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LAKE TOBA, A MULTIPLE CALDERA DEPRESSION, NORTH SUMATERA, INDONESIA

P.E. Hehanussa
Indonesian Institute of Sciences, Indonesia
phnussa@indosat.net.id

Abstract

A joint research on the geology of Lake Toba and its surrounding was executed by the Kyoto University and Indonesian Institute of Sciences during 1972-1988. The lake origin was explained by van Bemmelen (1949) as a volcano-tectonic depression. Ninkovich (1967) explained that Lake Toba is a caldera produced by a single eruption 70,000 years BC. Geological, geo-chronology, tephra-chronology, and gravity measurements by the Japan-Indonesia surveys revealed a more complex origin, the combined effect of volcanic, tectonic and sedimentation processes starting 1.9 M years ago (Nishimura *et al.* 1980).

Lake Toba water area is 1,129 km^2 excluding the 647 km^2 Samosir Island and several other smaller islands in the lake. The morphology formed a topographic depression surrounded by steep cliffs 400 to 1200 m above lake surface. The water is at 904.5 m above sea level, maximum depth 585 m. The joint Japan-Indonesia finding is a strong base for planning a sustainable management for local people, forestry, fisheries, agriculture benefits, industrial developments, hydropower generation, and an everlasting scenic view for tourists.

Introduction

Geological investigations in the central north Sumatera region was concluded in the famous book of van Bemmelen (1949) on the Geology of Indonesia, stating that this region formed a morphological culmination which he called the 'batak tumor'. The center of the batak tumor culmination is crowned by the occurrence of Lake Toba. Related to this morphological configuration, the origin of the lake was explained by van Bemmelen as a giant volcano-tectonic depression due to the collapse after an internal vacuum created by the expulsion of vast eruption material. He calculated that the lake depression volume was equal to the pyroclastic material that erupted as tephra airfall distributed to a vast area between Malaysia mainland in the east to the Indian Ocean south of Ceylon in the west where volcanic material has been discovered in drilling cores of the deep sea drilling projects (DSDP). A few ignimbrite samples from the Sigura-gura waterfall has been radiometric K-Ar dated by Ninkovich (1967) which shows an age of 70,000 years BP that he concluded as the age formation of this lake.

Joint field surveys to Lake Toba and its surrounding area has been executed by a team of Japanese-Indonesian scientist during the 1972-1988 era. Geological mapping, magneto stratigraphy surveys, tephra-chronology, and gravity measurements by the surveys found evidence that the lake and the island inside it was not formed by one single event but a combination of several caldera formation events (Nishimura, 1980). The combined K-Ar, fission track, paleomagnitism, carbon dating of ignimbrite, breccia, and sediments from the lake rim as well as in the the islands shows age clusters of 1.9-2.0; 1.2-1.3; 0.6-0.7; and 0.1 million (M) years and several younger ages of 70; 30; 12;

thousand years BP. This evidence proves that volcanic and sedimentation processes has occurred repeatedly as described in Yokoyama and Hehanussa (1981).

From the geographic aspects, Lake Toba is the largest lake of Indonesia measuring 1,129 km^2 excluding the 640 km^2 Samosir Island, 7 km^2 Pardapur islands and several other smaller islands in the lake area. The lake is surrounded by steep cliffs that climb 400-1,200 m above the water surface while the cliff continued downward as steep lake bottom along the circumference of the lake. The eastern lake bottom along the Samosir Island is less steep compared to the whole circumference of the lake. The lake water surface is normally located at 904.5 meter above sea level with a seasonal fluctuation of less than 2 m but since late 1980s has been reported going up to nearly 3 m. The lake water is a traditional agricultural water source, for fisheries, inter-village water transportation, urban and household needs of people, and an endless attraction for tourist visiting the area. The lake catchment area has shown some change from forestry to agricultural and rural developments. Major physical changes in the area during the last four decades are the construction of three step dams for hydropower generation in the Asahan River, new plantation in the catchment and slope areas, pulp industry near Porsea, urban developments, and a bottled water factory in the Balige area that used a spring near the lake rim as its principle water source. Due to these combined developments, several conflicts of interest have appeared especially on the priority setting of the water.

Samosir Island inside the lake has a dome like structure and was described by previous authors as having the shape of a turtle shell. The island geology is formed by ignimbrites or welded tuffs covered by coarse grained sediments that interfingered with finer grained nearly pure freshwater diatomea sediments. This is an indication that part of the island has been covered by fresh water for a considerable time. Rivers flowing toward the east of the island are short and some formed high waterfalls. Rivers flowing to west are longer and shows indications of tectonic movements as proved by rivers that 'disappear' into caves before debauching into the coastal plain. The soils of the island are thin compared to other andesitic volcanic areas on Indonesia and they show deep erosional patterns.

A more detailed understanding for further developments of the area are needed and this paper presents some of the geological related informations. Fisheries potentials of the oligotrophic lake has not been fully understood and developed. Introduction of new fish species was reported that has dominate the shallow aquatic environment. Management of the lake catchment area has long been debated over, whether to grow selected low water consumption species or to plant trees that is highly needed by the pulp industry in the Porsea area. Pollution by the pulp factory has created an intensive debate and there has not been a mutual consensus between both parties. One topic that has been repeatedly discussed is the need for additional water for the generation of the existing 285 MW hydropower to supply electricity for the aluminum smelters located in the shore of Sumatera Island. An option was proposed as for the construction of a tunnel to transfer water from an adjoining river located ten's of km in the west of the lake. Increasing lake water fluctuation has paralyzed many traditional harbors used by villages for transportation by katinting or small gasoline engine boats. Decreasing water level has caused sedimentation into the canal that separated Samosir Island from the mainland, so it is possible that in the future there will be no Samosir Island anymore.

Geology and Tephra-Chronology

The geology of the Toba area complex was described in pre-1949 literature as an oval shaped depression located in north Sumatera with a lake at the culmination. The rock unit that formed the whole area was described in one term as famous Toba Tuffs. A combined geological, geographical, tephra-chronology and magnet stratigraphy survey has come out with a result showing that this acid volcanic pyroclastic is not one single rock unit but are sequences of tephra deposits. The base consists of thick pyroclastic flows formed by ash flows, pumice flows, and welded tuff deposits or ignimbrites as described in Nishimura *et.al.* (1984). In the middle and younger stages are intercalations of the volcanic products and sediments such as coarse grained breccia mostly distributed at the rim and finer lacustrine deposits in and near the center of the depression. As conclusion of the surveys, this volcanic complex deposits was grouped into three tephra-chronology units closely related to the lake formation i.e. the Pre-Toba Deposit which are volcanic products older than 1.9-2.0 M years, then the Toba Deposits which geological age range between 1.3 M years down to 30.000 years BP, and the youngest unit is described as Post-Toba Deposits being younger than 30.000 years BP as reported in Yokoyama and Hehanussa (1981).

The Pre-Toba Deposits formed the base of this acid volcanic deposit complex consisting of dense welded tuff named the Tuk-tuk Dacite. K-Ar dating of this rock unit shows an age of 1.9 M years (Tjia, 1976) and paleomagnetism shows that they are located in the lower half of the Matuyama Reversed Chron (Yokoyama *et al.*, 1988). The outcrop of this unit has been observed in three sites, the most extensive one is cropping out along the steep slopes of the eastern Samosir Island with an excellent outcrop at cape of Tuk-tuk Siadong. Two other sites are along the lower lake site around Parapat and another one is along the steep winding road between Tele and Pangururan in the western end of the lake. This rock unit is build by very hard, light gray, dense welded tuffs containing light purple quartz grains that is up to 2 mm in size.

The second unit is the Toba Deposit that may be divided into the lower and upper unit. The lower Toba Deposits were discovered in the Haranggaol area north of Lake Toba and near Sigura-gura waterfall that drained the lake through the Asahan River. The stratigraphy of Lower Haranggaol Formation was measured along the lower end of the road between Haranggaol at the lake rim to Saribudolok at 1,100 m a.s.l. They show an age of 1.2-1.3 M years and paleomagnetic studies shows that they may be the lower half of the Matuyama Reversed Chron. Other outcrops in the Sigura-gura Formation revealed an age of 0.86-1.1 M years. The upper Toba Deposits are build by three formations i.e. the upper Haranggaol Formation with an age of 0.1-0.62 M years consisting of coarse clastics intercalated with welded ash layers. The Samosir Formation consists of breccias, graded beded conglomerates, and fine grained lacustrine diatomea sediments. It is located along the crest of Samosir Island and preliminary age dating shows an age of 0.1 to 0.39 M years. The third rock unit is the Parapat Formation and Porsea Formation. Their distribution is rather restricted and they show lacustrine deposits that is a fingerprint of the geological history of the area.

The uppermost unit is the Post Toba Deposit that is build by loose sediments which has been deposited near Porsea, Parapat, Haranggaol, Pangururan, and in Samosir Island. Another Post Toba Deposit is basalto-andesitic deposits originating from two volcanoes, one located in the very north end of the lake and another near Pangururan at the junction between Samosir Island and the mainland. The age of these deposits is less

than 30,000 years BP.

Lake Water Resources

Water has been traditionally regarded by people as a limitless free gift of the almighty. That is the background why not enough care has been given to them. According to the law in Indonesia (UU No.11/1974) there are three groups of water use priority. The highest is for drinking water, domestic use, national defense, observance of religious duties, urban use for fire prevention, flushing, and park. The second group is for small holder farms and other agricultural use, diary farm, estate plantation, and fisheries. The third group is for power and energy, industry, mining, transportation, and recreation. Although this priority classification is by law, there are cases where the need by people that benefit the water may over-rule this priority. The water from Lake Toba although large in quantity but need ecological understanding to plan for its sustainable feature. On a visit in 1997 clusters of free floating water hyacinth has been observed on the lake surface on a trip between Parapat and Tuk-tuk Siadong.

Contrary to the size of Lake Toba very limited survey results have been annually published on them. To understand the water dynamics, detailed bathymetric maps and systematic echosounding results are absent. The lake water drained through the Asahan River from 900 m above sea level through steep slopes from the lake side and more gentle slopes along the coastal area. Detailed geotechnical surveys was done by contractors prior to the construction of a regulating dam in Simorea and the two concrete dams in Sigura-gura and Tangga for hydropower generation. The discharge of the Asahan River has been measured as well as calculated resulting in a rather wide range of figures between 96-108 m^3/s. Rainfall distribution is not equal throughout the whole lake area but all of them are over 2,000 mm/y. The total catchment area is around 3,700 km^2 with medium and small rivers flowing into the lake, some of them enter the lake as waterfall.

One single river, the Asahan River located near Porsea in the south drains the lake. Water level of the lake is normally at 904.5 m a.s.l. although lately it went down to an alarming level below the construction elevation of the regulating dam. There were long discussions on the origin of drop in water level, which have not been come to a conclusion whether of a natural or anthropogenic, either overdraft or change in the ecosystem water balance. Management of land cover of the catchment area has been blamed, the climate has been accused, leakage has been proposed, and the industry that used the lake water has been asked to be responsible. Fluctuations of the lake water level have a serious effect by disruption power supply to the aluminum smelters located in the eastern coast of Sumatera.

A preliminary feasibility study has been executed to transport additional water into the lake by diverting water from the Renun River that is flowing along the Sumatera Fault which is parallel to the length of Lake Toba. A tunnel to transport the water has been proposed and the end of the tunnel will be above the lake water, high enough for an additional source for power generation. Ecological studies on the biotic, physical, chemical, as well as hydrodynamic effects on the lake as well as downstream of the Renun River have not been conclusive.

Some parameter values related to the general lake statistics and water quality (Hehanussa, 1995) are: maximum length is 80 km, width is 35 km, lake level fluctuation 1.5 m, catchment area 3,698 km^2, lake water electrical conductivity 130-162 μS/cm,

acidity 7.0-8.4, evaporation 1,582 mm/y, air temperature 19.1-21.2°C, water temperature 25.6°C, transparency or Sesschi disk reading 7.5-11 m, and its average rainfall is 2,264 mm/y.

Water Use and Management Needs

The lake has its direct influence to people living in the surroundings as well as to industries that have and is developing in the surrounding area. The local people has an emotional tie to the lake such as the holiness of the lake environment and the tradition for cooking a certain (disappearing) fish species prepared as the yellow fish in traditional events. Agriculture, household, urban, and water transportation are their daily needs. Possible hazard due to supersaturated carbon dioxide in the lake water is a topic to be revealed. Introduction and invasion of fish species in the last few decades was observed either direct to the lake or in floating cages. Hot water sources at the extinct volcano west of the lake is an attraction. The beautiful lake environment and its surroundings are strong magnet for domestic as well international tourists. Hydropower generation in the Asahan River has been completed. Industrial activities that have and are developing are pulp factory in Porsea, bottled water in Balige, tea plantation, and pineapple canning. The diatomea clay deposit in Samosir Island has not yet been exploited. Geothermal reservoirs were explored by UNOCAL that was discovered some distance south of the area. All these water and environmental related water uses need an overall management plan for its sustainable use.

Concluding Remarks

Lake Toba and its surrounding area is a challenging aquatic ecosystem that lately is developing but many natural systems have not been understood. Limnological, biological, ecological, climatological, and hydrological information to unravel such a big 'mystery' for the sustainable planning for one of the largest crater lake in world is needed. The bridge between scientific findings and development plans for people in the area through a joint and multiple discipline approach can and will create harmony between people and its environment.

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