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Ibu volcano, a center of spectacular dacite dome growth and long-term continuous eruptive discharges

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Ibu is one of the most isolated and least accessible volcanoes of Indonesia, located on Halmahera Island, in the province of Maluku, East Indonesia. This volcano is one of the most active volcanoes in Indonesia, but remains poorly studied. Since its resuming activity in 1998, Ibu has injected around 0.7 Tg of SO₂ into the atmosphere through 60–100 daily eruptive discharges. This long-term eruptive activity is very well retraced by seismic signals that highlight the progressive dome growth and the supply of new magma into Ibu reservoir. The lava dome which is of dacite composition is developing at a rate of 3182 m³ per day. This decadal dome growth of Ibu requires further attention and warrants monitoring as it is a hazard and risk concern.

1. Introduction

Ibu is a 7-km-width stratovolcano with a summit of 1340 m (a.s.l.); it is located on the northwestern part of Halmahera Island, East Indonesia (Fig. 1). With Gamkonora, Dukono, Gamalama and Kiebesi, it forms the group of five active volcanoes in the north of Maluku Province. Like many volcanoes in Indonesia, very little is known about Ibu as it is isolated and difficult to access. The long period of dormancy after a single eruption in 1911 (GVP database: <http://volcano.si.edu/volcano.cfm?vn=268030>) associated with well-developed and dense vegetation in its nested craters (Fig. 2) did not provide much opportunity for this volcano to be known. But this tranquility ceased on December 31, 1998, when the edifice entered a new phase of volcanic activity marked by recurrent eruptive events and spectacular dome growth that has progressively filled the nested craters to its rim over the past 14 years. This paper aims to highlight the activity of the little-known Ibu volcano and provide insights into this new activity phase based on seismic recordings, the chemistry of new lava products, and SO₂ mass discharge by the continuous eruptive activity.

2. Summary of the resuming activity of Ibu volcano

Ibu entered its new active phase unexpectedly. There were no monitoring means on Ibu prior to 1999 and difficulties accessing the summit prevented surrounding inhabitants from noticing any potential

changes in the crater prior to the eruption. The Center for Volcanology and Geological Hazard Mitigation (CVGHM), the Indonesian institute in charge of volcano monitoring, reported that strong eruptions occurred on December 31, 1998, propelling significant amounts of ash into the atmosphere, with subsequent heavy ash fall on villages downwind (01/1999-BGVN 24:01). Such strong eruption manifestations continued on January 2 and 5, 1999, with ash plumes rising to ~1000 m above the crater rim and depositing an ~3 mm thick layer of ash up to 5 km downwind.

The first seismometer on Ibu was installed on February 3, 1999, at ~2 km from the summit, allowing subsequent continuous monitoring of Ibu's activity. The first recordings in February emphasized continuous eruptive events on Ibu – clearly 1 eruption every 5 min. A month later in March 1999, the continuous eruptive events persisted with 1 eruptive event every 13–15 min (02/1999-BGVN 24:02). The rhythm of explosive events then slowed to around 1 event per 30 min in April and May 1999 (02/1999-BGVN 24:02). Between 2000 and 2005, Ibu's eruptive discharges continued at a rate fluctuating between 58 and 96 per day (Kristianto, 2006).

In May 2000, 16 months after the onset of Ibu's new activity, an aerial picture (Fig. 2) showed the bottom of Ibu's nested craters totally occupied by a lava dome. This dome started to form in early 1999 (Fig. 2). When we visited the summit in November 2012, the lava dome fully occupied Ibu's crater and it had grown as high as the inner crater rim. The rhythm of explosive events was still quite high, about 3 events per hour. Stronger events occurred in vent 1, while minor discharges and ash-free releases occurred from vent 2. Vent 3 is obstructed by a magma extrusion (Fig. 1).

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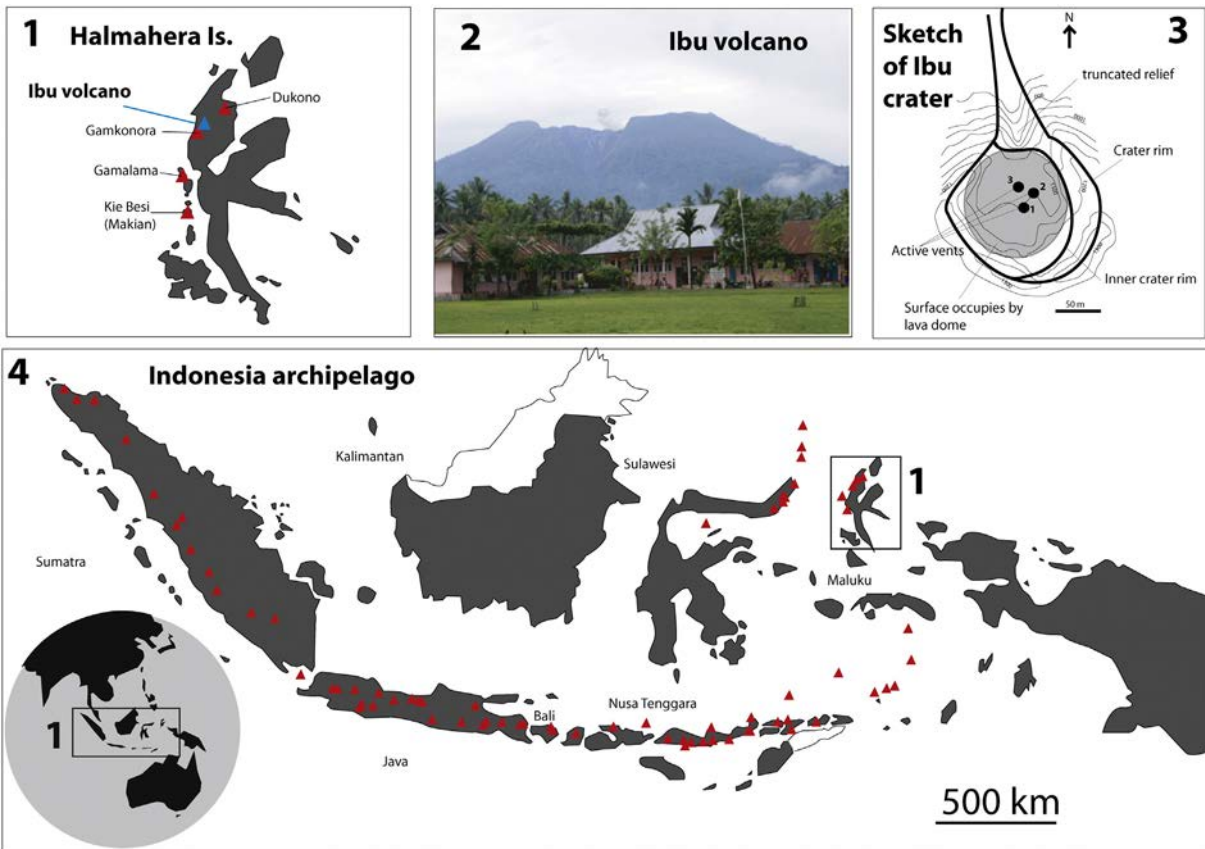


Fig. 1. Ibu volcano is located on the north-western part of Halmahera Island (1), in the Maluku Province, East Indonesia. The picture shows the Ibu volcano (background) with its truncated rim (2), looking from Goin village (north of the volcano). Ibu summit is constituted by a nested cratered that is now occupied by a lava dome. The active vents 1, 2, 3 are positioned (3). Triangles indicate active volcanoes across the Indonesian archipelago (4).

The activity of Ibu releases enough hot features to be detected by satellite sensors, and since May 2000 the MODIS sensor (<http://modis.higp.hawaii.edu/>) has detected thermal anomalies on the volcano. Thermal alerts happened strongly around August–September 2001 and October–December 2004, when the eruptive activity was likely very intense, and then almost continuously from May 2008 to 2012 and even after (Fig. 3), possibly in relation to dome growth.

3. Methodology

To gain insight into the recent volcanic episode on Ibu we statistically analyzed data series from the only available analog seismograph. The sensor is installed 2 km from the summit, on the north-western flank of the volcano and data are telemetered to the observatory post located 12 km south of the Ibu edifice. Seismic signals recorded on this volcano are classified into 4 categories, including deep volcanic signals (2.5–5 km) (VA-type), shallow volcanic signals (<2.5 km) (VB-type), explosive signals and rockfall signals. The seismic recordings in this work cover a period of 7 years, from March 2006 to November 2012.

In November 2012 a field survey on the Ibu volcano sampled pieces of a fresh lava bomb ejected over the crater rim. A sample was analyzed in the laboratory using XRF techniques. Eruptive SO₂ discharges from Ibu into the atmosphere were observed using a single 310 nm bandpass filter on an Apogee Alta U260 ultraviolet camera (Mori and Burton, 2006, 2009; Kantzas et al., 2010). The camera was positioned at Goin village, 6 km north of the crater. The plume drifted to the east during our measurements.

4. Results

4.1. Continuous seismic events

Over the 2006–2012 period, the seismometer recorded more than 250,000 volcanic events on Ibu, excluding recorded tectonic signals. The highest number of events was recorded during the 2010–2011 period with 116,000 events, representing 46% of all events recorded; 2007 was the year with the lowest number of events (4000 events recorded). When classifying the signals into 4 distinct categories including deep volcanic quakes (VA), shallow volcanic quakes (VB), explosive signals and rockfall signals (Fig. 4), 80% of the recorded signals are explosive ones. They occurred strongly in 2008 and 2011 but were almost nonexistent in 2007. Rockfall signals did not occur in the pre-2010 period, but they emerged suddenly and in number in April 2010 and were then strongly represented throughout the rest of 2010, 2011 and 2012. Deep volcanic quakes (VA) were present throughout the studied period (2006–2012), with most (78%) recorded during 2007 and 2008. A small increase occurred again at the end of 2012. There was no particular delay between VA and shallow volcanic signals (VB). The latter occurred typically within the same period as VA signals, with similarly 78% of the signals in 2007–2008 period. April 2008 accumulated the highest number of VB signals representing 25% of the VB-type signals over the whole period studied.

4.2. Lava composition

Lava freshly ejected over the crater rim in November 2012 (Fig. 5) is a dense, unvesiculated and dark-colored material with no phenocrysts.



December 1980.

The vegetation was well established in Ibu crater after a long dormant period following the last eruption in 1911.

Photo courtesy: Wirasaputra/VSI



February 1999.

A new dome was formed in the crater (200 m in diameter and 20 m height). About 30 eruptions in average per day were observed.

Photo courtesy: A. Solihin/VSI



May 2000.

The dome was well established and totally occupied the bottom of the crater.

Photo courtesy: B. Gemmel, PT Nusa Halmahera Minerals



November 2012.

The dome totally filled the inner crater. Explosions continued (40 eruptions in 12 h) from two active vents (vent 1 and vent 2 (Fig.1)).

Fig. 2. Evolution of Ibu crater, from the dense vegetation observed in December 1980 to a dome-filled-crater in 2012. In February 1999, the dome started to form, while in May 2000 the dome completely occupied the bottom of Ibu crater. In November 2012, the eruptive discharge is mainly from vent 3 while vent 2 exhibited ash-free emissions. Vent 1 is obstructed by lava extrusion.

The fracture is conchoidal, which is a primary characteristic of a near-absence of mineral crystal in glass.

Table 1 displays the composition of Ibu lava, based on major-element concentrations obtained from XRF analysis. It highlights the high content of SiO₂ (67%), thus positioning the source in the range of felsic and differentiated melt. Total alkalis versus SiO₂ (Fig. 6) plot indicates dacite composition, slightly below trachydacite and rhyolite with medium K calcoalkaline series for this Ibu new lava product. If we compare this result to the ash composition obtained at the beginning of Ibu's resumption of activity in 1998 (Table 1; Solihin, 1999), the compositions are

comparable (Fig. 6). However, these results contrast with the 1911 ash composition (Solihin, 1999) where the SiO₂ content was significantly lower at 54% (Table 1), and total alkalis versus SiO₂ indicates a basaltic andesite composition in accordance with hyperstene-augite-andesite material observed by Van Het (1964) on Ibu.

4.3. SO₂ emission

In over 2 h of continuous recordings on November 9, 2012, the ultraviolet camera detected 4 vigorous releases with plumes rising

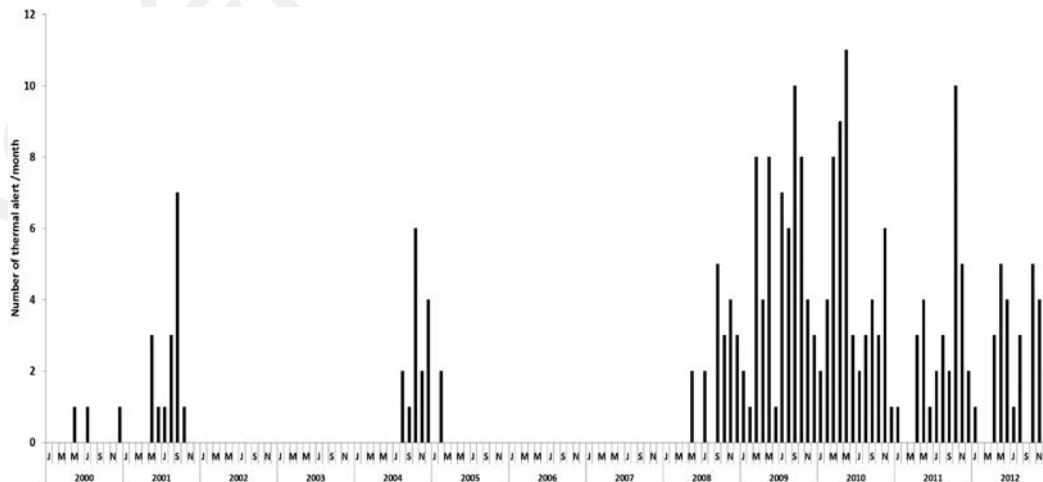


Fig. 3. Occurrence of thermal alert between 2000 and 2012. The high number of thermal alerts in 2001 and 2004 is likely related to a more intense eruptive activity while from 2008 the thermal heat is likely released by the combination of dome growth and eruptive activity.

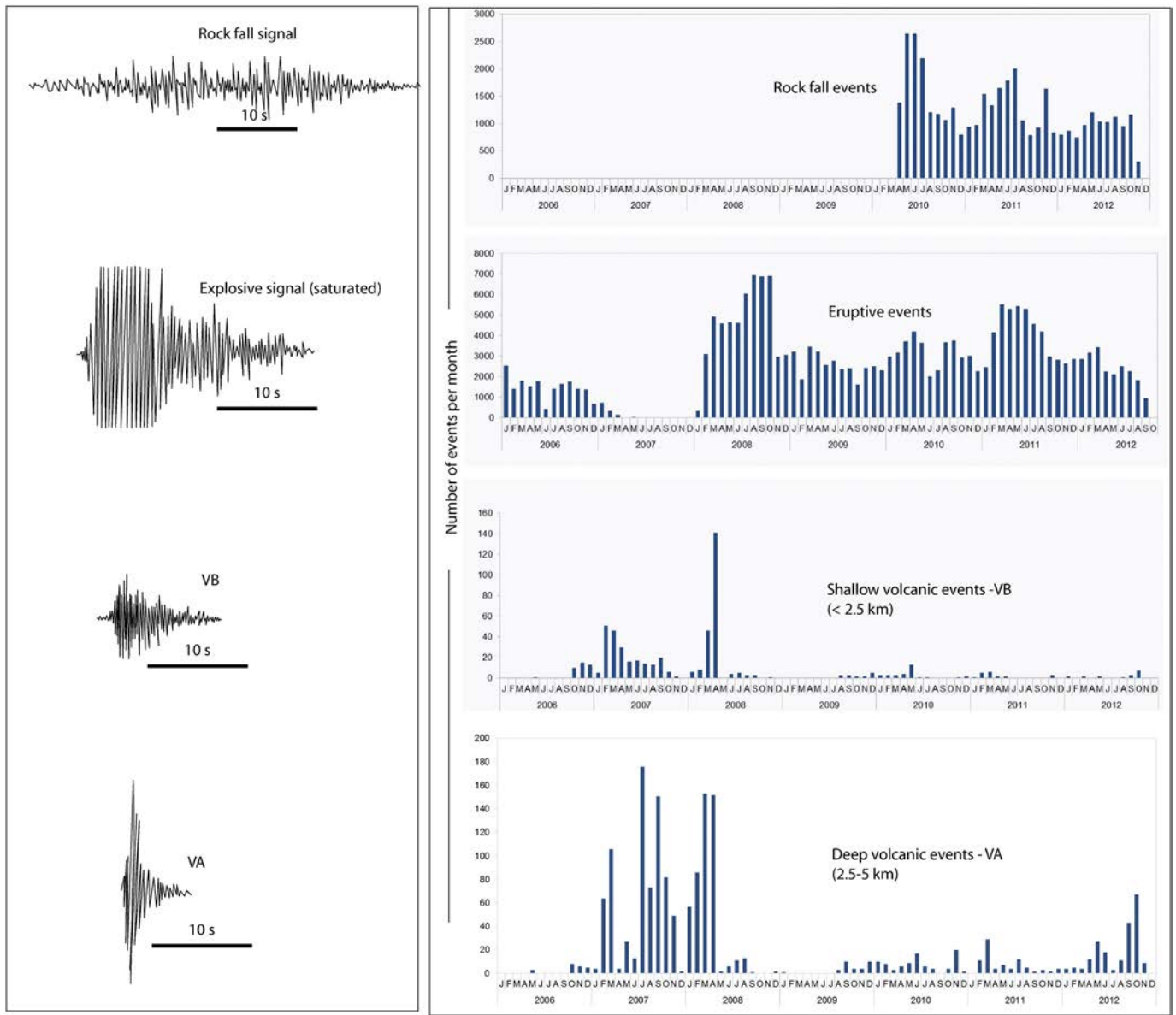


Fig. 4. Seismic recordings over the period of 2006–2012. Explosive events are highly represented throughout the recording period, except on the second portion of 2007 where the VA and VB signals are particularly present. Rock-fall signals started to occur in April 2010 probably when the dome reached Ibu truncated rim as highlighted in Fig. 2. Examples of recorded signals are provided.

up to 400 m above the crater rim and 3 minor discharges that reached only 150 m above the rim (Fig. 7). The SO₂ mass per discharge, calculated following the approach outlined by Mori and Burton (2009), was ~25 kg for each strong discharge and ~4 kg for minor releases (Fig. 8). It is likely that these values could overestimate the real amount of SO₂ as the

single 310 nm bandpass filter cannot distinguish contamination induced by aerosols. The error estimate for imperfect correction of scattering/absorption effects is 10% (Kern et al., 2010). Further, our reference images were taken between explosions and thereby totally ignored background passive degassing.

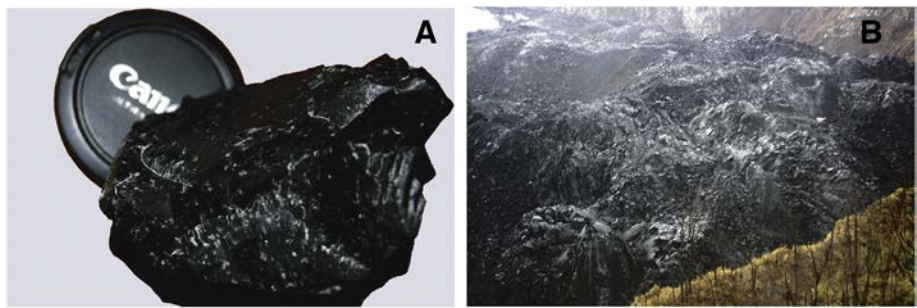


Fig. 5. Ibu lava sample with near-absence of mineral crystal (A). Ibu dacite lava dome (B).

Table 1
Lava and ash composition change between 1911 and 1999/2012, Ibu volcano.

Oxides	Ash eruption 2011 ^a	Ash eruption 1999 ^a	Lava 2012 ^b
SiO ₂ (wt.%)	53.69	67.53	66.94
Al ₂ O ₃ (wt.%)	18.51	14.47	14.57
Fe ₂ O ₃ (wt.%)	8.77	5.00	5.36
CaO (wt.%)	5.82	3.13	3.42
MgO (wt.%)	2.73	1.04	0.78
Na ₂ O (wt.%)	2.73	4.20	4.23
K ₂ O (wt.%)	1.71	3.31	3.46
TiO ₂ (wt.%)	0.88	0.65	0.77
MnO (wt.%)	0.16	0.14	0.17
P ₂ O ₅ (wt.%)	0.34	0.21	0.21

^a Analyses results from Solihin, 1999.

^b This study.

5. Discussion

5.1. Magma injections and Ibu eruptive activity

Since resuming activity in December 1998, Ibu volcano has continued to be strongly active 14 years later, in 2012 (GVP:01/1999-BGVN 24:01; GVP:02/1999-BGVN 24:02; Kristianto, 2006; Sukyar, 2011; this work). Recurrent explosive discharges and the subsequent dacite dome

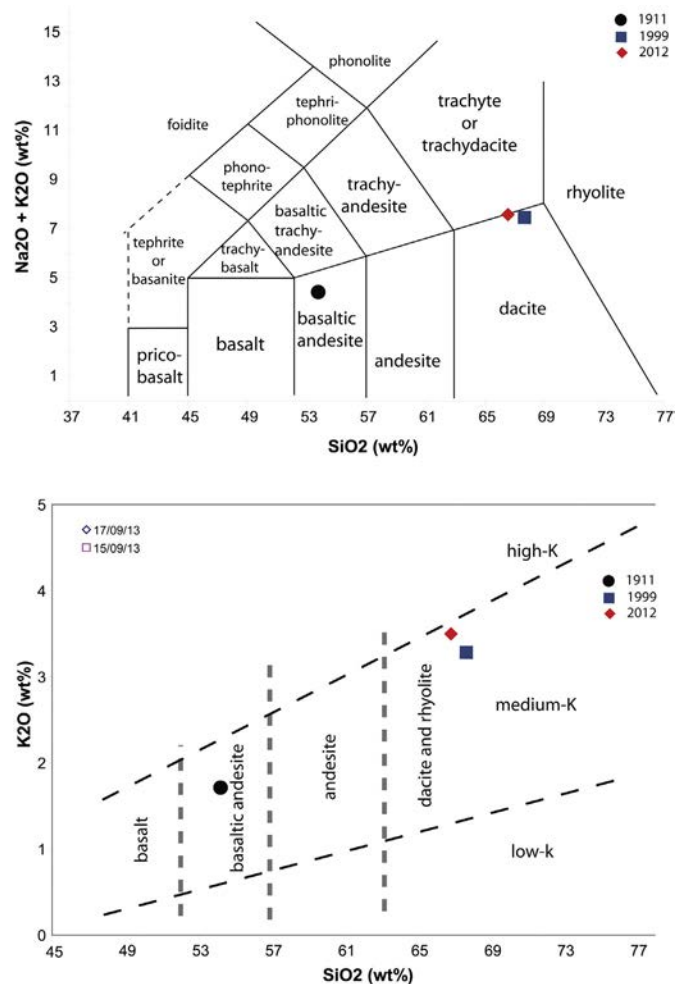


Fig. 6. Total alkalis and K₂O versus SiO₂ diagrams. The 1911 ash derives from a basaltic-andesite source. The 1999 ash composition and the 2012 lava composition are alike and derived from a dacite source.

growth are the main surface manifestations observed over this long active period. Commonly, extrusion of dacite lava is the last event in an explosive cycle. They are generally so thick that the term lava dome is often preferable to lava flow and they typically have high crystal contents (Francis and Oppenheimer, 2004). These characteristics contrast with the Ibu lava sample, for, with 67% SiO₂ (Table 1) it contains no phenocrysts. The very low crystal content suggests that the high viscous dacitic magma, with 67 wt.% of SiO₂, was rapidly quenched, allowing no chance for crystals to develop. The quasi continuous occurrence of VA and VB events (Fig. 4) over the studied period indicates that Ibu surface activity is sustained by regular supply of magma from the reservoir to the surface. In 2007 and early 2008, while the surface activity was relatively calm (Fig. 4), the seismograph recorded the strongest occurrence of VA and VB events suggesting injections of new magma leading to the strong eruptive manifestations observed in 2008 (Fig. 4).

The magmatic source highlighted in this work (Table 1; Fig. 6) evidences a change in the melt composition since the 1911 eruption, from a basalt-andesite magma (Van Het, 1964; Solihin, 1999) to a dacite source (this work). Ibu actual activity is fed by a differentiated dacite melt formed by one or more of the numerous dacite genesis outlined by Wanless et al. (2010), including crystal fractionation, partial melting of overlying crust, and/or assimilation of crustal material into an evolving magma chamber. Further works are required to specifically address this question, which is beyond the scope of this paper. However it is likely that the injections of magma (Fig. 4) into a more differentiated magmatic source (Singer et al., 2013) constitute one of the triggered factors of Ibu eruptive activity.

5.2. Dacite dome extrusion rate

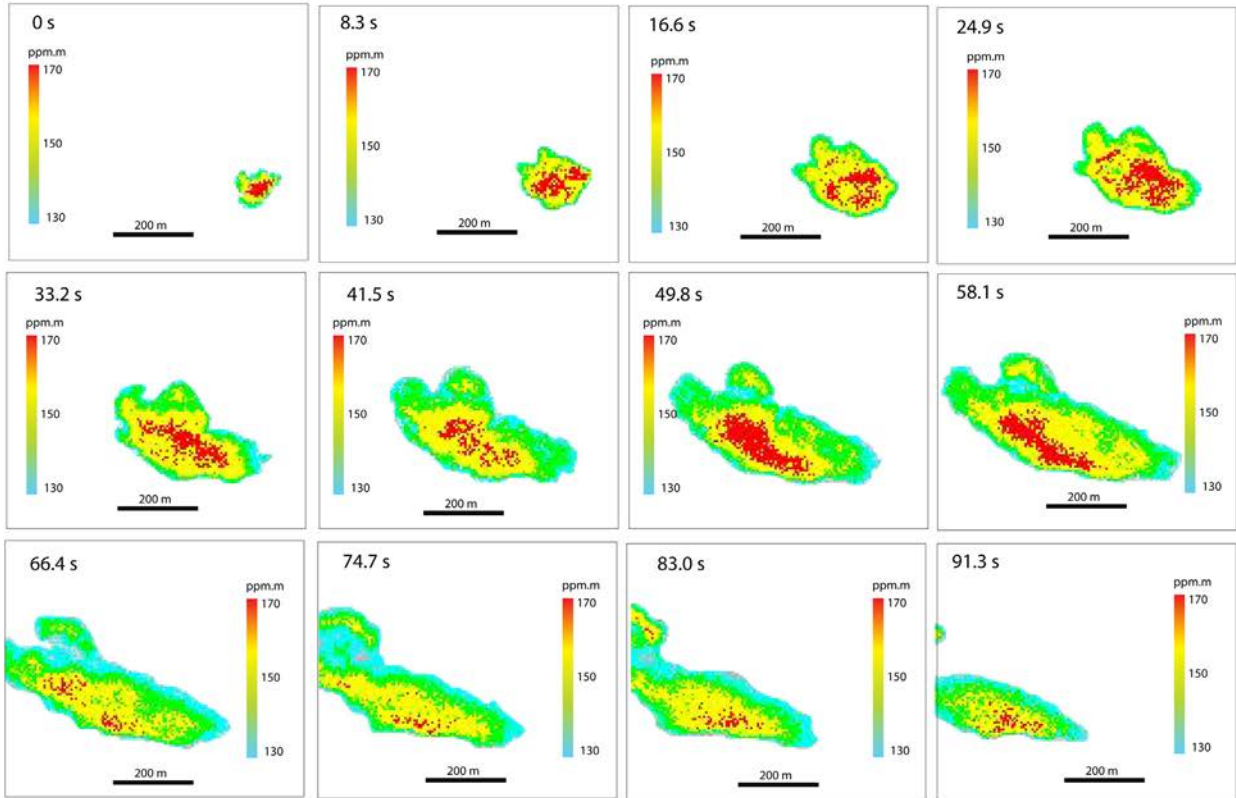
Prior to the actual eruptive activity, the bottom of Ibu nested craters was 980 m above sea level (Fig. 1), with a surface of 1.2×10^5 m², periodically occupied by 3 small lakes (Van Het, 1964). The elevation of the inner crater rim is 1200 m with a diameter of ~800 m. Thus the empty space in the crater was ~0.08 km³ that it is now filled by the Ibu dacite dome.

Ibu crater is truncated to the north with a crater rim of only 1050 m (a.s.l.) on that portion. During our field survey in November 2012, rock-falls were clearly observed exiting this lower crater rim. Assuming that the rockfall signals started to occur (Fig. 4) when the lava dome reached the 1050 meter rim of the truncated zone and taking into account that the dome started to form with the resuming eruptive activity, then the mean extrusion rate of the lava dome was 3182 m³ per day, much lower than the 13,800 m³/d of the dacite dome of Mount St. Helens (Anderson et al., 1995) or the lower extrusion rate (5000 m³/d) of Montserrat in 1996 (Young et al., 1997). Note, however, that there was no regular observation of the dome evolution, thus intermittent dome growth (Taisne and Jaupart, 2008) on Ibu seems likely, in which case the extrusion rate may be higher over shorter time scale.

5.3. Significant source of SO₂ into the atmosphere

Although further work is still necessary to better constraint the degassing of Ibu volcano, it appears clearly here that Ibu is a non negligible source of SO₂ into the atmosphere but poorly constrained. Assuming that the results obtained in this work are representative (Figs. 7, 8) then Ibu releases up to 1.3 t/d of SO₂ through explosions. If this figure is applied to the 2006–2012 explosive events then Ibu is likely to have injected 0.3 Tg of SO₂ into the atmosphere through explosions over the period of 2006–2012. The figure may increase to 0.7 Tg of SO₂ discharge if considering the whole eruptive period (1999–2012). Passive degassing, between explosions, at Ibu volcano was not estimated in this work, due to access difficulties. However up to 80–90% of SO₂ release is estimated to be from passive degassing from other volcanoes (e.g., at Stromboli (Allard et al., 1994; Mori and Burton, 2009) and at Vanuatu volcanoes

Ibu typical strong discharge



Ibu typical minor discharge

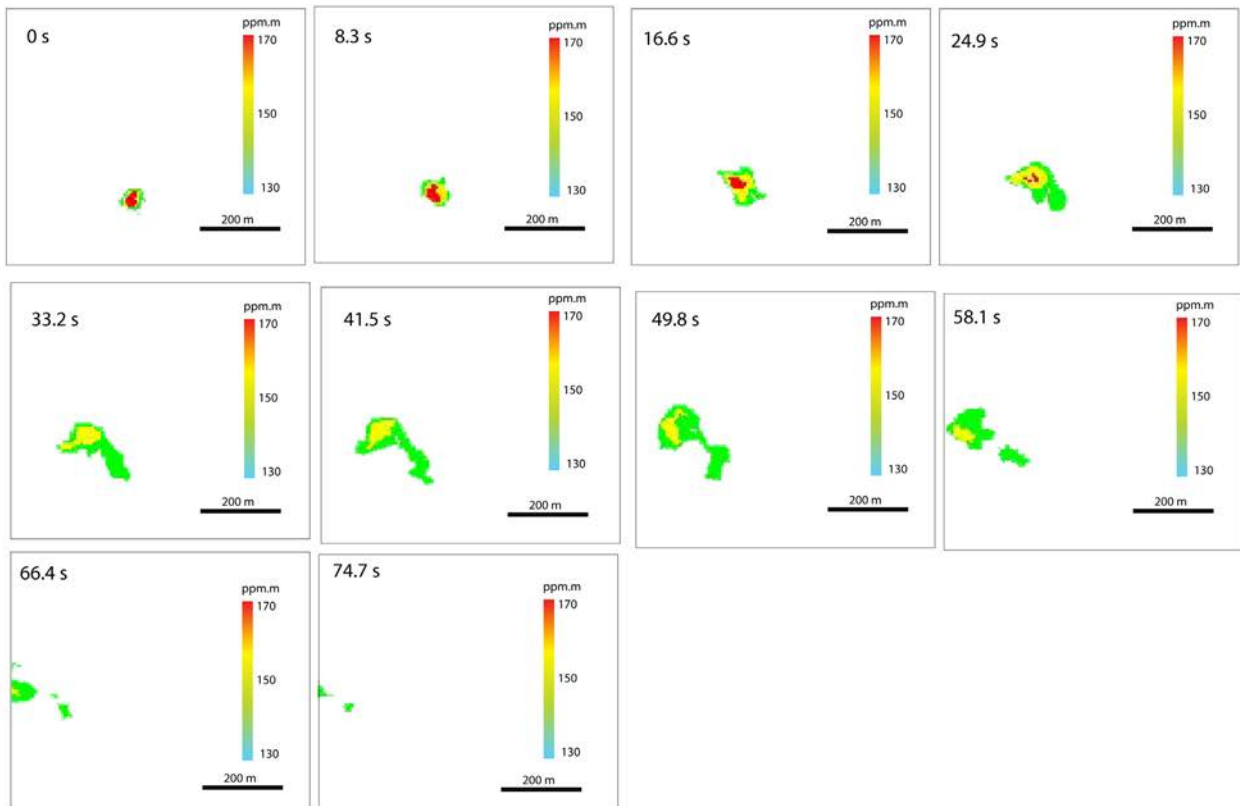


Fig. 7. Typical SO₂ release into the atmosphere from strong and minor discharges of Ibu volcano. The figure shows a sequence of a single plume release – from onset until it starts to drift away from the camera field of view. Strong discharges occurred from active vent 3 while the minor discharges occurred from vent 2 (see text).

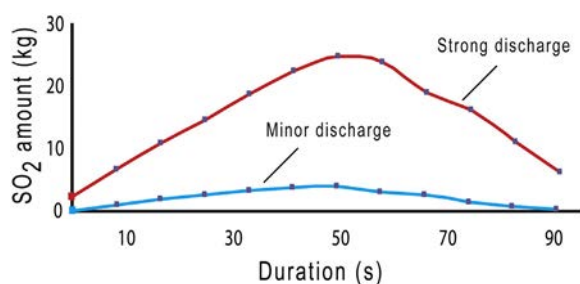


Fig. 8. Typical SO₂ mass discharge observed on Ibu and corresponding to strong and minor discharge. The duration of discharge is usually around 50 s.

(Bani et al., 2012)). Thus the figures presented above should be considered minimum as the total SO₂ contribution (passive and eruptive) from Ibu volcano into the atmosphere is likely to be much higher.

6. Conclusions

Located in Maluku Province, East Indonesia, Ibu is one of the most isolated and least accessible volcanoes in Indonesia. In December 1998, after nearly a century of dormancy period, this little known volcano entered a new phase of volcanic activity, that still continues in 2014 (GVP:11/2013-BGVN 38:11) with recurrent eruptive discharges (60–100 eruptions/day) and a lava dome growth at a rate of 3182 m³ per day. More than 0.7 Tg of SO₂ has been injected into the atmosphere through eruption discharges since resumed activity. This long-term eruptive activity on Ibu is sustained by intermittent supply of new magma into a differentiated reservoir, as suggested by seismic recordings and lava composition.

Ibu long term eruptive activity is not exceptional as many examples exist (i.e., Pacaya and Santa Maria in Guatemala, Arenal in Costa Rica, Sangay in Ecuador, Manam, Langila and Bagana in Papua New Guinea and also Semeru and Dukono in Indonesia (Simkin and Siebert, 1994)). However, because of this decadal dome growth and associated explosive episodes, Ibu activity requires further attention and warrants monitoring as it is a hazard and risk concern to the population.

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References

- Allard, P., Carbonelle, J., Metrich, N., Loyer, H., Zettwoog, P., 1994. Sulphur output and magma degassing budget of Stromboli volcano. *Nature* 468, 326–330. <http://dx.doi.org/10.1144/SP385.2>.in: Gómez-Tuena, A., Straub, S.M., Zellmer, G.F. (eds) *Orogenic Andesites and Crustal Growth*. Geological Society, London, Special Publications, 385, <http://dx.doi.org/10.1144/SP385.2>.
- Anderson, S.W., Fink, J.H., Rose, W.I., 1995. Mount St. Helens and Santiaguito lava domes: the effect of short-term eruption rate on surface texture and degassing processes. *J. Volcanol. Geotherm. Res.* 69, 105–116.
- Bani, P., Oppenheimer, C., Allard, P., Shinohara, H., Tsanev, V., Lardy, M., Garaebiti, E., 2012. First SO₂ emission budget for the Vanuatu island arc. *J. Volcanol. Geotherm. Res.* 211–212, 36–46.
- Francis, P., Oppenheimer, C., 2004. *Volcanoes*, 2nd edition. Oxford University Press (521 pp.). Global Volcanism Program, Ibu, 01/1999 (BGVN 24:01), First eruption since 1911 is being monitored.
- Global Volcanism Program, Ibu, 02/1999 (BGVN 24:02), Eruptions that began on 18 December 1998 continued in January 1999.
- Global Volcanism Program, Ibu, 11/2013 (BGVN 38:11), Growing lava dome; numerous thermal alerts September 2011–March 2014.
- Kantzas, E.P., McGonigle, A.J.S., Tamburello, Giancarlo, Aiuppa, A., Bryant, R.G., 2010. Protocols for UV camera volcanic SO₂ measurements. *J. Volcanol. Geotherm. Res.* 194, 55–60.
- Kern, C., Kick, F., Lubcke, P., Vogel, L., Wohrbach, M., Platt, U., 2010. Theoretical description of functionality, applications, and limitations of SO₂ cameras for the remote sensing of volcanic plumes. *Atmos. Meas. Tech.* 3, 733–749. <http://dx.doi.org/10.5194/atm-3-733-2010>.
- Kristianto, 2006. Laporan Peringatan dini Bahaya Gunungapi Ibu, Maluku Utara. , p. 47.
- Mori, T., Burton, M., 2006. The SO₂ camera: a simple, fast and cheap method for groundbased imaging of SO₂ in volcanic plumes. *Geophys. Res. Lett.* 33, L24804. <http://dx.doi.org/10.1029/2006GL027916>.
- Mori, T., Burton, M., 2009. Quantification of the gas mass emitted during single explosions on Stromboli with the SO₂ imaging camera. *J. Volcanol. Geotherm. Res.* 188, 395–400.
- Simkin, T., Siebert, L., 1994. *Volcanoes of the World*. Geoscience Press, Tucson, Arizona (349 pp.).
- Singer, B.S., Jicha, B.R., Fournelle, J.H., Beard, B.L., Johnson, C.M., Smith, K.E., Greene, S.E., Kita, N.T., Valley, J.W., Spicuzza, M.J., Rogers, N.M., 2013. Lying in Wait: Deep and Shallow Evolution of Dacite Beneath Volcan de Santa, Maria, Guatemala. *Geological Society, London, Special.* <http://dx.doi.org/10.1144/SP385.2>.
- Solihin, A., 1999. Laporan pengamatan kegiatan letusan G. Ibu 1998–1999. DI P. Halmahera, Maluku utara, p. 24.
- Sukyar, R., 2011. Data dasar gunung api Indonesia, edisi kedua. Kementerian energi dan sumber daya mineral, Badan Geologi, p. 450.
- Taisne, B., Jaupart, C., 2008. Magma degassing and intermittent lava dome growth. *Geophys. Res. Lett.* 35, L20310. <http://dx.doi.org/10.1029/2008GL035432>.
- Van Het, T., 1964. Some Volcanoes of Halmahera and Their Geomorphological Setting. koninklijk nederlandsch aardrijkskundig genootschap deel LXXXI No. 3.
- Wanless, V.D., Perfit, M.R., Ridley, W.I., Klein, E., 2010. Dacite petrogenesis on mid-ocean ridges: evidence for oceanic crustal melting and assimilation. *J. Petrol.* 15, 2377–2410. <http://dx.doi.org/10.1093/petrology/egq056>.
- Young, S.R., Barclay, J., Miller, A.D., Sparks, R.S.J., Stewart, R.C., Davies, M.A., MVO staff, 1997. Deformation of the Galway's wall and related volcanic activity, November 1996 to March 1997. Special Report, 2. Montserrat Volcano Observatory (<http://www.geo.mtu.edu/volcanoes/west.indies/soufriere/govt/specprep/specprep02.html>).