

Gabbroic enclave in intermediate ignimbrites: The youngest eruptive event in the northern Luzon Arc-Taiwan region

Yu-Ming Lai, Yu-Yun Cho, Hao-Yang Lee, Dung-Han Lee, Yoshiyuki Iizuka, and Long Xiang Quek

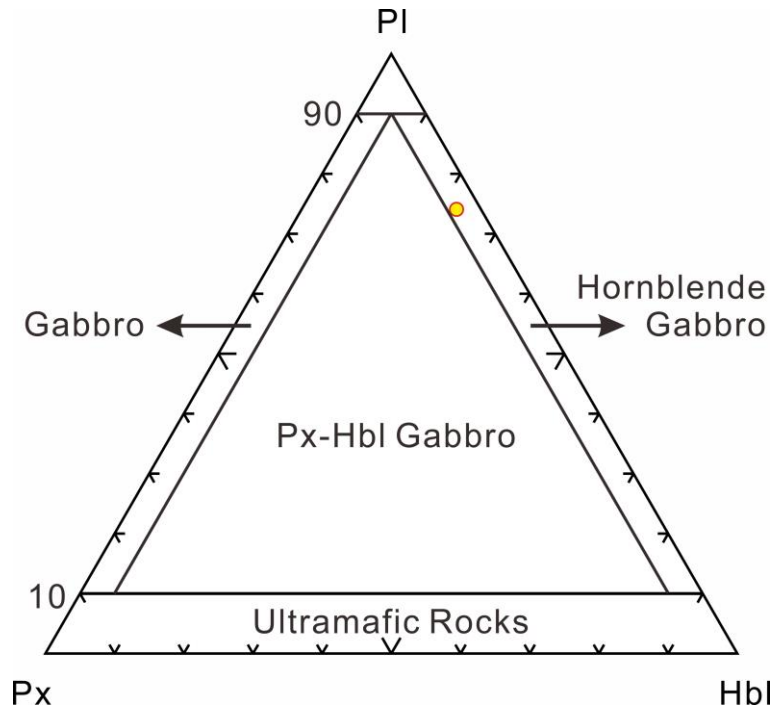


Fig. S1. The IUGS classification of the gabbroic rocks (Streckeisen 1976). The composition of the gabbroic enclave is marked by a yellow circle with red margin.

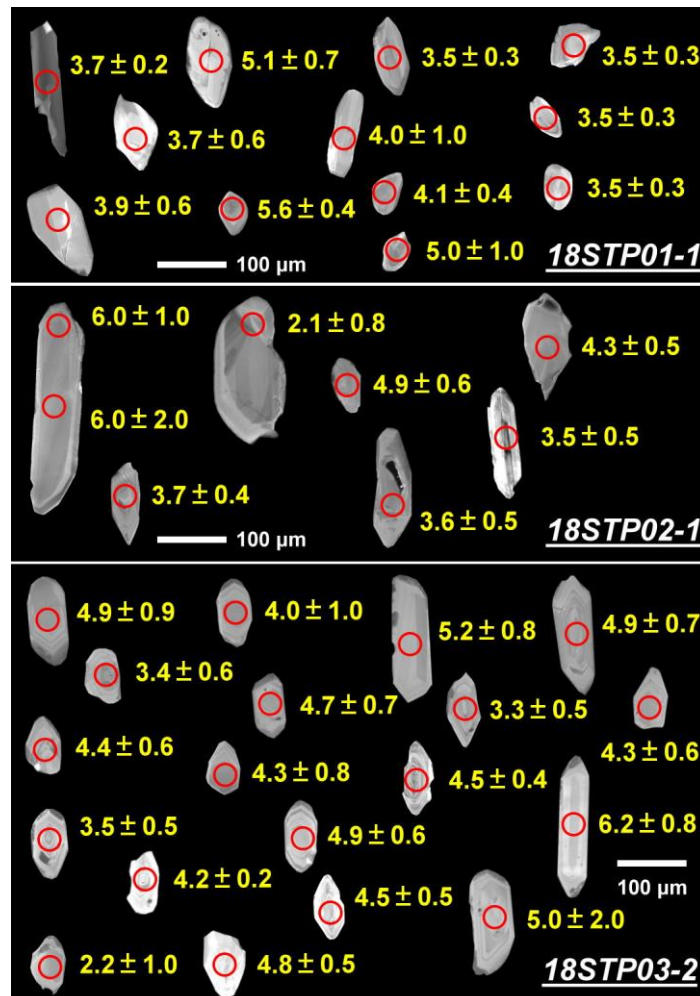


Fig. S2. CL images of zircons from the dated samples in the Shihtiping area.

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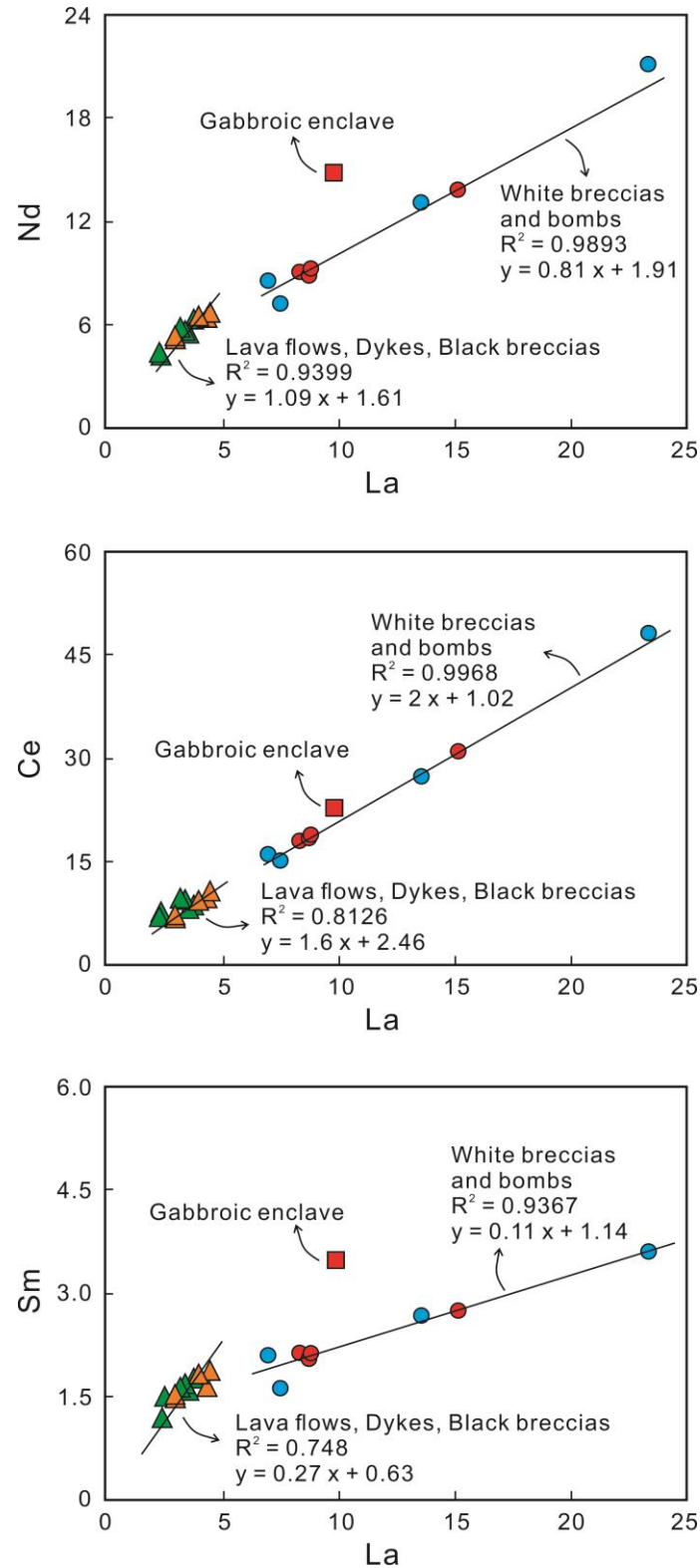


Fig. S3. The concentrations and fractionation of rare earth elements for the samples in the Chimei volcano. The plots show three selected rare earth elements (Nd, Ce, and Sm) versus La. White breccias and bombs in the ignimbrite show the significant different fractionation trends to the samples from lower volcanic sequences. Notably, the gabbroic enclave is out of both two regression lines.

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Table S1. Measured and recommended trace element data of USGS rock standards.

(ppm)	AGV-2						BCR-2						BHVO-2					
	Average lab results ¹		Recommended data ²	Analyses in this study			Average lab results		Recommended data	Analyses in this study		Average lab results		Recommended data	Analyses in this study			
	n = 66	RSD (%)		1 st	2 nd	3 rd	n = 24	RSD (%)		1 st	2 nd	n = 40	RSD (%)		1 st	2 nd		
Sc	12.2 ± 1.3	10.8	13.1	14.5	13.4	13.7	32.4 ± 2.0	6.19	33.5	37.0	36.2	31.1 ± 2.3	7.24	31.8	31.8	30.8		
V	115 ± 5	4.61	119	111	113	114	410 ± 8	1.96	417	413	416	313 ± 9	2.77	318	325	326		
Cr	15.0 ± 2.3	15.3	16.2	18.8	19.9	19.1	14.4 ± 1.4	9.39	15.9	18.4	18.2	280 ± 11	3.96	287	294	296		
Mn	745 ± 33	4.39	770	741	770	783	1517 ± 30	2.01	1520	1512	1511	1293 ± 35	2.70	1290	1283	1300		
Co	14.7 ± 1.0	6.66	15.5	15.6	15.7	15.7	36.8 ± 1.4	3.82	37.3	36.5	36.4	44.0 ± 1.2	2.79	44.9	43.5	44.0		
Ni	17.1 ± 1.1	6.15	18.9	17.6	17.9	18.3	11.4 ± 0.7	6.21	12.6	13.0	13.0	110 ± 5	4.79	120	114	114		
Cu	49.8 ± 2.8	5.51	51.5	54.9	53.7	53.9	19.8 ± 0.9	4.72	19.7	20.7	20.6	130 ± 4	2.72	129	130	130		
Zn	84.2 ± 3.1	3.72	86.7	85.6	87.1	87.5	129 ± 3	2.36	130	129	131	108 ± 5	4.97	104	104	106		
Ga	21.0 ± 0.8	3.78	20.4	20.0	21.0	21.2	23.0 ± 0.5	2.16	22.1	22.1	22.2	21.9 ± 0.5	2.37	21.4	21.3	21.7		
Rb	68.9 ± 3.8	5.46	67.8	65.1	67.5	68.3	48.6 ± 0.9	1.80	46.0	45.6	46.5	9.09 ± 0.48	5.30	9.26	8.85	9.10		
Sr	653 ± 18	2.82	660	642	651	662	344 ± 6	1.88	337	339	340	394 ± 10	2.64	394	390	400		
Y	19.6 ± 0.6	2.91	19.1	19.3	19.8	20.2	37.4 ± 0.6	1.72	36.1	35.5	35.6	27.0 ± 1.1	3.93	25.9	25.9	26.2		
Zr	231 ± 8	3.57	232	229	235	239	189 ± 3	1.34	187	183	183	171 ± 4	2.48	171	169	169		
Nb	14.2 ± 0.5	3.70	14.1	14.1	14.2	14.2	12.6 ± 0.3	2.45	12.4	12.2	12.3	18.5 ± 0.5	2.56	18.1	18.2	18.3		
Cs	1.16 ± 0.05	4.50	1.17	1.16	1.20	1.21	1.15 ± 0.02	1.72	1.16	1.14	1.16	0.0983 ± 0.0071	7.25	0.10	0.10	0.10		
Ba	1137 ± 65	5.74	1134	1114	1142	1146	696 ± 14	2.02	684	667	665	136 ± 8	6.20	131	128	129		
La	37.2 ± 1.8	4.75	38.2	36.1	38.3	39.1	25.3 ± 0.6	2.33	25.1	24.1	24.9	14.9 ± 0.7	4.57	15.2	14.5	15.2		
Ce	67.8 ± 2.6	3.78	69.4	66.5	70.0	71.5	53.2 ± 1.2	2.34	53.1	51.0	52.6	37.3 ± 1.1	3.01	37.5	35.9	37.7		
Pr	8.09 ± 0.30	3.77	8.17	7.75	8.27	8.41	6.89 ± 0.14	1.99	6.83	6.59	6.82	5.34 ± 0.15	2.80	5.34	5.11	5.33		
Nd	30.1 ± 1.0	3.26	30.5	29.2	30.6	31.2	28.7 ± 0.1	1.78	28.3	27.6	28.6	24.3 ± 0.6	2.37	24.3	23.4	24.4		
Sm	5.56 ± 0.19	3.50	5.51	5.28	5.61	5.68	6.75 ± 0.12	1.79	6.55	6.31	6.65	6.19 ± 0.12	1.92	6.02	5.79	6.13		
Eu	1.62 ± 0.06	3.55	1.55	1.60	1.65	1.66	2.07 ± 0.05	2.42	1.99	1.93	1.99	2.02 ± 0.05	2.53	2.03	1.95	2.04		
Gd	4.56 ± 0.14	3.02	4.68	4.43	4.61	4.68	6.95 ± 0.14	2.08	6.81	6.71	6.74	6.19 ± 0.12	2.14	6.21	6.15	6.39		
Tb	0.650 ± 0.024	3.62	0.65	0.65	0.66	0.67	1.05 ± 0.02	1.53	1.08	1.06	1.07	0.923 ± 0.023	2.47	0.94	0.94	0.95		
Dy	3.47 ± 0.08	2.36	3.55	3.45	3.58	3.58	6.44 ± 0.09	1.47	6.42	6.30	6.49	5.29 ± 0.10	1.89	5.28	5.23	5.35		
Ho	0.687 ± 0.017	2.44	0.68	0.66	0.69	0.69	1.35 ± 0.02	1.25	1.31	1.29	1.31	1.02 ± 0.02	2.30	0.99	0.98	1.02		
Er	1.84 ± 0.04	2.40	1.83	1.76	1.85	1.88	3.67 ± 0.04	1.21	3.67	3.58	3.65	2.54 ± 0.06	2.34	2.51	2.48	2.55		
Tm	0.260 ± 0.006	2.34	0.26	0.26	0.26	0.27	0.538 ± 0.006	1.13	0.53	0.53	0.53	0.340 ± 0.008	2.29	0.33	0.33	0.34		
Yb	1.65 ± 0.04	2.22	1.65	1.60	1.69	1.67	3.43 ± 0.05	1.36	3.39	3.35	3.38	2.01 ± 0.04	2.22	1.99	1.99	2.01		

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(ppm)	AGV-2						BCR-2						BHVO-2					
	Average lab results ¹		Recommended data ²	Analyses in this study			Average lab results		Recommended data	Analyses in this study			Average lab results		Recommended data	Analyses in this study		
	n = 66	RSD (%)		1 st	2 nd	3 rd	n = 24	RSD (%)		1 st	2 nd	n = 40	RSD (%)	1 st		2 nd		
Lu	0.250 ± 0.005	2.17	0.25	0.24	0.26	0.26	0.513 ± 0.006	1.22	0.50	0.50	0.51	0.284 ± 0.007	2.35	0.28	0.27	0.28		
Hf	4.99 ± 0.09	1.89	5.14	5.04	5.29	5.30	4.77 ± 0.08	1.76	4.97	4.84	4.89	4.25 ± 0.09	2.20	4.47	4.37	4.46		
Ta	0.936 ± 0.058	6.17	0.87	0.83	0.86	0.86	0.882 ± 0.056	6.36	0.79	0.77	0.78	1.32 ± 0.09	6.61	1.15	1.16	1.17		
Pb	13.3 ± 0.4	3.11	13.1	13.4	13.4	13.30	10.4 ± 0.3	3.16	10.6	10.4	10.3	1.70 ± 0.48	28.1	1.65	1.69	1.69		
Th	6.23 ± 0.15	2.37	6.17	6.31	6.16	6.15	6.07 ± 0.07	1.19	5.83	5.93	5.76	1.22 ± 0.04	3.35	1.22	1.22	1.20		
U	1.88 ± 0.03	1.30	1.89	1.97	1.89	1.87	1.70 ± 0.04	2.49	1.69	1.71	1.66	0.417 ± 0.011	2.72	0.41	0.43	0.41		

Note: 1: Average laboratory results are from Lin et al. (2012, Appendix Table A1). 2: Recommended data are from Jochum et al. (2005).

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Table S2. Major and trace element compositions for samples from Chimei volcano.

Sample no.	M96007	M96006	CRL05	CM-10	M97203	M98001	M95030	M97102	M95038-1	M95034	M97001	M95033
References	Lai et al. (2017)	Lai et al. (2017)	Lai et al. (2017)	Shao (2015)	Lai et al. (2017)	Lai et al. (2017)	Lai et al. (2017)	Lai et al. (2017)	Lai et al. (2017)	Shao (2015)	Lai et al. (2017)	Lai et al. (2017)
Occurrences	Lava flow	Lava flow	Pillow lava	Dyke	Dyke	Dyke	Black breccia	Black breccia	Black breccia	Black breccia	Black breccia	Black breccia
Ages (Ma)	- ^a	-	-	9.0 ± 0.3 ^b	-	-	-	-	-	-	-	-
<i>Major elements (wt.%)</i>												
SiO ₂	49.94	50.26	52.09	59.61	55.56	51.89	57.23	57.96	54.52	54.19	57.87	54.86
TiO ₂	0.52	0.53	0.44	0.44	0.50	0.38	0.54	0.56	0.46	0.46	0.44	0.49
Al ₂ O ₃	15.32	15.29	15.86	18.33	18.20	14.11	17.46	17.85	16.49	16.37	17.84	17.05
Fe ₂ O ₃ (T) ^c	7.27	7.46	6.91	5.12	6.66	8.62	6.28	6.13	6.93	7.02	5.83	6.67
MnO	0.12	0.12	0.13	0.14	0.27	0.08	0.11	0.10	0.13	0.14	0.11	0.13
MgO	8.09	8.44	8.91	3.27	4.58	11.38	5.46	4.86	6.85	7.19	5.26	6.75
CaO	13.50	12.68	9.54	6.15	6.58	9.82	7.62	7.46	9.32	9.21	7.84	9.53
Na ₂ O	2.43	2.30	2.30	3.00	3.00	2.67	3.30	3.96	2.32	2.27	3.66	2.44
K ₂ O	0.24	0.18	0.30	0.35	0.44	0.06	0.54	0.61	0.48	0.45	0.67	0.42
P ₂ O ₅	0.11	0.10	0.08	0.09	0.09	0.06	0.09	0.14	0.05	0.05	0.11	0.07
LOI	1.87	1.52	2.96	3.37	3.03	2.21	0.61	0.35	1.35	1.17	1.32	1.28
Total	99.41	98.88	99.52	99.87	98.91	101.29	99.25	99.99	98.90	98.52	100.94	99.68
<i>Trace elements (ppm)</i>												
P	418.0	-	-	-	374	251	530	707	343	356	416	425
Sc	29.0	33.0	14.6	53.8	25.8	8.00	25.2	24.9	23.1	29.9	19.2	17.5
Ti	3036	-	-	-	2873	2210	3131	3273	2747	2725	2468	2722
V	221	219	284	129	192	175	175	176	176	183	157	188
Cr	384	607	358	21.6	60.4	705	202	147	418	420	149	418
Mn	964	-	-	-	1983	542	845	768	1017	1065	799	974
Co	31.7	34.2	-	13.0	18.3	24.7	22.1	20.4	32.3	31.5	19.4	30.2
Ni	118	130	145	18.5	38.7	149	67.1	57.2	150	146	61.1	126
Cu	192	-	-	-	171	31.9	53.9	62.7	45.9	51.1	34.3	62.8
Zn	44.9	-	-	-	116	15.4	49.0	50.6	51.8	52.3	45.4	51.0
Ga	14.3	-	-	-	17.8	13.0	16.8	17.7	15.4	15.1	16.8	15.4
Rb	3.38	2.29	3.00	7.21	3.98	1.24	9.17	11.2	9.98	9.63	10.4	8.84
Sr	156	158	119	246	160	177	205	209	164	160	244	162
Y	15.0	15.1	14.0	10.9	13.6	10.7	14.4	14.7	12.9	12.8	11.5	12.6

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Sample no.	M96007	M96006	CRL05	CM-10	M97203	M98001	M95030	M97102	M95038-1	M95034	M97001	M95033
References	Lai et al. (2017)	Lai et al. (2017)	Lai et al. (2017)	Shao (2015)	Lai et al. (2017)	Lai et al. (2017)	Lai et al. (2017)	Lai et al. (2017)	Lai et al. (2017)	Shao (2015)	Lai et al. (2017)	Lai et al. (2017)
Occurrences	Lava flow	Lava flow	Pillow lava	Dyke	Dyke	Dyke	Black breccia	Black breccia	Black breccia	Black breccia	Black breccia	Black breccia
Ages (Ma)	- ^a	-	-	9.0 ± 0.3 ^b	-	-	-	-	-	-	-	-
Zr	35.7	33.9	52.0	66.3	55.9	13.2	67.5	70.3	42.4	41.8	60.5	42.2
Nb	0.68	0.68	-	0.81	0.81	0.50	1.47	1.57	0.81	0.81	0.86	0.82
Cs	0.16	0.11	-	0.80	0.438	0.09	0.58	0.65	0.86	0.84	0.59	0.74
Ba	37.0	36.5	10.0	28.5	31.4	16.4	74.3	93.1	56.0	54.5	69.7	52.0
La	3.79	3.71	2.82	3.55	3.43	2.37	3.92	4.44	3.07	3.01	4.27	3.05
Ce	7.95	7.85	7.48	8.58	8.38	6.61	8.59	10.3	6.99	6.86	9.13	6.99
Pr	1.30	1.28	-	1.16	1.15	0.87	1.34	1.38	1.09	1.07	1.38	1.09
Nd	5.94	5.89	-	5.25	5.36	4.08	6.11	6.36	4.99	4.92	6.02	4.95
Sm	1.76	1.74	1.47	1.47	1.61	1.14	1.78	1.83	1.50	1.47	1.61	1.47
Eu	0.58	0.58	0.63	0.51	0.56	0.41	0.59	0.65	0.52	0.51	0.53	0.52
Gd	2.01	2.00	-	1.65	1.84	1.37	2.00	2.08	1.73	1.71	1.77	1.71
Tb	0.35	0.35	0.26	0.28	0.35	0.26	0.35	0.38	0.31	0.31	0.29	0.31
Dy	2.40	2.40	-	1.77	2.18	1.59	2.33	2.40	2.1	2.08	1.90	2.09
Ho	0.54	0.54	-	0.39	0.50	0.36	0.51	0.54	0.47	0.47	0.41	0.47
Er	1.54	1.53	-	1.11	1.40	1.04	1.45	1.51	1.35	1.33	1.17	1.34
Tm	0.24	0.23	-	0.17	0.22	0.17	0.22	0.23	0.21	0.20	0.18	0.21
Yb	1.55	1.49	1.20	1.11	1.37	1.13	1.45	1.48	1.39	1.35	1.16	1.36
Lu	0.23	0.23	0.25	0.17	0.21	0.17	0.22	0.24	0.21	0.21	0.18	0.21
Hf	1.17	1.17	-	1.81	1.53	0.59	1.81	1.90	1.40	1.36	1.64	1.38
Ta	0.05	0.05	-	0.04	0.02	0.04	0.10	0.07	0.06	0.06	0.06	0.06
W	-	-	-	-	0.16	-	0.13	0.12	0.15	0.15	0.15	0.13
Tl	-	-	-	-	0.03	-	0.06	0.07	0.06	0.05	0.06	0.05
Pb	-	-	-	-	2.18	0.81	0.68	3.15	0.83	2.49	1.35	2.42
Th	0.95	0.94	-	0.83	0.71	0.41	0.88	0.88	0.89	0.90	1.15	0.85
U	0.23	0.24	-	0.27	0.22	0.21	1.51	1.28	0.30	0.32	0.35	0.42

Note: a: “-” Below detection limit or not determined. b: Age dating by zircon U-Pb method. c: Fe₂O₃(T) is total Fe expressed as Fe³⁺.