

# Impact of the 1815 Tambora Eruption to global climate change

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**Abstract :** Tambora volcano is located at Sumbawa island, Indonesia. Geological study shows a successive of geomorphological development of Tambora Volcano. During 190 to 86 K-Years BP, shield-like or effusive volcano were formed; During 86 to 4 K-Years BP, a strato or explosive-volcano was formed; However, during 80 to 4 K-Years BP flank eruptions occurred intermittently and cinders were formed; In April 1815, a paroxysmal destructive eruption occurred which were followed by caldera forming; Since 1815, lava domes and solphataric fields were formed. The 1815 Tambora eruption emitted 60 to 80 megatons of SO<sub>2</sub> to the stratosphere (44 km high). The SO<sub>2</sub> spread the tropics, circled the world and it was oxidized to form H<sub>2</sub>SO<sub>4</sub> so called sulphate aerosols protecting the sunlight to reach the earth surface causing global change effects. The Year of 1816 as the year without summer in Europe, the depressed situation in Europe, the epidemic disease of Benggal were three of examples of the impacts of the 1815 Tambora paroxysmal eruption. Therefore, characteristics of Tambora activity before paroxysmal should be learned for mitigation purposes.

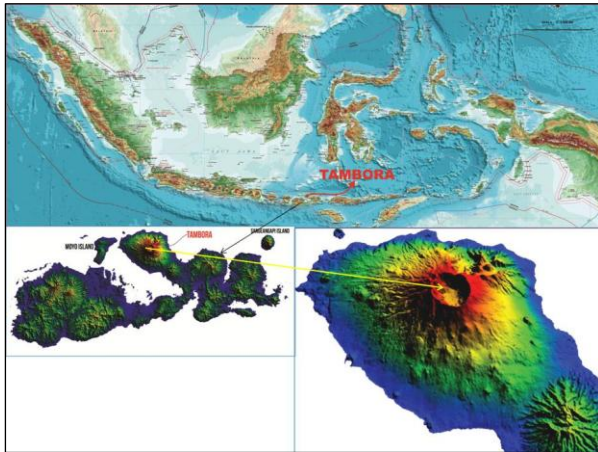
**Keywords :** paroxysmal eruption; caldera forming; global climate change.

## 1. Introduction

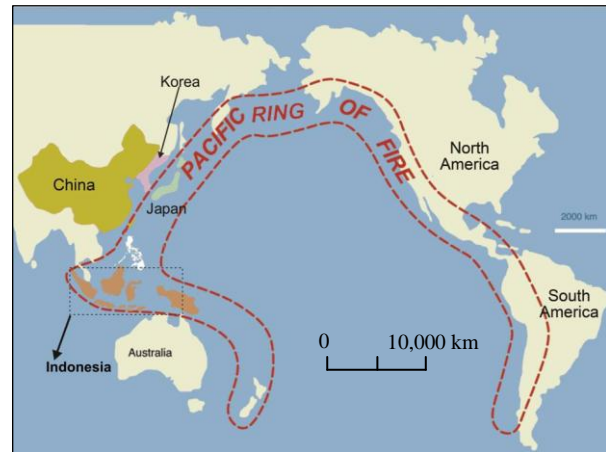
Tambora Volcano, Sumbawa Island, West Nusa Tenggara, Indonesia is geographically located at the middle of the 7000 km long Indonesian volcanic belt (Figure 1). The volcanic belt lies starting from Aceh of the North Sumatera continue to volcanoes along the west side of Sumatera towards the south, continues to volcanoes along Java island from west to east, continues to volcanoes on Bali and Nusa Tenggara islands, volcanoes on the East Nusa Tenggara islands, continues to volcanoes on Banda Sea, and continues to volcanoes on Maluku islands and North Sulawesi. A number of 127 active volcanoes are located in Indonesia, that means about 13 % of active volcanoes all over the world are located in Indonesia. The volcanic belt of Indonesia is a part of the Pacific Ring of Fire (Figure 2) including New Zealand and North America and South America [1].

According to the data base of active volcanoes in Indonesia [2], there are 3 Indonesian active volcanoes showing catastrophic eruption producing caldera (7 km in diameter) during the human life history. They consist of Tambora in 1815, Rinjani in 1257, and Krakatau in 1883. Tambora is a strato volcano with a caldera morphology that was caused by a production of a catastrophic eruption in 1815 [2]. According to the human life history, the 1815 Tambora Eruption is the biggest eruption in the world, resulting totally more than 200,000 people dead at around the volcano and many parts of the world, and damages of many kinds of casualties locally, regionally, and globally [1] and [2]. No





**Figure 1.** Location map of Tambora Volcano among the Indonesian active volcanoes.



**Figure 2.** Pacific Ring of Fire, including all volcanoes in Indonesia [1].

adequate volcanic mitigation facility was applied at Tambora volcano in 1815, and no responsible institution took care of active volcanoes in Indonesia at that time. Consequently, no volcanic information concerning the 1815 Tambora Eruption could be distributed to all people all over the world, nor within in Indonesia at that time.

Learning from the 1815 Tambora Volcano eruption event is very important to study as a part of the volcanic mitigation study in Indonesia and all over the world. That is why, this study will be focused into geological condition especially before, during, and after the Tambora 1815 eruption occurred, how strong the 1815 eruption was, what is the effect of the catastrophic eruption to the world, what kind of method and management that can be applied for volcanic mitigation purposes at Tambora active volcano.

## 2. Data and Method.

No one knew that Tambora would erupt catastrophically in the world even in Indonesia before the eruption occurred. Only some people heard that a very big blasting sound at far away from Sumbawa (at Bengkulu, Sumatera island, 1775 km away, also Ternate, Maluku islands, 1400 km away) and some looked directly at the giant eruption of Tambora volcano in April 1815 at areas close to the volcano. A huge number of events were not understandable in the world for several years after 1815, although finally a lot of people in the world knew after more than 6 decades that the cause of those events were actually the results of the 1815 eruptions of Tambora volcano.

By learning a similar activity to the 1815 Tambora that can be happened in the future at Tambora volcano or any volcano in Indonesia even all over the world, some methods in this study were carried out as follows.

The method was firstly preceded by a detailed geological study of Tambora volcano through a geologic map study of the volcano especially using volcanic-stratigraphy method. This study can be followed by making its Volcanic Hazard Map. Secondly, a collecting of technically by finding authentic information of deposits of Tambora eruption products all over the world was conducted. Thirdly, collecting several non-technically information by finding some proven histories through any kind of mass media from all over the world that could be related with the 1815 Tambora eruption were also conducted. Study and realization of proposed plans concerning the Tambora volcano Mitigation were also carried out.

## 3. Result and Discussion.

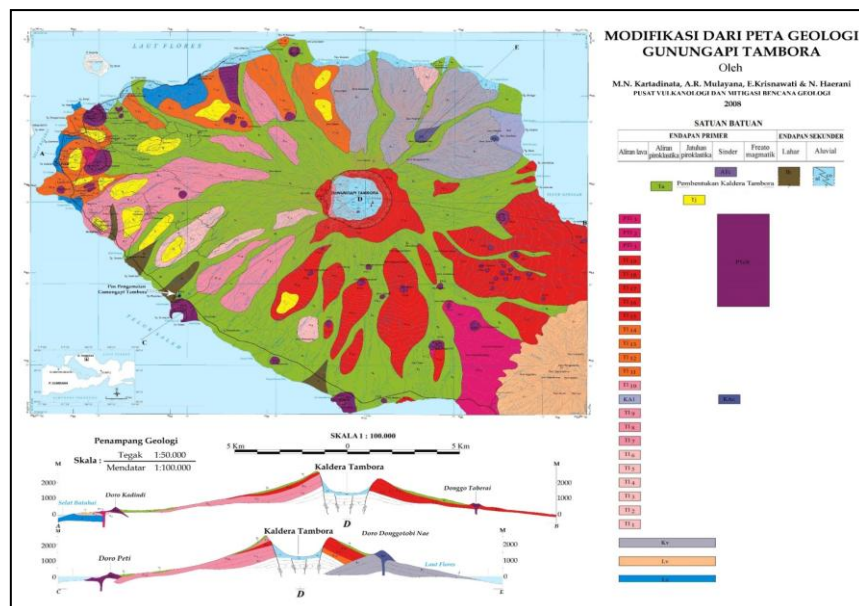
### 3.1. Geology of Tambora Volcano.

Tectonically, Tambora volcano includes volcanoes on Sumatera, Java, Bali, West Nusa Tenggara, and East Nusa Tenggara were closely related with the collision between the Indian-Australian Ocean Plate from the South and the European Continental Plate from the North. The collision part is tilting towards the north. A partial melting generates a molten rock of magma produced volcanic rocks, so called Tambora volcano. Tambora is located at a very complicated tectonic position generates the magma moves towards the surface.

A classification of Volcanic Stratigraphy Unit level based on volcanic eruption source, geography, and tectonic setting was introduced [3]. The classification consist of Volcanic Bregada, Volcanic Khuluk, Volcanic Gumuk, and Volcanic Manggala. Volcanic Khuluk is a basic unit in grouping a volcanic stratigraphy unit for volcano, i.e Volcanic Khuluk Tambora. Volcanic Gumuk is a part of the Volcanic Khuluk which was formed as eruption products on the Volcanic Khuluk both for central or flank eruptions, i.e Volcanic Gumuk Apitoi, Volcanic Gumuk of Katupa etc. Volcanic Bregada is a volcanic stratigraphic unit covering volcanic eruption products originating from two or more Volcanic Khuluk or related to a caldera forming. The volcanic Bregada always has a Volcanic Khuluk or more.

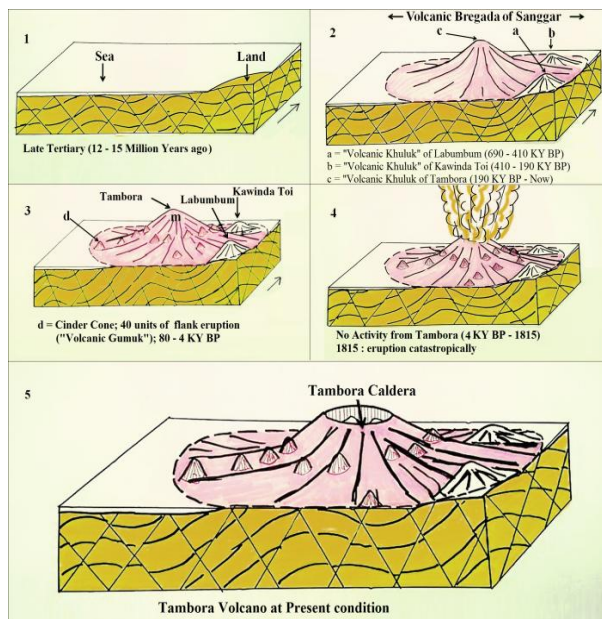
According to the Geological Map of Tambora Volcano complex (Figure 3) [4], which is combined with the implemented Volcanic Stratigraphy Unit Level [3] at Tambora, the Geological History of Tambora volcano forming can be explained as follows. A simple and general geological history sequently based on the Volcanic Stratigraphy Unit Level of Tambora is showed in Figure 4.

A great volcanic complex of Tambora which is located on Sumbawa island at 50 to 100 km north-west ward from Dompu, was preceded by forming a large volcano complex on a large area namely "Volcanic Bregada of Sanggar". The Volcanic Bregada was formed at least 690 KY BP consist of firstly, "Volcanic Khuluk of Labumbum" (690 – 410 KY BP) at the south-east part of the Volcanic Bregada, lithologically consisting of lava flow and pyroclastic rocks (andesitic in composition); secondly, "Volcanic Khuluk of Kawinda Toi" (410 – 190 KY BP) at the north-east part, lithologically consisting of lava flow and pyroclastic rocks with basaltic in composition; and thirdly, "Volcanic Khuluk of Tambora" (190 KY BP – now) at the center of the Bregada, lithologically consisting of lava flow and pyroclastic rocks (andesitic to andesitic basalt in composition). During the activities

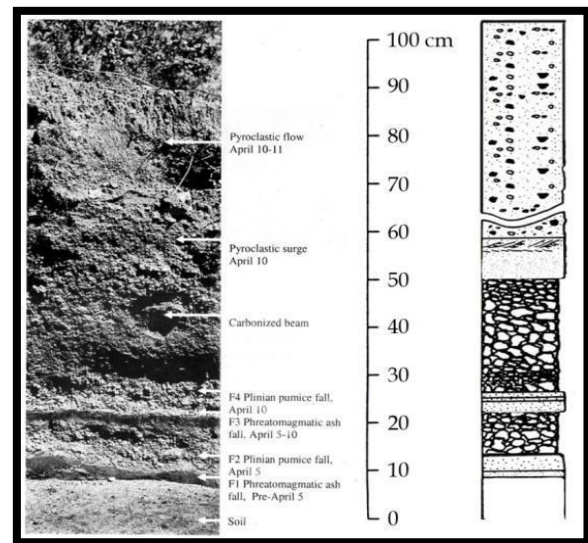


**Figure 3.** Geological map of Tambora volcano [4].





**Figure 4.** A Simple and General Geological History of Tambora Volcano Complex based on Volcanic Stratigraphy Level Unit, sketched by Wirakusumah.



**Figure 5.** Stratigraphy coloum of the eruption products during the 1815 Tambora activity [1].

through Tambora vent to form strato volcano, eruptions were also intermittently occurred between central eruption (Tambora crater) and the flank eruption starting from 80 KY BP, producing 40 cinder cones at all directions of Tambora flank especially at elevation between 0 and 1600 m asl. Lithologically, they consist of lava flow, pyroclastic crocks, phreatomagmatic, and phreatic eruption products. On the body of Kawinda Toi, two small flank eruptions were formed in 80 KY BP, that means they were formed during the Volcanic Khuluk of Tambora forming. According to the Volcanic stratigraphy [3], these flank eruptions are called “Volcanic Gumuk” e.i “Volcanic Gumuk of Katupa” as the child of the Volcanic Khuluk Tambora which is located on the Kawinda Toi body. The youngest Volcanic Gumuk of Tambora is the Volcanic Gumuk of Api Toi as central eruption which was produced after the 1815 Tambora eruption (between 1847 and 1914). This volcanic complex lies on a Late Tertiary sedimentary rocks consisting of mainly limestones (about 12 to 15 Million years ago) as the basement.

According to the data above, there were two times of the main central eruption sources shifting within the Volcanic Bregada of Sanggar. The eruption source were firstly at around Labumbum Volcano body (690 KY BP), secondly the eruption source moved to around Kawinda Toi Volcano body (410 KY BP), and finally the eruption source moved to Tambora Volcano (since 190 KY BP). The formed 40 cinder cones on around the Tambora flank especially produced freatomagmatic materials indicates that when magma were came up towards the Tambora flank surface through some diatremas, the magma or the magma heat contacted water (ground water originated from sea water or land ground water) producing freatomagmatic eruptions and some of them are produced freatic eruptions. Another explanation, that when lava flows were contacting ground water, then phreatomagmatic or phreatic eruptions occurred.

Oldest period of Tambora lithology (pre-caldera forming) were dominated by andesite basalt to basaltic-andesite lava with 49 to 53 %  $\text{SiO}_2$  content. These lava flows formed between 190 KY BP and 9 KY BP covering older rocks. This condition effect to form Tambora morphology of a shield volcano. However, starting 86,000 years some pyroclastic rocks were found producing a strato volcano characteristic. This indicates that there were shifting from lava dominantly (effusive eruptive

characteristics) to an intercalation between effusive and explosive eruptions. This effect that Tambora shows a break slope to be a steeper slope at elevation of 1,800m asl, event such kind condition was continued reaching up to an extrapolation elevation of 4,200 m asl [4]. No eruption activity during a big gap of age (between 4000 years BP and the year of 1815) was recorded, that probably means during about 2000 year the Tambora had been building energy which was finally in 1815 the Tambora produced a catastrophic eruption producing a great caldera (diameter = 7 km). A stratigraphic coloum of the 1815 Tambora eruption product is shown in Figure 5 [1].

### 3.2. Magnitude and Dtribution of the Eruption.

Tambora erupted catastrophically in 1815. The detail chronology of the eruption is shown in the Table 1.

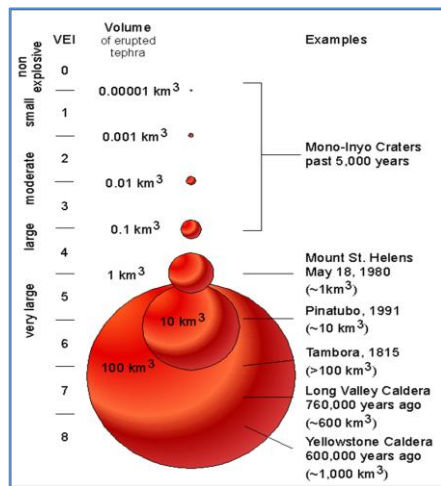
**Table 1.** The detail chronology of the 1815 Tambora eruption based on the eye witnesses [1].

DATE	TIME	OBJECT	COMMENTS
(1812)	A few days	Black ash eruption column from the summit accompanied by rumbling.	It indicated the Pre-initial phase.
April 5	Sun set	34 m high black eruption column. The eruption sound were heard for several times from Jakarta, Makasar, and Ternate.	The main eruption produced loud sounds due to the partial destruction of lava plug.
April 6-9	Afternoon	Ash fell on Surabaya (600 km to the west) for 4 days.	The wind blew from east to West-Northwest, to Java.
April 10	19:00 pm	Fire column rose from 3 places, followed by glowing ash looked like fire.	Stage of collapse of the Tambora summit part.
	20:00 pm	The three ash column was calesced, and were followed by a total fire covering all summit until flank area. Glowing rocks fell at 20 km away from the summit.	This stage is the strongest stage producing pyroclastic flow.
	21:00-22:00 pm	Volcanic ash & strong wind from all directions. The explosion sound was heard from Jakarta.	High velocity Turbulence wind indicate thepyroclastic flow (V = 80 km/hour)
	22:00 pm	Tsunami (4 m high) at Sanggar coast.	Pyroclastic flow reached the coast and generated tsunami (4 m) at Sanggar and at East Java (2 m) & Maluku islands (2m).
	24:00 pm	2 m di Jatim dan Maluku.	
April 11	07:00 am	Erption continued. The summit was claudy.	Paroxismal terminated. Eruption decreased.
	13:00 pm	Darkness for few days.	Ash covered sun ray.
	22:00pm	Ash fell on Java for 3 days.	The wind blew to the west and northwest.
	24:00 am	Eruption decreased significantly.	Magma began to retreat.
April 12-17	All the day	Ash fell on Java. Eruption terminated on17/4	Magma retreated& Eruption terminated.

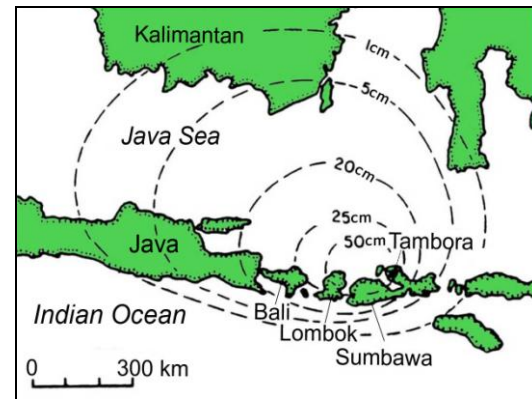
The 1815 Tambora eruption produced a number of  $> 100 \text{ km}^3$  of ejected material [2] and Volcanic Explosivity Index (VEI) of 7 from the highest scale of 8. Comparing to some other big volcanic eruption of many volcanos in the world based on the ejected eruption material, the 1815 Tambora eruption is classified into very large eruption that is illustrated in Figure 6 [5].

The 1815 Tambora eruption sound was heard from Bengkulu ( $> 1700 \text{ km}$  to the west), Makasar (400 km to the north), Ternate island ( $> 1400 \text{ km}$  to the north east). The ejected material of the 1815 Tambora eruption was probably reached 44 km high vertically [1] that means reaching the stratosphere layer. The volcanic ash was pushed by the wind blowing to the west-northwest as illustrated by Figure 7 [6]. The plume was probably circling over the earth globe for years. This indicates that the volcanic ash originated from the 1815 Tambora eruption was deposited all over the world.

The 1815 Tambora eruption emitted 60 – 80 megatons of  $\text{SO}_2$  (sulfur dioxide) to the stratosphere, which means 3-4 times as much as during the 1991 Pinatubo of the Philippines the biggest eruption of the 20<sup>th</sup> century [7].



**Figure 6.** A Volcanic Explosivity Index has been proposed in 1982 [5]. (The source of figure: [www.volcanoes.usgs.gov](http://www.volcanoes.usgs.gov)).



**Figure 7.** Map of volcanic ash movement originated from the 1815 Tambora eruption [6].

In the stratosphere, the SO<sub>2</sub> spread across aerosol the tropics, circled the globe and was oxidized within weeks to form H<sub>2</sub>SO<sub>4</sub>, a substance that condenses to tiny droplets called sulphate aerosol. These aerosols dimmed the sunlight and primary caused to the global climatic effects. The case of Tambora can be explained that the ejected ash and gases reaching the stratosphere, which after 2 weeks the sulphur gases circled the tropics in Stratosphere. After 8 weeks they were rapidly oxidized to Sulphate Aerosols, and after 1 year the Aerosols slowly spread poleward [7]. That is why the aerosol originated from 1815 Tambora eruption was found in the ice core in Greenland. This means that the product of the 1815 Tambora eruption spread to all over the world.

### 3.3. The Impact of the 1815 Tambora Eruption.

#### 3.3.1. The Impact of Pyroclastic Flow

Three kingdoms on Sanggar Peninsula close to Tambora volcano so called Kingdoms of Pekat, Tambora, and Sanggar were destroyed because of the 1815 Tambora eruption through pyroclastic flow deposit and tsunami. A total number of fatalities in these location of 10,000 people died directly was reported [1].

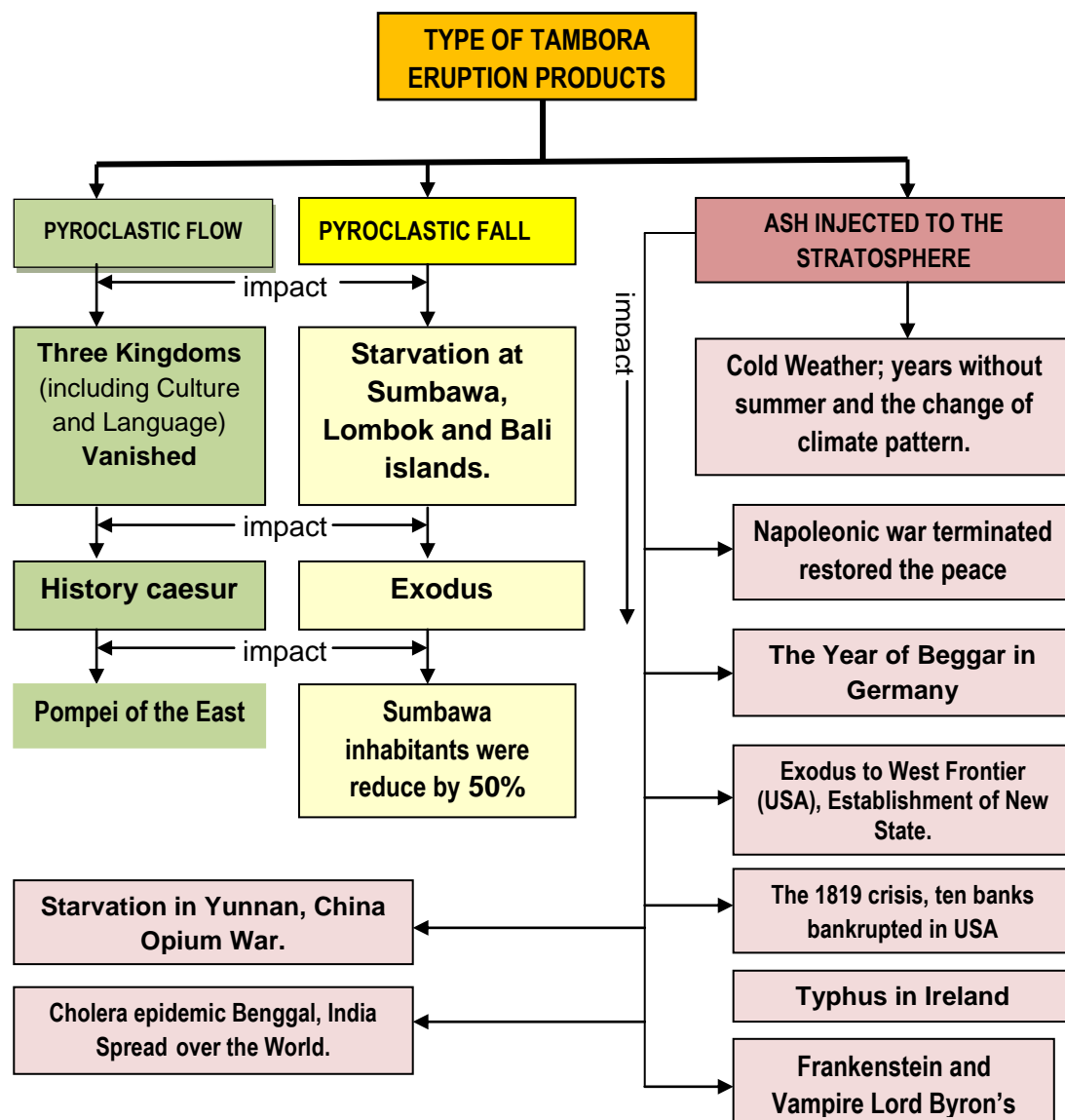
The other impact of the pyroclastic flow was the vanishing of houses, villages, cities, as well as kingdoms at Sanggar peninsula, consequently the population and its culture and language were also perished. A lot of folklore and caesura concerning all those stories were collected. One of great evidences is an ancient manuscript telling about the 1815 Tambora eruption written in Melayu language in Arabic character which is now is kept by Dr. Hj. Maryam S, a philologist in Sumbawa.

Some excavation of locations suspected as buried artifacts were carried out revealed those things including human remnant were really vanished and buried. That is why it is called as “The Pompeii of the East” (Figure 8).

#### 3.3.2. The Impact of Pyroclastic Fall.

In other place on Sumbawa island such as at Dompu Kingdom, at Bima Kingdom, and at Sumbawa Kingdom, some 38,000 people died indirectly through starvation and disease. Starvation and disease were appeared after the pyroclastic fall deposit originated from the eruption destroyed all plantation including agriculture belong the people or government. Consequently, food and many important things were difficult to provide. This resulted the Sumbawa’s inhabitants reduced for about 50 % (Figure 8).

Starvation and disease conditions also occurred in Lombok and Bali islands resulting a number of 44,000 people died in Lombok and that of 25,000 in Bali. Consequently, The total fatalities (directly and indirectly) in Indonesia was 117,000 people [1].



**Figure 8.** Schematic global impact of the 1815 Tambora eruption, modified from [1]

### 3.3.3. The Impacts of the Injected Ash to Stratosphere.

A number of thousands of people were died indirectly in Ireland (Europe) because of Typhus and food shortages. In Yunnan, China, a number of tens of thousands were died indirectly because of starvation and chilling summer. Another place, in Bengal, India, a number of ten thousands of people died indirectly caused by Cholera due to abrupt change of weather (Figure 8). The total fatalities in the world was > 200,000 people [1].

As it has been explained that a year after the 1815 Tambora eruption, the aerosol which was originated from Tambora eruption covered all of the globe. The aerosol became an obstacle for the sun ray to reach the ground surface freely. Consequently, the sky never showed a sunny day, people feel the weather on the earth very cold any where and every time especially at sub-tropic areas.



The global temperature in the world dropped 1° to 2.5° C and in some place reached 10° C. That is why in 1816 is called as “The Year without a summer” in Europe as well as in USA although a year after, the summer did not appear yet at both places [1]. This condition finally changed the climate pattern in the world.

The changed climate pattern resulted a lot of odd phenomenon but also a wisdom or philosophy such as rainy, cold and dry resulting the crops did not grow, the harvest failed, and food (including animals) shortages everywhere included in European countries, Asian countries, and USA. In Germany flood occurred along Rhine River caused food shortages in many cities the river's banks. In Britain and Ireland weather so cold, snow fell down. The starvation spread over the South Ireland. In 1816, typhus epidemic broke out in Ireland. The American sky was disturbed by the eruption ash of Tambora resulting the climate changed significantly in 1816. A lot of harvest failed and many of the farmed animals dead. Some of the arriving immigrant had to turn back to Europe because of food shortages condition occurred in the USA.

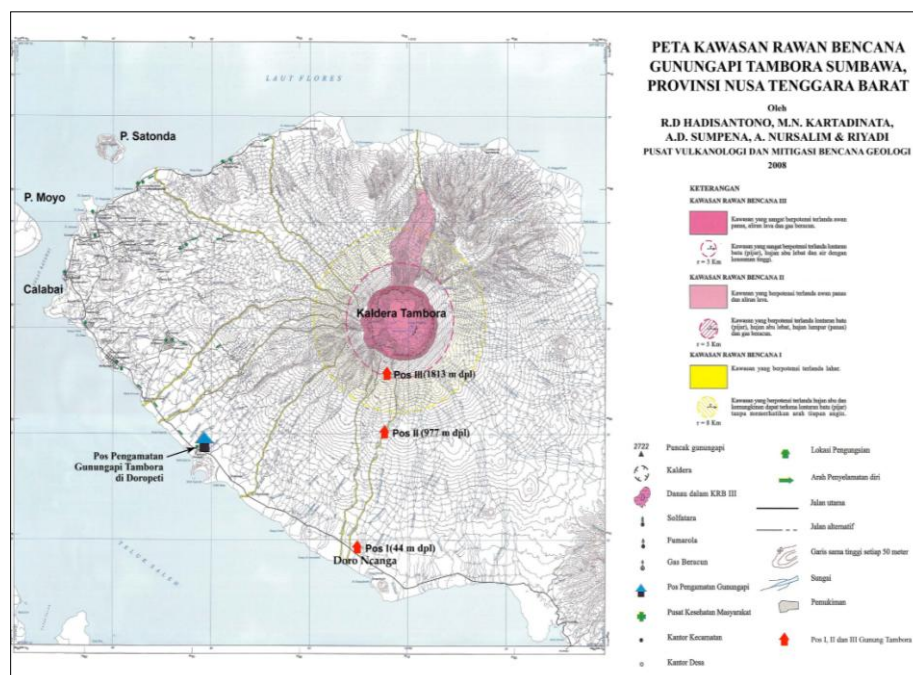
### 3.4. Volcanic Hazard Mitigation

Volcanic Hazard mitigation before, during and after the eruption should be done for reducing the volcanic risk purposes.

Volcanic Hazard mitigation activities consist of:

- Identification of volcanic activity
- Volcanic monitoring
- Establishing a statement of activity level of the volcano
- Volcanic Hazard Mapping
- Geological Mapping of the volcano
- Socialization concerning the development of volcanic activity
- Technical Reporting and based on Law Number 24 concerning Disaster Mitigation in Indonesia.
- Coordinating with the National Agency of the Natural Disaster Mitigation of Indonesia.

Volcanic Hazard Mitigation is technically preceded by volcanological study through methods of geology, geophysics, geodesy, geochemistry. To reduce a risk of volcanic hazard such as Tambora



**Figure 9.** Volcanic Hazard Map of Tambora Volcano [8].



volcano, a geological study is required as Tambora shows short and long periods of repose time.

The long period of repose time can be studied based on data base along the human life history, but it is probably also required a carbon dating method through rock samples to understand the age of the eruption products. This should be related with the magma composition chemically through studying on every eruption product. This will help to understand the characteristic and volcanic forming history. A catastrophic eruption like the 1815 Tambora eruption is usually preceded by having a long repose time and changing of magma composition chemically.

The short period of repose time can be studied by geology, geochemistry and geophysics including geodesy. The integrated data of them will help in making decision of the volcanic activity as this information will be taken as a reference to act the following mitigation activity.

Volcanic hazard mitigation for Tambora volcano need to make 2 versions both for long and short periods. The Volcanic Hazard Map of Tambora Volcano (short period) is shown in Figure 9 [8].

#### 4. Conclusion.

The 1815 Tambora catastrophic eruption with VEI of 7 resulted a great hole 7 km diameter and 1 km depth so called Tambora Caldera. The ash plume reached stratosphere, 44 km high covering all over the world for few years.

The 1815 Tambora eruption impacted a lot of phenomenon in the world especially the changed climate pattern to the globe such as the 1816 is called as The Year Without a Summer etc. The eruption was finally resulting a number of > 200,000 people dead all over the world.

Tambora volcano is a good example volcano to study in Indonesia even in the world as the volcano has 2 kinds of eruption characteristics which are related to a long period repose time and a short repose period, and having changing in magma chemical composition. Until now, the 1815 Tambora is classified as the most catastrophic eruption in the world within the human life history. Research and collecting information of Tambora volcano globally should be continued in order to make the data base more complete. Information of the volcano should be distributed to the involved institutions for volcanic mitigation purposes. This methods can be applied to study other volcanos in Indonesia even in the world.

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