CATASTROPHIC FLOODS IN ICELAND. H. Tómasson, National Energy Authority, Grensásvegur 9, 108 Reykjavík, Iceland. (ht@os.is)

INTRODUCTION: Glaciers are a part of the solid earth, but they move much faster than other parts of "terra firma". Their movement in interply with subglacial volcanism causes rapid changes and release of energy hardly known elsewhere in nature. The fastest movement and release of energy takes place in ice covered calderas and ice dam lakes (Tómasson 1991). If we define catastrophic flood as one with a peak flow of hundreds of thousands m^3/s we probably have a few every century in Iceland. The most recent observed event to meet this definition, is the Grímsvötn jökulhlaup in 1996 (Haraldsson et al. 1997). Its peak flow is estimated at 50,000 m^3/s. The catastrophic floods dealt with in this paper are Katla 1918; a prehistoric jökulhlaup from Mýrdalsjökull about 1700 years old, a very large jökulhlaup in Jökulsá á Fjöllum occuring about 2500 years ago and finally a series of jökulhlaups from ice-dam lake in Hvítá about 9500 years old.

THE LAND FORMS AND PROCESSES BY CATASTROPHIC FLOODS: The landforms created by catastrophic floods are alluvial plains on a gentle slope and the canyons eroded at steeper slopes. The flood-deposited alluvial plains do not differ much from other alluvial plains, but canyons differ much from most other such formations in size and cross-sectional area. There are two types of parent rock, i.e. hard basalt and soft móberg (tuff, breccia or pillow-lava). The erosion occurs in two ways, through stones rolling or jumping in saltation over the bottom or the rock is broken up by cavitation which acts like explosions and is a function of velocity and rock form.. The energy of a rock particle in movement is:

$$0,5*mv^2$$

Where m is mass and v is velocity. Particles in fast flowing water are rapidly worn down. This process might lead to depletion i of the big particles in the fluid and decreasing erosional capacity. Cavitation can play a part in this process and add to the erosive capasity by breaking the rock into particles, which will then further erosion. There is considerable difference between canyons eroded in bsaltic lava flows on one hand and móberg on the other. The basalt lava flows are eroded into wide canyons but the móberg into narrow ones. In the basalt lava flows cavitation is more intense as the columnar jointing and horizontal cleavage create more sharp edges necessary for cavitation. The moberg is eroded more by particles in saltation. Cavitation is probably also active in subglacial tunnels increasing the critical cross-sections and thereby eroding glacier ice and rock.

KATLA AND MÝRDALSSANDUR: The Katla caldera has been very active in recent centuries. Many of the eruptions have been fairly well described by eyewitness. The most recent eruption occured the 12th of October 1918. A detailed description based on eyewitness accounts was published in 1919 (Jóhannson; Sveinsson 1919), The flood volume is estimated by comparing the difference between the maps of the Danish Ordinance Survey from 1904 and the map of U.S. Army Map Service from 1946. The difference between the contour lines of these maps is about 1 km^3 which corresponds to the ash deposited on land in the eruption. Measurement done by Einarsson (1979) indicates that 90 % of the material on the sandur plains is volcanic ash from the eruption. The rest of the material (Tómasson 1995) extended the shoreline 1 km seawards, was carried by the eastern branch of the flood and was also airborne. The estimated total quantity of ash is 2,5 km^3, which corresponds to 0,9 km^3 of solid lava and melted 8 km^3 of ice. The maximum discharge was estimated from flow velocity based on eyewitness accounts and measured cross-sectional area as inferred from flood marks. The flow velocity was calculated as 10 m/s, and the cross-section 2700 m^2. The the main channel carried 270,000 m^3/s. An approximation of the magnitude indicates that the catastrophic flood at peak discharge carried 300 000 m^3/s of liquid water, suspended sediments and ice.

MARKARFLJÓT CANYON: About 2500 years ago catastrophic flood burst on from below Mýrdalsjökull flowing towards north. This flood eroded the Markarfljót canyon (Sigurðsson 1988), among the largest canyons in the country. In this canyon the difference between erosion in móberg and basalt is obvious. A wide almost dry canyon eroded into basalt is to be found in Innri Emstur and at the lower end of Markarfljót canyon. In between these is the main canyon eroded in móberg, narrow, but up to 200 m deep. The dating of this event is based on thick sand layer found in the soil at Landeyjar (Haraldsson 1981).

JÖKULSÁ Á FJÖLLUM: The greatest catastrophic flood in postglacial time occurred in Jökulsá á Fjöllum. Traces of that flood are obvious all the way from the Vatnajökull glacier dawn to the sea shore about 170 km away. The bedrock is basaltic lava of various age. On the interior high plateau the slope is gentle and the flood path is markedby plucked and eroded rock surface, alternating with huge depositional gravel and sandbars. At the highland margin the canyons are eroded mostly into thick-bedded basalt lava flows. The total eroded volume is estimated $500+10^6$ m^3. The uppermost part is eroded into thick lava flows. the middle part is Svínadalur, a basin filled with postglacial lava now to a great extentl eroded; the lower canyon is eroded into lava flows. Parallel to the lower canyon is the erosion form Ásbyrgi. The landforms at Jökulsá á Fjöllum have strong resemblance to the channeled scabbland and canyons of the Columbia basalt plateau in the U.S. The Columbia plateau was flooded in catastrophic floods from ice dam lake Missula (Bretz 1959) in Montana.

The catastrophic flood in Jökulsá has been dated with tephrocronology. (Þórarinsson 1960). According to that all tepra layers older than H_3, which is 2800 years old, are lacking in the flood path, but a tephra layer about

2000 years old is found at the bottom of the soil layer. This indicates that the flood event is about 2500 years old. Since the colonization of Iceland 1100 years ago 8 jökulhlaup are documented in annals. These descriptions indicate jökulhlaups in the rance of some thousand m^3/s (Þórarinsson 1960). Whithin the watershed of Jökulsá in Vatnajökull there is a very active volcanic area. Most active and probably largest is Bárðarbunga volcano. Measurements have shown that under Bárðarbunga there is (Björnsson 1987) a huge caldera. South of Bárðarbunga is another well-known caldera, the Grímsvötn. In following table the two calderas are compared. All conditions favor a much bigger flood from Bárðarbunga than Grímsvötn.

	Grímsvötn	Bárðar-bunga
Drainage area km^2	160	80
Caldera km^2	24	48
Threshold ele. m a.s.	1200	1400
Bottom ele. m a.s.	1050	1100
Volume km^3	3,6	14,4

There are two types of Jökulhlaup. One type that increases slowly with low peak-flow and a considerable time lapse before reaching the peak. Such floods are cool and the conduit under the glacier is enlarged through frictional heat and erosion. The other type of jökulhlaups increases very fast. They have above zero water geting heat from geothermal activity or a volcanic eruption. A good example is jökulhlaup from Grímsvötn. The volume of the Grímsvötn jökulhlaup in 1940 to 1990 was in the order of magnitude 1-3 km^3, and the peak flow reached 1000-7000 m^3/s and lasted 2 weeks from outbreak to peak. The 1996 jökulhlaup (Haraldsson 1997) increased very fast, was hot in the beginning, but lasted only about a day. The total volume was 3,6 km^3 and peak flow 50,000 m^3/s. This flood was associated with a volcanic eruption. The same processes are responsible for the jökulhlaup from the caldera in Bárðarbunga. The present condition in the caldera is such that it is full of ice and there is no water accumulated at its bottom (Björnsson 1987). The melted water must leak out of the caldera through rock. Every now and then the geothermal heat or volcanic activity increases substantially and meltwater accumulates in the caldera and escapes in jökulhlaups, which are usually small in comparisation to the catastrophic floods. But occationally all conditions are favorable for catastrophic floods. The last time this occurred was 2500 years ago.

This catastrophic flood is calculated from slope and cross-sectional area to have been 500,000 m^3/s. Probably, big floods have often taken place and even some of them have been classified as catastrophic (Elíasson 1977). But the whole picture is of one catastrophic flood, much bigger than any previous or later floods. The simultaneous maximum volume of water in the flood channel was about 5 km^3, and it took the water 11 hours to flow in wetted channel from the glacier to the sea (Tómasson 1973). The probable total volume of the flood is 15 km^3 and it lasted 1-2 days.

HVÍTÁ Í ÁRNESSÝSLA AND KJÖLUR: The catastrophic floods in Hvítá were different from the one described above, which all came from volcanic calderas and a accompanied by volcanic activity. But the floods in Hvítá came from ice dam lakes created when the main inland glacier in Iceland retreated over the water divide at Kjölur gradually creating a very big ice dam lakes south of the water divide (Tómasson 1993). Conditions favorable for the creation of the big floods has probably lasted 100-200 years. This was at the final stage of the last glaciation of Iceland some 9500 years ago.

The ice dam lakes left shorelines at different levels. The uppermost are formed above the water divide towards north, but the clearest are at the level of the water divide. At that level a continuous flow has been towards north. Most of the shorelines are at a lower level. At the level of Bláfellsháls a fairly clear shoreline is found indicating a continuous flow of some duration. That period ended with the catastrophic flood east of Bláfell..

The flood channel is clear from elevation 300 to 50 m a.s.l. The most conspicuous part of it is the Gullfoss canyon. It is at the edge of the high plateau, and the total volume is $100*10^6$ m^3. Down stream of the canyon is a hugh gravel bar laid down by the catastrophic floods. The maximum discharge is estimated at 200,000 m^3/s and the volume of the lake was approximately 25 km^3. This has been a cold lake with the floods lasting 2-3 weeks.

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