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Supporting Information S1 for

Evidence for Extrusive Mg-Suite Magmatism on the Moon? Fine-Grained Magnesian Clasts in an Apollo 16 Impact Melt Breccia

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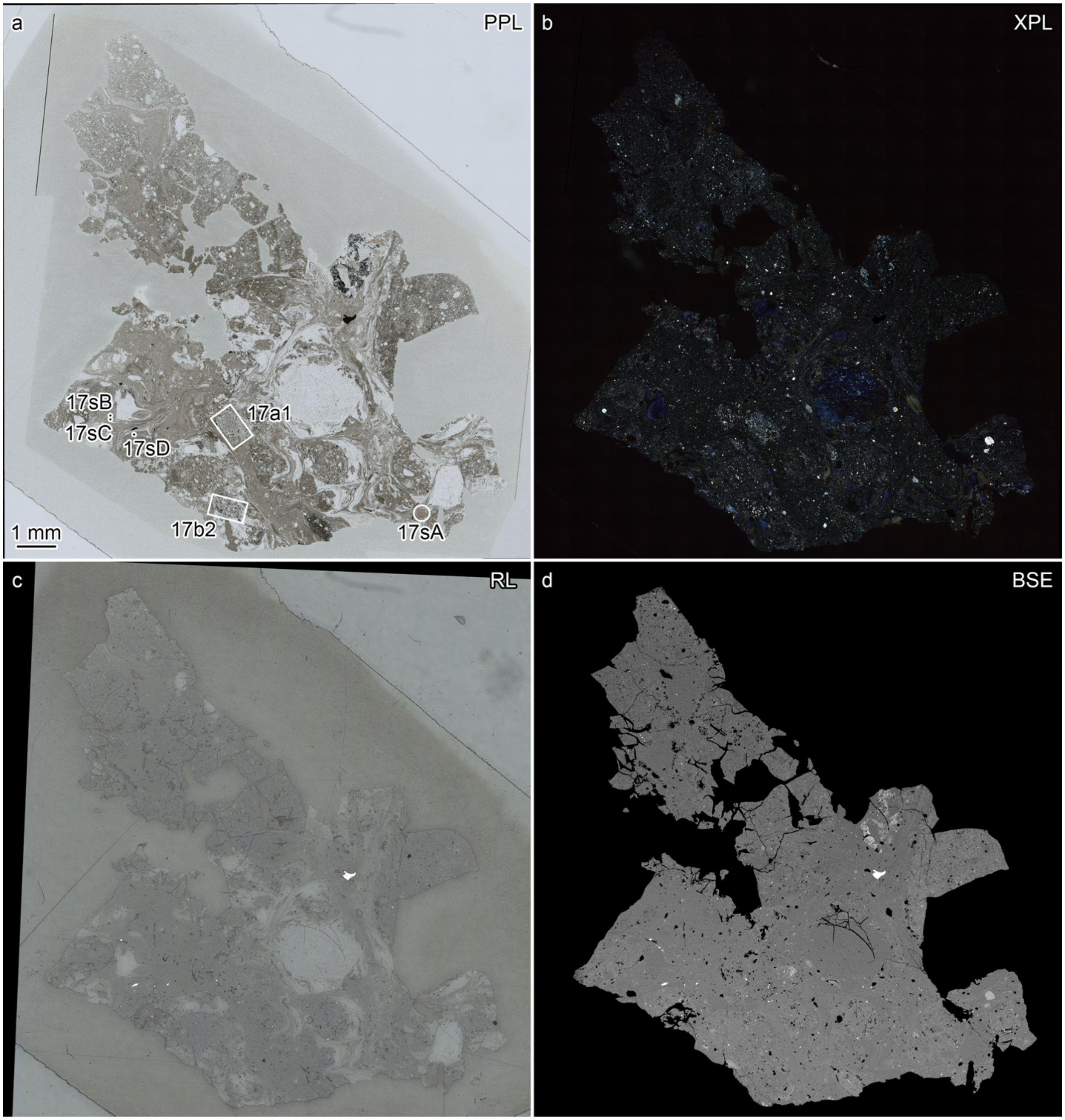


Figure S1. (a) Plane-polarized light (PPL) image of 68815,17 with labeled locations of clasts of interest. (b) Cross-polarized light (XPL) image of 68815,17. (c) Reflected light (RL) image of 68815,17. (d) Backscattered electron (BSE) image of 68815,17.

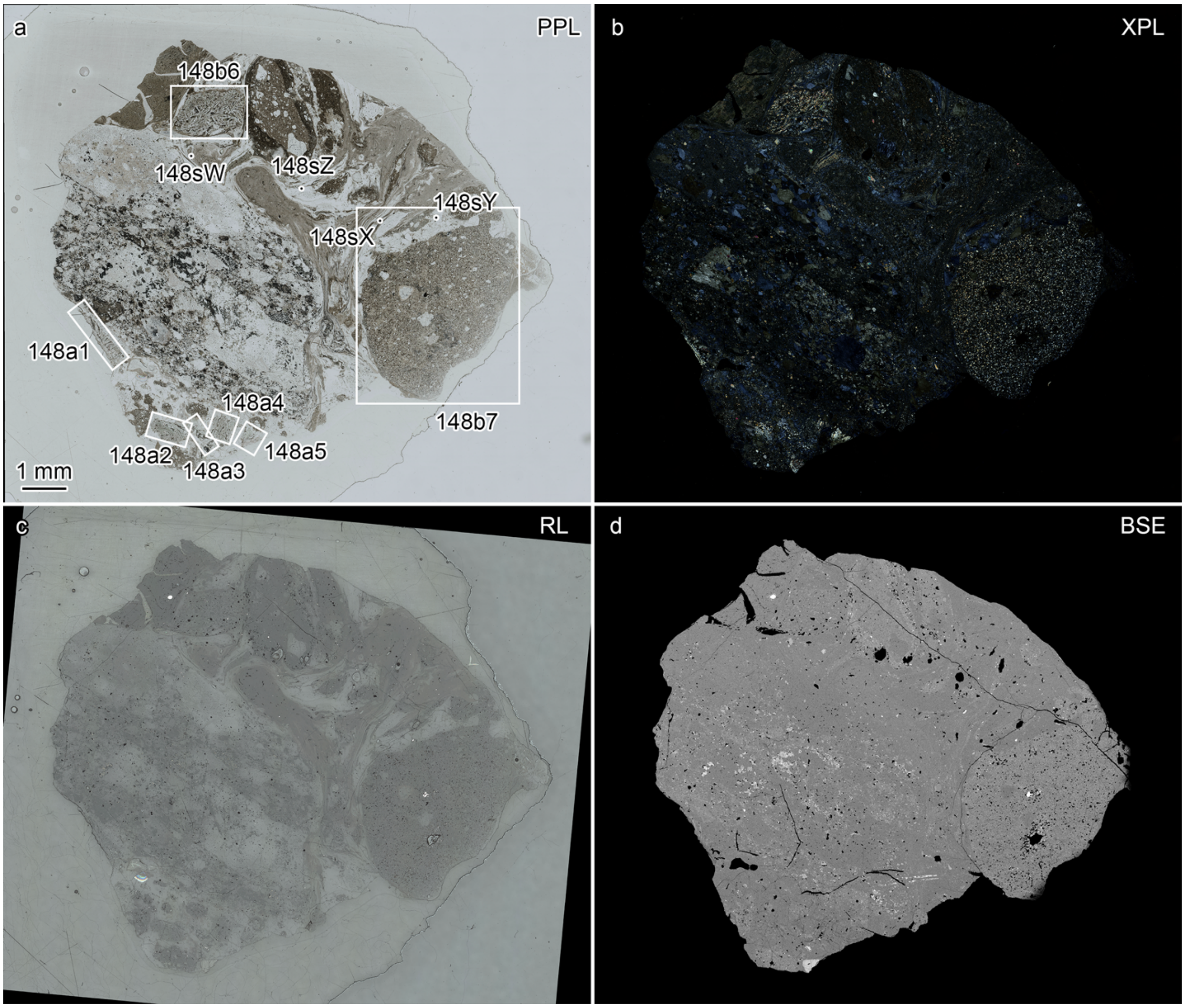


Figure S2. (a) PPL image of 68815,148 with labeled locations of clasts of interest. (b) XPL image of 68815,148. (c) RL image of 68815,148. (d) BSE image of 68815,148.

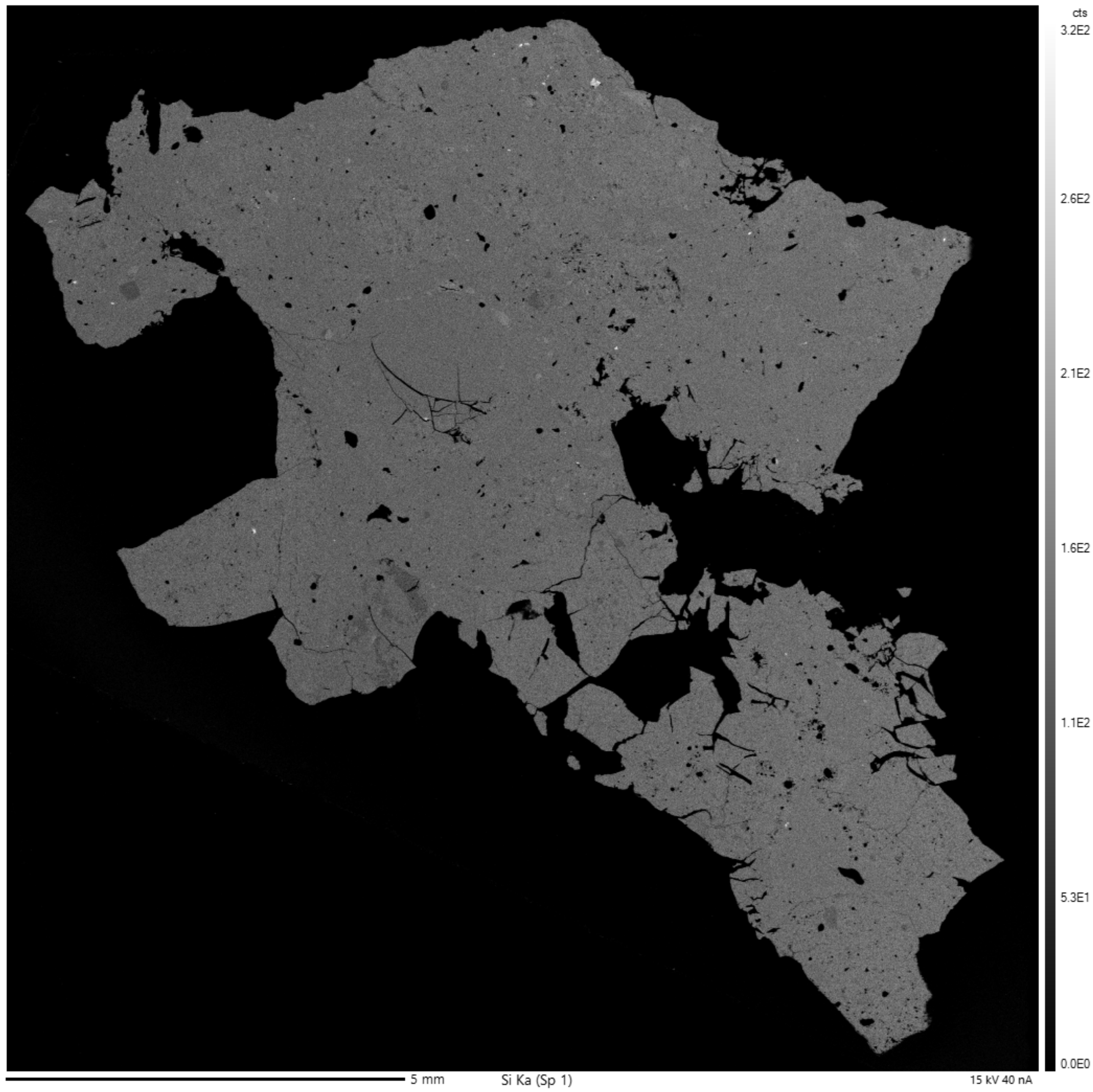
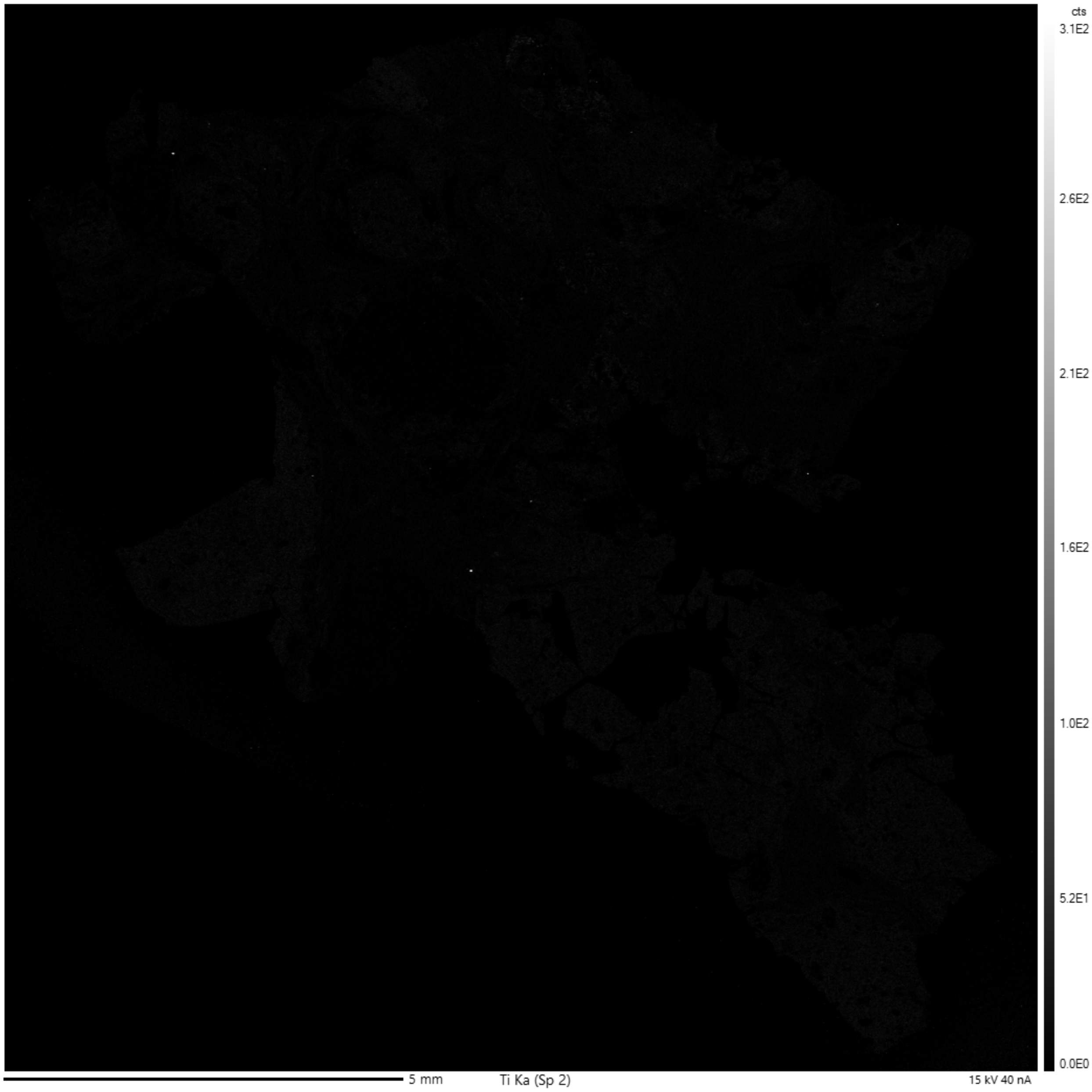


Figure S3. Si X-ray map of 68815,17.



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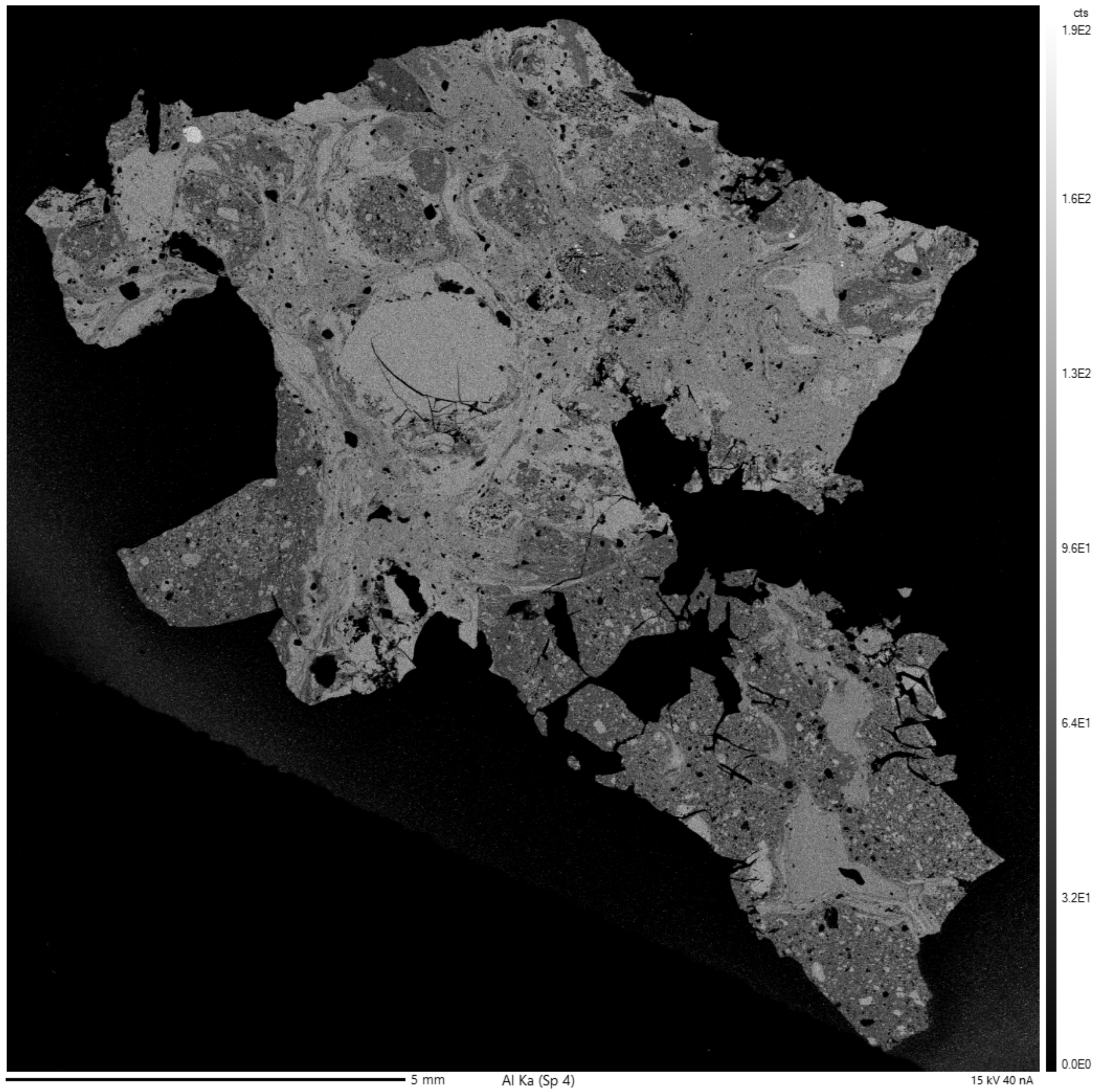
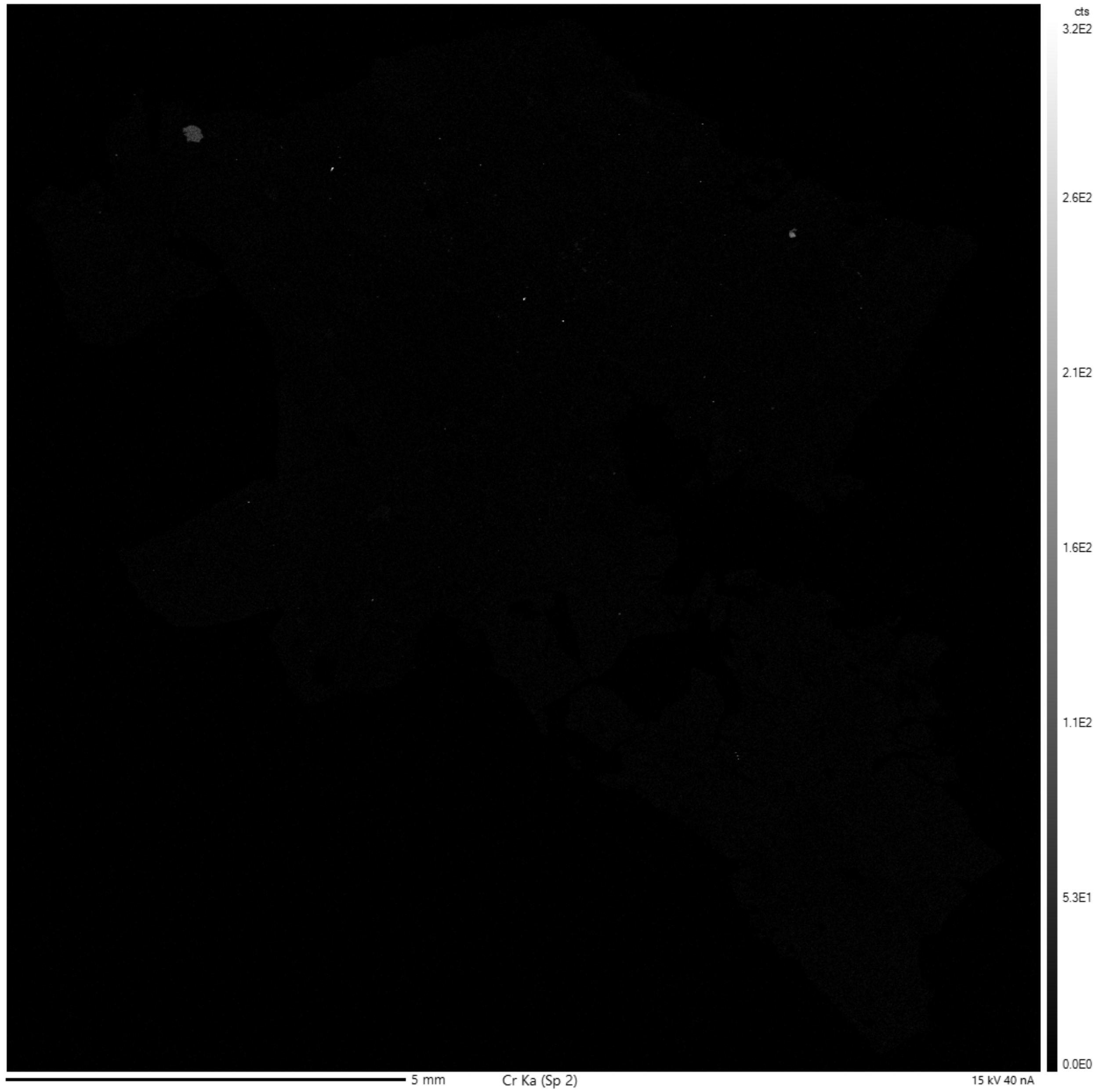


Figure S5. Al X-ray map of 68815,17.



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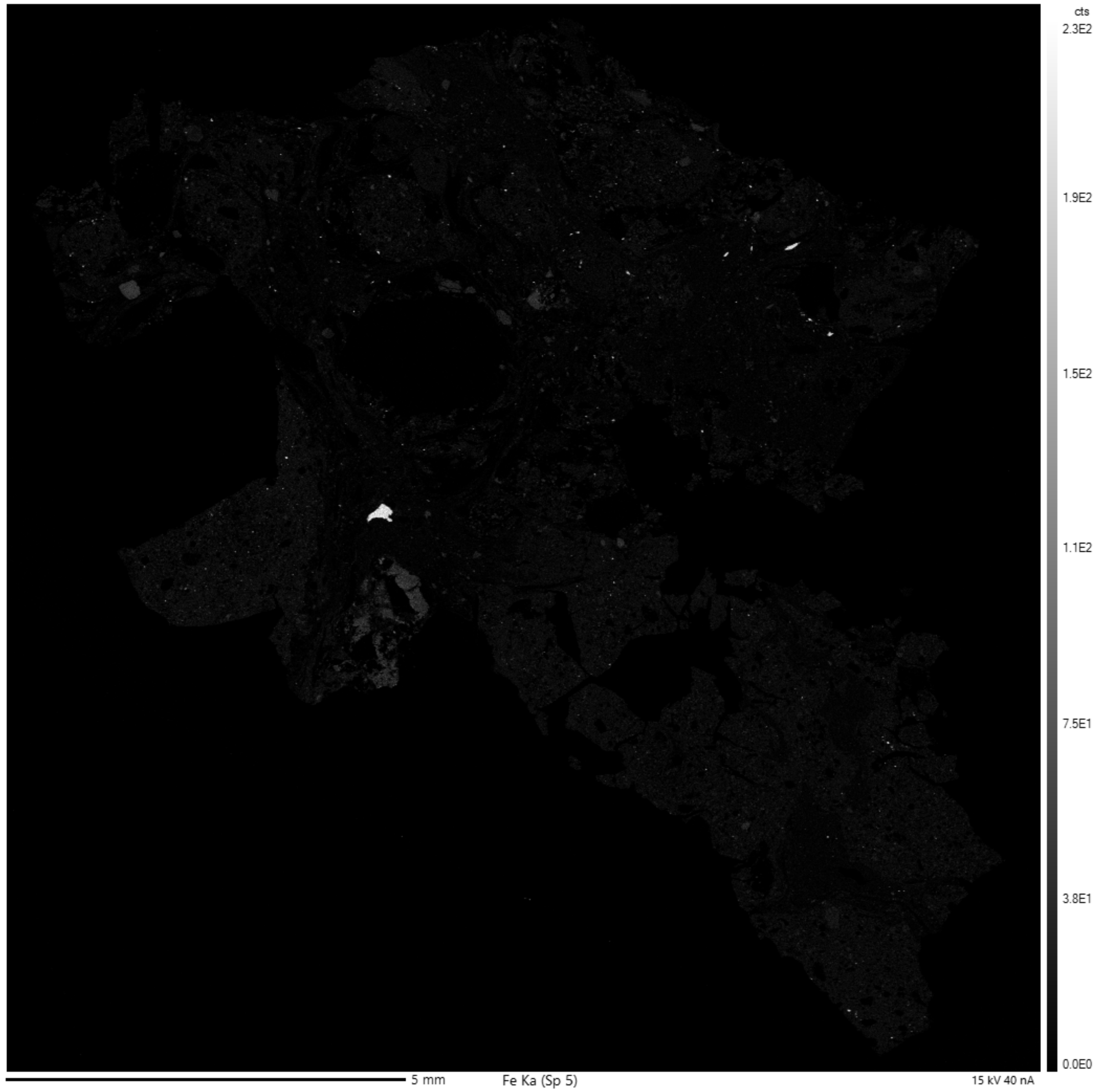


Figure S7. Fe X-ray map of 68815,17.

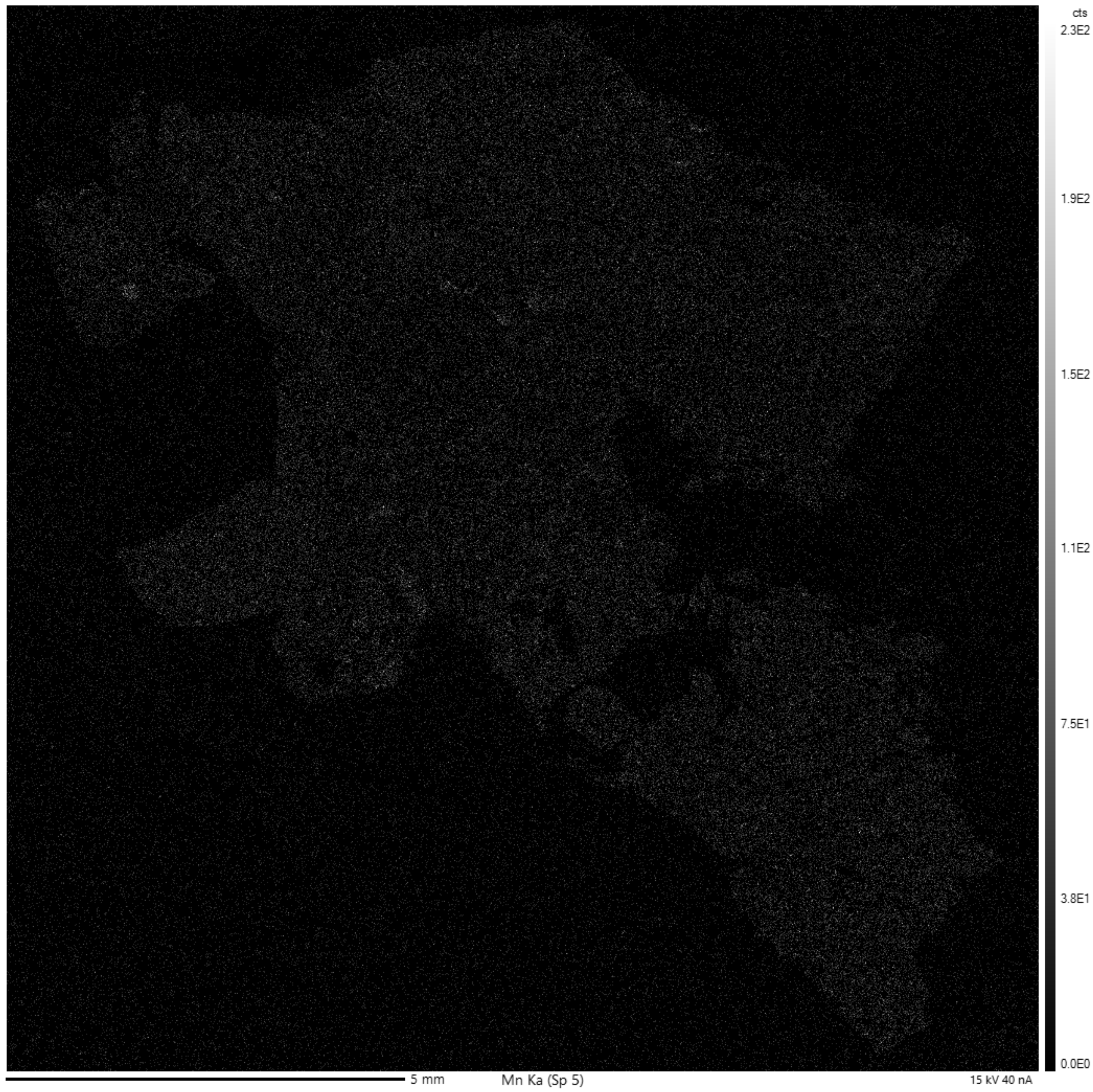


Figure S8. Mn X-ray map of 68815,17.

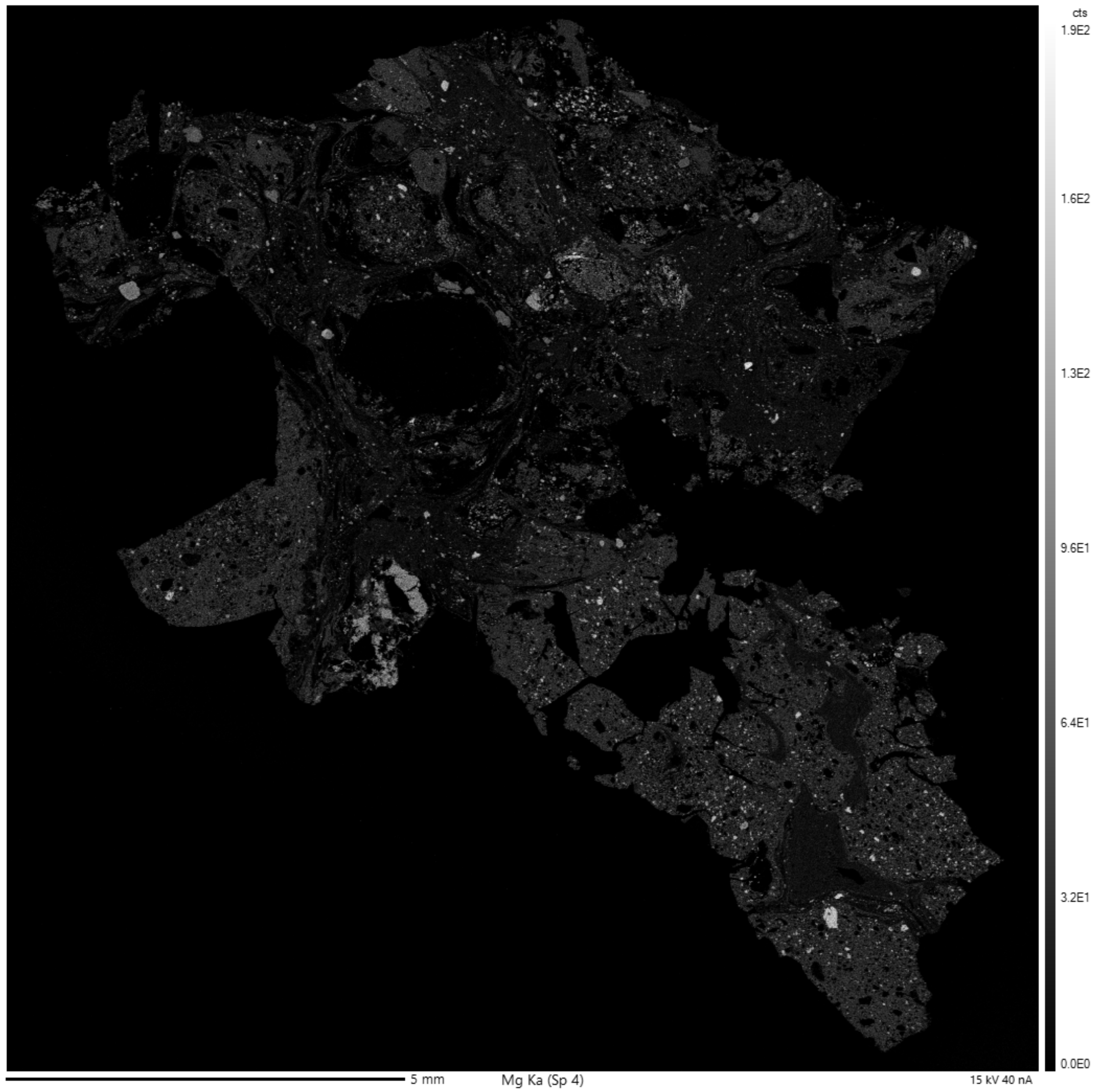
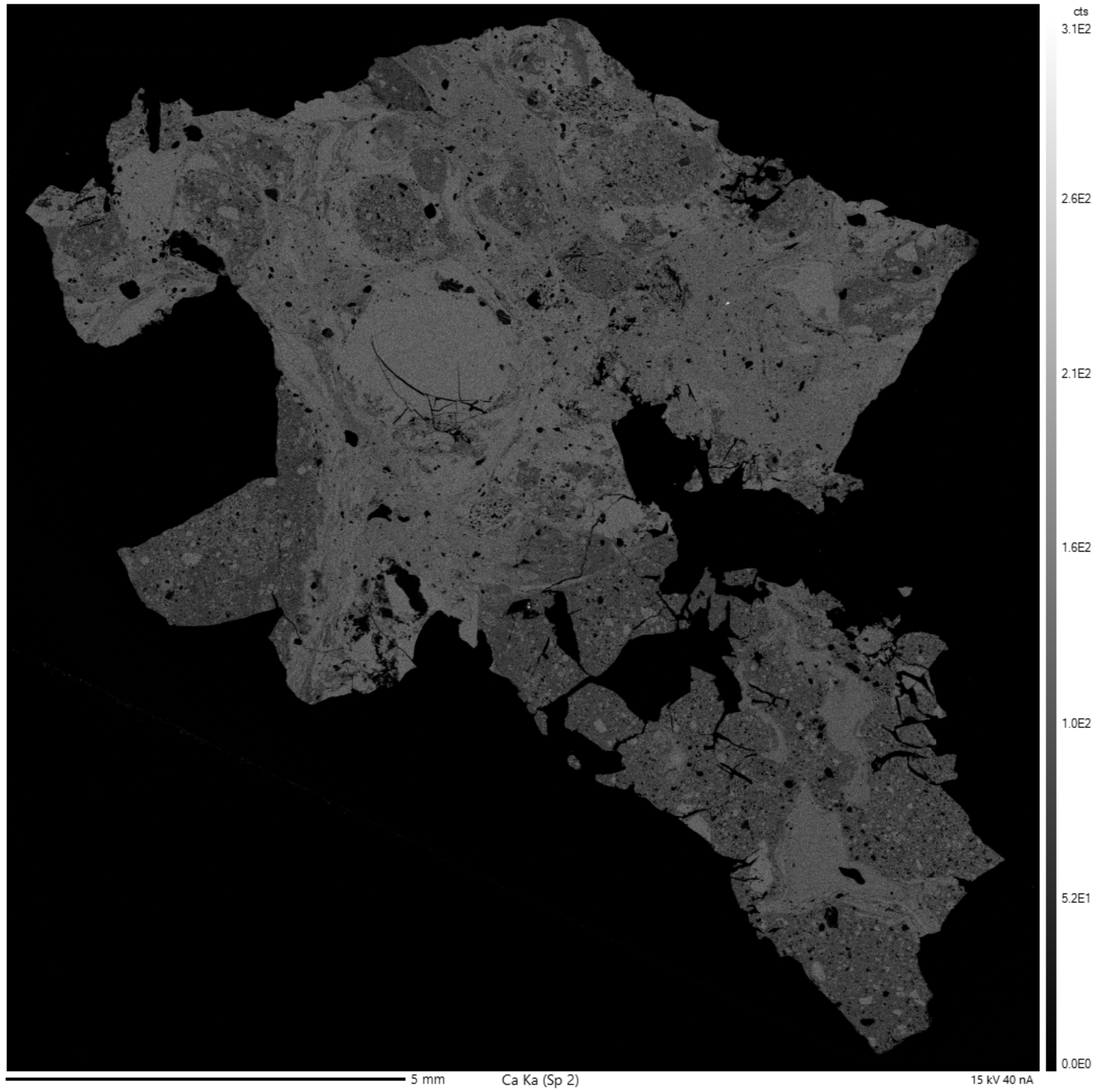


Figure S9. Mg X-ray map of 68815,17.



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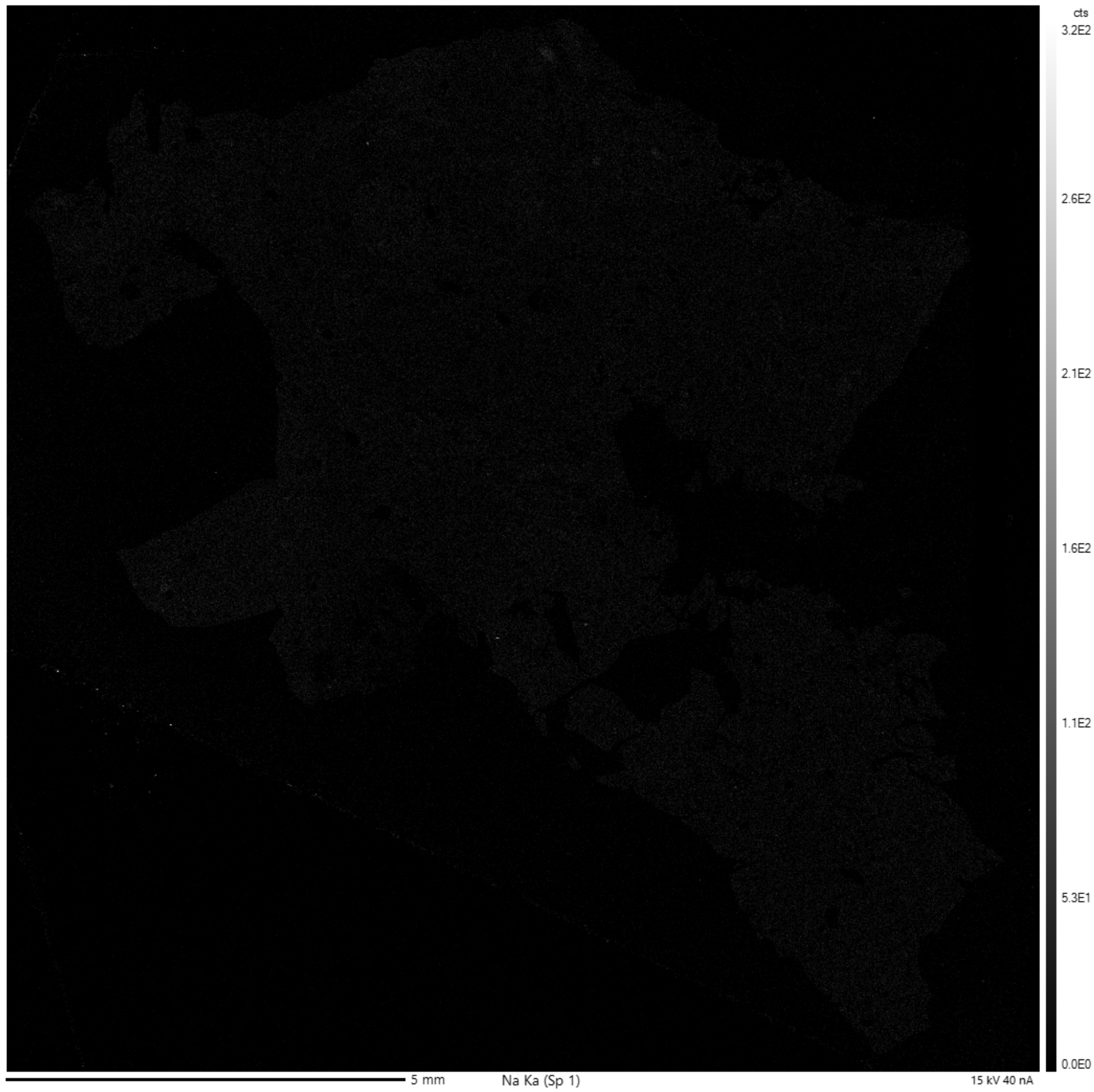
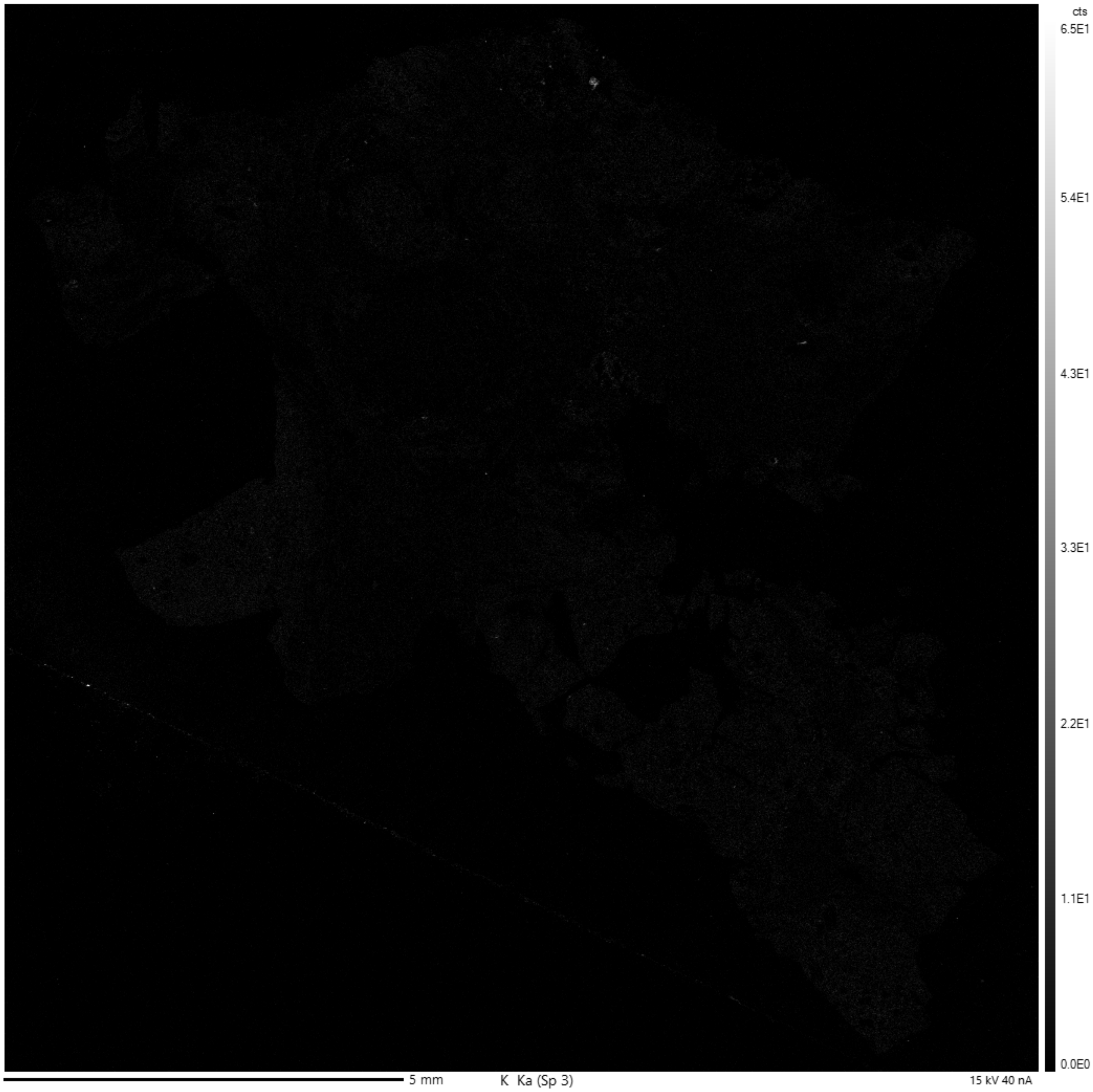


Figure S11. Na X-ray map of 68815,17.



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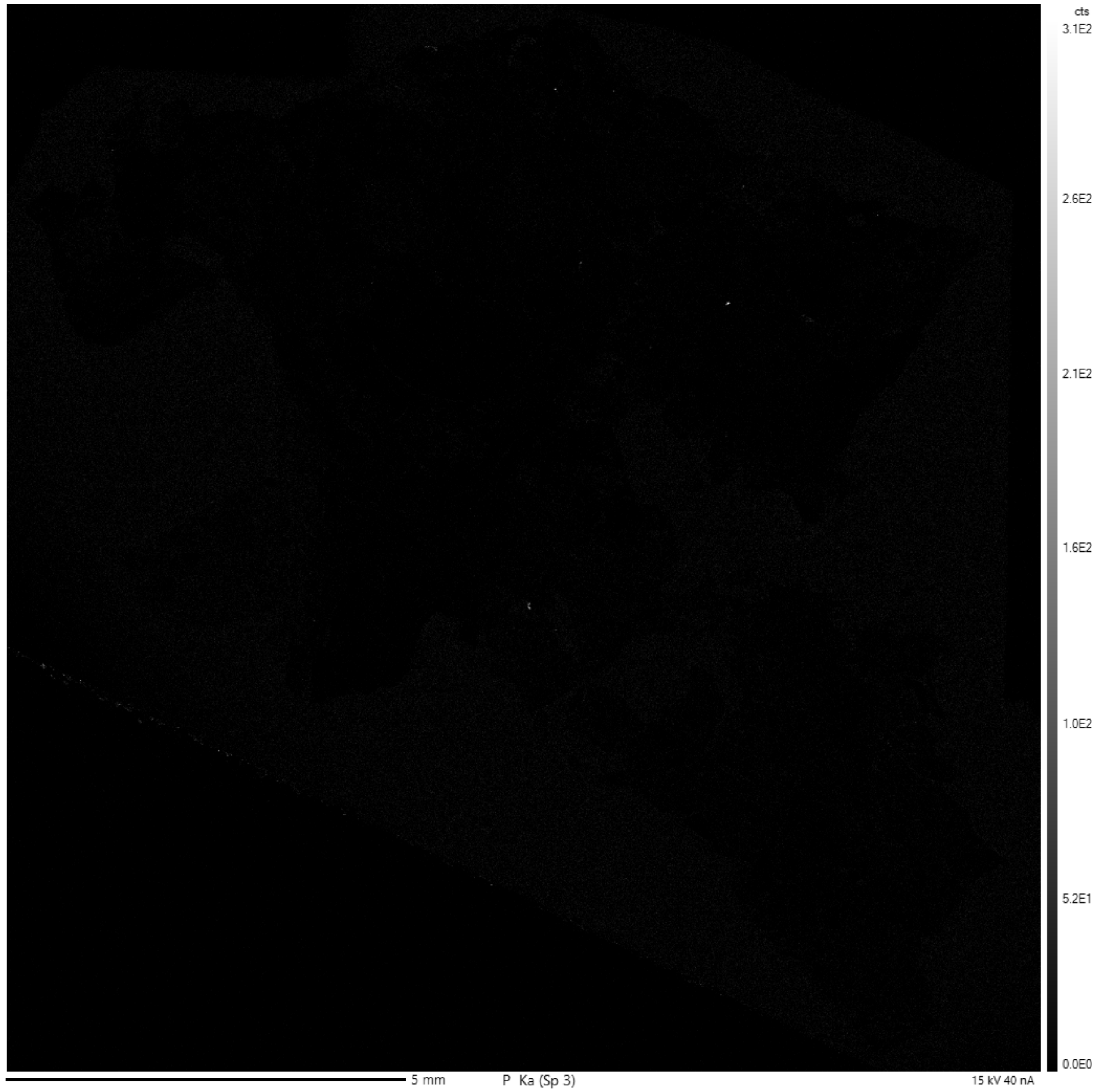

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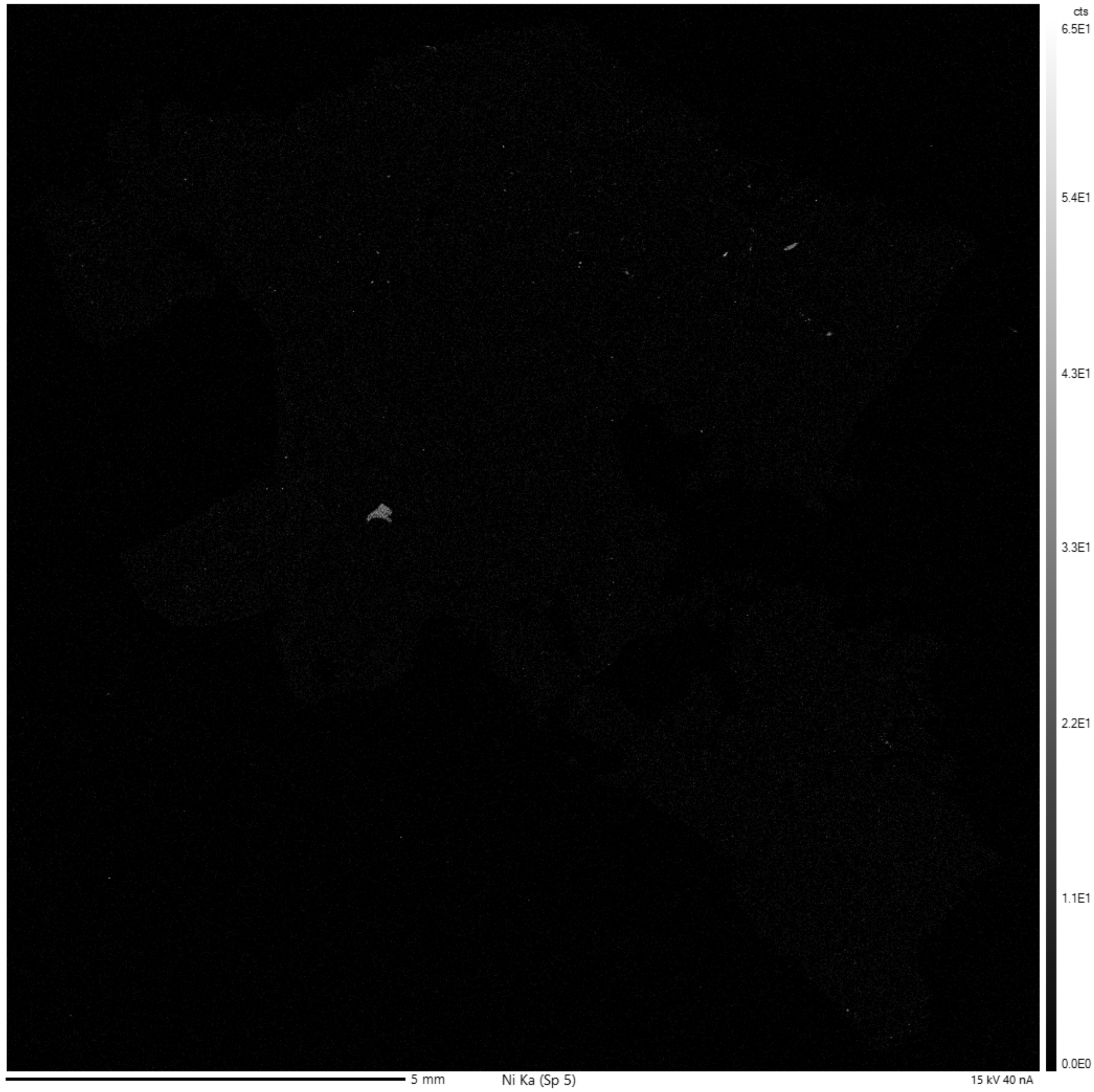
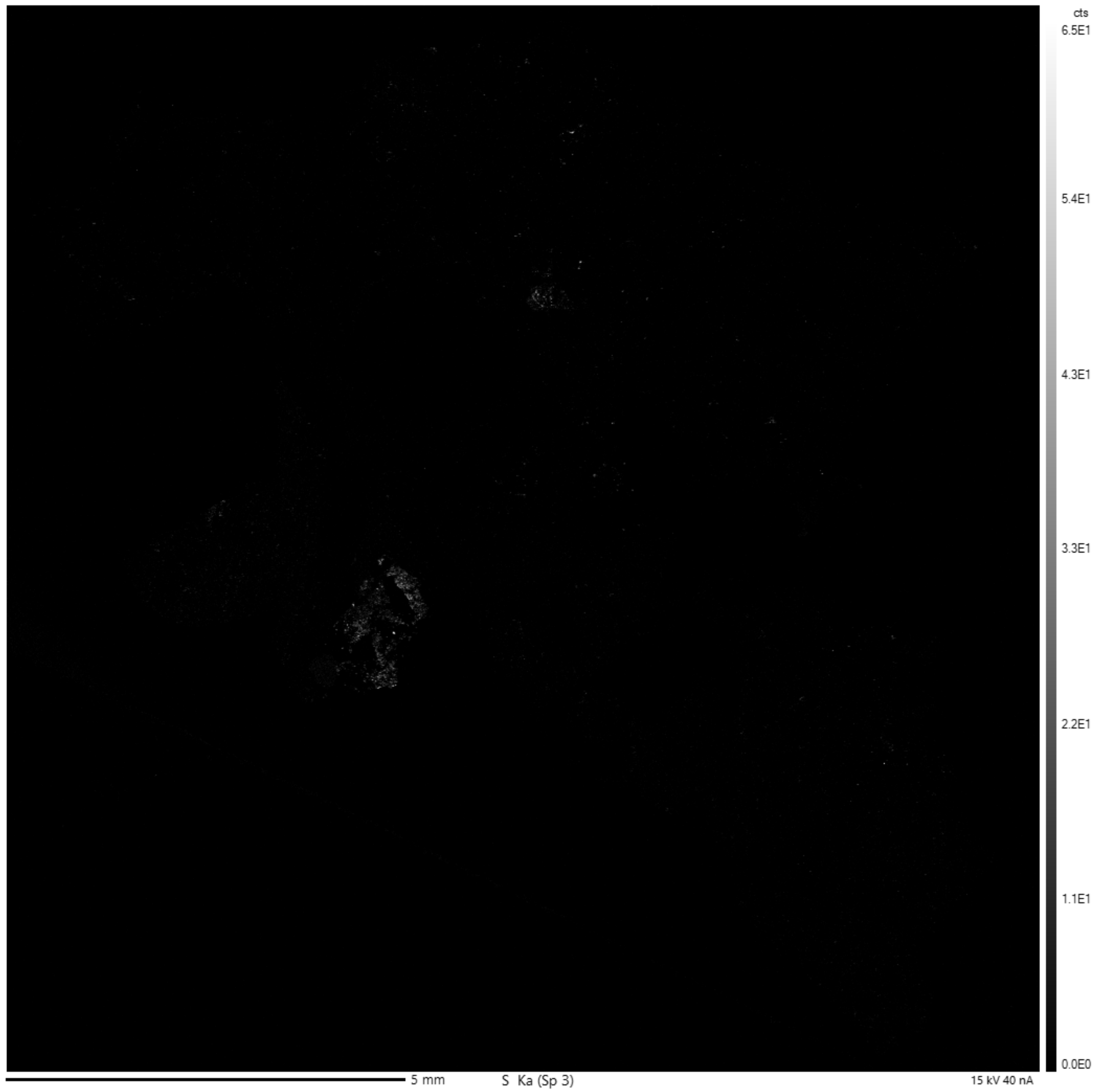


Figure S14. Ni X-ray map of 68815,17.



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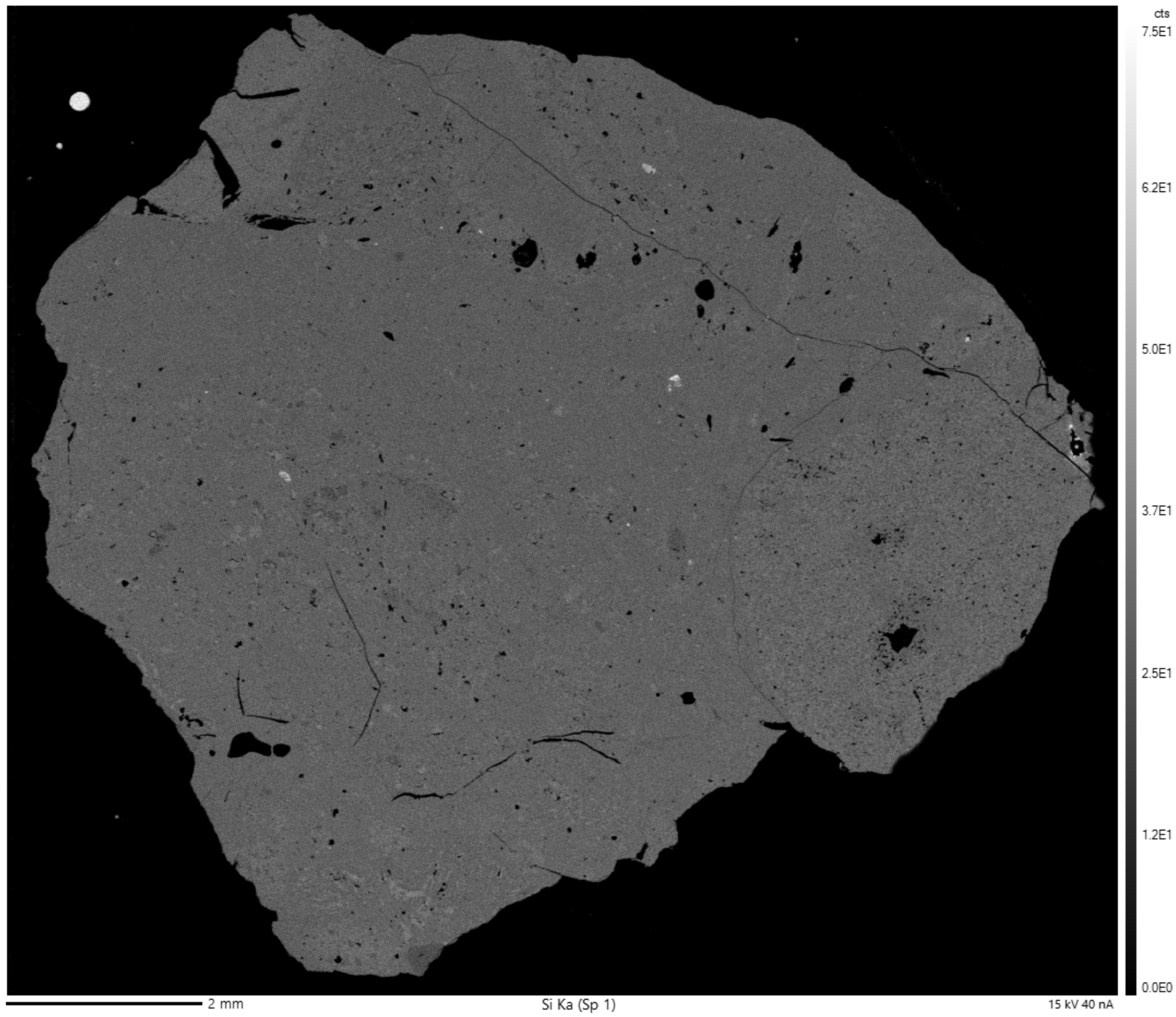
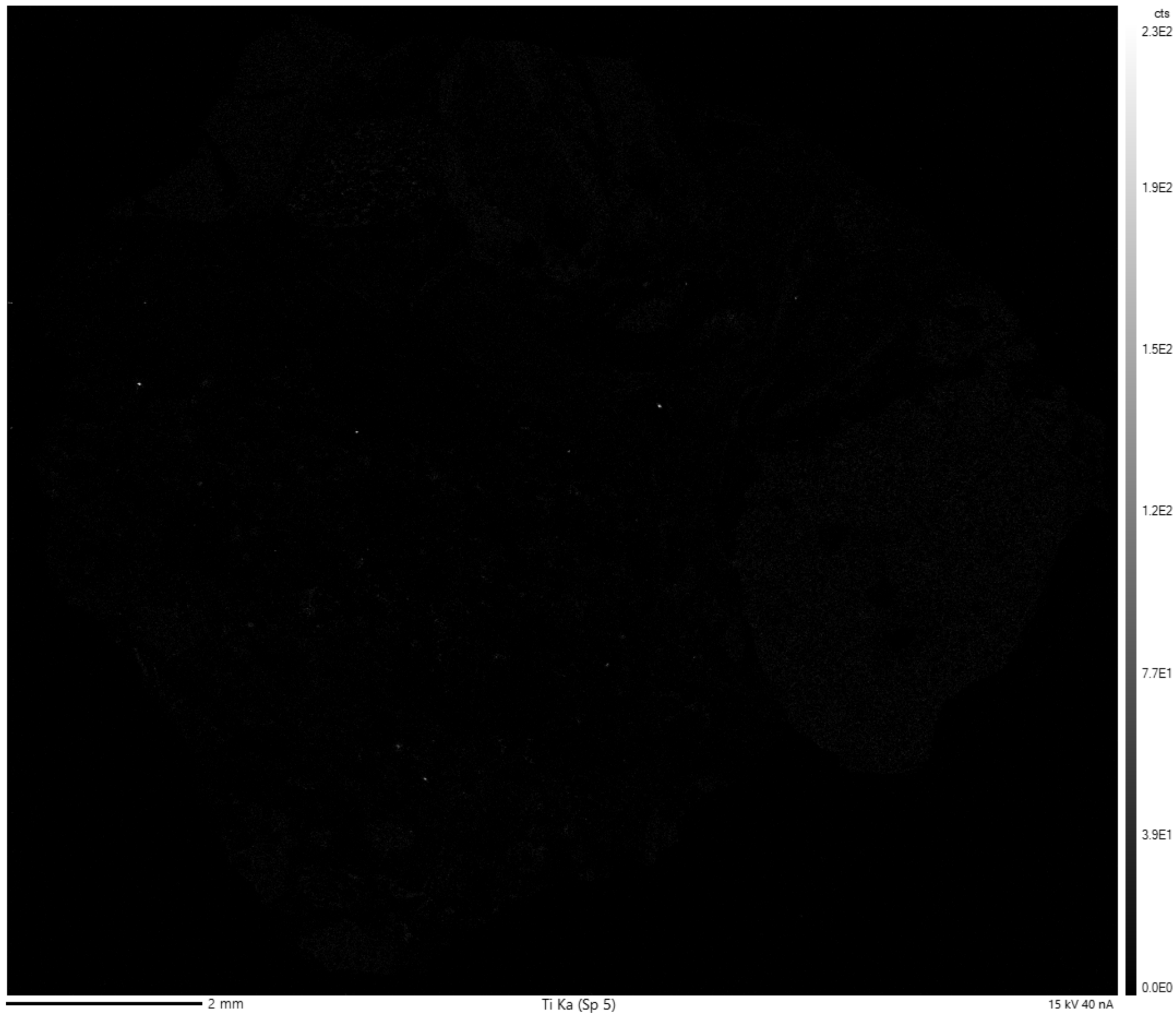


Figure S16. Si X-ray map of 68815,148.



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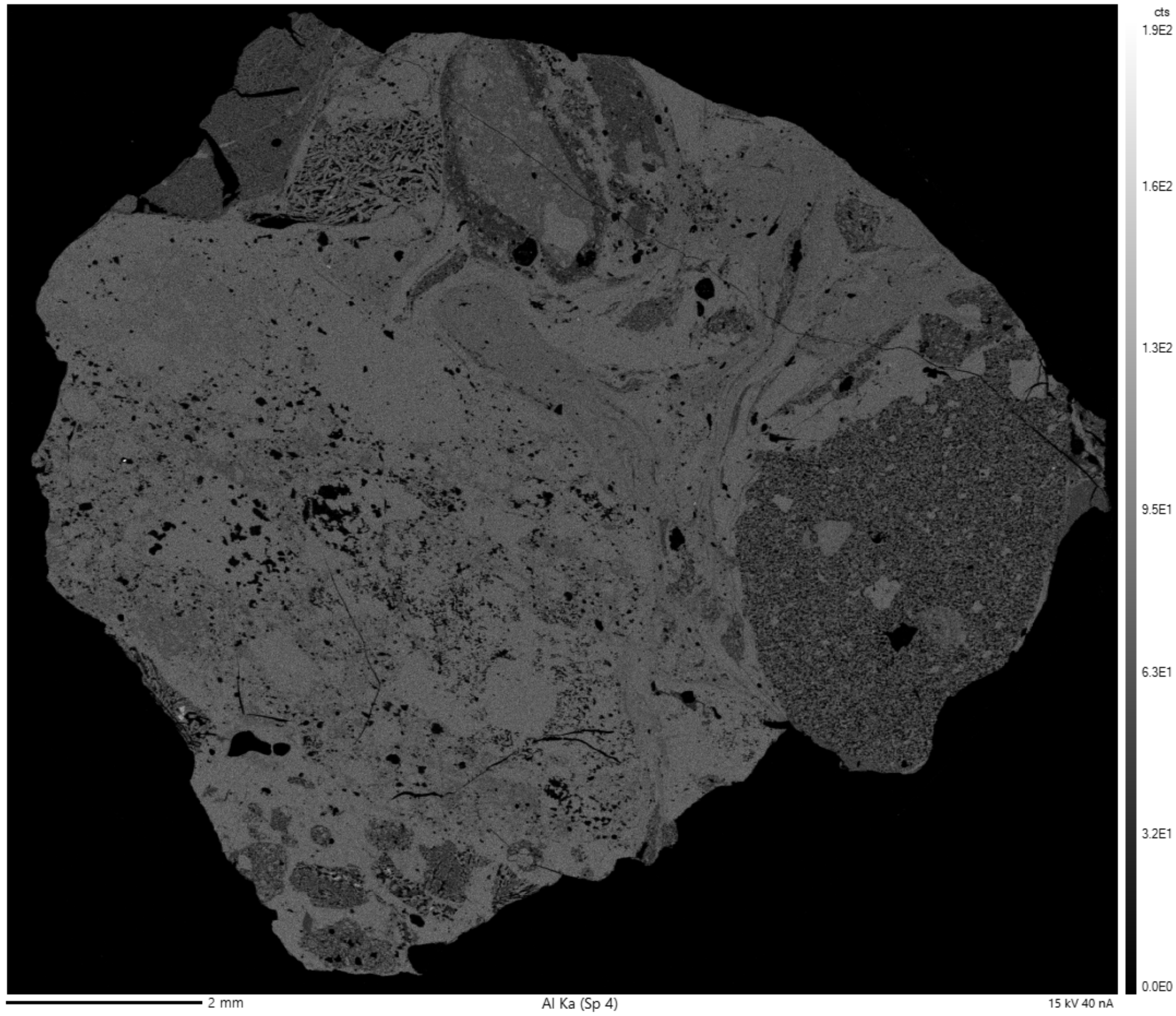

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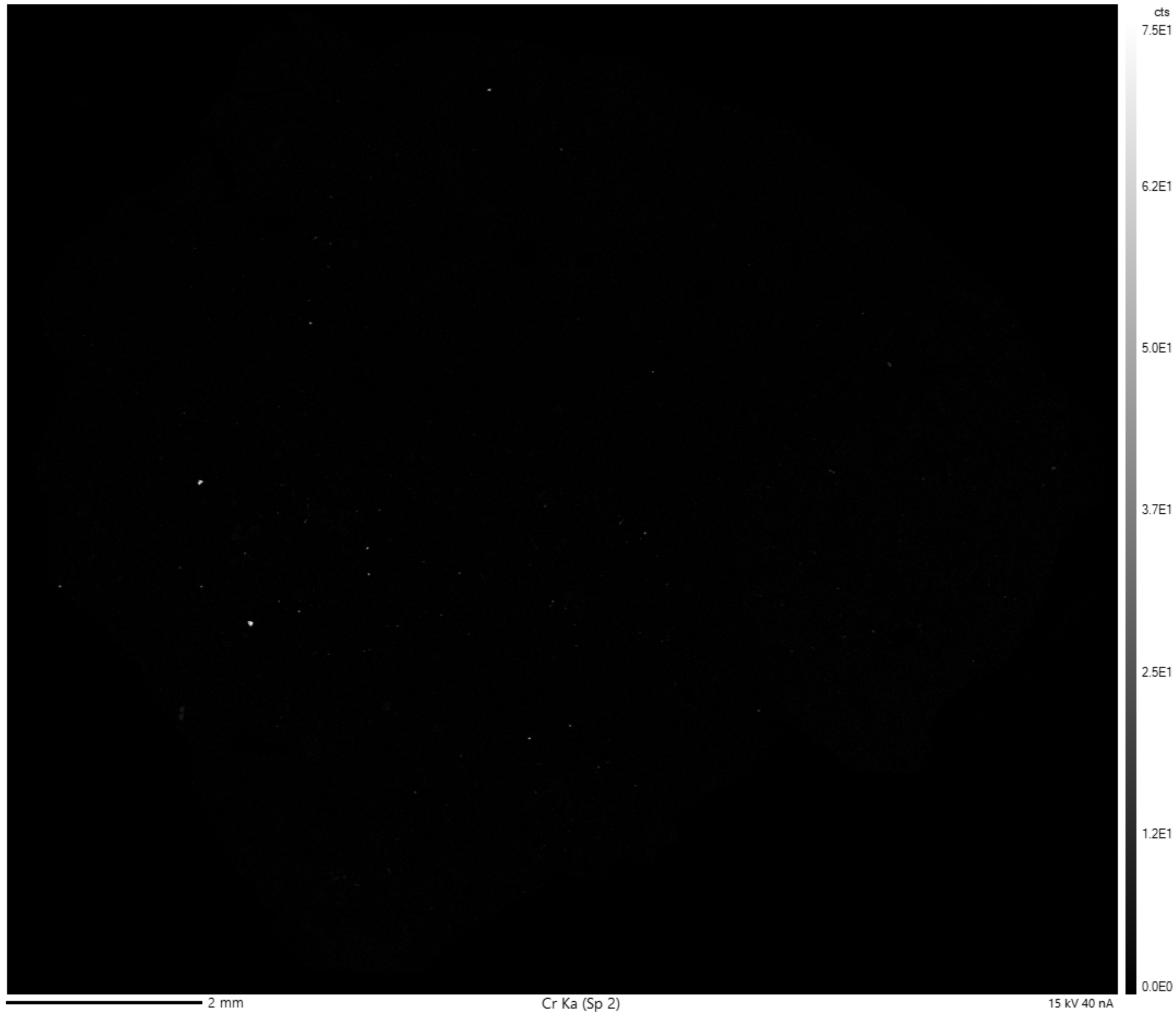

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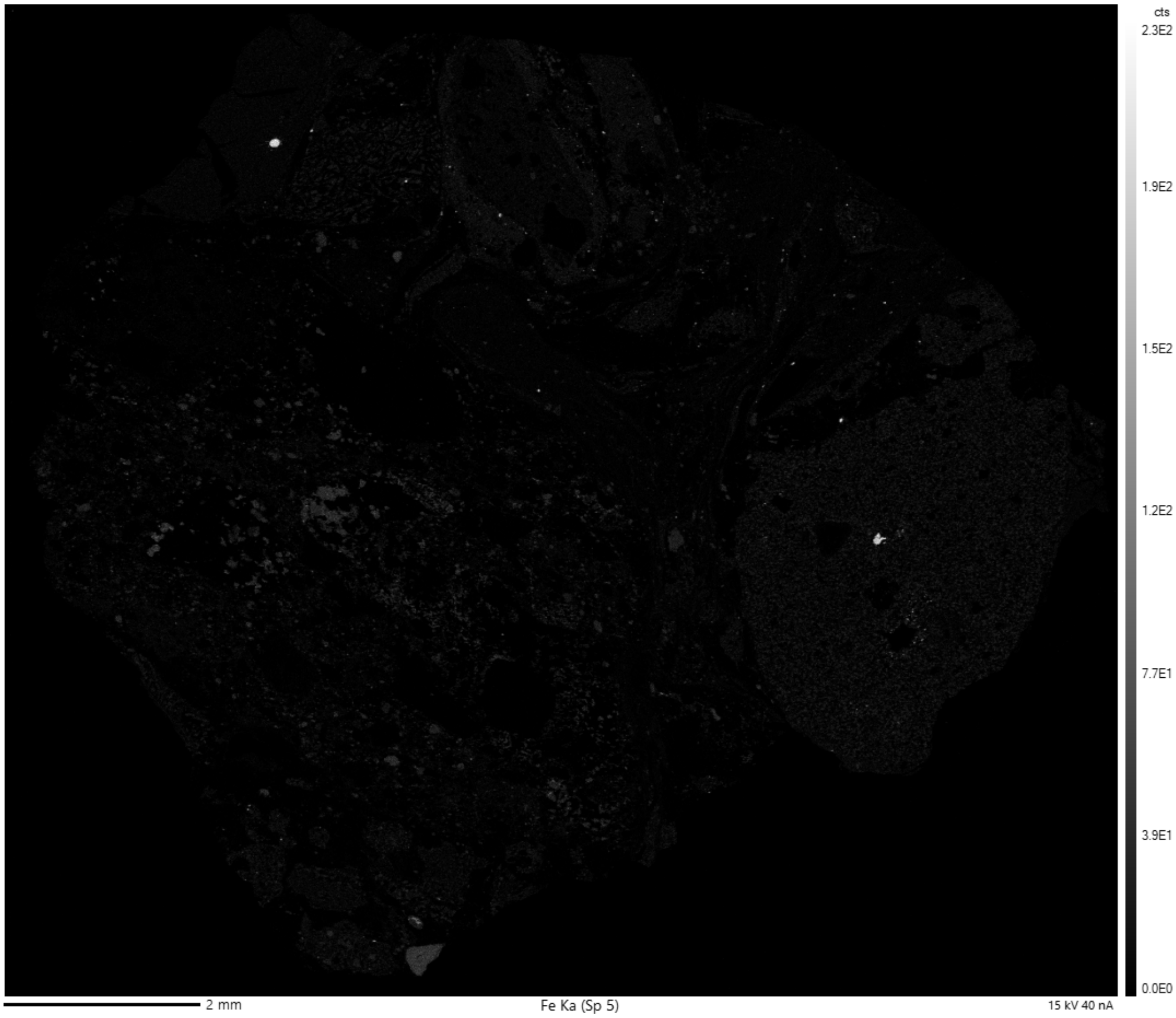

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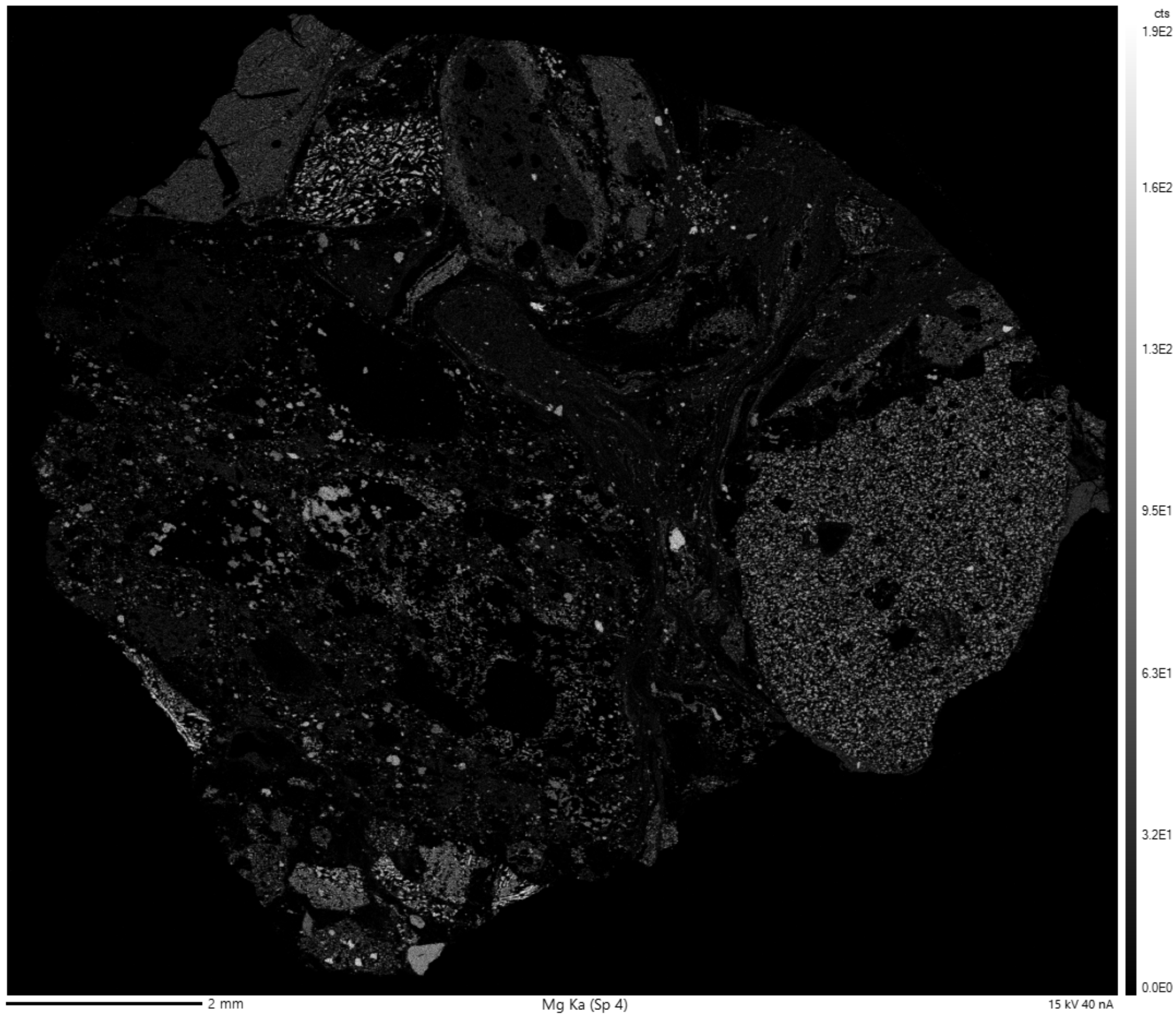

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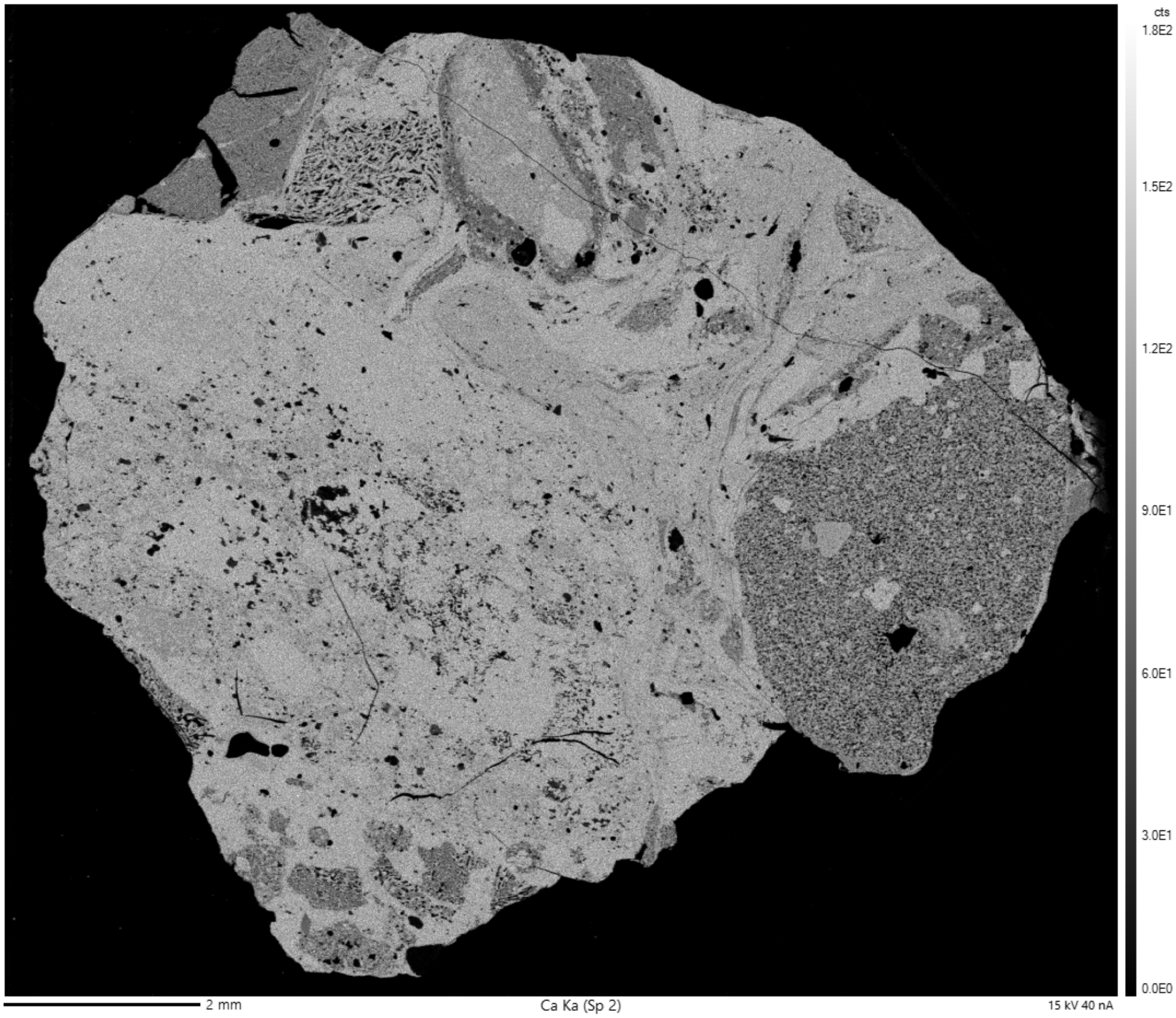

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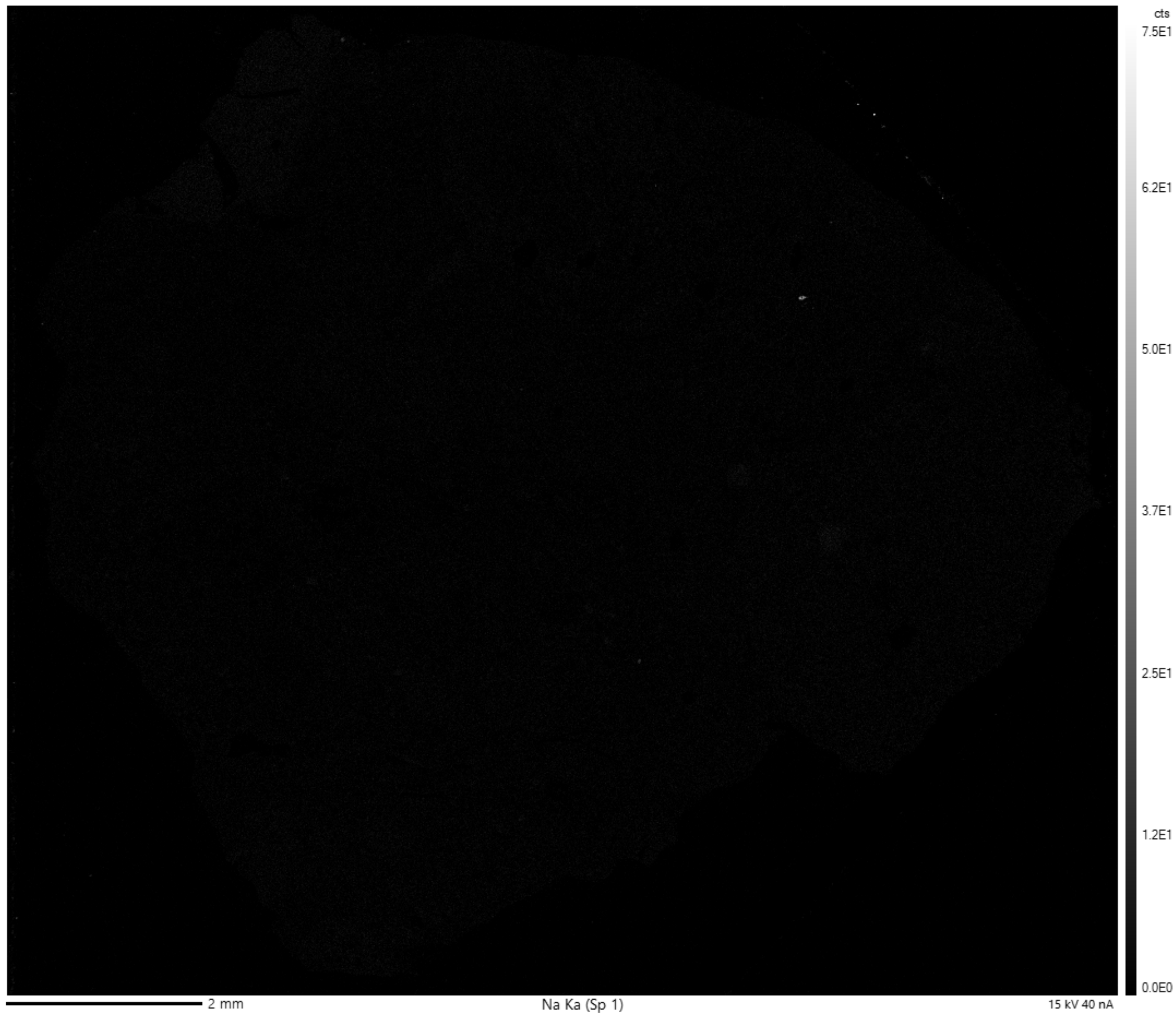
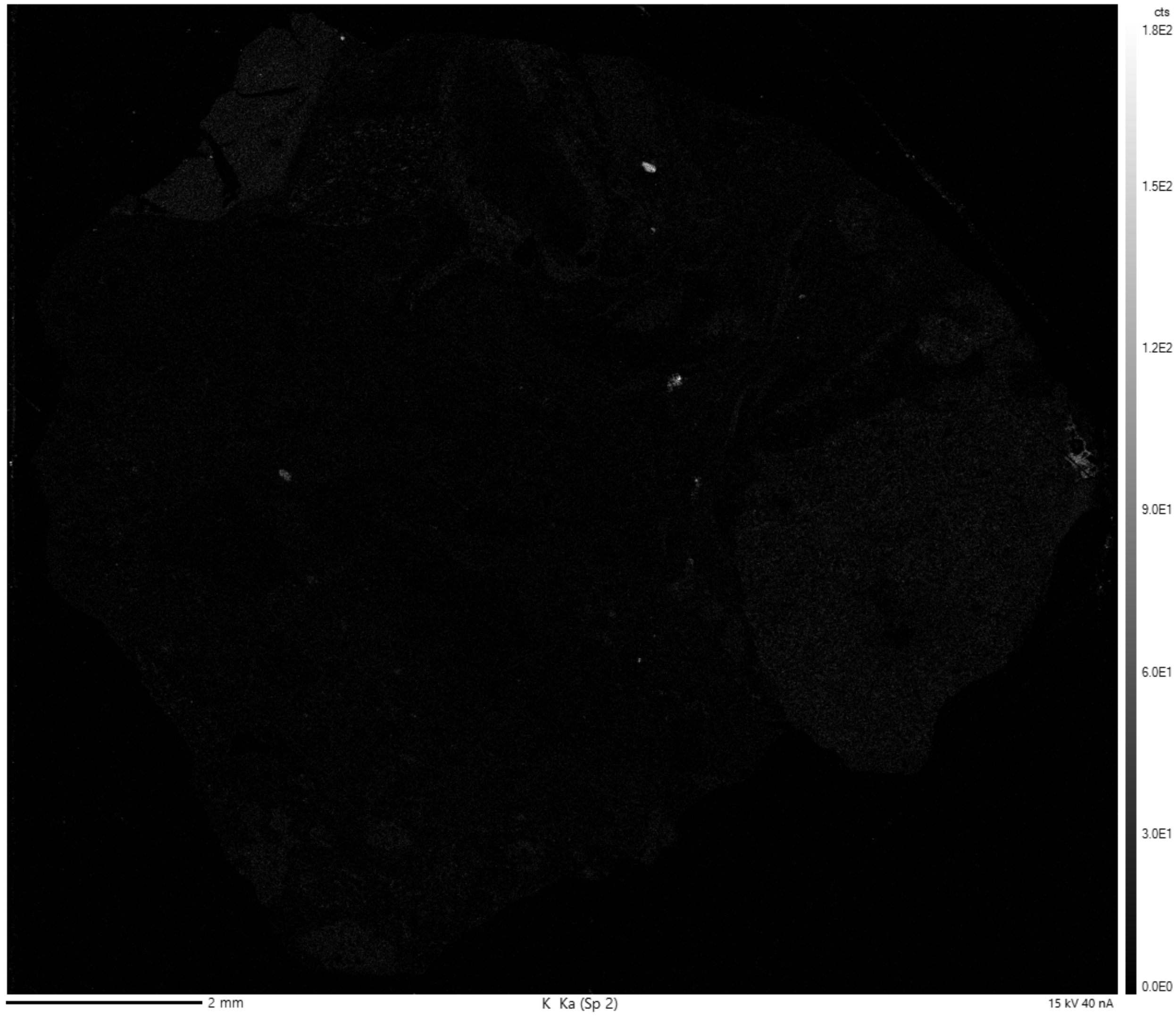


Figure S23. Na X-ray map of 68815,148.



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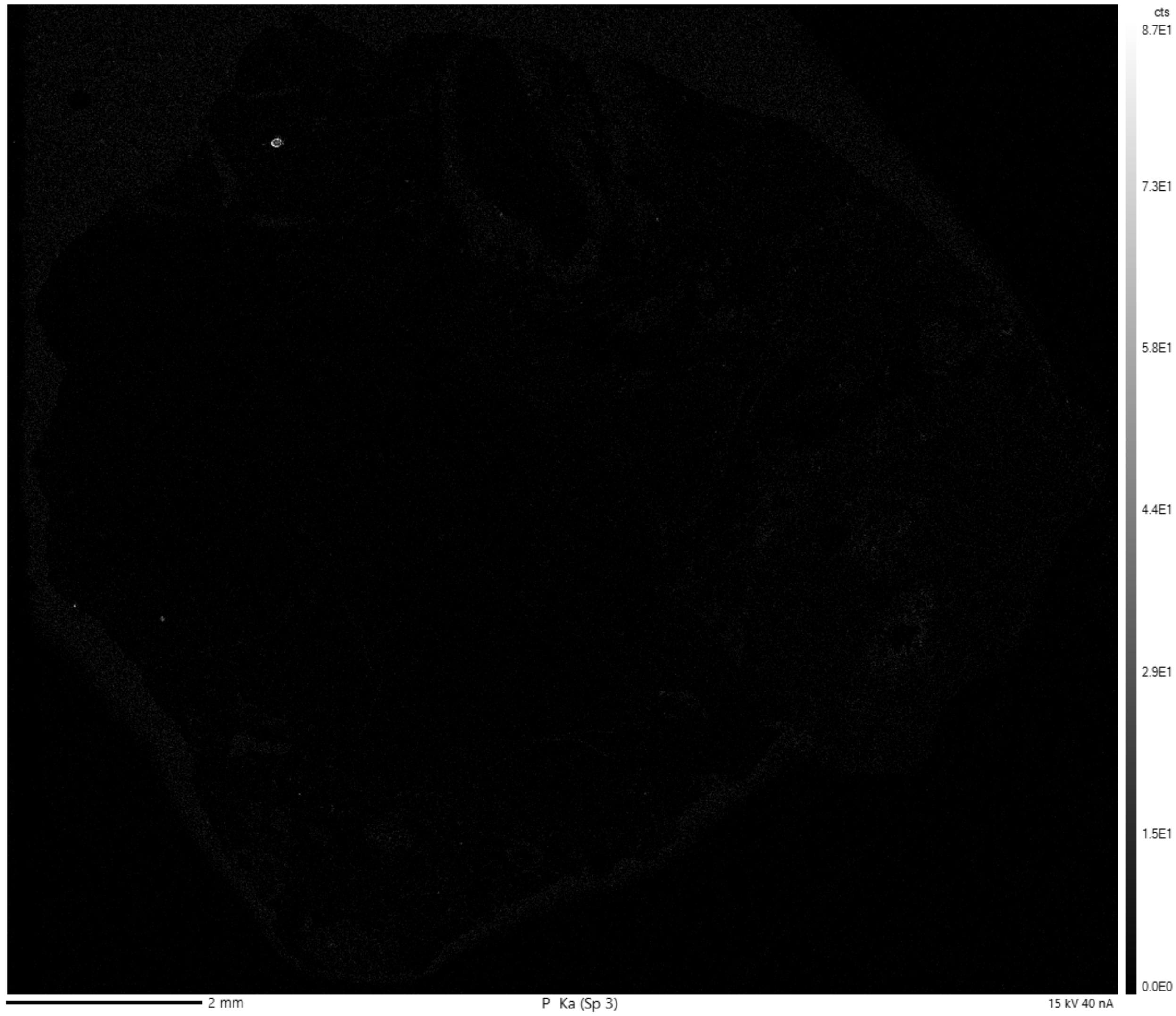

Figure S25. P X-ray map of 68815,148.

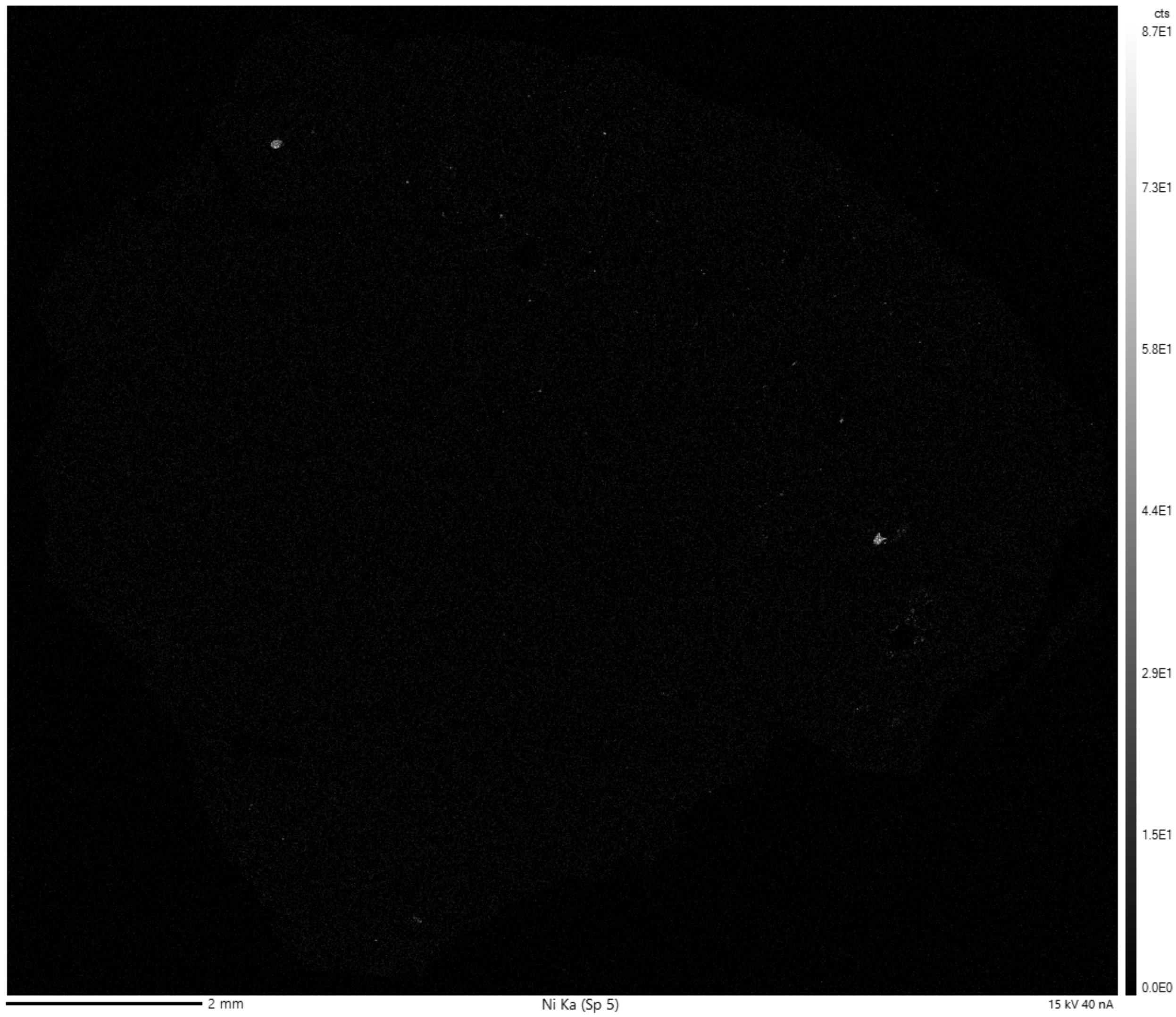

Figure S26. Ni X-ray map of 68815,148.

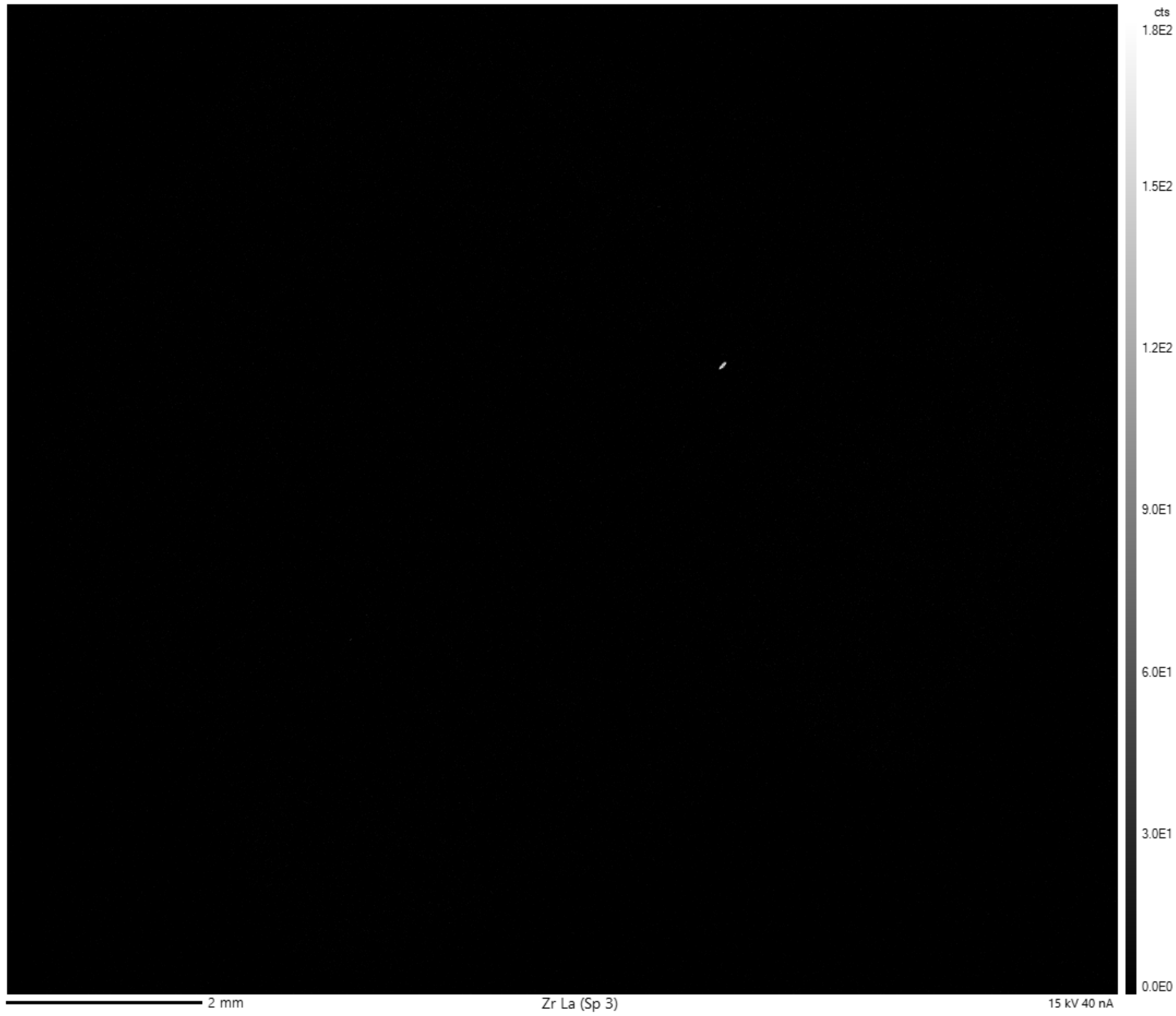

Figure S27. Zr X-ray map of 68815,148.

Figure S28. S X-ray map of 68815,148.

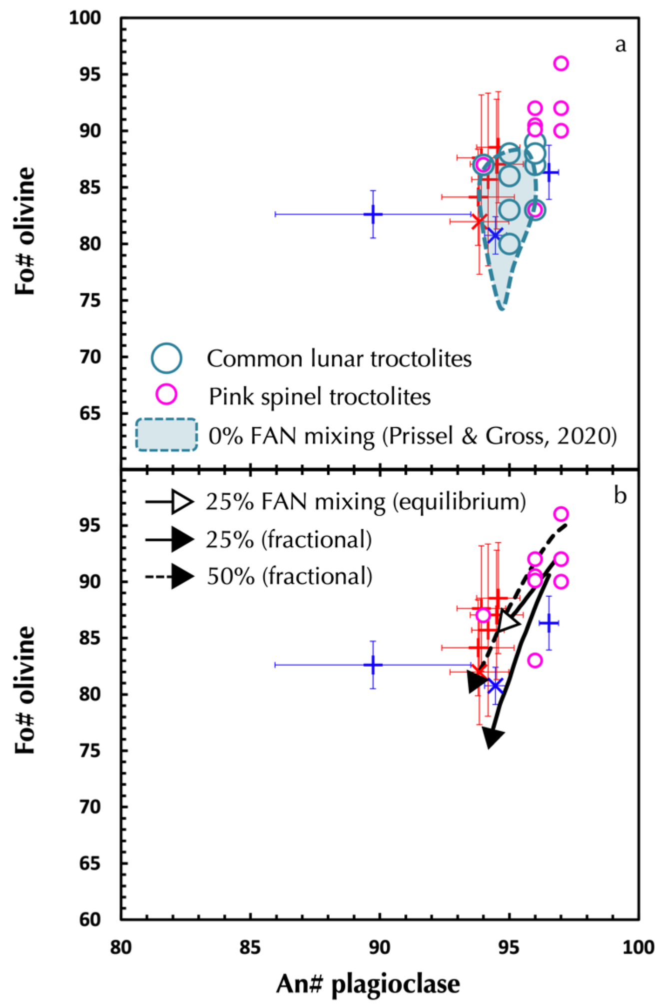

Figure S29. Forsterite content vs. anorthite content of co-existing plagioclase. (a) Symbols follow from previous figures with error bars encompassing the total observed variance relative to the median. Legend provided for common lunar troctolites (± chromite, no spinel) and pink spinel troctolites (*Shearer et al.*, 2015; and excluding only those data with undetermined values and evidence for metamorphism, i.e., cordierite). The combined equilibrium and fractional crystallization products from the mantle-derived Mg-suite primary melt from *Prissel and Gross* (2020) is shown and represents troctolitic assemblages produced with no crustal assimilation (i.e., common lunar troctolites). (b) Same as above, but now showing crystallization trends of the Mg-suite primary melt following 25 and 50% assimilation of lunar crust (equilibrium vs. fractional crystallization defined in the legend). Assimilation of crust by Mg-suite primary melts can explain the production of both pink spinel-bearing troctolites in addition to generally higher forsterite contents observed in the spinel troctolites. Additionally, the contaminated crystallization sequences provide linkages between the proposed basaltic clasts studied here to their plutonic equivalents in the Mg-suite. Further discussion provided in the main text.

References for Supporting Information S1 and Data Set S12

Albee, A. L., A. A. Chodos, R. F. Dymek, A. J. Gancarz, D. S. Goldman, D. A. Papanastassiou, and G. J. Wasserburg (1974), Dunite From the Lunar Highlands: Petrography, Deformational History, Rb-Sr Age, edited, p. 3.

Baker, M. B., and C. T. Herzberg (1980), Spinel cataclasites in 15445 and 72435: petrology and criteria for equilibrium, *Lunar and Planetary Science Conference Proceedings*, *1*, 535-553.

Bence, A. E., J. W. Delano, J. J. Papike, and K. L. Cameron (1974), Petrology of the highlands massifs at Taurus-Littrow: an analysis of the 2 - 4 mm soil fraction, *Lunar and Planetary Science Conference Proceedings*, *1*, 785-827.

Brown, G. M., A. Peckett, R. Phillips, and C. H. Emeleus (1973), Mineral-chemical variations in the Apollo 16 magnesio-feldspathic highland rocks, *Lunar and Planetary Science Conference Proceedings*, *4*, 505-505.

Daubar, I. J., D. A. Kring, T. D. Swindle, and A. J. T. Jull (2002), Northwest Africa 482: A crystalline impact-melt breccia from the lunar highlands, *Meteoritics & Planetary Science*, *37*(12), 1797-1813, doi:10.1111/j.1945-5100.2002.tb01164.x.

Dowty, E., K. Keil, and M. Prinz (1974a), Igneous rocks from Apollo 16 rake samples, *Lunar and Planetary Science Conference Proceedings*, *2*, 431-445.

Dowty, E., M. Prinz, and K. Keil (1974b), Ferroan anorthosite: A widespread and distinctive lunar rock type, *Earth and Planetary Science Letters*, *24*(1), 15-25, doi:10.1016/0012-821X(74)90003-X.

Dymek, R. F., A. L. Albee, and A. A. Chodos (1975), Comparative petrology of lunar cumulate rocks of possible primary origin: dunite 72415, troctolite 76535, norite 78235, and anorthosite 62237, *Lunar and Planetary Science Conference Proceedings*, *1*, 301-341.

Goodrich, C. A., G. J. Taylor, K. Keil, G. W. Kallemeyn, and P. H. Warren (1986), Alkali norite, troctolites, and VHK mare basalts from breccia 14304, *Journal of Geophysical Research: Solid Earth*, *91*(B4), 305-318, doi:10.1029/JB091iB04p0D305.

Gross, J., and A. H. Treiman (2011), Unique spinel-rich lithology in lunar meteorite ALHA 81005: Origin and possible connection to M3 observations of the farside highlands, *Journal of Geophysical Research: Planets*, *116*(E10), doi:10.1029/2011JE003858.

Hodges, F. N., and I. Kushiro (1973), Petrology of Apollo 16 lunar highland rocks, *Lunar and Planetary Science Conference Proceedings*, *4*, 1033.

James, O. B., and J. W. Hedenquist (1978), Spinel-Bearing Troctolitic Basalt 73215,170: Texture, Mineralogy, and History, edited, pp. 588-590.

Joy, K. H., R. Burgess, R. Hinton, V. A. Fernandes, I. A. Crawford, A. T. Kearsley, and A. J. Irving (2011), Petrogenesis and chronology of lunar meteorite Northwest Africa 4472: A KREEPy regolith breccia from the Moon, *Geochimica et Cosmochimica Acta*, *75*(9), 2420-2452, doi:10.1016/j.gca.2011.02.018.

Keil, K., T. E. Bunch, and M. Prinz (1970), Mineralogy and composition of Apollo 11 lunar samples, *Geochimica et Cosmochimica Acta Supplement*, *1*, 561.

Lindstrom, M. M., S. A. Knapp, J. W. Shervais, and L. A. Taylor (1984), Magnesian anorthosites and associated troctolites and dunite in Apollo 14 breccias, *Journal of Geophysical Research: Solid Earth*, *89*(S01), C41-C49, doi:10.1029/JB089iS01p00C41.

Ma, M.-S., R. A. Schmitt, G. J. Taylor, R. D. Warner, and K. Keil (1981), Chemical and Petrographic Study of Spinel Troctolite in 67435: Implications for the Origin of Mg-Rich Plutonic Rocks, edited, pp. 640-642.

Marvin, U. B., and D. Walker (1985), A transient heating event in the history of a highlands troctolite from Apollo 12 soil 12033, *Lunar and Planetary Science Conference Proceedings*, *90*, C421-C429.

Marvin, U. B., J. W. Carey, and M. M. Lindstrom (1989), Cordierite-Spinel Troctolite, a New Magnesium-Rich Lithology from the Lunar Highlands, *Science*, *243*(4893), 925-928, doi:10.1126/science.243.4893.925.

Prinz, M., E. Dowty, K. Keil, and T. E. Bunch (1973), Spinel Troctolite and Anorthosite in Apollo 16 Samples, *Science*, *179*(4068), 74-76.

Prissel, T. C., C. A. Crow, S. W. Parman, and K. D. McKeegan (2014), Petrogenesis of the Lunar Highlands Mg-Suite as told by Spinel, edited, p. 2514.

Prissel, T. C., and J. Gross (2020), On the petrogenesis of lunar troctolites: New insights into cumulate mantle overturn & mantle exposures in impact basins, *Earth and Planetary Science Letters*, *551*, 116531-116531, doi:10.1016/j.epsl.2020.116531.

Ridley, W. I., N. J. Hubbard, J. M. Rhodes, H. Weismann, and B. Bansal (1973), The Petrology of Lunar Breccia 15445 and Petrogenetic Implications, *The Journal of Geology*, *81*(5), 621-631, doi:10.1086/627910.

Roedder, E., and P. W. Weiblen (1973), Petrology of some lithic fragments from Luna 20, *Geochimica et Cosmochimica Acta*, *37*(4), 1031-1052, doi:10.1016/0016-7037(73)90198-1.

Shearer, C. K., S. M. Elardo, N. E. Petro, L. E. Borg, and F. M. McCubbin (2015), Origin of the lunar highlands Mg-suite: An integrated petrology, geochemistry, chronology, and remote sensing perspective, *American Mineralogist*, *100*(1), 294-325, doi:10.2138/am-2015-4817.

Sheikh, D., A. M. Ruzicka, M. Hutson, and C. Zlimen (2023), Pink Spinel Anorthosite (PSA) Clasts in Lunar Dimict Breccia Northwest Africa (NWA) 15500: Evidence for a Petrogenetic Link Between PSA and Mg-Suite, paper presented at Lunar and Planetary Science Conferencee.

Shervais, J. W., L. A. Taylor, J. C. Laul, and M. R. Smith (1984), Pristine highland clasts in consortium breccia 14305 Petrology and geochemistry, *Lunar and Planetary Science Conference Proceedings*, *89*, C25-C40, doi:10.1029/JB089iS01p00C25.

Simon, S. B., C. K. Shearer, S. E. Haggerty, D. P. Moriarty III, N. Petro, J. J. Papike, and Z. Vaci (2022), Multiple Shallow Crustal Origins for Spinel-Bearing Lithologies on the Moon: A Perspective From the Luna 20 Mission, *Journal of Geophysical Research: Planets*, *127*(11), e2022JE007249, doi:10.1029/2022JE007249.

Snyder, G. A., A. M. Ruzicka, L. A. Taylor, and A. D. Patchen (1998), Journey to the Center of the Regolith: A Spinel Troctolite and Other Clasts from Drive Tube 68001, edited, p. 1144.

Snyder, G. A., L. A. Taylor, A. Patchen, M. A. Nazarov, and T. S. Semenova (1999), Mineralogy and Petrology of a Primitive Spinel Troctolite and Gabbros from Luna 20, Eastern Highlands of the Moon, 1999.

Stoeser, D. B., U. B. Marvin, and J. F. Bower (1974), Petrology and Petrogenesis of Boulder 1, in *Interdisciplinary Studies of Samples from Boulder 1, Station 2 Apollo 17*, edited, Smithsonian Astrophysical Observatory.

Takeda, H., A. Yamaguchi, D. D. Bogard, Y. Karouji, M. Ebihara, M. Ohtake, K. Saiki, and T. Arai (2006), Magnesian anorthosites and a deep crustal rock from the farside crust of the moon, *Earth and Planetary Science Letters*, *247*(3), 171-184, doi:10.1016/j.epsl.2006.04.004.

Treiman, A. H., M. J. Kulis, and A. F. Glazner (2019), Spinel-anorthosites on the Moon: Impact melt origins suggested by enthalpy constraints, *American Mineralogist*, *104*(3), 370-384, doi:10.2138/am-2019-6652.

Walker, D., J. Longhi, T. L. Grove, E. Stolper, and J. F. Hays (1973), Experimental petrology and origin of rocks from the Descartes Highlands, *Lunar and Planetary Science Conference Proceedings*, *4*, 1013-1013.

Warner, R. D., H. N. Planner, K. Keil, A. V. Murali, M.-S. Ma, R. A. Schmitt, W. D. Ehmann, W. D. James, Jr., R. N. Clayton, and T. K. Mayeda (1976), Consortium investigation of breccia 67435, *Lunar and Planetary Science Conference Proceedings*, *2*, 2379-2402.

Warner, R. D., G. J. Taylor, W. L. Mansker, and K. Keil (1978), Clast assemblages of possible deep-seated (77517) and immiscible-melt (77538) origins in Apollo 17 breccias, *Lunar and Planetary Science Conference Proceedings*, *1*, 941-958.