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Cenozoic dynamic evolution of the Polish Platfom (reply)

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The comments advanced by P. Krzywiec in his discussion of our paper (Jarosiński *et al*., 2009) actually address only the evolution of the Carpathian Foredeep Basin (CFB) and thus only one tenth of our paper.

His main bones of contention pertain to the timing and controlling mechanisms of palaeovalley incision in the CFB and to the age and present-day configuration of the late Badenian–Sarmatian fill of the CFB.

In the following we respond point by point to the comments of P. Krzywiec on our paper.

CONCERNING PALAEOVALLEYS

1. **Krzywiec wrote**: "They [we] claimed that they [palaeovalleys] were incised into the Mesozoic series only".

Our response: The word "only" was added by Krzywiec in his discussion. In our paper there is no suggestion that these valleys are incised in Mesozoic basement only. We have stated that "These channels transect the peneplain that developed after the latest Cretaceous and Paleocene inversion of the Mid-Polish Swell and cut variably into Mesozoic, Paleozoic and Precambrian rocks" (Jarosiński *et al*., 2009, page 11).

2. **Krzywiec wrote**: "Jarosiński *et al*. (2009) proposed that these palaeovalleys developed in Late Oligocene–Miocene times"; "Jarosiński *et al*. (2009) did not however acknowledge that in the Sędziszów–Rzeszów area the axial parts of these palaeovalleys are filled by thick Paleogene deposits (Moryc, 1995), and this strongly suggests an older age of their incision".

Our response: Note that the Oligocene forms part of the Paleogene, and in this sense the origin of these palaeovalleys is Paleogene–Miocene. In the paper referred to by Krzywiec (Moryc, 1995), the basal conglomerates in these canyons are not dated. These conglomerates are overlain by continental siltstones, which pass upwards without discordance into lower Badenian marine fossiliferous mudstones. These non-marine siltstones contain terrestrial floral remnants which revealed a wide spectrum of sometimes confusing ages. Moryc (1995) mentioned that these floral remnants were poorly preserved, suggestive of their reworking, and that one analysis pointed to a Carboniferous age whilst others yielded ages ranging from Paleocene to Late Eocene. Correspondingly, Moryc (1995) felt that assigning a Paleocene or Eocene age to the palaeovalley fill was premature and that its Oligocene or Early Miocene age could not be excluded. In conclusion, he proposed to acknowledge a general Paleogene age of these deposits, which most probably were deposited in wetland and limnic environments. In the face of a wide spectrum of ages obtained from the palaeovalley fill and the suspicion of reworked flora remnants, preference is given to the youngest possible ages, thus Lower Miocene. In the light of careful reading of the source literature (Moryc, 1995), the argument advanced by Krzywiec is very weak and we would not recommend its application in regional reconstruction. Note that there are also several other papers that recognize these palaeovalley fill deposits as Lower Miocene (Czernicki and Moryc, 1990) and even lower Badenian (Połtowicz, 1994).

3. **Krzywiec wrote**: "They [we] mentioned an alternative model [palaeovalleys], based on data from the Czech part of the Carpathian arc mentioned above, with a well-constrained age of palaeovalleys incision, immediately following Late Cretaceous inversion of the Alpine–Carpathian foreland (i.e. Bohemian Massif). Jarosiński *et al*. (2009) apparently regarded this model as less probable, although they did not give any detailed explanation for this."

Our response: Although there was no room for detailed explanations in our overview paper, we have advanced arguments which were omitted by Krzywiec in his discussion: "Large parts of this peneplain are still preserved below the Miocene succession of the CFB, suggesting that the erosional event underlying the development of these channels was of short duration". If deep erosion had occurred 30–40 Ma before the Miocene transgression, we would rather expect more mature landscape features. Regarding the next point: "...in the Kraków area, where erosional channels are exposed at the surface the timing of their incision was estimated as being of Oligocene to Karpatian age (Felisiak, 1992)...", we believe that for palaeogeographic reconstructions it is more relevant to refer to areas a few tens of kilometres apart (Felisiak, 1992 – reference in our paper) rather than to areas four or five times more distant (that were also considered in our paper), particularly in view of the well-documented diachronous evolution of subsidence and deformation along the strike of the Carpathians and their foreland basin (Poprawa *et al*., 2002*a*; Poprawa and Malata, 2006).

4. **Krzywiec wrote**: "Additionally, their size [palaeovalleys] and widespread distribution seem to support a post-inversion genesis".

Our response: For sure, palaeovalleys developed in the Polish Carpathian foreland after the latest Cretaceous–Paleocene main phase of basin inversion, though the age of their main and deepest incision remains uncertain until more data are obtained from the basal parts of their sedimentary fill. Regardless of the possible but not proven (in the Polish segment) earlier stage of incision these palaeovalleys contain several hundred metres of Badenian marine deposits. This testifies to the persistence of considerably topography at the end of the Early Miocene. This can be explained by the processes proposed in our paper.

5. **Krzywiec wrote**: "Flexural bulges uplifted in front of advancing orogenic wedges are not usually characterized by high amplitudes (DeCelles and Giles, 1996; *cf*. Krzywiec, 2006), hence incision of rather deep (several hundreds metres or even more) palaeovalleys solely due to uplift of a flexural bulge does not seem to be very probable".

Our response: We can agree with this logic but regard it as an oversimplification that does not take into account the complexity and variability of foreland basin and forebulge development. During the Late Oligocene and Early Miocene evolution of the CFB a forebulge was uplifted in the area of the Meta-Carpathian Swell, whilst basin subsidence was accompanied by syn-flexural synthetic and antithetic normal faulting, with displacements of several hundred metres on individual faults. In the distal parts of the evolving CFB faulting was active during the Late Oligocene–Early Miocene under subaerial conditions. This permitted the incision of several hundred metres deep palaeovalleys into footwall blocks, exactly where they are now observed. Apparently this process was fast enough for part of the peneplain to be preserved beneath the transgressing Badenian deposits, during deposition of which syn-flexural tensional faulting persisted.

CONCERNING THE COMPRESSIONAL EVENT

Krzywiec wrote: "Jarosiński *et al*. (2009) proposed that at the Badenian–Sarmatian boundary the PCFB underwent a first phase of compressional deformation" and gave an argument that "This horst [Ryszkowa Wola] was formed within the restraining bend of two basement faults in late Badenian–early Sarmatian times, and has experienced sinistral strike-slip movements until at least the latest Sarmatian (Krzywiec *et al*., 2005; Nescieruk *et al*., 2007)".

Our response: Our wording was: "The first event of basement-involving contraction in the CFB is dated as straddling the Badenian–Sarmatian boundary (Jarosiński, 1992; Jarosiński and Krzywiec, 2000)". There is little difference between our statement and Krzywiec's "late Badenian–early Sarmatian", except that we attempt to narrow the interval of the first compressional event to the the latest Badenian–earliest Sarmatian. The second phase of compression, which is not described in our paper , because it is documented in only one locality, probably occurred during the latest Sarmatian. During this later phase pre-existing faults were probably selectively reactivated in a reverse mode by sinistral strike-slip movements as seen at the Ryszkowa Wola horst where the deformed uppermost Sarmatian succession crops out.

CONCERNING SUBSIDENCE

1. **Krzywiec wrote**: "Jarosiński *et al*. (2009) dated the post-evaporitic sedimentary infill of the easternmost PCFB as Sarmatian (see their fig. 7B), and, accordingly, dated the next phase of basin subsidence".

Our response: None of us has dated "the post-evaporitic sedimentary infill" and we have not indicated that the direct cover of the evaporites is Sarmatian in age.

2. **Krzywiec wrote**: "In fact, the lower part of the post-evaporitic siliciclastic succession contains also upper Badenian strata (see Oszczypko *et al*., 2006 for a more detailed overview), and therefore the onset of the important subsidence phase that was linked with the development of large normal faults and deposition of up to 3 km of the Miocene foredeep infill should be dated as late Badenian, not Sarmatian".

Our response: We acknowledge that the "...lower part of the post-evaporitic siliciclastic succession contains also upper Badenian strata...". In our paper we stated: "After the short compressional pulse at the Badenian–Sarmatian transition, a new phase of enhanced basin subsidence commenced in the Sarmatian (Oszczypko, 1999), during which the depot centre of the CFB shifted from its central to its eastern segment". Oszczypko (1999) clearly demonstrated that the centre of maximum subsidence of the CFB shifted from its central segment during the Badenian to its eastern segment at the onset of the Sarmatian. Indeed, quantitative subsidence curves show for the eastern segment of the CFB in front of the Carpathians a sharp acceleration in subsidence at the beginning of the Sarmatian (Oszczypko, 1999 his fig. 9), thus documenting the onset of a new subsidence phase.

CONCERNING CLINOFORMS

1. **Krzywiec wrote**: "They [we] claimed that inclination of the post-evaporitic succession, visible on seismic data, is in fact an effect of post-depositional rotation of this part of the basin caused by post-orogenic uplift within the orogenic wedge, and that the foredeep infill was deposited as an essentially flat-laying cover blanketing varied deeper topography".

Our response: This passage from our paper, as quoted by Krzywiec, pertains not to the entire CFB but only to the part represented by the cross-section shown in our figure 7.

2. **Krzywiec wrote**: "...as proposed by Jarosiński *et al*. (2009), as it would require not only *en-block* rotation of the entire basin infill".

Our response: We have never proposed "...*en-block* rotation of the entire basin infill..." but its regional uplift in response to unflexing of the foreland lithosphere following detachment of its subducted part around 10.5 Ma.

3. **Krzywiec wrote**: "I would like to reiterate my model (not discussed by Jarosiński *et al*., 2009) which suggests that the post-evaporitic siliciclastic succession was shed to the foredeep basin from the eroded orogenic wedge, and that in the central (Kraków–Tarnów) part of the basin a large-scale clinoform related to sediment progradation is still partly preserved (Krzywiec, 2001; Oszczypko *et al*., 2006)".

Our response: The same, well-documented model was presented earlier by Porębski in 1999 that is also referred to by Krzywiec. We accept this model and have no problem with clinoforms, which are obviously present in the Carpathian Foredeep. The question is whether in the area addressed by our paper (see fig. 7 in Jarosiński *et al*., 2009), which is located 10–30 km from the frontal thrust of the orogen, the observed inclination of the upper Badenian–Sarmatian strata can be attributed mainly to syn-depositional or post-depositional processes. In our opinion the effect of post-orogenic isostatic rebound-related northward tilting of the CFB prevails.

4. **Krzywiec wrote**: "Such a geometry could be interpreted as reflecting transition from shelf to proximal slope to distal slope ..." and "It should be also stressed that a depositional model, basically identical to the model based on seismostratigraphic interpretation (Krzywiec, 2001; Oszczypko *et al*., 2006), was proposed for this part of the basin using borehole data (Porębski, 1999; Porębski *et al*., 2002; Porębski and Steel, 2003)".

Our response: With reference to the area covered by our cross-section given in figure 7a (Jarosiński *et al*., 2009), Porębski (1999) recognized a "slope and basin plain" depositional regime but no transition from shelf to proximal and distal slope, as suggested by Krzywiec. This underlies our postulate that at a distance of over 15 km from the Carpathian thrust front sediments were deposited as near-horizontal beds. Based on clay compaction curves Poprawa *et al*. (2002*b* – cited in our paper) demonstrated that the magnitude of erosional truncation of the Badenian succession increases systematically towards the orogen. This is consistent with our reconstruction that reflects late-stage unflexing of the foreland lithosphere. Nevertheless, there is still scope for further research and discussion of this important issue.

GENERAL REMARKS

We agree that there are still some open questions regarding the evolution of the CFB that need to be investigated and further discussed beyond our response to the comments by Krzywiec.

REFERENCES

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