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Integrated fabric analysis (magnetic and petrographic) for magma flow determination of the Mafra Radial Dyke Swarm (Portugal)

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The anisotropy of magnetic susceptibility (AMS) has been considered a reliable tool for characterization of petrofabrics of rocks from a wide range of geological settings for at least the last four decades, with particular use for magma flow studies on dykes when the petrofabric is not evident. However, the assumption that the magnetic lineation (K1) should be considered as the inferred magma flow direction when in presence of normal magnetic fabrics is still controversial in face of discrepancies to flow-related magmatic petrofabrics described on several other studies.

Recent fabric analysis integrating AMS together with magma flow-related petrofabrics (SPO of plagioclases and deformed vesicles) on shallow dykes from the Mafra Radial Dyke Swarm (MRDS) proved to be a check-test to the usually adopted AMS criteria. The MRDS is assigned to the Late Cretaceous alkaline cycle of the western Iberia continental margin associated with the opening of the North Atlantic, but still poorly understood. Its radial pattern, unique in the Lusitanian Basin, suggests that at the time of emplacement the deviatoric stress should have been very low, which is in agreement with an emplacement after the rift phases and before the tectonic inversion. The petrofabrics (micro and mesoscale) were investigated independently and then compared with the magnetic fabric, and in special, with the magnetic lineation direction. First, the SPO analysis of plagioclase micro-phenocrystals and the opaque minerals were processed accordingly to the Intercepts method on oriented thin sections cut within the magnetic planes K1K2 (magnetic foliation plane) and K1K3 (perpendicular to the dyke margins) to confirm that the petrofabric was flow-related. Second, the presence of oriented elongated vesicles in the dykes was used to perform an analysis of magma flow within the dyke and estimate a mean flow direction.

Sampling was carried out on the margins of narrow vertical basalt/dolerite dykes, trending WNW-ESE, where the flow-related fabrics are expected to be more expressive. Approximately 200 standard sized oriented samples were collected. The magnetic susceptibility measurements were made using a Kappabridge KLY-2 (Agico, Brno) susceptibility bridge and the principal magnetic phases were examined by thermo-magnetic analysis in low magnetic field using a CS23 (Agico, Brno) furnace apparatus coupled to the KLY-2 susceptibilimeter, in an argon-controlled environment, up to a temperature of 700ºC. The AMS ellipsoid is defined by a second-order tensor with the principal magnetic susceptibility axes K1 $\geq$ K2 $\geq$ K3 and characterized by the P' and T parameters and the classical parameters$L$ and F. Statistical treatment of directional data was made using the bivariate extension of Fisher's statistics determining the uncertainties of each principal susceptibility direction for all samples and establishing 95% confidence ellipses for each mean principal susceptibility directions.

The bulk susceptibility (K) show a bimodal distribution (values from 0.2-600$\times10^{-3}$ SI), showing clearly the existence of low and high susceptibility dykes. The main magnetic carriers are titanomagnetites with different oxidation levels. The dominant AMS ellipsoid shape is oblate for both shape parameters,T and $L-F$, indicating a major importance of the magnetic planar fabric over the linear fabric. The magnetic fabric of all dykes show good clustering of minimum susceptibility axis (K3) close to the dyke pole and generally good clustering of the maximum (K1) and intermediate (K2) axis, with small non-overlapping confidence ellipses (K3 confidence ellipses smaller than K1 confidence ellipses), establishing a tri-axial magnetic fabric with a well defined magnetic foliation plane (MFP). This corresponds to typical normal magnetic fabrics assumed to be flow related. The overall projection of K3 and K1 axis for grouped margins (north and south) shows well concentrated K3 distribution on both margins relatively to K1 distribution enforcing the stability of MFP over the magnetic lineation, allowing the determination of several flow vectors by the MFP method, with mean direction of 28º dipping towards ESE.

The SPO showed that there is a good agreement between the preferred direction of the opaque phase and K1, the magnetic lineation (62%); however, some cases (17%) show a deviation of less than 30º to K2. The plagioclase phase showed a good agreement with the magnetic axis. This allows us to assume that plagioclase fabric is flow-related and regarding the correlation to the magnetic fabric, perhaps either K1 or K2 could represent the flow direction.

Photo-mosaics were made for the well exposed vesicle sections on different dyke locations, on the dyke margins or on its interior, measuring the major and minor ellipses axes or 3D when possible. This study shows that the vesicles fabrics are related to a sub-horizontal magma flow with the major and minor axes of the vesicles usually on a sub-horizontal or gently dipping plane. The average attitude of x-axis from 3D vesicles shows a value of 26º dipping towards ESE.

This integrated study shows that, for narrow dykes, the magnetic lineation is not always the best AMS criteria to define the magma flow vector. Instead, when the magnetic foliation plane is better represented and stable it can be used with good results. These data indicate a magma source located roughly at 3.2 km depth if a linear flow is assumed from the source located at a horizontal distance of 7 km to the sampled sites.