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DISCUSSION

ON Konon, A. **Strike-slip faulting in the Kielce Unit, Holy Cross Mountains, central Poland**, *Acta Geologica Polonica*, vol. 57, no. 4, 2007

JOLANTA ŚWIDROWSKA AND JULIETTE LAMARCHE comment: The title of the article is actually somewhat confusing, since the article concerns both parts of the Holy Cross Mts (Kielce Unit and Łysogóry Unit), not only the Kielce Unit.

Particular points, regarded by us as controversial, are systematically discussed and alternative interpretations proposed. The critical points listed below question the value of the main conclusions of the paper and of the methodology used by the author.

Point 1: Were longitudinal faults reactivated? The author mentioned (p. 417): “During folding, a reverse sense of the dip-slip component predominated on the longitudinal faults (e.g. Czarnocki 1957b; Kowalczewski and Rubinowski 1962; Filonowicz 1970, 1973) [...] On the surfaces of the steeply-dipping beds, in addition to the older dip-slip component resulting from the flexural slip mechanism (Text-fig. 4, area 1), evidence for a younger strike-slip component can also be seen (e.g. Text-fig. 4, area 2)”. The author has not clearly demonstrated that a genetic relationship exists between the dip-slip reverse movement on the bedding plane and the main fault. In particular, the structural position of the bed illustrated in Text-fig. 4 is not precisely related to the main fault. Consequently, the strike-slip striation on the bedding plane does not necessarily mean that the main fault was also reactivated. In several studies, Lamarche *et al.* (1999, 2000, 2002, 2003) have shown that the whole Holy Cross Mountains (HCM) and adjacent areas have been affected by numerous Late Cretaceous/Paleocene strike-slip faults, which reactivated Late Variscan fractures (Lamarche 1999). Therefore, we question the age of the strike-slip reactivation on the bedding plane shown by A. Konon. Our alternative explanation is that the strike-slip displacement results from the overall Late Cretaceous/Paleocene stress, and not from Late Palaeozoic reactivation of the larger faults.

Point 2: Is the fault pattern in the HCM typical example of strike-slip tectonics? The descriptions of structures associated with faults given by A. Konon cannot be treated as typical of strike-slip displacements. According to former field studies (Lamarche *et al*. 1999, 2000, 2002, 2003), the present-day fault pattern results from the superposition of several faulting events since the Devonian.

2.1. Contractional folds: The author interpreted the geometry of the southern limb of the Miedziana Góra Syncline as split by a dextral fault (X-X) into two parts with different styles of deformation (Text-fig. 6, reprinted from Konon 2006). The contractional fold hypothesis is not convincing. If the calculated strike-slip displacement of 25 m along the X-X fault were to be restored in Text-fig 6c, the folds in the lower face would lie at the foot of the zone in the upper face where the bedding planes are obscured (part 1 in Text-fig. 6c). In contrast to Konon`s interpretation, the degradation of this part of the face could have resulted from stronger fracturing of folded layers.

Part 1 in Text-fig. 6a in the upper level should be compared with an invisible fragment of the lower exploited level located to the left from the margin of this figure. The misleading interpretation is shown on a Text-fig. 6b. We may here add a remark to the author’s statement (p. 421): “…the faults were active as dextral strike-slip faults (Konon 2006b, fig. 7b)” - the dextral sense of displacement was first demonstrated by Prof. M. Szulczewski on the basis of the offset of Frasnian/Famenian boundary.

In the case of contractional folds synchronous with the fault, the fold axes ought to be bent in the vicinity of the fault, like drag folds. This is not observed in the case of the Kostomłoty Quarry. The figure discussed actually shows the fault cutting through the folds without any influence on the strikes of the fold axes. This favours a post-fold faulting origin.

The whole Kostomloty Quarry shows more deformations. Lamarche *et al.* (1999, p. 179, fig. 6b) published a ~80 m wide cross-section of the quarry which reveals a disharmonic style of folding of Variscan age. Dextral faults striking N–S and affecting Devonian rocks (Rzepka Quarry) have already been described by Lamarche *et al.* (1999) and by Lewandowski *et al.*

(1999) and referred to post-Permian (Late Cretaceous) deformation on the basis of structural and palaeomagnetic data.

2.2. Extensional imbricate fan of faults: The faults in Text-fig. 7 do not form a "fan". A fan is a semi-circular or smaller sector of circle shape (Harrap's Chambers concise dictionary 2004). The author states that (p. 421): "half-graben type tectonic blocks occur at the south-eastern tip of the Daleszyce Fault". The normal faults and half grabens evidently occur along almost the whole length of the Daleszyce Fault, and not only at its tip (see the length of DIF shown in Text-fig. 3. A. Konon also writes: "These faults strike about 60° at the Daleszyce Fault". His Text-figs 7 and 3 clearly display an average angle of ~90° between the Daleszyce Fault and the normal faults. This angle decreases only locally over short distances near the Daleszyce Fault. In any case, the fault geometry near the Daleszyce Fault is not similar to the typical fault termination with a fan of normal faults (see Twiss and Moores 1992, p. 121). Finally, the term "secondary fault" is not appropriate, as the normal faults are of comparable length to the main Daleszyce Fault. The "extensional imbricate fan" origin of the faults cannot be demonstrated in a dextral strike-slip context.

2.3. Horsetail splay: The horsetail splay is a strike-slip fault termination feature in which the main strike-slip fault divides into several faults of the same sense distributed in a fan shape (comp. Twiss and Moores 1992, p. 121). The Łysogóry Fault (Text-figs 2, 3) does not end near the splay (north of Nowa Słupia) but propagates northwestwards through the Wydryszów Anticline.

Secondly, the easternmost fault of the splay is sinistral or it could be interpreted as a dip-slip fault with a southeastern footwall (see the author's geological map, Text-fig. 2). Therefore, these faults are not a "horsetail splay" termination. We interpret this geometry as a set of synthetic faults, conjugate with the Łysogóry Fault. They developed in a curvature zone of the main fault. The relationships between the Łysogóry Fault and the associated faults were described and published by Jaroszewski in his handbooks (1974, 1980; Dadlez and Jaroszewski 1994).

2.4. Stepping and stopovers: A. Konon uses stepping geometry to decipher the strike-slip sense of movement along two fault zones cutting the Baćkowice Anticline (Bc a), and the Łagów-Michałów Fault (ŁMF) zone (Konon 2007, Text-figs. 2 and 3). The rule usually applied (see the article cited, Schreurs 2003; also Acocella and Neri 2005, p. 353, fig. 13; Katz *et al.* 2004, pp. 492, 493, figs 1, 3) is the following: right-stepping *en échelon* faults are sinistral and left-stepping *en échelon* faults are dextral. A. Konon interprets the faults stepping in the opposite way. According to the rules, the arrows along both fault zones (the ŁMF and zone cutting the Bc a) ought to be reversed. However, in particular conditions, the sense of displacement may be dextral as well as sinistral in both geometries (Twiss and Moores 1992, fig. 7.5, p. 117). Hence, the criteria to distinguish reliably between dextral or sinistral shear along faults are (1) compression or extension across the bends and stepovers; or (2) kinematic indicators on faults, such as slickensides. In the case of the ŁMF and fault zone cutting the Bc a, the stepping geometry on Text-figs 2 and 3 is not obvious because the step offsets are very small.

Another interpretation of strike-slip structure is presented northeast of Daleszyce. The general arrangement of several N–S faults is interpreted as a restraining stepover between longitudinal left-stepping fault segments. However, the southern longitudinal fault does not end, but continues to the ESE (the map on Text-fig. 8c). Hence, the conceptual model in the lower part of Text-fig. 8c does not reproduce the true fault pattern. Concerning the sense of shearing, dextral strike-slip along WNW–ESE main faults should have induced dextral shear along N-S faults (compare Dadlez and Jaroszewski 1994, p. 94, fig. 81). As the genetic and geometric relationship between N–S and WNW–ESE faults has not been demonstrated here (sinistral N-S faults), the model is not valid.

The offsets of slope values in Text-fig. 8d are treated as an argument for a sinistral strike-slip sense of the faults. The picture comes from a Digital Elevation Model (Konon and Śmigielski 2006). This means that the slope values relate to the topography. The offset of slope topography displayed in Text-fig. 8d cannot be directly interpreted in terms of strike-slip displacement of geological layers because reverse or normal displacements of homoclinic layers along faults result in an apparent strike-slip pattern after erosion.

In the case of the Piskrzyn Quarry (Text-fig. 8a), A. Konon argues for a sinistral strike-slip of three metric faults, albeit strike-slip zones should be characterized by steeper dips. This quarry is located (no. 11 on Text-fig. 13) almost on the fault zone cutting the Baćkowice Anticline. This fault zone was indicated in Text-fig. 3 as a right-stepping dextral one. These interpretations are mutually contradictory.

Most of the examples described by A. Konon as "stepping and stepovers" can be reinterpreted as transverse fault zones cutting through the main Variscan faults and folds. Therefore, they could have originated from the Late Variscan brittle event due to the post-folding uplift and stress relaxation. They were reactivated during the Late Cretaceous–Paleocene compression (Lamarche *et al.* 2002, 2003).

2.5. Drag of beds: We would like to point out that only one example illustrated in Text-fig. 9a is relevant. The three strike-slip faults shown in Text-fig. 9d (Śluchowice Quarry) have been already explained (Lamarche *et al*. 1999), together with an E–W sinistral set, as a consequence of NE–SW compression (Lamarche *et al.* 1999, fig. 5) and dated as Late Cretaceous, albeit their earlier origin cannot be excluded.

Another "drag fold" is shown in Text-fig. 9b as a map-scale structure. However, the colour scale is not given, so we do not know the significance of the picture and of the white dashed line. If it represents a bedding surface, the fault does not cut through or displace the dashed line. Therefore, it is hard to understand the drag fold interpretation.

2.6. Rotated blocks: This chapter starts with the interpretative sentence (p. 424): "To the north and south of the HCF there are two zones, up to 5 km wide, composed of fault-bounded block domains rotated around their vertical axes." The author develops the kinematic hypothesis presented by Mastella and Mizerski (2002) for the Łysogóry Unit. He quotes their results and accepts their conclusions but simultaneously, on his own map, he changes the sense of fault displacement between the Wiśniówka and Radostowa blocks and deletes the segment of the Łysogóry Fault on the southern side of the HCF (compare his Text-figs 14a and b with fig. 6 of Mastella and Mizerski 2002, p. 770). No argument is given for these important changes in the geological map, which is the basis for for the kinematic interpretations. Rotated blocks to the north of the HCF (Mastella and Mizerski 2002) were already the object of discussion (Świdrowska 2003).

A Konon states that the sense of rotation of the fault-bounded blocks is shown by rotation of fold axes within the individual blocks. However, fold axes are not displayed on the map (Text-fig. 14a) and the occurrence of one single fold axis prior to fault displacement has not been demonstrated. His kinematic reconstruction assumes that the major border fault cuts through the three blocks like a plane. This conceptual model is not appropriate for several reasons. First, the length ratio between longitudinal and transverse faults does not fit the mechanical rules for rotated blocks (compare Dadlez and Jaroszewski 1994, figs 81 and 193 D). Second, if the NW-edges of the blocks crossed the HCF, it would have impeded further dextral displacement. Third, these edges cannot disappear ("disintegrating part" – explanation of Text-fig. 14c).

The block-rotation model of the author, showing dextral shear between the two WNW–ESE major faults and the transverse NW–SE-striking sinistral faults, affords another counterargument to this model. A consequent position (NW–SE) of the transverse faults has to imply dextral displacements, while an obsequent (NE–SW) position implies sinistral displacements. It cannot be observed in the example south of the HCF (Text-fig. 14c).

In conclusion, we agree with the segmentation of the HCM into blocks, separated by NW–SE to N–S faults, but neither convincing data nor an appropriate kinematic model is presented in support of rotation of the blocks around vertical axes.

Point 3: Discussion of the quantitative method of fault and palaeostress analysis: In this chapter we point to the weakness of the palaeostress calculation and the disputable use of P and T axes. The author explains (p. 417) that faults are considered synchronous and conjugate (see chapter "Methods") when an angle of <75° separates two faults in a single bed observed in one outcrop. Although an angle of <75° is characteristic of conjugate faults, this feature alone is inadequate to demonstrate the synchronism of two faults. The geometrical aspect must be corroborated with arguments such as crosscutting relationships and the nature (sense, mineralization, size) of the striations. In this context, the methodology given by Konon for identifying conjugate faults is imprecise and incomplete.

The palaeostress calculations based on softwares such as the *TectonicsFP* used by A. Konon are statistical methods. The results are valid when the number of fault data is large (a minimum of four faults for each calculation, Angelier 1984, Carey 1979). In addition, the faults must be conjugate in order to obtain a well-constrained stress tensor.

Looking at Text-figs 11 and 12 of Konon's paper, 23 calculations out of 35 are made with only four or five fault measurements, and 18 calculations are applied to a single fault set without a conjugate one. Looking at the confidence cones, calculations based on sites 2a, 2b, 3, 5a, 6, 7, 8a, 8b, 8c, 9, 22, 12, 13, 16, 17, 18a, 19b, 20, 21, 22, 23, 25, 26 have such large confidence cones that they cannot be considered valid. As a result, only 12 calculations (1, 4, 5b, 10, 14, 15a, 15b, 18b, 19a, 24a, 24b, 27) are of good to medium quality.

A. Konon distinguishes two stress patterns associated with two fault systems. The first one (N–S to NE–SW dextral and W–E sinistral faults) is deduced from14 diagrams, but only six of them contain conjugate faults sets. The second stress pattern (W–E to WNW–ESE dextral and NW–SE to N–S sinistral faults) is deduced from 19 diagrams, of which only five have conjugate faults sets.

A. Konon deduces two average shortening directions (Text-figs 13d and e). We have to presume that the average direction is graphically deduced as the bisector of the angle comprising the shortening axes. If so, this method is not valid, since the author (1) does not take the confidence cones (Text-figs 11, 12) into consideration; (2) does not consider the distribution of the dots (values of greatest frequency); (3) arbitrarily separates two sets of P axes. Very similar shortening directions with an approximate E–W azimuth are split into two groups (Text-figs 13d and e) with perpendicular average shortening directions. If all shortening (dots) and extension (triangles) axes were plotted together on a single diagram, it would not have been possible to distinguish the two groups of axes. Axes are randomly ranging from N000° to N360° in azimuth. In particular, shortening axes with an azimuth around N090° have been separated in the diagrams of Text-figs 13d and e, albeit they have very similar azimuths. In contrast, the shortening directions with azimuth from ~E–W to ~N–S have been associated with the same average shortening direction.

Point 4: Timing of the strike-slip faulting: The age of faulting is indirectly discussed in the chapter "Minor strike-slip faults". Palaeostress calculations must be accompanied by bedding measurements because these are of major importance for dating purposes. This is omitted from the author's considerations, albeit it enables the pre-, syn- or post-folding age of faulting to be deciphered. This is particularly important in the Kielce Unit where the Palaeozoic rocks have been intensively deformed during Cretaceous/Paleocene tectonic activity.

The author writes (p. 424): "The attitudes of the measured fault sets in the Devonian rocks are similar to those occurring in the overlying Permian–Triassic rocks (Text-figs 11 and 12)." However, the comparison is made with only 12 faults from the Permian–Triassic rocks (8c, 19b, 22, Text-figs 11, 12) and only one site with conjugate faults (Jaźwica Quarry, diagram 19b). A. Konon does not take into consideration the Mesozoic age of displacements on the faults measured and shown on maps of the Palaeozoic area. According to the author, faults measured in the Palaeozoic rocks are of Variscan (or Late Variscan) age, and faults observed in the Mesozoic rocks, located north and south of the HCM, are of Maastrichtian/Paleocene age.

In considering the chronology of two brittle Palaeozoic events A. Konon writes (p. 430): "The N–S-striking dextral strike-slip faults such as the Łysogóry Fault, Psary Fault [...], as well as an **approximately NE–SW striking sinistral set** [our emphasis], were probably active during the I-1 event." In fact no NE-SW sinistral fault set is described in the whole paper. Concerning the age of the I-2 event A. Konon argues (p. 431): "the lack of significant displacement of Cambrian strata along the Łysogóry Fault […] indicates that the displacement which occurred along the HCF was younger than that which occurred along the Łysogóry Fault, which suggests that the occurrence of the I-2 event was after the I-1 event." This chronological argument is not acceptable, because the contrary feature is observed east and west of the Łysogóry Fault. At least four N–S-striking faults cut through and displace the HCF (Text-figs 2, 3 and 14).

Point 5: Are the presented results subjected to discussion? In the discussion chapter, hypotheses and interpretations presented earlier in the paper have been changed into statements. There is neither discussion nor comparison with the results of previous publications. In particular, there is no Jaroszewski (1972) on numerous Palaeozoic structures or of the studies by Lamarche *et al.* (1999, 2002, 2003), which established the succession of tectonic events based on over 4500 measurements (the age of the rock from Devonian to Miocene, the bedding attitude, the relationship to folds, and the chronological relationships). A. Konon (2007) does not make any reference to Pożaryski (1974, 1976), Wartołowska-Świdrowska (1976) and Świdrowska (1980), who all provided data on sinistral displacements along longitudinal faults cutting Palaeozoic as well as Mesozoic strata, including the Holy Cross Fault. Pożaryski (1974) produced strong arguments in favour of sinistral rejuvenation of the Holy Cross Fault, with the description of S-shaped Mesozoic folds of the Radomsko Elevation, in the prolongation of the HCF.

Considering that most of the strike-slip features accepted by the author in this paper are incompatible with modern structural principles (Dadlez and Jaroszewski 1994, Twiss and Moores 1992), the discussion concerning the origin, chronology and context of both the I-1 and I-2 strike-slip events in the Holy Cross Mountains needs to be reconsidered. Nevertheless, we want to discuss the main points of disagreement.

5.1. Event I-1: A. Konon writes (p. 431) that "…N–S-striking dextral strike-slip fault set and a NNE–SSW to NE–SW-striking sinistral strike-slip fault set probably developed, resulting from an approximately NNE–SSW shortening direction. The faults form a conjugate pair of fault sets". This NE–SW set of sinistral faults cannot be found anywhere in the text except in the final Text-fig. 16b, where it is shown in order to document the NNE–SSW Variscan compression, which has been known since the time of Czarnocki's investigations. The NNE–SSW direction of shortening cannot produce displacements on parallel NNE–SSW-striking faults. The N–S dextral and NNE–SSW sinistral faults make an angle 2Θ, which is too acute (Θ~11°) for conjugate, synchronous faults. Aware of this mechanical problem, the author explains that the observations have been made only in competent rocks. But 2Θ does not depend only on rock stiffness (i.e. on the angle of internal friction), but also on the σ_1, σ_2, σ_3 magnitudes and orientations, the Poisson and Young modules and on pore fluid pressure (Twiss and Moores 1992, Dadlez and Jaroszewski 1994).

A. Konon describes the N–S to NE–SW-striking dextral fault set and the W–E-striking sinistral set (similar to those measured by Lamarche *et al*. 1999). He interprets them as a result of an approximately NE–SW shortening direction and suggests (p. 432) that "These secondary fault sets could probably form locally as conjugate Riedel shears (R-R'), accompanying a first-order N–S-striking dextral strike-slip fault set…". These sets of faults have been measured all over the HCM, in Palaeozoic and Mesozoic rocks, as well as in the Radomsko Elevation. They are not restricted to the vicinity of N–S major dextral faults (LAMARCHE & *al.* 1999, 2002) and, therefore, cannot be Riedel-type secondary faults.

Numerous stylolitic picks as well as fold axes measured in the Mesozoic rocks corroborate the palaeostress calculations on fault planes and the Late Maastrichtian/Paleocene age of the NE–SW compression (Lamarche *et al.* 2002, Lamarche 1999). The shortening direction N050° has been dated as Late Maastrichtian/Paleocene in age and is not a subject of controversy in the literature (Jaroszewski 1972, Świdrowska 1980).

If N–S to NE–SW and W–E faults were respectively R and R' shear planes associated with a N–S major fault, the R' planes would make an angle of 90° with the N–S major shear, what does not fit with the mechanical model of Riedel. Consequently, Konon's opinion concerning the Riedel-type origin and Late Palaeozoic timing of the N–S to NE–SW and W–E fault sets is wrong.

At the end of the text concerning the I-1 event the author writes (p. 432): "…this suggests the domination of pure shear over the strike-slip component...". In our opinion pure shear can dominate over simple shear, but in both cases the strike-slip component can manifest within the deformation pattern.

5.2. Event I-2: The second event of brittle deformation has been identified due to "…network consisting of longitudinal **WNW–ESE**-striking dextral [..] faults and **NW–SE to NNW–SSE**-striking sinistral faults." [our emphasis] (pp. 432, 433). The fault pattern presented by the author in Text-fig. 13 does not show this network. Moreover, between sets of minor faults assumed earlier (p. 424) the author described: "**W–E to WNW–ESE**-striking dextral and **NW–SE to N–S**-striking sinistral strike-slip **conjugate fault sets**" [our emphasis]**.** These are illustrated in Text-figs 10d, 11 and interpreted in Text-fig. 13e. The strikes of these fault sets are somewhat changed in this part of the text (pp. 432, 433). The main change depends on a different interpretation following the analogue modelling experiments of Schreurs (2003). In this latter case, the displacements along longitudinal, dominating faults start earlier than along the set of smaller faults (p. 433): "…the results of the experiments suggest that the master dextral strike-slip faults and the sinistral strike-slip faults striking at 40–50° to these faults, **were not conjugate** [our emphasis] sets but were active coevally (Schreurs 2003)". This comparison is, however, very speculative for the HCM because Schreurs (2003) proposed nine structural criteria for identifying shearing zones active as a result of increasing strain in areas of long-lasting regional strike-slip movements. A. Konon does not show the similarities between the HCM and the model conditions presented by Schreurs (2003), except for angular relationships.

Summing up, the critical remarks of points 1–5 question the interpretations and conclusions of A. Konon on Late Variscan strike-slip faulting in the HCM. Most of the structural features described by him as characteristic of strike-slip deformation are not relevant. We also noticed that he does not analyse the fault pattern of the HCM as a whole. He restricts his interpretations to several local, isolated features and derives general rules from them. The numerous remaining faults that do not match the model are not described and have been passed over in silence.

For a convincing and scientifically valid method of brittle deformation analysis, the fault timing has to be based on chronology arguments, such as cross-cutting relationships between faults, double striations on fault planes, truncation by unfaulted beds or palaeomagnetic timing (Lewandowski *et al.* 1999).

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ANDRZEJ KONON replies: Świdrowska and Lamarche discuss different interpretations of the evolution of the fault network in the southern part of the Holy Cross Mountains (HCM). They concentrate on the difficulties in recognizing the strike-slip faulting, fault pattern, structures associated with strike-slip faults, reactivation of the longitudinal faults, and the timing of strike-slip faulting in the southern part of the HCM. Also, they compare my methods of palaeostress analysis with their own results (Lamarche *et al.* 1999, 2002, 2003).

The discussion of their arguments has to start with reference to the basic methods that are applicable in recognizing a map-scale fault network. Some of their arguments, particularly on the classification of structures, are highly misleading and need to be discussed and cleared up first. The specific comments of Świdrowska and Lamarche are discussed at the end of the reply. In response to their criticism, I will demonstrate that most of their allegations are unjustified and many of my arguments are based on well-documented textbook examples.

My 2007 paper focuses on the geometry and developmental stages of the Late Palaeozoic map-scale strike-slip fault network in the southern part of the HCM. These map-scale faults dissect folds and have traces up to a few dozen kilometres long, including the longitudinal Holy Cross Fault (HCF), which is at least 75 km long.

Świdrowska and Lamarche compare the results of my studies of the fault pattern in the HCM, based on map-scale faults, with their structural investigations, which (with the exception of the HCF) are based mainly on the analysis of minor faults. These two approaches have clearly led to different results. Also, each methodology requires a different area scale. The latter was probably the reason why Świdrowska and Lamarche criticized the extension of my research area northward of the HCF, in spite of the fact that it was not covered by the title of my paper. However, to carry out a reasonable analysis of a map-scale fault network for a tectonic unit the data from adjacent areas must also be included.

Classification of the structures associated with the strike-slip map-scale faults: Świdrowska and Lamarche criticize my interpretation of the evolution of the fault network in the southern part of the HCM. They doubt the correct classification of structures associated with strike-slip faults.

The claim of Świdrowska and Lamarche concerning the inappropriate classification of the structures associated with the strike-slip faults is curious. The examples given in my paper are fully in line with modern models for their formation. The listed diagnostic features indicating horizontal shear include an *en échelon* arrangement of faults or folds in the fault zone in map view (e.g. Harding 1973; Wilcox *et al.* 1973) and at terminations of major faults; imbricate fans of faults as horsetail splays (e.g. Woodcock and Fisher 1986; Sylvester 1988; Woodcock and Rickards 2003) and contractional folds (Ramsay and Huber 1987); strike-slip duplexes; and stepovers along the major fault (Woodcock and Fisher 1986; Woodcock and Schubert 1994). To this category of structures also belong blocks rotated in domino style according to the 'bookshelf' mechanism (e.g. Mandl 1987). The diagnosis of a strike-slip component may be problematic in vertical cross-sections (Woodcock and Rickards 2003, Coward 1996), where flower structures often occur (Wilcox *et al.* 1973). However, similar structures with upward-diverging faults can develop during dip-slip faulting (e.g. Woodcock and Schubert 1994; Coward 1996).

Contractional folds are described from the Kostomłoty Quarry. The eastern block of the dextral strike-slip fault was removed in 2007, exposing the whole fault plane with striae, showing drag of layers along the fault in the southern part of the quarry, and revealing the absence of folds in the western block, below the boundary of the Kostomłoty and Szydłówek beds. These observations fully confirm my interpretation of dextral displacement along the fault.

Extensional imbricate fan of faults, similar to the *contractional folds* but formed in the extensional sector of a fault, occur at the southeastern tip of the Daleszyce Fault. Świdrowska and Lamarche question the shape of the fan. The shape of the traces of the faults bounding the tilted half-graben-type tectonic blocks depend, however, on the mechanical properties of the dissected rocks. The Emsian (Devonian) quartzite sandstone rocks near Daleszyce are much stronger than the Cambrian mostly fine-grained siliciclastics (Filonowicz 1976). Consequently, the fault traces refracted strongly during propagation through rocks with significant differences in strengths. The Daleszyce Fault probably continues to the west along the northern limb of the Dyminy Anticline and is offset along the Mójcza Fault Zone (Czarnocki 1938; Konon 2007, fig. 2).

Criticising my interpretation of *extensional imbricate fan of faults* Świdrowska and Lamarche compared my fig. 7b (Konon 2007) with fig. 7.10b in Twiss and Moores (1992), claiming a serious discrepancy. However, the illustration in Twiss and Moores (1992) is only a model; if they were to compare my figure with a figure in Ramsay and Huber (1987, 23.45a), they could see a clear correspondence.

Horsetail splay consists of sub-parallel oblique-slip faults (e.g. Woodcock and Schubert 1994) or fractures (e.g. Kim *et al.* 2004), which tend to develop where slip decreases gradually towards the fault tip (e.g. Kim *et al.* 2004). Geometrically and mechanically this structure is similar to *wing cracks* (Kim *et al*. 2004), from which it differs in the smaller size of spacing and the lower values of the angles formed by the oblique slip-faults with the master fault. During faulting, in the opened fault/fracture of the damage zone near the Łysogóry Fault (Jaroszewski 1973), hydrothermal iron ore bodies originated (Samsonowicz in Czarnocki 1950). This indicates the possibility of the formation of the horsetail splay as tensile fractures characteristic of mode I cracks (Kim *et al.* 2004). This interpretation is entirely consistent with Jaroszewski (1973, fig. 7; 1980, fig. 227) and contradicts the interpretation of Świdrowska and Lamarche, who claim that the faults are synthetic. This is certainly wrong. The faults are mostly antithetic, as is well seen, for example, on the maps of Czarnocki (1950, 1961b). The secondary 'easternmost fault', cited by Świdrowska and Lamarche, is neither sinistral nor a dip-slip fault with a southeastern footwall block. Analysis of the maps of Czarnocki (1950, 1957, 1961b) clearly shows that this fault has a scissors fault geometry. Furthermore, their interpretation that the Łysogóry Fault cuts through the Mesozoic rocks is also wrong. The fact that this fault 'disappears' under the Triassic rocks was already documented by Czarnocki (1950, 1957).

Stepping and *stepovers* are discontinuities in the fault traces. Świdrowska and Lamarche state that only "...in peculiar conditions the sense of displacement may be dextral as well as sinistral on both geometries", but do not explain what they understand as "peculiar conditions". The criticism of the terminology of stepovers applied in my paper is curious; it follows the terminology common to e.g., Twiss and Moores (1992, fig. 7.5), Woodcock and Schubert (1994, figs 12.11, 12.12), Mandl (2000, fig. 8.24), Pollard and Fletcher (2005, fig. 9.36c), Segall and Pollard (1980, fig. 11), and Kim *et al*. (2003, fig. 8; 2004, figs 3, 5, 6, 9).

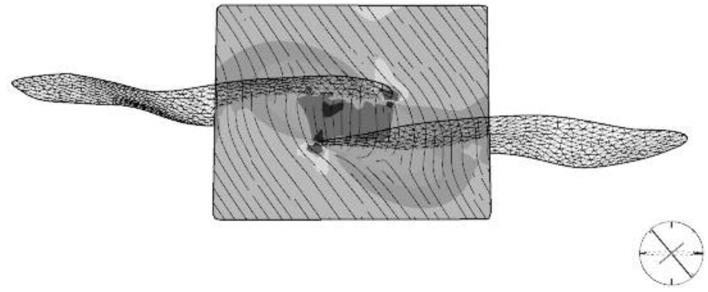
Restraining and *releasing stepovers* are characteristic discontinuities in fault traces (e.g. Woodcock and Schubert 1994; Kim *et al*. 2004). Interpreted by me as developed in a dextral restraining stepover are four smaller tectonic blocks between WNW–ESE-striking major left-stepping fault segments, near Daleszyce (Konon and Śmigielski 2006). The northern segment of the stepover probably continues eastward and dissects the southern limb of the Piotrów Syncline (Konon 2007, fig. 2). I cannot agree with Świdrowska and Lamarche's claim that along the N–S-striking faults the sense of displacements along the faults bounding the blocks should be dextral and result in anticlockwise rotation. The geological map of Filonowicz (1976) shows clearly that the tectonic blocks with Devonian beds are rotated clockwise, confirming my interpretation (it is actually consistent with recent models e.g., Kim *et al*. 2004, figs 5g, h).

The common feature of the strike-slip faults is that the angles of their planes change during propagation through rocks differing in bed-thickness and in mechanical properties. Such a situation is observed in the Piskrzyn Quarry (Konon 2007). The fault zone in the quarry is located a few dozen metres from the major fault that cuts the Baćkowice Anticline (see Konon 2007, figs 2, 13). The strike of the right-stepping fault cutting the Baćkowice Anticline is 334° but the strike of the left-stepping fault zone from the Piskrzyn Quarry is on average 354°, which indicates that these two fault zones are distinct and not the same as claimed by Świdrowska and Lamarche.

The stepping fault segments discussed could have been reactivated during the Maastrichtian/Palaeocene, resulting in the development of a dip-slip component. However, features presented by the author such as tectonic blocks rotated around vertical axes, horizontal striae on the slickensides, and offset of the fold axis along the transverse fault without significant change of width of the hinge zone, fully confirm the presence of a strike-slip component along the faults.

The *drag of beds* or *vertical folds* develops in generally steeply-dipping beds dissected by strike-slip faults where all surfaces are vertically inclined (e.g. Ramsay and Huber 1987, fig. 15.2.b). My examples of this structure (Konon 2007) come from the Śluchowice Quarry and from hills near the village of Nowa Zbelutka. Świdrowska and Lamarche interpreted the N–S-striking strike-slip faults from the Śluchowice Quarry as formed in the Late Cretaceous. Reference to their interpretation is difficult because it is presented on the stereoplot. As a matter of fact, their inference of the age of these faults is based on observation on the 'Rzepka Fault' in the Rzepka Quarry and not in the Śluchowice Quarry. The 'Rzepka Fault' is located in the southwestern part of the Kielce fold zone (Lamarche *et al*. 1999; Lewandowski *et al.* 1999), close to the Gnieździska-Brzeziny Fault dissecting the Mesozoic rocks (Czarnocki 1938; Mastella and Konon 2002). The 'Rzepka Fault' is a N30°-striking extensional fracture, filled by calcite and reactivated in strike-slip mode (Lewandowski *et al.* 1999), which indicates that the 'fault' differs in strike direction from faults in the Śluchowice Quarry. Moreover, it should be emphasized that the new paleomagnetic analysis of the fault from the Śluchowice Quarry indicates that the "..strike-slip component along oblique faults developed after main phase of folding and shows no connections with younger tectonic activity of this area on the boundary of the Maastrichtian and Paleocene" (Szaniawski in Konon and Szaniawski 2008).

The *rotated blocks* in the HCM were recognized in the Łysogóry Range (Mastella and Mizerski 2002), south



Text-fig. 1 The example of deflection of the σ_1 stress trajectories near right-stepping discontinuities. The differences between the local and far-field stress field are visible in the internal part, between overlapping segments of the faults where σ_1 trajectories are strongly deflected. The NW–SE direction of the σ_1 stress axis of the far-field is marked as a longer black line on the stereoplot. The analysis was carried out by M. Koprianiuk with Poly3D, a three-dimensional boundary element method (BEM) numerical code (Thomas 1993)

of the Holy Cross Fault (Konon 2007), and near Starochęciny (Mastella and Konon 2002). It is a common feature that tectonic blocks which include folds can be rotated after folding, which results in offset of their fold axes along strike-slip faults (e.g. Świderski 1953; Kuhn and Reuther 1999, fig. 6; Konon 2001, fig. 2, 24; Guarnieri 2004, figs 2, 3, 8). During rotation the corners of blocks can gradually disintegrate. This is clearly seen south of the HCF. The slip rate along an active fault averages 1 mm/y, with the rate for a very active fault attaining up to 10 mm/y (Moores and Twiss 1995, fig. 11.9). Accepting that the average rates of the disintegration of the margins of the rotated blocks along the HCF were at 0.1–0.2 mm/y or 0.01–0.02 mm/y through 10 Ma or 20 Ma respectively, the values obtained seem reliable.

Świdrowska and Lamarche compare the model of block rotation, based on the analogue model experiments by Schreurs (2003), with the one presented in Dadlez and Jaroszewski (1994, figs 81 and 193d). The latter refers, for example, to the consequent-obsequent positions of blocks and to the selective influence of rotation of shears in fracture cleavage. The figures in Dadlez and Jaroszewski (1994) and the analogue models of Schreurs (2003) thus relate to different geological phenomena.

The next are *minor strike-slip faults*. I accept Świdrowska and Lamarche's criticism of the sizes of the confidence cones. All of the stereoplots show the separate data consistent with the guidelines of Angelier (1994), without e.g. dip-slip faults, resulting in a substantial reduction of data, similarly as in the papers by Lamarche *et al.* (1999, 2002). The large confidence cones result from the amount of data. Fisher's statistic (1953) indicates that, using the confidence cones, good results are obtainable for ≥ 10 or even 25 measurements; adhering strictly to this requirement, would limit the investigations to the largest quarries.

The importance of fault-slip data obtained from analysis of minor faults has recently become a subject of discussion. The question is what fault-slip data can record – stress or strain (Twiss and Unruh 1998), local deformations or far-field strain fields (e.g. Gapais *et al.* 2000). Twiss and Unruh (1998) suggested that fault-slip data should be used as strain rather than as stress indicators. Gapais *et al.* (2000), based on field investigations of complex map-scale fault networks, brought new arguments. They compared the results of fault-slip data acquired by measurements on minor faults with the numerical restoration of offsets on major faults and the angles of rotation of tectonic blocks, based on palaeomagnetic methods. They concluded that the fields of stress or strain are variable and that this variation reflects the local interference of blocks, rather than far-field stresses (op. cit.).

All these statements indicate the need for very careful analysis of the fault network. It is particularly important in cases when it consists of map-scale strike-slip faults. Let us consider, for example, overlapping segments of map-scale faults where the trajectories of the principal stress axis can be significantly deflected (e.g. Segall and Pollard 1980; Bertolluzza and Perotti 1997), showing the differences between the far-field and local stress field (Text-fig. 1) (Mastella and Konon 2002). It is clear that, without analysis of the map-scale faults, an analysis based only on the minor faults can cause numerous errors in the identification of the directions of the principal stress or strain axes.

The need for care in using the fault data in the HCM area results from the fact that at least two significant strike-slip faulting stages took place in the area, namely in the Late Palaeozoic and the Maastrichtian/Palaeocene. An additional serious problem is caused by both these deformational events having for a certain periods of time a similar shortening directions. Lamarche *et al.* (1999, 2002) adopted the simple scheme that all minor faults dissecting the folds were formed in the far-field stress field during the Maastrichtian/Palaeocene event. However, palaeomagnetic data, discussed further below, indicate that the Palaeozoic rocks in the HCM could have been only slightly deformed during the Maastrichtian/Paleocene event, and only in the marginal southern part of the Kielce fold zone (Lewandowski 1985; Szaniawski 2008). Because of the similar shortening directions, the only 'strong evidence' for the timing of development of the minor faults is provided by palaeomagnetic investigations (Lewandowski *et al*. 1999; Szaniawski in Konon and Szaniawski 2008).

Timing of strike-slip faulting in the HCM and the sense of movements along the HCF: Świdrowska and Lamarche do not agree with my opinion concerning the timing of the strike-slip faulting in the HCM and the Palaeozoic evolution of some of the individual structures in the area (e.g., the HCF). According to Lamarche *et al.* (2003), transtensional strike-slip faulting was active in the HCM already in the Devonian, at the time when the HCF originated "...as a major strike-slip fault array". As evidence for the associated transtension they regard synsedimentary normal faulting and palaeomagnetic data. The strike-slip component was to be "...confirmed by the flower-like structure of the HCF zone" (op. cit).

I am of the opinion that the Late Palaeozoic map-scale strike-slip fault pattern formed as a result of two strike-slip events: I-1 and I-2 (Konon 2007). The I-1 event started during a late phase of folding or somewhat later as post-fold deformations. During this event the shortening direction during the development of the fault sets was NNE–SSW, similar to that obtaining during the post-Viséan folding, resulting in the prevalence of the pure shear component across the longitudinal faults. The time of formation of these strike-slip faults is documented by the occurrence of the pre-Late Permian hydrothermal iron ore bodies that developed in the horsetail splay of the Łysogóry Fault (Czarnocki 1950) and by the fact that this fault does not dissect the Triassic rocks (Samsonowicz in Czarnocki 1950, 1957). The time of the strike-slip faulting event is consistent with the palaeomagnetic investigations of the central part of the Kielce fold zone by Szaniawski (Konon and Szaniawski 2008).

During the I-2 event, the shortening direction rotated anticlockwise to an approximately NW–SE direction. The pure shear component decreased significantly across the master faults, which allowed the accommodation of dextral strike-slip displacements along the longitudinal faults and clockwise rotations of the tectonic blocks. The flower structure in the HCF zone, referred to by Lamarche *et al.* (2003) as evidence for Late Palaeozoic strike-slip movement, has not yet been confirmed. The strike-slip displacement along the HCF was verified by the occurrence of the clockwise-rotated small blocks in the Radostowa Block (Filonowicz 1970; Mastella and Mizerski 2002) and the Niewachlów, Małacentów and Baćkowice tectonic blocks, including folds, located to the south of the master fault (Konon 2007, figs 2, 14c). The zones consisting of the rotated blocks are most probably pre-Late Permian, as indicated by the differences between the complex structure of the zones and the simplified structural pattern in the overlying Upper Permian/Mesozoic strata around both tips of the HCF. The lack of significant displacement of Cambrian strata along the Łysogóry Fault at its southern termination (Czarnocki 1956, fig. 19, 1957) indicates that the displacement along the HCF was younger than along the Łysogóry Fault, which suggest the occurrence of the I-2 event after the I-1event (Konon 2007).

Świdrowska and Lamarche state that faults striking similarly to the Łysogóry Fault "...cut through and displace the HCF". It should be emphasized that along the Łysogóry Fault and across the 'similar fault' dissecting the Sobiekurów-Grocholice Syncline, a dextral strike-slip component and dip-slip component prevail respectively, which contradicts their suggestion. In the interpretation of Czarnocki (1950), the Łysogóry Fault does not cut the HCF, which indicates that the faults mentioned by Świdrowska and Lamarche are younger then the transverse fault.

Świdrowska and Lamarche also state that, during the Maastrichtian/Palaeocene tectonic inversion, the Holy Cross Fault was reactivated as a sinistral strike-slip fault which continues in the direction of the Radomsko Elevation (Lamarche *et al.* 2002). This contradicts the interpretation of Dadlez *et al*. (2000), who extend the HCF in a NW direction about 25 km from the Radomsko Elevation. Moreover, it is difficult to recognize the sinistral displacements in the Radomsko Elevation region on the basis of the figures of Pożaryski (1974 – figs 125, 126, 1976, fig. 2) and Lamarche *et al*. (2002, fig. 6) because of the lack of a figure showing clearly an *en échelon* arrangement of the folds, which would be consistent with e.g., Woodcock and Schubert's (1994) interpretation of such structures.

My observations (Konon 2007) of the differences in structure patterns in the Palaeozoic and Mesozoic rocks at the terminations of the HCF are consistent with the palaeomagnetic data, which indicate that the geometry of the folds in the Palaeozoic rocks in the HCM fold belt has remained virtually unchanged since the Triassic (Lewandowski 1985) and that the growth of the folds finished in the Early Permian (Szaniawski 2008). During the Maastrichtian/Palaeocene "....the rejuvenating of the Variscan fold structures, therefore, would be limited only to the southern margin of the Palaeozoic core..." (Lewandowski 1985) which confirms the recent investigations of Szaniawski (2008) suggesting more intensive deformations in the marginal (e.g. Chęciny region) than in the internal portions (e.g. Śluchowice Quarry) of the HCM. It suggests that the Maastrichtian/Palaeocene strike-slip faulting could have changed the structure of the HCM only slightly, and mostly in the marginal southern part of the Kielce fold zone.

Specific criticisms by Świdrowska and Lamarche:

1. Świdrowska and Lamarche refer to the value of the dihedral acute angle between the conjugate fault sets (their chapter 5.1), which changes when the fault sets dissect competent and incompetent rocks, and call my explanation into question. This is, however, quite simple. Moreover, they refer to Twiss and Moores (1992) and Dadlez and Jaroszewski (1994) and state that the value of the angle does not depend primarily on the internal friction of faulted rock masses. According to Coulomb theory, the orientations of shear fractures during brittle failure are independent of the magnitudes of the principal stresses and depend on the coefficient of internal friction, according to the equation

$$\gamma c = \frac{1}{2}\tan^{-1}\left(\frac{1}{\pm\mu_1}\right)$$

where γc is the angle between normal to the potential shear fractures and μ_1 is the coefficient of internal friction (Pollard and Fletcher 2005). According to the Coulomb theory, when the coefficient of internal friction equals zero the shear fractures make an angles of ±45° with the maximum stress axis (op.cit.). Under such circumstances, in brittle failure the formation of the shear fractures in the natural rocks is impossible (Dadlez and Jaroszewski 1994) [this rule was apparently not applied by Lamarche *et al.* 1999, as may be inferred from the stereoplots in their fig. 4 from the Józefka, Kostomłoty, Czarnów, Wietrznia and Jaźwica quarries].

2. Świdrowska and Lamarche claim to have collected over 4500 measurements for their analyses. However, most of their data are minor structures from the Mesozoic and Cenozoic rocks, including data from e.g,. the Kraków region. Additionally, they make no reference to the orders of the structures analysed. My database consists of map-scale strike-slip faults exclusively from the Kielce fold zone, which makes comparison with the very inhomogeneous data of Świdrowska and Lamarche very difficult. I want to point out, however, that their data from ten sites in the Kielce fold zone were included in the comparative material in my paper.

3. The suggestion of Świdrowska and Lamarche that the dextral strike-slip component along the fault in the Kostomłoty Quarry was recognized already by Professor M. Szulczewski, and that this view was adopted by me without a proper reference to his work, is not true. The fault was recognized by me, and Professor M. Szulczewski helped me to find the boundaries between the Kostomłoty and Szydłówek beds in both blocks of the fault. Based on this information, I was able to estimate the value of the strike separation. Professor M. Szulczewski allowed me to use his data and the necessary information is included in the captions to two figures in Konon (2006, fig. 7 and 2007, fig. 6).

4. I was reproached for not referring to papers by Wartołowska-Świdrowska (1976) and Świdrowska (1980) which, according to Świdrowska and Lamarche, are of primary importance in the recognition of sinistral displacement in the HCM. However, in the latter paper, the sinistral displacement is inferred based on observations of the slip along beds in a single outcrop, with no reference to the orders of the structures, and the former paper deals with a region outside the HCM.

5. It is equally difficult to agree with the Świdrowska and Lamarche statement that the N50° Maastrichtian/Palaeocene shortening direction should occur in every part of the HCM. As demonstrated in various papers, including Świdrowska (1980), these directions are quite variable. Świdrowska (1980, fig. 6) determined two directions, N20° and N45°, in the SW margin of the HCM; Jaroszewski (1972, fig. 46), in the area NE of the HCM, determined the the N–S direction of the principal stress axis during the development of the en echelon NW–SE-striking dextral strike-slip faults; and, finally, Wartołowska-Świdrowska (1976), determined the N20-30° shortening directions in the area SW of the HCM. All the data cited indicate the need for careful determination of the dominant far-field shortening directions, and the lack of a single uniform shortening direction for any point in the whole area of the HCM and adjacent regions.

6. Several critical comments referring to scientific plus editorial and/or graphic contents of the paper are completely groundless [e.g. their comments on figures 9b and 14, the determination of the age of the faults, the use of additional diagnostic structures for recognizing the strike-slip displacements along the map-scale faults, such as the fault that offset the axis of the Baćkowice Anticline, 'lacking' the NE–SW-striking sinistral fault set]. The authors have somehow managed to miss some of the elements indicated in their criticism. I would suggest more careful reading of the article.

Summing up, the discussion on the map-scale strike-slip fault-pattern in the HCM highlights important differences in methodological approach between me and Świdrowska & Lamarche. The arguments in the above discussion indicate that all the examples of the structures described by me from the HCM are characteristic of strike-slip deformation. In the original paper, I presented a new tectonic map of the fault network in the HCM (Konon 2007, figs 2, 3), based on the analysis of published geological maps (of Czarnocki and others; all cited in Konon 2007), field observations, including geological mapping, aerial photos, radar, satellite and DEM-derived images (Konon and Śmigielski 2006), as well as geophysical data such as palaeomagnetic investigations (e.g. Lewandowski 1985). In my opinion, the map and description of several quite new map-scale structures, and reference to the Late Palaeozoic wrenching event in the European Variscides, fully demonstrates that the map-scale fault pattern in the HCM was analyzed as a whole.

With the exception of the HCF Zone, the analyses of Świdrowska and Lamarche in the HCM are limited to the minor structures; they have never presented a map of the map-scale fault network in the HCM (Lamarche *et al*. 1999, 2002, 2003). They do not relate their results to the orders of the tectonic structures or to the locations of outcrops in relation to the major faults. This makes comparison of their results difficult because of the problem of distinguishing between the influence of variations in the local stress field and the far-field stresses.

I would like to emphasise that the analysis of the complex strike-slip fault network needs integration of studies of the map-scale fault system as well as of the minor structures.

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REFERENCES

Acocella, V. and Neri, M. 2005. Structural features on an active strike-slip fault on the sliding flank of Mt. Etna (Italy). *Journal of Structural Geology,* **27**, 343–355.

Angelier J. 1984. Tectonic analysis of fault slip data sets. *Journal of Geophysical Research*, **89**, 5848–5865.

Angelier, J. 1994. Fault slip analysis and paleostress reconstruction. In: Hancock P.L. (Ed.) Continental Deformation, pp. 53–100. Pergamon Press.

Bertoluzza, L. and Perotti, C.R. 1997. A finite-element of the stress field in strike-slip basins: implications for the Permian tectonics of the southern Alps (Italy). *Tectonophysics*, **280**, 185–197.

Carey, E. 1979. Recherche des directions principales de contrainte associées au jeu d'une population de failles. *Revue Geologie Geographie Physique*, **2**, 57–66.

Coward, N.P. 1996. Balancing sections through inverted basins. In: Buchanan, P.G., Nieuwland, D.A. (Eds), Modern Developments in Structural Interpretation, Validation and Modelling. *Special Publication Geological Society of London*, **99**, 51–57.

Czarnocki, J. 1938. Carte géologique générale de la Pologne, feuille 4, Kielce, Edition du Service Géologique de Pologne, scale 1:100,000.

Czarnocki, J. 1950. Geology of the Łysa Góra region (Święty Krzyż Mountains) in the connection with the problem of iron ores at Rudki. *Prace Państwowego Instytutu Geologicznego*, **6 a**, 3–400.

Czarnocki, J. 1956. Mineral raw materials in Święty Krzyż Mountains. *Prace Geologiczne Instytutu Geologicznego*, **12a**, 5–108.

Czarnocki, J. 1957. Tectonics of the Święty Krzyż Mountains. Geology of the Łysogóry Region. *Prace Instytutu Geologicznego*, **18**, 11–138. [In Polish with English summary]

Dadlez, R. and Jaroszewski, W. 1994. Tektonika. Wydawnictwa Naukowe PWN, 743 p.

Dadlez, R., Sylwester, M. and Pokorski, J. 2000. Geological Map of Poland, scale 1:1000 000, Warszawa Państwowy Instytut Geologiczny.

Filonowicz, P. 1970. Geological Map of Poland, Bodzentyn sheet, scale 1:50 000. Wydawnictwa Geologiczne; Warszawa

Filonowicz, P. 1976. Geological Map of Poland, Daleszyce sheet, scale 1:50 000. Wydawnictwa Geologiczne; Warszawa

Fisher, R. 1953. Dispersion on a sphere. *Proceedings of the. Royal Society, London*, **A217**, 295–305.

Gapais, D., Cobbold, P. R., Bourgeois, O., Rouby, D. and de Urreiztieta, M. 2000. Tectonic signicance of fault-slip data. *Journal of Structural Geology*, **22**, 881–888.

Guarnieri, P. 2004. Structural evidence for deformation by block rotation in the context of transpressive tectonics, northwestern Sicily (Italy). *Journal of Structural Geology*, **26**, 207–219.

Harding, P.T. 1973. Newport-Inglewood Trend, California – an example of wrenching style deformation. *American Association Petroleum Geologists Bulletin*, **57**, 97–116.

Harrap's Chambers concise dictionary, 2004. Chambers Harrap Publisher Ltd. Edinburg.

Jaroszewski, W. 1972. Mesoscopic structural criteria of tectonics of non-orogenic areas: an example from the north-eastern Mesozoic margin of the Świętokrzyskie Mountains. *Studia Geologica Polonica*, **37**, 215 pp. [In Polish with English summary]

Jaroszewski, W. 1973. Tectonic analysis of stress fields as a prospecting criterion. *Przegląd Geologiczny*, **10**, 523–528. [In Polish with English summary]

Jaroszewski, W. 1974. Tektonika uskoków i fałdów, 296 pp. Wydawnictwa Geologiczne; Warszawa.

Jaroszewski, W. 1980. Tektonika uskoków i fałdów, 359 pp. Wydawnictwa Geologiczne; Warszawa.

Katz, Y., Weinberger, R. and Aydin, A. 2004. Geometry and kinematic evolution of Riedel shear structures, Capitol Reef National Park, Utah. *Journal of Structural Geology,* **26**, 491–501.

Kim, Y-S., Peacock, D.C.P. and Sanderson, D.J. 2003. Mesoscale strike-slip faults and damage zones at Marsalforn, Gozo Island, Malta. *Journal of Structural Geology*, **25**, 793–812.

Kim, Y-S., Peacock, D.C.P. and Sanderson, D.J. 2004. Fault damage zones. *Journal of Structural Geology*, **26**, 503–517.

Konon, A. 2001. Tectonics of the Beskid Wyspowy mountains (Outer Carpathians, Poland). *Geological Quarterly*, **45**, 179–204.

Konon, A. 2006. Buckle folding in the Kielce Unit, Holy Cross Mountains, central Poland. *Acta Geologica Polonica*, **56**, 375–405.

Konon, A. 2007. Strike-slip faulting in the Kielce Unit, Holy Cross Mountains, central Poland. *Acta Geologica Polonica,* **57**, 415–441.

Konon A. and Szaniawski R. 2008. Młodopaleozoiczna ewolucja strukturalna Gór Świętokrzyskich w świetle badań strukturalnych i paleomagnetycznych. Abstrakty, I Polski Kongres Geologiczny Kraków 2008, 11R, 55.

Konon, A. and Śmigielski, M. 2006. DEM-based structural mapping: examples from the Holy Cross Mountains and the Outer Carpathians, Poland. *Acta Geologica Polonica*, **56**, 1–16.

Kuhn D. and Reuther C.-D. 1999. Strike-slip faulting and nested block rotations: structural evidence from the Cordillera de Domeyko, northern Chile. *Tectonophysics*, **313**, 383–398.

Lamarche, J. 1999. Evolution tectonique et role de la zone Teisseyre-Tornquist. Importance des structures heritees dans la formation des basins et la deformation de l`Europe Centrale. PhD-thesis. Memoires des Sciences de la Terre, Academie de Paris & Universite Pierre et Marie Curie, 226 p.

Lamarche, J., Bergerat, F., Lewandowski, M., Mansy, J. L, Świdrowska, J. and Wieczorek, J. 2002. Variscan to Alpine heterogenous palaeo-stress field above a major Palaeozoic suture in the Carpathian foreland (south-eastern Poland). *Tectonophysics*, **357**, 55–80.

Lamarche, J., Lewandowski M., Mansy, J. L. and Szulczewski, M. 2003. Partitioning pre-, syn- and post-Variscan deformation in the Holy Cross Mountains, eastern Variscan foreland. In: McCann, T. and Saintot, A. (Eds), Tracing tectonic deformation using the sedimentary record. *Geological Society, London, Special Publications*, **208**, 159–184.

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 the role of structural inheritance during Alpine tectonics. *Tectonophysics*, **313**, 171–186.

Lamarche, J., Mansy, J-L., Szulczewski, M. & Lewandowski, M. 2000. Pre-Variscan, Variscan and Alpine partitioning deformation in the Holy Cross Mts. (Poland). *Joint* Meeting of EUROPROBE (TESZ) and PACE Projects. Zakopane/Holy Cross Mountains, Poland. Abstracts volume, 56–59.

Lewandowski, M., 1985. On tectonics of the Holy Cross Mts in the light of paleomagnetic studies. *Publications of the Institute of Geophysics Polish Academy of Sciences*, A 16 (175), 131-150.

Lewandowski, M., Lamarche, J., Mansy, J.L., Averbuch, O. & Szaniawski, R. 1999. Palaeomagnetic dating of brittle tectonics structures: case studies on Ferques Fault (Boulonnais, France) and two faults from the Holy Cross Mountains (Poland). *Comptes Rendus de l'Academie des Sciences*, **329,** 495–502.

Mandl, G. 1987. Tectonic deformation by rotating parallel faults: the "bookshelf" mechanism. *Tectonophysics*, **141**, 277–316.

Mandl, G. 2000. Faulting in brittle rocks. An introduction to the mechanics of tectonic faults. Springer, 434 pp.

Mastella, L. and Konon, A. 2002. Non-planar strike-slip Gnieździska-Brzeziny fault (SW Mesozoic margin of the Holy Cross Mountains, central Poland). *Acta Geologica Polonica*, **52**, 471–480.

Mastella, L. and Mizerski, W. 2002. Geological setting of the Łysogóry Unit (Holy Cross Mountains, Central Poland) based on analysis of the radar images. *Przegląd Geologiczny*, **50**, 767–772. [In Polish with English summary]

Moores, E. M. and Twiss, R.T. 1995. Tectonics, 415 pp. W.H.Freeman and Company; New York.

Pollard, D. D. and Fletcher, R.C. 2005. Fundamentals of structural geology. 500 pp. Cambridge University Press.

Pożaryski, W. 1974. Budowa geologiczna Polski. Tektonika 1, Niż Polski. Obszar świętokrzysko-lubelski. Wydawnictwa Geologiczne, 314–362.

Pożaryski ,W. 1976. Ogólna charakterystyka tektoniczna mezozoiku świętokrzyskiego. Przewodnik 48 Zjazdu PTG Starachowice, 7–13.

Ramsay, J.G. and Huber, M.I. 1987. The Techniques of Modern Structural Geology - vol. 2 Folds and Fracture. Academic Press, 309–699.

Schreurs, G. 2003. Fault development and interaction in distributed strike-slip zones: an experimental approach. In: Storti, F., Holdsworth, R.E. and Salvini, F. (Eds), Intraplate Strike-slip Deformations Belts. *Geological Society, Special Publications*, **210**, 35–52.

Segall, P. and Pollard, D.D. 1980. Mechanics of discontinuous faults. *Journal of Geophysical Research*, **85**, 4337–4350.

Sylvester, A.G. 1988. Strike-slip faults. *Geological Society of America Bulletin*, **100**, 1666–1703.

Szaniawski, R. 2008. Late Paleozoic geodynamics of the Małopolska Massif in the light of new paleomagnetic data for the southern Holy Cross Mountains. *Acta Geologica Polonica*, **58**, 1–12.

Świderski, B. 1953. Geological Map of Poland, Rabka sheet, scale 1:50 000. Instytut Geologiczny, Warszawa.

Świdrowska J. 1980. Tectonic stylolites as tectogenetic index for the area of SW margin of the Holy Cross Mts. *Przegląd Geologiczny,* **28**, 159–164.

Świdrowska J. 2003. Geological setting of the Łysogóry Unit (Holy Cross Mountains, Central Poland) based on analysis of the radar images – discussion. *Przegląd Geologiczny,* **51**, 125–127.

Thomas, A.L. 1993. Poly3D: a three-dimensional, polygonal element, displacement discontinuity boundary element computer program with applications for fractures, faults, and cavities in the Earth's crust. MSc thesis, Stanford University, Stanford, California, U.S.A., p. 69.

Twiss, R.J. and Moores, E.M. 1992. Structural geology. W.H. Freeman and Company New York, 532 p.

Twiss, R.J. and Unruh, J.R. 1998. Analysis of fault slip inversions: do they constrain stress or strain rate? *Journal of Geophysical Research*, **103**, 12205–12222.

Wartołowska-Świdrowska, J. 1976. Structural Analysis of the Dobromierz Brachyanticline (South-Western Margin of the Holy Cross Mts). *Kwartalnik Geologiczny,* **20**, 765–782.

Wilcox, R.E., Harding, P.T. and Seely, D.R. 1973. Basic wrench tectonics. *American Association Petroleum Geologists Bulletin*, **57**, 74–96.

Woodcock, N.H. and Fisher, M. 1986. Strike-slip duplexes. *Journal of Structural Geology*, **8**, 725–735.

Woodcock, N.H. and Rickards, B. 2003.Transpressive duplex and flower structure: Dent Fault System, NW England. *Journal of Structural Geology,* **25**, 1981–1992.

Woodcock, N.H. and Schubert, C. 1994. Continental strike-slip tectonics. In: P.L. Hancock (Ed.), Continental Deformation, 251–263. Pergamon Press.

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