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The Pombal granite pluton: magnetic fabric, emplacement and relationships with the Brasiliano strike-slip setting of NE Brazil (Paraíba State)

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Abstract—The Pombal pluton (500 km^2), a suite of diorite, syenite and porphyritic granite bodies, is here used to constrain kinematics of Brasiliano-age tectonic episodes in northeast Brazil. The pluton intrudes high-grade to migmatitic gneiss forming the western basement of the Seridó belt, and is located at the intersection between two sets of continental-scale dextral strike-slip shear zones. The northern set of shear zone strikes NE–SW and branches, southwards, into the E–W Patos mega-shear zone. A detailed microstructural and low-field magnetic susceptibility study was performed to unravel the relationships between solid-state deformation in the country rocks and magma emplacement. Porphyritic granite and syenite have quite high magnetic susceptibilities (10^{-3}–10^{-2} SI units) indicative of magnetite as the principal carrier of susceptibility. The magnetic fabric is remarkably homogeneous in orientation throughout the pluton. It is characterized by a shape-preferred alignment of magnetite, itself parallel to the shape fabric of mainly biotite (±amphibole), i.e. to the magmatic fabric. Even close to the contact with the high-temperature mylonites of the Patos shear zone, south of Pombal, no imprint of the E–W-trending structures is observed in the fabrics of either the granite or the host rocks. Granite emplacement and its internal fabric development is concluded to be independent of the movement of the Patos shear zone. In the southwestern border of the pluton, a low-dip foliation bearing a NE–SW-striking lineation is shared in both the magmatic fabric of the pluton and the solid-state fabric. Farther to the north, approaching the NE–SW strike-slip shear zone, the magmatic fabric is characterized by a steeply dipping NE-striking foliation carrying a subhorizontal lineation. Transition from low to steep dips of the planar fabrics is progressive. Two models are proposed for emplacement of the Pombal pluton. One considers magma injection during an early episode of tangential tectonics, responsible for the gently dipping foliations, evolving later to strike-slip deformation. The other model considers that the pluton was emplaced in a pull-apart domain developed in the overlapping sector of a right-hand en échelon system of a dextral shear zone. Compatibility of these models with the tectonic evolution of the Seridó belt is discussed.

INTRODUCTION

GEOLOGICAL and geophysical studies of granite plutons emphasize the role of regional tectonics in the emplacement mode of the magma (Vigneresse 1988, Clemens & Mawer 1992, Hutton 1992). Voids generated in the crust by strike-slip deformation (Castro 1986, Guineberteau *et al.* 1987), thrusting (Schmidt *et al.* 1990) or a combination of the two (Hutton 1988) are sites able to receive significant volumes of magmas, thereby forming plutons at various depths in the crust. In these sites, deformation in the magma is responsible for the development of internal structures that allow us to make hypotheses about the mechanisms at the origin of the emplacement. By a precise description of the orientation and magnitude of any fabric in the magma, acquired both in the magmatic state (in presence of liquid) and in the solid state (fully crystallized), clues may be obtained concerning the kinematics and the evolution of orogens.

With a kinematic description in mind, we studied the Pombal pluton and its country rocks. This pluton belongs to the Borborema Province of NE Brazil (Fig. 1), characterized by an abundant granitic plutonism of 700–500 Ma ages (Almeida *et al.* 1981). Plutons in this province are emplaced in close relationships with ductile shear zones, either several kilometres wide and E–W-striking, the Patos and Pernambuco mega-shear zones, or relatively narrow and NE-striking, forming the frame of the Seridó and Cachoeirinha belts (Fig. 1). The Pombal pluton, located at an intersection of these two major regional sets of shear zones, can thus be used to unravel the relative chronologies of deformation events affecting the crust in this sector of the Pan-African–Brasiliano orogeny.

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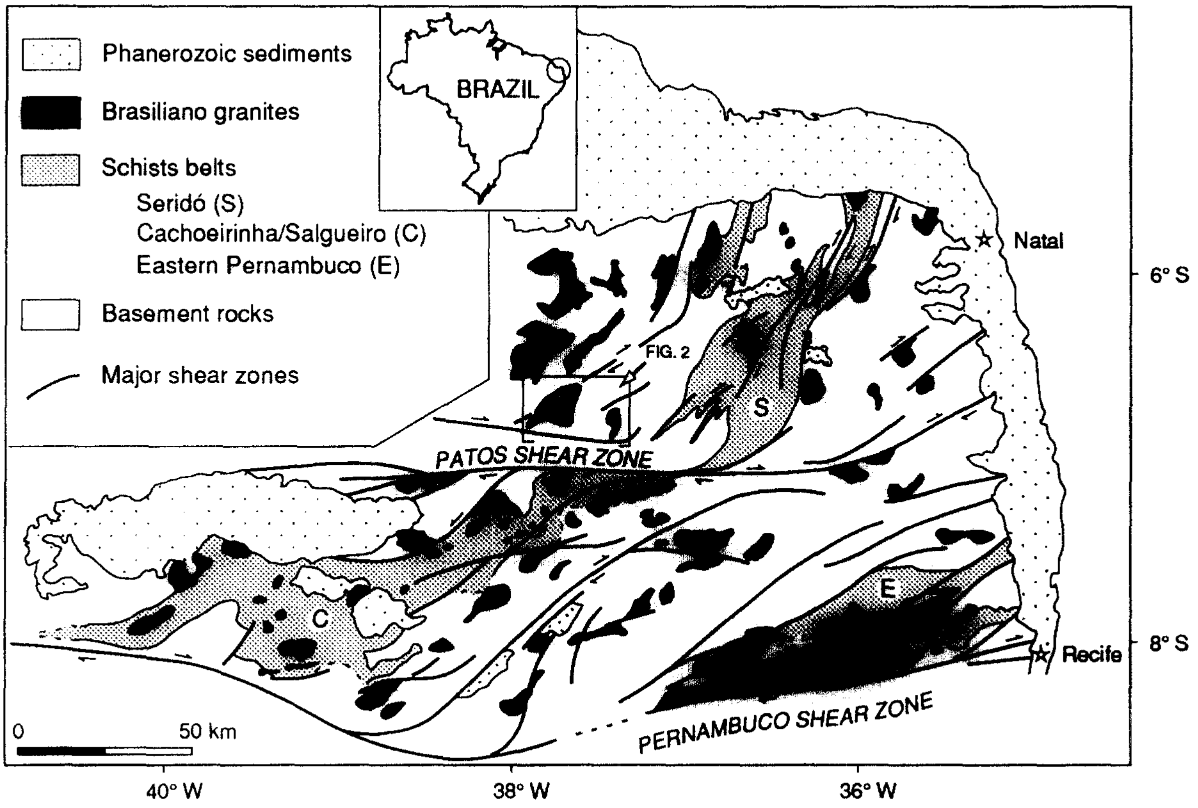

Fig. 1. Geological map of northeast Brazil. Boxed: the Pombal and Serra Negra plutons.

The structure of the massif has been mapped using mainly the anisotropy of magnetic susceptibility (AMS) technique. AMS has been demonstrated to be useful for fabric measurement in rocks (Borradaile 1988, Rochette *et al.* 1992) with particular effectiveness for magmatic fabrics of granites (Balsley & Buddington 1960, Ellwood & Whitney 1980, Hrouda & Lanza 1989, Bouchez *et al.* 1990). The technique is all the more useful in our study as the Pombal granite is slightly anisotropic, marked by a very weak foliation. This situation renders traditional structural measurement techniques impossible, particularly for the identification of a key element in a kinematic analysis, the magmatic lineation.

GEOLOGICAL BACKGROUND

General setting

The Pombal pluton, which is about 500 km^2 in area and roughly elongated parallel to NE–SW (Fig. 2), intrudes migmatitic gneiss that belongs to the Lower Proterozoic basement of the Seridó (Hackspacher *et al.* 1990, Souza *et al.* 1992). This pluton is correlated to a series of Brasiliano-age granites principally porphyritic in type and subalkaline to alkaline in composition (Sial 1986, Leterrier *et al.* 1990). It outcrops immediately to the north of the huge Patos shear zone, a dextral 15 km-wide corridor of tectonites that extends 400 km across the Borborema Province in an E–W direction (Corsini *et al.* 1991). The granite and basement rocks are cross-cut by a system of NE–SW strike-slip shear zones that constitute one of the many zones of dextral shear that characterize the Seridó (Fig. 1) (Archanjo & Bouchez 1991). The Serra Negra shear zone (SNSZ) system forms several en échelon transcurrent ductile faults which, in their terminations, become SW-verging thrust zones (Fig. 2, south of Desterro village). In the northwest sector, branching from the Patos shear zone and extending to the northeast in the Seridó, the Rio Piranhas shear zone (RPSZ) cross-cuts the Pombal pluton. As no apparent metamorphic or structural discontinuity is observed between the Patos and the Seridó shear zone systems, both are at amphibolite facies grade and both have a dextral sense of shear, Corsini *et al.* (1991) proposed that the systems formed during a single kinematic event.

Rock types

Four petrographic units may be distinguished in the Pombal pluton (Figs. 2a–d): (a) an amphibole (±biotite)-bearing and porphyritic granite in the centre and SW portion of the pluton; (b) a biotite porphyritic granite in the north; (c) an amphibole- and/or biotite-bearing syenite to quartz–syenite in the southeast portion; and (d) an equigranular and pink granite forming a NE–SW elongate body in the centre of the pluton. The porphyritic granites and syenites commonly contain dark enclaves of diorite to gabbro up to a few metres in size. In these enclaves, amphibole and biotite (±clinopyroxene) constitute the principal mafic minerals. Zircon, apatite, magnetite and large (up to 2 mm) crystals of sphene are the principal accessories. Magnetite grains, 0.3 mm in mean size, are found mainly in association with biotite, amphibole and sphene. These rocks may be cross-cut by metre- to decimetre-thick dikes of diorite. Late dikes of pegmatites and aplites (Fig. 2e), commonly trending NE–SW, are particularly abundant in the south-centre part of the pluton.

Structures in the basement

Two domains with differently oriented structures characterize the surroundings of Pombal (Fig. 2). The Patos shear zone domain in the south has mostly steep and northward-dipping foliations and subhorizontal stretching lineations. To the north, a broad NE–SW-trending area in which there are low-dip foliations with NE–SW lineations, is interrupted by shear zones with steep NE–SW foliations carrying subhorizontal stretching lineations. Transition between these two domains will be examined in detail.

The low-dip foliated domain is well preserved to the east and immediately south of the pluton. In the region of Desterro (Fig. 2), foliation of the basement gneiss dips gently to the east, parallel to a centimetre-thick banding of alternating mafic and felsic layers. The whole is locally invaded by granitic veins. The metamorphic banding displays feldspathic segregations, small aplite dikes and oriented sillimanite in the Al-rich bands typical of high-temperature metamorphism. In the augengneiss outcropping in the village of Desterro, the banding is made of discontinuous subcentimetric layers of comminuted feldspars, attesting to intense plastic strain. To the south of the village of Pombal, tonalitic gneiss of the country rocks dips moderately to the north beneath the granite (Fig. 2). The contact between the granite and the gneiss is pervasively migmatized with abundant pockets of granite and discordant leucosomes cross-cutting the foliation. Farther to the south, the planar fabric of the country rocks gradually becomes steeper and a mylonitic fabric appears approaching the Patos shear zone. In contrast, the gently dipping foliation of the rocks northwest of Malta is warped into a kilometre-scale fold about an E–W-striking axis against the northern border of the Patos shear zone.

Despite the presence of potentially good kinematic markers, the sense of shear in the low-dip foliated domain could not be ascertained. Feldspar porphyroclasts or deformed veins are mostly symmetric in shapes over large areas, suggesting dominant flattening rather than non-coaxial deformation. Some 10 km northwest of Malta (Fig. 2), however, disrupted aplitic veins clearly

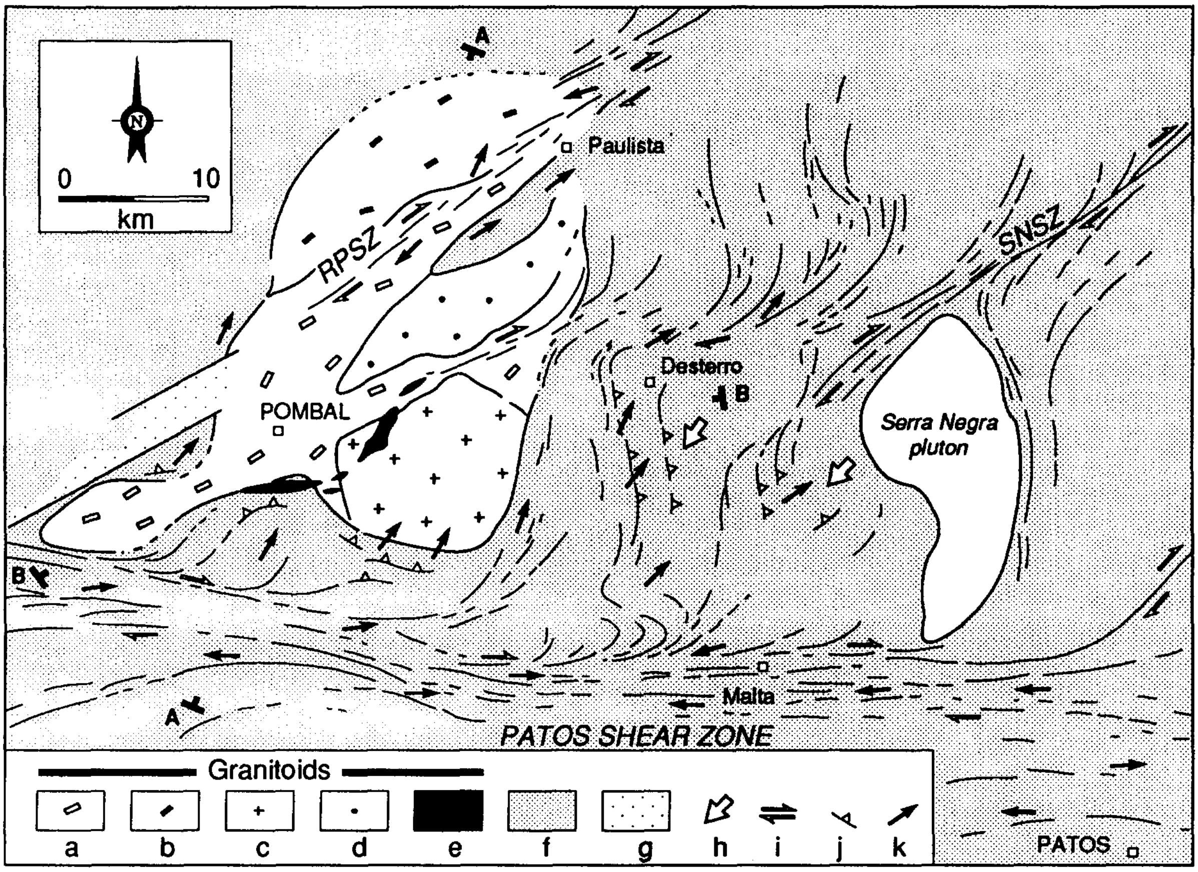

Fig. 2. Pombal and Serra Negra plutons showing the main structures in the country rocks (shaded) determined by field studies and satellite image interpretation. Pombal pluton: (a) biotite–amphibole porphyritic granite; (b) biotite porphyritic granite; (c) quartz–syenite; (d) pink equigranular granite; and (e) aplite. Country rocks: (f) gneiss and migmatites; (g) Mesozoic sediments; (h) shear-sense in low-angle shear zones; (i) dextral strike-slip shear zones; (j) low-dip foliation; and (k) stretching or mineral lineation. RPSZ, Rio Piranhas shear zone; SNSZ, Serra Negra shear zone. A–A and B–B, cross-sections of Fig. 10.

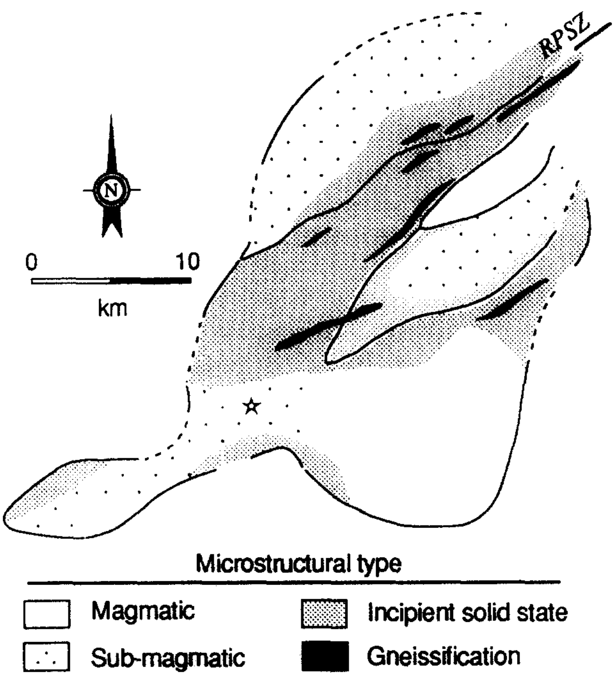

Fig. 3. Microstructures in the Pombal pluton.

show asymmetric tails with a top-to-the-southwest sense of shear. South of Pombal, the kinematic criteria are ill-defined, except at the border of the Patos shear zone where a dextral sense is observed in E–W-striking mylonites having 30–35° dips to the north. The kinematic incompatibility observed in these gently dipping foliations to the south of Pombal and in the Desterro region suggests that these structures were subjected to separate structural evolutions.

Finally, highly foliated zones running NE–SW cross-cut both the granites and the basement rocks. The RPSZ and SNSZ have foliations which are vertical to steeply dipping. Several kinematic markers (rotated porphyroclasts, *S–C* structures) unambiguously indicate a horizontal and dextral sense of shear. That high temperatures prevailed during shearing is indicated by aplite veins cross-cutting the foliation at different angles, by stable biotite and amphibole marking the foliation and by recrystallization of K-feldspars into microcline, plagioclase and quartz. The transition between the steep and shallow structure is sharp. To the north of the village of Desterro there is a good example of rapid transition between low and steep dips within foliations of the same metamorphic context. The lineation, more northerly trending in the low-dip foliation domain, is slightly reoriented toward the east, i.e. dextrally, along the vertical shear domain.

FABRICS AND MICROSTRUCTURES

Direct observations in the field and microscopic examinations of thin sections collected from a regular network of 93 sampling stations were used to evaluate the magmatic vs solid-state deformation and the origin of the fabrics of the magmatic rocks (Paterson *et al.* 1989). These data, presented in map form (Fig. 3), help constrain tectonic interpretations of the emplacement by detailing the structure of the granite with respect to both country rocks and neighbouring shear zones.

Magmatic fabric

Observed in the field, magmatic texture is characterized by equant quartz grains and by poorly aligned phenocrysts of feldspar that lack solid-state deformation features (Fig. 4a). Dark coloured enclaves of medium- to fine-grained diorite commonly display weak shape-preferred orientations (Fig. 4b). However, in proximity to the RPSZ to the north, highly flattened enclaves define a steep magmatic foliation parallel to the shear zone (Fig. 4c). Under the microscope, feldspars lack strain features; quartz exhibits undulose extinction or subgrains inside equant to slightly elliptical grains that form either single crystals or aggregates of a small number of large crystals. This magmatic texture is typically observed in the eastern and southwestern portions of the pluton, i.e. in the quartz–syenites and in the amphibole-bearing porphyritic granites (Fig. 3).

Close to the city of Pombal and also in the central and northeastern portions of the pluton, an 'incipient solid-state' deformation (Fig. 3) is recorded by the plutonic rocks. The microstructure is characterized by numerous subgrains in elliptical quartz; quartz does not, however, recrystallize at this stage. K-feldspars often show extensive development of myrmekites at the grain peripheries (Hibbard 1987); along with quartz and/or plagioclase infilling microfractures, they are considered to represent the ultimate melt fraction of the deforming granite (Bouchez *et al.* 1992). In the field, these rocks show a strong alignment of the K-feldspar megacrysts, in correlation with a stronger fabric of the mafic minerals. Despite indications of subsolidus deformation that slightly modified the texture and possibly increased the strength of the fabric, the bulk fabric of the rock remains that of a dominant magmatic imprint.

Solid-state deformation fabric

Textures corresponding to deformation in the solid state occur along elongate domains, mainly in the porphyritic types, in the central and northern areas of the pluton. In the field, this texture is characterized by pressure shadows on sides of K-feldspar megacrysts, strong planar-preferred orientation of biotite, and quartz grains flattened and/or elongate with aspect ratios larger than 2:1. Under the microscope, solid-state deformation in quartz is indicated by the development of neoblasts that either form mantles around the deformed primary grains or replace them totally. K-feldspars are also frequently mantled by new grains of feldspar and quartz, and amphiboles are observed to lose their coloration at their peripheries. With increasing strain, quartz ribbons with strong crystallographic fabrics develop, often incorporating biotite grains and pulled-apart amphibole crystals. At this textural stage, the rock has the aspect in the field of a true orthogneiss, with the

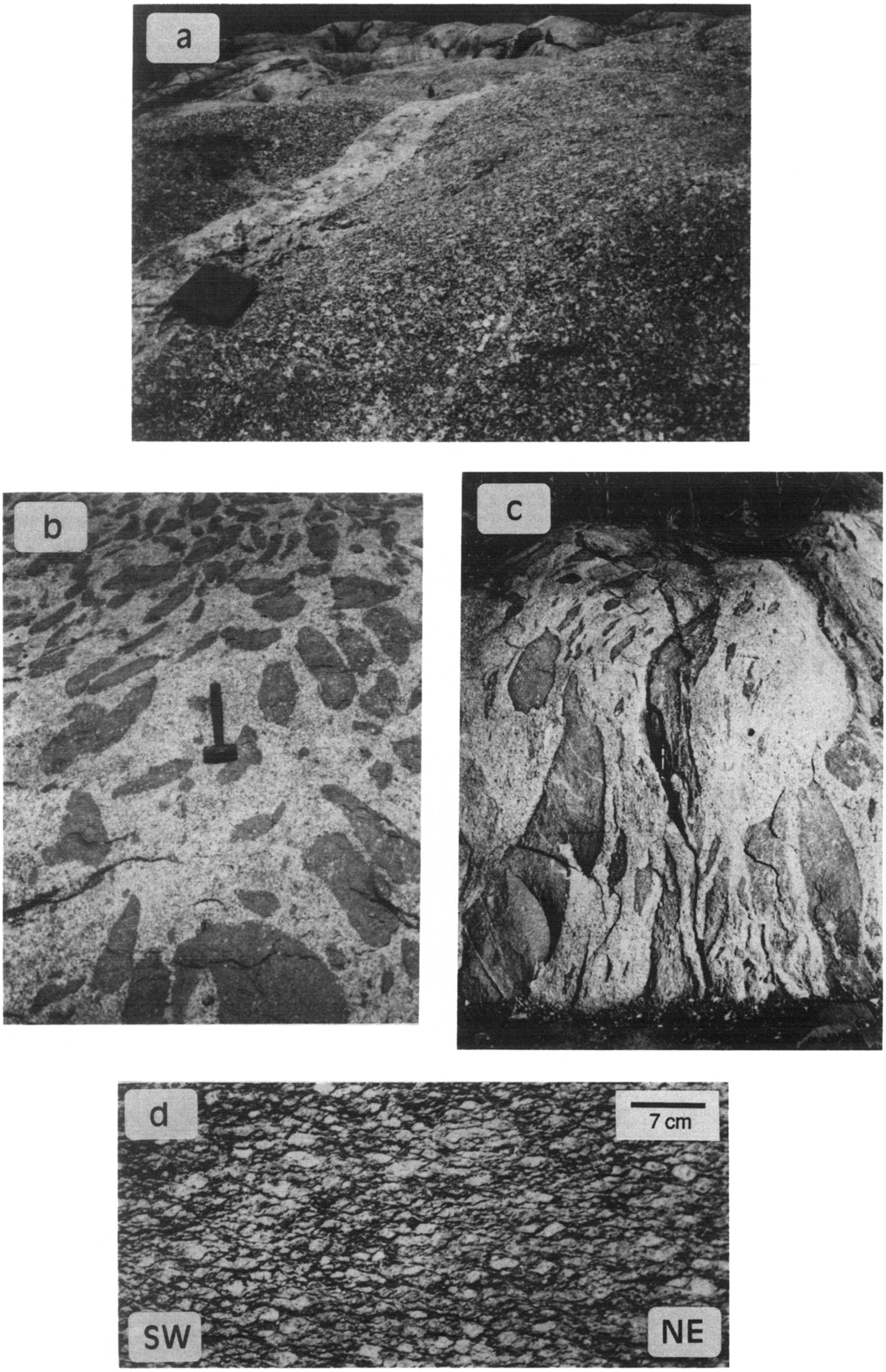

Fig. 4. Magmatic and solid-state structures in the Pombal pluton: (a) porphyritic granite cross-cut by late pegmatite dike; (b) mafic enclaves in quartz–syenite displaying a very slight shape-preferred orientation of their long axes; (c) aligned mafic enclaves in porphyritic granite marking a steep magmatic foliation, and (d) porphyritic granite deformed along the Rio Piranhas shear zone; the *C–S* surfaces, vertical in the photograph, indicate a dextral shear.

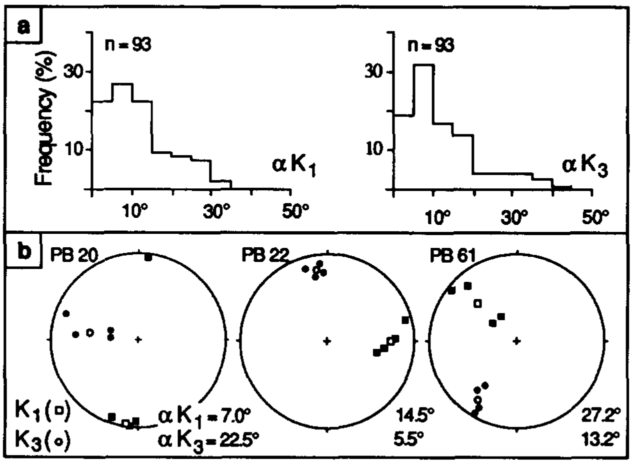

Fig. 5. Quality of the AMS measurements. αK_1 (or αK_3) is the angular departure (in degrees) between the four individual measurements k_{1j} (k_{3j}) of a given station ($j = 1, 4$). (a) Frequency histograms of αK_1 and αK_3 for whole pluton. (b) Stations PB20, PB22 and PB61, with their arithmetic mean values of αK_1 and αK_3, are given as representative examples (Schmidt, lower-hemisphere).

frequent development of *C–S* structures (Fig. 4d). Intensity of the plastic deformation is further marked by late aplite dikes that are folded and/or boudinaged. Such intensely deformed rocks are found in the cores of the NE-trending gneissified zones (Fig. 3), particularly along the RPSZ in the northern part of the massif. To the southwest of the pluton, tectonic reactivation more-or-less parallel to these fault zones occurred during Cretaceous times, forming the eastern extremity of the Souza intracontinental basin (Fig. 2).

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY

Procedure

We sampled the pluton systematically at 93 regularly spaced stations, an average of 1.5 km apart. At each station, two cores were obtained using a portable drill, and these were oriented *in situ* with respect to the geographical frame. Each core was then cut into two cylindrical specimens, 2.5 cm in diameter and 2.2 cm in height. Hence, each station is represented by four specimens totalling a rock-volume of about 43 cm^3. The specimens were measured for their anisotropy of magnetic susceptibility (AMS) using the KLY-2 Kappabridge susceptometer, working in low alternating field ($\pm 3.8 \times 10^{-4}$ T; 920 Hz) with a sensitivity better than 10^{-7} SI. Each specimen is therefore characterized by the geographical orientations and the magnitudes of the three principal axes of its AMS ellipsoid, $k_1 \geq k_2 \geq k_3$. The working data for each station ($j = 1, 4$) are the tensorial means of k_{ij} ($i = 1, 3$): long axis of the station's AMS ellipsoid, or magnetic lineation K_1, and short axis of the AMS ellipsoid, or normal K_3 to the magnetic foliation. The very good consistency of individual measurements within stations is shown in Fig. 5(a) by the arithmetic means (αK_i) of the angles between k_{ij} and K_i ($i = 1$ and $i = 3$): in 82% of the stations, αK_i is less than 20°. Figure 5(b) gives the stereoplots of k_{ij} and K_i for three ordinary stations of the Pombal pluton, illustrating the within-station directional variability as well as the significance of αK_i.

Magnetic susceptibility and anisotropy

The susceptibility magnitudes K of the different rock types vary from 2.8×10^{-4} to 4.5×10^{-2} SI (Fig. 6). Although most quartz–syenites have susceptibility magnitudes larger than 10^{-2} SI, no other particular relationship is observed between the petrographic composition and the susceptibility magnitude. However, the few stations with $K < 5 \times 10^{-4}$ SI belong to porphyritic types. Their low susceptibility magnitude can be explained by the rock iron-content entering entirely into the paramagnetic mineral species (Rochette 1987, Rochette *et al.* 1992), namely biotite and amphibole. Magnetic fabric of the rocks having the lowest susceptibility magnitudes is therefore due to crystallographic fabric of biotite and amphibole. In all the other stations, the high magnitude of the magnetic susceptibility points to a dominant ferromagnetic contribution. Magnetite is in fact the principal opaque phase. The large variations observed in magnetic susceptibility magnitudes between stations, and sometimes within the same station, are therefore attributed to small variations in the rock content in magnetite.

Total anisotropy magnitude, defined as the ratio

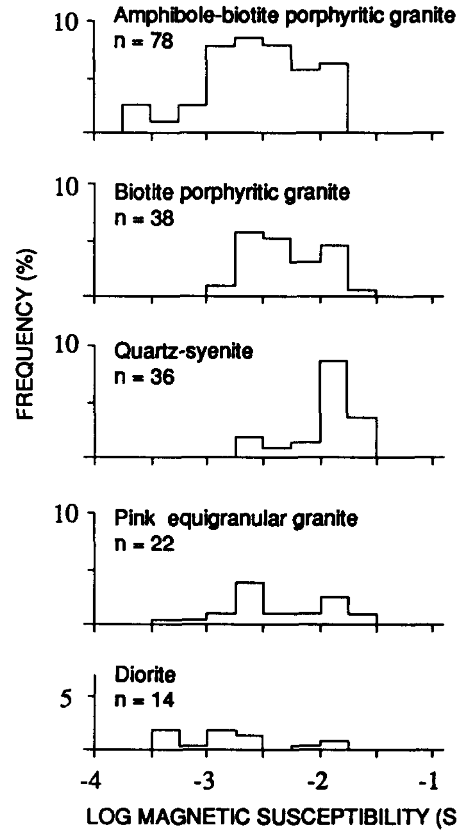

Fig. 6. Frequency histograms of the magnetic susceptibility magnitudes in the main petrographic units of Pombal pluton. n = number of specimens.

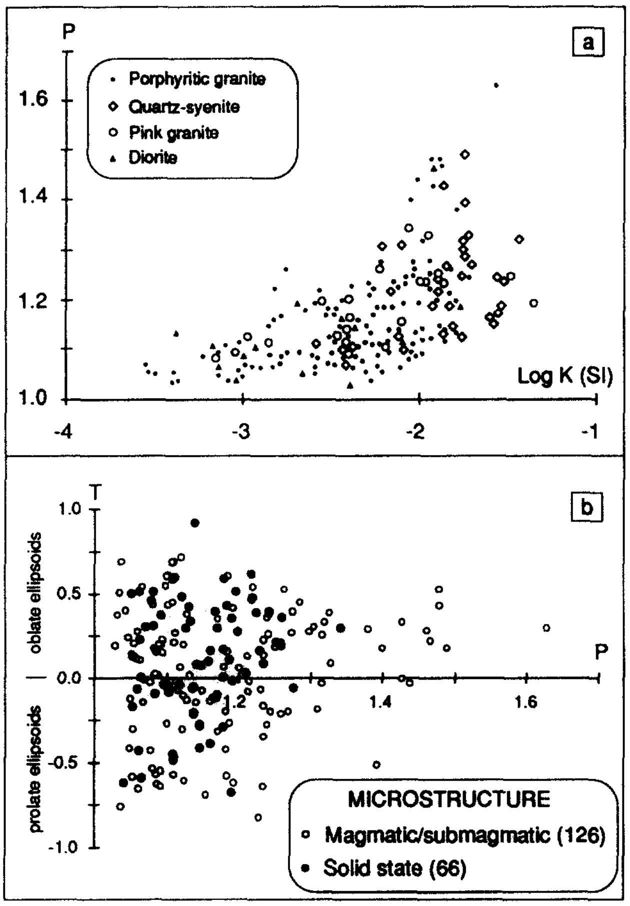

Fig. 7. AMS parameters. (a) Total anisotropy (P) vs magnetic susceptibility magnitudes (K) plot for the main petrographic units of the Pombal pluton. Same number of specimens as for Fig. 6. (b) Shape parameter (T of Jelinek 1976) vs total anisotropy, with distinction between specimens having magmatic or solid-state microstructures. Number of specimens in parentheses.

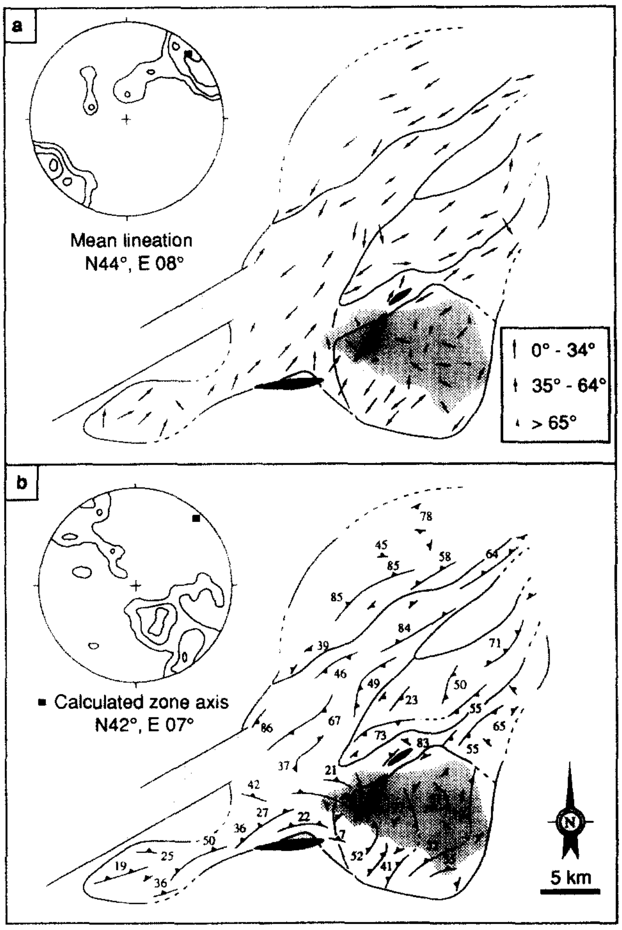

Fig. 8. Magnetic structures in Pombal pluton. (a) Lineations; (b) foliatio; trajectories. In black: aplites. Schmidt lower-hemisphere diagrams; contours: 2, 4, 6, 8 and 10% per 1% area.

between the maximum and minimum susceptibilities $P = K_1/K_3$, is highly variable. It ranges from 1.03 to 1.60, with 78% of the specimens falling between 1.05 and 1.25 (Fig. 7a). Variations of P show no clear correlation either with rock type or with the rock structure or microstructure (Fig. 7b). However, the average magnitude of P increases along with the increase of the bulk susceptibility (Fig. 7a). A similar correlation is observed among variously deformed magnetite-bearing rocks (Rochette *et al.* 1992). For no more than traces of magnetite ($K < 10^{-3}$ SI), variations of the magnitudes of P are attributed to competition between anisotropies of paramagnetic and ferromagnetic minerals (Borradaile 1988, Rochette *et al.* 1992). For high magnetite contents, variations in susceptibility and anisotropy magnitudes, when not directly related to intrinsic fabric magnitude variations, are due to the scattering in size and shape of the magnetite grains (Uyeda *et al.* 1963, Hrouda 1982), Shape of the AMS ellipsoid, defined by the parameter T of Jelinek (1978), is not correlated with P (Fig. 7b). However, oblate ellipsoids ($T > 0$) are slightly more abundant in granites displaying solid-state microstructures (62%) than magmatic microstructures (51%). Therefore, the magnetic ellipsoid shapes of granites under the influence of the RPSZ are not significantly different from those in the remainder of the Pombal pluton.

Magnetic fabric

With the exception of the southeastern sector of the pluton where steep plunges are common (Fig. 8a; greyish area), the magnetic lineations (K_1) have generally gentle plunges with NE–SW trends (calculated mean lineation: N44°, E08°). The magnetic foliations (planes normal to K_3), also with regular NE–SW strikes, have variable dips around a calculated axis at N42°, E07° (Fig. 8b). To simplify description of the magnetic fabric distribution, the pluton was divided into three domains, each having consistent orientations of their planar and/or linear structures (Fig. 9).

Domain I occupies about 15% of the total area, at the southwest of the pluton and comprises exclusively amphibole-bearing porphyritic granite. Microstructures are magmatic to submagmatic, except at the northern contact where solid-state deformation may be important (Fig. 3). Magnetic lineations in the granite plunge gently to the northeast (mean: N32°, E20°) and the magnetic foliations have moderate dips to the northwest (mean foliation: N70°, NW30°) (Fig. 9: orientation diagram). These orientations are very consistent with those of the

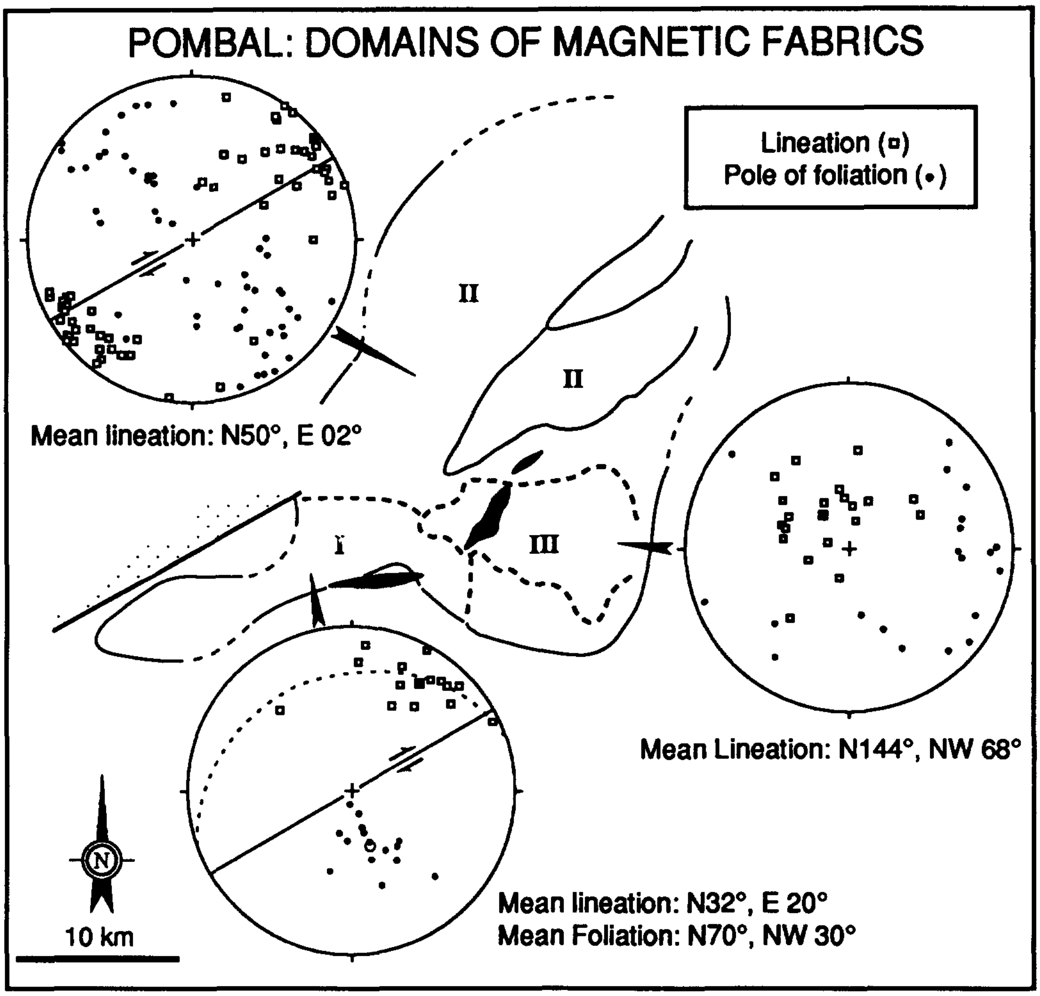

Fig. 9. The three domains of coherent magnetic fabrics in the Pombal pluton. The NE–SW vertical plane in the diagrams of domains I and II is parallel to the Rio Piranhas shear zone. In black: aplites. Schmidt lower-hemisphere diagrams.

country rocks south of the pluton (compare Figs. 2 and 9).

Domain II forms about 75% of the pluton and is composed of porphyritic granite (amphibole- and biotite-bearing) and pink equigranular granite. Northeast-trending shear zones, principally the RPSZ, with solid-state deformation microstructures of variable intensities, cross-cut the central part of this domain. However, microstructures remain typically magmatic on both sides of these shear zones (Fig. 3). The magnetic lineations have mostly gentle plunges either to the northeast or to the southwest (mean: N50°, E02°). The magnetic foliations, with NE-strikes and variable dips to the northwest or southeast, are oriented around a calculated axis (N50°, E03°) very close to the mean magnetic lineation. Note that the magnetic foliation strikes (N50°E) are more northerly trending by about 15° than the traces of the shear zones of this domain (Fig. 9: orientation diagram). These large-scale inflections of the planar fabrics are consistent with the dextral sense of the shear zones.

Domain III, the southeastern portion of the pluton with about 10% of total area, contrasts strongly with the other domains. It is mainly made of quartz–syenites, with magmatic structures everywhere, magnetic lineations plunging steeply, mainly to the northwest (mean lineation: N144°, NW68°) and magnetic foliations dipping steeply to the northwest.

DISCUSSION

Significance of the magnetic fabric

Homogeneity of the magnetic fabric within each of the three domains is particularly striking (compare Figs. 8 and 9). Since magnetite is the main carrier of AMS, the fabric is defined by the shape-preferred orientation of the magnetic particles dispersed in the rock matrix (Stacey 1960, Uyeda *et al.* 1963). These particles, with a mean size of 0.3 mm, represent less than 1% of total rock volume. Our purpose is to ascertain the parallelism between magnetic and mineral rock fabrics.

The directional regularity of the magnetic fabric, both within stations and between stations over several km^2 in the pluton, points to an efficient mechanism for the formation of AMS. In reflected light studies of thin sections, magnetite is slightly inequant in shape and always associated with biotite, amphibole and sphene. When in mutual contact with biotite or amphibole, magnetite grains have their long axes parallel to the crystallographic limits of these minerals. Therefore, if biotites and amphiboles have a shape-preferred orientation in the granite, statistical alignment of long axes of magnetite grains will develop a magnetic fabric. We believe that this kind of mimetic fabric of magnetite over biotite and amphibole is an important mechanism for producing consistent AMS fabrics over larger areas in granites.

Detailed fabric studies from magnetite-bearing plutons of the Seridó belt support the contention that magmatic and magnetic fabrics can be equated. In the Acarí pluton (150 km northeast of Pombal), Archanjo *et al.* (1992) demonstrated that the magnetic fabric was parallel to the magmatic fabric, at least in places where it was possible to make good measurements in the field. This has also been verified in a few stations of Pombal. In addition, an automatic image analysis of the shape fabric of magnetite and biotite grains in samples from Gameleiras, another magnetite-bearing pluton of the Seridó (200 km northeast of Pombal; Launeau & Archanjo 1992), showed: (i) that the axes of the shape fabric of biotite were subparallel to the axes of the AMS ellipsoid; and (ii) that the magnetite grains, which are primary and always slightly inequant in shapes, are approximately aligned parallel to the long axis of the rock fabric. Although these specific studies have not been conducted here, there is no reason why the behaviour of the granites of Pombal should differ from that of other magnetite-bearing granites of the Seridó. The possible complementary role of the anisotropy of distribution of the magnetite grains invoked by Stacey (1960) and reappraised by Hargraves *et al.* (1991) has not been examined in the present study.

Homogeneity of the directional magnetic fabrics contrasts, however, with the scattering of the scalar data from the AMS. The highly variable magnitudes, even within individual specimens from the same station, of both bulk magnetic susceptibility and anisotropy data, make these parameters impossible to use as gauges to evaluate strain intensity. Origin of scattering of large magnitudes, probably related to the small number of grains carrying the susceptibility, still remains unclear. Hopefully this does not affect the directional stability of the AMS ellipsoid.

Magmatic fabric in the pluton and solid-state fabric in the country rocks

A very conspicuous result of this study is the overall parallelism between the magnetic–magmatic fabric in the granite and the high-temperature solid-state deformation fabric in the country rocks. This is particularly obvious for the foliation. Except in domain III where they have high plunges, lineations in the granite have NE strikes, parallel to the mineral stretching lineations in the country rocks (Figs. 2 and 8). The south and southwestern contacts of the pluton (domain I) are of special interest: a remarkable continuity in orientations is observed between the magmatic foliations in the granite and the metamorphic foliation of the host gneiss, both dipping gently to the north. In the central and northern parts of the pluton (domain II), the foliation dips variably from gently to steeply (Figs. 8 and 9). The stereoplots of Fig. 9 show that foliation poles of domain II are distributed along a girdle whose pole roughly coincides with the mean lineation. In this domain, the magmatic foliation dips steeply and becomes parallel to the mylonitic foliation of the RPSZ. Domain III is a structurally anomalous region, with quartz–syenites totally devoid of solid-state deformation microstructures. It forms a large area (about 50 km^2) of steep lineations plunging mainly to the northeast. This peculiar domain is interpreted as a feeder zone entirely isolated from the subsequent deformations that affected the pluton.

Comparing magmatic and solid-state fabrics therefore allows us to stress that: (i) except in domain III, there is a clear concordance between the magmatic fabric and the solid state gently dipping foliation bearing a NE-striking mineral lineation in the host gneiss; (ii) in the vicinity of the RPSZ, the NE-striking magmatic foliation locally dips steeply, as does the mylonitic foliation; and (iii) absolutely no influence of the E–W mylonitic fabric of the Patos shear zone on the magmatic fabric of the pluton is recorded.

Two cross-sections, one at a high angle (Fig. 10a) and the other almost parallel (Fig. 10b) to the RPSZ allow us to summarize the observations. Variation in dip of the foliation (Fig. 10a) outlines a palm-like geometry of the planar fabrics in the pluton. In both sections, the planar fabric south of the pluton shows a dip which becomes gradually steeper where approaching the Patos shear zone.

Synkinematic emplacement of the Pombal pluton

The similarity between magmatic and metamorphic fabrics in the granite and host gneiss suggests that emplacement and fabric development of the Pombal pluton were controlled by the deformation of the country rocks. Owing to the domainal magmatic fabric underlined by AMS measurements, two tectonic models may be considered, depending on which domain is thought to represent the best record of the regional-scale deformation.

Parallelism of the gently dipping magmatic foliation of domain I with the solid-state foliation of the host rock suggests that the magma flow was driven by NE–SW-directed tangential tectonics. In this first model, the variably dipping foliation of domain II may represent an initially low-angle magmatic foliation, tilted before freezing in a zone that prefigures the RPSZ. Then, after total crystallization, the northwestern part of the pluton, together with the host rock, was mylonitized into the RPSZ that developed possibly coeval with the Patos shear zone (Corsini *et al.* 1991). Whether a tangential deformation of Brasiliano age existed at a regional scale is difficult to ascertain. Supporting data are the evidence of southwestward displacement observed in the Des-

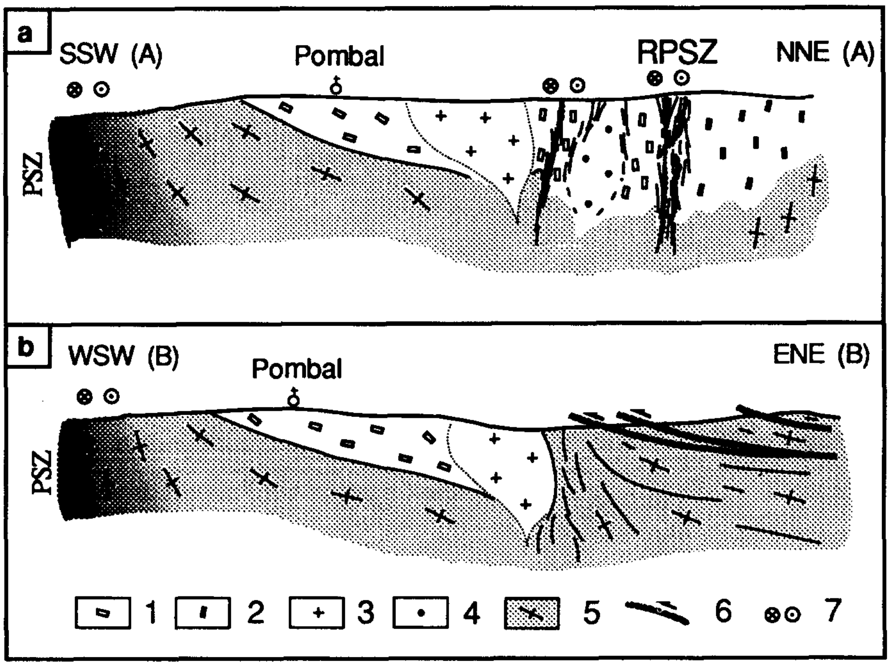

Fig. 10. Schematic cross-sections of the Pombal pluton and main structures in the country rocks (see Fig. 2 for location): (1) biotite–amphibole porphyritic granite; (2) biotite porphyritic granite; (3) quartz–syenite; (4) pink equigranular granite; (5) basement; (6) low-angle shear zones; and (7) dextral strike-slip shear zones. The NNE–SSW section (a) is oblique to the lineation and shear zones. Note the palm-like geometry in the traces of the magmatic planar fabric. Slightly oblique to the lineation, the ENE–WSW section (b) underlines the low-angle structures inside and around the pluton. Top-to-the-southwest sense of the shear, sketched in the east-northeast part of the pluton, has been observed in the Desterro region. In both sections, the planar fabric becomes progressively steeper approaching the Patos shear zone (PSZ).

terro area, the existence of an early flat-lying foliation in the Seridó belt (Ries & Schackleton 1977, Jardim de Sá *et al.* 1988), and a flat-lying magmatic fabric already observed in other granite plutons far away from the Pombal pluton (Archanjo *et al.* 1992). However, there is no conclusive evidence that all flat-lying foliations are coeval. An alternative view grounded on geochronological data (Macedo *et al.* 1984, Jardim de Sá *et al.* 1988) considers that most, if not all, flat-lying foliations of the Seridó belt are Transamazonian in age (*ca* 2.0 Ga) (Bertrand & Jardim de Sá 1990).

On the other hand, if one considers that the steeply dipping magmatic foliation of domain II indicates a magmatic state deformation in relation with regional-scale strike-slip faulting, a different model may be drawn (Fig. 11a). It may be assumed that before final emplacement of the granite, the regional-scale RPSZ and SNSZ already existed and formed a right-hand en échelon system of dextral shear zones. Magma upwelling may have been favoured by the development of a transtensional domain (hatched in Fig. 11a) in the overlapping sector of these shear zones. Low-dip foliations in both the porphyritic granite and the migmatitic gneiss in the south of the pluton, may have been formed in response

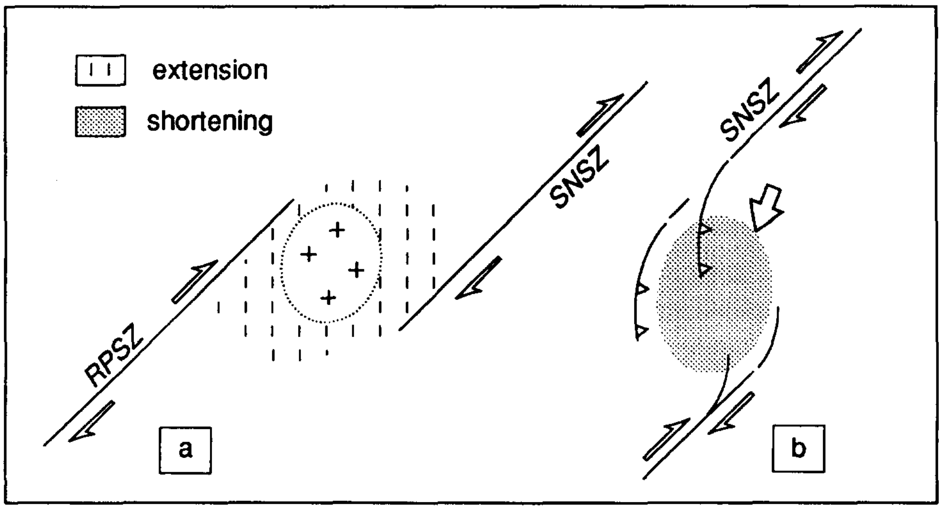

Fig. 11. En échelon fault models (a) for the emplacement of the Pombal pluton and (b) for the top-to-the-southwest low-angle shear zones of the Desterro region. The left and right arms of the fault segment (RPSZ, SNSZ) are correlated with the Rio Piranhas and Serra Negra shear zones. See text for discussion.

to the extensional deformation needed to transfer deformation from one shear zone to the other. In a similar way, the low-angle shear zones observed in the region of Desterro may represent perturbations of the deformation field due to a left-hand en échelon system of dextral faults. A compressive bridge may have taken place in the overlapping sector of the faults, favouring thrusts with a top-to-the-southwest motion (Fig. 11b). Kinematic compatibility and similar high-grade metamorphism in both steeply and gently dipping shear zones suggest that these structures formed in the same tectonic setting. Common association of granites with NE-striking shear zones in the Seridó belt supports this model. It should be noticed however that the RPSZ does not terminate in the Pombal pluton as suggested by the pull-apart model of Fig. 11(a), but has been observed northeastward over more than 100 km. To account for this, it may be speculated that the en échelon system was formed during an early stage of deformation; after emplacement of the granite, the RPSZ continued growing and propagated northeastward, probably in relation with onset of E–W-striking shearing of the Patos.

CONCLUSION

Magnetic–magmatic structural mapping of the Pombal pluton shows a good parallelism between the magmatic fabric in the granite and the solid state fabric in the country rocks. This supports a tectonic control on magma flow during emplacement. One of the clearest results of this study is the absence of imprint of E–W-striking transcurrent shearing typical of the Patos shear zone. This is particularly evident at the southwest border of the pluton. Transition from a gently dipping magmatic foliation carrying a NE-striking lineation to a metamorphic foliation with the same orientation then to a vertical foliation carrying an E–W stretching lineation, occurs over less than 1 km. Hence, we interpret the Pombal granite intrusion as not related with the kinematics of the mega shear zone of Patos.

The model of emplacement of the Pombal pluton is synkinematic with the NE–SW tectonics that extend northeastward in the whole Seridó belt. The magnetic–magmatic flow pattern displays mainly subhorizontal NE-striking lineations and foliations settled around an axis parallel to the lineation. Coexistence of low dip and steep dip foliations bearing a subhorizontal lineation suggests that the mechanism of emplacement combines flat and strike-slip shearing, at least during the latest stages before magma freezing. The same fabric pattern occurs in porphyritic plutons intruded in the Seridó belt 150 km northeast of Pombal (Archanjo *et al.* 1992), strongly suggesting that the granitic Brasiliano magmatism was controlled by the same tectonic setting over a wide region.

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