Anisotropy of Magnetic Remanence
A Brief Practical Guide
Application note

Introduction

Anisotropy of magnetic remanence (AMR) is a directional variability of ability to acquire a remanent magnetization (e.g. anhysteretic, isothermal). In the contrary to the anisotropy of magnetic susceptibility (AMS) its geological interpretation highlights the preferred orientation not of all rock constituent minerals but solely of the ferromagnetic (s.l.) fraction. The measurement procedure consists of the directional acquisition of magnetic remanence subsequently performed following a scheme of directions. AMR tensor is then calculated from a set of components of directional remanent magnetizations.

Anhysteretic remanent magnetization (ARM) is acquired when a specimen is subjected to an AC field of gradually decreasing amplitude simultaneously with a steady DC field (also referred to as a bias field). The combined action of AC and DC fields is much more efficient in producing a remanence than the application of a DC field alone. Simply said, AC field amplitude controls which particles, based on their coercivity, are involved in the magnetization process while DC field intensity controls how much the particles in question are magnetized. Typically, the DC field is maintained during the entire course of AC field decrease. In a special case, a DC field is applied only for a limited time within an AC coercivity window (ACmax to ACmin), to acquire a partial ARM (pARM).

Isothermal remanent magnetization (IRM) is usually understood as a remanence resulting from the application of a DC field to an assemblage of magnetic particles (without any aid of AC field).

Selection of AC and DC fields and magnetizing mode

Prior to any directional measurements, some sort of the ARM (IRM) acquisition (and AF demagnetization) experiment should be performed on representative specimens to get some idea about:

1. Coercivity distribution of rock constituent ferromagnetic (s.l.) minerals
2. Ability to get magnetized and demagnetized
3. Strength and direction of residual magnetization (not possible to demagnetize)

An example of such experiment is shown on Figure 1. Based on the experiment one can decide which combination of AC and DC fields and which set of magnetizing directions (Figure 2) will be used. AC field is set according to the coercivity of magnetic fraction of interest, DC field controls how much the specimen is magnetized. Considering the choice of magnetizing scheme, the generally rule is that the more magnetizing directions the more precise the tensor calculation is. Usually, we try to reach the optimum balance between precision and speed of the measurement. Whole procedure strongly depends on the residual magnetization so the first obvious step would be to demagnetize the specimen using the highest

AC field possible. If the strength of the residual magnetization is in the same order of magnitude as that of that magnetized states, one is strongly advised to use magnetizing schemes employing pairs of antipodal magnetizing directions (A- or C-modes) where the constant residue is fully compensated (Figure 3). By selecting higher DC field, one may reach up to two orders of magnitude difference between the magnetized and demagnetized states. If this is the case then B- or D-modes are sufficient. When the residual magnetization is comparable or higher than that of the magnetized states, AMR calculations may get very imprecise even when the antipodal magnetizing directions are used.

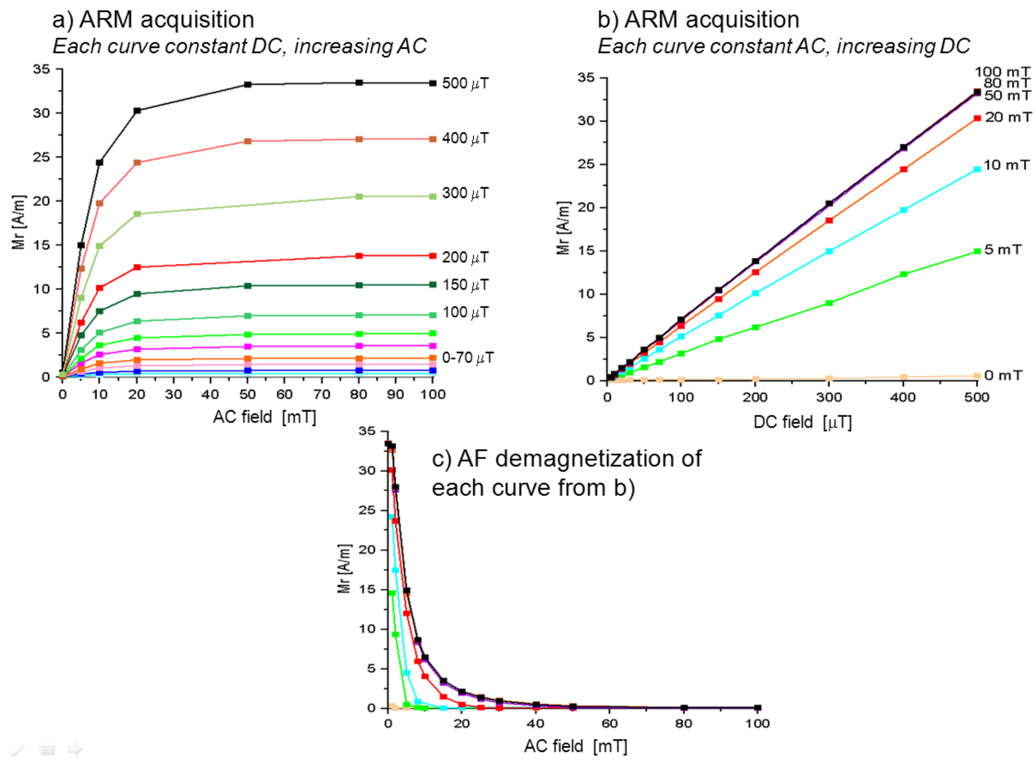
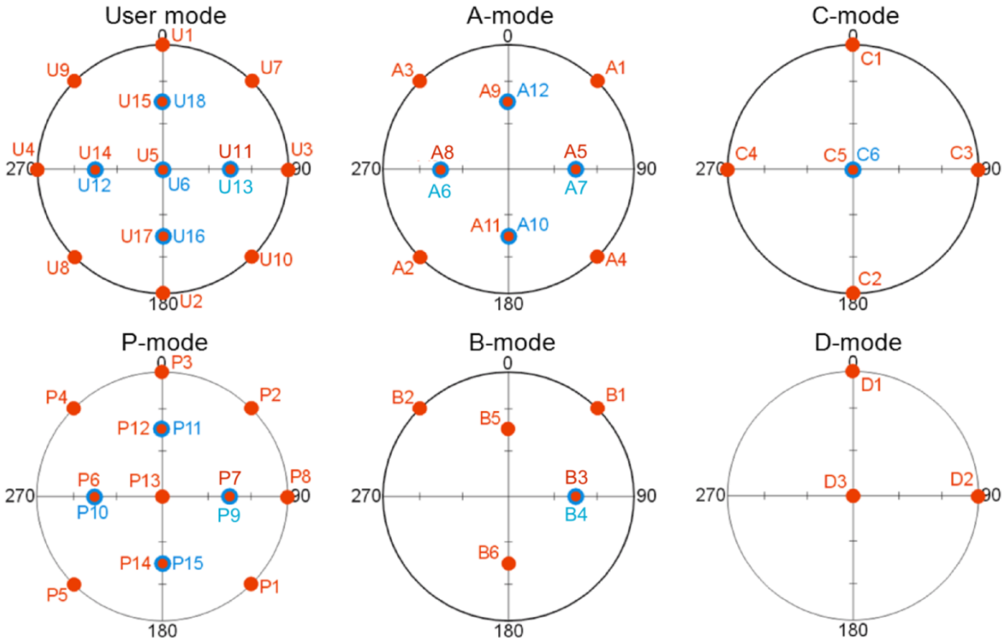


Figure 1: An example of the ARM acquisition experiment for a representative specimen of volcanic rock. a) or b) show that the coercivity distribution in the specimen is below 50 mT, i.e. using AC > 50 mT will not magnetize the specimen any further. Fig. b) shows that the specimen is linearly magnetized with the increasing DC field up to 500 μT. Fig. c) demonstrates that all previously acquired magnetization can be erased using AC field <= 50 mT. For that particular example the optimal combination of the fields would be AC = 50 mT and DC = 500 μT; AF demag. field should be slightly higher than AC mag. field, let's say 60 mT to make sure that all artificial magnetization has been erased.



User mode	Principal axes	A-mode	B-mode	C-mode	D-mode	P-mode	Direction
U1	+x-axis			C1	D1	P3	0/0
U2	−x-axis			C2			180/0
U3	+y-axis			C3	D2	P8	90/0
U4	−y-axis			C4			270/0
U5	+z-axis			C5	D3	P13	0/90
U6	−z-axis			C6			0/−90
U7		A1	B1			P2	45/0
U8		A2				P5	225/0
U9		A3	B2			P4	315/0
U10		A4				P1	135/0
U11		A5	B3			P7	90/45
U12		A6				P10	270/−45
U13		A7	B4			P9	90/−45
U14		A8				P6	270/45
U15		A9	B5			P12	0/45
U16		A10				P15	180/−45
U17		A11	B6			P14	180/45
U18		A12				P11	0/−45

Figure 2: The spherical projections of various sets of magnetizing directions, red dots – lower hemisphere, blue dots – upper hemisphere. Note that the User mode, A-mode, and C-mode consist of pairs of antipodal directions.

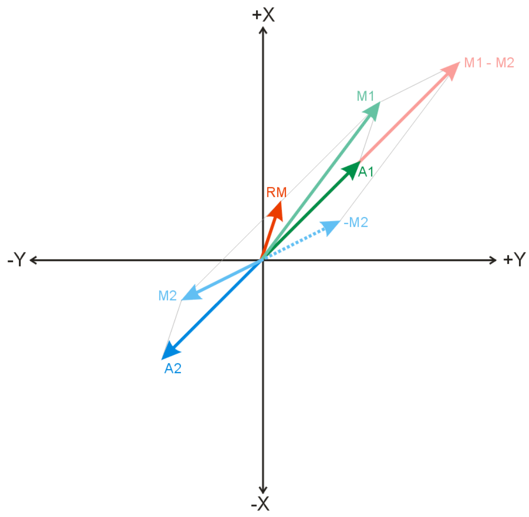
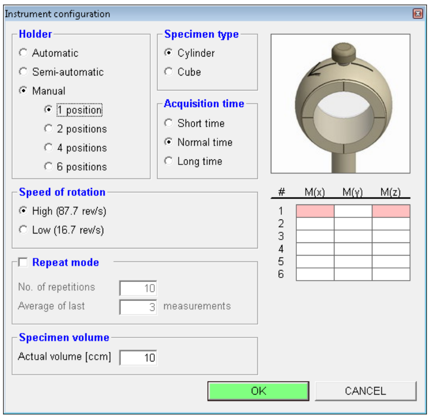


Figure 3: A sketch showing the principle of geometrical compensation of the residual magnetization effect applied in A- and C-modes. For the sake of simplicity the 3D situation is projected to the XY plane. When we magnetize an ideally isotropic specimen parallel to the A1 direction it acquires a remanent magnetization (A1 vector) but due to the residual magnetization (RM) we measure M1 vector instead. Magnetizing the same specimen along antiparallel A2 direction the A2 vector is acquired but combined with RM we actually measure M2 vector. By subtracting M1 – M2 vectors and dividing the resulting vector by two we obtain the original vector A1 without any directional effect of RM. Following this principle for other pairs of antipodal directions we end up with six or three (A- or C-modes, respectively) remanence vectors clear of any residual magnetization. The six-direction B-mode or three-direction D-mode is then used to calculate the anisotropy tensor.

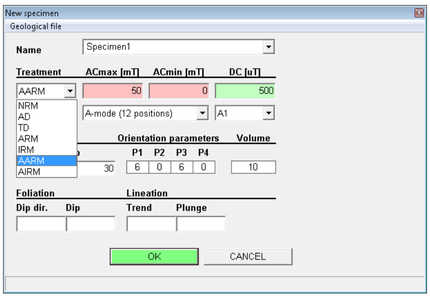
Data acquisition

1. Install **Rema6W**, version: 6.2.3., release: Feb 2, 2015
2. Start the program and initialize the JR-6 spinner magnetometer.
3. Go to the Main menu: Settings -> Instrument configuration, and make the desired settings of the magnetometer.

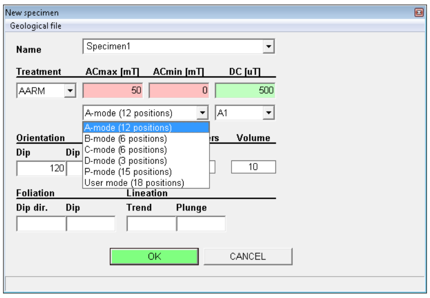


A hint: For the ARM (IRM) acquisition experiment you may save a great deal of time by magnetizing along one of the specimen axes (e.g. x-axis) and set the magnetometer to measure in 1 position only. Please note that not the full vector is measured but only its projection to the plane perpendicular to the spinning axis; component of magnetization parallel to spinning axis is not measured. Make sure that the magnetizing direction does not coincide with the specimen spinning axis. The 1 position measurement is NOT POSSIBLE to be used for actual directional measurements where a full vector is necessary! Automatic holder or 4-position manual scheme is recommended.

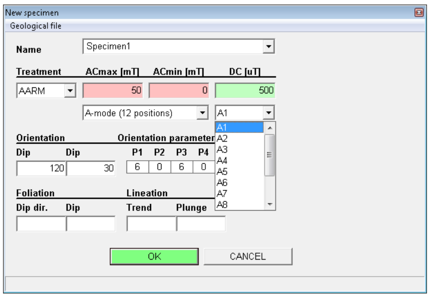
4. Open new jr6-file.
5. Switch to the Data acquisition tab.
6. Start **NEW SPECIMEN**. Please note that the specimen should be fully demagnetized prior to any artificial magnetization is imparted.
7. Fill the specimen **Name**, and respective orientation values.
8. Select desired **Treatment** (AARM or AIRM), fill respective **ACmax, ACmin, DC field** values. Please note that currently these values serve for the reference only, you will be prompted to enter them again prior to the tensor calculation.)



9. Select desired design of magnetizing directions.



10. Select the current magnetizing direction, and hit OK.



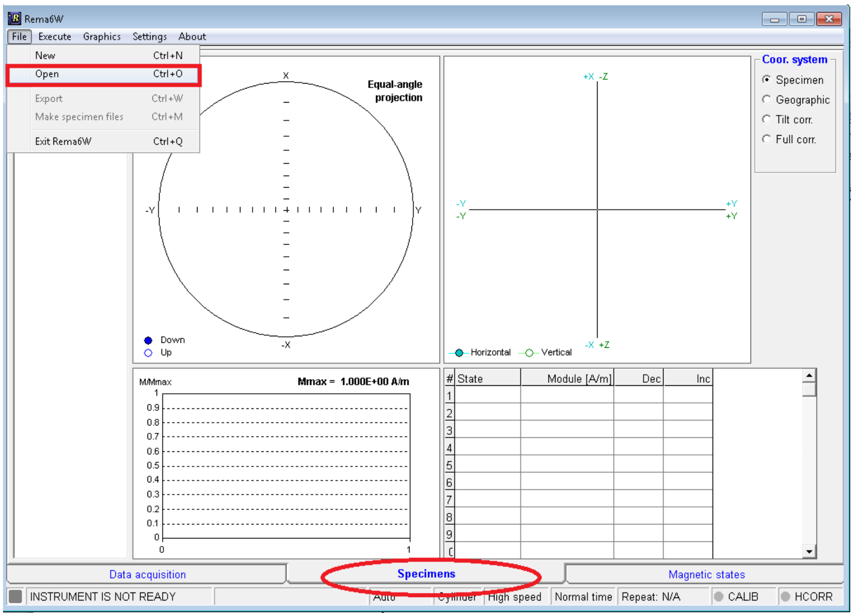
11. Magnetize the specimen, mount it to JR-6 holder and start the measurement.

12. Repeat Steps 10 and 11 until all necessary directions are measured. Before each magnetizing step, the previously imparted magnetization must be erased by AF demagnetization (the demagnetized state is not necessary to be measured).

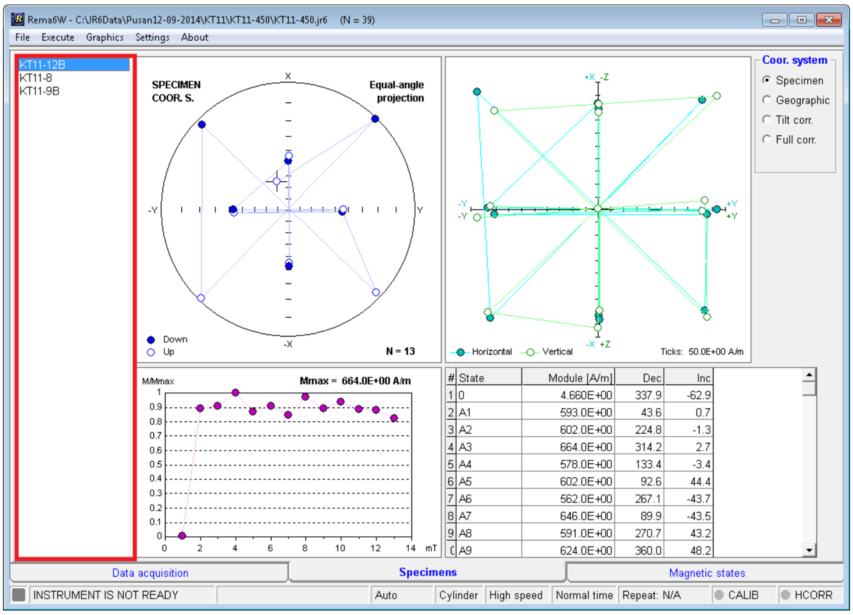
13. Alternatively, multiple specimens can be treated simultaneously by magnetizing (and measuring) each of them parallel to a certain direction and repeating Steps 10 and 11 until all necessary directions for all specimens are measured.

Data processing

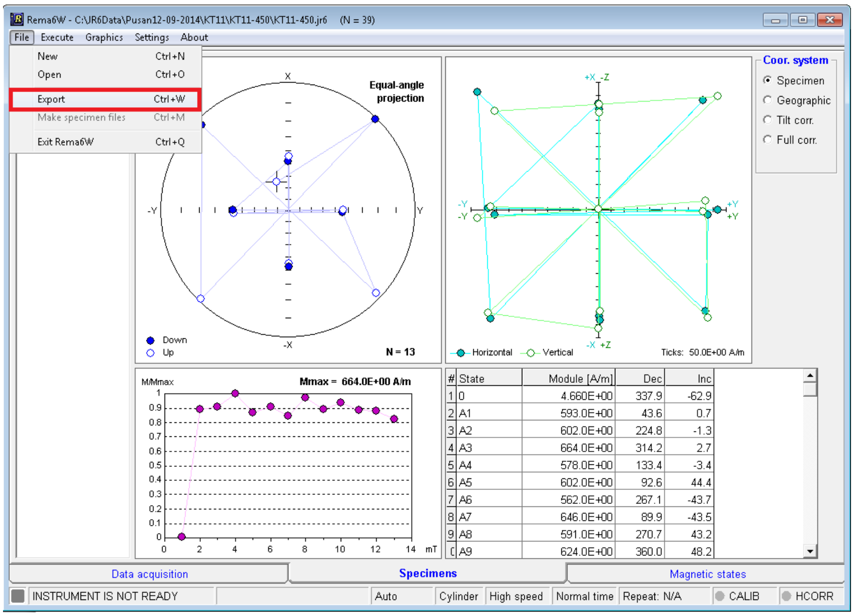
1. Switch to the *Specimen* tab.
2. When no file is open, go to the Main menu: *File -> Open*.



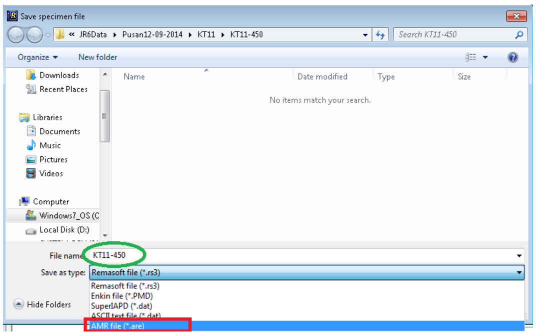
3. Click on the desired specimen name in the left-hand specimen list.



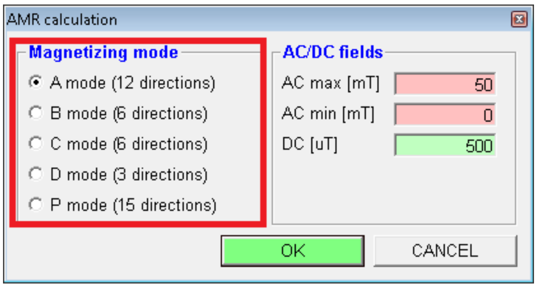
4. Go to the Main menu: *File -> Export*.



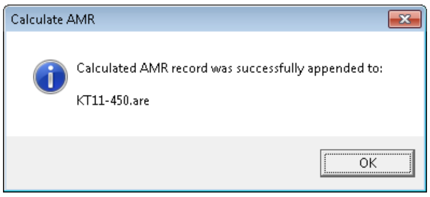
5. Select AMR file (*.are) as Save as type and assign new are-file name.



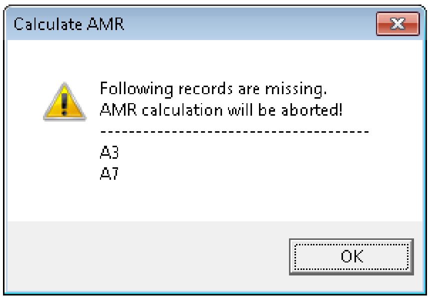
6. Select AMR mode and respective AC and DC fields.



7. If everything is OK, AMR tensor is calculated and new record is appended into *.are file.



If there are some missing directions you are warned by the following message:



8. Repeat Steps 3 – 7 until the AMR of all desired specimens is calculated.
9. Data for each specimen are appended as a new record to the following files:
   - *.are – binary file (can be visualized by Anisoft software)
   - *.prec – text file containing results of the F-test and Confidence ellipses
   - *.dat – text file with raw data used for tensor calculation (can be processed by old MS-DOS AREF software)