THE LIQUIÑE-OFQUI FAULT ZONE (LOFZ) IN THE PROVINCE OF PALENA: FIELD AND MICROSTRUCTURAL EVIDENCE OF A DUCTILE-BRITTLE DEXTRAL SHEAR ZONE

La zona de falla Liquiñe-Ofqui (LOFZ) en la provincia de Palena: Evidencias de terreno y microestructurales de una zona de cizalle dextral dúctil-frágil

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RESUMEN

La zona de falla Liquiñe-Ofqui (ZFLO) está marcada por un lineamiento cortical de rumbo NNE que se extiende desde los 39°S hasta los 47°S. El segmento de la ZFLO considerado aquí (41°50'S-42°10'S) está representado por plutones del batolito Norpatagónico, los cuales se encuentran heterogéneamente deformados, y por rocas metamórficas de la facies anfibolita que pertenecen al prisma de acreción paleozoico superior. Los cuerpos intrusivos se orientan aproximadamente en dirección NW y despliegan una foliación subvertical la cual es subparalela a aquella exhibida en la roca de caja. Lineaciones minerales subhorizontales son comunes en las rocas metamórficas, aunque no se encuentran completamente desarrolladas en los intrusivos.

Feldespato parcialmente recristalizado, agregados de cuarzo y feldespato recuperado junto con lentes de cuarzo y plagioclasa doblada/quebrada sugieren que los plutones fueron deformados dúctil y frágilmente bajo condiciones de facies anfibolita a esquistos verdes durante su emplazamiento y posterior enfriamiento en el Mioceno-Plioceno. Microestructuras tales como lentes de cuarzo recristalizado, mica "fish" y ojos asimétricos de feldespato encontrados en la roca de caja indica un estilo de deformación dúctil no coaxial que ocurrió previamente y durante el emplazamiento de los plutones. En conjunto, intrusivos y rocas de

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caja documentan la existencia de una antigua zona de cizalle dextral, lo que se evidencia fuertemente por la relación espacial existente entre el rumbo de la zona de cizalle (NNE) y las foliaciones de rumbo NNW subverticales, lineaciones subhorizontales y las asimetrías microestructurales diagnósticas observadas.

La ZFLO podría entonces representar en el área una zona de cizalle dextral de intraarco que fue reactivada como una estructura normal con ascenso del bloque oriental en el Cenozoico más tardío.

Reconstrucciones de placas para el Cenozoico son consistentes con cizalle dextral seguido de acortamiento (solevantamiento) dentro del arco magmático.

ABSTRACT

The Liquiñe-Ofqui fault zone (LOFZ) is marked by a NNE-trending crustal lineament stretching from 39°S to 47°S. The segment of the LOFZ considered herein (41°50'S to 42°10'S) is represented by heterogeneously strained plutons of the North Patagonian batholith and amphibolite facies metamorphic rocks belonging to the upper Paleozoic accretionary prism. The intrusive bodies trend roughly NW and display a NNW-striking, steeply-dipping foliation subparallel to the one exhibited in the wallrocks. Although not fully developed in the intrusives, subhorizontal mineral lineations are common in the metamorphic rocks.

Partially recrystallized feldspar, recovered aggregates of quartz and feldspar along with quartz ribbons and bent/broken plagioclase suggest that the plutons were ductilely-brittlely deformed under amphibolite to greenschist facies conditions during their emplacement and subsequent cooling in Miocene and Pliocene times. Microstructures such as recrystallized quartz ribbons, mica "fish" and asymmetric feldspar augen found in the wallrocks indicate a ductile, noncoaxial style of deformation that occurred prior and during the emplacement of the plutons.

As a whole, intrusives and country rock document the existence of an ancient dextral strike-slip shear zone, as strongly suggested by the spatial relationship between the trend of the shear zone (NNE) and the regional steeply-dipping NNW foliations, subhorizontal lineations and the diagnostic microstructural asymmetries observed.

The LOFZ may thus represent in the area a cenozoic intra-arc right lateral shear zone that was reactivated as a normal up-on-the-east structure in the latest Cenozoic.

Plate reconstructions for the Cenozoic are consistent with dextral shear followed by shortening (uplift) within the magmatic arc.

INTRODUCTION

Oblique subduction along a convergent margin may result in the development of a strike-slip fault zone in thermally weakened crust of the magmatic arc (Fitch, 1972; Beck, 1986; Jarrard, 1986a, b; Beck, 1991). Optimum conditions for intra-arc faulting are strong intraplate coupling and a continental overriding plate (Beck, 1986; Jarrard, 1986b). Several modern examples of these intra-arc features have been reported, such as the Semangko fault in Sumatra and the Dolores-Guayaquil fault of Colombia and Ecuador (Fitch, 1972; Jarrard, 1986a). In contrast, few ancient arc-parallel strike-slip faults have been recognized, probably because they are partially obliterated or buried by coeval or younger plutons and volcanic edifices (Jarrard, 1986b; Sylvester, 1988; Busby-Spera and Saleeby, 1990).

Highly oblique subduction of the Nazca plate beneath South America, which occurred between Eocene and Miocene times (52 to 26 Ma) (Pilger, 1983; Cande and Leslie, 1986; Pardo-Casas and Molnar, 1988), may have resulted in the initiation of the Liquiñe-Ofqui fault zone (LOFZ) (Hervé, 1976; Hervé and Thiele, 1987; Beck, 1988) in southern Chile (Figure 1). The LOFZ is a 1000 km long, NNE-trending crustal lineament roughly coincident with both the main axis of the Miocene belt of the North Patagonian batholith (NPB) and the present-day Southern Andes volcanic chain (Hervé and Thiele, 1987).

Although the LOFZ is commonly regarded as a right-lateral strike-slip fault (Hervé, 1976; Hervé et al., 1978; Hervé et al., 1990), its full geometry, motion history and tectonic importance remain obscure. Limited, indirect geologic evidence available to date (conjugate mesoscopic faults within a mylonitic zone, Hervé, M., 1976) suggests that dextral strike-slip motion occurred along the northern segment of the LOFZ during the Paleogene. However, conclusive evidence of lateral offset has not been found. A late Neogene dip-slip component, in contrast, is strongly indicated by the fact that deeper crustal levels have been brought to the surface east of the LOFZ main trace (Hervé, 1976; Hervé et al., 1990).

An intensive geologic, geochronologic, geochemical and paleomagnetic reconnaissance is currently being conducted by Chilean and U. S. scientists in the segment of the LOFZ exposed in the regions of Chiloé and Aysén (42°S-46°S). As part of this comprehensive study, this paper focuses on geologic evidence documenting the existence of an ancient right lateral shear zone within the LOFZ between 41°50' S and 42°10' S. A preliminary fabric study will be presented and discussed below, that, through the recognition of microstructural features, attempts to establish the nature, metamorphic conditions and relative timing of the deformational events recorded in plutonic and metamorphic rocks of the LOFZ.

REGIONAL GEOLOGICAL SETTING

The Andes of Chile and Argentina show a complex geologic evolution including terrane accretion during the Paleozoic and the development of a series of magmatic arcs and backarc basins during the Mesozoic. During this period of subduction, sharp latitudinal changes in the nature and distribution of tectonic elements and different structural styles defined several distinctive segments along the orogen (Mpodozis and Ramos, 1990).

Another tectonic segmentation occurred in Cenozoic time related to lateral changes in the geometry of the Nazca plate (Jordan et al., 1983).

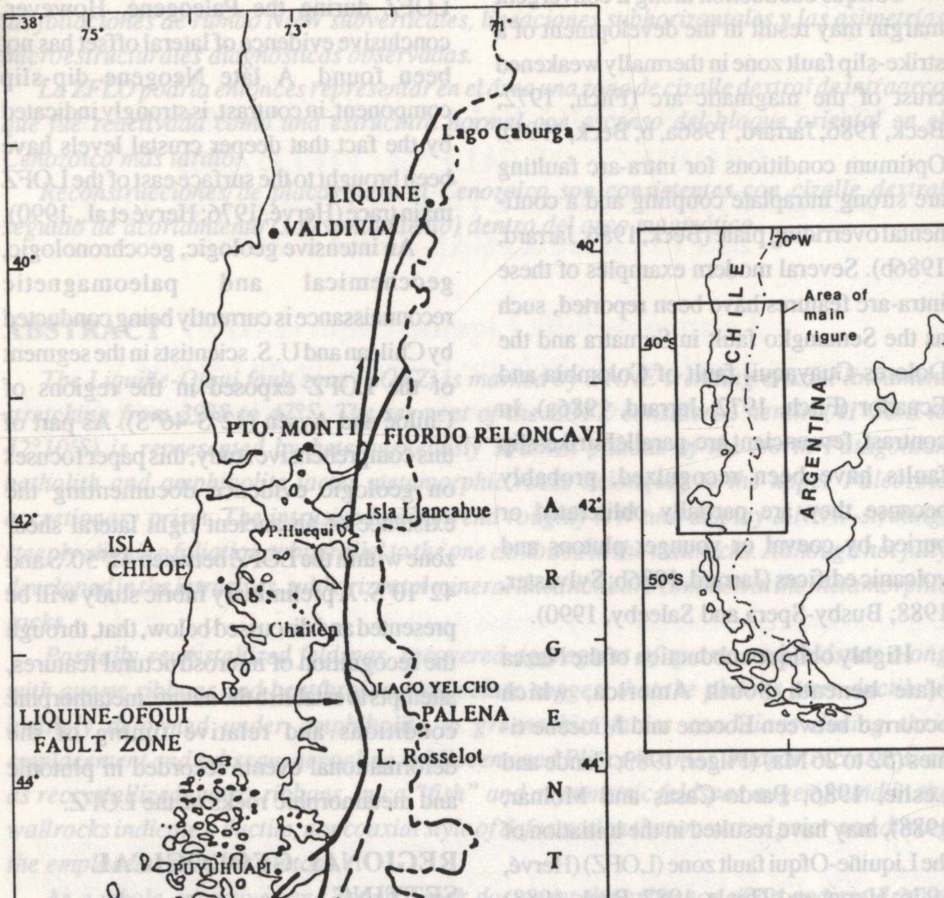

Figure 1 Main traces of the Liquiñe-Ofqui fault zone (Hervé and Thiele, 1987).
Fig. 1 Trazas principales de la zona de falla Liquiñe-Ofqui (Hervé y Thiele, 1987).

In contrast to the northern Chilean Andes, where episodic eastward migration of the magmatic arc and a well developed foreland fold and thrust belt are present, the Andean Cordillera between 41°S and 49°S shows a unique Meso-Cenozoic tectonic evolution characterized by: (1) and essentially static magmatic arc, represented by the Patagonian batholith; (2) a relatively small amount of crustal shortening in the foreland; and (3) an intra-arc strike-slip fault zone (LOFZ) (Mpodozis and Ramos, 1990, Hervé et al., 1990). The LOFZ is perhaps the most conspicuous tectonic element in the region. It probably developed along thermally weakened crust along the magmatic arc, as has been proposed for other major trench-parallel strike-slip faults (Beck, 1986; Jarrard, 1986a; Beck, 1991). Thus, the LOFZ has probably accomodated shear arising from oblique subduction of the Nazca plate and also has partly controlled the location of the Cenozoic magmatic arc.

In the region between 42°S and 44°S there are three distinct lithologic belts that parallel the LOFZ (Fig. 2). These are, from west to east, the Coastal Range Paleozoic forearc accretionary complex (AC) (Godoy

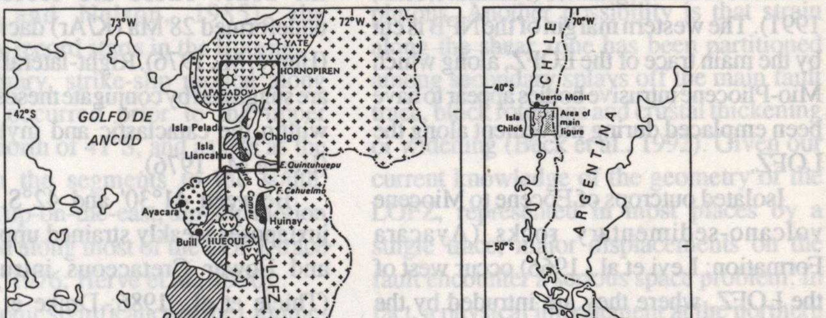

Figure 2 Regional geologic map of the province of Palena, Chile (42°-44°S) (Pankhurst et al., 1991). Box shows area of figure 3.

Fig. 2 Mapa geológico regional de la provincia de Palena, Chile (42°S-44°S) (Pankhurst et al., 1991). El recuadro corresponde al área de figura 3.

et al., 1984; Hervé, 1988), the North Patagonian batholith (NPB), and a sequence of Jurassic to Lower Cretaceous volcanic and volcanogenic sedimentary rocks.

The AC consists of low-grade metasedimentary rocks and interbedded tholeiitic metabasalts. To the east these are intruded by the NPB giving rise to isolated exposures of medium to high grade metamorphic rocks (Fiordo Comau Metamorphic Complex). The NPB is composed of several distinct belts that grade eastward from mostly Mio-Pliocene granodiorites and tonalites to Jurassic-Lower Cretaceous monzogranites (Pankhurst et al., 1991). The western margin of the NPB is cut by the main trace of the LOFZ, along which Mio-Pliocene intrusive bodies appear to have been emplaced during movement along the LOFZ.

Isolated outcrops of Eocene to Miocene volcano-sedimentary rocks (Ayacara Formation; Levi et al., 1966) occur west of the LOFZ, where they are intruded by the NPB.

Rocks of the third (easternmost) belt include the Jurassic Futaleufu Group and Lower Cretaceous Palena Group (Thiele et al., 1978). These dominantly subaerial and marine volcanics may represent a short-lived backarc basin (Hervé, 1991). The western flank of this volcanic belt is intruded by the NPB.

1.3 The Liquiñe-Ofqui fault zone (LOFZ)

The LOFZ is marked by a lineament that extends for about 1000 km along the main Cordillera from 39°S near the small town of Liquiñe to the Golfo de Penas at about 47°S (Figs. 1, 2).

Morphologically the LOFZ consists of a continuous set of aligned, north-south trending glacial valleys and fjords, along which isolated outcrops of cataclastic and mylonitic rocks are found.

It was first recognized at its northern end (Hervé, 1976; Moreno and Parada, 1976) and then extended to the south (Hervé, et al., 1978).

Several distinctive segments are identifiable along the LOFZ on the basis of structural and geologic features. From 39°30'S to 41°30'S the LOFZ appears to be a single linear trace that trends N10°E. A belt of cataclastic and mylonitic rocks, developed from gneisses and granitic rocks, is present along the northernmost section of the zone. These are crosscut by an undeformed 28 Ma (K/Ar) dacite porphyry (Hervé, M., 1976). Right-lateral movements are suggested by conjugate mesoscopic faults within the cataclastic and mylonitic zone (Hervé M., 1976).

Between 41°30' and 42°S, the LOFZ juxtaposes weakly strained upper Miocene and Lower Cretaceous intrusive rocks (Thiele et al., 1986; Drake et al., 1990). From 42°S to 43°15'S the LOFZ runs through both the NPB and AC, where it is marked by discontinuous strips of cataclastic and mylonitic rocks (Solano, 1978; Fuenzalida, 1979). Field relationships and petrographic studies suggest that Miocene to Pliocene tonalitic plutons located within and to the east of the LOFZ may have intruded during regional shear (Cembrano, 1990). After the late Miocene, movement on this section of the LOFZ must have had a significant vertical component, as shown by deeper crustal levels exposed to the east (Hervé, M., 1976; Hervé et al., 1990).

Quaternary volcanoes are located along the northern half of the LOFZ. These show no evidence of post-volcanic fault activity. The southern segment of the LOFZ, from 43°30' to 47°S, appears as a set of **en echelon** fault that defines a "scallop" pattern concave to the northwest. Generally, the structure is expressed by regional lineaments, some of which have associated fault rocks. The most conspicuous linear feature is a glacial valley, 2-3 km wide, running north-south from Lago Yelcho to Puyuhuapi (Fig. 1, 2). This is partially filled by Paleogene (?) volcanic and volcanogenic sedimentary rocks (Las Juntas strata) (Bobenrieth et al., 1983) and Neogene lacustrine sediments (La Silla strata) (Araya, 1979). The latter sediments are capped by a 1.2 Ma basalt flow (Hervé et al., 1990) which overlaps and seals the LOFZ trace. At Golfo de Penas, interpreted to be a pull-apart basin related to the LOFZ (Forsythe and Nelson, 1985), the sedimentary record starts in the Eocene.

In summary, strike-slip motion along the LOFZ occurred prior to the upper Oligocene north of 41°S, and as late as the Pliocene in the segments to the south. Subsequent up-on-the-east, dip-slip motion has occurred along most of the LOFZ trace (Hervé, M., 1976; Hervé et al., 1990).

The tectonic significance of the Liquiñe-Ofqui fault zone has been discussed by several authors. Hervé, M. (1976) and Beck (1988) speculate that it was caused by dextral shear related to oblique subduction of the Nazca (Farallon) plate beneath South America. Plate reconstructions (Pilger, 1983; Cande and Leslie, 1986; Pardo-Casas and Molnar, 1988) show a period of highly oblique NE-directed subduction from around 50 Ma to 26 Ma, roughly coeval with the timing of strike-slip motion along the LOFZ. The subsequent gradual change to a predominant dip-slip (normal) component after the Miocene (Hervé, 1976; Hervé et al., 1990) may be related to the nearly orthogonal Nazca-South America convergence that followed the breakup of the Farallon plate at 26 Ma.

An alternative model (Forsythe and Nelson, 1985) views the LOFZ as a result of collision of a "rigid indenter" (the Chile Rise) with the Peru-Chile trench. However, the timing for the collision of the Chile Ridge with the continental margin (6 Ma) is inconsistent with geochronological constraints for strike-slip motion along the LOFZ (Paleogene-Early Neogene; Cande and Leslie, 1986).

An important enigma posed by the LOFZ is why it shows so little clear evidence of lateral offset. One explanation could be that mapping of intrusive rocks is difficult and has not been done in most of the LOFZ. Alternatively, evidence of strike-slip displacement may be hidden beneath late Cenozoic strata or obscured by Mio-Pliocene plutons. Another possibility is that strain along the shear zone has been partitioned among secondary splays off the main fault trace, block rotations and crustal thickening or widening (Beck et al., 1992). Given our current knowledge of the geometry of the LOFZ, represented in most places by a single trace, major displacements on the fault encounter a serious space problem. In fact, a physical impedement at the northern end of the LOFZ probably inhibits latitudinal motion of outboard rocks (the buttress effect, Beck, 1991).

Systematic fabric studies may provide valuable information regarding strain partitioning, timing and sense of shear.

Paleomagnetism also is a good tool with which to address some of these problems, because it is sensitive to both north-south displacements and local vertical-axis rotations (see García et al., 1988; Cembrano et al., 1992; Rojas et al., 1992).

2. Geology of the LOFZ between 41°50' and 42°10'S

The Liquiñe-Ofqui fault zone (LOFZ) in the province of Palena (42°S-44°S) is expressed by NNE-trending regional lineaments along which weakly to moderately strained Mio-Pliocene plutons of the NPB intrude metasedimentary and metavolcanic rocks of the upper Paleozoic accretionary complex of southern Chile (Godoy et al., 1984; Hervé et al., 1988), (Figures 2, 3). The 2-3 km wide contact aureole adjacent to the NPB is composed of amphibolite facies metamorphic rocks grouped under the informal name of Fiordo Comau Metamorphic Complex (FCMC).

Preliminary structural data indicate that both the NPB and the FCMC exhibit a NNW striking, steeply-dipping foliation (Figures 3, 4). The FCMC displays NNW trending mineral lineations whereas the plutons, for the most part, lack lineations (Figures 3, 4).

Plio-Pleistocene volcanoes overlap the LOFZ main trace and show no signs of post-volcanic fault activity.

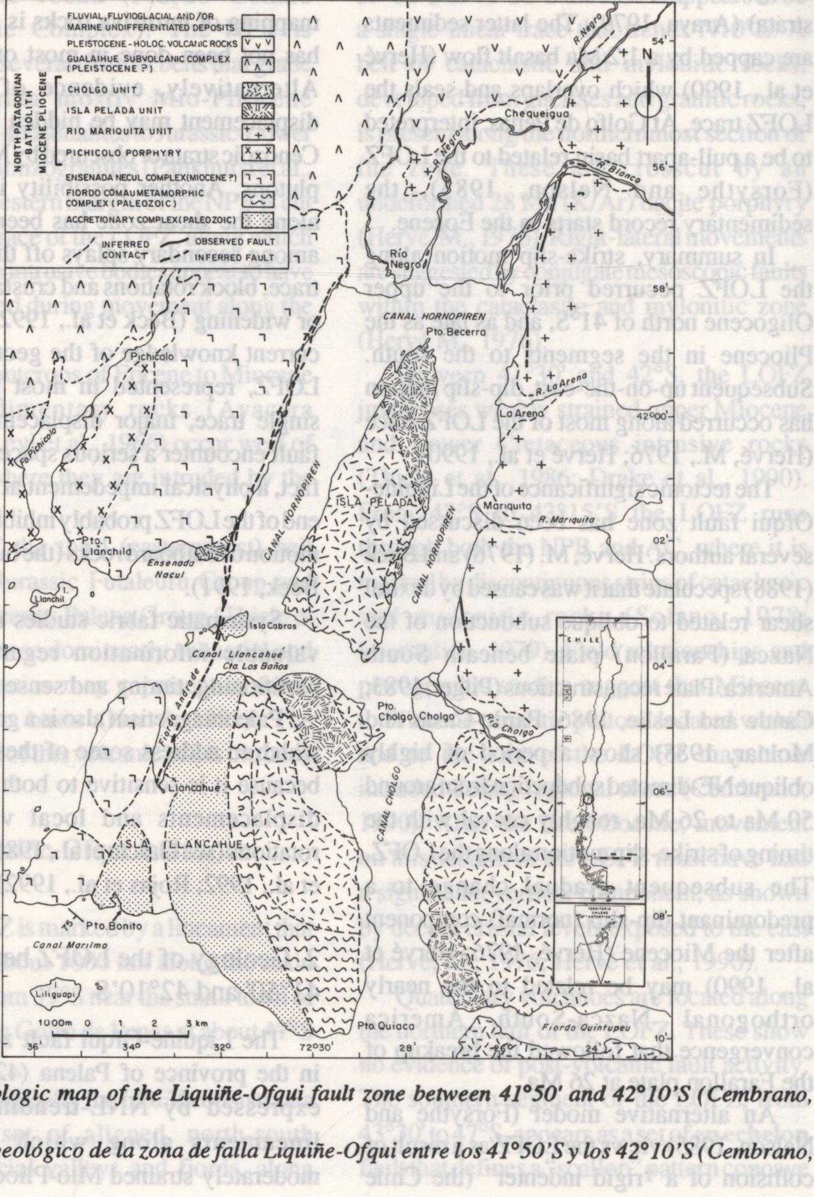

Figure 3 Geologic map of the Liquiñe-Ofqui fault zone between 41°50' and 42°10'S (Cembrano, 1990).

Fig. 3 Mapa geológico de la zona de falla Liquiñe-Ofqui entre los 41°50'S y los 42°10'S (Cembrano, 1990).

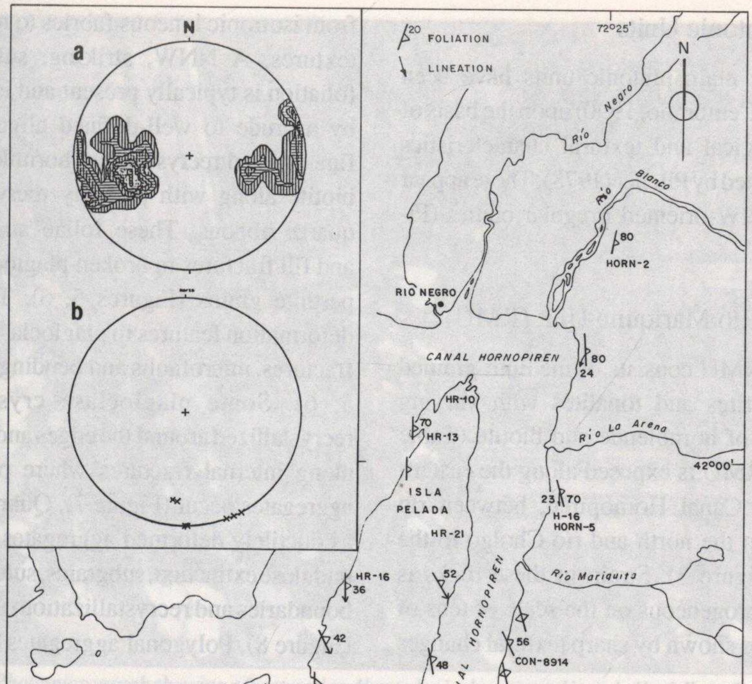

Figure 4 Map showing the overall pattern of foliations and lineations of plutonic and metamorphic rocks within the LOFZ.
Orientation of fabric elements: (a) Poles to foliations, contours at 2% intervals; (b) Lineations.
Fig. 4 Mapa que indica el patrón general de distribución de foliaciones y lineaciones de rocas plutónicas y metamórficas dentro de la ZFLO. Orientación de los elementos de fábrica: (a) polos de foliaciones, contornos a intervalos de 2%; (b) lineaciones.

2.2.1 Plutonic Units

Three main plutonic units have been defined (Cembrano, 1990) upon the basis of mineralogical and textural characteristics as suggested by Pitcher (1978). These appear to form NW-oriented irregular bodies (Figure 3).

2.2.1.1 Río Mariquita Unit (RMU)

The RMU consists of medium-grained granodiorites and tonalites with varying amounts of hornblende and biotite (Table 1). The RMU is exposed along the eastern shore of Canal Hornopirén, between río Blanco to the north and río Cholgo to the south (Figure 3). Strain in these rocks is very heterogeneous on the scale of tens of meters, as shown by sharp textural changes from isotropic igneous fabrics to mylonitic textures. A NNW, striking, subvertical foliation is typically present and is defined by a crude to well-defined alignment of fine-grained recrystallized hornblende and biotite along with partially recrystallized quartz ribbons. These foliae anastomose and fill fractures in broken plagioclase and perthite grains (Figures 5, 6). The main deformation features in plagioclase include fractures, microfaults and bending (Figures 5, 6). Some plagioclase crystals are recrystallized around the edges and, locally, along internal fractures where polygonal aggregates occur (Figure 7). Quartz occurs as ductilely deformed aggregates showing undulose extinction, subgrains, sutured grain boundaries and recrystallization of the rims (Figure 8). Polygonal aggregates of strain-

Table 1.- Modal composition for representative samples of the plutonic units. (Cembrano, 1990).

Sample*	Quartz	Plagioclase	Orthoclase	Biotite	Amphibole	Pyroxene	Chlorite	Epidote	Sericite	Apatite	Opaques
CHOLGO UNIT											
HORN25	18.0	41.6	1.0	8.6	30.0	0.0	0.0	0.6	0.0	0.1	0.1
HORN25	25.5	44.0	8.0	15.2	7.0	0.0	0.0	0.2	0.0	0.1	0.0
HORN11	28.1	59.5	5.7	3.8	2.6	0.0	0.0	0.1	0.0	0.1	0.1
LL11	31.0	43.0	0.4	25.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Q-4	16.8	52.2	7.9	16.7	4.6	0.0	0.0	0.1	0.0	0.1	1.6
Q-6	22.7	58.4	2.5	8.7	7.0	0.0	0.4	0.1	0.0	0.1	0.1
RIO MARIQUITA UNIT											
HORN2	16.2	67.1	0.0	0.0	2.9	0.0	7.8	3.3	0.0	2.0	0.7
HORN5	35.2	40.7	9.6	7.3	3.8	0.0	0.9	1.5	0.5	0.0	0.5
HORN6	32.6	42.8	5.0	13.6	4.9	0.0	0.0	0.7	0.0	0.1	0.3
HORN9	32.5	45.8	8.6	4.0	8.1	0.0	0.0	0.0	0.1	0.1	0.8
CON8914	20.0	40.3	3.0	20.9	2.3	0.0	2.2	10.5	0.4	0.0	0.4
ISLA PELADA UNIT											
HR21	10.0	61.6	2.0	17.7	5.6	0.6	0.1	0.1	0.0	0.3	2.1
HR10	4.9	57.9	0.0	0.0	20.6	0.0	0.9	0.9	1.2	0.1	5.8
LL5	2.7	68.3	0.0	0.0	19.3	1.0	0.0	0.0	3.5	0.0	0.4
LL7	1.2	72.0	0.0	0.0	14.6	1.5	0.0	0.0	0.0	0.0	0.2
HR13	5.8	50.3	0.0	5.9	36.2	0.0	0.0	0.0	0.0	0.1	0.5
HR3	7.6	60.4	0.0	11.1	6.8	12.3	0.0	0.0	0.3	0.2	1.1

* Sample locations in Figure 3

Figure 5 Photomicrograph showing a fractured and bent plagioclase crystal invaded by foliae of recrystallized aggregate of hornblende and biotite. Crossed nicols. Sample HORN-6, Rio Mariquita Unit.
Fig. 5 Microfotografía que muestra plagioclasa doblada y fracturada invadida por folias de un agregado recristalizado de biotita y hornblenda. Nícoles cruzados. Muestra HORN-9, Unidad Rio Mariquita.

Figure 6 Photomicrograph of microfaulted plagioclase crosscut by quartz ribbons. Crossed nicols. Sample HR-7, Rio Mariquita Unit.
Fig. 6 Microfotografía de plagioclasa microfallada y atravesada por lentes de cuarzo. Nícoles cruzados. Muestra HR-7, Unidad Río Mariquita.

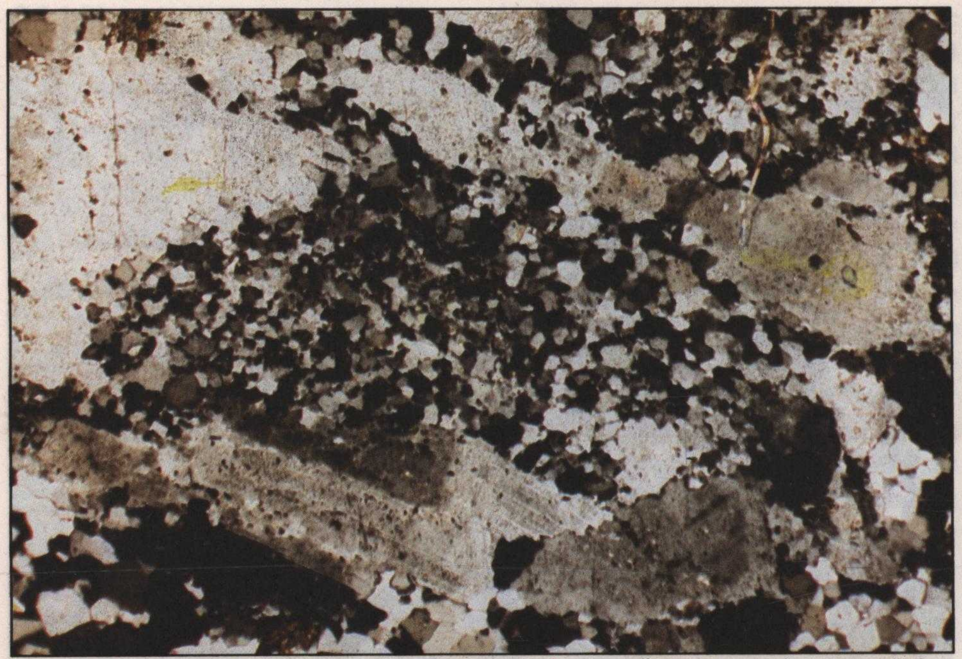

Figure 7 Photomicrograph of plagioclase exhibiting small recrystallized grains around the edges and along internal fractures. Polygonal aggregates of recrystallized plagioclase predominate towards the center of the original crystal. Crossed nicols. Sample HORN-9, Rio Mariquita Unit.
Fig. 7 Microfotografía de plagioclasa exhibiendo granos recristalizados pequeños en los bordes y a lo largo de fracturas internas. Agregados poligonales de plagioclasa predominan hacia el centro del cristal original. Muestra HORN-5, Unidad Río Mariquita.

Fig. 8 Microfotografía que muestra y subgranos, bordes suturados, extinción ondulosa y recristalización en torno a los granos de cuarzo. Nícoles cruzados. Muestra HORN-5, Unidad Río Mariquita.
Figure 8 Photomicrograph showing subgrains, sutured boundaries, undulose extintion and recrystallization around the edges of quartz grains. Crossed nicols. Sample HORN-5, Rio Mariquita Unit.

free grains of quartz, orthoclase and plagioclase also are present (Figure 9). No conclusive evidence of magmatic flow is preserved in these rocks, although the preferred orientation of recrystallized hornblende and biotite may have been inherited from an early magmatic fabric.

Mylonites occur in discrete zones up to 2 m wide within relatively less-strained rocks. The mylonites consist of plagioclase augen floating in a matrix of strongly flattened fine-grained foliae of biotite ± muscovite ± quartz. The plagioclase cores are partly or totally replaced by epidote and partial recrystallization of the rim has given rise to asymmetric tails (Figure 10). Isolated boudins of pseudotachylite are also present in the matrix.

Age

$^{40}Ar/^{39}Ar$ single-crystal laser fusion dating of biotite and hornblende has yielded ages of 6.6 ± 0.3 Ma and 8.7 ± 1 Ma, respectively (Drake et al., 1991). Although these are generally regarded as cooling ages, the age in hornblende may represent the timing of the solid-state deformation during which this mineral recrystallized.

Figure 9 Photomicrograph of a polygonal mosaic of quartz and orthoclase indicating recovery following deformation.
Recrystallized plagioclase along microcracks. Crossed nicols.
Sample HORN-9, Rio Mariquita Unit.
Fig. 9 Microfotografía de un mosaico poligonal de cuarzo y ortoclasa, lo que indica recuperación posterior a la deformación. Plagioclasa recristalizada a lo largo de microfracturas. Nícoles cruzados. Muestra HORN-9, Unidad Río Mariquita.

Figure 10 Photomicrograph of an asymmetric feldspar augen in mylonite formed from granodiorites of the Rio Mariquita Unit. Plane light. Sample H-16.
Fig. 10 Microfotografía de un ojo asimétrico de feldespato en milonita formada a partir de granodioritas de la Unidad Río Mariquita. Nícoles paralelos. Muestra H-16.

2.2.1.1 Cholgo Unit (CHU)

Medium to coarse-grained biotite ± hornblende tonalites and granodiorites make up this plutonic unit (Table 1). It crops out in isla Llancahué and isla Pelada where it seems to intrude an older dioritic pluton (Isla Pelada Unit, see below). The CHU is also exposed along the eastern shore of the Hornopirén canal and was recognized for several kilometers eastward along the fiordo Quintupeu (Figure 3). The contact relationship between the CHU and the RMU is hidden under fluvioglacial sediments along río Cholgo.

The CHU displays a NNW striking, subvertical magmatic foliation defined by the alignment of relatively unstrained plagioclase crystals (Figure 11). A subparallel solid-state foliation is evidenced by the preferred orientation of quartz ribbons and by partially recrystallized biotite-hornblende layers (Figure 11). Strain shown in these rocks is typically low, and is exhibited by ductilely deformed quartz, serrated intercrystalline contacts (Figure 11), some recrystallization of quartz, minor recrystallization of plagioclase and feldspar and slight bending of plagioclase crystals (Figure 12). Interstitial myrmekitic intergrowths (Figure 12) and patches of alkali feldspar are observed within microfaults in plagioclase (Figure 13).

Age

The rocks of the CHU have yielded a 4.7 ± 0.6 Ma Rb-Sr whole rock isochron (with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7047), interpreted to represent the age of emplacement (Pankhurst et al., 1990) Roughly similar $^{40}Ar/^{39}Ar$ ages in biotite and hornblende (3.3 to 7.0 Ma) (Drake et al., 1991) suggest rapid cooling rates and/or a late solid-state recrystallization.

Figure 11 Photomicrograph showing typical planar fabrics of the Cholgo Unit. Foliation defined by the alignment of plagioclase crystals is interpreted to be of magmatic origin. Quartz ribbons define a subparallel low-temperature solid-state foliation. Crossed nicols. Sample HORN-11.
Fig. 11 Microfotografía que muestra las fábricas planares típicas de la Unidad Cholgo. La foliación que está definida por el alineamiento de cristales de plagioclasa se interpreta como de origen magmático. Lentes de cuarzo definen una foliación subparalela formada al estado sólido.

Figure 12 Photomicrograph of a bent and broken plagioclase crystal surrounded in part by myrmekitic intergrowths. Crossed nicols. Sample HORN-25C, Cholgo Unit.
Fig. 12 Microfotografía de un cristal de plagioclasa doblado y quebrado rodeado en parte por intercrecimientos mirmequíticos.

2.2.1.3 Isla Pelada Unit (IPU)

The IPU consists of clinopyroxene microdiorites and hornblende ± biotite ± pyroxene diorites (Table 1). It crops out along the northwestern section of isla Pelada, the northeast edge of isla Llancahué and at the northern entrance of fiordo Quintupeu (Figure 3). The IPU intrudes the FCMC in isla Llancahué. To the east of the intrusive contact, there is a gradational contact with the CHU, within which deformed centimeter -to meter- wide septa of schist belonging to the FCMC are enclosed.

The IPU shows much less deformation than the other two plutonic units. However, there are some signs of brittle deformation expressed as ubiquitous fracturing of plagioclase (Figure 14). Foliation, where present, is parallel to the regional structure and is defined by the orientation of relatively strain-free minerals.

Age

Apparently contradictory $^{40}Ar/^{39}Ar$ ages of 8.6 ± 1 Ma (biotite, isla Pelada) and 115 ± 8 Ma (hornblende, isla Llancahué) have been reported (Drake et al., 1991) This may indicate that field work was unable to identify what appears to be the presence of two different units.

Figure 13 Photomicrograph of the deformational features exhibited by plagioclase in the Cholgo Unit: microfaulting and subsequent filling with weakly strained Alkali feldspar. Crossed nicols. Sample HORN-25C.

Fig.13 Microfotografía de los rasgos deformacionales exhibidos por plagioclasa en la Unidad Cholgo: microfallamiento y relleno posterior con feldespato alcalino levemente deformado. Nícoles cruzados. Muestra HORN-25C.

Figure 14 Photomicrograph showing the typical weakly strained igneous fabrics displayed by the isla Pelada Unit. Slight, brittle solid- state deformation is evidenced by fracturing. Crossed nicols. Sample LL-5.

Fig. 14 Microfotografía de la fábrica ígnea débilmente deformada, característica de la Unidad Isla Pelada. Una deformación débil al estado sólido, de carácter frágil, está evidenciada por fracturamiento.

2.2.2 Metamorphic units

2.2.2.1 Accretionary Complex (AC)

The AC consists of well-bedded metapelites and metabasites that are exposed along the western third of the LOFZ (Figure 3).

The western margin of the AC is marked by a NNE-trending zone of anastomosing faults defining the contact with volcaniclastic rocks of possible Eocene-Miocene age (Ensenada Necul complex; Cembrano, 1990) (Figure 3). Strata of the AC, which strike NNW and dip steeply to the north, define a homoclinal structure. The metapelites exhibit a NNW-striking slaty cleavage, whereas pillow basalts and volcanic breccia typically show anastomosing fracture cleavage. Although some rocks display cataclastic and mylonitic fabrics at the mesoscopic scale, poor sampling and insufficient structural data did not allow for a systematic study. Rocks undergo a gradational west-to-east textural and compositional change as they approach the contact with the NPB. An arbitrary limit between the AC and the FCMC was defined at the occurrence of spotted slates, at 3 km from the contact with the NPB, on isla Las Cabras (Figure 3).

2.2.2.2 Fiordo Comau Metamorphic Complex (FCMC)

The FCMC consists of amphibolite facies phyllites, schists and hornfels that crop out exclusively within and to the east (?) of the LOFZ. The FCMC comprises the 2 to 3 km wide contact aureole resulting from the NPB intrusion along the eastern section of the

AC. Most of the rocks of the FCMC are completely recrystallized and show a penetrative NNW-striking foliation with subhorizontal mineral lineations. The spatial distribution of mineral assemblages and facies appears to be directly related to the distance from the intrusive contact. Three roughly defined zones may be identified.

Outer zone (2-3 km from the contact): characterized by spotted slates and quartz-mica phyllites with the assemblage quartz-andalusite-muscovite-biotite-garnet.

Intermediate zone (0.5 to 2 km): represented by quartz-ribbon mica-schists with the mineralogical association quartz-andalusite-biotite-garnet-calcic plagioclase.

Inner zone (to 0.5 km): consists of schists, gneisses and hornfelses bearing the assemblage quartz-plagioclase-biotite-sillimanite (fibrolite) -cordierite (pelitic rocks) or hornblende-calcic plagioclase (mafic rocks).

Schists from the intermediate zone are characterized by ribbons of quartz and feldspar alternating with biotite ± muscovite foliae (Figure 15). This matrix wraps around plagioclase and andalusite porphyroclasts and relic feldspar.

Schists from the inner zone are coarser-grained. Cordierite and plagioclase porphyroblasts up to 2 mm in diameter are present.

Asymmetric tails occur around relic feldspar grains (Figure 16).

Some isolated mica "fish" (Lister and Snoke, 1984) are preserved despite the extensive recrystallization as are augen-shaped aggregates of recrystallized quartz (Figure 17).

Quartz ribbons, which are interpreted to be recrystallized aggregates of original single grains, have axial ratios of about 5:1. These provide a rough estimate of the x/z strain ratio (Simpson, 1985) (Figure 18).

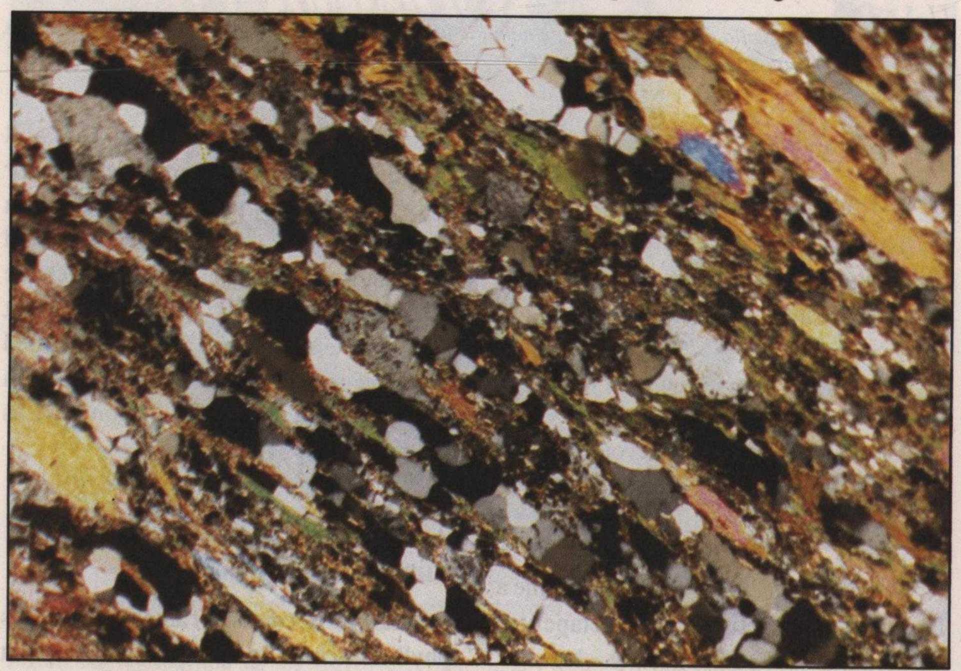

Figure 15 Photomicrograph showing the characteristic matrix from schists belonging to the intermediate and inner zones of the contact aureole: Recrystallized quartz ribbons and mica-rich layers. Crossed nicols. Sample HR-22, Fiordo Comau. Metamorphic Complex.
Fig. 15 Microfotografía que muestra la matriz característica de los esquistos pertenecientes a las zonas intermedia e interna de la aureola de contacto: Lentes de cuarzo recristalizados y películas micáceas. Nícoles cruzados. Muestra HR-22, Complejo Metamórfico. Fiordo Comau.

Figure 16 Photomicrograph of a feldspar porphyroclast with asymmetric tails of dynamically recrystallized feldspar, indicating dextral shear. Crossed nicols. Sample HR-23, Fiordo Comau. Metamorphic Complex.
Fig. 16 Microfotografía de un porfiroclasto de feldespato con colas de feldespato dinámicamente recristalizado, indicando cizalle dextral. Nícoles cruzados. Muestra HR-23, Complejo Metamórfico Fiordo Comau.

Figure 17 Photomicrograph of well preserved mica "fish" and associated trails of recrystallized mica defining shear surfaces. Shear sense is dextral. Crossed nicols. Sample HR-23, Fiordo Comau. Metamorphic Complex.
Fig. 17 Microfotografía de mica "fish" y sus rastros asociados mica recristalizada que definen superficies de cizalle. El sentido del cizalle es dextral. Nícoles cruzados. Muestra HR-23, Complejo Metamórfico Fiordo Comau.

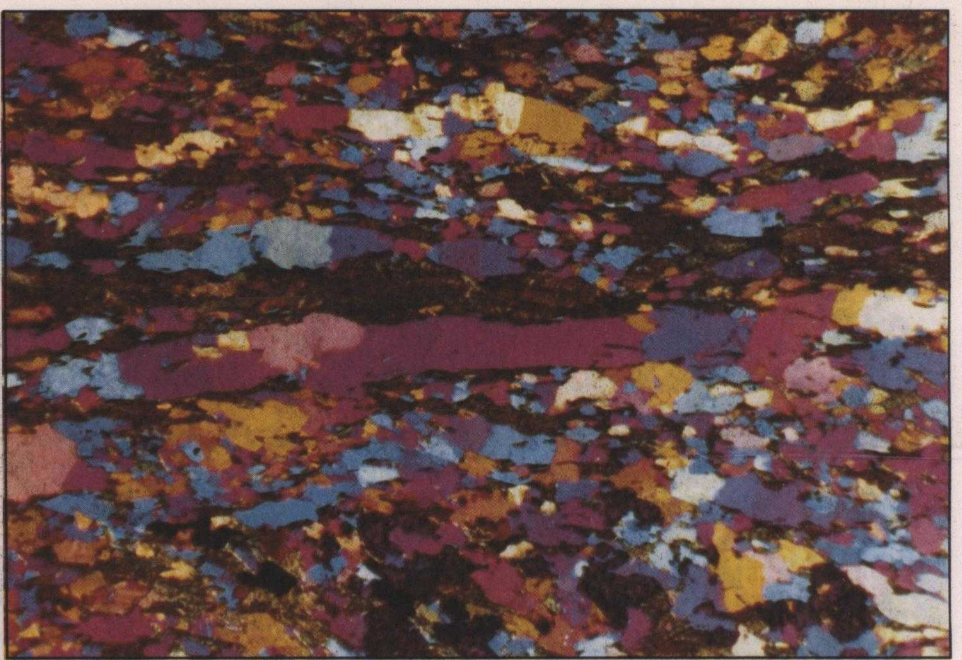

Figure 18 Photomicrograph showing some typical x/z ratios in quartz ribbons from schists of the Fiordo Comau Metamorphic Complex. Crossed nicols. Gypsum plate inserted. Sample HR-22.
Fig. 18 Microfotografía que muestra algunas razones X/Z típicas de lentes de cuarzo pertenecientes a esquistos del Complejo Metamórfico Fiordo Comau. Nícoles cruzados. Placa de yeso está insertada. Muestra HR-22.

2.3 Interpretation of the NPB and FCMC fabrics

The origin of the fabrics described for the plutonic units and wallrocks provides some insights regarding the mechanism and timing of emplacement and deformation of this section of the NPB.

Of particular interest is the nature of the microstructures present in the granitoids; are these of magmatic or solid-state origin? Likewise, it is important to determine whether the textures and structures in the country rock are spatially and/or temporally related to the LOFZ and the NPB emplacement. Thus, it is also critical to establish the type of strain regime (coaxial vs. noncoaxial) (Berthé et al., 1979; Simpson and Schmid, 1983; Lister and Snoke, 1984) recorded in the FCMC and NPB.

2.3.1 Magmatic vs. solid-state origin of the fabric in the plutonic units

2.3.1.1 Río Mariquita Unit

These rocks show fabrics suggesting that they underwent moderate to weak solid-state deformation at moderate temperatures (350° C to 450° C), probably under middle greenschist to lower epidote-amphibolite facies conditions. The main evidence includes:

(1) Ductile deformation of quartz, resulting in well developed ribbon structures most of which are recrystallized. This is indicative of middle to upper greenschist facies conditions (Voll, 1976; Sibson, 1983; Simpson, 1985).

(2) Weak to moderate recrystallization of plagioclase around the edges and along internal fractures is consistent with upper

greenschist facies conditions (recrystallization of feldspar at these relatively low temperatures occurs locally, where strain is high) (White, 1975). Complete recrystallization to a polygonal mosaic, although less commonly observed in the RMU, appears to require temperatures above 450° C at natural strain rates (Voll, 1976; Tullis, 1983; Paterson et al., 1989). This temperature, in turn, indicates amphibolite facies conditions (Simpson, 1985).

(3) Fine-grained recrystallized foliae of hornblende ± actinolite ± biotite that fill fractures in brittlely deformed feldspar and replacement of plagioclase cores by epidote show upper greenschist to amphibolite facies conditions.

2.3.1.2 Rio Cholgo Unit

The solid-state strain shown in these rocks is relatively lower than that recorded in the RMU, but this may be because the bulk of the deformation took place during the solidification of the pluton. The CHU has a pronounced magmatic foliation, evidenced by the alignment of plagioclase subparallel to the solid-state foliation defined by ductitely deformed quartz ribbons and recrystallized biotite foliae. This may mean that the strain regime in which magmatic flow took place prevailed until rocks were at sub-solidus temperatures. Although much of the solid-state deformation shown in these rocks appears to have occurred after consolidation (as indicated by microstructural evidence like that in the RMU), the presence of interstitial myrmekitic intergrowths (Hibbard, 1987) and alkali feldspar filling fractures in plagioclase indicate that small amounts of melt may have been present during this early stage of deformation. Alternatively, myrmekites may form during high temperature solid-state deformation (Simpson, 1985).

2.3.1.3 Isla Pelada Unit

The IPU records two distinctive sets of fabrics: magmatic and solid-state brittle. The consistently weak, brittle deformation recorded suggests that these rocks may have behaved as rigid, relatively cold bodies, which then did not undergo significant internal deformation. Alternatively, the lack of a solid-state preferred orientation fabric may be expected in these quartz-poor rocks. In fact, quartz is the mineral that most readily flows into ribbons giving rise to anisotropic textures that characterize mylonitic rocks (Sibson, 1977).

2.3.2 Coaxial vs non-coaxial nature of the foliations

2.3.2.1 Plutonic units

Asymmetric feldspar augen (Simpson and Schmid, 1983; Lister and Snoke, 1984) in mylonitic granodiorites (of the RMU) that contain the regional foliation indicate a predominant noncoaxial style of deformation. However, most of the evidence found in the plutonic units does not conclusively support either coaxial or noncoaxial deformation.

2.3.2.2 Metamorphic rocks

Microstructures observed in the FCMC suggest that they underwent noncoaxial deformation. Although extensive thermally-induced recrystallization may have erased some of the early fabrics, such as oblique foliations in dynamically recrystallized quartz aggregates, some diagnostic microstructures are preserved.

Asymmetric tails of recrystallized material around feldspar relic grains are evidence that the axes of incremental ellipsoids of strain have rotated during progressive deformation. Mica "fish" (Lister and Snoke, 1984), produced by boudinage and microfaulting of preexisting mica grains along shear surfaces (C surfaces of Berthé et al., 1979), also indicate a noncoaxial regime.

Kinematic indicators in one sample of the FCMC, both asymmetric tails and mica "fish" indicate dextral shear (Figures 2.15, 2.16).

The regional continuity of the planar fabrics in plutonic and metamorphic units suggests they developed in a similar strain regime. These planar fabrics show an overall sigmoidal pattern across the LOFZ (Figure 2.3) comparable to that described for a dextral simple shear zone in Ramsay (1980).

2.4. Tectonic evolution of the LOFZ

Some speculative remarks regarding the tectonic evolution of the LOFZ in the studied region can be made by combining field observations, microstructural evidence and available geochronological data:

(1) The upper Paleozoic accretionary complex probably underwent noncoaxial deformation in a dextral strike-slip shear zone prior to and probably during the intrusion of the Mio-Pliocene plutonic rocks. Strike-slip shear is indicated by steeply-dipping foliations with subhorizontal mineral lineations and by microstructures such as asymmetric feldspar augen, relic mica "fish" and augen-shaped recrystallized quartz aggregates.

Dextral shear sense is supported by the geometric relationship between the overall strike of the regional foliation (NNW) and the trend of the shear zone, assumed to be expressed by the NNE trending regional lineaments. Although a more systematic analysis of kinematic indicators is needed, preliminary microstructural evidence from one oriented sample in this study also suggest dextral shear.

(2) Plutons of the NPB may have intruded along the same shear zone during Miocene and Pliocene times. They developed an early magmatic fabric (Cholgo Unit) and produced contact metamorphism in the 2-3 km wide contact aureole. This may have partially obliterated microstructural evidence for the noncoaxial character of the initial deformation in the wallrocks.

A late medium-to low-temperature (450° C-350° C) solid-state deformation probably took place shortly after emplacement of the plutons in essentially the same strain regime. This is suggested by a subparallel foliation defined by Mio-Pliocene recrystallized biotite and hornblende, which appears to have formed under upper greenschist facies conditions. The task of determining whether magmatic and solid-state deformation developed in a continuous manner, as occurs in syntectonic plutons, is hampered by the fact that no widespread evidence of high-temperature solid-state deformation was found. However, such early deformation can be very difficult to ascertain, since a subsequent low temperature tectonic fabric -also expected in syntectonic plutons- may completely overprint the early fabric.

(3) The presence of a brittlely, slightly deformed Lower Cretaceous (?) plutonic unit within the LOFZ suggests that, in contrast to the Mio-Pliocene plutons, these rocks were relatively cold when deformed. Therefore, they are probably pre-tectonic.

This in turn would constrain the timing for the strike-slip activity of the LOFZ to between mid-Cretaceous and Mio-Pliocene.

A late Pliocene to Recent up-on-the-east, dip-slip component of motion must have occurred to explain the presence of deep crustal levels (represented by the Neogene plutons and 2-3 km wide aureole) within and to the east of the LOFZ.

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REFERENCES

Beck, M.E. Jr., 1991 Coastwise transport reconsidered: lateral displacements in oblique subduction zones, and tectonic consequences, Phys. of the Earth and Planet. Ints. 68, 1-8.

Beck, M., Cembrano J., Rojas C., Hervé F. and Mpodozis C. 1992. On the significance of curvature in strike-slip fault systems. Submitted to Geology.

Berthé, D., Choukroune, P. and Jegouzo, P. 1979. Orthogneiss, mylonite and non coaxial deformation of granites: the example of South American Shear-Zone. J. Struct. Geol. 1, 31-42.

Bobenrieth, L., Díaz, F., Davidson, J. and Portigliati, C. 1983. Complemento al Mapa Metalogénico XI Región, Sector Norte continental comprendido entre 45° Lat. S y el límite con la X Región. CORFO-SNGM, 154 pages, unpublished, Santiago.

Busby-Spera C. J. and Saleeby, J. B. 1990. Intra-arc strike-slip fault exposed at batholithic levels in the southern Sierra Nevada, California, Geology 18, 255-259.

Cande, S. C. and Leslie R.B. 1986. Late Cenozoic tectonics of the Southern Chile Trench, J. of Geophys. Res. 91, 471-496.

Cembrano, J. 1990 Geologia del Batolito Norpatagónico y de las rocas metamórficas de su margen occidental: 41°50' S-42°10' S, 67 pp., Thesis, Universidad de Chile, Santiago, Chile (unpublished).

Drake, R., Hervé F., Munizaga F. and Pankhurst R. 1990 Radioisotopic ages of the North Patagonian batholith and their relation to the Liquiñe-Ofqui Fault Zone, Chile (40°-42°S Lat.), ICOG-7, Camberra, Geol. Soc. Australia Abs. 27, 29.

Fitch, T.J., 1972. Plate convergence, transcurrent faults, and internal deformation adjacent to southeast Asia and the western Pacific, J. of Geophys. Res. 77, 4432-4460.

Forsythe, R.D. and Nelson E., 1985. Geological manifestation of ridge collision: Evidence for the Golfo de Penas, Taitao basin, southern Chile, Tectonics 4, 477-495.

Fuenzalida, J. L., 1979. Estudio geológico preliminar de Península Huequi, X Región. Thesis, Depto. de Geología, Universidad de Chile, Santiago, Chile, (unpublished).

García, A., Beck Jr. M. E., Burmester R. F., Hervé F. and Munizaga F., 1988. Paleomagnetic reconnaisance of the Región de los Lagos, southern Chile, and its tectonic implications, Revista Geológica de Chile, 15, 13-30.

Godoy, E., Davidson, J., Hervé, F., Mpodozis, C. and Kawashita, K., 1984. Deformación sobreimpuesta y metamorfismo progresivo en un prisma de acreción paleozoico: Archipiélago de los Chonos, Aysén, Chile. Actas IX Congreso Geológico

Argentino (San Carlos de Bariloche), 211-232.

Hervé, F., 1988. Late Paleozoic subduction and accretion in southern Chile, Episodes 11, 183-188.

Hervé, F., 1991. The southern Andes between 39° and 44° S Lat.: The geologic signature of a transpressive tectonic regime related to a magmatic arc, (in press).

Hervé, F., Moreno H. and Parada M. A., 1974. Granitoids of the Andean Range of Valdivia Province, Chile. Pacific Geology 8, 39-45.

Hervé, F., Araya, E., Fuenzalida, J.L. and Solano, A., 1978. Nuevos antecedentes sobre la geología de Chiloé Continental. Actas VII Congreso Geológico Argentino (Neuquén), 629-638.

Hervé, F. and Thiele, R., 1987. Estado de conocimiento de las megafallas en Chile y su significado tectónico. Comunicaciones (Universidad de Chile, Santiago) 38, 67-91.

Hervé, F., Pankhurst R., Cembrano, J. and Munizaga, F., 1990. Mamgmatism and tectonics in the Andes of Chiloé (42°-44° S), Chile. Abstract, Symposium international on Geodynamique Andine (Grenoble, France), p. 305, Orstom eds.

Hervé, M., 1976. Estudio geológico de la falla Liquiñe-Reloncaví en el área de Liquiñe; antecedentes de un movimiento transcurrente (Provincia de Valdivia). Actas I Congreso Geológico Chileno, B39-B56.

Hibbard, M.J. 1987. Deformation of incompletely crystallized magma systems: granitic gneisses and their tectonic implications. J. Geol. 95, 543-561.

Jarrard, R.D., 1986a. Relations among subduction parameters, Rev. of Geophys. 24, 217-234.

Jarrard, R.D., 1986b. Terrane motion by strike-slip faulting of forearc slivers. Geology 14, 780-783.

Jordan, T. E., Isacks B. L., Allmendinger R. W., Brewer J. A., Ramos V. A. and Ando C. J., 1983. Andean tectonics related to geometry of subducted Nazca plate, Geol. Soc. Am. Bull. 94, 341-361.

Levi, B., Aguilar, A. and Fuenzalida, R., 1966. Reconocimiento Geológico en las provincias de Llanquihue y Chiloé, Boletín 19, Instituto de Investigaciones Geológicas, Santiago, Chile, 45 pp.

Lister, G. S. and Snoke, A. W., 1984. S-C Mylonites. J. Struct. Geol. 6, 617-638.

Moreno, H. and Parada, M. A., 1976. Esquema Geológico de la Cordillera de los Andes entre los paralelos 39° y 41°30'S. Actas I Congreso Geológico Chileno (Santiago), A213-A226.

Mpodozis, C. and Ramos, V., 1990. The Andes of Chile and Argentine, in: Geology of the Andes and its relation to hydrocarbon and mineral resources. G. Ericksen, M. Pinochet and J. Reinemund Editors. Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series 11, 59-90.

Munizaga, F., Hervé, F., Drake R., Pankhurst, R. , Brook M. and Snelling N., 1988. Geochronology of the Lake Region of south central Chile (39°-42°S): Preliminary results, J. S. Amer. Earth Sci. 1, 309-316.

Pankhurst, R., Hervé, F., Rojas, L. and Cembrano, J., 1991. Magmatism and tectonics in continental Chiloé, Chile (42°-42°30'S), Tectonophysics (in press).

Parada, M. A., Godoy, E., Hervé, F. and Thiele, R., 1987. Miocene calc-alkaline plutonism in the chilean southern Andes, Revista Brasileira de Geosciencias 17, 450-455.

Pardo-Casas, F. and Molnar, P., 1988. Relative motion of the Nazca (Farallon) and South American plates since Late Cretaceous times, Tectonics 6, 233-248.

Paterson, S. R., Vernon, R. H., and Tobisch, O. T., 1989. A review of criteria for the identification of magmatic and tectonic foliations in granitoids. J. Struct. Geol. 11, 349-363.

Pilger, R. H. Jr., 1983. Kinematics of the South American subduction zone from global plate reconstructions. In: Geodynamics of the Eastern Pacific Region, Caribbean and Scotia Arcs (R. Cabre, editor). American Geophysical Union, Geodynamics, Series 9, 113-126.

Pitcher, W. S., 1987. The anathomy of a batholith. J. Geol. Soc. Lond. 135, 157-182.

Ramsay, J. G., 1980. Shear zone geometry: a review. J. Struct. Geol. 2, 83-99.

Rojas, C., Beck, M., Burmester, R., Cembrano, J. and Hervé, F., 1992. Paleomagnetism of the Mid-Tertiary Ayacara Formation, southern Chile: counterclockwise rotations in a dextral shear zone. Submitted to Journal of Geophysical Research.

Sibson, R. H., 1977. Fault rocks and fault mechanisms. J. geol. Soc. London 133, 191-213.

Sibson, R. H., 1983. Continental fault structure and the shallow earthquake source. J. geol. Soc. London 140, 741-767.

Simpson, C. and Schmid, S. M., 1983. Microstructural indicators of sense of shear in shear-zones. Bull. geol. Soc. Am. 94, 1281-1288.

Solano, A., 1978. Geología del sector Costero de Chiloé Continental entre los 41°50' y 41°10' la latitud sur. Thesis, Depto. de Geología, Universidad de Chile, Santiago (unpublished).

Sylvester, A. G., 1988. Strike-slip faults, Geol. Soc. Am. Bull. 100, 1666-1703.

Thiele, R., Hervé, F., Parada, M. A. and Godoy, E., 1986. La megafalla Liquiñe-Ofqui en fiordo Reloncaví (41°30'S), Chile, Comunicaciones (Universidad de Chile, Santiago) 37, 31-40.

Thiele, R. and Pincheira, M., 1987. Tectónica transpresiva y movimiento de desgarre en el segmento sur de la Zona de Falla Atacama, Revista Geológica de Chile 31, 77-94.

Tullis, J. A., 1983. Deformation of feldspars. In: Feldspar Mineralogy (edited by Ribba, P. H.). Miner. Soc. Am., short course notes, Vol. 2 (2nd edition), 297-323.

Voll, G., 1976. Recrystallization of quartz, biotite and feldspar from Erstfeld to the Levantine Nappe, Swiss Alps, and its geological significance. Schwerz. Miner. Petrogr. Mitt. 56, 641-647.

White, S., 1975. Tectonic deformation and recrystallization of Oligoclase, Contrib. Mineral. Petrol. 50, 287-304.

White, S. H., Burrows, S. E., Carreras, J., Shaw, N. D. and Humphreys, F. J., 1980. On mylonites in ductile shear zones. J. of Struct. Geol. 2, 175-187.