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The emplacement of the granitic Las Tazas complex, northern Chile: the relationship between local and regional strain

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Abstract

The Coastal batholith of northern Chile grew under transtensional–extensional conditions that prevailed along the Andean margin during the Mesozoic. The batholith hosts the Atacama Fault Zone, a major arc-parallel fault system which was characterised by sinistral transtensional shearing during the Early Cretaceous. The Las Tazas complex is a composite granitoid intrusion that was emplaced syntectonically along the Atacama Fault Zone at ~130 Ma. Syntectonic emplacement is indicated by a consistent kinematic history between the complex and its wall rocks, together with synchronous crystallisation and shearing ages. In contrast to regional patterns, the Las Tazas complex was emplaced during a local change from vertical east-side-down to dextral transcurrent displacement along the fault zone. During intrusion, strain was partitioned between non-coaxial simple shearing within country-rock mylonites and a flattening strain across the crystallising complex. This combination indicates that the pluton was emplaced under temporary transpressive conditions that were localised around the pluton, probably induced by magma emplacement. Such a difference between local and regional strain suggests that emplacement-related structures should only be related to regional strain-states with great care.

1. Introduction

The Las Tazas granodiorite and munzunite plutonic complex was emplaced along the Atacama Fault Zone, a major structure that was intimately linked with the construction of the Mesozoic Coastal batholith of northern Chile. The Las Tazas is one of a number of complexes associated with the Atacama Fault Zone, but is unusual in displaying evidence of syntectonic emplacement under localised transpression, within an otherwise transtensional arc setting. This is of particular interest, since many syntectonic intrusion models are based on the injection of magma into tensional segments of fault zones (e.g. Guineberteau et al., 1987; Hutton et al., 1990; Grocott et al., 1994; Ferré et al., 1995), while the strain patterns around syntectonic plutons are commonly used to define regional strain patterns. This study illustrates that neither of these common assumptions need be correct.

The study focused on a comparison of magmatic fabrics and kinematic criteria across the complex and within high-temperature ductile shear zones along its edges. This is complemented by an examination of magnetic fabrics across the complex using the low-field anisotropy of magnetic susceptibility (AMS) technique (Tarling and Hrouda, 1993). The combination of field, petrographic and magnetic susceptibility structural data has allowed definition of the kinematic framework during emplacement, the mode of pluton construction and strain partitioning between the intruding magma and its wall rocks.

2. Regional geology

The Coastal batholith of northern Chile crops out between 18°S and 26°S along the Coastal Cordillera. It comprises Permian to Early Cretaceous plutonic complexes that were emplaced into Palaeozoic metasedi-

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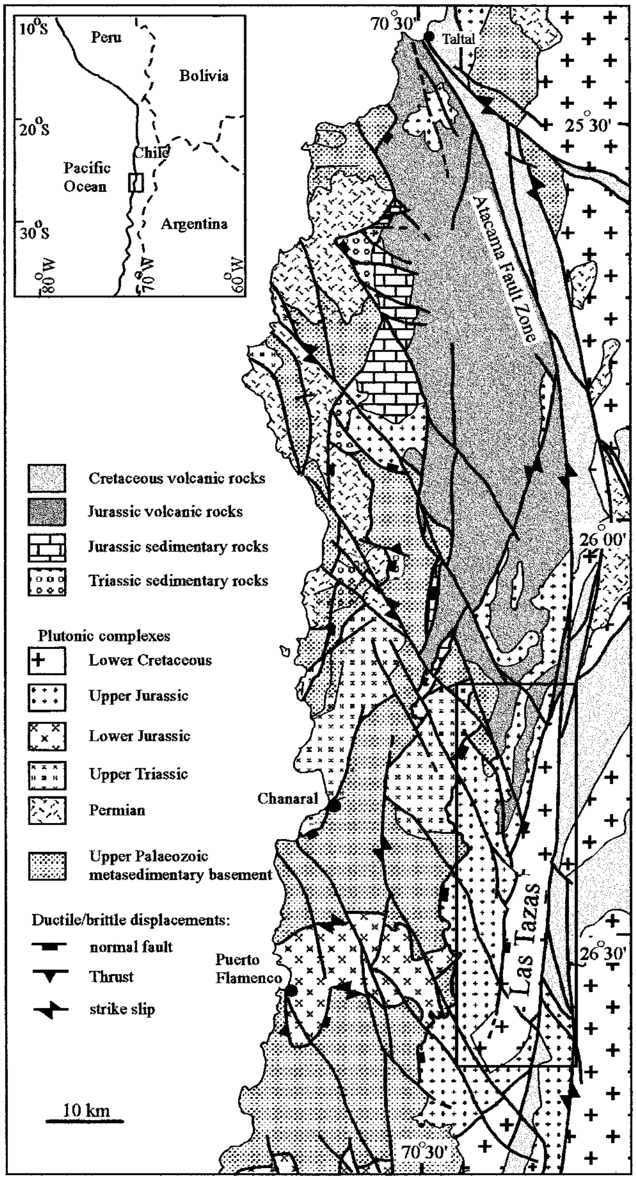

Fig. 1. Geological map of the area between 25°30′S and 26°30′S, in the Atacama region of northern Chile. Box indicates location of Fig. 2.

mentary basement (Fig. 1; Brook et al., 1986). The complexes range from calc-alkali hornblende–biotite gabbros, through diorites, tonalites and granodiorites to subsidiary granites that were emplaced into the upper crust (Dallmeyer et al., 1996). They have a common metaluminous character, with low Sr_i (0.703–0.705), and display similar geochemical patterns, suggesting a similar, possibly common mantle source (Berg and Baumann, 1985; Brown, 1991). The batholith grew episodically during a succession of volcanic and plutonic events that were separated by magmatic hiati (Brown, 1991; Dallmeyer et al., 1996). The Permo-Triassic and Jurassic plutons were emplaced as laccoliths, sometimes along low-angle extensional shear

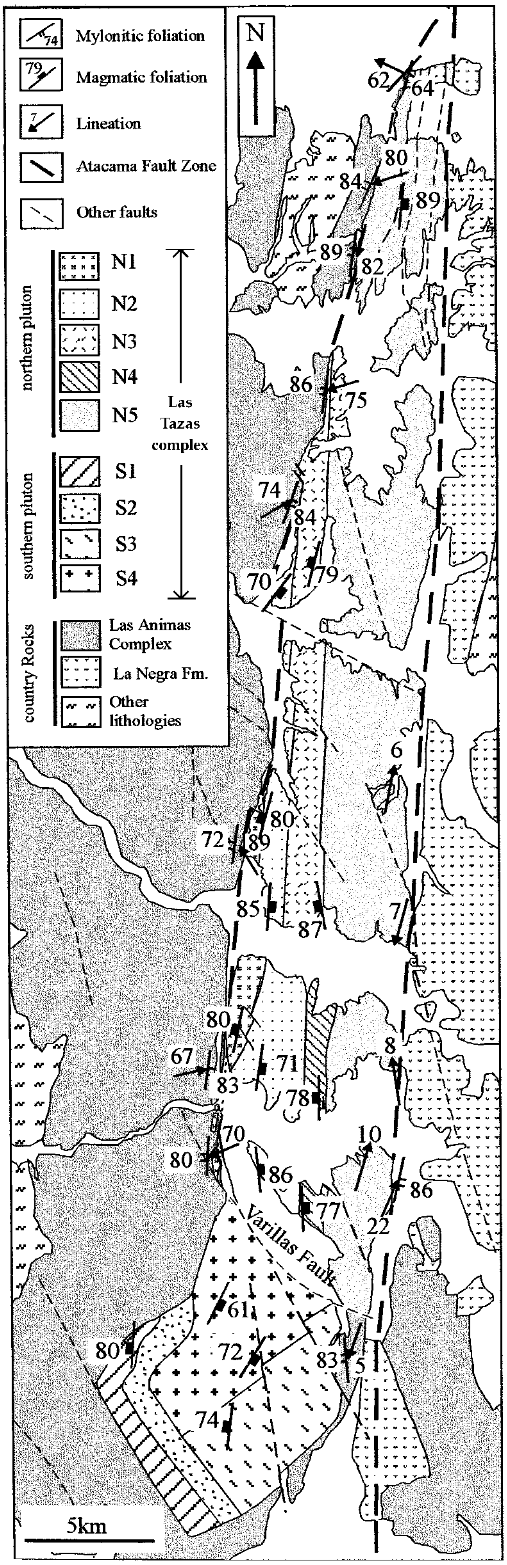

Fig. 2. Geological map of the Las Tazas complex. The complex is composed of two composite plutons, a granodioritic northern and monzonitic southern pluton. They are bounded by Upper Jurassic tonalites of the Las Animas complex to the west and Cretaceous volcanic rocks of the La Negra Formation to the east. Two mylonitic shear zones of the Atacama Fault Zone bound the Las Tazas complex to the east and west.

zones (Grocott et al., 1994; Grocott and Wilson, 1997). In contrast, the Early Cretaceous plutons were emplaced as vertical sheets during arc-parallel transcurrent displacement along the Atacama Fault Zone (Hervé, 1987; Uribe, 1987; Scheuber and Andriessen, 1990; Brown et al., 1993; Scheuber et al., 1995). The Atacama Fault Zone is defined by a number of subparallel brittle shear zones that trend along the Coastal Cordillera of Chile, with localised ductile segments in the vicinity of plutons (Brown et al., 1993; Scheuber et al., 1995). It became active between the Late Jurassic and Early Cretaceous, displaying a pattern of early dip-slip and later sinistral transcurrent displacement (Scheuber and Andriessen, 1990; Scheuber et al., 1995; Dallmeyer et al., 1996). It has been interpreted as a trench-linked transcurrent fault (*sensu* Woodcock, 1986) which formed in response to oblique subduction (Zonenshayn et al., 1984; Scheuber and Andriessen, 1990; Brown et al., 1993). Active displacement ended in the middle Cretaceous, when the arc was abandoned.

3. The Las Tazas complex

The Las Tazas complex crops out at 26°S in the Coastal Cordillera of northern Chile and covers an area of 232 km^2 (Fig. 2). It comprises an elongate, granodioritic northern pluton and a square, monzonitic southern pluton (Fig. 2). Both plutons have a calc-alkali, metaluminous character, comprising andesine, orthoclase, hornblende, biotite, quartz and magnetite $\pm$ clinopyroxene. Initial ^{87}Sr/^{86}Sr values of 0.7033–0.7035 and ϵNd (130) values of $+5.1$ to $+6.4$ indicate that they were produced from a LREE-enriched mantle or juvenile crust magmatic source (Berg and Baumann, 1985; Hodkinson et al., 1995). The complex forms a north–south striking vertical slab which is flanked by La Negra Formation andesites to the east, and tonalites of Upper Jurassic Las Animas complex to the west (Fig. 2). Al-in-hornblende geobarometry indicates that the northern pluton was emplaced in the brittle upper crust at 7 km depth (Dallmeyer et al., 1996), giving an ambient rock temperature of ~200°C, at normal geothermal gradients.

Although the Las Tazas complex intruded the brittle upper crust, mylonite zones flank its western and eastern edges (Fig. 2). These mylonite zones define a localised ductile segment within the otherwise brittle Atacama Fault Zone, and are restricted to the length of the complex, giving way to brittle structures along strike. The mylonites along the western edge formed during pre-emplacement dip-slip shearing, while those along the eastern edge formed during post-emplacement transcurrent shearing. Concordant ~130 Ma crystallisation and cooling ages from the complex and mylonitic zones indicate that the complex was emplaced syntectonically during this kinematic switch (Naranjo et al., 1984; Dallmeyer et al., 1996).

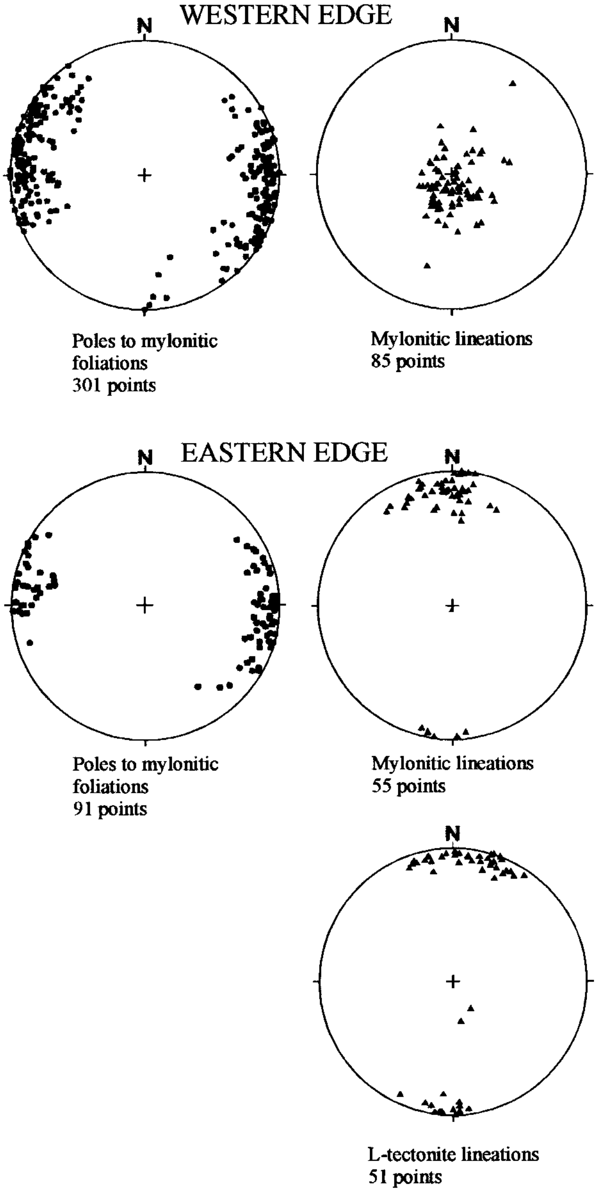

Fig. 3. Stereographic projections of structural data along the western and eastern edges of the Las Tazas complex.

The Las Tazas complex intruded a 250-m-wide mylonitic branch of the Atacama Fault Zone, which forms the western contact of the complex (Fig. 2). Post-emplacement shearing has reworked large sections of this contact, but segments of it retain their original intrusive character, especially towards the southern end of the complex. Las Tazas granodiorite is exposed against country-rock mylonites along a sharp, vertical and planar contact. In addition, detached screens of mylonitic wall rock crop-out within the pluton. The country-rock mylonites are tonalitic with amphibolite

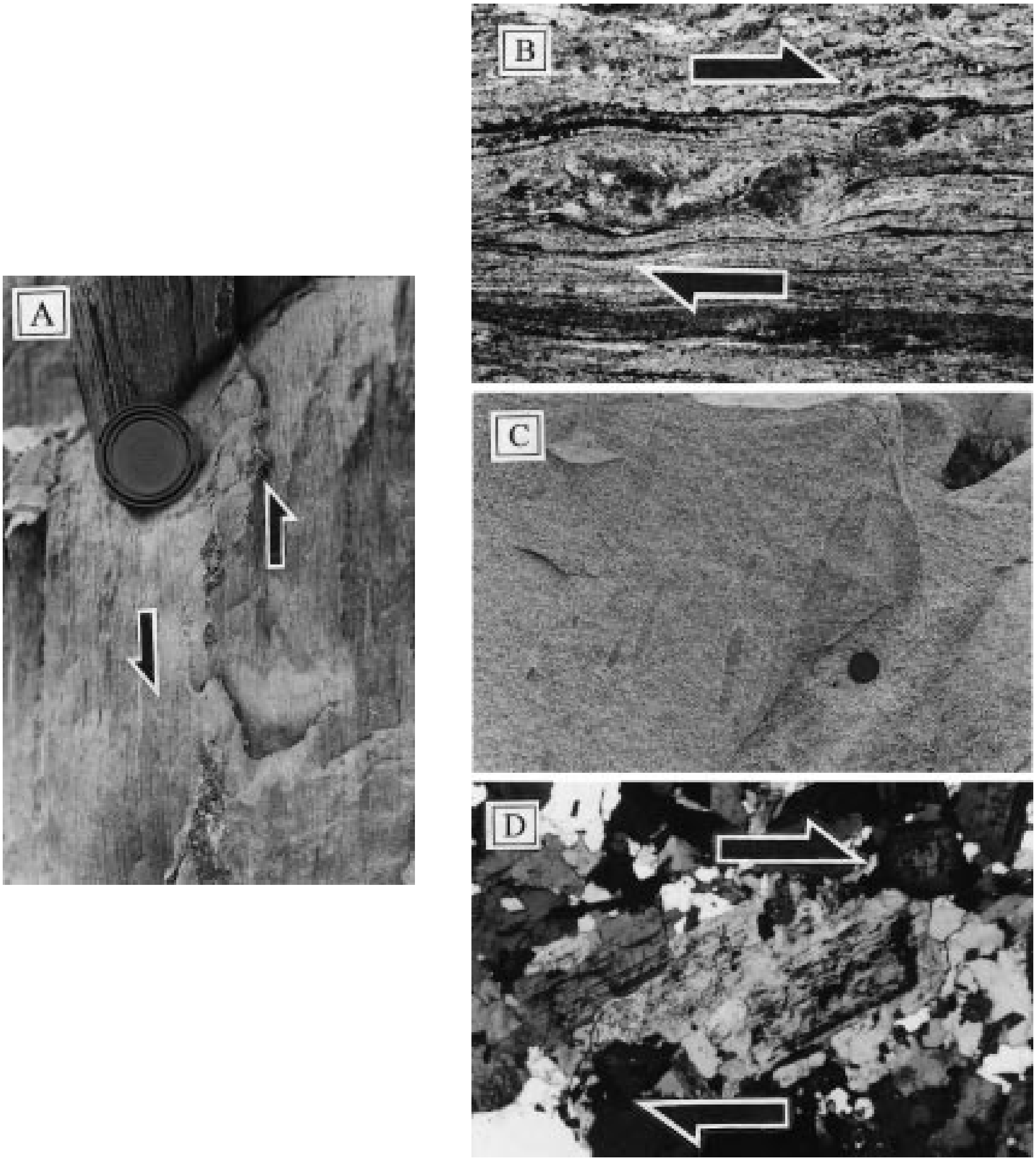

Fig. 4. (a) Photograph of plagioclase porphyroclasts from the dip-slip mylonites, indicating left-side-down (east-side-down) asymmetry. (b) Photomicrograph of dextral plagioclase porphyroclasts within transcurrent mylonites, indicating top-to-the-right (dextral) asymmetry. Field of view, 9 × 14 mm. (c) Photograph of southward-plunging enclaves within unit N1. (d) Photomicrograph of three imbricate plagioclase megacrysts within unit N5 with a top-to-the-right (dextral) asymmetry. Field of view, 4 × 6 mm.

facies assemblages, and a 0.2–0.5 mm grain size. Microfabrics are granoblastic, with high-angle grain boundaries along biotite 001 faces and spongiform diopside grains that cross-cut the main foliation. These features reflect thermal metamorphism without dynamic strain (Rutter and Brodie, 1992), which occurred in response to magma emplacement. The mylonites display a penetrative vertical foliation, which strikes 000°–040° parallel to the contact, and a subvertical hornblende stretching lineation (Fig. 3), implying formation during vertical shearing. Asymmetric andesine σ- and δ-porphyroclasts (Passchier and Simpson, 1986) within the mylonites display consistent crystal imbrication (Choukroune and Lagarde, 1977), asymmetric pull-aparts (Hippertt, 1993), and asymmetric pressure shadows (Simpson and Schmid, 1983). These display a uniform east-side-down shear sense (Fig. 4a). In addition to porphyroclasts, veined C'-surfaces deflect the foliation in the wall rock mylonites (Platt and Vissers, 1980). The C'-surfaces dominantly dip to the west and display an east-side-down shear sense. The veins are granodioritic and petrographically identical to the Las Tazas complex. Neither C'-surfaces nor veins are observed separately, implying that east-side-down shearing was concomitant with granodioritic intrusion.

The eastern edge of the Las Tazas complex was deformed during post-emplacement shearing and is marked by a ductile shear zone, which consists of mylonites up to 300 m wide with the highest strains centred along the contact. The eastern edge of the complex displays a progressive eastward increase in ductile strain over 500 m, from undeformed granodiorites though a transitional belt of protomylonitic *L*-tectonites, to ultramylonites at the contact. The *L*-tectonites have a well-defined magmatic linear fabric defined by elongate plagioclase and hornblende crystals, though strongly overprinted by ductile shearing. It has a horizontal plunge and trends north–south (Fig. 3). The country-rock mylonites are tonalitic, with a very fine, 5-μm grain size. They contain a vertical foliation, which strikes north–south (Fig. 3), and a horizontal stretching lineation (Fig. 3), reflecting formation during transcurrent shearing. Asymmetric δ- and σ-porphyroclasts (Fig. 4b) and folded veins within the main foliation display a dextral shear sense, together with quartz *c*-axis fabrics which have a component of dextral asymmetry (Law, 1990). Sinistral C'-surfaces (Platt and Vissers, 1980) cross-cut the *L*-tectonites and the country-rock mylonites, reflecting a later switch from dextral to sinistral displacement along the shear zone.

The northern and southern plutons in the Las Tazas complex comprise several closely related units that are discriminated by differences in grain size, crystal form and foliation intensity. Five main lithological units have been identified within the granodioritic northern pluton, referred to as N1–N5 (Fig. 2), which are separated by vertical contacts that strike north–south. Overall lithological variation is asymmetric, and varies from intensely foliated tonalites in the west to foliation-free porphyritic monzogranites in the east. There are sharp fabric changes at the internal contacts, which young eastward. The contact between units N1 and N2 is sharp and planar. The eastern edge of unit N1 displays intense magmatic foliations and highly elongate enclaves (Fig. 4c), while the eastern edge of unit N2 displays weak magmatic foliations and randomly aligned enclaves, suggesting that unit N1 had undergone significant magmatic strain before unit N2 was emplaced against it. Similarly, the contact between units N4 and N5 is sharp and irregular. Angular stoped blocks of N4 granodiorite are set within exposure of the unit N5, which was clearly emplaced later. The eastward-younging contacts and asymmetric lithological zoning demonstrate that the intruding magmas became progressively more felsic as emplacement progressed.

Magmatic plagioclase foliations (*sensu* Hutton, 1988) are observed across units N1–N4. They strike north–south with a vertical dip, parallel to the internal contacts, the eastern contact and transcurrent mylonites (Fig. 5), but oblique to the western contact and the dip-slip country-rock mylonites. The magmatic foliations do not contain a visible lineation, although highly elongate enclaves within unit N1 display a consistent steep southward plunge (Fig. 4c). Magnetic fabrics across the Las Tazas complex are controlled by magnetite and are parallel to the magmatic fabrics (Wilson, 1998). On this basis, thin sections have been cut along the plane normal to the magnetic (and magmatic if present) foliation, parallel to the magnetic lineation, to examine kinematic indicators in apparently isotropic hand specimens. These have yielded occasional asymmetric features. Sections from unit N1 display orthoclase phenocrysts with plagioclase crystal populations that display a systematic clockwise obliquity with respect to the main plagioclase foliation, reflecting an element of east-side-down vertical shearing during crystallisation. In addition, sections from unit N5 display megacryst tiling, reflecting an element of dextral shearing during crystallisation (Fig. 4d; Blumenfeld and Bouchez, 1988).

Four lithological units have been identified within the monzonitic southern pluton, referred to as units S1–S4, separated by vertical internal contacts. They become progressively more felsic from quartz monzodiorites within S2, through S1 and S3 to porphyritic monzogranites within S4. While the contacts are poorly exposed, the lithological evolution probably reflects the emplacement sequence, in the same manner as the northern pluton. Vertical magmatic foliations are observed across units S2–S4, defined by plagioclase and hornblende megacrysts, with a strike of 010 across the pluton (Fig. 5). They do not display a visible lineation or demonstrable kinematic indicators. The contact between the northern and southern plutons trends northwest–southeast and is marked by a 1-km-wide belt of pervasive brittle deformation and clay alteration, which is referred to here as the Varillas Fault (Fig. 2). The mylonitic shear zones along the complex edges dip vertically, but are displaced in different directions across the Varillas Fault (Fig. 2). The dip-slip mylonites along the western contact display a 200-m left-lateral horizontal separation across the fault, while the transcurrent mylonites along the eastern contact display a 1400-m right-lateral horizontal separation.

3.1. Magnetic structure

The magmatic-state structure of granitic plutons can be examined by measuring low-field magnetic suscepti-

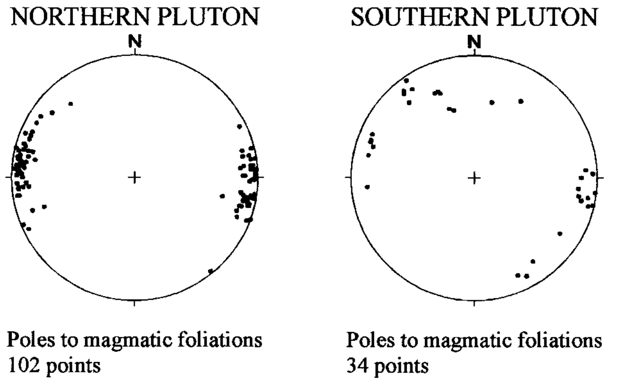

Fig. 5. Stereographic projections of poles to magmatic foliations across the northern and southern plutons.

bility patterns (reviews in Tarling and Hrouda, 1993; Borradaile and Henry, 1997). Magnetic susceptibility fabrics form from the alignment of magnetic minerals during igneous crystallisation and solid-state deformation. A total of 133 samples have been measured from 30 stations across the complex, with an average station spacing of 1 km (Fig. 6). Between two and five oriented 25-mm-diameter cores have been drilled at each site, 1–2 m apart. Each core yielded two to three 22-mm-long samples, which have been analysed using a Kappabridge KLY-2 susceptometer (Geofyzika Brno). Fifteen oriented susceptibility measurements have been taken from each sample, and resolved into a magnetic susceptibility ellipsoid, with three principal axes $K_1 > K_2 > K_3$ (Tarling and Hrouda, 1993) by a classical eigenvector procedure (Harvey and Laxton, 1980). The orientations of the axes define the magnetic foliation and lineation, which are parallel to their magmatic counterparts (Archanjo et al., 1995; Geoffroy et al., 1997; Wilson, 1998), and the relative magnitudes of the axes define the shape of the ellipsoid, analogous to a magmatic strain ellipsoid. Magnetite controls the

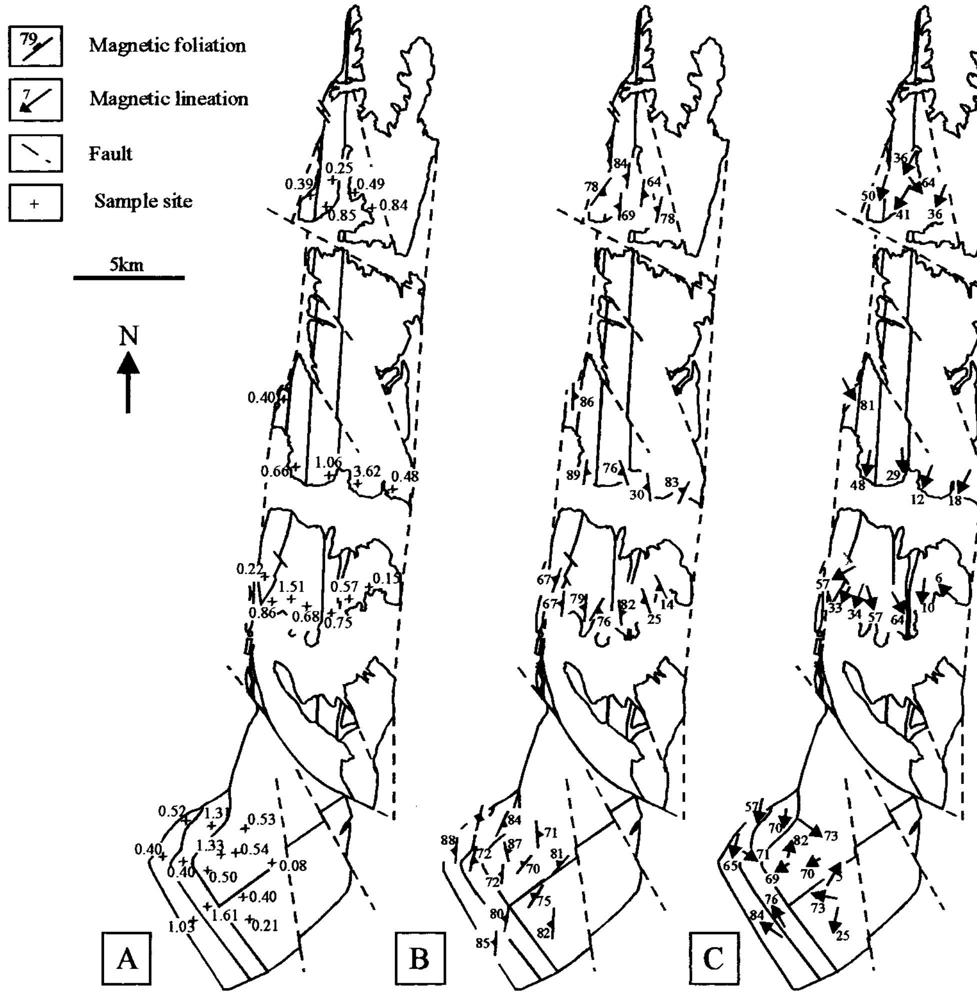

Fig. 6. Maps of (a) AMS ellipsoid shape parameter P_{Flinn} (analogous to the K shape parameter); (b) magnetic foliations and; (c) magnetic lineations. Magmatic strain ellipsoids are dominantly flattening ($0<P_{\text{Flinn}}<1$), although the well-defined linear orientations suggest a subordinate non-coaxial strain component.

magnetic susceptibility patterns across the Las Tazas complex, displaying a preferential alignment mimetic to the magmatic plagioclase foliation (Wilson, 1998). Magnetic ellipsoids across both plutons are dominantly oblate (Fig. 6a), reflecting the presence of magmatic foliations. Magnetic foliations are vertical and strike broadly north–south across both plutons (Fig. 6b), parallel to the magmatic foliations. Magnetic lineations plunge steeply within the southern pluton around a vertical axis, and southwards across the northern pluton. This southward plunge shallows eastwards across the northern pluton, and lineations are horizontal in parts of unit N5 (Fig. 6c).

4. Emplacement

The Las Tazas complex was emplaced against a dip-slip mylonite zone to the west, and deformed by transcurrent shearing along its eastern edge, demonstrating intrusion during a kinematic switch. Concordant crystallisation and cooling ages from the complex and the country-rock mylonites infer that emplacement was syntectonic (Naranjo et al., 1984; Dallmeyer et al., 1996 and unpublished data). In detail, field and microstructural observations indicate that the complex was emplaced during a change from dip-slip to dextral displacement, which subsequently switched to sinistral. It is likely that the southern pluton was emplaced during the early dip-slip shearing, based on a correlation of vertical lineations within the dip-slip mylonites and vertical magnetic lineations in the pluton. However, this is circumstantial and not well constrained by field evidence, since the dip-slip mylonites do not crop out against the southern pluton. It is likely that the northern pluton was emplaced slightly later, during the kinematic switch. Unit N1 intruded and thermally metamorphosed the dip-slip country-rock mylonites. Steeply plunging enclaves and magnetic lineations indicate that this occurred during vertical or steep, oblique-dextral shearing. Magmatic kinematic indicators in unit N1 and melt-filled C'-surfaces within the country-rock mylonites display a consistent east-side-down shear sense. The internal contacts young eastwards across the northern pluton, reflecting growth by episodic magma addition along its eastern edge. It follows that the magmatic fabrics young eastward across the pluton and preserve progressively later parts of the kinematic history. Magnetic and magmatic lineations shallow eastwards, reflecting a shallower slip direction along the Atacama Fault Zone, from oblique dextral displacement during the emplacement of units N2 through N4, to dextral transcurrent shearing during the emplacement of unit N5. This unit contains horizontal magnetic lineations and dextral kinematic indicators, which give way eastwards to *L*-tectonites with a horizontal fabric and country-rock mylonites with horizontal mineral lineations and dextral kinematic indicators. This represents a fundamental kinematic similarity between the country-rock mylonites and the northern pluton, providing strong evidence that it was emplaced during active shearing along the Atacama Fault Zone.

The intruding magma was probably accommodated by dominant fracture dilation, without significant components of in situ radial expansion, stoping, doming or assimilation. Several observations support this conclusion. Most obviously, the complex is a highly elongate intrusion with extensive evidence of vertical and lateral fault displacement close to the time of emplacement. Further, plutonic foliations are not parallel to those in the dip-slip mylonites, and country-rock mylonites do not display the uniform flattening strain that is characteristic of in situ ballooning (Bateman, 1984; Ramsey, 1989). In addition, there is only very localised field evidence of piece-meal stoping and no evidence of roof doming. Lastly, the Las Tazas complex exhibits a juvenile lower crust/mantle isotopic signature precluding significant upper crustal batch melting or wall-rock assimilation (Berg and Baumann, 1985; Hodkinson et al., 1995). The Las Tazas complex grew by the incremental addition of magma batches to edges of the two plutons. The dominance of fracture dilation and the presence of significant internal contacts suggests that the geometry of the internal contacts within the complex can be related to the displacement of the external contacts during emplacement, and constrain the apparent horizontal dilation direction. As described earlier, internal contacts within the southern pluton are vertical. As such the simplest way to accommodate units S1 and S2 is an apparent east–west dilation (Fig. 7a). In contrast, units S3 and S4 were probably accommodated by a northwest–southeast extension (Fig. 7b). The square geometry of the southern pluton, together with its position between two fault branches, suggests that it was emplaced in a normal fault relay ramp (*sensu* Peacock and Sanderson, 1994) within the Atacama Fault Zone. The northern pluton has a northward-tapering, vertically sheeted internal geometry. This suggests magma emplacement by an apparent east–west horizontal dilation across the Atacama Fault Zone, to give a wedge-shaped pluton (Fig. 7c). This dilation was accommodated by displacement along the Varillas Fault. As described earlier, the two mylonite zones dip vertically and are displaced in different directions across the Varillas Fault (Fig. 8a). This differential displacement is most simply explained by magma-induced dilation. The dip-slip mylonites mark the position of the contacts during pre-emplacement vertical shearing (Fig. 8b), while the transcurrent mylonites mark their position during the post-emplacement transcurrent

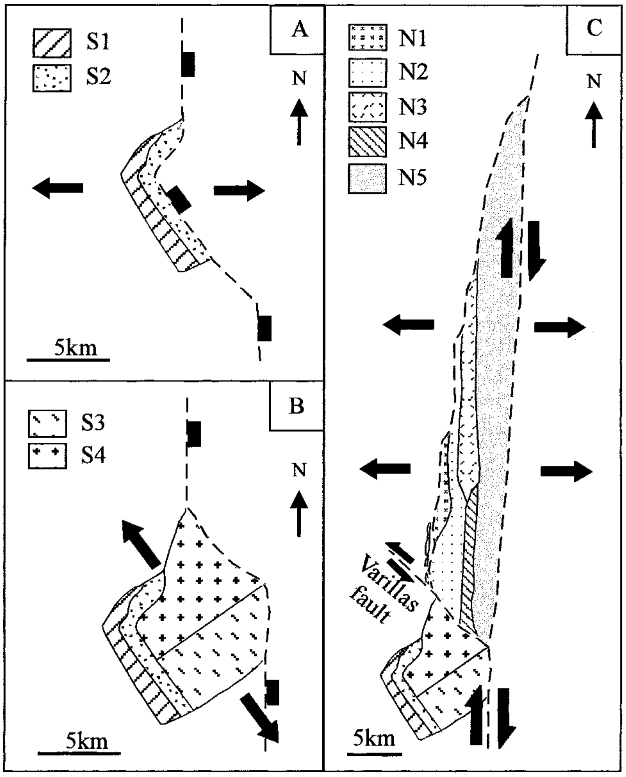

Fig. 7. Schematic map illustrating the growth of the Las Tazas complex. Space is created by the interaction of the mylonitic shear zones with subsidiary faults. (a) Units S2 and S1 emplaced during east–west extension. (b) Units S3 and S4 emplaced during northwest–southeast extension. (c) Growth of the northern pluton by east–west dilation.

shearing (Fig. 8c). To displace the Atacama Fault Zone between the pre- and post-emplacement positions requires 2400 m sinistral and 5600 m dextral apparent horizontal displacement across the Varillas Fault (Fig. 8c), which was induced by the emplacement of the northern pluton.

The emplacement-related strain-state can be estimated from a qualitative comparison of country-rock and plutonic fabrics. Kinematic similarity and concordant ages between the country-rock mylonites and the complex infer that ductile shearing was concomitant with emplacement, implying that fabrics within both reflect the emplacement-related strain-state. The country-rock mylonites are north–south-striking, vertical *L–S* tectonites with well-defined foliations, lineations and frequent asymmetric microstructures. This combination of structures reflects a plane-strain simple shear. In contrast, the complex displays vertical north–south-striking magmatic *S*-fabrics with oblate magnetic ellipsoids, and only occasional asymmetric microstructures. This reflects crystallisation during a horizontal coaxial flattening strain across the magma chamber. The combination of coaxial flattening and non-coaxial simple shearing suggests that the Las Tazas complex was emplaced under transpressive conditions (Sanderson and Marchini, 1984). Emplacement along a pre-existing fault zone causes strain to partition into a zone of coaxial flattening surrounded by planes of simple shearing (Jones and Tanner, 1995). This is highly likely across a zone with low friction or cohesion, such as a low crystal content magma in a shear zone (Jones and Tanner, 1995). Transpressive shearing

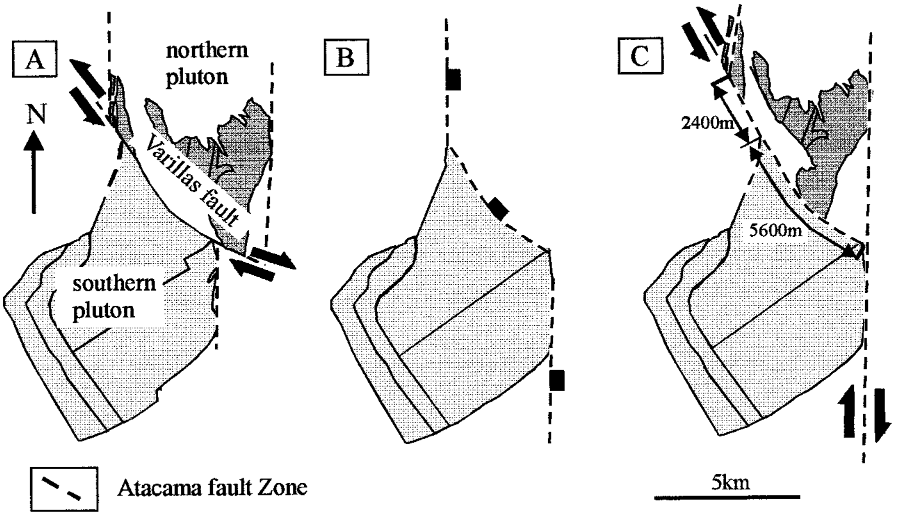

Fig. 8. Schematic maps illustrating displacement across the Varillas Fault. (a) Current positions of the Atacama Fault Zone branches. The two mylonite zones dip vertically and are displaced in different directions across the Varillas Fault. (b) Positions of mylonite belts during early dip-slip shearing. (c) Positions of mylonite belts during later transcurrent shearing. To displace the fault branches between the pre- and post-emplacement positions requires 2400 m sinistral and 5600 m dextral apparent horizontal displacement across the Varillas Fault, which was induced by the emplacement of the northern pluton.

along the Atacama Fault Zone induced a flattening strain across the complex during crystallisation, while simple shearing continued along its edges. This system was probably laterally unconfined (Jones et al., 1997), as the crystallising magma should have been able to extrude vertically and horizontally along the fault plane. Unconfined country-rock contraction caused magma flow and crystal rotation to form magmatic fabrics across the complex. Fabric trajectories cross-cut the internal contacts in the southern pluton, demonstrating that they formed after initial pluton construction, and reflect emplacement-level strain, rather than forming during magma ascent. The magmatic lineation reflects the dominant transport direction along the Atacama Fault Zone, as preserved by the incremental growth of both plutons. Towards the end of crystallisation, magmatic viscosities rose dramatically (Arzi, 1978; van der Molen and Paterson, 1979; Scaillet et al., 1997) and strain was progressively taken up along the external contacts within the fine-grained foliated country-rock mylonites, and deformed the plutonic contacts.

The vertical magmatic flattening fabrics across the northern pluton record crystallisation during horizontal, east–west contraction. Paradoxically, it is likely that the vertically sheeted internal structure of the northern pluton was constructed by a dominant horizontal east–west extension across the Atacama Fault Zone. In effect, magma from the Atacama Fault Zone was dilated parallel to the maximum contractional strain axis during the intrusion of the northern pluton. Clearly this is difficult to reconcile with conventional extensional/transtensional emplacement models. Rather, it suggests that the pluton grew from magma batches that intruded the fault zone and mechanically forced the main fault planes apart under contractional conditions (Fig. 9), rather than injection into a dilatational jog. While major structures like the Atacama Fault Zone clearly influence magma emplacement in the upper crust, the intruding magma appears to have the potential to displace country-rocks during pluton construction under extension or contraction.

4.1. Regional implications

Displacement along the Atacama Fault Zone was characteristically sinistral during the Early Cretaceous (Scheuber and Andriessen, 1990; Brown et al., 1993; Scheuber et al., 1995). The dextral displacement identified along the edge of the Las Tazas complex demonstrates that Early Cretaceous displacement patterns are more complicated than currently understood, and that large segments of such regional scale fault zones can display shearing patterns at any one time. In this context, it is interesting to observe sinistral C'-surfaces cross-cutting the post-emplacement dextral mylonites. While the C'-surfaces have not been dated, they are ductile microstructures that have formed within the brittle upper crust. Such ductile structures require elevated temperatures to form at this level in the crust. Concordant cooling data have been interpreted to reflect rapid cooling (Dallmeyer et al., 1996), inferring that the elevated temperatures required for C'-surface formation were short-lived, and that the kinematic change from dextral to sinistral shearing occurred while the pluton was cooling, shortly after emplacement. This suggests that dextral displacement only occurred during emplacement. Such restricted timing raises the possibility that the intruding magma caused a temporary kinematic switch along this segment of the Atacama Fault Zone, which then reverted to regional displacement patterns after emplacement was completed.

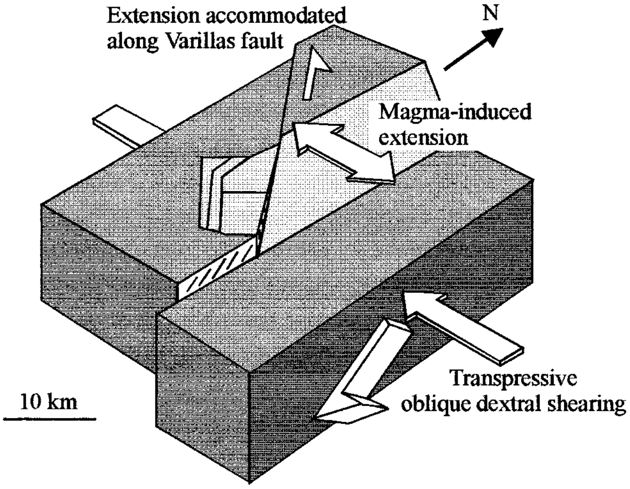

Fig. 9. Block diagram illustrating the emplacement of the northern pluton. The magma actively dilated the Atacama Fault Zone, under a dominant flattening strain during oblique dextral displacement. Dilation is accommodated by displacement along the Varillas Fault.

The occurrence of dextral displacement also has bearing on the relationship between local and regional strain patterns. A combination of different features has led a number of authors to suggest that the Andean margin had an extensional to transtensional arc style between the Triassic and middle Cretaceous. These include extensive rift and back-arc basins (Coira et al., 1982; Mpodozis and Ramos, 1990; Ardill et al., 1998), low-angle extensional faulting (Mpodozis and Allmendinger, 1993), voluminous basic volcanic rocks and orogen-parallel dykes associated with vertical faulting (Scheuber and Reutter, 1992), together with plutonic geochemistry characteristic of thinned crust (Pankhurst et al., 1988). The transpressional conditions associated with emplacement of the Las Tazas complex would appear to be in conflict with this regional pattern. However, the complex does display similar field relations to other Early Cretaceous syntectonic plutons along the Atacama Fault Zone. Like the Las Tazas complex, the other plutons are bounded by mylonites and display flattening magmatic foliations along their interiors (Hervé, 1987; Uribe, 1987; Scheuber et al., 1995; Grocott and Wilson, 1997). They have been previously interpreted as transtensional intrusions, though their field relations are more consistent with localised transpressive conditions, within the regional transtensional setting. If this is correct, it follows that the strain recorded in the vicinity of these intrusions may not reflect the regional strain-state, and should not be used to constrain the subduction style of the arc.

5. Conclusions

The Las Tazas complex intruded the Atacama Fault Zone syntectonically during a change from east-side-down vertical to dextral transcurrent displacement along the Atacama Fault Zone. The complex was emplaced under laterally unconfined transpressive conditions, and grew by the active dilation of the fault zone by successive magma batches. Strain partitioned during magma emplacement into a pure shear flattening strain across the intrusion, while plane-strain simple shear continued in the wall rocks. The dextral displacement and transpressive strain-state were local responses to magma emplacement, superimposed on regional sinistral transtension along the Atacama Fault Zone. This demonstrates that pluton emplacement-related strain cannot be used to directly indicate the regional strain-state of the Early Cretaceous Andean arc.

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