RESPONSE TO DAVIES (Referee 1):

Specific comment 1: The authors recognize the problems that can arise with the use of SEM-EDS techniques, especially on samples that are not polished and not embedded within a mounting media (5436, line 20). As such I feel that the authors need to provide further information on the quality of the data, particularly in relation to the certified mineral and glasses used as reference standards. Ideally, these should be presented alongside the analyses presented in Table 1. I also agree with the comments of Kurbatov requesting information on the SEM operating conditions and analyses of reference material from Vesuvius.

Response: Please see our response to the above question. We have incorporated this material into Table 1, as well as including a paragraph outlining the SEM operating conditions and analyses of reference materials.

Specific comment 2: An assessment of the data presented in Table 1, clearly shows that there is scatter within the data-set. In particular Particle 1 and 2 seem to be offset from particles 3-6. To explore this, I quickly plotted the data in Table 1 on biplots relative to the data presented by Santacroce et al. 2008 (see below). These plots emphasize the compositional heterogeneity of Vesuvian products, but also highlights some offsets between the new data and the reference data-set. This is most clearly seen in the TiO_2 values, and SiO_2 and FeO values on Particle 1 and 2. Particles 1 and 2 in particular seem to be offset from the other analyses with low FeO values and slightly higher SiO_2 values. It would be useful if the authors could explore this by using such graphical plots and consider the likely reasons for the offsets shown. Other plots do show consistency between the data-sets e.g. Ca vs K_2O total alkali silica plot (for 4 of the particles) Ca vs SiO_2 (for 4 of the partlcles) which in most instances shows a correlation to the white pumice component of the Vesuvian proximal deposits. However, a discussion of the offsets is required. Do all particles relate to the Veusvius 79 AD eruption?

Reponse: We thank the reviewer for these suggestions as well as the example biplots. We have incorporated these suggestions into two new figures (Figures 4 and 5) and the associated discussion in the text. Figure 4 compares the six GRIP tephra particles to the geochemical characterization of relatively coeval volcanoes (listed in Table 2). Figure 5 includes a collection of biplots as suggested by the reviewer. Ideally, we would like to be able to create such biplots comparing the particles analyzed in this study with the composition of tephra from coeval volcanoes (Table 2 and Figure 4). We would especially like to compare our results with tephra from Sete Cidades and Furnas, as these volcanoes are the most similar in composition to the Vesuvius A.D. 79 eruption. Unfortunately, to the best of our knowledge, such detailed analyses of tephra or pumice from these two volcanoes do not exist. Such a comparison would certainly shed light on if all particles relate to the Vesuvius A.D. 79 eruption. We have included the following discussion in the paper (changes in italics):

When compared against the total range of possible geochemical classifications, the six GRIP tephra fragments all fall within the phonolitic classification (Figure 4). However, when comparing the tephra fragments with whole-rock and individual pumice samples from the Pompeii A.D. 70 Vesuvius eruption, the GRIP particles appear relatively heterogenous (Figure 5; Santacroce et al., 2008; Balcone-Boissard et al., 2009). The GRIP tephra all contain high alkali (K_2O and Na_2O) concentrations and biplots demonstrate that for these elements all GRIP particles are consistent with previously determined Vesuvius chemistry (Figure 5). This high alkali concentration is important as, when comparing the Vesuvius eruption to coeval (A.D. 50-100) eruptions, only Vesuvius and eruptions from the Azores have high alkali concentrations (Figure 4; Table 4). The GRIP tephra differ from the Vesuvius values in FeO and TiO_2 versus CaO biplots (Figure 5), yet the range of Fe and Ti weight percentages remain within or close to those of Vesuvius (Figures 5 and 6). It is difficult to compare the GRIP FeO and TiO_2 values to other sources as using SEM-EDS to determine these oxides results in a high percentage of standard deviation *even when analyzing standard reference materials (Table 1). Particles 1 and 2 contain higher SiO_2 values than the other tephra and plot near the phonolite-trachyte boundary (Table 1; Figure 4), suggesting that the Sete Cidades (A.D. 90 ± 100) eruption could be a source of these two particles. Comparing the geochemical composition of particles 1 and 2 to ejecta from the Sete Cidades eruption could illuminate if these particles are from the Azores, but to the best of our knowledge, no detailed geochemical analysis of the A.D. 90 Sete Cidades tephra exists. As particles 1 and 2 remain within the phonolitic chemical characterization (Figure 4) and as they are similar to other GRIP and Vesuvius products (Figure 5), we assume that they are from the same source as the other GRIP tephra.*

Between A.D. 50 to 100 eruptive products from relatively coeval volcanoes with a similar eruptive strengths could have potentially reached the Greenland ice sheet (Table 2). The volcanic explosivity index (VEI) measures the magnitude and associated tephra volumes of eruptions (Newhall and Self, 1982). A VEI of 4 or greater suggests that the volcano was sufficently explosive to have injected material into the stratosphere (Newhall and Self, 1982), and so Southern Hemisphere volcanoes with a VEI of ≥ 4 are included in Table 2. Although stratospheric particles originiating in the Southern Hemisphere can reach Greenland (Zielinski et al., 1994), tephra from neighboring or Northern Hemisphere volcanoes are more likely to be deposited on the ice sheet (Langway et al., 1988, Clausen and Hammer 1988, Clausen et al., 1997). Many of the coeval eruptions, such as Ambrym, Vauatu or Raoul Island in the Kermadic Island chain, are located in areas where it is difficult for the volcanic aerosols to have reached the Greenland ice sheet. The K-phonolitic characteristics of the Vesuvius products differ from the composition of the tephra from known explosive eruptions between A.D. 50-100 (Table 2; *Figure 4*). *Of the coeval eruptions, only Sete Cidades and Furnas also have high alkali contents, although their geochemical classification (resulting either from higher SiO_2 contents and/or lower K_2O+Na_2O contents) differs from that of Vesuvius (Table 2; Figure 4). The consistently high K_2O and Na_2O weight percentages of all analyzed GRIP tephra makes it likely that the GRIP tephra are from any known coeval volcano other than Vesuvius, Sete Cidades or Furnas (Figures 4 and 5). The high GRIP K_2O and Na_2O values and their correspondence with multiple measurements of Vesuvius pumice, strongly suggest that Vesuvius is the source of these tephra.*

Specific comment 3: "The box plots as shown are not easy to interpret and it is unclear what the different boxes represent – mean, median, and maximum values? What do the blue, green and orange boxes represent? Also there are faint circles plotted above and below each box—what do these represent? This is an all-inclusive way of observing possible matches within 6 key major elements but I would prefer to see the authors also presenting these data on biplots (see above) so that the compositional heterogeneity that they mention is schematically shown. I would also urge the authors to plot the geochemical composition of other major eruptions between 50 – 100 AD. Although other volcanic candidates are listed in Table 2, their geochemical compositions are not shown. The authors state that the tephra composition is consistent with K-phonolitic composition of the Vesuvius juvenile ejecta and differs from the chemical composition of other major eruptions between 50 -100 AD. It would be helpful to see this observation on the geochemical figures.

Response: We have included biplots, and plotted the geochemical composition of other major eruptions (Figures 4 and 5). Please see our response to specific comment 3 for more details. We have change the figure caption for Figure 6 to address the concerns regarding the box plots (changes in italics):

Figure 6: Box and whiskers plots representing analyses of this work (red) compared with the range of EDS glass analyses of Vesuvius tephra (Santacroce et al., 2008). AP1 to AP6 signify explosive activity occurring between the larger Avellino and Pompeii eruptions (Santacroce et al., 2008 and references within). *The box and whiskers diagrams outline the median values (middle line), the middle two quartiles (shaded boxes), outer quartiles (whiskers), and outlying values (circles). The orange boxes demonstrate the strongly SiO_2-underaturated glasses younger than A.D. 79, the green boxes represent the mildly SiO_2-*

undersaturated glasses from 8900 B.P. to A.D. 79, while the blue boxes mark the composition of the slightly SiO_2-undesaturated glasses older than 8900 BP as defined by Santacroce et al., 2008

Specific comment 4: "The authors recognize the compositional heterogeneity of Vesuvius AD79 products which is thought to be related to the presence of microlites. It is stated that there are no microlites within the analyzed particles but I would like the authors to elaborate on this. How was this assessed?

Response: We agree that we should expand our statement declaring that we did not find microliths wihin the analyzed particles. We have included the following sentences, where the changes are highlighted in italics.

"The analyzed shards in this paper do not contain microliths, *as determined by visually inspecting each tephra particle with the SEM before beginning EDS analysis. In addition, the absence of characteristic spectra (ie Ba) in each tephra particle further suggests the lack of microliths."*

Specific comment 5: "It would be useful to provide information on the shard size and morphology (see also comments by Andrei Kurbatov). Inclusion of SEM images would also be beneficial."

Response: We do have SEM images of the fragments, but unfortunately these are poor quality images. We would have liked to have included the images, but they are not publication quality.

Specific comment 6: "Sanidine fragments were also recovered with the volcanic glass particles. Is it also possible to include these data in Table 1?"

Response: We agree with the reviewer that these analyses should be included in the paper, and we have included them in Table 1.

Specific comment 7: I am intrigued by the second peak in microparticles which falls before the acid and sulphate peak (Figure 2). Elemental compositions reflect the input of continental crust, but can the authors offer an explanation of what may have caused a sharp and sudden peak in particulate material? Are such events common during the Late Holocene?

Response: Such microparticle peaks are relatively common during the Late Holocene, and the fairly generic continental crust composition does not provide additional information regarding a possible source area. Investigating the trace elemental composition of this layer could provide more details (ie if this dust has a Saharan or Asian source) but this is outside the scope of this paper. We have expanded our discussion of this microparticle peak in the text to:

"The microparticle profile in a core sequence only serves to indicate if an unusually high concentration of particles are present rather than serving as a guaranteed indicator of where to search for volcanic ash particles in a core sequence, as the majority of microparticles in Greenland ice cores originate from continental dust (Steffensen, 1997). *No volcanic glass particles were found in the 429.15-429.25 m microparticle peak, and all microparticles had elemental chemical composition typical of continental crust. This large microparticle peak does not influence any conclusions regarding volcanic activity."*

Specific comment 8: I would like the authors to comment on the dispersal of this tephra to Greenland. As stated on page 5433 the main eruptive products were dispersed in SSE/SE dispersal trajectory and I think it would be useful for the author's to elaborate on the most likely transport pathway to Greenland.

Response: We have changed this section in the introduction in order to highlight that the most important aspect regarding if a mid-laltitude volcano can transport tephra to the poles is if the eruption plume enters the stratosphere. This section in the introduction now reads:

"The grey pumice has a SE dispersal, with a slight counterclockwise rotation with respect to the white pumice axis. Following the shift in magma composition a new, rapid increase of magma discharge rate (up to 1.5 x 10^8 kg/s) occurred with the growth of a column up to 32 km (Carey and Sigurdsson, 1987; Sigurdsson et al., 1990)……. The height of the convective columns *reaching the stratosphere* suggest that tephra and volcanic acids could reach the Greenland ice sheet surface."

We have omitted the following sentence from the conclusions: "The low number of glass fragments in the ice is likely due to the relatively low height of the eruption column (26-32 km), and the SSE trajectory of the plinian phase of the eruption (Carey and Sigurdsson, 1987; Sigurdsson et al., 1990)."

Technical comments: We have made all suggested changes requested by the reviewer.