

Háskóli Íslands
Verkfræði- og náttúruvísindasvið
Líf- og Umhverfisfræðideild



Landscape classification in Iceland and its underlying geological factors

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Febrúar 2009

60 ECTS eininga MS-ritgerð í umhverfis og auðlindafræði

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Hér með lýsi ég því yfir að ritgerð þessi er byggð á mínum eigin athugunum, er samin af mér og að hún hefur hvorki að hluta né í heild verið lögð fram áður til hærri prófgráðu.

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Ágrip

Aðferð til flokkunar á landslagi út frá sjónrænum eiginleikum hefur nýlega verið þróuð á Íslandi í tengslum við Rammaáætlun um nýtingu vatnsafls og jarðvarma. Hún byggist á 23 sjónrænum eiginleikum svo sem útlínun og formum í landslagi, grunnlögun landslagsins, fjölbreytileika gróðurs og gróðurþekju, fjölbreytileika í áferð og munstri, breytileika í hæð, víðsýni. Hér var þessari aðferð beitt á landslagssvæði yfir landið allt með það að markmiði að greina og flokka helstu landslagsgerðir á Íslandi. Fylgni landslags við jarðsögu og berggrunn var einnig könnuð.

Við val á svæðum var byggt á 10x10 km hnitakerfi Náttúrfræðistofnunar Íslands. Það nær til landsins alls en hér var valinn þriðji hver reitur í þriðju hverri röð. Í þessari rannsókn voru notaðir 98 reitir. Farið var í þá alla og gögnum safnað í fyrirfram þekktum GPS punkti í miðjum reit. Gátlisti með áðurnefndum 23 sjónrænum breytum var fylltur út á hverju svæði og myndir teknar til heimildasöfnunar. Eiginleikum var gefin einkunn á bilinu 0-5 eftir magni eða þéttleika. Gögnin voru meðhöndluð með kláðugreiningu (Cluster Analysis). Prófað var að aðskilja þá eiginleika sem höfðu lægsta tíðni (endurtekin form og jökla), og skilaði það hærra bootstrap gildi og hámarkaði betur einsleitni innan hópa og mun milli hópa. Gögnin, án áðurnefndra breyta, voru síðan unnin frekar með meginþáttagreiningu (Principal Components Analysis) til að komast að því hvaða eiginleikar vógu þýngst í hverjum landslagsflokki fyrir sig

Niðurstöðurnar benda til þess að 8 megingerðir landslagshópa sé að finna á Íslandi. Þær eru: (1) Strendur sem ásamt fjörðum greinast fá öðrum flokkum vegna staðsetningar við sjó. Strendur skiptust í tvo undirhópa klettastrendur og flatar sandstrendur. (2) Firðir sem einkennast af U-laga grunnformi í landinu. Firðir eru aðallega á eldri tertíera hluta landsins þ.e. Vestfjörðum, Mið-Norðurlandi og Austfjörðum. (3) Djúpir U-laga dalir inn á milli hárra fjalla með mikilli gróðurþekju (4) Grynri inndalir eru fáliðaðasti flokkurinn og greinast m.a. frá flokki 3 vegna grunnlögunar og minni gróðurs. Inndalir eru aðallega við jaðar miðhálandisins. (5) Gróið láglandi og heiðalönd sem er stærsti flokkurinn. (6) Grónar sléttur með miklu víðsýni sem einkennast af því að langt er í næstu fjöll eða hæðir og grunnlögun er flöt. (7) Gróðursnauðar og einsleitar hálendissléttur með miklu víðsýni og grófri blettastærð. (8)

Gróðursnautt hálendi sem er að mestu leyti eins og í flokki 7 nema þar er stöðuvatn og/eða ár.

Fylgni milli landslagsflokka og undirliggjandi jarðfræðilegra þátta, þ.e. jarðsögulegs aldurs og berggrunns var könnuð með því að reikna út flatarmál aldurs-eða berggrunnsflokka innan 5 km radiusar út frá ákvörðuðu GPS hnitunum á stafrænum jarðfæðikortagrunni Náttúrufræðistofnunar Íslands. Fylgni milli fylkis sjónrænna landslagsþátta og jarðfræðiþátta var reiknuð með Canonical Correlation Analysis og einföldum fylgnireikningum (Correlation Analysis). Í ljós kom sterk fylgni sjónrænna og jarðfræðilegra þátta í íslensku landslagi. Ákveðnir eiginleikar eins og beinar línur í landi fylgja háum jarðfræðilegum aldri, enda setja beinir láréttir eða hallandi staflar tertíer jarðlaga sterkan svip á fjöllin á Vestfjörðum og Austfjörðum U-laga grunnlögun einkennir einnig þessi svæði og önnur þar sem jöklar hafa náð að sverfa og móta landið.

Abstract

A method for the classification of landscape according to visual characteristics has recently been developed in Iceland, in connection with the Framework plan for the utilization of geothermal and hydropower energy". It is based on 23 visual physical variables, including forms and lines in the landscape, basic landscape shape, vegetation cover and diversity, patch size, the diversity of textures and patterns, elevational range, and landscape depth. Here, this method was applied on a national scale in order to identify and classify the main landscape types in Iceland. I also examined the correlation of landscape with geological age and bedrock type.

A systematic sampling design was considered to better represent large-scale variation rather than a random design. We used the 10 * 10 km grid system of the Icelandic Institute of Natural History, selecting every 3rd grid in every 3rd row which gave a total sample size of 130. Sample size in the work presented here was 98. For each grid the sampling point was identified as a predetermined GPS point in the centre of the grid. All the data were sampled in the field by a team of two. A checklist with the aforementioned 23 visual variables was completed and photographs taken for reference and later standardization. Variables were scored on a scale from 0 to 5, according to quantity or density. Cluster Analysis was applied to obtain a general landscape classification. Two variables with a low frequency (repeated forms and glaciers) were excluded from the final analyses. This yielded higher bootstrap values and better maximized similarities within groups, as well as dissimilarities between them. The data were then further treated by Principal Components Analysis, in order to ascertain which characteristics were most important for each type of landscape.

Our results indicate that there are 8 main landscape categories in Iceland: (1) **Coastal areas** along with fjords are distinguished from other categories due to their proximity to the ocean. Coastal areas are further divided into two subcategories: *Rocky coasts* and *flat sandy beaches*. (2) **Fjords** are mainly found in the older, Tertiary parts of the country, i.e. the West Fjords, the Central North, and the East Fjords. (3) **Deep, U-shaped and well vegetated valleys**, lying between high mountains (4) **Shallower inland valleys** comprise the category with the fewest representatives. This category is distinguished from category 3, among others, by basic shape and less vegetation. Inland

valleys are mainly to be found at the the margins of the Central Highlands. (5)

Vegetated lowlands and heathlands comprise the largest category. (6) **Vegetated plains with a high landscape depth**. A distinguishing feature of this group is that the nearest mountains or hills lie at a great distance, and the basic shape is flat. (7) **Sparsely vegetated highland plains**, displaying relatively little diversity, large field of view, and coarse texture. (8) **Sparsely vegetated highlands**, which are for all intents and purposes identical with category 7, except that they contain **water and/or rivers**.

I also studied the correlation between landscape categories and underlying geological factors, geological age and bedrock type. Using the geological database of the Institute of Natural History, I calculated the proportional cover of different age and bedrock classes within a 5 km radius from the the known GPS coordinates. The correlation between the matrix of visual landscape characteristics and geological factors was calculated by Canonical Correlation Analysis, as well as simple Correlation Analysis. This revealed a strong correlation between visual and geological factors in the Icelandic landscape. For example, certain features such as straight lines in the landscape, are correlated with a high geological age. Straight lines of Tertiary geological layers are highly prominent in the mountains of the West and East Fjords, which are the oldest regions of Iceland. Another example of this is basic shape. This is more commonly a U-shape where glaciers have scoured and molded the landscape, while it is flat in younger, geologically active regions, where the land is constantly being added to.

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1. Introduction

The entities of life and nature are numerous and complex. Earth, for example, is home to just under 1 million described species of insects, with an estimate of up to 30 - 80 million species yet to be discovered (Gullan and Cranston, 2005), about 70 000 described species of fungi with an estimated 1.5 million species yet to be discovered, and about 235 000 described species of angiosperms (Raven et al., 2005). Despite this enormous number of species with which we share our atmosphere, it is easy to read through a book about these species and discover their basic characteristics, their phylogenetic relationships, and their behavior. Such knowledge is most easily gained from books that apply a taxonomic system. Such a system groups similar species together according to some shared character, behavior or history.

The well known similarity of genetic material binomial categorization of species has its roots in the work of Carl von Linné. His work, published in *Systema Naturae* (Linnaeus, 1735) laid the foundation for the systematic classification of the biological world for which many were and still are grateful. The French philosopher Jean-Jacques Rousseau, for example wrote: “Tell him I know no greater man on earth” (Tibell, 2008). Natural scientists are grateful because with the Linnaean system began the ordination of the world of species which their work applies to, an ordination journey that stills keeps on developing. In this thesis a classification system is applied to the Icelandic landscape.

A universally used method resembling the Linnaean classification of species is unavailable in the field of landscape research. This makes our work more difficult, since we must develop a classification system before we can start to classify the landscape. We are, however, not the first group of scientists to attempt to categorize landscape. For example the European Landscape Character Assessment Initiative (ELCAI) project, which had the aim of reviewing state-of-the-art landscape character assessment at the national and the international level in Europe, demonstrates how many classification systems are available in Europe alone (Wascher, 2005). This overview of the methods available in Europe provides an idea as to why a universally accepted landscape classification method is not available: Different countries seem to place specific emphasis on various aspects of the landscape. Our method will have new emphasis and therefore contributes to the flora of European landscape classification methods.

1.1. Landscape classification methods

In general landscape classification methods face several problems that have to be overcome. First of all, landscapes are large, complex, and multi-faceted entities. Landscapes are constructed from physical attributes, which are usually built up by two factors, a natural factor and an anthropogenic factor (Ermischer, 2004). Each landscape, however, also has a non-physical, i.e. a mental aspect, which is comprised of values, meanings and experiences of the human beings that interact with these landscapes. Although nonmaterial, such cultural, societal and aesthetic characteristics can define landscapes in ways that are no less definitive than physical ones. Secondly, landscape rarely has fixed boundaries, but rather, tends to overlap to some degree or another with those landscapes surrounding it. This creates a complex interrelation of a large number of factors which could be used to distinguish between two adjoining landscapes. Thirdly, comparison between different landscapes is important in order to gain a better understanding of their structure. Such comparison is also necessary for purposes of classification, as one must have knowledge of individual landscapes and their situation within a larger whole, e.g. a geographical region, or even an entire country, in order to be able to systematically relate landscapes and landscape characteristics to one another. Finally, the creation of a classification system involves a lot of data sampling and gathering of facts of entities to which the classification is to be applied. For systems that have the aim of describing the complexity of the “real world” with simple models, this data sampling is of the utmost important.

The development of a classification system for Icelandic landscapes faced most, if not all, of the challenges outlined above. Little research had previously been carried out on Icelandic landscapes at all, let alone on their definition and classification. Also, after reviewing existing typologies and classification systems from elsewhere in Europe, it became quite clear that none of these systems could be used in Iceland without considerable modification of the methods and criteria used.

A large number of landscape classification systems have been developed around the world, often very different one from another. This is not surprising, e.g. given the wide variety of possible methodological approaches, the different aims and needs of landscape classification systems, and the differences in landscape character in different

countries. The end result is that methods similar in aim and scope to the one described here tend to be designed specifically for a given country with its specific landscape conditions and character in mind and therefore often have limited applicability outside the country of origin. Although they share some basic aims and common themes, the actual measurements employed may be quite different. These classification systems are usually intended as an assessment tool for policy making, so as to manage land-use with landscape sustainability in mind. Landscape character assessment is important in attaining these management goals.

In the United Kingdom the Countryside Agency and Scottish Natural Heritage have developed a very thorough guide for categorizing and evaluating the character of the landscape. The system is twofold, first description and categorization, and then, evaluation of the landscape. The first part is mainly objective, while the second part is subjective. Despite this the aim is that the results obtained by two independent researchers should not be different (Swanwick, 2002).

In the USA the Bureau of Land Management has developed a visual landscape evaluation method for construction sites which has three aims: 1) to evaluate the visual appeal of an area, 2) assess the public concern for scenic quality, and 3) determining whether the tract of land in question is visible from travel routes and observation points. The results of this evaluation are then used as a guide in development planning for the so called Resource Management Plan for landscape areas (United States Department of Agriculture and Forest Service, 2005).

The Norwegian Forest and Landscape Institute has described the overall character of the Norwegian natural landscape. The Norwegian method is based on 6 landscape components. These components are: major landform, minor terrain form, water and watercourses, vegetation, agricultural land, and built up areas/technical installations. A description of the overall character of the natural landscape includes these components, along with specific regional qualities, challenges, or trends of development (Puschmann, 2005).

So the question rises whether we could choose to use one of these methods? In short the answer is no, at least not without some modification, because these models are

not applicable to Icelandic landscapes. This, however, does not imply that they are unsuited to the landscapes they were developed to classify.

But why are they not applicable to Iceland? There are two main reasons, the first one being mainly technical. We feel that the subjective part of the British method cannot be used for classification. The perception of landscape certainly is both objective and subjective, in view of the physical and non-physical components mentioned above. We do not, however, see that subjective measurements may be used in a statistical classification as they will most likely differ between people measuring the same object. This will doubtless influence the results of the classification, resulting in different conclusions between different users. Subjective measurements by one person only should therefore be avoided. Instead, the subjective perception of the landscape should be evaluated by a larger study that at least tries to incorporate views from all possible stakeholders, rather than those of specialists only.

Another basic issue that we wish to emphasize is that our method will make it possible to quantify the relationship between the resulting groups of the classification. This would first of all make it easier to analyze the groups in relation to each other, and to discover reasons why particular landscapes group together or not. This would also make it easier to analyze particular landscape sites and include them in the classification. The American method is based on evaluating each site independently, and no landscape groups are formed. The developmental planning that makes use of the method is, therefore, unaware of the environmental affect on the landscape as a whole, at a regional scale or even the entire country. This is perhaps not an issue in such a country as large as the United States but it certainly is in small countries, such as like Iceland. Every planning decision regarding landscape in Iceland will certainly have to take into account the effect it has on the country as a whole.

The Norwegian method (Puschmann, 2005), unlike the American one, takes the entire country into consideration. The interrelationships among the resulting groups, however, are not easily available. The Norwegian classification resulted in 45 landscape regions, with 444 sub-regions which could further be divided into landscape areas. The great number of regions clearly makes it difficult, if not impossible, to relate them to one another and it is difficult for someone who is not familiar with the Norwegian landscape

to figure out whether one landscape area is similar to another area or not, or to discover how many landscape areas may be found that have the same character. If this relationship were clear then landscape planning decisions made for one landscape area could be applied to other landscape areas with a similar or identical character. It would also be easy for the planning agency to ascertain whether a given landscape area is common or rare, which could then be used as a factor in landscape protection decisions.

The second reason why these models are not applicable to Iceland is the unique landscape of the country in European context. The natural landscape is altered by a human factor and its action on the 'perceived' character of the Icelandic landscape is unique in a European context. The European landscape is highly influenced by human actions, and Meeus (1995) even goes so far as to say that landscape devoid of human influence can hardly be found in Europe. One could argue otherwise in regard to the Icelandic landscape, judging the human influence in Icelandic landscape weak, but this would not be entirely true. The massive deforestation following the settlement of Iceland, as well as with extensive draining of wetlands during the 20th century had a great effect on large parts of the island (Oskarsson, 1998, Jonsson 2005). However, this deforestation is obviously hard to 'perceive' unless one is familiar with Icelandic history. The visible character of the Icelandic landscape is therefore distinctively 'perceived' as natural, at least in a European context.

1.2. Icelandic landscape

Iceland is situated on the Mid-Atlantic ridge, which separates the North-American and the Eurasian tectonic plates. This is a major factor in landscape formation, with active volcanism producing lava flows that periodically change the landscape (Thordarson and Höskuldsson, 2008), along with intense erosive action of extrinsic factors (such as wind, ocean, rain, rivers, and glaciers) (Arnalds et al. 1997). The types of volcanoes in Iceland are so diverse that all known volcanic types may be found on the 103 000 km² island (Thordarson and Höskuldsson, 2008). Almost half of the country is a barren desert-like

central highland plateau, with vegetation cover mostly under 5%, with occasional “oases” with continuous vegetation. Only a quarter of the country’s area is inhabited.

The central highland may be regarded as a dynamic display of the geological action students usually only read about in textbooks. Due mainly to its young geological age and relative lack of vegetation, a great geodiversity may be easily experienced in a matter of days. Also, depending on which definition one uses, the central highland is perhaps one of the largest wilderness areas in Europe (Thorhallsdottir, 2002; 2005). The bedrock is relatively young compared to neighboring countries, with the oldest part dating from the Miocene period (15 – 8.5 m. y. BP.). The oldest parts are the extreme west and east, and extreme central north, with progressively younger bedrock towards the centre. The presently active volcanic zone is a single belt running north-south in the north of Iceland. In the southern part, it forms two separate zones running north-east and south-west (Jakobsson et al., 2008). Numerous high temperature geothermal areas occur in the volcanic zones. These areas are often colorful, while the vast highland plateau can often be uniform in colour, with long expanses of dark basaltic moraines (Thorhallsdottir, 2002). The geology of Iceland and its strong influence on the landscape will be discussed in greater detail in the second paper of this thesis.

The flora comprises 485 vascular plant species and 605 moss species (Flóra Íslands, 2009). Iceland lies between the 63°33’ and 66°33’ north, with the northernmost islands reaching the Arctic Circle at 66°33’ north. The vegetation is classified as arctic tundra or sometimes as alpine tundra at higher altitudes. Continuous vegetation covers a mere quarter of the land and only 1% is classified as cultivated land (Thorhallsdottir, 1997). The precipitation has a gradient with 700-1600 mm-yr⁻¹ in the south, and 400-700 mm-yr⁻¹ in the north. Almost all of the country’s climate may be classified as oceanic (Einarsson, 1984).

The classification of the vegetation into alpine or arctic tundra indicates that the landscape is more or less treeless. Mountain birch (*Betula pubescens*) is the only native forest-forming tree in Iceland. It forms forests inland and in sheltered valleys, and low woodland in coastal areas and at higher altitudes. At present, birch forest and woodland cover about 1 165 km² (Gudjonsson and Gislason, 2008), while their area at the time of settlement in the 9th century is considered to have been much larger, perhaps even up to

40 000 km² (Hallsdottir and Caseldine, 2005; Jonsson, 2005). The highland plateau is mostly desert with very sparse vegetation, except for heathlands at an altitude of approx. 300-500 m a.s.l., and islands of vegetation, mostly wetlands, at higher altitudes (Thorhallsdottir, 2007a; 2007b).

Agriculture in Iceland is mostly extensive, with pastures and meadows used as basis for dairy and sheep farms. However, intensive arable croplands are found on only a small scale. In the past widespread wetlands characterized the large lowland areas, particularly in the south and west, but these have largely been drained by ditching (Oskarsson, 1998; Thorhallsdottir et al., 1998). It is estimated that less than 3% remains of the 1 100 km² of mires and riverine wetlands present in the southern lowlands around 1900 (Thorhallsdottir et al., 1998).

Glaciers are also important in the Icelandic landscape. There are 6 large glaciers in Iceland and the largest one, Vatnajökull, is the largest glacier in Europe or 8 100 km³ (Björnsson and Pálsson, 2008). In all glaciers cover about 10% of the country. Glaciers were important factors in the formation of the many valleys and the fjords around Iceland during the last Ice Age, and they retain their importance in landscape formation, not least as the source for the many glacial rivers running through and shaping the landscape all around Iceland (Björnsson and Pálsson, 2008).

This short description of the landscape character in Iceland shows that it is very different from that of the rest of Europe. The massive influence of the human factor on the character of the European landscape is reflected in the landscape classification systems used in Europe. This human factor has affected the landscape character quite differently in the Icelandic landscape. We therefore had to construct a classification method which would better fit the character of the Icelandic landscape.

1.3. Landscape studies in Iceland

Landscape studies in Iceland that could have been helpful in developing the classification method are few and far between. This might be interpreted as a lack of interest regarding landscape in Iceland but this is unlikely to be the case. Landscape has been, and still is, a very important part of Icelandic culture and is perhaps even the single most important national symbol of national heritage in the mind of the people of

Iceland, even more so than the language which is not shared by any other nation in the world (Arnason, 2005).

The studies that have been published so far have studied the difference between the perception and evaluation of the landscape among a focal group of experts and a large group of students (Kristinsdottir, 2004), the sales and analyses of postcards depicting landscape (Oladottir, 2005), and finally the perception of colours in the Icelandic landscape (Eymundardottir, 2007). Several environmental impact assessments have also touched upon the subject of landscape, but those are most often limited to construction areas (e.g. Arnalds 2001, Linuhönnun, 2006).

The description of Icelandic landscape was the subject of a doctoral thesis in philosophy by Hubertus Preusser (1976). The approach was both deductive and inductive, field work for the collection of data, as well as an intensive review of the literature. This study was very thorough and provided a good overview of the geological landscape. The study revealed 9 landscape types and 26 landscape regions. Landscape region is more a description of the landscape in different parts of Iceland, e.g. the Western lowlands and the Northern lowlands, while the description of the landscape types is of a general nature e.g. Lowlands. Without delving too deeply into the methods used we find fault with the approach, which is the combination of qualitative and quantitative methods. The resulting landscape types are thus based on the authors own ideas of what should comprise a landscape type, whilst our method uses statistical methods to derive landscape groups based on purely quantitative data. Although our approaches are quite different the resulting landscape groups are quite similar or almost identical. However the statistical approach will prove better when dealing with landscape sites that are difficult to place within any of the landscape groups. In such cases the quantitative sampling method will limit all unnecessary doubt. The quantitative and statistical method is also repeatable by all, also the likelihood of getting the same results between different researchers are much higher than in the qualitative method.

In 1999 a Framework plan for hydroelectric and geothermal development was initiated by the Ministry of Industry, Energy, and Tourism (Thorhallsdottir, 2007b). Its objective was to rank and evaluate potential sites for energy development according to several criteria. Four workgroups were established, each of which proceeded from a

different viewpoints. One workgroup ranked the sites according to the impact on the environment and cultural heritage. This particular workgroup began the work of evaluating landscape according to visual physical characteristics, and the work published here may be conducted in relation to the second phase of that work. The method we developed during this second phase is based on 23 visual physical characteristics that are quantitatively analyzed and given scores between 0 (not existing) to 5 (large in quantity). These physical characteristics are e.g. vegetation cover, landscape depth, basic landscape shape, water cover, lines, and forms etc.

Further outlines of the method employed are not discussed in this thesis, for more detail on these physical characters and the general development of the method see Thorhallsdottir (in prep.). In the first article of this thesis the result of the classification method is presented. The scores of the physical attributes from 98 sites around Iceland are analyzed with multivariate statistical methods. These methods are Cluster analysis and Principal Component Analysis. The second article analyzes the correlation between the resulting landscape groups discussed in the former article with underlying geological factors such as geological age. The main objective of this thesis is therefore to analyze how effectively these multivariate statistical methods can translate the data into meaningful landscape classification, along with analyzing the correlation with geology in Iceland.

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Article 1: Landscape Classification in Iceland

1. Summary

A method has been developed for the classification of Icelandic landscape based on visual, physical characteristics. Here it is applied to a dataset of 98 sites, sampled in a nationwide systematic sampling design of 10*10 km grids. In the field, sampling points were located as predetermined GPS coordinates in the centre of each grid and a checklist of 23 visual landscape variables filled in. Three different combinations of variables were subjected to Cluster Analysis and the one yielding the highest bootstrap values and cluster of high similarity selected for further Principal Components Analysis to explore the variables most associated with different landscape groups. Eight major landscape groups were identified: flat coastal areas (1), fjords (2), deep U-shaped vegetated valleys (3), shallow inland valleys with less vegetation (4), vegetated lowlands plains and heathlands (5), low diversity vegetated plains with high landscape depth (6), barren highland plateau with large patch size and high landscape depth (7) and barren highland plateau with rivers (8). The results demonstrate the benefits of having a objective classification method which for example can reveal the influence of each landscape visual variable on the classification which can not be so easily done with similar but subjective classifications. This study is hopefully only one of many landscape researches in Iceland to come.

2. Introduction

Land use planning and landscape conservation are important issues in contemporary societies, especially in densely populated and intensively farmed countries such as those in Europe. The European landscape convention in Florence, for example, emphasised that the participating countries acknowledge: “that the quality and diversity of European landscapes constitute a common resource, and that it is important to co-operate towards its protection, management and planning.” (European Landscape Convention, 2006).

Although historically and politically a part of Europe, Iceland is unlike many other European countries. It has, for instance, not signed the agreement of the European Landscape Convention, unlike many other countries in Europe. This is especially surprising considering that landscape is a most important national symbol in the mind of the Icelandic people, according to a recent survey (Arnason, 2005). The sparse population and little arable land for agriculture make the human impact not as significant a landscape factor in Iceland as in other countries of Europe. The landscape seems, therefore, more or less natural in a European context. Land use has, likewise, been minimal in comparison with European countries and pressure for sustainable land use, and landscape conservation has, therefore, not been strong. This has, however, changed recent years, as may be seen in regard to a large hydropower project in the central highlands of eastern Iceland (Benediktsson, 2006).

The Icelandic Landscape Project was launched in 2006 as a part of the Framework Plan for the use of hydropower and geothermal energy (Bragason et al., 2006). It is divided into two parts, first of which is the classification of Icelandic landscape according to visual physical characteristics. The project presented here is part of the landscape classification, and has the aim of analysing a data sample of 98 landscape sites. The sampling procedure is explained in detail elsewhere (Thorhallsdottir *in prep.*). Here, only the results of our analysis are presented. Multivariate statistical analysis, i.e. Cluster Analysis and Principal Component Analysis were applied to reveal patterns in the sampling data on which to base our classification.

3. Materials and Methods

3.1. Sampling design

A systematic sampling design was adopted, making use of the nationwide 10*10 km grid system of the Icelandic Institute of Natural History (Kristinsson and Johannsson, 1970) which has a known GPS point at the centre of each square of the grid. Every third square in every third row was selected, giving a total sample size of 130 points or sites. The present study includes a sample size of 98 sites. The remaining 32 include urban sites (1, site, excluded as outside the scope of the project), glaciers (11), inaccessible sites (1), and sites that were either unsampled by the end of 2007 or had to be revisited, mostly because of unsatisfactory weather conditions and/or visibility during the first visit (18).

3.2. Sampling procedure

Field sampling took place in July and August of 2006 and 2007. A two man team located the centre of the selected squares with a hand held GPS device (Magellan eXplorist 500 LE). Although every effort was made to reach the preselected GPS coordinates, this was not always possible due to the presence of natural barriers, e.g. cliffs, canyons, or large rivers.

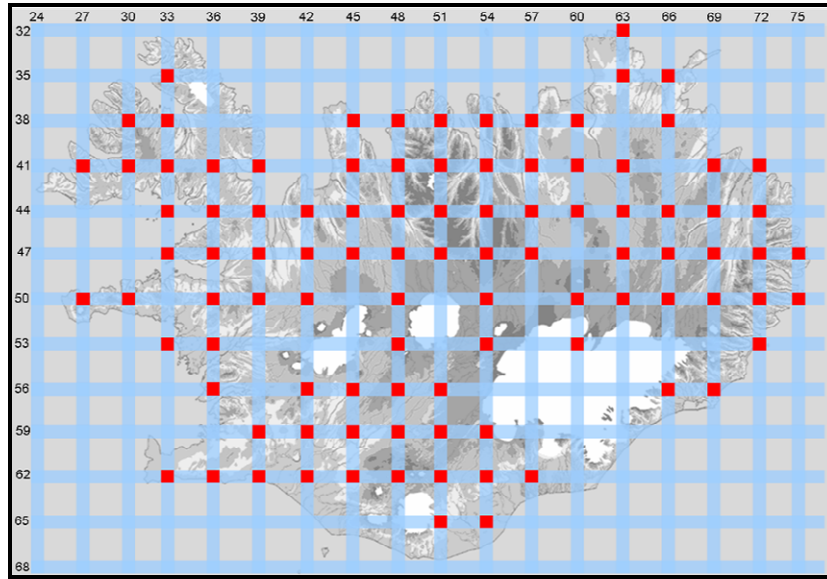


Figure 1 The 10*10 km grid system (Kristinsson and Johannsson, 1970). The distribution of the 98 sites (shown as red squares) sampled for the Icelandic Landscape project in 2006-2007. The numbering of the grid squares is combined with the numbers at the top of the figure, followed by the numbers on the left, e.g. the empty square at the top left corner would be numbered as 2432

For a few sampling points, a maximum distance of 5 km from the predefined GPS point was accepted. At the sampling point, the actual GPS coordinates were noted and the checklist (see below) was completed. Digital photographs (taken with Nikon D70 and Nikon D80 cameras) and videos (JVC Everio GZ-MG255) were recorded for reference, as well as for other potential and scheduled uses in the project. In order to ensure comparability, the procedure was standardized with respect to:

- 1) Landscape colours, e.g. of vegetation. The sampling period was restricted from June to early September.
- 2) Time of day, so as to avoid long shadows and light associated with sunrise or sunset
- 3) A clear sky was preferable, but in practice this is almost unattainable in Iceland. A minimum requirement was that mountains and peaks should be visible, free of cloud, and the weather clear enough to allow accurate evaluation of landscape colours.
- 4) Angle and elevation above ground. The camera was mounted on a tripod at a set height, and two sets of photos were then taken until a 360° circle had been completed, first by positioning the horizon in the middle of the view-field, and then placing the horizon 1/3 from the top of the photo, as this displayed the foreground more prominently.

3.3. Field checklist:

The visual physical features of the landscapes were quantitatively evaluated using a checklist of 23 variables (Figure 2), plus a qualitative (presence/absence) scoring of 37 colours. The actual GPS coordinates, height above mean sea level, and the common name of the site were noted on the checklist. Each attribute in the checklist was given a score of 0-5 depending on the amplitude, quantity, or diversity of the variable in question.

For more detailed description of the checklist and its attributes, see Torhallsdottir (in preparation).

variable		scoring				
basic landscape shape		concave (∪)		straight		convex (∩)
visible landscape depth (score for ¼ parts of horizon)		≤ 3 km	3-10 km	11-20 km	21-40 km	>40 km
elevational range		small		to		great
landscape forms	straight	not present		to		very prominent
	rolling	not present		to		very prominent
	sharp	not present		to		very prominent
	sinuous	not present		to		very prominent
	diversity	homogenous		to		diverse forms
repeated forms		none		to		very prominent
vegetation	cover	low		to		continuous
	diversity	low		to		high
colour range		low		to		high
patterns	patch size	large		to		small
	diversity	low		to		high
texture	diversity	low		to		high
	surface roughness	smooth		to		very rough
water	cover	low		to		high
	current	calm		to		torrent
	expression	1 form only		to		many different
sea	cover	none		to		prominent
snow, glacier, ice		none		to		prominent
contrasts		low		to		high
magnificence		low		to		high
diversity		low		to		high

Figure 2. The field checklist. The 23 variables in the checklist were quantifiably given scores between 0-5 at each site visited.

3.4. Analysis

Three different matrices containing the attributes' scores for all the sites were prepared: 1) a matrix including all attributes, 2) excluding repeated forms and 3) excluding glacial cover and repeated forms. These analyses were applied to a matrix formed by the scores from the field checklist.

3.4.1. Cluster analysis

Cluster analysis is a widely used multivariate statistical method with applications in numerous sciences, e.g. many fields of biology (Arciola et al., 2007; Finnie et al., 2007; Yonemoto et al., 2007; Justenhoven et al., 2008), and sociology (Del Campo et al., 2008). The aim of cluster analysis is to identify relationships between objects by what are known as similarity or distance measurements. This is usually achieved by arranging the data into a matrix and then calculating the similarity (or difference) between each pair of objects. The results may then be combined into a new matrix, comprised of coefficients of similarity. Similarity measures between objects usually range from between 1 (complete agreement) and 0 (complete dissimilarity). One may also measure the dissimilarity (often termed distance measures), in which case the range simply inverts, i.e. 1 then represents complete dissimilarity and 0 complete agreement. The cluster analysis employed for this project measured dissimilarity.

There are many different measurement methods by which to determine similarity. The simplest sums up agreements between objects, using the equation, $S(x_1, x_2) = \frac{q}{p}$,

where p = number of descriptors and q is the number of agreements between descriptors, S = similarity coefficient, X_1 = object 1 and X_2 = object 2. This simple similarity measure works well with binary data, but less well when there is a quantitatively measurable difference such as is the case here. When the similarity matrix has been calculated it may then be used to construct a dendrogram, by submitting it to a cluster analysis. There are several different kinds of cluster analysis methods available (for a detailed discussion refer to Legendre and Legendre, 1998).

The clustering analysis method was performed with the statistical computing software R (Suzuki and Shimodaira, 2006). This particular program allows the user to

choose which algorithm to use, and has the advantage over other methods of allowing bootstrap re-sampling with p-values, which is important for internal validation (Legendre and Legendre, 1998). Several different kinds of algorithms and distance measure methods were tested, and the results were all rather similar. The methods used were the average agglomerative method in conjunction with the uncentered distance measure, along with 10 000 bootstraps. For more details on these methods refer to Legendre and Legendre (1998), Shimodaira (2002), and Suzuki and Shimodaira (2006).

3.4.2. Principal components analysis:

Principal components analysis (PCA) is used to handle multivariate data and has been used with diverse applications, e.g. in geology (Abouchami et al., 2000), environmental research (Lourenco et al., 2006), remote sensing (Couteron et al., 2006), and landscape and urban planning (Bryan, 2003; Gao and Asami, 2007). PCA's main function is to present variation in data sets with fewer variables than contained in the original set, and to reveal patterns in the data that cannot be revealed by examining the variables separately (Legendre and Legendre, 1998; Quinn and Keough, 2002). PCA works by computing eigenvalues and eigenvectors, which are a measurement of the covariance or correlation between variables. Eigenvalues represent the amount of variation explained by each principal component. If the original data show strong correlations between variables, then the first two or three components will usually explain most of the variation in the original data. The eigenvectors, on the other hand, are the principal axes of the PCA. These eigenvalues and eigenvectors are usually presented as an ordination graph with two axes, most often the two that explain the largest amount of variance. The objects resulting from the data are then placed on a multidimensional ordination graph, according to the Euclidian distance between them. Therefore, the position of objects on the ordination graph and the angle between them are important, and may be used to explain the general gradient in the original data. For a detailed discussion of Principal Component Analysis refer to Legendre and Legendre (1998) and Quinn and Keough (2002).

4. Results

4.1. Dendrogram 1: All attributes included

4.1.1. Cluster Analysis

The results from the three dendrograms that were analysed will be explained consecutively and then the Principal Component Analysis of the third dendrogram. Dendrogram 1 incorporated all 23 attributes, and the resulting dendrogram yielded the greatest number of groups, a total of 12 (Figure 3). The dendrogram had slightly more low similarity clusters than did dendrograms 2 and 3. This indicates that the repeated forms and glacial cover attributes had the effect of lowering the overall similarity of the data, which yielded more groups but less well defined than the following two (Figures 4 and 5). The AU bootstrap values were rather high for most clusters, indicating that the clusters were reasonably stable and not formed by some random factor.

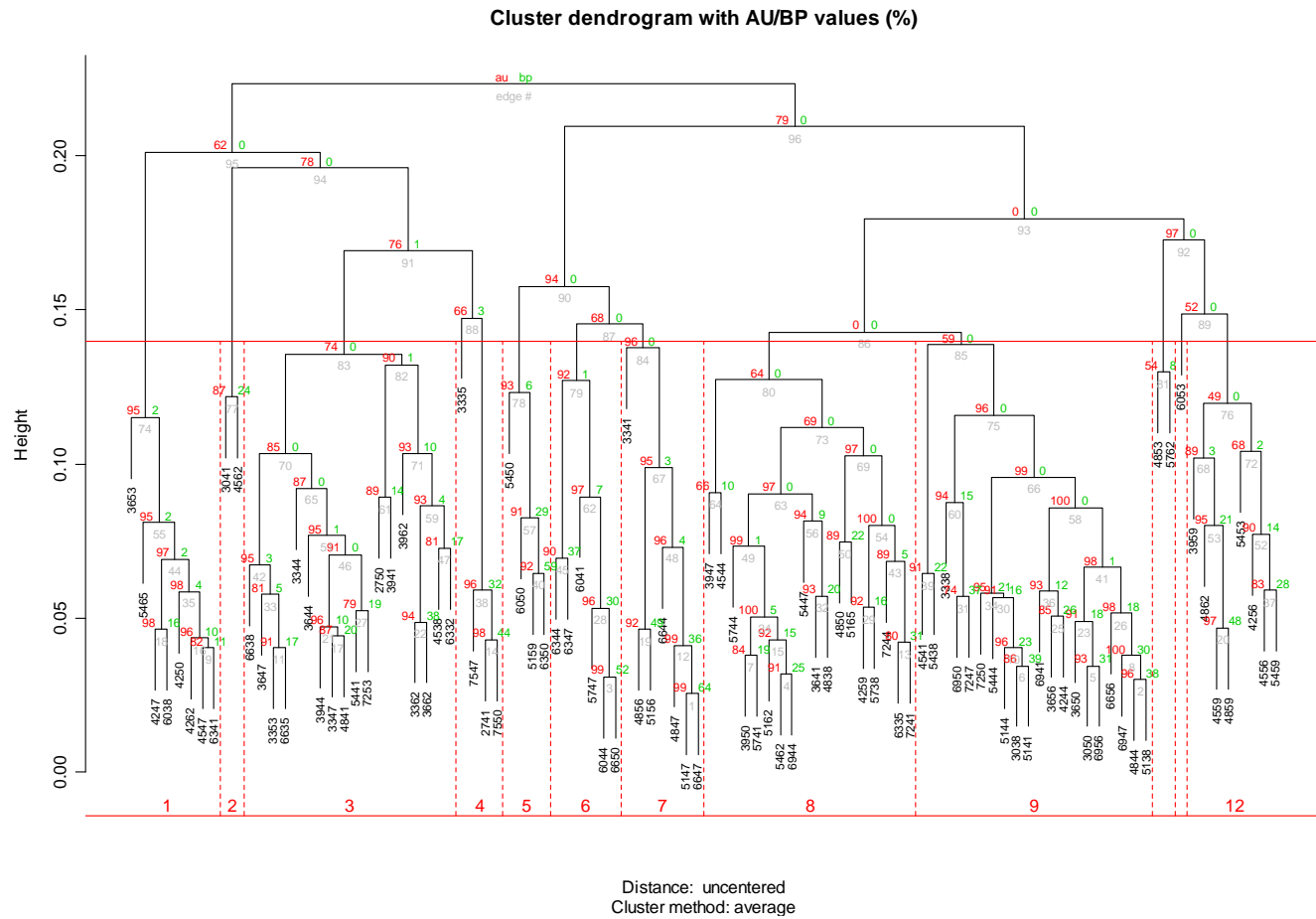


Figure 3. Dendrogram 1. Cluster Analysis dendrogram of major Icelandic landscape groups based on 23 visual physical characteristics of 98 sites. The Y- axis indicates level (height) of dissimilarity. The eight groups are demarcated in red lines on the dendrogram and numbered at the bottom. The red and green numerals at branch dividing points show bootstrap resampling values, grey numerals show the sequential cluster numbers. The line of numbers at the bottom of each cluster-line refers to landscape site grid-numbers, see Figure 1. The uncentered distance method and the average cluster method were applied (Suzuki and Shimodaira, 2006). Groups 10 and 11, not numbered, are simply too small for the numerals to fit, so they are not shown.

4.1.2. Group features

The major divisions in dendrogram 1 were not as clear-cut as in dendrograms 2 and 3. The first division from the top, separated sites with ocean covers (groups 3 and 4), along with a group with flat landscape shape (group 1), from the rest. Group 4 contained four fjords, three on the east coast, and one in the west fjords, separated from the rest, mainly due to the presence of prominent straight lines. The second major division separated sites with low vegetation (5, 6, and 7) from the rest. Groups 5, 6, and 7 included clusters

with low similarity (higher up), compared to other clusters, both in this dendrogram, as well as in two following ones. Groups 8 and 9 consisted mostly of concave U-shaped valleys. Finally, groups 10, 11, and 12 consisted of sites that had repeated forms, and a few that had glacial cover.

The dendrogram was therefore divided into 12 distinct groups: Flat plains (1), outlier sites (2), coastal areas consisting of fjords and beaches (3), coastal areas with prominent straight lines (4), sparsely vegetated highland areas with smooth texture and a moderate elevation range (5), rough-textured highlands (6), smooth-textured (i.e. sandy) highlands with limited elevation range (7), heathlands, plains, and valleys with moderate to prominent rolling lines, but few straight and angular lines (8), valleys with prominent straight and angular lines and wide elevation range (9), and finally, sites with glacial cover and prominent repeated forms (10-12).

The dendrogram was constructed by drawing a line at a 0.14 level of similarity, resulting in 12 groups, or four more than in the following two analyses. The groups were very different in size, the smallest consisted of only one member (group 11), and the largest consisting of 20 (group 9). Few subgroups could be identified within the 12 major groups. Group 3, for example, combined concave fjords and flat beaches, which were separated in the latter two dendrograms. A subgroup may be identified within group 3, with a clear division. Cluster 70 (left) consisted of coastal areas with extensive vegetation cover, while cluster 82 (right) was not as vegetated. Group 8 included both concave U-shaped valleys and flat plains, which were separated in the later two dendrograms.

4.2. Dendrogram 2: Repeated forms excluded

4.2.1. Cluster Analysis

Dendrogram 2 excluded repeated forms. The dendrogram revealed 8 main groups and 1 outlier group (Figure 4).

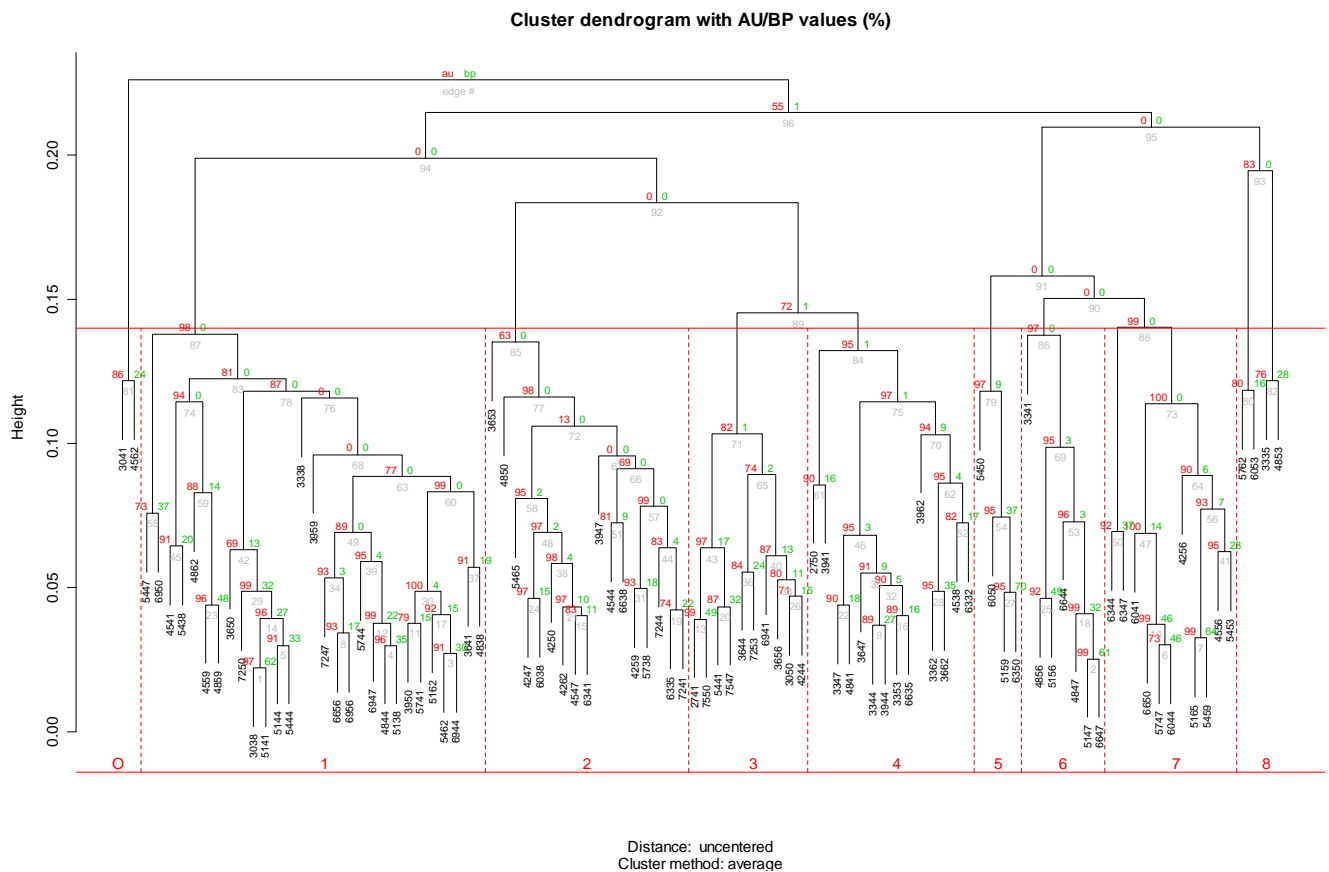


Figure 4. Dendrogram 2. Cluster Analysis dendrogram of major Icelandic landscape groups based on the visual physical characteristics (repeated forms excluded) of 98 sites. The Y- axis indicates level (height) of dissimilarity. The uncentered distance method and the average cluster method were applied (Suzuki and Shimodaira, 2006). For more information, refer to Figure 3.

Most clusters were formed at a high similarity level, or below the 0.10 distance height (Figure 4). The clusters usually had high AU-values and were thus strongly supported by the bootstrap iterations. However, more clusters were formed with lower similarity than in dendrogram 3 (Figure 5).

4.2.2. Group features

The first major division of dendrogram 2 separated the outliers from the rest. The outliers were the same as in dendrogram 3, consisting of two sites that had very few attributes in common. The second major division contrasted the barren highland areas and sites of similar low vegetation cover (groups 5, 6, 7, and 8), as opposed to more highly vegetated areas (groups 1-4).

The concave glaciated valleys formed group 1, separated from the flat plains and heathlands (group 2), as well as from coastal sites (3 and 4). The coastal areas were divided into U-shaped fjords and more horizontal shores. Groups 5, 6, 7, and 8 were all sites with low vegetation cover and large pattern size, at or near the highlands, but were further categorized according to the amount of water cover, type of texture and glacial cover.

The groups formed were: One outlier group (group O), valleys with a concave shape (1), plains and heathlands (2), coastal sites with a flat landscape (3) or a concave shape (4), highland sites with smooth texture (5), highlands sites with smooth texture and water cover (6), highland sites with rough texture (e.g. lavafields, 7), and finally, glacial cover (8).

The groups were quite different in size ranging from 4 to 29 members, group 1 being the largest and groups 5 and 8 being the smallest. The valleys within group 1 could, for example, be subgrouped according to factors such as concavity, narrowness of visual depth and the prominence and diversity of forms and lines in the landscape. The addition of glacial cover influenced group 7, which was subgrouped into highland sites with and without glacial cover.

4.3. Dendrogram 3: Glacial cover and repeated forms excluded

4.3.1. Cluster Analysis

Dendrogram 3 identified eight main landscape groups, within the sample of 98 sites, as well as one outlier group (Figure 5). The groups were demarcated by the straight horizontal line at a 0.14 level of dissimilarity.

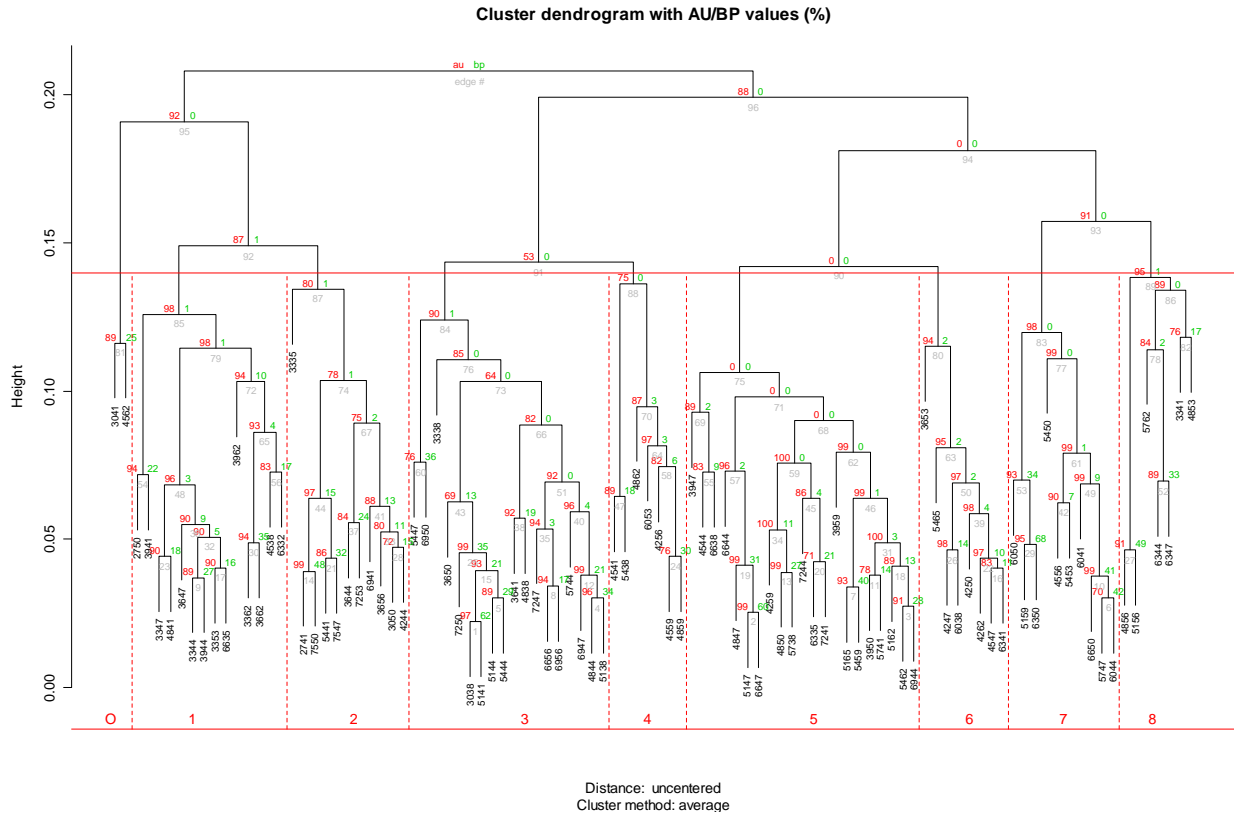


Figure 5. Dendrogram 3. Cluster Analysis dendrogram of major Icelandic landscape groups based on the visual physical characteristics (excluding repeated forms and glacial cover) of 98 sites. The Y-axis indicates level (height) of dissimilarity. The uncentered distance method and the average cluster method were applied (Suzuki and Shimodaira, 2006). For more information, refer to Figure 3.

Most of the clusters had high AU-values, i.e. they were strongly supported by the data. AU-values of zero, which were rarely observed, were probably due to the random position of a large cluster positioned high within the dendrogram, which may appear either to the left or right of the other clusters formed earlier. It was also evident that most clusters were defined at a relatively low level of dissimilarity (a third having a value less than 0.05), indicating that the sites within each cluster had strong similarities.

4.3.2. Group features

The dendrogram displayed three major divisions, which defined the main landscape characters (Figure 5). The first division from the top of the dendrogram split the sample into two parts, i.e. groups 1 and 2 versus all other groups. This separated the sites with

sea cover from the rest. Groups 1 and 2 comprised coastal areas and were further divided into coastal areas with concave landscape shape, i.e. glaciated fjords (group 2) and beaches with more or less horizontal landscape shape (group 1).

The second division resulted in a separation of groups 3 and 4, which were concave glaciated valleys, from the sites in groups 5 - 8, which were more level. The visual depth is also less in groups 3 and 4. Finally the lack of vegetation in sites within groups 7 and 8 resulted in the third major division.

Eight main landscape groups were thus defined: Coastal areas (1 and 2), U-shaped landscapes (3 and 4), flat, vegetated landscape (5 and 6), and flat sites with sparse vegetation cover (7 and 8). The groups were quite different in size, group 5 being the largest with 21 members, and groups 4 and 8 being the smallest with seven members each.

Several subgroups could be identified within the main groups. Group 5, for example, contained three or four subgroups. Cluster 68, within group 5, could be regarded as containing two subgroups, the one on the right having slightly higher scores for rolling lines, diversity in texture, pattern, forms and lines. There were, however, more subgroups within the previous dendrogram than there were in this one, due to clusters with a higher level of similarity.

The outlier group was made up of sites 3041 and 4562. These sites should not be considered as a well defined landscape group, as their combination of characteristics was not similar enough internally. Their characteristics were also not sufficiently similar to the other landscape groups to be considered anything other than outliers.

4.4. Principal Component Analysis

A Principal Component Analysis was performed on the data from dendrogram 3, i.e. the one from which repeated forms and glacial cover were excluded. The eigenvalues in Table 1 indicate the total amount of variance in the data represented by each eigenvector. The first component accounts for most of the variation, followed by the second, etc. Together the components comprise all of the variation in the data.

Table 1. Additive eigenvalues calculated from a Principal Component Analysis of the visual physical landscape characteristics of 98 sites in Iceland. Model 3 was used in the analysis. Eigenvalues indicated the cumulative proportion of variation in the original data explained by the components. The first components had the greatest explanatory value, and the eigenvalues added up to the total variation

Comp1 25.7	Comp2 42.9	Comp3 55.3	Comp4 62.3	Comp5 67.9	Comp6 72.5	Comp7 76.8	Comp8 81.0
Comp9 84.3	Comp10 87.4	Comp11 89.7	Comp12 91.6	Comp13 93.4	Comp14 94.8	Comp15 96.0	Comp16 97.0
Comp17 97.9	Comp18 98.7	Comp19 99.2	Comp20 99.7	Comp21 100.0			

The eigenvalues of the first two components accounted for about 43% of the total variation, and the first eight for 81%. Usually the first two or three components account for more than what we see here. This indicates moderate covariance between the attributes in the original data, i.e. the higher the covariance in the original data the more the is accounted for by the first axis (Legendre and Legendre, 1998; Quinn and Keough, 2002). This moderate percentage for the first two components means that the biplot does not show a clear division between sites as could be expected with PCA, i.e. the more accounted for by the components, the clearer the division.

The loadings indicated the degree of influence of each attribute, and only a few showed moderate correlations (>0.5) for the first three components (Table 2). For example, sea cover showed strong positive correlation with component 2, and a weak negative correlation with component 1. This suggested that the sites that had high scores for sea cover should have been influenced more strongly by component 2, than by component 1. Several attributes showed low correlation with component 2, e.g. size and diversity in patterns, along with roughness and diversity in texture (Table 2). These attributes were represented by the cluster of arrows, pointing to the right on the ordination graph, rather than upwards or downwards (Figure 6).

Table 2. The loadings for each attribute on the first three components of a PCA of the visual physical landscape characteristics of 98 sites in Iceland. The attributes are from model 3. The numbers are correlation coefficients and most of them are rather low. Attributes with low correlation with a component do not show any distribution trends in the biplot (Figure 6). In other words, sites that have high scores for weakly correlated attributes are not situated differently visually from sites with low scores for the same attribute.

Attributes	Component 1	Component 2	Component 3
Basic shape	-0.243	-0.011	0.09
Visual depth	-0.298	0.066	0.074
Elevation range	0.310	0.087	0.145
Straight lines/forms	0.425	0.191	0.134
Rolling lines/forms	-0.003	-0.360	0.155
Angular lines/forms	0.329	0.180	0.278
Sinuuous lines/forms	0.271	-0.213	0.001
Diversity of lines/forms	0.289	-0.023	0.146
Vegetation cover	0.131	0.314	-0.753
Vegetation diversity	0.146	0.129	-0.298
Colour range	0.146	0.040	0.029
Pattern size	-0.136	-0.006	0.144
Pattern diversity	0.167	0.012	-0.024
Texture diversity	0.213	0.015	0.023
Texture roughness	0.113	0.046	0.166
Water cover	0.120	-0.276	-0.193
Water current	0.239	-0.284	-0.081
Water expression	0.113	-0.174	-0.123
Sea	-0.066	0.660	0.212
Snow	0.154	-0.029	0.120
Overall diversity	0.181	0.023	-0.005

The biplot ordination graph showed the 98 sample sites positioned according to their scores from the eigenvalue and eigenvector calculations, plotted with the first two eigenvectors (Figure 6, Table 2). The influence of each attribute was represented by a black arrow drawn from the origin (i.e. middle) of the plot, and stretched according to the strength of the eigenvector for that particular attribute. The direction and length of the arrow were, therefore, important, i.e. they showed the direction of increase of each attribute, and the length indicated the rate of increase, i.e. the shorter the length, the greater the increase (Quinn and Keough, 2002). The numbers represented group numbers of the sites from the dendrogram in Figure 5. The position of the points is crucial, because the farther they are apart, the greater the difference between them. This was the most important use of PCA for this landscape classification.

Clear clusters which corresponded to the results produced by the Cluster Analysis were revealed in Figure 6. It was obvious that most of the arrows pointed to the right of the graph, while few pointed to the left (visual depth, basic shape, and pattern size), and two arrows were oriented primarily upwards (sea cover and vegetation cover). This is also reflected in Table 2, where only a few attributes had negative loadings. Those sites that were to the left scored highly for visual depth, basic shape, and pattern size. Likewise, the sites on the top of the graph had high scores for sea and vegetation cover.

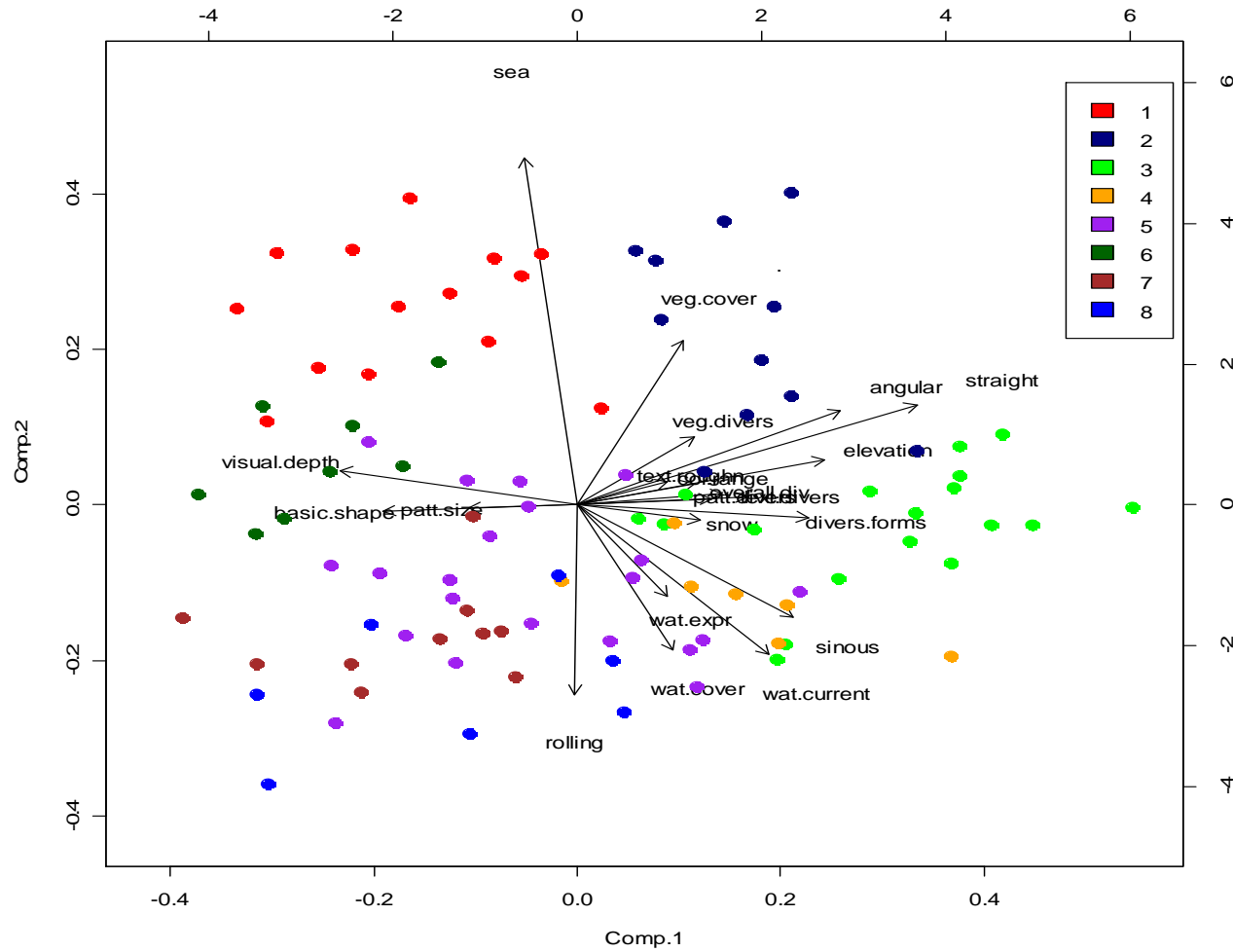


Figure 6. First and second axes of the Principal Component Analysis based on the visual physical landscape characteristics used in dendrogram 3 (Figure 5). Different colours represented sites in the major 8 landscape groups, according to Figure 5. Arrows indicated the weight of each attribute. The attributes in the “soup” of arrows above snow in the figure are: Colour range, pattern diversity, texture diversity, texture roughness, and overall diversity.

5. Discussion

5.1. Comparison of the three dendrograms

The three models yield broadly similar results but nevertheless vary both in the degree of clarity and the composition of groups. The two excluded attributes (glacial cover and repeated forms) were present at only a few of the sites visited, while most others were generally present, although to a differing degree at all the sites. The definition of repeated forms was not always clear cut. These two attributes were also unconnected with any of the other attributes. The highly elevated and large glaciers forms are often visible from afar and can therefore be a part of many different kinds of landscapes. For these reasons we excluded these attributes for the major analyses. We see that some of the sites, where glaciers were detected, do form a distinct group in dendrogram 1 and 2 (Figure 3 and 4) but are separated in dendrogram 3 (Figure 5). This also demonstrates the flexibility of our approach, which makes evaluation of the effect of each landscape attribute easy, by removing and/or adding it. It is, for example, clear that adding repeated forms to the calculations resulted in a separate additional group in the first dendrogram (Figure 3). Adding glacial cover also had this effect (Figure 4), but the effect was not as pronounced as with repeated forms. An interesting consequence of adding attributes is the effect they have on similarity levels, pushing more clusters to a higher level. This is most evident in the first dendrogram where the 0.14 level separation line resulted in 12 groups, but in only 8 for the second two dendrograms (Figure 3). Although the similarity levels were higher for the clusters, the AU bootstrap value was quite large throughout the different combination of attributes. It is also clear that some groups were more stable than others, and formed in all three dendrograms, for example U-shaped valleys, coastal sites, and fjords. The flat shaped plains and heathlands were also stable. Some sites were less stable, and jumped between groups on separate dendrograms. These were most often sites that could be described as consisting of characteristics that may be found in more than one group, for example the sites that ended up in group 4 in dendrogram 3. The last dendrogram, which excludes glacial cover and repeated forms (Figure 5), has the clearest division of major groups, and was

also the easiest to interpret. I will, therefore, examine it more closely in the following sections.

5.2. Group 0: Outliers

The two sites farthest to the left on dendrogram 3 may be regarded as outliers (Figure 5), with low similarity to other sites. They were among the last clusters to be formed in the dendrogram, and such late clusters are usually situated at the end of the dendrogram.

Their distribution may be seen in Figure 7.

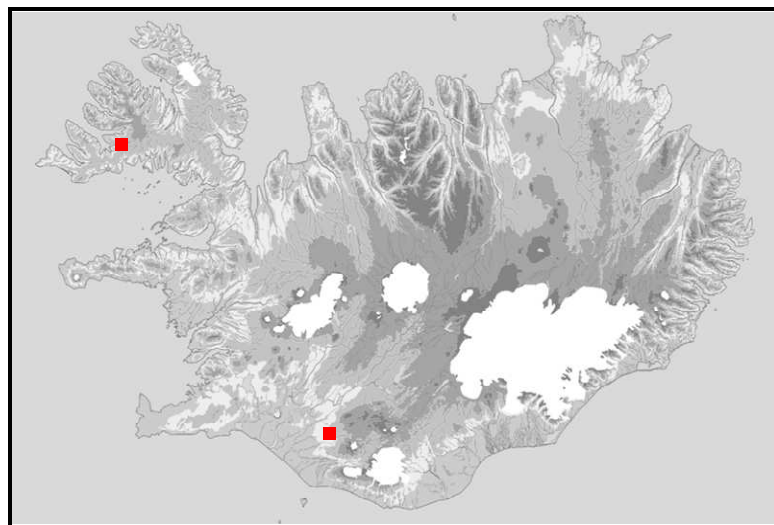


Figure 7. Distribution of landscape sites (red squares) within group 0. These are Dynjandisheiði, 3041 (upper) and Fjallabaksleið syðri, 4562 (lower).

Dynjandisheiði (3041), is a wind eroded, high plateau with an ocean view on one side, and clusters of mountains and peaks on the other. It has very low vegetation cover and unusual, oddly coloured, rough- textured moraines covering the ground (Figure 8). The combination of high-altitude and low vegetation with high sea cover is unusual, as is the rough textured moraine.



Figure 8. Dynjandisheiði (site 3041), a wind swept and eroded high plateau moraine, with odd colouring and rough texture. The site is situated above Arnarfjörður, which is one of the West fjords. Photograph: Hlynur Bárðarson

The other site is 4562, Fjallabaksleið syðri (Figure 7) The name translates as “The southern route behind the mountains”, and is a brilliantly descriptive name for this particular site. It is characterised by moderately large, roughly textured highland plains, partly covered with grey and green moss, surrounded by a complete circle of mountains at a moderate distance in the background. The site, therefore, imparts moderate visual depth and a considerable elevation range, an unusual combination of these attributes.

These two sites include characteristics otherwise typical of two or more major landscape groups. Therefore they do not fit within the eight landscape groups and are not similar enough internally to be considered as something other than an outlier group with “hybrid sites”.

5.3. Group 1: Coasts and islands

The first landscape group has 14 members and consists of sites at or near the coastline (Figure 9). They are largely characterized by a flat basic shape, although it is not uncommon to find high mountains to one side, occasionally yielding a partially concave shape. Vegetation cover may be low or high, but vegetation diversity is mostly low. Diversity of forms and lines is also below average.

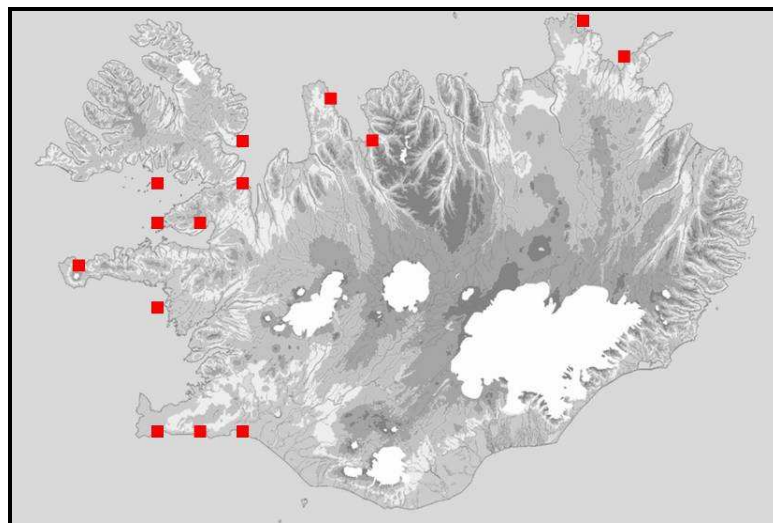


Figure 9. Distribution of landscape sites (red squares) within group 1. The sites are coastal areas and characterised mainly by their sea cover.

The sites within group 1 are situated at the top left corner of the Principal Component Analysis ordination graph (Figure 6). This position indicates high scores for sea cover, visual depth, basic shape (i.e. flat), as well as for a coarse pattern size, all of which are defining variables for this group. One factor which greatly influences the landscape of coastal sites is wave action, which shapes the outlines of coasts. The character of the actual coastline may be roughly divided into two different types: a) Rocky, mountainous, and clifflike, or b) flat and wide sand beaches with fine grained sand (Plummer et al., 2005). Herdísarvík (3662) is a typical sandy beach, situated on the southwest coast of Iceland (Figure 10). There is a substantial upload of sand at this beach, and this is collected for construction work, e.g. at Eyrarbakkafjara (3962). The sand at Eyrarbakkafjara is deposited there by the Ölfusá-river, which is a combined glacial and spring fed river, with the highest discharge of any Icelandic river

(Orkustofnun, 2009). The landscape is shaped by this sedimentation along with the erosive action of ocean waves. The diversity of the vegetation is low, and the pattern size is large.



Figure 10. Herdísarvík (site 3662). A sandy beach situated at the south west coast of Iceland. This kind of wide sand sedimentation is very common along the south coast of the volcanically active island, and the sediment is often harvested for use in construction work. Photograph: Hlynur Bárðarson

Site 4538 is a rocky, mountainous coast in the northern part of Iceland (Figure 11). Here, the physical character is formed by erosive action of waves upon the coastline, leaving a clifflike structure, and a much smaller beach. These rocky coasts are typical of the old Tertiary parts of Iceland, i.e. the west, central north, and the east, while sandy beaches are found in the younger parts. Our classification does not differentiate between these two coastal types.



Figure 11. Bjargavík on the Skagi peninsula in the northern part of Iceland. This site is a typical rocky coast. These kinds of cliffs are home to a large population of seabirds which breed in Iceland (Burfield and Van Bommel, 2004). Such cliffs are more common in the older Tertiary part of Iceland. Photograph: Hlynur Bárðarson

5.4. Group 2: Fjords.

Group 2 is also characterized by sea cover, clustering it with group 1 at a higher level in the dendrogram. The most pronounced difference between groups 1 and 2 lies in their basic shape, group 2 having a predominantly concave shape. Group 2 contains 11 sites, in or near fjords (Figure 12).

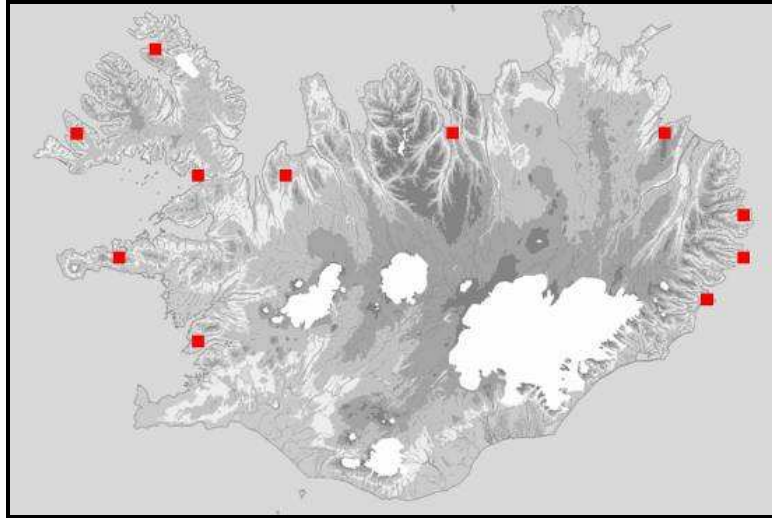


Figure 12. Distribution of landscape sites within group 2 (red squares). The 11 sites are distributed in the old Tertiary regions, and are characterised by sea cover and a concave landscape shape.

The fjords are predominantly in the old Tertiary regions of Iceland, in the west, central north, and eastern Iceland, as well as in the Northwest Peninsula. The fjords were formed during glaciations periods in the geological history of Iceland. The glaciers scraped the bedrock into a concave U-shape (Plummer et al., 2005). They are absent from the south coast, which is dominated by sandy beaches. The difference between the two coastal groups may be clearly identified from the ordination graph (Figure 6), where group 2 is concentrated at the top right hand corner, indicating high scores for sea cover, but low scores for basic shape (i.e. concave), while group 1 is in the top left corner, indicating medium scores for basic shape (i.e. flat). Likewise, the scores for elevation range are higher than in group 1, an effect which may be attributed to the high mountains along the fjords.



Figure 13. Norðfjörður (7547) near the town Neskaupsstaður in east Iceland. Norðfjörður is a good representative for the fjords in group 2. Sea cover is the most prominent attribute along with high mountains, concave shape, and often prominent straight lines in stacks of basaltic Tertiary lava flows. Photograph: Hlynur Bárðarson

The fjords are U-shaped, scoured by glaciers, with high mountains to each side, moderately narrow to narrow visual depth, and high elevation range. The mountains commonly have diversity in lines and forms, especially the mountains of the west-fjords and the east-fjords, which often contain highly prominent straight lines which represent horizontal stacks of basaltic Tertiary lava flows (Hardarson et al., 2008). Norðfjörður, situated in the east fjords, is a good representative of group 2 (Figure 13). The U-shaped form can be clearly seen as well as the horizontal stacks of lava flows.

5.5. Group 3: Valleys

The most prominent characteristics of group 3 are a basic U-shape, a narrow landscape depth over the greatest part of the 360° field of vision, along with moderate to high elevation range, due to the presence of high mountains on each side. Valleys such as result from the carving of Pleistocene outlet glaciers, which left concave troughs after

the glaciers melted (Plummer et al., 2005). Group 3 is the second largest group with 18 sites, second only to group 5, and its distribution is also widespread in Iceland, although it is absent from the geologically youngest regions and the active volcanic zone (Figure 14).

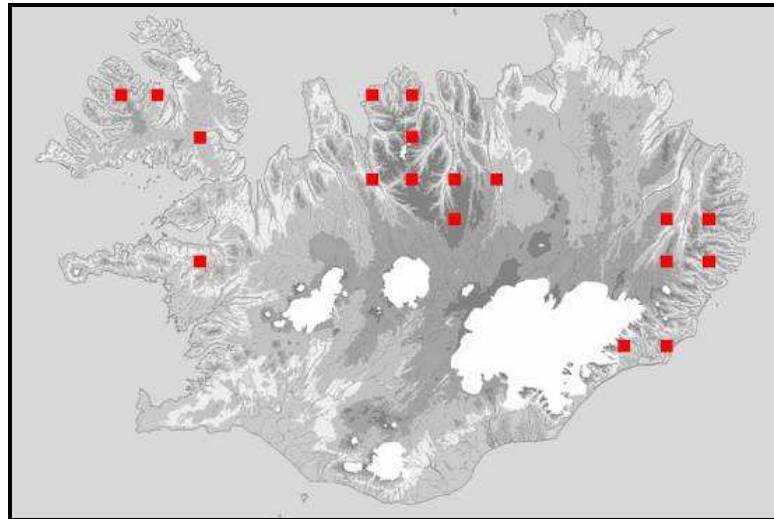


Figure 14. Distribution of landscape sites within group 3 (red squares). As for group 2, these sites are located in the older Tertiary parts of Iceland.

The concave shape, narrow field of view, and large elevation range are emphasised by the PCA ordination graph, where sites within group 3 cluster just right of centre (Figure 6). Other characteristics of the valleys include extensive vegetation cover and high vegetation diversity, with grasslands (meadows, pastures and rough grasslands), wetlands, woodlands, and sometimes traces of heathlands.

Skíðadalur is a glacially formed valley, situated near the town of Dalvík in northern Iceland (Figure 15). Several different kinds of vegetation types may be found in this valley and the concave shape is quite prominent.



Figure 15. Skíðadalur in north Iceland. This glacially formed valley has the U-shape which is characteristic of sites within group 3. The vegetation cover is high, except on the steep scree slopes and mountain cliffs and tops. The visual depth is moderately narrow to narrow and the elevation range high. Photograph: Hlynur Bárðarson

5.6. Group 4: Shallow valleys

Group 4 is best described as transitional, as it comprises features of three other groups: valleys, heathlands, and the central highlands. The common characteristics of these landscapes are therefore shared with several other groups. It is one of the smallest groups, containing seven members (Figure 16).

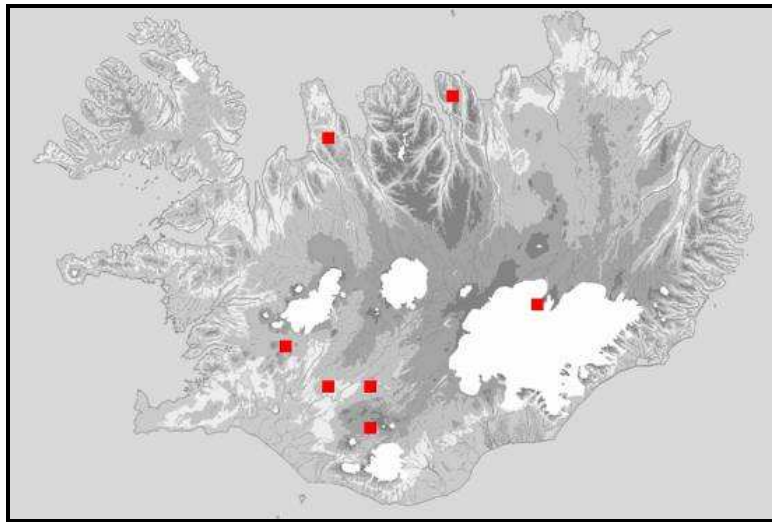


Figure 16. Distribution of landscape sites within group 4 (red squares). The sites are mostly situated in the volcanic zone, and are best described as a transitional group between groups 3, 5, 7, and 8.

The sites in this group are situated at the margin of the central highlands, which are usually characterized by heathlands (group 5), although these sites deviate from the heathlands in their moderately concave shape and moderately narrow visual depth (otherwise characteristic of group 3), prominent rolling lines (otherwise characteristic of group 5) and low vegetation cover (otherwise characteristic of groups 7 and 8). Some of these sites have high diversity in texture and form. The ordination graph (Figure 6) reveals that sites within group 4 are situated between groups 3 and 5. These sites lie to the right of group 5, indicating lower scores for basic landscape shape, (i.e. concave trends), while group 5 is characterized by flat landscape shape. The group 4 sites are also below those in group 3, indicative of prominent rolling lines. Site 4859 is one of these sites and has high diversity in form and texture (Figure 17).



Figure 17. Site 4859 close to Hrauneyjarlón, showing the moderate diversity in forms and texture possessed by some of the sites in group 4. Photograph: Hlynur Bárðarson

5.7. Group 5: Heathlands and plains

Group 5 comprises heathlands, lowlands, and plains. They share a flat basic shape, moderate to great visual depth, continuous vegetation cover, moderately smooth surface texture, often a large pattern size, prominent rolling lines, moderate to low diversity in forms and lines, and most often a restricted elevation range. The 21 sites are distributed evenly around Iceland, but are particularly common on the fringes of the central highlands. Many lie above inhabited areas but still at a reasonably low altitude. They represent a common landscape type (Figure 18).

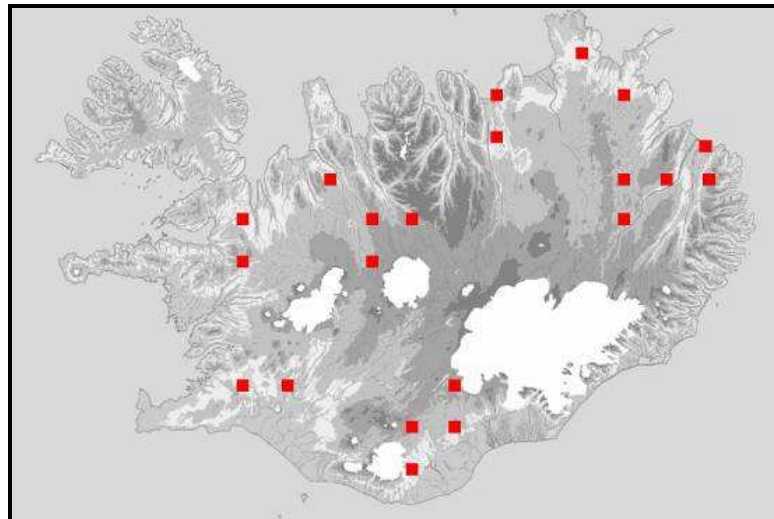


Figure 18 Distribution of landscape sites within group 5, (red squares). This is the largest group with 21 members, scattered around Iceland in marginal areas between inhabited areas and the highland plateau. They are characterized by a flat basic shape and large vegetation cover, along with rolling lines.

Sites within group 5 are somewhat scattered and do not form a solid cluster on the ordination graph, although all of them are situated at a similar location on the graph (Figure 6). It must be borne in mind that this is the largest group, with 21 members, and such a large group is more likely to be more scattered than smaller ones. It may easily be argued that the sites within this group should be grouped together, but it can just as easily be argued that subgroups may be identified herein. This demonstrates the necessity of comparing the results between the two methods used, i.e. the PCA and the Cluster Analysis, so as to best explain the results of the classification.



Figure 19. Smjörvatnsheiði, a heathland in eastern Iceland. The heathlands are often largely vegetated, rolling lines are prominent, but diversity in forms and lines is usually low. The heathlands are often marked by heavy grazing by sheep and sometimes also by horses. In fact, upon closer examination of the photograph, one may discern several sheep in the distance. Photograph: Hlynur Bárðarson

Smjörvatnsheiði, situated in the eastern part of Iceland, is representative of the heathlands (Figure 19). The site has vegetation typical for the heathlands, vegetation cover is mostly continuous but the diversity of vegetation, as well as of forms and lines, is low. Visual depth is considerable and soft rolling lines prominent.

5.8. Group 6: Flatlands

Landscape group 6 may be described as a subgroup of the heathlands and plains. This may clearly be seen by examining the dendrogram, where groups 5 and 6 are clustered together within cluster number 90 (Figure 5). This group has many features in common with group 5, but it also has some strong internal characteristics. Sites in group 6 all have a score of 3 for basic shape, indicative of their flat shape. They have above average or high scores for visual depth, vegetation cover, and pattern size. Diversity in

forms and lines, pattern, and overall diversity are, however, all low. One quite distinct characteristic, low scores for rolling lines, is not shared with group 5. The low scores are probably due to the fact that any hills or mountains are a considerable distance away, and the changes in horizontal view are negligible. There are 8 sites within group 6, in lowland areas or the transitional zone between inhabited areas and the highland plateau (Figure 20).

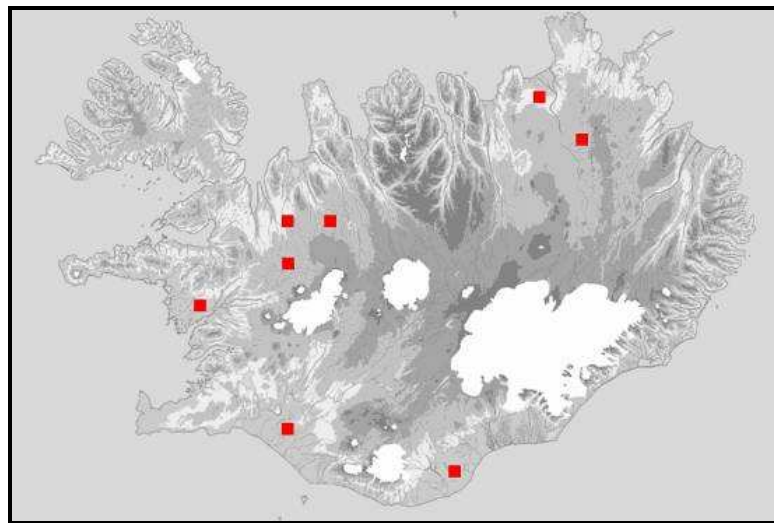


Figure 20. Distribution of landscape sites within group 6 (red squares). The eight sites have extensive visual depth and mountains and hills are usually some distance away. The sites have largely continuous vegetation cover, and have a flat basic shape.

The characteristics of this group are revealed in the results of the PCA, where the sites are clustered to the centre left on the graph (Figure 6). Low scores for rolling lines, and high scores for vegetation cover shift the points towards the top of the graph, above sites in group five, while high scores for pattern size, visual depth and basic shape, along with low scores for elevation range shift them towards the left of the graph.



Figure 21. Laxholt (3653) near Mýrar, in western Iceland is a good representative of the plains in group 6. The lack of diversity in forms and lines, and the large visual depth are due to the great distance to the next elevation change, i.e. mountains or hills are very distant. Photograph: Hlynur Bárðarson

Laxholt near Mýrar (3653), in western Iceland is one of the eight flatlands in group 6 (Figure 20). Mýrar is a flatland, so named because of the extensive wetlands in the area. The nearest mountains are quite distant from the site, as reflected in the photograph above, as well as in high scores for visual depth, low scores for elevation range and low diversity in forms and lines, especially rolling lines.

5.9. Group 7: Central highland plateau

The cluster that forms groups 5 and 6 is connected to another cluster that forms groups 7 and 8 (cluster 94 in Figure 5). This indicates that the sites within these four groups have some characteristics in common. The sites within group 7 are either flat or convex in basic shape, with one exception, site 5450 (Bergvatnaskvísl), which is concave, although it is assigned to this group for other reasons. The sites also have a large pattern size and moderate to high scores for rolling lines, making them similar to the heathlands and the

plains. The distinctive characteristic that makes this group special are its below average, and even zero, scores for vegetation cover and diversity. There is one exception to the low scores for vegetation, site 6041 (Krafla), which, despite its high vegetation cover, has the other characteristic attributes for group 7, such as prominent rolling lines and large pattern size. Krafla is also special among the eight sites in this group, as it is the only site which is strictly speaking not situated in the central highlands (Figure 22).

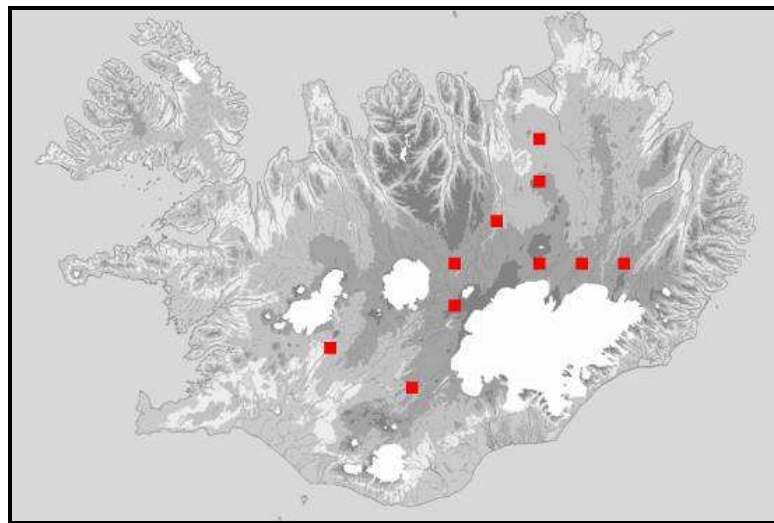


Figure 22. Distribution of landscape sites within group 7 (red squares). The sites are characterized by low vegetation cover and diversity, large pattern size and flat to convex shape. The 10 sites are all situated on the central highland plateau.

The ordination graph reveals the same key characteristics as the dendrogram, the sites within group 7 being situated at the lower left corner, i.e. in the opposite direction from the arrow representing the loadings for vegetation cover, indicative of the low scores (Figure 6).



Figure 23. Fljótsdalsheiði near Þrælaháls (6650). The site is a good example of the barren and sparsely vegetated ground of the central highland plateau. Hills, such as the one in the background, are common, and influence moderate to high scores for rolling lines. Photograph: Hlynur Bárðarson

Fljótsdalsheiði, a part of the east central highlands, is characterized by a sparsely vegetated, wind eroded landscape (Figure 23). In fact, the central highland plateau in Iceland is an area with such severe soil erosion and desertification that it could be considered as the largest desert in Europe (Arnalds et al., 2001).

5.10. Group 8: Highland plateau rivers

Sites in landscape group 8 are similar to those in group 7. These sites have similar scores for vegetation diversity and cover, a flat basic shape and great visual depth. The difference between these groups, however, lies in their location. Sites within group 8 are situated near rivers or lakes, imparting higher scores for water cover and water current. It is, therefore, difficult to separate the sites within these two groups on the ordination graph, as the only measurable difference between them is this small difference in water cover (Figure 6). The rivers in group 8 are all situated in the highlands, except for site 5762 (Núpsvötn on Skeiðarársandur), but it is easy to argue that the characteristics of this large sandy flatland in the south of Iceland, with almost no vegetation to speak of, should be grouped along with sites in the central highlands (Figure 24).

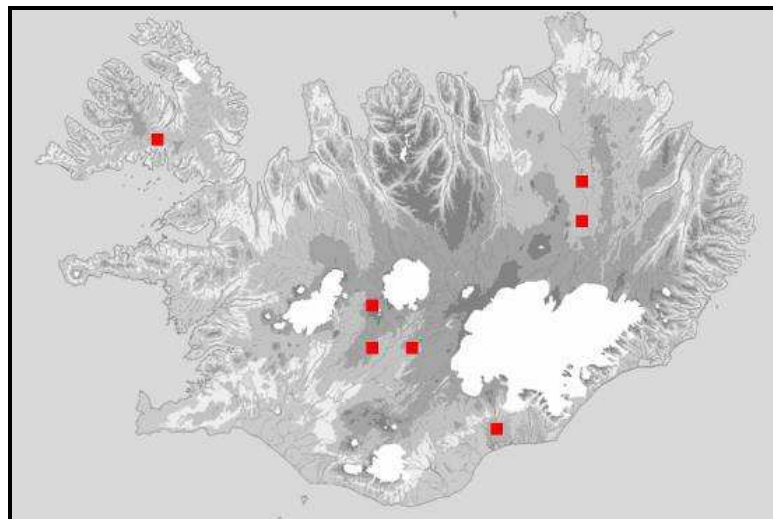


Figure 24. Distribution of landscape sites within group 8, shown in red. The sites are distinct, as they are all situated at or near large rivers. Nevertheless, their character is almost identical to the sites in group 7, with low vegetation cover being the key characteristic.

Site 3341 is not situated next to a river, but rather next to several small lakes, that cumulatively give a moderate score for water cover. Site 3341 is a highland plateau like the others, although it is situated in the West fjords (Figure 24). Jökulkvísl is a typical highland river situated near the Kerlingarfjöll mountains area (Figure 25).



Figure 25. Jökulkvísl river, near Gýgjarfoss (4853). This is a typical highland river with similar characteristics to sites in group 7, except for more water cover. Photograph: Hlynur Bárðarson

6. Conclusion

We wished to ascertain whether the method we developed to classify Icelandic landscape could be successfully applied. We argued that in order to do this it is necessary to examine the results, i.e. did these landscape groups reflect real entities? We have shown that the hierarchical properties of the Cluster Analysis and the simplicity of the PCA yielded results which are both clear and intuitive. We also demonstrated the flexibility of the approach by showing how easy it is to add or subtract attributes and evaluate the resulting effects. The evaluation of other attributes, such as cultural aspects or even subjective characteristics of the landscape can thus easily be added to the matrix.

There were 98 out of 130 possible landscape sites sampled for this article and the sampling is still taking place. Adding sites to the cluster analysis may yield a clearer picture regarding the landscape groups. We have mentioned that there are several subgroups that can be identified, e.g. the sandy coastal areas and the cliff coastal areas in group 1. This could perhaps result in two distinct groups if more coastal areas are sampled. Also new possible landscape types or groups, which we have not identified within these 98 sites, could arise with more sites sampled. Another important gain with larger sample size is the estimate of the occurrence of different landscape types, i.e. which are more common than others. This could be useful for planning agencies that want to know the impact on the landscape as a whole in Iceland.

The results also provide good incentives to continue, and especially, to attempt to discover landscape type boundaries of the landscape types. We also hope that our results may assist in policymaking, by making it easier to manage those decisions that may impact the landscape in some way. Further studies are planned, which are intended to facilitate mapping, as well as to enhance our understanding of the value of Icelandic landscapes.

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Article 2. Icelandic landscape and underlying geological factors

1. Summary

Using a nationwide 10 * 10 km grid system and sample of 98 sites, the landscapes of Iceland were classified into 8 major groups based on 23 visual characteristics scored in the field. Here, I explore the relationship of the visual landscape classes with underlying geological factors, i.e. geological age and bedrock types, using Canonical Correlation. The digital geological data base of the Icelandic Institute of Natural History is arranged within the same grid system, and for each site, the proportional cover of geological age classes and bedrock types within each 100 km² square was calculated. The multivariate method revealed a strong correlation between the landscape groups and both geological factors. This correlation was explored further by comparing these combinations of the geological factors within each landscape group. The correlation of the visual landscape attributes and geological age revealed that some of these attributes characterize regions of old (Tertiary) bedrock, while others are prominent in the presently active volcanic zone. The landscape groups showed some correlation with elevation above sea level. The results indicate that the visual landscape character of Iceland is influenced by geological factors.

2. Introduction

The Icelandic landscape is unique in European context. Iceland is a volcanic island with diverse geological phenomena, such as hyaloclastite mountain ridges, and an extensive inland high plateau which mostly carries sparse or very sparse vegetation and with large tracks that could be classified as wilderness, i.e. a “large area of unmodified or slightly modified land retaining its natural character and influence, and without permanent or significant habitation. Areas without permanent or significant habitation...” (IUCN 2009). Landscape postcards and their popularity in terms of sales were used as a proxy for landscape preferences of tourists in Iceland (Óladóttir, 2005) and the aesthetic appreciation of landscape and its relations with sociological factors among university students and a group of connoisseurs were studied by Kristinsdóttir (2004). In an earlier investigation, Preusser (1976) attempted a description of Icelandic landscape types and their regional variability. A number of landscape surveys have been performed in relation to environmental impact assessments (e.g. Arnalds, 2001; Linuhonnun, 2006).

In 1999-2006, the first systematic analysis of landscape was performed. This was carried out in connection with the Framework plan for the use of hydropower and geothermal energy development (Verkefnisstjórn um gerð Rammaáætlunar 2003). All potential hydropower and geothermal energy projects were evaluated in several respects, one of which was the landscape at the site in question. A landscape classification based on visual physical characteristics has already been described (Bardarson *in prep.*). This resulted in 8 distinct landscape groups.

Landscape classification has been carried out in other European countries such as the UK (Swanwick, 2002) and Norway (Puschmann, 2005). Landscape classification methods in Europe generally focus more on the cultural landscape than on the natural landscape. This emphasis is not suitable for the Icelandic landscape, as the human impact on the visual character of the landscape is not as great as in Europe. The Icelandic landscape is – in appearance at least – more natural and geology plays a bigger role in the visual character of the landscape than agricultural land use that forms the basis of many of the European classification systems (e.g. Washcer 2005).

In this article I explore the underlying geological factors that may influence the visual characteristics of the landscape. These factors are geological age, bedrock and height above sea level. I examine the correlation between these factors using the multivariate method Canonical Correlation which examines the correlation between two sets of descriptors. This reveals whether the 8 landscape groups previously identified share some distinctive composition of bedrock type, are of similar age, or whether this is simply random. A 10*10 km grid sampling procedure that was used for the landscape classification is applied to two different kinds of geological data maps: a geological age map and a bedrock map. The relationship between the landscape groups and their height according to Mean Sea Level is also explored.

The aim of this part of the thesis is to explore the relationship between the visual physical character of the Icelandic landscape and its geology. The question is whether the geology influences with the visual character of the landscape and, if so, how strong is this relationship? Which factors of the geology influence the visual character the most, and how is this relationship reflected in the landscape classification?

Finally, a comparison of two other landscape classification methods that are in part based on geology will be discussed. These methods are the British Landscape Character Assessment method (Swanwick, 2002) and the national reference system for landscape in Norway (Puschmann, 2005)

3. An overview of the geology of Iceland

Iceland is a 103 000 km² oceanic island situated on the Mid-Atlantic ridge, and therefore on the boundary of the diverging Eurasian and North-American tectonic plates (Einarsson, 2008). It is one of Earth's most volcanically active regions, with eruptions occurring about every 4-5 years on average, emitting solid lavas and volcanic tephra. The bedrock of Iceland is relatively young compared to neighboring countries, and may be divided into four time-periods based on geological age (Saemundsson, 1980). Miocene (Tertiary) bedrock (>3.3 m. yrs. BP) is the oldest, followed by Pliocene-Pleistocene bedrock (3.3 – 0.78 m. yrs. BP.), Late Pleistocene bedrock (0.78 - 0.01 m. yrs. BP.) and, finally, Holocene lava flows (younger than 11 000 years BP.). The oldest

parts are the extreme west and east of Iceland, with progressively younger bedrock towards the centre (Figure 1).

The plate boundary crossing Iceland is often separated into different rift units based on location. The Northern-Rift Zone is single zone that is connected by a transform fault to the Kolbeinsey-Ridge north of Iceland. Further south it diverges into two overlapping spreading centres, the Eastern-Rift Zone and the Western-Rift Zone. Farther away from the main spreading axis is the Snæfellsnes Flank Zone to the west and the Öräfajökull-Snæfell Flank Zone to the east (Jakobsson et al., 2008 (Figure 1)).

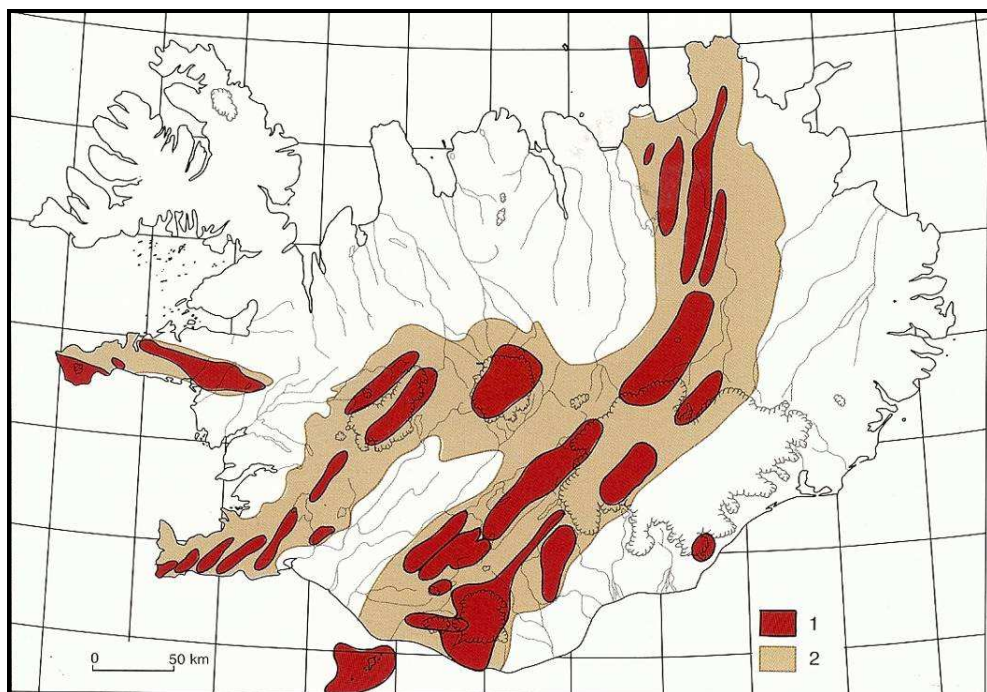


Figure 1. The currently active volcanic zone. The zone is divided into a single Northern-Rift Zone in the north, and diverging Eastern-Rift and Western-Rift Zones in the south (1). The two flank Zones, The Snæfellsnes flank and the Öräfajökull-Snæfell flank are shown also (2). The oldest parts (Miocene-Tertiary) of Iceland are to the extreme west and east Based on Einarsson (1994)

3.1. Tertiary bedrock

Iceland is one of the largest basalt areas of the world with 80-90% of the bedrock being of basaltic nature (Einarsson, 1994). The typical magma erupted at diverging plate boundaries such as Iceland is tholeiite which is relatively fluid (non-viscous), and can flow over long distances, similar to conditions on Hawai'i. The oldest bedrock in the

west and east is composed of fine grained, basaltic lavas, formed during the Tertiary. This period was characterized by a succession of extremely large lava flows that built up flat plateaus. Today, these are evident as stacks of horizontal layers (each layer representing one lava flow) in the upper parts of the mountains of the North West peninsula, central north, east and west. In the lower parts of the mountains, these horizontal layers are covered by slopes of loose scree (Figure 2). During the Pleistocene, the land was more depressed inland due to active loadings of volcanic products, lavas, dykes etc., near the rift axis, along with subsidence of the rift zone crust, which decreases towards the rift zone (Hardarson et al., 2008). This is still evident today as a tilt of these layers, so that they are higher towards the sea and lower inland.



Figure 2. Mountain Tungufjall in Tungudalur valley inside Önundafjörður which is one of the west fjords. Here the stacks of horizontal layers of lava are quite distinctive.

3.2. The Pliocene-Pleistocene epoch

Iceland was heavily glaciated during the Pleistocene, and it is now believed that at the last glacial maximum (~20.000 years BP), glaciers extended well beyond the present coastline in all parts of the island (Norddahl et al., 2008). The Pleistocene was a period marked by alternation between glaciated and nonglaciated (interglacial) environment. Volcanic activity continued during the Pleistocene and Upper Pleistocene periods, and includes both subglacial volcanic forms and formations produced during interglacial stages (Eiriksson, 2008). The Tertiary basalts are mostly fine grained and dark in colour while the interglacial Pleistocene basalts are typically coarser grained and lighter in colour (Norddahl pers. comm.).

Volcanic eruptions in Iceland are mostly basaltic in nature. Acidic eruptions are much more localized, and are associated with the major central volcanoes with an underlying magma chamber. Acidic eruptions usually emit rhyolitic magma, which may become yellow, orange, or even pink in colour, due to later alterations. Additionally, later alterations in subglacial acidic eruptions may impart distinctive colours, e.g. sediments that are green or even blue, unlike the basaltic magma at the Rift-Zones. The acidic magma is highly viscous and spreads only short distances, instead building up steep mountains, or thick lava flows with a very rough surface that tumbles forwards rather than flows. Acidic eruptions are known in Tertiary and Pleistocene bedrock, but have only occurred rarely during the Holocene (Einarsson 1994).

Basalts erupted under glaciers during the subglacial periods of the Pleistocene often produced a tuff like breccia, and/or hyaloclastites, with quite different structural properties, although chemically they are identical to the free flowing basalts. Hyaloclastites are created by fragmentation of magma, when it reacts explosively with meltwater in the glacier generated by the heat of the eruption. Due to rapid cooling, these hyaloclastites are associated with glassy fragments that gradually glue together to form a grainy type of rock, which is much more erodible than basaltic rock, but has much greater water retaining capacity (Gudmundsson and Kjartansson, 1996).

Although hyaloclastite table mountains and ridges are common in Iceland, they are relatively rare in volcanic regions elsewhere in the world. They are one of the most distinctive geological characteristics of the Icelandic landscape. The ridges form

continuous rows of semi-repeated peaks as a result of volcanic activity of fissures which is concentrated along a row of craters. The mountains are formed in similar eruptions although here eruption is concentrated in a single, central crater rather than a row of craters (Jakobsson and Gudmundsson, 2008).

3.3. Holocene and historical period

Postglacial or Holocene volcanic eruptions are numerous and quite diverse in magma types and eruption styles. They may be divided into three major groups according to their combination of erupted products: 1) effusive, if lava comprises $\geq 95\%$ of the volume, 2) explosive if the Dense Rock Equivalent is $\geq 95\%$, and 3) mixed if the volume is anything in-between. The mixed and explosive eruptions are more common in Iceland than in other comparable volcanic regions, and together yield a diversity of morphological forms, that is unparalleled elsewhere in the world. Volcanoes are so diverse in Iceland that all types of volcanoes known on Earth may be found there (Thordarsson and Höskuldsson, 2008). Explosive eruptions are common as the most active volcanoes are situated beneath glaciers, and also due to the high groundwater level in Iceland. The high frequency of mixed eruptions is mainly due to prolific activity at the Hekla volcano. (Thordarson and Höskuldsson, 2008).

The Holocene lavas are confined to the active volcanic zones, and are a distinctive feature of the central highland landscape (Figure 1 and 5). Most of the highland Holocene lava flows are barren, even the early Holocene ones. Some lower elevation lava flows are vegetated, carrying birchwood or sparse grassland. The great lava flows in the mild oceanic climate of the south and south-west are characterized by a thick carpet of the moss *Racomitrium lanuginosum*.

4. Materials and methods

4.1. Landscape sampling

The landscape data were sampled during the summers of 2006 and 2007. The sampling design was based on a nationwide grid of 10x10 km squares developed originally by the Icelandic Institute of Natural History for mapping the distribution of plant species (Kristinsson and Johannsson, 1970). Every third square in every third row was selected, which yielded a sample of 130 squares, some of which are not easily accessible and were therefore not included. By the end of 2007, 98 sites had been sampled, and these represent the data set (Figure 3). Each of the 10*10 km squares has a known GPS point in the middle, which constituted the exact sampling location. The precise sample point was reached, except in a minority of cases where it was inaccessible, e.g. due to rivers or cliffs, in which case the closest accessible point was used instead.

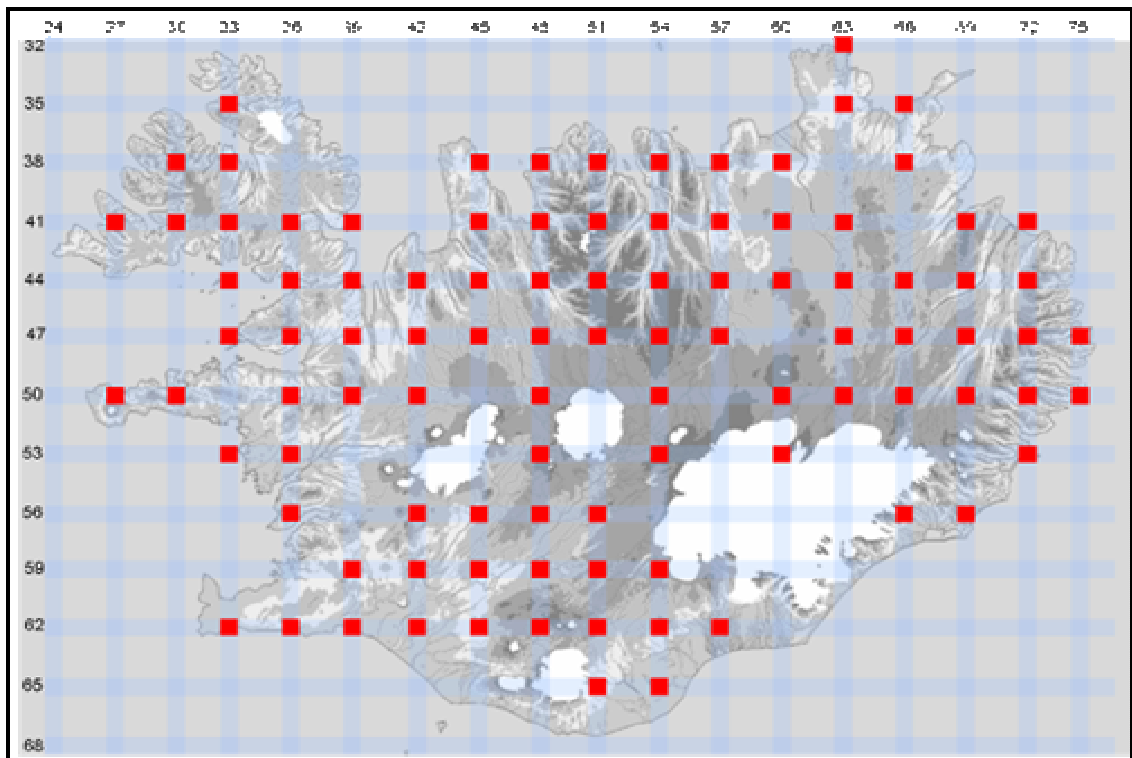


Figure 3. The 10*10 km grid system of the Icelandic Institute of Natural History (Kristinsson and Johannsson, 1970). The red squares show the 98 sites sampled in 2006-2007. The four digit code for the sites is the west-east (x-axis) number, followed by the north-south (Y-axis) number. For example the northernmost square in the northeast has the reference number 6332.

A checklist of 23 visual physical variables (see below) was filled in at the sampling points and photographs and videos were taken and recorded.

4.2. Landscape visual variables

The sampling of landscape data involved a checklist of 23 visual physical characteristics that were given a quantitative score from 0-5 according to amplitude or diversity. The checklist was completed according to the visible landscape in a 360° field of view, as seen from the GPS points. Elevation above sea level according to a GPS device was also recorded, as well as the common name of the place visited. For more detail on the checklist see Thorhallsdottir (2008, in prep.).

4.3. Landscape analysis

The landscape analysis had the aim of revealing a pattern in the data on which to base the classification of Icelandic landscape. This was achieved by multivariate methods, i.e. Cluster Analysis and Principal Component Analysis. The Cluster Analysis is used to quantify relationships between objects by so called similarity or distance measurements. Measures of similarity are then used to group the objects in question into clusters. The Cluster Analysis of the landscape data resulted in 8 distinctive landscape groups, along with one outlier group of 2 sites that did not fit into other groups. These 8 groups are used in this study to explore underlying physical and historical factors.

Principal Component analysis was, however, used to reveal the most important variables for each landscape group, and its results are particularly useful when exploring the correlation between the visual attributes and geological age as explained later. For more details of these methods see (Legendre and Legendre, 1998 and Quinn and Keough, 2002).

4.4. Geological data

The data were obtained from two digital geological maps, courtesy of the Icelandic Institute of Natural History. The first is a distribution map of bedrock by age and type (Figure 4), while the second is a geochronological map (Figure 5). The map showing both age and type recognizes 12 different classes, while the simpler geochronological map distinguishes 7 periods (Table 1).

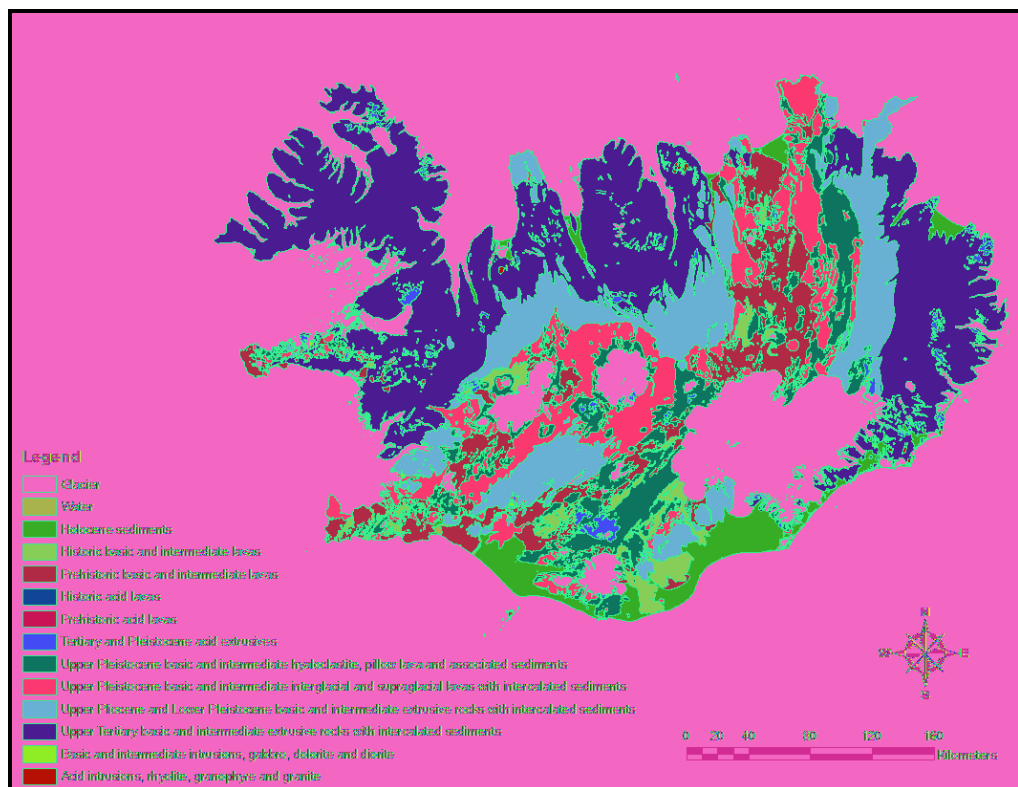


Figure.4 Bedrock map of Iceland depicting bedrock type and age. Courtesy of the Icelandic Institute of Natural History (Johannesson and Saemundsson, 1998a).

Table 1. Major geological periods of Icelandic bedrock. Based on tectonic maps provided by the Icelandic Institute of Natural History (1998) see below.

Geological age type	Age
Holocene lava flows	Less than 11 000 yr BP.
Upper Pleistocene bedrock	Less than 0.8 m.yr BP.
Lower Pleistocene and Late Pliocene bedrock	0.8 – 3.3 m.yr BP.
Lower Pliocene and Upper Miocene bedrock	3.3 – 8.5 m.yr BP.
Upper Miocene bedrock	8.5 – 10 m.yr BP.
Upper and Middle Miocene	10 – 15 m.yr BP
Lower Miocene bedrock	More than 15 m.yr BP.

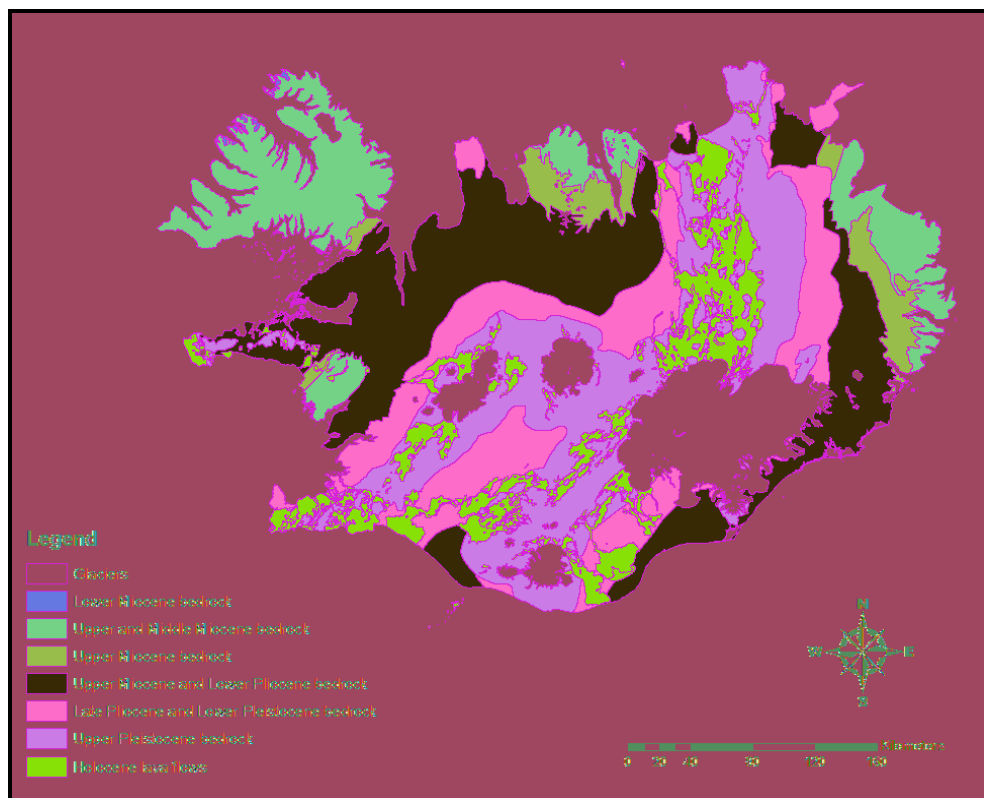


Figure 526. Geochronological map of Iceland provided by The Icelandic Institute of Natural History (Johannesson and Saemundsson, 1998b).

The acidic lavas, whether historic or prehistoric, were not included in the final correlation calculations, as none of the landscape sites lay in the vicinity of such lavas. This left a total of 10 bedrock age and type classes. We added two physical factors: sea

cover and glaciers. The correlation of visual landscape characteristics with physical factors included therefore 12 factors, 10 geological plus sea and glaciers.

The oldest bedrock group (Lower Miocene) did not occur in the sample and was therefore excluded from the analysis. Correlation of visual landscape characteristics with geological age thus included 8 factors, i.e. 6 age classes plus sea and glaciers.

4.5. Correlation analysis

Our analysis of geological factors was performed with the GIS software package, ArcInfo. The aim was to reveal relationships between landscape and geology by calculating the correlation between geological age and landscape characteristics on one hand, and bedrock types and landscape on the other. At each site, a 5 km buffer polygon was defined around each landscape site, and the area of each geological class was calculated.

Canonical Correlation Analysis (CCorA), developed by Hotelling in 1936, was used for calculating correlations. CCorA seeks to reveal a correlation between two sets of descriptors, describing the same objects (Legendre and Legendre, 1998). It has been widely used, especially by ecologists interested in correlations between two different kinds of descriptors, e.g. correlation between usual biological descriptors and environmental descriptors (see e.g. Sullivan, 1982). CCorA is well suited to examining the correlation between bedrock types and landscape visual physical characteristics.

For our analysis we used the CCA package within the statistical software R (Gonzalez et al., 2008). The landscape data were prepared in the form of a matrix of 23 columns, comprised of scores between 0-5 according to the abundance or amplitude of the physical characters at the 98 sites we analysed. The results from the bedrock and geological age calculations were transformed into similar scores for each unit (type or time period). This was accomplished by dividing the scores into five even intervals, 1-20%, 21-40%, 41-60%, 61-80% and 81-100%, and assigning a score of 0 for 0%.

In this way, three similarly structured matrices with three different kinds of descriptors were generated. The Canonical Correlation Analysis extracts linear combinations from the landscape matrix, and one of the two geological matrices, in such a way that the first component from the first matrix has the maximum correlation with

the first component from the second matrix. The extracted components are limited to the numbers of variables within the smaller matrix, i.e. the geological matrices in both cases (Quinn and Keough, 2002). This was then repeated for the second geological matrix.

4.6. Other analyses

The composition of each bedrock age and type and bedrock geological age for the 8 landscape groups was examined from the results of the area calculation. This revealed the major types within each landscape group. The relationship of landscape groups to elevation above sea level was also explored.

Finally, the correlation of individual landscape visual attributes to geological age was calculated. Geological age was reduced to a single number by assigning a value of 1 to the youngest type (Holocene lava flows), the value 2 for the second youngest and up to a value of 6 to the oldest type (Upper and Middle Miocene). The sum of the percentage of the area of each age group results in a single number indicating the relevant age. For example, a landscape with an area consisting of 20% Holocene lava flows and 80% Upper Pleistocene bedrock has a geological age of 2 as shown here: $(0.2 \times 1 + 0.8 \times 2 = 1.8 \approx 2)$.

5. Results

5.1. Canonical correlation

The correlation coefficients revealed a high correlation between visual landscape characteristics and geological factors (Figure 6). The correlation was consistently high among the first dimensions and decreased slowly, indicating a strong correlation. The correlation was almost 0.9 for both geological age and bedrock classes, slightly higher for geological age.

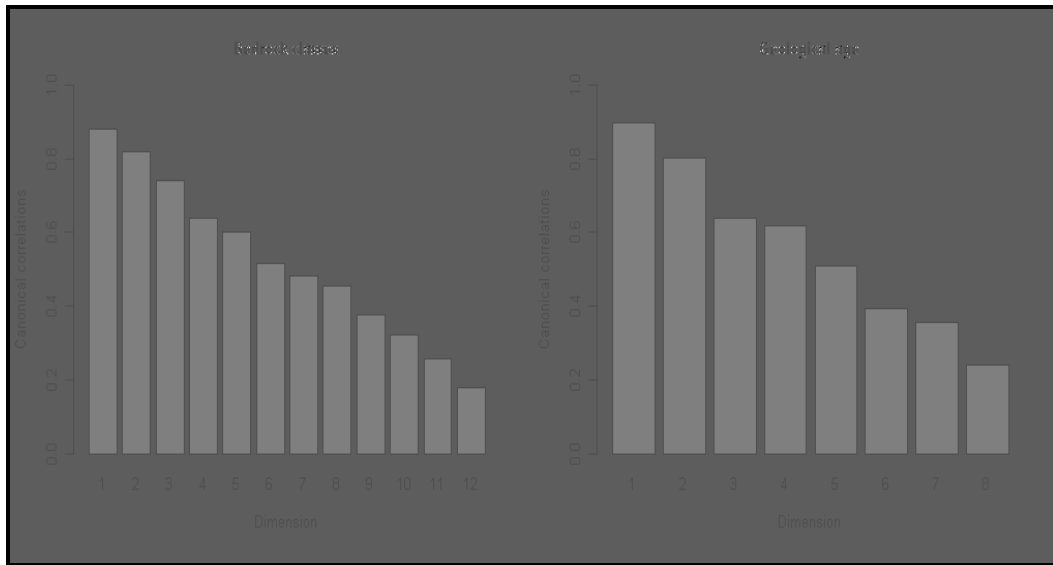


Figure 6. Correlation coefficients between the landscape visual physical characteristics and the geological age and bedrock classes.

The eight landscape groups varied considerably in size, ranging from 7 members in groups 4 and 7, to 21 in group 5 (Figures 7 and 8). The sizes of the groups may, to some degree reflect the frequency or aerial cover of each landscape type, the smaller groups probably representing landscape types that are less common than those of the larger groups. More sites need to be sampled so as to answer this question with more certainty. The groups were also situated at noticeably different distances from the central highlands. Groups 8 and 7 were on or near the central highlands, while Groups 1 and 2 were coastal. Groups 3, 4, 5 and 6 largely represented transitional areas between the inhabited lowlands and the central highlands.

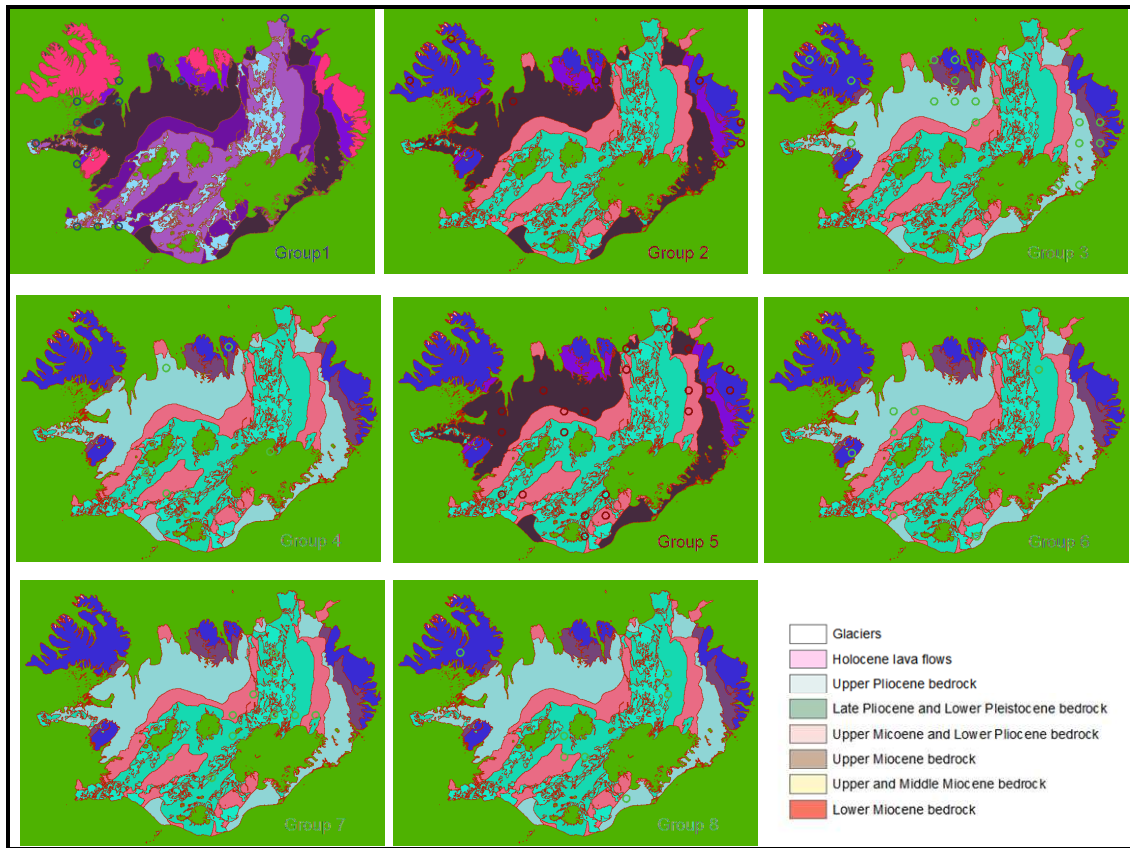


Figure 7. The distribution of the landscape sites (open red circles), superimposed on the geochronological map. The first two groups are situated at or near the ocean, while the others gradually approach the central highlands. Map courtesy of The Icelandic Institute of Natural History (Johannesson, H. and Saemundsson, K., 1998a).

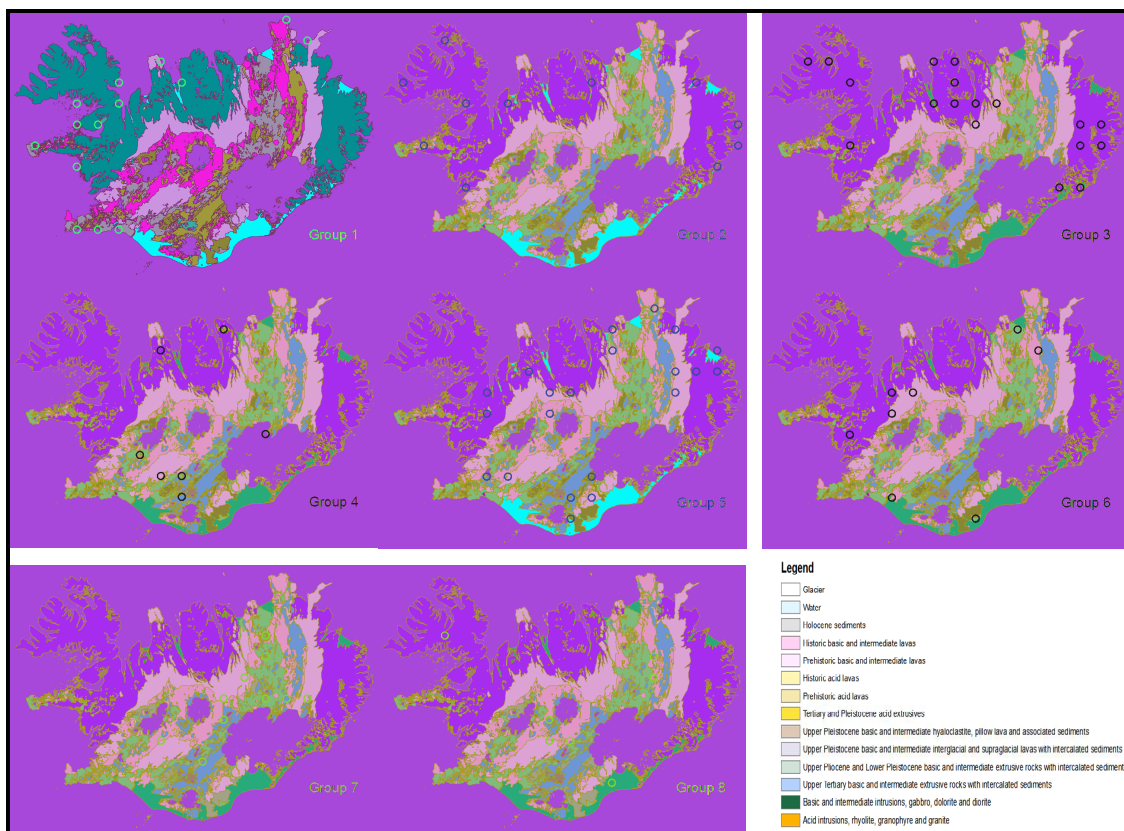


Figure 8 The distribution of the landscape sites (open red circles), superimposed on a bedrock map of Iceland. Bedrock map courtesy of the Icelandic Institute of Natural History (Johannesson, H. and Saemundsson, K., 1998a).

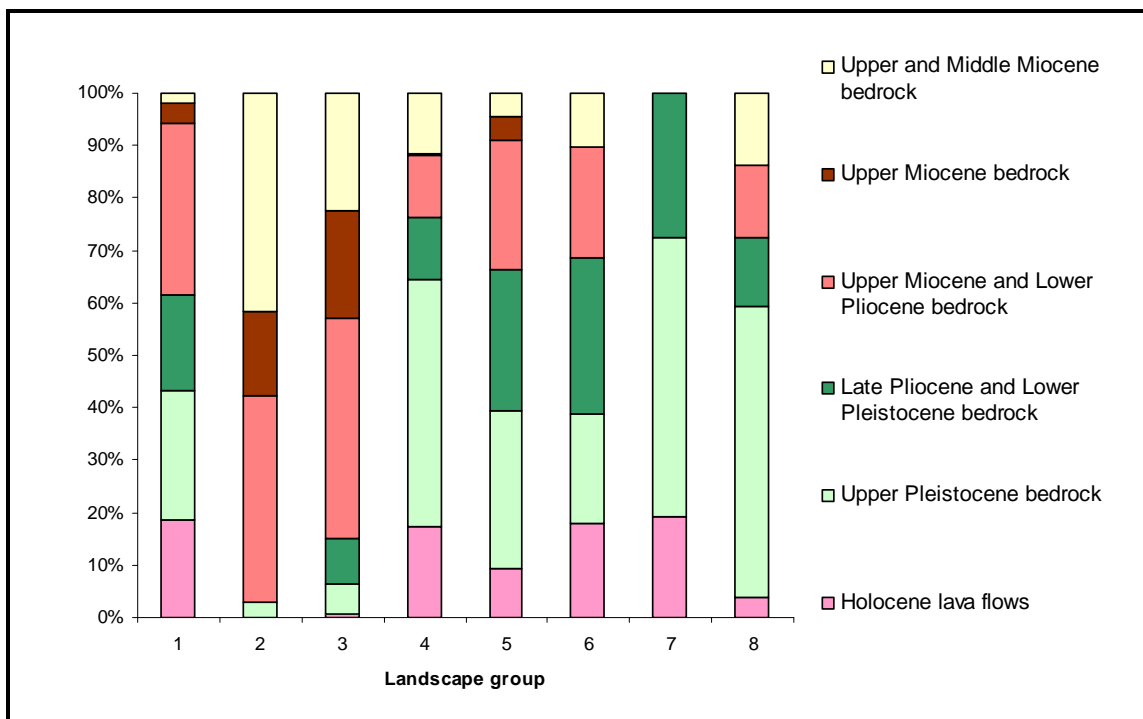


Figure 9. The percentage composition of each geochronological type within each landscape group.

There was a clear difference in the composition of geological age classes among the landscape groups. Older Miocene and Lower Pliocene bedrock was very prominent in groups 2 and 3, while younger Late Pliocene and Pleistocene bedrock characterized groups 1, 4, 5, 6 and 8. Group 7 contained the geologically youngest sites (Figure 9). The same age relationships may be seen in the bedrock classes (Figure 10).

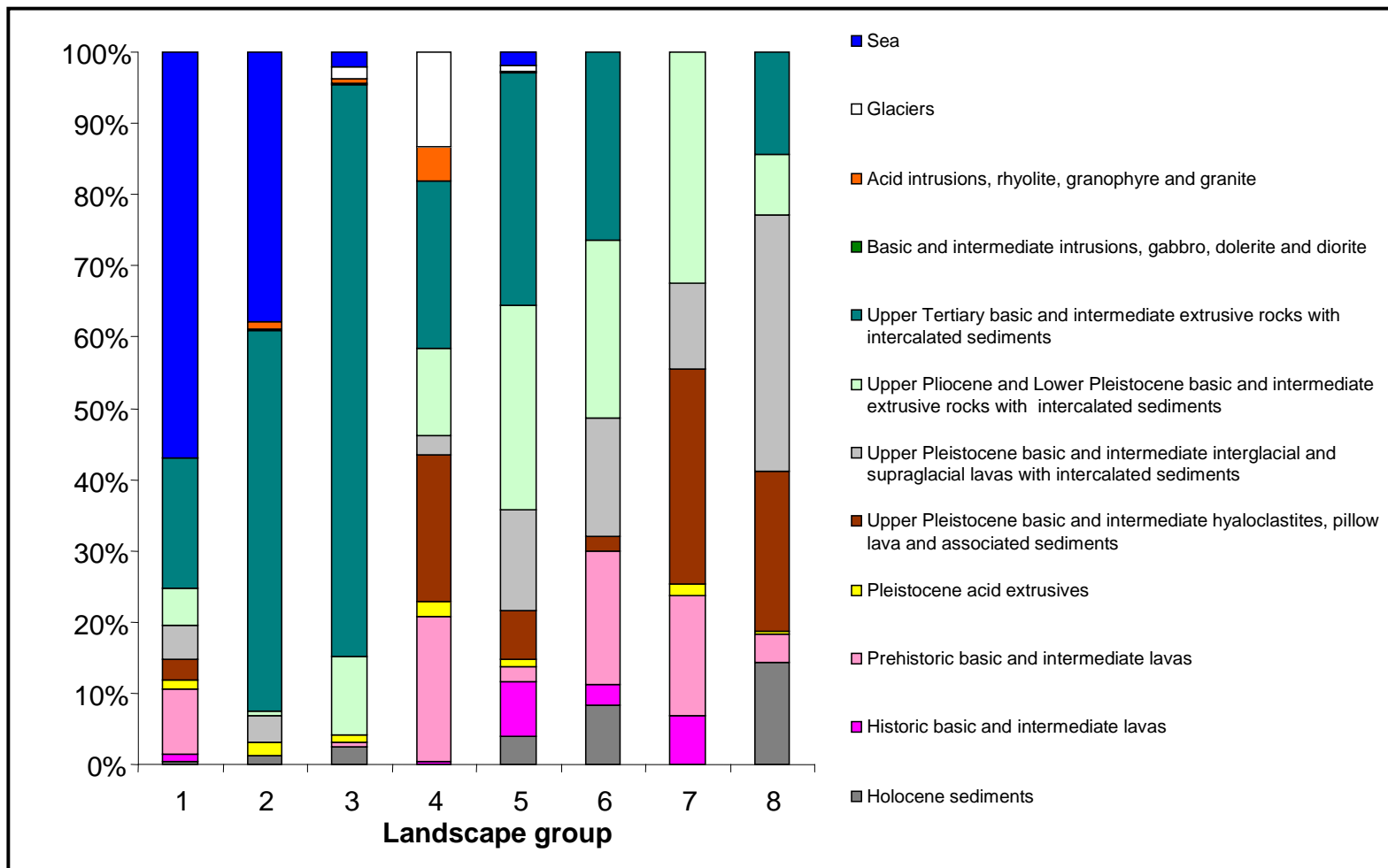


Figure 10. The percentage composition of bedrock classes for each landscape group, along with sea and glacial cover.

5.2. Elevation above sea level

The groups differed slightly in altitude (Figure 11). Groups 1 and 2 included low altitude sites with only 1 site above 200 m a.s.l. Other groups were more heterogeneous, and most spanned a wide range of altitude. In several groups, outliers may be identified. This includes the aforementioned 270 m altitude site in group 1, a high altitude site at 900 m a.s.l. in group 4. Groups 7 and 8 lie primarily at high altitudes, but each contains one clear outlier, a mid altitude (300 m a.s.l.) site in group 7, and a low altitude site in group 8 (~80 m a.s.l.). Sites within groups 3-6 were evenly distributed, and were found at both low and high altitudes.

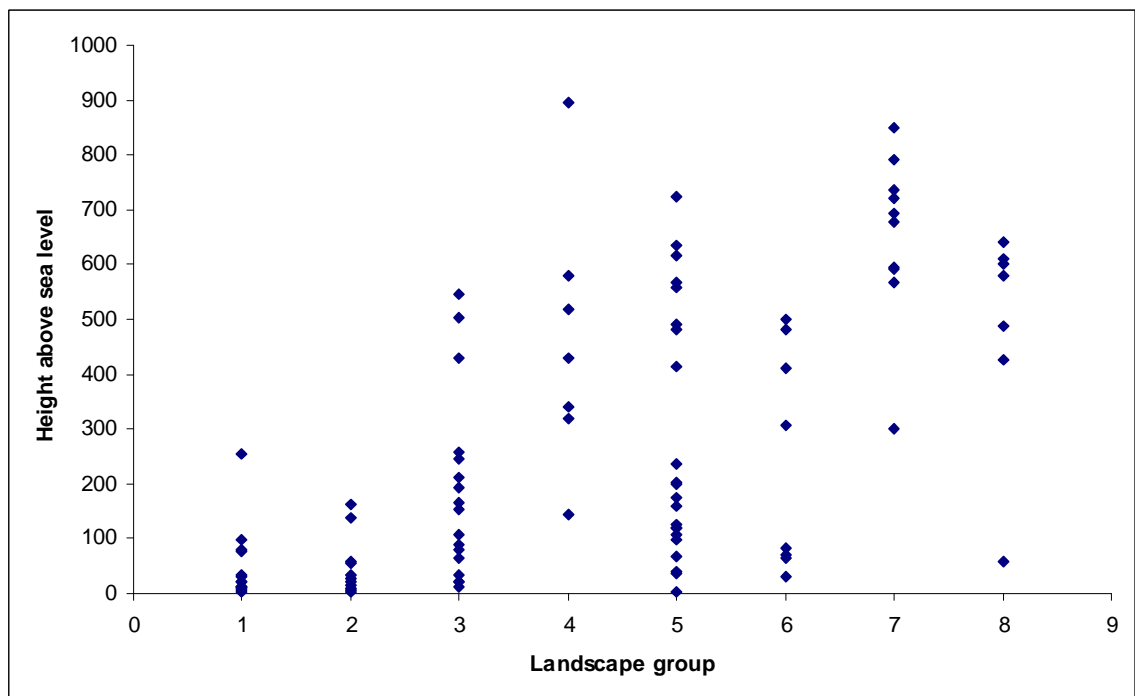


Figure 11. Elevation above sea level for each landscape group. The first two groups lie at the lowest altitude while the last two groups lie at the highest average altitude. The groups in between these have sites that are found at both low and high altitudes.

5.3. Correlation with geochronology

The correlation between the geological age and the visual landscape visual attributes revealed different correlation strengths, both negative and positive (Figure 12). Low correlation indicated that the attribute in question was not influenced by geological age,

while the attributes with highest correlation (negative and positive) could be expected to be influenced by age.

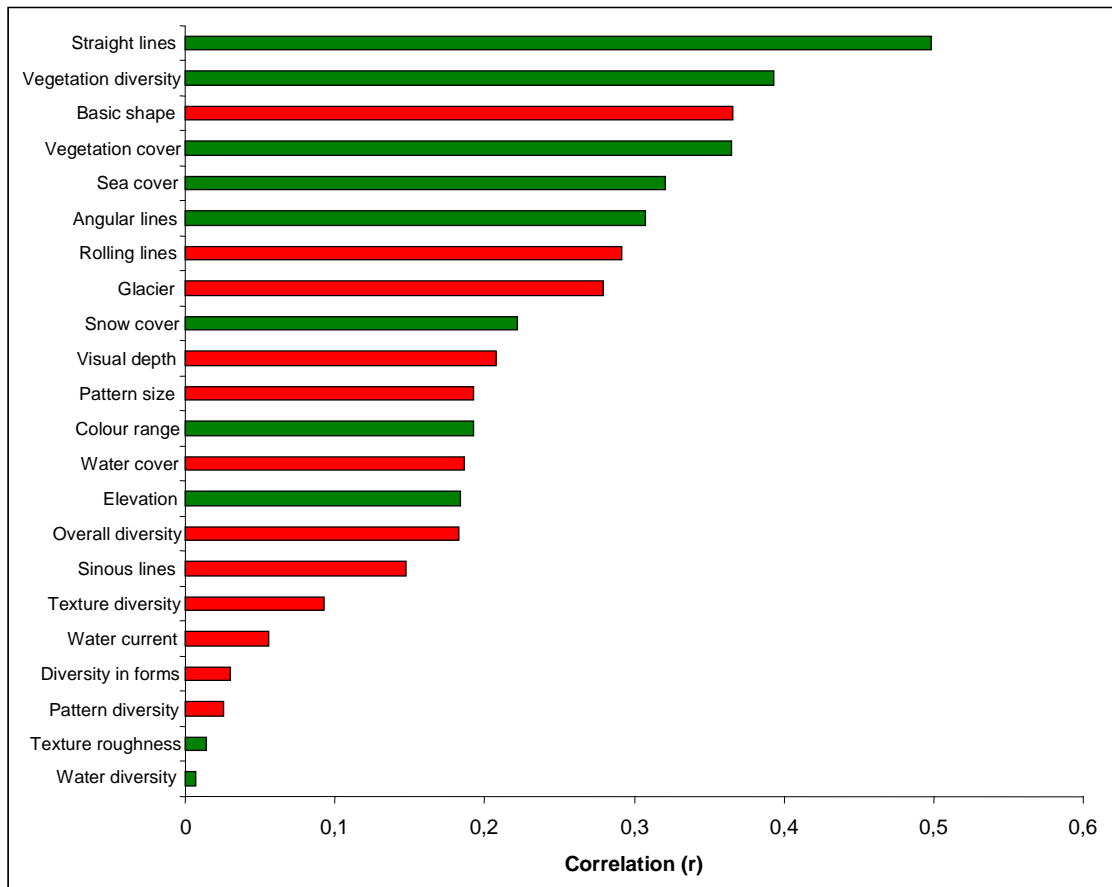


Figure 12. The correlation between the visual physical landscape characteristics and geological age. The red bars indicate negative correlation and the green bars indicate positive correlation.

6. Discussion

The Canonical Correlation revealed a high correlation between the landscape matrix and both geological age and bedrock types. This indicates that visual physical characteristics of the landscape in Iceland are related to geochronology and bedrock type. This also indicates that the landscape groups represent neither a random composition of geological age, nor of bedrock type. The relationship is evident when the landscape groups are superimposed on the bedrock and tectonic maps (Figure 7 and 8).

6.1. Group 1: Coasts and islands

The sites within group 1 were identified as low lying coastal areas. In addition, one island is found within this group. The sites were characterized by extensive sea cover, flat basic shape and high landscape depth (i.e. a distant horizon). Group 1 consists of both old Miocene bedrock and young Holocene lavas (Figure 9 and 10). This may be explained by the fact that Miocene bedrocks now lies far away from the active volcanic zone in the centre of Iceland, i.e. the extreme west, east and central north (Figure 1). In some regions, Holocene lava flows reach down to the sea, and two of the sites within group 1 are situated close to such lava flows, one in the south-west near Herdísarvík, and the other one at Eyrarbakki in the south (Figure 7). With one exception, sites lie below 200 meters. The exception is a site on a mountain slope near the glacier Snæfellsjökull in the west (Figure 11).

6.2. Group 2. Fjords

Old Miocene bedrock is better represented within group 2 than within group 1, but both groups are characterized by a large sea cover (Figure 9). The major difference between the groups lies in the basic landscape shape. While group 1 contains mostly level landscapes, sites within group 2 are mostly concave in shape. Young Pleistocene bedrock and Holocene lavas are absent from this group, making it the group with the oldest combination of bedrock types, along with sites in group 3.

The sites within group 2 are situated, as are the sites within group 1, at low altitude near the sea, all of them below 200 m (Figure 11).

6.3. Group 3: Valleys

Group 3 contains a combination of all geochronological types, as well as some glacial cover, although the older Miocene types are more common than the late Pliocene and Pleistocene types. These valleys were formed by the carving actions of Pleistocene glaciers in Miocene bedrock, forming the familiar U-shaped glacial valleys (Einarson 1994). The bedrock types within group 3 are mostly from the Upper and Middle

Miocene, along with the Upper Miocene and Lower Pliocene bedrock type, making this the oldest group along with group 2 (Figure 9).

Many valleys stretch from the lowlands up to the borders of the highlands, explaining the occurrence of lower Pliocene bedrock within this group. This may also be seen in the elevation of the sites, which lie at both low and high altitudes (Figure 11).

6.4. Group 4: Shallow valleys

The sites within group 4 may be described as shallow valleys. They range from an altitude of below 200 m up to 900 m (Figure 11) and contain an even mix of different age and bedrock classes (Figure 9 and 10). As with groups that follow, the sites within group 4 differ from the first three in that late Pliocene, young Pleistocene bedrock, and the Holocene lava flows are more prominent than the Miocene. Here, the important connection between the landscape and the geology is that the landscape sites within group 4 are mostly situated at boundary between two or more geochronological types, which is reflected in the even division between the percentage of Miocene and Pliocene bedrock (Figure 9).

6.5. Group 5 & 6: Heathlands and plains

The landscape within groups 5 and 6 is visually similar, and this is also reflected in its geological age distribution. Hence, these groups will be discussed together.

These sites are characterized by flat shape and great visual depth, and most often represent heathlands or vegetated plains, which are common in Iceland. These heathlands and plains are found in the lowlands or in the marginal zone between inhabited areas and the central highlands. Younger Pleistocene and Holocene bedrock is therefore more prominent here than in the preceding groups. Miocene rock may still be found at these sites but, although in less quantity (Figure 9). The heathlands lie mostly at medium altitudes, while the plains, such as the large flatlands in the south, are more prominent at lower altitudes (Figure 11).

6.6. Group 7 & 8

The landscape within groups 7 and 8 is quite similar. Both groups represent highland sites, characterized by lack of vegetation, large pattern size, large visual depth, and flat to convex shape. The only difference is that sites within group 8 are situated near large rivers, yielding significant water cover, while the sites within group 7 represent dry deserts. Younger Pleistocene and Holocene lava flows are the most prominent elements in the geology, and Miocene rock is not found within group 7, making it the youngest group (Figure 9). Geologically, the sites within group 8 are similar to group 7, although sites in the former group, rest not only upon younger Pleistocene bedrock, but also on Miocene bedrock. The percentage of Miocene rock occurrence may be explained by the fact that of the 7 sites found within group 8, two are situated at or near older Miocene and Pliocene rock (Figure 7). These two sites, however, are very similar to the central highland areas within group 7, when considering the landscape. Both are low in vegetation, with great visual depth, and large pattern size.

6.7. Correlation with geological age

The correlation between the visual landscape and geochronology may either be negative or positive. This determines whether the landscape attribute in question has high scores at the old Miocene bedrock area, and low scores at the young Pleistocene area, yielding a positive correlation or vice versa, i.e. low scores at the Miocene area, and high scores at the Pleistocene area, yielding a negative correlation. Visual attributes that have very low correlation have randomly distributed high and low scores with respect to geological age.

The visual attributes of the landscape with the highest positive correlation are straight lines, high vegetation diversity and vegetation cover, sea cover, and angular lines. The visual attributes that show the highest negative correlation are basic shape, rolling lines, and glaciers (Figure 12). These visual attributes are defining characteristics for different landscape groups.

The characteristics of group 1, sea cover and flat basic shape, correlate differently with geological age. Both show high correlations with geological age, but sea

cover is positively correlated while basic shape shows negative correlation. This is explained by the fact that sites with large sea cover, i.e. sites within group 1 and 2, are mostly situated where Miocene bedrock is dominant, so a high number for geological age increases the probability of high sea cover. This correlation between the old geochronology and sea cover is fairly obvious, but there are more interesting correlations. The basic shape yields scores in such a way that 1 and 2 represent a concave shape, 3 a flat shape and 4 and 5 a convex shape. The sites that have concave shape, i.e. the fjords (group 2) and the valleys (group 3), have the lowest number for basic shape, but are also the groups with the oldest composition of bedrock types, so this negative correlation is easily understood.

The positive correlation between geological age and vegetation cover and diversity may be explained by the fact that the lack of vegetation and diversity is characteristic for groups 7 and 8, the groups that are situated on the youngest bedrock. Also, the oldest groups, the fjords and the valleys, have high vegetation cover. The scores for the vegetation are therefore correlated with the scores in geological age.

Straight lines and angular lines are prominent in the old mountains found in the fjords and the valleys in the east, west and extreme north, while the rolling lines are more prominent in the highland groups. The positive correlation for straight lines and angular lines, and negative correlation for rolling lines, is therefore to be expected.

The last attribute that shows high correlation is the glaciers, which are found mainly in the central highlands where the young Pleistocene groups (7 and 8) are situated. The negative correlation may explain this (Figure 12), as the composition of the groups show that glaciers have the highest scores in group 4. The only explanation is the fact that the great visual depth of these sites results in a high presence of glaciers, even though they are further away than the 5 km radius we defined as our buffer zones.

6.8. Comparison with other classifications

Some differences are evident when our results are compared to other landscape classification methods that have included geology, e.g. the British Landscape Character Assessment (LCA) method (Swanwick, 2002) and the Norwegian method (Puschmann, 2005). The treatment of geology in these two methods is quite different. In the British

method the information on geology is collected from data obtained by the British Geological Survey, especially on drift deposits and solid geology. The Norwegian method is based on 6 landscape components which are summed up to build up the overall landscape character. Two of these components describe the so called major landform and minor terrain form in the landscape (*landskapets hovedform*, and *landskapets småformer*). In practice, this is the form of the landscape resulting from the underlying geology. They describe the visual character of the landscape, e.g. the basic shape (whether it is a U-shaped or a V-shaped valley, etc.)

Our methods yielded quite different results. They demonstrate a connection and a relationship between the visual landscape properties and the geology of Iceland. This was easily demonstrated by both complex (Figure 4) and simple (Figure 10) correlation calculations. The numerous places in Iceland where the ‘naked’ bedrock is actually visible, is therefore clearly a big influence on the landscape. The clear weight of the geology on the visual character, such as pattern sizes, lines, vegetation, basic shape etc., is therefore established by our method. The landscape in the United Kingdom is dominated by the man made cultural landscape, rather than a natural landscape so the landscape is not clearly connected with the geology. There are certainly are some areas in the UK, especially in Scotland, where the geology is the main factor of the landscape, but when compared to Iceland human factors seem dominant.

The Norwegian landscape, however, is more natural than the British landscape, so the connection between the landscape and geology should be stronger. The Norwegian method estimates the influence of each of the six landscape components on the overall landscape character of the landscape regions. The Norwegian method resulted in 45 major landscape regions and 444 sub-regions. Of these 45 regions, the major and minor landscape forms are usually categorized as important, or even dominating in the overall character. This estimation of the weight of geology is, *sensu stricto*, qualitative and based on the subjective perception of the individual researcher, but not on statistical analysis.

7. Conclusion

The strong canonical correlation between the landscape groups and the underlying geological factors give reason to believe that the geological maps of the Icelandic Institute of Natural History can provide a starting point for the development of a new map, revealing the types of Icelandic landscape. The correlation indicates that the visual physical characteristics are related to geology. From this we can see that the landscape classification and the resulting landscape groups can provide the foundation for possible further study, especially of the landscape groups and their connection to other factors, such as vegetation, land use, etc.

The cultural aspect of the landscape, e.g. the views of the Icelandic people towards different kinds of landscape, as well as the value they place on them is also important and needs to be studied. The landscape groups can provide the first step in these landscape studies. This will be important in the near future, as the demand for land is increasing, making policy planning for landscape conservation and land use more important.

8. Acknowledgements

The research presented in this MS thesis was carried out at the University of Iceland. It was supervised by Prof. Þóra Ellen Þórhallsdóttir and Dr. Þorvardur Árnason. I thank them both for their inspiration, help, knowledge, and delightful times. I would also like to thank my coworkers Karen Pálsdóttir, Jóna Björk Jónsdóttir, Hafdís Hanna Ægisdóttir, Rut Kristinsdóttir for their help in the summertime sampling and all my friends at Askja. Very special thanks to Ólafur Patrick Ólafsson for his help in translating my thoughts into English, and the indispensable tea-time with Sæmundur Ari Halldórsson and me.

I thank my family without even trying to put it into words. And to Helga Ýr for all your love, this could not have been done without you.

The research was funded by Orkusjóður Orkustofnunar (National Energy Authority of Iceland), Rannsóknarnámssjóður Rannís (The Icelandic Centre for Research), Umhverfisstofnun (The Environment Agency of Iceland).

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