Paleomagnetic Research on Icelandic Rocks

LEÓ KRISTJÁNSSON
Science Institute, University of Iceland,
Dunhagi 3, 107 Reykjavík, Iceland

ABSTRACT

This paper covers the history of paleomagnetic research in Iceland from its beginnings to about 1981. It is primarily written for students and geoscientists who may be interested in using paleomagnetic directions as an aid in stratigraphic and tectonic mapping in Iceland. Emphasis is on laboratory measurements of magnetic direction and intensity in rocks; coverage of rock-magnetic measurements is also fairly complete, but studies of magnetic polarity in the field are only partly covered. Papers interpreting magnetic field anomalies over Iceland in terms of magnetic measurements on rocks are included, but many papers dealing with other aspects of magnetic anomalies have been omitted.

This review is mostly restricted to published papers containing predominantly original results from Iceland, with only occasional references to conference abstracts, theses, summary papers, and internal reports. Papers that deal with paleofield directions are reviewed first, roughly in time sequence by authors. This is followed by chapters on paleointensities, anomaly interpretation, rock magnetism, and miscellaneous other topics.

It may be concluded that paleomagnetic research in Iceland has played a significant part in the development of modern ideas on the history of the geomagnetic field in geological time (especially during the 1950’s and 1960’s) and in research on magnetic properties of rocks. A few biographical details are included.

INTRODUCTION

Paleomagnetic research in Iceland may be said to have begun in 1950-51. This was a time when many important branches of earth science were entering a period of rapid expansion and general acceptance, after either having been the pursuit of few isolated individuals for decades, or having sprung into existence with new technical inventions made during the war. Many geoscience concepts, methods, and pieces of equipment that are now familiar even to high school students, had not been heard of in 1950.

Due to its relevance to navigation (and later to communication, surveys, and prospecting) the geomagnetic field had been studied in many observatories and laboratories since the early 19th century. A major monograph on Geomagnetism by S. Chapman and J. Bartels, appeared in 1940. However, the origin of the internal field and its variations was not understood, and by the 1930’s it was appreciated that studies on fossil remanent magnetization in rocks and artifacts might aid this understanding. Research groups in France, Japan and Germany had begun to study the intensity, direction and stability of natural remanent magnetization (N. R. M.) in rocks early in this century, and described individual occurrences of inverse remanence. The first book on the subject, H. Haalek’s Gesteinsmagnetismus, was published in 1942. This book concludes that observed variations of remanence in rocks are predominantly due to local phenomena, such as temperature variations in the rock strata, lightning, and seismic activity.

Through the late forties, it must be presumed that appreciation of the potential usefulness of paleomagnetism in studies of stratigraphy, tectonics, and apparent polar wandering was gradually increasing among solid earth scientists. In 1947-50, several landmark papers on the subject of geomagnetism and paleomagnetism appeared, These included a new description and analysis of the geomagnetic field by E. Vestine and others, papers on the nature of this field inside the earth by E. Bullard and by W. Elsasser, L. Néel’s classic theories of thermo-remanence (T. R. M.) and viscous remanence (V. R. M.) in crystal grains, extensive remanence measurements on sediments.
L. Observationer paa tvende Socreiser

være bekendte, at beregne Langdragsskikkene imellem disse tvende Puntete (1). Man fandt at efter den ene Dags Observationer blev Middelfalset for Movilise
ningen 25' 21", men efter den anden Dags 31° 40", altsaa en forskel af 3' 42" paa samme Sted i samme Havn, og det paa samme tid af Dagen i to hinanden strax foranliggende Dage, og jeg fandt at have Compassten fraadende fandt det fundt fra Yrev i Stedet, i det mindste de mig synlige foare Natter, hvorfor man ikke skulle formode fandt det megen Forskel, hvorfor jeg ikke vil någe muligheden af et eller andet fiasket Yrev, dog saa nu at fells
visningen fandt blive saa stort var mig uroligt; jeg mener derfor, at man
maa sige Stærken i en anden Grund (2). Vi saa nemlig i en islandf
Havn, og meget nær Landt; den ene Dag var Vindlen Nordoest, men den
anden Dag var den Nord, og altsaa fandt fæstet for forskellige Stillinger og
Afstand fra det omfattende Landt; nu indeholder Island upaaavistelig
færre Mineraler, især Basalter, som efter Naturforskeres Erfaringer er
formadleyt sin Jernholdighed bevidt at virke paa Magnetnader. Nимвige
viser det ikke værre Stærken i denne Formering, hvilket Sammenlignin
ningen af følgende Observationer paa Holmenhavn synes at beviste; og jeg erin
nere endnu med beforret Visshed, at paa en De, kaldet Bilden, i Kystområdet
Havn har jeg selv sett en betryggende Mængde Basalts. Skibet saa omtrent
imellem 3 til 5 Mill fra denne De. Om det var Basalt paa disse Steder, er mig udebestemt; men man har grunden Aar fra at tros, at disse i Landet
till Compassten Formering værende Wirningsaftager maaske være krystlige nok
til en yo at funde fornemmes paa Stedene, som tage ude saa Havnen.
Muligheden fandt fæstet Havnunden under Skibet indeholdt flere magnettrækkende
Mineraler, og da, ifølge Obyden, har Wirning.

Man fandt at No. 203 disse Observationer ere tage i Holmenhavn paa
samme Sted, og fællesen ligger juist under samme Meridian, og ikke mere end

Fig. 1. A page from P. Lövenørn's paper: 'Observations of the compass' declination at different locations during two marine voyages, with explanatory notes, as well as some observations on the confusion of the compass needle in Icelandic ports, its daily variation there, and a few observations of the magnetic inclination'. Nye Samling af det Kongelige Danske Videnskabernes Selskabets Skriftter, Femte Deel, Copenhagen 1799: 299-326 (in Danish).

Mynd 1. Ælægning Lövenörns á kompasssekkiðum við Ísland.

by J. Graham and collaborators in the U. S., and
detailed description of inversely magnetized
igneous rock outcrops from Europe by A. Roche
and others.

However, the origin of the main magnetic field
was still not understood, as may be seen from the
1952 publication of P. M. S. Blackett's work regarding
his hypothesis that a magnetic dipole field might
be an intrinsic property of all rotating objects. In
the first edition of T. Nagata's book on Rock Magnetism
in 1953, the reality of geomagnetic field reversals is doubted, partly in view of the discovery of a
repeatably self-reversing rock type in Japan; how-
ever, this rock has turned out to be quite unique in
its properties, and numerous subsequent studies have
also shown that even irrepeatable self-reversal
must be a relatively rare phenomenon.

It must have been known to many travellers and
navigators that Icelandic rocks can be quite
strongly magnetic. Thus, it is mentioned in the
Ferdahök (Travelogue) of E. Ölfsson and B. Pál-
son, first published in 1772, that during their
famous ascent of Snæfellsjökull in 1753 their
compass had behaved very erratically. In a 1799 paper,
P. Lövenörn (Fig. 1) reported that during his care-
ful declination measurements in Icelandic harbors
in 1786 he had obtained confusing results which he
attributed to the magnetic effects of iron-rich minerals
in nearby basaltas.

Early in this century R. Chevalier and P. Mer-
canton measured the magnetization (N. R. M.) of a
number of oriented and semi-oriented basalt
samples collected during French and Swiss Arctic
expeditions. Basalts from Mull, Disko, the Faeroes
and Spitzbergen turned out to be generally
inversely magnetized, but samples from Jan Mayen
were normally magnetized. Mercanton (1931, 1932)
reported laboratory measurements on altogether 11
basalt samples which he collected, during the 1929
and 1931 cruises of Pourquoi Pas? at Eskifjörður,
Eyjafjörður, Vatneyri, Pingvellir, and Hvammsey
in Hvalfjörður. The magnetization of all of these
was normal except in one sample from Eskifjörður
which gave an inclination of −7°. However, as these

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were taken from scattered outcrops, the potential of Iceland for the mapping of polarity reversals was not realized until the field work of J. HSPERS (Fig. 2) began in 1950. By 1950, the geology of Iceland had been studied by several eminent geologists, but the emphasis in their work was naturally on the active volcanic, tectonic and geothermal manifestations of the country. In older regions, individual localities of plant and marine fossils, alteration minerals, intrusions, and glacial deposits had received most attention. Of course, no radiometric dates were available on Icelandic rocks; the oldest fossil occurrences had long been considered to be of Miocene age, but the opinion of an Eocene age grew stronger during the forties to middle sixties. Systematic mapping of stratigraphy in the pile of flood basalts had not started in 1950, and it may indeed have seemed a dull and difficult task given the apparent uniformity of lava flows in the pile.

J. HSPERS

During the 1950's R. W. van Bemmelen and M. G. Rutten from Utrecht carried out extensive field mapping of Plio-Pleistocene extrusive and glacial formations in Iceland. In 1950 they were joined by J. HSPERS, a student from Utrecht who was beginning graduate research at Cambridge University. He took part in their mapping effort in the Akureyri to Mývatn area, including both geological and gravity work, and collected 25 samples from lavas in Ljósavatnsskarð for paleomagnetic measurements (HSPERS 1951). Van Bemmelen intended to find if magnetic intensity variations could be used for stratigraphic studies in lavas (J. HSPERS, pers. comm. 1982). In 1951 HSPERS continued his paleomagnetic work in Iceland, collecting that summer altogether 633 hand samples. Some of these he measured in the field only, using a portable vertical-field magnetometer. Specimens from others were measured in Cambridge (except for sediment samples which were measured in Blackett's laboratory in Manchester). Those collections that were reported in HSPERS' published papers included five Hekla lava flows, eight other postglacial flows, 65 Plio-Pleistocene and Tertiary flows from Snaefellsnes, over 50 flows from Esja and Hvalfjördur and 80 from Ljósavatnsskarð, as well as over 40 samples of sediments from five different Icelandic localities. Collections were also made e.g. from lavas in Tjörnes and from the Palagonite formation in the Eyjafjöll area.

HSPERS' thesis (1953a) and papers on these magnetic measurements from Iceland and elsewhere (1953b, 1954a, b, c, d, 1955) had considerable impact upon the geoscience community and were widely quoted. His laboratory measurements of remanence directions yielded self-consistent results which showed e.g. that the mean direction of the field since the Pliocene approximated that of an axial geocentric dipole; it followed that polar wandering in this time had been much slower than some authors had suggested. They also showed that the lavas occurred in zones of several consecutive flows which had alternating polarities but were otherwise similar in overall mean directions, in other magnetic properties, and in gross chemistry. (The term "reverse" magnetization was first used by HSPERS in the above papers; he was also the first to calculate pole positions from paleomagnetic directions). As there was considerable variation on the character of the lavas within each zone, HSPERS

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could not account for such grouping of polarities by self-reversal, local field anomalies, tectonics, or temporary phenomena. Tests of stability, within-sample consistency, and magnetic behaviour on heating, produced positive results. Along with baked-contact studies which began elsewhere in the early to middle fifties, Hospers' work provided some of the strongest evidence to convince earth scientists of the reality of global geomagnetic reversals (see e.g. conference report in Nature, 17 Nov 1956).

Hospers estimated the length of time covered by each polarity group to be 0.25-0.5 M. y., and he demonstrated their possible use in stratigraphic correlation (Hospers 1954c). However, it must be remembered that Hospers generally measured only one sample per lava flow in the laboratory, without any demagnetization treatment. Some of his results from Snaefellsnes were later revised by Doell (see below).

R. A. Fisher (1953) had developed normal statistics on a spherical surface, to use in analysis of directional measurements. The first application of these was to Hospers' Icelandic data. To quote Sir Ronald himself (in a letter to T. Einarsdóttir, dated 21 May 1955), they provided a "tolerably expeditious method by which the observations can be combined and summarized", and they have in fact been used for all within-unit calculations of directional dispersions to the present day. Fisher's statistics have also been widely used for between-unit paleomagnetic dispersion (i.e. secular variation) estimates, although there is some doubt as to their applicability in that case. For historical background, see J. Hospers' book review in Tectonophysics vol. 5, p. 345-352, 1968.

T. EINARSSON, T. SIGURJONSSON, A. BRYNJOLFSSON

Hospers' work was soon to be continued by Icelandic scientists who realized its potential as a geological mapping aid in the volcanic pile. Their studies began in 1953. Einarsson and Sigurgeirsson (1955) and Einarsson (1957a, b) pioneered the measurement of magnetic polarity in rocks by means of a compass in the field, and measured thousands of lava flows across Iceland using this method. It was soon found in this way that the intensity of primary remanence decreased with increasing age and alteration, so that measurement could be difficult, or this primary remanence might be masked by secondary or induced magnetization. These problems could, however, be minimized by sampling from the bottom contact zone of flows.

The polarity measurements were important in Einarsson's stratigraphic mapping of long sections through the volcanic pile of SW-Iceland and central W-Iceland, and E-Iceland where about 30 polarity zones were mapped (Einarsson 1957a). There were also more detailed regional studies, e.g. in Snaefellsnes, central N-Iceland, and Tjörnes (Einarsson 1958a, b, 1959, 1962, 1963). Einarsson found that the average thickness of magnetic polarity zones was 200-350 m, and he initiated a numbering system for these (N1, R1, N2, ...). The conclusion of Einarsson and Sigurgeirsson (1955) that normal and reverse polarity zones have approximately equal mean thicknesses, has been confirmed by subsequent work. Einarsson's polarity results from lavas have also been found to be very reliable, but he has expressed reservations about the value of such measurements on clastics and sediments (Einarsson and Sigurgeirsson 1953, Einarsson 1957c).

Due to dating difficulties, Einarsson's polarity zones have only to a limited extent been correlated with other geomagnetic polarity timescales. There are also ambiguities in long-distance correlations of these zones within Iceland because of the very different rates of buildup of the lava pile in different parts of the country. Sigurgeirsson (1957) and Brynjolfsson (1956, 1957) designed a sensitive shielded 5-Hz rotation magnetometer (Fig.3) for the measurement of remanence in hand samples of rock, and one-axis a-c demagnetization apparatus that reached 140 Oe peak field. This equipment was used for accurate direction determination in several hundred lava samples. Those measurements that were published in detail included a study of a lava section through a gradual geomagnetic polarity transition in the mountains of the Hvalfjörður area. It was suggested by their results that a polarity zone corresponded to 0.1-1 M. y. (Einarsson 1958a), that the reversal process took of the order of 1000 years, and that the geomagnetic field was likely to have weakened considerably during these transitions. The Hvalfjörður location was one of the very few known sites in the world for a decade or more to yield details on geomagnetic transitions, but their existence was very important evidence on the nature and long-term behaviour of the geomagnetic field.

Various theoretical and experimental work on the magnetization and demagnetization processes
in lavas was also carried out, chiefly by Brynjolfsson. Thus, inconsistencies in NRM directions within lavas were shown to be due to V. R. M. acquired in the earth's field over a long period of time. The effect of VRM in these rocks could be eliminated by demagnetizing in a peak a-c field of 100 Oe or so; a negative correlation between the VRM intensity and the stability of primary remanence was also demonstrated. This was the first successful application of alternating field demagnetization to actual geological strata.

Brynjolfson (1957) measured the remanence directions in samples of 25 dated Recent lavas from unspecified locations in Iceland, and plotted a secular variation path from these.

Rutten's mapping in Iceland cannot be said to be of lasting value. His stratigraphic studies in Iceland were based on concepts like the "Graue Stufe", which are now discounted (see e.g. Piper (1973b)); he also assumed that N2 covered most or all of the Pliocene, R2 and N3 the Miocene, and R3, N4 most of the Oligocene.

Along with a party of students, H. Wensink (1964, 1965) carried out field mapping of polarity in basals during stratigraphic studies in Jökuldalur, Fljótsdalur, Tjörnes and Vopnafjörður. The most extensive effort was in Jökuldalur, and included the sampling of 16 flows for laboratory magnetic measurements from a sequence in Jökulsá and Hnjúksá. Not all these samples (6 per flow) were demagnetized.

Wensink noted the presence of short "extra" polarity zones within the R1 and N2 in Jökuldalur and elsewhere. Such short zones were just then being reported from localities in Africa and the U. S., and were named "events", as distinct from the major geomagnetic epochs. The four youngest epochs and some of these events were delineated and named in 1964-65 (see review by Watkins, 1972).

In the very first paper to report radiometric (K-Ar) dates from Iceland, McDougall and Wensink (1966) confirmed that R1 and N2 in Jökuldalur corresponded to the lower Matuyama and the Gauss epoch respectively. They also dated the possibly split normal event in R1 at 1.6 M. y., the R1/N2 boundary at 2.5 M. y. and a lava overlain by
of duplicate specimens from many of these lavas was measured in an astatic meter in Reykjavík.

The SW-Iceland profiles did not constitute a complete stratigraphic section, and detailed remanence results from these have not been published. Wilson et al. (1972) presented polarity diagrams and plots for the individual profiles, including polarity zone numbers according to Einarsson’s scheme, but few correlations were indicated. Independently, however, J. D. A. Piper of Imperial College (later of Liverpool University) carried out field mapping in the Hvalfjörður-Borgarfjörður area and made the first detailed correlation of geomagnetic polarity zones in SW-Iceland with the named epochs of the polarity time scale (Piper 1971, 1973b). Although various aspects of this correlation and of his associated conclusions on crustal growth in Iceland have now been revised (see below), Piper’s work served as a useful basis for discussions of the geology of SW-Iceland for several years.

Initial paleomagnetic results from E-Iceland were published by Dagley et al. (1967). Radiometric data on cores, although poor, indicated a maximum age of 20 M. y. Dagley et al. estimated that 60 reversals occurred in their complete profile, though correlations between some of their 21 sections were uncertain due to the long distances involved. This result was in good agreement with reversal rates that were being deduced from ocean floor magnetic lineations in 1966-67, and Dagley et al. attempted some correlations with these time scales. They also estimated volcanic production rates and revised Wensink’s (1964) polarity scheme for Fjótsdalur.

Details of the E-Iceland work were published in a large paper by Watkins and Walker (1977). These included paleomagnetic data for all flows and flow units, stratigraphic profiles with correlations, statistical treatment of remanence directions, and much other information. It should be noted that Watkins and Walker (1977) use a much less stringent rejection criterion for internally discordant flows than most other paleomagnetic workers, and this criterion has even not been applied consistently in constructing polarity columns in their Appendix.

The main other publications on paleomagnetic work from the E-Iceland fjords are that of McDougall et al. (1976a) which correlates a long normal-polarity zone in Dagley et al.’s (1967) profiles E, F and J with polarity epoch 9, and work by Piper et al. (1977) on 40 lavas and 103 dykes in the Reydarfjördur area. Magnetic measurements on large numbers of Reydarfjördur rock units are in the press.
(J. Geophys. Res. no. B8, 1982); preliminary magnetic results from the deep core drilling in Reyðarfjörður are reported by Gibson (1979).

In Fljótsdalur, Walker (in Dagley et al. 1967) mapped six profiles on the NW side of Norðurárdalur. A team from the National Energy Authority carried out field mapping and polarity measurements in this area in 1970 (Vilmundardóttir 1972), duplicating some of Walker’s work but also adding several new profiles within and outside the area mapped by Walker.

Einarsson (1971) summarised polarity measurements made by Wensink (1964) the I.C./Liverpool group, and himself in the Fljótsdalur and Jökuldalur areas, but his correlations between these areas were not substantiated by later dating results.

McDougall et al. (1975), sampled at Bessastaður, well beyond a short profile of Dagley et al. (1976) in that river. Magnetic measurements and K-Ar dates at this locality and at Hengifoss allowed a correlation with the geomagnetic polarity time scale and eliminated a 4 M. y. volcanic hiatus that had recently been suggested to occur at the thick sedimentary sequences outcropping in these rivers.

In the meantime, however, Wilson and McElhinny (1974) had noted a considerable difference in mean remanence direction between lavas in Fljótsdalur and those in the fjord profiles to the east (yielding respectively “far-sided” and “near-sided” poles). This they suggested might be due to 10° apparent polar wandering during the above mentioned 4 m. y. hiatus. However, far-sided mean poles have not been confirmed to occur in comparable sequences of similar age to Fljótsdalur, and the deviating mean direction in the Fljótsdalur collection has yet to be satisfactorily explained.

Finally, Guðmundsson (1978) extended previous stratigraphic mapping efforts to all of Norðurárdalur and Suðurárdalur, aided by fluxgate polarity measurements. Some revision of previous correlations was necessitated, and others may remain tentative. Thus, the Kaena reverse event was suggested by Watkins and Walker (1977) to be represented by flows U 15 and V 8/9. However, the U 15 direction may only be a brief excursion of the virtual pole to low latitudes rather than an event; V 8 is rather unstable and V 9 is actually of normal magnetization.*

In central Iceland, Piper (1973a, 1979) has carried out mapping of volcanic units in two limited areas. Some of these units are reversely magnetized and most likely belong to the Late Matuyama epoch.

N. D. WATKINS AND OTHERS: PALEOMAGNETISM

N. D. Watkins, then of the University of Rhode Island, collected core samples for paleomagnetic work from Jökuldalur and Bessastaðavatn in 1927-73 as mentioned above. With L. Kristjánsson and I. McDougall, he also sampled in 1973 two sections in Borgarfjörður that had previously been mapped in the field by Sæmundsson and Núll (1974) and by Jóhannesson (1975). Results from these, with several K-Ar dates, were published by Mc Dougall et al. (1977), Watkins et al. (1977) and McDougall (1977). In this work, two events in the Gilbert epoch were dated for the first time. The Borgarfjörður profiles reach up into the Lower Matuyama, and were thought to include a normal polarity event, but due to incomplete sampling and instabilities in flows NT102-110 its presence was not fully ascertained. Additional sampling (Bragason 1981) indicates that flows 107-112 all are reverse with low pole latitudes (< 45°) except NT108 which may be normal. Flows below 107 are reverse.

Watkins and collaborators sampled in 1974-76 and dated a long composite section in central northern Iceland, including a normally magnetized sequence identified with geomagnetic epoch 9. In 1973-77, a composite section in Esja, Eyjarfjall and Akrafjall was sampled. These results were published respectively by Sæmundsson et al. (1980) and Kristjánsson et al. (1980). See Fig. 6.

Statistical aspects of the geomagnetic secular variation and reversal rates in these collections have been discussed by Harrison (1980), Harrison and Watkins (1979), Harrison et al. (1979), Kristjánsson and McDougall (1982) and others.

NW-ICELAND: PALEOMAGNETISM

Apart from a few very local details (Mercanton 1931, Einarsson 1963) the first paleomagnetic data from the Northwest peninsula were reported by Friedrich (1966) who mapped magnetic polarities in a several hundred m thick lava pile around the Brjánslaekur fossiliferous sediments, by a compass. Kristjánsson (1968) sampled over 60 lava flows in the

* These lavas were resampled by the present author for laboratory measurements in 1977 (unpublished). Other new polarity results obtained then include flows T G (underlying basaltic lava), T 31 (above tillite, N), U 1 (N), V6 (conglomerate) and V 19 (pedestal to Laugarfell, N).
Súgandafjörður area in 1966-67 for laboratory magnetic measurements. Until K-Ar dates appeared in 1967-68, these oldest lavas in NW-Iceland were still thought by many to be possibly Eocene and to have been deeply buried. Kristjánsson’s mean field direction corresponded to a magnetic pole at 83°N, 155°E; previous published pole positions from Iceland had been based partly on undemagnetized samples (Hospers 1953b, Wensink 1964) and partly on much smaller collections of single samples (Sigrurðsson 1957, Smith 1967a). This result indicated little net apparent polar wandering (<8°) during the buildup of the lava pile, and subsequent work has further reduced this estimate.

Kristjánsson et al. (1975) provided detailed remanence results from a profile of 44 lava flows south of Arnarfjörður, and suggested a stratigraphic correlation between this area and that of Friedrich (1966).

A substantial sampling effort (1261 lavas) was carried out on a section through NW-Iceland in 1975-77 by the late N. D. Watkins and others (in press 1982), cf. Fig. 6.

PALEOINTENSITY, TRANSITIONS, ETC.

P. Smith sampled a number of baked sediments underlying Cenozoic Icelandic lavas during the 1964 expedition referred to above. These and deuteronically oxidized lava samples were found to be good material for studying the intensity of the paleomagnetic field. Results were published by Smith (1967a); additional experimental details are given by Smith (1967b) and Wilson and Smith (1968). These Icelandic data provided useful information on the geomagnetic field strength; according to Smith’s review this field appears to have been on average somewhat weaker in the Tertiary than at present.

Lawley (1970) and Dagley and Lawley (1974) studied six transitions in E-Iceland resampled in 1967, and some transitions from SW-Iceland previously reported by Wilson et al. (1972). No preferred pole path emerged in these or other similar studies reviewed by Dagley and Lawley. Shaw (1975; Shaw and Wilson 1977) sampled the R3/N3 geomagnetic transition in detail at six separate localities in Esja and Hvalfjörður, assuming a certain time sequence for the lavas sampled at these sites. He found that most but not all of the lavas yielding low-latitude poles also have relatively weak virtual dipole moments.

Dagley and Wilson (1971) and Wilson et al. (1972) carried out a quantitative analysis of relative Upper Tertiary geomagnetic dipole moment strengths by grouping intensity data from cores of the SW- and E-Iceland collections. They also pointed out that normally magnetized lavas are more common than reverse lavas in these collections. Some of the conclusions in these papers have been discussed by
Kristjánsson and McDougall (1982). A recent paper by Shaw et al. (1982) continues the Liverpool work on this topic, but it may not take the effects of e.g. secondary alteration sufficiently into account. Schweizer and Soffel (1980) have published paleointensity determinations from some post-glacial lava flows. Einarsson (1976), Peirce and Clark (1978), and Kristjánsson and Guðmundsson (1980) studied occurrences of very young transitional and reverse lavas in the volcanic zone.

ROCK MAGNETISM

Several of the papers already mentioned contain results of rock magnetic investigations. These include thermomagnetic curves, susceptibility results, storage tests for V.R.M. etc., mostly performed in connection with remanence measurements to ascertain the carrier of the remanence and its stability. Icelandic basalts are also represented in some early general compilations of rock magnetic properties in igneous rocks, e.g. that of Turtling (1966) who points out that intensity and susceptibility values in rock samples from various areas follow approximately a lognormal frequency distribution.

The Imperial College/Liverpool group was in the early sixties studying the relationship between the opaque mineralogy and magnetic properties of igneous rocks. Using samples from various areas including Iceland (collected by J. Hoppers and T. Sigurgeirsson) they made major advances towards the understanding of magnetic stability, including the development of a classification index for the oxidation state of opaque iron-titanium minerals as seen in polished section (Ade-Hall 1964, Wilson 1966, Wilson and Haggerty 1967, and others). These papers contain probably the first published electron microprobe analyses on Icelandic rocks. Later, the Liverpool group have published important papers on the relation of oxidation state to magnetic stability and other factors, both in their collection of lavas from E-Iceland as a whole (Smith 1967b, Ade-Hall 1969, Ade-Hall and Lawley 1970) and in single units (Watkins and Haggerty 1965, 1968; Smith 1967c, Wilson et al. 1968).

The effect of low-temperature hydrothermal alteration upon the magnetic properties of lavas from Iceland has also been studied in a major paper by Ade-Hall et al. (1971) which demonstrates e.g. that Curie points in basalts rise during burial in the lava pile. The effect of alteration on remanence intensity is discussed by Wood and Gibson (1976) and Watkins and Walker (1977). Oxidation state of opaques in an E-Iceland dyke swarm was investigated by Bird and Piper (1980).

SEDIMENTS AND MISCELLANEOUS

After Hoppers, the only detailed study on magnetic properties in Iceland sediments is that of Griffiths et al. (1960) who measured varved clay from Haga-vatn. Measurements on remanence in baked sediments are reported briefly by Doell (1972, Appendix) and Smith (1967a,b). Sediments in the Tertiary sequence have been sampled for magnetic measurements by Soviet authors, but only their work on Tjörnes sediments has yet been reported in papers (see above). An Edinburgh University expedition collected mud cores from a few lakes in Iceland for magnetic measurements in 1979.

Measurements on the anisotropy of susceptibility in Icelandic igneous rock units have been reported by Elliswood and Fisk (1977) and Elliswood (1978, 1979).

Some polarity measurements from Skagi, N-Iceland, are mentioned by Eoerts et al. (1972). Magnetic measurements from Surtsey island are reported by Sigurgeirsson (1974), Carmichael (1974), and Grommé (in press 1982).

Some studies of the effects of dyke intrusion upon the magnetic properties of nearby country rock are included in papers by Kristjánsson (1970), Doell (1972) and Becker (1980).

MAGNETIZATION IN ANOMALY INTERPRETATION

Magnetization intensity values have not been reported in all palaeomagnetic papers from Iceland, but this aspect may be important in the interpretation of magnetic anomalies on a local or regional scale. Several papers have been written to emphasise intensity measurements.

The first major effort in this field was made by a group from Munich University, who worked mostly in the neovolcanic zone in NE-Iceland. It is reviewed by Angenheister et al. (1977) and Becker (1980).

Other work includes that of Sigurgeirsson (1970), Kristjánsson (1970, 1972, 1976), Kristjánsson and Watkins (1977) and Palmason et al. (1979). These authors have made e. g. magnetic measurements on
a large number of samples from geothermal drill holes in order to find the effect of alteration on magnetite content in basalts. Kristjansson (1975, 1976) has discussed some aspects of drill hole measurements that are specific to Iceland.

Specific anomalies have been studied by Fridleifsson and Kristjansson (1972), Schönharting and Pedersen (1978) and Schönharting (1979). Magnetic properties of dredge samples from offshore anomaly areas were measured by de Boer (1975) and Kristjansson et al. (1976, 1977). Piper (1973c) also discussed the possible effect of large-scale remagnetization, by reheating and alteration, upon magnetic anomalies.

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SEGULMÆLINGAR Á ÍSLENSKU BERGI 1951–1981

Leó Kristjánsson, Rannsóknastofnun

Gefið er yfirlið yfir þær greinar, sem komið hafa út á prenti og fjalla um mælingar á seguleiginleikum íslenskrar bergsýna í rannsóknastofnum. Einnig er drepið á nokkrar rannsóknir sem gerðar hafa verið með segulmælingum utan hús, og tókun þeirra.

Greinilegur er, að niðurstöður bergsegulmælinga frá Íslindi skiptu verulegu mál við þrunn skilnings manna á eigileinkum jörðsegulviðiðins, einkum á sjótta og sjóunda áratugnum. Einnig hafa bergsegulmælingar verið áfar gagnilegar við jörðfræðikortlagningu, sérlæga á Tertír varðum landsins.

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