Mineral Resources in Iceland

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By

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Cambridge
Scholars
Publishing

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This book first published 2021

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN (10): 1-5275-6717-6
ISBN (13): 978-1-5275-6717-7

»ÞEIR SEM EKKI HAFA GULLIÐ,
VERÐA AÐ NOTA LÁTÚNIÐ«

(“*Those who do not have gold must use brass*”)

Ólafur Ólafsson, 8 September 1915

In memory of

professor Mikhail A. Akhmetiev

January 23, 1935 – October 17, 2020

and his book “Late Cenozoic Stratigraphy And Flora Of Iceland”

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PREFACE

Coal mining has been linked with the flourishing of Icelandic economy for centuries. Iceland is not among the countries known for their large coal reserves; instead, it is known for its spectacular landscape shaped by active volcanoes and its position between two continents sitting on a hot spot over the Mid-Atlantic Ridge. In contrast to the touristic places in the centre of the island, the eastern and western fjords of Iceland are less travelled and less touristic. It is there, where many of the close to two-hundred sites with lignite (brown coal) described in this book are found. Unlike at other places of the "Brito-Arctic Igneous Province" such as the Faroe Islands, western Greenland and Spitsbergen, where lignite was mined on a large scale (Larry 2020), in Iceland, the extraction of coal never became a success story because of the small size of the coal reserves, the high mining costs and the low calorific value of the coal. This may be due to the much older age of lignite found at the margins of the Brito-Arctic Igneous Province, related to warmer and more equable conditions favouring coal formation in the Paleogene. Coal seams in Iceland formed between 15 and 3 million years ago, when climate was considerably cooler than during the Paleogene (Zachos et al. 2001).

This book is devoted to these coal seams, which, on average, are not more than several centimetres thick and only in some cases have been commercially exploited. And yet, like in other countries, mining efforts in Iceland increased during times of economic crises, after World War I and again in the 1980s.

The authors of this book provide an up-to-date summary of the geologic and climatic evolution of Iceland, followed by descriptions of all coal seams known from Iceland and physical-chemical properties of Icelandic coals. This opens up a wide range of future studies including the investigation of coal-forming processes related to palaeoenvironmental conditions (e.g., Steininger et al. 1988) and cutting-edge new approaches to extract terrestrial palaeoclimate from lignites (e.g., Inglis et al. 2013).

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ACKNOWLEDGEMENTS

This book could not have been written without the help of the following people and institutions. We sincerely thank the staff of Icelandic museums and libraries, especially Erlendur Már Antonsson and Halldóra Kristinsdóttir (Landsbókasafn Íslands – Háskólabókasafn / National and University Library of Iceland), Rósa S. Jónsdóttir (Orkustofnun – Bókasafn / National Energy Authority – Library), Magnús Guðmundsson and Anna Sveinsdóttir (Náttúrufræðistofnun Íslands / The Icelandic Institute of Natural History) and Snorri G. Sigurðsson (Héraðsskjalasafn Þingeyinga / Þingeyinga Regional Archives) for providing access to important articles and manuscripts. We are grateful to Kristín Halla Baldvinsdóttir (Þjóðminjasafn Íslands / National Museum of Iceland) and Jóna Símonía Bjarnadóttir (Byggðasafn Vestfjarða / Westfjords Heritage Museum) for supplying historical photographs from the museum's depository. Helgi Torfason is thanked for translating Icelandic poems and proofreading the translation of medieval Icelandic texts. Lothar Herbert Vallon and Tina Kjeldahl-Vallon are acknowledged for translating medieval Danish. We also thank Einar G. Pétursson (Háskóli Íslands / University of Iceland) for his advice on Icelandic medieval literature. Last but not least, we thank Thomas Denk (Swedish Museum of Natural History) for writing an interesting and positive preface, Lukáš Kraft for providing geodetic measurements and drawing plans, and Jiří Adamovič (Institute of Geology of the Czech Academy of Sciences) for the proofreading. The editor-in-chief's editing of the manuscript and the highly valuable advice and recommendations by the reviewers and also by Guido W. Grimm (Independent researcher, Orléans, France) were much appreciated. Financial support for research in Iceland was provided by the J. E. Purkyně University Internal Grant Agency UJEP-SGS-2020-44-003-3 "*Subarctic Undisturbed Regions – Transdisciplinary Utility Research (SURTUR)*". The book was created within the activities of the *Institute Julius von Payer for Subarctic and Arctic Research* (J. E. Purkyně University in Ústí nad Labem, Faculty of the Environment).

INTRODUCTION

Iceland enters the 20th century. An island at the north-western periphery of Europe, being under the yoke of Denmark for centuries, and known as a land of myths and legends among the people of Europe. The economy of Iceland rests upon fishery and manufacture of fish products: their export accounts for 77 % of all exported goods. The gross domestic product *per capita* is one of the lowest in western Europe.

The population of Iceland is less than 80,000, with close to no annual increase; this is due to massive recession and famine after the eruption of the Askja volcano in 1875. Many young Icelanders have left for Canada and the United States of America with a prospect for a better life. Most of the population live scattered on farms, and the first gravel roads are being built. Reykjavík is a mere fisherman community with about 6,000 inhabitants. Electricity will start to serve parts of the town no sooner than in 1921.

Two-thirds of the energy are produced from coal, which is mostly imported from Great Britain, the other third of the energy is produced mainly from peat, that is exploited at a number of places along the coast. The use of hydropower and geothermal power is a distant future.

Fifteen years later, Iceland finds itself amidst cruel reality of war-disrupted Europe. Although Denmark remains a neutral state during World War I, financial and economic instability hit its overseas subjects, including Iceland. Already during the first winter 1914/1915 of World War I a "chilly" problem arises: Great Britain radically restricts the export of coal. Moreover, the North Sea is cruised by marine and submarine fleets of the Triple Entente as well as the Allied Forces, and thousands of naval mines are deployed here. As a result, the price of imported coal rapidly increases. The Icelanders are facing the threat that they will soon have nothing but peat to feed their fireplaces and heat their dwellings with.

In these strained times, the strong Icelandic sense of survival and national pride came forth. Several visionaries, mostly entrepreneurs, builders and engineers come up with a revolutionary idea: "Let's mine the *surtarbrandur*". *Surtarbrandur* (coal) is known to occur on the island and is locally mined by farmers and utilized as fuel during winter. There is no information about the economic value of these deposits and neither is it known whether the coal can be industrially exploited. Nevertheless, all this can be resolved. The entrepreneurs decide to establish mining companies, invest their own capital, raise additional funds in Denmark and ask for support from the Parliament of Iceland. They also invite experts in coal prospection and coal deposit exploitation from Sweden, Great Britain and the United States of America. They plan to complete a detailed exploration and, wherever possible, open mines.

The whole of Iceland becomes acquainted with the names Guðmundur E. J. Guðmundsson, Sigurður Jósúa Björnsson, Skúli Skúlason, Jónas Þorsteinsson, Ivar Svedberg and Guðmundur G. Bárðarson. There hardly passes a week without a new article in the press informing about the progress in exploratory works and mining. The first mines are being opened: Dufansdalur, Þernudalur, Stálfjall, Botn, Gil, Skarð and Jökulbotn. Coal is being explored at a number of other sites and even subjected to surface mining at some places.

The term *surtarbrandur* suddenly becomes familiar throughout the island. After the first notion that the crisis is over, new problems emerge. The deposits are of low grade, and the early calculations of reserves and profits appear to be exaggerated. Coal mining often proceeds under highly demanding conditions, in difficult terrain, with the lack of appropriate equipment, devices and explosives. Coal is of a low calorific value, and yet additional financial resources are invested by the state to promote prospection and mining. Alas, the individual mines declare financial losses, and coal supplies for Reykjavík are commonly delayed and are much lower than promised. G. E. J. Guðmundsson is called by a defamatory name “coal emperor” in the press, and the Members of Parliament dispute on further financial support of mining from the government.

These problems culminate in 1918. The war in Europe comes to an end, international trade is slowly re-established, and imported coal from Great Britain is the final drop to induce bankruptcy and closure of all Icelandic coal mines.

This development will be repeated two decades later. Another war conflict is coming close, impending over all of Europe. After their World War I experience, the Icelanders start to consider the local coal reserves again. Their worries soon appear to be justified. Germany occupies Denmark in spring 1940 and a month later, Iceland is taken over by the British with the aim of preventing a German occupation of the island. In 1941, the “military protection” of Iceland is taken over by the United States. Both civil and trading sea transport become restricted and the prices of fuel are steeply rising. The Parliament of Iceland decides on the renewal of mineral exploration. Two most promising sites are chosen: Gil and Botn. Finally, mining is rehabilitated in the latter mine only. The deposit at Tindar is opened, representing the first vertical-shaft mine in Iceland. However, history is repeated in the course of World War II: the mines face financial problems and mining is terminated at a considerable financial loss before the end of the war.

Although the benefits of Icelandic coal are disputable, it is still considered as an energy source in the latter half of the 20th century. A renewal of mining at Tindar is decided upon in connection with the intensification of the hydroelectric power station at Elliðaár. Besides the production of heat and energy, the use of local coal in petrochemical industry is also considered; promoters of this idea speculate on the manufacture of liquid fuels, plastics, as well as pharmaceutical products. Nevertheless, none of these become materialized in the end.

Even though only one-tenth of the originally planned production became exploited in 1954–1956, the mining was relatively intensive: the total amount of mined coal exceeded that produced in the course of World War II. Anyway, the closure of the Tindar mine marks the ultimate end of coal mining in Iceland.

In the early 1980s, the World experiences a global economic recession, and the prices of fuel rise again. Despite the intensive utilization of renewable energy (geothermal, water) at that time, previous experience motivates Iceland towards the highest possible energy self-sufficiency, making use of a broad portfolio of available resources. Therefore, specialists in coal prospection are summoned from Great Britain upon the direction of the Parliament of Iceland. At the same time, an extensive feasibility study is conducted with the focus on a renewal of intensive industrial coal mining at selected sites. The result is by no means reassuring for Iceland: local coal appears to be 3–7 times more expensive than imported coal. Moreover, the only site evaluated as being of at least partial economic value is the deposit around the Botn mine. After this, the Icelanders finally regard their coal mining as non-economic.

Sixty-four years have elapsed since the last mine cart of coal was brought to the surface by the miners of Iceland. The mining period around World War II is gradually losing its eyewitnesses, and the awareness of a broad public is waning. Still, each individual miner contributed with his small lot to the survival of the Icelanders as a nation through the hard times of the past. Their effort is worth to be remembered forever. Therefore, the following chapters cover not only "descriptive" geology of the coal deposits in Iceland and their genesis, but also the history of prospection for the mineral which received the sonorous name "*surtarbrandur*" by the Islanders as early as in medieval times. Alas, the authors endeavour to present the numerous historical and socio-economic circumstances related to the discovery, exploration and mining.

The authors visited all the deposits known across the island within their field survey. Where possible, they also conducted a detailed investigation of the mines, including sampling and geodetic surveys to provide plans of the galleries. The book provides the reader with a variety of information ranging from exact data on calorific values or sulphur contents in coals from different sampling sites, year-by-year history of prices per tonne of extracted material, to the names of the domestics who were cooking for the miners during their work in the mine.

In this book the history of coal mining in Iceland is presented for the first time. It is wishful that the younger generations of Icelanders never forget about the hard work of their forefathers and mothers and keep pride in their nation's struggle for independence and self-sufficiency. Let that be the principal message of this book.

I

CLIMATE EVOLUTION OF ICELAND

Today, two main ocean currents with very contrasting properties define the climate in Iceland: the cold, euhaline East Greenland Current, approaching the island from the north, and the warm, salty North Atlantic Current, which is a continuation of the Gulf Stream, encircling the island from the south (Stefánsson 1991). Climate in Iceland can be generalized as cold, mildly oceanic. The southern and western parts of the island and bottoms of fjords, in both northern and eastern Iceland, are governed by mild perhumid climate with cold and short summers (Cfc climate *sensu* Köppen-Geiger, Kottek et al. 2006). The average temperature of the warmest month is *ca.* 10 °C; that of the coldest month is > –3 °C. In contrast, peninsulas in northwestern, northern and eastern Iceland, much like the central highlands, are dominated by Arctic climate (ET climate, *sensu* Köppen-Geiger) with the average temperature of the warmest month being <10 °C (Einarsson 1984).

In the past, the climate in Iceland was substantially different. Globally, climate underwent a gradual cooling throughout the Cenozoic, with three major episodes of rapid temperature drop. These events took place in the late Eocene–early Oligocene (*ca.* 34 Ma), in the mid Miocene (*ca.* 14 Ma) and at the Pliocene/Pleistocene boundary (*ca.* 2.6 Ma; Zachos et al. 2001). The first two episodes coincided with the rapid development of an Antarctic continental ice sheet, while the third resulted from the entry of large ice sheets in the Northern Hemisphere (Zachos et al. 2001).

The oldest sedimentary rocks in Iceland document the end of the mid Miocene short-term global warming phase, the so-called Mid Miocene Climatic Optimum, peaking at 17–15 Ma. Fossil floras from the Miocene of Iceland suggested that the island's climate between 15 and 12 Ma was warm and humid, with no dry seasons and warm summers (Cfa climate *sensu* Köppen-Geiger). At that time, dense hygrophilous forests dominated the Icelandic lowlands and well-drained forests dominated higher elevations (Denk et al. 2011). The average temperature was between 12 and 15 °C at 12 Ma (Denk et al. 2005, 2011, Grímsson and Símonarson 2008b). The mild and warm conditions prevailed in Iceland as late as at 12

Ma. The influx of warm southern waters (Gulf Stream) may have delayed the climate cooling in the northern North Atlantic region for at least two million years (Denk et al. 2013).

Fossil finds evidence that Iceland was heavily forested from the mid to late Miocene (Denk et al. 2011). Global cooling occurred from the mid Miocene onwards and is well documented in the palaeobotanical record of Iceland. One can observe a stepwise retreat of warmth-loving plants from successively younger fossiliferous sedimentary rock formations (Denk et al. 2005, 2011, Grímsson and Símonarson 2008b).

The first detectable climate shift in Iceland occurred between *ca.* 12 and 10 Ma. At that time, mountain regions were probably under the influence of Cfb climates while lowlands were governed by the Cfa climate. A sudden boom of herbaceous elements was recorded at 10 Ma (Denk et al. 2011), including representatives of various Apiaceae, Asteraceae, Caryophyllaceae, Chenopodiaceae, Cyperaceae, Ericaceae, Poaceae, Polygonaceae, Ranunculaceae and Rosaceae. This period was also characterized by the first appearance of small-leaved heath (Ericaceae), which evidenced climate cooling in the early late Miocene. Still, the vegetation in Iceland continued to be dominated by temperate hardwood taxa thriving under mild climate (Cfa, Cfb) conditions until *ca.* 5.5 Ma (Denk et al. 2011, 2013).

The second major climate shift in Iceland took place during the period from the latest Miocene to the Plio-Pleistocene. This interval was marked by a transition from mild and warm climate conditions to the present Cfc and ET climate, i.e., tundra climate (see figure 5 in Denk et al. 2013).

Boreal forests dominated Iceland in the late Pliocene, shortly before the onset of Pleistocene glaciations, including, e.g., pine (*Pinus*), spruce (*Picea*), fir (*Abies*), larch (*Larix*), birch (*Betula*), alder (*Alnus*) and willow (*Salix*) (Denk et al. 2011). The earliest signs of glacial activity in Iceland can be observed in the stratigraphic record of eastern Iceland, in the area of Fljótsdalur Valley, dating to 3.8–3.4 Ma. Thereafter, both floras and marine faunas, in and around Iceland, were affected by late Pliocene to early Pleistocene cooling (Norðdahl et al. 2008). During the subsequent glaciations, the Icelandic flora became successively less diverse (Denk et al. 2011).

The first massive glaciation of Iceland took place at 2.55–2.45 Ma (Eiríksson 2008). Climate during the Pleistocene interglacials was probably similar to the present one; however, mean annual temperatures during the glacials were decreased by 5–10 °C. During the Last Glacial Maximum, Iceland became almost completely covered with ice. A progressive partial deglaciation of Iceland and the formation of present-day glaciers occurred with the onset of the Holocene (Norðdahl et al. 2008).

II

GEOLOGY OF ICELAND – AN OUTLINE

The inland section of the Mid-Atlantic Ridge is characterized by rift and volcanic zones with ongoing volcanic activity, stretching across the island from its southwestern to its central northern parts. Tectonic activity concentrates in volcanic systems 10–100 km in length. These systems feature open cracks, tensional fractures, faults, craters, cones and shield volcanoes. The island expands at an average rate of 20 km/1 Myr (Sæmundsson 1979, Steinþórsson and Thorarinsson 1997).

Iceland owes its existence to the activation of the northern reach of the Mid-Atlantic Ridge in the early Paleogene (at *ca.* 55 Ma). At that time, the divergence of the North American/Greenland and Eurasian (Scandinavian) plates was initiated (Eldholm et al. 1994). In the early stages of northern North Atlantic spreading, the two plates were coupled by a subaerial ridge, the Greenland–Scotland Transverse Ridge (GSTR). This ridge was perpendicular to the course of the spreading Mid-Atlantic Ridge and connected North America/Greenland to Scotland/Eurasia. Its existence is explained as a superficial expression of a mantle plume, the Iceland hotspot, lying at the contact of the two diverging plates. After the initial divergence, Eastern Greenland and margins of continental Europe including the Faroe Islands would have been submerged if it was not for the activity of the Iceland hotspot which kept the GSTR above sea level during the Paleogene (Vink 1984). The eastern and western parts of the GSTR became submerged during the Neogene as a result of continued spreading and crustal cooling. The precise timing for the stepwise submersion of this land bridge, the North Atlantic Land Bridge (NALB), is uncertain. However, both geological and palaeontological data (see table 12.1 in Denk et al. 2011) suggested that parts of the NALB were still above sea level during the Miocene (e.g., Grímsson et al. 2007, Denk et al. 2010, 2011).

The oldest tectonic structure in the northern North Atlantic region is probably the Aeiger Ridge, which was activated at *ca.* 70–60 Ma. Another spreading activity occurred at 55–36 Ma, resulting in the formation of the Reykjanes Ridge and the Kolbeinsey Ridge. The Aeiger Ridge, lying north of present Iceland, became inactive and was replaced by the Kolbeinsey Ridge at 27 Ma. The activity along this new spreading zone led to the detachment of the Jan Mayen Ridge from Eastern Greenland (Talwani and Udintsev 1976, Talwani and Eldholm 1977, Larssen 1980, Vogt et al. 1980, Vink 1984).

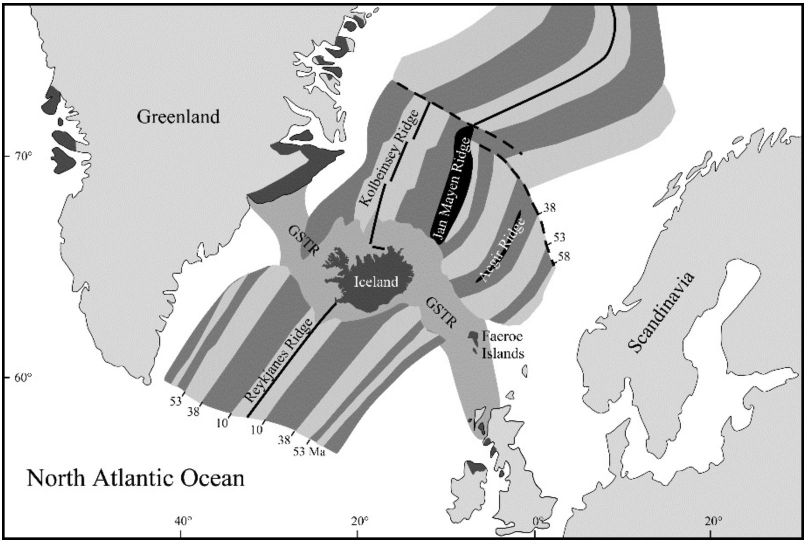

Fig. 1 Iceland – North Atlantic Basalts. A schematic map showing Iceland and major adjacent geological features. Terrestrial basalts in Greenland, Iceland, the Faroe Islands and the British Isles are coloured dark grey. Ocean-floor anomalies appear in different shades of grey along with their relative age shown in Ma. The Greenland-Scotland Transverse Ridge (GSTR) is outlined. The map was modified from Talwani and Eldholm (1977), Larsen (1980) and Steinþórsson (1981).

Volcanic systems with extensive central volcanoes and effusions along fissures and crevices characterized Iceland in the mid Miocene to Pliocene (16–3.1 Ma) (Sæmundsson 1979, Steinþórsson and Thorarinsson 1997). During that time, the oldest prevailing geological complexes were established that constitute present-day Iceland. These extend over an area larger than 50,000 km^2, which equals about one-half of the island's total area. In their geological nature, these complexes are mostly composed of basaltic lava sequences, typical for the northwestern, western, northern and eastern parts of Iceland (Jóhannesson 1980). The lava sequences consist mostly of subaerial tholeiitic lavas and acidic rocks. The stratigraphy is generally very regular, with basalts reaching *ca.* 5–15 m in thickness,