Paleomagnetic laboratory, University of Iceland

Historical (to 1968; see paper by L. Kristjansson in Terra Nova 5, p. 6-12, 1993).

The potential of the paleomagnetic method for geological research in Iceland was first demonstrated in the early 1950's by the work of Jan Hospers, a Dutch Ph.D. student in Cambridge, U.K. His research was followed up by prof. Trausti Einarsson of the University of Iceland, working with Thorbjörn Sigurgeirsson who was at the time Director of the National Research Council. Sigurgeirsson who became professor at the University in 1958, designed equipment for making accurate remanence measurements on hand samples. With this equipment and an alternating field (AF) demagnetizer, pioneering research on the paleomagnetism of the lava pile in Iceland was done in the late 1950's. Among its notable early results were the demonstration of the suitability of the AF method to remove viscous magnetization from basalts, and the discovery of intermediate directions at boundaries between polarity zones in the lava pile. In 1964, Sigurgeirsson installed an astatic magnetometer and improved AF-demagnetizer. These were used e.g. for some measurements on core samples from a large U.K.-Icelandic expedition in 1964-65.

In 1957, Sigurgeirsson set up a geomagnetic observatory at Leirvogur near Reykjavik which has been in continuous operation since then. See www.raunvis.hi.is/~halo/haloft.html

Typical sampling localities for paleomagnetic studies. Left: Mt. Tradarhyrna above Bolungavik village, NW-Iceland, where approx. 50 lava flows of 16 Ma age were sampled (Geophys. J. Int. vol. 155, 2003). Right: Mt. Hafursfell, W-Iceland, with a sampling profile containing over 110 flows of about 8 Ma age (Earth, Planets, Space vol. 51, 1999)

Developments 1968-80; instrumentation etc.

Leo Kristjansson was employed in paleomagnetic research and magnetic surveys at the University of Iceland in 1968-69 and from 1971. An extensive paleomagnetic research effort on Icelandic rocks (totalling some 2400 lava flows in several regional surveys) was begun in 1972 by N.D. Watkins of the University of Rhode Island in collaboration with I. McDougall of the Australian National University, L. Kristjansson, and other Icelandic scientists. Watkins also collaborated with G.P.L. Walker of Imperial College on completing other projects in East Iceland. Most of the measurements were made at the U.R.I. through 1978, but after the untimely death of Dr. Watkins from cancer in 1977, the paleomagnetic measurements from the major surveys were concluded, processed and written up by L. Kristjansson with the other collaborators. A Foster spinner magnetometer, presented to the University by Dr. Watkins in 1975, was in service for a few years.

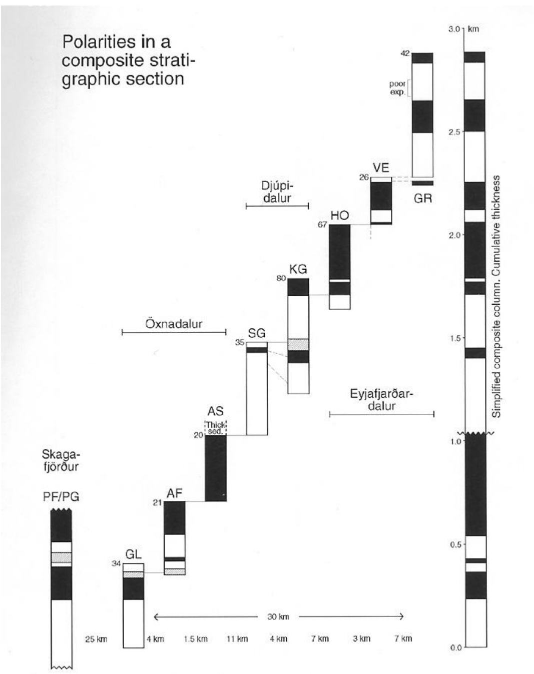
In 1978 the University acquired an "Institut Dr. Förster" static four-probe fluxgate magnetometer which has been in constant use since then. In this instrument the x, y, and z components of the dipole moment of a 1" rock core specimen are each measured in eight positions, and the results averaged. It is very convenient in use, and comparisons with results from other magnetometers abroad have given excellent agreement. A "Molspin" AF tumbler demagnetizer was obtained in 1989, replacing older equipment constructed at the Science Institute.

In addition to the instruments already mentioned, the paleomagnetic laboratory has three portable fluxgate magnetometers, two gasoline-powered 1" diamond core drills, and various other minor equipment. The only permanent staff member has been L. Kristjansson, assisted by technical and clerical personnel of the Institute as needed. Students are employed occasionally in field work and routine measurements. The laboratory has not been involved in any graduate student theses. Through the years, rock samples and paleomagnetic data have been supplied on request to several parties abroad; advice and aid with logistics has also been provided to numerous expeditions.

Using a proton magnetometer and other instruments designed by himself, Th. Sigurgeirsson carried out an aeromagnetic survey over most of Iceland at 3-4 km spacing in 1968-80. The results were published on nine 1:250,000 maps. L. Kristjansson surveyed parts of the insular shelf by ship in 1972-75. Magnetic anomalies observed may reach 2 μT or more in amplitude. Various rock types in Iceland were sampled and measured in order to aid in the interpretation of the surveys; the average remanence intensity in basalt lavas is around 4 A/m, but values up to an order of magnitude greater do occur.

Developments 1980-2006.

In order to maximize the scientific return on the available resources, research at the University of Iceland paleomagnetic laboratory has concentrated on simple measurements of remanence directions in a large number of basalt lava flows. Mostly, these efforts have had direct connections to stratigraphic mapping of various parts of the 0- 16 Ma lava pile. Only a few minor studies have been made on e.g. sediments, intrusives, or altered rocks. Thermal demagnetizations, microscope work, paleointensity measurements, and rock-magnetism projects including anisotropy have not been carried out here to any significant extent. Such studies tend to be time-consuming and require expensive equipment; the results are often ambiguous and of limited relevance to specific geological or geomagnetic problems.

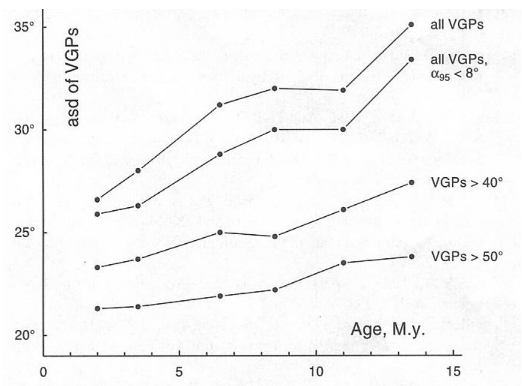


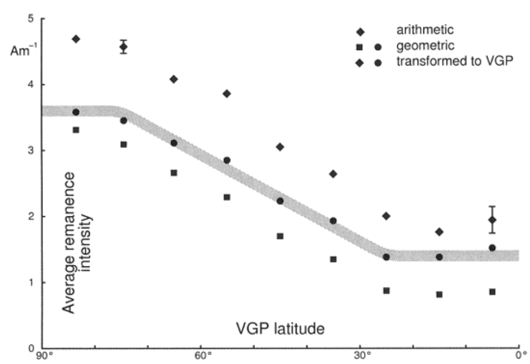
Left: A stratigraphic section of 2.9 km thickness in Eyjafjördur, N- Iceland. It is estimated to cover the time interval 9-5 Ma ago. 320 lavas were measured. (Int. J. Earth Sci. 93, 2004) Right: L. Kristjansson collecting samples in Talknafjördur fjord, NW-Iceland 2005.

Due to the high stability of the primary directions in the lavas (after removal of viscous remanence, usually complete by 10 mT AF treatment), collecting four samples from each lava flow and demagnetizing at 3-5 steps has been found to be quite adequate to obtain excellent within-site agreement (average directions with a 95% confidence radius of 5° or less in recent years). Low-field susceptibility data and thermomagnetic curves (obtained with a "Bartington" MS 2W furnace meter which the University acquired in the early 1990's) and ARM observations (using an attachment provided with the Molspin demagnetizer) have aided in interpreting some of the remanence measurements.

Emphasis has been on obtaining results from lava flows with minimal alteration (< 100°C secondary heating) and small tectonic tilts (< 7° or so). Most summers since 1979, of the order of 100 or more lava flows have been sampled by L. Kristjansson. Mostly, lavas of > 2 Ma age have been targeted, as in younger rocks stratigraphic complications occur due to glaciations and rapid erosion. However, some studies have involved younger lava flows, e.g. those on the late Quaternary "Skalamaelifell geomagnetic excursion" in the Reykjanes peninsula of SW-Iceland. Part of a study on Quaternary lavas around Skaftafell, SE-Iceland carried out by J. Helgason (Geology, vol. 29, 2001), also made use of the laboratory's facilities.

As a by-product of these stratigraphic surveys, a large body of high-quality paleomagnetic direction and intensity data from Iceland is available, in fact mostly published in detail. These data are in many ways unique, as there are no other regions in the world where a comparable number of relatively fresh lava flows covering a fairly complete 16-Ma interval are easily accessible. They have been used for statistical studies of some overall properties of paleomagnetic field in Iceland. It should be kept in mind that such studies have limitations due firstly to the time elapsing between successive lava flows in the pile (which is highly variable but averaging 5-10 ka), and secondly to the rather small number of radiometric age determinations so far carried out on Icelandic rocks. Nevertheless the analysis of these data has led to interesting results, cf. the following diagrams. Among these is the observation of a significant reduction in the scatter of paleomagnetic poles taking place since 16 Ma ago, and an estimate of the variation of the mean geomagnetic dipole moment as the virtual pole moves away from the geographic pole.





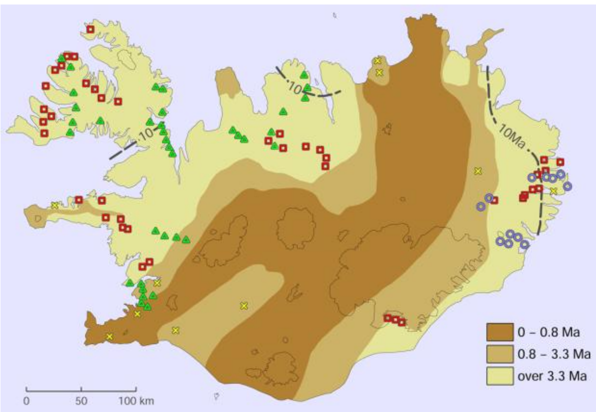
Left: Angular standard deviation of grouped virtual geomagnetic poles in Icelandic lava flows. 4230 flows with a stable reliably determined remanence direction are included in the top graph. Various rejection criteria are applied in the lower ones (Phys. Chem. Earth vol. 27, 2002). Right: Variation of the mean geomagnetic field intensity in Iceland (bottom, *geometric averages). Variation of this property after transformation of the intensity in each lava to the location of its virtual geomagnetic pole (middle: geometric averages; top: arithmetic averages). These are plotted as functions of the latitude of the virtual geomagnetic pole. The diagram was derived from primary remanence intensities in almost 5000 lava flows, both polarities combined (Jökull vol. 58, 2008)*

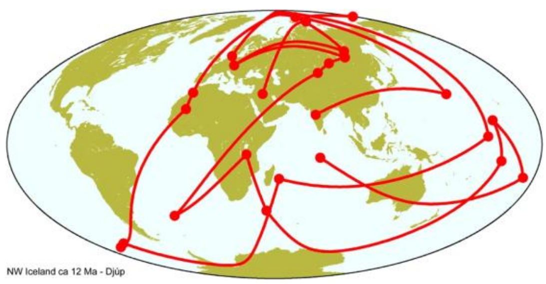
The laboratory has participated in investigations initiated by the University of Aarhus in Denmark, comparing magnetic minerals in Icelandic rocks with those analysed by Mars landers (paper published in Phys. Earth Planet. Inter. vol. 154, 2006). A paper containing paleomagnetic results from Antarctica appeared in Antarctic Science vol. 17, 2005.

In continuation of the magnetic surveys mentioned above, aeromagnetic measurements over parts of the shelf were carried out by the laboratory in 1985-86 and 1990-92. A detailed survey of the Reykjavik area, made in 1993, has also been published. No surveys have been made subsequently, but the data from the older ones over all of Iceland have been digitized and interpreted (see e.g. paper by G. Jonsson et al. in Tectonophysics vol. 189, 1991). The laboratory owns two proton magnetometers which are used for ground surveys, teaching purposes and as backup for instruments at the University's observatory.

<u>Recent and current projects; opportunities</u>

Reviews of some aspects of paleomagnetism and magnetic surveys in Iceland appeared in J. Geodynamics (vol. 43, 2007), and in Jökull (vol. 58, 2008). Since 2007, several stratigraphic/ paleomagnetic studies have been completed or initiated by the laboratory. Completed projects include one of over 300 lava flows in the southern part of the Northwestern peninsula (Jökull vol. 59, 2009) and one of about 100 flows in Early Quaternary lavas in SW- and S- Iceland (Jökull vol. 60, 2010). A new study of the above-mentioned Skálamælifell geomagnetic excursion with scientists from the U.S. and elsewhere (Earth Planet. Sci. Letters vol. 310, 2011) yielded a revised age of about 90 ka for this excursion. In collaboration with M. S. Riishuus at the University of Iceland and R.A. Duncan of Oregon State University, a project on the age and stratigraphy of the oldest exposed lava flows in Iceland is in progress. A manuscript describing new ground magnetic surveys at two of the major localized magnetic anomalies in SW-Iceland has been submitted for publication. A 1980s discovery of a prolonged instability of the geomagnetic field (see right-hand diagram below) in an area of NW-Iceland is being followed up by new sampling nearby.





Left: Overview of paleomagnetic sampling in Iceland in 1964-2008. Circles: Field work in 1964-65. Triangles: Field work in 1972-78. Squares: Field work since 1979. Each sign *represents 60-100 lava flows. Crosses show locations of some smaller surveys. Right: Instability of the geomagnetic field recorded by a lava series in NW-Iceland of 12 Ma age.*

A few foreign expeditions have visited Iceland to collect samples for paleomagnetic or rock magnetic studies in the last decade. However, all these projects have been on a small scale. Many opportunities exist for interesting and significant projects in both fields, notably in stratigraphic mapping and correlation: it is evident from the map above that large areas of Iceland remain unexplored by paleomagnetists (as well as by stratigraphers and geochronologists). Projects also worth exploring include analyses of long-term characteristics of the geomagnetic field, where Iceland offers a unique position. The worldwide paleomagnetic surveys on which various models of the paleo-geomagnetic fields in the literature have been based, are almost always much too small in size to give a realistic picture of fundamental properties of the field such as its secular variation and reversals. This unfortunate situation is further compounded by for instance the tectonic and hydrothermal disturbances that many sampled formations have suffered, by poor stability of their original remanence vectors, and by the arbitrary rejection of low-latitude geomagnetic poles before statistical analysis. Great efforts have been spent in recent decades on so-called absolute paleointensity determinations, using igneous rocks from sites around the globe. However, it can be demonstrated conclusively with reference to remanence data from Iceland, that the quality criteria for these determinations are in need of serious revision.

Among other scientifically valuable projects that may be performed on Icelandic rocks in the future, are radiometric dating of geomagnetic polarity transitions and major excursions, within-unit variations of magnetic properties, magnetic anomaly modelling, and effects of hydrothermal alteration upon the magnetic minerals of igneous rocks.

(Revision Jan. 2013, L.Kr.; further information may be obtained from leo@hi.is)