



Crustal Contamination Versus Subducted Components: An Example from The West Java Arc, Indonesia and Its implications in Magma Genesis

MIRZAM ABDURRACHMAN¹ and MASATSUGU YAMAMOTO²

¹Department of Geology, Bandung Institute of Technology, Bandung 40132, Indonesia

²Department of Geosciences, Geotechnology, and Material Resource Engineering, Akita University, Akita-shi, 010-8502, Japan

Corresponding author: mirzam@gc.itb.ac.id

Manuscript received: December, 12, 2020; revised: February, 23, 2021;
approved: November, 19, 2022; available online: Februari, 10, 2023

Abstract - New Sr isotope and K₂O data are presented for Papandayan and Cikuray Volcanoes in West Java. The data are combined with published Sr isotope and K₂O data, and compared with arc that has a similar geological setting, namely Northeast Japan Arc (NJA, N 38° ~ 41°) to constrain the relative importance of crustal assimilation and subducted input of crustal material in magma genesis beneath West Java Arc (WJA). New strontium isotope and K₂O data from fifty-four Quaternary volcanic rocks from WJA were collected and compared to forty-six Quaternary volcanic rocks from NJA. The increasing K₂O and decreasing of ⁸⁷Sr/⁸⁶Sr ratios with distance from trench have been found in NJA, but there are rough and no across arc variation of K₂O and Sr isotopic ratios in WJA. This study shows that the across arc variation of magma chemistry on the WJA is attributed to the crustal assimilation and the involvement of subducted sediments and slab fluids from altered oceanic crust.

Keywords: West Java Arc, Northeast Japan Arc, magma genesis, crustal assimilation, subducted sediments, slab fluid

© IJOG - 2023

How to cite this article:

Abdurrachman, M. and Yamamoto, M., 2023. Crustal Contamination Versus Subducted Components: An Example from The West Java Arc, Indonesia and Its implications in Magma Genesis. *Indonesian Journal on Geoscience*, 10 (1), p.97-107. DOI: [10.17014/ijog.10.1.97-107](https://doi.org/10.17014/ijog.10.1.97-107)

INTRODUCTION

Background

The magma genesis in convergent margin such as on WJA, Indonesia, can be examined by whole rock geochemistry and isotopic compositions. However, these data are not always indicative of actual magma source characteristics, as they have commonly undergone through complicated processes such as mafic recharge, magma mixing, mingling, assimilation, and fractional crystallization. Furthermore, the geochemical variations of the mantle wedge, subducted oce-

anic crust, subducted sediments, or melts and slab configuration also play an important role in magma genesis.

Past studies place some constraints on magma genesis in WJA. They believed that there is across arc variation on WJA (Whitford, 1975; Whitford *et al.*, 1979; Soeria-Atmadja *et al.*, 1991; Abdurrachman, 2012; Abdurrachman and Yamamoto, 2012). Although much geological data have been reported in Java, the main cause of the rough across arc variation of magma chemistry on the WJA is not clearly defined. This study provides further constraints on magma genesis beneath WJA.

Here whole-rock Sr isotope and K_2O data for WJA and new data from Papandayan and Cikuray Volcanoes were presented. The new data are combined with previously published geochemical and isotopic data and with other published WJA and NJA volcanic rock data to increase the understanding of the relative importance of both crustal assimilation and subduction input of crustal material in WJA

Regional Geology

Tectonic Settings

Indonesia is located at the boundaries of three plates, Eurasia, Indian-Australia, and Pacific-Philippine Plates (Hamilton, 1979). The Indian-Australia Plate moves northward and is being subducted beneath Eurasian Plate with convergent rate about 7 cm/year (Turner and Foden, 2001).

On the Late Cretaceous, a microcontinental fragment (Argoland) was detached from Gondwana and drifted northeastward approaching the subduction zone (Metcalf, 2011). The collision of microcontinent fragment was believed as the cause of termination of Late Cretaceous subduction as well as the one which shifted the subduction to the south of Java. According to Katili (1975), the suture zone may exist beneath Papandayan and Cikuray Volcanoes (Figure 1a).

Volcanism in West Java

Volcanic arc on Java Island has existed on present position at least since 10 Ma (Carn and Pyle, 2001). On the WJA, number of Quaternary volcanoes formed a group of volcanoes that are referred to the Triangular Volcanic Complex (TVC) along three fault zones (Figure 1b). Some of those volcanoes, such as Papandayan and Cikuray Volcanoes, are located in the volcanic front of TVC, West Java, and lie within the boundary of Late Cretaceous to Early Tertiary suture zone (Figure 1a).

METHODS

Thirty-five samples from early to late stages of Papandayan and also from Cikuray were collected during field campaign in August 2008 to

February 2009, and cut to obtain fresh interior and crushed using an automatic agate pestle and mortar system to $<40 \mu\text{m}$. They were then analyzed for the major elements (SiO_2 and K_2O) and trace elements (Zr and Nb) using a Rigaku 3270 X-ray fluorescence spectrometer (XRF) at Akita University, Japan. Powdered samples were ignited in a muffle furnace for two hours at 900°C before the preparation of fused glass beads containing 1.8 g of sample and 3.6 g of alkali flux (1:2). The alkali flux was a mixture of lithium metaborate (LiBO_2) and lithium tetraborate ($\text{Li}_2\text{B}_4\text{O}_7$) in a ratio of 1:4. Analytical precision is better than 2% for major elements and better than 10% for trace elements (Kimura and Yamada, 1996).

Thirty selected samples were analyzed for Sr isotope using a Finnigan MAT 261 at Akita University, Japan. The methods for extraction and acquisition were adapted from Kagami *et al.* (1982) and Yamamoto and Maruyama (1996). NBS-987 and La Jolla standards were also measured in the same runs, yielding values of $^{87}\text{Sr}/^{86}\text{Sr} = 0.710241 \pm 0.000008 (2\sigma)$.

RESULTS

SiO_2 , K_2O , and Sr isotopic ratios of basaltic to dacitic volcanic rocks from Papandayan and Cikuray area are listed in Table 1. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of Papandayan plot in the fourth quadrant; they range from 0.705243 to 0.705907. Early stage exhibits the widest range in $^{87}\text{Sr}/^{86}\text{Sr}$ (0.705243-0.705907), extending well outside the 2σ error, whereas in each subsequent stages and Cikuray, $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are more constant, varying by 0.705539-0.706133 for Papandayan middle and late stages and 0.704172 to 0.704257 for Cikuray.

DISCUSSION

The ranges of SiO_2 wt.% are 54.03-58.10 (early stage), 58.66-61.35 (middle stage), 63.58-75.81 (late stage), and 55.05-29.20 (Cikuray),

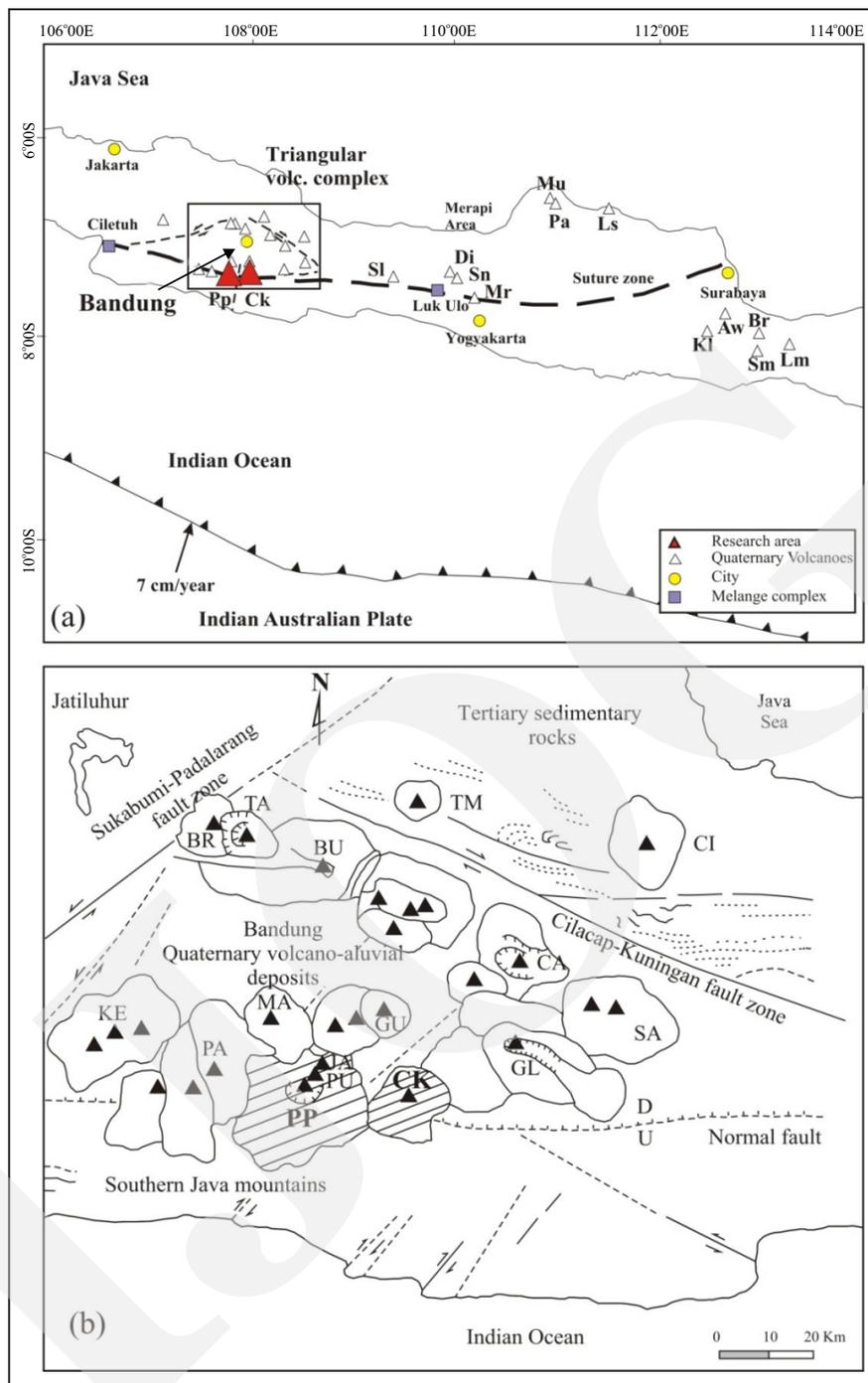


Figure 1. Historical earthquakes in Sumatra. Yellow star symbols indicate historical GSF earthquakes with $M > 6$. Blue star symbols indicate historical megathrust earthquakes with $M \geq 6.5$ after 2004. Colour straight lines indicate the GSF segmented by geometrical irregularities into nineteen major segments by Sieh and Natawidjaja (2000). (Br: Burangrang; TA: Tangkuban Prah; BU: Bukit Unggul; TM: Tampomas; CI: Ciremai; CA: Cakrabuana; SA: Sawal; CI: Ciremai; GL: Galunggung; CK: Cikuray; PP: Papandayan; PU: Puntang; JA: Jaya; GU: Guntur; MA: Malabar; PA: Patuha; KE: Kendeng; U: Hanging wall; D: Foot wall.

implying that fractional crystallization is probably not the only process in the evolution of Papan-dayan. Crustal contamination and magma mixing could also be involved. Previous studies on the

WJA suggested that Sr isotope and K_2O contents increased from the trench side to the backarc side volcanoes (Whitford, 1975; Whitford *et al.*, 1979; Soeria-Atmadja *et al.*, 1991; Abdur-

Table 1. SiO₂, K₂O, And Sr Isotopic Ratio of Papandayan and Cikuray Volcanoes

Volcano	Stage	Sample No	SiO ₂	K ₂ O	⁸⁷ Sr/ ⁸⁶ Sr	2σ
Papandayan	Early	MA-1	55.88	1.00	0.705243	8
		AK-3	57.67	1.26	0.705793	8
		AK-1	57.44	1.23	0.705264	8
		AK-13	54.69	0.96	0.705431	8
		AK-14	54.84	0.71	-	-
		MA-8A	54.34	0.81	0.705287	9
		MA-3B	54.07	0.78	0.705311	12
		MA-2A	58.10	1.38	0.705907	7
		MA-5B	54.03	0.72	0.705324	6
		IM2-3A	56.57	1.11	0.705811	9
		MH-7	52.98	0.79	0.705509	8
		IM2-5A	57.40	1.23	0.705905	8
		MIL-5	57.88	1.31	0.705902	8
	MH-1	54.20	0.60	-	-	
	A21-B	54.08	0.58	-	-	
	Middle	AK-5	60.93	1.47	0.705593	6
		AK-11	61.35	1.67	0.70559	9
		MC-2	58.66	1.72	0.705803	7
		MMK-2	59.37	1.48	0.705539	8
		IN-22	60.93	1.70	0.705696	9
		AK-7	64.09	1.88	0.705891	19
		MM-7B	71.07	2.93	0.705802	9
		MZ-1	65.50	2.40	0.705924	7
CRG-TJL		67.39	2.91	0.705849	7	
MZ-9		63.58	2.05	0.706133	8	
Late	IN 4	75.82	1.00	0.705618	8	
	A-23	63.62	2.30	0.70569	9	
	IP2-7	65.03	2.25	-	-	
	IN 13	67.26	2.92	-	-	
	IM-5	56.86	0.74	0.704182	8	
	5.1	55.40	0.70	0.704184	8	
	IM-3B	57.54	0.73	0.704172	8	
Cikuray	MH-9	55.05	0.32	0.704236	17	
	MH-12	55.97	0.70	0.704257	9	
	IM-7	59.20	0.82	0.704223	8	

rachman, 2012; Abdurrachman and Yamamoto, 2012). In detail, however, when the normalized of K₂O wt.% to SiO₂ = 55 wt.% from the WJA are closely examined and compared with the NJA, the WJA shows rough across-arc variation and more diverse in K₂O, especially in the volcanic front (Figure 2a). The decreasing of ⁸⁷Sr/⁸⁶Sr ratios with distance from trench has been found in NJA (e.g. Notsu 1983; Shibata and Nakamura, 1997), but there is no across arc variation of Sr isotopic ratios in WJA (Figure 2b).

Papandayan and Cikuray volcanic rocks are not the only end members of K₂O and Sr-Nd isotopic ratios in TVC but also the whole Java volcanoes

(Figure 3). Therefore, the genetic relationship between these volcanoes is suitable to explain the diversity of all the TVC and Java volcanic rocks.

Mantle Source Characteristics

Immobile trace elements are generally assumed to be unmodified by the subduction processes (e.g. Wood *et al.*, 1979). In order to identify the mantle source beneath Papandayan and Cikuray, immobile element ratios of Zr/Nb were employed. Table 2 and Figure 4 show that Zr/Nb ratios do not change significantly with differentiation and are relatively homogeneous in both Papandayan and Cikuray. The Zr/Nb ratios

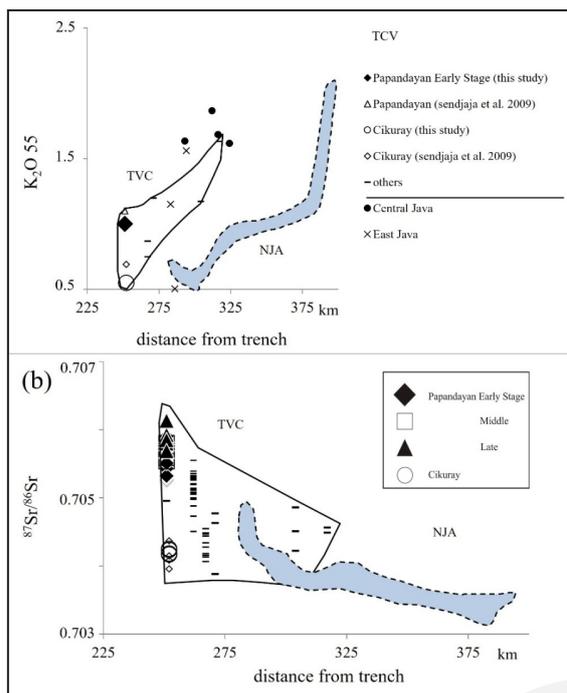


Figure 2. Diagram showing across-arc variation of (a) K_2O contents, (b) $^{87}Sr/^{86}Sr$ ratios in TVC (fifty-four samples from eight volcanoes) compared with NJA (forty-six samples from six volcanoes). The K_2O content of each volcanoes is normalized to $SiO_2 = 55$ wt.% on the empirically determined regression curve. (Data sources of Java volcanoes: Whitford, 1975; Gerbe *et al.*, 1992; Bourdier *et al.*, 1997; Carn and Pyle, 2001; Reubi *et al.*, 2002; Gertisser and Keller, 2003; Bernard and Mazot, 2004; Sendjaja *et al.*, 2009; this study. NJA: Katsui *et al.*, 1979; Ishikawa *et al.*, 1984; Sakuyama and Koyaguchi, 1984; Yoshida and Aoki, 1984; Maruyama *et al.*, 1988; Fujimaki *et al.*, 1990; Ohba and Umeda, 1999; Kimura and Yoshida, 2006; Yamamoto *et al.*, 2010.

are similar to Indian Mid- Oceanic Ridge Basalt (I-MORB). When they are compared to NJA (Figure 4), they are flatter and nearly identical to I-MORB rather than N-MORB. Considering these evidences, magma sources beneath Papan-dayan and Cikuray are nearly identical in term of Zr and Nb compositions indicating that the mantle wedge beneath both volcanoes is similar to the source of I-MORB.

The Role of Crustal Contamination

The summits of Papandayan and Cikuray Volcanoes are contiguous (~ 14 km, Figure 1), therefore the local tectonic settings under these volcanoes are expected to be constant (convergent rate of Sunda Arc: Turner and Foden, 2001; the depth of the Wadati-Benioff Zone: Abdurachman

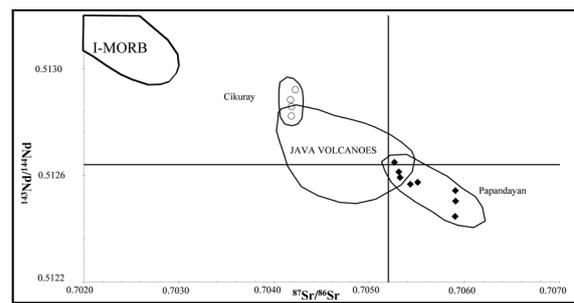


Figure 3. $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ isotope ratio diagram showing the Papandayan and Cikuray data compared to basaltic rocks of Java volcanoes, symbols as in Figure 2. I-MORB (Chauvel and Blichert-Toft, 2001); Java volcanoes: (Edwards *et al.*, 1991; Gerbe *et al.*, 1992; Edwards *et al.*, 1994; Carn and Pyle, 2001; Turner and Foden, 2001; Gertisser and Keller, 2003; Chadwick *et al.*, 2007; Handley *et al.*, 2009; Sendjaja *et al.*, 2009; Abdurrachman and Yamamoto, 2010; this study).

Table 2. Average Zr/Nb Ratio of Papandayan and Cikuray compared to I-MORB, N-MORB, NJA. Data sources: I-MORB (Chauvel and Blichert-Toft, 2001), N-MORB (Sun and McDonough, 1989), NJA (Shibata and Nakamura, 1997)

Ratio	I-MORB	N-MORB	NJA	Papandayan	Cikuray
Zr/Nb	26	32	19-37	20-32	18-29

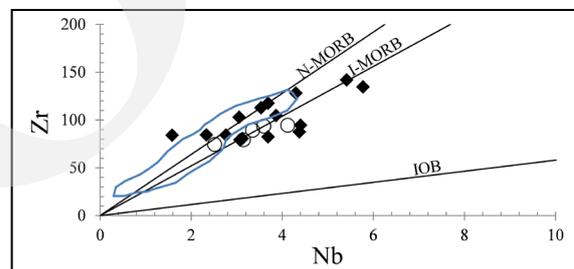


Figure 4. Zr vs. Nb for Papandayan and Cikuray compared to NJA. Symbols as in Figure 2. Data sources: I-MORB (Chauvel and Blichert-Toft, 2001), N-MORB and IOB (Sun and McDonough, 1989), NJA (blue solid line curve; Shibata and Nakamura, 1997).

et al., 2015; distance to the trench axis and crustal thickness: Gasparone and Varne, 1998) and the chemical diversities of the mantle wedge by subducted inputs as proposed by Edwards *et al.* (1991) also to be constant.

The new Sr isotope and K_2O data of Papandayan and Cikuray volcanic rocks provide surprising observation, that volcanic rocks from both volcanoes have distinctively differences in K_2O and Sr isotopic ratios showing end members of TVC (Figure 3). These seem to

be related to other condition, *e.g.* local crustal composition.

Sr-Nd Isotopic Mixing Model: I-MORB + AOC + Granites + Sediment

Figure 5a shows a mixing model, where I-MORB is contaminated by altered oceanic crust (AOC) fluid and Indian Ocean sediments end members. Mixing curves fail to provide a good fit to isotopic variation of the TVC, and could not explain the steep mixing line, also the downward bend of Papandayan isotopic trend, suggesting that an additional isotopically distinct component is needed.

The mixture of basaltic andesite of Cikuray, AOC fluid, and crustal contaminants of older crust (*e.g.* Australian granites) have been added to produce steep mixing lines. The involvement of AOC fluid is clearly shown by the starting points of Cikuray which are not on I-MORB (Figure 5b).

The involvement of subducted sediment to the source of I-MORB mantle wedge is evidence since the most Nd radiogenic rocks of Cikuray are still below than I-MORB-AOC line (Figure 5b). The basaltic andesite of Cikuray represents the least evolved sample with the highest Nd isotopic ratio in the TVC area. The crustal contaminant represents Australian granites as a possible microcontinent beneath southern Java as proposed by zircon study (Clements and Hall, 2007; Smyth *et al.*, 2007) which collided to the eastern margin of Sunda Land during Late Cretaceous to Early Tertiary (Sribudiyani *et al.*, 2003). The ages of contaminant granites range from Silurian to Devonian (SE Australian, McCulloch and Chappell, 1982) and Pre-Cambrian (SW Australian, Bickle *et al.*, 1989, 1993). The contaminants used in the mixing modelling are listed in Table 3. They are older than the initial age of the segregation of Gondwana Supercontinent (Late Devonian), also the formation of microcontinent fragments (Late Jurassic) (Metcalf, 1996). Papandayan and Cikuray are located at the boundary of Late Cretaceous to Early Tertiary suture zone (Katili, 1975) (Figure 1) and on the extension of East Java continental

fragment to West Java (Clement and Hall, 2007; Abdurrachman *et al.*, 2018). Therefore, it is appropriate to use Australian granites as candidates for crustal contaminant.

The results show that many mixing curves of granitic rocks produce reasonable fit to the TVC trends compared to Indian Ocean sediments (Figure 5b). Considering this mixing model we argue that the presence of “Argoland” beneath southern West Java was responsible for Sr-Nd isotopic ratios diversity in Papandayan area as well as in the TVC as illustrated in Figure 6.

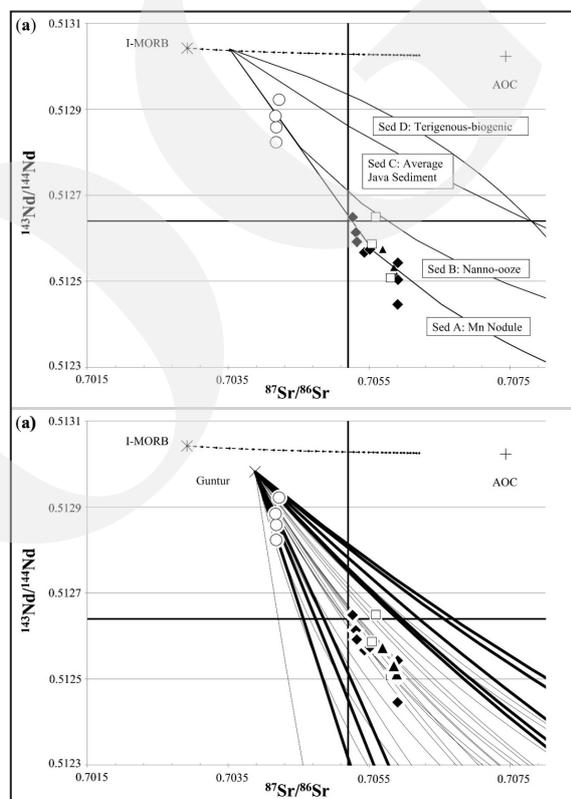


Figure 5. Sr-Nd isotopic mixing model; symbols as in Figure 2. (a) Mixture of I-MORB (I-MORB*0.1, assuming 10% melting) and AOC fluid and sediments. (b) Mixture of basaltic andesite of Cikuray with crustal contaminant from Australia (SE: thin line; SW: thick line) and Data sources: I-MORB (Chauvel and Blichert-Toft, 2001); basaltic andesite of Cikuray (this study. Sediment A, Mn Nodule, V34-62 (White and Dupré, 1986; Ben Othman *et al.*, 1989); B, nanno-ooze, DSDP site 211 (Gasparon and Varne, 1998); C, average Java sediment (Plank and Langmuir, 1998); D, terrigenous-biogenic average of V33-75, -77, -79 (Ben Othman *et al.*, 1989; Gasparon and Varne, 1998); AOC fluid (Handley *et al.*, 2007); AOC (Staudigel *et al.*, 1995); SE Australian granites (McCulloch and Chappell, 1982); SW Australian granites (Bickle *et al.*, 1989, 1993); TVC volcanoes (dashed line curve): (Whitford, 1975; Gerbe *et al.*, 1992; Sendjaja *et al.*, 2009; this study).

Crustal Contamination Versus Subducted Components: An Example from The West Java Arc, Indonesia and Its implications in Magma Genesis (M. Abdurrachman and M. Yamamoto)

Table 3. End-member Compositios Used in the Mixing Calculation for Figure 5

	Sr (ppm)	Nd (ppm)	Sr/Nd	⁸⁷ Sr/ ⁸⁶ Sr	¹⁴³ Nd/ ¹⁴⁴ Nd
I-MORB source	13.5	0.97	13.92	0.702915	0.513042
Basaltic member of Guntur	225	10.3	21.84	0.703882	0.512982
AOC fluid	22.42	0.697	32.17	0.704584	0.513070
Sediment					
A	857	187.9	4.561	0.709117	0.512236
B	126	51.9	2.428	0.716430	0.512228
C	218	33.95	6.421	0.716820	0.512160
D	398	15.36	25.911	0.708875	0.512411
SE Australian Granites					
Tingariny granodiorite	30.34	168	0.18	0.728400	0.511252
Numbla Vale adamellite	25.31	97	0.26	0.752810	0.511246
Cooma granodiorite	70.13	127	0.55	0.738900	0.511111
Cooma gneiss	44.74	114	0.39	0.758390	0.511193
Jillamatong granodiorite	22.29	139	0.16	0.737890	0.511186
Ingebyrah granodiorite	32.23	163	0.20	0.730180	0.511255
Kalkite adamellite	27.96	117	0.24	0.744050	0.511242
State Circle shale	39.3	23	1.71	0.879330	0.511094
Buckley Lake adamellite	191	37.12	5.15	0.723520	0.511483
Buckley Lake adamellite	175	33.18	5.27	0.725550	0.511514
Tara granodiorite	252	24.51	10.28	0.712030	0.511441
Namungo adamellite	33	8.98	3.67	0.808030	0.511640
Delegate adamellite	131	34.39	3.81	0.729060	0.511520
Iona granodiorite	264	22.36	11.81	0.713570	0.511452
Wullwye granodiorite	189	42.26	4.47	0.716170	0.511596
Maffra adamellite	121	25.5	4.75	0.729860	0.511595
Bimbimbie granodiorite	243	28.48	8.53	0.717630	0.511282
Currowong granodiorite	231	23.8	9.71	0.717110	0.511339
Merumbago granodiorite	139	18.42	7.55	0.726910	0.511160
Finister granodiorite	123	19.79	6.22	0.729480	0.511213
Jindagyne tonalite	254	17.96	14.14	0.713620	0.511393
Grosses Plain granodiorite	256	13.95	18.35	0.709020	0.511479
SW Australian Granites					
Porphyritic granites					
SB 599	398	39	10.21	0.738310	0.510432
Y1-5	364	48	7.58	0.741870	0.510520
Y1-7	376	48	7.83	0.739930	0.510650
Leuco-adamellite					
SB 437	203	42	4.83	0.709113	0.510245
SB 450	199	50	3.98	0.81437	0.510248
Contact tonalite					
SB 611	739	28	26.39	0.710580	0.510208
SB 615	815	35	23.29	0.709150	0.510191
SB 616	777	32	24.28	0.709970	0.510319

Data Sources: I-MORB (Chauvel and Blichert-Toft 2001), basaltic member of Guntur (Sendjaja *et al.*, 2009); sediment: A, Mn nodule, V34-62 (White and Dupré, 1986; Ben Othman *et al.*, 1989); B, nanno-ooze, DSDP site 211 (Gasparon and Varne, 1998); C, average Java sediment (Plank and Langmuir, 1998); D, terrigenous-biogenic average of V33-75, -77, -79 (Ben Othman *et al.*, 1989; Gasparon and Varne, 1998); AOC fluid (Handley *et al.*, 2007); AOC (Staudigel *et al.*, 1995); crustal contaminant: SE Australian granites (McCulloch and Chappell, 1982), SW Australian granites (Bickle *et al.*, 1989, 1993).

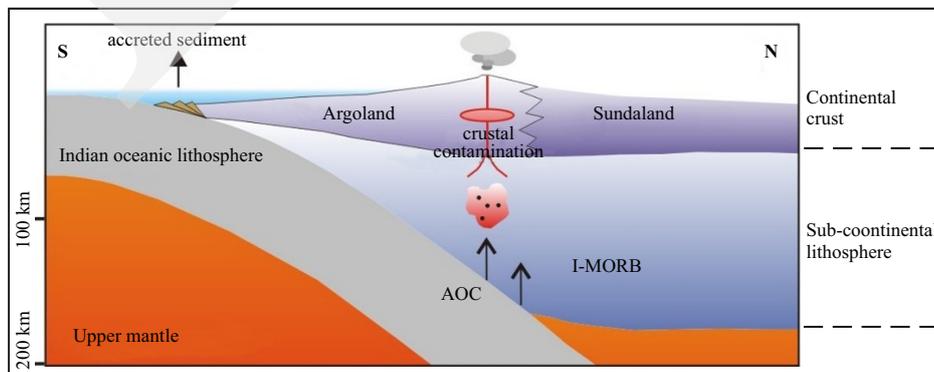


Figure 6. Illustration of magma genesis beneath Papandayan Volcano (no scale). AOC: altered oceanic crust; S: south; N: north.

CONCLUSION

The WJA shows rough across-arc variation and more diverse in K_2O and no across arc variation for Sr isotopic ratio especially in the volcanic front, it is due to Papandayan data. The contrasting Sr-Nd isotopic ratios in Papandayan area can be explained by the mixing of clear mantle wedge (I-MORB + AOC \pm Indian Sediments) with Paleozoic to Pre-Cambrian Australian Granites as the missing "Argoland" which have separated from Western Australia in the Late Jurassic and collided to SE Sundaland in the Late Cretaceous. We note that the presence of "Argoland" beneath southern West Java is thought to contribute significantly to the spatial geochemical source input variations exhibited by TVC volcanoes.

ACKNOWLEDGMENTS

Authors thank to Professor Shintaro Hayashi from Akita University, Japan, for X-ray fluorescence facilities. This research was supported by DIKTI grant, Indonesia. Finally, thank you to the anonymous reviewers for their insightful and constructive comments.

REFERENCES

- Abdurrachman, M. and Yamamoto, M., 2010. Geochemical variation of volcanic rocks in Papandayan Area: A new indication of the existence of micro-continent in West Java, Indonesia. *Abstracts with Programs of Geological Society of Japan Annual Meeting*, 117, *the Geological Society of Japan*, O-177.
- Abdurrachman, M., 2012. *Geology and petrology of Quaternary Volcano and genetic relationship of volcanic rocks from the Triangular Volcanic Complex around Bandung Basin, West Java, Indonesia. Doctorate Thesis*, Akita University, Japan 131pp.
- Abdurrachman, M. and Yamamoto, M., 2012. Geochemical variation of Quaternary volcanic rocks in Papandayan area, West Java, Indonesia: A role of crustal component. *Journal of the Geological Society of Thailand, GEOSEA*, p.40-57.
- Abdurrachman, M., Widiyantoro, S., Priadi, B., Alim, M. Z. A., and Dewangga, A. H., 2015. Proposed new wadati-benioff zone model in Java-Sumatra subduction zone and its tectonic implication. *Proceedings, Joint Convention Balikpapan, Indonesia*. DOI 10.1007/978-3-030-01575-6_5
- Abdurrachman, M., Widiyantoro, S., Saepuloh, A., and Kurniawan, I. A., 2018. Tracing the Missing Argoland Beneath Java: Evidence from Geochemical Signature and Seismic Tomogram. In: Doronzo D., Schingaro E., Armstrong-Altrin J., and Zoheir B. (eds.), *Petrogenesis and Exploration of the Earth's Interior, CAJG*. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham, p.37-40. DOI: 10.1007/978-3-030-01575-6_9
- Ben Othman, D., White, W.M., and Patchett, J., 1989. The geochemistry of marine sediments, island arc magma genesis, and crust-mantle recycling. *Earth and Planetary Science Letters*, 94, p.1-21. DOI: 10.1016/0012-821x(89)90079-4
- Bernard, A. and Mazot, A., 2004. Geochemical evolution of the young crater lake of Kelud volcano in Indonesia. *Proceedings, the Eleventh International Symposium on Water-Rock Interaction, Saratoga Springs, New York, USA*, 1, p.87-90. DOI: 10.4324/9780203023907
- Bickle, M.J., Bettenay, L.F., Chapman, H.J., Groves, D.I., McNaughton, N.J., Campbell, I.H., and Laeter, J.R., 1989. The age and origin of younger granitic plutons of the Shaw Batholith in the Archean Pilbra Block, Western Australia. *Contributions to Mineralogy and Petrology*, 101, p.361-376. DOI: 10.1007/bf00375320
- Bickle, M.J., Bettenay, L.F., Chaman, H. pJ., Groves, D.I., McNaughton, N.J., Campbell, I.H., and Laeter, J.R., 1993. Origin of the

- 3500-3300 Ma cal-alkaline rocks in the Pilbara Archean: isotopic and geochemical constraints from the Shaw Batholith. *Precambrian Research*, 60, p.117-149. DOI: 10.1016/0301-9268(93)90047-6
- Bourdier, J.L., Pratomy, I., Thouret, J.C., Boudon, G., and Vincent, P.M., 1997. Observations, stratigraphy and eruptive processes of the 1990 eruption of Kelut volcano, Indonesia. *Journal of Volcanology and Geothermal Research*, 79, p.181-203. DOI: 10.1016/s0377-0273(97)00031-0
- Carn, S.A. and Pyle, D.M., 2001. Petrology and geochemistry of the Lamongan field, East Java, Indonesia: Primitive Sunda Arc Magmas in an Extensional Tectonic Setting? *Journal of Petrology*, 42, p.1643-1683. DOI: 10.1093/petrology/42.9.1643
- Chadwick, J.P., Troll, V.R., Catherine, G., Morgan, D., Gertisser, R., Waight, T.E., and Davidson, J.P., 2007. Carbonate assimilation at Merapi Volcano, Java, Indonesia: insights from crystal isotope stratigraphy. *Journal of Petrology*, 48, p.1793-1812. DOI: 10.1093/petrology/egm038
- Chauvel, C. and Blichert-Toft, J., 2001. A hafnium isotope and trace element on melting of the depleted mantle. *Earth and Planetary Science Letters*, 190, p.137-151. DOI: 10.1016/s0012-821x(01)00379-x
- Clements, B. and Hall, R., 2007. Cretaceous to Late Miocene stratigraphic and tectonic evolution of West Java. *Proceedings, Indonesian Petroleum Association 31st Annual Convention and Exhibition*. DOI: 10.29118/ipa.1520.07.g.037
- Edwards, C., Menzies, M., and Thirlwall, M., 1991. Evidence from Muriah, Indonesia, for the interplay of supra-subduction zone and intraplate processes in the genesis of potassic alkaline magmas. *Journal of Petrology*, 32, p.555-592. DOI: 10.1093/petrology/32.3.555
- Edwards, C.M.H., Menzies, M.A., Thirlwall, M.F., Morris, J.D., Leeman, W.P., and Harmon, R.S., 1994. The transition to potassic alkaline volcanism in island arc: The Ringgit-Beser Complex, East Java, Indonesia. *Journal of Petrology*, 35, p.1557-1595. DOI: 10.1093/petrology/35.6.1557
- Fujimaki, H., Aoki, K., and Yoshida, T., 1990. Spatial variations in the composition of island arc volcanics of Northern Japan. In: Marumo, F. (eds.), *Dynamic processes of material transport and transformation in the earth's interior*. Tokyo: Terra Scientific, Dordrecht, p.377-392. DOI: 10.1007/978-94-011-3314-2_21
- Gasparon, M. and Varne, R., 1998. Crustal assimilation versus subducted sediment input in West Sunda arc volcanics: An evaluation. *Mineralogy and Petrology*, 64, p.89-117. DOI: 10.1007/bf01226565
- Gerbe, M.C., Gourgaud, A., Sigmarsson, O., Harmon, R.S., Joron, J.L., and Provost, A., 1992. Mineralogical and geochemical evolution of 1982-1983 Galunggung eruption (Indonesia). *Bulletin of Volcanology*, 54, p.284-98. DOI: 10.1007/bf00301483
- Gertisser, R. and Keller, J., 2003. Trace element and Sr, Nd, Pb, O isotope variations in Medium-K and high-K volcanic rocks from Merapi volcano, Central Java, Indonesia: evidence for the involvement of subducted sediments in Sunda arc magma genesis. *Journal of Petrology*, 44, p.457-89. DOI: 10.1093/petrology/44.3.457
- Hamilton, W., 1979. *Tectonics of the Indonesian region. Geological Survey Professional Paper 1078*, U.S. Government Printing Office, Washington, D.C., 345pp.
- Handley, H.K., Macpherson, C.G., and Davidson, J.P., 2009. Geochemical and Sr-O isotopic constraints on magmatic differentiation at Gede volcanic complex, West Java, Indonesia. *Contributions to Mineralogy and Petrology*, 159, p.885-908. DOI: 10.1007/s00410-009-0460-z
- Handley, H.K., Macpherson, C.G., Davidson, J.P., and Berlo, K., 2007. Contrasting Fluid and sediment Contributions to subduction-related magmatism in Indonesia: Ijen volcanic complex. *Journal of Petrology*, 48, p.1155-1183. DOI: 10.1093/petrology/egm013

- Ishikawa, K., Yoshida, T., and Aoki, K., 1984. Fractional crystallization in magma of Quaternary Iwate volcano, the northern sub-zone of Nasu volcanic zone. *Research Report of Laboratory of Nuclear Science, Tohoku University*, 17, p.330-345.
- Kagami, H., Okano, O., Sudo, H., and Honma, H., 1982. Isotope analysis of Rb and Sr using a full-automatic thermal ionization mass spectrometer. *Okayama Daigaku Onsen Kenkyusho Hokoku*, 52, 51-70.
- Katili, J.A., 1975. Volcanism and plate tectonics in the Indonesian island arcs. *Tectonophysics*, 26, p.165-88. DOI: 10.1016/0040-1951(75)90088-8
- Katili, J.A. and Sudradjat, A., 1984. *Galunggung, the 1982-1983 Eruption*. Volcanological Survey of Indonesia, 102pp.
- Katsui, Y., Yamamoto, M., Nemoto, S., and Niida, K., 1979. Genesis of calc-alkaline andesites from Oshima-ōshima and Ichinomegata volcanoes, North Japan. *Journal Faculty of Science, Hokaido University*, 19, p.157-168.
- Kimura, J.I. and Yamada, Y., 1996. Evaluation of major and trace element XRF analyses using a flux to sample ratio of two to one glass beads. *Journal of Mineralogy, Petrology and Economic Geology*, 91, p.62-72. DOI: 10.2465/ganko.91.62
- Kimura, J.I. and Yoshida, T., 2006. Contribution of slab fluid, mantle wedge and crust to the origin of quaternary lavas in the NE Japan Arc. *Journal of Petrology*, 47, p.2185-2232. DOI: 10.1093/petrology/egl041
- Maruyama, T., Yamamoto, M., and Yoshioka, S., 1988. Geology and Petrology of Kampo volcano, Oga Peninsula, Japan (in Japanese with English abstract). *Report of the Research Institute of Natural Resources, Mining College, Akita University*, 53, p.1-16.
- McCulloch, M.T. and Chappell, B.W., 1982. Nd isotopic characteristics of S- and I-type granites. *Earth and Planetary Science Letters*, 58, p.51-64. DOI: 10.1016/0012-821x(82)90102-9
- Metcalf, I., 1996. Pre-Cretaceous evolution of SE Asian terranes. In: Hall, R. and Blundell, D.J. (eds.), *Tectonic Evolution of SE Asia*, Geological Society of London Special Publication, 106, p.97-122. DOI: 10.1144/gsl.sp.1996.106.01.09
- Metcalf, I., 2011. Tectonic framework and Phanerozoic evolution of Sundaland. *Gondwana Research*, 106, p.97-122. DOI: 10.1016/j.gr.2010.02.016
- Notsu, K., 1983. Strontium isotope composition in volcanic rocks from the Northeast Japan arc. *Journal of Volcanology and Geothermal Research*, 18, p.531-548. DOI: 10.1016/0377-0273(83)90024-0
- Ohba, T. and Umeda, K., 1999. Geology of Hachimantai volcanic field and temporal-spatial variation of magma compositions (in Japanese with English abstract). *Journal of Mineralogy, Petrology and Economic Geology*, 94, p.187-202. DOI: 10.2465/ganko.94.187
- Plank, T. and Langmuir, C.H., 1998. The chemical composition of subducting sediment and its consequences for the crust and mantle. *Chemical Geology*, 145, p.325-394. DOI: 10.1016/S0009-2541(97)00150-2
- Reubi, O., Nicholls, I.A., and Kamenetsky, V.S., 2002. Early mixing and mingling in the evolution of basaltic magmas: evidence from phenocryst assemblages, Slamet Volcano, Java, Indonesia. *Journal of Volcanology and Geothermal Research*, 119, p.255-274. DOI: 10.1016/S0377-0273(02)00357-8
- Sakuyama, M. and Koyaguchi, T., 1984. Magma mixing in mantle xenolith-bearing calc-alkalic ejecta, Ichinomegata Volcano, Northeastern Japan. *Journal of Volcanology and Geothermal Research*, 22, p.199-224. DOI: 10.1016/0377-0273(84)90003-9
- Sakuyama, M., 1981. Petrological study of the Myoko and Kurohime volcanoes, Japan: crystallization sequence and evidence for magma mixing. *Journal of Petrology*, 22, p.553-583. DOI: 10.1093/petrology/22.4.553
- Sendjaja, Y.A. and Kimura, J.I., 2010. Geochemical variation in Tertiary-Quaternary lavas of the West Java arc, Indonesia: Steady-state subduction over the past 10 million years. *Journal*

- of Mineralogical and Petrological Sciences*, 105, p.20-28. DOI: 10.2465/jmps.080930
- Sendjaja, Y.A., Kimura, J.I., and Sunardy, E., 2009. Across-arc geochemical variation of Quaternary lavas in west Java, Indonesia: Mass-balance elucidation using arc basalt simulator model. *Journal Island Arc*, 18, p.201-224. DOI: 10.1111/j.1440-1738.2008.00641.x
- Shibata, T. and Nakamura, E., 1997. Across-arc variations of isotope and trace element compositions from Quaternary basaltic volcanic rocks in northeastern Japan: Implications for interaction between subducted oceanic slab and mantle wedge. *Journal of Geophysical Research*, 102, p.8051-8064. DOI: 10.1029/96jb03661
- Smyth, H.R., Hamilton, P.J., Hall, R., and Kinny, P.D., 2007. The deep crust beneath island arcs: Inherited zircons reveal a Gondwana continental fragment beneath East Java, Indonesia. *Earth and Planetary Science Letters*, 258, p.269-282. DOI: 10.1016/j.epsl.2007.03.044
- Soeria-Atmadja, R., Suparka, M.E., and Yuwono, Y.S., 1991. Quaternary calc-alkaline volcanism in Java with special reference to Dieng and Papandayan-Galunggung complex. *Proceedings International Conference Volcanology and Geothermal Technology*, IAGI-Bandung.
- Sribudiyani, Muchsin, M., Ryacudu, R., Astono, P., Prasetya, I., Sapiie, B., Asikin, S., Harsolunmakso, A.H., and Yulianto, I., 2003. The collision of the Java Microplate and its implication for hydrocarbon occurrences in the east Java basin. *Proceedings, Indonesian Petroleum Association 29th Annual-Convention and Exhibition*. DOI: 10.29118/ipa.1530.03.g.085
- Staudigel, H., Davies, G.R., Hart, S.R., Marchant, K.M., and Smith, B.M., 1995. Large scale isotopic Sr, Nd and O isotopic anatomy of altered oceanic crust: DSP/ODP sites 417/418. *Earth and Planetary Science Letters*, 130, p.169-189. DOI: 10.1016/0012-821x(94)00263-x
- Sun, S.S. and McDonough, W.F., 1989. Chemical and isotopic systematics of oceanic basalts: implication for mantle composition and processes. In: Saunders, A.D. and Norry, M.J. (eds.), *Magma-tism in ocean basins*. Geological Society of London Special Publication, 42, p.313-345. DOI: 10.1144/gsl.sp.1989.042.01.19
- Turner, S. and Foden, J., 2001. U, Th and Ra disequilibria, Sr, Nd, and Pb isotope and trace element variations in Sunda arc lavas: Predominance of a subducted sediment component. *Contributions to Mineralogy and Petrology*, 142, p.43-57. DOI: 10.1007/s004100100271
- White, V.M. and Dupré, B., 1986. Sediment subduction and magma genesis in the Lesser Antilles: isotopic and trace element constraints. *Journal Geophysic Research Solid Earth*, 91, p.5927-5941. DOI: 10.1029/jb091ib06p05927
- Whitford, D.J., 1975. Sr isotopic studies of the volcanic rocks of the Sunda arc, Indonesia, and their petrogenetic implications. *Geochemica et Cosmochimica Acta*, 39, p.1287-302. DOI: 10.1016/0016-7037(75)90136-2
- Whitford, D.J., Nicholls, I.A., and Taylor S.R., 1979. Spatial variation in the geochemistry of Quaternary lavas across the Sunda arc in Java and Bali. *Contributions to Mineralogy and Petrology*, 70, p.341- 56. DOI: 10.1007/bf00375361
- Wood, D.A., Joron, J.L., and Treuil, M., 1979. A re-appraisal of use of trace elements to classify and discriminate between magma series erupted in different tectonic setting. *Earth and Planetary Science Letters*, 45, p.326-336. DOI: 10.1016/0012-821x(79)90133-x
- Yamamoto, M. and Maruyama, T., 1996. The Sr and Nd isotopic analysis and the quantitative analysis of Rb and Sr by using MAT 261. *Memoir Faculty of Mining, Akita University*, 61, 17-30 (in Japanese with English abstract).
- Yamamoto, M., Takeda, R., Kondou, A., and Maruyama, T., 2010. Sr and Nd isotopic ratios of hornblendes and plagioclases in mafic xenoliths from Ichinomegata, Northeast Japan. *Magma*, 91, p.1-16.
- Yoshida, A. and Aoki, K., 1984. Geochemistry of major and trace elements in the Quaternary volcanic rocks from Northeast Honshu, Japan. *The Science Reports of the Tohoku University*, XVI, p.1-34.