1 The Late Quaternary tephrostratigraphy of annually laminated sediments from

2 Meerfelder Maar, Germany

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- 17 Abstract

18 The record of Late Quaternary environmental change within the sediments of Meerfelder Maar in the Eifel region of Germany is renowned for its high precision chronology, which is 19 20 annually laminated throughout the Last Glacial to Interglacial transition (LGIT) and most of 21 the Holocene. Two visible tephra layers are prominent within the floating varve chronology of Meerfelder Maar. An Early Holocene tephra layer, the Ulmener Maar Tephra (~11,000 22 23 varve years BP), provides a tie-line of the Meerfelder Maar record to the varved Holocene 24 record of nearby Lake Holzmaar. The Laacher See Tephra provides another prominent time 25 marker for the late Allerød, ~200 varve years before the transition into the Younger Dryas at 26 12,680 varve years BP. Further investigation has now shown that there are also 15 27 cryptotephra layers within the Meerfelder Maar LGIT-Holocene stratigraphy and these 28 layers hold the potential to make direct comparisons between the Meerfelder Maar record 29 and other palaeoenvironmental archives from across Europe and the North Atlantic. Most 30 notable is the presence of the Vedde Ash, the most widespread Icelandic eruption known from the Late Quaternary, which occurred midway through the Younger Dryas. The Vedde 31 32 Ash has also been found in the Greenland ice cores and can be used as an isochron around 33 which the GICC05 and Meerfelder Maar annual chronologies can be compared. Near the 34 base of the annual laminations in Meerfelder Maar a cryptotephra is found that correlates 35 to the Neapolitan Yellow Tuff, erupted from Campi Flegrei in southern Italy, 1200 km away. This is the furthest north that the Neapolitan Yellow Tuff has been found, highlighting its 36 importance in the construction of a European-wide tephrostratigraphic framework. The co-37 38 location of cryptotephra layers from Italian, Icelandic and Eifel volcanic sources, within such a precise chronological record, makes Meerfelder Maar one of the most important 39 40 tephrostratotype records for continental Europe during the Last Glacial to Interglacial transition. 41

42 *Keywords:* tephrostratigraphy, cryptotephra, Lateglacial, varves, Meerfelder Maar.

43

44 1. Introduction

- 45 The detection of microscopic layers of volcanic ash (cryptotephra) within terrestrial, marine
- 46 and ice core records is revolutionising the way widespread palaeoenvironmental archives
- 47 are dated and compared. Tephra isochrons provide stratigraphic tie-lines between records,
- 48 which permit precise inter-site correlation and comparison of the proxy record, whilst

- 49 avoiding un-grounded assumptions of synchronicity. In addition, where tephra can be
- 50 correlated to eruptions of known age, absolute age estimates can be achieved and
- 51 transferred between records. Consequently, the last two decades have seen rapid growth in
- 52 cryptotephra research, most notably within Late Quaternary palaeoenvironmental studies
- 53 (e.g., Dugmore et al., 1995; Lowe, 2001; Wulf et al., 2004), but also within archaeological
- 54 investigations (e.g., Plunkett, 2009; Housley et al., 2012; Lane et al., 2014). Across Europe in
- 55 particular, there is now a wealth of tephrostratigraphic and chronological data that can be
- built into a regional tephrostratigraphic framework of interconnected sites, within which
 questions about the timing of environmental and climatic changes can be addressed
- (Blockley et al., 2012; Davies et al., 2012; Lane et al., 2012a; Wulf et al., 2013).
- 59 Key to the development of a regional tephrostratigraphic framework are two different sorts
- of distal sites: (i) *linking sites* that contain tephra records of multiple eruptions from
- 61 different volcanic sources (e.g., Lane et al., 2011a) and (ii) chronological reference sites with
- 62 annual to decadal precision, that can feedback dating information to sites around the
- 63 network (e.g. the Greenland ice core records, Mortensen et al., 2005; Abbott and Davies,
- 64 2012). The rare sites that are able to fulfil both of these criteria are typically (partially, or
- 65 wholly) varved records that sit within the fallout ranges of multiple volcanic centres.
- 66 European examples include the Lateglacial to Early Holocene record in Soppensee,
- 67 Switzerland (Hajdas, 1993; Lane et al., 2011b) and the 133 ka record in Lago Grande di
- 68 Monticchio, Italy (Wulf et al., 2004; Wulf et al., 2008; Wulf et al., 2012).
- 69 A major strength of varve sequences lies in the opportunity to date the intervals between
- tephra isochrons, with annual to decadal precision. This *differential dating* approach
- 71 provides important chronological constraints that can be built into a regional
- 72 tephrostratigraphic framework and used to precisely compare periods of known equivalent
- 73 duration wherever the same tephra layers are found co-registered. The combination of
- videspread tephra layers in varve palaeoenvironmental sequences therefore provides the
- rare, but exceptionally valuable, opportunity to study subtle variations in the timing and
- rate of environmental response to past abrupt climate changes (Lane et al., 2013).
- A cryptotephra study of the Lateglacial to Holocene age sediments from Meerfelder Maar,
- in the Eifel region of Germany, was carried out with the aim of establishing a new European
- 79 tephrostratotype sequence in a site that has high (seasonal to annual) chronological
- 80 resolution as well as the potential to contain tephra from a number of European volcanic
- centres (the Eifel, Massif Central, Icelandic and Italian). This paper presents the full results
 of this study, with the following three objectives:
- i. To report the Lateglacial and Holocene tephrostratigraphy of Meerfelder Maar.
- 84 ii. To provide improved varve-age estimates, with uncertainties, for a number of the tephra
- 85 layers within Meerfelder Maar and to constrain the inter-eruption ages.
- 86 iii. To place the Meerfelder Maar record within a broader European tephrostratigraphic
- 87 framework, which permits direct correlation of palaeoenvironmental archives from the
- 88 North Atlantic, Europe and the Mediterranean.
- 89
- 90 2. Site & methods
- 91 2.1. The site
- 2 Lake Meerfelder Maar (50°06' N, 6 ° 45' E, 336.5 m a.s.l.) is located in the Eifel region,
- 93 Germany (Fig. 1), within a volcanic crater formed a minimum of 30 ka BP according to
- 94 previous radiocarbon dating (Büchel and Lorenz, 1984; Brauer et al., 1999) or even ca 80 ± 8

- 85 ka BP according to recent thermoluminescence dating (Zöller and Blanchard, 2009). The lake
- has a surface area of approximately 248 m² and a maximum depth of 18 m. The lake
- 97 catchment is small, defined by the steep, vegetated, crater walls, which reach up to 520 m
- 98 at their highest.

99 The Holocene varved sediments are composed of spring/summer diatomaceous organic sub-layers and winter sub-layers of allochthonous sediment (Brauer et al., 1999), whereas 100 101 the lateglacial sediments exhibit a succession of different varves types including siderite 102 varves (late Allerød) and clastic-dominated snow melt varves (second half of Younger 103 Dryas), triggered by rapid climate changes and lake evolution (Brauer et al., 1999). The 104 sediment formation in Lake Meerfelder Maar is sensitive to North Atlantic climate 105 variability. Abrupt sedimentary and biological responses to Lateglacial and Holocene climatic 106 shifts recorded at Meerfelder have provided new insights into the nature and mechanism of Late Quaternary climate dynamics (Brauer et al., 2008; Martin-Puertas et al., 2012a; Martin-107 108 Puertas et al., 2012b; Lane et al., 2013).

109 2.2. Field work and varve counting

110 During a coring expedition in 2009 seven new and parallel core sequences were retrieved

from the deepest part of the lake basin using a UWITEC piston corer. The maximum distance

between individual coring sites was 20 m. These sediment profiles, labelled as cores

113 MFM09-A to MFM09-G, were split, imaged, described and correlated. Each of this sediment 114 profiles consists of a sequence of 5-6 up to 2 m long core segments, typically with gaps of a

few cm between each individual core. Two sediment profiles were selected for thin sections

- analyses: core MFM09-A (11.50 m long) and core MFM09-D (10.58 m long). Core A was
- recovered from the water/sediment interface, whereas core D starts 70 cm below. A
- composite profile (MFM09; 11.71 m long) was constructed through detailed correlation
- based on macroscopic and microscopic marker layers. Martin-Puertas et al. (2012) used the
- same marker layers to correlate the new sediment profile with a previous profile MFM-6
- 121 (Brauer et al., 1999; Brauer et al., 2000a). The new continuous sediment record (MFM09) so
- 122 far has been investigated in particular for Holocene climate and environment changes
- 123 (Martin-Puertas et al., 2012a).
- 124 Varve counting was carried out on a continuous series of thin sections (100 x 35 mm, with 2
- 125 cm overlaps) using a petrographic microscope under parallel and polarized light (Brauer et
- al., 1999; Martin-Puertas et al., 2012a). Varve counting involved thickness measurements
- 127 for each varve at higher microscopic magnification (100x). In order to assess the individual
- 128 error, varve counting was realized twice by the same counter.
- 129 2.3. Cryptotephra investigations
- 130 The entire core sequence MFM09-D was investigated for the presence of cryptotephra
- following the non-destructive density floatation method of Turney (1998); Blockley et al.
- 132 (2005). Tephra glass shards within the 1.95-2.55 g/cm³ residue (and also >2.55 g/cm³ for low
- 133 resolution samples) were identified and absolute numbers counted under high powered
- 134 polarised light microscopy, then quantified as shards per gram of dry sediment (s/g). Where
- 135 tephra glass shards were discovered in initial low-resolution contiguous samples, these 10
- cm lengths were re-investigated at 1 cm resolution to better define the location of the
- tephra layer. Where possible, thin section inspection of the cores was then used to locate
- 138 the tephra layer to its exact varve position. All Tephra layers are given sample codes based

- upon their first occurrence depth below lake floor (cm) and these are used throughout themanuscript.
- 141 2.4. Geochemical analysis

In order to concentrate glass shards for geochemical analysis, they were picked from 142 143 samples under high-powered microscopy, using a gas chromatography syringe (Lane et al., 2014). The tephra shards were then mounted in epoxy resin, sectioned and polished for 144 145 geochemical analysis. Major and minor element concentrations were measured by wavelength dispersive electron probe micro-analysis (WDS-EMPA), using the Jeol JXA 8600 146 147 microprobe in the Research Laboratory for Archaeology, University of Oxford. Instrument operating conditions: 15 keV accelerating voltage, 6 nA current, 10 µm beam diameter and 148 149 10-30 s peak count times. The ATHO-g (rhyolitic) and StHs6/80-g (andesitic) MPI-DING fused 150 volcanic glass secondary standards (Jochum et al., 2006) were analysed with the tephra 151 samples to monitor instrument precision and accuracy (Supplementary Information Table 152 S2). Major element (SiO₂, Al₂O₃, FeOtot, CaO, Na₂O, K₂O) precision on secondary standard 153 analyses ranges from <1 to <10 % (at 2σ), precision for the less abundant elements varies 154 between 10-30%.

155 Trace element compositions were measured by laser ablation inductively coupled plasma

mass spectrometry (LA-ICP-MS), using the Agilent 7500 ICP-MS coupled to a 193 nm

157 Resonetics ArF eximer laser ablation system, in the Department of Earth Sciences, Royal

158 Holloway University of London. Analytical protocols and data quantification followed those

described in Tomlinson et al. (2010): a 5Hz repetition rate and 40 second sample and gas
 blank count times were used. NIST 612 was used as a standard for calibration, with ²⁹Si as

- 161 the internal standard element having been previously measured by WDS-EPMA within each
- individual grain. Laser spot sizes of between 25 μ m and 34 μ m were used according to the
- size of the glass shards. For consistency with WDS-EMPA, the ATHO-g and StHs6/80-g MPI-
- 164 DING secondary glass standards were used to monitor precision and accuracy
- 165 (Supplementary Information Table S2). Precision on secondary standard analyses (at 2σ)

averages < 10 % for all elements, with the exception of Sm, Dy and Yb, <18%, which are

167 present in very low concentrations. Due to small grain sizes and low glass shard

- 168 concentrations (section 3.1), not all samples were successfully analysed by LA-ICP-MS.
- 169 3. Results

170 The uppermost two meters of the new core MFM09 are not laminated, but varves are well-

- 171 preserved over most of the lower part of the record. This confirms reports from the
- 172 previous MFM-6 core (Brauer et al., 2000).
- 173 3.1. Varve chronology

174 In this study, we present a new and slightly revised varve chronology for MFM labelled as MFM2015 chronology. This chronology has been established for the latest MFM composite 175 profile (MFM-09) and is for the Holocene part (0-753 cm sediment depth) identical with the 176 177 MFM2012 chronology (Martin-Puertas et al. (2012a). For the interval from the Laacher See 178 Tephra (LST; 12,880 varve yrs BP, late Allerød) up to the early Holocene Ulmener Maar 179 tephra (UMT; 11,000 varve yrs BP) the chronology is identical to the MFM-6 chronology 180 (Brauer et al., 1999). Varve ages were transferred from the MFM-6 to the MFM-09 core 181 sequence (753-876 cm depth interval) through correlating a series of macroscopic and

182 microscopic marker layers. The revision only affects the older part of the lateglacial

- 183 sediment interval below the LST down to the onset of distinct and continuous varve
- 184 preservation (876-1073 cm sediment depth, Fig. 2-3). Because of the better varve
- preservation in this section of the new composite MFM-09 profile this interval has been re-
- counted and revealed in total 1350 ±50 varves, i.e. 100 varves more than in the previous
 MFM-6 chronology (Fig. 3). This resulted in a revised age for the onset of continuous varve
- preservation at 14,230 ±90 varve yrs BP. Absent or very poor varve preservation prevented
- from varve counting in the early Lateglacial interstadial. The duration of ca. 400 years from
- 190 the beginning of the Lateglacial interstadial, defined as Meiendorf pollen zone by Litt and
- 191 Stebich (1999), thus had to be extrapolated based on measured varve thickness in the
- 192 lowermost interval of continuous varve occurrence (Fig. 3).
- 193 The error estimate for the new MFM2015 chronology adds ±50 varve yrs derived from
- 194 multiple counting of the revised section to the previously defined error estimate for the LST
- 195 (12,880 ±40 varve yrs BP; Lane et al., 2013). The resulting error estimate for the age of the
- onset of continuous varve formation in MFM (14,230 \pm 90 varve yrs BP) is considered a
- 197 minimum error because the counted interval includes a small slumped section which is also
- 198 present in the MFM-6 sediment profile (Brauer et al., 2000b). The duration of this section
- 199 (110 estimated varve years) has been calculated by interpolation and adopted from the
- 200 MFM-6 chronology (Brauer et al., 2000b). A reliable error estimate for this interpolated
- 201 interval is difficult to determine (Brauer et al., 2014).
- 202 3.2. Tephrostratigraphy and correlation of tephra layers
- 203 Figure 2 shows the results of cryptotephra investigations in Meerfelder Maar. Throughout 204 most of the core tephra glass shards were found in discrete layers, or restricted zones, with 205 low concentrations (<200 s/g). However, between ~ 900 – 700 cm depth, tephra counts are 206 much higher. This zone of increased shard counts begins with the visible (>10 cm thick) 207 Laacher See Tephra layer (MFM_876), and continues through the Younger Dryas sediments. 208 No evidence of background tephra material, from the Meerfelder Maar crater itself, was observed. Samples of Meerfelder Maar tephra reveal shards densely packed with microlites 209 and visually very different to those observed reported in this study. In total, 17 layers 210
- containing tephra were studied at 1 cm resolution, and these are labelled in Figure 2
 according to their depth. Beginning at the base of the core, the size (longest axis length),
- appearance and chemical composition (normalised values) of each of these tephra layers is
- 214 described here.
- Of the 17 tephra samples studied from the Meerfelder Maar sediments, only four can be
- confidently correlated to known eruption events and one other correlated to a volcanic
- source (Table 3, Figures 4 5). Section 3.2 discusses the issues and difficulties involved in
- 218 correlating some of the unidentified tephra layers.
- 219 MFM_T1137 (1137 cm; before the onset of continuous varve formation):
- 220 The oldest tephra layer in the Meerfelder Maar core, with a concentration of 50 s/g, shows
- both morphological and chemical variability. Most of the glass shards are thin, with
- 222 curvilinear form representing bubble-wall junctions. Longest axis lengths are < 150 μ m.
- 223 However there are also a number of distinct and smaller glass shards, showing either
- deformed and elongated vesicle textures, a high number of un-expanded vesicles and also
- some containing microlites (<5 μ m).

- 226 Four glass shards were analysed on the microprobe, all of rhyolitic composition (Table 1 and
- 227 Figure 4a). Three of these have 71.2-71.8 wt% SiO₂, 13.9-14.9 wt% Al₂O₃, 1.8-2.3 wt% CaO
- 228 2.7-3.9 wt% Na₂O, 3.5-3.9 wt% K_2O and are likely to have derived from the same eruption
- event. The fourth shard has a much higher SiO_2 content of 77.1 % and lower values of FeO,
- 230 MgO and CaO.
- 231 MFM_T1130 (1130 cm; before the onset of continuous varve formation):

232 MFM_T1130 has only 32 s/g, which is the lowest concentration in the core. Glass shards are 233 dominantly < 120 μ m, blocky in appearance and have no internal vesicles, however a small 234 number of 120-150 μ m plate-like glass shards were noted as well as two highly vesicular 235 shards < 40 μ m. Of the nine shards analysed by WDS-EPMA, four show a homogeneous 236 phonolitic composition, with 57.4-60.8 wt% SiO₂, 20.0-20.7 wt% Al₂O₃, 2.1-2.6 wt% FeO, 5.1-

- $6.2 \text{ wt\% Na}_2\text{O}$ and $7.5-8.9 \text{ wt\% K}_2\text{O}$. This composition is consistent with that of MFM_T876.
- The remaining shards show a range of rhyolitic compositions (Table 1 and Figure 4a), which are not interpreted to represent a single volcanic event.
- 240 MFM_T1072 (1072 cm; 14,230 ± 90 varve yrs BP):

This tephra material is found in the first sample directly after the onset of continuous varve 241 preservation. Tephra glass shards in MFM T1072 are all < 70 μ m and have irregular 242 243 vesicular forms displaying closed, expanded and elongated vesicles. Glass shard 244 concentrations were 113 s/g. With the exception of three rhyolitic outliers, the glass shards 245 from MFM_T1072 show a bi-modal phono-trachyte to trachyte composition (Table 1, Figure 246 4). The phono-trachyte end member has 57.3-59.3 wt% SiO₂, 4.2-5.3 wt% FeO, 0.9-1.5 wt% CaO, 3.4-3.8 wt% Na₂O and 7.8-8.9 wt% K₂O. The trachyte end-member has 61.3-62.0 wt% 247 SiO₂, 2.5-3.3 wt% FeO, 2.2-2.5 wt% CaO, 3.5-4.3 wt% Na₂O and 8.7-9.4 wt% K₂O. Trace 248 249 element analysis of these two end-member compositions show consistent values of ~320 250 ppm Rb, ~30ppm Y, ~300 ppm Zr, ~45 ppm Nb and clear bi-modality in Sr (trachy-phonolite ~900 ppm, trachyte 460 ppm) and Ba (phono-trachyte ~1570 ppm, trachyte 780 ppm). As 251 252 shown in Figure 4b, MFM T1072 correlates to the Neapolitan Yellow Tuff; generated by a Plinian eruption from the Campi Flegrei Volcanic Zone (CFVZ) in Southern Italy ~14.2 ka BP 253 254 (Section 4.3).

- 255 The CFVZ was highly active during the Lateglacial and many tephra layers were widely dispersed that have trachyte to phonolite glass compositions (Siani et al., 2004; Wulf et al., 256 257 2004; Smith et al., 2011). The Neapolitan Yellow Tuff can be distinguished from other CFVZ 258 eruptions as it straddles the phono-trachyte boundary (Figure 4a) and is composed of two 259 members: a compositionally bi-modal lower member and an upper member that spans the 260 full compositional range between the two lower member populations (Tomlinson et al., 2012). MFM T1067 is chemically correlated to the bi-modal lower member of the 261 Neapolitan Yellow Tuff, which is consistent with other distal occurrences in Austria and 262 263 Slovenia, where only the lower member is found (Schmidt et al., 2002; Lane et al., 2011a).
- 264 MFM_T876 (876 cm; 12,880 varve yrs BP):

This visible tephra layer has been previously correlated to the LST (Brauer et al., 1999) on
the basis of its stratigraphic position and appearance in thin section. The MFM09 cores
preserve 5 cm of tephra, with a sharp basal contact at 876 cm. Glass shards have very high
vesicularity, characteristic of the LST, which appears like microscopic pumices, with grain
sizes < 300 µm. The 10 cm layer has a homogeneous phonolite composition (Figure 4c), with

- 270 58.9-63.2 wt% SiO₂, 18.8-21.2 wt% Al₂O₃, 1.1-2.3 wt% CaO and variable alkali contents, 4.9-
- 9.3 wt% Na₂O and 6.6-9.0 wt% K₂O. Trace element analysis of two shards also show
- 272 compositions of 183 and 198 ppm Rb, 224 and 334 ppm Sr, 15 and 16 ppm Y, 452 and 466
- ppm Zr and 93 and 104 ppm La (Table 2; Figure 4c). Comparison to compositional data
- generated on pumice glasses from proximal LST deposits shows that MFM_T876 correlates
 to the Upper phase of the LST, which is the only phase believed to have distributed ash to
- to the Upper phase of the LST, which is the only phase believed to have distributed ash to
 the west of the eruption centre in the East Eifel region (van den Bogaard and Schmincke,
- 277 1985; Riede et al., 2011).
- 278 Tephra from the LST continued to be input into the Meerfelder Maar sediments for about
- 279 1600 years after the eruption. Concentrations of morphologically and geochemically
- identical tephra glass shards are seen to decrease upward within the ~70 cm above the
 appearance of the LST at 876 cm, and trace amounts (>100 s/g) are present throughout the
 full length of the Younger Dryas sediments.
- 283 MFM_T801 (801 cm; 12,140 varve yrs BP):

High concentrations of glass shards, ~7060 s/g, were found at 801 – 775.5 cm depth. The

layer is composed of colourless shards with plate-like and curvilinear forms, <200 μ m, as

well as light to dark brown shards, <130 μ m, with many expanded and some elongate

- 287 vesicles.
- 288 Excluding one shard (EPMA #29, Table 1) that has a phonolitic composition consistent with
- 289 MFM_T876, major and trace element analysis of MFM_T801 (n=40 and n=15 respectively)
- show a bi-modal composition. One end member shows a trend from basaltic-andesite to
- andesite (52.8-61.9 wt% SiO₂, 8.4-13.1 wt% FeO, 4.9-10.5 wt% CaO and 1.1-2.4 wt% K₂O)
- and the second end-member is a homogeneous rhyolite (71.8-72.5 wt% SiO₂, 3.6-4.0 wt%,
 FeO, 1.3-1.5 wt% CaO and 4.5-5.5 wt% K₂O). Trace element compositions also describe bi-
- modality, with approximately 80-90 ppm Rb, 850-950 ppm Zr and 120-130 ppm Nb in the
- rhyolitic end member and approximately 30-50 ppm Rb, 350-560 ppm Zr and 50-80 ppm Nb
- 296 in the basaltic-andesite member (Figure 4d).
- Bimodal MFM_T801 is correlated to the rhyolitic and intermediate phases of the Vedde Ash (Figure 4d) (Lane et al., 2013), however the Vedde Ash basaltic end-member was not found in MFM. The Vedde Ash is an important tephra isochron found widely across Europe and the North Atlantic, erupted from the Katla volcano in Iceland, occurring midway through the Younger Dryas in many European sediment records (Mangerud et al., 1984; Lane et al.,
- 2012b), and within Greenland Stadial 1 in the NGRIP ice core (Mortensen et al., 2005;
- Rasmussen et al., 2006). MFM_T801 represents the first appearance within the record of
- any shards with Katla Vedde-type composition.
- 305 MFM_T711 (711cm; 11,000 varve years BP):

A tephra layer found at 710-711 cm depth has previously been correlated to the Ulmener

Maar tephra, dated to 11,000 varve years BP (Zolitschka et al., 1995; Brauer et al., 1999), on

308 the basis of its appearance and stratigraphic position. This tephra layer contains no typical

309 aphyric tephra glass shards, but rather crystal-rich juvenile fragments, which are

- distinctively isotropic (glassy) but range in shape from rounded to sub-angular, indicating
- formation within a very crystal rich melt. Volcanic crystals (pyroxene, olivine, mica, oxide
- minerals) and lithic fragments are also present within the denser fraction of the separated
- 313 sample. Grain sizes of all fractions are < 90 μ m. This texture is consistent with other samples

- of the UMT taken from proximal outcrops, where pumice clasts are holocrystalline. In the
- absence of areas of aphyric glass, no chemical analysis was made on this tephra layer.
- 316 MFM_T687 (687 cm; 10,648 varve yrs BP) & MFM_T685 (685 cm; 10,619 varve yrs BP):

Tephra concentrations decrease dramatically at ~730 cm during the first centuries of the 317 318 Holocene (Figure 2) and associated with climatic amelioration and resultant increase in vegetation cover and stabilisation of the landscape in and around the Meerfelder Maar 319 320 catchment. The first appearance of tephra glass shards in the Holocene is of concentrations 321 of 3 – 232 s/g found between 678 and 667 cm. From this zone of tephra, two 1 cm samples with the highest shard concentrations were picked out for analysis. Both MFM T687 (232 322 s/g) and MFM T685 (113 s/g) are dominated by highly vesicular tephra shards, <70 μ m, 323 324 which have both morphological and chemical affinity to MFM T876 (Figure 4). In both 325 samples, a smaller number of $<120 \mu m$ plate-like shards are also present, and these are 326 represented by a number of rhyolitic major and trace element analyses from MFM T685.

Thin section analysis of the sediments around 685-687 cm revealed a number of fine minerogenic detrital layers, which are interpreted as extreme runoff events (Martin-Puertas et al., 2012b; van Geel et al., 2013). It suggests these layers are not formed from volcanic airfall events, but from reworking of older tephra-bearing sediment within the Meerfelder Maar catchment.

332 MFM_T573 (573 cm; 7,744 varve yrs BP):

Glass shard concentrations in MFM T573 are 92 s/g. Tephra glass shards are $< 80 \mu m$ and 333 fairly blocky in shape, with concave edges from fragmented vesicle walls. Four analyses 334 were achieved on these small shards and reveal peralkaline pantellerite compositions 335 336 (following Macdonald, 1974), with 69-75 wt% SiO₂, 6.1-7.5 wt % Al₂O₃, 3.0-4.7 wt % FeO, 1.6-1.8 wt % MgO, 1.8-3.0 wt% CaO, 5.6-6.1 wt% Na₂O and 6.5-8.7 wt% K₂O. Just one LA-337 ICP-MS analysis was made on a pantellerite glass shard and this has approximately 220 ppm 338 339 Rb, 30 ppm Zr, 11 ppm Nb and 349 ppm Ba (Table 2). Also within this sample there are a number of highly vesicular shards, <200 µm, of phonolitic composition consistent with 340 341 MFM T876 (MFM T573, #1-8 in Table 1) and two more platy shards (MFM T573, #9-10 342 Table 1) with rhyolitic major, minor and trace element compositions consistent with 343 MFM_T801.

344 Pantellerite tephra are rare and commonly come from volcanic centres associated with continental or ocean ridge rifting (Civetta et al., 1984). In Europe and the North Atlantic, 345 346 Holocene Pantellerites have been reported from Pantelleria Island in the Mediterranean 347 (Mahood and Hildreth, 1986; Magny et al., 2011) and Jan Mayen in the North Atlantic 348 (Lacasse and Garbe-Schönberg, 2001). Terceira volcano in the Azores has also erupted 349 peralkaline trachytes (Gertisser et al., 2010). However, the available glass data from these 350 volcanic centres does not correlate with MFM_T573 (Figure 4e), therefore the source 351 eruption remains unidentified.

352 MFM_T568 (568 cm; 7,633 varve yrs BP):

Distinctly plate-like shards, < 50 μm in size, characterise MFM_T568. A concentration of 75

s/g was calculated from a small sample size of only 0.04g, therefore although replicable;

only 3 shards were counted in the original 1 cm sample. A single shard was analysed by

356 WDS-EPMA and had a rhyolitic composition consistent with MFM_T801.

MFM_T552 (552cm; 7,314 varve yrs BP), MFM_T550 (550 cm; 7,279 varve yrs BP)&
 MFM T548 (548 cm; 7,245 varve yrs BP):

Low concentrations (<20 s/g) of tephra were observed in the low resolution (10 cm) scans 359 between 484 and 540 cm depth (Figure 2). At 1 cm resolution, tephra was seen to be 360 present through much of this depth, again in concentrations <20 s/g. The three samples 361 with the highest shard concentrations were found at 527-548 cm (50 s/g), 529-550 cm (38 362 s/g) and 531-552 cm (61 s/g). These three samples were selected for analysis. All three 363 364 layers contained equant and platy tephra shards with curvilinear surfaces, $< 90 \mu m$. 365 MFM T552 and MFM T548 also contained $< 40 \,\mu$ m shards with many expanded vesicles. EMPA was only possible on five shards from across these three samples and did not reveal 366 367 any consistent chemical compositions. The glass shard in MFM T552 is an alkali-trachyte, 368 which plots close to the composition of MFM T1067 on elemental bi-plots (Figure 4a). Two shards, one in each of MFM_T550 and MFM_T548, correlate to MFM_T876. A rhyolitic 369 370 shard was also found in MFM T550 and another alkali-trachytic shard was measured in 371 MFM_T548.

372 MFM_T334 (334 cm; 3,382 varve yrs BP):

Tephra glass shards in MFM_T334 are <50 μm in their longest axis and very thin, with 373 374 curved shapes and closed circular and irregular vesicles. Very fine microlites (< 10 µm) were 375 noted in a couple of shards. Glass shard concentrations were 113 s/g. Three trachytic glass 376 shards were analysed from this sample, with approximately 62.5-64.6 % SiO₂, 16.6-18.0 wt 377 % Al₂O₃, 3.9-4.4 wt% FeO, 7.3-8.3 wt% Na₂O and 4.9-5 wt % K₂O. One shard is distinct as it 378 has a higher CaO content of 1.7 wt% and this differentiation is also evident in the trace 379 element composition (Tables 1 and 2). As apparent in Figure 4e the compositions of the remaining two shards from MFM T334 show some similarity to Late Holocene tephra layers 380 381 found in Western Ireland, in the sites of Loch Mor, Inis Oirr (Chambers et al., 2004) and 382 Derrycunihy (Reilly and Mitchell, 2014). The tephra layers in Loch Mor have been correlated to trachytic eruptions from Jan Mayen, however they are much younger than MFM T334, 383 being dated to between AD 1400 and AD 1915. At Derrycunihy, tephra with a similar 384 composition has been tentatively correlated to the Mt Furnas volcano in the Azores and this 385 386 may in fact offer a better correlation for many of the cryptotephra currently correlated to 387 Jan Mayen in Western Ireland (Reilly and Mitchell, 2014; Johannesson, in press). The 388 available summary glass data from Mt Furnas is plotted in Fig. 4 and it is anticipated that 389 forthcoming data will secure the correlation of MFM T334 to an eruption of this Azores 390 volcano.

- 391 MFM_T325 (325cm; 3,230 varve yrs BP):
- 392 Thin, curvilinear glass shards with open vesicles, < 90 μ m long, were found in a
- concentration of 100 s/g at 325 320 cm. However, no shards were successfully recovered
 for chemical analysis from this layer (Section 3.2).
- 395 MFM_T322 (322 cm; 3,162 varve yrs BP):
- This tephra layer contained highly vesicular shards, <60 μ m, similar in morphology to the LST. A glass shard concentration of 63 s/g was found. Again, extraction of tephra shards
- 398 from this layer for geochemical analysis was unsuccessful.
- 399 MFM_T238 (238 cm; 2,020 varve yrs BP):

- 400 Tephra glass shard concentrations of 90 s/g and 72 s/g were found in 1 cm samples from
- 238 239 cm and 237 238 cm, respectively. Across these two samples the shard
- 402 morphologies were very similar, with large (< 150 μ m) irregular forms, containing either
- 403 small closed circular vesicles or expanded vesicle forms. Due to the high organic content of
- these samples, the absolute number of shards observed in each 1cm sample was 13 and 9,
- 405 respectively; these samples were therefore combined for geochemical analysis. The two
- 406 resultant WDS-EPMA analyses reveal two different trachytic compositions, as evident in
- 407 Table 1 and Figure 4a.

408 3.2. Unidentified tephra samples

- 409 12 of the cryptotephra layers located within MFM remain unattributed to a volcanic source
- 410 or a specific eruption event. The reasons for this include insufficient chemical analysis due
- 411 to the small shard concentrations (e.g. MFM_T568), heterogeneous compositions (e.g.
- 412 MFM_T1130) and a lack of correlative data (e.g. MFM_T334). Tephra shards with
- 413 compositions that correlate to the Vedde Ash or Laacher See Tephra (MFM_T889 or
- 414 MFM_T801) are found intermittently throughout the record and these may indicate re-
- deposition of tephra from within the maar catchment. In the case of MFM_T687 and
- 416 MFM_T685, detrital layers have been identified by thin section analysis.
- 417 Nevertheless, multiple eruptions from Katla have been shown to deliver compositionally similar tephra layers to northern Europe (Wastegård, 2002; Koren et al., 2008; Matthews et 418 419 al., 2011; Lane et al., 2012b) and this could also explain the presence of tephra shards with a 420 Vedde Ash-like rhyolite composition. MFM_T568 for example, which is dated to ca 7617 421 varve yrs BP may be correlated to the Suduroy tephra, described by Wastegård (2002) from 422 the Faroe Isles and dated to 8308 - 7868 cal years BP (7240 ± 95 14C years, calibrated in 423 OxCal v4.1 using the IntCal13 calibration curve (Bronk Ramsey, 2001; Reimer et al., 2013). 424 Correlations based upon a few isolated shards are however, not robust. This is exemplified 425 by the scatter within some samples (e.g.MFM_T573), which illustrates the need for multiple analyses to build a complete picture of a tephra sample's chemical composition. Such mixed 426 427 populations could of course come from more than one eruption event, closely spaced in 428 time. Samples were taken at 1 cm resolution, which represents approximately 20 - 30 years
- 429 of sedimentation.
- 430 Finally, it is of course possible that some tephra layers were missed altogether, either due to
- 431 the presence of cm-scale gaps between individual core segments of MFM09, or due to
- 432 patchy preservation within the lake floor sediments.
- 433
- 434 4. Discussion
- 435 4.1. A new tephrostratotype sequence for Europe

436 The preservation of multiple tephra layers within an annually resolved archive establishes

- 437 the Meerfelder Maar Lateglacial sediment record as a key tephrostratotype site (Figure 5).
- 438 By providing high precision varve ages for co-located tephra layers from different volcanic
- 439 centres, Meerfelder Maar provides an important chronological contribution to the existing
- tephrostratigraphic framework that connects sites from the North Atlantic to the
- 441 Mediterranean (Davies et al., 2012; Lane et al., 2012a)

- 442 The four tephra layers successfully identified in Meerfelder Maar record eruptions from
- three different volcanic centres: the nearby Eifel volcanic zone (West and East Eifel); Katla, 443
- in the eastern volcanic zone of Iceland; Campi Flegrei volcanic zone, in Southern Italy. With 444
- 445 the exception of the Ulmener maar tephra, which is less widespread, the tephra layers
- 446 facilitate direct correlations between a large number of palaeoenvironmental archives from
- 447 across Europe and the North Atlantic (Figure 6).

Of particular note is the discovery of the Neapolitan Yellow Tuff in Western Germany, ~1200 448 449 km from the source in Campi Flegrei. The Neapolitan Yellow Tuff isochron allows the

- 450 Meerfelder Maar record to be directly linked to the varve record of Lago Grande di 451 Monticchio in Southern Italy (Wulf et al., 2004) (Figure 6), a discontinuously varved
- 452 sediment record of Mediterranean environmental change spanning approximately 133 ka
- 453 (Brauer et al., 2007). This discovery therefore highlights the potential for making high-
- precision comparisons of the phasing of environmental transitions between Lateglacial 454
- 455 sediment records from Central Europe and the Mediterranean.
- 456 4.2. Addressing the unknowns

457 A number of important points with regards to the limitations of characterising cryptotephra layers are highlighted by the number of unattributed cryptotephra layers in Meerfelder 458 Maar (13 of 17). 459

- 460 Primarily, it is evident that our existing knowledge of widespread tephra layers is
- 461 incomplete, even for a region and time period as well-studied as the European Lateglacial
- and Holocene. In the case of some layers, e.g. MFM T334, volcanic sources can be 462
- tentatively attributed, but for others no correlation is suggested. The addition of 51 well-463 defined tephra isochrons (16 Icelandic, 17 Italian, 9 Massif Central, 3 Eifel, 2 Hellenic Arc, 3 464
- 465 Anatolian and 1 Carpathian) to the latest INTIMATE event stratigraphy back to 60,000 years 466 BP (Blockley et al., 2014) illustrates the focus of European cryptotephra research on archives
- 467 dominated by Icelandic and Italian tephra layers. This in part reflects the prevalence of far
- 468 travelled tephra from these volcanic regions during the Lateglacial, but also highlights that detailed studies, generating compatible tephra glass shard compositional data, are much 469
- needed from other volcanic regions of Europe (e.g. the Massif Central, Azores). 470

471 Secondly, the majority of unattributed tephra layers contain low concentrations of glass 472 shards of variable rhyolitic compositions (e.g. MFM T1137, MFM T1130, MFM T573, 473 MFM_T568, MFM_T550; outliers in MFM_T1072). Rhyolitic magmas are common in the 474 European record, being frequently generated from volcanoes in Iceland, the Aegean, the 475 Aeolian Islands, the Carpathians and Central Anatolia (Tomlinson et al., in press). Typically 476 rhyolites are erupted during highly explosive eruptions (sub-plinian to plinian) and are 477 characterised by bubble-wall to plate-like glass shards. This material is therefore able to be 478 transported extreme distances in the atmosphere and the sources for these tephra shards 479 may be far beyond the volcanic centres of Europe. Whilst comparisons to all available 480 datasets have been made in attempt to identify the unattributed tephra shards from Meerfelder Maar, the small concentrations and often variable compositions suggest that 481 482 robust correlations are not likely for many of the layers. Trace element analyses could be used to help narrow down the source region of these glasses (e.g. Tomlinson et al., in press), 483 484 however larger datasets would be needed than are available here.

- 485 Finally, the importance of both robust compositional characterisation and a good
- 486 understanding of taphonomy of cryptotephra layers are highlighted by this study. Working

487 in the undisturbed laminated sections of the Meerfelder Maar sequence, for which detailed thin section micromorphology has been carried out, has allowed the recognition of at least 488 one area of the core where tephra has been reworked and later re-deposited within the lake 489 sediments. Thin section analyses confirmed that tephra shards, found in concentrations of 490 <232 s/g between 690-684 cm, are located coincident with fine detrital material, indicating 491 492 these are reworked deposits (section 3.1). This was supported by EMPA of MFM T687 and 493 MFM T685, which turned out to be composed of tephra glass shards from the LST and VA 494 eruptions. Critically, this reworking event was only confirmed by the thin section work, 495 whereas within a less well-studied sediment sequence, the layers may have been 496 considered as genuine air fall tephra layers. Indeed, it may be the case that some of the 497 remaining Holocene tephra layers in the Meerfelder cores could also represent reworked 498 wind-blown or in-washed tephra.

499 4.3. Improved dating of eruptions and events

500 Table 3 provides varve age estimates for the Ulmener Maar tephra (UMT), Vedde Ash (VA), 501 Laacher See tephra (LST) and Neapolitan Yellow Tuff (NYT), all of which were found within 502 the varved portion of the Meerfelder Maar record. These ages agree with independently generated age estimates for each of the eruptions and in the case of the NYT significantly 503 504 improve on the existing dating precision. The Neapolitan Yellow Tuff has been dated by the ⁴⁰Ar/³⁹Ar method to 14.9 ±0.4 ka (Deino et al., 2004). This age, however, is older than ages 505 obtained by radiocarbon dating of proximal and distal material associated with this ash 506 507 (Blockley et al., (2008) and predates an IntCal-13 (Reimer et al., 2013) modelled date of 14,366 - 14,022 cal BP by (Bronk Ramsey et al., in press-a), obtained by Bayesian 508 509 combination of radiocarbon age-estimates from multiple sites. The Neapolitan Yellow Tuff is also located in Lago Grande di Monticchio, southern Italy, where it is varve dated to 14,120 510 ± 710 yrs BP (Wulf et al., 2008). The revised Meerfelder Maar chronology (MFM-2014) 511 512 presented in this paper dates the NYT at 14,230 ± 90 varve yrs BP. The NYT in MFM is 513 located at the boundary between discontinuous and poor varve preservation of the early 514 Lateglacial interstadial and continuous preservation of distinct varves that is related to the 515 stabilisation of the catchment by vegetation cover. Differential dating between the most 516 important Lateglacial and early Holocene tephra layers in MFM reveals 1350 ± 50 varve yrs between the NYT and the LST, 740 \pm 40 varve yrs between the LST and the VA, and 1140 \pm 517 518 40 varve yrs between the VA and the UMT. This information can be imported into other archives containing two or more of these tephra layers and used to increase age model 519 520 precision and accuracy.

Varve counting between each of the tephra layers and regional biostratigraphical 521 522 boundaries preceding and post-dating them, helps to explore the timing and duration of 523 some the local palaeoenvironmental responses to widely observed climatic transitions (Table 3). These differential ages can be compared to other high resolution archives 524 containing the same tephra layers and precise assessments of the synchronicity of local 525 526 environmental transitions can be made. Whilst some tephra layers have a limited dispersal, 527 such as the UMT, which occurs 590 years after the transition into the Holocene, others such 528 as the VA, can be correlated over continental distances.

The relative durations of GS-1 (Greenland) and the Younger Dryas (Europe) have been
discussed previously (Brauer et al., 1999; Brauer et al., 2008; Muscheler et al., 2008; Lane et
al., 2011b; Lohne et al., 2013), however, even annually resolved records suffer from decadal
to centennial-scale uncertainties that have prevented precise comparisons of abrupt

533 transitions. The Vedde Ash provides a means of directly synchronising the Meerfelder varve chronology with GICC05, facilitating precise comparison of the timing of the Younger Dryas 534 in Meerfelder Maar and GS-1 in NGRIP for the first time (Table 3). The Younger Dryas in 535 Meerfelder Maar (12,679-11,590 varve years BP) began 539 varve years before the 536 deposition of the Vedde Ash and the transition into the Holocene occurred 550 years 537 538 afterwards (Table 3). These transitions are defined by major biostratigraphical boundaries 539 (Litt and Stebich, 1999) accompanied by abrupt changes in sediment proxies of Meerfelder Maar (Brauer et al., 1999). Using the GICC05 chronology, the GS-1 onset and end in NGRIP 540 are defined by the deuterium excess record ($\delta D - 8\delta^{18}O$), which records abrupt shifts within 541 1-3 years (Rasmussen et al., 2006; Steffensen et al., 2008). The Vedde Ash (12,171 ±114 b2k) 542 543 in NGRIP lies 725 GICC05 years after the start and 468 GICC05 years prior to the end of GS-1 544 (Table 3). Accepting both of the chronologies as correct implies that the onset of GS-1 in 545 NGRIP leads the onset of the Younger Dryas in Meerfelder by 186 years and also leads at the start of the Holocene by 132 years. Refining the correlation between these important 546 547 Lateglacial archives provides a sound platform from which the nature of abrupt climate 548 changes over continental distances and the complexities of environmental proxy

sensitivities can be explored (e.g., Lane et al., 2013; Rach et al., 2014)

550 5. Conclusions

551 Meerfelder Maar now stands out as an important Western European tephrostratotype

- record for the Lateglacial, providing improved age estimates for, and precise dating of
- intervals between, tephra layers from three different volcanic centres. Using tephra layers
- as tie-points between Meerfelder Maar and other archives with annual to decadal-scale
- 555 chronological resolution has allowed, for the first time, precise layer-counted comparisons
- between the timing and duration of regional palaeoclimate signals across Europe and the
 North Atlantic. These results contribute to a better understanding of proxy-response to
 complex climate forcing events (Lane et al., 2013; Rach et al., 2014). There remains great
- potential for extending these correlations to other sites containing the Vedde Ash, Laacher
 See Tephra and Neapolitan Yellow Tuff, as suitably high-resolution palaeoenvironmental
 records are produced. Furthermore, as detailed records emerge from less well-studied
- volcanic centres, it is envisaged that some of the unattributed cryptotephra within the
- 563 Meerfelder Maar record will be identified and will provide additional valuable marker layers
- 564 for the correlation of Lateglacial and Holocene records.

565 6. Acknowledgements

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575 7. Tables and Figures

- 576 Table 1:
- 577 Single-shard major and minor element oxide compositions (wt%) for all tephra layers
- analysed within the Meerfelder Maar record, measured by electron microprobe (section
- 579 2.3). For samples with n>12 analyses, a reduced representative dataset is shown and the full
- 580 dataset is contained within Supplementary Information (Table S1). Data are presented
- normalised to water-free compositions, with original totals shown, after filtering points with
- analytical totals below 94 weight %. Secondary standard data, which provide a measure of
- 583 precision and accuracy, are presented within Supplementary Information (Table S2).

	FPMΔ #	SiO	TiO.	AL ₀	FeO	MnO	MaO	CaO	Na ₂ O	K.0	P.O.	Total	Std file
MFM T1137.	before th		t of co	ontinuo	us varv	/e forn	nation	ouo	14420	100	1 205	Total	
		71 82	0.02	13 93	3 53	0.19	1 61	2.28	2 70	3 91	0.00	96 79	а
	2	71.02	0.23	14.94	3.22	0.09	1.01	1 75	3.90	3.67	0.00	99.08	a
	3	71.20	0.37	14.91	3.12	0.07	1.04	1.70	3.91	3.51	0.02	99.24	e
	4	77.09	0.06	12 71	1.05	0.01	0.03	0.56	3 79	4 70	0.02	94 42	
		11.00	0.00	12.71	1.00	0.01	0.00	0.00	0.70	4.70	0.00	01.12	
MEM_T1130	l hefore th		t of co	ontinuo	us varv	/e forn	nation						
	1	57 81	0.33	20 14	2.36	0 17	0.67	3 49	6 18	8 81	0.05	96 77	f
	2	57 46	0.43	20.00	2.60	0.14	0.94	3.38	6 11	8.92	0.00	97 49	a
	3	60.28	0.61	20.00	2.35	0.24	0.32	1.94	5.09	8.58	0.00	96.22	a
	4	60.79	0.57	20.66	2.00	0.14	0.02	2 17	5.77	7 46	0.10	99.53	a
	5	71.83	0.62	11 53	4 04	0.05	1 21	0.25	2.82	7.61	0.10	95.60	f
	6	71.00	0.02	13.14	4 19	0.00	1.21	2.61	2.62	4 04	0.04	98.05	n I
	7	74 60	0.12	12 17	2 15	0.01	0.81	0.89	2.57	6 70	0.00	95 50	g
	8	76.89	0.12	12.17	0.90	0.01	0.01	0.00	3.84	4 64	0.03	95 19	f
MEM_T1072.	14 230 v	arve vi	's RP	12.00	0.00	0.10	0.04	0.00	0.04	4.04	0.00	00.10	
<u>wii wi_ 11072</u> .	14,200 1	57 34	0.61	18 67	5 33	0.10	1 50	4 51	3.80	7 83	0.30	94 91	f
	3	57 71	0.59	19 18	4 72	0.04	1.30	4 24	3.53	8.36	0.32	97.62	e
	5	58 10	0.58	18.80	4 84	0.01	1.37	4 16	3 44	8.30	0.31	96.23	a
	7	58.30	0.59	18.66	4 78	0.13	1.07	3.95	3.82	8.33	0.28	94 12	f
	9	58.93	0.48	18.92	4.28	0.14	1.13	3.78	3.59	8.46	0.29	97.74	a
	11	61.35	0.42	18.51	3.31	0.10	0.62	2.52	3.91	9.16	0.11	94.51	e
	13	61.80	0.49	18.76	2.92	0.18	0.44	2.26	4.29	8.77	0.10	97.28	a
	15	62.02	0.43	18.80	2.98	0.22	0.40	2.24	4.10	8.72	0.09	96.88	f
	16	62.19	0.39	18.91	2.53	0.12	0.41	2.21	4.09	9.08	0.08	95.62	a
	17	75.14	0.15	14.16	1.74	0.05	0.76	1.15	2.44	4.13	0.29	96.60	f
	18	72.34	0.59	12.92	3.64	0.24	1.98	1.68	3.20	3.38	0.02	99.46	f
	19	77.08	0.14	11.82	2.38	0.08	0.02	0.69	4.41	3.38	0.01	96.26	f
MFM T876: 1	2.880 va	rve vrs	BP										
	1	58.91	0.29	21.21	2.22	0.11	0.18	1.09	9.33	6.64	0.03	97.19	е
	3	59.49	0.37	20.74	2.26	0.10	0.20	1.40	8.44	6.96	0.04	97.36	e
	5	59.72	0.57	20.34	2.56	0.08	0.24	1.96	6.70	7.78	0.06	98.51	e
	7	59.88	0.58	20.08	2.45	0.09	0.30	1.93	6.68	7.90	0.10	96.06	e
	9	60.41	0.57	20.05	2.36	0.11	0.28	1.75	6.73	7.70	0.05	98.36	b
	11	60.53	0.57	20.02	2.08	0.09	0.25	1.71	6.86	7.82	0.08	97.31	е
	13	60.56	0.40	20.18	2.36	0.07	0.25	1.74	6.95	7.43	0.05	98.20	е
	15	60.60	0.57	20.16	2.24	0.06	0.16	1.37	7.57	7.20	0.08	96.85	е
	17	60.86	0.55	19.78	2.49	0.22	0.27	2.03	5.75	7.98	0.08	96.22	b
	19	63.19	0.33	19.62	1.26	0.07	0.12	1.49	4.87	9.03	0.03	99.07	b
MFM_T801: 1	2,140 va	rve yrs	5 BP										
	1	52.88	3.58	13.61	12.26	0.21	3.93	8.18	3.45	1.36	0.54	96.93	С
	5	53.21	3.44	13.47	12.70	0.28	3.81	8.17	3.15	1.32	0.46	97.52	С
	9	55.01	3.23	13.52	11.54	0.19	3.50	7.20	3.81	1.57	0.43	98.42	С
	13	55.39	3.17	13.64	11.28	0.15	3.49	7.27	3.61	1.56	0.44	97.23	С
	21	56.93	2.88	13.36	10.92	0.12	3.29	6.95	3.60	1.61	0.34	97.68	d
	25	58.43	2.25	14.30	9.48	0.19	2.60	5.98	4.38	1.73	0.67	98.30	С
	29	60.39	0.60	20.17	2.26	0.09	0.29	1.82	6.50	7.83	0.06	97.02	С
	34	71.78	0.34	13.39	3.95	0.14	0.22	1.36	5.34	3.40	0.08	97.05	d
	38	72.15	0.27	13.60	3.68	0.18	0.20	1.43	5.00	3.49	0.01	98.22	d
	40	72.50	0.28	13.79	3.80	0.18	0.21	1.28	4.49	3.46	0.03	96.67	d

		SiO	TIO		E ₂ O	MnO	Mao	C-0		KO		Total	Std file
	0.40	310 ₂		AI_2U_3	reu	WINO	wgo	CaU	Na ₂ U	$n_2 U$	P_2U_5	Total	Sturile
IVIFIVI_1687:10	,648 var	ve yrs	BP	00.40			0.00	0.10	0.54		0.10	~~	
	1	58.90	0.92	20.10	2.87	0.03	0.33	2.42	6.54	7.78	0.12	96.57	е
	5	60.13	0.60	20.16	2.35	0.04	0.32	1.87	6.59	7.88	0.07	96.41	е
	9	59.43	0.37	21.23	1.92	0.21	0.15	1.60	8.46	6.56	0.06	97.78	а
	13	60.28	0.57	20.05	2.50	0.21	0.32	1.75	7.02	7.23	0.07	96.86	а
	17	59.27	0.74	20.01	2.90	0.17	0.44	2.26	6.88	7.23	0.10	98.78	а
	30	60.13	0.50	20.26	2.23	0.10	0.31	1.83	6.64	7.94	0.08	98.14	е
	34	60.21	0.48	20.37	2.27	0.15	0.29	1.82	6.74	7.59	0.08	98.21	а
	38	60.18	0.61	20.03	2.30	0.15	0.33	1.88	6.59	7.86	0.08	98.87	а
	42	60.69	0.42	20.59	2.12	0.14	0.20	1.20	7.35	7.25	0.04	99.02	а
	46	63.95	0.62	18.02	2.42	0.08	0.31	1.49	5.64	7.37	0.11	98.64	а
	47	71.57	0.30	13.95	3.64	0.19	0.24	1.45	5.10	3.47	0.09	97.26	а
	51	71.45	0.27	13.78	3.95	0.14	0.22	1.34	5.27	3.52	0.06	98.85	а
MFM_T685: 1	0,619 va	rve yrs	s BP										
	3	60.07	0.52	20.09	2.52	0.21	0.28	1.65	6.77	7.79	0.08	95.89	С
	5	60.48	0.29	20.71	1.96	0.20	0.18	1.42	7.80	6.89	0.07	96.20	а
	7	59.37	0.63	20.37	2.70	0.14	0.35	2.19	6.29	7.82	0.13	98.25	а
	9	60.20	0.55	20.30	2.26	0.15	0.29	1.82	6.73	7.65	0.07	97.55	С
	11	60.41	0.56	20.25	2.17	0.10	0.27	1.87	6.49	7.68	0.18	97.47	a
	13	60.21	0.60	20.28	2.43	0.18	0.28	1.69	6.82	7.45	0.06	98.19	с С
	15	59.88	0.74	20.16	2 76	0.19	0.44	1.82	6.41	7 49	0.12	99.16	a
	17	61 13	0.71	19.60	2.80	0.30	0.35	1.02	6.21	6.96	0.08	97.45	a
	20	60 59	0.45	20.12	2.00	0.00	0.00	1.85	6.64	7 69	0.00	98.97	a
	21	71 63	0.40	13.62	3 70	0.12	0.00	1.00	5 30	3.61	0.00	98.54	۵ ۵
	22	71.05	0.23	13.02	3 95	0.03	0.20	1.37	5.00	3.52	0.00	98.85	a
	22	75.70	0.27	13.10	1.66	0.06	0.22	0.23	2.53	6 15	0.00	05.85	а Э
MEM 1572.7	20 744 yor	10.10	0.27 RD	13.10	1.00	0.00	0.10	0.23	2.55	0.15	0.15	35.05	a
<u>IVII IVI_1373.7</u>	144 Val	60 40		10.01	2 /1	0.17	0.21	1.05	6 5 9	7 7 2	0.00	07.57	
	1	60.60	0.50	19.01	2.41	0.17	0.31	1.95	0.00	7.55	0.09	97.57	y a
	 	60.60	0.55	20.02	2.23	0.20	0.31	1.03	6.00	7.00	0.09	97.45	g
	5	00.10	0.47	20.45	2.11	0.17	0.24	1.00	0.73	7.09	0.10	99.33	a
	0	61.29	0.38	20.22	1.77	0.05	0.20	1.72	0.03	7.70	0.04	97.66	g
	/	01.11	0.39	20.52	2.02	0.20	0.21	1.67	0.21	7.60	0.07	98.90	I
	8	62.19	0.33	19.12	2.06	0.13	0.42	1.33	6.26	8.12	0.02	99.28	g
	9	71.81	0.30	13.56	3.76	0.20	0.23	1.36	5.09	3.64	0.06	96.52	g
	10	71.48	0.28	13.50	4.01	0.13	0.21	1.34	5.50	3.50	0.03	97.87	g
	11	69.00	0.69	7.45	4.68	0.11	1.60	1.89	5.93	8.59	0.06	98.65	Ť
	12	72.21	0.46	7.29	3.38	0.09	1.78	2.71	5.39	6.62	0.08	98.48	g
	13	71.93	0.60	6.69	4.38	0.10	1.72	3.00	5.04	6.51	0.05	98.93	t
	15	75.25	0.11	6.86	3.00	0.05	1.17	2.17	4.56	6.81	0.02	98.94	g
MFM_1568: 7	633 var	ve yrs	BP										
	1	71.76	0.30	13.96	3.69	0.13	0.21	1.37	4.89	3.63	0.06	98.49	а
MFM_T552: 7	314 var	ve yrs	BP										
	1	62.49	0.64	19.03	2.22	0.24	0.34	1.49	6.40	7.04	0.12	100.33	а
MFM_T550: 7	279 var	ve yrs	BP										
	1	60.68	0.61	19.83	2.30	0.19	0.28	1.34	7.95	6.75	0.08	97.18	f
	2	75.26	0.49	13.70	1.33	0.11	0.36	0.46	3.59	4.70	0.02	95.67	f
MFM_T548: 7	245 var	ve yrs	BP										
	1	60.25	0.52	20.10	2.30	0.23	0.25	1.71	7.01	7.58	0.05	98.78	f
	2	63.61	0.27	17.96	3.66	0.27	0.19	0.70	7.98	5.31	0.04	98.33	f
MFM_T334: 3	382 var	ve yrs	BP										
	1	62.49	0.64	17.99	3.92	0.21	0.58	1.67	7.30	5.00	0.20	96.73	f
	2	63.88	0.41	17.16	4.28	0.24	0.28	0.86	7.95	4.87	0.08	97.18	f
	3	64.59	0.21	16.62	4.38	0.22	0.12	0.60	8.33	4.90	0.03	98.00	f
MFM_T238: 3.	230 var	veyrs	BP										
	1	63.87	0.08	19.03	0.96	0.09	0.41	1.78	6.39	7.38	0.01	100.36	а
	2	67.85	0.59	14.73	4.68	0.17	1.88	0.25	2.80	6.86	0.18	99.85	а

587 Table 2:

- 588 Single-shard trace element compositions (ppm) of tephra layers within the Meerfelder Maar
- record, measured by laser ablation inductively coupled plasma mass spectrometry (section
- 590 2.3). Secondary standard data, which provide a measure of precision and accuracy, are
- 591 presented within Supplementary Information. "<LOD" indicates the element concentration
- 592 was below the limits of detection for that analyses.

	EPMA #	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Er	Yb	Lu	Та	Th	U	Std fild
MFM_T1072: 14,	230 varve y	rs BP																				
	7	335	863	30	303	47	1482	74	137	16	57	11.6	2.2	<lod< td=""><td>5.7</td><td>2.3</td><td><lod< td=""><td><lod< td=""><td>2.5</td><td>25.3</td><td>8.6</td><td>а</td></lod<></td></lod<></td></lod<>	5.7	2.3	<lod< td=""><td><lod< td=""><td>2.5</td><td>25.3</td><td>8.6</td><td>а</td></lod<></td></lod<>	<lod< td=""><td>2.5</td><td>25.3</td><td>8.6</td><td>а</td></lod<>	2.5	25.3	8.6	а
	4	318	903	29	295	44	1597	71	136	13	59	10.4	23	6.3	5.6	2.9		0.4	21	26.2	7.5	h
	8	308	926	30	292	44	1643	72	148	13	62	10.8	2.2	4.8	4.6	2.9	27		2.0	26.2	79	÷ h
	11	221	466	21	224	44	792	65	125	12	52	0.0	2.2	5.7	4.0	2.0	2.7		2.0	26.0	8.0	h
	47	2021	400	047	324	40	702	54	120	12	10	9.0	2.0	00.0	4.9	2.9	5.4		2.5	20.9	0.0	D
	17	303	221	217	00	0	341	54	110	12	40	11.9	2.2	23.2	39.0	14.7	5.2	0.4	0.5	15.5	11.5	a
	18	63	158	40	21	13	113	48	98	11	46	10.8	1.4	7.9	7.6	4.0	3.8	0.6	0.6	9.4	2.9	а
MFM_T876: 12,8	80 varve yrs	s BP															-					
	4	198	224	16	452	146	265	104	158	13	37	<lod< td=""><td><lod< td=""><td><lod< td=""><td>2.3</td><td>1.7</td><td>2.2</td><td><lod< td=""><td>6.3</td><td>15.7</td><td>4.1</td><td>b</td></lod<></td></lod<></td></lod<></td></lod<>	<lod< td=""><td><lod< td=""><td>2.3</td><td>1.7</td><td>2.2</td><td><lod< td=""><td>6.3</td><td>15.7</td><td>4.1</td><td>b</td></lod<></td></lod<></td></lod<>	<lod< td=""><td>2.3</td><td>1.7</td><td>2.2</td><td><lod< td=""><td>6.3</td><td>15.7</td><td>4.1</td><td>b</td></lod<></td></lod<>	2.3	1.7	2.2	<lod< td=""><td>6.3</td><td>15.7</td><td>4.1</td><td>b</td></lod<>	6.3	15.7	4.1	b
	7	183	330	15	466	132	392	93	144	12	35	4.0	1.0	2.4	2.4	1.6	2.2	0.3	5.2	15.0	3.9	b
MFM_T801: 12,1	40 varve yrs	s BP																				
	1	28	396	42	355	50	278	36	83	11	46	10.6	3.2	10.8	8.9	4.3	3.7	<lod< td=""><td>3.0</td><td>3.8</td><td>1.2</td><td>с</td></lod<>	3.0	3.8	1.2	с
	2	29	397	46	370	53	296	39	89	11	49	11.1	3.3	10.3	9.5	4.7	3.8	<lod< td=""><td>3.4</td><td>4.2</td><td><lod< td=""><td>С</td></lod<></td></lod<>	3.4	4.2	<lod< td=""><td>С</td></lod<>	С
	4	32	395	46	400	56	333	43	95	11	52	10.9	3.3	10.6	10.0	5.4	4.3	<lod< td=""><td>3.4</td><td>4.4</td><td><lod< td=""><td>с</td></lod<></td></lod<>	3.4	4.4	<lod< td=""><td>с</td></lod<>	с
	5	32	363	46	393	54	301	40	92	11	47	10.6	2.9	11.2	9.1	4.5	3.7	<lod< td=""><td>3.3</td><td>4.2</td><td><lod< td=""><td>с</td></lod<></td></lod<>	3.3	4.2	<lod< td=""><td>с</td></lod<>	с
	7	31	391	44	364	52	289	38	88	11	48	11.8	3.1	11.3	8.9	4.4	4 1		3.1	4 1		c C
	0	25	200	49	424	50	200	42	00	10	50	10.1	2.1	11.0	0.0	5.0	4.1		2.6	4.7	1 5	0
	9	35	300	40	424	00	320	43	90	12	53	12.1	3.2	11.0	9.3	5.0	4.1	<lod< td=""><td>3.0</td><td>4.7</td><td>1.5</td><td>U C</td></lod<>	3.0	4.7	1.5	U C
	10	38	386	51	448	63	358	45	105	12	52	13.2	3.3	10.7	10.3	5.5	4.5	<lod< td=""><td>3.8</td><td>5.1</td><td>1.7</td><td>c</td></lod<>	3.8	5.1	1.7	c
	15	36	414	55	454	63	385	49	110	13	62	14.9	3.7	12.3	11.7	5.5	4.4	<lod< td=""><td>3.5</td><td>5.1</td><td><lod< td=""><td>С</td></lod<></td></lod<>	3.5	5.1	<lod< td=""><td>С</td></lod<>	С
	18	29	378	43	364	50	318	38	86	11	46	11.4	3.2	10.5	8.8	4.4	3.4	<lod< td=""><td>3.4</td><td>4.2</td><td>1.4</td><td>С</td></lod<>	3.4	4.2	1.4	С
	23	46	328	55	514	73	396	52	117	14	60	12.7	3.3	12.3	11.8	5.9	4.9	<lod< td=""><td>4.3</td><td>6.0</td><td>2.1</td><td>С</td></lod<>	4.3	6.0	2.1	С
	25	41	451	61	507	70	413	57	127	16	65	17.6	4.8	13.7	12.8	6.4	5.0	<lod< td=""><td>4.0</td><td>5.8</td><td>1.7</td><td>С</td></lod<>	4.0	5.8	1.7	С
	28	44	410	64	562	77	460	64	133	17	73	16.3	4.6	16.1	13.2	6.7	5.6	<lod< td=""><td>4.3</td><td>6.4</td><td>2.0</td><td>с</td></lod<>	4.3	6.4	2.0	с
	34	86	123	84	922	126	673	88	191	22	84	19.5	3.5	16.3	15.8	8.7	8.2	<lod< td=""><td>7.0</td><td>11.6</td><td>3.4</td><td>С</td></lod<>	7.0	11.6	3.4	С
	35	78	118	79	870	120	655	88	186	21	91	19.5	3.7	16.2	16.0	8.7	7.5	<lod< td=""><td>7.3</td><td>11.6</td><td>3.6</td><td>С</td></lod<>	7.3	11.6	3.6	С
	36	87	127	88	948	132	696	93	201	24	92	20.1	3.7	18.1	17.4	9.3	8.7	<lod< td=""><td>7.6</td><td>12.6</td><td>3.8</td><td>с</td></lod<>	7.6	12.6	3.8	с
MFM_T687:10.64	8 varve vrs	BP																				
	9	216	26	14	606	152	31	109	151	10	25				1.8	17	22	0.4	4.8	21.3	55	а
	16	101	240	15	269	117	529	91	121	10	20								4.0	11.0	2.4	u 0
	10	200	340	10	300	400	530	70	400	10	32							<lod< td=""><td>4.0</td><td>40.4</td><td>3.4</td><td>a</td></lod<>	4.0	40.4	3.4	a
	25	200	300	13	411	120	595	79	123	9	27	<lod< td=""><td><lod< td=""><td><lod< td=""><td>2.0</td><td>1.2</td><td>1.6</td><td>0.3</td><td>4.Z</td><td>13.1</td><td>3.5</td><td>а</td></lod<></td></lod<></td></lod<>	<lod< td=""><td><lod< td=""><td>2.0</td><td>1.2</td><td>1.6</td><td>0.3</td><td>4.Z</td><td>13.1</td><td>3.5</td><td>а</td></lod<></td></lod<>	<lod< td=""><td>2.0</td><td>1.2</td><td>1.6</td><td>0.3</td><td>4.Z</td><td>13.1</td><td>3.5</td><td>а</td></lod<>	2.0	1.2	1.6	0.3	4.Z	13.1	3.5	а
	32	267	98	16	981	249	49	111	167	12	30	<lod< td=""><td><lod< td=""><td>3.3</td><td>2.2</td><td>1.7</td><td>2.9</td><td>0.5</td><td>5.4</td><td>34.1</td><td>8.0</td><td>а</td></lod<></td></lod<>	<lod< td=""><td>3.3</td><td>2.2</td><td>1.7</td><td>2.9</td><td>0.5</td><td>5.4</td><td>34.1</td><td>8.0</td><td>а</td></lod<>	3.3	2.2	1.7	2.9	0.5	5.4	34.1	8.0	а
	34	199	359	15	455	137	527	96	143	11	30	<lod< td=""><td>1.0</td><td><lod< td=""><td>2.1</td><td><lod< td=""><td><lod< td=""><td><lod< td=""><td>5.3</td><td>14.2</td><td>3.8</td><td>а</td></lod<></td></lod<></td></lod<></td></lod<></td></lod<>	1.0	<lod< td=""><td>2.1</td><td><lod< td=""><td><lod< td=""><td><lod< td=""><td>5.3</td><td>14.2</td><td>3.8</td><td>а</td></lod<></td></lod<></td></lod<></td></lod<>	2.1	<lod< td=""><td><lod< td=""><td><lod< td=""><td>5.3</td><td>14.2</td><td>3.8</td><td>а</td></lod<></td></lod<></td></lod<>	<lod< td=""><td><lod< td=""><td>5.3</td><td>14.2</td><td>3.8</td><td>а</td></lod<></td></lod<>	<lod< td=""><td>5.3</td><td>14.2</td><td>3.8</td><td>а</td></lod<>	5.3	14.2	3.8	а
	38	188	374	18	438	144	525	104	159	13	35	<lod< td=""><td><lod< td=""><td><lod< td=""><td>2.9</td><td>1.8</td><td>2.3</td><td>0.4</td><td>5.9</td><td>15.2</td><td>3.6</td><td>а</td></lod<></td></lod<></td></lod<>	<lod< td=""><td><lod< td=""><td>2.9</td><td>1.8</td><td>2.3</td><td>0.4</td><td>5.9</td><td>15.2</td><td>3.6</td><td>а</td></lod<></td></lod<>	<lod< td=""><td>2.9</td><td>1.8</td><td>2.3</td><td>0.4</td><td>5.9</td><td>15.2</td><td>3.6</td><td>а</td></lod<>	2.9	1.8	2.3	0.4	5.9	15.2	3.6	а
	39	172	454	16	380	129	697	91	143	11	34	<lod< td=""><td>0.9</td><td><lod< td=""><td>2.3</td><td>1.6</td><td><lod< td=""><td><lod< td=""><td>5.0</td><td>13.3</td><td>3.2</td><td>а</td></lod<></td></lod<></td></lod<></td></lod<>	0.9	<lod< td=""><td>2.3</td><td>1.6</td><td><lod< td=""><td><lod< td=""><td>5.0</td><td>13.3</td><td>3.2</td><td>а</td></lod<></td></lod<></td></lod<>	2.3	1.6	<lod< td=""><td><lod< td=""><td>5.0</td><td>13.3</td><td>3.2</td><td>а</td></lod<></td></lod<>	<lod< td=""><td>5.0</td><td>13.3</td><td>3.2</td><td>а</td></lod<>	5.0	13.3	3.2	а
	44	224	23	12	537	126	19	97	131	9	22	<lod< td=""><td><lod< td=""><td><lod< td=""><td>1.7</td><td>1.4</td><td>1.8</td><td><lod< td=""><td>4.2</td><td>19.2</td><td>5.3</td><td>а</td></lod<></td></lod<></td></lod<></td></lod<>	<lod< td=""><td><lod< td=""><td>1.7</td><td>1.4</td><td>1.8</td><td><lod< td=""><td>4.2</td><td>19.2</td><td>5.3</td><td>а</td></lod<></td></lod<></td></lod<>	<lod< td=""><td>1.7</td><td>1.4</td><td>1.8</td><td><lod< td=""><td>4.2</td><td>19.2</td><td>5.3</td><td>а</td></lod<></td></lod<>	1.7	1.4	1.8	<lod< td=""><td>4.2</td><td>19.2</td><td>5.3</td><td>а</td></lod<>	4.2	19.2	5.3	а
	45	189	97	22	309	147	119	128	218	18	55	6.6	1.0	4.6	3.7	2.2	2.4	0.3	7.2	9.7	2.2	а
	46	207	252	26	386	110	227	95	155	13	43	6.4	<lod< td=""><td><lod< td=""><td>4.4</td><td>2.5</td><td>2.8</td><td>0.5</td><td>4.7</td><td>18.8</td><td>3.9</td><td>а</td></lod<></td></lod<>	<lod< td=""><td>4.4</td><td>2.5</td><td>2.8</td><td>0.5</td><td>4.7</td><td>18.8</td><td>3.9</td><td>а</td></lod<>	4.4	2.5	2.8	0.5	4.7	18.8	3.9	а
	49	90	128	89	956	132	716	96	207	22	93	20.3	4.0	18.6	17.3	9.1	9.0	1.2	7.4	12.4	4.0	b
	50	89	122	87	873	126	660	86	193	21	83	19.1	3.7	15.3	15.7	8.3	7.8	1.1	6.9	10.6	3.2	b
	51	83	141	89	923	126	725	93	196	23	96	20.5	4.2	18.2	16.3	8.9	8.1	1.2	7.6	12.2	3.9	a
	EPMA #	Rh	Sr	Y	7r	Nh	Ba	la	Ce	Pr	Nd	Sm	Fu	Gd	Dv	Fr	Yh	1.0	Та	Th		Std fild
MEM T685: 10 6	19 varve vr	RD RD	51					_4						54	-,	-			. u		-	2.4 114
10.000.10,0	F F	105	120	15	111	122	709	00	140	11	24	47	1 0		26	1 5	20	0.2	5.2	12.0	27	d
	10	190	400	GI 44	911	104	190	00	140	11	34	4.7	1.2		2.0	6.1 4 C	2.0	0.3	0.3	10.0	3.7	u d
	10	197	394	14	3/4	124	664	89	137	11	31	4.0	1.0	<lud< td=""><td>2.2</td><td>1.6</td><td>1.8</td><td>0.3</td><td>4.7</td><td>13.3</td><td>3.5</td><td>d</td></lud<>	2.2	1.6	1.8	0.3	4.7	13.3	3.5	d
	15	218	280	20	398	154	426	110	176	15	45	5.1	1.3	<lod< td=""><td>3.1</td><td>2.2</td><td>2.3</td><td>0.4</td><td>7.3</td><td>13.5</td><td>2.8</td><td>d</td></lod<>	3.1	2.2	2.3	0.4	7.3	13.5	2.8	d
	16	212	375	15	437	143	584	100	148	12	33	4.0	1.0	<lod< td=""><td>2.4</td><td>1.7</td><td>2.0</td><td>0.3</td><td>5.8</td><td>16.3</td><td>4.1</td><td>d</td></lod<>	2.4	1.7	2.0	0.3	5.8	16.3	4.1	d
	17	242	118	32	563	235	168	145	254	22	67	7.8	1.3	5.8	5.3	3.5	4.1	0.6	10.4	19.3	4.7	d
	20	192	377	18	348	107	587	88	140	11	34	5.0	1.0	<lod< td=""><td>2.6</td><td>1.9</td><td>2.3</td><td>0.3</td><td>4.3</td><td>14.4</td><td>3.4</td><td>d</td></lod<>	2.6	1.9	2.3	0.3	4.3	14.4	3.4	d
MFM_T573: 7,74	4 varve yrs	BP																				
	2	209	400	15	437	134	653	97	146	11	32	<lod< td=""><td>1.1</td><td><lod< td=""><td>2.3</td><td>1.5</td><td>2.0</td><td><lod< td=""><td>5.3</td><td>16.0</td><td>3.8</td><td>b</td></lod<></td></lod<></td></lod<>	1.1	<lod< td=""><td>2.3</td><td>1.5</td><td>2.0</td><td><lod< td=""><td>5.3</td><td>16.0</td><td>3.8</td><td>b</td></lod<></td></lod<>	2.3	1.5	2.0	<lod< td=""><td>5.3</td><td>16.0</td><td>3.8</td><td>b</td></lod<>	5.3	16.0	3.8	b
	3	194	197	12	493	136	166	102	140	10	25	<lod< td=""><td><lod< td=""><td><lod< td=""><td>1.8</td><td>1.4</td><td>2.0</td><td><lod< td=""><td>4.6</td><td>16.9</td><td>4.5</td><td>b</td></lod<></td></lod<></td></lod<></td></lod<>	<lod< td=""><td><lod< td=""><td>1.8</td><td>1.4</td><td>2.0</td><td><lod< td=""><td>4.6</td><td>16.9</td><td>4.5</td><td>b</td></lod<></td></lod<></td></lod<>	<lod< td=""><td>1.8</td><td>1.4</td><td>2.0</td><td><lod< td=""><td>4.6</td><td>16.9</td><td>4.5</td><td>b</td></lod<></td></lod<>	1.8	1.4	2.0	<lod< td=""><td>4.6</td><td>16.9</td><td>4.5</td><td>b</td></lod<>	4.6	16.9	4.5	b
	4	190	200	13	498	140	178	102	145	10	24	<lod< td=""><td>0.6</td><td><lod< td=""><td>1.8</td><td>1.4</td><td>2.2</td><td>0.3</td><td>4.8</td><td>17.6</td><td>4.6</td><td>d</td></lod<></td></lod<>	0.6	<lod< td=""><td>1.8</td><td>1.4</td><td>2.2</td><td>0.3</td><td>4.8</td><td>17.6</td><td>4.6</td><td>d</td></lod<>	1.8	1.4	2.2	0.3	4.8	17.6	4.6	d
	6	218	310	11	424	118	542	86	124	9	21	<lod< td=""><td>0.7</td><td><lod< td=""><td>1.6</td><td>1.3</td><td>17</td><td>0.3</td><td>4.1</td><td>14.6</td><td>4.1</td><td>b</td></lod<></td></lod<>	0.7	<lod< td=""><td>1.6</td><td>1.3</td><td>17</td><td>0.3</td><td>4.1</td><td>14.6</td><td>4.1</td><td>b</td></lod<>	1.6	1.3	17	0.3	4.1	14.6	4.1	b
	11	2.0	121	86	876	130	65/	98	102	22	25	18 0	3.5	16 1	15.7		9.7	1.0	6.5	11 7	3.2	~ h
	12	216	325	1/	2010	11	240	200	102	22	10	30.9	1.0	0.1	26	1 /	1.0		0.5	20	1.0	5
MEM T204: 0.00	10		323	14	30		349	22	43	3	10	3.9	1.0	2.1	2.0	1.4	1.0	~LOD	0.5	5.9	1.0	u
IVIFIVI_1334: 3,38	∠ varve yrs	DP	400		4.10		c		400	4.0	<i>i</i> =			• -			<u> </u>					
	1	94	130	30	448	87	9/4	65	123	13	47	8.6	2.4	6.7	5.5	3.3	3.2	0.5	4.8	8.2	2.3	а
	2	134	50	49	881	158	279	99	185	19	59	11.1	1.2	8.3	8.6	5.0	5.9	0.8	8.7	13.3	4.8	а

595 Table 3:

- 596 Mean varve ages of the main Lateglacial tephra layers and the UMT and their age
- relationships to the major biostratigraphic units (pollen zones) as defined by Litt and Stebich
- 598 (1999) in the MFM sediment record. *Varve ages from the re-counted interval of the
- 599 MFM2015 varve chronology. For comparison with the GRIP/NGRIP ice cores the Meiendorf
- pollen zone has been tentatively correlated with GI-1e and the Oldest Dryas with GI-1d,
- 601 respectively (Brauer et al., 2000b).

Tephra layer	Boundary	Varve ages BP	Local biostratigraphic position
MFM_T711 / Ulmener Maar	tephra, West Eifel, Germany	11,000	590 years after transition to Holocene
	Younger Dryas / Holocene	11,590	
MFM_T801 / Vedde Ash, Ka	atla, Iceland	12,140	539 years after transition to YD; 550 years before transition to Holocene
	Allerød / Younger Dryas	12,679	
MFM_T876 / Laacher See T	ēphra, East Eifel, Germany	12,880	470 years after start of Allerød; 200 years before transition to YD;
	Meiendorf / Oldest Dryas	13,995*	
MFM_T1072 / Neapolitan Ye	ellow Tuff, Campi Flegrei, Ita	14,230*	350 - 400 years after start ofMeiendorf235 yearsbefore transition to Oldest Dryas
	Pleniglacial / Meiendorf	ca. 14,600*	duration extrapolated (no varve counting)

602 603

- 604
- 605 Figure 1:
- Location map showing Meerfelder Maar, in the West Eifel, volcanic centres and other sites
- 607 mentioned in the text. Insert shows topography of the Meerfelder crater and bathymetry of
- the lake basin, with the MFM-09 and MFM-6 core locations.



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610

612 Figure 2:

a) Plot of tephra glass shard counts (shards per gram dry sediment) against MFM09

614 composite depth (left hand axis) in the Meerfelder Maar composite profile. Tephra layers

sample codes are based upon their first occurrence depth below lake floor (cm). b) the

616 MFM2015 age-depth profile for MFM09 is shown with the LST and UMT marker tephra

- 617 layers indicated alongside (c) the varve counted sections from the previous MFM cores that
- 618 comprise the final MFM2015 chronology (section 3.1).
- 619



621 Figure 3:

Core photograph of the section below the Laacher See Tephra (LST) for which the published 622 MFM-6 chronology (red line; Brauer et al., 1999) has been slightly revised by varve counting 623 in new cores (MFM09), labelled as updated MFM2015 chronology (blue line). (a) Core photo 624 and lithological description. (b) Age-depth model for the MFM-6 (in red) and MFM2015 (in 625 blue) chronologies. The upper slumped section (*, 8 cm thick) is present in both composite 626 profiles and 110 varves have been interpolated (Brauer et al., 1999). The lower slumped 627 section (**, 80 cm thick) is well laminated in the profile MFM-6 and 200 varves have been 628 629 adopted from the MFM-6 chronology. Both records are precisely correlated using four

- 630 macroscopically visible (ML28 ML31) and microscopic (not shown) marker layers. The 631 position of the non-visible Neapolitan Yellow Tuff (NYT) is indicated with an arrow in the
- 632 lower part.

633

b) a) Age (varve ka) Depth (cm) MFM-09 12.8 13.0 13.2 13.4 13.6 13.8 14.0 14.2 14.4 870 LST MFM2015 chronology 880 MFM-6 chronology 890 Diatomaceous varves \approx Slumps 900 Poorly preserved diatomaceous varves 910 920 ML 28 930 ML 29 940 950 ML 30 960 ** 970 980 990 1000 1010 1020 1030 ML 31 1040 1050 1060 1070 NYT 1080 12.8 13.0 13.2 13.4 13.6 13.8 14.0 14.2 14.4

635 Figure 4:

Selected bi-plots showing tephra glass shard major, minor and trace element compositions. (a) The
full dataset from the analysed tephra layers in Meerfelder Maar, plotted using the Total Alkali Silica
classification by Le Bas et al. (1986). (b) The correlation of the trachytic-phonolitic shards from
MFM T1067 to the Neapolitan Yellow Tuff (data from Tomlinson et al., 2012). (c) MFM T876

MFM_T1067 to the Neapolitan Yellow Tuff (data from Tomlinson et al., 2012). (c) MFM_T876
 correlated to the Laacher See Tephra (proximal glass data from the RESET database, (Bronk Ramsey)

641 et al., in press-b). Also plotted are other layers containing reworked LST-like tephra (MFM_T548;

- 642 MFM_T550; MFM_T685/687; MFM_T573; MFM_T876; MFM_T1130). A reduced dataset is plotted
- 643 for MFM_T685+687 for clarity. (d) MFM_T801 correlated to the Vedde Ash (composite of data from
- Lane et al., 2012b); MFM_T568 is compositionally indistinguishable on major elements. Error bar
- 645 insets show approximate 2 sigma uncertainty range, based on precision of secondary standard glass 646 analyses (supplementary information table 1). (e) Comparison of MFM T334 to Holocene trachytic
- analyses (supplementary information table 1). (e) Comparison of MFM_T334 to Holocene trachytic
 tephra from Western Ireland correlated to Jan Mayen (*i*.) and Mt Furnas in the Azores (Chambers et
- 648 al., 2004; Reilly and Mitchell, 2014; Johannesson, in press) and MFM T573 to published pantelleritic
- tephra correlated to eruptions of Pantelleria (Magny et al., 2011) and Jan Mayen (*ii*.) (Lacasse and
- 650 Garbe-Schönberg, 2001).



652 Figure 5:

- Lithological profile and summary of the Lateglacial and early Holocene tephrostratigraphy of
- Lake Meerfelder Maar, from the Ulmener Maar tephra to the onset of varve formation in
- 655 MFM09 sequence.



656

657 Figure 6:

658 Map showing the known distributions of tephra from the Neapolitan Yellow tuff (Lane et al.,

659 2011a and references therein), the Laacher See Tephra (Riede et al., 2011 and references

therein), and the Vedde Ash (Lane et al., 2012b and references therein). Key sites, and those

where the tephra layers are co-located, are numbered: 1. Meerfelder Maar, 2. NGRIP

- 662 (Mortensen et al., 2005); 3. Kråkenes (Mangerud et al., 1984); 4. Endinger Bruch (Lane et al.,
- 2012c); 5. Rotmeer; 6. Soppensee; 7. Rotsee; 8. Lago Piccolo di Avigliana (Lane et al., 2012a);
- 9. Lake Bled (Lane et al., 2011a); 10. Lago Grande di Monticchio (Wulf et al., 2004).



666 Supplementary information:

- 667 Table S1:
- 668 Complete datasets of single-shard major and minor element oxide compositions for all
- tephra layers analysed within the Meerfelder Maar record, measured by electron
- 670 microprobe (section 2.3). Data are presented normalised to water-free compositions, with
- original totals shown, after filtering points with analytical totals below 94 weight %.
- 672 Secondary standard data, which provide a measure of precision and accuracy, are presented
- 673 within Supplementary Information (Table S2).

	EPMA#	SiO ₂	TiO ₂	AI_2O_3	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T1137	1	71.82	0.02	13.93	3.53	0.19	1.61	2.28	2.70	3.91	0.00	96.79	а
MFM_T1137	2	71.20	0.23	14.94	3.22	0.09	1.01	1.75	3.90	3.67	0.01	99.08	а
MFM_T1137	3	71.27	0.37	14.91	3.12	0.07	1.04	1.77	3.91	3.51	0.02	99.24	е
MFM_T1137	4	77.09	0.06	12.71	1.05	0.01	0.03	0.56	3.79	4.70	0.00	94.42	е
		SiO ₂	TiO ₂	AI_2O_3	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T1130	1	57.81	0.33	20.14	2.36	0.17	0.67	3.49	6.18	8.81	0.05	96.77	f
MFM_T1130	2	57.46	0.43	20.00	2.62	0.14	0.94	3.38	6.11	8.92	0.00	97.49	а
MFM_T1130	3	60.28	0.61	20.46	2.35	0.24	0.32	1.94	5.09	8.58	0.13	96.22	а
MFM_T1130	4	60.79	0.57	20.66	2.06	0.14	0.27	2.17	5.77	7.46	0.10	99.53	а
MFM_T1130	5	71.83	0.62	11.53	4.04	0.05	1.21	0.25	2.82	7.61	0.04	95.60	f
MFM_T1130	6	71.17	0.45	13.14	4.19	0.14	1.52	2.61	2.67	4.04	0.08	98.05	g
MFM_T1130	8	74.60	0.12	12.17	2.15	0.01	0.81	0.89	2.55	6.70	0.01	95.50	g
MFM_T1130	9	76.89	0.04	12.88	0.90	0.13	0.04	0.59	3.84	4.64	0.03	95.19	f
		SiO ₂	TiO ₂	AI_2O_3	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T1072	1	57.34	0.61	18.67	5.33	0.10	1.50	4.51	3.80	7.83	0.30	94.91	f
MFM_T1072	2	57.67	0.55	19.12	4.76	0.05	1.36	4.19	3.51	8.50	0.31	95.46	е
MFM_T1072	3	57.71	0.59	19.18	4.72	0.04	1.30	4.24	3.53	8.36	0.32	97.62	е
MFM_T1072	4	57.98	0.50	18.87	4.63	0.01	1.24	4.31	3.70	8.43	0.32	97.36	е
MFM_T1072	5	58.10	0.58	18.80	4.84	0.11	1.37	4.16	3.44	8.30	0.31	96.23	а
MFM_T1072	6	58.25	0.54	18.66	4.57	0.17	1.22	3.90	3.83	8.63	0.23	95.92	f
MFM_T1072	7	58.30	0.59	18.66	4.78	0.13	1.17	3.95	3.82	8.33	0.28	94.12	f
MFM_T1072	8	58.72	0.64	18.75	4.42	0.11	1.21	3.92	3.50	8.46	0.28	96.72	а
MFM_T1072	9	58.93	0.48	18.92	4.28	0.14	1.13	3.78	3.59	8.46	0.29	97.74	а
MFM_T1072	10	59.29	0.48	19.14	4.15	0.06	0.94	3.17	3.69	8.87	0.20	94.72	е
MFM_T1072	11	61.35	0.42	18.51	3.31	0.10	0.62	2.52	3.91	9.16	0.11	94.51	е
MFM_11072	12	61.78	0.40	18.56	3.06	0.14	0.54	2.50	3.52	9.42	0.08	97.63	а
MFM_T1072	13	61.80	0.49	18.76	2.92	0.18	0.44	2.26	4.29	8.77	0.10	97.28	a
MFM_11072	14	61.98	0.40	18.77	2.70	0.06	0.47	2.38	3.99	9.14	0.10	95.49	t
	15	62.02	0.43	18.80	2.98	0.22	0.40	2.24	4.10	8.72	0.09	96.88	t
MFM_11072	16	62.19	0.39	18.91	2.53	0.12	0.41	2.21	4.09	9.08	0.08	95.62	a
MFM_11072	1/	75.14	0.15	14.16	1.74	0.05	0.76	1.15	2.44	4.13	0.29	96.60	t (
	18	72.34	0.59	12.92	3.64	0.24	1.98	1.68	3.20	3.38	0.02	99.46	T (
MFM_11072	19	77.08	0.14	11.82	2.38	0.08	0.02	0.69	4.41	3.38	0.01	96.26	
	1	50.01	110 ₂	AI ₂ U ₃	reu				Na_2O	h ₂ U	$P_2 U_5$	10tal	Starlie
	1	50.91	0.29	21.21	2.22	0.11	0.10	1.09	9.33	0.04	0.03	97.19	e
	2	59.35	0.00	19.97	2.00	0.05	0.47	2.11	0.70	6.06	0.12	90.10	e
	3	59.49	0.37	20.74	2.20	0.10	0.20	1.40	6.06	7.90	0.04	97.30	e
MEM 1976	4 5	50.72	0.04	20.03	2.01	0.02	0.30	1.03	6.70	7.00	0.04	90.52	6
	5	50.97	0.57	20.34	2.00	0.00	0.24	2.27	6.20	7.52	0.00	96.01	e
MEM T876	7	59.04	0.40	20.49	2.45	0.11	0.30	1 93	6.68	7 90	0.31	96.06	
MEM 1976	7 Q	60.01	0.50	10.60	2.45	0.03	0.30	1.03	6.95	7.06	0.10	90.00	0
MFM_T876	0 0	60.01	0.00	20.05	2.40	0.01	0.34	1.33	6.73	7.30	0.00	93.44	b b
MEM_T876	10	60.44	0.37	10.03	2.30	0.11	0.20	1.73	7 28	8 17	0.03	90.50	0
MFM T876	11	60 53	0.42	20.02	2.17	0.00	0.13	1 71	6 86	7.82	0.04	97 31	
MFM T876	12	60.53	0.61	19.82	2.00	0.03	0.20	1 79	6.00	7.81	0.00	97 55	h
MFM T876	13	60.56	0.01	20 18	2.75	0.20	0.20	1 7/	6 92	7 42	0.05	98.20	- 5 - 6
MFM T876	14	60 59	0.57	20.01	2.50	0.07	0.28	1 76	6.80	7 32	0.05	97.61	P
MFM T876	15	60.60	0.57	20.16	2.00	0.06	0.16	1.37	7.57	7.20	0.08	96.85	e
MFM T876	16	60.62	0.52	20.03	2.40	0.18	0.28	1.56	6.71	7.60	0.10	98.20	b
MFM T876	17	60.86	0.55	19,78	2,49	0.22	0.27	2.03	5.75	7.98	0.08	96.22	b
MFM T876	18	61.18	0.48	19.89	2.03	0.16	0,27	1.61	6.74	7.57	0.06	98.59	b
MFM T876	19	63.19	0.33	19.62	1.26	0.07	0.12	1.49	4.87	9.03	0.03	99.07	b

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		SiO ₂	TiO ₂	AI_2O_3	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T801	1	52.88	3.58	13.61	12.26	0.21	3.93	8.18	3.45	1.36	0.54	96.93	С
MFM_T801	2	52.90	3.59	13.50	12.54	0.20	3.95	7.91	3.61	1.31	0.49	96.65	С
MFM_T801	3	52.96	5.15	12.95	13.06	0.24	3.45	6.84	3.44	1.53	0.38	96.03	С
MFM_T801	4	53.16	3.55	13.57	12.32	0.23	3.90	7.87	3.62	1.34	0.43	96.64	С
MFM_T801	5	53.21	3.44	13.47	12.70	0.28	3.81	8.17	3.15	1.32	0.46	97.52	С
MFM_T801	6	53.22	2.84	10.70	11.80	0.20	7.17	10.06	2.63	1.05	0.33	98.06	С
MFM_T801	7	54.14	3.45	13.46	11.85	0.28	3.83	7.95	3.23	1.33	0.48	96.25	С
MFM_T801	8	54.43	3.12	13.77	11.81	0.20	3.58	7.55	3.49	1.59	0.46	96.73	С
MFM_T801	9	55.01	3.23	13.52	11.54	0.19	3.50	7.20	3.81	1.57	0.43	98.42	С
MFM_T801	10	55.05	3.18	13.69	11.14	0.13	3.47	7.36	3.96	1.58	0.43	98.25	С
MFM_T801	11	55.20	2.13	10.85	10.11	0.37	6.50	10.46	2.77	1.33	0.29	97.54	С
MFM_T801	12	55.32	3.26	13.12	11.14	0.18	3.92	7.55	3.66	1.46	0.40	95.01	d
MFM_T801	13	55.39	3.17	13.64	11.28	0.15	3.49	7.27	3.61	1.56	0.44	97.23	С
MFM_T801	14	55.62	2.98	13.81	10.97	0.22	3.44	7.15	3.72	1.72	0.38	97.27	С
MFM_T801	15	55.95	2.80	14.14	10.63	0.30	3.07	6.78	3.99	1.72	0.64	97.97	С
MFM_1801	16	56.08	2.81	13.96	10.79	0.25	3.19	6.82	3.92	1.65	0.52	97.79	С
	1/	56.18	3.00	13.51	10.98	0.30	3.27	6.74	3.89	1./1	0.43	97.50	С
MFM_1801	18	56.34	2.95	13.73	11.05	0.28	3.21	7.05	3.39	1.62	0.37	93.38	С
	19	50.35	2.84	13.56	10.75	0.21	3.3/	0.95	3.83	1.69	0.45	98.19	C
	20	56.72	2.69	13.54	10.97	0.22	3.11	6.71	3.82	1.82	0.38	97.89	C
	21	50.93	2.88	13.30	10.92	0.12	3.29	6.95	3.60	1.01	0.34	97.68	a
MEM T801	22	57.12	2.00	14.13	10.20	0.10	2.09	6.50	4.07	1.04	0.55	90.01	C C
MEM T801	23	57.62	2.01	14 17	0.05	0.10	2.13	6.29	3.90	1.03	0.37	97.20	
MEM_T801	24	58 /3	2.01	14.17	9.95	0.20	2.05	5.08	4.02	1.73	0.02	08.30	с С
MEM_T801	20	58.86	2.23	13 50	9.40	0.13	3.05	6.13	3.94	1.75	0.07	96.83	C C
MFM_T801	20	59.35	2.42	14 57	8.98	0.10	2.38	5 51	4 33	1.33	0.07	98.22	C C
MFM_T801	28	60.07	1.91	14.40	9.00	0.26	2.24	5.18	4.39	1.97	0.58	97.66	C C
MFM T801	29	60.39	0.60	20.17	2.26	0.09	0.29	1.82	6.50	7.83	0.06	97.02	С
	30	60.42	2.13	14.28	8.88	0.23	2.10	5.18	4.25	2.15	0.38	97.40	С
MFM_T801	31	61.44	1.81	13.81	8.37	0.19	2.17	4.95	4.64	2.28	0.35	98.67	С
MFM_T801	32	61.88	1.66	13.96	8.35	0.17	2.08	4.87	4.34	2.36	0.33	97.51	С
MFM_T801	34	71.78	0.34	13.39	3.95	0.14	0.22	1.36	5.34	3.40	0.08	97.05	d
MFM_T801	35	71.85	0.29	13.43	3.68	0.20	0.20	1.47	5.35	3.47	0.06	95.58	d
MFM_T801	36	71.86	0.28	13.56	3.55	0.17	0.19	1.34	5.51	3.48	0.05	98.62	d
MFM_T801	37	72.01	0.34	13.71	3.71	0.17	0.18	1.36	5.09	3.37	0.06	99.20	d
MFM_T801	38	72.15	0.27	13.60	3.68	0.18	0.20	1.43	5.00	3.49	0.01	98.22	d
MFM_T801	39	72.25	0.34	13.76	3.65	0.13	0.20	1.30	4.87	3.42	0.07	94.40	d
MFM_1801	40	72.50	0.28	13.79	3.80	0.18	0.21	1.28	4.49	3.46	0.03	96.67	d
		SIO ₂	110 ₂	AI_2O_3	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P_2O_5	Iotal	Std file
	1	58.90	0.92	20.10	2.87	0.03	0.33	2.42	6.54	1.18	0.12	96.57	e
NEN TOOT	2	59.80	0.58	20.22	2.42	0.10	0.32	1.88	0.89	7.64	0.09	95.85	C
MEM T697	3	09.0Z	0.03	20.10	2.24	0.14	0.31	1.75	6.42	7.57	0.07	90.01	
MEM T687	4	60.21	0.00	20.20	2.49	0.05	0.20	1.91	6.50	7.70	0.00	90.19	e 0
MEM T687	5	50.13	0.00	20.10	2.33	0.04	0.32	1.07	6.37	7.88	0.07	90.41	0
MEM T687	7	58 76	0.02	10.88	2.00	0.00	0.30	1.95	7.06	7.00	0.03	08 75	0
MFM_T687	8	59.67	0.07	20.03	2.56	0.00	0.43	2.04	6.96	7.50	0.11	90.75	
MFM_T687	9	59 43	0.02	21.23	1.92	0.00	0.25	1.60	8 46	6 56	0.27	97.78	a
MFM T687	10	60.01	0.63	19.99	2.27	0.02	0.32	1.97	6,68	8.05	0.07	96.88	e
MFM_T687	11	60.05	0.63	20.03	2.30	0.06	0.32	2.06	5.43	8.95	0.18	97.00	e
MFM T687	12	60.07	0.60	20.51	2.30	0.06	0.32	1.83	6.79	7.43	0.09	97.09	e
MFM_T687	13	60.28	0.57	20.05	2.50	0.21	0.32	1.75	7.02	7.23	0.07	96.86	a
MFM_T687	14	60.11	0.49	20.23	2.36	0.08	0.30	1.84	6.85	7.69	0.05	97.21	е
MFM_T687	15	60.31	0.63	20.30	2.42	0.12	0.30	1.81	6.39	7.64	0.07	96.99	а
MFM_T687	16	60.25	0.58	20.38	2.48	0.15	0.32	1.86	6.54	7.37	0.08	97.17	а
MFM_T687	17	59.27	0.74	20.01	2.90	0.17	0.44	2.26	6.88	7.23	0.10	98.78	а

| NFM T687 19 59.70 0.58 2.20 0.25 1.83 6.97 7.62 0.06 9.22 e NFM T687 21 59.86 0.55 20.44 2.20 0.15 0.27 2.00 661 7.84 0.04 97.84 e NFM T687 22 60.40 0.55 2.01 1.03 1.82 0.04 67.84 0.04 97.84 e NFM T687 24 60.23 0.05 0.13 0.14 0.75 67.7 0.74 0.05 97.30 e NFM T687 27 60.12 0.29 0.78 1.44 0.10 0.28 1.86 0.75 67.7 0.77 0.73 e MFM T687 27 60.12 0.29 0.71 1.14 0.22 1.18 6.02 7.05 0.8 7.20 A MFM T687 36 0.05 9 1.35 </th <th>MFM 1687</th> <th>18</th> <th>59.88</th> <th>0.55</th> <th>20.14</th> <th>2.52</th> <th>0.04</th> <th>0.33</th> <th>1.85</th> <th>7.02</th> <th>7.59</th> <th>0.08</th> <th>97.84</th> <th>е</th>
 | MFM 1687 | 18 |
59.88
 | 0.55 | 20.14
 | 2.52 | 0.04 | 0.33 | 1.85 | 7.02
 | 7.59 | 0.08 | 97.84 | е |
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NFM TG87 20 60.06 0.56 22.48 0.00 0.34 1.32 6.38 7.85 0.07 9.775 e NFM TG87 1 59.86 0.55 0.24 0.26 0.15 0.27 0.06 0.74 0.68 0.74 0.68 7.64 0.04 0.78 e 0.04 0.78 e 0.05 0.72 0.74 e 0.04 0.78 e 0.05 9.72.0 a NFM TG87 26 0.05 0.72.0 a N N 0.05 9.72.0 a A N 0.07 9.749 e N N 0.05 9.75.0 a A N N 0.05 9.75.0 a N N 0.05 9.75.0 a N N N N 0.05 9.75.0 a N N N N N N N N N N N N </td <td>MFM_T687</td> <td>19</td> <td>59.70</td> <td>0.58</td> <td>20.50</td> <td>2.40</td> <td>0.09</td> <td>0.25</td> <td>1.83</td> <td>6.97</td> <td>7.62</td> <td>0.06</td> <td>98.22</td> <td>e</td>			
 | MFM_T687 | 19 |
59.70
 | 0.58 | 20.50
 | 2.40 | 0.09 | 0.25 | 1.83 | 6.97
 | 7.62 | 0.06 | 98.22 | e |
| FMD TBB7 21 59.86 0.55 20.4 2.20 0.57 2.200 66.7 78.4 0.04 97.84 e MFW TBB7 22 0.04 0.58 22.20 0.01 0.23 1.07 65.3 7.40 0.04 97.84 e MFW TBB7 22 0.04 0.28 1.01 0.26 0.05 7.01 7.30 e MeW TBB7 26 0.05 0.05 1.01 0.26 1.01 0.26 1.01 0.26 1.01 0.26 1.01 0.26 1.01 0.07 0.75 7.5 7.7 P MFW TB87 27 0.012 0.29 0.28 1.01 0.15 1.24 2.42 1.16 0.05 7.93 e MFW TB87 1.02 0.01 0.07 9.74 0.01 0.03 9.74 e 0.01 0.01 9.02 1.01 0.01 9.02 1.01
 | MFM_T687 | 20 |
60.06
 | 0.56 | 20.26
 | 2 48 | 0.09 | 0.34 | 1 92 | 6.38
 | 7.83 | 0.07 | 97 75 | 6 |
| NYM NYM <td>MEM_T697</td> <td>21</td> <td>50.00</td> <td>0.00</td> <td>20.20</td> <td>2.40</td> <td>0.00</td> <td>0.04</td> <td>2.00</td> <td>6.61</td> <td>7.84</td> <td>0.07</td> <td>08.08</td> <td>~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~</td>
 | MEM_T697 | 21 | 50.00

 | 0.00 | 20.20 | 2.40
 | 0.00 | 0.04 | 2.00 | 6.61
 | 7.84 | 0.07 | 08.08 | ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ |
| NYM, T867 ZZ R0.04 L362 ZZ R0.04 R37.56 a MPN, T867 Z4 R0.23 R0.23 <td></td> <td>21</td> <td>09.00</td> <td>0.55</td> <td>20.44</td> <td>2.20</td> <td>0.15</td> <td>0.27</td> <td>2.00</td> <td>0.01</td> <td>7.04</td> <td>0.08</td> <td>90.00</td> <td>a</td>
 | | 21 | 09.00

 | 0.55 | 20.44 | 2.20
 | 0.15 | 0.27 | 2.00 | 0.01
 | 7.04 | 0.08 | 90.00 | a |
| MFM IB87 23 60.25 0.57 2.44 0.12 0.11 0.53 1.49 0.53 1.49 0.53 1.49 0.14 0.75 0.63 0.74 0.05 0.77 0.6 MFM I687 2.26 60.30 0.51 2.04 0.11 0.28 1.76 6.7 7.70 0.77 0.6 3.75 0.7 1.76 6.7 7.70 0.77 0.6 3.75 0.6 3.75 0.6 3.75 0.6 3.75 0.6 3.75 0.6 3.75 0.6 3.75 0.6 3.75 0.6 3.75 0.6 3.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.6 0.76 0.76 0.76 0.76 0.76 0.76 0.76
 | | 22 |
60.04
 | 0.58 | 20.19
 | 2.55 | 0.05 | 0.33 | 1.84 | 0.62
 | 7.76 | 0.04 | 97.84 | e |
| MFM T687 24 60.23 0.62 1.97 2.51 0.13 0.16 0.22 7.01 7.33 0.09 97.67 e MFM T687 26 60.39 0.51 2.046 2.21 0.10 0.28 1.78 6.75 7.47 0.07 97.50 a MFM T687 28 60.15 0.56 2.018 2.46 0.07 0.29 1.88 6.73 7.67 0.60 97.33 e MFM T687 29 60.45 0.648 2.022 2.20 0.20 1.88 6.64 7.44 0.08 98.14 e MFM T687 31 60.21 0.54 2.05 0.01 0.72 6.67 0.00 97.80 e MFM T687 34 60.21 0.48 2.22 2.25 0.17 0.25 1.27 0.17 0.00 97.80 9.80 1.88 6.91 7.86 0.08 9.8.4 a MFM T687 36 0
 | MFM_1687 | 23 |
60.25
 | 0.57 | 20.42
 | 2.29 | 0.11 | 0.33 | 1.87 | 6.53
 | 7.49 | 0.14 | 97.58 | а |
| MFM T687 25 60.56 0.46 20.39 2.21 0.16 0.28 1.76 6.75 7.74 0.07 9.75 0 a MFM T687 27 60.12 0.29 2.78 1.84 0.13 1.55 6.73 7.70 0.05 9.73 e MFM T687 29 60.45 0.48 0.22 2.28 1.81 6.59 7.90 0.07 9.749 e MFM T687 31 60.28 0.47 2.42 2.12 0.07 0.24 1.88 6.47 1.60 1.09 3.0 a MFM T687 33 60.37 0.64 2.53 2.23 0.00 0.30 1.72 6.66 7.60 0.06 9.74 e a 1.74 7.91 7.68 0.08 9.83 a a MFM 1.82 6.77 7.72 0.11 9.82 a a MFM 1.86 5.77 7.72 0.03 8.56 a A a A A <t< td=""><td>MFM_T687</td><td>24</td><td>60.23</td><td>0.62</td><td>19.70</td><td>2.51</td><td>0.13</td><td>0.36</td><td>2.03</td><td>7.01</td><td>7.33</td><td>0.09</td><td>97.67</td><td>е</td></t<>
 | MFM_T687 | 24 |
60.23
 | 0.62 | 19.70
 | 2.51 | 0.13 | 0.36 | 2.03 | 7.01
 | 7.33 | 0.09 | 97.67 | е |
| MFM TBB7 26 60.39 0.51 2.24 2.21 0.10 0.28 1.75 C.75 7.47 0.07 97.50 a MFM TBB7 28 60.15 0.56 20.18 2.46 0.07 0.29 1.85 6.73 7.67 0.06 97.33 e MFM TBB7 29 60.45 0.64 20.22 2.20 0.10 0.21 1.86 6.47 7.49 0.07 97.49 e MFM TBB7 2.20 0.20 0.21 1.86 6.47 7.49 0.08 98.30 a 0.85 r.66 0.06 97.95 e MFM TBB7 34 60.21 0.42 0.22 2.21 0.17 2.66 0.06 97.84 e MFM TBB7 35 60.50 0.32 1.10 1.22 1.21 7.21 1.11 8.21 2.21 1.11 1.21 7.21 0.11 8.21 2.21 <td>MFM_T687</td> <td>25</td> <td>60.56</td> <td>0.46</td> <td>20.39</td> <td>2.21</td> <td>0.16</td> <td>0.28</td> <td>1.61</td> <td>6.62</td> <td>7.65</td> <td>0.05</td> <td>97.20</td> <td>а</td>
 | MFM_T687 | 25 |
60.56
 | 0.46 | 20.39
 | 2.21 | 0.16 | 0.28 | 1.61 | 6.62
 | 7.65 | 0.05 | 97.20 | а |
| NFM TB87 27 60.12 0.29 2.78 1.84 0.13 0.15 1.24 8.24 7.18 0.02 0.73 e NFM TB87 29 60.45 0.64 0.02 0.22 1.00 1.86 6.37 7.00 0.79 7.49 e NFM TB87 30 60.13 0.22 0.12 0.11 88 6.47 7.61 0.05 98.0.5 NFM TB87 34 60.27 0.54 2.25 0.22 0.01 0.22 1.62 6.64 7.66 0.06 98.24 e NFM TB87 34 60.27 0.53 2.23 0.10 0.22 1.62 6.64 7.66 0.06 98.34 e MR TB87 34 60.27 0.63 1.76 7.77 1.18 6.63 7.66 0.69 9.63 a MR MR TB87 34 60.16 0.53 2.23 <t< td=""><td>MFM_T687</td><td>26</td><td>60.39</td><td>0.51</td><td>20.46</td><td>2.21</td><td>0.10</td><td>0.28</td><td>1.75</td><td>6.75</td><td>7.47</td><td>0.07</td><td>97.50</td><td>а</td></t<>
 | MFM_T687 | 26 |
60.39
 | 0.51 | 20.46
 | 2.21 | 0.10 | 0.28 | 1.75 | 6.75
 | 7.47 | 0.07 | 97.50 | а |
| NPM Trager 2.8 0.12 0.56 2.46 0.02 0.28 1.25 0.72 0.26 0.02 0.28 1.26 0.72 0.26 0.72 0.26 0.72 0.26 0.72 0.28 1.26 0.72 0.00 0.73 0 0.73 0.00 0.73 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.72 0.72 0.72 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.74 0.00 0.72 0.10 0.72 0.10 0.74 0.00 0.75 0.02 0.23 0.17 0.72 0.11 9.82 0.41 0.72 0.11 9.82 0.41 0.72 0.11 9.86 0.77 0.72 0.
 | MEM_T687 | 27 |
60.12
 | 0.20 | 20.78
 | 1.8/ | 0.13 | 0.15 | 1 24 | 8 24
 | 7 18 | 0.02 | 07.03 | ~ |
| NYM 1687 246 0.01 0.23 1.63 0.73 7.90 0.07 7.49 e MYM 1687 30 60.13 0.64 20.23 2.23 0.10 0.31 1.83 6.64 7.94 0.03 89.44 e MYM 1687 31 60.28 0.44 0.04 2.22 0.01 0.35 6.77 6.01 98.05 e MYM 1687 32 6.01 0.42 0.03 0.22 0.00 0.17 6.66 6.06 7.95 e MYM 1687 34 6.021 0.42 0.15 0.33 1.88 6.57 7.68 0.68 97.84 e MYM 1887 36 0.01 0.32 2.27 1.10 0.03 1.76 0.67 0.72 2.22 0.16 0.17 7.77 0.10 38.23 a MYM 1887 2.28 0.01 0.01 0.01 0.01 0.01
 | | 21 |
00.12
 | 0.23 | 20.70
 | 0.40 | 0.13 | 0.15 | 1.24 | 0.24
 | 7.10 | 0.02 | 07.00 | 6 |
| MFM 1687 29 60.45 0.42 2.23 0.10 0.21 0.47 0.47 0.48 0.41 0.45 MFM 1687 31 60.28 0.47 0.24 2.23 0.10 0.31 1.83 6.64 7.94 0.08 98.05 e MFM 1687 33 60.27 0.54 0.22 0.22 0.21 0.21 2.66 7.60 0.06 97.95 e MFM 1687 36 60.19 0.52 2.22 2.21 0.11 0.21 1.24 7.29 7.68 0.06 97.84 e MFM 1687 36 60.19 0.55 0.22 2.25 0.11 0.31 1.83 6.64 7.65 0.06 98.34 a MFM 1687 39 60.01 0.55 0.20 2.23 0.15 0.22 0.51 6.63 7.75 0.07 99.22 a MFM 1687 39 60.01 <th0.52< th=""> 0.22 0.22<td></td><td>28</td><td>60.15</td><td>0.56</td><td>20.18</td><td>2.46</td><td>0.07</td><td>0.29</td><td>1.85</td><td>6.73</td><td>1.01</td><td>0.05</td><td>97.93</td><td>е</td></th0.52<>
 | | 28 |
60.15
 | 0.56 | 20.18
 | 2.46 | 0.07 | 0.29 | 1.85 | 6.73
 | 1.01 | 0.05 | 97.93 | е |
| MFM_T687 30 60.13 0.50 22.30 0.10 0.31 18.31 6.64 7.94 0.08 89.14 e MFM_T687 32 60.14 0.60 19.87 2.62 0.25 0.30 2.01 6.95 7.16 0.10 98.30 a MFM_T687 34 60.21 0.42 0.237 2.27 0.15 1.22 7.27 6.76 0.06 97.84 e MFM_T687 36 60.19 0.55 0.29 2.25 0.17 0.25 1.82 6.78 7.60 0.08 98.21 a MFM_T687 36 60.18 0.61 0.13 2.23 0.16 0.73 7.72 0.14 99.24 a MFM_T687 36 60.18 0.61 0.23 2.21 0.16 0.20 7.75 0.02 99.22 a MFM_T687 40 60.66 0.42 2.23 0.16 0.20 7.75 0.03 98.26 a MFM_T687 44 6.60.42 2.23 0.16 </td <td>MFM_1687</td> <td>29</td> <td>60.45</td> <td>0.48</td> <td>20.23</td> <td>2.08</td> <td>0.12</td> <td>0.28</td> <td>1.81</td> <td>6.59</td> <td>7.90</td> <td>0.07</td> <td>97.49</td> <td>е</td>
 | MFM_1687 | 29 |
60.45
 | 0.48 | 20.23
 | 2.08 | 0.12 | 0.28 | 1.81 | 6.59
 | 7.90 | 0.07 | 97.49 | е |
| MFM. T687 31 60.28 0.42 2.12 0.07 0.24 1.60 6.98.05 e MFM. T687 32 60.47 0.54 2.03 2.23 0.00 0.30 1.72 6.66 7.60 0.06 97.95 e MFM. T687 33 60.37 0.54 0.237 0.15 0.23 1.27 7.65 0.26 7.52 7.60 0.06 97.85 e MFM. T687 33 60.35 0.55 0.22 2.25 0.17 0.55 1.82 0.77 7.20 1.01 98.24 a MFM. T687 36 60.16 0.67 0.27 0.20 0.23 0.37 1.86 0.21 0.37 7.26 0.03 99.22 a MFM. T687 40 60.56 0.66 0.61 1.37 7.77 0.00 99.22 a MFM. T687 44 61.68 0.32 0.27 1.22 0.35 1.37 7.42 0.03 9.33 a MFM. T687 44 61.60 0.
 | MFM_T687 | 30 |
60.13
 | 0.50 | 20.26
 | 2.23 | 0.10 | 0.31 | 1.83 | 6.64
 | 7.94 | 0.08 | 98.14 | е |
| NFM Tigs7 32 60.71 0.52 0.30 2.01 6.95 7.16 0.10 98.30 a NFM T687 34 60.21 0.42 2.23 0.00 0.01 7.22 6.6 7.60 0.60 97.95 e NFM T687 35 60.50 0.32 2.23 0.01 0.25 1.82 6.77 7.62 0.06 97.84 e NFM T687 36 60.16 0.61 2.03 2.25 0.11 0.25 1.82 6.77 7.62 0.06 98.36 a MFM T687 36 60.16 6.61 2.03 2.75 1.80 0.37 7.45 0.09 98.44 a MFM T687 44 60.70 0.22 0.73 7.45 0.09 99.02 a MFM T687 44 61.60 0.52 1.21 1.14 1.56 1.11 7.21 <td< td=""><td>MFM T687</td><td>31</td><td>60.28</td><td>0.47</td><td>20.42</td><td>2.12</td><td>0.07</td><td>0.24</td><td>1.60</td><td>6.94</td><td>7.81</td><td>0.05</td><td>98.05</td><td>е</td></td<>
 | MFM T687 | 31 |
60.28
 | 0.47 | 20.42
 | 2.12 | 0.07 | 0.24 | 1.60 | 6.94
 | 7.81 | 0.05 | 98.05 | е |
| NFM TBS7 23 60.37 0.23 0.23 0.23 0.24 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.26 7.29 0.27 7.27 0.11 8.2.4 a MFM T687 36 6.0.16 0.56 0.51 0.13 1.11 0.10 0.17 0.77 7.77 0.11 82.44 a MFM T687 36 6.016 0.02 2.23 1.16 0.21 7.77 0.01 99.22 a MFM 1687 44 6.0.56 0.22 0.23 1.16 1.21 7.77 0.01 99.22 a MFM 1687 44 6.0.56 1.22 1.01 7.21 0.01 99.23 a MFM 1
 | MFM_T687 | 32 | 60
14
 | 0.60 | 19.87
 | 2.62 | 0.25 | 0.30 | 2 01 | 6 95
 | 7 16 | 0.10 | 98 30 | a |
| NYM 1607 33 00.37 0.33 2.23 0.30 0.33 1.24 0.10 0.30 0
 | MEN 1697 | 22 |
60.27
 | 0.00 | 20.52
 | 2.02 | 0.20 | 0.00 | 1 72 | 6.66
 | 7.60 | 0.10 | 07.05 | <u>u</u> |
| MPM_T687 34 60.21 0.34 20.37 2.27 0.18 0.04 9.05 98 90.24 8 MPM_T687 35 60.50 0.34 2.05 0.15 1.42 6.78 7.62 0.09 98.38 a MPM_T687 36 60.19 0.55 0.22 1.01 0.02 0.03 1.79 6.63 7.75 0.07 99.22 a MPM_T687 38 60.16 0.67 0.22 0.015 0.03 1.20 6.73 7.45 0.09 98.44 a MPM_T687 41 60.70 0.22 0.27 1.66 0.77 7.60 0.03 9.856 a MPM_T687 41 60.60 0.42 0.49 0.42 1.77 7.60 0.02 9.774 a MPM_T687 42 61.69 0.42 0.59 1.14 0.21 7.35 3.61 0.03 1.34 6.47 7.30 1.44 <td>NENA TOO7</td> <td>33</td> <td>00.37</td> <td>0.54</td> <td>20.33</td> <td>2.23</td> <td>0.00</td> <td>0.30</td> <td>1.72</td> <td>0.00</td> <td>7.00</td> <td>0.00</td> <td>97.95</td> <td>e</td>
 | NENA TOO7 | 33 |
00.37
 | 0.54 | 20.33
 | 2.23 | 0.00 | 0.30 | 1.72 | 0.00
 | 7.00 | 0.00 | 97.95 | e |
| MFM T687 35 60.50 0.54 2.25 0.71 0.25 1.22 0.78 7.62 0.09 98.38 a MFM T687 37 60.35 0.51 0.21 2.21 0.17 0.25 1.22 0.17 0.33 1.88 65.97 7.66 0.08 98.87 a MFM T687 39 60.01 0.57 2.02 2.23 0.16 0.33 1.88 65.97 86 0.03 98.86 a MFM T687 40 60.56 0.68 1.22 7.71 0.66 0.37 7.74 0.03 98.56 a MFM T687 44 61.68 0.33 2.02 1.05 1.51 1.127 7.13 6.03 9.86 a MFM T687 44 61.68 0.53 1.64 0.20 1.21 7.13 6.13 1.03 1.03 1.03 1.03 1.03 1.03
 | IVIFIVI_1687 | - 34 |
60.21
 | 0.48 | 20.37
 | 2.27 | 0.15 | 0.29 | 1.82 | 6.74
 | 7.59 | 0.08 | 98.21 | а |
| MFM_T687 36 60.19 0.55 20.29 2.25 0.17 0.25 1.82 6.78 7.62 0.09 98.38 a MFM_T687 38 60.18 0.61 2.03 1.10 0.03 1.78 6.59 7.86 0.08 98.74 a MFM_T687 40 60.56 0.68 1.935 2.23 0.18 0.37 2.01 6.63 7.75 0.07 99.22 a MFM_T687 41 60.70 0.23 2.21 0.14 0.21 0.16 0.17 7.05 0.03 98.56 a MFM_T687 42 61.60 0.66 1.82 1.61 1.27 1.63 0.06 98.44 a MFM_T687 44 61.68 0.33 2.09 1.01 0.21 1.45 5.11 1.27 1.63 0.06 98.44 a MFM_T687 47 71.16 0.33 1.24 0.03 1.48 6.43 </td <td>MFM_T687</td> <td>35</td> <td>60.50</td> <td>0.34</td> <td>20.63</td> <td>1.85</td> <td>0.08</td> <td>0.15</td> <td>1.42</td> <td>7.29</td> <td>7.68</td> <td>0.06</td> <td>97.84</td> <td>е</td>
 | MFM_T687 | 35 |
60.50
 | 0.34 | 20.63
 | 1.85 | 0.08 | 0.15 | 1.42 | 7.29
 | 7.68 | 0.06 | 97.84 | е |
| NFM T687 37 60.35 0.51 2.30 0.51 0.33 1.88 65.9 7.86 0.08 9.88.7 a NFM T687 38 60.01 0.67 20.20 2.23 0.18 0.33 1.88 65.9 7.86 0.03 9.85.44 a NFM T687 40 60.56 0.62 2.75 0.22 0.16 1.21 7.77 7.06 0.03 9.85.64 a MFM T687 42 60.69 0.42 2.059 1.21 0.16 1.21 7.71 7.06 0.03 9.85.6 a MFM T687 44 61.68 0.53 1.68 1.22 7.13 6.33 0.06 9.84 a MFM T687 44 61.63 0.53 1.84 7.13 0.13 9.03 3.33 0.00 0.31 1.49 5.41 7.30 0.39 3.68 7.37 0.11 9.85.8<
 | MFM_T687 | 36 |
60.19
 | 0.55 | 20.29
 | 2.25 | 0.17 | 0.25 | 1.82 | 6.78
 | 7.62 | 0.09 | 98.38 | а |
| IFM_TEB7 38 60.18 0.61 20.31 2.30 1.88 6.59 7.86 0.08 98.27 a MFM_TE67 39 60.01 0.57 20.20 2.23 0.18 0.37 2.01 6.63 7.75 0.07 99.22 a MFM_TE67 40 60.56 0.68 13.35 2.75 0.22 0.35 1.80 6.73 7.45 0.09 98.64 a MFM_TE67 42 60.66 0.42 2.05 1.01 1.51 1.27 1.70 0.00 99.02 a MFM_TE67 44 61.68 0.32 0.16 1.51 1.27 1.70 0.00 99.72 a MFM_TE67 46 63.95 0.62 1.62 1.24 1.45 5.10 3.47 0.09 97.26 a MFM_TE67 47 71.57 0.30 13.95 0.44 0.21 1.34 5.05 97.38 e
 | MFM T687 | 37 |
60.35
 | 0.51 | 20.13
 | 2.11 | 0.19 | 0.30 | 1.79 | 6.77
 | 7.72 | 0.11 | 98.24 | а |
| NUM Cost
 | MEM_T687 | 38 | 60 18

 | 0.61 | 20.03 | 2 30
 | 0.15 | 0.33 | 1.88 | 6 59
 | 7 86 | 0.08 | 98.87 | 2 |
| mm micro 39 00.011 0.011 0.012 0.03 2.01 0.03 7.75 0.09 98.44 a MFM T687 41 60.70 0.23 20.77 1.86 0.21 0.16 1.21 7.77 7.06 0.039 98.56 a MFM T687 43 62.12 0.24 1.05 0.15 1.11 7.27 7.05 0.02 97.74 a MFM T687 45 61.60 0.56 18.37 2.09 0.19 0.35 1.76 6.42 7.53 0.10 99.31 a MFM T687 45 61.60 0.55 16.37 1.49 5.10 3.47 0.09 97.26 a MFM T687 47 7.15.7 0.30 13.89 3.81 0.31 0.22 1.35 5.01 3.47 0.09 97.33 a MFM T687 71.45 0.31 1.36
 | MENI TEOT | 20 |
60.04
 | 0.01 | 20.00
 | 2.00 | 0.10 | 0.00 | 2.00 | 6.00
 | 7.75 | 0.00 | 00.07 | α |
| mmm test test< test test< test< test<
 | | 39 | 00.01

 | 0.07 | 20.20 | 2.23
 | | 0.37 | 2.01 | 0.03
 | 1.10 | 0.07 | 33.22 | a |
| MHM_1087 41 60.70 0.23 20.77 1.86 0.21 0.16 1.21 7.77 7.06 0.03 9.86 a MFM_17687 42 60.90 0.42 0.59 1.21 0.14 0.20 1.25 7.25 7.25 0.06 98.74 a MFM_17687 44 61.68 0.33 1.20 0.15 0.15 1.22 7.13 6.93 0.06 98.46 a MFM_17687 46 63.95 0.62 1.80 0.24 1.48 5.40 7.09 97.26 a MFM_17687 47 7.15.1 0.21 1.35 5.33 3.47 0.09 97.33 a MFM_17687 50 71.61 0.21 1.36 9.22 0.00 0.21 1.35 5.43 3.61 0.04 9.02 1.35 5.43 3.61 0.04 9.02 1.35 5.43 3.61 0.04 9.07 9.05 9.73
 | IVIFIVI_1687 | 40 |
60.56
 | 0.68 | 19.35
 | 2.75 | 0.22 | 0.35 | 1.80 | 6.73
 | 1.45 | 0.09 | 98.44 | а |
| NFM TE87 42 60.69 0.42 20.59 2.12 0.14 0.20 7.25 7.25 0.04 9.02 a NFM TE87 44 61.68 0.33 20.69 1.67 0.15 0.15 1.22 7.13 6.93 0.06 98.46 a MFM TE87 44 61.68 0.33 2.22 0.08 0.31 1.48 5.64 7.37 0.09 97.34 a MFM TE87 47 71.57 0.30 13.95 3.64 0.13 0.22 1.35 5.36 3.47 0.05 97.38 e MFM TE87 49 71.61 0.31 1.378 3.95 0.14 0.22 1.35 5.36 3.47 0.06 97.96 e MFM TE87 1.47 0.22 M.24 5.20 0.06 9.33 1.60 0.40 0.20 S.06 0.67 0.33 1.66 0.77 7.79 <td>MFM_T687</td> <td>41</td> <td>60.70</td> <td>0.23</td> <td>20.77</td> <td>1.86</td> <td>0.21</td> <td>0.16</td> <td>1.21</td> <td>7.77</td> <td>7.06</td> <td>0.03</td> <td>98.56</td> <td>а</td>
 | MFM_T687 | 41 |
60.70
 | 0.23 | 20.77
 | 1.86 | 0.21 | 0.16 | 1.21 | 7.77
 | 7.06 | 0.03 | 98.56 | а |
| NFM. T687 44 61.68 0.33 20.69 1.67 0.15 0.15 1.22 7.13 6.93 0.06 98.46 a MFM. T687 45 61.60 0.56 1.937 2.09 0.19 0.35 1.78 6.42 7.53 0.01 99.31 a MFM. T687 46 63.95 0.62 1.80 0.24 1.45 5.10 3.47 0.09 97.26 a MFM. T687 48 71.61 0.31 1.372 3.69 0.04 0.22 1.35 5.36 3.59 0.05 97.33 a MFM. T687 50 71.61 0.31 1.372 3.69 0.04 0.22 1.35 5.36 3.59 0.05 97.38 e MFM. T687 52 74.93 0.39 1.36 2.28 0.20 0.47 0.33 1.46 5.43 3.61 0.04 97.35 C 0.75 C 0.75 C 0.75
 | MFM_T687 | 42 |
60.69
 | 0.42 | 20.59
 | 2.12 | 0.14 | 0.20 | 1.20 | 7.35
 | 7.25 | 0.04 | 99.02 | а |
| MFM_T687 44 61.68 0.33 20.69 1.67 0.15 0.15 1.22 7.13 6.93 0.00 99.46 a MFM_T687 45 61.60 0.56 19.37 2.09 0.19 0.35 1.78 6.42 7.53 0.10 99.31 a MFM_T687 47 71.57 0.30 13.95 3.64 0.13 0.22 1.35 5.36 3.47 0.05 97.33 a MFM_T687 49 71.61 0.31 13.54 3.93 0.00 0.19 1.41 5.36 3.47 0.05 97.38 e MFM_T687 50 71.61 0.31 13.69 0.04 0.20 1.35 5.36 3.61 0.04 98.55 c motile 5.27 4.93 0.39 1.40 0.23 1.35 5.30 7.91 1.32 1.61 0.31 2.03 5.90 7.91 0.32 1.97 6.65 1.14 <td< td=""><td>MFM T687</td><td>43</td><td>62.12</td><td>0.21</td><td>20.49</td><td>1.54</td><td>0.15</td><td>0.15</td><td>1.11</td><td>7.21</td><td>7.00</td><td>0.02</td><td>97.74</td><td>а</td></td<>
 | MFM T687 | 43 |
62.12
 | 0.21 | 20.49
 | 1.54 | 0.15 | 0.15 | 1.11 | 7.21
 | 7.00 | 0.02 | 97.74 | а |
| MPM_T687 45 61.00 0.50 0.31 0.44 5.50 0.10 99.31 a MFM_T687 47 71.61 0.31 1.372 3.69 0.04 0.20 1.35 5.43 3.61 0.04 97.38 e 0.47 0.33 2.64 2.00 0.33 2.64 2.00 0.33 2.64 2.00 0.33 2.64 2.00 0.33 2.64 2.00 0.79 6.66 c 0.77 7.90 0.89 8.5 a Mem Mem MES 0.10 0.22 1.31
 | MFM T687 | 44 | 61
68
 | 0.33 | 20 60
 | 1 67 | 0.15 | 0 15 | 1 22 | 7 1 2
 | 6 03 | 0.06 | 98.46 | 2 |
| mm mm<
 | MEN T207 | 15 | 61.00

 | 0.00 | 10.03 | 2.00
 | 0.10 | 0.15 | 1.22 | 6 40
 | 7 50 | 0.00 | 00.40 | α |
| MPM_T087 46 0.5.2 18.0.2 2.4.2 0.0.8 1.4.9 5.64 7.37 0.11 98.64 a MPM_T087 47 71.57 0.30 13.69 3.78 0.19 0.24 1.45 5.36 3.47 0.05 97.33 a MPM_T087 48 71.61 0.31 13.72 3.99 0.00 0.19 1.41 5.36 3.59 0.05 97.33 a MPM_T087 50 71.61 0.31 13.72 3.69 0.04 0.20 1.35 5.43 3.61 0.44 97.66 e MPM_T087 51 71.45 0.27 13.78 3.95 0.14 0.22 1.34 5.27 3.52 0.06 98.85 a MPM_T0857 50 7.43 0.39 1.36 2.21 1.34 2.03 9.25 To 1.42 1.86 6.77 7.79 0.08 9.76 C a 9.76 a <td></td> <td>40</td> <td>01.00</td> <td>0.00</td> <td>19.37</td> <td>2.09</td> <td>0.19</td> <td>0.35</td> <td>1.78</td> <td>0.42</td> <td>1.33</td> <td>0.10</td> <td>39.31</td> <td>a</td>
 | | 40 |
01.00
 | 0.00 | 19.37
 | 2.09 | 0.19 | 0.35 | 1.78 | 0.42
 | 1.33 | 0.10 | 39.31 | a |
| MFM_11687 47 7.1.57 0.30 13.95 3.64 0.19 0.24 1.45 5.10 3.47 0.09 97.26 a MFM_17687 49 71.61 0.31 13.022 1.35 5.36 3.59 0.05 97.38 e MFM_17687 50 71.61 0.31 13.72 3.69 0.04 0.20 1.35 5.43 3.61 0.04 97.96 e MFM_17687 52 74.93 0.39 13.69 2.28 0.00 0.47 0.33 2.64 5.20 0.69.85 a MFM_17687 1 60.60 0.60 0.00 0.20 1.41 2.35 0.06 98.55 c a 5.35 c a 5.5 c a
 | IMFIN_1687 | 46 | 63.95

 | 0.62 | 18.02 | 2.42
 | 0.08 | 0.31 | 1.49 | 5.64
 | 1.37 | 0.11 | 98.64 | а |
| NFM. T687 48 71.64 0.30 13.69 3.78 0.13 0.22 1.35 5.36 3.47 0.05 97.33 a MFM. T687 50 71.61 0.32 13.72 3.69 0.04 0.20 1.34 5.36 3.61 0.04 97.96 e MFM. T687 51 71.45 0.27 13.78 3.95 0.04 0.22 1.34 5.27 3.52 0.06 98.85 a MFM. T687 52 74.39 0.39 1.86 2.74 7.82 0.09 97.71 1.1 94.55 c MFM. T685 2 60.61 6.54 1.99 0.32 1.97 6.85 7.36 0.08 95.71 c MFM. T685 4 59.63 0.68 0.22 0.21 1.97 6.85 7.36 0.08 97.67 a MFM. T685 7.59.70 0.33 2.24 1.9
 | MFM_T687 | 47 |
71.57
 | 0.30 | 13.95
 | 3.64 | 0.19 | 0.24 | 1.45 | 5.10
 | 3.47 | 0.09 | 97.26 | а |
| NFM. T687 49 71.61 0.32 13.72 3.93 0.00 0.19 1.41 5.36 3.51 0.04 97.96 e MFM_ T687 50 71.61 0.31 13.72 3.69 0.04 0.20 1.35 5.43 3.61 0.04 97.96 e MFM_ T687 52 74.39 0.39 13.69 2.28 0.00 0.47 0.33 2.64 5.20 0.07 94.66 c MFM_ T685 1 60.60 0.60 2.00 2.52 1.21 0.11 1.44 5.5 c 1.35 5.33 1.01 1.41 5.36 0.88 5.59 c MFM_ T685 4 59.63 0.68 2.02 2.01 1.81 1.62 7.80 0.08 97.67 a MFM_ T685 6 0.64 0.29 0.21 1.28 0.77 7.77 0.07 97.25
 | MFM_T687 | 48 |
71.64
 | 0.30 | 13.69
 | 3.78 | 0.13 | 0.22 | 1.35 | 5.36
 | 3.47 | 0.05 | 97.33 | а |
| MFM_T687 50 71.61 0.31 13.72 3.68 0.04 0.20 1.35 5.43 3.61 0.04 97.96 e MFM_T687 51 71.45 0.27 13.78 3.95 0.14 0.22 1.34 5.27 3.52 0.06 97.90 e 0.68 98.85 a MFM_T685 52 74.39 0.39 1.86 7.47 0.33 2.64 5.20 0.07 94.66 c MFM_T685 1 60.60 0.60 2.002 2.41 0.13 1.86 6.77 7.79 0.08 95.57 c MFM_T685 2 60.61 0.54 1.94 2.33 1.42 7.80 0.88 9.7.67 a 0.95 7.65 c 0.46 0.29 2.19 6.29 7.82 0.13 96.20 a 1.65 7.77 7.77 0.08 97.67 a MFM_T685 5 9.60.20 0.29 7.82
 | MFM_T687 | 49 |
71.61
 | 0.32 | 13.54
 | 3.93 | 0.00 | 0.19 | 1.41 | 5.36
 | 3.59 | 0.05 | 97.38 | е |
| Init Biol Init Biol <t< td=""><td>MEM_T687</td><td>50</td><td>71.61</td><td>0.31</td><td>13 72</td><td>3.60</td><td>0.04</td><td>0.20</td><td>1 35</td><td>5 /3</td><td>3.61</td><td>0.04</td><td>07.06</td><td>0</td></t<>
 | MEM_T687 | 50 | 71.61

 | 0.31 | 13 72 | 3.60
 | 0.04 | 0.20 | 1 35 | 5 /3 | 3.61
 | 0.04 | 07.06 | 0 |
| MFM_T687 31 71.45 0.27 13.69 2.28 0.00 71.03 2.24 5.27 5.20 0.00 94.66 c MFM_T685 1 60.60 0.60 2.00 2.41 0.33 1.26 5.20 7.97 7.01 Stdf file MFM_T685 1 60.60 0.60 2.41 0.13 0.31 2.33 5.90 7.91 0.11 94.55 c MFM_T685 1 60.60 0.52 20.90 2.52 0.21 0.28 1.65 6.77 7.79 0.08 95.69 c MFM_T685 5 60.48 0.29 2.21 0.21 0.28 1.65 7.78 0.08 97.16 c MFM_T685 5 60.48 0.29 2.21 0.18 1.42 7.80 0.89 0.09 6.20 a MFM_T685 7 59.37 0.63 2.37 2.20 0.18 1.65 7.77 70 <td></td> <td>50</td> <td>71.01</td> <td>0.01</td> <td>10.72</td> <td>3.03</td> <td>0.04</td> <td>0.20</td> <td>1.00</td> <td>5.45</td> <td>3.01</td> <td>0.04</td> <td>91.90</td> <td>6</td>
 | | 50 |
71.01
 | 0.01 | 10.72
 | 3.03 | 0.04 | 0.20 | 1.00 | 5.45
 | 3.01 | 0.04 | 91.90 | 6 |
| MFM_1687 52 74.93 0.39 113.69 2.28 0.00 0.47 0.33 2.64 5.20 0.07 94.66 c MFM_17685 1 60.60 0.60 20.00 2.41 0.13 0.31 2.03 5.90 7.91 0.11 94.55 c MFM_17685 2 60.16 0.54 19.94 2.33 0.18 0.33 1.86 6.74 7.82 0.09 95.57 c MFM_17685 4 59.63 0.68 20.22 0.22 1.91 0.32 1.97 6.85 7.36 0.08 97.16 c MFM_17685 5 60.48 0.29 2.01 1.96 0.20 1.82 6.35 0.08 97.16 c a MFM_17685 7 59.37 0.63 20.37 2.70 0.14 0.35 2.19 6.29 7.82 0.13 98.25 a MFM_17685 16 0.33 0.56<
 | | 51 |
71.45
 | 0.27 | 13.78
 | 3.95 | 0.14 | 0.22 | 1.34 | 5.27
 | 3.52 | 0.06 | 98.85 | a |
| SiO, TiO, IALO, FeO Mno(MgO CaO Na, O, Total Std file MFM T685 1 60.01 0.60 2.000 2.41 0.13 0.31 2.03 5.90 7.91 0.11 94.55 c MFM T685 2 60.016 0.52 20.02 2.67 0.19 0.32 1.97 6.85 7.36 0.08 97.16 c MFM T685 5 60.48 0.29 2.071 1.96 0.20 0.18 1.42 7.80 6.89 0.07 96.20 a MFM T685 6 59.60 0.67 20.37 2.70 0.14 0.35 2.03 6.77 7.77 0.03 98.25 a MFM T685 8 60.20 0.55 2.03 2.71 0.15 0.29 1.82 6.73 7.65 0.07 97.55 c MFM T685 11
 | MFM_1687 | 52 |
74.93
 | 0.39 | 13.69
 | 2.28 | 0.00 | 0.47 | 0.33 | 2.64
 | 5.20 | 0.07 | 94.66 | C |
| NFM. T685 1 60.60 0.00 2.41 0.13 0.31 2.03 5.90 7.91 0.11 94.55 c MFM. T685 2 60.16 0.54 19.94 2.33 0.18 0.33 1.86 6.74 7.82 0.09 95.57 c MFM. T685 3 60.07 0.52 20.09 2.52 0.21 0.28 1.85 6.77 7.79 0.08 97.16 c MFM. T685 5 60.48 0.29 20.71 1.96 0.20 0.18 1.42 7.80 6.89 0.07 96.20 a MFM. T685 6 59.07 0.63 2.03 2.26 0.16 0.35 2.03 2.24 1.65 6.77 7.77 0.07 97.25 c MFM. T685 9 60.20 0.52 2.03 2.26 0.15 0.29 1.82 6.73 7.65 0.07 97.47 a MFM. T685 10 60
 | | | SiO
₂
 | TiO₂ | AI_2O_3
 | FeO | MnO | MgO | CaO | Na ₂ O
 | K₂O | P_2O_5 | Total | Std file |
| MFM_T685 2 60.16 0.54 19.94 2.33 0.18 0.33 1.86 6.74 7.82 0.09 95.57 c MFM_T685 3 60.07 0.52 20.09 2.52 0.21 0.28 1.65 6.77 7.79 0.08 95.89 c MFM_T685 5 60.48 0.29 20.71 1.96 0.20 0.18 1.42 7.80 6.89 0.07 96.20 a MFM_T685 6 59.60 0.67 20.18 2.69 0.16 0.35 2.19 6.29 7.82 0.13 98.25 a MFM_T685 8 60.34 0.49 20.34 2.17 0.15 0.29 1.82 6.77 7.77 0.07 97.75 c MFM_T685 10 60.13 0.56 20.48 2.32 0.20 0.30 1.88 6.67 7.45 0.07 97.77 a MFM_T685 11 60.21 <th>MFM_T685</th> <th>1</th> <th>60.60</th> <th>0.60</th> <th>20.00</th> <th>2.41</th> <th>0.13</th> <th>0.31</th> <th>2.03</th> <th>5.90</th> <th>7.91</th> <th>0.11</th> <th>94.55</th> <th>С</th>
 | MFM_T685 | 1 |
60.60
 | 0.60 | 20.00
 | 2.41 | 0.13 | 0.31 | 2.03 | 5.90
 | 7.91 | 0.11 | 94.55 | С |
| MFM_T685 3 60.07 0.52 20.09 2.52 0.21 0.28 1.65 6.77 7.79 0.08 95.89 c MFM_T685 4 59.63 0.68 20.24 2.67 0.19 0.32 1.97 6.85 7.36 0.08 97.16 c MFM_T685 5 60.48 0.29 20.71 1.96 0.20 0.18 1.42 7.80 6.89 0.07 96.20 a MFM_T685 7 59.37 0.63 20.37 2.70 0.14 0.35 2.09 6.77 7.77 0.07 97.55 c MFM_T685 8 60.34 0.49 20.30 2.26 0.15 0.03 1.88 6.677 7.45 0.07 97.55 c MFM_T685 10 60.13 0.56 20.48 2.32 0.20 0.30 1.88 6.677 7.45 0.07 97.55 c MFM_T685 14 60.47<
 | MFM_T685 | 2 | 60
16
 | 0 5 4 | 40.04
 | | 0.40 | | 4.00 | 0 - 4
 | | 0.00 | 05 57 | |
| MIM T003 5 00.01 0.02 2.02 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.21 0.22 0.23 0.23 0.27 0.22 0.23 0.23 0.27 0.23 0.23 0.27 0.23 0.
 | | |

 | 0.54 | 1994
 | 233 | I () 18 | 0.33 | 1 1 86 | 6 74
 | 1 82 | 0.09 | 95.57 | C |
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		SiO ₂	TiO ₂	AI_2O_3	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM T568	1	71.76	0.30	13.96	3.69	0.13	0.21	1.37	4.89	3.63	0.06	98.49	а
		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T552	1	62.49	0.64	19.03	2.22	0.24	0.34	1.49	6.40	7.04	0.12	100.33	а
		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T550	1	60.68	0.61	19.83	2.30	0.19	0.28	1.34	7.95	6.75	0.08	97.18	f
MFM_T550	2	75.26	0.49	13.70	1.33	0.11	0.36	0.46	3.59	4.70	0.02	95.67	f
		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T548	1	60.25	0.52	20.10	2.30	0.23	0.25	1.71	7.01	7.58	0.05	98.78	f
MFM_T548	2	63.61	0.27	17.96	3.66	0.27	0.19	0.70	7.98	5.31	0.04	98.33	f
		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T334	1	62.49	0.64	17.99	3.92	0.21	0.58	1.67	7.30	5.00	0.20	96.73	f
MFM_T334	2	63.88	0.41	17.16	4.28	0.24	0.28	0.86	7.95	4.87	0.08	97.18	f
MFM_T334	3	64.59	0.21	16.62	4.38	0.22	0.12	0.60	8.33	4.90	0.03	98.00	f
		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K₂O	P_2O_5	Total	Std file
MFM_T239	1	63.87	0.08	19.03	0.96	0.09	0.41	1.78	6.39	7.38	0.01	100.36	а
MFM T239	2	67.85	0.59	14.73	4.68	0.17	1.88	0.25	2.80	6.86	0.18	99.85	а

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678 Table S2:

- 679 Summary of measured secondary standard glass ((ATHO-G and StHs6/80-G from the MPI-DING
- 680 collection, Jochum et al., 2006) compositions by (a) WDS-EPMA and (b) LA-ICP-MS. Preferred values
- from the online GeoREM database are listed for comparison (Jochum et al., 2005).

a) WDS-EPMA											
	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na₂O	K₂O	P ₂ O ₅	
Observed values:					wt	%					
a. ATHO-g											
average (n=11)	75.02	0.25	12.30	3.28	0.09	0.11	1.70	4.15	2.68	0.03	
2σ	0.47	0.07	0.18	0.21	0.08	0.03	0.07	0.39	0.14	0.04	
a. StHs6/80-q											
average (n=10)	63.07	0.71	17.43	4.36	0.07	1.96	5.22	4.40	1.31	0.15	
2σ	0.71	0.05	0.40	0.25	0.09	0.10	0.12	0.98	0.05	0.04	
h ATHO-a	0.1.1	0.00	0.10	0.20	0.00	0.10	0.12	0.00	0.00	0.01	
average (n=4)	75 51	0.25	12 15	3 35	0.09	0 10	1 71	4 11	2 65	0.01	
2σ	0.19	0.03	0.29	0.23	0.07	0.02	0.04	0.21	0.09	0.02	
b StHs6/80-a	0.15	0.00	0.23	0.20	0.07	0.02	0.04	0.2 1	0.00	0.02	
2verage (n=3)	63 13	0.60	17 50	4 40	0.10	1 00	5 21	4 56	1 31	0.11	
average (II=3)	0.25	0.03	0.25	0.34	0.10	0.05	0.08	4.50	0.07	0.11	
	0.20	0.09	0.20	0.04	0.02	0.00	0.00	0.22	0.07	0.01	
	75.00	0.25	12.26	2 21	0.11	0.00	1.67	4.04	2 75	0.02	
average (II=19)	10.09	0.20	0.25	0.01	0.11	0.09	1.07	4.04	2.13	0.03	
20	0.63	0.05	0.25	0.14	0.05	0.03	0.07	0.20	0.11	0.03	
c. StHS 6/80-g	00.00	0.70	47.00	4.00	0.00	4.05	5.04	4.54	4.00	0.40	
average (n=17)	03.20	0.70	17.68	4.39	0.08	1.95	5.24	4.51	1.30	0.16	
20	0.44	0.08	0.41	0.34	0.07	0.06	0.10	0.32	0.07	0.04	
d. ATHO-g			10.15				4.07				
average (n=6)	74.74	0.25	12.45	3.24	0.11	0.09	1.67	4.06	2.71	0.02	
2σ	0.81	0.04	0.25	0.24	0.05	0.04	0.08	0.31	0.08	0.04	
d. StHs6/80-g											
average (n=4)	64.07	0.72	17.98	4.27	0.06	1.99	5.26	4.56	1.28	0.15	
2σ	0.48	0.10	0.26	0.43	0.09	0.06	0.10	0.42	0.08	0.02	
e.ATHO-g											
average (n=15)	75.21	0.26	12.38	3.33	0.05	0.10	1.69	4.13	2.74	0.03	
2σ	0.78	0.05	0.22	0.28	0.07	0.03	0.09	0.27	0.11	0.04	
e.StHs6/80-g											
average (n=20)	63.63	0.70	17.84	4.40	0.03	1.95	5.30	4.50	1.31	0.15	
2σ	0.51	0.06	0.35	0.33	0.03	0.07	0.19	0.27	0.08	0.03	
f.ATHO-g											
average (n=16)	75.07	0.26	12.28	3.38	0.11	0.09	1.68	3.99	2.75	0.02	
2σ	0.46	0.04	0.16	0.23	0.07	0.04	0.09	0.36	0.13	0.03	
f.StHs6/80-g											
average (n=14)	63.43	0.72	17.53	4.33	0.08	1.94	5.33	4.45	1.29	0.15	
2σ	0.55	0.06	0.28	0.19	0.08	0.09	0.13	0.24	0.08	0.03	
g. ATHO-g											
average (n=5)	75.34	0.24	12.18	3.27	0.09	0.10	1.67	4.10	2.72	0.02	
2σ	0.29	0.08	0.10	0.28	0.09	0.03	0.07	0.28	0.17	0.02	
g. StHs6/80-g											
average (n=7)	63.64	0.72	17.54	4.35	0.10	1.97	5.30	4.58	1.34	0.16	
2σ	0.42	0.06	0.38	0.21	0.09	0.08	0.14	0.21	0.08	0.04	
Preferred values:											
ATHO-G											
preferred value	75.60	0.26	12.20	3.27	0.11	0.10	1.70	3.75	2.64	0.16	
95% CL	0.70	0.02	0.20	0.10	0.01	0.01	0.03	0.31	0.09	0.02	
StHs 6/80-g											
preferred value	63.70	0.70	17.80	4.37	0.08	1.97	5.28	4.44	1.29	0.03	
95% CL	0.50	0.02	0.20	0.07	0.00	0.04	0.09	0.14	0.02	0.00	

b) LA-ICP-MS																			
.,	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Er	Yb	Та	Th	U
									(F	opm)									
Observed valu	ies:																		
a. ATHO-g																			
average (n=3)	67	98	94	511	59	567	56	125	15	62	15	2.6	14.7	16.8	10.3	10.7	3.8	7.4	2.4
2σ	5.9	9.4	3.2	35.2	6.7	40.6	1.4	8.0	1.2	4.0	2.0	0.2	1.3	0.4	0.9	0.9	0.1	0.4	0.3
a. StHs6/80-g																			
average (n=3)	30	489	11	117	6	300	12	25	3	13	<lod< td=""><td>1.0</td><td><lod< td=""><td>2.2</td><td>1.2</td><td><lod< td=""><td><lod< td=""><td>2.3</td><td>1.0</td></lod<></td></lod<></td></lod<></td></lod<>	1.0	<lod< td=""><td>2.2</td><td>1.2</td><td><lod< td=""><td><lod< td=""><td>2.3</td><td>1.0</td></lod<></td></lod<></td></lod<>	2.2	1.2	<lod< td=""><td><lod< td=""><td>2.3</td><td>1.0</td></lod<></td></lod<>	<lod< td=""><td>2.3</td><td>1.0</td></lod<>	2.3	1.0
2σ	2.1	10.4	0.9	4.4	0.4	14.0	0.9	0.3	0.1	0.7	<lod< td=""><td>0.1</td><td><lod< td=""><td>0.2</td><td>0.1</td><td><lod< td=""><td><lod< td=""><td>0.1</td><td>0.0</td></lod<></td></lod<></td></lod<></td></lod<>	0.1	<lod< td=""><td>0.2</td><td>0.1</td><td><lod< td=""><td><lod< td=""><td>0.1</td><td>0.0</td></lod<></td></lod<></td></lod<>	0.2	0.1	<lod< td=""><td><lod< td=""><td>0.1</td><td>0.0</td></lod<></td></lod<>	<lod< td=""><td>0.1</td><td>0.0</td></lod<>	0.1	0.0
b. ATHO-g																			
average (n=3)	67	95	91	499	59	553	56	122	14	63	15	2.5	14.2	16.7	10.2	10.4	3.8	7.2	2.2
2σ	1.8	8.0	7.0	35.6	2.1	26.0	4.2	8.4	0.6	9.8	2.3	0.2	1.3	1.8	0.7	1.3	0.2	1.0	0.2
b.StHs6/80-g																			
average (n=3)	31	480	11	115	6	297	12	25	3	12	<lod< td=""><td>0.9</td><td><lod< td=""><td>2.2</td><td>1.4</td><td><lod< td=""><td><lod< td=""><td>2.2</td><td>1.4</td></lod<></td></lod<></td></lod<></td></lod<>	0.9	<lod< td=""><td>2.2</td><td>1.4</td><td><lod< td=""><td><lod< td=""><td>2.2</td><td>1.4</td></lod<></td></lod<></td></lod<>	2.2	1.4	<lod< td=""><td><lod< td=""><td>2.2</td><td>1.4</td></lod<></td></lod<>	<lod< td=""><td>2.2</td><td>1.4</td></lod<>	2.2	1.4
2σ	2.5	20.3	0.7	7.7	0.3	10.4	1.1	1.2	0.1	1.3	<lod< td=""><td>0.0</td><td><lod< td=""><td>0.1</td><td>1.1</td><td><lod< td=""><td><lod< td=""><td>0.2</td><td>1.4</td></lod<></td></lod<></td></lod<></td></lod<>	0.0	<lod< td=""><td>0.1</td><td>1.1</td><td><lod< td=""><td><lod< td=""><td>0.2</td><td>1.4</td></lod<></td></lod<></td></lod<>	0.1	1.1	<lod< td=""><td><lod< td=""><td>0.2</td><td>1.4</td></lod<></td></lod<>	<lod< td=""><td>0.2</td><td>1.4</td></lod<>	0.2	1.4
c.ATHO-g																			
average (n=3)	67	96	90	495	60	555	55	123	14	62	15	2.5	14.5	16.4	10.1	10.2	3.8	7.1	2.3
2σ	7.7	6.5	5.9	39.0	5.3	29.7	2.4	7.8	0.9	2.9	1.9	0.2	0.5	0.9	0.6	0.7	0.3	0.3	0.1
c.StHs6/80-g																			
average (n=3)	30	471	11	112	7	294	11	25	3	13	3	0.9	3.1	2.2	1.3	1.3	<lod< td=""><td>2.2</td><td>0.9</td></lod<>	2.2	0.9
2σ	2.7	18.3	0.6	3.9	0.5	7.1	0.6	1.1	0.1	1.3	0.8	0.0	1.3	0.5	0.6	0.3	<lod< td=""><td>0.3</td><td>0.0</td></lod<>	0.3	0.0
d. ATHO-g																			
average (n=3)	68.1	99.3	93.8	507.3	61.3	575.2	57.0	125.4	14.7	62.9	14	2.8	14.4	16.4	10.5	10.6	3.9	7.6	2.3
2σ	3.0	2.0	3.0	20.5	1.6	6.4	1.3	2.5	0.5	1.2	2.1	0.1	0.3	0.6	0.6	0.5	0.1	0.3	0.1
d.StHs6/80-g																			
average (n=3)	31.8	485.0	11.0	115.5	6.6	301.0	11.9	25.6	3.0	12.8	<lod< td=""><td>0.9</td><td>2.8</td><td>2.1</td><td>1.2</td><td>1.2</td><td>0.5</td><td>2.2</td><td>1.0</td></lod<>	0.9	2.8	2.1	1.2	1.2	0.5	2.2	1.0
2σ	1.0	10.8	0.4	2.8	0.5	2.5	0.3	0.8	0.2	1.3	<lod< td=""><td>0.0</td><td>0.6</td><td>0.2</td><td>0.1</td><td>0.1</td><td>0.0</td><td>0.2</td><td>0.0</td></lod<>	0.0	0.6	0.2	0.1	0.1	0.0	0.2	0.0
Preferred valu	ies:																		
Atho-G	65	94	95	512	62	547	56	121	15	61	14	2.8	15.3	16.2	10.3	10.5	3.9	7.4	2.4
StHs6/80-G	31	482	11.4	118.0	6.9	298.0	12.0	26.1	3.2	13.0	2.8	1.0	2.6	2.2	1.2	1.1	0.4	2.3	1.0

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