

## Appendix 5: Glossary of magnetic terms and Parameters

**$\alpha_{95}$  (Alpha 95).** This is a measure of angular dispersion (in degrees), commonly used in archaeomagnetism, which is derived from *Fisher Statistics*. It is the angular radius of a cone about the mean direction, in which the true population mean is found. There is 95% probability that the population mean lies within this range.

**CRM (Chemical Remanent Magnetisation).** The type of remanent magnetisation is acquired when magnetic grains capable of carrying a remanence nucleate from fluids, or are formed from other minerals (such as during weathering/pedogenesis). Such grains need to grow through a critical size (below which they are superparamagnetic), called its blocking volume.

**Declination.** The angle between north and the horizontal projection of the magnetisation vector. i.e.  $0^\circ$  == North directed;  $180^\circ$  == South directed;  $90^\circ$  == East Directed;  $270^\circ$  == West directed.

**Diamagnetic.** Pure materials and minerals which acquire an induced magnetisation in the *opposite direction* to an applied magnetic field, are diamagnetic. Such phases have a small negative magnetic susceptibility. When the magnetic field is removed, they retain NO remanent magnetisation. Common examples of diamagnetic minerals are non-Fe or Mn bearing silicates (quartz, feldspar).

**Ferrimagnetic/ Ferromagnetic.** Minerals that acquire a permanent magnetisation, which can be retained in the absence of an applied magnetic field (e.g. magnetite). There are a number of sub-groups of magnetic behaviour within this broad grouping. These minerals generally have a large magnetic susceptibility compared to paramagnetic and diamagnetic materials. Common examples are titanomagnetites, haematite (canted antiferromagnetic), Pyrrhotite or greigite (ferrimagnetic).

**Fisher Statistics:** The common statistical method of averaging 3-dimensional vectors (Butler, 1992). Three- dimensional equivalent of the 1-dimensional normal statistics.

**Frequency dependent magnetic susceptibility ( $\% \chi_{FD}$ ).** The percentage of frequency-dependant susceptibility is calculated from  $\chi_{LF}$  and  $\chi_{HF}$ , by:  $\% \chi_{FD} = 100 * ( \chi_{LF} - \chi_{HF} ) / \chi_{LF}$ . The difference between these two measurements of magnetic susceptibility is due to a smaller number of superparamagnetic particles flipping their magnetisations in response to the higher frequency AC field in the susceptibility meter.

**Geocentric Axial Dipole:** A model of the Earth's magnetic field which excludes the non-dipole magnetic field components. In this model the magnetic north and south pole are located over the spin axes of the Earth, and the relationship between latitude ( $\lambda$ ) and inclination (I) is described by  $\tan(I) = 2 \tan(\lambda)$ .

**Inclination.** The angle between horizontal and the magnetisation vector, such that a down-wards directed vector has positive inclination and an upwards-directed vector has negative inclination.

**Induced Magnetisation** (See magnetisation and magnetic susceptibility).

**Koenigsburger factor ( $Q_{NRM}$ ):** A value which ratios the magnitude of NRM magnetisation intensity to the magnetisation intensity which would be induced (i.e. caused by the magnetic susceptibility) by the Earth's magnetic field on the specimen. Values larger than 1 indicate that the remanence intensity is stronger than the induced magnetisation. Often the larger the  $Q_N$  value the more stable (better) is the magnetisation.  $Q_N$  was calculated as the ratio between the  $NRM_1$  and the induced magnetisation in a 50  $\mu T$  field. (the 50  $\mu T$  value was close enough for this purposes to the International Geomagnetic Reference Field estimate for Catholme for the year 2004, which is 48.6  $\mu T$ ; NASA, 2004).

**Magnetic Susceptibility .** When a material is exposed to a magnetic field (H) it acquires an *induced magnetisation*,  $J_i$ , such that  $J_i = \chi H$ , where  $\chi$  is the magnetic susceptibility. All materials possess a magnetic susceptibility, including *diamagnetic*, *paramagnetic* and *ferrimagnetic* materials, but because ferrimagnetic materials (e.g. magnetite) have magnetic susceptibility several orders of magnitude larger than paramagnetic materials, it is common to think of magnetic susceptibility as a measure of the 'concentration of magnetic materials'. Volume specific magnetic susceptibility has no units in SI (i.e.  $J_i$  and H have same units), but when expressed on a mass specific basis its units are  $m^3 Kg^{-1}$ . Commonly a low frequency ( $\chi_{LF}$ ) and a high frequency ( $\chi_{HF}$ ) magnetic susceptibility is measured, by the application of magnetic fields with 0.47 kHz and 4.7 kHz in the Bartington magnetic susceptibility MS2B sensor.

**Magnetisation.** The magnetisation of a material is the net magnetic moment per unit volume. There are two types of magnetisation, *induced* and *remanent magnetisation*. The *induced magnetisation* is associated with the magnetic susceptibility, and is ONLY found and measured when materials are in a magnetic field. Remanent magnetisation is a 'permanent magnetisation' and is that which enables

sediments to record the direction of magnetic fields at their time of formation.

**Multidomain:** (see single domain).

**NRM** (*Natural Remanent Magnetisation*). The remanent magnetisation of a rock, as it is first measured, prior to laboratory treatment. This may be composed of one or more magnetisation components, perhaps acquired in different times and under different processes.

**Paramagnetic.** Pure materials and minerals that acquire an induced magnetisation in the direction an applied magnetic field are paramagnetic. These also have a positive magnetic susceptibility, generally related to the Fe and Mn-content of the mineral. When the magnetic field is removed, they retain NO remanent magnetisation. Common examples of these are Fe or Mn-bearing silicates and carbonates.

**Remanent Magnetisation.** The magnetisation of a specimen which is permanent, and can be likened to that of a bar magnet, having a north and a south pole (i.e. has vector properties). The remanent magnetisation vector is expressed in terms of *declination*, *inclination* and magnitude. When this magnitude is expressed on a volume specific basis its units are A/m (or mA/m  $\equiv 10^{-3}$  A/m), but on a mass specific basis (to allow for changes in density) its units are  $\text{Am}^2 \text{ Kg}^{-1}$  (magnetic moment per Kg).

**Single Domain:** In ferromagnetic particles, as a result of the energy-charge configuration, individual magnetic particles may be internally sub-divided into *domains*. These domains each have different directional alignment of the magnetisation, and contribute to the overall magnetisation of the whole grain. When the particles are small ( $< \sim 0.1 \mu\text{m}$  for spherical magnetite) these particles consist of only 1 domain, and are called *single domain* grains. When magnetite particles are larger than  $\sim 5 \mu\text{m}$  they consist of lots of domains. This type of particle is called a *multidomain* grain. Single domain and multidomain grains of a specific mineral each have characteristic magnetic properties. Unfortunately, natural magnetic particles also come in different shapes, and are intergrown or subdivided by other (perhaps non-magnetic) sub-regions, so that 'magnetic grain size' (i.e. single domain or multidomain behaviour) may not correspond to the physical size of a magnetic grain. For example, a detrital magnetite particle of say  $30 \mu\text{m}$  may be sub-divided internally (by exsolution of other minerals, etc.) so that this single detrital grain may possess single domain **and** multidomain behaviour, or perhaps only single domain behaviour.

**Susceptibility** (see magnetic susceptibility).

**Superparamagnetic.** Particles which display ferromagnetic/ferrimagnetic behaviour can also be superparamagnetic when these grains are very small. This means that they can retain a remanent magnetisation, but only for a very short period of time. The time over which this retention occurs is grain size dependent (superparamagnetic magnetite grains are  $< \sim 0.02 \mu\text{m}$ ), perhaps from  $10^{-10}$  seconds to a convenient value of 100 seconds considered by Butler (1992). Such superparamagnetic grains lose the retained remanence due to thermal agitation of the atoms. In many ways such grains are similar to paramagnetic grains, and do not carry an archaeomagnetic remanence.

**TRM** (**Thermoremanent magnetisation**). A remanent magnetisation produced in ferrimagnetic minerals by heating to high temperature and its subsequent cooling in a magnetic field.

**Viscous Decay:** The acquisition of VRM can be reversed, if the specimen is left in a zero magnetic field for long enough. Putting a specimen in such a zero field space allows any acquired VRM component to decay to some extent. The natural decay of any acquired VRM is utilised by placing samples in a near zero magnetic field. This reduces any VRM which may have been acquired during laboratory handling.

**VRM** (*Viscous Remanent Magnetisation*). Remanent magnetisation which is acquired by magnetic grains when exposed to a weak magnetic field over a period of time. This may 'overprint' the original magnetisation of the sediment. The magnitude of VRM acquisition can be described by  $S \cdot \log(t)$ , where  $S$  = the viscosity coefficient and  $t$  is time.  $S$  is related to the grain volume, whether it is a multidomain or single domain grain and the temperature (Butler, 1992). Generally in sediments, either ultra-fine grains near the single-domain to superparamagnetic transition or multidomain grains acquire VRM most effectively.