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Climatic control on Icelandic volcanic activity during the mid-Holocene

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We identify flaws in the criticisms of Harning et al. (2018).

**Volcanic activity**—We are fully aware of the limitation of the tephra datasets but contend that the combination of distal and proximal records are an extremely novel and powerful tool to investigate volcanic activity in Iceland. This combination ensures that both silicic and non-silicic events were included in the analysis. It is correct that the northern European volcanic ash (NEVA) record only captures tephra dispersion eastward. However, the principal transport direction for volcanic ash from Iceland is easterly to south-easterly toward northern Europe. We are aware that Icelandic plumes disperse in other directions and that is why data from within Iceland and from the Northern Icelandic Shelf were also analyzed. Harning et al. state that <50% of the events in the NEVA database are verified Icelandic eruptions. Plunkett and Pilcher (2018) calculated that roughly a quarter of the NEVA layers are non-Icelandic. It is true that some events have not been linked to specific Icelandic eruptions although their geochemistry suggests they are Icelandic. We removed tephra layers with a known source eruption outside of Iceland prior to analysis. Despite these criticisms, the lull in the tephra records at 5.5-4.5 ka remains. There is no comprehensive tephrostratigraphy of Iceland, but we combined the NEVA dataset with a selection of reliable high-quality, continuous, tephra published datasets from Iceland. We did not include any data from non-peer-reviewed publications, which precludes the unpublished and non-peer-reviewed M.Sc. thesis of Jóhannsdóttir (2007). We did not include the detailed tephra record from eastern Iceland (Gudmundsdóttir et al., 2016) but have included an analysis of it here (right). It clearly shows the decrease in volcanic activity centered on 5.5-4.5 ka corroborating our original findings (Swindles et al., 2018). The tephra layers presented in Jennings et al. (2014) were included in our analysis. We agree that water-magma interaction alters the grain-size distribution of eruptive products. Nevertheless, it does not follow that glacier-free basaltic volcanoes will produce ash-poor eruptions. There is a detailed record of explosive basaltic eruptions that produce ash rich eruptions in glacier-free areas (e.g., Houghton et al., 2004). Our use of distal and proximal datasets, and the new analysis above, makes Harning et al.’s criticism not stand up under scrutiny.

**Paleoclimate**—To contend that all the dates of glacier advance we use have large uncertainties is incorrect. Some are very well constrained using tephrochronology. Using clear geomorphological evidence (e.g., moraines), is important to constrain ice dynamics. Other lines of evidence can be ambiguous. The assertion that the GISP2 K/Na records are not reflecting changes in the Siberian High/Icelandic Low is incorrect; we refer the authors to Meeke and Mayewski (2002). Several authors have shown a cooling event at ca. 6.4 ka from terrestrial and marine proxies (Larsen et al., 2012; Gírísðóttir et al., 2013, and references therein). Our identification of the key event in different proxies makes a climate shift at this time hard to dispute. Blair et al. (2015) showed short-term proxy variability associated with tephra deposition in the lake alongside centennial-scale Holocene climatic changes. They identified a shift in climate (to cooler summers) after ca. 5.7 ka which is interpreted as neoglacialiation. Other criticisms of Harning et al. actually support our argument. For example, Harning et al. (2016) clearly showed a cooling period between 6.4 ka. There is strong evidence that glaciers advanced in response to the transition from the Holocene Thermal Maximum to the Neoglacial in Iceland (Larsen et al., 2012). However, we agree that the geomorphic evidence for glacier retreat is less clear. Moraine ridges marking termini positions are much more likely to be preserved at distal extents than during ice-margin regression (which can be continuous, or without sufficient still stands or minor re-advances to generate moraine ridges). However, glaciers on Iceland must have responded to the marked climate event at ca. 6.4 ka and the subsequent climatic amelioration in terms of ice thickening/thinning or advance/recede. The hypothesis proposed in Swindles et al. (2018) is understandably controversial. Harning et al. are quick to criticize our work but do not propose an alternative mechanism for the unambiguous lull in the NEVA and the Icelandic tephra datasets. Even small changes in surface loading can alter the stress field around shallow magma chambers, changing the likelihood of eruptions. Until the findings of Swindles et al. (2018) can be clearly refuted with evidence and through demonstration of an alternative mechanism, our assertions hold.

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