Response to Dr. Baillie's interactive comment on "Greenland ice core evidence of the 79 AD Vesuvius eruption" by C. Barbante et al.

We welcome Dr. Baillie's suggestions to ensure that many paleoclimate proxies have the best possible chronologies. The goal of this paper is to publish tephra recorded in the GRIP ice core. The presence of tephra in ice core records has only one possible source, and is a clear indication of past volcanic activity. We completely agree with Dr. Baillie that recent literature highlights that tephra "can occur in the ice record without acid and vice versa" (Davies et al, 2010: Coulter et al., 2012). Tephra are incontrovertible, tangible proof of volcanic activity and although acid peaks are often associated with volcanic activity, they may also have other sources (Mortensen et al., 2008: Davies et al, 2010a and b; Lowe, 2011; Coulter et al., 2012 and references within). Throughout the text of our paper, we freely acknowledge that our work is based on a limited number of tephra particles. We meet our goal of demonstrating a tephra record in the GRIP ice core, and provide a concrete example of using tephra to identify volcanic horizons in strata that have a controversial source.

In extrapolating our tephra and acidity layers to other paleoclimate records, Dr. Bailie mentions the offset between ice acidities and bristlecone pine frost rings, as well as historical records of dust veils. While we agree with Dr. Bailie that bristlecone pine frost rings are often caused by volcanic activity resulting in sudden cooling, volcanic activity is not the only cause of these decreased temperatures. Therefore, while the presence of tephra offers definitive proof of volcanic activity, bristlecone pine frost rings are possible secondary effects of volcanic activity. We applaud the comparison between multiple paleoclimate proxies, and feel that such comparisons are necessary in order to better constrain chronologies and to check the assumptions underlying these timescales. Our aim in this paper is to determine if cryptotephra can better identify important stratigraphic age horizons, but we do not attempt to directly change time scale development. The compilation of existing knowledge suggests that Dr. Baille's comment "links to tree ring chronologies may be the only way to impose an absolute chronology on the ice cores" is premature.

We would like to highlight some aspects of Figure 2 that appear to have caused confusion. We have explicitly addressed these concerns in the figure caption and in the figure itself in order to clarify our arguments and to ensure that this confusion is not further propagated. In addition, we do not attempt to calculate the acid or sulpher output of Vesuvius and have omitted any mention of this output as quantified in other studies.

The stable oxygen isotope values ($\delta^{18}O$) demonstrate the seasonality recorded in the ice core, where the warmer temperatures result in less negative $\delta^{18}O$ values, while cooler temperatures result in more negative $\delta^{18}O$ ratios. Diffusion of the $\delta^{18}O$ signal in the firn layer of the ice sheet does, however, not allow firm conclusions to be made as to the exact seasonality of deposition of the tephra layer. In figure 2 we have now included both the raw measured $\delta^{18}O$ data as well as the diffusion corrected data originally shown. While the mathematical deconvelution method allows us to correct for the diffusion and recover annual cycles lost to diffusion, this cannot be done with the precision needed for discerning separate seasons. We can therefore only broadly define summer as the peaks in $\delta^{18}O$ ratios. We highlight these warm seasons as wider bars in Figure 2, which better demonstrates the depth range attributed to summer rather than the original individual lines. However, the shoulder seasons of spring and autumn are quite difficult to discern when using deconvoluted $\delta^{18}O$ ratios to define seasonality, unless the accumulation is extremely high countering the diffusion process.

Dr. Baillie emphasized the two microparticle peaks and single acid peak in Figure 2. We separately examined the large microparticle peak occurring between 429.15-429.25 m depth and did not identify a single tephra particle (discussion on page 5439). All microparticles between 429.15-429.25 m had chemical compositions indicative of continental crust as determined by both examining individual particles and the major ionic composition of the melted ice. This large microparticle peak does not influence any conclusions regarding volcanic activity.

Figure 2 clearly demonstrates the stratigraphic offset of 20 cm between the acidity peaks and the location of the tephra particles. Throughout the paper, we argue that this offset may be due to the differential transport and deposition of tephra particles and volcanic aerosols injected into the stratosphere. This explanation of differential deposition pathways is supported in the literature (Vinther et al., 2006; Lowe, 2011; Folch, 2012 and references within) and offers the simplest possible solution. Dr. Baillie argues that "there is no absolute guarantee that the tephra and the acid need to be from the same volcano". Table 2 lists the location, magnitude, and general geochemical characteristics of relatively coeval volcanoes. As we demonstrate in Figure 4, the GRIP tephra are geochemically similar to the Vesuvius tephra (Santacroce et all, 2008). It is possible that one of the volcanoes with eruption ages calculated between A.D. 50-100 (Table 2) may have occurred within months of the Vesuvius eruption and may only be recorded in the Greenland ice sheet as an acidity peak. However, this explanation requires that the two separate volcanoes only deposit tephra or volcanic acids, respectively, on the Greenland ice sheets within months of each other. Invoking two separate volcanoes to explain the 20 cm offset in peaks is a much more complex solution. As we cannot completely rule out this solution, we include the following sentences in the paper: "*An alternate explanation for the 20 cm offset between the acidity peak and microparticle peak containing tephra fragments (Figure 2) is that these two peaks were caused by two separate high-VEI volcanic eruptions within a matter of months (Table 2). This argument requires that one volcano only deposited acidic volcanic aerosols, while the other volcano deposited only a few tephra particles. This is a more complex solution than explaining the difference in peak depth due to differential deposition pathways.*"

We appreciate Dr. Baillie's comment on our work and the associated opportunity to clarify some of our arguments. We feel that examining any chronology in detail helps the paleoclimate community as a whole. We look forward to future work examining the possibilities for geochemically constraining individual volcanic horizons in ice cores with implications for timescale development.