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Magnetic study of a late Alpine dike crosscutting the regional foliation

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ABSTRACT

Dikes crosscutting existing folds or foliation are one of the classic time markers used in establishing relative geological chronology. We examine the paleomagnetic directions and magnetic fabric in a deformed gneiss from the Southern Steep Belt, which lies immediately north of the Insubric fault, and in an aplite dike that transects this foliation. No clear foliation or other evidence of internal deformation is discernible in the aplite dike in the field and it was originally interpreted as post-tectonic, with its intrusion age placing a young limit on the timing of deformation in the adjacent gneiss. The aplite dike does not carry a stable remanent magnetization and cannot be used to resolve the age of intrusion. The characteristic paleomagnetic remanence in the gneiss is compatible with Eurasian paleomagnetic directions during the last 20 Ma. These results suggest that the timing of magnetization postdates dextral motion along the Insubric and Rhine–Rhone faults. The low-field anisotropy of magnetic susceptibility (AMS) in the gneiss is controlled by the regional schistosity. High-field AMS suggests that both paramagnetic and ferromagnetic minerals contribute to the magnetic fabric, whereby the ferromagnetic minerals show a stronger lineation. This is further confirmed by the anisotropy of anhysteretic remanent magnetization (AARM). Rock magnetic experiments show that multi-domain magnetite is the main ferromagnetic mineral in the gneiss. Unexpectedly, the AMS results from the aplite dike show that it also has a magnetic fabric, which is shown by high-field AMS, AARM and rock magnetic experiments to be carried by superparamagnetic magnetite. The presence of magnetic fabric in the dike demonstrates that regional deformation was still on-going in the Southern Steep Belt of the Central Alps at the time of its intrusion.

1. Introduction

Dike intrusion in a deformed region can supply information on the relative timing of geological events. In particular, late undeformed dikes, when dated by radiometric methods, can provide a minimum age for the structures they transect. This approach has been used in many areas, including the region of the Central Alps considered here (e.g. Romer et al., 1996). Paleomagnetic studies have often been used to help date intrusive events, and baked contact tests aid in constraining the timing of acquisition of the magnetization (e.g. Buchan et al., 2012; Harlan et al., 2008; McGlynn et al., 1974). Less common is the use of magnetic fabrics to record changes in the direction of strain field during an orogenic event (e.g. Hirt et al., 1995; Lowrie and Hirt, 1987). Hirt et al. (1995) demonstrated that Devonian shales in the Appalachian Plateau in the eastern United States have a paramagnetic subfabric, which reflects the alignment of sheet silicates during the main deformation phase of the Appalachian orogeny. The ferromagnetic subfabric, however, records the orientation of the final deformation, because it is carried by magnetite, which formed late in the deformation history.

Paleomagnetic data from the Central Alps is limited, but a summary of early results is given in Heller et al. (1989). Whereas most rocks from the Helvetic Nappes have undergone widespread remagnetization (Kligfield and Channell, 1981), recent work by Cardello (2013) suggests that pre-tectonic directions may be preserved in the Helvetic Wildhorn Nappe and Rawil Depression. Heller (1980) reported two sites from the Aar Massif, which show normal and reverse polarities, with declinations compatible with Miocene age magnetization for Eurasia. Inclinations are steeper than expected. The Lepontine area to the south of the Aar Massif has inclinations comparable with a Miocene age, but the declinations are rotated 27° ± 13° anticlockwise. Heller speculated that these are due to dextral movement along the Insubric and Rhine–Rhone faults.

The current study employs magnetic methods to gain insight into the timing of intrusion of an aplite dike in the southern part of the Central Alps in Ticino, Switzerland (Fig. 1). The dike was thought to be undeformed, post-dating the Alpine deformation in this area. Paleomagnetism is used to help constrain the age of magnetization and any tectonic rotation at this time. Particular attention is given to the minerals that are responsible for the observed low-field anisotropy of magnetic susceptibility, because mineralogy is an important consideration when interpreting magnetic fabrics in a geological context (e.g. Almqvist

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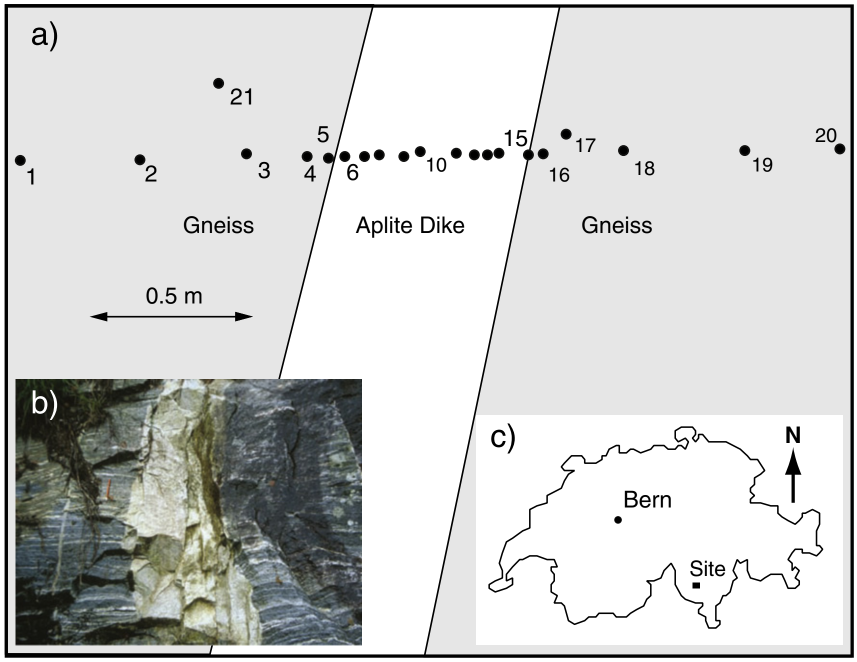

Fig. 1. a) Schematic map of outcrop at Tierra di Fuori with sample profile; b) photo of aplite dike and gneiss before drilling; c) site location within Switzerland.

et al., 2012; Borradaile, 1987; Borradaile and Jackson, 2010; Cifelli et al., 2005; Hirt and Almqvist, 2012).

2. Geology

2.1. Regional geology

The Central Alps are dominated by a series of polyphase, generally recumbent folds and thrusts resulting in interleaving of the older basement granite and paragneiss with remnants of the Mesozoic cover (e.g. Argand, 1911; Milnes, 1974a; Preiswerk, 1918; Schmidt and Preiswerk, 1908). Reflecting the tight to isoclinal nature of these regional-scale fold nappes, the dominant schistosity is effectively parallel to the lithostratigraphic contacts in the elongate limb regions that dominate the map pattern. This packet of tightly folded layering and generally subparallel schistosity is overprinted by two more upright fold sets. The first of these (F3 of Grujic and Mancktelow, 1996) is regionally developed and strongly oblique to the trend of the orogeny. It is ultimately responsible for the double-dome pattern of the Central Alps, consisting of the Simplon subdome to the west and the Ticino dome to the east, separated by the Maggia synform (e.g. Merle, 1989). The second fold set is reflected in the gradual but rapid steepening of the lithostratigraphy and main foliation into the Southern Steep Belt (Milnes, 1974b), immediately north of the Insubric (or Periadriatic) fault (e.g. Schmid et al., 1987, 1989). This fault separates the weakly metamorphosed Southern Alps from the upper amphibolite facies units of the southern Central Alps. Several aplite dikes with a NNE strike and near vertical dip sharply transect the foliation and folds in the Southern Steep Belt. The two best known dikes are: i) the ca. 2 km long dike running from west of Alpe Mognora in a NNE-direction to Madone (Swiss Grid Coordinates 713.850/121.900; see the 1:25,000 Bellinzona geological map sheet, No 66, 1974 and p. 13 of the accompanying notes); and ii) the youngest, crosscutting aplite at Lavertezzo, dated by Romer et al. (1996) using single-zircon U–Pb at 20.2 + 4.4/−7.8 Ma. The dike sampled for this study was discovered in a readily accessible creek and road section ca. 1.5 km WSW of Gordevio in the lower Maggia Valley (Fig. 1).

2.2. Geologic setting and location of samples

The Maggia Nappe in the lower Maggia Valley consists predominantly of biotite-rich paragneiss that has been folded in tight, upright ESE striking folds (F3 of Grujic and Mancktelow, 1996). The peak grade of Alpine metamorphism is upper amphibolite facies (~650 °C, 6.5 kbar; Todd and Engi, 1997). The gneiss in the sample area is locally migmatic with leucosomes that are folded by F3 and form lenses and veins approximately parallel to the axial plane of these folds. The dominant S2 foliation in the gneiss is ~88° toward 013° and the lineation dips at ~10°/105°. U–Pb dating of zircons from such leucosomes further east of the sample area has shown that partial melting developed intermittently over some 10 Ma from 32 to 22 Ma (Rubatto et al., 2009). The aplite dike in the current study crosscuts the gneiss discordantly near the southern contact of the Maggia Nappe with the Mergoscia zone, taken as an approximate lateral equivalent of the Antigorio Nappe on the Tectonic Map of Switzerland (Spicher, 1980). The dike walls dip ~85°I toward 290° and are nearly perpendicular to both the F3 fold axes and the regionally dominant S2 schistosity (Fig. 1, inset). The age of the dike is unknown but cooling curves for the gneisses in the lower Maggia valley indicate rapid cooling from 500° to 250 °C between 23 and 19 Ma (Hurford, 1986; Hurford et al., 1989). Other late aplitic/pegmatitic dikes from the Southern Steep Belt of the Alps have given ages around 20–25 Ma (Gebauer, 1996; Romer et al., 1996).

The dike and surrounding country rock were sampled along a profile normal to the trend of the walls of the dike (Fig. 1). The creek outcrop (Swiss grid coordinates 699.350/119.750) is accessed from the road through Tierra di Fuori, in the lower Maggia valley. Samples were taken using a portable gasoline drill, and were cut into cylindrical specimens with a diameter of 2.54 cm and length of 2.3 cm. Two to three specimens were obtained from each core.

3. Methods

Acquisition of isothermal remanent magnetization (IRM) was imparted to selected samples of gneiss and aplite at both room temperature and liquid nitrogen temperature (77 K), using an electromagnet with a maximum field of 1 T. For the low temperature measurements,