Journal of Structural Geology, Vol. 9, No. 7, pp. 911 to 914, 1987
Printed in Great Britain

0191–8141/87 $03.00 + 0.00

Magnetic structural analysis of the Montmarault granite (French Massif Central)

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(*Received* 20 *October* 1986; *accepted in revised form* 17 *March* 1987)

Abstract—A magnetic fabric study has been made in the eastern branch of the Montmarault granite. Magnetic foliation (in accordance with the visible foliation of the country rocks) and magnetic lineation dip typically towards the SE in the eastern part of the massif (monzonitic granite) and towards the WNW in the western part (granodiorite), thus indicating an antiformal structure with a SW-dipping axis. This SW direction coincides with the magnetic lineation at some sites. The susceptibility ellipsoid is oblate, showing a clear predominance of foliation relative to lineation. We infer that the granite was thus probably subjected to strong compression during or shortly after its emplacement, at the end of the Upper Devonian metamorphism, or, more probably, during the latest tectono-metamorphic event in this area, in Early Westphalian time. The antiformal structure most probably corresponds to a Stephanian deformation.

INTRODUCTION

THE GRANITIC massif of Montmarault is situated on the northern border of the French Massif Central, east of the La Marche area. Its absolute age cannot be determined (initial Strontium strongly heterogeneous). It would seem to be of Westphalian age, like the nearby Saint Caprais granite (Grolier *et al.* 1980) and Cerilly granite (Vachette 1972), although a Givetian–Frasnian age has been obtained for the neighbouring Tronçais granite (Vachette 1972). Quenardel *et al.* (1984) assumed a late Westphalian age, for the *post-tectonic* intrusions of the La Marche area. Sossa-Simawango (1980) has shown that this massif includes two different facies (monzonitic granite and granodiorite) which may not be quite contemporaneous. The Montmarault Massif is bounded in the east by a major fault (Sillon Houiller), which has had important transverse movement between Stephanian and Permian times. A classical structural analysis is very difficult to carry out in these rocks, which exhibit no clear visible structures and which moreover appear at the surface in very limited outcrops. Thus, in order to define the emplacement age relative to the main tectonic phases and the structural evolution of this granite, we have chosen to use the magnetic structural method (Graham 1954, Daly 1970, Henry 1980, Hrouda 1982).

The analysis of anisotropy of magnetic susceptibility is in fact a well established method of structural analysis of magmatic intrusions. The magnetic fabric often reflects the magma flow, and the viscous deformation from pressure exerted by the country rocks (King 1966, Van der Voo & Klootwijk 1972, Chlupacova *et al.* 1975, Henry & Meurisse 1978, Henry 1980, Guillet *et al.* 1983) or by regional stresses (Heller 1973, Henry 1980). However, magnetic anisotropy can also be related to deformation in the solid state (Henry 1980), late hydrothermal events (Hrouda & Chlupacova 1980) or from a combination of events (Henry 1974, 1987).

Owing to the wide surface area of the Y-shaped Montmarault Massif (>600 km^2), and in order to obtain consistent and significant results, sampling has been concentrated along two parallel E–W cross-sections of about 10 km, 5 km away from one another, in the eastern branch (bordered to the east by the Sillon Houiller, a major fault in the Massif Central). The poor quality of the rare granite outcrops does not allow a regular distribution of the sampling sites (Fig. 1a). Here 53 large samples (110 cm^3) were collected from 33 different sites. Mean susceptibility $\bar{\chi}$ is often weak ($<4 \times 10^{-7}$ SI for 85% of the samples). Measurements of magnetic susceptibility anisotropy have been made with a torque magnetometer (Daly & Formont 1969), using fields from 40 (corresponding to samples with the highest mean susceptibility) to 300 Oe (lowest mean susceptibility); these relatively high values of field show that the anisotropy percentage is probably weak in these rocks. The shape parameter used is $f = (\chi_1 - \chi_2)/(\chi_1 - \chi_3)$, where χ_1, χ_2 and χ_3 are the principal susceptibilities ($\chi_1 > \chi_2 > \chi_3$). f can be determined from the torque magnetometer data, and varies from 0 (foliation without lineation) to 1 (lineation only), the value 0.5 corresponding to $\chi_2 = (\chi_1 + \chi_3)/2$. In sites with several samples, the mean orientation of susceptibility axes has been determined by Fisher's analysis.

THE MAGNETIC FABRIC OF THE MONTMARAULT GRANITE

Magnetic foliation

The orientation of the magnetic foliation is shown in Fig. 1. Three main areas (Sossa-Simawango 1980) clearly appear (Fig. 1a).

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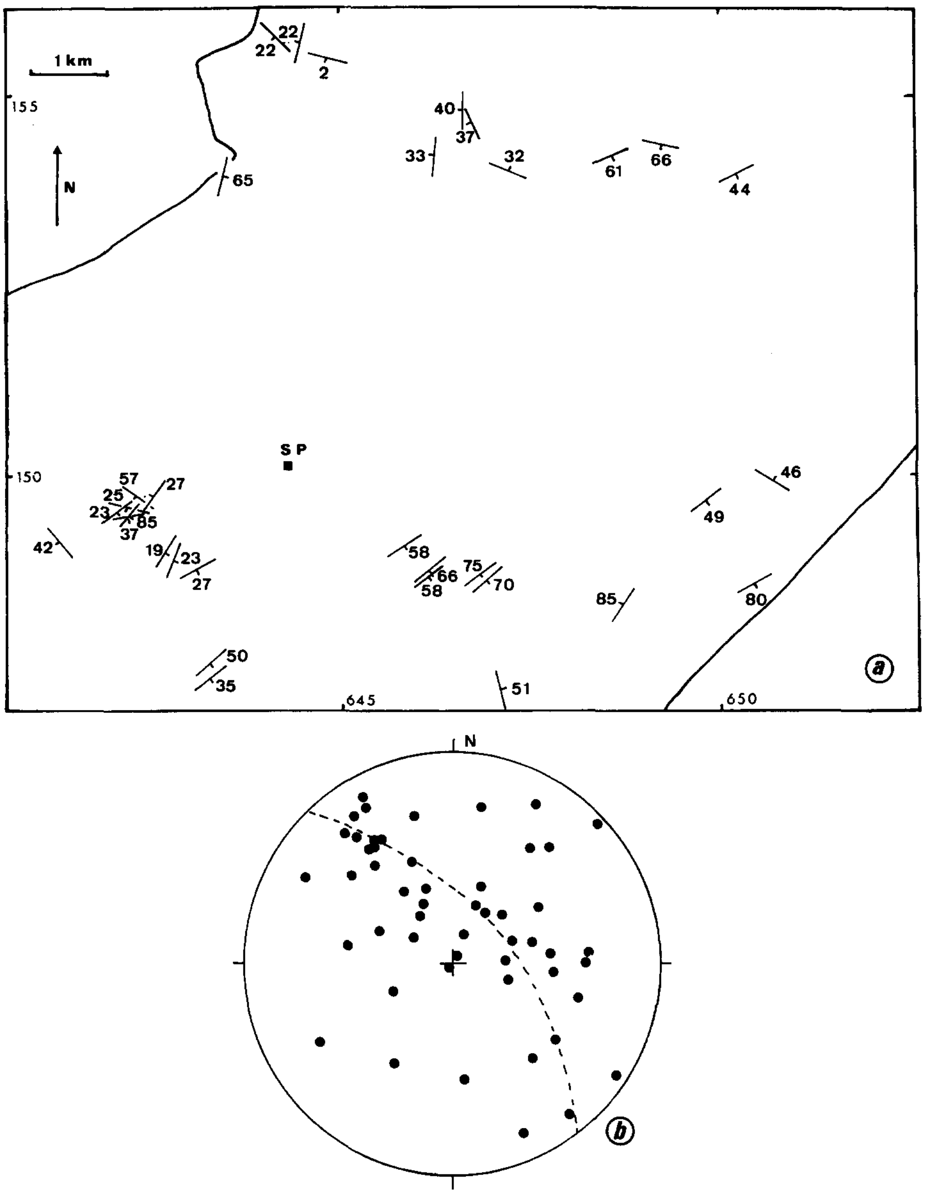

Fig. 1. (a) Map of the magnetic foliation, with its dip in degrees. SP is the village of Saint-Priest en Murat (46°21′N, 2°54′E).
(b) Minimum susceptibility axes with their best-fit plane of distribution (lower hemisphere stereographic projection).

(1) In the southeastern part of the massif (corresponding to the monzonitic granite), magnetic foliation has a very consistent NE–SW direction, with an increasing dip towards the SE.

(2) In the northwestern part (granodiorite), the magnetic foliation dips mainly towards WNW–W.

(3) In the central part (intermediate facies), the magnetic foliation orientation is more variable.

However, at some sites, the magnetic foliation is oriented NW–SE, dipping to the SW or NE.

Magnetic lineation

The disposition of the magnetic lineation (Fig. 2) is very similar to that of the foliation: in most cases, the lineation dips towards the SE in the southeastern area and towards the WNW in the northwestern part, and has a more variable orientation in the central zone; at some sites, the lineation has a SW dip (SW-dipping lineations do not correspond generally to NE–SW foliations).

Shape parameter

The shape parameter *f* indicates a clear predominance of the oblateness (minimum, mean and maximum values are, respectively, 0.04, 0.28 and 0.68). The most prolate ellipsoids are found at the northwestern border or in the central area; they do not correspond to a particular orientation of the magnetic fabric. The lineation determined in samples with the most oblate fabric has a similar orientation as lineation in sites with more prolate fabric, and seems therefore to be significant in all sites.

DISCUSSION

Magnetic foliation, clearly predominant relative to the magnetic lineation, has a very consistent orientation, particularly in the southeastern part of the massif; it does not reflect the complexity of flow structures previously found in other intrusions, and has therefore been sub-

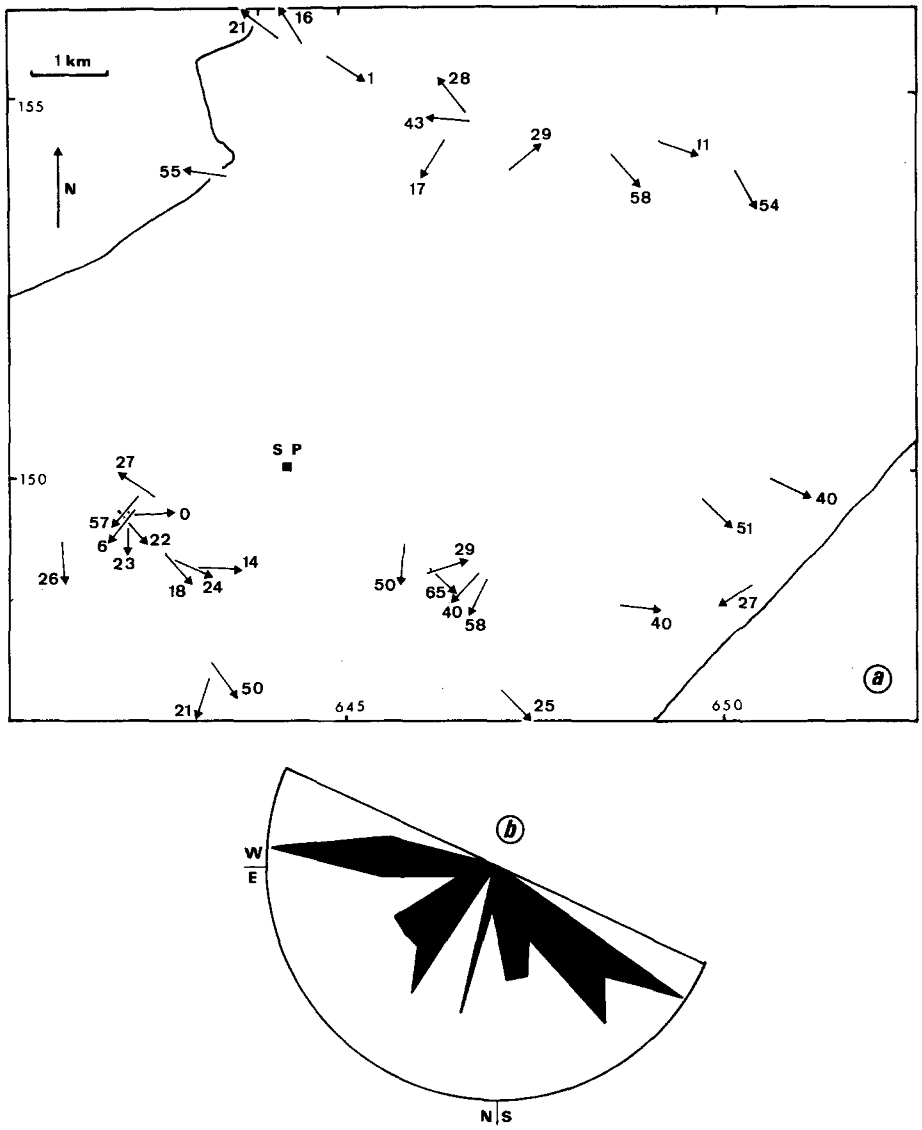

Fig. 2. (a) Map of the magnetic lineation, with its dip in degrees. SP is the village of Saint-Priest en Murat. (b) Azimuth of the maximum susceptibility axes.

jected to strong compression (Henry & Meurisse 1978, Henry 1980). Besides, the magnetic foliation in the granite margins has the same orientation as visible foliation in the neighbouring metamorphic country rocks (Sossa-Simawango 1980) in the west (dip mainly W, south of L'Aumance river, west of Chavenon) as in the east (dip mainly SE, between Le Montet and Montmarault). Such a disposition seems to indicate that these two foliations have a common origin. However, the granite itself does not show visible effects of metamorphism, and it was therefore not in a solid state during this orogenic period. It might be concluded that the granite was emplaced during the end of the Upper Devonian metamorphism; consistent NW–SE magnetic lineation would then correspond to the stretching direction during this period. However, Rollin & Quenardel (1982) have observed very similar structures in the Crozant granite, of Early Westphalian age, in the neighbouring La Marche area: concordant structures in granite and country rocks, foliation of weak mean dip and NW–SE lineations. The Crozant granite has been emplaced during the latest tectono-metamorphic event (Chambon thrust) in this area. It is thus assumed that the Montmarault granite is a *syntectonic* intrusion of the same period, or was emplaced shortly before this event.

The actual disposition of the magnetic foliation and lineation suggests a later antiformal deformation with a NE–SW axis (Figs. 1b and 2b). The northwestern limb dips WNW–W, the southeastern towards the SE (with an increasing dip towards this direction), and the fold axis towards the SW. This last direction is also that of some magnetic lineations, which thus seem to be related to this folding. It is also possible that the local magnetic NW–SE foliation resulted from a disturbance of the primary fabric during the folding. Alternatively a relation with the late Westphalian–early Stephanian sinistral movement along the Sillon Houiller fault under N–S compressions (Lerouge & Quenardel 1985) might be concluded, but such a shearing would lead to an increasingly SW lineation from the west to the east which does not appear here. The deformation is earlier than the Autunian deposits of the L'Aumance basin, and so the

NE–SW fold was therefore probably synchronous (during Stephanian times) with the formation of tectonic breccias on the eastern border of the granite, which are related to a NW–SE compression (Lerouge & Quenardel 1985).

CONCLUSION

During or shortly after its emplacement, the Montmarault granite was submitted to strong compression, corresponding to the end of the Upper Devonian metamorphism or, more probably, to the Early Westphalian tectono-metamorphic event, in a manner similar to the Crozant granite; magnetic foliation and lineation are for the most part related to this compression. Folding on a NE–SW axis later (probably during the Stephanian) produced the present geometry of the massif and a secondary magnetic fabric in some sites.

Acknowledgements—The authors are very grateful to John Thompson for his help with the manuscript.

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