**Analytical methods for the data acquired at NGU and NTNU**

Whole-rock chemistry at the ULB (Belgium)

Major and trace element analyses were carried out at the Laboratoire G-Time (ULB, Brussels, Belgium). Around 50 mg of powdered and homogenized samples were melted by alkaline fusion after adding 0.8 g of lithium metaborate and 0.2 g of lithium tetraborate in a graphite crucible. After 5 minutes at 1000 °C, the beads were re-dissolved in a stirring solution of 5% HNO3. Major elements were measured on the ICP-OES Thermofischer Scientific iCAP at ULB, using Y as internal standard. Two USGS standards were used (BHVO-2 and AGV-2) and the total reproducibility was better than 2% for each element. An additional standard (BCR 032) was used for P content. Loss on ignition was measured on a 0.5 g aliquot after 5 h at 800 °C. Trace elements were measured on an Agilent 7700 ICP-MS, also at ULB, by adding In as internal standard. The same three standards were used. The total reproducibility was systematically better than 5%.

Whole-rock chemistry at the NGU (Norway)

Whole-rock analyses were performed at the Geological Survey of Norway using X-ray Fluorescence (XRF, PANalytical Axios 4 kW - Rh-X-ray tube) for major and trace elements, primarily for alkali, alkaline Earth and transition metals, while Laser Ablation Inductively Coupled Mass Spectrometry (ICP-MS) was used to measures concentrations of Rare Earth Elements (REE) and High Field Strength elements (HFSE). XRF major element and trace LA ICP-MS analyses were performed on glass pellets composed of 0.6 g of sample powder, mixed with 4.2 g of lithium tetraborate (Li2B4O7), while XRF trace element analyses were performed on pressed pellets. Analyses were performed on powders that underwent lost on ignitions at 1100 ֯C. Uncertainties and precisions of the various analyses are reported in table 1, 2 and 3.

*Table S1: Detection limit and uncertainties associated with XRF major element analyses.*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **INSTRUMENT:** | **PANalytical Axios 4 kW XRF (Rh-X-ray tube)** |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| **METODE:** | **The analytical method is described in NGU-SD:2.3: XRF-analyses, major elements** |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| **Analyses** | **Major elements** |  |  |  |  |  |  |  |  |
|  | Analyses were performed on glass pellets made of melted sample powder (0.6g) mixed with 4.2 g of lithium tetraborate (Li2B4O7) |
|  | Analyses are performed on samples which underwent loss on ignition (at 1000 °C). Data are then recalculated for the whole sample. |
|  |  |  |  |  |  |  |  |  |  |  |
| Detection limit and uncertainties (%) |  | \*) Accredited analyses |  |  |  |  |
| Oxide | **SiO2\*** | **Al2O3\*** | **Fe2O3\*** | **TiO2\*** | **MgO\*** | **CaO\*** | **Na2O\*** | **K2O\*** | **MnO\*** | **P2O5\*** |
| Detection limit | 0.5 | 0.02 | 0.01 | 0.01 | 0.04 | 0.01 | 0.1 | 0.01 | 0.01 | 0.01 |
| Concentration % | ± % | ± % | ± % | ± % | ± % | ± % | ± % | ± % | ± % | ± % |
| 0.01 |   |   | 0.005 | 0.005 |   | 0.005 |   | 0.005 | 0.005 | 0.005 |
| 0.1 |   | 0.010 | 0.027 | 0.009 | 0.036 | 0.027 | 0.02 | 0.031 | 0.004 | 0.009 |
| 0.5 | 0.05 | 0.031 | 0.046 | 0.015 | 0.062 | 0.046 | 0.03 | 0.054 | 0.008 | 0.015 |
| 1 | 0.09 | 0.042 | 0.063 | 0.021 | 0.084 | 0.063 | 0.04 | 0.073 | 0.010 | 0.021 |
| 5 | 0.20 | 0.090 | 0.135 | 0.050 | 0.181 | 0.135 | 0.09 | 0.158 | 0.050 | 0.050 |
| 10 | 0.29 | 0.127 | 0.191 | 0.100 | 0.254 | 0.191 | 0.13 | 0.222 | 0.100 | 0.100 |
| 25 | 0.45 | 0.250 | 0.301 |   | 0.401 | 0.301 | 0.25 | 0.351 | 0.250 |   |
| 50 | 0.64 | 0.500 | 0.500 |   | 0.566 | 0.500 |   |   |   |   |
| 75 | 0.78 | 0.750 | 0.750 |   | 0.750 | 0.750 |   |   |   |   |
| 100 | 1.00 |   |   |   |   |   |   |   |   |   |
|  |  |   |   |   |   |   |   |   |   |   |
| Stated uncertainties represent 1σ (68% conf. Interval). |  |  |  |  |  |  |  |
| Loss on ignition (LOI) is reported with a lower limit of detection at 0.05% and an uncertainty of 2.5% rel. (2σ). Some samples may have larger uncertainties. |

*Table S2: Detection limit and uncertainties associated with XRF trace element analyses.*

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*Table S3: Detection limit and uncertainties associated with ICP-MS trace element analyses*

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| **INSTRUMENT:** | **Thermo Fisher Scientific "ELEMENT XR" associated with a New Wave 193 nm laser** |  |  |  |  |  |
| **Method:** | Bulk-rock analysis of REE, Be, Bi, Cs, Y, Zr, Nb, Ba, Hf, Ta, Th, U and W in samples, melted with Li3B4O7 into glass tablets.  |  |  |  |
|  | Analyses are performed on samples which underwent loss on ignition (at 1000 °C). Data are then recalculated for the whole sample. |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Estimated detection limits, based on 10 times the standard deviation of repeat analyses on RM PCC-1 (USGS). All values are given in µgg-1 |  |  |
|  | **Be** | **Y** | **Zr** | **Nb** | **Cs** | **Ba** | **La** | **Ce** | **Pr** | **Nd** | **Sm** | **Eu** | **Gd** |
|  | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* |
|  | 1 | 0.2 | 1.1 | 0.07 | 0.4 | 0.9 | 0.1 | 0.07 | 0.03 | 0.21 | 0.13 | 0.03 | 0.3 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | **Tb** | **Dy** | **Ho** | **Er** | **Tm** | **Yb** | **Lu** | **Hf** | **Ta** | **W** | **Bi** | **Th** | **U** |
|  | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* | *g/g* |
|  | 0.04 | 0.16 | 0.04 | 0.09 | 0.04 | 0.2 | 0.04 | 0.13 | 0.04 | 0.2 | 0.5 | 0.03 | 0.01 |

Microprobe analyses at the NTNU (Norway)

Microprobe data on apatite were acquired on a JEOL JXF-8530F PLUS microprobe, at the Norwegian University of Science and Technology. The operating conditions were set at 15 kV and 10 nA, using a focused beam of 3 µm.

LA-ICPMS at the NGU (Norway)

Trace element analyses of apatite were performed by LA ICP-MS at the Geological Survey of Norway using a Photon Machines 193 nm excimer laser coupled to an Agilent 8900 QqQ-ICP-MS. A 25-μm-diameter beam was used to ablate pits using a fluence of ~3.5 J/cm2 and repetition rate of 6 Hz. Ablations were carried out in a two-volume laser cell with a He atmosphere, and ablated material was transported in a He carrier gas and mixed with Ar just before entering the ICP torch. Twenty-five-second ablations were preceded by 20-s “gas-blank” baselines and followed by 5-s washout periods. The following analytes were measured with 10.3 ms dwell times, resulting in a duty cycle of ca. 0.393 s: 29Si, 31P, 35Cl, 43Ca, 44Ca, 47Ti, 49Ti, 51V, 55Mn, 75As, 88Sr, 89Y, 90Zr, 111Cd, 137Ba, 139La, 140Ce, 141Pr, 146Nd, 147Sm, 153Eu, 157Gd, 159Tb, 163Dy, 165Ho, 166Er, 169Tm, 172Yb, 175Lu, 206Pb, 207Pb, 208Pb, 232Th, 238U, 248(ThO). The NIST 612 reference glass⎯used to calibrate sensitivity factors for most elements⎯was analyzed at the beginning and end of each run, as well as bracketing every 8−13 analyses of unknowns and other quality-control ("secondary") glass and apatite reference materials.

Data reduction was carried out using the “Trace Elements” data reduction scheme in Iolite 4. On-peak gas-blank baselines were fit with an “automatic spline” and subtracted from each channel. Calcium-43 was used as an internal elemental standard. The NIST 612 reference glass was used to calibrate ratios in sensitivity between each analyte and 43Ca, except for 35Cl, for which the “Dur-DonG” reference apatite (Chew *et al.*, 2016) was used. The Cl concentration of the Dur-DonG apatite fraction is not known, and so a Cl content of 4000 ppm (the average of values reported for another fraction of Durango apatite by Chew *et al.*, 2014) was used here. For this reason, Cl determinations are considered only semi-quantitative. Because Pb in apatite is variably radiogenic, an assumed common-Pb isotopic composition cannot be used to calculate Pb concentration from individual Pb isotopes, and therefore the total 206Pb+207Pb+208Pb signal was used to calculate the "PbTotal" concentration. Limits of detection were calculated with the method outlined by Pettke *et al*., (2012). The NIST 610 and GSE reference glasses (GeoReM preferred reference concentrations and average EPMA Cl concentrations from Marks *et al.*, 2017) and Dur-DonG and McClure Mountain reference apatite (fractions characterized by Chew *et al.*, 2016) were used to assess data accuracy and repeatability.

Elemental concentrations determined for the secondary glass reference materials were accurate to within 15% (typically within 5−10%) for most analytes, with the following exceptions: The average Cl concentration determined for NIST 610 and GSE yielded biases >20% from the reference values used here. There is, however, considerable variation in the Cl concentrations determined for these glasses by various methods (Marks *et al.*, 2017). We consider the Cl concentrations determined here to be semi-quantitative regardless (as explained above). The average As and Cd concentrations determined for GSE are ~40% higher than the GeoReM preferred reference values. However, the reference values are quoted with ~70% and 60% uncertainties (2 RSD) for As and Cd, respectively. The As and Cd concentrations determined for NIST 610 are accurate.

The secondary reference apatite used here lack reference values for Si, Cl, Ti, V, Zr, Cd, and Ba. Concentrations of the remaining analytes measured in the Dur-DonG and McClure Mountain apatite are within 15% (typically within 5−10%) of the reference values from Chew and co-authors (2016), except for As and Pb. Significant variation in the As and Pb contents of these apatite fractions were identified by Chew and co-authors (2016). There is much greater variance (typically >50% 2 RSD) in the concentrations determined for the McClure Mountain apatite, but this is also consistent with the greater variance determined for this fraction by Chew and co-authors (2016).

There are no reference Ti concentrations for the reference apatite used here, but there are large discrepancies between the apparent Ti concentrations determined using 47Ti and 49Ti. Furthermore, the apparent Ti concentrations are very similar for most of the apatite measurements. The apparent Ti is likely predominately due to signal from 31P16O and 31P18O on masses 47 and 49. The apparent Ti concentrations are therefore disregarded here. Quantified P concentrations are also omitted but are not considered relevant, as P is a stoichiometric component in apatite.

# References

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