

A record of superimposed late- and post-Variscan regional-scale tectonic events at the NE margin of the Bohemian Massif: structural evolution of the Kamionki Graben (SW Poland, Sudetes) – discussion

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The title of the recently published article by Kowalski and Pacanowski (2025) is already provocative. Does the structural evolution of the small (~2.3 km²) Kamionki tectonic graben provide a reliable basis for representing, at a regional scale, tectonic processes over the last 340 Myr, covering a large area of the northeastern margin of the Bohemian Massif, i.e., the Sudetes and the Fore-Sudetic Block (>20,000 km²)? In this discussion, I examine this proposed model of structural evolution of the Kamionki Graben.

The Kamionki Graben, which is one of a few tectonic grabens containing Mississippian sedimentary rocks in the Góry Sowie Mountains (Grocholski, 1967; Oberc, 1972), occurs on the Pieszyce sheet of the Detailed Geological Map of the Sudetes (DGMS) 1:25,000. Only its minor, SE terminus appears on the Jugów sheet of the DGMS 1:25,000 map. New geological mapping on the Pieszyce DGMS 1:25,000 map was gathered during a geological project (Cymerman et al., 2017). Geophysical investigations for this project were carried out using electrical resistivity tomography (ERT) and seismic refraction tomography (SRT-P) along three profiles with a total length of 5.0 km. A new geological map of the KG was made by Kowalski during 2019–2022 during compilation of the Pieszyce DGMS 1:25,000 map (Cymerman et al., 2022).

It was incorrectly reported in the article that “the field mapping survey covered an area of ~10 km²” (Kowalski and Pacanowski, 2025: p. 4). In fact, 10 km² covers the entire area shown in their figure 3, including nearly 8 km² of the Góry Sowie metamorphic complex (GSMC). It is unclear why the geology of the GSMC in this figure is based on the earlier map by Gawroński (1961), rather than the much newer geological map of the Pieszyce sheet of the DGMS 1:25,000 map, which was co-

authored by Kowalski (Cymerman et al., 2022). It is also unclear why Kowalski and Pacanowski (2025) do not explain crucial information about the number of documentation points investigated. These points include 31 mechanically made research trenches within the Kamionki Graben, or those from its surroundings in the GSMC. Mississippian sedimentary rocks were found in 12 trenches. Kowalski and Cymerman (in Cymerman et al., 2022) worked together on these research trenches in 2021.

A total number of 42 boreholes were drilled in the Kamionki Graben and its northern surroundings (Cymerman et al., 2022: appendixes 2 and 15). Metamorphic rocks of the GSMC were identified in 18 boreholes, Mississippian sedimentary rocks from the Kamionki Graben in 4 boreholes, and Cenozoic strata in the other 20 boreholes. In the article, the locations of only two boreholes are indicated. These are marked on the Pieszyce DGMS 1:25,000 map (Cymerman et al., 2022) as borehole No. 37 with 108.6 m of Mississippian rocks and borehole No. 43 with 141.5 m of the Mississippian rocks.

The new map of the Kamionki Graben differs from the earlier maps in several respects. Gneissic conglomerates are not exposed in the Kamionki Graben area, although they were distinguished as a lower part of the Kamionki Graben, bordering serpentinites (Dathe, 1902; Gawroński, 1961). Kowalski and Pacanowski (2025) apparently presume that these are present sporadically in the NW part of the Kamionki Graben (their fig. 4), although there is no field-based evidence for this. Gneissic conglomerates were not found in boreholes 37 or 43. The revised extent of the Mississippian formations in the eastern part of the Kamionki Graben is associated with the absence of gneissic conglomerates; instead, fault rocks have been identified in part of this area (Kowalski, in Cymerman et al., 2022).

The Pieszyce DGMS 1:25,000 sheet, in the Kamionki area, shows six belts of tectonic breccias and cataclasites of Carboniferous-Neogene(?) age (Cymerman et al., 2022). These fault rock belts are oriented NW–SE to E–W. Four such fault rock belts occur in the GSMC to the east of the Kamionka valley (Cymerman et al., 2022). Although all six fault rock belts are located in the area shown in figure 3 of Kowalski and Pacanowski

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(2025), only two of them, located west of the Kamionka valley, are marked on that figure.

Like most tectonic grabens, the Kamionki Graben is bounded by framing faults. These are mostly covered by Quaternary slope talus and deluvial tills, however, so they are inferred, except for the Middle Kamionki Fault (Kowalski and Pacanowski, 2025: fig. 3). The names of these three frame faults, taken in part from Oberc's (1972) terminology, need to be corrected. The Eastern Kamionki Fault should be formally named the Northern (NE) Kamionki Fault and the Western Kamionki Fault should be named the South-Western Kamionki Fault. The north-striking Pniaki Fault (Oberc, 1972; Kowalski and Pacanowski, 2025) should be renamed the Eastern Kamionki Fault. This latter fault was suggested to be part of the hypothetical Pniaki-Kamionki-Rościszów dislocation (Grocholski, 1967).

No reason was given by Kowalski and Pacanowski (2025) as to why the ERT and SRT-P geophysical profiles are exaggerated by a factor of two (their figs. 5A and 6), while the interpretative geological cross-section is presented at 1:1 scale (their fig. 5B). Also, each of the geological profiles in figure 4 was prepared at a different scale ranging from 1:7,500 (profile D–D') to 1:12,500 (profile C–C'). It is therefore very difficult to compare the four geological profiles with the geological map, at a scale of 1:27,500 (their fig. 3).

It is unfortunate that only 900 m of the 1250 m ERT geophysical profile 1A was geologically interpreted, its further 200 m continuation towards the NNE was not evaluated, and the interpretation terminated in the middle of the low resistivity serpentinite outcrop. It is therefore impossible to provide an unambiguous geological interpretation of ERT profile 1A. Steep zones with low resistivity (<150 Ω m) presumably indicate fault zones, but serpentinites are also characterized by low resistivity (~65–150 Ω m). In addition, the zone of tectonic breccias and cataclases is also characterized by low resistivity values ranging from 65 to 250 Ω m.

The interpretation of resistivity data on the ERT profile on both sides of the Middle Kamionki Fault (Kowalski and Pacanowski, 2025: fig. 5A) is totally erroneous. Polymictic conglomerates are interpreted to occur there as rocks with completely variable resistivities: high (~500–1000 Ω m) to the SSW of the Middle Kamionki Fault and low (~65–150 Ω m) to the NNE of it. On the geological map of the Pieszyce DGMS 1:25,000 sheet, the occurrence of schlieric migmatites is indicated (Cymerman et al., 2022), whereas on the geological map (Kowalski and Pacanowski, 2025: fig. 3) and geological cross-section (Kowalski and Pacanowski, 2025: figs. 4C and 5B), polymictic conglomerates are indicated there.

Although the article is highly structural in nature, no statement is made on the number of measured tectonic structures (Kowalski and Pacanowski, 2025). There are 35 bedding measurements indicated on the geological map (Kowalski and Pacanowski, 2025: fig. 3), and 16 bedding and 15 structural element orientations are given on the figures (Kowalski and Pacanowski, 2025: figs. 7, 8 and 9). The figures indicate orientations of planar structures in a two-part record, whereas table 1 lists 32 fault orientation measurements in a three-part notation with strike azimuth and dip angle, but without dip direction. No reasoning is provided for why different attitude conventions are used for the same planar structures, which complicates the analysis of the field data collected.

There are many inconsistencies in the number of faults listed in the article. The 32 faults with striae numbered (Kowalski and Pacanowski, 2025: table 1) do not accord with the 35 faults indicated in figure 10. Additionally, in table 1 and figure 10, it should be side no. 3, not side number 2. The normal fault with an orientation of 140/50 SW within fault population IV

(Kowalski and Pacanowski, 2025: table 1 – Id. 9) on the diagram with striae with moderate plunge to the SW is not shown. On their figure 7D, two curved reverse faults (~20/55 to 80) with SSW displacements are described, but are not listed in their table 1.

Why is there no description of exposure no. 5, which is located in the area of nebulite migmatites of the GSMC (Cymerman et al., 2022)? It is puzzling that only a few (5 or 6?) meso-faults were measured at one location of the GSMC, whereas there are tens of large nebulite migmatite (diatexite) outcrops to the east and south-west of the Kamionki Graben.

Why were no joint measurements presented for locality no. 6 and 7? What is the authors' suggestion regarding clockwise joint rotation at locality no. 4?

A large number of kinematic data (fault-slip data) is required to fully present the structural evolution of the Kamionki Graben. Unfortunately, there are only ~35–37 given for the Kamionki Graben. For comparison, the structural evolution of the Wleń Graben (Góry Kaczawskie Mountains) was based on the analysis of 806 fault-slip data (Kowalski, 2021).

From a variety of palaeostress analyses (e.g., direct inversion, dynamic numerical analysis, dihedrals, and PBT axes), the graphically constructed PBT method was selected to reconstruct the main stress axes ($\sigma_1 > \sigma_2 > \sigma_3$) (Kowalski and Pacanowski, 2025). *FaultKin8* software was used to analyse data on fault displacement from the Kamionki Graben. In other methods of reconstructing reduced stress tensors (programs such as *Win-Tensor* 4.0, *Tectoniscs FP*, or *T-TECTO* 3.0), calculations can be verified on Mohr diagrams and fluctuation histograms. *FaultKin8* software does not take into account the quality of kinematic indicators (from excellent to poor). In the case of conglomerates such as those in the Kamionki Graben, the fault displacement data are of rather poor quality. How precisely (accuracy of 1°) were the trend and plunge of the striae on the rough fault surfaces measured (Kowalski and Pacanowski, 2025: table 1)?

Although the authors stated that "The relative ages of the deformation events were determined from the cross-cutting relationships between folds and brittle structures (fractures and faults)" (Kowalski and Pacanowski, 2025: p. 4), I did not find these in their report. Despite this, a model of the structural evolution of the Kamionki Graben was presented with four inferred phases from the Late Namurian to the Neogene (Kowalski and Pacanowski, 2025: fig. 11). The synchronous development of dextral strike-slip faults (population I) with NNE–SSW compression (locality 3) and reverse faults displaced to the NNE during the Late Namurian (Kowalski and Pacanowski, 2025: fig. 11) is mechanically unacceptable.

Two reverse faults displaced to the SSW are reported at locality 7 (their fig. 7D), but asymmetrical folds with N-vergent fault-propagation folds were also found at the same locality (fig. 7A, C). The development of these structures with opposite directions of tectonic transport has not been explained.

It is unclear why this dextral transpression regime was attributed to the Late Serpukhovian. It is surprising that fault population II (Late Carboniferous–early Permian) and fault population IV (Neogene) were formed by the very same NE–SW oriented extension.

It is difficult to infer that during the formation of fault population IV under a NE–SW extension regime, a large GSMC block was displaced several hundred metres to the WNW along strike-slip faults, without simultaneously deforming the Mississippian sedimentary rocks of the Kamionki Graben.

Summary of average data of attitudes σ_1 and σ_3 stress axes was compiled to show comparative data on palaeostress tensors from selected areas of the Bohemian Massif (Table 1).

Summary of average data of the azimuth of the σ_1 maximum and σ_3 minimum principal stress axes from selected areas of the NE margin of the Bohemian Massif

Selected areas (author/authors)	Azimuth of the compressional stress axis (σ_1)					Azimuth of the tensional stress axis (σ_3)		
	Compressional regime			Strike-slip regime		Extensional regime		
Lusatian Fault Belt Coubal et al. (2015)	N-S (α_2 phase; Paleocene) NNW-SSE (α_3 phase; Oligocene)	NE-W (γ phase; Mid to Late Miocene)	NE-SW to NNE-SSW (α_1 phase; latest Cretaceous)	W-E to WNW-ESE ($\alpha\beta_3$ phase; Early Oligocene)	NW-SE to NNW-SSE (δ phase; Pliocene to Pleistocene)	WNW-ESE ($\alpha\beta_{1-2}$ phase; ~80–61 Ma)	N-S to NE-SE (β phase; Late Oligocene– Early Miocene)	
Oherský Rift Graben Adamovič and Coubal (1999)	WNW-ESE (δ phase, Middle– Late Miocene)	NE-SW to NNE-SSW (α_1 phase; Sub-hercinian); (γ phase, Miocene)					NNW-SSE to N-S (β_2 phase Oligocene)	NE-SW (β_1 phase; pre-Oligocene)
“Turów” brown coal mine Cymerman (2009)		NE-SW to NNE-SSW (post-Miocene)		N-S (post-Miocene)			NNW-SSE (post-Miocene)	NE-SW to NNE-SSW (post-Miocene)
North-Sudetic Depression – eastern part Cymerman et al. (2008)	WNW-ESE (post-Santonian)	NNE-SSW to NNW-SSE (post-Santonian)		WNW-ESE to W-E (post-Santonian)	NE-SW to NNE-SSW (post-Santonian)			NE-SW to ENE-WSW (post-Santonian)
Kaczawa Meta- morphitic Complex – northern part Cymerman et al. (2008)	WNW-ESE to ENE-WSW (post-Variscan)	NNE-SSW to NNW-SSE (post-Variscan)		NW-SE to W-E (post-Variscan)	NNW-SSE to NE-SW (post-Variscan)	WNW-ESE to W-E (post-Variscan)	NNW-SSE to N-S (post-Variscan)	
Kaczawa Meta- morphitic Complex – Cieszów Unit Cymerman (2014)	ENE-WSW to W-E (post-Variscan)	N-S to NNE-SSW (post-Variscan)		WNW-ESE to W-E (post-Variscan)				
North-Sudetic Depression –Wleń Graben Kowalski (2021)		NE-SW (WNW-ESE) (2 phase; latest Cretaceous-early Paleogene?)	N-S to NNW-SSE (3 phase; late Paleogene–Neo- gene ?)			NE-SW (1 phase; post-Santonian); (4 phase; Miocene–Pleistocene)		
Góry Sowie Meta- morphitic Complex – Kamionki Graben Kowalski and Pacanowski (2025)		N-S to NNE-SSW (1 phase; late Namurian) (?)	NE-SW (3 phase; late Cretaceous–early Paleogene?)				NE-SW (2 phase; late Carbonifer- ous–early Permian); (4 phase; Neogene ?)	
Intra-Sudetic De- pression Boguszów Gorze – closed barite mine Cymerman et al. (2008)		NNE-SSW to NE-SW (post-Cisuralian)	ENE-WSW to W-E (post-Cisuralian)		ENE-WSW (post-Cisuralian)	NNW-SSE to NW-SE (post-Cisuralian)	NNE-SSW (post-Cisuralian)	
Bardo Structure Cymerman et al. (2008)	WNW-ESE to W-E (post-Variscan)		NE-SW to N-S (post-Variscan)	NW-SE to NNE-SSW (post-Variscan)	NE-SW to E-W (post-Variscan)	WNW-ESE to NW-SE (post-Variscan)		NE-SW to ENE-WSW (post-Variscan)
Intra-Sudetic De- pression – Hronov-Poříčí Fault Zone Nováková (2014)	NW-SE (3 tectonic phase)	NNE-SSW (oldest 4 tec- tonic phase)	NE-SW (youngest 1 tectonic phase; Neogene)		ENE-WSW (2 phase; Saxonian tectogenesis)			
Złoty Stok – Trzebiechowice shear zone Cymerman et al. (2008)	W-E to WNW-ESE (post-Variscan)		NE-SW to N-S (post-Variscan)		WNW-ESE (post-Variscan)		NE-SW to NNE-SSW (post-Variscan)	ENE-WSW (post-Variscan)
Stare Město Unit Nováková et al. (2010)	WNW-ESE to NW-SE (B tectonic phase)	N-S (C tectonic phase)		NNW-SSE (D tectonic phase)	NE-SW (E tectonic phase)			NE-SW to NNE-SSW (A tectonic phase)
Sudetic Marginal Fault Zone – SE part Pešková et al. (2010)		NNW-SSE (oldest 4 tec- tonic phase)	NE-SW (youngest 1 tec- tonic phase)	NW-SE (2 tectonic phase; Saxonian tectogenesis)	ENE-WSW (3 tectonic phase; transtension; Neogene)			
Sudetic Marginal Fault Zone – SE part Nováková (2015)	W-E (3 tectonic phase; Cenozoic)	NW-SE (Variscan tec- tonic phase)		NNE-SSW (2 tectonic phase; late Variscan)	ENE-WSW (4 tectonic phase; Quaternary)			

However, these data are not straightforward to interpret because the quality of the palaeostress analytical results is subject to limitations and uncertainties about the methods used and the multiphase, superimposed tectonic history. It is worth emphasizing that a comparison of the structural evolution of the Wleń Graben and the Kamionki Graben, located >80 km apart, illustrates their contrasting kinematic evolution (Table 1). These kinematic models were prepared using the same calculation program (*FaultKin8* software) and graphic analysis of fault-slip data included in the PBT method (Kowalski, 2021; Kowalski, Pacanowski, 2025). For the Wleń Graben, five post-Santonian deformation phases with changes in stress fields were estab-

lished, including three extensional phases. In turn, for the Kamionki Graben, four deformation phases were determined since the post-Serpukhovian, including only one compressional phase and one extensional phase since the post-Santonian.

In conclusion, the record suggested of superimposed late- and post-Variscan regional-scale tectonic events at the NE margin of the Bohemian Massif, based on the structural evolution of the Kamionki Graben, is unfortunately rather speculative. This is because regional implications cannot be drawn based on an insufficient set of structural data, especially from a small tectonic unit such as the Kamionki Graben.

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