Characteristic of the Mount Colo Volcano, Una-Una Island, Central Sulawesi Province: Tectonic Evolution and Disaster Mitigation

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Abstract. The Una-Una Island is in the Gulf of Tomini, Central Sulawesi Province. This island is a soliter active volcano island with Mount Colo as volcano name. The island is located between the North Arm and East Arm of Sulawesi, which are having complex tectonic regime, situated between two subduction zones. Volcanic rocks from Una-Una Island are basaltic-trachyandesite until trachydasite composition with magma affinity is calc-alkaline, high-K calc-alkaline and shoshonite. Tectonic reconstruction in this area started at Miocene (15 Ma) where the Celebes Sea Plate subducted below the North Arm of Sulawesi with a gentle slope produced adakite-type volcanic rocks. Along with the continuous subduction process and increasingly steep angle of subduction, the magma source then underwent. Intensive movement of the Banggai-Sula microcontinent, resulted in obduction of the ophiolite during collision, whereas volcanic activity in Una-Una Island and surrounding islands are still ongoing. Recent eruption of the Mount Colo in 1983 produced abundant of pyroclastic material with acid silica and still adakite type composition with mineralogical assemblages consist of hornblende-phlogopite-biotite, gives the impression that it originated from the same magma sources. According to composition of magma and eruption history which were produced magmatic explosion followed by pyroclastic surge, flow and fall, the disaster mitigation focus to eruption forecasting through visual and instrumental monitoring provide by Centre for Volcanology and Geological Hazard Mitigation, Geological Agency, Ministry of Energy and Mineral Resources Republic of Indonesia.

Keywords: Colo; Una-Una; Volcano; Adakite; Mitigation.

1. Introduction

Una-Una Island is a soliter volcano island with Mount Colo as volcano name. This island located at gulf of Tomini, Central Sulawesi Province, lies between the North and South Arm of Sulawesi. Quaternary volcanism especially in Una-Una Island has been subject to controversy with many interpretation of tectonic setting from some authors i.e.: the volcano related to the southeastward dipping dormant subduction zone of the Celebes Sea [1]; part of the extinct volcano located in Togean islands, which were shifted to the northward [2]; due to East Sangihe Subduction zone, resulting quaternary volcanic
belt in the eastern part of the north arm and continuing to the southwest [3]; and subduction with shallow subduction angle of Celebes Sea plate beneath the North Arm of Sulawesi [4, 5].

Colo volcano separated from the Indonesia’s volcanic belt that stretches from the north end of Sumatera - Java - Nusa Tenggara - Maluku to the North Sulawesi as show in Figure 1 [6]. This area is a complex transition where three plates (Celebes sea plate, Molluca sea plate and micro continent Banggai Sula) subducted and obducted during Miocene until Quaternary period. The volcanic arc is built as the result of double subductions, i.e. the North Sulawesi Subduction Zone in the north arm of Sulawesi, and the East Sangihe Subduction Zone in the East- & South of the north arm (Figure 2). Those subductions gave result in a magmatic- and volcanic- activities producing widely spread of the plutonic- and volcanic- rocks. The North Sulawesi subduction zone is thought to have been active since the Early Tertiary, generating a Tertiary volcanic arc stretching from around Toli-toli to near Manado. Age dating of calk alkaline rocks associated with subduction from the north took place 2.35 Ma-Pliocene age [7].

Figure 1. Volcanic arc of Indonesia [6].

Figure 2. Major structures of Sulawesi Island [9,10].
2. Data and Method

Samples of volcanic rocks were collected from the Togean Islands during doctoral dissertation project in 2008-2013. Sendjaja [5] examines that the Togean Islands could be divided into three distinguish area base on geochemical data and age dating of volcanic rocks, that are the Una-Una (UN) for the Tertiary to Quarternary adakites volcanic rocks; Togean (TG) Tertiary adakites volcanic rocks and Walea (WL) for Tertiary suprasubduction zone (SSZ) ophiolites (Figure 3). All geochemical and petrographic data describes in [5] for detail.

![Figure 3. Geological map of the Togean Islands and radiometric dating of volcanic rocks (Modification from [5, 8, 11]).](image)

Focus on volcanic rock from Colo Mountains, the colors of the rocks are variations in grey or very light grey. Pyroclastic bombs are dominated by plagioclase, k-feldspar, hornblende, and biotite with glassy matrix. Similar in composition to the lavas, they are having the porphyritic texture and dominated by plagioclase, k-feldspar, hornblende, biotite and mica as phenocryst with groundmass consist of glass and microlites plagioclase. Very characteristic of the rocks is the developed zonal structure of plagioclase and simple twinning of the K-feldspar sanidine. Compare to Tertiary samples from TG and WL determine as lava dome with trachytic texture and pillow lava as a part of Suprasubduction zone ophiolite.

Representative whole rock geochemical data of the Quarternary Una-Una Volcanic rocks (UN) characterized by moderate-high SiO$_2$ (56.79 wt% - 64.33 wt%) contents, low MgO (1.70 wt% - 2.74 wt%) and high Na$_2$O (4.50 wt% - 5.44 wt%) and low TiO$_2$ (0.30 wt% - 0.54 wt%), plot in the fields of trachyandesite (latite) and trachydacite on a K$_2$O.Na$_2$O vs SiO$_2$ diagram. All the lava and pyroclastic from Una-Una Area have high SiO$_2$ content (> 56 wt%) and classified as calk alkaline series. Una-Una volcano and Tertiary Togean lava dome are adakites and proposed to subduction with shallowing subduction angle of Celebes Sea plate beneath the North Arm of Sulawesi [4, 5].

Tectonic reconstruction used modified tectonic model by [12, 13, 14] (Figure 4) which is suitable for the explanation the complex tectonic regime of Sulawesi Island. In this paper, we proposed the tectonic reconstruction from 20 Ma where the Una-Una already exist base on radiometric dating from the lava.
3. Result and Discussion

According to petrographic, geochemical, age dating and tectonic model from previous authors for this area, we proposed the model of tectonic reconstruction and disaster mitigation from especially Una-Una Volcano. Based on the age and tectonic model modified from [13, 15] (Figure 4), the evolution begins at 20-5 Ma, where the subduction of the Celebes Sea produces adakite in Una-Una Islands. On the other hand, the Eastern segment (E) showing subduction under ESO produced Neogene volcaniclastic Rocks (NVC), in the East Arm of Sulawesi (Figure 5).

Figure 4. Tectonic configuration of Sulawesi Island at Recent time with the surrounding tectonic component (CS = Celebes Sea Plate, MS = Molucca Sea Plate, PS = Pacific Plate, BS = Banggai Sula Microcontinent, ESO = East Sulawesi Ophiolite; NSA = North Sulawesi Arm and TGN = Togean Islands; thrust, subduction, continent plate, oceanic plate, metamorphic, blue line representing border of island at Recent time (Modified from [12, 13, 14]).

Figure 5. Tectonic Miocene-Pliocene tectonic configuration (20-5 Ma). Cross section (A-A'-A '') for the reconstruction in Figure 6. Cross section (B-B'-B '') for reconstruction in Figure 7. Abbreviations and legends refer to Figure 4. (20-5 Ma tectonic models, modified from [13, 15]).
Northern section (N) is showing subduction segment that produced adakite at UN, while the eastern segment (E) indicated SSZ ophiolite related to subduction and possibility of slab rollback in the East Arm of Sulawesi (Figure 6). The tectonic evolution continues, and the important age dating were 5 Ma for SSZ and 2 Ma for TG adakite (Figure 7). North Segment (N) section presenting adakite in UN and TG with the changes of subduction angle become steeper, whereas in the southern segment (S) described collision of Banggai Sula microcontinent in the East Arm of Sulawesi (Figure 8).

Along with the continuous subduction process and increasingly steep angle of subduction, the magma source then underwent; a process of mixing in the mantle wedge and differentiation in the magma chamber produced more acid rock composition, but still gives the impression that it originated from the same magma source. Due to acid magma which have higher viscosity, explosive eruption was destroyed almost 2/3 of the island in 1983 with pyroclastic rocks as a dominant product, and still adakite magma type composition with mineralogical assemblages consist of hornblende-phlogopite-biotite. However, lava flows only exposed on the summit area and partly in the flank. After this eruption, Colo Volcano in Una-Una Islands monitored continuously. Volcano monitoring techniques and instruments were applied such as making hazard zonation maps, designed and implemented the warning system (Figure 11). At least two strategies have been articulated and adopted in this island (1) relocation of settlements from the hazard zones to another islands; and (2) installation of monitoring through visual and instrumental provide by Centre for Volcanology and Geological Hazard Mitigation, Geological Agency, Ministry of Energy and Mineral Resources Republic of Indonesia.

**Figure 8.** Pliocene-Recent (5 Ma – Recent) tectonic configuration. Cross section (C-C’-C”) for the reconstruction in Figure 9. Cross section (D-D’-D”) for reconstruction in Figure 10. Abbreviations and legends refer to Figure 4. (5 Ma-Recent tectonic models, modified from [13, 15]).

**Figure 9.** Cross section of the C-C’ line.

**Figure 10.** Cross section of the D-D’ line.
4. Conclusion

There are some conclusions could be accepted related to tectonic setting and evolution in this area:

1. Volcanic activities in the Togean Islands occurred since Miocene until Recent with many volcanic rocks found in the Una-Unia (UN), Togean (TG) and Walea (WL) region, assumed to be the result of continuous volcanism.

2. In the Miocene-Pliocene period (20-5 Ma), volcanic activities occurred in Una-Unia (UN) and Togean (TG) region. Volcanic rocks of the UN (15Ma) represents the product of the subduction of Celebes Sea Plate beneath North Arm of Sulawesi with gentle slope. Whereas the volcanic rocks of WL reflect subduction activity in the south-eastern part of the Togean Islands. The set is interpreted as part of suprasubduction ophiolite (SSZ).

3. Intensive movement of the Banggai-Sula microcontinent to the west at this time, resulted in obduction of the ophiolite during collision, ESO emerging to the surface in the East Arm of Sulawesi and SSZ ophiolite in Togean Island; whereas in the UN and TG, volcanic activity is still ongoing.

4. Continuously monitoring by government is still on going and reported periodically provide by Centre for Volcanology and Geological Hazard Mitigation, Geological Agency, Ministry of Energy and Mineral Resources Republic of Indonesia.

References

[1] Katili J A 1975 Volcanism and plate tectonics in the Indonesian island arcs Tectonophysics 26 pp 165-188.
[2] Katili J A and Sudradjat A 1984 The devastating 1983 eruption of Colo volcano Una Una Island Central Sulawesi Indonesia Geologisches Jahrbuch A75 pp 27-47.
[3] Effendi A C and Bawono S S 1997 Geological map of the Menado sheet North Sulawesi scale 1:250.000 Geological Research and Development Centre, Bandung.
[4] Sendjaja P and Sucipta E IGB 2008 Adakite rock from Una-Unia Island Central Sulawesi Proc. The 37th Annual Convection and Exhibition IAGI August 2008 Bandung.
[5] Sendjaja P 2013 Petrology and geochemistry of volcanic rocks from the Togean Islands Gulf of Tomini Central Sulawesi Province: Implication for the tectonic setting of Sulawesi Island Doctoral Dissertation Bandung Institute of Technology (ITB).
[6] Katili J A and Sudrajat A 1989 A short note on the birth of a volcano in Flores Island Geology of Indonesia 12 No 1 pp 397-411 Jakarta.
[7] Perello J A 1994 Geology porphyry Cu-Au and epithermal Cu-Au-Ag mineralization of
Tombulilato district North Sulawesi Indonesia J. Geochemical Expl. 50 Elsevier pp 221-256.

[8] Rusmana E, Koswara A and Simanjuntak T O 1993 Geological map of the Luwuk sheet scale 1:250.000 Geological Research and Development Centre Bandung.

[9] Kavalieris I, van Leeuwen T M and Wilson M 1992 Geological setting and styles of mineralization north arm of Sulawesi Indonesia J. SE Asian Earth Sci. 7 (2/3) pp 113-129.

[10] Hall R and Wilson M E J 2000 Neogene sutures in eastern Indonesia J. Asian Earth Sci. 18 pp 781-808.

[11] Sukamto R 1975 Geologic map of Indonesia Ujung Pandang sheet scale 1:1.000.000 Directorate Geology Geological Survey of Indonesia Ministry of Mine.

[12] Sukamto R, Ratman N and Simanjuntak T O 1996 Geological map of Indonesia scale 1:5.000.000 Geological Research and Development Centre Bandung.

[13] Hinschberger F, Malod J A, Réhault J P, Villeneuve M, Jean-Yves Royer J-Y and Burhanuddin 2005 Late Cenozoic geodynamic evolution of eastern Indonesia Tectonophysics 404 pp 91-118.

[14] Pubellier M C Rangin X and Le Pichon 2005 DOTSEA – Deep Offshore Tectonics of South East Asia: A synthesis of deep marine data in SouthEast Asia Mémoire de la Société géologique de France & American Association of Petroleum Geologists No 176.

[15] Elburg M and Foden J 1998 Temporal change in arc magma geochemistry Northern Sulawesi Indonesia Earth and Planetary Science Letter 163 pp 381-398.

[16] Chaniago R., Hadisantono, R D, Nasution A, Marono A, Purwoto and Santoso M S 2004. Volcanic hazard map of Colo Volcano, Central Sulawesi Province, scale 1:25.000, Directorate of Volcanology and Geological Hazard Mitigation, Bandung.