Geochemical Perspectives Letters

Comment on "Ultra-high pressure and ultra-reduced minerals in ophiolites may form by lightning strikes"

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Comment

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Ballhaus *et al.* (2017) use electric-discharge experiments to argue that lightning strikes could produce ultra-high pressure (UHP) and super-reduced (SuR) phases "identical to those found in 'high-pressure' ophiolites" and that thus there is "not sufficient evidence to challenge long-established models of ophiolite genesis", specifically for the UHP processing of Tibetan ophiolites. However, the authors produced no evidence for UHP phases in their experiments. There are pertinent observations, relevant to the authors' assertions, in the literature regarding the relationship between the UHP and SuR assemblages in the Tibetan peridotites. Their conclusions are not consistent with this evidence.

(1) There is no clear genetic connection between the UHP phases and the SuR assemblage in the Tibetan ophiolites. The SuR phases, such as moissanite, native metals, carbides, Ti-nitrides and silicides, found in mineral separates or *in situ*, have no confirmed textural connection with UHP phases (*e.g.*, Robinson *et al.*, 2004; Xu *et al.*, 2015), with the possible exception of a moissanite inclusion in diamond (Moe *et al.*, 2017), and coesite surrounding an alloy ball (Dobrzhinetskaya *et al.*, 2009).

(2) The SuR assemblage reported in the Tibetan chromitites is very similar to one documented in Cretaceous mafic pyroclastic rocks in Israel. These SuR phases are interpreted as products of reactions between mantle-derived CH_4-H_2 fluids and basaltic to ultramafic melts (Griffin *et al.*, 2016a; Xiong *et al.*, 2017).

In both the Israeli and the Tibetan examples, many of the SuR phases occur in melt pockets trapped in skeletal corundum crystals, rapidly crystallised from Al_2O_3-supersaturated melts (Xu *et al.* 2013; Griffin *et al.* 2016a; Xiong *et al.*, 2017). These melts were depleted in Fe and Si by the immiscible separation of Fe-Ti-Si-C melts and crystallisation of SiC (crystals >4 mm in the Israeli examples, ≤2 mm in Tibetan ones), leading to very high Al contents. The presence of native vanadium in late-stage Si-depleted melts requires very low oxygen fugacities (ΔIW -11; Griffin *et al.*, 2016a). The abundance of carbides (TiC, SiC) and amorphous carbon indicates high carbon contents in the melts. Textural evidence for the reaction corundum+melt – anorthite in the Israeli examples indicates crystallisation pressures of 9-10 kb, and temperatures of *ca.* 1450 °C (Goldsmith, 1980).

These SuR phases are clearly related to deep magmatic processes in the mantle, rather than lightning strikes.

(3) The diamonds in Tibetan ophiolites (Bai *et al.*, 1993) have been largely ignored by geoscientists, because of their similarity to those grown by high-pressure high-temperature (HPHT) synthesis, and because their lack of nitrogen aggregation (pure Ib) is inconsistent with the originally proposed (Yang *et al.*, 2014) deep origins. Detailed studies of these diamonds provide compelling evidence for their natural origins (Howell *et al.*, 2015; Moe *et al.*, 2017), and describe characteristics that are hard to reconcile with the environment proposed by Ballhaus *et al.* (2017), which resembles the chemical vapour deposition (CVD) process used to produce some synthetic diamonds. Growth rates of high-quality single crystals in carefully-controlled laboratory CVD synthesis are in the region of 100 μm/hr (*e.g.*, Liang *et al.*, 2009; Lu *et al.*, 2013). Thus, the plasma temperatures of the lightning strike would need to be sustained for hours to produce the diamonds (100 - 500 μm) in the Tibetan ophiolites; this would be inconsistent with the lack of nitrogen aggregation (P. Cartigny, *pers. comm.* 2018). The diamonds clearly formed at high T (metal-alloy inclusions) but the nitrogen-aggregation data are inconsistent with formation in the transition zone. We have suggested (Xiong *et al.*, 2017) that they formed in systems like the Israeli one, but at greater depths.

(4) The Tibetan peridotites and chromitites are typical of those formed at shallow depths, in the mantle wedges of subduction zones (Griffin *et al.*, 2016b). The evidence for their subsequent subduction to the deep upper mantle or Mantle Transition Zone is difficult to attribute to lightning strikes.

(a) Exsolution of pyroxenes (+rare coesite) as oriented lamellae in chromite. Yamamoto *et al.* (2009) suggested that a UHP precursor with a calcium ferrite structure originally formed at >12.5 GPa, and then decomposed to low-P chromite containing silicate exsolution lamellae. The stability range of

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this polymorph (14- ≥18 GPa at 1400 °C), and its ability to incorporate percent levels of Ca and Si, have been demonstrated experimentally (Zhang *et al.*, 2017).

(b) Microstructures suggesting that the chromitites recrystallised under static conditions from fine-grained, highly-deformed mixtures of wadsleyite and an orthorhombic polymorph of chromite (Satsukawa *et al.*, 2015).

(c) Harzburgites with coarsely vermicular symplectites of orthopyroxene + Cr–Al spinel ± clinopyroxene. Reconstructions suggest that these are the breakdown products of high-Cr (6-8 wt. % Cr_2O_3; peridotitic) majoritic garnets, with estimated minimum pressures up to *ca.* 13 GPa (Gong *et al.*, 2016; Griffin *et al.*, 2016b).

(d) The presence in the Luobusa chromitites of an inverse-ringwoodite phase with minor levels of Mg and Al (Griffin *et al.*, 2016b). This phase has been produced in the magnesiochromite-forsterite system at 20 GPa and 1600 °C (L. Bindi, *pers. comm.* 2017), further confirming the Transition-Zone metamorphism of the Tibetan chromitites and their host peridotites.

Conclusions, Acknowledgements

The experiments described by Ballhaus *et al.* (2017) did not produce any UHP phases. The large body of evidence for the UHP metamorphism of some collision-zone ophiolites cannot be dismissed on the basis of a speculation that other experiments *might* do so. However, we thank the authors for an entertaining contribution, and the opportunity to provide this clarification for the scientific community.

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