

Reply to comment on “Deep subduction of felsic rocks hosting UHP lenses in the central Saxonian Erzgebirge: Implications for UHP terrane exhumation”

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We thank H.-J. Massonne (in press) for his comment on our paper published in *Gondwana Research* (Schönig et al., 2020). Our conclusion that a substantial part of felsic country rocks surrounding the well-known lenses of ultrahigh-pressure (UHP) rocks in the Saxonian Erzgebirge also underwent UHP metamorphism justifies a critical examination, in particular when taking the controversial views on this topic into account. Notably, H.-J. Massonne argues from a single

perspective considering the references cited in his comment; only three out of 18 (including the paper commented on and a geological map) are not authored or co-authored by himself. We appreciate the opportunity to underline the robustness of our results and conclusions.

Before replying to the individual points of criticism, we think some rock terminology should be clarified for the readership. We termed the diamond-bearing lenses at the eastern shore of the Saidenbach reservoir (fig. 1 in Schönig et al., 2020) ‘diamond-bearing paragneiss’ due to the origination from a sedimentary protolith (e.g., Massonne and Tu, 2007) and because it is frequently used in the literature. The term ‘diamondiferous gneiss’ was also used by H.-J. Massonne (e.g., fig. 1 in Massonne and Czambor, 2007), even after his interpretation that this rock type is of magmatic origin (Massonne, 2003). Anyway, the terms ‘diamondiferous quartzofeldspathic rock’ and ‘saidenbachite’ used by H.-J. Massonne designate the same rock type we called ‘diamond-bearing paragneiss’; in the following called ‘diamond-bearing rock’. The diamond-bearing rock lenses and coesite-bearing eclogite lenses (the known UHP rocks) are surrounded by various felsic gneisses. Depending on the classification used, one may subdivide them into different assemblages (Willner et al., 1997) or use different names as applied by H.-J. Massonne. All these subtypes have previously been interpreted as high-pressure (HP) to medium-pressure (MP) rocks hosting the UHP lenses (Willner et al., 1997), and thus we call them ‘country rock gneiss’.

The first major point of criticism by H.-J. Massonne relates to the source of the detrital UHP garnet grains. He quotes that most coesite- and diamond-bearing garnet grains derive from known UHP rocks and those which do fit to the reported garnet compositions of country rock gneiss, may also be derived from other UHP lenses.

Indeed, the chemical composition of most UHP detrital garnet grains matches or is close to the composition of garnet from previously reported coesite-bearing eclogite and diamond-bearing rock. However, our paper focuses on the nine coesite- and four diamond-bearing grains with compositions clearly deviating from garnet reported from the known UHP rocks of the investigated area (Fig. 1).

[Insert Fig. 1]

H.-J. Massonne suggests that the four diamond-bearing grains may derive from the known diamond-bearing rock and not from the surrounding country rock gneiss, because our study (i) did not consider garnet zoning, (ii) did not consider some extreme garnet compositions which have not been published, and (iii) did not consider unpublished data of a finer grained diamond-bearing rock type (it remains unclear in the comment if such data exist or not).

With regard to zoning, fig. 16 in the field trip guide of Massonne (2011) is cited to exemplify the compositional range of garnet in the diamond-bearing rock which was claimed to not be considered in our study. We already considered the corresponding data (table 6 in Massonne, 2011) for compositions of garnet core, mantle, and rim (see table A.1 in Appendix A of Schönig et al., 2020). Accordingly, the data matches with the 95 % confidence regions shown in figs. 2, 3, and 5 of Schönig et al. (2020). This is highlighted in Fig. 1A where the zoned garnet composition of Massonne (2011) is marked. Note that 95 % confidence is a conservative approach, which already takes considerable variation into account. Neither we nor the readership can evaluate unpublished data which may or may not point in another direction.

In addition to the considered zoning for the diamond-bearing rock garnet, the composition of each of the detrital garnet grains has been determined at nine spots per grain (one at the center,

four at the mantle, and four at the rim) to avoid any zonation bias. Although we considered all data available for the compositional range, all nine spots analyzed for each of the four diamond-bearing detrital grains do not match with garnet from the known diamond-bearing rock. In contrast, their composition matches well with garnet of the country rock gneiss.

Without presenting any further reasons than discussed above, H.-J. Massonne mentioned that coesite-bearing grains in samples JS-Erz-3s, -5s, -6s, and -8s may also be derived from other diamond-bearing rock lenses or coesite-bearing eclogite. We agree on this point for most of the coesite-bearing grains but some clearly differ and solely match with country rocks (Fig. 1B). Additionally, samples JS-Erz-13s and -14s also contain coesite-bearing garnet with compositions solely matching with the country rock gneiss.

The second major point of criticism encompasses that (i) the garnet content of country rock gneiss is much lower compared to the known UHP rocks, (ii) the garnet size is much smaller at $\sim 100\ \mu\text{m}$, and (iii) country rock garnet should thus be under-represented in our dataset by considering a grain-size range of $63\text{--}500\ \mu\text{m}$.

First of all, the garnet size in the country rock gneiss is often larger than the $\sim 100\ \mu\text{m}$ mentioned. For the country rock gneiss surrounding the diamond-bearing lenses this is evidenced by fig. 3 in Willner et al. (1997) and sample JS-Erz-11h taken close to this locality (Fig. 2, N 50.72694° , E 13.24681°). Generally, for country rock gneiss of the investigated area garnet crystal sizes up to several millimeters are reported (Willner et al., 1997). Secondly, although the garnet content of the country rock gneiss is much lower, the volume is much larger (fig. 1 in Schönig et al., 2020),

and therefore the proportional contribution of country rock garnet is expected to be higher than the ratio of the modal contents (i.e., country rock vs. UHP lenses), for most of the catchments.

[Insert Fig. 2]

We agree, however, that detrital country rock garnet is depleted relative to garnet from eclogite and diamond-bearing rock lenses when compared to the bedrock proportions in the catchments. Nevertheless, our samples contain detrital garnet from the country rock gneiss and garnet composition implies that nine coesite-bearing grains as well as four diamond-bearing grains derive from those country rocks. Considering the depletion, this means that UHP metamorphism of the country rocks might be even more frequent than expected from the amount of detrital UHP garnet from the country rocks.

The third major point of criticism relates to the geodynamic models of exhumation. First of all, we do not propose a specific exhumation model in our paper. Many different exhumation mechanisms and models for continental UHP terranes have been proposed (e.g., Zhang and Wang, 2020). Favoring a specific scenario for the Saxonian Erzgebirge is beyond the scope of our paper. Instead, we place well-considered constraints regarding, e.g., the size of the rock body affected by UHP metamorphism and the lithologies involved, although we cannot exactly delimit it. We thus vehemently refuse the implied interpretation of our results by Massonne (in press), as illustrated in his figure 2C along with the insinuation that it is done “*on the basis of the description by Schönig et al. (2020)*”. Such a statement is incorrect and misleading.

Based on our results, we state that (i) the known UHP lenses, as well as substantial parts of the country rocks, experienced UHP metamorphism, (ii) this points to subduction to UHP conditions

as a largely coherent slab, and (iii) consequently coesite can be expected to have been present as a matrix phase in the voluminous felsic country rocks. This in turn has significant implications for the buoyancy development during exhumation when coesite transforms to quartz. Many factors contribute to the exhumation velocity, some may be more important than buoyancy, but whatever exhumation mechanism is considered, the effective pressure gradient in the subduction/exhumation channel ($\partial P/\partial x$) is among the controlling factors (Zhang and Wang, 2020):

$$\frac{\partial P}{\partial x} = (\rho_{Mantle} - \rho_{Channel})g \sin\theta$$

where ρ_{Mantle} is the density of the surrounding mantle, $\rho_{Channel}$ is the density of rocks in the subduction/exhumation channel, g is the gravitational acceleration, and θ is the subduction angle. Thus, decreasing the density of the voluminous felsic rocks in the subduction channel at the coesite-to-quartz transition increases the effective pressure gradient and consequently exhumation velocities in all models.

H.-J. Massonne defends his model of a magmatic ascent of the diamond-bearing rock lenses through the mantle wedge by referring to the extreme exhumation rates suggested by Stöckhert et al. (2009). Based on this, H.-J. Massonne rules out any other exhumation model. Stöckhert et al. (2009) observed partially healed fractures originating from polyphase inclusions in garnet of the diamond-bearing rock. The inclusions contain diamond/graphite, phlogopite, quartz, phengite, and minor amounts of other minerals. The authors suggest that carbonaceous fluids were entrapped in the stability field of diamond and that brittle failure (decrepitation) occurred at UHP conditions leading to a drop in inclusion pressure and crystallization of silicates at 750°C and <2.5 GPa. Based on this assumption, exhumation rates must have been fast enough to overcome

the garnet dislocation creep at the high temperatures and build up the inclusion overpressures required for decrepitation. Because many factors are unknown like the equation of state parameters of the supercritical fluid, the evolution of fluid composition, density, and solubility, the inclusion shape, the variability of inclusion assemblages, and the possibility of accidental trapping of fluid plus crystals, Stöckhert et al. (2009) use a conservative lower bound for the strain rates at decrepitation. By this inspiring approach, the authors conclude that exhumation rates of 100 m/a are necessary.

Such extreme rates require that the assumptions of decrepitation conditions of $\sim 750^\circ\text{C}$ at UHP as well as silicate crystallization after decrepitation are fulfilled. This is highly speculative: (i) the inclusion assemblages are not indicative for a specific temperature. Considering 200°C less at decrepitation results in a change of the strain rate and thus the estimated exhumation rate of approximately four orders of magnitude (fig. 6 in Stöckhert et al., 2009); (ii) it is unclear whether the silicates crystallized after or prior to decrepitation. It cannot be ruled out that changes of the fluid properties and inclusion pressure due to the early precipitation of carbonaceous phases enabled also silicate crystallization at an early stage without decrepitation; (iii) there is no evidence that decrepitation occurred at UHP conditions. Alternatively, the inclusion strains may elastically re-equilibrated during decompression and decrepitation resulted from later cooling at lower pressure, which agrees with Raman shifts of the diamond main band to higher frequencies observed by Schönig et al. (2019). Based on the high uncertainties, the extreme exhumation rates estimated by Stöckhert et al. (2009) do not prove a magmatic ascent of the diamond-bearing rock lenses.

Massonne et al. (2007) estimated an exhumation velocity >10 cm/a based on SHRIMP U–Pb dating. However, the reported ages of 337.0 ± 2.7 Ma for zircon cores, 336.8 ± 2.8 Ma for the

diamond-bearing mantles, and 330.2 ± 5.8 Ma for the rims only allow to estimate minimum exhumation velocities from core-mantle to rim, if at all. The high uncertainty is highlighted by figure 14 in Massonne et al. (2007; note the use of 1σ -errors only). Mean square weighted deviation and probability of concordance are not given. In addition, zircon cores and mantles have later been dated by LASS-ICP-MS at 341.8 ± 2.0 and 340.1 ± 1.8 Ma, respectively (Kylander-Clark et al., 2013).

Considering also earlier works (Kröner and Willner, 1998; Werner and Lippolt, 2000), Kylander-Clark et al. (2012) concluded that the chronologic data of the Saxonian Erzgebirge does not define a coherent picture and roughly supposed <7 Ma for the exhumation. Hence, the current data referring to exhumation velocities of UHP rocks in the Erzgebirge are insufficient and partly contradictory. Velocities in the order of plate tectonic rates seem more likely than extreme velocities of up to 100 m/a. It should be mentioned that exhumation rates in the order of plate tectonic rates were also considered for HP rocks of the same age (~ 340 Ma) all over the Central European Variscides (e.g., Willner et al., 2002 and references therein).

In conclusion, all points of criticism raised by H.-J. Massonne on our paper do not hold out against objective and detailed examination. Based on the presented data compared to the available literature data, our conclusion that a substantial part of country rocks underwent UHP metamorphism is the most likely interpretation. A depletion of detrital garnet derived from the country rock gneiss in our samples does not affect this conclusion. The model of a magmatic ascent of the diamond-bearing rock lenses favored by H.-J. Massonne is very speculative, in particular when considering the high uncertainties of exhumation rates which the model is based

on. Thus, it remains unclear how this should disprove our conclusion of a largely coherent slab subducted to UHP conditions.

Acknowledgements

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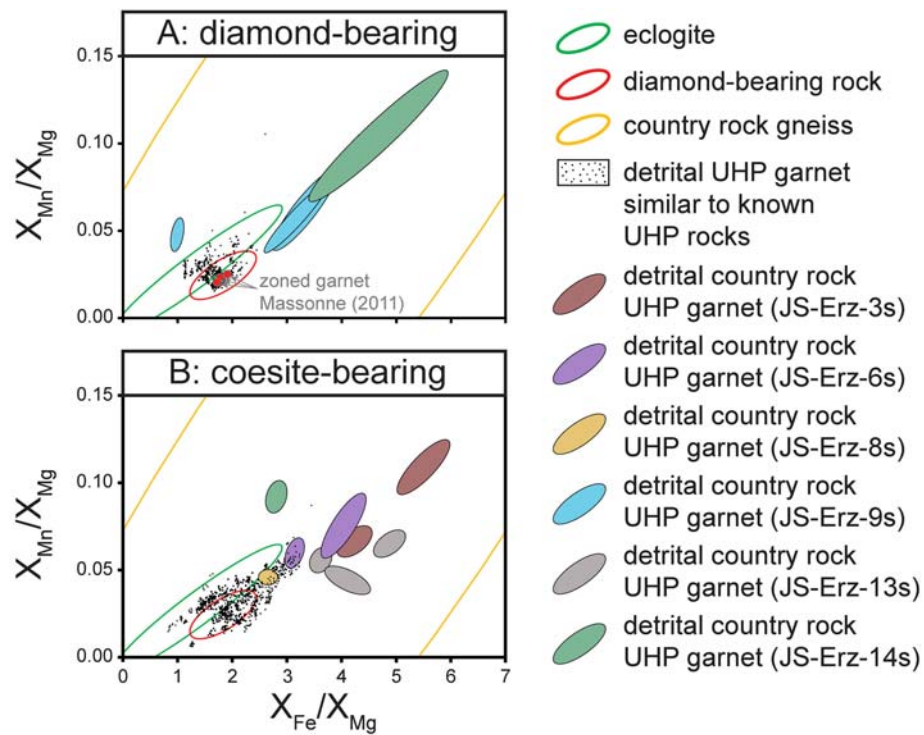


Figure 1. Composition of (A) diamond- and (B) coesite-bearing detrital garnet summarized after Schönig et al. (2020). Compositions similar to the known eclogite and diamond-bearing rock lenses are shown as small black dots and compositions solely matching with country rock gneiss as colored envelopes (nine spots per grain analyzed). See also figures 2 and 3 in Schönig et al. (2020).

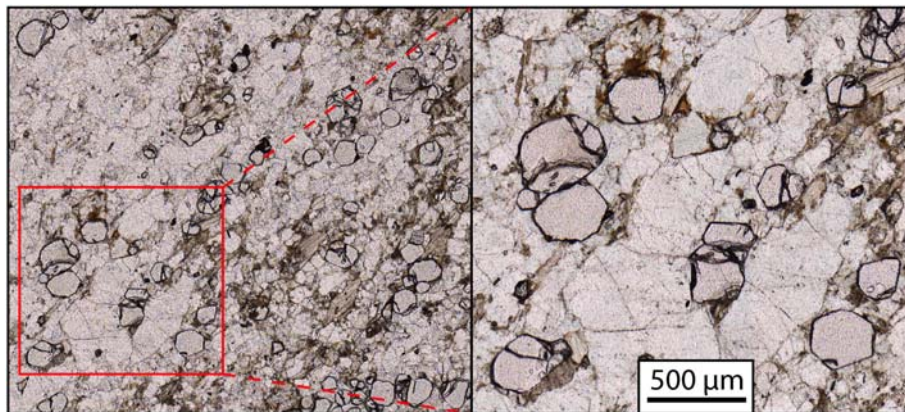


Figure 2. Photomicrograph of banded country rock gneiss sample JS-Erz-11h taken close to a diamond-bearing rock lens (N 50.72694°, E 13.24681°).