Geochemical Perspectives Letters

Reply to Comment on "Ultra-high pressure and ultra-reduced minerals in ophiolites may form by lightning strikes" by Griffin *et al.*, 2018: No evidence for transition zone metamorphism in the Luobusa ophiolite

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OPEN ACCESS

Reply

doi: 10.7185/geochemlet.1810

Received 6 January 2018 | Accepted 29 January 2018 | Published 9 March 2018

Griffin *et al.* (2018) discard our lightning experiments because we did not identify ultra-high pressure (UHP) phases. Our experiments (Ballhaus *et al.*, 2017) provide the first rational explanation of many unusual findings in the so-called UHP ophiolites and hence undermine the foundations on which the resulting speculative geotectonic scenarios are based. Little room seems left to postulate that ultramafic rocks along the Jarlung-Zangbo suture zone have seen Transition Zone (TZ) pressures (McGowan *et al.*, 2015; Griffin *et al.*, 2016a); that chromite crystallised as high pressure polymorph in the calcium ferrite (CF) structure (Xiong *et al.*, 2015); or that the upper mantle is super-reduced (Griffin *et al.*, 2016b).

(1) Griffin *et al.* (2018) assert that there is no confirmed textural connection of ultra-reduced phases with UHP minerals. That is incorrect. Yang *et al.* (2007) document symplectites from Luobusa rocks in which Fe-Ti-Si alloys are intergrown with pseudomorphs of coesite after stishovite.

(2) The glass composition Griffin *et al.* (2016b) report from Mount Carmel has 4.8 wt. % MgO and zero FeO. That melt is not in equilibrium with an upper mantle mineralogy. So how could one speculate that ultra-reduced phases like Ti_2O_3, Fe-Si alloys, Ti nitrides and borides inside that glass are diagnostic of mantle redox states?

(3) Griffin *et al.* (2018) doubt that the diamonds of Luobusa are vapour deposited (CVD) diamonds. We brought up the CVD option because we synthesised shell fullerenes, known to be potential precursors to diamond. Alternative origins are (1) isochoric shock heating following lightning bolts: the Popigai astrobleme (Koeberl *et al.*, 1997) was also short-lived but did produce diamonds millimetres in size, so the size-time argument may not be valid; and (2) contamination: all transition elements Griffin *et al.* (2016a) found concentrated in metal inclusions in Luobusa diamonds are used in industry to flux the graphite-diamond transition (Sung and Tai, 1997). We consider a mantle origin unlikely. How could mantle diamonds have coexisted with Fe-free $Ni_{70}Mn_{20}Co_5$ metal melts (Griffin *et al.*, 2016a) when the lithologies that supposedly carried those diamonds (chromitite, harzburgite) are ferrous and ferric iron bearing? Based on nitrogen aggregation states, Howell *et al.* (2015) calculate for the Luobusa diamonds residence times of ~100 years. Why are the implications of this important finding being ignored?

(4) Griffin *et al.* (2016a) document oxide and silicate spherules and relate them to an unspecified high temperature event. Are the authors aware of magmatic activity that produces near-perfectly spherical wüstite globules? Zuxiang (1984) suggested the globules are extraterrestrial in origin because he identified Fe-Si alloys in their cores. We reproduce those spherules with electric discharges in all detail, and we offer a sensible explanation: they are ejecta of plasma fountains released from lightning flash tubes, quenched and oxidised extremely rapidly in air.

(5) Griffin *et al.* (2016a), Yamamoto *et al.* (2009), and Xiong *et al.* (2015) assert that podiform chromite crystallises (or recrystallises) in the CF structure at >12 GPa because it carries clinopyroxene exsolutions. In the Griffin *et al.* (2016a) scenario, chromite is first enriched to ore grades at low pressure, then subducted to 600 km, then exhumed back to the surface. Along that path, magmatic chromite would recrystallise twice: first at high pressure in the CF structure to incorporate the silicate component, then back to spinel to exsolve silicate in the form of clinopyroxene needles. Are the authors aware that liquidus chromite also incorporates SiO_2 and CaO to the tune of 0.3 wt. % each (Barnes, 1986; Kinzler, 1997)? That is more than enough to exsolve clinopyroxene needles during annealing. As for the inverse ringwoodite octahedra brought up by Griffin *et al.* (2016a) in support of their UHP model, we wait for the site occupancies of the cations based on structural refinement data and/or High Resolution Transmission Electron Microscopy (HRTEM) images. As for coesite, isochoric heating following lightning strikes may reach pressures well inside coesite stability (Chen *et al.*, 2017).

(6) If the mantle sections of the Tibetan ophiolites were subducted to 600 km then exhumed, why after emplacement are ultramafic lithologies juxtaposed to gabbros? Gabbro cumulates do not tolerate pressures above 1 GPa, neither texturally nor mineralogically. In the Luobusa ophiolite, the classic ophiolite lithostratigraphy appears to be preserved

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(Xuchang *et al.*, 1983) even though it may have been modified during obduction. Should we assume then that at Luobusa, the juxtaposition of harzburgite and dunite to gabbros is coincidental? Or did the gabbros wait patiently in place while the ultramafic sections of the ophiolite were being cycled down and up through the TZ for 1200 km?

(7) We are not convinced that lithologies with zero pressure densities around 3300 kg m^{-3} could have been exhumed so easily from 600 km depths over 2000 km along the Jarlung-Zangbo suture zone. Diamonds are reported in ophiolites along that suture for 1300 km (!) along strike (Howell *et al.*, 2015). No numerical model covers exhumations from TZ pressures on such grand scales.

Thirty years of research failed to acknowledge similarities between phases in the so-called UHP ophiolites and in fulgurites. This is surprising. Chromitites and serpentinised (magnetite bearing) harzburgites are electrically quite conductive. At the elevation of the Tibetan ophiolites cloud-to-ground lightning bolts are common (Qie *et al.*, 2003). When lightning hits solid rock, a thermal pulse is generated that may impose extreme shock pressures in excess of 10 GPa (Chen *et al.*, 2017). The fulgurite glasses resulting may carry a wide range of super-reduced minerals including metallic Fe, Si, Fe-S-Ti alloys, and moissanite (Essene and Fisher, 1986; Plyashkevich *et al.*, 2016). If these exotic phases are recovered from oxidised FeO-Cr_2O_3 bearing lithologies, should we not search for other terrestrial occurrences in rocks from tectonic settings that cannot have seen high pressure?

Griffin and coworkers should analyse Luobusa diamonds for radiogenic carbon.

Acknowledgements

We thank Griffin *et al.* (2018) for giving us the opportunity to communicate more details.

Editor: Graham Pearson

Additional Information

Cite this letter as: Ballhaus, C., Fonseca, R.O.C., Bragagni, A. (2018) Reply to Comment on "Ultra-high pressure and ultra-reduced minerals in ophiolites may form by lightning strikes" by Griffin *et al.*, 2018: No evidence for transition zone metamorphism in the Luobusa ophiolite. *Geochem. Persp. Let.* 7, 3-4.

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