# A magmatic copper and fluid source for the sediment hosted Mount Isa deposit

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## Supplementary Information

The Supplementary Information includes:

## Methodology

Ninety chalcopyrite samples were collected from drill holes across well-known ore bodies and the low-grade envelope around the Mt Isa deposit. The textural position of chalcopyrite grains targeted for analysis were determined before the sulphides were analysed, and sulphides in similar textural positions were compared. Full log and assay data were available for all drill holes. The sampling strategy involved:

- to sample across the ore body from the core of the ore body to the most distal parts that contain chalcopyrite and to systematically collect samples in relationships with major structures,

- to sample within the same stratigraphic horizon,

- to sample across the entire deposit.

Chalcopyrite grains were handpicked from each sample at the Juniata College, USA and sampled with a drill dremel tool. Between 10 to 50 mg of chalcopyrite was dissolved in 4 ml of ultrapure, heated, aqua regia overnight. Due to the fact copper is a dominant ion in the mineral, no column chemistry was conducted on the chalcopyrite samples as demonstrated in (Mathur *et al.*, 2005; Zhu *et al.*, 2000; Zhang *et al.*, 2020). Isotope analyses were carried out on MC-ICP-MS instruments at various facilities (Penn State University, Washington State University and Rutgers University). Cu isotope values were corrected for mass bias using traditional standard–sample–standard bracketing with the NIST-SRM976 standard reference material and data are presented in the traditional delta notation (in per mil) compared to this standard. The instruments were in wet-plasma mode and the solutions were measured at 200 ng/g. Samples and reference materials matched to within 30 % of the $^{63}$Cu signal. QA/QC for the results was monitored using an in-house USA coin (1838 USA CENT $\delta^{65}$Cu = 0.01 ± 0.06 ‰ (n=39 combined from all three locations) and BVHO-2 with values overlapping those reported in the literature.

## Supplementary Tables

**Table S-1** $\delta^{65}$Cu values measured from each sample, their distance to the nearest major structure and the ore texture.

| Sample ID | Section | $\delta^{65}$Cu (‰) | Distance from major structure (meters) | Ore texture |
|---|---|---|---|---|
| 15 | MIM | -0.87 | 77 | veins |
| MT03 | MIM | -0.64 | 26 | veins |
| 30 | MIM | -0.63 | 46.2 | fault/shear |
| MT12 | MIM | -0.53 | 23 | fault/shear |
| MT11 | MIM | -0.46 | 5 | fault/shear |
| 12 | MIM | -0.41 | 66 | veins |
| MT10 | MIM | -0.34 | 18 | fault/shear |
| 8 | MIM | -0.31 | 20 | veins |
| 38 | MIM | -0.26 | 23.1 | veins |
| 1 | MIM | -0.23 | 17 | fault/shear |
| 10 | MIM | -0.22 | 18 | breccia |
| 3 | MIM | -0.21 | 30 | breccia |
| 476 | MIM | -0.20 | 121 | veins |
| 52 | MIM | -0.17 | 50 | fault/shear |
| 32 | MIM | -0.17 | 231 | veins |
| 6 | MIM | -0.17 | 6 | veins |
| 31 | MIM | -0.14 | 18 | veins |
| 24 | MIM | -0.12 | 10 | veins |
| 1096 | MIM | -0.12 | 15 | veins |
| MT01 | MIM | -0.07 | 80 | fault/shear |
| 11 | MIM | -0.07 | 43 | veins |
| 9 | MIM | -0.06 | 75 | veins |
| 36 | MIM | -0.06 | 8 | disseminated |
| 2 | MIM | -0.06 | 39 | breccia |
| 43 | MIM | -0.04 | 60 | veins |
| GF22 | MIM | -0.02 | 35 | fault/shear |
| 479 | MIM | -0.02 | 231 | veins |
| 11 | MIM | -0.02 | 147 | veins |
| 28 | MIM | 0.01 | 200 | veins |
| MT05 | MIM | 0.01 | 333 | fault/shear |
| 477 | MIM | 0.02 | 44.4 | fault/shear |
| 35 | MIM | 0.02 | 210 | veins |
| MT07 | MIM | 0.03 | 39.6 | veins |
| 14 | MIM | 0.04 | 13 | disseminated |
| 480 | MIM | 0.04 | 20 | veins |
| 1 | MIM | 0.06 | 80 | breccia |
| MT23-4 | MIM | 0.06 | 112 | veins |
| 26 | MIM | 0.06 | 87 | veins |
| 12 | MIM | 0.06 | 40 | fault/shear |
| 22 | MIM | 0.07 | 214.5 | veins |
| 29 | MIM | 0.07 | 330 | veins |
| 3 | MIM | 0.08 | 39.6 | disseminated |
| 478 | MIM | 0.08 | 210 | veins |
| 10 | MIM | 0.09 | 165 | veins |

| Sample ID | Section | $\delta^{65}Cu$ (‰) | Distance from major structure (meters) | Ore texture |
|---|---|---|---|---|
| 7 | MIM | 0.10 | 132 | veins |
| 17 | MIM | 0.10 | 140 | veins |
| 26 | MIM | 0.15 | 88.4 | veins |
| 5 | MIM | 0.16 | 221 | disseminated |
| 39 | MIM | 0.17 | 136 | disseminated |
| 24 | MIM | 0.17 | 90 | veins |
| 4 | MIM | 0.17 | 97 | disseminated |
| 481 | MIM | 0.17 | 100 | veins |
| 40 | MIM | 0.18 | 89 | breccia |
| 15 | MIM | 0.18 | 77 | veins |
| 51 | MIM | 0.19 | 40 | breccia |
| 474 | MIM | 0.20 | 62 | veins |
| 25 | MIM | 0.23 | 200 | veins |
| 488 | MIM | 0.24 | 250 | veins |
| 14 | MIM | 0.24 | 150 | veins |
| 29 | MIM | 0.25 | 41 | fault/shear |
| 9 | MIM | 0.26 | 180 | veins |
| 8 | MIM | 0.26 | 240 | breccia |
| 487 | MIM | 0.27 | 210 | veins |
| 25 | MIM | 0.27 | 230 | veins |
| 37 | MIM | 0.27 | 150 | disseminated |
| 5 | MIM | 0.31 | 155.1 | veins |
| 23 | MIM | 0.33 | 61 | veins |
| 483 | MIM | 0.33 | 56.1 | veins |
| 7 | MIM | 0.33 | 68 | veins |
| 50 | MIM | 0.36 | 41 | breccia |
| 13 | MIM | 0.37 | 91 | veins |
| 41 | MIM | 0.40 | 183 | breccia |
| 454 | MIM | 0.40 | 50 | veins |
| 16 | MIM | 0.42 | 236 | veins |
| 27 | MIM | 0.43 | 210 | veins |
| 42 | MIM | 0.43 | 221 | breccia |
| 458 | MIM | 0.44 | 25 | breccia |
| MT30 | MIM | 0.47 | 63 | veins |
| MT02 | MIM | 0.52 | 115.5 | veins |
| 462 | MIM | 0.55 | 320 | veins |
| 27 | MIM | 0.59 | 97 | veins |
| 6 | MIM | 0.60 | 95.7 | veins |
| GF23 | MIM | 0.61 | 180 | veins |
| MT18 | MIM | 0.62 | 236 | veins |
| 451 | MIM | 0.68 | 250 | veins |
| 45 | MIM | 0.70 | 193 | veins |
| 452 | MIM | 0.70 | 180 | veins |
| 28 | MIM | 0.79 | 211 | veins |
| 2 | MIM | 0.83 | 242 | breccia |
| MT27 | MIM | 0.88 | 273 | disseminated |

# Supplementary Figures
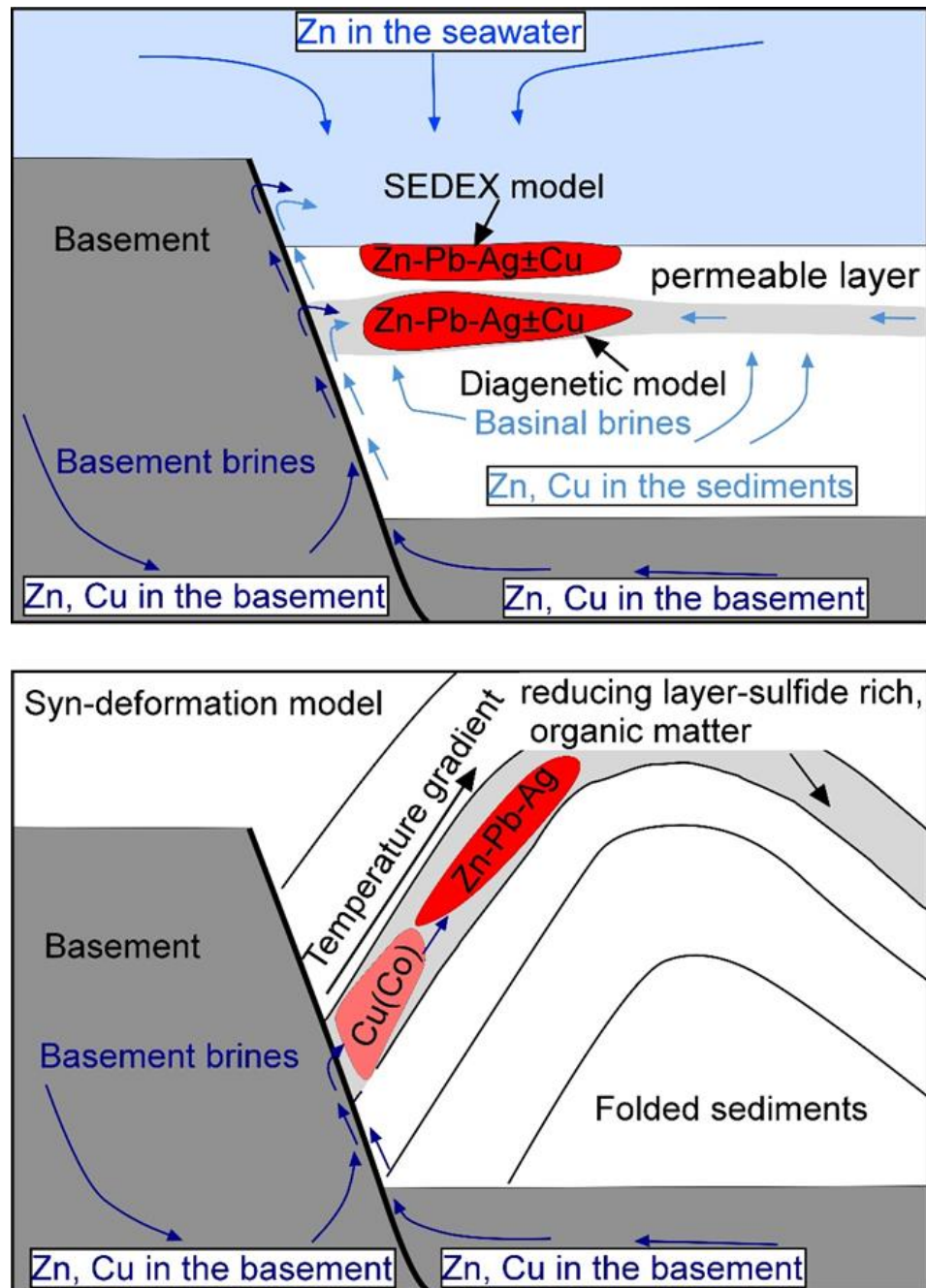


**Figure S-1**      Schematic representation of the two models used to explain the formation and the close spatial relationship between the Cu and Zn-Pb-Ag mineralisation at the Mount Isa deposit. The top image illustrates the syngenetic and diagenetic models whereas the bottom image illustrates the epigenetic model.
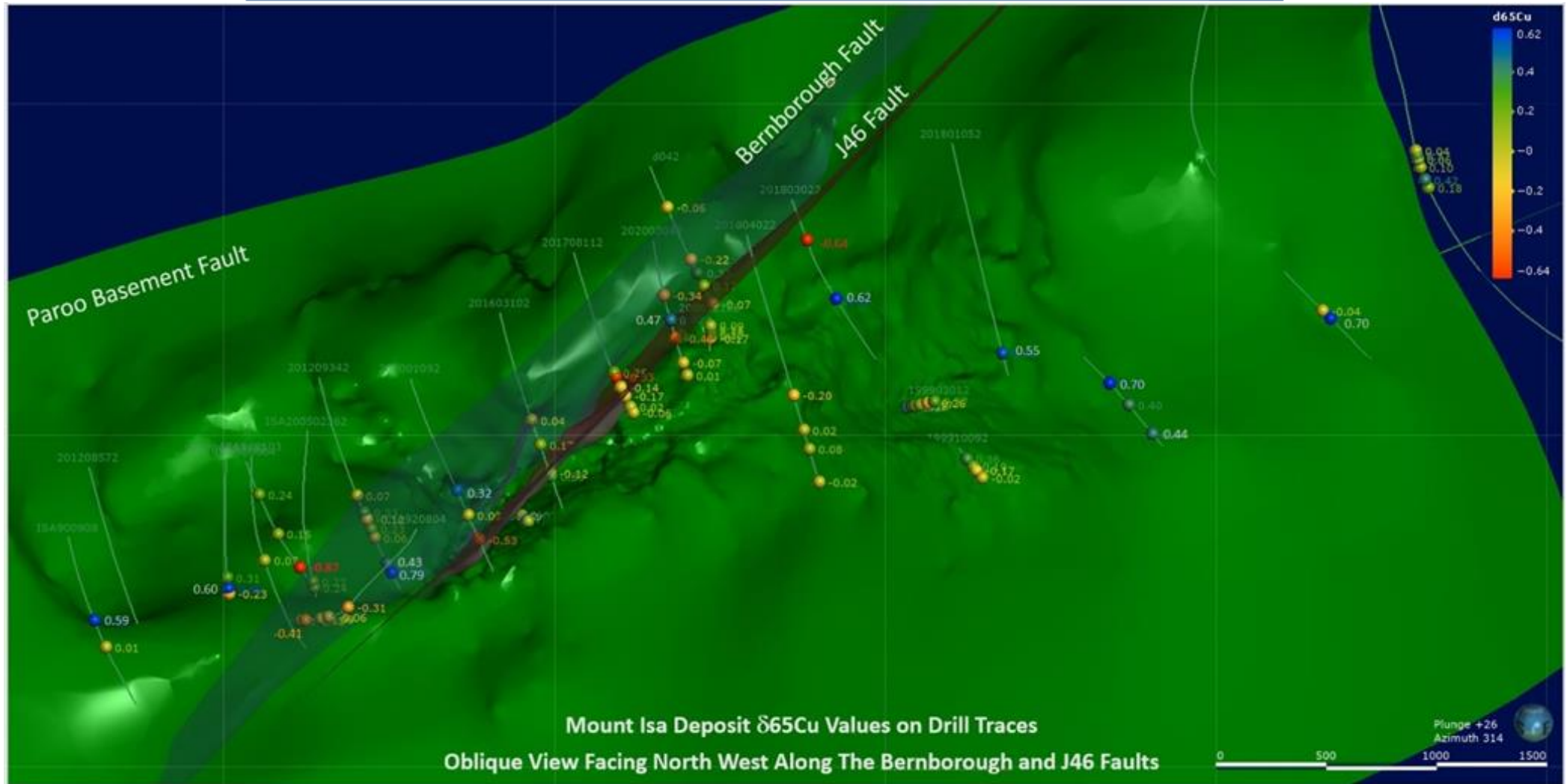
**Figure S-2**          Oblique view showing the distribution of samples analysed for Cu isotopes and the $\delta^{65}Cu$ values (coloured circles, corresponding to scale bar in the top right) in relationship to the main structures across the entire deposit and the surrounding low-grade envelope.
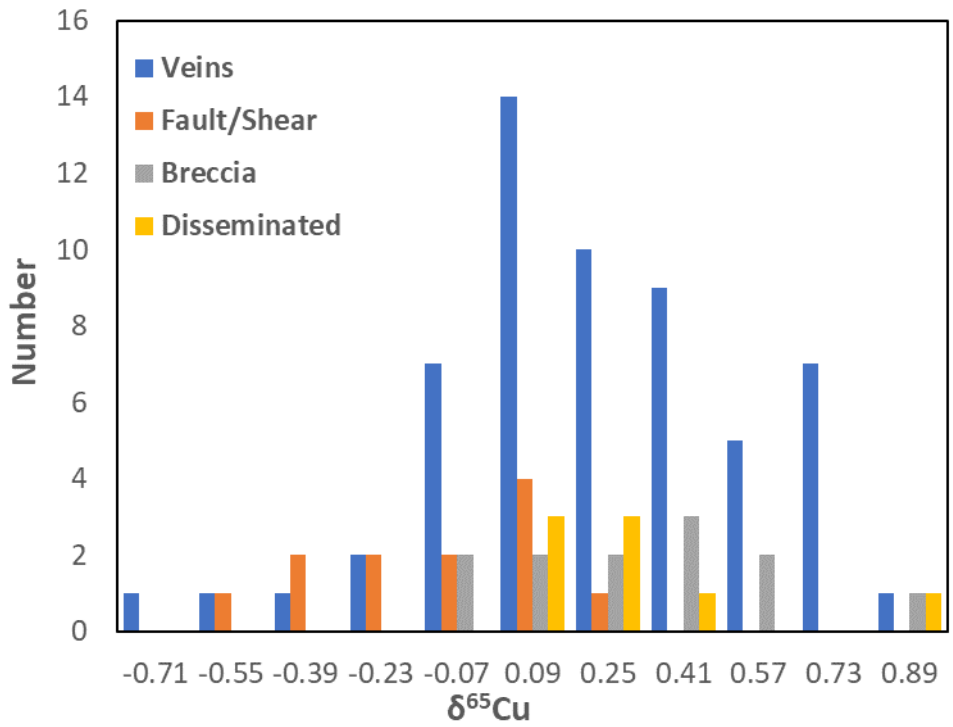
**Figure S-3**      Histogram showing the relationship between $\delta^{65}Cu$ and the distance to the nearest major structure.
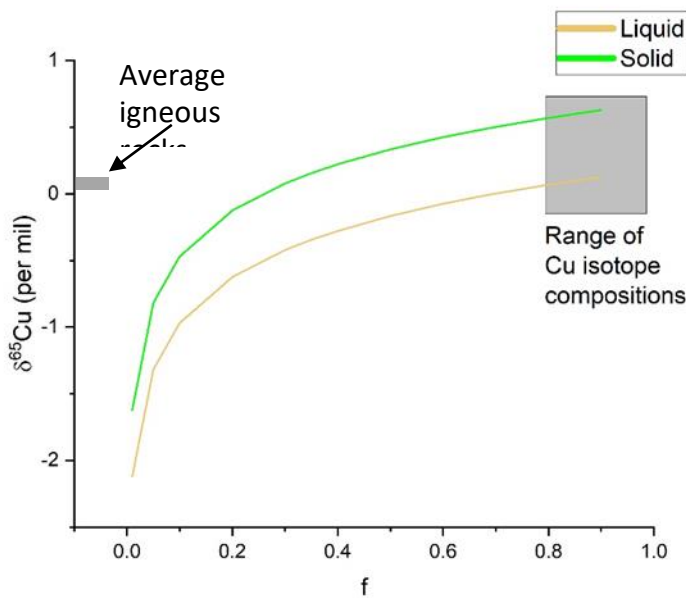


**Figure S-4**      Rayleigh distillation models using fractionation factors from Pekala *et al.* (2011) (alpha=1.0005) generate the observed range of fractionation measured of Mt Isa chalcopyrite for high values of f. This modelling suggests that there was an effective removal and deposition of copper in the chalcopyrite. The average $\delta^{65}Cu$ of Proterozoic basalts is +0.14‰ (Liu *et al.*, 2015) whereas the average $\delta^{65}Cu$ of the BSE is +0.07‰ (Moynier *et al.*, 2017).

# Supplementary Information References

Liu, S.-A., Huang, J., Liu, J., Wörner, G., Yang, W., Tang, Y.-J., Chen, Y., Tang, L., Zheng, J., and Li, S. (2015) Copper isotopic composition of the silicate Earth. *Earth and Planetary Science Letters* 427, 95-103. https://doi.org/10.1016/j.epsl.2015.06.061

Mathur, R., Ruiz, J., Titley, S., Liermann, L., Buss, H., and Brantley, S. L. (2005) Cu isotopic fractionation in the supergene environment with and without bacteria. *Geochimica et Cosmochimica Acta* 69, 5233-5246. https://doi.org/10.1016/j.gca.2005.06.022

Moynier, F., Vance, D., Fujii, T., and Savage, P. (2017) The isotope geochemistry of zinc and copper. *Reviews in Mineralogy and Geochemistry* 82, 543-600. https://doi.org/10.2138/rmg.2017.82.13

Pekala, M., Asael, D., Butler, I. B., Matthews, A., and Rickard, D. (2011) Experimental study of Cu isotope fractionation during the reaction of aqueous Cu(II) with Fe(II) sulphides at temperatures between 40 and 2008C. *Chemical Geology* 289, 31–38. https://doi.org/10.1016/j.chemgeo.2011.07.004

Zhang, Y., Bao, Z., Lv, N., Chen, K., Zong, C., and Yuan, H. (2020) Copper isotope ratio measurements of Cu-dominated minerals without column chromatography using MC-ICP-MS. *Frontiers in Chemistry* 8, 609. https://doi.org/10.3389/fchem.2020.00609

Zhu, X. K., O'Nions, R. K., Guo, Y., Belshaw, N. S., and Rickard, D. (2000) Determination of natural Cu-isotope variation by plasma-source mass spectrometry; implications for use as geochemical tracers. *Chemical Geology* 163, 139-149. https://doi.org/10.1016/S0009-2541(99)00076-5