**Supplementary material 1**

***Comparing the results obtained by XRF and ‘wet chemistry’ methods***

In order to validate the XRF method for the determination of major oxides, a comparison to an accepted method was performed. In the Center for Geodynamics and Geochronology of the Institute of the Earth’s Crust the ‘wet chemistry’ methods (WC) are the standard routine methods for the determination of major oxides [Jeffery 1970; Revenko 2014; Ryaschenko & Ukhova 2008; Sizykh 1985]. The accuracy of the XRF measurements was checked by classic wet chemistry. To perform silicate rock analyses, two different portions of the powdered sample were used. In the first portion, SiO2, TiO2¸ Al2O3 and P2O5 were determined after fusion with a mixture of sodium carbonate and borax. Concentrations were determined by spectrophotometric method using composite reagents for the formation the colored complex compounds. Measurements of colored complexes were carried out using a spectrophotometer GENESYS-10S (Thermo Fisher Scientific, USA). Alkalis, CaO, MgO, MnO and Fe2O3 were measured in the second portion by an atomic absorption spectrophotometer SOLAAR M6 (Thermo Elemental, INTERTECH Corporation, USA) after dissolution in a mixture of HF and HClO4. Lanthanum chloride as a spectrophotometric buffer was added to the sample solutions in order to eliminate the interelement effects. Loss on ignition (LOI) was determined by heating the samples in porcelain crucibles reaching constant mass at 1000 °C.

The XRF results were compared with the WC results (**Table 1S**). The results were plotted against each other and parameters of the linear regression (*C*XRF = *a*·CWC + *b*) are presented in **Table 2S**. The slope (*a*) of the straight line of the above relationships represents the systematic proportional error, while the free term (*b*) in the equation represents the systematic constant error [Sitko *et al.* 2004].

As follows from the **Table 2S**, a good relationship between the results obtained by XRF and chemical methods is confirmed by linear regression coefficients and absolute and relative residual errors of functions presented. The maximum value of relative standard deviation *SD*rel was obtained for Na2O and equal to 10 %. But when excluding samples with low Na content (< 0.2 %) for calculation of *SD*rel, this value decreases to 4.5 %.

**Table 2S.** *Concentration range of compounds in meimechites and values of parameters for linear regression (LR) analysis between data obtained by XRF (CXRF) and ‘wet chemistry’ (CWC) methods*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  Compound | Range of content,wt% | correlationR*2* | Slope*a* | Intercept*b* | *SD*,wt% | *SD*rel,% |
| Na2O | 0.10–0.50 | 0.987 | 0.936 | 0.039 | 0.032 | 10 |
| MgO | 18.51–36.90 | 0.997 | 0.962 | 1.110 | 0.40 | 1.1 |
| Al2O3 | 2.08–4.43 | 0.979 | 0.961 | –0.063 | 0.24 | 5.7 |
| SiO2 | 36.11–41.43 | 0.984 | 0.984 | 0.660 | 0.18 | 0.31 |
| P2O5 | 0.19–0.60 | 0.999 | 0.995 | –0.004 | 0.008 | 2.6 |
| K2O | 0.30–1.60 | 0.999 | 0.992 | –0.009 | 0.02 | 2.1 |
| CaO | 3.75–12.60 | 0.998 | 0.978 | –0.081 | 0.26 | 2.8 |
| TiO2 | 1.68–4.15 | 0.999 | 1.014 | –0.043 | 0.02 | 0.62 |
| MnO | 0.14–0.26 | 0.983 | 0.822 | 0.032 | 0.010 | 3.8 |
| Fe2O3 T | 11.42–17.23 | 0.992 | 0.979 | 0.418 | 0.25 | 1.3 |
| LOI | 1.53–10.22 | 0.998 | 1.021 | 0.176 | 0.31 | 5.0 |

Regression analysis: LR model *C*XRF = *a*·CWC + *b*; 95% confidence level

**Table 1S.** Comparing the results (%) obtained by ‘wet chemistry’ (WC) and XRF methods

|  |  |
| --- | --- |
|  | Meimechite samples |
| **87/189** | **87/196** | **87/200** | **87/216** | **87/217** | **87/220** | **87/224** | **M 214** | **1656-2** | **1985/228** |
| WC | XRF | WC | XRF | WC | XRF | WC | XRF | WC | XRF | WC | XRF | WC | XRF | WC | XRF | WC | XRF | WC | XRF |
| **SiO2** | 37.63 | 37.92 | 37.06 | 36.81 | 38.45 | 38.43 | 38.88 | 38.94 | 37.89 | 37.85 | 41.56 | 41.43 | 38.81 | 38.97 | 38.76 | 38.63 | 38.76 | 38.90 | 39.14 | 39.01 |
| **TiO2** | 4.16 | 4.15 | 2.12 | 2.12 | 3.44 | 3.42 | 1.65 | 1.68 | 2.54 | 2.52 | 2.46 | 2.48 | 4.08 | 4.08 | 1.78 | 1.80 | 1.90 | 1.95 | 2.49 | 2.52 |
| **Al2O3** | 4.40 | 4.40 | 2.74 | 3.00 | 3.70 | 4.00 | 1.92 | 2.08 | 2.81 | 3.05 | 3.43 | 3.59 | 3.99 | 4.43 | 2.03 | 2.22 | 2.49 | 2.69 | 2.95 | 3.11 |
| **Fe2O3** | 17.30 | 17.23 | 13.16 | 13.01 | 16.37 | 16.50 | 11.67 | 11.42 | 13.47 | 13.30 | 12.20 | 12.13 | 16.83 | 16.67 | 11.62 | 11.49 | 13.05 | 13.10 | 14.97 | 14.83 |
| **MnO** | 0.23 | 0.25 | 0.17 | 0.17 | 0.20 | 0.21 | 0.16 | 0.15 | 0.18 | 0.18 | 0.15 | 0.14 | 0.22 | 0.22 | 0.15 | 0.15 | 0.18 | 0.17 | 0.19 | 0.20 |
| **MgO** | 18.35 | 18.51 | 31.11 | 31.30 | 25.65 | 25.24 | 36.82 | 36.90 | 30.18 | 30.52 | 27.46 | 27.11 | 21.89 | 21.01 | 36.46 | 36.78 | 33.99 | 34.14 | 31.10 | 31.36 |
| **CaO** | 12.07 | 12.60 | 3.54 | 3.75 | 6.83 | 7.25 | 3.88 | 4.06 | 5.63 | 5.82 | 6.61 | 6.86 | 10.74 | 10.84 | 3.95 | 4.17 | 4.75 | 4.98 | 5.17 | 5.45 |
| **Na2O** | 0.26 | 0.26 | 0.12 | 0.16 | 0.43 | 0.46 | 0.08 | 0.14 | 0.13 | 0.18 | 1.18 | 0.98 | 0.38 | 0.40 | 0.10 | 0.11 | 0.12 | 0.17 | 0.42 | 0.45 |
| **K2O** | 1.39 | 1.42 | 0.40 | 0.40 | 1.10 | 1.13 | 0.46 | 0.46 | 0.67 | 0.69 | 0.61 | 0.64 | 1.60 | 1.60 | 0.38 | 0.40 | 1.02 | 1.03 | 1.08 | 1.12 |
| **P2O5** | 0.59 | 0.59 | 0.27 | 0.26 | 0.34 | 0.33 | 0.19 | 0.19 | 0.29 | 0.29 | 0.24 | 0.23 | 0.61 | 0.60 | 0.22 | 0.21 | 0.23 | 0.23 | 0.32 | 0.30 |
| **LOI** | 2.80 | 2.79 | 9.14 | 8.81 | 3.40 | 3.03 | 3.95 | 3.66 | 5.95 | 5.53 | 4.16 | 3.78 | 1.53 | 1.25 | 4.30 | 4.05 | 3.04 | 2.86 | 1.78 | 1.70 |
| **Sum** | 99.18 | 100.12 | 99.83 | 99.79 | 99.91 | 100 | 99.66 | 99.68 | 99.74 | 99.93 | 100.06 | 99.37 | 100.68 | 100.07 | 99.75 | 100.01 | 99.53 | 100.22 | 99.61 | 100.05 |

**References**

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**Supplementary material 2**

**Table S2.** ICP-MS data (ppm) for meimechite samples, obtained using the lithium metaborate fusion and open acid decomposition

|  |  |
| --- | --- |
|  | Meimechite samples |
| **87/189** | **87/196** | **87/200** | **87/216** | **87/217** | **87/220** | **87/224** | **M 214** | **1656-2** | **1985/228** |
| a.d. | fus. | a.d. | fus. | a.d. | fus. | a.d. | fus. | a.d. | fus. | a.d. | fus. | a.d. | fus. | a.d. | fus. | a.d. | fus. | a.d. | fus. |
| **V** | 195 | 404 | 114 | 176 | 170 | 332 | 81 | 139 | 109 | 229 | 100 | 203 | 148 | 334 | 113 | 151 | 117 | 187 | 77 | 205 |
| **Cr** | 1365 | 1305 | 1140 | 2076 | 1372 | 1782 | 1480 | 1993 | 1686 | 2364 | 1354 | 1328 | 1469 | 1413 | 1080 | 1452 | 1547 | 2306 | 1618 | 2024 |
| **Co** | 92 | 95 | 110 | 110 | 109 | 112 | 112 | 113 | 105 | 110 | 93 | 90 | 99 | 99 | 103 | 109 | 110 | 123 | 111 | 116 |
| **Ni** | 560 | 725 | 1330 | 1447 | 970 | 1258 | 1715 | 1897 | 1264 | 1447 | 1163 | 1236 | 765 | 959 | 1627 | 1892 | 1433 | 1717 | 1433 | 1370 |
| **Cu** | 164 | 175 | 79 | 80 | 116 | 130 | 65 | 72 | 84 | 98 | 129 | 134 | 156 | 168 | 63 | 67 | 75 | 79 | 75 | 75 |
| **Zn** | 125 | 139 | 93 | 99 | 112 | 126 | 73 | 82 | 88 | 114 | 105 | 110 | 112 | 121 | 80 | 85 | 88 | 104 | 84 | 110 |
| **Ga** | 16.4 | 16.0 | 8.0 | 8.1 | 12.1 | 11.5 | 6.2 | 5.7 | 8.9 | 9.1 | 11.2 | 9.6 | 14.3 | 13.6 | 5.8 | 5.9 | 6.7 | 7.0 | 6.9 | 8.8 |
| **Ge** | 1.6 | 1.9 | 1.3 | 1.2 | 1.4 | 1.5 | 1.0 | 1.2 | 1.1 | 1.4 | 1.4 | 1.5 | 1.5 | 1.8 | 1.2 | 1.3 | 1.3 | 1.4 | 1.0 | 1.4 |
| **Rb** | 42 | 42 | 11 | 11 | 32 | 32 | 16 | 16 | 23 | 23 | 12 | 12 | 42 | 43 | 13 | 13 | 29 | 31 | 29 | 27 |
| **Sr** | 677 | 699 | 213 | 206 | 507 | 485 | 285 | 287 | 433 | 426 | 1051 | 997 | 757 | 766 | 285 | 284 | 438 | 432 | 438 | 532 |
| **Y** | 22 | 22 | 11 | 11 | 17 | 18 | 7 | 8 | 11 | 12 | 17 | 16 | 18 | 18 | 8 | 9 | 9 | 10 | 11 | 13 |
| **Zr** | 182 | 359 | 129 | 176 | 187 | 347 | 82 | 118 | 117 | 190 | 210 | 292 | 114 | 306 | 122 | 139 | 114 | 147 | 88 | 212 |
| **Nb** | 15 | 110 | 8 | 30 | 18 | 59 | 5 | 22 | 11 | 36 | 18 | 63 | 5 | 82 | 10 | 27 | 9 | 38 | 7 | 42 |
| **Cs** | 0.8 | 0.9 | 0.1 | 0.1 | 0.4 | 0.4 | 0.1 | 0.1 | 0.2 | 0.2 | 0.4 | 0.3 | 0.6 | 0.5 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 |
| **Ba** | 671 | 689 | 178 | 175 | 324 | 314 | 236 | 223 | 310 | 318 | 167 | 156 | 711 | 732 | 256 | 266 | 290 | 316 | 317 | 339 |
| **La** | 85.9 | 88.7 | 26.6 | 26.4 | 54.8 | 55.4 | 18.6 | 19.1 | 30.3 | 30.7 | 87.3 | 86.6 | 77.8 | 80.0 | 21.1 | 22.8 | 29.4 | 32.2 | 33.3 | 35.2 |
| **Ce** | 183.1 | 184.3 | 60.7 | 59.5 | 127.8 | 130.6 | 43.3 | 43.0 | 67.4 | 68.3 | 180.1 | 182.6 | 163 | 164 | 48.6 | 49.3 | 59.4 | 63.9 | 71.4 | 73.0 |
| **Pr** | 21.1 | 21.4 | 7.6 | 7.7 | 15.9 | 16.4 | 5.4 | 5.5 | 8.5 | 8.8 | 19.1 | 19.2 | 18.5 | 19.9 | 6.0 | 6.2 | 7.0 | 7.6 | 8.2 | 9.2 |
| **Nd** | 74.5 | 76.7 | 29.5 | 30.2 | 58.2 | 60.8 | 20.8 | 21.6 | 32.2 | 34.0 | 63.8 | 63.0 | 68.8 | 73.0 | 22.9 | 25.3 | 25.2 | 30.4 | 36.2 | 37.7 |
| **Sm** | 13.2 | 13.6 | 6.2 | 6.2 | 10.6 | 10.9 | 4.3 | 4.3 | 6.5 | 6.6 | 10.3 | 10.4 | 12.2 | 12.8 | 4.7 | 5.1 | 4.8 | 5.8 | 7.0 | 7.3 |
| **Eu** | 3.4 | 3.6 | 1.7 | 1.7 | 2.7 | 2.8 | 1.2 | 1.2 | 1.8 | 1.8 | 2.5 | 2.4 | 3.1 | 3.4 | 1.3 | 1.4 | 1.3 | 1.5 | 1.7 | 2.0 |
| **Gd** | 9.2 | 9.3 | 4.3 | 4.3 | 7.2 | 7.5 | 2.9 | 3.0 | 4.7 | 4.8 | 7.9 | 7.2 | 8.6 | 8.6 | 3.2 | 3.5 | 3.4 | 3.9 | 4.6 | 5.1 |
| **Tb** | 1.2 | 1.2 | 0.6 | 0.6 | 0.9 | 1.0 | 0.4 | 0.4 | 0.6 | 0.6 | 1.0 | 0.9 | 1.1 | 1.0 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 |
| **Dy** | 5.6 | 5.7 | 2.9 | 2.9 | 4.5 | 4.8 | 1.9 | 2.0 | 3.0 | 3.1 | 4.5 | 4.3 | 4.9 | 5.0 | 2.1 | 2.2 | 2.2 | 2.5 | 3.3 | 3.5 |
| **Ho** | 0.9 | 0.9 | 0.5 | 0.5 | 0.8 | 0.8 | 0.3 | 0.3 | 0.5 | 0.5 | 0.7 | 0.7 | 0.8 | 0.8 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.6 |
| **Er** | 1.9 | 1.9 | 1.1 | 1.1 | 1.6 | 1.7 | 0.7 | 0.7 | 1.1 | 1.1 | 1.6 | 1.5 | 1.6 | 1.7 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 1.2 |
| **Tm** | 0.2 | 0.2 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Yb** | 1.3 | 1.3 | 0.7 | 0.7 | 1.0 | 1.1 | 0.5 | 0.5 | 0.7 | 0.8 | 1.1 | 1.0 | 1.1 | 1.2 | 0.5 | 0.6 | 0.5 | 0.6 | 0.6 | 0.8 |
| **Lu** | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Hf** | 3.9 | 8.2 | 3.3 | 4.0 | 5.2 | 8.2 | 2.3 | 2.8 | 3.2 | 4.5 | 5.5 | 7.1 | 2.5 | 7.6 | 3.0 | 3.3 | 2.9 | 3.5 | 2.4 | 5.1 |
| **Ta** | 1.1 | 6.9 | 0.7 | 2.0 | 1.6 | 4.0 | 0.4 | 1.5 | 0.9 | 2.5 | 1.6 | 4.2 | 0.4 | 5.8 | 0.7 | 1.9 | 0.8 | 2.5 | 0.5 | 2.8 |
| **Pb** | 5.6 | 5.9 | 1.9 | 1.2 | 3.7 | 2.7 | 1.4 | 1.2 | 2.0 | 2.4 | 2.7 | 2.8 | 6.1 | 5.8 | 1.7 | 1.3 | 2.9 | 3.4 | 2.5 | 2.6 |
| **Th** | 8.7 | 9.8 | 2.4 | 2.5 | 4.9 | 5.5 | 1.7 | 1.7 | 2.7 | 3.0 | 6.4 | 6.5 | 7.1 | 8.3 | 2.0 | 2.3 | 2.5 | 3.2 | 2.9 | 3.7 |
| **U** | 2.4 | 2.4 | 0.7 | 0.7 | 1.5 | 1.5 | 0.5 | 0.5 | 0.8 | 0.8 | 2.1 | 2.1 | 1.8 | 1.8 | 0.6 | 0.6 | 0.7 | 0.8 | 0.8 | 0.9 |

a.d. is the open acid digestion; fus. is the lithium metaborate fusion

**Supplementary material 3**

**Table S3.** ICP-MS analysis of reference materials

|  |  |  |
| --- | --- | --- |
| Element | OPY-1 | BIR-1 |
| X ICP-MS ± Δ, μg/g | XA ± Δ, μg/g | X ICP-MS ± Δ, μg/g | XA |
| Ga | 7.86 ± 0.12 | 9.01± 0.52 | 15 ± 1 | 16 |
| Ge | 0.39 ± 0.03 | – | 1.38 ± 0.04 | 1.50 |
| Rb | 0.90 ± 0.11 | 1.04 ± 0.08 | 0.21 ± 0.02 | 0.25 |
| Y | 10.33 ± 0.30 | 9.44 ± 0.54 | 16 ± 1 | 16 |
| Nb | 0.35 ± 0.11 | – | 0.64 ± 12 | 0.60 |
| Cs | 0.16 ± 0.02 | 0.18 ± 0.02 | 0.004 ± 0.001 | 0.005 |
| La | 0.44 ± 0.06 | 0.42 ± 0.04 | 0.60 ± 0.03 | 0.62 |
| Ce | 1.27 ± 0.07 | 1.33 ± 0.10 | 1.88 ± 0.04 | 1.95 |
| Pr | 0.24 ± 0.01 | 0.24 ± 0.02 | 0.36 ± 0.01 | 0.38 |
| Nd | 1.51 ± 0.07 | 1.49 ± 0.11 | 2.44 ± 0.06 | 2.50 |
| Sm | 0.79 ± 0.05 | 0.70 ± 0.06 | 1.10 ± 0.02 | 1.10 |
| Eu | 0.30 ± 0.08 | 0.31 ± 0.03 | 0.50 ± 0.01 | 0.54 |
| Gd | 1.20 ± 0.07 | 1.15 ± 0.09 | 1.75 ± 0.05 | 1.85 |
| Tb | 0.25 ± 0.01 | 0.23 ± 0.02 | 0.35 ± 0.02 | 0.36 |
| Dy | 1.64 ± 0.09 | 1.56 ± 0.12 | 2.50 ± 0.02 | 2.50 |
| Ho | 0.42 ± 0.01 | 0.35 ± 0.03 | 0.56 ± 0.01 | 0.57 |
| Er | 1.12 ± 0.05 | 1.02 ± 0.08 | 1.70 ± 0.01 | 1.70 |
| Tm | 0.18 ± 0.01 | 0.15 ± 0.02 | 0.25 ± 0.01 | 0.26 |
| Yb | 1.11 ± 0.17 | 1.01 ± 0.08 | 1.65 ± 0.03 | 1.65 |
| Lu | 0.18 ± 0.01 | 0.15 ± 0.02 | 0.25 ± 0.01 | 0.26 |
| Hf | 0.61 ± 0.12 | 0.55 ± 0.05 | 0.59 ± 0.01 | 0.60 |
| Ta | 0.02 ± 0.01 | 0.03 ± 0.004 | 0.04 ± 0.01 | 0.04 |
| Pb | 0.18 ± 0.10 | – | 2.98 ± 0.16 | 3.00 |
| Th | 0.04 ± 0.01 | 0.03 ± 0.004 | 0.04 ± 0.01 | 0.03 |
| U | 0.03 ± 0.01 | 0.01 ± 0.002 | 0.007 ± 0.003 | 0.01 |

X ICP-MS, measured concentration; XA, certiﬁed concentration; Δ, 95% conﬁdence interval; “–“,, data is not assigned