Emplacement of the Whin Sill – magma flow geometries and mechanisms

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The Whin Sill is a large Permo-Carboniferous dolerite intrusion in Northern England that is dated at 294 ± 2 Ma (Timmermann, unpublished data). On land the sill underlies an area of approximately 5000km^2 and has an estimated volume of 200km^3. As the sill dips underneath the North Sea these numbers probably only represent a fraction of its actual size and volume. The stratigraphic horizons in which the sill is emplaced range from Dinantian to Westphalian.
Francis (1981) proposed an emplacement model for the Whin Sill and suggested that major E-W to ENE-WSW orientated dykes intruded into the shoulders of the regional basin. The magma then flowed down adjacent bedding planes into the basin centre where the sill reached its maximum thickness. This model carries major implications about the direction of magma flow, both in the dykes and the sill.
The aim of this work is to study the emplacement process of the Whin Sill and to analyse the magma flow geometries within the body. We present a dataset that is based on macroscopic magma flow indicators and a large scale AMS- and detailed palaeomagnetic study. The combination of these techniques enables the reconstruction of magma flow patterns within the Whin Sill at the time of its emplacement.
The palaeomagnetic methods were applied to evaluate the regional tectonic history of the area after the sill was emplaced. This allows us to estimate whether the amount of block tilting/rotation is significant and whether the magnetic fabric has to be reconstructed to the time of intrusion. The remanence dataset also reveals a secular variation pattern of the Early-Permian earth magnetic field, which suggests that the Whin Sill consists of three geographically separate intrusions, which were not emplaced during one distinct intrusion event. Additionally the technique allows the identification of the potential feeder dykes for the individual sills.
The AMS lineations of the sill show that: 1. there are geographically separated areas where the magma flow orientations are different and; 2. the magma flow was not just down-dip, and in some areas was parallel to the general strike of the host rock bedding planes. Furthermore the AMS data near the upper and lower sill contacts were corrected relative to the dip direction of the surrounding host rock bedding. This corrected dataset reveals the magnetic imbrication fabrics from which the magma flow directions within the sill can be derived. These directional results together with macroscopic magma flow indicators suggest that the magma flow was generally parallel to the strike of the host rock bedding or up-dip out of the basin, but not gravitationally controlled as proposed by Francis (1981).

Francis, E.H., 1982. Magma and sediment – I. Emplacement mechanism of late Carboniferous tholeiite sills in northern Britain. J. geol. Soc. London, Vol. 139, p. 1-20.