Working Report 2007-22

Preliminary Paleomagnetic Study on Different Rock Types in Olkiluoto Area

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ABSTRACT

Paleomagnetic test samples have been measured from different rock types in the Olkiluoto area. The main aim of the study has been to resolve the suitability of the rock types to paleomagnetic studies. Paleomagnetic studies are aimed to investigate the geological evolution of the Olkiluoto area by using remanent magnetization that has been blocked in the rocks in different geological processes.

Altogether 20 cylinders were measured from five different rock types. The cylinders were demagnetized with alternating field and the remanent magnetizations were measured. The results were analysed with multicomponent analysing methods.

According to preliminary studies, most of the test samples are weakly magnetized and do not carry stable remanent magnetization. However, part of the samples and rock types carry stable or semistable remanent magnetizations and are therefore favourable for further investigations. Especially the diabase dykes carry stable multicomponent magnetizations. Also the pegmatite dykes are worth of additional studies. Remanent magnetizations of test samples from TGG-gneisses, potassium feldspar porphyries and sulphidized rocks are weaker, but it is suggested that some new test samples would be useful for further studies.

Keywords: paleomagnetism, remanent magnetization, Olkiluoto, Finland

Olkiluodon alueen eri kivilajien alustavat paleomagneettiset tutkimukset

TIIVISTELMÄ

Olkiluodon alueen eri kivilajeista on mitattu paleomagneettisia testinäytteitä. Tutkimuksen tarkoituksena on määrittää kivilajien soveltuvuutta paleomagneettisiin tutkimuksiin. Paleomagneettisilla tutkimuksilla pyritään selvittämään alueen geologista evoluutiota eri geologisissa prosesseissa kiviin lukkiutuneen remanentin magnetoituman avulla.

Viidestä eri kivilajista otetusta testinäytteestä mitattiin yhteensä 20 sylinteriä. Sylintereille tehtiin vaihtovirtademagnetoinnit ja remanentin magnetoituman mittaukset. Tulokset analysoitiin monikomponenttianalyyseillä.

Alustavien tulosten mukaan suurin osa näytteistä on heikosti magnetoituneita ja kantavat epästabiilia remanenttia magnetoitumaa. Osasta näytteistä saatiin kuitenkin stabiilit tai melko stabiilit tulokset, jotka antavat aihetta lisätutkimuksiin. Erityisesti diabaasijuonten remanenssi on kovaa ja stabiilia ja siten otollista jatkotutkimuksiin. Myös pegmatiittijuonista saadut tulokset antavat aihetta jatkotutkimuksiin. TGG-gneissien, kalimaasälpäporfyyrien ja sulfidisaatioiden remanenssit ovat heikompia, mutta osasta kohteista ehdotetaan otettavaksi uusia testinäytteitä jatkotutkimuksia varten.

Asiasanat: paleomagnetismi, remanentti magnetoituma, Olkiluoto, Suomi.

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1 INTRODUCTION

The geology of Olkiluoto area has been thoroughly investigated. However, the geological evolution and the connections of the geology of the Olkiluoto area with the overall geological evolution of the surrounding areas are still under way of keen studies. In that sense, different methods that can shed light to the geological processes affecting the Olkiluoto area are required. Paleomagnetic method has been previously used to detect multiple geological processes within single formations, for example in the weakness zones of the Helsinki and its surrounding areas (Mertanen et al., 2007). Paleomagnetic method in detecting these processes is based on the ability of remanent magnetization to record different thermal, hydrothermal and tectonic events as separate remanent magnetizations components in a rock. By applying multicomponent analysing methods, the components can be separated and paleomagnetically dated. The dating is based on comparison of the obtained remanent magnetization directions to known directions from Fennoscandian rocks that are isotopically dated. In Olkiluoto area it is especially hoped that paleomagnetic studies could bring new knowledge on younger geological events, such as Subjotnian and/or Postjotnian or even younger Paleozoic oveprinting on Svecofennian rocks.

The main aim of this preliminary study is to determine the suitability of Olkiluoto rocks for paleomagnetic investigations. The suitability is defined as the ability of rocks to retain stable remanent magnetization directions, which is largely dependent on the amount and composition of magnetic minerals, their grain sizes and mode of occurrence. Based on the results from the test samples, the report gives suggestions for further paleomagnetic studies.

2 PALEOMAGNETIC TEST SAMPLES

Eight hand samples for paleomagnetic measurements were obtained from Irmeli Mänttäri at GTK, who has carried out isotopic datings from the samples for Posiva (Mänttäri et al., 2005, 2006). Two core samples from ONKALO investigation tunnel were obtained from Ismo Aaltonen from Posiva. The ten test samples are taken from five different rock types, so that each rock type is represented by two samples. The eight hand samples were taken from diabase dykes, pegmatitic granite, TGG-gneiss and potassium feldspar porphyry. The two core samples were taken from a hydrothermally altered zone with sulphidization within or close to a sheared weakness zone in the tunnel. Two standard cylindrical specimens (diameter 2.4 cm and hight 2.1 cm) were prepared from each sample. Consequently, altogether 20 specimens were prepared for the measurements.

3 METHODS

Petrophysical properties; density and magnetic susceptibility were first measured for each specimen before paleomagnetic measurements (Table 1). Koenigsberger ratios (Q-values) which define the relative amount of remanent magnetization (J) over the induced magnetization (magnetic susceptibility) were determined for each specimen. In paleomagnetic measurements the specimens were stepwise demagnetized with increasing alternating field (AF) in 15 steps up to a field of 160 mT. The remanent magnetization was measured with cryogenic three-axes Squid (RF)-magnetometer between the different steps. The demagnetizations and measurements are done automatically for each specimen.

Separation of remanent components was done by using least square method of the Tubefind program (Leino, 1991). Fitting of lines (Zijderveld plots, Zijderveld, 1967), with the minimum of three demagnetization points, was done automatically with the maximum angular deviation of the line being 6°. In addition, the specimens were treated manually, when components with angular deviations as high as 10° were also considered.

4 RESULTS

In the following, the petrophysical and paleomagnetic results are shown for each sample (Table 1). More detailed descriptions of the rock types can be found e.g. in Mänttäri et al. (2005, 2006). In Table 1 the sample numbers in parentheses refer to numbers used in isotopic studies and Posiva's numbering. Paleomagnetic sample names were modified from those numbers. Demagnetization behaviours of one specimen from each sample are shown in Appendicies 1-10.

In addition to numerical values, Table 1 gives the evaluation of the ability of the specimens to preserve geologically meaningful remanent magnetizations. In that evaluation, two criteria are used:

1) Hardness of remanence which is related to the ability of the rock to keep high remanence **intensities** in increasing AF fields. The specimen's magnetization is defined as hard, if the intensity at 20 mT demagnetization step is over 60% of the original NRM intensity, semihard, if the magnetization is 30-60% of NRM, and unstable if the intensity is below 30% of NRM and/or the intensity is jumping from high to low values during demagnetizations.

2) Stability of remanence which defines the steadiness of remanence **direction** during demagnetization. The remanence direction is defined as stable, if the remanence vectors are close to each other (one component case) or move along a great circle to another steady direction (two or more components) in different demagnetization steps. In Zijderveld plots, these directions are shown as successive points defining a straight line. A semistable specimen has quite coherent directions, but the scatter of directions between demagnetization steps is notable. An unstable specimen does not carry any remanence direction, but the directions between demagnetization steps are highly scattered.

4.1 Diabases

Sample OL37 (A1337)

Both specimens from this diabase show hard and stable behaviour (Appendix 1) which is ideal for paleomagnetic studies. Remanence intensities and Q-values are comparatively high. The intensity decreases to low values in 50-60 mT after which it starts to increase again. Simultaneously, the remanence direction is moving from one direction to another. These results, combined with vector diagrams (Zijderveld plot) that show linear points with sharp angels between components, imply that there are two stable components with significantly deviating remanence directions. In addition, in both specimens a small component, probably of recent origin without geological meaning, is found in low coercivities.

Table 1. *Petrophysical and paleomagnetic properties of the Olkiluoto samples.*

Sample	Coordinates x, y	Rock type	Dens. kg/m3	K x 10^{-6}	J (mA/m)	Q	NRM properties	Comp.
OL37-1A (A1337)	6791879, 1523590	Diabase	3041	14949	741.08	1.25	Hard, stable	3
OL37-2A		Diabase	2958	13414	614.53	1.15	Hard, stable	3
OL38-1A (A1337B)	6791879, 1523590	Diabase	2846	65	1.18	0.46	Semihard, semistable	2
OL38-2A		Diabase	2843	93	1.84	0.50	Hard, semistable	2
OL18-1A (A1818)	6792822, 1523252	Pegmatite	2596	8	0.22	0.69	Hard, semistable	1
OL18-2A		Pegmatite	2585	11	0.45	1.03	Hard, semistable	1
OL83-1A (A1883)	6792816, 1525513	Pegmatite	2606	67	0.64	0.24	Hard, semistable	3
OL83-2A		Pegmatite	2604	100	0.84	0.21	Semihard, semistable	2
OL79-1A (A1879)	6791784, 1527471	TGG-gneiss	2955	1028	187.31	4.58	Unstable	-
OL79-2A		TGG-gneiss	2877	987	186.25	4.74	Unstable	-
OL80-1A (A1880)	6792913, 1525867	TGG-gneiss	2780	356	18.46	1.30	Unstable	-
OL80-2A		TGG-gneiss	2781	404	126.37	7.86	Semihard, semistable	2
OL82-1A (A1882)	6792000, 1525925	Kfsp-porphyry	2698	182	1.44	0.20	Unstable	-
OL82-2A		Kfsp-porphyry	2707	209	4.17	0.50	Unstable	-
OL84-1A (A1884)	6792155, 1525790	Kfsp-porphyry	2680	174	0.99	0.14	Unstable	-
OL84-2A		Kfsp-porphyry	2636	89	0.45	0.13	Unstable	-
OL20-6A (ONK-PVA3, 20.60)		Sulphidized rock	2705	220	0.46	0.05	Unstable	-
OL20-6B	6791949, 1525991	Sulphidized rock	2634	37	0.90	0.61	Unstable	-
OL21-2A (ONK-PVA3, 21.25)		Sulphidized rock	2713	299	3.69	0.31	Unstable	-
OL21-2B	6791949, 1525991	Sulphidized rock	2634	80	2.26	0.71	Unstable	-

Note: Sample names in parenthesis refer to isotopically dated samples (e.g. A1337) or tunnel samples (e.g. ONK-PVA3, 20.60). Coordinates are given for known locations. Dens. = density, K = magnetic susceptibility, J = NRM intensity, Q = Koenigsberger ratio (Q-value). For NRM properties, see text. Comp. = number of components isolated in Zijderveld plots.

Sample OL38 (A1337B)

Compared to the previous diabase sample, this sample shows more scattered remanence directions although the remanence intensity is quite hard, especially in specimen OL38-2A. Specimen OL38-1A (Appendix 2) exhibits more scattered decay of intensity. In both specimens there are two components, but the high coercivity component is scattered and no stable direction is obtained. Based on low density, susceptibility and remanence intensity values, this diabase sample is probably hydrothermally altered. However, the relatively hard coercivities and semistable behaviour of remanence directions make also this diabase dyke a potential target for paleomagnetic studies.

4.2 Pegmatites

Sample OL18 (A1818)

The remanence intensity and susceptibility values are very low, but the Q-values are comparatively high. The remanence direction in both samples is also quite stable (Appendix 3). AF demagnetization could not demagnetize the hard remanent magnetization, which most probably indicates that hematite is the remanence carrier. Vector plots do not show straight lines between the demagnetization steps, despite in low fields. The sample is unoriented and therefore nothing can be said about the meaning of the remanence direction. However, oriented samples could bring some new knowledge on the real remanence direction and on the age of the pegmatite, because the direction stays quite stable during demagnetization. On the other hand, if the remanence is carried by hematite, it may be of rather late origin formed in weathering.

Sample OL83 (A1883)

Both specimens are comparatively hard and semistable (Appendix 4), even though the Q-values are low and significantly lower than in the previous sample. Both specimens display three or two remanence components with clearly deviating directions. Linear segments can be separated in vector plots, although the points are partly scattered. The clearly differing remanence components, comparative hardness and stability of directions make this sample a potential target for paleomagnetic studies.

4.3 TGG-gneisses

Sample OL79 (A1879)

Both specimens of this sample show high Q-values and remanence intensities (Table 1). However, the remanence directions during demagnetization are scattered and the intensities are jumping between demagnetization steps (Appendix 5). This behaviour makes the sample unsuitable for paleomagnetic studies. The reason for high Q-values, which would rather point to a remanence dominated magnetization and, thus, paleomagnetically good sample, is not clear. It may be due to a strong viscous remanent magnetization which has no geological meaning.

Sample OL80 (A1880)

Both specimens show comparatively high remanence intensity and Q-values, especially specimen OL80-2A (Appendix 6) which has the highest Q-value of all studied samples. In this specimen the remanence is stable up to field of 20 mT. However, in higher AF fields both specimens are unstable. The high remanence intensity and Q-values and directional stability, even though in low fields, make this kind of sample a potential target for paleomagnetic studies, although also unstable results are expected.

4.4 Kfsp-porphyries

Sample OL82 (A1882)

Both specimens have low Q-values, but still measurable remanence intensities during the demagnetization procedure. Remanence directions and intensities are unstable (Appendix 7) which make this sample unsuitable for paleomagnetic studies.

Sample OL84 (A1884)

This sample has even lower magnetization and Q-values compared to the previous sample. The remanence directions and intensities are unstable (Appendix 8) and therefore, it is implied that further studies would be useless.

4.5 Sulphidized rocks

Sample OL20

The sample has low magnetization and Q-values and very scattered remanence directions during demagnetization (Appendix 9). Therefore, the sample is unsuitable for paleomagnetic studies.

Sample OL25

This sample is quite similar to the previous sample, although the magnetization and Q-values are slightly higher. Specimen OL25-1B (Appendix 10) shows some stability of remanence in low fields (up to ca. 10 mT), but in higher fields both specimens are unstable. Therefore, this kind of sample is not suitable for paleomagnetic studies.

5 SUGGESTIONS FOR FURTHER WORK

Based on paleomagnetic behaviour of the studied test samples, following suggestions are presented for future paleomagnetic studies in the Olkiluoto area.

Of all studied samples only the firstly presented diabase dyke (sample OL37-1A) showed hard and stable remanence directions and intensities. The sample carries at least two distinct remanence components which makes it an interesting target for paleomagnetic studies. Furthermore, because the isotopic dating (Mänttäri et al., 2005, 2006) could not absolutely define the age of the rock, paleomagnetic studies can give some additional information. It is possible that paleomagnetic data can clearly demonstrate whether the primary magnetization was acquired during Svecofennian (ca. 1.9-1.8 Ga), Subjotnian (ca. 1.6 Ga) or Postjotnian (ca. 1.25 Ga) time. Also the other diabase dyke (sample OL38) can be used for paleomagnetic studies although the expected results are not so certain compared to the previous one. In order to make a conclusive paleomagnetic study on the dykes where the local secular variation of the magnetic field is adequately averaged out, one should collect samples from as many dykes as possible. A minimum of five samples would be needed from each dyke. Naturally, if there are not many dykes, one has to study as many as there are.

The pegmatites, which are typically quite unstable in paleomagnetic studies, showed such stability that they could be worth of further studies. In addition, two components in the other sample could give indications of superimposed geological processes. However, as the remanence may reside in hematite, which is a typical weathering product, the results are not so certain. It is suggested that new samples could be taken from the now studied pegmatites, and if there are more of them, at least limited sampling could be carried out of them.

Both studied TGG gneisses have rather high remanence intensity values and significantly high Q-values which could point to their usefulness in paleomagnetic studies. Furthermore, the visually inspected hand samples seem to be quite even and small grained which could also support their use in paleomagnetic studies. However, demagnetizations reveal that the remanence is unstable. In order to be certain of the rather contradicting results, it is suggested that some new oriented samples would be taken in the field.

The potassium feldspar porphyries are paleomagnetically unstable, and therefore, no further studies are suggested.

The sulphidized samples that were taken from the vicinity of a shear zone in a tunnel do not carry a stable remanent magnetization. Therefore, at least these samples are unsuitable for further paleomagnetic work. However, as some of the shear zones in the capital area (Mertanen, 2007) have shown to carry stable remanent magnetizations, it could be considered if there are some other shear zones in the Olkiluoto area that might give better results.

6 CONCLUSIONS

In general, most of the studied test samples are rather weakly magnetized and do not carry stable remanent magnetizations, except the one studied test sample from a diabase dyke. However, some of the samples are worth of further studies.

It is suggested that further paleomagnetic studies in the Olkiluoto area could be carried out on diabase dykes and on pegmatite dykes. The test samples from these formations showed most stable results with multicomponent magnetizations. The TGG-gneisses are paleomagnetically unstable, but because their remanent magnetizations are strong compared to the induced magnetization, it is suggested that at least some new test samples could be taken in the field. The studied potassium feldspar porphyries and the sulphidized rocks from a shear zone did not carry stable remanent magnetizations and they are therefore not worth of further paleomagnetic studies. However, it is suggested that some new test samples could be taken from some other shear zones in the field for testing the stability of remanence.

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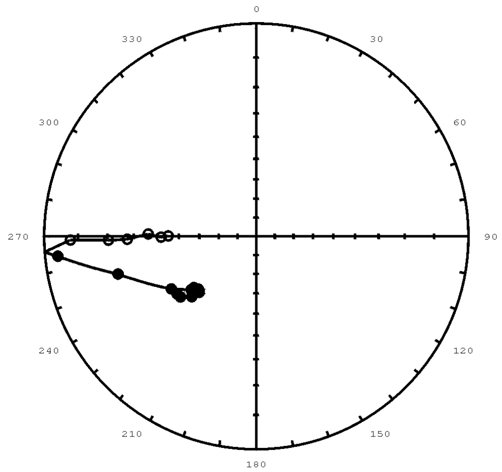
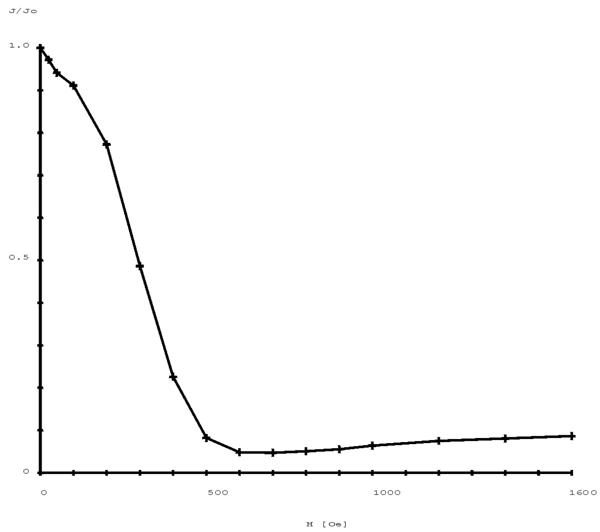
APPENDICES

1132SM07-OL37-1A (A1737) Diabase

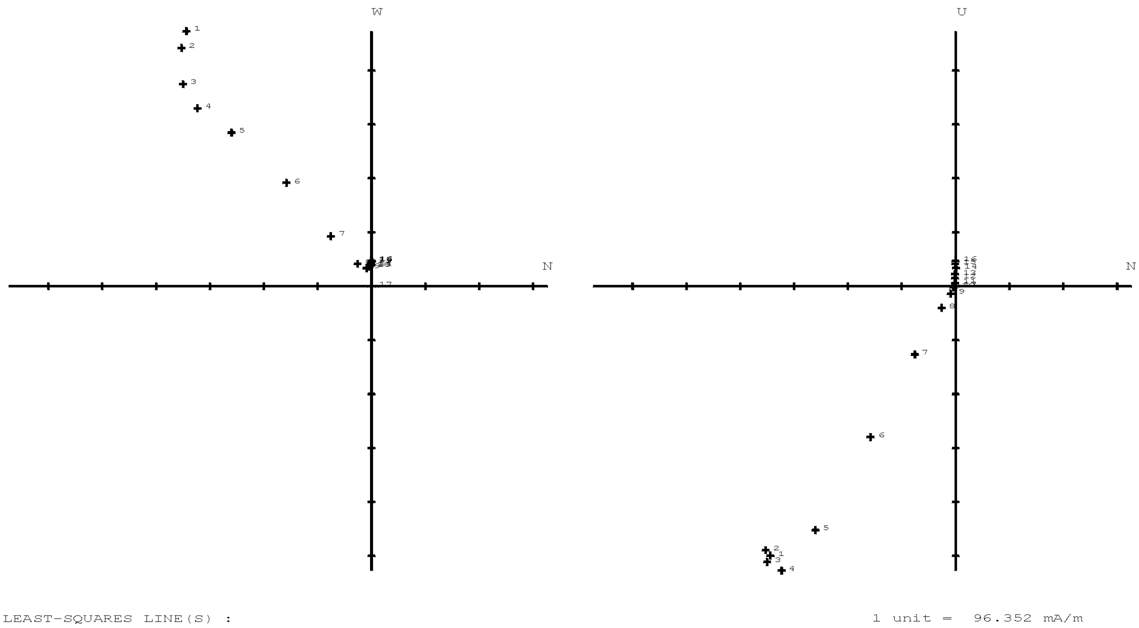
[A] Stereoplot



[B] Intensity

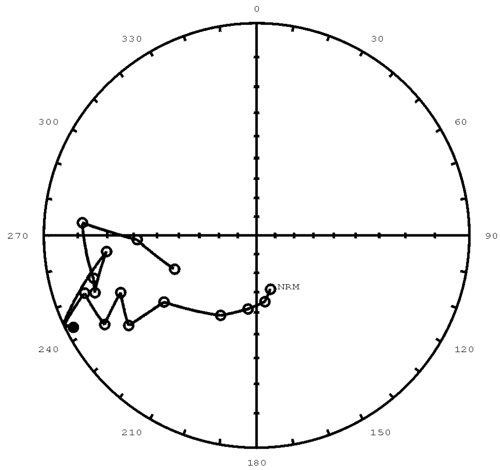


[C] Zijderveld plot



1132SM07-OL38-1A (A1737B) Diabase

[A] Stereoplot



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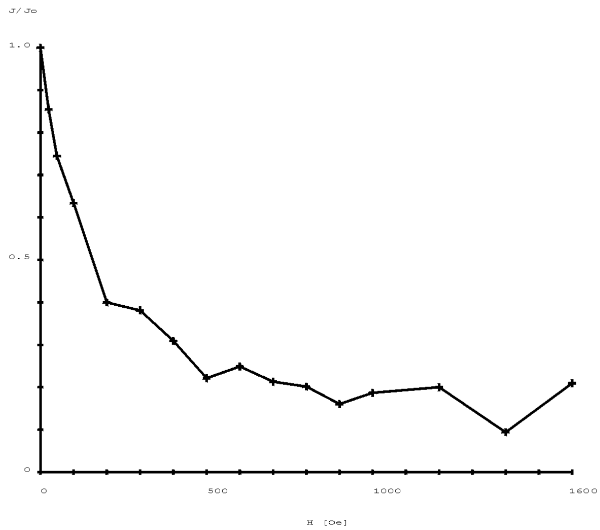

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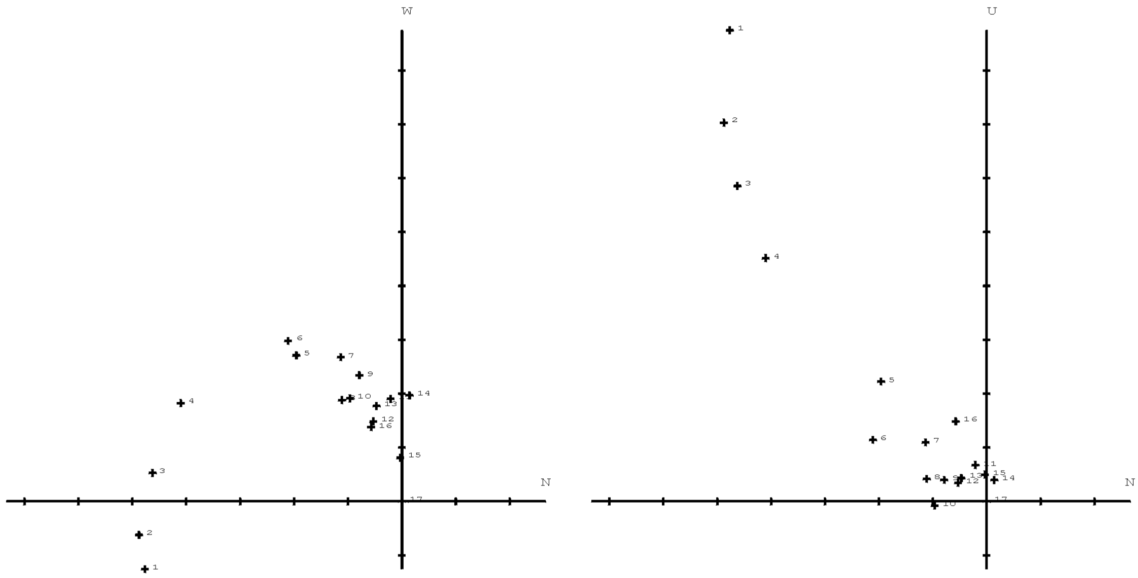
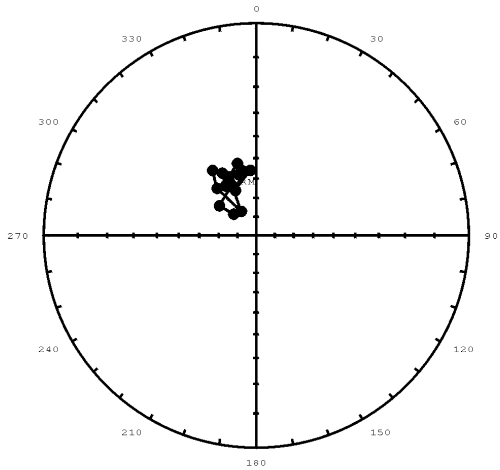


LEAST-SQUARES LINE(S) :

1 unit = .11781 mA/m

1132SM07-OL18-1A (A1818) Pegmatite

[A] Stereoplot



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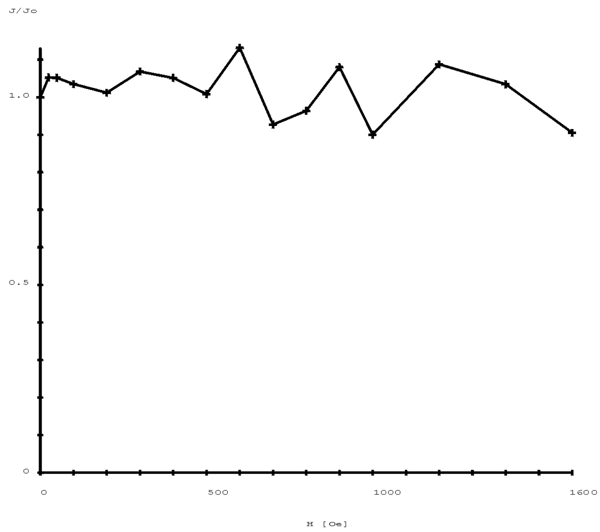
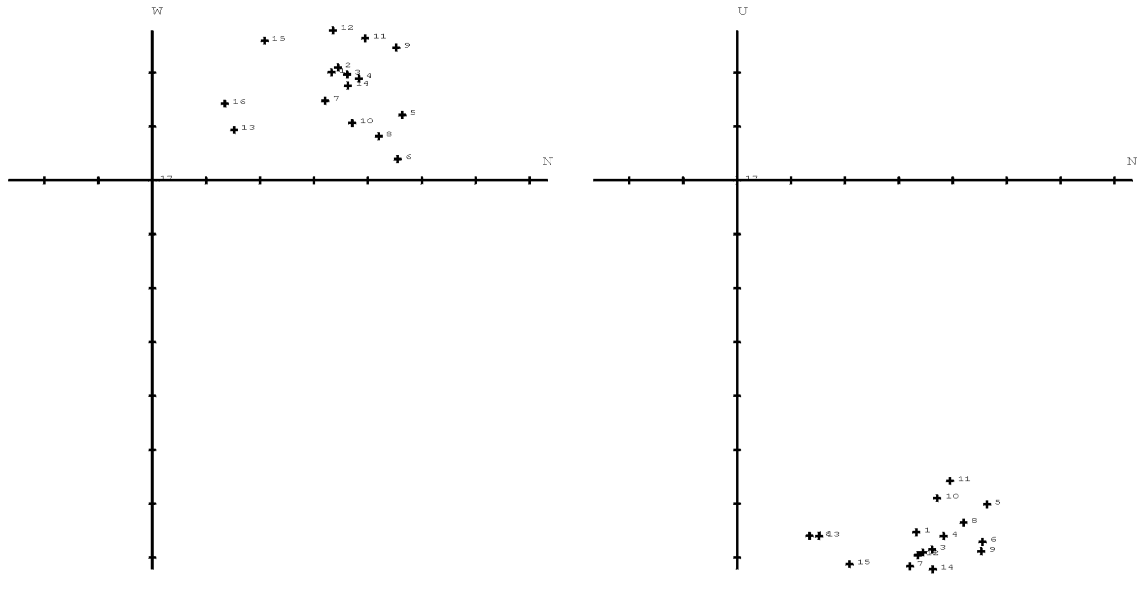


[C] Zijderveld plot



LEAST-SQUARES LINE(S) :

1 unit = 2.8999 mA/m

1132SM07-OL83-1A (A1883) Pegmatite

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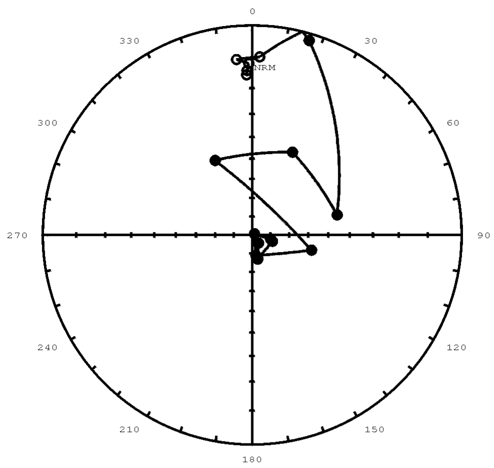

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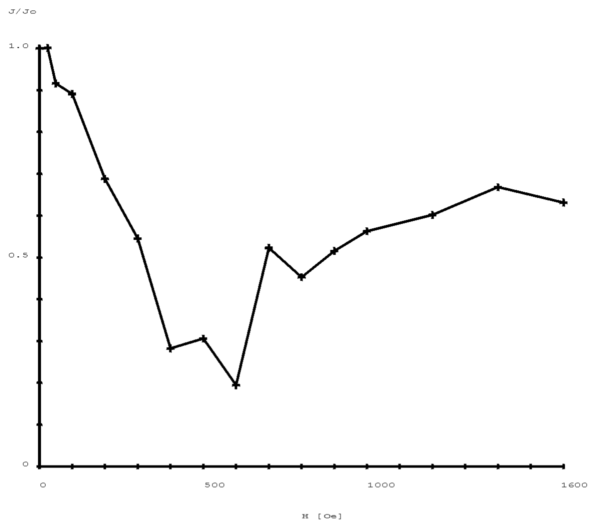

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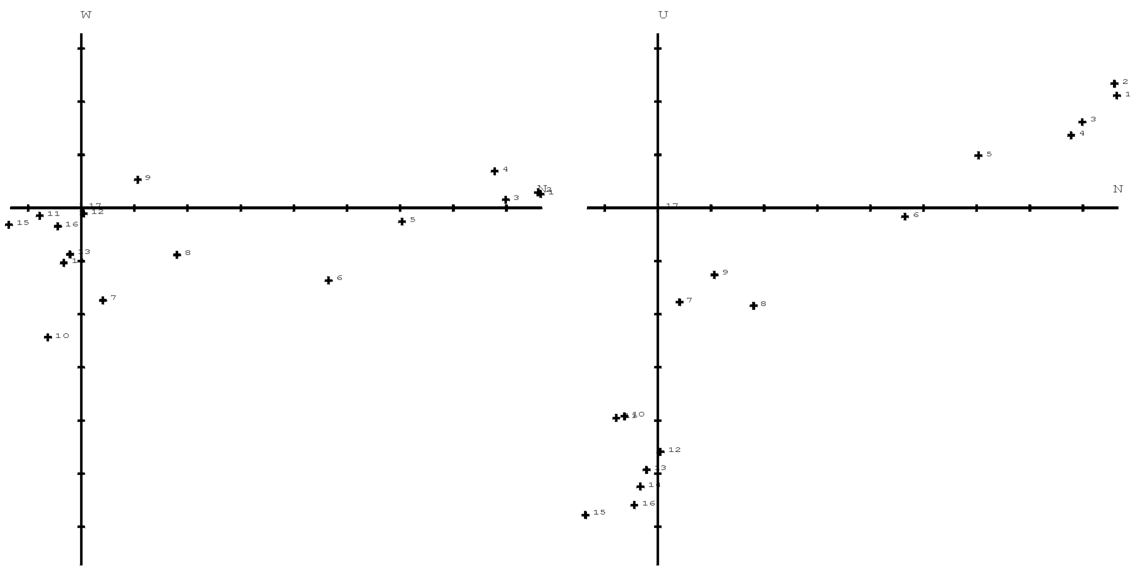

LEAST-SQUARES LINE(S) :

1 unit = 7.1524 mA/m

1132SM07-OL79-1A (A1879) TGG-gneiss

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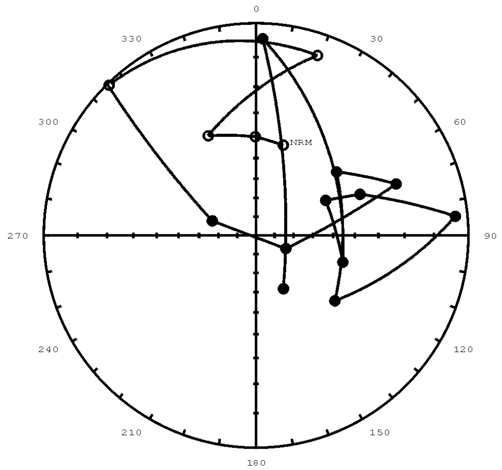

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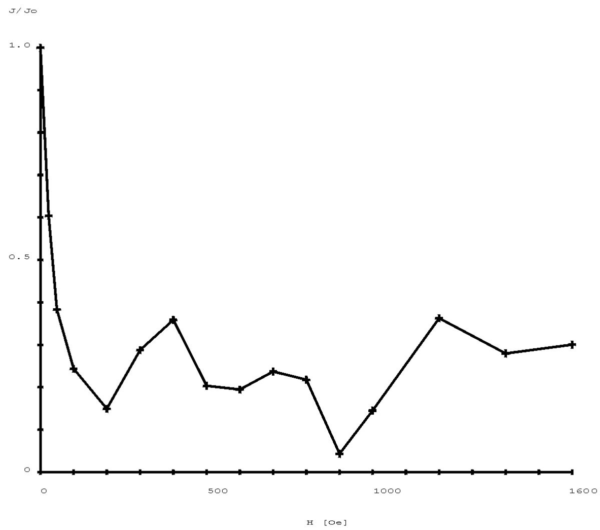
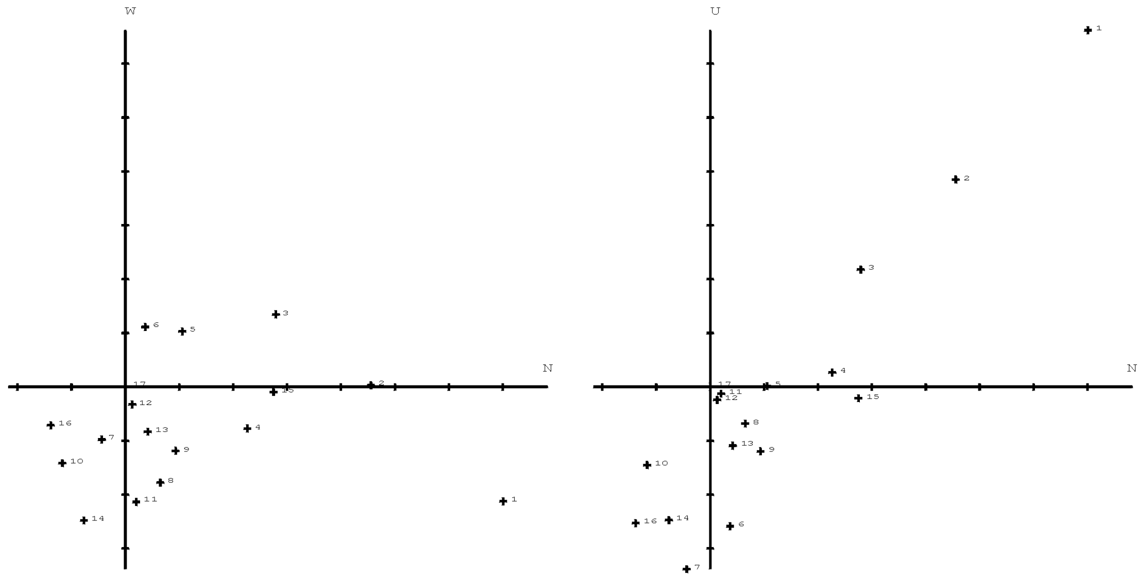


[C] Zijderveld plot



LEAST-SQUARES LINE(S) :

1 unit = 18.972 mA/m

1132SM07-OL80-2A (A1880) TGG-gneiss

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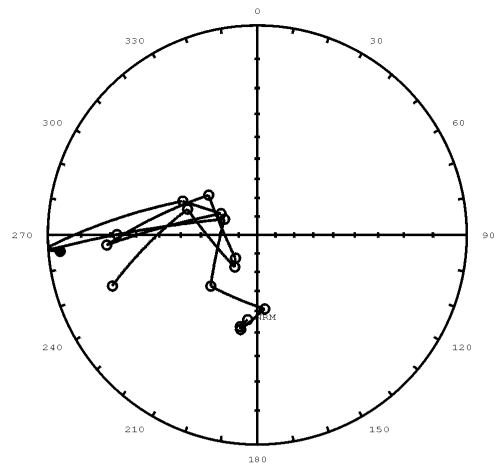

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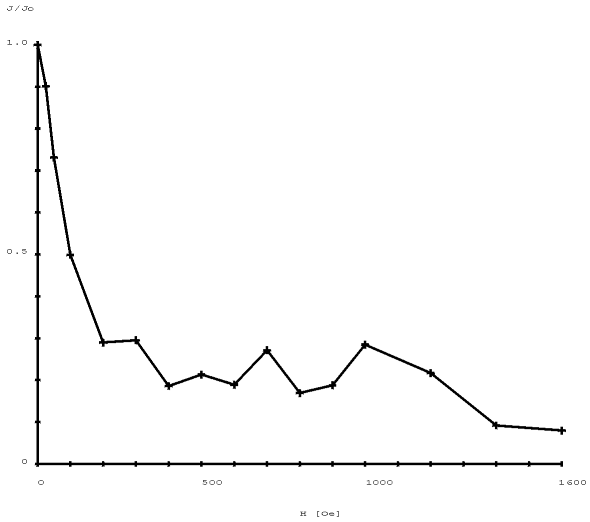
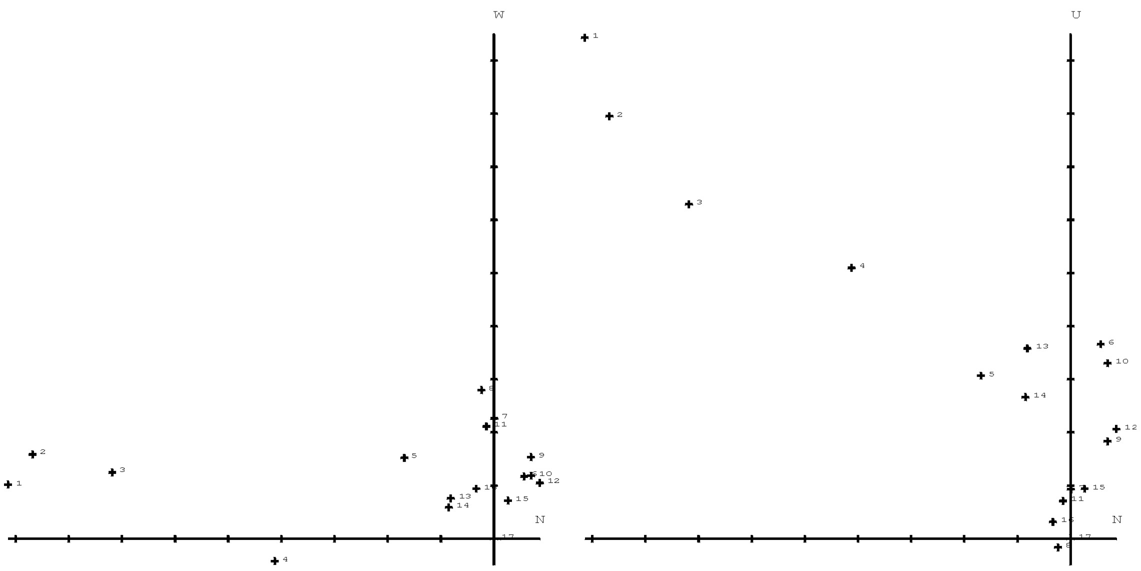


[C] Zijderveld plot

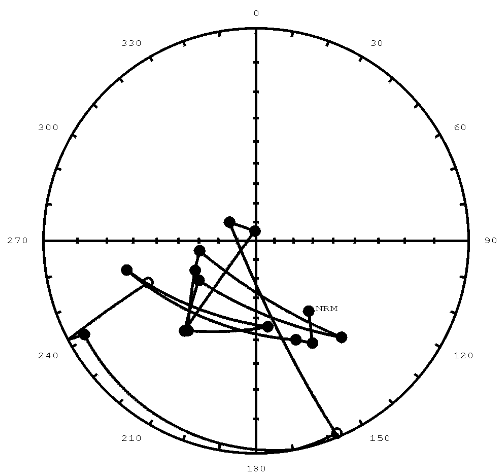


LEAST-SQUARES LINE(S) :

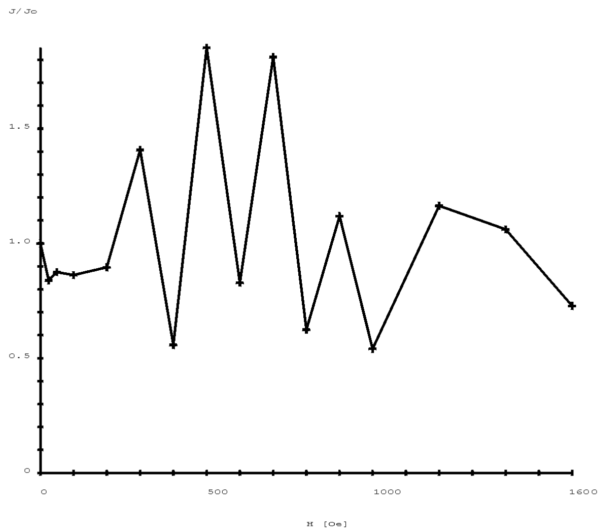
1 unit = 9.5957 mA/m

1132SM07-OL82-1A (A1882) Kfsp-porphyry

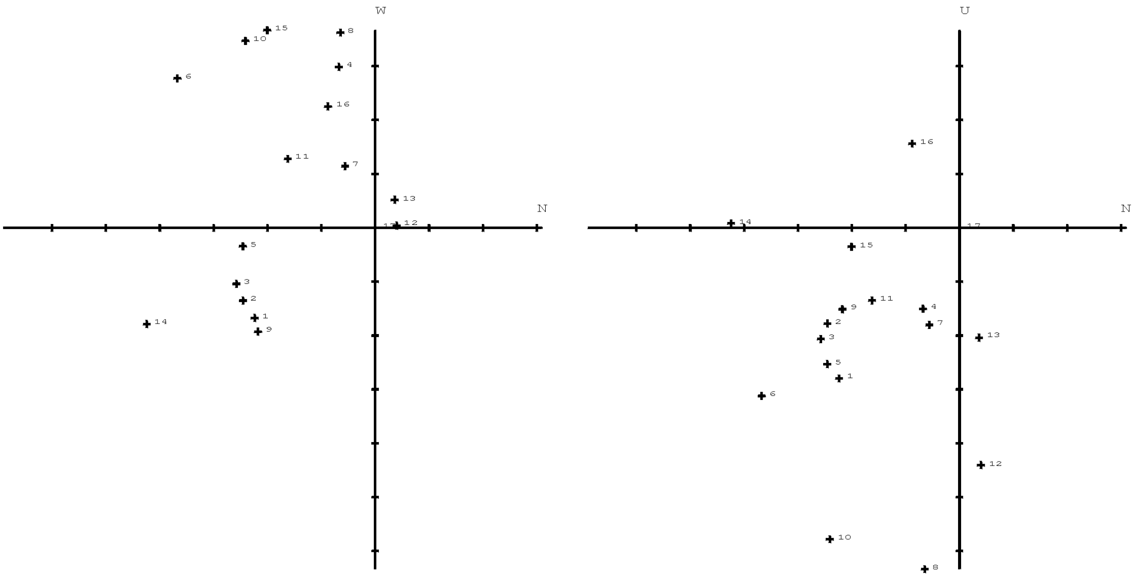
[A] Stereoplot



[B] Intensity



[C] Zijderveld plot

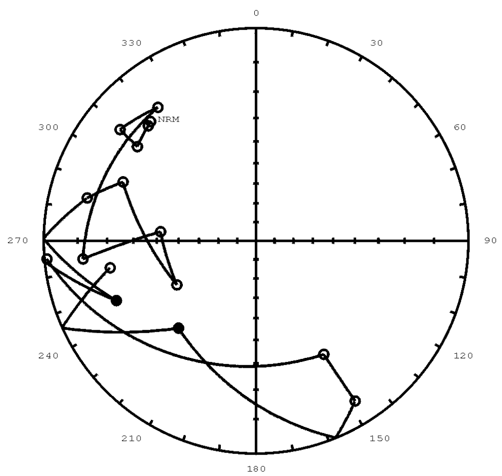


LEAST-SQUARES LINE(S) :

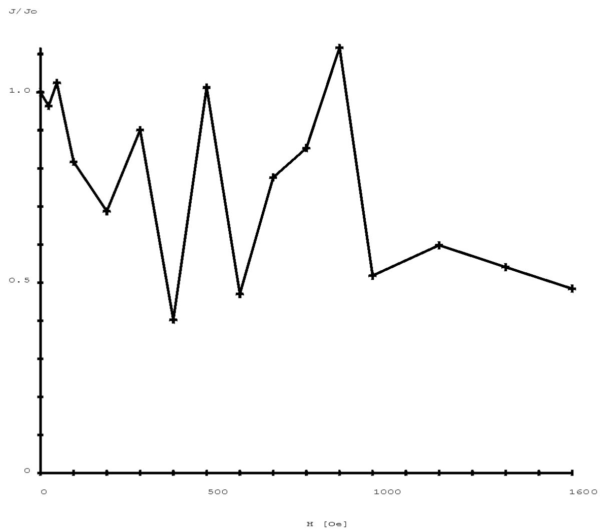
1 unit = .36512 mA/m

1132SM07-OL84-1A (A1884) Kfsp-porphyry

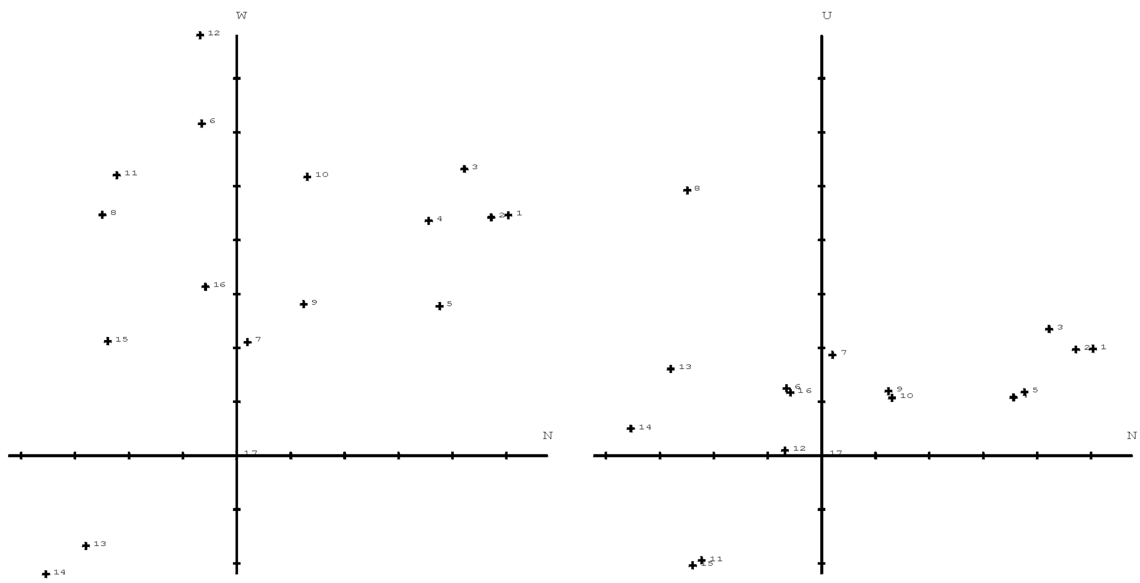
[A] Stereoplot



[B] Intensity



[C] Zijderveld plot

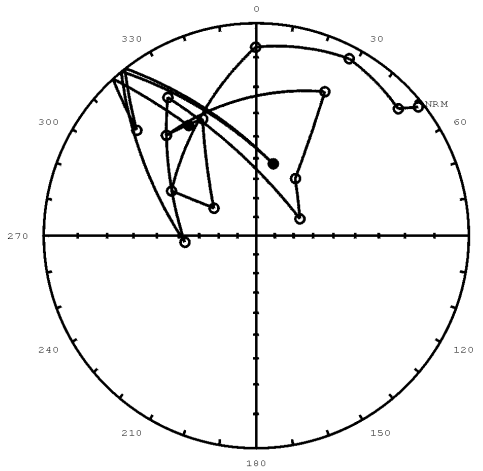


LEAST-SQUARES LINE(S) :

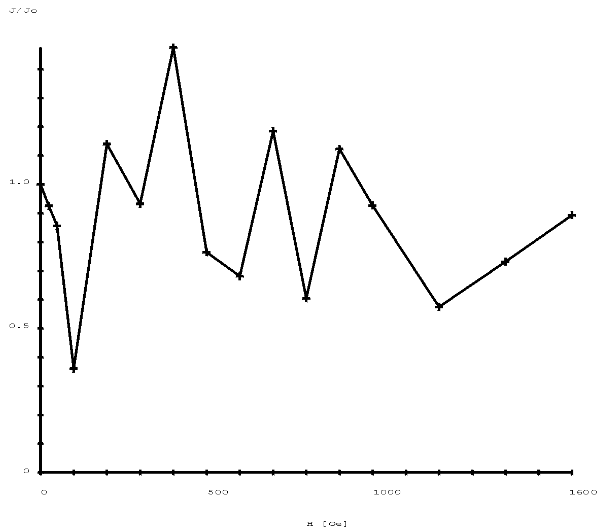
1 unit = .14156 mA/m

1132SM07-OL20-6B Sulphidized rock

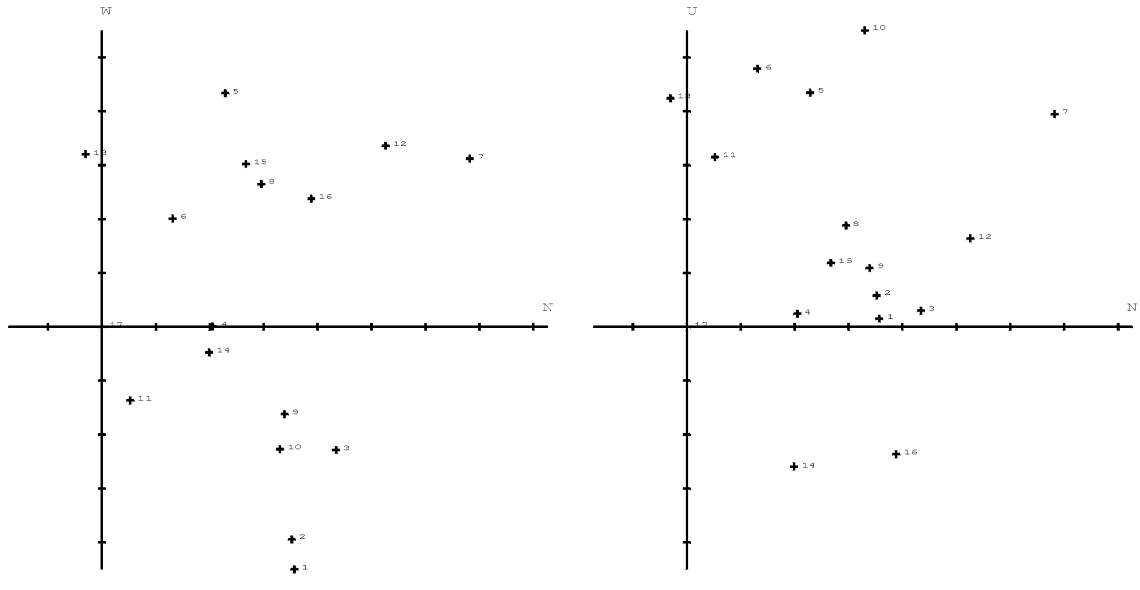
[A] Stereoplot



[B] Intensity



[C] Zijderveld plot

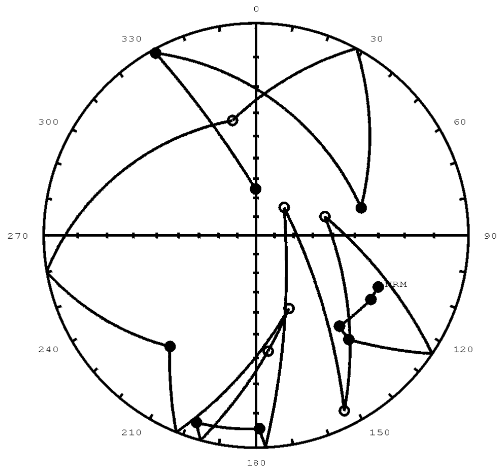


LEAST-SQUARES LINE(S) :

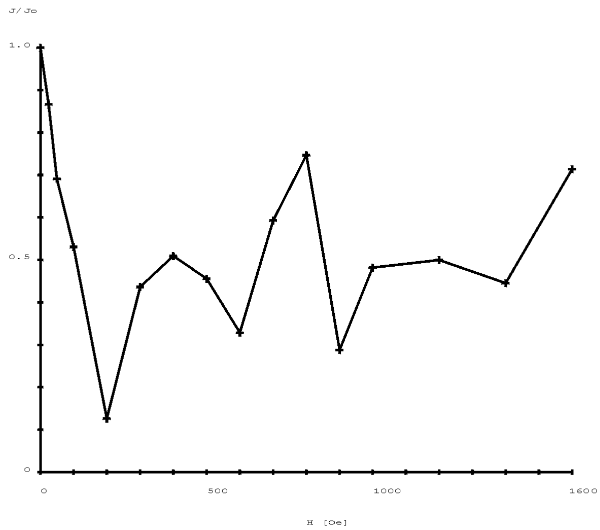
1 unit = .15752 mA/m

1132SM07-OL25-1B Sulphidized rock

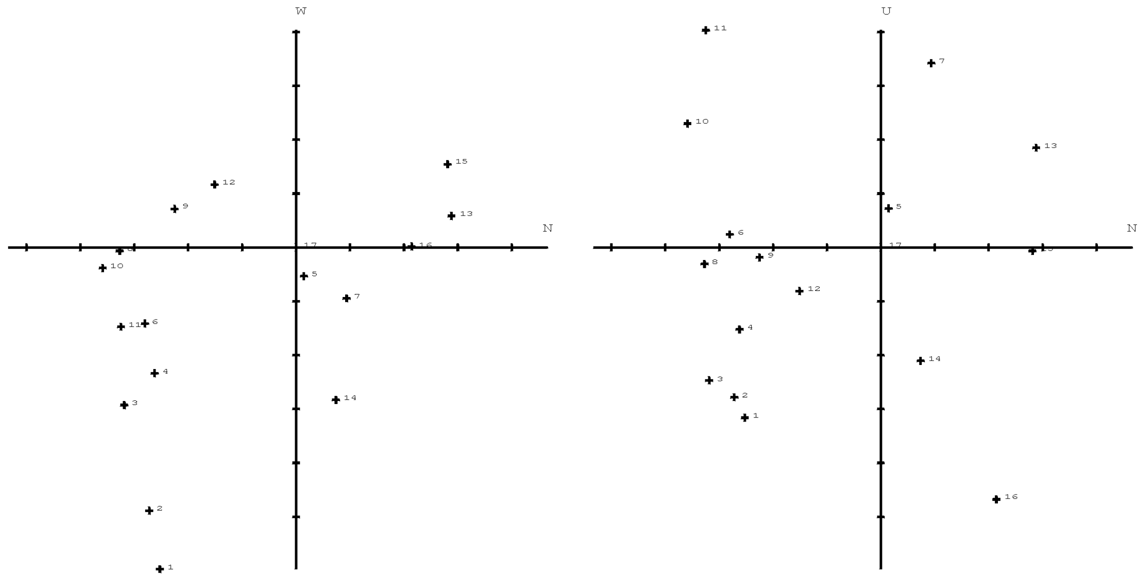
[A] Stereoplot



[B] Intensity



[C] Zijderveld plot



LEAST-SQUARES LINE(S) :

1 unit = .31344 mA/m