

MAGNETIC CONSIDERATIONS OF THE VOLCANIC DYKES ON LUNDY ISLAND

By

CLIVE L. ROBERTS

Dept. of Geography and Geology, Shaftesbury Hall,
Cheltenham and Gloucester College of Higher Education,
CHELTENHAM, Glos. GL50 3PP

At the present time, there is a geophysical research project being undertaken on Lundy Island by Dr. Sandy Smith of the Open University and myself, which will form part of my Ph.D. programme of study in the Bristol Channel area. The broad aims of the project are to determine the trends of basaltic dykes over the planed island surface by completing a ground based magnetometer survey, partly by setting up an accurate grid network and partly by prospecting for dyke-related magnetic anomalies.

The following account is a brief summary of the theory and rationale behind the research objectives, the main conclusions remaining unstated until all work has hopefully been completed by September 1992. A full summary should thus be available for publication in next year's Annual Report.

GEOLOGICAL BACKGROUND

Lundy has attracted some interest amongst geologists as far back as 1839, but the first serious study of the igneous nature of the island is attributed to Rev. D. Williams in 1843. A more complete account of both the geology and mineralogy of the whole island was presented by T.M. Hall in 1871. It was Hall who coined the term Lundyite for the large dyke of intermediate composition cropping out near to the landing beach.

However, the most modern comprehensive paper on Lundy was written by A.T.J. Dollar (1941), in which he considers the petrography, petrogenesis and tectonics of the island's rocks. One of the main proposals put forward by Dollar was that the alkaline granites constituted an amalgamation of four distinct igneous intrusions, which he numbered G1, G2, G3 and G3a. The former two are coarse grained, whereas the latter two were deemed younger with a microgranitic texture and volumetrically smaller. Dollar considered the age of the granite to be Permo-Carboniferous, consistent with the opinions of Hall (1871), Williams (1843), Osman (1931) and Davison (1932).

Dollar also noted and quantified the existence of a dyke-swarm, numbering around 150 intrusions, cutting both the granites and slates. He petrographically divided them into a basaltic group of dykes (91%) and a trachytic group of dykes (9%), both with an overall NW-SE strike direction. A Tertiary age was suggested for these post-granite intrusives, on the basis of their orientation and chemical similarity to other Tertiary basalts of the Inner Hebrides, Scotland.

The position of central complexes within the British Tertiary Volcanic Province has been well documented from many years of research, the Thulean Province being an early descriptive term meaning the same. Lundy Island is the mostly southerly expression of this episode of volcanism, which is depicted in fig. 1. The inset shows an interpretation of the dyke swarm around the island from marine-based magnetic information.

Both Dodson and Long (1962) and Miller and Fitch (1962), whilst utilizing differing techniques, obtained radiometric ages of 52 - 57 Ma for the granite, which clearly rejects the Upper Palaeozoic suggestion.

In recent years, there has been a fair amount of renewed geochemical interest in Lundy. Thorpe, Tindle and Gledhill (1990), in a detailed piece of work on the Lundy granite, suggested a bi-modal magma-genetic origin, comprising both a mantle derived component and a crustal element. Although the granites of Devon and Cornwall are older than those of Lundy, both types originated from a similar source in the Earth's crust. Thorpe and Tindle also indicate granite crystallization at a relatively shallow

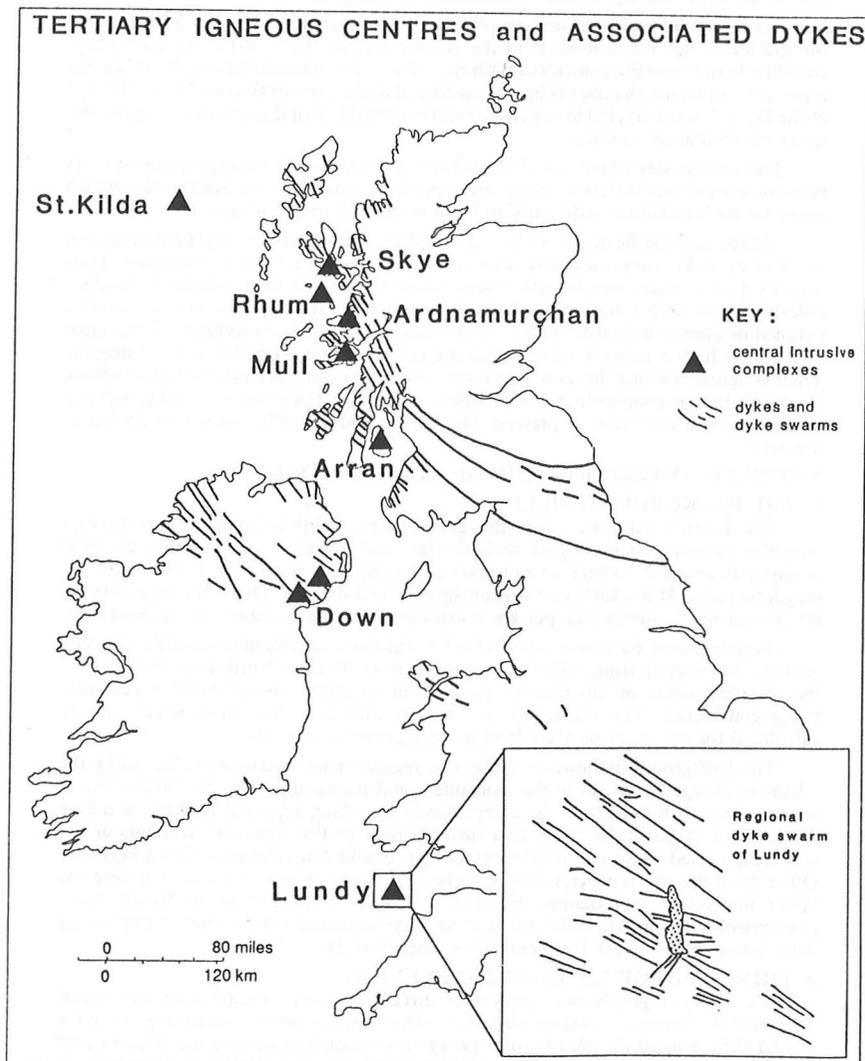


Fig. 1: Major centres in the British Tertiary Volcanic Province and the position of Lundy. Note the dominant northwest-southeast trend of dykes and dyke swarms.

crustal level, presumably within the confines of a magma chamber.

There is good geological and geophysical evidence that the lateral spatial extent of the granite is not much more than the surface area of the island itself, the eastern coastline being virtually coincident with the edge of the acidic intrusion. Whether this represents a magma chamber is being considered at the present time by Dr. O. Thorpe of the Open University, but in any case, it seems probable that the generated magma was never erupted at the surface.

The present day island has either isostatically readjusted through the crust to its present level or has suffered significant superficial erosion of overlying rocks, which could be both Devonian sediments and sub-strata of Lundy volcano.

Thorpe and Tindle (in press), have also addressed the petrology and petrogenesis of the Lundy dyke association and offer a bimodal model for these intrusives. They identify two separate trends with fractional crystallization of a dolerite to produce dolerite/basalt, minor trachyte and rhyolite sequences, the rhyolites mainly having a peralkaline composition with a rarer subalkaline modality. Some dykes are vesiculated in places, which is interpreted as indicating rapid high-level emplacement of magma. Their conclusion is that the nature and style of this phase of volcanic activity is evidence for a substantial composite bimodal basalt — (minor trachyte) — rhyolite volcano situated somewhere near to present day Lundy and possibly measuring 25 km in diameter.

MAGNETIC INTERPRETATION OF IGNEOUS ROCKS

a. THE BACKGROUND FIELD

The Earth's magnetic field (the geomagnetic field) is complex and displays irregular variations with respect to both time and position. For instance, the field strength is about 25 000nT (nanoteslas) at the equator and up to 70 000nT at the magnetic poles. At Rocket Pole, the geomagnetic field strength has a value around 48050 nT, increasing by about 2nT per km northwards. Lateral variations are insignificant.

Superimposed on this is a background regional component created by the deep geology and ranging from +20nT at South Light to -50nT at North End. Fig. 2 shows the complex nature of this regional pattern, an interpretation for which is currently being considered. The net result is a background base-line value, which can be calculated for any point on the island to an accuracy within 10nT.

The background is however subject to regular daily fluctuations, caused by the effects of charged particles in the ionosphere and measuring some 25 - 90nT. This is termed diurnal drift and can be compensated by taking repeated readings at a base station in a magnetically quiet area (usually near to the Marisco!) throughout the surveying period, and then simply correcting the field data relative to the background. Other irregular discrepancies can be caused by charged solar particles entering the upper ionosphere, stimulating magnetic storms of amplitude up to 100nT. Such phenomena are unpredictable and lead to large statistical errors when manipulating data, hence reliable work is sabotaged on disturbed days.

b. PRINCIPLES OF MAGNETIC SURVEYING

The current geophysical project is directed towards establishing the spatial distribution of these dykes throughout the island. Dykes can be seen to crop out in the coastal cliffs around the island, but exposure is extremely poor over the planed island surface, thus the trends of the dykes are uncertain. One possible technique to determine strike trends is to utilise their magnetic properties in order to locate their sub-surface distribution. This is the essence of the research project.

Magnetic surveys utilise the property of induced magnetization, which is related to the level of magnetic susceptibility within the rocks themselves. Materials with a high susceptibility, e.g. basic rocks, act like a giant magnet and acquire an induced field when placed in a stronger external field, usually the geomagnetic field (see fig. 3b). Susceptibility is carried by relatively few minerals, the three most important being magnetite (Fe_3O_4), ilmenite (FeTiO_3) and pyrrhotite (FeS).

The induced flux has the effect of either enhancing or partially negating the total

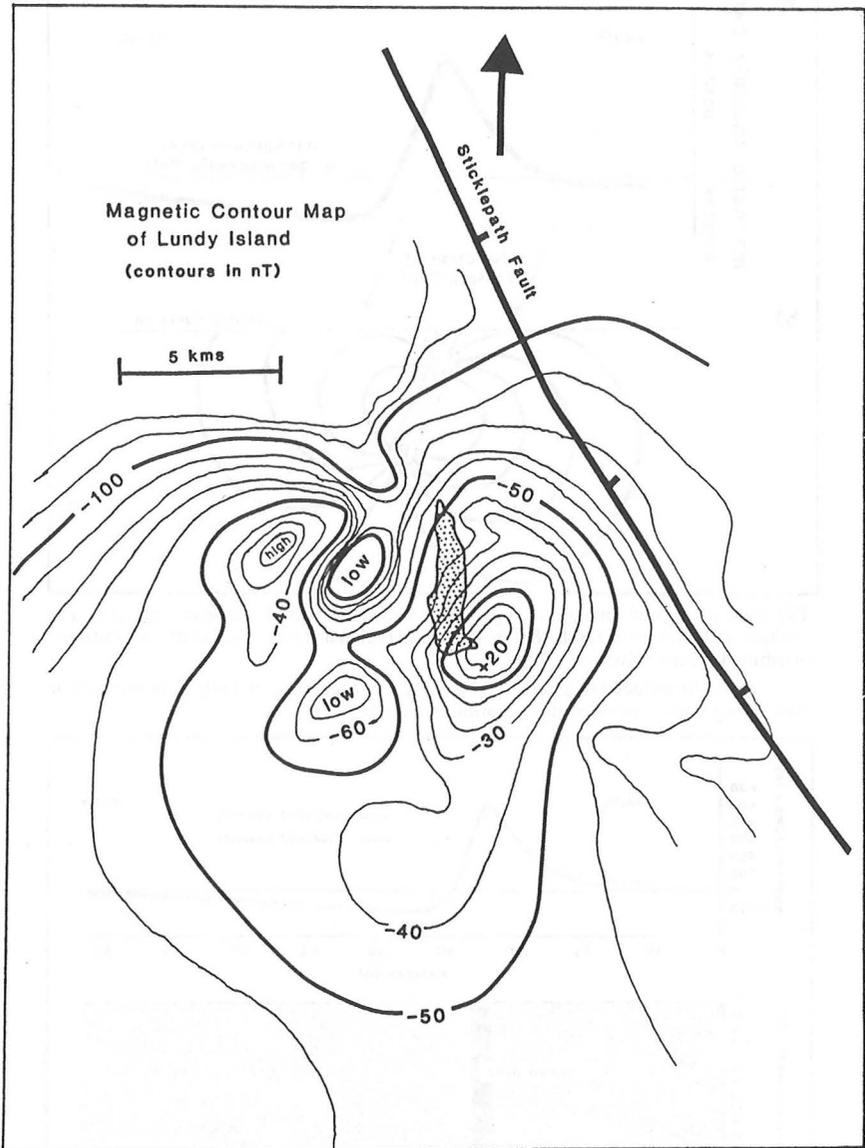


Fig. 2: Magnetic anomaly map for Lundy, contour intervals at 10nT. The data for this map was collected by aeroplane at an altitude between 500 and 1000 metres. The large scale geological features are picked out by this aeromagnetic technique, but small aspects are smoothed over with increasing altitude.

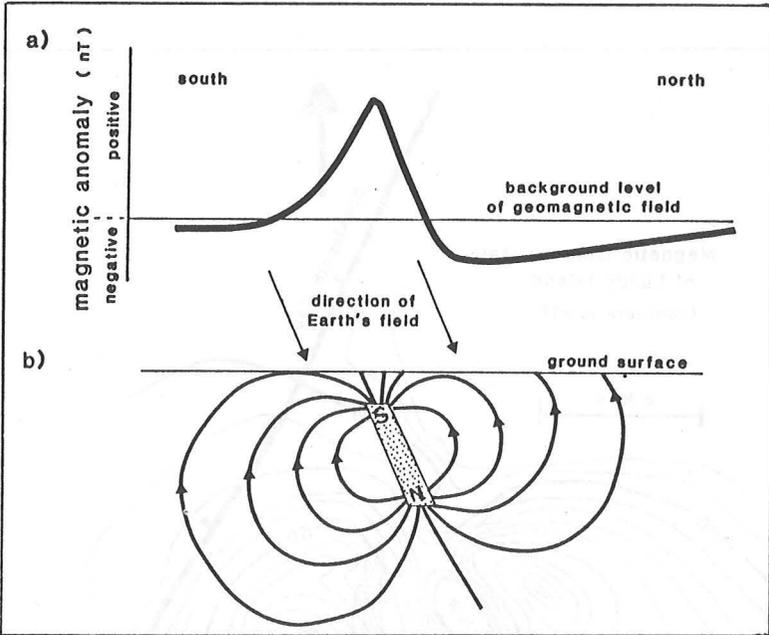


Fig.3: a) A typical magnetic signature, called a paired anomaly profile. The background level includes the Earth's field and regional variations, and by convention is attributed a zero value.

b) The induced magnetic field of a buried magnetic rock body. The anomaly in part a) is a direct result of the situation in part b).

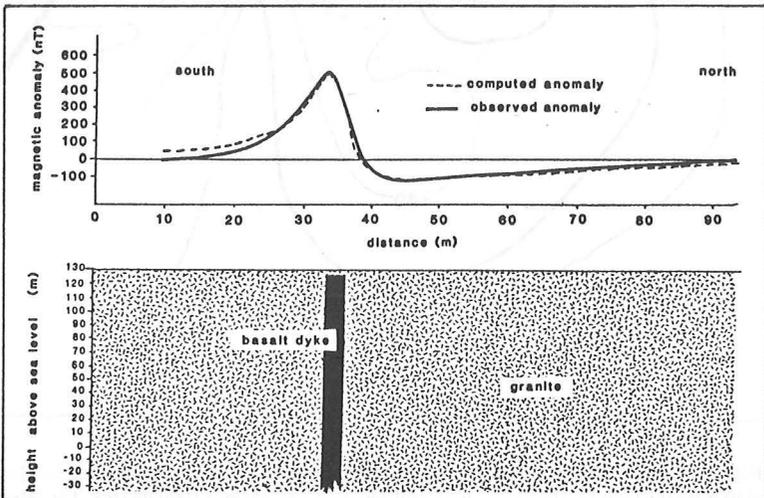


Fig. 4: A simple observed anomaly profile taken from Ackland's Moor and the computed interpretation of the sub-surface geology. When several basaltic dykes are located close together, interference occurs and interpretation is more difficult.

field strength, creating a paired anomaly profile, as demonstrated in fig. 3a. The actual shape of the anomaly is sensitive to many parameters, including the form and orientation of the magnetic body, but on Lundy, the usual shape is positive to the south and negative to the north with a sharp dividing boundary (see fig. 4). This will be dealt with in greater detail in the next paper.

On Lundy, magnetite is by far the most significant mineral and has a relatively high concentration in basalts and dolerites, which numerically are the dominant dyke types. Although Dollar (1941) records some pyrrhotite in the granite, field observations indicate it is magnetically quiet with a differential of 15nT. Paired anomaly profiles with an amplitude of up to 900nT are discernable over the island and are interpreted as the surficial magnetic expressions of underlying basic dykes. Rhyolitic dykes do not present a viable magnetic signature.

c. FIELD SURVEYING TECHNIQUES

The proton magnetometer is a convenient digitized machine which measures the total field strength, taking on average three seconds to register a reading. Two methods have been applied to systematically map the field relations of the basic dykes. The first is to prospect for a suitable paired anomaly profile by completing short north-south traverses to specify dyke positions, and then to laterally follow the peaks. A marker is positioned every 10-20m, which then allows accurate compass bearings and location of dyke sub-crops to be plotted on a map. The second involves the setting up of an accurately measured grid. At the present time, a grid (bearing 354°) has been completed on Ackland's Moor with a line spacing of 30m. The total field strength is measured every 5m along the traverse lines and the peaks of paired anomalies are marked as in the first method. It is then a simple process to prospect between markers in order to determine trends in the dykes. The main advantage of systematic gridding is to provide a much greater degree of confidence in recorded field data, in that all viable dykes should be quantified by this technique and it is also easier to manipulate data at a later stage.

d. COMPUTER MODELLING

Although we can obtain quantitative anomaly profiles from magnetic surveying on Lundy and infer that these may be caused by basaltic dykes, interpretations of the geological relationships are difficult to synthesise from raw data. Computer modelling procedures are used to constrain the sub-surface spatial form of the dykes.

The program essentially considers a profile within a two dimensional cross-sectional framework through a land mass, the operator having to specify both orientation of the line and appropriate properties of the geomagnetic field. Polygonal shapes are then added to simulate dykes, the operator again being able to adjust all associated physical characteristics of the model. The program then calculates the magnetic response of the simulated model and compares this to the actual observed anomaly profile.

Both polygons and physical parameters are modified until the computed anomaly profile calculated by the program matches as closely as possible the observed profile pattern. The model then offers an opinion on the form and extent of the dykes. Fig. 4 demonstrates this for a short traverse over Ackland's Moor in which there is reasonable agreement between computed and observed anomalies.

Early results from modelling procedures indicate that the dykes are extremely sensitive to height of dyke emplacement above sea level and to overlying soil cover, dykes over 7m below the ground surface being very difficult to model. This suggests that such dykes may not be picked up by magnetic surveying techniques. The dip of the dykes varies from vertical to about 45° and the dyke thickness ranges from 1 to 2.5m.

By the time all work has been completed on the island, we should have a more refined impression of the orientation and extent of the Lundy dyke swarm, in particular how it relates to the postulated dominant NW-SE trend. The relationship between dykes and jointing system is important on Lundy and will therefore constitute the next phase of research, namely establishing prevailing stress regimes and tectonics of the region during volcanism. There is clearly considerable work to be done before Lundy unravels more of its complex geological history.

ACKNOWLEDGEMENTS

My grateful thanks go to the party of Open University students involved in 1991's summer field trip organised by David Care and led by Dr. Sandy Smith, to the Landmark Trust for permission to collect small hand specimens and to carry out magnetic surveying procedures, to Andrew Gibson and all other island staff for support and encouragement, to the farm animals for not knocking over any survey poles and to Lundy for being there.

REFERENCES

- Arthur, M.J. 1989. The Cenozoic evolution of the Lundy pull-apart basin into the Lundy Rhomb Horst. *Geol. Mag.*, 126, 187-98.
- British Geological Survey 1983. *Lundy: Solid Geological Map, Sheet 51N-06W*.
- Davison, E.H. 1932. The age of the Lundy granite. *Geol. Mag.*, 69, 76-79.
- Dodson, M.H. and Long, L.E. 1962. The age of Lundy granite, Bristol Channel. *Nature*, 195, 975-6.
- Dollar, A.T.J. 1941. The Lundy complex: its petrology and tectonics. *Q. J. Geol. Soc. Lond.*, 97, 39-77.
- Dollar, A.T.J. 1968. Tertiary dyke swarms of Lundy. *Proc. Geol. Soc. Lond.*, 1649, 119-120.
- Hall, T.M. 1871. Notes on the geology and mineralogy of the Island of Lundy. *Trans. Devon Ass.*, 4, 612-617.
- Miller, J.A. and Fitch, F.J. 1962. Age of the Lundy Granites. *Ibid.*, 195, 553-555.
- Osman, C.W. 1927. The granites of the Scilly Islands and their relations to the Dartmoor Granites. *Q. J. Geol. Soc. Lond.*, 84, 258-262.
- Thorpe, R.S., Tindle, A.G. and Gledhill, A. 1990. The Petrology and origin of the Tertiary Lundy Granite (Bristol Channel, UK). *Journal of Petrology* 31, 1379-1406.
- Thorpe, R.S. and Tindle, A.G. (in press) Petrology and Petrogenesis of the Tertiary bimodal dolerite-peralkaline/subalkaline trachyte/rhyolite dyke association from Lundy, Bristol Channel, UK. *Geological Journal*.
- Williams, Rev. D. 1843. On the granite and other volcanic rocks of Lundy Island. *Rep. Brit. Ass.*, pt. 2, sect. C., p.57.

GLOSSARY

Basaltic

Basalt is the fine grained equivalent of dolerite, essentially being made up by pyroxene, plagioclase feldspar and iron minerals, of which magnetite is the commonest. Some basalts contain varying amounts of olivine. They can be extrusive or intrusive and are created in a variety of geological settings, usually by partial melting of the mantle at a temperature around 1400°-1500°C.

Earth's Magnetic Field

This has existed for at least 2 600 million years and can be likened to the effects of a dipolar bar magnet lying in the Earth's core (geocentric position) and aligned at about 11° to the rotational axis of the Earth. At the present time, the field points towards the north, evidenced by a simple compass needle, but reversals happen periodically when the field points towards the south. One such reversal straddled the formation of Lundy, around 50 million years ago.

Geophysics

The branch of Earth Science which deals with the study of physical properties of the Earth, giving insights into many divergent topics, e.g. earthquakes, volcanism, structure of the Earth, magnetism, rate of heat flow, radioactivity, etc.

Induced Magnetization

Non-permanent magnetization induced in a body when it is placed in a stronger field, making the body act like a magnet. Once the stronger field is removed, the induced magnetization stops and the body reverts to its original form.

Ionosphere

That part of the atmosphere from about 50 - 500 kilometers above sea level with temperature varying from about -70°C at 80kms to 2000°C at 400kms. The ionosphere is noted for the ionization (electrically charged) by solar radiation of its concentration of thinly-distributed gas molecules.

Isostatic Readjustment

Large or small areas of land often suffer vertical movements in response to mass density contrasts. An analogy might be a block of wood pushed into a bucket of tar. Once the block is released, it will tend to move vertically back towards a position of stability. Scandinavia is currently rising due to pressure release from the melting of ice after the last Ice Age. Granites are less dense than the average crust and so will tend to rise, but this will be opposed by the rigidity of solid material in the crust.

Magma

A molten liquid or mushy viscous mix of crystals, which forms within the crust or upper mantle by partial melting under a wide range of temperatures, depending on the composition of the melt. Granites crystallize at a lower temperature than basalts. In terms of volcanic activity, magma often collects in a chamber at variable depths.

Magnetic Induction

The number of lines of magnetic force passing through a unit area, sometimes referred to as flux density. Magnetic induction is directly proportional to the field strength of intensity.

Nanotesla (nT)

The tesla (T) is the SI unit of magnetic induction. The SI system of units was established in 1948, in an effort to simplify and standardize scientific notation. $1\text{nT} = 10^{-9}\text{T}$, and in older literature, $1\text{nT} = 1\text{gamma}$.

Permo-carboniferous

The combined Permian and Carboniferous Periods. The Permian lasted 55 million years (Ma) from 280 - 225 Ma, and the Carboniferous lasted 65 million years from 345 - 280 Ma. Apart from coal deposits in Britain, the Carboniferous was marked by extensive volcanic activity, especially in Scotland and Northern England.

Petrogenesis

A general term used to describe all aspects of the formation of rocks. This might include physical and chemical processes, alterations and modifications, evolution and final composition of the rock.

Petrography

The systematic study and description of rocks, primarily by using thin sections, which are thin slices of the rock, usually 30 microns thick. The sections are analysed under a polarizing microscope by utilizing the optical properties of minerals in the rock, revealing a great deal of information of many aspects of the rock's history.

Susceptibility

Minerals which are able to become magnetized are said to possess magnetic susceptibility. On the whole, the higher the susceptibility, the greater the degree of induced magnetization, increasing the amplitude of the magnetic signature.