Geotourism Of Banyuputih Catchment Area, Mount Ijen, East Java, Indonesia

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Abstract. Mt. Ijen, especially along the Banyupait/Banyuputih Catchment Area is located within part of 3 regencies in East Java Province which are Bondowoso, Situbondo, and Banyuwangi regencies. Geological Study at Mt. Ijen Complex was conducted to get better understand concerning Characteristics of Geology and geomorphology of Ijen Volcano Complex which compose of highly attractive places to be geotourism purposes. According to the geological study, Ijen Geotourism can be divided into three parts. Firstly, natural views inventory within the Ijen Caldera, along the Banyupait/Banyuputih Catchment Area which are closely related with geological processes; secondly, Man-made geotourism site at Banyuputih River on the north flank of Ijen Volcano; and thirdly, Planned Buildings that can be made in the future such as a small museum and geosites in open field including infrastructures that consist of media-tools explaining about the Ijen Volcano and a lot of geological processes related with the all natural views at around Ijen Volcano. On the other hand, the water of the Ijen crater-lake is extremely acid (pH<1). The water of the crater-lake infiltrates into the only one river called Banyupait / Banyuputih River flowing towards the north to reach the north-coast of Java at Asembagus Sub-district, where the pH at this area is still 3-4 after mixing between the acid water and normal water coming from springs within the Banyupait / Banyuputih Catchment Area. A recommended segregation of normal water from the acid water is the best alternative to produce normal water along the Banyuputih River which flows through Asembagus Village. This effort will change the Asembagus citizen to be having much better welfare. This effort will also support the Ijen Complex to be a good Geotourism, even to lift up the Mt. Ijen Complex to be an International Geopark.

1. Introduction
Mount Ijen is one of active volcanoes located in East Java, Indonesia. The summit area is a caldera where administratively belongs to three regencies, so called, Banyuwangi (east part), Bondowoso (west part), and Situbondo (north part) Regencies. The Banyupait / Banyuputih Catchment Area (270 km²) covers the summit area expanded towards the north along Banyupait/Banyuputih rivers for about 45 km reaching the north cost of Java through Asembagus District (Figure 1).

Banyuputih Catchment area is geomorphological covers a caldera so called Ijen Caldera with the dimension of 6 to 7 km in diameters and along Banyupai and Banyuputih River area. 17 small volcanoes within the caldera and 5 small volcanoes out of the caldera were produced after the caldera forming [1][2]. The most active volcano recently is Young Ijen caldera with the dimension of the crater of 600 to 700 m in diameters consisting of 30 million m³ of water in the crater lake [3].
The Old giant volcano so called Ijen Volcano is a great volcano erupted many times producing lavas, pyroclastics rocks and also lahar breccias [4]. The volcano has ever erupted catrostrophically producing a caldera so called Ijen Caldera. The Young Ijen volcano as the most active volcano produced lavas and pyroclastics rocks at adjacent the volcano [4,5] (, and according to [3], a lot of volcanic gas especially sulphured gas was emitted through crater floor and around the crater causing the crater lake water relatively very acid (pH = 0.5 – 1).

Several hills and craters at Old Ijen summit area show places which have morphologically very attractive landscapes to see and a lot of geologically explanations can be made on them, such as the landscapes of the small volcanoes in the caldera and small volcanoes out of the caldera including waterfalls and caldera walls (Figure 2). Therefore, Mt Ijen complex consists of several high level in Geologic based Tourism potential.

On the other side, the acid water has been infiltrating through the only one river Banyupait / Banyuputih starting from its upstream closed to the Ijen Crater lake until its down stream at the north flank of The Old Ijen Volcano. The environment of the places where are passed by the acid water are worse especially for their human life at its downstream. Consequences tourist places can be disturbed by nature. One of the conditions to create a geotourism area or even Geodiversity that must be save from any natural dangerous.

These backgrounds above inspires ideas to develop the great lands, and objects to protect people from the dangerous acid water even try to find out how to separate the acid water from the neutral water so that the neutral water can be utilized by people at around Mt Ijen complex especially along the Banyuputih catchment area. These positive and negative objects which contain a lot of geological explanation can be made inspires us to conduct the research to create a great Geotourism at Mt Ijen complex especially along the Banyuputih Catchment area. Hopefully, this idea will able to lift up a higher level of geotourism such as to be a Geoheritage even to be Geopark of Mt. Ijen in the future.

2. Data and Method

A mechanism of study has been done in this geological research. They consist of: Inventory of supremacy and unique geotourism objects of Mt. Ijen complex especialy at along the Banyupait / Banyuputih Catchment area. This was continued by Proposing a tracking tour to the summit of the Young Ijen crater and its adjacent to show areas and geosite. Preparing geological explanations popularly were conducted in this research such as: Geological and morphological information about Mt. Ijen complex, Sulphur mining, Blue fire, Natural gypsum forming, and Water falls. Inventory and proposing areas to be human made geotourism destination such as: Complementing Buildings for Geotourism, Rafting tourism, Dam views tourism. Planning of some Educatve geotourism object by building a small volcano museum consists of a lot of explanation of many aspects concerning Mt Ijen.
Trying to find geotourism places for installing some warning especially for tourists at the tourist areas to avoid crisis in dangerous areas including the extremely acid water.

### 3. Result and Discussion

Geological research on Mt Ijen was conducted with the aim of geological data inventory providing for Geotourism purposes. Some excellent Geotourism were found.

#### 3.1. Geological information of Mt Ijen complex.

According to physiography of eastern part of Java island [6], Mt Ijen complex appeared within a wide depression stretching along Central Java as the west part up to East Java as the east part, so called Solo Depression. According to a regional geology (Figure 3), The Ijen volcanic complex was probably appeared starting at the same period as those of the Iyang (Argopuro) volcanic complex which was at the Upper Pleistocene or about 700,000 years ago [6].

According to a local geology of the Mt Ijen complex can be explained as follows. Coral-limestones were found on around the complex, on the east flank (close to Ketapang harbor), north flank, north-west flank, and south-east flank of the Old Ijen volcano. The rocks were covered by volcanick rocks produced by the Old Ijen volcano. This is assumed that the Old Ijen volcano was appeared on the shallow marine environment.

The volcanism of the Old Ijen is assumed starting from 700,000 years ago up to about 294,000 years ago. This volcanic phase produced lava flows and pyroclastic deposits with basaltic to dacitic in composition [4,5]. The volcanism persisted for a long time (during about 400,000 years). This period at Mt. Ijen complex is called Pre-caldera of Ijen.

After volcanism at Ijen went on for about 400,000 years, a great scale Plinian eruption through the old Ijen summit area as the volcanic vent occurred along a short time (days), but unfortunately the exact time has not been obtained, how ever, it was between 294,000 and 50,000 years ago producing a giant caldera of 14 to 16 km in diameters, so called Ijen caldera [4,5] reconstructed the elevation of the Old Mt Ijen summit was about 4000 meter above sea level. The products of the great eruption were pyroclastic flow deposits (ignimbrite) and pyroclastic fall deposits. The out crop are found at almost all direction of the flank such as about 50 m thick in the bottom of the caldera, and about 15 m thick at Liwung village, Assembagus District, north flank of the Old Ijen volcano. [4] judged, that the Ijen caldera was formed by the catastrophic eruptions followed by subsidence of the summit area.

During the Post caldera forming, volcanism processes were continued since the last about 50,000 years ago by forming 17 small to large young volcanoes within the Ijen caldera, and those (5 volcanoes) beyond the caldera. From the 22 young volcanoes, 12 of them can be classified into...
monogenetic volcanoes and the rest are polygenetic type. The products of young volcanoes especially within the caldera consist of lava flows and pyroclastic deposit and also Lahar deposit. On the other side the volcanism activity was decrease unless process of reworked of los material from steep caldera wall producing lahar deposit. The deposit became consolidate, and consequently water could not infiltrate. Blawan at the north part of the caldera located closed to the north caldera wall is a lowest place within the caldera became a lake socalled Blawan lake. However, erosion and sedimentation went on within and out side of the caldera continuously. This was supported by geological structure especially Blawan fault striking north-south direction and finally the north hard caldera wall especially at Blawan was cut by the fault and consequently the lake became empty and the water flows through Banyuputih River towards the north up to Java Sea at Asembagus district (Figure 4)

![Diagram of Mt. Ijen complex formation history](image)

**Figure 3.** Skets of Mt. Ijen complex formation history geologically.

One of the 17 young vocano within the Ijen caldera is Young Ijen which has crater lake, that’s why the volcano is called “Ijen crater”. This volcano is the youngest (since the last 6000 years ago) and the most active among the 22 post caldera young volcanoes at the Ijen complex. The crater lake water is extremly acid (pH <1 in the crater). The only river which flows the water exit from the lake is Banyupait River flowing towards Blawan and continues to pass the north caldera Ijen at Blawan and afterword the name of the river becommes Banyuputh River. The valley along the Banyupait River / Banyuputh River in this case is called Banyuputh Catchmen Area.

Geomorphology along the Banyuputh Catchmen Area show a lot of fantastic and unique views, which could be interested especially by tourists. Many spots that can be explained geologically to the tourists through proporsional medias in the field etc. This way can be inspiring us to develop Geotourism purposes.

3.2. Geological inventory during Tracking to Ijen Crater summit area and its adjacents.

3.2.1. View of Ijen Crater Lake.

Since the last 6000 years ago, the Young Ijen volcano has been formed and grown as polygenetic volcano producing pyroclastic flow and pyroclastin aircfall deposits. This young volcano is one of the childs of the Old Ijen volcano located within the Ijen Caldera. Eruptions through the Young Ijen volcano produced a crater of 900 m as the longest and 600 m as the shortest diameter. The crater was filled by meteoric water producing a crater lake which is 200m depth and 30 m$^3$ volume[7].

The crater lake water is extremly acid (pH < 1) showing green colour sometimes change from dark to light green and viceverza which depends on sulphur gas content. The colour of rocks at the crater wall are grey and redish brown, and yellow colour of sulphur gas at several points at and around the lake. The colour combination from the toscaic green of the crater lake water, gas of sulphur, volcanic rocks, and white gas plume shows an extremly fantastic view (Figure 5). The high acidity level is close related with a release of H$^+$ ion as seperation of chemical compound occurences [7] caused by ionizations of HCl, H$_2$SO$_4$, and H$_2$CO$_3$. The chemical reactions of them are as follow.
Figure 4. The Young Ijen crater taken from north east of the lake (Source: Garuda Indonesia).

\[
\begin{align*}
\text{CO}_2 + \text{H}_2\text{O} & \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}_3^+
n4 \text{SO}_2 + 4 \text{H}_2\text{O} & \leftrightarrow 3(\text{SO}_4)^{2-} + \text{H}_2\text{S} + 6\text{H}^+
n3 \text{SO}_2 + 2 \text{H}_2\text{O} & \leftrightarrow 2(\text{SO}_4)^{2-} + \text{S}_8 + 4\text{H}^+
\end{align*}
\]

3.2.2. Sulphur Mining.
Volcanic gases content in solfataras at and adjasen of the Ijen crater (Table 1) are very high, consequently the solid sulphur sublimate (S) can be mined (Figure 6). Chemical reaction of the natural solid sulphur sublimates is explained as follows.

\[
\text{SO}_2(\text{gas}) + 2 \text{H}_2\text{O}(\text{gas}) \leftrightarrow 3\text{S(solid)} + 3 \text{H}_2\text{O(}^{\text{gas}}\text{)}
\]

Table 1. Volcanic gases content rises from solfataras at summit area of Ijen Crater (Sumarti, 2016).

| GAS (%) MOL | JULY 1991 | MAY 2006 | AUGUST 2016 |
|------------|-----------|----------|-------------|
| CO₂        | 16.89     | 10.97    | 22.48       |
| SO₂        | 0.15      | 3.08     | 0.39        |
| H₂S        | 0.62      | 1.00     | 4.92        |
| HCl        | 0.76      | 0.70     | 0.09        |
| HF         | 0         | 0.010    | 0.009       |
| H₂O (steam)| 80.77     | 81.82    | 71.89       |
| Temp Solfatara (°C) | 201.00 | 214.00 | 215.32 |

Figure 5. Solphatara and mining of sulphur sublimate at Ijen Crater side (Photo: Geological Agency).

The estimated solid sulphur sublimate potential is 100 ton per day, while the mined sulphur just 15% of the total potential (Sumarti 2016). In early stage, the brownish red hot liquid sulphur sublimate flows in a short distance and they were cooling down to produce the solid sulphur sublimate which was changed in colour to be yellow.

3.2.3. Blue Fire
During the night the solfataras show sulphur gas shine in blue so called Blue fire. The blue fire is signed by occurrence of burned huge of solid sulphur producing SO₂ gas. When it is being burned, the solid sulphur (S₈) was reacted with the air (O₂) producing SO₂ gas and radiating fire of blue in colour. In Ijen crater lake, the blue fire is a reflection of SO₂ gas flowing from summit field of solfatara to a “kitchen” through about 100 pipes network system of condensed sulphur (Figure 7). The chemical reaction of natural blue fire phenomenon can be explained as follows.
2 \text{S8 (solid)} + 8 \text{O}_2 (\text{gas}) \leftrightarrow 8 \text{SO}_2 (\text{gas}).

The Blue fire at Ijen crater lake are interested by 400 to 600 tourists every night by climbing through summit area of Ijen crater for about 1.5 to 2.5 hours walking from car parking at Paltuding, Banyuwangi District. This environment makes the local economic at around Ijen people will be lifted up, and makes Indonesian country be promoted concerning Geotourism in the world. There are only two countries in the world where the known natural Blue fires can be found. They are in Iceland (Europe), and in Indonesia which is at Ijen crater.

3.2.4. Natural Gypsum Forming.

Phenomenon of the Natural Gypsum Forming can be found at around the Ijen crater lake especially at Banyupait River. The gypsum was formed as reaction between limestone and Hydrogene sulphate.

![Figure 6. Natural Fenomenon of Blue fire at the south side of the Young Ijen crater.](image)

The limestone is originated from the Tertiary based rock as the floor of the Old Ijen volcano. Parts of the limestone (CaOH) was lifted up when magma was pushing up during the Old Ijen volcano forming. On the other side the Hydogene sulphate (H2SO4) is originated from sulphur gas of the active volcano which rise up through a lake water of the Young Ijen volcano crater. Reaction between chalk (CaOH) which is originated from the limestone and the Hydrogene sulphate (H2SO4) producing gypsum (CaSO4) with their chemical reaction is as follows.

\[ \text{H}_2\text{SO}_4 + \text{CaOH} \leftrightarrow \text{CaSO}_4 + \text{H}_2\text{O} \]

The natural Gypsum outcrops at the Young Ijen Crater lake areas and along the Banyupait river are only afew as the limestone outcrops are also not so much. They are generally assemble at river bank of the up stream area along the Banyupait River or Valley which is about 2 km from the Young Ijen crater lake. The gypsum outcrops are fantastic (Figure 8). This places can be developed to be a geotourism destination area.

![Figure 7. Natural gypsum forming at Banyupait River close to the Ijen Crater lake (Photos by Geological Agency).](image)

3.2.5. Waterfalls.

Other natural phenomenons within the Ijen Celdera are waterfalls such as Waterfalls of Margahayu, Watucapil, Paltuding, Blawan etc. The Paltuding Waterfall is a step wall waterfall located slose to the Carparking of Paltuding with the height is 30 m. The rock is andesitic lava flow, while the water is
still acid (pH around 1). One thing that have to be paid attention which is a warming to tourists that they are not a loud to touch the river water at this area. Some similar cause and kondition of waterfalls within the Ijen caldera can be found at Margahayu and Watucapil. Both are still close to Paltuding. Another waterfall which is close related with the active fault is Blawan waterfall located at the north wall of the Ijen Caldera, close to Blawan. The active Blawan fault is close related with the Blawan waterfall cutting the north caldera wall and could make the ancient Blawan lake dry.

3.3. Inventory of Man-made Geotourism objects.

3.3.1. Accessories of Geotourism Building.
Buildings which are classified into Accessories of Geotourism objects are Villa, buildings for tourism such as places for children playing, those for family gathering or camping ground, building for outlook points, Bilboard for warming any dangerous things, or information board for tourists etc. These can be applied and developed at Geotourism location areas. On the other hand it is also potential for applying a Microhydro Electric Power where all of the system including dam, water piping, power house has been surveyed to be placed at the north part of the Old Ijen volcano [8][1,9]. The power house is proposed to be placed at Samir village, south of Asembagus.

Equipmen for taking water from the Banyuputih River to be used for farming purposes can also be placed along the Banyuputih River close to Samir or Asembagus. Clean water treatment from the Banyuputih river is also proposed to be placed at around south part of Asembagus. However, these proposal can be realized when the water of Banyuputih River is a normal water. The present real water at this area are still acid (pH is between 2.5 and 4.0).

3.3.2. Rafting Tourism.
Rafling tourism is periodically (at lease once a year) conducted at Banyuputih River by local government of Asembagus [8].This is interested and is taken placed by tourists. However the water here is steel acid (pH is between 3 and 4) which is dangerous to skin of the tourists. They don’t know the water condition here.

3.3.3. Dam View Tourism.
A Tertiary dam has been built since the last a few decades on Banyuputih River at Asembagus District. This area looks well managed with good views. In fact, many domestic tourists come and enjoy this area.

3.4. Planned Educative Geotourism Points

3.4.1. Building a museum for alocating Geotourism information.
Building a museum for informing or explaining concerning Earth Science about Mt. Ijen through medias of posters or, diorama, 3 dimention maket, vidio etc is proposed. The aim of building the museum is to educate tourists effectivly and efficiently in understanding about Mt. Ijen scientipically. The Museum Building is placed at a good situation, condition, based on easy to be accesed, good infrastructre etc. One of the alternative places is at Paltuding. The building must be well managed so that tourists are interested to come and enjoy the content of the museum.

3.4.2. Building geosites in the field.
Some areas where can be installed permanent posters to explain geologically the uniqueness of the view, or a geological structures, or geological processes, that can be added by the uniqueness of biological and culture or environement existences that interested by the tourists. Several places that have been surveyed to be good geosites ar : Nature conservation of Cedeng, Blawan, At Planed Microhydro Electric Power area, At car parking park area, Paltuding. Post of Rest area at tracking path to the Young Ijen Crater (from Paltuding). At Kawah Wurung area. At Geothermal area close to Kawah Wurung area. At Planned Power house area of the Microhydro Electric system (at Samir). At Tertiary dam area, Samir, South Asembagus District. At Planned area for Clean Water Treatment, at Samir, Asembagus. At Blawan waterfall area.
3.5. Geotourism in Indonesia.

Applied Level of Geotourism in Indonesia is start from the basic level which is very simple so-called “geodiversity”, followed by medium level so-called “geoheritage”, and the top level which is the most complex geotourism so-called “geopark” [10]. Geodiversity is a diversity of a substance, form, and process of which produce a part of or the hole of the Earth. The Substace means things include mineral, rocks, sedimen, fossil, soil, and water. The form means things include a geological fold, a geological falt, natural view, and other morphologies, or relation between or among those forms [10].

Mt. Ijen area has not been registered as a candidate for Geoheritage or even Geopark in Indonesia. However, efforts toward the Geoheritage must be conducted. Geological research and surveys to unique, outstanding, rareness of geological phenomenon are required to be conducted to realize the Mt Ijen complex as a Geotourism. The results of geological research in this study are being hoped that a geotourism of Mt. Ijen can be realized. Mt. Ijen area has an unique rocks and mineral such as natural gypsum, solfataras, blue fire, good landscapes such as volcanic crater, caldera, active fault, waterfalls, etc to fulfil unique of landscape, unique of rocks, unique of geological processes as a condition to fulfill the component of conservation area, and criteria of unique landscape area. However, on the other hand, a realization to make the Banyuputih River water to be normal water is absolutely required soon.

4. Conclusion

According to results of Geological research for Geotourism purposes done in Mt Ijen, especially along the Banyupait / Banyuputih River of Mt. Ijen, East Java, Indonesia, several conditions based on uniqueness of rocks, that of landscape, and that of geological processes for realizing Mt. Ijen as a Geotourism area has actually been fulfilled. On the other hand, a save condition is also an absolutely stipulation in building a Geotourism area. That is why an effort to make the acid water to be a normal water is also an absolutely suggestion. Segregation the acid water from normal water is a proposed method to do. Realization of the segregation method will simplify the way to realize the Geotourism of Mt. Ijen that might be lift up the Geotourism of Mt. Ijen to be a high International level of Geotourism in the world

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