Three synthetic reference glasses were prepared by directly fusing and stirring 3.8 kg of high-purity oxide powders to provide reference materials for microanalytical work. These glasses have andesitic major compositions and are doped with fifty-four trace elements in nearly identical abundance (500, 50, 5 µg g⁻¹) using oxide powders or element solutions, and are named ARM-1, 2 and 3, respectively. We further document that sector-field (SF) ICP-MS (Element 2 or Element XR) is capable of sweeping seventy-seven isotopes (from ⁷Li to ²³⁸U, a total of sixty-eight elements) in 1 s and, thus, is able to quantify up to sixty-eight elements by laser sampling. Micro- and bulk analyses indicate that the glasses are homogeneous with respect to major and trace elements. This paper provides preliminary data for the ARM glasses using a variety of analytical techniques (EPMA, XRF, ICP-OES, ICP-MS, LA-Q-ICP-MS and LA-SF-ICP-MS) performed in ten laboratories. Discrepancies in the data of V, Cr, Ni and Tl exist, mainly caused by analytical limitations. Preliminary reference and information values for fifty-six elements were calculated with uncertainties [2 relative standard error (RSE)] estimated in the range of 1–20%.

Keywords: glass reference materials, microanalysis, sector-field ICP-MS, LA-ICP-MS, multiple-element quantification.
elements (which the mass fractions are high enough for nearly all trace are synthetic NIST SRM 610 and NIST SRM 612 glasses in Enzweiler 2014). The most widely used reference materials Centre for Geoanalysis, China (NRCG; Jochum and glasses are available for microanalysis, provided and tested different laboratories. Currently, about twenty reference materials are commonly used for calibration, quality control accuracy (Jochum and Enzweiler 2014). Such reference glasses are generally used for the Thermo Element 2 and Element XR SF-ICP-MS instrument that is capable of sweeping seventy-seven isotopes (from $^7$Li to $^{238}$U, a total of sixty-eight elements) in less than 1 s. The acquisition efficiency is around 77%, which is four-fifths to that of Q-ICP-MS (acquisition efficiency: 85%). The long-term reproducibility and accuracy of this acquisition method were validated by measurement data of reference materials from NIST, MPI-DING, USGS and NRCG.

**Experimental**

**Preparation of ARM glasses**

The ARM glasses were made by fusing and stirring high-purity oxide powders in proportions of an andesite major element composition. The starting material was doped with fifty-four trace elements at similar abundance (500, 50 and 5 ng g$^{-1}$, respectively). For Th and U we used element solutions (see details in Appendix S1, Table S1). Considering that the abundance of Ba is higher compared with other trace elements (e.g., REEs) in most natural geological samples, the amount of Ba added in the three glasses were increased by a factor of ~4. Due to the limited amount of other element solutions, the values of Th and U are significantly lower than other trace elements, as well as for ARM-1 and ARM-2.

The glasses were prepared at the China Building Materials Academy, China, by a procedure outlined in Figure 1. Briefly, a total of 3.8 kg mixed oxide powders in a designed proportion were fused at a temperature of 1550–1600 °C. About 20 g of As$_2$O$_3$ was added into the sample to help complete degassing of the melts, which results in a 3500 μg g$^{-1}$ As in final glasses. A thin-walled platinum crucible was used to contain the melts. The melts were held at 1550 to 1600 °C for 4 h and then stirred for 5 h at a
speed of 20 rpm using a Pt80Rh20 spindle immersed into the melts. Stirring is a necessary procedure to achieve complete homogeneity of the highly viscous melt (Jochum et al. 2000). The spindle was removed from the melt, and the melt removed rapidly from the furnace and quenched by pouring into a custom designed mould at ambient temperature. Homogeneous, bubble-free glass blocks of about 3.0 kg were obtained by this procedure. The glasses were further annealed at 600 °C for 1 h and then cut as 10 mm × 10 mm × 3 mm glass splits (n > 800).

Because of long and high-temperature melting procedure, loss of volatile (e.g., Tl) was unavoidable. Potential sources of contaminations included Pt crucibles, remnants of previous samples and all other furnace components. ARM-2 glass was contaminated by the remnants of previous samples (Li, B, Zn and Yb) that were fused previously in the same crucible. However, even though the melts might be depleted by volatility or contaminated by furnace components, stirring and homogenisation ensured homogeneity of elements.

**Analytical techniques for ARM glasses**

The ARM glasses were characterised by different bulk and microanalytical techniques in ten laboratories from five institutions: MPI Mainz (Germany), NRCG, Beijing, China, Institute of Geology and Geophysics, Chinese Academy of Sciences, China (IGGCAS), Leibniz Universiität Hannover, Germany (LUH) and China University of Geosciences, Beijing, China (CUG). Electron probe microanalysis (EPMA) was conducted at LUH for major element characterisation. Two ICP-OES analyses were undertaken at NRCG and IGGCAS, respectively. The digestion procedure is given by Wu et al. (2014). X-ray fluorescence spectrometry (XRF) was performed at IGGCAS. Two LA-ICP-MS analyses were conducted for trace element characterisation at NRCG and IGGCAS, respectively. Two LA-Q-ICP-MS measurements were performed at CUG and IGGCAS. Two LA-SF-ICP-MS measurements were conducted at MPI Mainz and IGGCAS, respectively. The analytical procedure at MPI Mainz is given by Jochum et al. (2007). The analytical procedure at IGGCAS is similar as outlined by Wu et al. (2018b). All the LA-ICP-MS measurements used NIST SRM 610 as the calibration material and Ca as the internal standard. The Ca values were collected as averaged results from XRF, ICP-OES and EPMA. The detail information on the above analytical techniques is summarised in Appendix S2.

**Acquisition method for LA-SF-ICP-MS**

Seventy-seven isotopes (from 7Li to 238U for sixty-eight elements) could be swept in only 1 s using this acquisition method. The dwell time and mass settling times (both for electrostatic analyser jumps and for magnet jumps, including the jump back from 238U to 7Li) are given in Appendix S1 (Table S2). This method covers almost all elements of interest in geochemistry (e.g., LILE, HFSE, REEs and Th, U). The total sampling time for all scanned isotopes was 770 ms and total magnet settling time was 230 ms. Hence, the acquisition efficiency is estimated at about 77%. This acquisition method was achieved by simply reducing the magnet settling time and the number of samplings per peak (see details in Appendix S1, Table S2). For this approach, the

![Scheme of the preparation of ARM glasses.](image)

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stability, as revealed by the intermediate measurement precision, and the accuracy, as demonstrated by measurement data of reference glasses, needed to be confirmed for practical application of this acquisition method (as outlined in the Results and discussion section).

The experiments were performed at Geowissenschaftliches Zentrum Göttingen, University of Göttingen Germany (GZG) and IGGCAS. A RESolution M-50 laser ablation system (Australian Scientific Instruments, Australia) coupled to an Element 2 sector-field ICP-MS (Thermo Fisher Scientific, Bremen, Germany) was used in GZG. A Photo Machine G2 laser ablation system (Teledyne CETAC technologies, USA) coupled to an Element XR sector-field ICP-MS (Thermo Fisher Scientific, Bremen, Germany) was used in IGGCAS. Daily optimisation of instrumental performance with NIST SRM 612 involved maximising the signal-to-background intensity ratios for Sr, La and U, while satisfying low oxide production rates ($\text{ThO}^+ / \text{Th}^+ < 0.5\%$), low secondary ions ($\text{Ca}^{2+} / \text{Ca}^+ < 1.0\%$) and robust plasma conditions (sensitivity ratio $S(\text{U}^+) / S(\text{Th}^+)$ in a range of 0.95–1.05).

Homogeneity test

The homogeneity of the glass at bulk and microscale was evaluated using ICP-OES, ICP-MS, EPMA, LA-Q-ICP-MS and LA-SF-ICP-MS. For the bulk-scale homogeneity test, ICP-OES and ICP-MS techniques were used. Both techniques require 50–100 mg samples. The homogeneity of major elements was evaluated using EPMA technique at LUH. For this approach, the homogeneity was assessed by comparing the standard deviation of all measurements ($n = 30$) with the predicted error resulting from the counting statistics of the raw signals. The error by counting statistics took the Gaussian error propagation of the respective three measurement signals (peak signal, lower-, upper-background signal) into account. Three laboratories (MPI, IGGCAS and CUG) conducted a LA-Q (SF)-ICP-MS homogeneity test. For this technique, we define chemical heterogeneities as variations in elemental mass fraction that are excess of the analytical precision.

Results and discussion

Capability of LA-SF-ICP-MS for large mass range (7Li to 238U) multiple-element determination

Analytical results of the andesitic MPI-DING StHs6/80-G ($n = 359$), which were collected at GZG over 3 years from 2015 to 2017, are provided to demonstrate the precision and accuracy of the proposed method. The (long-term) analytical reproducibility is plotted in Figure 2. Analytical results were calculated using NIST SRM 610 as calibration material and Ca as an internal standard. Figure 2a documents the long-term analytical reproducibility (given as 1RSD %) of Ce in StHs6/80-G is 3.94%, which is around two times larger than the short-term precision (Appendix S3, Figure S1). For practical purposes, it is reasonable to take the daily instrumental variation into consideration rather than long-term variations over years. Figure 2b shows the histogram distribution of Ce results ($n = 359$) that clearly
indicates a Gaussian distribution, further demonstrating that the stability of our acquisition method is practical for multiple-element quantification.

To validate the accuracy of this acquisition method, T1-G, BCR-2G and CGSG-4 reference glasses were analysed using NIST SRM 610, GSD-1G and StHs6/80-G as calibration materials, and Ca as internal standard element. The red line represents the mean results from using three calibrators. The relative deviations are given as the discrepancy (%) with the reference values [(analysed results-reference values)/reference values *100]. The results and standard deviations of T1-G, BCR-2G and CGSG-4 are derived from 78, 73 and 29 repeated analyses. The grey zone represents the uncertainty of reference values at 95% confidence level. The results of our major element analysis match reference values within 5%, except TiO₂, FeO, MgO, K₂O that were calibrated using NIST SRM 610. Trace elements results are in agreement with reference values within 10%. Exceptions are observed for Pb in T1-G and Zn in BCR-2G and CGSG-4. [Colour figure can be viewed at wileyonlinelibrary.com]
Table 1. LA-SF-ICP-MS measurement results for USGS NKT-1G and TB-1G reference glasses

| Elements | USGS NKT-1G | Information value | This study (n = 8) | USGS TB-1G | Information value | This study (n = 8) |
|----------|-------------|-------------------|-------------------|------------|-------------------|-------------------|
|          | Value       | 2s                | Value             | 2s         | Value             | 2s                |
| SiO₂     | 38.9        | 38.6              | 1.9               | 54.3       | 53.8              | 1.1               |
| TiO₂     | 3.92        | 3.64              | 0.09              | 0.84       | 0.87              | 0.04              |
| Al₂O₃    | 10.5        | 10.1              | 0.5               | 17.1       | 16.5              | 0.6               |
| FeO(Ⅱ)  | 12.2        | 12.4              | 0.5               | 8.67       | 8.27              | 0.54              |
| MnO      | 0.24        | 0.21              | 0.03              | 0.18       | 0.18              | 0.02              |
| MgO      | 14.2        | 14.0              | 1.8               | 3.51       | 3.51              | 0.07              |
| CaO      | 13.4        |                   | 6.7               |            |                   |                   |
| Na₂O     | 3.85        | 3.48              | 0.19              | 3.56       | 3.10              | 0.09              |
| K₂O      | 1.27        | 1.33              | 0.14              | 4.52       | 4.43              | 0.31              |
| P₂O₅     | 0.95        | 0.95              | 0.15              | 0.61       | 0.56              | 0.07              |
| Li       | –           |                   | –                 |            |                   |                   |
| Be       | –           |                   | –                 |            |                   |                   |
| B        | –           |                   | –                 |            |                   |                   |
| Sc       | –           | 23.3              | 2.3               | 23.0       | 22.6              | 3.0               |
| Y        | –           | 300               | 10                | 1.79       | 1.99              | 7                 |
| Cr       | –           | 508               | 18.4              | 55.8       | 56.1              | 3.0               |
| Co       | –           | 67.2              | 2.3               | 22.8       | 23.2              | 1.1               |
| Ni       | –           | 352               | 41                | 14.5       | 17.6              | 0.4               |
| Cu       | –           | 543               | 4.4               | 76.1       | 79.4              | 6.7               |
| Zn       | –           | 152               | 25                | 106        | 127               | 21                |
| Ga       | –           | 27.7              | 1.1               | 23.6       | 23.2              | 1.4               |
| Rb       | 30.7        | 33.7              | 3.1               | 142        | 151               | 10                |
| Sr       | 1195        | 1192              | 30                | 1352       | 1295              | 41                |
| Yb       | 32.0        | 27.6              | 2.1               | 26.4       | 23.4              | 2.6               |
| Zr       | 310         | 278               | 30                | 245        | 224               | 32                |
| Nb       | 95.9        | 89.9              | 6.8               | 29.8       | 27.7              | 2.2               |
| Mo       | –           | 0.86              | 0.14              | –          | 1.45              | 0.15              |
| Sn       | –           | 2.95              | 0.58              | –          | 1.76              | 0.19              |
| Sb       | –           | –                 | –                 | –          | –                 | –                 |
| Cs       | –           | –                 | 0.10              | –          | –                 | –                 |
| Ba       | 753         | 773               | 58                | 976        | 939               | 50                |
| La       | 63.3        | 63.5              | 2.0               | 44.1       | 43.5              | 1.6               |
| Ce       | 126         | 134               | 5                 | 92.0       | 87.4              | 1.8               |
| Pr       | –           | 15.1              | 0.7               | 10.7       | 9.9               | 0.4               |
| Nd       | 61.4        | 61.3              | 1.9               | 40.1       | 38.2              | 2.4               |
| Sm       | 12.3        | 12.0              | 0.4               | 7.23       | 6.99              | 0.49              |
| Eu       | 3.75        | 3.73              | 0.18              | 1.81       | 1.73              | 0.12              |
| Gd       | 10.1        | 10.1              | 0.7               | 5.79       | 5.65              | 0.61              |
| Tb       | 1.30        | 1.27              | 0.07              | 0.78       | 0.76              | 0.06              |
| Dy       | 6.69        | 6.64              | 0.68              | 4.79       | 4.38              | 0.61              |
| Ho       | 1.09        | 1.08              | 0.06              | 0.90       | 0.86              | 0.08              |
| Er       | 2.54        | 2.53              | 0.29              | 2.67       | 2.53              | 0.38              |
| Tm       | 0.30        | 0.30              | 0.03              | 0.41       | 0.36              | 0.04              |
| Yb       | 1.79        | 1.72              | 0.18              | 2.64       | 2.47              | 0.30              |
| Lu       | 0.23        | 0.22              | 0.02              | 0.39       | 0.37              | 0.05              |
| Hf       | 6.44        | 6.34              | 0.39              | 5.93       | 5.46              | 0.34              |
| Ta       | 4.99        | 4.70              | 0.58              | 1.60       | 1.40              | 0.17              |
| Pb       | 3.10        | 3.59              | 0.87              | 16.8       | 18.1              | 4.4               |
| Th       | 7.35        | 6.87              | 0.44              | 15.1       | 13.8              | 1.2               |
| U        | 2.28        | 2.23              | 0.17              | 4.11       | 4.08              | 0.24              |

Element mass fractions were calculated as the mean using NIST SRM 610, MPI-DING StHs6/80-G and USGS GSD-1G as calibration materials with Ca as the internal standard element. Major and trace element mass fractions are given in % m/m and µg g⁻¹, respectively. ‘–’ means that data are not available or lower than the detection limit. 2s is derived from the corresponding number of measurements. Several elements due to low mass fractions (Ti, Fe, Mn, Mg, K and P in NIST SRM 610, Be, Mo and Sb in StHs6/80-G) or potential under/overestimated certified values (Cr, Ni in StHs6/80-G and Sn, Sb in GSD-1G) may result in imprecise calibrations. Thus, these elements in corresponding calibration materials were not used for the calibration procedure.
uncertainty of reference values. It is important to point out that, although we collected signal data for sixty-eight elements, only fifty elements were quantified, mainly because of very low mass fractions that are near or below the detection limit for the other elements. In Appendix S3 (Figure S3), we compare the results of NIST SRM 612, ML3B-G and BCR-2G obtained from GZG and IGGCAS. These two independent laboratories yielded very similar and accurate results, further demonstrating the reliability of our LA-SF-ICP-MS technique for multiple-element quantification.

All the above results indicate that our acquisition method for Element 2 or Element XR is useful for a wide mass range (from $^7$Li to $^{238}$U) multiple-element quantification and yields reliable results. Compared with Q-ICP-MS, the sensitivity of Element 2 or Element XR is higher by a factor of 3–5, which allows smaller beam sizes and thus results in improved spatial resolution. Here, the results of USGS NKT-1G and TB-1G using the LA-SF-ICP-MS are reported (Table 1). Information values collected from Elburg et al. (2005) and Kimura and Chang (2012) are listed for comparison (Table 1). The values of these two reference glasses have been rarely reported, and our data may be useful for the certification procedures.

### Homogeneity

The homogeneity of major and trace elements is a fundamental requirement of any reference material. Tables 2 and 3 illustrate that there is no statistical difference between

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**Table 2. Major element mass fractions in ARM-1, ARM-2 and ARM-3**

|          | ICP-OES $^a$ (n = 4) | ICP-OES $^b$ (n = 4) | XRF (n = 3) | EPMA (n = 30) | LA-ICP-MS (n = 225) |
|----------|----------------------|----------------------|-------------|---------------|---------------------|
|          | Value    | 2s   | Value    | 2s   | Value    | 2s   | Value    | 2s   | Value    | 2s   |
| ARM-1    |          |      |          |      |          |      |          |      |          |      |
| SiO$_2$  |          | 58.4 | 0.1     | 58.1 | 0.4     | 58.7 | 0.4     |      |          |      |
| TiO$_2$  | 0.94     | 0.01 | 1.02    | 0.02 | 0.99    | 0.01 | 0.99    | 0.06 | 0.95    | 0.07 |
| Al$_2$O$_3$ | 13.2   | 0.2  | 13.3    | 0.1  | 13.4    | 0.1  | 13.4    | 0.4  |          |      |
| FeO$\text{(t)}$ | 5.67   | 0.03 | 5.79    | 0.02 | 5.61    | 0.02 | 5.79    | 0.26 |          |      |
| MnO      | 0.05     | 0.01 | 0.05    | 0.02 | 0.02    | 0.01 | 0.04    | 0.04 | 0.05    | 0.01 |
| MgO      | 3.64     | 0.03 | 3.95    | 0.01 | 3.75    | 0.02 | 3.76    | 0.12 |          |      |
| CaO      | 5.00     | 0.05 | 5.09    | 0.06 | 5.08    | 0.02 | 5.12    | 0.22 |          |      |
| K$_2$O   | 3.11     | 0.03 | 3.16    | 0.03 | 3.13    | 0.02 | 3.12    | 0.08 |          |      |
| P$_2$O$_5$ | 4.47   | 0.07 | 4.44    | 0.03 | 4.43    | 0.02 | 4.36    | 0.20 |          |      |
| ARM-2    |          |      |          |      |          |      |          |      |          |      |
| SiO$_2$  |          | 58.3 | 0.1     | 57.6 | 0.3     | 57.8 | 0.5     |      |          |      |
| TiO$_2$  | 0.92     | 0.01 | 1.03    | 0.02 | 0.97    | 0.01 | 0.97    | 0.06 | 0.99    | 0.09 |
| Al$_2$O$_3$ | 13.0   | 0.2  | 13.3    | 0.1  | 13.0    | 0.1  | 13.1    | 0.2  |          |      |
| FeO$\text{(t)}$ | 5.63   | 0.14 | 5.84    | 0.07 | 5.68    | 0.04 | 5.71    | 0.24 |          |      |
| MnO      | 0.05     | 0.01 | 0.05    | 0.05 | 0.05    | 0.01 | 0.06    | 0.06 | 0.06    | 0.01 |
| MgO      | 3.65     | 0.07 | 3.90    | 0.01 | 3.76    | 0.02 | 3.65    | 0.20 |          |      |
| CaO      | 4.89     | 0.11 | 5.04    | 0.02 | 5.06    | 0.04 | 5.05    | 0.24 |          |      |
| K$_2$O   | 4.36     | 0.04 | 4.44    | 0.01 | 4.48    | 0.01 | 4.40    | 0.22 |          |      |
| P$_2$O$_5$ | 2.92   | 0.05 | 3.04    | 0.02 | 3.00    | 0.02 | 3.05    | 0.10 |          |      |
| ARM-3    |          |      |          |      |          |      |          |      |          |      |
| SiO$_2$  |          | 60.8 | 0.1     | 60.3 | 0.5     | 60.4 | 0.6     |      |          |      |
| TiO$_2$  | 0.97     | 0.01 | 1.06    | 0.02 | 1.01    | 0.01 | 1.02    | 0.06 | 1.01    | 0.10 |
| Al$_2$O$_3$ | 13.8   | 0.3  | 13.8    | 0.1  | 13.8    | 0.1  | 13.8    | 0.2  |          |      |
| FeO$\text{(t)}$ | 5.95   | 0.10 | 5.77    | 0.09 | 5.92    | 0.02 | 6.00    | 0.24 |          |      |
| MnO      | 0.05     | 0.01 | 0.05    | 0.02 | 0.05    | 0.01 | 0.05    | 0.04 | 0.05    | 0.01 |
| MgO      | 3.41     | 0.04 | 3.63    | 0.01 | 3.52    | 0.01 | 3.50    | 0.16 |          |      |
| CaO      | 5.25     | 0.07 | 5.34    | 0.09 | 5.37    | 0.05 | 5.34    | 0.30 |          |      |
| K$_2$O   | 4.64     | 0.06 | 4.62    | 0.06 | 4.64    | 0.02 | 4.74    | 0.24 |          |      |
| P$_2$O$_5$ | 3.14   | 0.06 | 3.25    | 0.11 | 3.16    | 0.05 | 3.18    | 0.08 |          |      |

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ARM-1, ARM-2 and ARM-3 were analysed by XRF, ICP-OES and EPMA. Data are given in % m/m. ICP-OES $^a$ represents ICP-OES at IGGCAS. ICP-OES $^b$ represents ICP-OES at NRCG.
two ICP-OES and two ICP-MS measurements, except for TiO₂ and MgO, which are presumably caused by a systematic analytical bias of the technique using different calibration procedures. The obtained homogeneity factors (standard deviation/predicted error) from EPMA for major elements scatter around unity and do not exceed a value of 2.0 (Harries 2014). Therefore, all these ARM glasses can be regarded as homogeneous within the spatial resolution (10 \( \mu m \)) of the microprobe for all major elements.

The homogeneity within and between glass splits of trace elements was evaluated using the LA-Q (SF)-ICP-MS in three laboratories. In IGGCAS, thirty-one glass splits were randomly picked from \(~800\) splits for each ARM glass. Five spot analyses (spot size: 50 \( \mu m \)) have been randomly located in each glass split. Figure 4 plots the La mass fractions obtained for ARM-2. A total of 155 spot analyses yielded an RSD of 3.18%, which is comparable to that of well-characterised and homogenous MPI-DING reference glasses (Figure 5). The data scatter follows a Gaussian distribution. Appendix S3 (Figure S4) shows the RSDs of other elements in ARM glasses. Most RSDs are smaller than 4%, except Be and Cr in ARM-1 glasses. LA-SF-ICP-MS measurements at MPI were done on five glass splits randomly picked from a total of \(~800\) splits. Each glass was analysed with nine spots (spot size: 80 \( \mu m \), length: 300 \( \mu m \)) and nine lines (spot size: 80 \( \mu m \), length: 300 \( \mu m \)). Spot analysis yields an RSD of only about 1.2%, which emphasises the high homogeneity of the glasses and the reproducibility of the measurements as well. The mean RSD for the line scanning analysis is about 2% except for ARM-3 (ca. 7%), which is caused by one extremely high outlier value. We attribute these high outlier values to instrument/technical problems instead of random scatters. At CUG, homogeneity was evaluated on a large glass split (10 mm x 10 mm) with a profile line analysis with 40 spots (spot size: 50 \( \mu m \)) at a spacing of approximately 150 \( \mu m \). Mean RSD values were 1.0%, 1.7% and 2.5% for ARM-1, ARM-2 and ARM-3, respectively.
In Figure 5, a comparison of the RSD between well-characterised MPI-DING glasses and ARM glasses is plotted. There is a significant negative linear correlation between mass fraction and RSD on a logarithmic scale for MPI-DING glasses. This trend follows a Poisson counting uncertainty, demonstrating that the measurement reproducibility is derived from the counting statistics of the measurements. Therefore, the RSD obtained for MPI-DING glass defines the LA-ICP-MS analytical precision. The results illustrate that the mean of RSD of ARM-1, ARM-2 and ARM-3 from all three laboratories is within the range of the LA-ICP-MS measurement precision. This demonstrates that the homogeneity of our new ARM glasses is as good as the well-characterised MPI-DING glasses, which are widely used as LA-ICP-MS reference materials (Jochum et al. 2000, 2006). Homogeneity of the three ARM glasses was further demonstrated by ICP-OES, ICP-MS, EPMA and LA-ICP-MS measurements on a small scale (within a glass split) and large scale (between glass splits) (see Tables 2 and 3).

Characterisation of the ARM glasses

Table 2 lists the measurement results for major elements in the ARM glasses obtained by XRF, ICP-OES, EPMA and LA-ICP-MS (only for TiO₂, MnO and P₂O₅) and includes the total analytical uncertainties (%) of the used techniques. The consistency of the mass fraction data obtained by different methods is a measure of their analytical quality. Two ICP-OES analyses of ARM glasses were performed on different glass splits. The data agree within 3% of relative deviation, except TiO₂ and MgO. These differences are presumably caused by a systematic analytical bias of the technique using different calibration procedures, because these differences were observed for all ARM glasses. The total major oxides are below 100%, which is due to the addition of about 0.5% As₂O₅ to assure degassing of the melts, contamination by the Li-B flux (only for ARM-2) and of trace elements added (in particular for ARM-1).

Table 3 summarises the trace element data for the ARM glasses obtained by XRF, ICP-OES, ICP-MS and LA-ICP-MS. Two ICP-MS analyses were performed on different glass splits. All LA-ICP-MS data were calibrated with NIST SRM 610 and using Ca as the internal standard. Calcium contents were taken as the mean of XRF, ICP-OES and EPMA measurements. This may be important for data traceability and comparison with other data from other techniques. Figure 6 illustrates that all data agree well for most elements.
Table 3. Measurement results for trace elements in ARM-1, ARM-2 and ARM-3 determined by XRF, ICP-OES, ICP-MS and LA-ICP-MS

| ARM-1 | XRF | ICP-OES | ICP-MS | ICP-MS | LA-SF-ICP-MS | LA-Q-ICP-MS | LA-Q-ICP-MS | LA-SF-ICP-MS |
|-------|-----|---------|--------|--------|-------------|-------------|-------------|-------------|
| Li     | 464 | 535     | 478    | 490    | 528         | 510         | 523         | 557         |
| Be     | 452 | 463     | 486    | 492    | 475         | 420         | 475         | 534         |
| B      | 500 | 455     | 529    | 467    | 504         | 497         | 497         | 524         |
| Sc     | 453 | 481     | 417    | 280    | 511         | 438         | 438         | 474         |
| V      | 553 | 557     | 544    | 535    | 592         | 584         | 591         | 611         |
| Cr     | 438 | 614     | 418    | 422    | 442         | 440         | 444         | 456         |
| Co     | 506 | 508     | 475    | 503    | 494         | 477         | 505         | 510         |
| Ni     | 515 | 451     | 454    | 448    | 476         | 470         | 491         | 510         |
| Cu     | 430 | 396     | 430    | 426    | 457         | 452         | 487         | 491         |
| Zn     | 501 | 580     | 571    | 588    | 552         | 629         | 591         | 591         |
| Ga     | 488 | 472     | 565    | 509    | 453         | 461         | 475         | 491         |
| Ge     | 588 | 593     | 564    | 626    | 655         | 685         | 685         | 685         |
| As     | -   | -       | -      | -      | -           | -           | -           | -           |
| Rb     | 477 | 471     | 449    | 443    | 498         | 503         | 517         | 530         |
| Sr     | 458 | 458     | 453    | 450    | 479         | 461         | 477         | 480         |
| Y      | 493 | 409     | 437    | 444    | 460         | 443         | 443         | 467         |
| Zr     | 417 | 465     | 430    | 438    | 445         | 430         | 432         | 456         |
| Nb     | 498 | 501     | 452    | 463    | 466         | 442         | 471         | 477         |
| Mo     | 496 | 459     | 447    | 485    | 492         | 500         | 500         | 520         |
| Cd     | 450 | 467     | 468    | 465    | 423         | 517         | 451         | 510         |
| Sn     | -   | -       | -      | -      | -           | -           | -           | -           |
| Cs     | 487 | 556     | 552    | 590    | 598         | 622         | 622         | 633         |
| Ba     | 2170| 40      | 1970   | 20     | 2070        | 2070        | 2120        | 2080        |
| Ca     | 471 | 480     | 436    | 443    | 452         | 452         | 456         | 449         |
| Pr     | 475 | 409     | 425    | 435    | 456         | 466         | 466         | 449         |
| Nd     | 486 | 466     | 417    | 415    | 425         | 402         | 431         | 419         |
| Sm     | 483 | 494     | 442    | 450    | 463         | 411         | 465         | 468         |
| Eu     | 490 | 452     | 436    | 443    | 467         | 448         | 448         | 467         |
| Gd     | 487 | 445     | 427    | 442    | 445         | 419         | 446         | 454         |
| Tb     | 474 | 480     | 411    | 419    | 431         | 406         | 431         | 430         |
Table 3 (continued).

Measurement results for trace elements in ARM-1, ARM-2 and ARM-3 determined by XRF, ICP-OES, ICP-MS and LA-ICP-MS

|          | XRF | ICP-OES \(^2\) | ICP-MS \(^1\) | ICP-MS \(^2\) | LA-SF-ICP-MS \(^3\) | LA-Q-ICP-MS \(^4\) | LA-Q-ICP-MS \(^1\) | LA-SF-ICP-MS \(^1\) |
|----------|-----|----------------|---------------|---------------|---------------------|---------------------|---------------------|---------------------|
|          | \(n = 4\) | \(n = 4\) | \(n = 4\) | \(n = 45\) | \(n = 45\) | \(n = 40\) | \(n = 20\) | \(n = 100\) | \(n = 15\) |
| Dy       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Ho       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Er       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Tm       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Yb       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Lu       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Hf       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Ta       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| W        | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Ti       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Pb       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Bi       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| Th       | –    | –              | –             | –             | –                   | –                   | –                   | –                   |
| U        | –    | –              | –             | –             | –                   | –                   | –                   | –                   |

**Values**

| Element | XRF | ICP-MS \(^1\) | ICP-MS \(^2\) | LA-SF-ICP-MS \(^3\) | LA-Q-ICP-MS \(^4\) | LA-Q-ICP-MS \(^1\) | LA-SF-ICP-MS \(^1\) |
|---------|-----|---------------|---------------|---------------------|---------------------|---------------------|---------------------|
| Dy      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Ho      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Er      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Tm      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Yb      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Lu      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Hf      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Ta      | –    | –             | –             | –                   | –                   | –                   | –                   |
| W       | –    | –             | –             | –                   | –                   | –                   | –                   |
| Ti      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Pb      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Bi      | –    | –             | –             | –                   | –                   | –                   | –                   |
| Th      | –    | –             | –             | –                   | –                   | –                   | –                   |
| U       | –    | –             | –             | –                   | –                   | –                   | –                   |

**Values**

| Element | XRF | ICP-MS \(^1\) | ICP-MS \(^2\) | LA-SF-ICP-MS \(^3\) | LA-Q-ICP-MS \(^4\) | LA-Q-ICP-MS \(^1\) | LA-SF-ICP-MS \(^1\) |
|---------|-----|---------------|---------------|---------------------|---------------------|---------------------|---------------------|
| Li      | 1100 30 | 1220 20 | 11500 10 | 11500 20 | 1280 30 | 1310 30 | 1340 40 | 1340 10 |
| Be      | 51.5 2.0 | 516 1.3 | 554 1.0 | 548 1.2 | 542 3.8 | 554 7.4 | 568 38 | 580 6.4 |
| B       | 9810 460 | – | – | 10700 400 | 8220 220 | 10560 360 | 11610 290 | 112200 530 | 11370 140 |
| Sc      | 47.7 1.1 | 536 1.0 | 517 0.7 | 525 1.4 | 517 1.1 | 517 0.7 | 507 2.6 | 526 1.4 |
| V       | 53.7 5.3 | 506 1.0 | 555 0.7 | 534 0.6 | 577 1.4 | 593 1.6 | 588 2.1 | 589 1.1 |
| Cr      | 58.6 1.1 | 600 1.2 | 600 0.9 | 578 1.2 | 592 1.5 | 590 2.0 | 611 1.9 | 606 0.6 |
| Nb      | 62.6 5.2 | 631 0.8 | 572 1.5 | 573 1.9 | 535 2.7 | 579 2.5 | 589 3.2 | 607 2.6 | 615 1.3 |
| Cu      | 47.5 6.1 | 550 2.9 | 517 1.7 | 548 1.2 | 525 1.0 | 566 1.5 | 583 0.6 | 638 2.6 | 603 0.8 |
| Sn      | 4830 70 | 4500 70 | 5130 70 | 4290 90 | 5480 110 | 5190 190 | 5260 120 | 5080 1700 | 5850 300 | 5580 100 |
| Ga      | 657 1.1 | 673 0.5 | 790 2.5 | 703 1.1 | 653 2.0 | 699 2.3 | 714 4.5 | 702 1.1 |
| Ge      | 57.7 1.5 | – | – | 673 0.7 | 622 1.6 | 678 1.7 | 726 3.6 | 759 4.0 | 748 4.0 |
| As      | – | – | – | 3570 100 | 3350 120 | 3200 70 | 3430 50 | 3750 170 | 3560 40 |
| Sb      | 51.3 2.5 | 549 1.1 | 565 0.7 | 546 1.3 | 581 1.7 | 612 1.8 | 625 1.9 | 619 0.6 |
| Sr      | 63.6 1.0 | 614 0.8 | 601 1.1 | 657 0.3 | 656 1.1 | 656 1.4 | 655 1.4 | 654 2.6 | 651 0.7 |
| Y       | 51.1 1.0 | 47.8 1.3 | 519 0.9 | 525 1.9 | 520 1.3 | 520 2.1 | 498 2.8 | 512 1.3 |
| Zr      | 55.3 1.8 | 500 0.9 | 527 1.3 | 602 1.2 | 597 2.1 | 591 1.6 | 592 1.7 | 570 3.4 | 583 1.8 |
| Nb      | 51.4 1.2 | 602 1.5 | 592 1.0 | 595 1.0 | 571 1.3 | 553 0.6 | 589 2.0 | 575 0.8 |
| Mo      | 54.1 1.4 | – | – | 561 1.1 | 526 1.3 | 569 2.1 | 611 1.5 | 596 2.7 | 603 1.9 |
Table 3 (continued).
Measurement results for trace elements in ARM-1, ARM-2 and ARM-3 determined by XRF, ICP-OES, ICP-MS and LA-ICP-MS

| Element | XRF | ICP-OES | ICP-MS | LA-SF-ICP-MS | LA-Q-ICP-MS | LA-Q-ICP-MS | LA-SF-ICP-MS |
|---------|-----|---------|--------|--------------|-------------|-------------|--------------|
|         | Spot | Line | Spot | Spot | Spot | Spot | Spot | Spot | Spot |
| Cl      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Sn      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Sb      | 531  | 0.3   | 684   | 1.1 | 603 | 1.9  | 629 | 1.8  | 649   | 1.6 | 685  | 3.1 | 66.6 | 0.9 |
| Cs      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Ba      | 269  | 78    | 214   | 5    | 245 | 3    | 245 | 3    | 245   | 3   | 250  | 9  | 245   | 6  |
| La      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Ce      | 51.3 | 0.7   | 55.6  | 1.1 | 51.9 | 0.8  | 52.5 | 0.9  | 51.7  | 1.0 | 51.4 | 0.8 | 51.2 | 2.3 | 50.1 | 0.6 |
| Pr      | 58.4 | 0.7   | 589   | 1.2 | 554 | 0.5  | 559 | 1.0  | 541  | 1.3 | 540  | 4.3 | 541  | 3.4 | 53.5 | 2.4 |
| Nd      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Sm      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Eu      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Gd      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Tb      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Dy      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Ho      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Er      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Tm      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Yb      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Lu      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Hf      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Ta      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| W       | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| Th      | –    | –     | –     | –    | –    | –    | –    | –    | –    |
| U       | –    | –     | –     | –    | –    | –    | –    | –    | –    |

Table continues on next page.
Table 3 (continued).

Measurement results for trace elements in ARM-1, ARM-2 and ARM-3 determined by XRF, ICP-OES, ICP-MS and LA-ICP-MS.

|          | XRF | ICP-OES | ICP-MS | LA-SF-ICP-MS | LA-Q-ICP-MS (Exp.1) | LA-Q-ICP-MS (Exp.2) |
|----------|-----|---------|--------|--------------|---------------------|---------------------|
| Values   | n=4 | n=4    | n=4    | n=45         | n=40                | n=100               |
| Values   | 2s  | Values | 2s     | Values 2s    | Values 2s           | Values 2s           |
| Co       | 7.61| 0.19   | 7.59   | 0.40         | 7.25                | 0.26                | 7.58 | 0.18 | 7.44 | 0.36 | 6.70 | 0.36 | 7.76 | 0.33 | 7.67 | 0.22 |
| Ni       | 1.30| 0.56   | 1.44   | 0.69         | 1.31                | 0.35                | 2.91 | 1.24 | 0.40 | 1.06 | 0.75 | 1.06 | 1.07 | 0.97 | 1.07 | 0.97 |
| Cu       | 29.1| 3.24   | 30.0   | 0.90         | 17.2                | 0.40                | 8.19 | 0.64 | 1.64 | 0.40 | 7.38 | 0.40 | 7.14 | 0.64 | 1.64 | 0.40 |
| Zn       | 7.61| 0.19   | 7.59   | 0.40         | 7.25                | 0.26                | 7.58 | 0.18 | 7.44 | 0.36 | 6.70 | 0.36 | 7.76 | 0.33 | 7.67 | 0.22 |
| Ga       | 7.61| 0.19   | 7.59   | 0.40         | 7.25                | 0.26                | 7.58 | 0.18 | 7.44 | 0.36 | 6.70 | 0.36 | 7.76 | 0.33 | 7.67 | 0.22 |
| Ge       | 7.61| 0.19   | 7.59   | 0.40         | 7.25                | 0.26                | 7.58 | 0.18 | 7.44 | 0.36 | 6.70 | 0.36 | 7.76 | 0.33 | 7.67 | 0.22 |

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although quite different techniques were applied. Nearly all the lithophile elements are in agreement within ± 15%. The poor agreement observed for some chalcophile/siderophile elements (Cu, Zn, Ni and Tl) may be attributed to their low abundances (Tl in ARM-2) and/or analytical limitations. The solution ICP-MS data are in agreement with the LA-ICP-MS results (Figure 6), also demonstrating the good quality of LA-ICP-MS analytical measurements.

**Preliminary reference values**

The three ARM glasses were made to provide new reference materials for geochemical, microanalytical in situ techniques, in particular for LA-ICP-MS. It is desirable that these glasses should comply with the ISO definition of a reference material, namely a ‘material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials’ (ISO Guide 30, 1992). However, the number of analytical data presented here is still insufficient for a certification procedure defined by ISO Guide 35. Therefore, we follow the IAG recommendations to determine preliminary reference values for the ARM glasses. Traceability is a key concept in the characterisation of reference materials. In this study, the traceability of our analytical results was established by the use of international reference materials for calibrations and by using various analytical techniques. NIST SRM 610 was used as the calibration material and Ca as the internal standard for all LA-ICP-MS analyses; thus, our LA-ICP-MS data are traceable to the well-characterised NIST SRM 610. All chemical data are reported here with analytical uncertainties. The collaborating laboratories have previously demonstrated their analytical competence using well-established methods. Therefore, the results of analytical data presented here for the ARM glasses are robust and the averaged analytical results from different laboratories using independent techniques can be considered reliable preliminary reference values for the ARM glasses. Statistical outliers were excluded as they are probably caused by technical problems during analysis or are due to calibration errors. Results listed in Table 4 are classified into two categories: preliminary reference values and information values. Preliminary reference values are reported when data obtained from at least three laboratories using three or more independent, well-defined techniques were in statistical agreement. Their quoted uncertainties are defined as two times the standard error (2SE, standard deviation of the mean of n contributing laboratory mean data). Information values with a standard deviation of the mean are derived from the data of at least two laboratories using two
Table 4. Preliminary values (in bold) and information values for ARM-1, ARM-2 and ARM-3

| Elements | Values | 2SE | 2RSE (%) | n |
|----------|--------|-----|----------|---|
| SiO₂     | 58.4   | 0.5 | 0.8      | 2 |
| TiO₂     | 0.98   | 0.03| 2.8      | 4 |
| Al₂O₃    | 13.3   | 0.1 | 0.5      | 4 |
| FeO      | 5.72   | 0.13| 1.4      | 4 |
| MgO      | 3.78   | 0.11| 2.9      | 4 |
| CaO      | 5.07   | 0.06| 0.9      | 4 |
| Na₂O     | 4.43   | 0.04| 0.9      | 4 |
| K₂O      | 3.13   | 0.02| 0.6      | 4 |
| P₂O₅     | 0.26   | 0.01| 3.6      | 3 |
| K        | 511    | 21  | 4.1      | 8 |
| Ca       | 475    | 22  | 4.6      | 8 |
| Mg       | 463    | 52  | 11.2     | 8 |
| Sc       | 428    | 42  | 9.8      | 8 |
| V        | 575    | 19  | 3.3      | 8 |
| Cr       | 463    | 38  | 8.3      | 9 |
| Co       | 497    | 9   | 1.8      | 8 |
| Ni       | 473    | 17  | 3.7      | 9 |
| Cu       | 446    | 19  | 4.2      | 9 |
| Zn       | 558    | 27  | 4.9      | 10 |
| Ge       | 389    | 23  | 4.8      | 8 |
| Be       | 462    | 32  | 5.2      | 7 |
| As       | 3360   | 249 | 5.6      | 10 |
| Sr       | 465    | 7   | 1.6      | 9 |
| Y        | 449    | 16  | 3.7      | 8 |
| Zr       | 437    | 10  | 2.3      | 9 |
| Nb       | 471    | 14  | 2.9      | 8 |
| Mo       | 486    | 17  | 3.6      | 7 |
| Cd       | 463    | 20  | 4.3      | 7 |
| Sn       | 592    | 25  | 4.2      | 6 |
| Sb       | 533    | 29  | 5.4      | 7 |
| Cs       | 474    | 19  | 3.9      | 8 |
| Ba       | 2030   | 53  | 2.6      | 10 |
| La       | 452    | 11  | 2.4      | 8 |
| Ce       | 444    | 14  | 3.2      | 8 |
| Pr       | 430    | 18  | 4.2      | 8 |
| Nd       | 440    | 16  | 3.7      | 8 |
| Sm       | 462    | 13  | 2.9      | 8 |
| Eu       | 457    | 12  | 2.7      | 8 |
| Gd       | 446    | 13  | 3.0      | 8 |
| Tb       | 435    | 18  | 4.1      | 8 |
| Dy       | 453    | 13  | 3.0      | 8 |
| Ho       | 450    | 18  | 4.1      | 8 |
| Er       | 461    | 10  | 2.2      | 8 |
| Tm       | 423    | 15  | 3.6      | 8 |
| Yb       | 460    | 11  | 2.4      | 8 |
| Lu       | 446    | 13  | 2.9      | 8 |
| Hf       | 457    | 16  | 3.5      | 8 |
| Ta       | 454    | 14  | 3.2      | 8 |
| W        | 454    | 23  | 5.2      | 7 |
| Ti       | 350    | 4   | 10.9     | 6 |
| Pb       | 614    | 34  | 5.5      | 8 |
| Bi       | 591    | 40  | 6.8      | 7 |
| Th       | 124    | 0.3 | 2.1      | 7 |
| U        | 125    | 0.5 | 3.9      | 8 |

Major and trace element mass fractions are given in % m/m and μg g⁻¹, respectively. The quoted uncertainties are defined as two times the standard error (2SE, standard deviation of the mean of n contributing laboratory mean data).
independent techniques. All other results from only one single laboratory or analytical technique are listed as information values without standard deviations.

Further characterisation with different in situ and bulk techniques (e.g., SIMS, LA-MC-ICP-MS, ID-ICP-MS, ID-TIMS, ID-MC-ICP-MS) is underway in approximately fifty laboratories. We are confident that on this characterisation, the three ARM glasses may be established as new reference materials for in situ techniques, as a complement and alternative to widely used NIST and USGS GS glasses for LA-MC-ICP-MS analysis in the near future. High Li-B contents (~1000 µg g⁻¹ for Li and ~10000 µg g⁻¹ for B) of ARM-2 make this glass potentially suitable also for in situ Li-B isotope reference material.

Conclusions

In this study, we prepared and preliminarily characterised three new synthetic andesite reference glasses for microanalytical work, in particular for LA-ICP-MS. These andesitic glasses (‘Andesite Reference Glass Materials’: ARM-1, 2 and 3) contain fifty-four trace elements with nearly identical abundance (~500, ~50, ~5 µg g⁻¹). Micro- and bulk analyses indicate that the glasses are well homogenised with respect to major and trace elements. Discrepancies in the data for V, Cr, Ni, and Ti exist, which are mainly caused by analytical limitations. Based on the new analytical data, preliminary reference and information values for fifty-six elements were presented. The analytical uncertainties (2 relative standard error (RSE)) were estimated to be in the range of 1–20%. The three ARM glasses (after a further certification project) should become new certified reference glasses for in situ techniques, in particular for LA-ICP-MS.

We further document an acquisition method for SF-ICP-MS (Element 2 and Element XR), which is capable of sweeping seventy-seven isotopes (sixty-eight elements) from ⁷Li to ²³⁸U in 1 s. The stability and accuracy were confirmed by analysing several well-characterised reference glasses. We also report the results of USGS NKT-1G and TB-1G by analysing several well-characterised reference glasses. The values of these two reference glasses have been rarely reported, and our data may be useful for certification procedures.

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Availability of ARM glasses

We are willing to distribute appropriate but limited amounts of the ARM glasses to the scientific community on request (S.T Wu, e-mail: shitou.wu@mail.iggcas.ac.cn).

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Supporting information

The following supporting information may be found in
the online version of this article:

Appendix S1. Tables S1–3: Oxide chemicals used for
ARM glasses; acquisition list parameters of sector field ICP-
MS; reference values of NIST SRM 610, MPI-DING StHs6/
80-G and USGS GSD-1G.

Appendix S2. Information on all instrument operating
parameters for this study.

Appendix S3. Figures S1–S4: Measurement repeatability
and intermediate measurement precision of laser ablation
sector-field ICP-MS on MPI-DING StHs6/80-G; Rare earth
patterns normalised to Chondrite C1 for TI-G and BCR-2G
and CGSG-4; Comparison of the results of NIST SRM 612,
ML3B-G and BCR-2G obtained from GZG and IGGCAS;
Relative standard deviation (%) of multiple spot analyses for
ARM glasses.

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