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⁴⁰Ar-³⁹Ar step heating ages of North American tektites and of impact melt rock samples from the Chesapeake Bay impact structure

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Abstract

This study presents ⁴⁰Ar-³⁹Ar step heating ages of four North American tektites (three bediasites and one georgiaite) and two groundmass samples extracted at different depths from clast-rich impact melt rocks (CB-W61 and CB-W84) recovered by the USGS-ICDP Eyreville B drill-core about 9 km from the centre of the Chesapeake Bay impact structure. Radiometric age determination on both North American tektites and impact melt rocks from within Chesapeake Bay craters offers the first possibility to confirm the origin of these tektites. For this aim, argon data from 13 samples/aliquots of tektite rims, cores and bulk, and 4

samples/aliquots from two impact melt rocks were obtained over 15 to 26 step heating
 extractions. Age spectra of all tektite samples show plateaux comprising 62-98% of the ^{39}Ar
 release over consecutive intermediate and high temperature heating steps. Few low
 temperature extractions indicate excess ^{40}Ar . Inverse isochron $^{40}\text{Ar}/^{36}\text{Ar}$ intercepts of tektite
 samples are indistinguishable from air (295.5). However, impact melt rock spectra presented
 complex Ar-release affecting primarily the low temperature heating-steps. Inverse isochrones
 indicated excess argon from which the $^{40}\text{Ar}/^{36}\text{Ar}$ intercept was used to correct the age
 calculation. CB-W61 and CB-W61-2 $^{40}\text{Ar}/^{36}\text{Ar}$ intercepts are 354.5 ± 2.5 and 327.2 ± 6.3 ,
 respectively, and those for CB-W84 and CB-W84-2 are 332.0 ± 7.3 and 329.6 ± 5.6 ,
 respectively. The inverse isochron weighted mean age (according to currently suggested K-
 decay constant revisions by Schwarz et al., 2011 and Renne et al., 2011) for all four tektites is
 34.86 ± 0.25 Ma (MSWD=0.96, P=0.41; n=4) and for the two impact melt rocks is 37.16 ± 3.65
 Ma (MSWD=0.83, P=0.36). The combined tektite and impact melt rocks isochron mean age
 of 34.86 ± 0.23 (0.32) Ma (MSWD=0.87, P=0.43) is slightly – though not significantly - higher
 than the plateau mean age of 34.55 ± 0.27 (0.36) Ma (MSWD=0.66, P=0.62). Placing the age
 in the Global Stratotype Section and Point (GSSP) marine section exposed at Massignano,
 Italy, it falls below the Eocene/Oligocene (E/O) boundary overlapping with the 10.28 m Ir-
 anomaly. These results agree within errors with previously reported ages of 35.20 ± 0.54 Ma
 mainly those derived from K-Ar and Ar-Ar total fusion analysis. An age of 34.86 ± 0.32 Ma
 sets the Chesapeake Bay impact event close to the youngest of the three Ir anomalies at ~ 35.0
 Ma in the case the impactor was Ir-rich (e.g, a chondrite, primitive achondrite, stony-iron or
 iron meteorite). The concordance with the E/O boundary at ~ 33.9 Ma seems only marginally
 possible, and only if the Ir contribution from the ejecta were, potentially, due either to its
 small amount becoming diluted in the geologic record or the impactor being Ir poor, e.g., of
 differentiated achondritic composition. This study also brings to front the need to re-establish
 the stratigraphic and palaeo-magnetic correlations across the globe for the Ir-anomalies and

the magneto-stratigraphy during the mid- to late-Eocene and early-Oligocene, and the need to re-evaluate the markers for the Eocene-Oligocene boundary.

1. Introduction

Impact structures on Earth are important geologic markers, and their ejecta layers present isochronous strata, in some cases of global extent (Artemieva and Morgan, 2009). The Chicxulub impact event resulted in the global mass-extinction at the Cretaceous-Paleogene (K-Pg) boundary (Hildebrand et al. 1991; Pope et al. 1991). The associated Ir-anomaly and the shocked-quartz rich ejecta layer represent the strata boundary separating sediments of the Mesozoic and Cenozoic eras, strongly arguing that the impact event was instrumental for the environmental calamities terminating the Mesozoic era (e.g., Alvarez et al., 1980; Schulte et al., 2010). The impact flux onto Earth has not been steady over time; instead, it has been marked by episodes of relatively intense bombardment, e.g., part of the Ordovician period (Schmitz et al., 2001; Korochantseva et al., 2007) or part of the late Eocene epoch (Farley et al., 1998). During the late Eocene, at least 2 large and 2 smaller impact structures formed on Earth: Chesapeake Bay (85 km diameter in size; 35.3 ± 0.1 Ma old: Horton and Izett, 2005), Popigai (100 km; 35.7 ± 0.2 Ma: Bottomley et al., 1997; recalculated by Jourdan et al., 2009 to 36.42 ± 0.81 Ma), Mistastin (28 km; 36.4 ± 4 Ma: Mak et al., 1976), and Wanapitei (7.5 km; 37.8 ± 1.6 Ma: Winzer et al., 1976). Other impact structures are Logoisk (15 km diameter) in Belarus, and Beenchime-Salaaty (8 km) and Longancha (15 km) in Russia (Bodiselitsch et al., 2004).

During part of the late Eocene and coeval with the formation of two large impact structures (Popigai and Chesapeake Bay) and several small impact ones, a 2 My period with increased flux of extra-terrestrial ^3He -rich material is reported by Farley et al. (1998). This increase in extra-terrestrial ^3He -rich material was interpreted to result from either a comet (Farley et al., 1998) or an asteroid shower (Tagle and Claeys, 2004; Fritz et al., 2007; Boschi et al. 2017)

79 onto the Earth-Moon system. This intense shower of extra-terrestrial material onto Earth
80 predates the Eocene/Oligocene (E/O) boundary (33.9 ± 0.1 Ma; Cohen et al., 2013 and
81 references therein) by ~ 1.5 My.

82 The late Eocene, including the E/O boundary, is well established in the Global Stratotype
83 Section and Point (GSSP) marine section exposed at Massignano, Italy (Premoli-Silva and
84 Jenkins, 1993). Hilgen and Kuiper (2009) concluded that accurate and precise dating of the
85 E/O boundary is crucial to unravel the cause(s) underlying the major climatic transition
86 associated with it. From the bottom to the top of the GSSP section, three iridium anomalies
87 were reported at 5.61 m, 6.17 m and 10.28 m by Montanari et al. (1993) and Bodiselitsch et
88 al. (2004). Using astronomical calibration, Jovane et al. (2006) determined the age of the
89 oldest (5.61 m) and youngest (10.28 m) Ir-anomalies to ~ 35.427 Ma and ~ 34.829 Ma,
90 respectively, and the E/O boundary to 33.714 Ma. These absolute ages are shifted upwards by
91 0.186 My if the updated tuning and age of the E/O boundary (33.9 ± 0.1 Ma) recommended
92 by the International Commission of Stratigraphy are used (Cohen et al., 2013) is used. In an
93 attempt to reduce the difference between radio-isotopic and astrochronology ages, Sahy et al.
94 (2017) suggest a slightly older age for the E/O boundary of 34.09 ± 0.08 Ma, and interpolated
95 ages of 35.49 ± 0.05 and 35.0 ± 0.07 Ma for the Ir-anomalies at 5.61 and 10.28 m, respectively,
96 in the Massignano outcrop.

97 The two lowermost Ir anomalies (older; 5.61 m and 6.17 m) in the Massignano section are
98 interpreted to be ejecta from the Popigai and, probably, the Chesapeake Bay impact
99 structures, respectively (Bodiselitsch et al., 2004). So far, no impact structure has been
100 assigned to the ~ 0.6 Ma younger Ir-anomaly at 10.28 m.

101 In terms of paleo-magnetostratigraphy, there is much debate about correlations for the Ir-
102 anomalies and the magnetostratigraphy during the mid- to late-Eocene (Montanari et al.,
103 1993). According to these authors, the Ir-anomalies along the Massignano GSSP are located:
104 1) within Chron 16n2 and a minor one at Chron 16r1, and 2) two smaller Ir-anomalies within

Chron 13r in the Contessa section located 80 km from the Massignano GSSP. Bodiselitsch et al. (2004) considered the negative carbon and oxygen isotopic excursions associated with the Ir-anomalies as evidence for a short-lived warm episode during the continuous cooling occurring between mid-Eocene and Oligocene. This episode is coeval with the Ir-anomaly at 10.28 m in the Massignano quarry, potentially resulting from large amounts of methane being released during and after an impact event onto the continental shelf, e.g., the Chesapeake Bay impact appears as a plausible candidate.

2. The Chesapeake Bay impact structure: geology and age

An impact structure near the present mouth of Chesapeake Bay in eastern Virginia, U.S.A. (Fig. 1) is buried beneath sediments of the Atlantic Coastal Plain. The ~85 km diameter Chesapeake Bay crater displays the so-called “inverted sombrero” geometry. The crater structure has a central peak inside a ~40 km diameter deep inner basin, which is surrounded by a shallower brim (Poag et al., 2004; Collins and Wünnemann, 2005). The comparatively shallower outer section was suggested to have formed by resurge-related removal of unconsolidated marine sediments, which constitute the Exmore breccia filling the central crater (Poag et al., 2004). According to numerical models, these structural peculiarities of the Chesapeake Bay crater are consistent with the impact of a 3.2 km diameter projectile that formed a transient cavity of 28 km diameter and a corresponding final crater of ~40 km diameter (Collins and Wünnemann 2005). Notably, the projectile that formed Chesapeake Bay crater was 2.5 times smaller (~10 times less massive) than the ~8 km diameter projectile required to form the 100 km diameter Popigai impact structure. Compared to Popigai, the significantly smaller and less energetic Chesapeake Bay event likely did not develop a global ejecta layer (e.g., Glass 2002).

Outcrops of the Chesapeake Bay impact structure are limited and, therefore, sampling relies heavily on drill-cores (Horton et al., 2009a, 2009b). In 2005–2006, a project under the

auspices of the International Continental Scientific Drilling Program (ICDP) and the U.S. Geological Survey (USGS) acquired the ICDP-USGS Eyreville drill-core from the deepest part of the impact structure, about 9 km from its centre on the Delmarva Peninsula. Several other cores obtained earlier (e.g., the Langley drill-core, Fig. 1) did not sample impact melt rock. The ICDP-USGS Eyreville drill-core is composed of three segments, A, B and C (Gohn et al., 2009), amounting to a total core-length of 1766 m, providing a representative geologic section from the impact structure (Gohn et al., 2006, 2008, 2009). Section A comprises material obtained between 126.9 and 940.9 m, section B includes depths between 737.6 and 1766.3 m, and section C provides material from 0 to 140.2 m depth (Horton et al., 2009a). Sections A and B partly overlap between the depths of 618.2 and 1095.7 m, and section C completely overlaps with the top portion of section A (Horton et al., 2009a; Gohn et al., 2009).

2.1 Stratigraphy of the ICDP-USGS Eyreville drill-core

The stratigraphy obtained from the ICDP-USGS Eyreville drill-core is comprehensively described in Horton et al. (2009a) and Edwards et al. (2009a, 2009b). The drilling apparently did not reach the crater floor, as surmised from geophysical data (Catchings et al. 2008). A summary of bottom to top (i.e., older to younger) stratigraphy in the 1766-m-long section is reported below:

1) 1766.3 m – 1551.2: 215 m of basement-derived metamorphic and igneous rocks (mainly schist, pegmatite, coarse granite) along with local dikes and veins of polymict impact breccia that may exhibit shocked minerals (Horton et al., 2007, 2009b), occasionally showing planar fractures (PFs) and rarely planar deformation features (PDFs) in quartz (Horton et al., 2009b).

2) 1551.2 m- 1397.2 m: 154 m sequence of polymict impact breccias intermingled with suevites, i.e., impact melt-bearing breccia. This section of the ICDP-USGS Eyreville drill-core was the source of two well-indurated, clast-rich impact melt rocks for which we here

report the ^{40}Ar - ^{39}Ar data. These samples are designated M1 (CB-W84 hereafter; 1451.22-1450.22 m depth) and M2 (CB-W61 hereafter; 1407.49-1402.02 m depth) by Wittmann et al. (2009). The lower and thinner (1 m thick) impact melt rock CB-W84 is clast-rich and has a hypocrySTALLINE melt matrix (Wittmann et al. 2009). In places, the matrix shows alteration and contains remnants of unaltered glass and microphenocrysts. The upper and thicker (5 m thick) clast-rich impact melt rock CB-W61 has a holocrystalline melt matrix, which is altered in places (e.g., smectite) and contains microphenocrysts. Shocked quartz is ubiquitously distributed in the suevites and lithic impact breccias, with many grains showing two to three sets of decorated PDFs (Horton et al., 2009b). Ballen-quartz, a high-temperature annealing texture; Ferrière et al., 2009) is found as particles in impact melt-rich samples (Horton et al., 2007a, 2009b).

3) 1397.2 m – 1371.1 m: - A 26 m long section consists of quartz-sand with an amphibolite block and lithic boulders and overlies the suevite. The gravelly sand consists of very fine to very coarse quartz sand, minor silt and clay, granules of quartz and feldspar, and sparse quartz pebbles. Self-Trail et al. (2009) also reported early Cretaceous pollen and spores suggesting them to be sourced from the lowest part of the target sediment layer.

4) 1371.1 m – 1095.7 m: A 275-m-thick allochthonous granite slab devoid of any magmatic emplacement features. This slab consists of four intermingled granite types: gneissic biotite granite, fine-grained biotite granite (ubiquitous), medium- to coarse-grained biotite granite, and a 7 m thick basal zone of altered red biotite granite (e.g., Horton et al., 2009 and references therein). Horton et al. (2009b) reported ion-microprobe (SHRIMP) U-Pb zircon age of 615 ± 7 Ma for the gneissic biotite granite and an age of 254 ± 3 Ma for the medium- to coarse-grained biotite granite.

5) 1095.7 m - 443.9 m: A 652 m thick sequence of crater-fill sediments and sediment blocks interpreted as having been deposited by avalanche and ocean-resurge deposits (Gohn et al. 2009a; Reimold et al 2009).

6) 443.9 m – 0 m: A 444 m thick sequence of post-impact sediments (Gohn et al., 2008; Edwards et al. 2009a,b).

2.2 North American tektites

Bediasites, georgiites and a single tektite from Martha's Vineyard are considered to be melted ejecta from the Chesapeake Bay structure (Fleischer and Price, 1964; Fleischer et al., 1965; Storzer and Wagner, 1971, 1979; Garlick et al., 1971; Glass et al., 1973). Previous geochemical studies (e.g., Koeberl et al., 1996; Deutsch and Koeberl, 2006) attempted to identify the potential precursor rock(s) from which these tektites were produced providing a firm link to the Chesapeake impact structure.

2.3 Summary of reported ages

Evidence for a coeval origin of the Chesapeake Bay impact structure and the North American tektites is based on biochronology (planktonic, foraminifera, bolboformids and calcareous nanofossils; Poag and Comeau, 1995). Isotopic age determination of this impact structure relies on North American tektites only, specifically fission track dating (Fleischer and Price, 1964; Fleischer et al., 1965; Storzer and Wagner, 1971, 1979; Garlick et al., 1971; Glass et al., 1973), and $^{40}\text{K}/^{40}\text{Ar}$ and $^{40}\text{Ar}-^{39}\text{Ar}$ total fusion dating (Glass et al., 1986, 1995; Albin et al., 1996; Horton and Izett, 2005). A summary of literature ages is shown in Table A1 in the appendix. The various revisions of monitor ages used for $^{40}\text{Ar}-^{39}\text{Ar}$ dating (e.g., Renne et al., 1998; Jourdan and Renne, 2007; Schwarz and Trieloff, 2007), call for a consistent recalculation of the $^{40}\text{Ar}-^{39}\text{Ar}$ age data using the best available age monitor values. Table A1 lists the values for the monitor ages and the ^{40}K decay constants used originally and in the consistent recalculations reported here. For example, the current age of the Taylor Creek sanidine age monitor is 28.02 ± 0.28 Ma (Renne et al., 1998). For this monitor Horton and Izett (2005) used an older age of $t = 28.32 \pm 0.08$ Ma (based on MMhb-1 age of 520.4 ± 1.7

Ma; Samson and Alexander, 1987) and Glass et al. (1995) used a younger age of 27.82 Ma (Dalrymple and Duffield, 1988). In another study, Glass et al. (1986) used the Bern 4B biotite with an age of 17.33 ± 0.10 Ma, which has not been updated since, and also the Hb3gr-hornblende with an age of 1070 ± 2 Ma, with an updated age of 1073.6 ± 4.6 Ma (Schwarz and Tieloff, 2007).

Age data of North American tektites based on the ^{40}Ar - ^{39}Ar total fusion technique (Glass et al., 1986, 1995; Albin and Wampler, 1996; Horton and Izett, 2005) yields a recalculated mean age of 35.20 ± 0.54 Ma (Table A1). A short conference abstract by Obradovich et al. (1989) reported an age of 35.5 ± 0.3 Ma for North American tektites found in a drill-core obtained by ^{40}Ar - ^{39}Ar step heating data. Because there is no specification on the age monitor used in that study, the reported age cannot be corrected for the updated age of the monitor sample used; consequently this age is not included in our revision of CB impact age from the combined data set. Kunk et al. (2009) reported an age range of ~ 33 to ~ 47 Ma using ^{40}Ar - ^{39}Ar step heating on orthoclase, muscovite and microcline extracted from material from the central moat of Chesapeake Bay crater. These ages could not be corrected due to lack of information regarding the age-monitor used in the study. Moreover, Kunk et al. (2009) did not report the full dataset and respective plots, therefore full evaluation of step heating experiments is not possible, e.g., presence of excess argon.

3. Samples and Methods

This work presents - for the first time - a comprehensive ^{40}Ar - ^{39}Ar step heating data set for four North American tektites linked to the Chesapeake Bay impact structure, and glass portions extracted from the first two clast-rich impact melt rocks acquired within this impact structure. Contrary to total fusion gas extraction, the use of the step heating technique allows differential extraction of radiogenic, and atmospheric and/or inherited, and potentially other sources of argon (collectively denominated as excess) components within the specimen. In

turn, the step-heating approach is ideal to correct for this potential trapped/excess ^{40}Ar and reliably determine a geologically meaningful age.

The step-heating analyses on tektites were carried out on core and rim aliquots prepared prior to irradiation. Two bediasite samples (Be281-A and Be281-B) were cut into core and rim fractions and each crushed to ~1-2 mm diameter grains. Due to insufficient material to separate core and rim material, a third bediasite (Be283) and a georgiaite found by one of the co-authors (H. Povenmire) were analysed as bulk.

Two small slabs, one of the holocrystalline impact melt rock CB-W61 (2.1x0.7x0.4 cm, from 1404.96 m depth) and the other from the hypocrySTALLine impact melt rock CB-W84 (2.05x1.95x0.7 cm, from 1450.74 m depth) found in the ICDP-USGS Eyreville drill-core, and provided by A. Wittmann (now at Arizona State University, U.S.A.), were cut-off the faces where thin-section slices were taken and used by Wittmann et al. (2009) to conduct Scanning Electron Microscope (SEM) and identify the pristine glass. The impact melt groundmass samples extracted from these two these slabs were used for the step-heating ^{40}Ar - ^{39}Ar experiments described below.

Microscopically, CB-W84 exhibits some glassy, banded, isotropic and clear domains used for ^{40}Ar - ^{39}Ar step heating experiments reported below. These clear domains contain <100- μm -long, zoned orthopyroxene crystals of single-lath and dendritic morphologies, and euhedral, ~5- μm -wide spinel crystals. In ~1-mm-wide clear melt schlieren, brown, spherulitic, ~100- μm -wide aggregates of radially intergrown aluminosilicate microphenocrysts are present (Figs. 3A–3D in Wittmann et al., 2009). The dark, aphanitic melt schlieren contain euhedral, ~3- μm -diameter Fe-Ti-O crystals, a few fan-like plagioclase phenocrysts, and small, equant quartz clasts in a smectitic groundmass.

Impact melt CB-W61 must have cooled comparatively slower, and thus, is fully crystallized. The clasts present in CB-W61 appear more assimilated by the melt groundmass, but abundant small, lithic fragments remain. Al-rich orthopyroxene of acicular and skeletal

habits is partly corroded. The glassy portion of the melt used for the ^{40}Ar - ^{39}Ar step heating crystallized mainly into radial laths of plagioclase that are locally intergrown with SiO_2 , and sometimes overgrown by cordierite.

Backscattered electron (BSE) images and chemical composition for four tektites, shown in Figures. 2 and 3, respectively, were obtained at the Museum für Naturkunde Berlin using a JEOL Superprobe JXA-8500F with online data reduction. Chemical composition data were obtained using a cup current of 15-20 nA, an acceleration potential of 15 keV, and an electron beam diameter of 2 μm . Peak counting time was 30s for most elements, with the exception of Na, for which a counting time of 20s was used, to minimize loss during measurements and Mn with a counting time of 40s. The background was evaluated for 15s on either side of the peak.

Tektites and impact melts were analysed using the ^{40}Ar - ^{39}Ar step-heating technique at the Klaus-Tschira-Labor für Kosmochemie, Institut für Geowissenschaften, Universität Heidelberg. Samples were exposed to neutron irradiation at the Portuguese Research Reactor (RPI) located at the Nuclear and Technologic Institute (ITN), Sacavém, Portugal. Two irradiation series were performed in order to check results of the first irradiation series by repeated analyses and using slightly different irradiation conditions. The *first* irradiation series included two aliquots for each of the three bediasite samples, where “c” stands for core and “r” stands for rim: bediasite Be281-A core samples Be281-Ac, Be281-Ac2, rim samples Be281-Ar, Be281-Ar2; bediasite Be281-B core samples Be281-Bc, Be281-Bc2, and rim samples Be281-Br, Be281-Br2; two bulk samples of bediasite Be283, Be283-1, Be283-2; one bulk aliquot of one georgiaite (Ge-1); and two bulk Chesapeake Bay impact melt samples CB-W61, CB-W84. The *second* irradiation series included one piece of each of the two bulk impact melt samples (CB-W61-2, CB-W84-2), a second aliquot of the previously measured bulk georgiaite (Ge-2) and a third core sample of bediasite Be281-B (Be281-Bc3). Prior to each irradiation, impact melts, tektites and Bergell granodiorite biotite fluence monitors (HD-

B1; 24.18 ± 0.09 Ma; Schwarz and Trieloff, 2007) were wrapped in Al-foil and loaded into vacuum-sealed pure-silica vials. Cd-shielding was used to reduce isotopic interferences from thermal neutrons during irradiation at the RPI. Each sample was bracketed by two monitors in order to calculate J-values and neutron flux variation uncertainties (e.g. Schwarz and Trieloff, 2007). J-values per sample are given in the appendix Tables A4-A20; the errors of plateau, K-Ar and isochron ages (Table 1) include errors related to neutron flux uncertainty.

After irradiation, the samples were step heated in an inductively heated Mo-furnace up to 1750°C . For each individual sample argon was extracted over 15-26 steps (Tables A4-A20 and Table 1) by consecutively increasing the temperature by 20 to 150°C . The gas was cleaned by hot (400 - 600°C) and cold Zr-Al- and Ti-getters. Argon isotopes were measured using a modified VARIAN MAT CH5 mass spectrometer. All argon data were corrected for mass discrimination (checked daily via calibration with gas of air composition), radioactive decay, isotopic interferences and blanks from the extraction line and furnace. The ^{40}Ar blank varied between $1 \cdot 10^{-9} \text{ cm}^3$ at 800°C and $2 \cdot 10^{-8} \text{ cm}^3$ at 1400°C for the first series, and $1 \cdot 10^{-10} \text{ cm}^3$ at 800°C and $2 \cdot 10^{-9} \text{ cm}^3$ at 1400°C for the second irradiated series. Both blanks had no measurable ^{37}Ar and ^{39}Ar , and negligible mass spectrometer background. Blank series were usually measured in 5 consecutive temperature steps (i.e., from high to low temperature) prior to each sample insertion in the furnace to precisely correct the sample gas (see appendix Fig. A3). Applied blank values are an exponential fit by interpolating through these five temperature extractions. The argon isotopic composition of blank extractions was atmospheric within uncertainty.

Ages were calculated using K-Ar decay constants recommended by Steiger and Jäger (1977). Correction factors for interfering isotopes, based on data obtained from degassed CaF_2 and a quaternary sanidine from the Käsegrotte volcanics in the Eifel region of Germany, were: $(^{36}\text{Ar}/^{37}\text{Ar})_{\text{Ca}} = (2.67 \pm 0.27) \cdot 10^{-4}$; $(^{39}\text{Ar}/^{37}\text{Ar})_{\text{Ca}} = (6.66 \pm 0.67) \cdot 10^{-4}$; $(^{40}\text{Ar}/^{39}\text{Ar})_{\text{K}} = (4 \pm 0.4) \cdot 10^{-4}$; $(^{38}\text{Ar}/^{39}\text{Ar})_{\text{K}} = (1.21 \pm 0.01) \cdot 10^{-2}$ for the first irradiation series, and for the second irradiation

series: $(^{36}\text{Ar}/^{37}\text{Ar})_{\text{Ca}} = (2.65 \pm 0.08) \cdot 10^{-4}$; $(^{39}\text{Ar}/^{37}\text{Ar})_{\text{Ca}} = (6.72 \pm 0.34) \cdot 10^{-4}$; $(^{40}\text{Ar}/^{39}\text{Ar})_{\text{K}} = (1.23 \pm 0.24) \cdot 10^{-2}$; $(^{38}\text{Ar}/^{39}\text{Ar})_{\text{K}} = (2.24 \pm 0.16) \cdot 10^{-2}$. Using more recent suggestions for K-Ar decay constants, better enabling comparison with other age determination methods, calculated $^{40}\text{Ar}/^{39}\text{Ar}$ ages increase by about 1%, for Mesozoic ages (Villeneuve et al., 2000; Renne et al., 2010 and 2011; Schwarz et al., 2011). Plateau ages (Table 1) were obtained by taking the portion of an age spectrum composed of contiguous gas extractions representing $\geq 50\%$ of the total ^{39}Ar released (McDougall and Harrison, 1999). Plateau ages were calculated from these extractions as inverse variance weighted means with an additional weight for the ^{39}Ar release.

The reported mean age values (e.g., table 2) were calculated as inverse variance weighted means, MSWD and P values using ISOPLOT (Ludwig, 2012). Isochron regressions were also performed using ISOPLOT. All age uncertainties shown in figures and tables are at the 2σ level, unless stated otherwise. Uncertainties in brackets include the fluence monitor HD-B1 age uncertainty, $t = 24.18 \pm 0.09$ Ma (Schwarz and Trieloff, 2007).

Excess ^{40}Ar is a combination of atmospheric, inherited radiogenic ^{40}Ar , and any other parentless ^{40}Ar (^{40}Ar that exists in the sample but with no relation to the K content of the sample) released during erosion of the target rock, e.g. from the ~ 615 Ma gneissic biotite granite prior to the impact event, but stored in the target rock complex. Evaluating this excess ^{40}Ar was one of the main aims of the project and the reason for carrying out step-heating argon extraction from both tektites commonly assigned to the Chesapeake Bay crater and the recently found first set of impact melt rocks. The $^{40}\text{Ar}/^{36}\text{Ar}$ ratio value for the excess component was evaluated using the y-intercept in the inverse isochron. This $^{40}\text{Ar}/^{36}\text{Ar}$ ratio value was used to correct each set of heating steps obtained for each analysed impactite sample. During, and immediately after the impact event, the environment is turbulent, and the isotopic composition of the gas in the system is feasibly not homogeneous. Consequently, the $^{40}\text{Ar}/^{36}\text{Ar}$ ratio of the trapped component cannot be assumed the same for all the Chesapeake Bay impactites. Hence, individual values for the trapped ^{40}Ar data correction were obtained

for each sample using per-sample data regression. The y-intercept value is used to correct the age spectrum only if the trapped $^{40}\text{Ar}/^{36}\text{Ar}$ ratio is significantly different from atmospheric composition. If not, atmospheric composition is used. The age plateau should then correspond to the heating steps in the regression line from where the trapped values were derived.

4. Results

The BSE images of North American tektites and inclusions therein are shown in Fig. 2. Electron microprobe analyses (EMPA) for MgO, K₂O, CaO and Na₂O are displayed in Fig. 3 and all other main elements oxide weight percent are given in Appendix Tables A2 and A3. $^{40}\text{Ar}/^{39}\text{Ar}$ data for North American tektites and impact melt samples from the ICDP-USGS Eyreville drill-core section B are shown as $^{40}\text{Ar}/^{39}\text{Ar}$ apparent age and K/Ca (derived from $^{37}\text{Ar}_{\text{Ca}}/^{39}\text{Ar}_{\text{K}}$) spectra versus fractional ^{39}Ar release spectra and as inverse isochrons (i.e., $^{36}\text{Ar}/^{40}\text{Ar}$ vs. $^{39}\text{Ar}/^{40}\text{Ar}$) in Figs. 4-6. A summary of the results is given in Table 1, and the complete data set is presented in Appendix Tables A4-A20.

The plateau ages are based on consecutive intermediate and high temperature heating steps (53-99% ^{39}Ar release) dominated by radiogenic ^{40}Ar as confirmed from respective inverse isochron plots. As shown below and in Table 1 and 2, the apparent ages for plateaux and inverse isochrons are consistent, and the samples have not experienced obvious secondary ^{40}Ar loss. While the tektites are overall devoid of an excess ^{40}Ar component, as determined from $^{36}\text{Ar}/^{40}\text{Ar}$ vs. $^{39}\text{Ar}/^{40}\text{Ar}$ plots (Figs. 4-6), some extractions at low and high temperatures indicate excess argon, e.g., sample Be281-Br (Fig. 4D), and have corresponding higher K-Ar age of 36.65 Ma. Excess argon is a combination of inherited radiogenic ^{40}Ar with atmospheric, and any trapped non-quantifiable argon component that may have existed in the turbulent environment after the impact event, e.g. derived from the degassing and weathering of the targeted rocks. Such an excess argon component was clearly evident for the Ar isotopes extracted from the melt portion of the two impact melt rocks.

4.1. SEM inspection and EMP analyses of tektites

Inspection of tektite samples using BSE images and optical microscopy shows that these are composed of quenched glass but also include lithic clasts, microlites, devitrified melt spheres, and vesicles (Fig. 2). Furthermore, an inclusion within tektite Be281-A (Fig. 2c) shows an immiscibility texture between melts of different composition, appearing light and darker grey in the BSE images, with the brighter features representing cross-sections of 3D dendritic crystallites enriched in chlorine. This Cl may represent remnants of late-Eocene saline water, e.g., ocean water, as this crater formed in a marine environment.

Elemental composition analyses show variations between different tektites, potentially revealing moderate intra- and inter-tektite heterogeneities. The EMPA data (Fig. 3) shows that each tektite covers a limited range of chemical composition. Devitrified spherules of about 120 μm diameter found within bediasite Be281-B show a larger K_2O content than that of the glassy matrix of the tektite (star in Fig. 3a and b) at ~ 2.5 to ~ 3.2 wt%. Nevertheless, the K-rich spherules have a low ≤ 2 vol% modal abundance, and thus, a minor influence on the bulk K budget.

4.2 ^{40}Ar - ^{39}Ar step heating analyses of tektites

The argon isotopic composition of rim and core material was acquired over 15 to 26 heating steps from two bediasites (Be281-A and Be281-B), and bulk material from one bediasite (Be283), one georgiaite (Ge), and melt extracted from the groundmass of the two impact melt rocks CB-W61 and CB-W84, replicated (Figs. 4-6). Plateau and inverse isochron ages with respective Mean Square Weighted Deviation (MSWD) and Probability (P) values are shown in Table 1 and on the respective plots. Table 2 shows mean ages also in comparison with age values calculated with updated decay constants (Renne et al. 2010, 2011, Schwarz et al. 2011). The aim in studying bediasite rim and core samples separately is to

391 evaluate whether argon is heterogeneously distributed within tektites, including the presence
392 of either inherited excess ^{40}Ar , or secondary ^{40}Ar loss. Material permitting, 2-3 aliquots were
393 analysed to investigate the reproducibility of the results (Table 1).

394 In general, the argon age spectra of the tektites show well-defined age plateaux (we use
395 plateaux instead of plateaus to follow the correct French spelling of the word) encompassing
396 up to 99% of the fractional ^{39}Ar released. For all tektite aliquots analysed, the inverse
397 isochron plots indicate atmospheric $^{40}\text{Ar}/^{36}\text{Ar}$ ratios within uncertainties, i.e., no evidence of
398 excess ^{40}Ar . However, in a few cases, relatively high apparent ages were observed along the
399 initial 5-10% of the ^{39}Ar released, and also for high temperature extractions between 1500 and
400 1750°C. These steps had relatively large uncertainties due to large blank corrections,
401 indicating small amounts of excess argon. For example, these features occur in sample Be281-
402 Br (Fig. 4D), resulting in a higher total K-Ar age of 36.65 Ma, which is equivalent to a total
403 fusion age. Such extractions with high apparent ages in the initial Ar-extraction steps were
404 rejected from plateau age calculations (Table 1). In general, the ages calculated from inverse
405 isochrons agree within uncertainties with those obtained from plateaux (Table 1, Figs. 4-6),
406 thus all corrections applied and ages obtained are considered reliable. The MSWD values
407 generally lead to acceptable P values >5%, meaning that the selected step heating schedule for
408 age determination resulted in apparent ages and respective uncertainties that are representative
409 and with a meaningful statistical distribution. The displayed tektite spectra are corrected for
410 trapped argon of atmospheric composition, as inverse isochron plots did not yield values
411 significantly different from air (Table 1).

412 413 4.2.1 Bediasite Be281-A

414 Two aliquots of core and rim samples from bediasite Be281-A were analysed. Figs. 4A and
415 B (Appendix Figures A1-A and A1-B) show the spectra and isochron plots of core and rim
416 samples for this tektite (Table 1). The K/Ca spectra are flat and similar for the subsamples.

The ages calculated for each of the four plateaux comprise between 62 to 96% ^{39}Ar release from consecutive heating steps. These ages are indistinguishable within uncertainties, and vary from 34.23 ± 0.54 Ma (MSWD=1.49, $P=0.11$; rim aliquot Be281-Ar, Fig. 4B) to 33.28 ± 0.71 Ma (MSWD=0.35, $P=0.98$, rim aliquot Be281-Ar2, Fig. A1-B), while the isochron ages vary from 33.36 ± 0.80 Ma (MSWD=0.64, $P=0.87$; Fig. A1-B) and 34.49 ± 0.82 Ma (MSWD=1.01, $P=0.44$; Fig. 4B). The calculated weighted mean age based on all four aliquots for this tektite (Table 2 and Fig. 7) is 33.83 ± 0.66 Ma (MSWD=1.7, $P=0.16$) from plateaux, and 33.92 ± 0.84 Ma (MSWD=1.3, $P=0.27$) for isochrons.

4.2.2 *Bediasite Be281-B*

Similar to above, argon was extracted from three core and two rim aliquots of sample Be281-B (Figs. 4C and D, Appendix Figs. A1-C and A1-D; Table 1). The K/Ca spectra are essentially flat, with high uncertainties, potentially due to the low amount of nucleogenic ^{37}Ar , which was nearly decayed at the time of the measurements. Age plateaux comprised between ~79 and ~98% of the total ^{39}Ar release. The plateau ages determined for the five aliquots range from 34.72 ± 0.94 Ma (MSWD=0.65, $P=0.84$) for core aliquot Be281-Bc (Fig. A1-C) to 33.32 ± 0.90 Ma (MSWD=1.07, $P=0.38$) for the rim aliquot Be281-Br2 (Fig. A1-C), being all indistinguishable within uncertainties. The inverse isochron plots yield ages between 33.69 ± 0.82 Ma (MSWD=1.29, $P=0.21$; Fig. 4D) and 35.13 ± 0.88 Ma (MSWD=0.82, $P=0.67$; Fig. A1-C). The error weighted mean of plateaux ages determined for this tektite (Table 2 and Fig. 7) is 34.27 ± 0.49 Ma (MSWD=1.7, $P=0.14$) and 34.54 ± 0.28 Ma (MSWD=0.75, $P=0.56$) for the inverse isochrons.

4.2.3 *Bediasite Be283*

The ^{40}Ar - ^{39}Ar step heating data acquired for the two bulk Be283 tektite aliquots (Figure 4E, Fig. Appendix A1-E; Table 1) display flat K/Ca spectra and flat age spectra yielding

plateau ages of 34.45 ± 0.66 Ma (MWSD=0.56, P=0.87; Fig. 4E) and 34.70 ± 0.66 Ma (MSWD=1.61, P=0.08; Fig. A1-E) and for Be283-2 and Be283-1, respectively. Inverse isochron ages are 34.67 ± 0.66 Ma (MSWD=0.75, P=0.72; Fig. 4E) and 35.05 ± 0.66 Ma (MSWD=1.05, P=0.4; Fig. A1-E), respectively. The mean age calculated for the plateaux derived for the two aliquots of the Be283 tektite (Table 2 and Fig. 7) is 34.57 ± 0.75 Ma (MWSD=0.29, P=0.59), and for isochrons is 34.86 ± 0.76 (MSWD=0.66, P=0.42). These results agree within error with those obtained for tektites Be281-A and Be281-B.

4.2.4 Georgiaite

Two bulk georgiaite aliquots were analysed yielding plateau ages of 33.80 ± 0.83 Ma (MSWD=0.45, P=0.96; Fig. 5) calculated over 82% of ^{39}Ar released, and of 34.82 ± 0.85 Ma (MSWD=1.79, P=0.04; Fig. A2) calculated over 86% of ^{39}Ar released, with a mean age of 34.30 ± 1.03 Ma (Table 1). The inverse isochron ages are 33.99 ± 0.88 Ma (MSWD=0.84, P=0.68) and 34.89 ± 0.54 Ma (MSWD=1.10, P=0.34), respectively, and with a mean of 34.64 ± 0.84 Ma (MSWD=3.0, P=0.08; Fig. 7 and Table 2). These results agree within error with those obtained for tektites Be281-A, Be281-B and Be283 as reported above.

Overall, the ^{40}Ar - ^{39}Ar step-heating spectra of the North American tektites yielded well defined plateau and isochron ages, agreeing within their uncertainties (Fig. 7 and Table 2). For all tektites the mean plateau age is 34.22 ± 0.29 Ma (MSWD=0.78, P=0.51), and the mean isochron age is 34.53 ± 0.25 Ma (MSWD=0.96, P=0.41).

4.3 ICDP-USGS Eyreville drill-core Impact melts CB-W61 and CB-W84

The ^{40}Ar - ^{39}Ar data acquired for two splits of the holocrystalline groundmass from impact melt rock CB-W61 (Fig. 6A) and for two splits of hypocrySTALLINE ground mass extracted from impact melt rock CB-W84 (Fig. 6B) show complex release spectra. The amount of excess ^{40}Ar in each sample was evaluated individually and the data were corrected accordingly. The

469 $^{40}\text{Ar}/^{36}\text{Ar}$ intercept of CB-W61 is 354.2 ± 2.5 , while two distinct isochrones were identified for
470 CB-W61-2 with $^{40}\text{Ar}/^{36}\text{Ar}$ intercept of 363.8 ± 5.4 and 327.2 ± 6.3 . For CB-W84 the $^{40}\text{Ar}/^{36}\text{Ar}$
471 intercept is 332.0 ± 7.3 , and for CB-W84-2 an indistinguishable intercept of 329.6 ± 5.6 was
472 obtained. To better show the effect of this correction, both uncorrected (grey) and corrected
473 (black) spectra are shown in Figs 6A and 6B.

474 Splits CB-W61 and CB-W61-2 show a non-uniform K/Ca spectrum suggestive of the
475 existence of different argon carrier phases. The CB-W61-2 K/Ca ratio of the first heating
476 steps is higher than in CB-W61 suggesting an additional argon carrier phase in the latter. The
477 inverse isochron plots clearly show the presence of excess ^{40}Ar yielding $^{40}\text{Ar}/^{36}\text{Ar}$ values
478 distinct from air. This is not surprising considering the complexities in texture and clast
479 components of this impact melt rock as observed by Wittmann et al. (2009). For the first
480 $\sim 45\%$ of ^{39}Ar release, the uncorrected age spectrum of impact melts CB-W61 and CB-W61 -2
481 (grey spectra in Fig. 6A) are affected by significant release of excess ^{40}Ar causing high
482 apparent ages, but differently for each split. While in sample CB-W61 only one additional
483 excess argon carrier phase was identified, in sample CB-W61-2 at least two phases: one phase
484 released excess ^{40}Ar during the low temperature heating steps representing $\sim 47\%$ of the ^{39}Ar -
485 release, and producing a non-constant K/Ca increase. The other phase provided a different
486 excess ^{40}Ar component that was released along the intermediate and high-temperature steps
487 reflecting $\sim 53\%$ of the ^{39}Ar -release. This part of the spectrum shows lower apparent ages and
488 a nearly constant K/Ca ratio. When separating out low temperature steps from intermediate-
489 high temperature steps, two different slopes for the inverse isochrons are discriminated (Fig.
490 6A bottom row: isochron sample CB-W61-2, dark grey and black dashed-lines and symbols.
491 Hence, when calculating the age for sample CB-W61-2 two initial values for the $^{40}\text{Ar}/^{36}\text{Ar}$
492 ratio have to be considered to correct the excess argon component. This correction yields a
493 flat spectrum over 84% of ^{39}Ar released (see Fig 6A, sample CB-W61-2 dark grey and black
494 boxes for age spectrum, and respective initial $^{40}\text{Ar}/^{36}\text{Ar}$ values).

CB-W61 data comprise a linear correlation in $^{36}\text{Ar}/^{40}\text{Ar}$ vs. $^{39}\text{Ar}/^{40}\text{Ar}$ plot (Fig. 6A) yielding an initial $^{40}\text{Ar}/^{36}\text{Ar}$ ratio of 354.2 ± 2.5 , which is used to correct the corresponding age spectrum (black spectrum in Fig. 6A). Using the part of the spectrum with over 90% ^{39}Ar released, an age of 32.75 ± 2.20 Ma is calculated, with an isochron age of 31.70 ± 2.80 Ma (Fig. 6A; Table 1). For sample CB-W61-2 two inverse isochrons can be calculated, with initial values of 363.8 ± 5.4 for initial low-temperature steps 5-11, and a value of 327.3 ± 6.3 for the following intermediate and high temperature steps 12-21, leading to isochron ages of 31 ± 12 and 37.50 ± 2.60 Ma, respectively. Using these $^{40}\text{Ar}/^{36}\text{Ar}$ initial values to correct the respective step-heating data used for the apparent age spectrum, an age of 35.93 ± 5.31 Ma (MSWD=0.43, P=0.98) is obtained corresponding to 84% of ^{39}Ar released.

Similarly, correction of impact melt splits for sample CB-W84 age spectra (Fig. 6B, Table 1) for excess ^{40}Ar with $^{40}\text{Ar}/^{36}\text{Ar}$ initial ratios of 332.0 ± 7.3 (CB-W84) and 329.6 ± 5.6 (CB-W84-2), yielding within uncertainty indistinguishable plateau ages of 36.83 ± 2.40 Ma (MSWD=0.38, P=0.94) and 37.48 ± 2.60 Ma (MSWD=1.13, P=0.32) for the age spectra, with inverse isochron ages of 38.30 ± 2.50 Ma (MSWD=1.60, P=0.10) and 37.50 ± 2.10 Ma (MSWD=2.50, P= 1×10^{-4}).

All impact melt rock ages agree within uncertainties with a mean age of 35.43 ± 2.13 Ma (plateau; MSWD=3.5, P=0.06) and 36.82 ± 3.81 Ma (inverse isochron; MSWD=0.83, P=0.36), which is indistinguishable from the mean age for the North American tektites of 34.22 ± 0.29 Ma (MSWD=0.78, P=0.51) and 34.53 ± 0.25 (MSWD=0.96, 0.41) Ma for plateau and inverse isochrons, respectively (Table 1). When calculating mean ages, sample W84-2 was excluded due to its very low isochron P value. The age for the melt rocks slightly tends towards higher ages, this may be due to a small excess argon component not included in the isochron correction procedure, leading to slight older ages, which is not unusual for impact melts (e.g., Schwarz and Lippolt, 2014).

5. Discussion

In the present study ^{40}Ar - ^{39}Ar step heating data were acquired on core, rim and bulk aliquots of four North American tektites and two bulk impact melt fragments from the ICDP-USGS Eyreville drill-core. The corrected plateau ages are either unaffected by secondary ^{40}Ar loss or other disturbances providing an age of 34.22 ± 0.29 Ma (MSWD=0.78, $P=0.51$) and a corresponding error weighted mean inverse isochron age of 34.53 ± 0.25 Ma (MSWD=0.96, $P=0.41$) for the North American tektites (Table 2). The Chesapeake Bay impact melt samples have excess ^{40}Ar , and the approach mentioned above (section 4.3) allowed to correct most of the cases. A mean of plateau ages of 35.43 ± 2.13 Ma (MWSO= 3.5, $P=0.06$; Table 1) and an indistinguishable mean inverse isochron age of 36.82 ± 5.81 Ma (MSWD=0.83, $P=0.36$) were obtained from pristine impact melt groundmass extracted from impact melt rocks CB-W61 and CB-W84. These are the first radio-isotopic ages reported for impactites found within the Chesapeake Bay crater together with the first complete set of $^{40}\text{Ar}/^{39}\text{Ar}$ step-heating data obtained from North American tektites. Assuming North American tektites were generated by the impact that formed the Chesapeake Bay impact structure, an average age of 34.53 ± 0.23 Ma (MSWD=0.87, $P=0.43$) is calculated when combining the tektite and impact melt rock inverse isochron $^{40}\text{Ar}/^{39}\text{Ar}$ step heating data (Table 2). The statistical error of 0.23 Ma and the error in the age of HD-B1 monitor result in a combined error of ± 0.32 Ma (2σ). The impact age with full external error of decay constant uncertainties is 34.86 ± 0.32 Ma for the isochron mean age and 34.55 ± 0.40 Ma for the plateau mean age, and take into account recent decay constant revisions (Renne et al. 2010, 2011, Schwarz et al. 2011). Our preferred age for the Chesapeake Bay impact event is 34.86 ± 0.32 Ma and should be the one quoted when comparing with ^{40}Ar - ^{39}Ar data obtained using different age monitors. This younger age is an improvement for the age of 35.20 ± 0.54 Ma previously considered for the Chesapeake Bay crater (see literature data compilation in Table A1).

Although our new data and the compiled average of previous data – statistically biased by the Horton and Izett (2005) total fusion Ar-Ar data - are marginally consistent, the nominal age difference of <1 My may be caused by systematic uncertainties. One possibility could be the presence of excess argon, which is not possible to estimate when performing one-step maximum-temperature total fusion ^{40}Ar - ^{39}Ar measurements. While it appears that excess argon was of only minor importance in our samples, and we corrected for it in the impact melt rocks, excess argon can be present in much higher concentration in tektites, such as in indochinites and australites (e.g., Schwarz et al. 2016). It is possible that sometimes the excess argon components remain undetectable in internal isochron diagrams, especially at a level of ~1-2% of the radiogenic argon component, compared to the nominal age of the sample (Schwarz et al. 2014). Because the ^{40}Ar - ^{39}Ar total fusion technique does not allow the use of *internal* isochrons, it is more likely to fail in identifying the presence of excess argon.

For example, the total fusion data in Horton and Izett (2005) were obtained for 4 different North American tektites (3 bediasites and one georgiaite) with an age range from 34.82 ± 0.30 Ma to 35.48 ± 0.31 Ma for single total fusion measurements (see Appendix Table A1) with mean ages of 35.01 ± 0.05 and 35.39 ± 0.19 Ma (uncertainties at a 2σ level). These means are only consistent within three sigma uncertainty limits, showing the possibility of excess argon in some samples. This is in principle not unusual for impact melt rocks and tektites, where excess argon is effectively only noticeable in high-resolution step heating age spectra, e.g. for moldavites, Ries glasses or australasian tektites (Schwarz and Lippolt 2002, 2014, Di Vincenzo and Skala 2009, Schwarz et al. 2014, 2016).

A second explanation for the age discrepancy between the current new data and previous ^{40}Ar - ^{39}Ar total fusion data could be related to the different standards used to monitor the neutron fluence. While in the present study the HD-B1 standard was used, Horton and Izett (2005) used Taylor Creek sanidine (TCs) as fluence monitor. These authors already noted that a different value for TCs of 27.92 Ma, i.e., 28.32 Ma, would lead to an age reduction of 0.5

Ma, a value much closer to the result reported in the present study. Although this TCs age is considered to be obsolete, highlighting the need for standards to be frequently calibrated not directly against each other, but tied to another standard by a complex chain of cross calibrations. Hence, a direct comparison and improvement of the HD-B1 and TCs standard intercalibration is recommended.

Another theme worth discussion is the pronounced occurrence of excess argon in impact melts. Thickness and cooling rates by conductive heat transfer for the impact melts CB-W61 and CB-W84 were reported by Wittmann et al. (2009): impact melt rock CB-W84 is about 1 m thick and cooled in 7 weeks, and impact melt rock CB-W61 is about 5 m thick and cooled in 4 years. The different cooling time for each impact melt sections does not affect the amount of radiogenic ^{40}Ar produced. However, this time interval and a temperature of the host rock above closure temperature are probably sufficient for argon to diffuse out of target rock clasts (e.g., 615 $\pm$ 7 Ma old gneissic granite or 254 $\pm$ 3 Ma old massive biotite granite; Horton et al., 2009b) into the melt, where it remained as excess ^{40}Ar with no relation to the chemistry of the rock, or the age of the melt. This excess argon, if not properly accounted for and subtracted from the total ^{40}Ar measured, leads to erroneous older ages. Considering that the use of the ^{40}Ar - ^{39}Ar step-heating technique permits proper evaluation of different argon components in the sample, the present data set offers the best estimate for the age of the Chesapeake Bay impact event.

6. Conclusions

High resolution step heating ^{40}Ar - ^{39}Ar ages were obtained for different North American tektites and melt extracted from clast-rich impact melt rocks found within the ICDP-USGS Eyreville drill-core from the Chesapeake Bay impact structure. The results are in agreement with the interpretation that the Chesapeake Bay impact cratering event produced the North American tektites. The mean isochron age of 34.86 $\pm$ 0.25 (0.34) (2 σ) Ma (MSWD=0.96,

P=0.41) determined for the North American tektites and the total mean isochron age of 34.86±0.23 (0.32) (2σ) Ma (MSWD=0.87, P=0.43) age for the Chesapeake Bay impact event (including the age of the Chesapeake Bay impact melts; Table 2) are within uncertainties consistent with, but nominally slightly younger than the average of the recalculated literature ages of 35.20±0.54 Ma (2σ; Glass et al., 1986, 1995; Horton and Izett, 2005). Possible explanations include excess argon undetected by total fusion ⁴⁰Ar-³⁹Ar measurements, especially at low excess argon concentrations of only ~1-2% of the radiogenic argon component, and insufficient inter-calibration of the HD-B1 and TCs standards.

Including the most recently suggested revision of the ⁴⁰K-decay constants (Renne et al. 2010, 2011; Schwarz et al. 2011), and a recalculated age 24.40±0.18 Ma for the HD-B1 monitor used in this study, **the data reported here for NA tektites and impact melt found within the ICDP-USGS Eyreville drill-core suggest an age of 34.86±0.23 (0.32) (2σ) Ma for the Chesapeake Bay impact event.** Concerning worldwide events recorded by the Massignano stratigraphic section (Fig. 8), two different scenarios are possible:

1) If the impact bolide caused an Ir-anomaly (e.g., the impactor was composed of Ir rich material, such as chondrites, primitive achondrites, stone-iron or iron meteorites), the Chesapeake Bay impact / North American tektite event possibly corresponds to the uppermost iridium layer at 10.28 m in the GSSP section at Massignano, Italy (Montanari et al., 1993; Bodiselitsch et al., 2004). As indicated by astronomical calibration (Jovane et al., 2006), the youngest of the three reported Ir-anomalies in the Massignano section precedes the E/O boundary by 1.12 My, which translates into an absolute age of 35.02±0.10 Ma, if the currently accepted ICS value of the E/O boundary of 33.9±0.1 Ma (Cohen et al. 2013) is applied. On the other hand, following the more recent estimate for the E/O boundary age of 34.09 ± 0.08 (2σ) Ma by Sahy et al. (2017), the age of this Ir-anomaly would be 35.21±0.10 Ma. This value is still consistent with the 34.86±0.32 (2σ) Ma weighted mean of age for the Chesapeake Bay

impact event (Fig. 8). For the older iridium layer at Massignano (e.g., the 35.61 Ma old layer at 5.61 m) the Chesapeake Bay impact event still appears too young.

2) If the Chesapeake Bay impact bolide did not cause an Ir-anomaly, e.g., the ejecta being strongly diluted in the sediments, or the projectile being an Ir-poor differentiated achondrite, this cratering event could be closer to, though only marginally coeval with, the E/O boundary at 34.09 ± 0.08 Ma (Sahy et al., 2017), Fig. 8, corresponding to the ~ 19.22 m level of the GSSP section at Massignano, Italy.

This study has demonstrated that ^{40}Ar - ^{39}Ar step heating is an indispensable analytical approach to date complex impactites produced from large meteorite impacts and the dynamic environment that results from such events where these impactites formed. Additionally, it is also important to perform complementary careful inspection of the samples using the SEM and EMPA techniques to evaluate potential contaminants, and sources of excess ^{40}Ar , within both tektites and impact melt rocks. The age of 34.86 ± 0.32 (2σ) Ma is suggested here as that of the event that formed the Chesapeake Bay crater, and it calls for re-establishing the stratigraphic and palaeo-magnetic correlations across the globe during the late-Eocene and early-Oligocene. Although it is probable that the Chesapeake Bay impact event affected life and environmental conditions in its vicinity, it may, however, not have been the inducer of the ice-house climatic change which was already taking place.

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Figure captions

Figure 1 Modified map after Gohn et al. (2006) and Horton et al. (2009a) showing the location of the International Continental Scientific Drilling Program (ICDP)–U.S. Geological Survey (USGS) Eyreville drill site in the Chesapeake Bay impact structure, 9 km from the centre of the impact structure.

Figure 2 Back-scattered electron (BSE) images of Chesapeake Bay related tektite BE281A: a) spherule embedded in the bediasite showing partly crystalline glassy inclusions (microlites) with dendritic texture; b) close-up of the partly crystalline glassy inclusion showing devitrification; c) oblong melt particle with cross-sections of 3D dendritic Cl-rich crystallites in a different area of the bediasite; d) vesicles of different sizes in the georgiaite tektite used in this study.

Figure 3 Electron microprobe analyses obtained for three bediasites and for inclusions found within these tektites: a) K₂O vs. MgO and b) CaO vs. Na₂O. Data in wt%.

Figure 4A ⁴⁰Ar-³⁹Ar results obtained for a **core** aliquot of bediasite Be281-A (Be281-Ac); shown are age and K/Ca spectra (left graphs), and inverse isochron diagrams (right graph). Error boxes correspond to 1σ uncertainty, errors of age and ⁴⁰Ar/³⁶Ar initial values are 2σ.

Figure 4B ⁴⁰Ar-³⁹Ar results obtained for a **rim** aliquot of bediasite Be281-A (Be281-Ar); shown are age and K/Ca spectra (left graphs), and inverse isochron diagrams (right graph). Error boxes correspond to 1σ uncertainty, errors of age and ⁴⁰Ar/³⁶Ar initial values are 2σ.

Figure 4C ^{40}Ar - ^{39}Ar results obtained for a **core** aliquot of bediasite Be281-B (Be281-Bc); shown are age and K/Ca spectra (left graphs), and inverse isochron diagrams (right graph). Error boxes correspond to 1σ uncertainty, errors of age and $^{40}\text{Ar}/^{36}\text{Ar}$ initial values are 2σ .

Figure 4D ^{40}Ar - ^{39}Ar results obtained for a **rim** aliquot of bediasite Be281-B (Be281-Br2); shown are age and K/Ca spectra (left graphs), and inverse isochron diagrams (right graph). Grey symbols are excluded from isochron calculation. Error boxes correspond to 1σ uncertainty, errors of age and $^{40}\text{Ar}/^{36}\text{Ar}$ initial values are 2σ .

Figure 4E ^{40}Ar - ^{39}Ar results obtained for a **bulk** aliquot of bediasite Be283 (Be283-2); shown are age and K/Ca spectra (left graphs), and inverse isochron diagrams (right graph). Error boxes correspond to 1σ uncertainty, errors of age and $^{40}\text{Ar}/^{36}\text{Ar}$ initial values are 2σ .

Figure 5 ^{40}Ar - ^{39}Ar results obtained for **bulk** aliquot of georgiaite tektite (Ge-1 and Ge-2); shown are age and K/Ca spectra (left graphs), and inverse isochron diagrams (right graphs). Error boxes correspond to 1σ uncertainty, errors of age and $^{40}\text{Ar}/^{36}\text{Ar}$ initial values are 2σ .

Figure 6A ^{40}Ar - ^{39}Ar results for both aliquots of **bulk** impact melt rock samples CB-W61 (CB-W61 and CB-W61-2) obtained from the USGS-ICDP Eyreville drill-core. Presented are age and K/Ca spectra (top graphs), and inverse isochron diagrams (bottom graphs). The grey spectra correspond to an initial $^{40}\text{Ar}/^{36}\text{Ar}$ value of 295.5 ± 0.5 (Steiger and Jäger, 1977) and the dark grey/black spectrum corresponds to apparent ages corrected for trapped $^{40}\text{Ar}/^{36}\text{Ar} = 354.2\pm2.5$ (CB-W61) and $363.8\pm5.4/327.3\pm6.3$ (CB-W61-2) values obtained from the y-axis intercept of the inverse isochron graph. Light grey symbols are excluded from isochron calculation. Error boxes correspond to 1σ uncertainty, errors of age and $^{40}\text{Ar}/^{36}\text{Ar}$ initial values are 2σ .

925

926 **Figure 6B** ^{40}Ar - ^{39}Ar results for both aliquots of **bulk** impact melt rock samples CB-W84
927 (CB-W84 and CB-W84-2) obtained from the USGS-ICDP Eyreville drill-core. Presented are
928 age and K/Ca spectra (top graphs), and inverse isochron diagrams (bottom graphs). The grey
929 spectrum corresponds to an initial $^{40}\text{Ar}/^{36}\text{Ar}$ value of 295.5 ± 0.5 (Steiger and Jäger, 1977) and
930 the black spectrum corresponds to apparent ages corrected for trapped $^{40}\text{Ar}/^{36}\text{Ar} = 332.0 \pm 7.3$
931 (CB-W84) and 329.6 ± 5.6 (CB-W84-2). Light grey symbols are excluded from isochron
932 calculation. Error boxes correspond to 1σ uncertainty, errors of age and $^{40}\text{Ar}/^{36}\text{Ar}$ initial
933 values are 2σ .

934

935 **Figure 7** Summary of ^{40}Ar - ^{39}Ar results. Left: summary of ^{40}Ar - ^{39}Ar plateau ages; right:
936 summary of ^{40}Ar - ^{39}Ar inverse isochron ages. Open symbols represent single measurements;
937 filled symbols are mean values for aliquots of NA tektites/Chesapeake Bay melt samples;
938 dashed lines represent error weighted mean and its assigned uncertainty of all samples. All
939 uncertainties represent 2σ uncertainty limits

940

941 **Figure 8** Comparison of Chesapeake Bay impact structure impactatite ages obtained in this
942 study (tektites = 34.86 ± 0.34 Ma, impact melts = 37.16 ± 3.85 Ma, and tektites&melts =
943 34.86 ± 0.32 Ma) with a) Eocene/Oligocene boundary age: 33.9 ± 0.1 Ma (Cohen et al., 2013)
944 and the 34.09 ± 0.08 Ma (Sahy et al., 2017), and b) the ages from the younger at (10.28 m) and
945 older (5.61 m) iridium layers found in the GSSP section at Massignano, Italy (Montanari et
946 al., 1993; Bodiselitsch et al., 2004).

Table 1 Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ step heating data obtained for bediasites Be281-A, Be281-B, Be283, georgiites, and melt groundmass extracted from clast-rich impact melt rocks, CB-W61 and CB-W84, found in the ICDP-USGS Eyreville drill core. Errors shown at 2σ level of uncertainty. Errors for plateau, K-Ar and isochron ages include neutron flux uncertainty. Ages calculated with Steiger and Jäger (1977) values for the ^{40}K decay constants. Age averages at the bottom of the table are error weighted means. * denotes samples from the second irradiation series.

Sample	Weight [mg]	Temp range for plat. [°C]	% ³⁹ Ar rel.	Plateau age [Ma]	MS WD	P	inverse isochron age [Ma]	MSW D	P	Total K-Ar age [Ma]	$^{40}\text{Ar}/^{36}\text{Ar}$ intercept
Be281-Ac	214.9	900-1700	96	33.81±0.91	1.46	0.10	33.98±0.88	0.81	0.68	33.73±0.91	297±13
Be281-Ac2	76.00	800-1400	85	33.35±1.33	1.22	0.27	33.88±0.92	1.17	0.29	32.55±1.25	293.9±1.6
Be281-Ar	229.2	960-1700	94	34.23±0.54	1.49	0.11	34.49±0.82	1.01	0.44	34.08±0.45	300.9±2.8
Be281-Ar2	124.3	1000-1500	62	33.28±0.71	0.35	0.98	33.36±0.80	0.64	0.87	33.06±1.11	299.8±3.2
Be281-Bc	218.1	900-1700	94	34.72±0.94	0.65	0.84	35.13±0.88	0.82	0.67	34.55±0.93	295.7±2.7
Be281-Bc2	127.6	1050-1420	79	34.49±0.91	1.57	0.09	34.75±0.88	0.90	0.58	34.69±0.98	304.3±4.0
Be281-Bc3*	109.2	960-1750	98	34.57±0.63	1.00	0.46	34.78±0.49	1.17	0.26	34.69±0.63	296±10
Be281-Br	163.5	960-1600	84	33.94±0.95	0.99	0.45	34.19±0.84	1.07	0.38	36.65±1.55	301.9±4.5
Be281-Br2	138.2	900-1700	94	33.32±0.90	1.07	0.38	33.69±0.82	1.29	0.21	33.28±0.86	296.2±3.4
Be283-1	95.10	800-1700	99	34.70±0.66	1.61	0.08	35.05±0.66	1.05	0.40	34.59±0.47	299.8±4.0
Be283-2	139.4	960-1700	91	34.45±0.66	0.56	0.87	34.67±0.66	0.75	0.72	34.38±0.57	296.3±2.6
GE-1	48.90	800-1360	86	34.82±0.85	1.79	0.04	34.89±0.54	1.10	0.34	33.45±2.15	294.8±1.3
GE-2*	109.7	1000-1620	82	33.80± 0.83	0.45	0.96	33.99±0.88	0.84	0.68	33.93±0.78	304.0±5.4
CB-W61	335.2	740-1400	90	32.75±2.20	1.32	0.17	31.70±2.80	1.45	0.09	29.75±7.05	354.2±2.5
CB-W61-2*	100.9	830-1040	84	35.93±5.31	0.43	0.98	31.00±12.00	-	-	-	363.8±5.4
		1070-1400					37.50±2.60	1.70	0.10		327.3±6.3
CB-W84	137.6	650-1150	83	36.83±2.40	0.38	0.94	38.30±2.50	1.60	0.10	37.45±2.00	332.0±7.3
CB-W84-2*	93.6	600-1350	96	37.48±2.60	1.13	0.32	37.50±2.10	2.50	1·10 ⁻⁴	35.11±4.82	329.6±5.6

Table 2 Mean ages for $^{40}\text{Ar}/^{39}\text{Ar}$ dating results of bediasites Be281-A, Be281-B, Be283, georgiaite, and impact melt rock groundmass samples CB-W61 and CB-W84. Mean ages are error weighted means with 2σ level of uncertainty. Results shown for Steiger and Jäger (1977) and Renne et al. (2011) values of the ^{40}K decay constants. Age error in brackets includes additional error from the age monitor.

Sample	No. of samples	Mean plateau age [Ma]	MSWD	P	inverse isochron age [Ma]	MSWD	P		
		Steiger & Jäger (1977) convention	Renne et al. (2011)		Steiger & Jäger (1977) convention	Renne et al. (2011)			
Be281-A	4	33.83±0.66 (0.70)	1.7	0.16	33.92±0.84 (0.86)	1.3	0.27		
Be281-B	5	34.27±0.49 (0.56)	1.7	0.14	34.54±0.28 (0.37)	0.75	0.56		
Be283	2	34.57±0.75 (0.78)	0.29	0.59	34.86±0.78 (0.81)	0.66	0.42		
GE	2	34.30±1.03 (1.03)	2.9	0.09	34.64±0.84 (0.86)	3.0	0.08		
<i>Tektite mean</i>	4	34.22±0.29 (0.38)	34.54±0.29 (0.38)	0.78	0.51	34.53±0.25 (0.34)	34.86±0.25 (0.34)	0.96	0.41
CB-W61	2	33.20±3.02 (3.02)	1.2	0.27	34.81±5.81 (5.81)	9.2	0.002		
CB-W84	1	37.48±2.60 (2.60)			38.30±5.00 (5.00)	1.60	0.10		
<i>Melt rock mean</i>	2	35.43±2.13 (2.13)	34.76±2.15 (2.15)	3.5	0.06	36.82±3.81 (3.81)	37.16±3.85 (3.85)	0.83	0.36
Total mean	5	34.23±0.27 (0.36)	34.55±0.27 (0.36)	0.66	0.62	34.53±0.23 (0.32)	34.86±0.23 (0.32)	0.87	0.43

Figure 1

Figure 2

Figure 3

Figure 4A

Figure 4B

Figure 4C

Figure 4D

Figure 4E

Figure 5

Figure 6A

Figure 6B

Figure 7

Figure 8

Table A1 Summary of literature age data for NA Tektites and the Chesapeake Bay impact structure obtained using different analytical techniques: biostratigraphy, fission-track, $^{40}\text{Ar}/^{39}\text{Ar}$ total fusion and step heating, K/Ar and U/Pb. Where possible, sample ages have been corrected using the Steiger and Jäger (1977) decay constants and consistent monitor ages (Schwarz and Trieloff, 2007).

Author	Age [Ma]	Method	Age monitor	Sample	Corrected age [Ma]	Comments
Poag et al. (2004)	35.2 - 36.0	Biostratigraphy	-	-	-	-
Fleischer and Price (1964)	34.5±1.5	Fission-track	-	3 bediasites	-	-
Fleischer et al. (1965)	33.7±2.2 33.9±1.7	Fission-track	-	Martha's Vineyard Georgiaite	-	Fission decay constant: $6.85 \times 10^{-17}/\text{a}$.
Storzer and Wagner (1971)	35.4±5.1 36.4±1.5	Fission-track	-	10 bediasites 1 Martha's Vineyard	-	-
Storzer and Wagner (1979)	34.6±0.7	Fission-track	-	?	-	-
Garlick et al. (1971)	35.9±2.4 35.6 ± 2.8 34.4 ± 2.8	Fission-track	-	Cuban tektite	-	-
Glass et al. (1973)	34.6 ± 4.2	Fission-track	-	Core RC9-58 microtektites	-	-
Obradovich et al. (1989)	35.5±0.3	Ar-Ar Step-heating	?	Tektites in DSDP 612		An abstract with no plots shown or age monitor reported, thus, no age correction possible
Glass et al. (1986)	34.85±1.16	Ar-Ar Total fusion	Bern-4B	BG-5	-	Tektite fragments + microtektites from Barbados.
	35.78±1.86		Bern-4B	BG-6	-	Steiger and Jäger, 1977;
	35.38±0.44		Bern-4B	BG-7	-	Bern-4B – 17.33±0.10 Ma and Hb3gr - 1070±2 Ma.
	35.22±0.44		Bern-4B	BG-8	-	Corrected for monitor age (Schwarz and Trieloff, 2007; Jourdan and Renne, 2007).
	35.20±0.60		Bern-4B	BG-9	-	27.92±0.08 Ma Taylor Creek Rhyolite sanidine relative to an age of 513.9 Ma for MMhb-1.
	35.32±0.26 35.89±0.40		Hb3gr Hb3gr	Tek2-B-1 Tek2-B-2	35.44±0.31 36.01±0.44	28.32±0.08 Ma Taylor Creek Rhyolite sanidine relative to an age of 520.4 Ma for MMhb-1.
Glass et al. (1995)	34.52±0.1 35.01±0.1	Ar-Ar Total fusion	TC-s	MNGaTek	35.01±0.1	
Horton and Izett (2005)	34.53±0.22	Ar-Ar Total fusion	Taylor Creek sanidine	Georgia	34.97±0.30	The mean age of 34.69±0.36 Ma using a TC-s age of 27.92±0.08 Ma based on a 513.9 Ma age for MMhb-1 (Duffield and Dalrymple, 1990; Lanphere and Dalrymple, 2000).
	34.51±0.22			Georgia	34.95±0.30	
	34.67±0.21			Georgia	35.11±0.29	
	34.39±0.23			Georgia	34.82±0.30	
	34.5±0.22			Georgia	34.94±0.30	The mean age of 35.13±0.36 Ma using a TC-s age of 28.32±0.08 Ma based on a 520.4±1.7 Ma age for MMhb-1 (Samson and Alexander, 1987; Horton and Izett, 2005).
	34.46±0.26			Texas	34.90±0.33	
	34.56±0.24			Texas	35.00±0.31	
	34.6±0.21			Texas	35.04±0.31	
	34.79±0.24			Texas	35.23±0.31	If, a TC-s age of 28.34±0.28 Ma (Renne et al., 1998) a mean age of 35.15±0.36 Ma is calculated.
	34.63±0.23			Texas	35.07±0.30	
	34.72±0.22			Texas	35.16±0.30	
	34.83±0.21			Texas	35.27±0.29	
	34.71±0.21			Texas	35.15±0.29	Reported in a GSA abstract, no plot(s) or data shown
	34.71±0.21			Texas	35.15±0.29	
	35.04±0.24			Texas	35.48±0.31	
	34.93±0.22			Texas	35.37±0.31	
Kunk et al. (2009)	34.88±0.24	Ar-Ar Step-heating	?	Orthoclase Muscovite	35.32±0.31	K-decay Aldrich and Wetherhill (1958) $\lambda_K=0.585 \times 10^{-10}/\text{a}$; $\lambda_{Ca}=5.30 \times 10^{-10}/\text{a}$; $\lambda_{tot}=5.885 \times 10^{-10}/\text{a}$.
	34.9±0.21 34.76±0.22				35.34±0.29 35.20±0.30	
Reynolds (1960)	~ 33.0 ~ 47.0	K-Ar	-	Bediasite Empirite	29.01±0.9 32.02±1.0	Corrected for Steiger and Jäger (1977) K decay constants.
	29.0±0.9 32.0±1.0					
Zähringer and Gentner (1963)	34.0	K-Ar	-	Georgia	34.02±1.0	Corrected for Steiger and Jäger (1977) K decay constants.
	34.2			Texas	34.22±1.0	
	33.7			M. Vineyard	33.72±1.0	
Albin and Wampler (1996)	35.2±0.3	K-Ar	-	Georgiaite	-	-
	33.5±0.7			Twiggs Clay glauconite	-	
Kamo et al. (2002)	~ 35	U-Pb (zircon)	-	Bath Cliff Site 904	-	Barbados microtektites lower intercept at 35.4 Ma and an upper intercept at 400 Ma (this older age is thought to be the time of a meta-event that affected the basement rock of about 1021 Ma; similar lower intercept for micro tektite from sites 904 and 903.

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Table A2 Chemical composition for a profile along a bediasite obtained by electron microprobe (in wt%).

Point	SiO₂	Al₂O₃	P₂O₅	TiO₂	FeO	MnO	MgO	CaO	Na₂O	K₂O	Total
1	77.8	13.3	--	0.73	3.69	--	0.48	0.46	1.15	1.89	99.49
2	77.6	13.3	0.01	0.72	3.46	--	0.49	0.44	1.14	1.88	99.05
3	79.4	12.56	0.01	0.72	3.40	0.03	0.47	0.40	1.15	1.86	100.00
4	76.5	14.5	0.01	0.82	3.91	0.01	0.51	0.46	1.21	1.83	99.79
5	78.0	13.6	--	0.78	3.68	0.05	0.48	0.43	1.20	1.90	100.11
6	79.0	13.0	--	0.77	3.41	0.05	0.52	0.44	1.14	1.92	100.29
7	79.1	13.0	--	0.74	3.67	0.01	0.50	0.42	1.23	1.95	100.61
8	79.5	12.6	0.06	0.76	3.44	0.01	0.51	0.44	1.15	2.00	100.43
9	79.1	12.7	--	0.71	3.46	0.02	0.51	0.45	1.17	1.98	100.18
10	80.2	12.2	0.01	0.66	3.12	0.01	0.44	0.40	1.18	2.02	100.24
11	79.6	12.7	0.01	0.71	3.45	0.01	0.49	0.40	1.20	2.01	100.58
12	79.2	12.5	0.00	0.73	3.33	0.02	0.47	0.39	1.14	2.00	99.80
13	79.2	12.7	0.01	0.73	3.24	0.03	0.46	0.44	1.18	1.98	100.00
14	79.2	12.6	--	0.71	3.41	0.10	0.47	0.40	1.19	1.98	100.01
15	79.7	12.3	0.01	0.69	3.22	0.02	0.47	0.39	1.16	2.00	100.04
16	80.1	11.8	--	0.66	2.99	0.04	0.44	0.38	1.18	1.94	99.50
17	80.1	11.9	0.01	0.67	3.09	0.05	0.45	0.42	1.13	1.96	99.78
18	80.0	12.1	0.02	0.67	3.15	0.02	0.47	0.41	1.20	1.98	99.87
19	79.5	12.2	--	0.71	3.27	0.05	0.47	0.40	1.18	1.96	99.69
20	79.8	12.3	--	0.68	3.37	0.04	0.47	0.43	1.20	2.02	99.84
21	79.3	12.2	0.02	0.69	3.19	--	0.48	0.43	1.12	2.01	99.43
22	79.4	12.3	0.05	0.70	3.31	0.03	0.49	0.46	1.17	2.00	99.94
23	79.5	12.3	0.03	0.68	3.19	--	0.48	0.44	1.20	2.02	99.78
24	78.9	12.5	--	0.72	3.29	0.02	0.49	0.42	1.18	2.06	99.52
25	78.3	13.0	0.01	0.70	3.44	--	0.52	0.47	1.16	1.99	99.57
26	79.0	12.5	0.01	0.74	3.18	--	0.47	0.42	1.15	2.01	99.46
27	78.2	12.7	0.01	0.77	3.55	0.04	0.49	0.42	1.19	1.97	99.36
28	77.9	13.1	0.01	0.77	3.46	0.08	0.50	0.47	1.23	1.97	99.50
29	77.7	13.2	0.02	0.76	3.43	0.01	0.49	0.43	1.21	1.93	99.19
30	78.3	12.7	0.04	0.74	3.40	--	0.46	0.44	1.12	1.98	99.21
31	77.9	12.9	0.02	0.76	3.48	--	0.49	0.43	1.18	1.99	99.06
32	77.5	13.5	0.02	0.77	3.57	0.06	0.51	0.45	1.20	1.84	99.34
33	76.7	13.8	--	0.77	3.65	0.03	0.51	0.47	1.24	1.88	99.07
34	76.3	14.1	--	0.77	3.79	0.07	0.53	0.46	1.25	1.90	99.14
35	78.0	13.1	0.01	0.73	3.51	0.02	0.47	0.42	1.16	1.91	99.32
36	78.7	12.5	0.02	0.68	3.33	--	0.43	0.41	1.13	1.89	99.07
37	78.9	12.6	--	0.71	3.25	0.06	0.47	0.41	1.16	1.90	99.45
38	77.9	13.1	0.02	0.76	3.51	0.03	0.48	0.47	1.10	1.90	99.29
39	78.5	12.8	0.02	0.73	3.36	0.06	0.46	0.39	1.14	1.81	99.27
40	79.6	12.0	--	0.68	3.14	--	0.42	0.39	1.15	1.89	99.24
41	79.6	12.1	--	0.69	3.09	0.06	0.42	0.39	1.09	1.89	99.33
42	78.5	12.7	0.02	0.76	3.32	0.03	0.47	0.42	1.14	1.90	99.25
Average	78.7	12.7	0.01	0.72	3.39	0.03	0.48	0.43	1.17	1.94	99.64
1σ	1.0	0.6	0.01	0.04	0.20	0.03	0.03	0.03	0.04	0.06	0.43

Table A3 Chemical composition for a profile along a georgiaite obtained by electron microprobe (in wt%).

Point	SiO ₂	Al ₂ O ₃	P ₂ O ₅	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Total
1	79.7	12.1	0.06	0.60	3.36	0.14	0.73	0.52	1.00	2.31	100.47
2	80.1	11.9	0.05	0.50	3.20	0.16	0.67	0.50	1.06	2.30	100.45
3	79.6	12.3	--	0.60	3.32	0.08	0.71	0.54	1.06	2.32	100.45
4	80.5	11.7	--	0.55	3.41	0.10	0.69	0.55	1.01	2.33	100.84
5	80.5	11.7	0.03	0.57	3.28	0.11	0.70	0.50	0.97	2.35	100.70
6	79.7	12.1	0.02	0.59	3.37	0.12	0.70	0.50	0.99	2.33	100.44
7	78.9	12.5	0.02	0.59	3.37	0.06	0.72	0.55	1.08	2.28	100.05
8	79.1	12.3	--	0.62	3.46	0.06	0.76	0.50	1.04	2.30	100.17
9	79.5	12.7	0.05	0.58	3.54	0.05	0.75	0.55	1.00	2.34	100.99
10	80.4	11.8	0.01	0.57	3.22	0.04	0.67	0.51	1.03	2.29	100.59
11	79.8	12.2	0.01	0.60	3.34	0.06	0.71	0.51	1.01	2.27	100.51
12	79.9	12.4	0.03	0.61	3.41	0.11	0.72	0.52	0.98	2.29	100.95
13	79.7	12.4	0.01	0.56	3.35	0.06	0.77	0.52	0.99	2.26	100.66
14	79.4	12.5	0.02	0.62	3.42	0.12	0.74	0.51	1.03	2.30	100.64
15	79.4	12.4	0.02	0.58	3.31	0.04	0.77	0.53	1.06	2.39	100.48
16	79.4	12.3	0.01	0.51	3.50	0.11	0.73	0.55	1.02	2.37	100.55
17	79.2	12.3	0.01	0.57	3.46	0.04	0.74	0.53	1.00	2.26	100.16
18	79.5	12.4	0.05	0.59	3.47	0.16	0.75	0.56	1.03	2.39	100.94
19	79.1	12.5	0.03	0.61	3.50	0.07	0.75	0.50	1.06	2.29	100.38
20	78.9	12.4	0.03	0.61	3.57	0.10	0.78	0.51	1.06	2.27	100.29
21	78.9	12.5	0.04	0.60	3.45	0.17	0.74	0.56	1.05	2.38	100.39
22	78.8	12.4	0.01	0.62	3.41	0.05	0.76	0.55	1.07	2.29	99.88
23	79.1	12.2	0.04	0.59	3.38	0.09	0.71	0.50	1.01	2.32	99.93
24	79.3	12.3	0.01	0.58	3.40	0.09	0.70	0.53	1.02	2.30	100.18
25	79.3	12.2	0.05	0.56	3.33	0.08	0.67	0.50	1.00	2.27	99.90
26	79.4	12.0	--	0.55	3.31	0.04	0.73	0.52	0.99	2.35	99.88
27	79.6	11.9	0.04	0.59	3.34	0.10	0.70	0.50	1.02	2.33	100.13
28	79.4	11.8	--	0.59	3.24	0.13	0.72	0.51	1.02	2.31	99.76
29	79.3	11.9	0.04	0.55	3.26	0.11	0.68	0.49	1.00	2.26	99.55
30	79.7	11.8	--	0.58	3.25	0.10	0.70	0.48	1.01	2.37	99.98
31	79.6	11.8	0.03	0.55	3.15	0.08	0.72	0.51	1.00	2.32	99.77
32	79.8	11.8	0.03	0.58	3.27	0.09	0.68	0.54	1.00	2.27	100.07
33	79.4	11.8	--	0.61	3.16	0.14	0.69	0.51	1.00	2.33	99.58
34	79.5	11.9	0.03	0.54	3.29	0.04	0.68	0.51	1.02	2.29	99.74
35	79.5	11.9	0.03	0.56	3.33	0.04	0.67	0.53	0.95	2.34	99.87
35	79.2	11.9	--	0.54	3.30	0.05	0.71	0.52	0.98	2.27	99.37
37	79.6	11.9	--	0.59	3.23	0.13	0.69	0.47	1.00	2.32	99.86
38	80.1	11.9	0.03	0.55	3.27	0.04	0.69	0.49	1.00	2.30	100.28
39	80.3	11.7	0.01	0.56	3.27	0.07	0.67	0.48	0.95	2.33	100.38
40	80.3	11.5	0.04	0.53	3.16	0.05	0.68	0.48	0.99	2.32	100.05
Average	79.6	12.1	0.02	0.58	3.34	0.09	0.71	0.52	1.01	2.31	100.23
1σ	0.5	0.3	0.02	0.03	0.11	0.04	0.03	0.02	0.03	0.04	0.40

Appendix tables A4-A20 display measured argon isotopes corrected for mass discrimination, sensitivity, system blanks, decay and relative neutron doses. All isotopes are also corrected for interfering isotopes produced on K and Ca during irradiation. Remaining argon isotopes are given in ccSTP/g and have the following composition:

$^{36}\text{Ar} = ^{36}\text{Ar}_{\text{atm}}$	atm:	terrestrial atmospheric argon
$^{37}\text{Ar} = ^{37}\text{Ar}_{\text{Ca}}$	Ca:	argon derived from Ca
$^{38}\text{Ar} = ^{38}\text{Ar}_{\text{atm}} + ^{38}\text{Ar}_{\text{Cl}}$	Cl:	argon derived from Cl
$^{39}\text{Ar} = ^{39}\text{Ar}_{\text{K}}$	K:	argon derived from K
$^{40}\text{Ar} = ^{40}\text{Ar}_{\text{rad}} + ^{40}\text{Ar}_{\text{atm}} + ^{40}\text{Ar}_{\text{exc}}$	rad:	in situ radiogenic argon from K decay
	exc:	excess argon

Apparent ages reported in the tables below were calculated by subtracting trapped ^{40}Ar from total ^{40}Ar . For tektite samples that yielded inverse isochron $^{40}\text{Ar}/^{36}\text{Ar}$ intercepts indistinguishable from air, we used the atmospheric $^{40}\text{Ar}/^{36}\text{Ar}$ ratio of 295.5 ± 0.5 for each temperature extraction. For Chesapeake Bay Crater impact melt samples, we used the $^{40}\text{Ar}/^{36}\text{Ar}$ intercepts from inverse isochrones as listed in Table 1 and listed in table headers A17-A20. Uncertainties of apparent ages do not include flux uncertainties and monitor age uncertainty. Uncertainties are 1σ , italic: total gas (age); bold: steps for plateau calculation, calculated with Steiger and Jäger (1977) recommended values (for age and atmospheric corrections).

Table A4 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for core fragment **Be281-Ac** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J=0.001335\pm 0.000017$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm\text{Age}$ (Ma)
600	640	10	2	1	0.57	0.07	5	5	2.06	0.11	31.01	30.86
800	7670	40	193	1	3.43	0.18	38	8	15.88	0.25	36.52	0.86
900	6670	40	436	3	0.73	0.18	74	12	1.77	0.11	33.36	0.23
960	8470	160	536	10	1.39	0.22	98	12	2.98	0.19	33.57	0.27
1040	10810	200	717	13	0.94	0.26	95	11	2.01	0.15	33.74	0.18
1100	19860	360	1384	26	1.83	0.47	223	14	0.41	0.10	33.75	0.13
1140	21590	400	1517	28	2.11	0.53	234	20	-	-	33.70	0.12
1180	23450	430	1639	30	2.12	0.56	256	11	-	-	33.86	0.11
1220	20050	370	1406	26	1.34	0.48	245	18	-	-	33.76	0.11
1260	22900	430	1606	31	1.59	0.53	253	18	-	-	33.76	0.11
1300	20520	400	1451	29	1.64	0.5	228	13	-	-	33.49	0.11
1320	15560	30	1097	4	0.79	0.38	220	11	-	-	33.59	0.13
1350	13240	30	939	3	1.02	0.37	157	23	-	-	33.40	0.11
1380	7150	20	503	2	0.22	0.22	104	11	0.03	0.03	33.64	0.39
1420	6390	10	442	2	0.44	0.18	96	12	0.02	0.02	34.15	0.47
1460	6250	20	435	2	0.29	0.22	73	16	0.00	0.00	34.00	0.14
1540	15340	40	1059	3	0.88	0.39	150	19	0.02	0.02	34.27	0.48
1600	34250	70	2209	6	3.73	0.81	348	16	8.60	1.10	33.98	0.36
1700	36260	90	2087	7	5.31	0.83	286	22	20.70	2.20	34.19	0.74
1750	19150	80	670	4	5.74	0.76	109	32	35.50	3.40	30.69	3.52
Total	316200	1000	20328	73	36.1	2.1	3293	74	89.90	4.20	33.73	0.15

Table A5 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for core fragment **Be281-Ac2** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J = 0.001318 \pm 0.000017$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm\text{Age}$ (Ma)
400	3180	40	1	1	2.0	0.2	7	5	11.5	0.4	0.00	0.00
500	2060	30	14	1	1.4	0.2	1	1	6.5	0.3	23.23	14.43
600	2440	40	74	1	1.3	0.3	11	5	5.0	0.3	30.12	2.63
700	30330	390	64	1	19.6	0.5	26	3	98.2	1.5	47.42	9.04
800	5820	90	243	4	2.6	0.4	59	8	7.9	0.4	33.58	1.01
900	3800	20	206	2	0.7	0.4	30	6	2.8	0.4	33.89	1.17
1000	12690	60	635	5	2.6	0.6	98	10	11.1	0.7	34.56	0.75
1100	38620	150	2617	12	3.6	1.0	385	11	2.3	0.7	33.88	0.21
1150	29950	130	2037	11	1.6	0.8	278	9	2.2	0.7	33.61	0.26
1170	19650	220	1382	16	1.3	0.7	208	9	-	-	33.22	0.12
1190	17170	200	1211	14	1.1	0.6	174	9	-	-	33.13	0.55
1240	26830	320	1664	20	3.6	0.8	235	10	10.0	1.1	33.56	0.43
1300	28430	390	1519	21	6.0	0.9	231	10	23.1	1.5	33.27	0.62
1350	42110	560	1195	16	18.0	0.9	170	8	85.7	2.4	32.85	1.22
1400	43510	670	1118	18	17.2	0.9	157	10	96.3	3.5	31.46	1.90
1500	81400	1300	806	13	45.2	1.4	106	11	249.2	6.5	22.55	4.44
1600	130530	680	1444	9	70.0	2.1	158	18	378.9	8.9	30.07	4.11
Total	518500	1800	16230	50	197.6	3.6	2334	38	990.8	12.1	32.55	0.47

Table A6 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for rim fragment **Be281-Ar** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1 σ level.J=0,001306 $\pm$ 0,000015

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm$ Age (Ma)
600	780	10	3	1	0.56	0.06	2	2	2.32	0.09	60.50	18.36
800	10690	80	189	2	5.20	0.18	15	15	26.33	0.31	35.72	0.88
900	5600	40	226	2	1.77	0.12	44	15	7.25	0.18	35.40	0.53
960	3480	30	191	2	0.54	0.11	52	11	2.35	0.07	33.76	0.31
1040	8360	70	526	4	0.96	0.20	67	17	2.27	0.10	33.89	0.17
1100	16390	130	1087	9	1.04	0.39	135	23	1.01	0.13	34.28	0.14
1140	15710	30	1033	4	1.31	0.38	150	15	1.58	0.10	34.19	0.16
1180	17030	30	1143	4	1.00	0.39	167	16	-	-	34.53	0.12
1220	17850	30	1204	4	0.92	0.43	182	16	-	-	34.33	0.11
1260	24520	50	1654	5	1.05	0.55	255	18	-	-	34.33	0.10
1300	20930	40	1421	4	1.50	0.48	209	18	-	-	34.13	0.11
1350	17750	30	1205	4	1.05	0.42	208	27	-	-	34.13	0.12
1380	13290	30	898	3	0.74	0.32	154	19	-	-	34.28	0.11
1420	12430	30	838	3	0.69	0.31	119	15	-	-	34.38	0.11
1500	10920	20	743	2	0.80	0.31	116	13	-	-	34.06	0.11
1560	19230	40	1282	4	1.35	0.49	232	23	1.09	0.49	34.17	0.28
1620	33510	60	2214	6	2.04	0.78	360	25	3.28	0.88	34.05	0.29
1700	34090	90	2300	7	1.58	0.87	381	25	0.03	0.03	34.33	0.41
1750	9090	70	717	6	0.31	0.31	90	35	0.01	0.01	29.39	2.18
Total	291640	240	18874	19	24.40	1.90	2937	85	47.50	1.10	34.08	0.11

Table A7 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for rim fragment **Be281-Ar2** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level.J=0,001310 $\pm$ 0,000015

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm$ Age (Ma)
600	1890	30	15	1	1.00	0.10	0.1	0.1	5.44	0.21	43.96	8.66
800	27280	360	259	4	15.40	0.50	47.3	6.2	78.50	1.30	36.54	2.14
900	3710	50	205	3	0.50	0.20	31.0	4.0	3.09	0.27	31.80	0.90
1000	6760	90	392	5	1.00	0.30	58.5	4.8	4.12	0.18	32.92	0.33
1050	15240	180	1031	13	1.40	0.30	168.9	6.3	1.74	0.24	33.20	0.20
1090	22970	270	1516	18	2.00	0.70	227.3	6.5	4.52	0.28	33.17	0.17
1120	12160	150	798	10	1.30	0.40	115.2	7.2	2.81	0.21	33.00	0.22
1140	12880	330	851	22	1.20	0.50	118.5	7.3	2.65	0.22	33.03	0.22
1160	15590	390	1035	26	1.20	0.40	147.6	6.4	2.70	0.24	33.23	0.20
1180	13320	350	895	24	1.40	0.40	144.7	6.2	1.57	0.27	33.37	0.24
1200	10740	300	722	20	0.90	0.30	110.2	6.4	1.42	0.34	33.25	0.36
1240	12090	180	823	13	0.40	0.40	115.2	6.8	1.15	0.35	33.20	0.31
1300	12880	210	884	15	1.20	0.40	116.2	5.0	1.03	0.35	33.08	0.31
1360	10920	230	762	16	0.70	0.40	123.9	7.5	0.01	0.01	33.28	0.65
1420	10330	280	710	19	0.50	0.40	101.4	6.5	0.07	0.07	33.77	0.64
1500	9960	470	647	31	1.00	0.50	93.8	7.5	1.20	1.20	34.46	1.46
1550	16320	80	842	6	4.00	0.70	131.5	5.8	16.90	2.10	31.24	1.71
1600	21330	110	1169	7	4.30	0.90	178.0	11.0	17.80	2.80	31.92	1.63
1650	33920	160	1597	9	8.10	1.20	234.0	13.0	39.00	4.60	32.60	1.98
1700	62680	250	2297	11	19.70	1.80	347.0	18.0	102.30	7.00	32.83	2.08
1750	23570	320	543	8	9.90	2.70	58.0	25.0	52.50	9.90	34.53	12.41
Total	356600	1200	17993	71	77.20	3.90	2669.0	43.0	340.60	13.60	33.06	0.52

Table A8 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for core fragment **Be281-Bc** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level.J=0,001297 $\pm$ 0,000016

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm$ Age (Ma)
600	1020	10	2	1	0.90	0.10	4	4	3.36	0.11	29.91	32.82
800	16180	60	187	1	8.80	0.30	46	13	44.11	0.58	38.67	2.02
900	5530	20	235	2	1.40	0.10	48	14	6.70	0.12	34.71	0.40
960	4570	20	208	2	1.10	0.10	31	10	4.71	0.13	35.10	0.50
1040	6630	30	365	2	1.20	0.20	58	9	3.67	0.16	34.99	0.34
1125	12970	310	819	20	1.10	0.30	95	9	1.97	0.15	34.80	0.18
1150	13700	330	909	22	0.80	0.30	97	9	0.02	0.02	34.65	0.19
1200	18200	440	1201	29	1.20	0.40	155	16	-	-	34.86	0.14
1240	17860	440	1169	29	1.20	0.40	167	14	0.01	0.01	35.15	0.19
1300	16480	430	1082	28	0.60	0.40	153	14	0.07	0.07	34.98	0.22
1320	17070	450	1130	30	1.00	0.40	185	14	0.04	0.04	34.72	0.27
1350	16370	450	1077	30	0.40	0.40	118	10	-	-	34.97	0.21
1380	15140	30	995	3	0.80	0.40	97	13	-	-	35.02	0.11
1400	11930	20	786	2	0.60	0.30	74	14	0.05	0.05	34.88	0.25
1440	9070	20	592	3	0.50	0.30	94	11	0.07	0.07	35.16	0.39
1480	7840	20	521	2	0.50	0.20	54	11	0.02	0.02	34.58	0.56
1520	6850	20	451	2	0.30	0.30	71	11	0.07	0.07	34.81	0.82
1600	21480	50	774	3	6.90	0.40	86	11	34.20	1.10	33.81	1.00
1700	82560	110	2917	6	26.50	1.20	399	23	132.50	2.70	34.24	0.62
1750	41420	80	857	3	18.60	0.80	109	22	101.60	3.10	30.63	2.40
Total	342900	1100	16278	73	74.40	2.00	2143	60	333.20	4.30	34.55	0.18

Table A9 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for core fragment **Be281-Bc2** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J=0.001281\pm 0.000016$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm\text{Age}$ (Ma)
600	23740	410	245	5	13.10	0.50	42	9	65.75	1.38	39.62	2.18
800	2200	50	72	2	0.50	0.10	12	6	3.83	0.21	33.48	1.76
880	2790	60	182	5	0.40	0.10	20	5	0.01	0.01	34.81	0.69
940	2960	60	200	4	0.20	0.10	22	6	0.01	0.01	33.50	0.55
1000	5170	100	330	7	0.30	0.20	41	4	0.08	0.08	35.47	0.38
1050	7150	60	475	5	0.50	0.20	53	4	0.01	0.01	34.18	0.26
1090	27230	230	1787	15	0.90	0.60	222	10	0.01	0.01	34.63	0.14
1120	25930	220	1721	15	1.10	0.60	210	8	0.07	0.07	34.21	0.14
1150	15640	130	1036	9	1.00	0.50	131	8	-	-	34.31	0.11
1180	15340	140	1012	9	0.80	0.40	118	6	0.03	0.03	34.45	0.21
1210	12880	30	852	3	0.80	0.40	108	8	0.03	0.03	34.35	0.21
1240	12950	30	844	3	0.80	0.40	108	5	0.04	0.04	34.82	0.21
1300	19990	50	1307	5	1.40	0.50	151	9	-	-	34.74	0.12
1360	26780	50	1759	6	1.80	0.60	227	8	-	-	34.60	0.12
1420	13010	50	857	5	1.30	0.50	108	8	0.04	0.04	34.46	0.52
1500	9900	50	633	4	0.70	0.40	70	9	0.01	0.01	35.56	1.20
1550	5960	50	387	4	0.50	0.50	59	8	0.04	0.04	34.88	2.12
1600	8380	70	523	5	0.40	0.40	54	9	0.04	0.04	36.35	2.17
1650	10470	110	704	8	0.00	0.00	80	9	0.08	0.08	33.73	2.57
1700	10680	140	687	9	0.00	0.00	78	12	0.06	0.06	35.25	3.81
Total	259150	620	15615	33	26.20	1.80	1914	35	70.11	1.40	34.69	0.24

Table A10 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for core fragment **Be281-Bc3** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J=0.0004731\pm 0.0000032$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm\text{Age}$ (Ma)
600	577	23	1.5	0.2	0.26	0.07	6.5	8.2	1.56	0.11	65.37	16.65
800	11243	483	39.9	1.8	6.52	0.35	14.6	16.9	31.19	1.39	42.52	2.44
900	3133	138	57.2	2.6	0.66	0.10	12.8	12.9	2.21	0.18	36.38	0.72
960	4395	191	83.2	3.7	0.92	0.13	9.7	11.4	3.39	0.19	34.23	0.44
1000	4269	186	75.8	3.3	0.73	0.13	6.0	10.2	3.95	0.25	34.33	0.60
1030	3857	168	80.7	3.6	0.36	0.09	13.9	13.9	1.94	0.16	34.13	0.45
1060	4523	197	106.6	4.7	0.30	0.13	35.3	12.3	0.34	0.09	34.80	0.33
1090	13801	120	244.4	2.3	2.50	0.21	17.9	9.7	13.00	0.25	34.20	0.26
1120	10239	89	238.9	2.5	0.68	0.16	36.9	11.3	1.21	0.13	34.71	0.24
1150	14514	127	346.2	3.7	0.49	0.19	71.1	23.2	1.09	0.15	34.40	0.23
1180	11442	101	265.8	2.5	0.85	0.16	70.9	11.5	1.43	0.12	34.78	0.15
1210	9864	88	225.2	2.4	0.48	0.13	43.4	12.8	2.04	0.14	34.51	0.27
1240	9967	90	227.0	2.5	0.70	0.21	15.0	10.0	2.18	0.20	34.45	0.29
1280	10853	169	220.6	3.8	1.28	0.19	21.7	14.1	6.06	0.25	34.47	0.35
1320	8377	135	204.5	3.6	0.21	0.13	19.3	12.6	0.01	0.13	34.37	0.23
1360	7535	125	183.6	3.2	0.01	0.16	22.6	17.3	0.01	0.16	34.45	0.17
1400	5636	101	139.4	2.7	0.07	0.11	6.8	9.6	0.01	0.14	33.92	0.23
1450	4320	90	105.9	2.4	0.35	0.12	16.0	14.7	0.00	0.19	34.22	0.26
1500	4722	96	112.0	2.5	0.00	0.14	28.8	9.5	0.17	0.30	34.98	0.73
1550	4526	108	112.2	3.1	0.00	0.14	22.2	14.5	0.00	0.34	33.84	0.45
1600	6027	154	146.8	4.3	0.06	0.23	12.7	16.9	0.01	0.49	34.44	0.48
1650	7485	209	175.7	5.7	0.25	0.25	49.4	18.0	0.01	0.66	35.71	1.08
1700	9334	316	217.9	8.8	0.32	0.34	31.7	31.8	0.15	1.11	35.77	1.47
1750	19910	595	483.8	16.9	0.30	0.60	67.7	45.8	0.02	1.79	34.53	0.62
Total	190549	1038	4095	24	18.3	1.1	653	85	72.0	2.8	34.69	0.13

Table A11 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for rim fragment **Be281-Br** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level.

J=0,001235 0,000015

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm\text{Age}$ (Ma)
600	1110	400	6	2	1.0	0.4	30	30	3.60	1.30	22.91	14.79
800	168900	42500	201	51	97.0	24.0	800	240	456.30	114.90	340.29	10.03
900	9300	2500	360	96	2.3	0.6	50	50	11.00	3.00	36.51	0.76
960	9300	2500	480	130	1.6	0.5	20	20	6.30	1.70	34.06	0.59
1040	18000	30	924	4	3.1	0.4	190	70	12.05	0.44	34.21	0.34
1100	41300	70	2604	9	1.7	0.9	370	90	3.37	0.24	33.90	0.14
1150	46340	80	3000	12	2.1	1.0	560	100	0.13	0.13	33.80	0.16
1200	30600	60	1987	6	1.6	0.7	400	80	-	-	33.73	0.11
1250	33220	60	2145	7	1.6	0.8	230	100	0.05	0.05	33.90	0.14
1300	35530	60	2280	7	1.5	0.8	250	120	-	-	34.12	0.16
1350	38210	70	2450	11	2.0	0.9	520	100	-	-	34.15	0.15
1400	26130	70	1674	7	0.7	0.7	110	70	0.05	0.05	34.15	0.33
1500	27040	40	875	6	9.8	0.7	40	40	44.93	0.79	34.45	0.62
1600	83590	170	3837	14	18.0	1.9	640	100	83.20	1.90	33.67	0.34
1700	85860	250	4128	25	13.0	1.6	330	120	66.10	4.40	35.16	0.71
Total	654400	42700	26950	170	157.0	25.0	4530	400	687.10	115.10	36.65	0.64

Table A12 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for rim fragment **Be281-Br2** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J = 0.001206 \pm 0.000014$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm\text{Age}$ (Ma)
600	560	10	4	1	0.60	0.10	20	10	2.16	0.12	0.00	0.00
800	20270	40	125	1	11.60	0.20	30	20	61.48	0.71	36.17	3.52
900	3570	10	189	1	0.70	0.10	10	10	2.10	0.19	33.30	0.66
960	3090	10	188	1	0.50	0.10	40	20	0.64	0.15	32.97	0.53
1040	6450	20	395	2	0.40	0.20	50	20	1.06	0.17	33.26	0.33
1100	21690	50	1385	5	1.40	0.50	200	20	0.43	0.16	33.31	0.13
1150	24740	60	1576	6	1.40	0.60	260	30	0.01	0.01	33.57	0.13
1200	15900	40	1019	4	0.30	0.30	120	20	-	-	33.37	0.12
1250	17100	40	1099	4	0.60	0.60	140	20	0.01	0.01	33.29	0.17
1300	15830	30	1010	3	0.40	0.40	150	20	0.07	0.07	33.47	0.18
1350	17830	30	1127	4	0.60	0.50	130	20	0.06	0.06	33.82	0.16
1400	19070	40	1218	4	1.70	0.50	180	20	0.06	0.06	33.46	0.21
1500	9100	20	591	3	0.20	0.20	80	20	0.09	0.09	32.85	0.52
1600	23750	60	1552	5	0.60	0.60	180	40	-	-	32.75	0.50
1700	56840	120	3651	12	1.90	1.40	390	50	-	-	33.31	0.50
1750	12240	110	810	8	0.60	0.60	50	40	0.01	0.01	32.31	2.97
Total	268030	220	15938	19	23.40	2.10	2040	110	68.20	0.81	33.28	0.16

Table A13 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for bulk fragment **Be283-1** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level.J=0,001417 $\pm$ 0,000013

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm$ Age (Ma)
600	1670	20	16	1	1.00	0.20	5	5	4.58	0.21	50.22	9.01
800	22990	240	661	7	10.60	0.40	83	9	46.47	0.82	35.16	0.74
900	13370	150	825	10	2.10	0.40	108	8	6.77	0.30	34.60	0.31
1000	19550	210	1167	13	4.10	0.50	158	10	10.57	0.34	35.32	0.25
1100	40280	440	2773	31	4.90	1.20	361	20	6.96	0.37	34.62	0.16
1140	24480	680	1766	49	2.00	0.70	238	18	-	-	34.79	0.11
1200	38000	1000	2719	75	3.00	1.00	333	15	-	-	35.05	0.15
1240	46100	1300	3311	92	0.70	0.70	386	19	-	-	34.97	0.15
1280	41400	1200	2985	86	3.50	1.10	366	18	-	-	34.83	0.12
1340	33300	1100	2419	76	2.70	0.80	311	18	-	-	34.60	0.11
1400	26000	1000	1873	75	2.90	0.70	257	15	-	-	34.84	0.12
1460	23200	1200	1703	86	1.90	0.70	219	15	0.04	0.04	34.18	0.36
1520	18000	1400	1350	110	1.80	0.70	181	19	0.05	0.05	33.49	0.78
1600	32900	2700	2150	180	3.10	1.30	279	34	8.80	3.00	35.37	1.00
1700	89200	6000	3820	260	27.00	2.50	465	37	126.30	9.70	34.17	0.91
1750	8100	2600	670	220	0.60	0.60	68	26	1.10	1.10	29.25	3.44
Total	478600	7800	30200	450	71.90	4.00	3816	79	211.60	10.20	34.59	0.17

Table A14 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for bulk fragment **Be283-2** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J = 0.001415 \pm 0.000013$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm\text{Age}$ (Ma)
600	1230	10	15	1	0.70	0.10	95	81	3.4	0.2	36.83	10.63
800	23240	110	218	1	13.70	0.30	178	65	68.7	0.8	33.68	2.51
900	6320	30	250	2	2.60	0.20	140	56	9.5	0.3	35.15	0.81
960	3620	20	242	2	0.40	0.20	7	7	1.2	0.1	33.75	0.48
1040	4940	30	350	2	0.50	0.20	113	66	0.6	0.2	34.16	0.44
1100	14650	120	1018	9	1.40	0.40	205	46	2.5	0.2	34.30	0.19
1150	19930	170	1434	12	1.60	0.60	320	100	0.7	0.1	34.54	0.13
1200	15310	130	1111	10	1.50	0.40	110	65	-	-	34.56	0.12
1250	15030	140	1081	11	0.60	0.40	175	55	0.6	0.3	34.43	0.26
1300	16620	160	1212	12	1.30	0.50	271	39	0.3	0.3	34.21	0.22
1350	14810	150	1079	11	0.90	0.40	282	62	-	-	34.43	0.13
1400	12010	200	876	15	1.90	0.60	210	74	-	-	34.39	0.13
1500	15900	30	1151	4	1.50	0.50	133	62	-	-	34.64	0.37
1600	25770	70	1770	6	1.90	0.70	181	65	4.8	1.6	34.49	0.67
1700	56300	130	3734	14	7.40	1.50	200	130	16.5	3.5	34.53	0.69
1750	12650	70	950	7	1.30	0.80	19	19	0.4	0.4	33.09	2.76
Total	258320	460	16493	35	39.00	2.30	2650	270	109.3	4.0	34.38	0.24

Table A15 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for bulk fragment **Georgiite GE1** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J=0.001373\pm 0.000010$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm\text{Age}$ (Ma)
600	6900	100	164	2	6.7	0.5	14	11	14.9	0.5	36.54	2.19
700	40500	100	289	2	23.9	0.6	45	14	122.4	1.4	36.98	3.29
800	22800	100	646	5	8.8	0.7	59	14	45.5	0.9	35.35	0.96
880	15500	200	801	10	4.3	0.5	79	15	13.5	0.6	35.11	0.52
940	13700	200	700	9	2.8	0.5	69	15	12.5	0.7	34.66	0.75
1000	24300	300	1151	14	4.9	0.7	86	13	25.6	1.0	35.30	0.60
1050	20100	200	1416	18	2.2	0.7	115	13	-	-	34.55	0.27
1090	25500	300	1818	22	2.4	0.7	187	16	-	-	34.13	0.20
1120	27900	300	1981	25	1.1	0.8	211	13	-	-	34.20	0.29
1150	22800	300	1605	21	1.8	0.9	113	27	-	-	34.63	0.28
1180	44000	100	1839	8	13.2	0.9	196	16	57.9	1.1	35.65	0.43
1210	27100	100	1915	9	1.3	0.7	208	20	-	-	34.45	0.26
1240	26600	100	1756	9	3.3	0.9	155	20	2.9	1.1	35.67	0.48
1300	20500	100	1327	8	3.1	1	130	15	5.0	1.1	34.88	0.61
1360	10400	100	735	6	1.7	0.7	73	12	0.1	0.1	34.45	1.36
1420	8800	100	462	6	1.1	0.8	50	14	5.3	1.8	38.00	2.81
1500	24800	200	391	4	13.4	1	45	11	67.9	2.9	29.49	5.32
1600	674600	1100	1529	6	414.1	3.4	251	21	2242.0	18.0	19.49	8.47
1700	250000	800	60	2	155.8	2.9	26	22	859.0	14.0	0.00	0.00
1750	416600	1100	91	2	265.3	4.1	2	2	1413.0	20.0	0.00	0.00
Total	1723400	1900	20675	52	931.2	6.9	2114	71	4888.0	31.0	33.45	1.05

Table A16 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for bulk fragment **Georgiite GE2** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1 σ level. J=0,0006447 $\pm$ 0,0000087

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma)	$\pm$ Age (Ma)
600	1802	62	5.3	0.2	1.034	0.102	0.2	12.4	5.469	0.243	42.19	10.28
700	957	34	26.5	1.0	0.117	0.059	9.7	9.8	0.433	0.113	37.41	1.57
800	9614	316	55.2	1.9	5.220	0.218	11.5	13.5	26.419	0.909	39.11	1.77
900	3836	128	103.2	3.5	0.698	0.114	21.1	15.4	3.134	0.173	33.75	0.52
960	4482	149	129.0	4.3	0.480	0.104	25.1	11.7	2.591	0.138	34.48	0.35
1000	5076	168	131.9	4.4	1.036	0.122	40.1	11.7	4.629	0.220	33.65	0.47
1030	5257	99	150.4	3.0	0.699	0.116	4.7	8.9	3.517	0.191	33.57	0.46
1060	5448	103	182.9	3.6	0.452	0.131	20.7	14.7	0.997	0.132	33.73	0.30
1090	16313	305	541.1	10.4	1.028	0.213	31.0	16.3	3.556	0.146	33.76	0.17
1120	11609	217	401.8	7.7	0.534	0.221	12.8	12.8	1.184	0.073	33.55	0.14
1150	13568	254	472.0	9.0	1.004	0.204	54.3	13.6	0.990	0.137	33.66	0.16
1180	8879	168	305.3	5.9	0.435	0.160	32.0	23.1	0.888	0.108	33.78	0.20
1210	6869	18	239.5	1.6	0.227	0.179	4.1	12.4	0.398	0.364	33.74	0.57
1240	5319	9	183.5	1.1	0.255	0.128	8.5	10.1	0.378	0.144	33.97	0.33
1300	7900	13	277.5	1.2	0.158	0.142	37.1	11.1	0.119	0.111	33.91	0.19
1360	16361	24	578.5	2.6	0.164	0.262	45.8	16.4	0.016	0.131	33.84	0.14
1420	26870	37	948.8	3.5	0.484	0.403	75.2	26.9	0.027	0.188	33.89	0.12
1500	20266	33	719.4	3.3	0.162	0.385	109.4	16.2	0.020	0.223	33.72	0.14
1560	4870	157	171.1	6.2	0.341	0.181	17.5	18.5	0.005	0.409	34.06	0.55
1620	4510	179	156.2	7.2	0.149	0.212	32.0	22.6	0.027	0.465	34.49	1.33
1680	6098	289	227.6	13.0	0.006	0.274	16.5	26.2	0.006	0.842	32.07	1.00
1740	14797	554	507.5	21.8	0.015	0.444	13.3	37.0	0.015	1.361	34.88	0.72
1800	6670	633	227.4	27.9	0.007	0.647	9.3	60.0	0.267	2.341	34.68	4.50
Total	207371	1130	6742	44	14.7	1.2	632	103	55.1	3.1	33.93	0.18

Table A17 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for **CB-W61** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J=0.001305\pm 0.000018$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma) <small>$^{40}\text{Ar}/^{36}\text{Ar}=295.5\pm 0.5$</small>	$\pm\text{Age}$ (Ma)	Age (Ma) <small>$^{40}\text{Ar}/^{36}\text{Ar}=343.5\pm 2.0$</small>	$\pm\text{Age}$ (Ma)
400	120776	1066	2.5	0.1	67.2	0.7	199.3	45.9	365.7	3.6	3627	112	-	-
600	2999696	26552	321.0	4.1	1643.8	15.7	4619.5	126.8	9938.0	96.2	411	74	-	-
650	118159	330	92.6	0.4	62.6	0.4	274.1	40.2	329.8	2.2	458	12	-	-
700	410599	1158	628.2	2.7	217.2	1.0	1506.9	74.0	1161.2	7.7	235.1	6.9	-	-
740	450882	1279	858.0	3.0	230.9	1.1	1573.6	72.3	1236.3	7.6	219.0	5.2	34.83	10.57
780	889682	2517	1792.7	6.2	445.7	2.2	1850.5	80.2	2461.8	15.8	199.9	5.0	22.91	10.15
800	292107	825	665.4	2.6	146.3	1.0	815.0	70.1	793.1	5.2	192.1	4.5	38.77	8.83
830	368619	1060	771.2	3.1	186.2	1.2	936.3	77.5	1002.3	6.6	207.2	4.9	40.85	9.61
860	411527	1260	725.5	3.6	210.3	1.0	716.1	98.8	1133.3	7.8	231.2	6.0	32.11	11.80
900	413123	4470	755.2	8.4	210.3	2.4	764.3	50.3	1140.6	13.6	221.3	4.9	28.16	10.62
940	342058	3701	952.6	10.7	173.1	2.0	632.8	65.4	930.4	11.1	157.6	3.4	30.53	6.97
990	251369	2726	1922.5	21.2	118.9	1.5	799.4	53.5	630.7	7.7	77.34	1.28	33.72	2.40
1020	96189	1043	1463.6	16.2	42.0	0.7	357.8	57.8	217.5	2.7	50.28	0.65	30.35	1.14
1075	72338	785	1528.8	17.1	28.9	0.6	350.8	50.8	145.0	1.8	44.53	0.42	31.80	0.73
1100	126565	1372	3016.9	33.3	49.0	1.1	834.1	45.2	243.6	2.9	41.78	0.31	30.92	0.58
1150	107902	1170	2128.5	23.6	45.2	0.9	752.1	68.5	226.4	2.8	44.47	0.45	30.18	0.80
1190	56068	610	952.1	10.7	24.7	0.4	402.0	32.3	122.8	1.5	47.88	0.60	30.56	1.01
1220	18516	35	286.0	1.1	8.0	0.1	144.1	35.6	40.9	0.3	51.79	0.75	32.62	1.20
1240	11294	22	180.1	0.7	4.9	0.1	76.2	45.0	24.6	0.2	51.62	0.87	33.36	1.29
1280	15921	31	255.4	1.0	7.0	0.2	155.4	28.7	34.2	0.3	52.56	0.72	34.66	1.13
1320	11485	25	194.5	0.9	5.0	0.1	110.7	30.2	24.8	0.2	49.43	0.76	32.37	1.15
1370	8693	19	163.9	0.6	3.9	0.1	140.2	37.0	17.8	0.2	48.13	0.88	33.54	1.22
1400	7698	19	135.9	0.7	3.4	0.1	54.5	31.6	16.4	0.2	48.14	1.12	31.91	1.50
1500	3334	15	82.8	0.6	1.1	0.1	13.2	27.5	5.0	0.2	51.44	1.63	43.33	1.98
1600	7110	28	134.5	0.7	3.0	0.1	159.5	42.1	13.2	1.0	55.01	5.10	41.92	6.18
1750	19518	42	253.6	1.2	9.7	0.3	67.9	70.3	50.8	1.0	41.14	2.62	14.10	3.38
Total	7631228	27666	20264	55	3948	17	18306	310	22306	101	116.12	1.58	29.75	3.53

Table A18 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for **CB-W-61-2** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. J=0.0006747 $\pm$ 00000067

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma) $^{40}\text{Ar}/^{36}\text{Ar}=295.5\pm0.5$	$\pm\text{Age}$ (Ma)	Age (Ma) $^{40}\text{Ar}/^{36}\text{Ar}=327.3\pm6.3$	$\pm\text{Age}$ (Ma)	Age (Ma) $^{40}\text{Ar}/^{36}\text{Ar}=363.8\pm5.4$	$\pm\text{Age}$ (Ma)
500	105476	2250	3.3	0.4	60.0	1.4	8.9	4.1	315.8	7.5	2264.6	197.94	653.65	593.86	-	-
600	2016135	40341	270.2	6.7	1100.8	22.8	246.0	24.7	5943.6	130.0	902.14	44.38	293.73	157.73	-	-
700	672624	18251	394.8	13.0	369.3	10.4	265.7	14.1	1891.4	54.9	320.33	16.05	157.99	38.28	-	-
750	1010312	21099	832.5	18.4	535.5	11.6	343.5	18.6	2776.3	63.2	258.25	9.78	142.77	26.15	0.41	25.70
800	582349	13522	661.5	15.8	302.8	7.4	216.1	15.4	1536.8	38.5	221.70	7.20	140.38	18.38	42.28	17.70
830	862807	17966	589.3	12.7	454.7	9.8	244.2	10.8	2321.0	52.9	332.83	11.27	201.40	30.02	37.70	29.91
860	214442	4519	250.3	5.6	113.2	2.6	63.7	6.2	574.1	13.3	205.73	7.41	124.73	18.41	27.03	17.75
890	265880	5589	295.1	6.4	142.0	3.1	67.8	8.4	718.1	16.5	208.78	7.41	122.87	19.35	18.95	18.65
920	245501	5291	316.5	7.1	128.9	3.0	82.5	9.5	650.8	15.3	193.76	6.47	120.81	16.44	33.28	15.72
950	251055	5359	449.1	9.8	132.3	3.0	120.8	10.6	661.3	15.4	144.83	4.76	91.46	11.97	28.18	11.31
980	128627	3049	426.4	10.5	67.4	1.8	86.1	5.5	322.9	8.4	92.43	2.78	64.37	6.38	31.61	5.97
1010	116857	2527	777.6	17.2	60.3	1.7	134.7	10.0	275.8	6.6	54.52	1.30	41.15	3.01	25.69	2.79
1040	59883	1424	526.8	12.9	31.1	1.0	96.1	8.2	130.4	3.4	48.69	1.01	39.34	2.15	28.55	2.00
1070	73668	1559	717.1	15.5	38.0	1.2	133.8	9.9	160.3	3.8	44.10	0.83	35.63	1.90	25.87	1.76
1100	101237	2352	964.6	24.3	52.6	1.7	223.8	10.3	216.8	5.7	46.29	1.10	37.79	2.05	27.98	1.93
1130	117702	2492	959.5	20.5	63.2	1.8	242.9	7.1	270.5	6.3	47.29	1.01	36.63	2.39	24.32	2.21
1160	73758	1684	487.7	11.3	40.4	1.1	127.2	7.7	178.6	4.5	51.64	1.41	37.82	3.15	21.82	2.94
1190	36181	876	196.6	5.0	20.7	0.6	61.0	5.6	92.6	2.4	53.73	1.80	35.94	4.05	15.31	3.77
1220	36908	799	185.8	4.5	21.0	0.6	65.8	5.9	95.6	2.3	55.79	1.98	36.37	4.42	13.82	4.10
1250	38446	833	168.2	3.7	21.3	0.6	55.3	5.6	101.0	2.4	61.27	2.27	38.67	5.15	12.38	4.82
1350	35662	792	93.7	2.2	20.4	0.5	33.5	3.7	101.0	2.5	74.05	4.03	33.55	9.27	-	-
1500	43723	980	33.4	0.9	27.1	0.7	12.5	7.5	139.8	3.5	85.89	15.92	-	-	-	-
1750	96750	2147	22.3	1.1	59.9	1.5	0.4	14.3	315.7	7.7	179.33	47.74	-	-	-	-
Total	7185983	55387	9622	57	3863	31	2932	52	19790	172	153.21	1.92				

Table A19 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for **CB-W84** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J=0.001268\pm 0.000018$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma) $^{40}\text{Ar}/^{36}\text{Ar}=295.5\pm 0.5$	$\pm\text{Age}$ (Ma)	Age (Ma) $^{40}\text{Ar}/^{36}\text{Ar}=332.0\pm 7.3$	$\pm\text{Age}$ (Ma)
400	128600	234	46.4	0.4	72.1	0.5	501.5	64.3	389.8	2.7	559	28	-	-
550	199773	377	264.5	1.7	113.1	0.8	1018.8	119.9	589.5	3.6	207	8	34.39	37.46
650	109801	172	1000.0	3.5	56.2	0.6	823.5	98.8	283.4	2.3	58.24	1.51	35.36	4.90
740	143844	301	3275.5	11.9	54.2	1.2	1323.4	172.6	265.8	2.2	44.70	0.47	38.12	1.41
800	58231	145	1718.9	8.3	17.8	0.6	617.2	122.3	86.6	0.9	42.59	0.38	38.50	0.91
860	39785	84	933.5	3.4	15.1	0.4	580.9	119.4	71.8	0.7	44.63	0.49	38.41	1.36
900	18820	59	371.0	2.1	7.8	0.2	532.6	86.6	38.1	0.4	45.70	0.74	37.39	1.85
940	30761	57	533.1	2.1	13.4	0.3	412.2	76.9	66.0	0.5	47.36	0.67	37.34	2.14
1000	63198	98	1161.8	4.2	27.6	0.5	739.4	120.1	132.8	1.0	46.22	0.61	36.97	1.97
1100	233957	342	3892.6	11.2	100.8	1.4	1357.0	93.6	521.3	3.6	46.02	0.63	35.16	2.28
1150	126012	178	1820.5	6.9	57.0	0.8	655.3	88.2	291.3	1.9	49.11	0.71	36.15	2.71
1200	94833	75	1270.9	4.3	43.3	0.7	303.5	94.8	218.0	1.8	53.51	0.94	39.66	2.97
1240	50730	66	608.7	2.1	23.7	0.4	380.5	96.4	117.8	1.1	58.36	1.18	42.75	3.39
1300	25667	32	285.3	1.2	12.7	0.2	25.7	74.4	60.0	0.5	62.12	1.16	45.20	3.63
1370	15005	19	150.4	0.9	7.0	0.1	93.0	72.0	34.7	0.5	70.46	2.15	52.00	4.42
1450	10031	24	138.0	0.9	4.2	0.4	56.2	73.2	20.3	0.5	65.33	2.31	53.55	3.50
1600	4344	30	104.9	1.1	0.9	0.3	246.7	78.6	4.6	0.8	63.15	4.93	59.60	5.58
1750	16273	83	119.4	1.1	8.4	0.6	190.4	203.4	47.7	2.6	41.04	14.5	8.38	17.80
Total	1369665	728	17695	22	635	3	9858	462	3240	8	52.15	0.30	37.45	1.02

Table A20 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating results for **CB-W84-2** $\times 10^{-11}$ ccSTP/g. Uncertainties at 1σ level. $J=0.0006528\pm 0.0000044$

Temp. (°C)	^{40}Ar	$\pm^{40}\text{Ar}$	^{39}Ar	$\pm^{39}\text{Ar}$	^{38}Ar	$\pm^{38}\text{Ar}$	^{37}Ar	$\pm^{37}\text{Ar}$	^{36}Ar	$\pm^{36}\text{Ar}$	Age (Ma) <small>$^{40}\text{Ar}/^{36}\text{Ar}=295.5\pm 0.5$</small>	$\pm\text{Age}$ (Ma)	Age (Ma) <small>$^{40}\text{Ar}/^{36}\text{Ar}=329.6\pm 5.6$</small>	$\pm\text{Age}$ (Ma)
500	403227	8265	219.0	5.3	235.48	5.40	246.0	16.9	1199.6	27.1	244.80	16.19	41.68	40.37
600	123556	3459	490.4	15.7	74.26	2.36	248.3	19.8	331.0	10.0	60.79	2.82	34.39	5.31
700	120487	2587	1201.1	26.5	66.27	1.94	286.8	12.5	255.4	6.4	43.60	0.95	35.24	1.73
750	50143	1259	636.3	16.5	26.27	1.16	211.1	16.9	87.9	2.8	44.22	0.93	38.80	1.36
800	55426	1178	827.3	18.1	28.38	1.17	190.7	19.8	85.9	2.3	42.26	0.59	38.18	0.93
830	28946	686	355.2	9.4	15.17	0.73	98.7	12.9	51.5	1.4	44.92	0.84	39.23	1.28
860	24551	538	255.7	6.1	13.43	0.57	88.9	13.6	51.3	1.5	42.73	1.40	34.84	2.01
890	11189	1044	121.5	15.6	6.10	0.64	28.1	8.3	21.4	2.5	46.49	5.96	39.58	6.10
920	20901	437	163.8	3.6	11.85	0.37	43.7	8.6	49.1	1.1	45.48	1.10	33.71	2.28
950	16559	366	126.2	2.9	8.69	0.28	38.7	4.4	39.6	1.1	44.74	1.73	32.40	2.79
980	23563	494	181.4	3.9	12.87	0.39	66.7	6.7	54.7	1.4	47.42	1.40	35.59	2.49
1010	22209	484	169.1	3.8	12.17	0.46	48.2	7.8	50.5	1.3	49.94	1.33	38.23	2.42
1040	46989	967	407.6	8.8	25.70	0.84	110.0	10.6	102.5	2.4	47.63	1.03	37.77	1.97
1070	56039	1184	441.7	9.7	30.21	0.85	101.4	9.2	128.8	3.1	47.28	1.12	35.84	2.25
1100	99200	2351	722.5	18.9	51.48	1.57	132.9	11.4	229.9	6.1	50.24	1.42	37.76	2.56
1130	75358	1667	459.2	10.5	40.02	1.07	100.2	7.9	181.2	4.4	55.06	1.44	39.63	2.99
1160	46508	1067	262.7	6.2	24.88	0.66	50.7	8.9	113.6	2.8	57.13	1.49	40.23	3.23
1190	31754	726	164.5	3.9	18.07	0.56	57.8	8.7	79.0	2.1	59.14	2.25	40.38	3.98
1220	24265	542	117.9	2.8	13.61	0.44	29.8	7.3	60.3	1.5	63.16	2.23	43.19	4.11
1250	16829	386	73.4	1.8	8.95	0.31	31.6	7.3	42.4	1.2	67.82	3.01	45.35	4.99
1350	31600	675	122.0	2.7	17.29	0.53	34.8	7.6	82.4	2.0	68.54	2.42	42.23	5.11
1500	40407	888	74.1	1.7	24.24	0.62	29.9	5.7	118.2	2.9	84.85	5.54	22.70	12.13
1750	85690	1895	12.5	0.8	54.67	1.43	12.0	19.7	290.7	7.2	-18.9	-95.0	-1353	-411
Total	1455396	10497	7605	52	820	7	2287	57	3707	32	54.57	1.68	35.11	2.92

Figure A1-A

Figure A1-B

Figure A1-C

Figure A1-D

Figure A1-E

Figure A2

Figure A3 Blank levels for all analysed tektites/impact melts, showing the correction curve for blank measurements (furnace and line). The first (first three rows) and the second (last row) irradiation series differ in blank height by a factor of 5-10.