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# Reply to comments by A. Krohe and A.P. Willner on "Structural evolution of the central part of the Krušné Hory (Erzgebirge) Mountains in the Czech Republic—evidence for changing stress regime during Variscan compression" [Journal of Structural Geology 23 (2001) 1373–1392]☆

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We thank Alexander Krohe and Arne Willner (2002) for starting a discussion about the structural evolution of the Erzgebirge. In their contribution, the authors discuss correlation of separate tectonic units in the central Erzgebirge, tectonic mechanisms responsible for observed superimposed folding, the tectonic position of eclogite-facies rocks, and the role of extension in the exhumation of the high-pressure units. Moreover, they address several important issues of Saxothuringian geology, such as the decreasing metamorphic conditions towards the west, and the status of the HP/HT and of UHP metamorphism in the Erzgebirge. Although we are aware that our observations have important implications for the tectonic evolution of the eastern part of the Saxothuringian domain, the later points in the discussion are not related to our paper which only aims to interpret the observed metamorphic and structural evolution of the Czech part of the central Erzgebirge. Thus, our reply will only address those issues of the discussion which are directly related to our work.

The critical remarks in the whole discussion are based on the assumption that the Saxothuringian basement reveals metamorphic and structural characteristics of a core complex with high-pressure rocks in the deepest structural position. With this philosophy in mind, the exhumation of deepest HP rocks can only be explained using the concept of vertical rebound controlled by extensional tectonics. We do not want to challenge the results of Krohe (1996, 1998) and Willner et al. (2000) coming from other parts of the Saxothuringian domain, because the aim of our paper (Konopásek et al., 2001) was to document inversion of metamorphic zones connected with the development of a thrust-related fabric in the eastern Erzgebirge.

## 1. The Lower Crystalline nappe vs. the Münchberg nappe

Obviously, there is a substantial misinterpretation of the Introduction section in the discussed paper. We are certainly not saying that the Lower Crystalline nappe defined by us should be correlated with the Münchberg, Frankenberg and Wildenfels klippens. The only reason for mentioning these structures was to show that in the western Erzgebirge, obvious sharp change in metamorphic conditions allows easy definition of the allochthonous bodies. This is not the case in the central Erzgebirge where all the exposed lithologies show evidence for medium- to high-temperature metamorphism. Careful reading of the paper will reveal that the definition of the orthogneiss nappe overlying the parautochthonous metasedimentary sequence is not the result of a *presupposed* correlation of the eastern and western Erzgebirge, but the summary of published metamorphic, and presented structural data (see Sections 3 and 4 in the discussed paper). We are aware of the fact that the Münchberg eclogites show much higher ages of the HP metamorphism compared with those of the Erzgebirge eclogites. On the other hand, underlying deformed Carboniferous sediments suggest that final emplacement of the

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Münchberg nappe occurred much later. What happened between the HP metamorphism of associated eclogites and the final emplacement is just a matter of interpretation of the Erzgebirge tectonics.

## 2. D2 vs. D3

The backbone of the criticism of Krohe and Willner is based on the assumption that there is no superposition of two deformations resulting from two distinct stress regimes. Instead, they propose that all structures result from a single extensional event.

Our interpretation is based on the following observations: the D2 deformation is characterised by the development of pervasive metamorphic fabric locally connected with the development of isoclinal, often rootless folds in metasediments (fig. 5b in Konopásek et al., 2001). Obviously, more common is a complete transposition of the $S_1$ planar fabric, and the development of unique $S_2$ mylonitic fabric in less anisotropic gneisses. This fabric is evidently refolded by post-metamorphic $F_3$ folding at a high angle to the original anisotropy (fig. 5c and d in Konopásek et al., 2001). These arguments, as well as the fold interference pattern, which is visible on the geological map, are in our opinion sufficient evidence to discuss a polyphase structural evolution.

(i) We completely agree that the D3 kink bands have formed later (e.g. under lower temperatures) than all the $F_3$ folds and the $S_3$ foliation in the south. A remarkable decrease of the D3 strain intensity from the Klínovec antiform (southern part of the studied area) towards the north suggests widening of the zone of the D3 deformation. The presence of the D3 kink-bands in the north, as well as occasionally developed axial $S_3$ spaced cleavage in the south are certainly rather late features, according to our interpretation indicative of the temperature decrease during D3 (see fig. 12 in the discussed paper).

(ii) If we accept the concept that fold axial planes coincide with the *XY* plane of the finite strain ellipsoid, then it is very difficult to imagine the development of the $F_3$ folds during the same stress regime producing the $S_2$ foliation. In our interpretation, the change in shape and interlimb angle of both large-scale $F_3$ antiforms with the same orientation of vertical axial plane from south to north is attributed to an increase of the D3 intensity towards south.

It is possible to imagine that both D2 and D3 phases of the deformation actually originated during a single westward shearing associated with a strike slip movement e.g. the model of Coward and Potts (1983). If the core of the transcurrent shear zone is located in the south, then the tightest fold (Klínovec antiform) should, in agreement with analogue kinematical models, exhibit a sub-horizontal fold hinge and a vertical axial plane (Odonne and Vialon, 1983). This was also our working hypothesis at the beginning of our research. However, there are several observations that are not consistent with such a kinematical model. The most contradictory evidence against a simple shear model is the presence of steep omphacite lineations in the eclogites. These eclogites are located in both hinge and limb domains of the Klínovec antiform, and are surrounded by weaker orthogneisses exhibiting horizontal stretching lineations (Klápová et al., 1998). If we consider only a single tectonic regime, then the discrepancy between fabric in the competent eclogites and surrounding incompetent gneisses is not justified. Therefore, the linear fabric in ecolgites originated during a different tectonic phase than that in adjacent weak gneisses, and the only acceptable explanation of this pattern is the passive rotation of eclogitic boudins during D3, as shown in fig. 7 in Konopásek et al. (2001). The whole finite strain analysis and subsequent strain modelling (figs. 8 and 10 in Konopásek et al., 2001) were carried out to verify the possibility of superposed deformation. In our calculations, the finite strain in the gneisses resulted from superposition of a horizontal plane strain on a vertical plane strain ellipsoid. We note that the resulting flattening may originate due to horizontal simple shear in a strike slip zone, too! However, our analysis has shown that the structures resulting from high finite strain accumulation and those reflecting instantaneous strain share the same orientation of strain axes. There are no asymmetrical variations in fold axes and axial planes trajectories typical for simple shear. Therefore, the superposition of non-coaxial simple shear deformation was rejected.

(iii) The contemporaneous development of the D2 and D3 pattern, i.e. flat extensional fabric connected with transcurrent faulting could result in theory within a transtensional regime (Krabbendam and Dewey, 1998). However, such a fabric would vary between plane strain to highly constrictional, which is not the case.

## 3. Structural position of the eclogites

In the area described in the discussed paper, the largest occurrences of mafic eclogites are spatially associated with the orthogneiss body. Many of the small eclogite boudins are disseminated throughout the area, mainly in the northern domain of flat-lying $S_2$ foliation. In our interpretation, the D2 thrusting is associated with strong and multiple imbrication of the actual thrust zone, and the development of duplexes. One such duplex is shown in the lithotectonic column in fig. 2 of the discussed paper. This in our opinion causes the presence of eclogites within the metasedimentary unit, but still close to the inferred thrust plane.

Close examination of the position of eclogites in the Erzgebirge antiform shows (see e.g. fig. 1 in Willner et al., 2000) that the only outcrops within the Micaschist-eclogite unit of Willner et al. (1994) are those closely associated with the orthogneiss body of the Oberwiesenthal structure (see fig. 2 in Konopásek et al., 2001). Field observations suggest that this orthogneiss body represents a direct continuation of the Klínovec structure and thus is a part of our Lower Crystalline nappe. Therefore, the suggested presence of eclogites within the metasediments is, in our opinion, just a result of imbrication of the parautochthonous metasediments and the base of the Lower Crystalline nappe, and their re-folding during late D2 and D3.

## 4. Extension tectonics in the Czech part of the Erzgebirge

Indeed, in our interpretation both the D2 and D3 phases are compressive. Models of exhumation of deep-seated rocks by thrusting were published several times, and their discussion is beyond the scope of this contribution. What we do see in the field is the juxtaposition of eclogites with lower-pressure and lower-temperature metasediments. Unfortunately, PT conditions of the overlying orthogneisses cannot be determined due to their mineralogy. However, this is a classic example of an inverted metamorphic gradient (of course, tectonically induced), which to our knowledge cannot be explained by anything other than a thrusting mechanism. As the orthogneisses do not show any relics of eclogite-facies overprint, we suppose that they never reached the jadeite stability field, and conclude, that we "…are not able to provide any information about the mechanism of emplacement of eclogites from a depth corresponding to 26 kbar to the base of the non-eclogitic orthogneiss nappe". In other words, we interpret the orthogneisses to be a 'carrier' of eclogites from depths and temperatures below the plg/cpx transition, but do not discuss the mechanism for how eclogites reached the base of the orthogneisses.

In the southern part of the studied area, in the paper presented (and discussed above) $F_3$ folds obviously show a compressional character for the D3 deformation and the final D4 vertical compression (e.g. extension) is minor. Moreover, there are no lower-grade metasediments overlying the described lithologies, which would allow comparison of this part of the Erzgebirge with the situation in the western Erzgebirge.

To conclude, the 'unroofing' connected with eastward sliding of units was not observed in the Czech part of Erzgebirge, and only top-to-the-west-oriented kinematic criteria associated with the D2 fabric have been documented so far (Matte et al., 1990; Mlčoch and Schulmann, 1992; Schulmann et al., 1996; Konopásek et al., 2001).

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