Introduction 1

If you want to understand the natural forces that shape our planet, then the place to go to is Iceland. There is no equally small area on this planet that offers such a variety of easily observed geological processes as Iceland. You can observe the **tectonic plates** that constitute the Earth's surface moving apart, also known as **spreading**, and thereby giving rise to volcanic eruptions, earthquakes, geysers, and geothermal energy. Then there are the large rivers with beautiful waterfalls, as well as the ice caps and the outlet glaciers that have cut or eroded deep valleys and fjords into the land, the surface of the crust, forming tall mountains in-between. All these are easily observed and understood in Iceland.

Because the geological processes and structures are so clear and easily observed in Iceland they can be understood without any geological background. Just looking at the landscapes and the rocks, you should, with the help of this book, be able to recognise the main landforms, by which processes they are generated, and how the processes operate. The aim of the book is to illustrate and explain what main landforms and geological processes can be seen during five **one-day excursions** (described below) in a way that is understandable to those without a formal education in geology. With this in view, I keep technical concepts and jargon to a minimum and use everyday examples and analogies to explain the landforms and processes that you can see in Iceland. Every concept is defined when it is first introduced, and in addition there is a detailed **glossary** at the end of the book, summarising in simple terms the meaning of some common geological and other scientific terms. I use **boldface** type for emphasis and for words that are explained in the glossary. More specifically, boldface is used for important items, technical or semi-technical terms, particularly where first used, and for the stops during the excursions.

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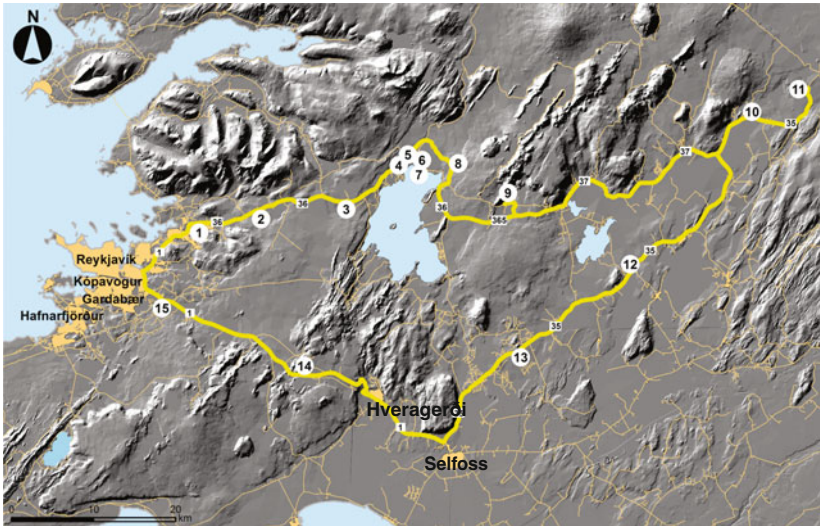

Fig. 1.1 The location of the Golden Circle, shown in yellow. The large encircled numbers, here and on other similar maps, refer to the main stops during the excursions. The small numbers in squares indicate the road numbers. The orientation of north is shown by an arrow in the upper left corner, whereas the scale is indicated in the lower left corner. The city of Reykjavik and the main towns are indicated in orange-brownish colour. The location of the Golden Circle within Iceland as a whole is provided in Fig. 1.5 and a larger version, with more details, in Fig. 4.1. Although the real geometry of the Golden Circle is that of a triangle rather than a circle, the name is traditional and use here. Fig. 4.1 is a larger version of this figure

All the processes mentioned above and their products can be seen in the southwestern part of Iceland, and many along the so-called 'Golden Circle'. While there are somewhat different definitions of the Golden Circle—which is geometrically not really a circle but rather closer to a triangle (Fig. 1.1)—to most people the Circle is composed of the following trips:

- From Reykjavik to the Thingvellir Graben.
- From Thingvellir to the Geysir geothermal field.
- From Geysir to the waterfall of Gullfoss.
- From Gullfoss to the crater of Kerid.
- From Kerid to Reykjavik.

Some versions of the Golden Circles include additional stops. For example, some prefer to stop at the Skalholt Cathedral in central South Iceland, an important historical site but geologically of little interest—and thus omitted here. Similarly, some include the town of Hveragerdi and the power plant of Hellisheidarvirkjun. Both are located in geologically interesting places, not only in relation to geothermal fields and geothermal power but also because they are located close to (Hveragerdi) or inside (Hellisheidarvirkjun) active volcanoes (Hengill) and zones of earthquakes. Hveragerdi and Hellisheidarvirkjun are both discussed briefly in the present version of the Circle, and are optional stops.

The Golden Circle described here is the one in Fig. 1.1. It includes 15 main stops or sites and thus many more than listed in the bullet points above. These additional stops are chosen because of their geological interest. I show photographs from some of the main sites in Fig. 1.2. But the descriptions are not confined to the main sites—Esja, Thingvellir, Geysir, Gullfoss, and Kerid. There are many interesting geological features that can be observed between the main sites. Most of these can be seen from the roads that constitute the standard Circle; for others you need to drive a short distance off the main road. For example, on Road 365 from Thingvellir to Geysir, a short drive to north off that road to Laugarvatnshellar (the Caves of Laugarvatn, the ninth stop) offers many geological features of interest. Not only are the caves themselves interesting (they were inhabited in the early part of the 20th century), but nearby is a section through an inactive volcano that allows you to understand how volcanoes and volcanic islands form during eruptions in water, such as the meltwater of ice caps. In particular, the ninth stop is the location of beautiful **pillow lava** (Fig. 1.3), the type of lava commonly formed at great water depths at mid-ocean ridges. The pillows are found here because the mountain formed in deep water, more specifically in the melt water within the ice sheet of the last ice age. Eruptions in deep water, in the sea or under ice caps, are still happening in Iceland. For example, one such eruption occurred in the Vatnajökull ice cap (located in Fig. 2.2) in 1996 (Fig. 1.4), and the 2010 Eyjafjallajökull eruption (Chap. 14) was partly within an ice cap.

The chapters related to the Golden Circle are broadly of two types. One type describes remarkable geological features and processes seen on the way between the main sites (for example, between Thingvellir and Geysir). The other type describes the main sites themselves, the interesting features that can be seen, and by which geological processes they form and develop.

There are many exciting and beautiful geological structures and activities that can be seen in the vicinity of **Reykjavik** in addition to those of the Golden Circle. I presume many who come to Reykjavik would be interested in seeing more of Iceland's fascinating geology than just the Golden Circle. I have therefore added

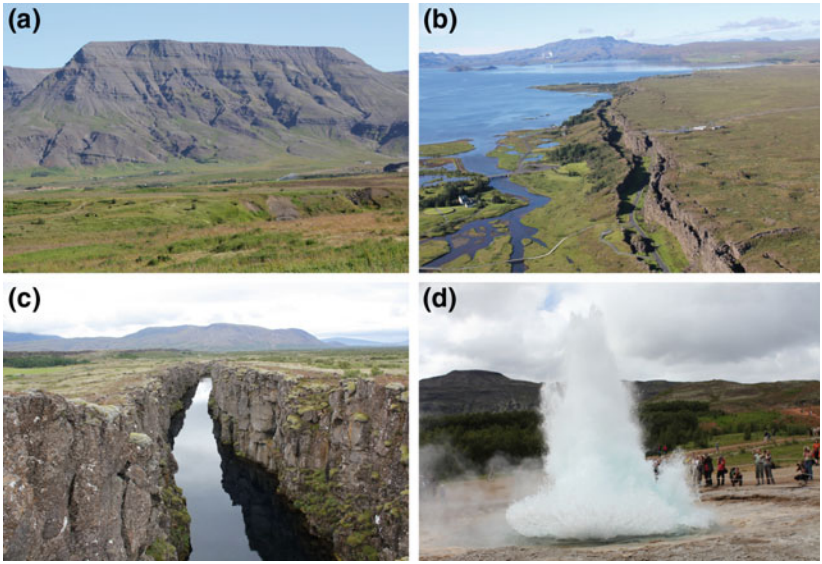

Fig. 1.2 Examples of geological and landscape features seen while travelling along the Golden Circle. All these features are shown again, and discussed in great detail, in Chaps. 4–9. **a** The mountain Esja, which can be seen from Reykjavik (first stop in Fig. 1.1). The rock layers that constitute this mountain originated tens of kilometres to the east, in the volcanic rift zone at Thingvellir, and have been carried through slow spreading (about 1 centimetre per year) to where they are seen now. **b** Part of the active volcanic rift zone at Thingvellir. The photograph is taken from an aircraft, view southwest across Lake Thingvallavatn to the central volcano (stratovolcano, composite volcano) of Hengill—the white 'smoke' is from geothermal fields. The large fracture is an earthquake fault, as wide (open) as 60 m, formed by spreading or plate-tectonic forces (the fourth, fifth, and sixth stop in Fig. 1.1). The land left (to the east) of the fracture has subsided by 40 m. **c** A tension (open) fracture at Thingvellir (the seventh stop in Fig. 1.1). The maximum opening (aperture) of the fracture is about 15 m and the maximum visible depth 25 m, but it may reach to a depth of several hundred metres. The fracture is filled with very clean groundwater. **d** The erupting hot spring, geyser, Strokkur (the tenth stop in Fig. 1.1). The fractures supplying the boiling water for the eruptions maintain their openings or apertures through earthquake activity. **e** The Gullfoss waterfall (the eleventh stop in Fig. 1.1). The total drop is about 32 m and occurs in two steps which follow the directions of the main earthquake fractures in South Iceland. Through erosion, the waterfall is gradually migrating further inland, by about 30 centimetres per year. **f** The crater (volcano) Kerid (the thirteenth stop in Fig. 1.1). It is a collapsed small lava pond, a pit crater, now partly filled with groundwater. Its maximum diameter is about 300 m and depth about 50 m

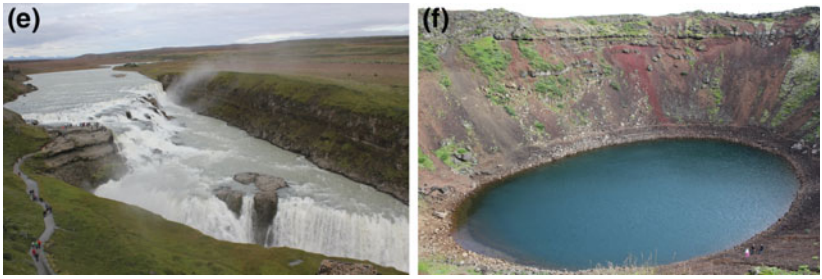

Fig. 1.2 (continued)

several one-day excursions to sites in the vicinity of Reykjavik, namely the following (Fig. 1.5):

- Reykjavik-Hvalfjördur.
- Reykjavik-Hengill.
- Reykjavik-Kleifarvatn-Reykjanes.
- Reykjavik-Eyjafjallajökull-Reynisfjara.

Some of the highlights from these additional excursions are shown in Fig. 1.6. In Hvalfjördur, for example, you can observe the magma-filled fractures (now frozen as solid rock, that is, **dikes**) that supply magma to volcanic eruptions. In Hengill, an active volcano, there is a very unusual and beautiful landscape of valleys and ridges, formed by eruptions and earthquake fractures, that is, **faults**. In the excursions to Reykjanes, you can explore a major geothermal field, explosion craters, the Blue Lagoon, and the fracture referred to as the 'Bridge Between Two Continents'. And in the excursion to Reynisfjara you can observe the famous volcanoes Hekla (from a distance), Eyjafjallajökull, and Katla, in addition to beautiful waterfalls and sets of fractures, referred to as columnar joints, formed when hot molten rock, magma, freezes or solidifies slowly.

Most people who visit Iceland arrive at the Keflavik Airport (Keflavikurflugvöllur). From there most of them drive to the capital Reykjavik or one of its surrounding towns. The Keflavik Airport is located on the Reykjanes Peninsula, which has many interesting geological features in addition to the well-known Blue Lagoon. Some of these features can be seen from the road while driving to Reykjavik. Since this drive provides the introduction of most people to

the landscapes and geology of Iceland—although few would describe this part of the country as beautiful—it is logical to start the present book with a brief chapter on the geology seen from the road from Keflavik to Reykjavik (Figs. 1.5 and 2.1).

Before we begin that journey, however, a few words about numbers and spelling of names. As for numbers, particularly the ages of rocks, I commonly give only the first digits and then add the appropriate word, such as thousands or millions. For example, I write 13 thousand years old and 2 million years ago. When the number is presumed very accurate, then I write out the entire number, such as for an eruption that occurred in the year 1000 or the settlement of Iceland which is supposed to have happened in the year 874. I do not use commas in 4-digit numbers, including years. Thus, I write 1200 °C rather than 1,200 °C.

Fig. 1.3 Lava flows that resemble a stack of pillows, that is, ellipsoidal bodies of (mostly basaltic) lava are named pillow lavas (ninth stop in Fig. 1.1). Molten rock, magma, forms pillow lavas under water, the water being meltwater when the eruption occurs beneath a glacier (subglacial eruptions) like here. Individual pillows are commonly about 1 m or less in diameter. Pillow lavas form the lowermost layers in many volcanoes seen in Southwest Iceland, most of which are formed in subglacial eruptions and referred to as hyaloclastite (in Icelandic moberg) mountains. Pillow lavas are also very common at mid-ocean ridges, and some in Iceland are formed in eruptions in the sea (submarine eruptions)

Fig. 1.4 The 1996 Gjalp eruption in the ice sheet Vatnajökull (located in Fig. 2.2) in Iceland. This eruption melted through the glacier, forming hyaloclastite and presumably pillow lava (Fig. 1.3), and caused an enormous flood on the sandur plaines in southern Iceland. Vatnajökull and its volcanoes are outside the scope of the present excursions, but this photograph is a reminder that the processes forming the pillow lavas and most of the volcanoes that you see in the excursions in Southwest Iceland are still operating. The dark, fractured surface is the surface of the ice sheet and the depression and fractures are because of melting from the hot magma beneath the ice sheet. This photograph is from the beginning of the eruption

For 5-digit numbers and higher, however, I use comma, such as in describing a map scale as 1:17,000. As for names, Icelandic has ten letters that do not exist in English. These are the letters á, ð, é, í, ó, ú, ý, þ, æ, and ö. Notice that the letters ö and æ are specific letters and sounds, as are the letters with acute accents, such as á and é. In the book, I transliterate the letters ð as d and þ as th, as is normally done, and æ as ae. Also, I keep ö but omit all acute accents: that is, I write a for á and u for ú, and so forth (as in my own name, which is Ágúst in Icelandic but Agust in English). In the following chapters where the name occurs for the first time (and for some more often) in the main text I give the Icelandic spelling in parentheses following the English spelling. In some chapter headings, I also give the Icelandic spelling when it differs much from the English spelling, such as in the word

Thingvellir, which in Icelandic is Þingvellir. I have translated some of the Icelandic geographical names, particularly those that are geologically interesting, but most are untranslated. In the road maps showing the excursions I use the Icelandic spellings of names because that is the way the spelling is on the topographic and geological maps that you are likely to buy and use.

Which brings me to the topic of **maps**. While I show all the main roads associated with the excursions, and associated digital elevation (shaded topographic) maps, I do not provide detailed topographic maps. Nor do I provide geological maps, but I give full reference to the most important ones for this book in the list of references at the end of the book. Topographic and geological maps are readily available in bookstores and elsewhere in Reykjavik. In particular, there

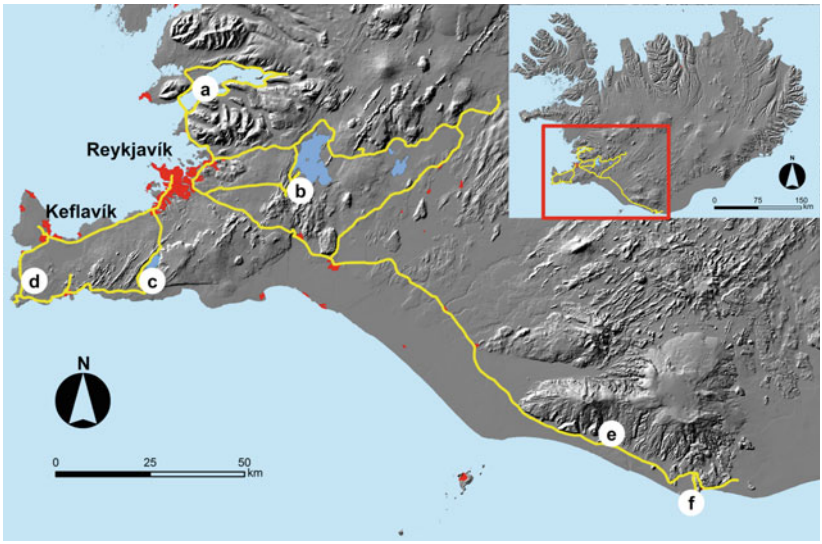

Fig. 1.5 The standard 'Golden Circle' is indicated in Fig. 1.1. To make the book more useful, it covers four additional excursions, shown here in addition to the Golden Circle, in relation to Iceland (inset map). These are to **a** the fjord north of Reykjavik (Hvalfjördur), **b** the Hengill Volcano (seen in Fig. 1.2b), **c**, **d** the Reykjanes Peninsula, and **e**, **f** Eyjafjallajökull (erupted in 2010) and the coast of Reynisfjara (cf. Fig. 10.1). These extra excursions allow you to see deep into the structure of (inactive or extinct) volcanoes, observe geothermal fields and explosion craters, see the famous volcanoes of Hekla and Eyjafjallajökull (located in Figs. 14.1 and 14.12 b) as well as exploring some of the most beautiful waterfalls and beaches of Iceland. Some of the photographic highlights of these excursions are located by the letters **a** to **f**, the corresponding photographs being shown in Fig. 1.6

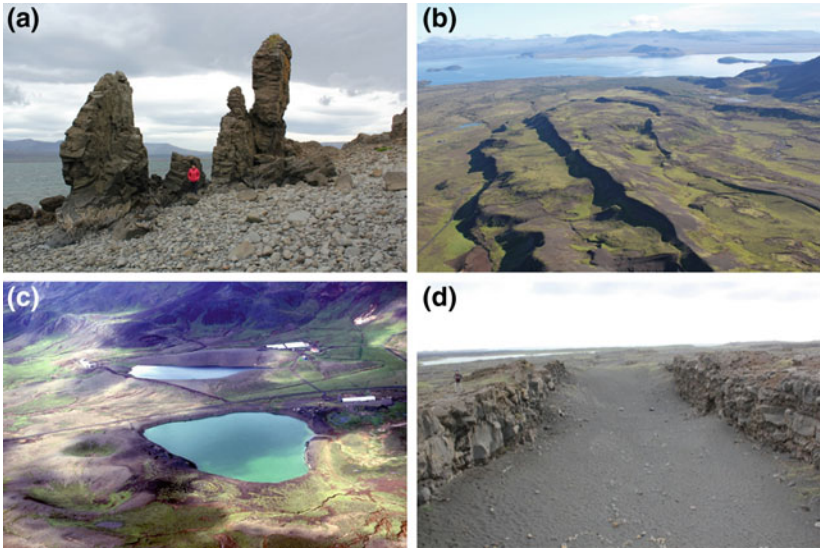

Fig. 1.6 Examples of geological and landscape features seen while making the extra excursions shown in Fig. 1.5. All these features are shown again, and discussed in great detail, in Chaps. 11–14. **a** Molten rock or magma is normally transported in the Earth's outermost solid layer, the crust, along fractures. When the magma subsequently freezes in the fractures, it forms structures named dikes (or dykes). Here is a dike in the fjord Hvalfjördur (located at **a** in Fig. 1.5) which forms a sea stack because it is harder (more resistant to erosion) than the surrounding host rock. The horizontal columns form during cooling of the magma (discussed in **f** below). **b** Aerial view of earthquake fractures (normal faults) in the Hengill area (located at **b** in Fig. 1.5). View north to Lake Thingvallavatn, the faults are large in the old rocks but become smaller in the young lava flow close to the lake. **c** Aerial view of explosion craters, also known as maars, near Lake Kleifarvatn (located at **e** in Fig. 1.5). The one with the green water has a maximum diameter of about 360 m and a depth of 45 m. **d** The tension fracture across which is the 'Bridge Between the Two Continents' (located at **d** in Fig. 1.5). The maximum opening or aperture of the fracture is about 30 m (15 m where the bridge crosses it). **e** The Skogarfoss waterfall (located at **c** in Fig. 1.5) falls or drops vertically about 60 m off an old sea cliff. The cliff was formed some 13 thousand years ago when the sea level was much higher than today. **f** When a magma body cools to form a solid rock (here a basaltic intrusion), the body shrinks and may generate beautiful columns. Here some of the rock columns in Reynisfjara (located at **f** in Fig. 1.5) are seen. The columns are vertical, indicating that they formed in a horizontal sheet-like magma-filled fracture known as a sill

Fig. 1.6 (continued)

exists a very detailed geological map (scale: 1:100,000, meaning that one centimetre on the map corresponds to one hundred thousand centimetres, or one kilometre, in nature) of Southwest Iceland. There are also available geological maps of Southwest and South Iceland (scale: 1:250,000) that cover all the excursions. For those who like great details, perhaps the best are the photomaps, that is, aerial photographs with all the place names and elevation contours shown. Such maps (scale: 1:17,000) are available of the Reykjanes Peninsula, Gullfoss and Geysir, and some other areas. The topographic map Reykjanes-Þingvellir (scale: 1:100,000) is very useful and includes a special and more detailed map of Thingvellir (Þingvellir) itself. In addition, there are many other geological and topographic maps, of parts of Iceland as well as the entire country.

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