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Latest Permian chars may derive from wildfires, not coal combustion

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We thank Grasby et al. (2015) for their Comment, which provides us with the opportunity to expand on our interpretation that the Permian vesicular char, presented by Grasby et al. (2011), derives from wildfires rather than coal combustion. We presented (Hudspith et al., 2014) vesicular chars produced during wildfires that occurred in a range of ecosystems (peat bog, tundra, and boreal forest), as well as inertinite (fossil charcoal) from Russian Permian coals, in order to demonstrate that vesicular chars can be formed naturally during wildfires, in a variety of ecosystems. Grasby et al. argue that the Permian vesicular chars, in particular, could have been produced by *both* coal combustion and wildfires because (1) they consider that global transport of char produced in surface fires in Russian Permian peatlands is unlikely, (2) wildfires do not produce cenospheres or spheroidal carbonaceous particles (SCPs; a unique particle morphology produced as a byproduct of coal combustion in a power station), and (3) Grasby et al. erroneously assume that Permian peatland wildfires and Siberian Traps volcanism were contemporaneous. These three points are explored in more detail here.

(1) We argue that a global transport mechanism for wildfire-derived char is not required because, as we have outlined (Hudspith et al., 2014), higher atmospheric oxygen levels during the Permian Period led to a doubling of ignition potential of vegetation; thus, wildfires were far more prevalent than in the present day. This is evidenced by high inertinite (fossil charcoal) contents in Permian coals, compared to modern peatlands (Glasspool and Scott, 2010). Not only were there more wildfires in the Permian, but we have demonstrated that vesicular char, which is equal in appearance to that presented by Grasby et al. (2011), can be produced in wildfires in a range of ecosystems (Hudspith et al., 2014). There is therefore no need for a global transport mechanism of wildfire-derived char, because Permian wildfires likely occurred in many vegetated areas, potentially even closer to Lake Buchanan (Arctic Canada), the location in which latest Permian vesicular char was found by Grasby et al. (2011).

(2) We do not dispute that cenospheres (or SCPs) are a product of coal combustion; however, experimental combustion of pulverized biomass (wood chips) can also generate cenosphere-like particles (e.g., Borrego et al., 2009). More importantly, the 'cenosphere' illustrated by Grasby et al. (2011, their figure 2a), upon which their entire argument is based, would not be classified as a cenosphere according to official fly ash classification schemes (e.g., Bailey et al., 1990). In order to demonstrate that these particles derive from combustion of vitrinite, hence coal, Grasby et al. would have to demonstrate that their Permian cenospheres are anisotropic (Goodarzi and Hower, 2008). However, they state that their chars are isotropic, which does not provide definitive proof that these were produced by coal combustion, as opposed to wildfires.

(3) We (Hudspith et al., 2014) did not expand on the stratigraphic relationships between our Permian coals and the Siberian Trap eruptions. Two lava flows occur within the overlying coal-barren Triassic sandstone units in the Kuznetsk Basin (Siberia; Davies et al., 2010), providing firm evidence that the coals of Hudspith et al. (2014) are stratigraphically *older* than the Siberian Traps units. Basaltic intrusions into Carboniferous and Permian age coals in the Tunguska Basin (Ryabov et al., 2014) further demonstrate that these peats were already coals at the time of trap magmatism (ca. 250 Ma). However, they were likely low-rank coals, and coals with ranks lower than bituminous typically produce carbon in fly ash with morphologies that resemble the precursor vitrinite, rather than vesicular chars (e.g., Goodarzi and Hower, 2008). Therefore, Grasby et al.'s argument that the vesicular chars found in our Kuznetsk Permian coals derived from intrusion-ignited coal is erroneous.

Fundamentally, beyond the 'fly ash' presented by Grasby et al. (2011), there is no field evidence for explosive coal combustion during Siberian Traps volcanism (Ryabov et al., 2014). There is, however, definitive evidence of magma-coal interaction in Siberia in the form of native iron/ graphite, but these are strictly associated with layered intrusions (Ryabov and Lapkovsky, 2010). Indeed, the majority of intruded coals form coke and/or anthracite (Ryabov et al., 2014). Yet, neither coke, graphitized coal, or graphite (e.g., Kwiecińska and Petersen, 2004) resemble fly ash. There is also evidence from Siberian layered intrusions for assimilation of upper crustal materials (such as hydrocarbon-rich sediments) into magmas, resulting in the generation of native metal and sulfide ore deposits, as well as small amounts of bitumen (oil-derived) (Ryabov et al., 2014). Even if bitumen was formed in the explosive phase of eruptions, it is only present in minor amounts, and bitumen is not visually comparable to fly ash (e.g., Rimmer et al., 2015). It is also unclear how such layered intrusions interacting with coal seams could generate particles with the same morphology, and size, as a pulverized coal (typically <75 μm particle size) combusted in a power station, as none of the products derived from magma-coal/hydrocarbon interaction observed in Siberia are comparable to particles of fly ash.

To clarify, our analysis does not state that Permian wildfires contributed to the end-Permian extinction. We merely document the occurrence of wildfire-derived vesicular char, akin to those interpreted by Grasby et al. (2011) as fly ash, in a wide range of modern and ancient ecosystems. Grasby et al. in fact agree that our photomicrographs of Permian vesicular chars strongly resemble the particles observed by them in the Lake Buchanan section. Therefore it is more likely that these represent inertinite (fossil charcoal) produced in Permian wildfires, as part of the natural fire regime at the time. We therefore refute Grasby et al.'s assertion that their (Grasby et al., 2011) particles derive from both wildfires and coal combustion, because we believe that there is abundant evidence for Permian wildfires, but no viable mechanism for generating fly ash, or for the explosive coal combustion required to disperse it, during Siberian Traps volcanism.

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