Supplement

Table S1 Major elements in the crushed minerals of granite and basalt and the leaf compost material used to make mineral-OM mixtures.

	Si (g kg^{-1} bulk)	Ti (g kg^{-1} bulk)	Al (g kg^{-1} bulk)	Fe (g kg^{-1} bulk)	Mn (mg kg^{-1} bulk)	Mg (g kg^{-1} bulk)	Ca (g kg^{-1} bulk)	Na (g kg^{-1} bulk)	K (g kg^{-1} bulk)	P (g kg^{-1} bulk)
Granite 38–75 µm	310	0.67	69	14	400	N.D.	8.4	33	34	N.D.
Basalt 38–75 µm	255	4.8	83	78	1320	42	64	18	4.6	0.71
Basalt 20–38 µm	251	7.2	85	87	1720	38	66	18	4.0	0.60
Leaf compost	56	0.41	8.6	6.9	500	3.1	33	N.D.	3.7	1.1

Total elemental compositions were determined by XRF analysis (NEX CG, Rigaku Corporation, Tokyo, Japan).

$n = 1$

N.D. Not detected.

Table S2 Specific surface area and extractable Al, Fe, and Si in the initial granite, basalt, sand, and leaf compost materials used to prepare the mineral-OM mixtures.

	Specific surface area ($m^2\ g^{-1}$)
Granite 38–75 µm	0.73
Basalt 38–75 µm	2.9
Basalt 20–38 µm	3.5
Sand 100–300 µm	0.76
Leaf compost	N.A.

	Sodium pyrophosphate (PP)			Acid oxalate (OX)			Dithionite-citrate (DC)		
	Al ($mg\ g^{-1}$)	Fe ($mg\ g^{-1}$)	Si ($mg\ g^{-1}$)	Al ($mg\ g^{-1}$)	Fe ($mg\ g^{-1}$)	Si ($mg\ g^{-1}$)	Al ($mg\ g^{-1}$)	Fe ($mg\ g^{-1}$)	Si ($mg\ g^{-1}$)
Granite 38–75 µm	N.D.	N.D.	N.D.	0.29 ± 0.01	0.77 ± 0.02	0.21 ± 0.01	0.35 ± 0.13	3.3 ± 1.1	1.7 ± 0.6
Basalt 38–75 µm	0.17 ± 0.01	0.35 ± 0.03	0.59 ± 0.06	5.6 ± 0.1	32 ± 1	3.4 ± 0.0	0.82 ± 0.05	5.8 ± 0.8	10 ± 1
Basalt 20–38 µm	0.22 ± 0.04	0.47 ± 0.07	0.76 ± 0.15	6.8 ± 0.8	40 ± 1	4.8 ± 0.7	0.77 ± 0.25	5.3 ± 1.6	7.8 ± 2.4
Sand 100–300 µm	N.D.	N.D.	N.D.	0.027 ± 0.015	0.091 ± 0.027	N.D.	0.32 ± 0.24	2.9 ± 1.9	1.2 ± 1.1
Leaf compost	0.075 ± 0.009	0.10 ± 0.00	4.4 ± 0.1	1.5 ± 0.0	1.5 ± 0.0	0.91 ± 0.05	0.38 ± 0.02	1.0 ± 0.0	2.2 ± 0.1

Al, Fe, and Si were extracted sequentially with sodium pyrophosphate, acid oxalate, and dithionite-citrate.

Value shows mean ± standard deviation (n = 3 for granite, basalts, and sand; n = 2 for leaf compost).

N.A. Not analyzed.

N.D. Not detected.

Table S3 Gravimetric water content in the mineral-OM mixtures at the start and end of wet-and-dry cycles during the 55-day incubation.

	Wet condition (%)	Dry condition (%)
Granite 38–75 μm	62 ± 1	~0
Basalt 38–75 μm	62 ± 1	~0
Basalt 20–38 μm	63 ± 1	~0
Sand 100–300 μm	52 ± 4	~0

The average water content of eight wet-and-dry cycles, expressed on an air-dried basis.

Value shows mean ± standard deviation (n = 3).

Table S4 The amounts of C and N, and C:N ratio in each density fraction after the incubation (Day 55).

	Low-density fraction (< 1.8 g cm^{-3})			Meso-density fraction (1.8–2.4 g cm^{-3})			High-density fraction (> 2.4 g cm^{-3})		
	C (mg g^{-1} bulk)	N (mg g^{-1} bulk)	C:N ratio	C (mg g^{-1} bulk)	N (mg g^{-1} bulk)	C:N ratio	C (mg g^{-1} bulk)	N (mg g^{-1} bulk)	C:N ratio
Granite 38–75 μm	39 ± 1	0.99 ± 0.03	40 ± 0	0.55 ± 0.03	0.028 ± 0.002	20 ± 1	0.46 ± 0.02	0.12 ± 0.05	5.1 ± 1.6
Basalt 38–75 μm	41 ± 0	1.0 ± 0.0	40 ± 1	0.93 ± 0.04	0.056 ± 0.005	17 ± 1	0.72 ± 0.02	0.10 ± 0.01	7.1 ± 0.9
Basalt 20–38 μm	43 ± 0	1.1 ± 0.0	40 ± 0	1.3 ± 0.0	0.090 ± 0.013	15 ± 2	0.76 ± 0.01	0.11 ± 0.01	6.9 ± 0.9
Sand 100–300 μm	37 ± 0	0.92 ± 0.03	40 ± 1	0.10 ± 0.01	0.0063 ± 0.0012	17 ± 2	0.25 ± 0.02	0.10 ± 0.04	3.6 ± 1.2

Value shows mean ± standard deviation (n = 3).

Table S5-1 Concentrations (per fraction) of extractable Al, Fe, and Si in each density fraction of the mineral-OM mixtures on Day 0.

	Sodium pyrophosphate (PP)			Acid oxalate (OX)			Dithionite-citrate (DC)		
	Al (mg g^{-1} fraction)	Fe (mg g^{-1} fraction)	Si (mg g^{-1} fraction)	Al (mg g^{-1} fraction)	Fe (mg g^{-1} fraction)	Si (mg g^{-1} fraction)	Al (mg g^{-1} fraction)	Fe (mg g^{-1} fraction)	Si (mg g^{-1} fraction)
Low and meso-density fraction (< 2.4 g cm^{-3})									
Basalt 38–75 µm	0.26 ± 0.01	0.76 ± 0.03	1.5 ± 0.0	11 ± 0	39 ± 1	5.7 ± 0.2	2.1 ± 0.1	13 ± 0	10 ± 0
Basalt 20–38 µm	0.28 ± 0.01	0.90 ± 0.04	1.6 ± 0.0	14 ± 0	53 ± 1	7.4 ± 0.0	2.2 ± 0.0	13 ± 0	9.2 ± 0.0
High-density fraction (> 2.4 g cm^{-3})									
Basalt 38–75 µm	0.20 ± 0.00	0.35 ± 0.02	0.71 ± 0.05	5.4 ± 0.2	30 ± 1	3.7 ± 0.1	0.42 ± 0.05	3.5 ± 0.2	10 ± 1
Basalt 20–38 µm	0.19 ± 0.01	0.40 ± 0.00	0.92 ± 0.33	4.5 ± 0.1	31 ± 1	3.2 ± 0.1	0.41 ± 0.05	4.7 ± 0.3	10 ± 0

Value shows mean ± standard deviation (n = 3).

Table S5-2 Distribution of extractable Al, Fe, and Si in each density fraction of the mineral-OM mixtures on Day 0.

	Sodium pyrophosphate (PP)			Acid oxalate (OX)			Dithionite-citrate (DC)		
	Al (mg g^{-1} bulk)	Fe (mg g^{-1} bulk)	Si (mg g^{-1} bulk)	Al (mg g^{-1} bulk)	Fe (mg g^{-1} bulk)	Si (mg g^{-1} bulk)	Al (mg g^{-1} bulk)	Fe (mg g^{-1} bulk)	Si (mg g^{-1} bulk)
Low and meso-density fraction (< 2.4 g cm^{-3})									
Basalt 38–75 µm	0.025 ± 0.000	0.062 ± 0.003	0.56 ± 0.00	0.88 ± 0.03	2.8 ± 0.1	0.48 ± 0.01	0.18 ± 0.01	1.0 ± 0.0	0.91 ± 0.02
Basalt 20–38 µm	0.025 ± 0.001	0.067 ± 0.003	0.55 ± 0.00	1.1 ± 0.0	3.5 ± 0.1	0.56 ± 0.01	0.18 ± 0.00	0.93 ± 0.01	0.80 ± 0.01
High-density fraction (> 2.4 g cm^{-3})									
Basalt 38–75 µm	0.20 ± 0.00	0.35 ± 0.02	0.71 ± 0.05	5.4 ± 0.2	30 ± 1	3.7 ± 0.1	0.42 ± 0.05	3.5 ± 0.2	10 ± 1
Basalt 20–38 µm	0.19 ± 0.01	0.40 ± 0.00	0.92 ± 0.33	4.5 ± 0.1	31 ± 1	3.2 ± 0.1	0.41 ± 0.05	4.7 ± 0.3	10 ± 0

Al, Fe, and Si were extracted sequentially with sodium pyrophosphate, acid oxalate, and dithionite-citrate.

Value shows mean ± standard deviation (n = 3).

Table S6 Distribution of extractable Al, Fe, and Si in each density fraction of the mineral-OM mixtures on Day 55.

	Sodium pyrophosphate (PP)			Acid oxalate (OX)			Dithionite-citrate (DC)		
	Al (mg g^{-1} bulk)	Fe (mg g^{-1} bulk)	Si (mg g^{-1} bulk)	Al (mg g^{-1} bulk)	Fe (mg g^{-1} bulk)	Si (mg g^{-1} bulk)	Al (mg g^{-1} bulk)	Fe (mg g^{-1} bulk)	Si (mg g^{-1} bulk)
Low-density fraction (< 1.8 g cm^{-3})									
Granite 38–75 µm	0.030 ± 0.003	0.023 ± 0.001	0.28 ± 0.00	0.094 ± 0.005	0.15 ± 0.01	0.047 ± 0.002	0.027 ± 0.003	0.14 ± 0.01	0.25 ± 0.02
Basalt 38–75 µm	0.047 ± 0.001	0.051 ± 0.002	0.19 ± 0.01	0.13 ± 0.01	0.32 ± 0.01	0.065 ± 0.002	0.036 ± 0.001	0.20 ± 0.00	0.39 ± 0.01
Basalt 20–38 µm	0.059 ± 0.002	0.080 ± 0.001	0.18 ± 0.00	0.23 ± 0.01	0.71 ± 0.02	0.13 ± 0.00	0.054 ± 0.001	0.37 ± 0.01	0.73 ± 0.01
Sand 100–300 µm	0.033 ± 0.001	0.021 ± 0.001	0.26 ± 0.01	0.092 ± 0.005	0.14 ± 0.00	0.043 ± 0.001	0.022 ± 0.003	0.10 ± 0.01	0.21 ± 0.02
Meso-density fraction (1.8–2.4 g cm^{-3})									
Granite 38–75 µm	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Basalt 38–75 µm	0.031 ± 0.001	0.054 ± 0.002	0.12 ± 0.01	0.98 ± 0.26	3.7 ± 1.0	0.45 ± 0.12	0.19 ± 0.02	1.1 ± 0.1	0.68 ± 0.05
Basalt 20–38 µm	0.057 ± 0.001	0.089 ± 0.005	0.22 ± 0.01	2.4 ± 0.1	9.5 ± 0.3	1.2 ± 0.0	0.31 ± 0.00	1.8 ± 0.0	1.2 ± 0.0
Sand 100–300 µm	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
High-density fraction (> 2.4 g cm^{-3})									
Granite 38–75 µm	0.0 ± 0.0	0.0093 ± 0.0050	0.0 ± 0.0	0.11 ± 0.02	0.62 ± 0.03	0.12 ± 0.02	0.16 ± 0.01	1.7 ± 0.0	0.65 ± 0.02
Basalt 38–75 µm	0.059 ± 0.009	0.19 ± 0.01	0.30 ± 0.02	3.1 ± 0.1	21 ± 1	1.9 ± 0.1	0.59 ± 0.03	4.0 ± 0.2	7.3 ± 0.2
Basalt 20–38 µm	0.11 ± 0.00	0.21 ± 0.00	0.43 ± 0.01	3.5 ± 0.1	25 ± 0	2.4 ± 0.0	0.45 ± 0.04	3.7 ± 0.5	6.9 ± 0.1
Sand 100–300 µm	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.014 ± 0.008	0.13 ± 0.09	0.0 ± 0.0	0.080 ± 0.013	1.2 ± 0.2	0.073 ± 0.019

Al, Fe, and Si were extracted sequentially with sodium pyrophosphate, acid oxalate, and dithionite-citrate.

Value shows mean ± standard deviation (n = 3).

N.A. Not analyzed due to limited mass recovery of MF.

Table S7 Molar ratios of total C to sequentially extracted metals in MF for the two basalt treatments after the 55-day incubation.

	Extraction reagent	Meso-density fraction (1.8–2.4 g cm^{-3})	
		C:Al	C:Fe
Basalt 38–75 μm	PP + OX	2.3 ± 0.9	1.3 ± 0.5
	PP + OX + DC	1.9 ± 0.7	1.0 ± 0.3
Basalt 20–38 μm	PP + OX	1.2 ± 0.0	0.64 ± 0.02
	PP + OX + DC	1.1 ± 0.0	0.54 ± 0.01

Al and Fe were extracted sequentially with sodium pyrophosphate (PP), acid oxalate (OX), and dithionite-citrate (DC).

Value shows mean ± standard deviation (n = 3).

Table S8 Cell number and alpha diversity index of the bacterial community in the meso-density fraction (1.8–2.4 g cm^{-3}; n = 1) for granite, coarse basalt, and fine basalt treatments and bulk for all four treatments (n = 3) on Day 55 compared to bulk in the initial leaf compost (n = 3).

			16S rRNA copy number (copies g^{-1} dry soil)		Chao1		Shannon		InvSimpson	
Granite 38–75 µm	Meso-density fraction	Day 55	1.51E+09		1833		5.3		23	
	Bulk	Day 55	4.25E+08	± 7.89E+07	1923	± 179	6.0	± 0.1	154	± 17
Basalt 38–75 µm	Meso-density fraction	Day 55	3.85E+08		1873		5.7		56	
	Bulk	Day 55	3.70E+08	± 1.04E+08	1906	± 79	5.8	± 0.2	91	± 39
Basalt 20–38 µm	Meso-density fraction	Day 55	5.47E+08		1574		5.6		77	
	Bulk	Day 55	3.84E+08	± 3.97E+07	1750	± 76	5.7	± 0.1	103	± 23
Sand 100–300 µm	Bulk	Day 55	6.20E+08	± 1.21E+08	1788	± 115	5.7	± 0.2	122	± 27
Leaf compost	Bulk	Day 0	9.49E+08	± 2.39E+08	1849	± 52	6.1	± 0.0	170	± 10

Value shows mean ± standard deviation (n = 3 for bulk samples).

Table S9 Mantel test showing correlations between the bacterial composition and the mineral properties in the meso-density fraction for granite, coarse basalt, and fine basalt treatments on Day 55 (1.8–2.4 g cm^{-3}; n = 1), the bulk for all four treatments on Day 55 (n = 3), and the bulk for the initial leaf compost (using the average of n = 2).

Factor	R^2	P value
TC	**0.86**	0.001
TN	**0.86**	0.002
pH(KCl)	**0.82**	0.001
pH(H_2O)	**0.80**	0.001
Fe_{pp}	**0.30**	0.013
Al_{pp}	**0.22**	0.04
Fe_{ox}	0.22	0.068
Al_{ox}	0.14	0.286

Significant mantel coefficient is shown in bold.

Al and Fe were extracted sequentially with sodium pyrophosphate (PP), acid oxalate (OX), and dithionite-citrate.

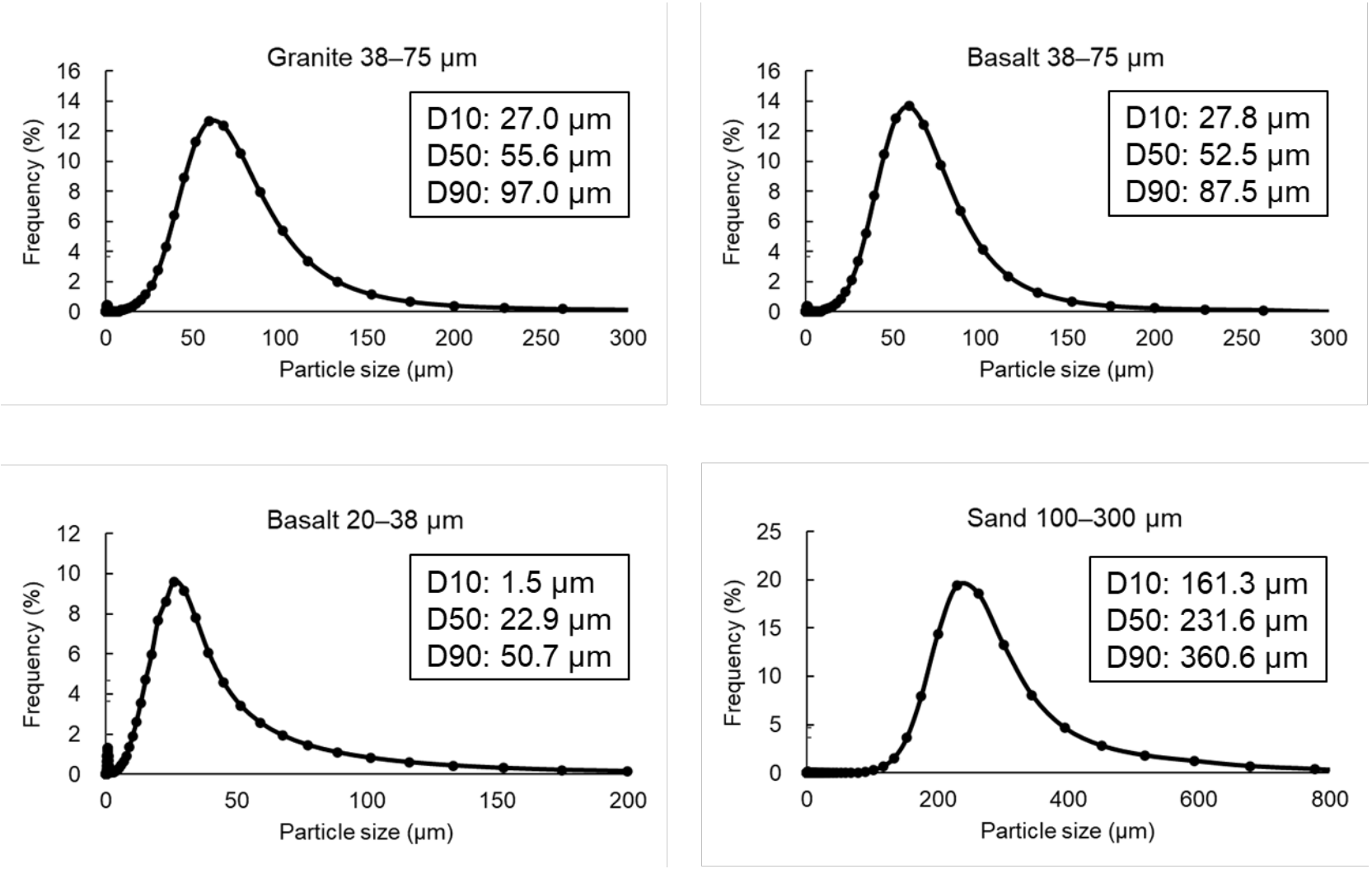
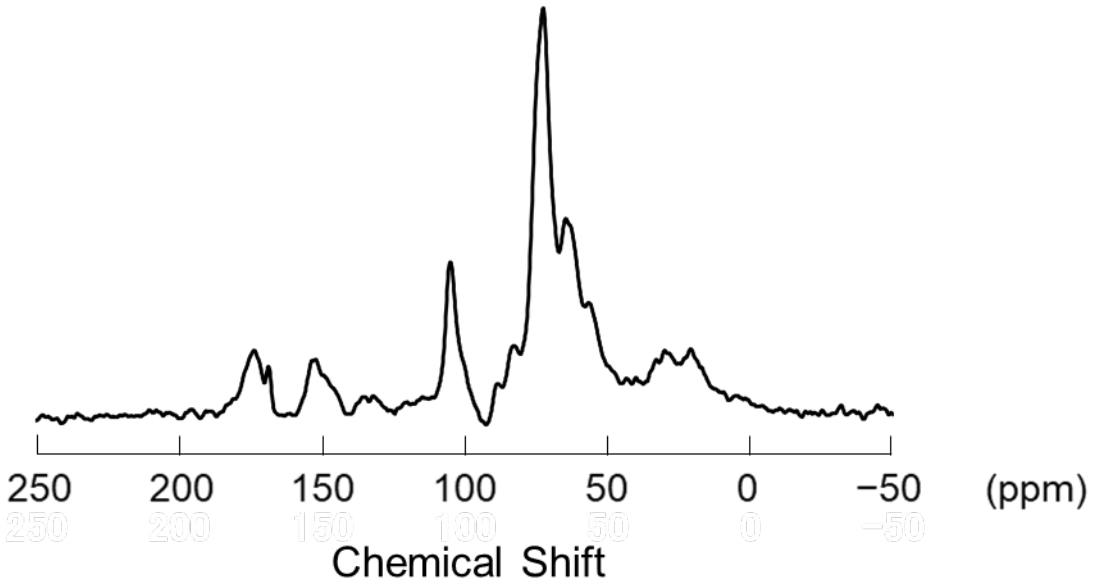


Fig. S1 Particle size distribution of the crushed rocks (granite and basalt) and sand used in this experiment.



C type	(%)
Carbonyl-C	7.7
Aromatic-C	9.6
O-alkyl-C	63
Alkyl-C	19

Fig. S2 Solid-state MS ^{13}C NMR spectrum and the proportion contributed by each C type to the total signal intensity in leaf compost used as a source of OM in this experiment.

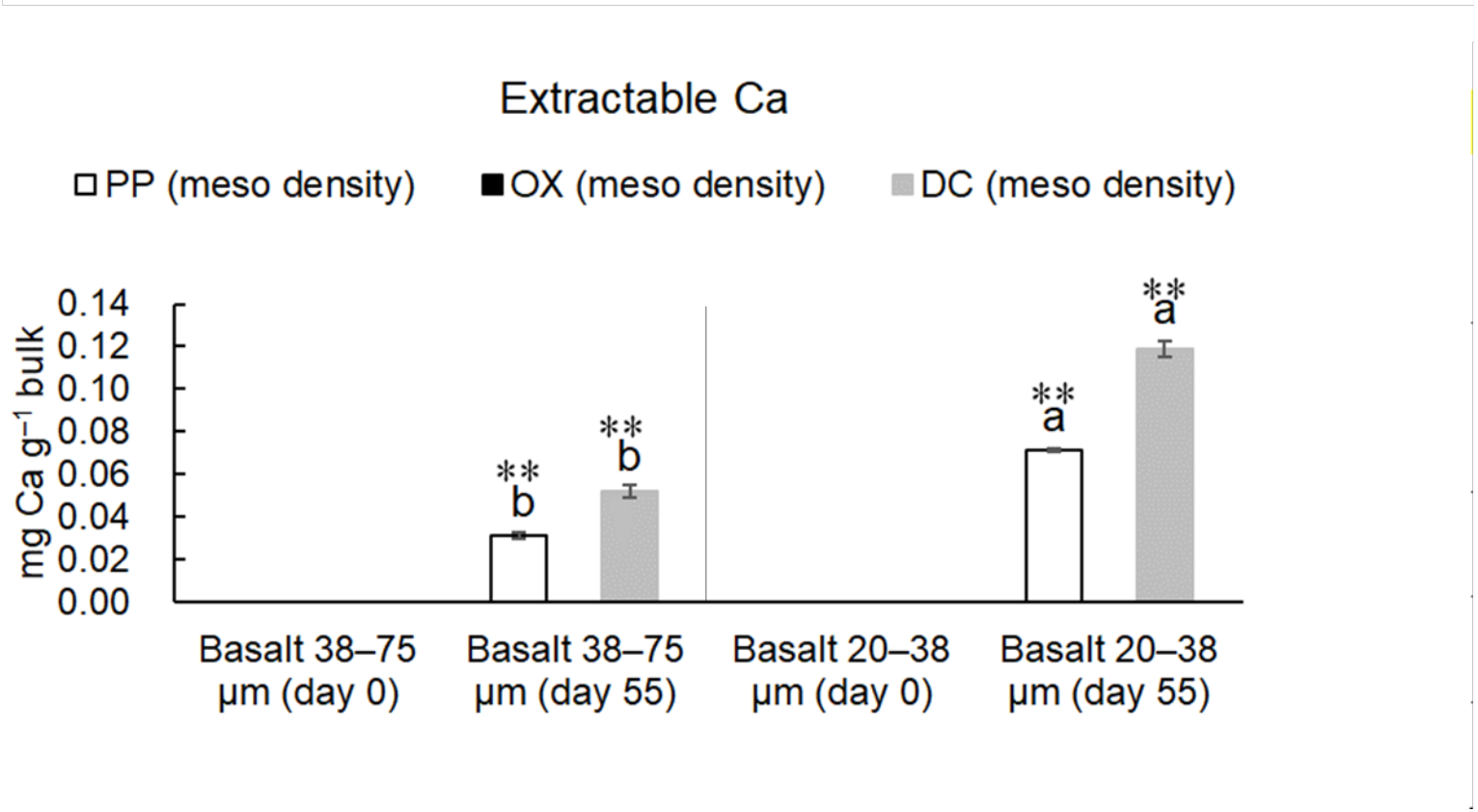


Fig. S3 Amounts of extractable Ca in the MF from the mineral-OM mixtures on Day 0 and Day 55. The extractions were done sequentially with sodium pyrophosphate (PP), acid oxalate (OX) and dithionite-citrate (DC). The same letters in each extraction (i.e., PP, OX, or DC) on Day 55 are not significantly different at $P < 0.05$ (Tukey's test; $n = 3$). Differences between the "on Day 0" and "on Day 55" in both each mineral-OM mixture and each extraction (i.e., PP, OX, or DC) are significant at $^{**}P < 0.01$ (*t*-test).

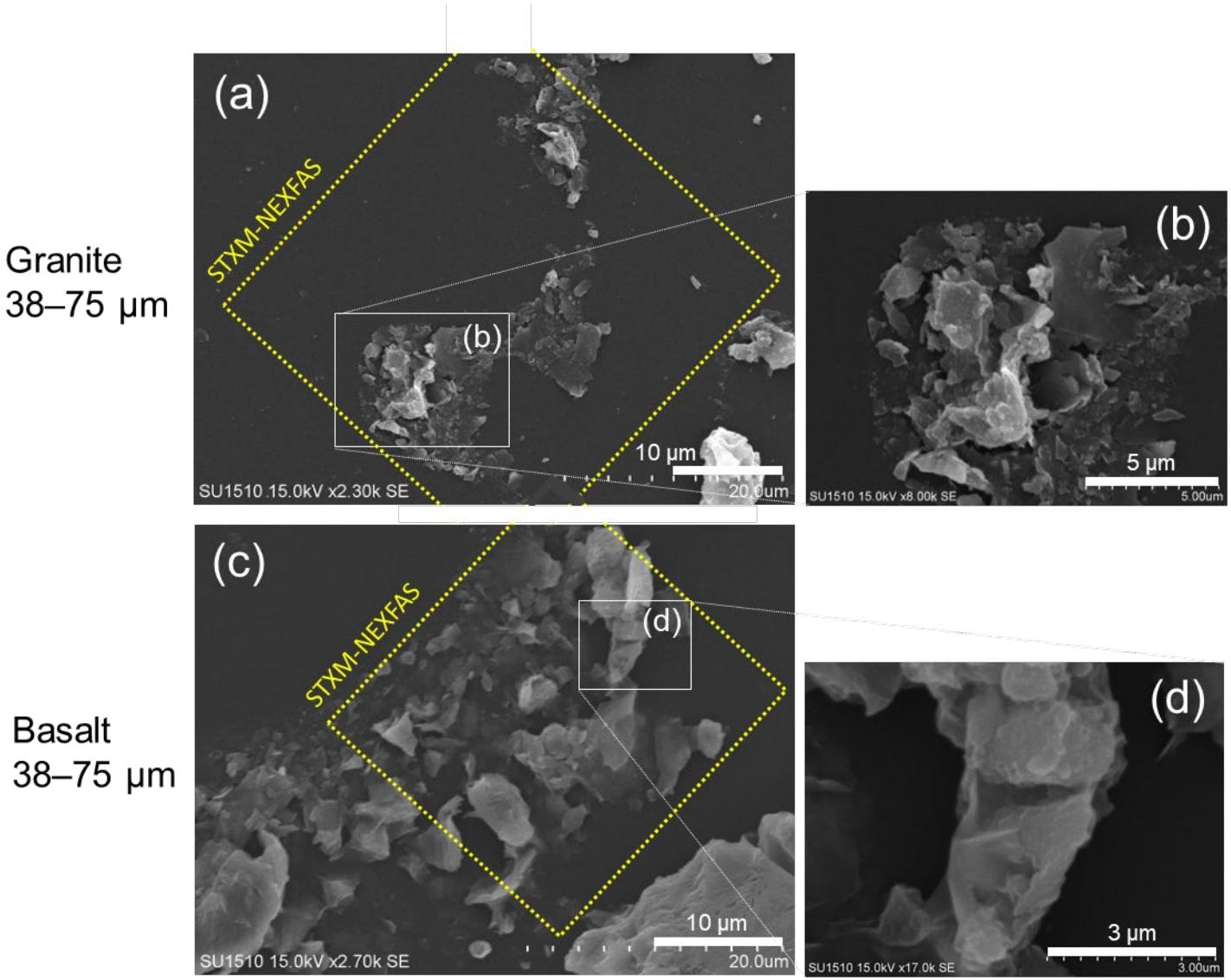


Fig. S4 MF dispersed for STXM-NEXAFS. (a) and (b) granite treatment on Day 55, and (c) and (d) coarse basalt treatment on Day 55. Yellow dotted box in (a) and (c) represents the ROI used for STXM-NEXAFS analysis shown in Fig. 7 (A) and Fig. 7 (B), respectively. (b) and (d) corresponds to the higher resolution images used for STXM C optical density shown in Fig. 7 (a) and Fig. 7 (b), respectively.