Supporting Information

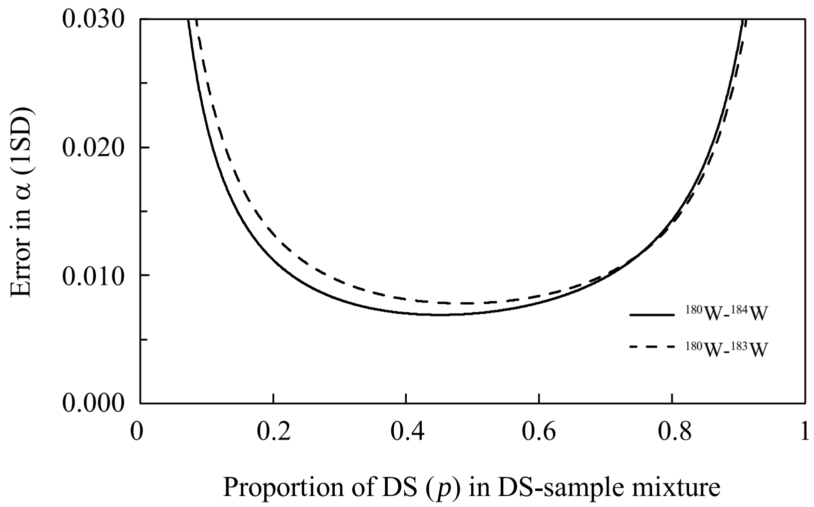

Figure S1. Comparison of theoretical errors in the natural fractionation factor (α) plotted against the proportion (p) of DS in a DS-sample mixture. The two curves denote the results of optimal ^{180}W-^{184}W and ^{180}W-^{183}W double spikes (both using ^{180}W-^{183}W-^{184}W-^{186}W inversion), respectively, both from Oak Ridge National Laboratory (ORNL). The ORNL single-spike compositions (^{180}W, ^{182}W, ^{183}W, ^{184}W, ^{185}W) are ^{180}W = (11.35%, 42.80%, 14.80%, 19.80%, 11.27%), ^{183}W = (<0.03%, 5.51%, 79.03%, 13.46%, 2.00%), and ^{184}W = (<0.05%, 1.79%, 1.64%, 94.64%, 1.92%).

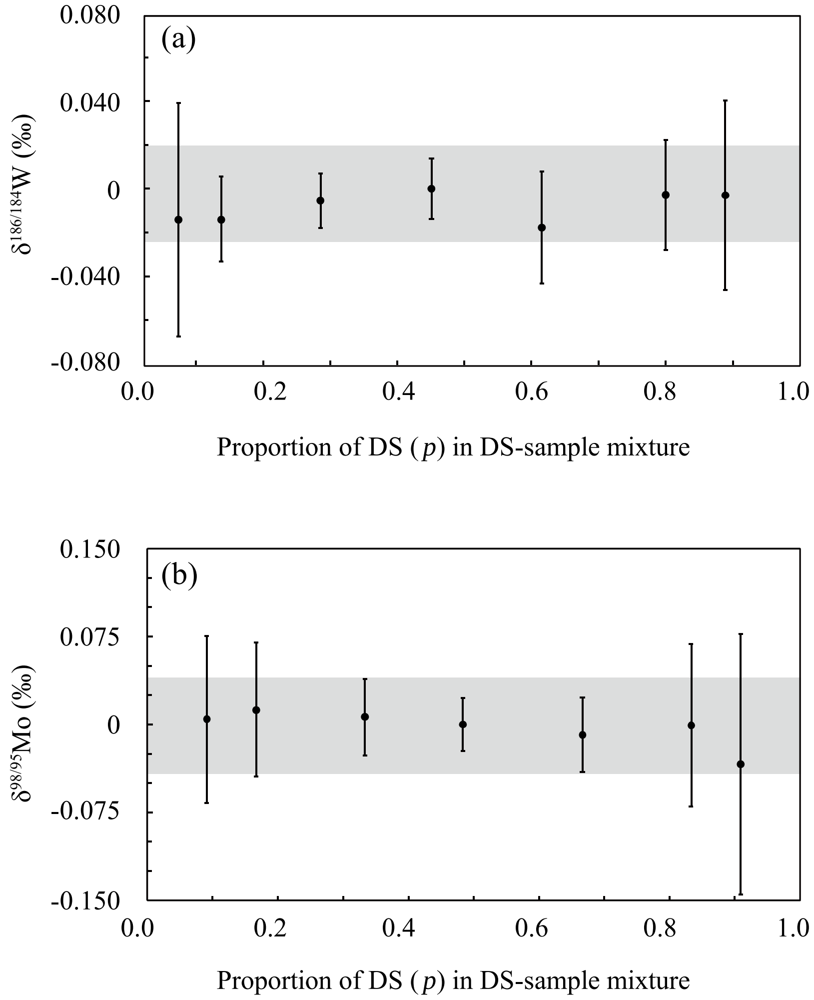

Figure S2. (a) δ^{186}W and (b) δ^{98}Mo values of DS-NIST mixtures with variable DS proportions (*p*). Error bars represent 2 SD of individual measurements (n = 3). The shaded area shows the external reproducibility of ±0.03 (2 SD, n = 51) obtained for NIST 3163 solution (W) and ±0.04 (2 SD, n = 31) for NIST 3134 solution (Mo).

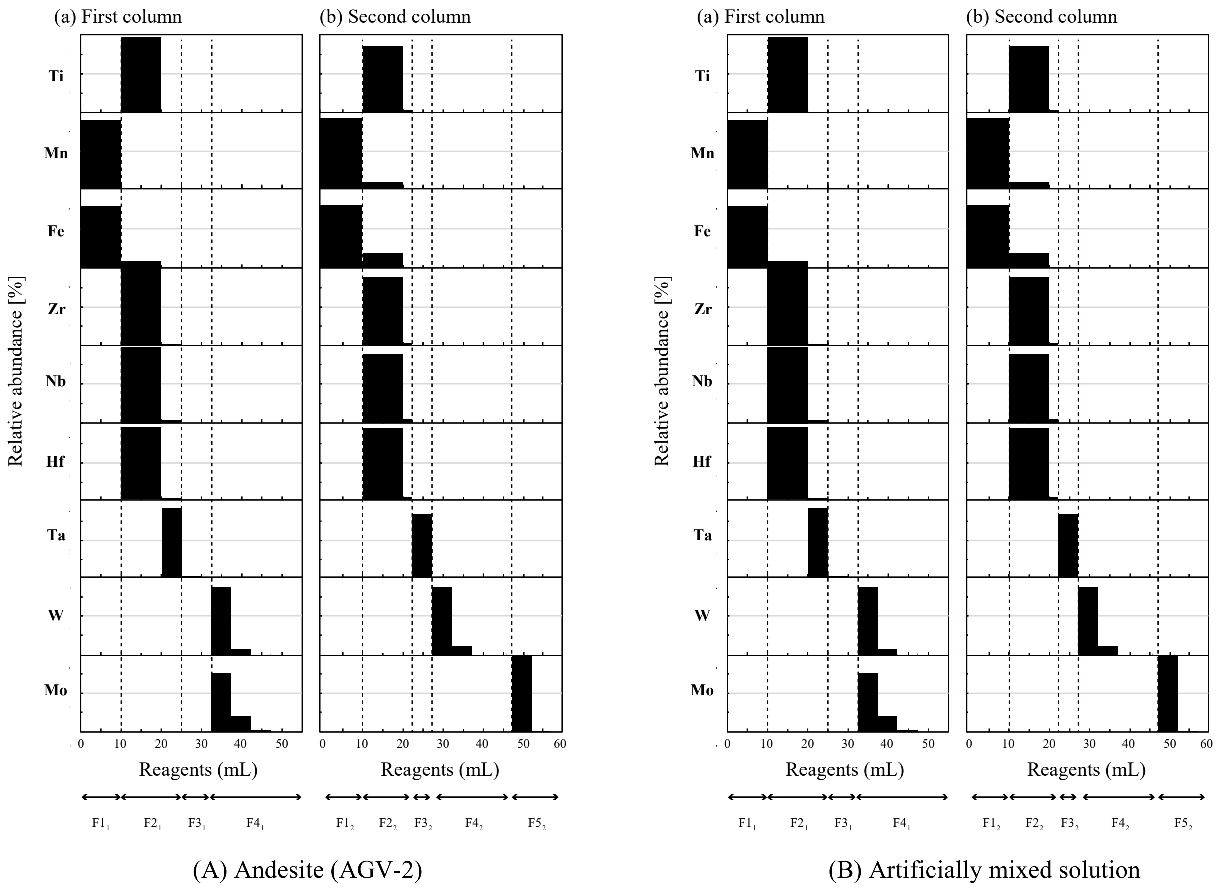

Figure S3. Elution profiles using anion exchange resin (AG1-X8) for the solutions of (A) AGV-2 (300 mg) with added interfering elements (1 μg each of Ru and Ta) and (B) artificially mixed solution of single elements (1 μg each of W, Mo, Ti, Mn, Fe, Zr, Nb, Ru, Hf, Ta): (a) the first-column and (b) the second-column procedures. The elution of Ru is not shown because it was removed during digestion and evaporation procedures.

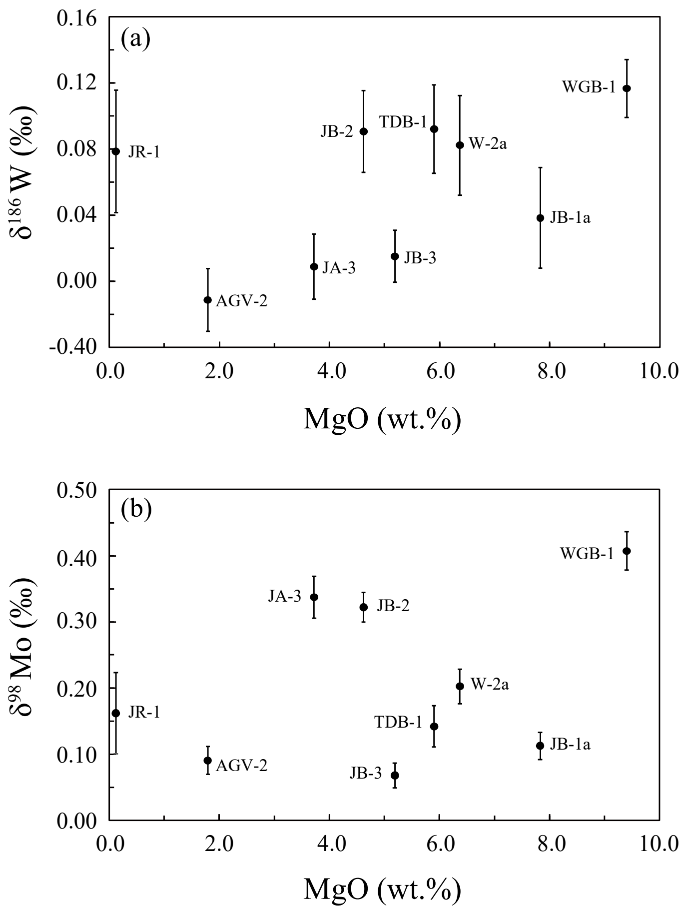

Figure S4. (a) δ^{186}W and (b) δ^{98}Mo versus MgO for the geochemical reference materials of igneous rock series analyzed in this study. Error bars are the 2 SD obtained from replicate measurements of samples. MgO contents were obtained from online databases of the providers (USGS, GSJ, and CANMET-CCRMP). $\delta^{98/95}$Mo are normalized relative to NIST 3134 (= 0‰) + 0.25‰.

Table S1. Matrix elements in the JMn-1 solution (10 mg) obtained via the first column

	Average ± 2SD[a] (ng)	Residual fraction[b]	X/W	X/Mo
Ti	3.00 ± 2.58	3.3E-05	6.5E-03	8.3E-04
Mn	1.05 ± 1.25	4.0E-07	2.7E-03	3.5E-04
Fe	336 ± 703	3.3E-04	8.6E-01	1.1E-01
Zr	0.10 ± 0.10	3.0E-05	3.3E-04	4.3E-05
Nb	0.03 ± 0.19	9.0E-05	8.7E-05	1.1E-05
Ru	0.02 ± 1.35	9.8E-03	4.0E-05	5.2E-06
Hf	0.003 ± 0.030	4.5E-05	8.6E-06	1.1E-06
Ta	0.050 ± 0.049	6.7E-03	1.3E-04	1.7E-05

Table S2. Matrix elements in the purified W and Mo solutions of the JMn-1 (10 mg) after the second column

	Purified solution of W			Purified solution of Mo		
	Average ± 2SD[a] (ng)	Residual fraction[b]	X/W	Average ± 2SD[a] (ng)	Residual fraction[b]	X/Mo
Ti	0.230 ± 0.086	3.0E-06	6.4E-04	0.352 ± 0.035	4.6E-06	1.3E-04
Mn	Not Detected	–	<5.4E-4	Not Detected	–	<7.2E-5
Fe	0.261 ± 1.069	2.5E-07	7.4E-04	3.292 ± 2.079	3.1E-06	1.2E-03
Zr	0.002 ± 0.003	4.0E-07	4.8E-06	0.003 ± 0.009	7.1E-07	1.1E-06
Nb	0.002 ± 0.001	6.3E-06	6.6E-06	0.011 ± 0.004	2.9E-05	3.9E-06
Ru	0.005 ± 0.341	2.7E-03	1.3E-05	0.010 ± 0.692	6.0E-03	3.7E-06
Hf	Not Detected	–	<1.5E-6	Not Detected	–	<2.0E-7
Ta	Not Detected	–	<5.0E-6	Not Detected	–	<6.7E-7

[a] 2SD was given by performing the separation procedures in triplicate.

[b] Proportions were calculated using the recommended or preferable data for JMn-1 reported in Imai et al. (1999).

Reference list cited in Table 4

1. M. Tsujisaka, S. Takano, M. Murayama and Y. Sohrin, *Anal. Chim. Acta*, 2019, **1091**, 146-159.
2. D. Stubbs, R. Yang, C. D. Coath, T. John and T. Elliott, *Geochim. Cosmochim. Acta*, 2022, **334**, 135-154.
3. N. Krabbe, T. S. Kruijer and T. Kleine, *Chem. Geol.*, 2017, **450**, 135–144.
4. F. Kurzweil, C. Münker, J. Tusch and R. Schoenberg, *Chem. Geol.*, 2018, **476**, 407-417.
5. L. Roué, F. Kurzweil, M. Wille, A. Wegwerth, O. Dellwig, C. Münker and R. Schoenberg, *Geochim. Cosmochim. Acta*, 2021, **309**, 366-387.
6. T. Zhang, J. Liu, Q. Zhang, Y. Zhang and L. Qin, *Geostand. Geoanal. Res.*, 2022, **47**, 169-183.
7. R. Yang, T. Li, D. Stubbs, T. Chen, S. Liu, D. B. Kemp, W. Li, S. Yang, J. Chen, T. Elliott, O. Dellwig, J. Chen and G. Li, *Geochim. Cosmochim. Acta*, 2022, **322**, 227-243.
8. T. Breton and G. Quitt´e, *J. Anal. At. Spectrom.*, 2014, **29**, 2284–2293.
9. K. Abraham, J. Barling, C. Siebert, N. Belshaw, L. Gall and A. N. Halliday, *J. Anal. At. Spectrom.*, 2015, **30**, 2334–2342.
10. P. P. Zhao, J. Li, L. Zhang, Z. B. Wang, D. X. Kong, J. L. Ma, G. J. Wei and J. F. Xu, *Geostand. Geoanal. Res.*, 2016, **40**, 217-226.
11. M. Willbold, K. Hibbert, Y.-J. Lai, H. Freymuth, R. C. Hin, C. Coath, F. Vils and T. Elliott, *Geostand. Geoanal. Res.*, 2016, **40**, 389-403.
12. K. Irisawa and T. Hirata, *J. Anal. At. Spectrom.*, 2006, **21**, 1387.
13. N. Imai, S. Terashima, S. Itoh, and A. Ando, *Geochem. J.*, 1995, **29**, 91-95.
14. S. E. Mazza, A. Stracke, J. B. Gill, J.-I. Kimura and T. Kleine, *Earth Planet. Sci. Lett.*, 2020, **530**, 115942.
15. D. Asael, F. L. Tissot, C. T. Reinhard, O. Rouxel, N. Dauphas, T. W. Lyons, E. Ponzevera, C. Liorzou and S. Chéron, *Chem. Geol.*, 2013, **362**, 193-210.
16. K. T. Goto, G. Shimoda, A. D. Anbar, G. W. Gordon, Y. Harigane, R. Senda and K. Suzuki, *Mar. Geol.*, 2015, **369**, 91-99.
17. J. Li, X. k. Zhu, S. h. Tang and K. Zhang, *Geostand. Geoanal. Res.*, 2016, **40**, 405-415.
18. N. Gaspers, T. Magna and L. Ackerman, *Geostand. Geoanal. Res.*, 2020, **44**, 363-374.
19. T. Goldberg, G. Gordon, G. Izon, C. Archer, C. R. Pearce, J. McManus, A. D. Anbar and M. Rehkämper, *JAAS*, 2013, **28**, 724-735.
20. J. S. Kane, B. Arbogast and J. Leventhal, *Geostand. Newsl.*, 1990, **14**, 169-196.
21. B. Kendall, S. Wang, P. Lillis, L. Xing, W. Zheng and C. Zhu, *Chem. Geol.*, 2023, **617**, 121244.
22. N. Imai, S. Terashima, S. Itoh and A. Ando, *Geostand. Newsl.*, 1996, **20**, 165-216.
23. G. P. Sindol, M. G. Babechuk, J. Conliffe, J. F. Slack, C. Rosca and R. Schoenberg, *Precambrian Res.*, 2022, **379**, 106750.
24. USGS Geochemical and Microanalytical Reference Materials Distribution:

https://www.usgs.gov/centers/gggsc/science/usgs-geochemical-and-microanalytical-reference-materials-distribution

25. NRC Digital Repository from National Research Council Canada: https://nrc-digital-repository.canada.ca/eng/home/
26. Canadian Certified Reference Materials Project: https://natural-resources.canada.ca/mining-materials/resources/canadian-certified-reference-materials-project/price-certificates-list/8001