3. General Description of a Glacier

3. 1 Background Knowledge of a Glacier

To understand a glacier lake it is necessary to understand the glacier itself and its characteristics in the context of the Nepal Himalaya.

3. 1. 1 Glacier

A glacier is a huge flowing ice mass. The flow is an essential property defining a glacier. Usually a glacier develops under conditions of low temperature but the cold climate in itself is not sufficient to create a glacier. There are such regions on the earth where the amount of the total depositing mass of snow exceeds the total mass of snow melting during a year in both the polar regions and high mountain regions. A stretch of such an area is defined as *accumulation area*. Thus, snow layers are piled up year after year in the accumulation area because of the fact that the annual net mass balance is positive.

As a result of snow layers piling up continuously, the deeper snow layers are compressed by the overburden pressure due to their own weight. As a consequence, the density of the snow layers increases whereby snow finally changes to ice beyond a certain depth. At the critical density of approximately 0.83 g/cm^3, snow becomes impermeable to air. The impermeable snow is called ice. Its density ranges from 0.83 to pure ice density of 0.917 g/cm^3. Snow has a density range from 0.01 g/cm^3 for fresh snow layers just after snowfall to the transition to ice at a density of 0.83 g/cm^3. Perennial snow with high density is called *firn*.

When the thickness of ice exceeds a certain critical depth, the ice mass starts to flow down along the slope like a starch syrup by a plastic deformation and sliding on the ground driven by its own weight .

The lower the altitude, the warmer is the climate. Below a critical altitude, the annual mass of deposited snow is melted out completely. Snow disappears during the hot season and may not accumulate year after year. Such an area in terms of negative annual mass balance is defined as *ablation area*. A glacier is divided into two such areas, accumulation area in the upper part of the glacier and ablation area in the lower part. The boundary line between them is defined as the *equilibrium line* where the deposited snow mass is equal to the melting mass in a year.

Ice mass in the accumulation area flows down into the ablation area and melts away. Such a dynamic mass circulation system is defined as a glacier. There are three components of a glacier mass, that is, 1) the total mass obtained in the accumulation area, 2) the total mass flowing down from the accumulation area to the ablation area through the equilibrium line and 3) the total loss of mass in the ablation area. If the climate were to remain constant and to continue long enough, the annual amount of incoming mass in the accumulation area would be equal to the amount of the flowing mass and also melting mass in the ablation area. As a result, annual net mass balance of the whole glacier would be ideally zero for a long period. Though the ice mass is continuously moving, the size and shape of the glacier never change ; the glacier terminus stands at the same position.

Actually a glacier sometimes changes in size and shape subject to the influence of climatic change. A glacier would advance with climate changing to a cool summer and a heavy snowfall in winter and the monsoon season ; the size would expand and the terminus would shift down to a lower altitude. A glacier would retreat with climate changing to a warm summer and less snowfall ; the glacier would shrink and the terminus would climb up to the higher altitude. The climatic change results in a glacier shifting to another equilibrium size and shape.

3. 1. 2 Moraine

Steep slopes beside a glacier exposed to the severe climate suffer continuous violent weathering. Fractured materials fall down on a glacier from the slopes and are sometimes buried in the glacier by successive snow accumulation. A flowing glacier scrapes and polishes the floor and the walls of the valley under the glacier like a bulldozer making and producing fine materials. These materials are called *debris*. The debris is transported downstream by a glacier working like a conveyer belt and piles up at the margin of the glacier terminus as a result of the glacier ice melting at that point. This glacial sediment is collectively called *moraine*. A moraine is composed of materials with random composition because it is formed without undergoing any fluvial action.

A moraine adjacent to the present glacier tongue is very fresh in the Nepal Himalaya since it was formed during the last advancing stage of the Little Ice Age between the 16th and 19th centuries. The structure is not yet consolidated and is composed of very loose materials.

3. 1. 3 Debris on a Glacier

There are two types of glacier in the Nepal Himalaya. One is a debris-covered type glacier (D-type glacier) and the other is a clean type glacier (C-type glacier) free form debris on the glacier surface (Moribayashi and Higuchi, 1977). The former glacier is seen in a relatively large valley glacier. A large valley glacier produces a huge amount of debris by the manner mentioned in the previous section. The glacier tongue is covered by thick debris and contains debris in the glacier body. The latter is a cirque glacier and a hanging glacier with comparatively small size. Since the production of debris is limited, the surface has no debris and looks white and very clean in comparison with the D-type glacier. The terminus area of a D-type glacier tongue does not cause flowing action and may remain stagnant or congealed as a dead ice mass. This area is separated from the dynamic mass balance system of the presently active glacier. Its real terminus is now located in the upper part, though this area looks apparently connected to the present real terminus of the glacier.

The existence of a D-type glacier is a distinct characteristic of the valley glaciers in the Nepal Himalaya. As a result of glacier melting from the surface, the debris contained in the glacier is exposed on the glacier surface. The D-type glacier is essential to the development of a glacier lake, since this type of glacier is only subject to diminish its thickness and does not yet melt away in the retreating processes during the few hundred years subsequent to the Little Ice Age. The rich debris on the surface acts as a heat insulator and restrains glacier melting. Other glaciers with poor debris on the surface, for instance, the glaciers in Alaska and the European Alps shift their terminus

position up to higher altitude in their retreating processes and stagnant ice mass never remains at the glacier tongue. If there would be no rich debris on a glacier surface, the present glacier tongue would be expected to have melted away and disappeared. This debris covered glacier tongue prepares the field for a glacier lake formation.

3. 2 Glacier Lakes in the Nepal Himalaya

Water mass existing in sufficient amount and extending with a free surface in, under, beside and/ or in front of a glacier originated by glacier activities and / or retreating processes of a glacier is defined as a *glacier lake*. Actually two types of glacier lakes are found in the Nepal Himalaya, moraine-dammed lakes and ice-dammed lakes as illustrated schematically in Fig. 1. The solid line and broken line indicate respectively a present glacier and a past glacier in the figure. The ice-dammed lake is rarely formed in Nepal. Almost all glacier lakes in the Nepal Himalaya are moraine-dammed lakes.

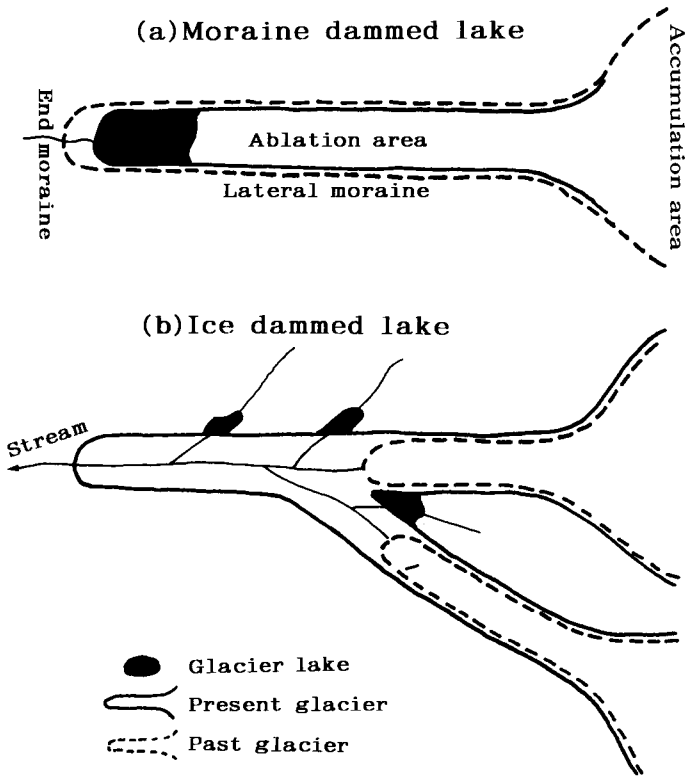

Fig. 1 : Schematic explanation of two types of a glacier lake in the Nepal Himalaya : a) moraine-dammed lake ; b) ice -dammed lake.

3. 2. 1 Moraine-dammed Lake

A typical example of a moraine-dammed lake (Fig. 1-a) is one formed on the tongue of the Imja glacier in the Khumbu region, East Nepal. This is shown in Photo 1 taken on 25 April, 1991. The position of the lake is shown by number 1 and an arrow in Fig. 4. In the retreating processes of a glacier, glacier ice tends to melt in the lowest part of the glacier surrounded by lateral and end moraines. As a result, many supra-glacial ponds are formed on the glacier tongue ; the ponds sometimes enlarge to become a lake by interconnection with each other accompanied by further deepening. A moraine-dammed lake is thus born. The lake is filled up with meltwater and rainwater pouring into the lake from the drainage area behind the lake and overflow from the outlet of the lake even in winter season when the flow is a minimum.

There are two kinds of moraine, an ice-free and a ice-cored moraine. Before the ice body of the glacier completely melts away, glacier ice exists in the moraine and beneath the lake bottom. As glacier ice continues to melt, the lake becomes deeper and wider. Finally ice contained in the moraines and glacier ice beneath the lake melt away ; the container of lake water consists of only the bedrock and the moraines. The ice bodies cored in the moraine and beneath the lake are sometimes called *dead ice* or *fossil ice*.

Photo 1 : Typical moraine-dammed lake ; a glacier lake formed on the Imja glacier in the Khumbu region, East Nepal (No. 1 in Fig. 5).

3. 2. 2 Ice-dammed Lake

An ice-dammed lake is produced on the side/sides of a glacier, when an advancing glacier happens to intercept tributary/tributaries pouring into a main valley where a glacier is flowing (Fig. 1-b). A typical lake is shown in Photo 2. Three lakes are seen on the right bank off the debris covered glacier tongue of the Ngozumpa glacier, the largest glacier in the Nepal Himalaya, which flows from right to left in the photo. The lakes were still frozen and covered by snow when the photo was taken on 25 April, 1991. Since the glacier in the Nepal Himalaya produces relatively rich debris, thick lateral moraines are deposited on both sides of the glacier tongue. Since such an ice-dammed lake is usually small in size and does not come into contact with glacier ice. This type of lake is less susceptible to GLOF than a moraine-dammed lake. A moraine-dammed lake is the only dangerous threat in the Nepal Himalaya. The description hereafter is, thus, concentrated on only a moraine-dammed lake and its outburst flood.

A glacier lake is only formed and maintained up to a certain stage of glacier fluctuation. If one follows the life span of an individual glacier, it is found that the glacier lake builds up and disappears with a lapse of time. A moraine-dammed lake may disappear, once the dam is fully destroyed or when debris fills up the lake completely or the mother glacier advances again to lower altitude beyond the moraine-dam position. The existence of a glacier lake is essentially ephemeral and not stable from the point of view in the life of a glacier.

Photo 2 : Typical ice-dammed lake ; three lakes covered by snow off the right bank of Ngozumpa glacier in the Khumbu region (No. 2 in Fig. 5).