Gullfoss 8

The drive from Geysir to the waterfall Gullfoss along Road 35 is short. The waterfall, which constitutes the **eleventh stop (11)**, is located in Fig. 4.1. The main features to see on the way are the hyaloclastite mountains north of Geysir and, if the visibility is good, the southern part of the ice cap **Langjökul**l (the Long Ice Sheet). However, to really enjoy the glaciers or ice caps, one needs to approach them, and such a trip is beyond the present excursion. We therefore drive on to Gullfoss, the most famous waterfall in Iceland (Fig. 8.1).

8.1 Why Has Gullfoss Two Oblique Steps?

Gullfoss (The Golden Waterfall) is in the glacier river **Hvita** (**Hvítá, White River**). Part of the beauty of Gullfoss lies in the **two main steps** that constitute the waterfall whose total drop (waterfall height) is 32 m (Fig. 8.1). These steps make an (acute) angle of about 60°—and thus a larger (obtuse) angle of about 120° (Fig. 8.2). More specifically, the upper waterfall or step has a direction (trend, strike, azimuth) of about 75° (the angle is always referred to the geographical north), whereas the lower waterfall or step (into the main channel or gorge) has a direction of about 15°. Then main river channel to the southwest of Gullfoss has a general trend or azimuth of about 40°. All these fracture directions are indicated schematically in Fig. 8.2.

The same main directions are seen at other locations southwest along the main river channel, that is, the main channel itself trends about 40° (always referring to azimuth, that is, east of north) and is dissected by fractures with the two other trends, the one at about 15° and the other at about 75°. These fracture trends are also seen in some of the nearby river channels and all over South Iceland. These directions clearly mark systems or sets of earthquake fractures and are easy to explain.

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Fig. 8.1 General overview of the waterfall Gullfoss. View east, the waterfall consists of two main steps, with a total drop (waterfall height) of 32 m. The waterfall is located in the river of Hvita (Fig. 8.2)

Fractures with the trend of about 40°, that is, trending northeast-southwest, characterise all the volcanic systems in the southern half of Iceland, as well as the West and East Volcanic Zones (Fig. 2.2). As we already know from the Reykjanes Peninsula and Thingvellir (Chaps. 2, 5 and 6) the larger fractures with this trend are mostly **normal faults**, and that applies to the fracture forming the main channel southwest of Gullfoss (marked by B in Fig. 8.2). Thus, the main canyon presumably developed along a normal fault zone, containing also tension fractures, which may originally have been partly similar to Almannagja (Figs. 5.1, 5.2 and 5.8).

The other two directions, 15° (marked by C in Fig. 8.2) and 75° (marked by A in Fig. 8.2) coincide with well-known fracture systems that produce earthquakes in entire South Iceland. These fracture systems are faults that are generated (slip, move) in the same stress field as controls the presently active **South Iceland Seismic Zone** (Chaps. 9 and 14). Everywhere in South Iceland there are faults with these two directions: one is north-northeast (about 15° at Gullfoss but somewhat variable), and the other one is east-northeast (about 75° at Gullfoss but also somewhat variable). In contrast to the normal faults at Thingvellir, such as

Almannagja, where the movement of the fault walls is primarily vertical (up and down the fault plane; Figs. 4.14 and 5.9), the movements of the walls of the faults that characterise South Iceland Seismic Zone are primarily horizontal. Such faults are named **strike-slip faults**—San Andreas in California (the United States) is among the most famous examples of such a fault. Beautiful examples of these types of faults can be seen in some of the hyaloclastite mountains in South Iceland, perhaps the best example being in **Vördufell**, which we will discuss at the twelfth stop later today (Chap. 9).

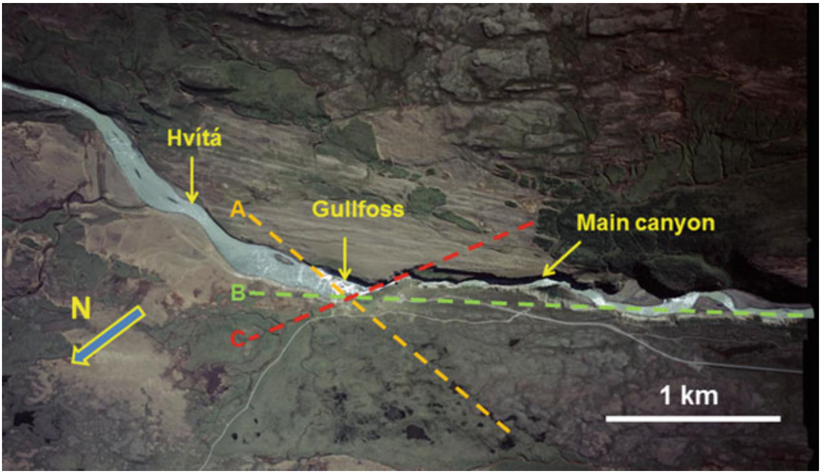

Fig. 8.2 Aerial view of the canyon of the river Hvita (Hvítá), namely Hvitargljufur (Hvítárgljúfur), and Gullfoss. The main steps that constitute Gullfoss have very different orientations, and are also different in orientation from the trend of the main canyon itself. All the three orientations are related to earthquake fractures, that is, faults. The main canyon, running parallel with the broken green line B, relates to a normal fault zone, perhaps originally similar to Almannagja (Chap. 5), and trends about 40°. The upper step, running roughly parallel with the broken orange line A, is related to a fault, and so is the lower step, which runs parallel with the broken red line C. All the faults A, B, and C are typical for South Iceland. A is called a sinistral or left-lateral strike-slip fault, whereas C is called a dextral or right-lateral strike-slip fault. These technicalities need not concern us here, but are mentioned in case you wanted to explore the fault pattern in greater detail—here and in later chapters. The direction of geographic north (N) is indicated with a thick arrow, and so is the scale, that is, the length of 1 km

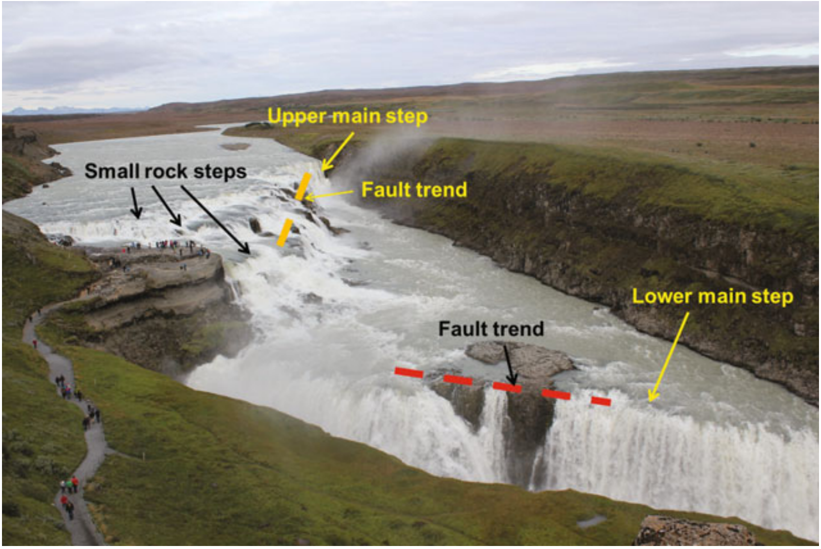

Fig. 8.3 Details of Gullfoss. View east, the main upper step is composed of several smaller rock steps (forming a series of cascades). By contrast, the lower main step is a single one. The upper step is about 11 m in total, whereas the lower step is about 21 m. Also indicated, crudely, are the two fault trends that contribute to the formation of the oblique steps (Fig. 8.2)

So the earthquake fractures offer zones of weakness in the rocks that the water of the river Hvitá can easily erode, forming a major gorge or canyon (Figs. 8.2, 8.3, 8.4 and 8.5). The main canyon (Fig. 8.2) follows the more fractured and thus more easily eroded normal fault zone. It is named for the river as Hvitargljufur (**Hvítárgljúfur**, White River Canyon) has a maximum depth of about 70 m and a length of some 2500 m. The **zig-zag geometry** of the river channel (Fig. 8.2), particularly close to and at Gullfoss, is, as discussed, the consequence of the two other main earthquake fault (strike-slip fault) directions (A and C in Fig. 8.2) that make for fractured rocks and easy erosion.

Fig. 8.4 The part of the canyon that is parallel with the strike-slip fault, indicated by red broken line in Figs. 8.2 and 8.3. View south, at its south end, this canyon joins the main canyon at an acute angle of about 35°

8.2 How Did the Canyon Evolve?

How easily the river **erodes** the rocks and expands the canyon depends on the properties of the rock layers themselves (Figs. 8.1, 8.3 and 8.6). The lower step in the waterfall, and the associated canyon, is primarily composed of a thick basaltic lava flow with numerous columnar or cooling fractures (Figs. 8.4 and 8.5). The upper step, however, is composed of various rock layers. The layers are primarily of two types: basaltic lava flows with columnar joints, and sedimentary layers. The **lava flows** were formed during interglacial (ice free) periods, whereas the **sediments** (rocks formed through erosion and transport of rock particles) were mostly formed during the glacial (ice) periods of the past several hundred thousand years (Chaps. 3 and 4).

How the rock layers respond to the flowing water and its pressure depends on many factors and is not always easy to forecast. We might think that the 'strong' basaltic lava flows would be very resistant to erosion, but that is not necessarily so. This follows because the vertical cooling fractures, **columnar or cooling joints**, make the lava flows weak in response to water pressure from above. The lava flow resistance to erosion also depends on the layer thickness: thin layers with numerous vertical fractures are generally more easily eroded by flowing water than thick layers.

Some sedimentary rock layers are comparatively strong, whereas others are weak; the strength depends on their grain size and other properties. What we see is that the top lava flow has been largely eroded whereas the topmost sedimentary layer (the one the people are standing on in Fig. 8.6) is comparatively strong—and thus forming an overhang. The sedimentary layer below is easily eroded, whereas the lowermost sedimentary layer is comparatively strong. Below that layer is again a lava flow that is comparatively resistant to erosion. This layering of the upper

Fig. 8.5 The same part of the canyon as in Fig. 8.4 but from a different perspective. The canyon is primarily composed of basaltic lava flows, indicated, with numerous vertical columnar joints. These are aa lava flows, and thus formed of a single unit, in contrast with the pahoehoe lava flows seen in the walls of Almannagja, which are composed of many thin flow units (Figs. 5.5 and 5.6). The columnar joints are very well developed in these lava flows and made them comparatively easy to erode by the river

Fig. 8.6 Gullfoss gradually moves inland as the erosion of the steps that constitute the waterfall continues. View east, the upper step, seen here, is composed of rock layers of different composition and strength. 'Strength' here means resistance to erosion. The lava flows are only moderately resistant to river erosion because they contain numerous fractures, columnar or cooling joints (Fig. 8.5), that make the rocks more easily eroded, or 'weaker'. The sedimentary layers are of several types. Depending on the grain size and other factors, some of the layers are comparatively strong or resistant to river erosion, whereas others are weaker or less resistant to erosion, as indicated. The different layers are reflected in the small rock steps that characterise the upper step (Fig. 8.3)

step can be seen in the geometry of the waterfall itself. The layering results in the upper step not being a single one, but rather composed of four to five **small rock steps**, **cascades** (Figs. 8.1 and 8.3), each of which corresponds to one of the layers in Fig. 8.6.

Gradually, however, the layers become eroded and the canyons become longer. The main canyon, Hvitargljufur (Figs. 8.4 and 8.5) and all the structural features associated with Gullfoss itself as seen today must be formed since the ice caps of the last ice period disappeared. This follows because glaciers always tend to change narrow river canyons and valleys into larger U-shaped valleys. This has not happened here—the canyon walls are clearly vertical (Figs. 8.4 and 8.5)—so that the canyon and the entire associated landscape must be younger than the last glaciers in this part of Iceland. This part of Iceland became permanently ice free some 8–9 thousand years ago. If, as is likely, the entire 2500 m long Hvitargljufur was formed in the past 8–9 thousand years, then the rate of growth or expansion of the canyon must have been, on average, about 30 cm per year. And this is the same rate as Gullfoss itself is moving up the canyon. So every year, on average, the waterfall itself moves some 30 cm to the northeast, that is, further inland.

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