (2006) merely suggested that detachment horizons played a significant role in the deformation, although not during the "Alpine orogenesis" as indicated by Jurewicz and Stępień, but during Late Paleozoic deformation when the Holy Cross Mountains fold belt formed by buckle – folding of the sedimentary rocks.

A typical diapiric fold forms when the strong/brittle overburden is pierced by ductile rocks (Dadlez and Jaroszewski, 1994). Jurewicz and Stępień (2012) did not consider the problem of how the strong overburden could have been pierced in the hinge zone or the bending of the fold limbs if the longitudinal faults, along which such processes took place, are normal faults as the authors suggest (Jurewicz and Stępień, 2012: fig. 7A). They discussed also the absence of any faults in the process, as shown in the block-diagram of the Chęciny and Wrzosy anticlines and Rzepka Syncline (Jurewicz and Stępień, 2012: fig. 4) and in geological maps documenting the present-day geological setting after the youngest deformation stages (Jurewicz and Stępień, 2012: fig. 2A, B).

On both sides of the core of the Chęciny Anticline exposures of Devonian rocks occur, the position of which suggest the activity of reverse faults occurring mainly on the boundary between the Cambrian and Devonian strata, as suggested by Kowalski (1975; Fig. 2). Moreover, the authors did not take into account the facies variability of Cambrian deposits observed in the Kielce region. The core of the Dyminy Anticline, located to the north of the study area, is built of Lower Cambrian sandstones and siltstones with a much larger compressive strength than the Cambrian rocks occurring in the core of the Chęciny Anticline. These Cambrian sandstones cannot indicate possibly

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Received: October 15, 2012; accepted: October 17, 2012; first published online: January 11, 2013

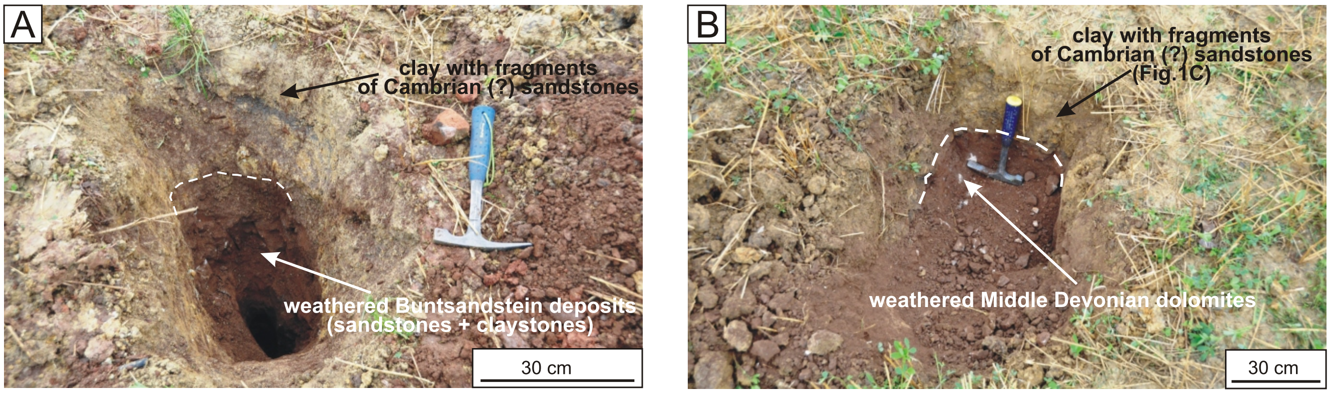

Fig. 1. Excavations within the weathered Buntsandstein rocks

A – location N50°48'04.5", E20°26'07.9" – Middle Devonian dolomites; **B** – location N50°48'03.6", E20°26'06.7" near Korzecko village; **C** – detailed view of fragments of Cambrian (?) sandstones from the sub-surface

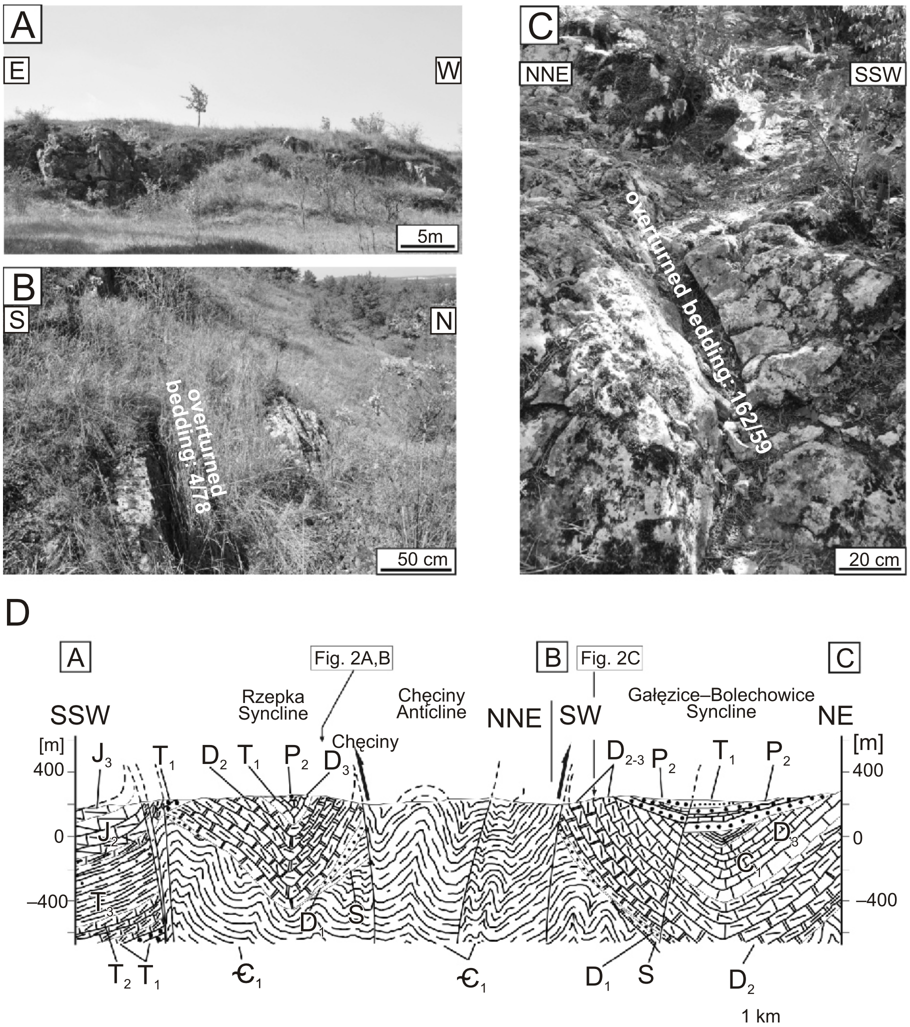

Fig. 2. Outcrops of overturned strata of the Devonian limestones on the northern slope of Sosnówka Mt. (A, B) and on the ridge of Zelejowa Mt. (C) and geological cross-section (D) through the southern part of the Kielce fold zone

$Ꞓ_1$ – Lower Cambrian sandstones and shales; S – Silurian shales; D_1 – Lower Devonian sandstones; D_2 – Middle Devonian dolomites and limestones; D_3 – Upper Devonian limestones and shales; C_1 – Lower Carboniferous shales; P_2 – Upper Permian conglomerates and limestones; T_1 – Lower Triassic sandstones and shales; T_2 – Middle Triassic limestones; T_3 – Upper Triassic shales; J_2 – Middle Jurassic gaizes and shales; J_3 – Upper Jurassic limestones; for location of the cross-section see Figure 3

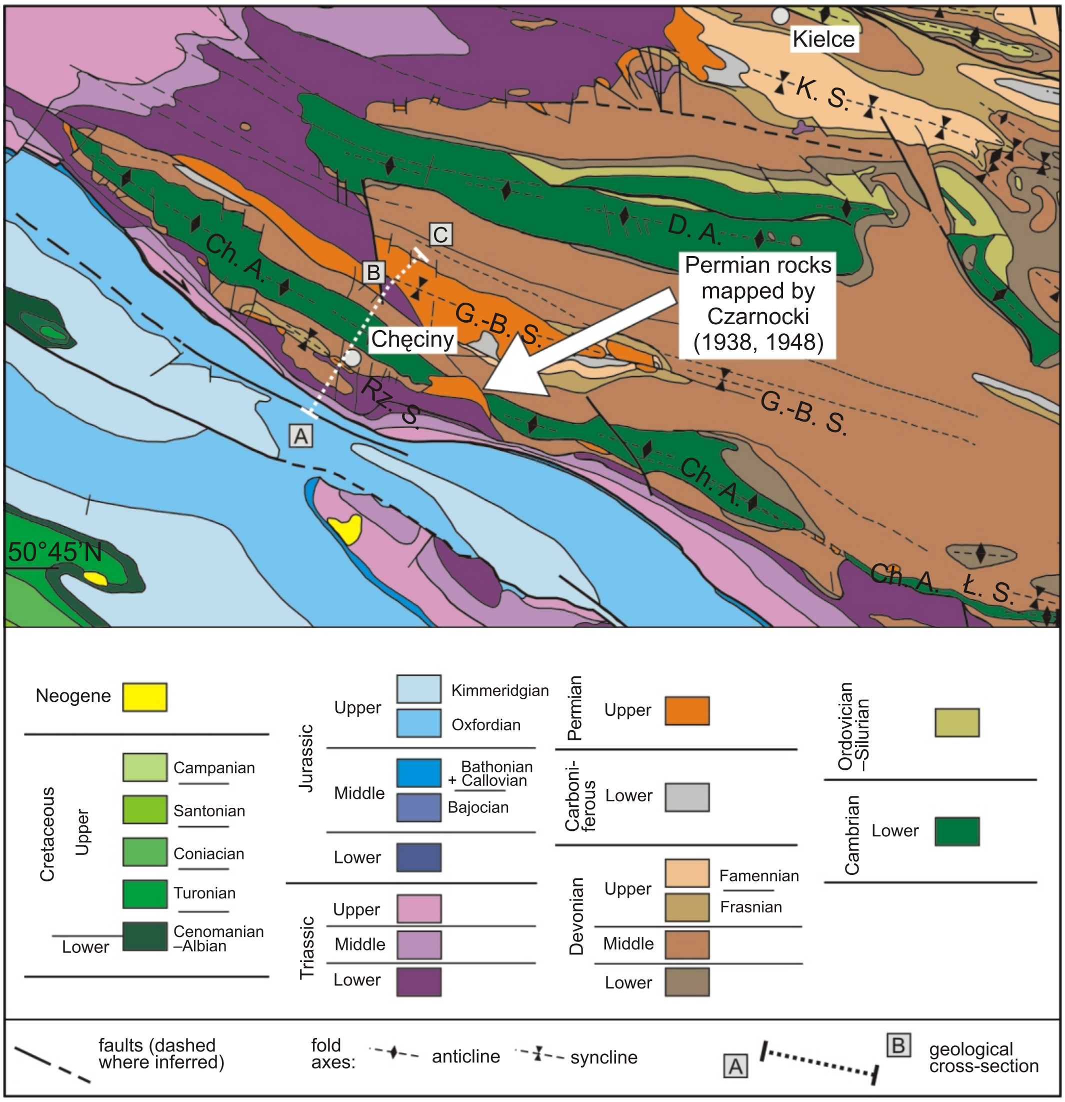

Fig. 3. Geological map of the southwestern part of the Holy Cross Mountains (after Czarnocki, 1938, 1948; Filonowicz, 1973; Konon, 2007, modified)

Map-scale folds: Ch. A. – Chęciny Anticline; D. A. – Dyminy Anticline; G.-B. S. – Gałęzice–Bolechowice Syncline; K. S. – Kielce Syncline; Ł. S. – Łabędziów Syncline; Rz. S. – Rzepka Syncline

highly ductile behaviour if the Devonian rocks that are folded with them do not show any signs of metamorphism.

The possibility of fold formation due to horizontal shortening, in the presence of normal faults or in the absence of any faults as indicated by Jurewicz and Stępień (2012) is also in contradiction to the results of Dębowska (2004: fig. 5 – stage C), in which the tectonic evolution of the Chęciny Anticline near Miedzianka Hill was described.

Jurewicz and Stępień (2012) described in their paper the formation of folds as well as extensional fractures and normal faults in the Holy Cross Mountains fold belt and provide their own interpretations. For example, they discussed the uplift stage of this fold belt based on what they suggest is new data, although the presence of exposures of Permian rocks unconformably covering folded Cambrian and Devonian strata has been known from the area for over 70 years (Czarnocki, 1938). These exposures are very important, because they directly indicate the significant role of Late Paleozoic deformation in the development of the Holy Cross Mountains fold belt as well as the considerable uplift of the fold belt immediately before the Permian. One of the most well-known exposures of Permian rocks occurs ca. 2 km to the east of Chęciny and was first marked on the maps of Czarnocki (1938, 1948), and later also on 1:50 000 geological maps by Filonowicz (1967) and Hakenberg (1973), something not noted by the authors, although they did refer to these maps (Jurewicz and Stępień, 2012; Fig. 3). Thus the question again arises of when the folds formed in the Holy Cross Mountains fold belt and when their shape profiles could have been modified, if according to Jurewicz and Stępień (2012) the diapiric-like re-arrangement of the Variscan anticline structures was a result of Alpine orogenesis. As shown by geological maps (Czarnocki, 1938, 1948; Filonowicz, 1967; Hakenberg, 1973), Permian rocks unconformably cover Cambrian rocks in the hinge zone and Devonian rocks on the limbs. This obvious inconsistency remains unexplained by Jurewicz and Stępień (2012).

Based on observations carried out in Rzepka Quarry, Jurewicz and Stępień (2012) described a model of formation of calcite-filled extensional fractures, suggesting their syn-fold origin. However, the age of brittle fractures cutting the Devonian rocks is variable, as shown e.g., by Konon (2004). We suppose that Jurewicz and Stępień (2012) desired to discuss the age of the calcite-filled extensional fractures described from Rzepka Quarry, but the age of these structures has been earlier determined in several studies (e.g., Konon, 2004, with references therein). Jurewicz and Stępień (2012) referred to these papers in the Introduction, but not in the discussions and conclusions chapters of their paper.

Similarly, when describing the folds and their ages, Jurewicz and Stępień (2012) omitted the palaeomagnetic data from the area, from which the age and magnitude of deformation may be estimated more precisely. These studies showed the Late Paleozoic age of the folds (Szaniawski et al., 2011, with references therein), although they do not exclude slight modification of the earlier formed folds, which probably took place at the Maastrichtian/Paleocene boundary (Szaniawski et al., 2011, with references therein).

Application of digital image analysis to geological data is almost always a good choice when values of geometric or statistical parameters need to be obtained. Rapid and precise data on areas, orientations of elongations or distribution of grain diameters may be obtained using digital methods in comparison to traditional methods such as spot or linear metering. On the other hand, these methods, like all computational methods, are based on the rule: garbage in, garbage out. Poor quality or incorrect data will provide incorrect results.

In Jurewicz and Stępień (2012) such flaws are clearly evident. The main goal of image analysis was to obtain the percentage ratio of clasts and mineralization in the two types of breccia. Jurewicz and Stępień (2012) assumed that only clasts and pixels relating to mineralization are visible on the images. This assumption is true only when there are no: (a) third parts (i.e., pore space, fluids, organic matter), and (b) areas where detection and subsequent verification of classification is non-unique or impossible. In their figure 8A the second condition is not fulfilled; the photograph shows areas of shadow that are detected as clasts. In their figure 8B the areas that look like "iron" mineralization are classified sometimes as clasts and sometimes as mineralization. It is impossible, due to the quality of the printed photograph, to distinguish whether the "iron" mineralization mentioned above is on the surface of the outcrop or is part of the rock, i.e. at the boundary between the clasts and mineralization. In both images presented in the paper, the analysis should be divided into two separate parts: detection of clasts and detection of mineralization.

An additional problem is the lack of cleaning methods after thresholding. Even the simplest methods, such as median filtration or morphology operation (e.g., Gonzales and Woods, 2008), may eliminate small objects and gaps, which the classification is not capable to verify (e.g., isolated pixels). These small areas are mainly the results of noise – artefacts caused by the thresholding process (i.e., a problem with precise and adequate values and the thresholding method). Lack of description of these methods and the final results presented suggest that the method mentioned above was not applied. It was used for example in the paper by Heilbronner (2000), which was cited by the authors, and may significantly improve the quality of the analysis.

Moreover, Jurewicz and Stępień (2012) did not state the number of the images analysed and the percentage part of analysis area in comparison to the area of the entire outcrop/sample/thin section. It is impossible to determine whether the results of their analysis may be extended over the entire area; they analysed only two types of breccias and there is no information about the differences between these two types (i.e., whether the transition between the breccias is continuous or sharp).

All of these make the results of the analysis doubtful. The interpretation of shadows as clasts, lack of post-thresholding filtration or of statistical information regarding the analysis (such

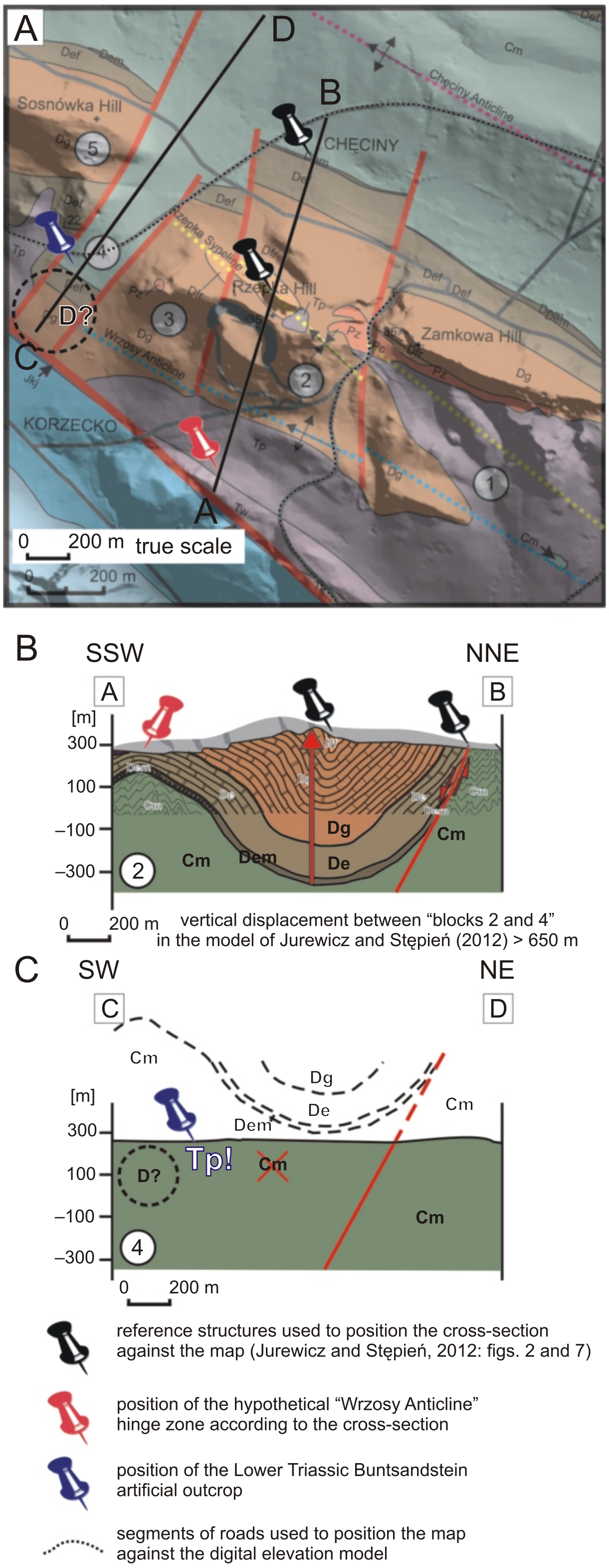

Fig. 4. Geological map and schematic cross-sections through "blocks 2 and 4" (based on Jurewicz and Stępień, 2012, modified herein)

A – bedrock geology merged with a digital elevation model; **B** – cross-section through "block 2", red vertical arrow shows the minimal amount of relative displacement between "blocks 4 and 2" needed to generate the geological model presented by Jurewicz and Stępień (2012); **C** – cross-section through "block 4", dashed circle – position of Devonian strata according to the map of Jurewicz and Stępień (2012); Tp – Lower Triassic (Buntsandstein), D – Devonian (Dg – Givetian, De – Eifelian, Dem – Emsian), Cm – Cambrian as errors and the number of images analysed) detract from the results of Jurewicz and Stępień (2012).

Another issue is their describing all image processing methods using the phrase "numerical". It is commonly accepted to refer to these methods the phrase "digital" or "computer" (i.e., Gonzales and Woods, 2008; Pratt, 2001). The phrase "numerical" is limited only to some classes of algorithms, applied to estimate the solution of mathematical problems (examples of these algorithms can be found in, e.g., Press et al., 1988).

Jurewicz and Stępień (2012) stated that "...the Rzepka Syncline and Wrzosy Anticline together form a subordinate (second-order) fold within the southern limb of the Chęciny Anticline". This statement suggests that the authors define a fold as a tectonic structure composed simultaneously from an anticline and a syncline. Such definition was used many decades ago, but at present, with the significant development of geophysical analysis, a fold is defined as a bend or flexure of layered rock in one of two basic types: anticline and syncline (e.g., Twiss and Moore, 1992; Shaw et al., 2005). The application of an older definition may lead to extreme cases when the major fold types recognized in fold-and-thrust belts comprising fault-propagated folds, fault-bend folds and detachment folds (e.g., Thorbjornsen and Dunne, 1997) would be described as "half-folds".

As we show on Figure 4, the cross-section and geological map presented by Jurewicz and Stępień (2012) are mutually contradictory. The presence of Devonian rocks in the southwestern part of "block 4" cannot be explained by normal faulting and was not discussed by the authors; the large amount of vertical displacement (>650 m) needed to create the proposed geological structure remains also unclear (Fig. 4).

Summing up, Jurewicz and Stepień (2012) concluded that their observations carried out in two newly found outcrops of Cambrian rocks and in Rzepka Quarry allow the formulation of new interpretations of the geological structure of the Chęciny Anticline near Chęciny. According to us, the authors did not present any evidence in the form of photographic documentation for the existence of these exposures of Cambrian rocks at the locations given, while our geological mapping did not confirm the presence of such rocks. This place doubt on their conclusions.

The model of fold formation in the Holy Cross Mountains fold belt presented by Jurewicz and Stępień (2012) based on a small fragment of the Chęciny Anticline, suggests the possible activity of "diapiric-like movement" and "diapiric-like tectonics". However, their arguments are mutually contradictory, because by suggesting horizontal compression during folding they support the formation of normal faults that are parallel to the fold axis, as well as the absence of longitudinal faults. Moreover, their observations are inconsistent with earlier observations of the junior author of this note, that showed the formation of a longitudinal contractional fault of Triassic–Early Jurassic age, i.e. after the main deformations in the Holy Cross Mountains fold belt. How this was determined remains an open question. Additionally, when describing the uplift of the Holy Cross Mountains fold belt Jurewicz and Stępień (2012) did not refer to the well known geological maps of Czarnocki (1938, 1948), Filonowicz (1967) and Hakenberg (1973).

Jurewicz and Stępień (2012) inferred the age of calcite-filled extensional fractures, but did not refer in discussion earlier reports on this topic (e.g., Wrzosek and Wróbel, 1961; Rubinowski, 1971; Wierzbowski, 1997; Lewandowski, 1999; Konon, 2004), in which the model of fracture formation was extensively discussed. When describing the tectonic structures in the Holy Cross Mountains fold belt, the authors made no reference to published palaeomagnetic data (Szaniawski et al., 2011, with references therein).

Image analysis conducted by Jurewicz and Stępień (2012) has been carried out incorrectly. Flaws include image analysis of an uneven surface, where distinct shadows visible on the photographs presented are interpreted as clasts or mineralization, lack of information on the number of samples analysed (perhaps only the two examples illustrated?), lack of measurements of the calcite veins and the bedding result in concern whether the extension was correctly estimated, particularly in the light of the fact that the analysis was made from a 200-m long quarry wall and extended over the entire Kielce fold zone. It remains an open question of how the 30% shortening was calculated on the basis of the cross-section by Hakenberg (1973), as this cross-section was not balanced.

In our opinion, the absence of exposures of Cambrian rocks at locations stated, incorrect application of the terminology and methodology, mutually inconsistent observations, and lack of reference to the conclusions of earlier reports indicate that the interpretations of the authors as regards the geological structure of the part of the Chęciny Anticline analysed remain undocumented and largely unjustified.

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