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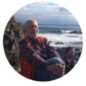

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Magmatism and tectonics in continental Chiloé, Chile (42°–42°30′S)

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ABSTRACT

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The Chiloé–Chonos region seems to preserve the oldest depositional events in the fore-arc accretionary complex of the Southeast Pacific margin. There are isolated occurrences of low-grade metamorphic rocks, including slates with a Devonian trilobite fauna and schists that give Rb–Sr evidence of a ca. 290 Ma metamorphism. Pillow basalts and ultramafic rocks may represent parts of the Pan-Thalassic ocean floor on which the Palaeozoic sediments were laid down. Emergence of a magmatic arc is indicated by Jurassic to Early Cretaceous volcanogenic and marine deposits. During the mid-Cretaceous climax of plutonic activity, these were intruded by monzogranites, which here constitute the eastern portion of the North Patagonian batholith. They give Rb–Sr isochron ages of 120–100 Ma (Barremian–Albian). Initial $^{87}Sr/^{86}Sr$ ratios of 0.7040–0.7045, and ϵ_{Nd_t} values of +0.5 to +1.5, indicate a simple petrogenesis with a mantle source. The western part of the batholith is petrologically more primitive, being composed predominantly of tonalite, diorite and gabbro, and initial $^{87}Sr/^{86}Sr$ ratios are more variable.

Late Cenozoic movement of the Liquiñe–Ofqui fault zone (LOFZ) generated deep pull-apart basins to the west of the uplifted batholith/basement complex. These were filled by thick marine sequences of volcanogenic debris, indicating the wide extent of a mainly rhyolitic volcanic field during Miocene times. Pliocene tonalite and granodiorite plutons (dated by a Rb–Sr whole-rock isochron at 4.7 ± 0.5 Ma) and Holocene andesite-basalt stratovolcanoes are located along the LOFZ. The latter feature has thus been a major influence on the tectonic evolution of the area. There is no evidence for major post-Palaeozoic compression or crustal shortening.

Introduction

Active volcanicity in the Andes is genetically associated with subduction of Pacific Ocean floor beneath the South American continent, but the geological structure of the Andean mountain range has developed through the action of related processes over a very long period of time. The study of older rocks is important in revealing and understanding the changes which have occurred in this geodynamic system.

The area of "continental Chiloé" (the mainland opposite the island of Chiloé) is one of the geologically lesser-known parts of Chilean territory, due to difficult access resulting from heavy forestation, precipitous slopes, and other causes. Geological observation is largely restricted to coastal outcrops in the inter-tidal zone. The one significant previous publication (Levi et al., 1966) has been supplemented by graduation theses of students from the University of Chile, synthesized in Hervé et al. (1978) and Thiele et al. (1978). Further work, including sampling for geochronological and geochemical analysis, was instigated by the senior authors (FH and RJP) in 1988, as part of Operation Raleigh Expedition 13B, and subsequently. The results of this work, reported

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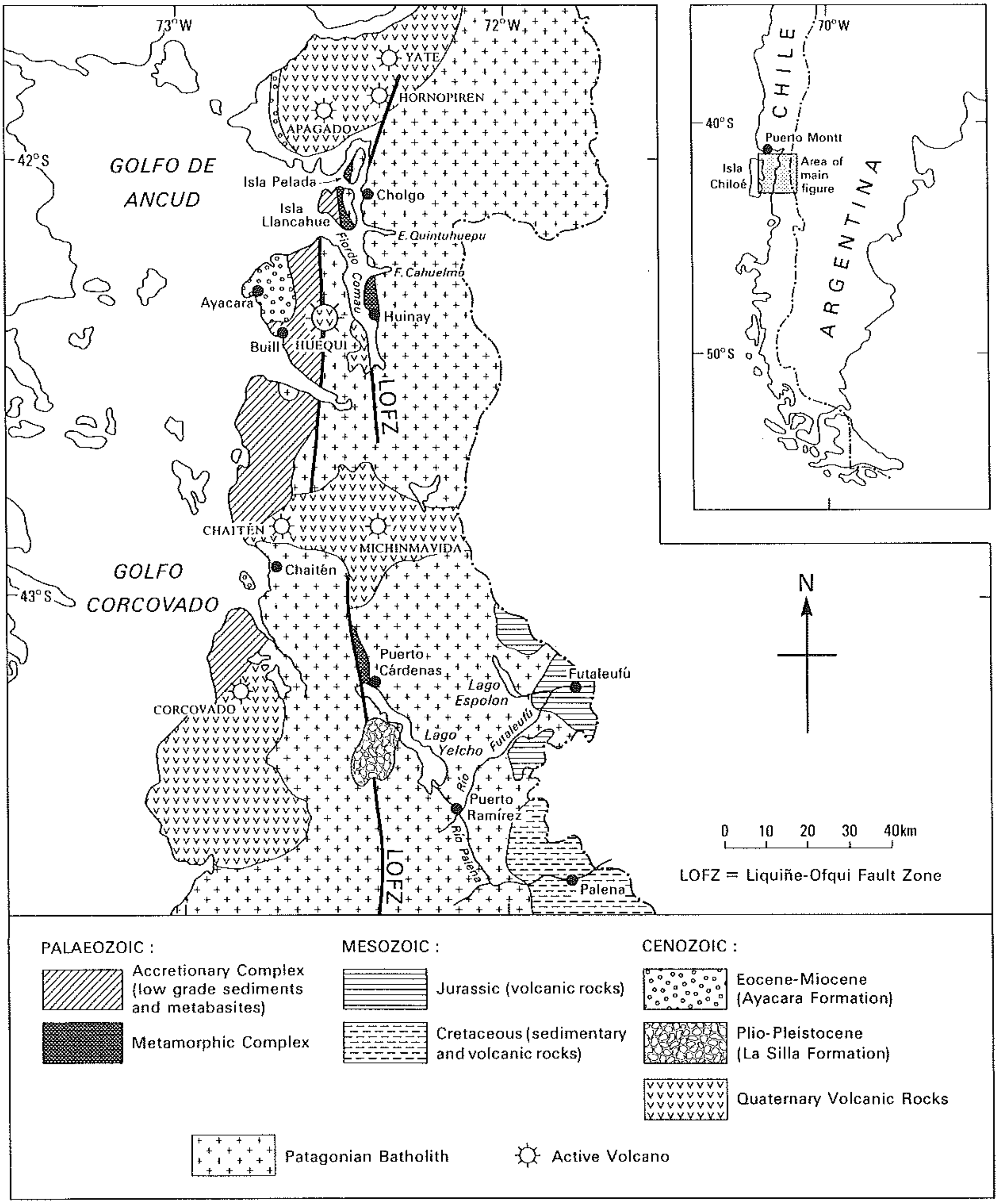

Fig. 1. Geological sketch map of continental Chiloé, modified from Instituto de Investigaciones Geológicas Mapa Geológico de Chile, 1:1,000,000, 1981.

here, have enabled a more complete interpretation of the timing of magmatic events and the tectonic development of the area.

Geological setting

The island of Chiloé is geographically and geologically part of the Coast Ranges of southern Chile, which consist mostly of low-grade metasedimentary rocks that have been interpreted as Palaeozoic fore-arc accretionary complex (Godoy et al., 1984; Davidson et al., 1987; Hervé et al., 1988). Most of the area to the east of this (Fig. 1), as far as the main Andean cordillera, consists of plutonic igneous rocks of the Patagonian batholith, a 1000-km-long body which passes north–south through the region. Previous studies of the batholith have been carried out in the Aysén region to the south (Bartholomew and Tarney, 1984) and east of Puerto Montt to the north (Parada et al., 1987). As in these cases, there is an east–west zonation of the batholith into relatively narrow north–south belts of different type. The easternmost belt is of rather homogeneous pink leuco-monzonite, giving way to darker diorite/tonalite and white granodiorite westwards.

The eastern margin of the batholith shows intrusive contacts with the Jurassic and Lower Cretaceous volcano-sedimentary sequences of the central and western cordillera. The western margin is geographically associated with the Liquiñe–Ofqui fault zone (LOFZ), a major dextral transcurrent dislocation, and is geologically more complex. Within the batholith close to this zone, the igneous rocks are intrusive into sporadic outcrops of regionally metamorphosed schists and gneisses, as at Huinay on the east shore of Fiordo Comau (Fig. 1). At the northwest end of Fiordo Comau, the batholith is in tectonic contact with an ultramafic body; on Llancahue Island and elsewhere, intrusive relationships are observed with metasedimentary units with basic volcanic intercalations, including pillow lavas. The mafic igneous rocks are considered to constitute remnants of an ophiolite sequence of unknown age, but probably part of the Palaeozoic accretionary complex of the Chilean Coast Ranges and Chiloé Island. To the immediate west of the batholith, fore-arc marine basins generated during the Eocene–Miocene, were filled by acid volcano-sedimentary deposits which were folded and intruded by Miocene/Pliocene plutons.

Geochronology

Standard methods of Rb–Sr whole-rock and K–Ar dating were used, as in previous work by the senior authors (Hervé et al., 1988; Munizaga et al., 1988). A few Sm–Nd analyses were also carried out for petrogenetic control. Further analytical details are given, along with the data, in Tables 1, 2 and 3.

Palaeozoic metamorphic rocks

Outcrops of metamorphic rocks are found along the east coast of Fiordo Comau, from Huinay in the south to Estero Cahuelmó in the north (Fig. 1). These range from low-grade chlorite–muscovite–albite–epidote greenschist facies rocks at Huinay to medium-grade biotite–muscovite–andalusite/sillimanite gneisses in the north. There are abundant pegmatites with muscovite and biotite, particularly in the higher-grade rocks.

A set of the low-grade rocks was analyzed by the Rb–Sr whole-rock method, and the analytical data are presented in Table 1. They show a great deal of scatter in an isochron plot (Fig. 2), with the four most radiogenic samples lying on a line which yields an age of 292 ± 4 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7116 ± 0.0001. Since the other samples fall well below this line, this age must be treated with a great deal of caution. Nevertheless, it is comparable to Rb–Sr dates that have been obtained previously from other outcrops of the accretionary complex in southern Chile (e.g. Hervé, 1988), and could be similarly interpreted as representing partial isotopic re-homogenization during metamorphism. The high initial $^{87}Sr/^{86}Sr$ ratio implies an older depositional or provenance age, confirmed by the Nd isotope data (Table 3) which support a maximum probable source age of about 1300 Ma. This interpretation agrees with reports of Devonian fossils in rocks of

TABLE 1

Rb–Sr Data for Continental Chiloé

Sample	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	s.d. (%)	$^{87}Sr/^{86}Sr$
Huinay Schists					
HUI-1	152	188	2.3530		0.721441
HUI-4	12.9	589	0.0632	2.0	0.711894
HUI-8	173	126	3.9770		0.728088
HUI-9	147	143	2.9699		0.723984
HUI-5	139	175	2.2892		0.717747
HUI-6	164	163	2.9143		0.720611
HUI-10	32.1	376	0.2469	1.2	0.706924
HUI-3	181	139	3.7724		0.719382
Isla Pelada					
CON89.9B	71.3	192	1.0795		0.717130
Futaleufu East					
CH.88-31	141	146	2.8100		0.709219
CH.88-32	147	134	3.1568		0.709835
CH.88-33	123	137	2.6031		0.708899
CH.88-34	97.1	302	2.7031		0.708899
ESPOLON	34.8	395	0.2553	0.8	0.704778
Futaleufu West					
CH.88-35	143	126	3.2922		0.709320
CH.88-36	97.6	273	1.0359		0.705682
CH.88-37	98.4	256	1.1132		0.705812
CH.88-38	67.7	294	0.6659		0.705262
CH.88-39	165	127	3.7655		0.710025
CH.88-40	161	98.8	4.7271		0.711532
Lago Yelcho diorites					
CH.88-50	53.2	310	0.4963		0.706152
CH.88-51	66.3	323	0.6942		0.706277
Palena					
CH.88-41	64.4	525	0.3555		0.704858
CH.88-42	89.4	246	1.0582		0.705776
CH.88-43	117	182	1.8620		0.707035
CH.88-44	118	194	1.7669		0.706783
CH.88-45	116	207	1.6269		0.706575
CH.88-46	131	151	2.5147		0.707979
CH.88-47	137	146	2.7050		0.708275
CH.88-48	125	151	2.3990		0.707843
CH.88-49	94.8	200	1.3678		0.706168
Cahuelmó Granite (fiordo Comau)					
CH.88-6 (Mu)	3588	5.08	2154	5.0	1.263780
CH-88-7 (WR)	51.7	358	0.4187		0.704963
CH-88-7 (Bi)	440.1	15.097	84.63		0.743100
CH-88-7 (Mu)	250.9	25.295	32.62		0.725338
CH.88-9	34.9	306	0.3304	0.9	0.705000
CH.88-27	132	33.6	11.4127	0.6	0.717220

TABLE 1

Sample	Rb (ppm)	Sr (ppm)	^{87}Rb/^{86}Sr	s.d. (%)	^{87}Sr/^{86}Sr
Fiordo Quintuheupu Granite					
CH.88-22	27.5	420	0.1885	1.0	0.704490
CH.88-23	55.9	268	0.6032		0.705087
CH.88-24	35.9	310	0.3346	0.8	0.705444
F. Comau Tonalite					
CH.88-2	108	279	1.1155		0.704081
CH.88-3	22.5	365	0.1775	1.0	0.705247
CH.88-4	72	347	0.6007		0.704183
CH.88-5	74.4	244	0.8826		0.705013
CH.88-10	46.1	200	0.6675	0.7	0.704191
CH.88-11	47.2	201	0.6805	0.6	0.704246
CH.88-12	49.7	333	0.4337		0.705085
CH.88-13	141	149	2.7406		0.709224
CH.88-14	142	164	2.5065		0.708769
CH.88-17	33.2	392	0.2457	0.9	0.704510
CH.88-29A	9.9	271	0.1058	1.8	0.703896
Isla Llancahue Granodiorite					
CH.88-19	19.5	380	0.1490	1.2	0.704387
Pichanco Granodiorite					
HORN 26B	142	39.9	10.290	0.7	0.705152
HORN 26A	184	50.6	10.521		0.705491
HORN 26E	126	55.5	6.606		0.705216
HORN 26F	649	3.0	637.2	7.0	0.745809
Cholgo Tonalite					
HORN 25A	68.8	225	0.8859		0.704776
HORN 25B	72.9	232	0.9082		0.704645
HORN 25C	84.9	247	0.9929		0.704744
HORN 25D	96.1	211	1.3176		0.704716
HORN 25E	77.9	230	0.9802		0.704766
HORN 11	72.5	252	0.8329		0.704632
HORN 26	59.5	333	0.5180		0.704629
CH.88-21	85.7	233	1.0657		0.704705

Rb, Sr on whole-rocks determined by X-ray fluorescence, on minerals (Mu = muscovite, Bi = biotite) by Isotope Dilution. Analytical errors (1σ): 2% on Rb and Sr ppm; 0.5% on Rb/Sr (except where higher figure is stated); 0.01% on ^{87}Sr/^{86}Sr. ^{87}Sr/^{86}Sr normalised to ^{86}Sr/^{88}Sr = 0.1194; relative to NBS 987 value of 0.710220 ± 7.

the accretionary complex (Biese, 1954; Miller and Sprechmann, 1978) and with an overall consideration of the crustal evolution of Sr isotopes in these rocks over a period of some 400 Ma (Hervé et al., 1988). At Buill (Fig. 1), there is a small beach completely covered with blocks and finer debris of slates which must be derived from a nearby, but so far undiscovered, outcrop. This is one of the few known trilobite-bearing localities in Chile, first reported by Biese (1954): during the present work further specimens were found which confirm a Devonian age (Fortey et al., in press).

Another outcrop area of medium-grade metamorphic rocks with pegmatitic patches occurs to the south, along strike of the LOFZ, near the western end of Lago Yelcho (Fig. 1). A sample of coarse muscovite in a tourmaline-bearing pegmatite vein cross-cutting the foliation of the gneisses in a road cut 5 km north of Puerto Cárdenas gave a K–Ar age of 120 Ma (Table 2).

TABLE 2

K–Ar age determinations for continental Chiloé

Sample no.	Material	K (%)	Atmos. Ar (%)	Radiogenic Ar (nl/g STP)	Age (Ma)	Source
AS37	Amphibole	0.12	85	0.184	36 ± 15	1
AS38	Amphibole	0.32	93	0.111	20 ± 5	1
AS39	Amphibole	0.33	80	0.313	24 ± 2	1
JF76	Amphibole	0.34	89	0.168	13 ± 5	1
EACH2	Biotite	6.54	59	0.365	12.1 ± 0.4	1
AS32	Amphibole	0.53	99	0.115	12 ± 10	1
EACH56	WR	0.77	92	0.158	12 ± 5	1
YEL 1C	Muscovite	8.20	18	38.886	118 ± 3	2
EA2	Amphibole	0.120	93	0.2856	60 ± 16	3
JF76	Amphibole	0.246	91	0.130	14 ± 6	3
YEL 2	Basalt WR	1.138	96	0.052	1.2 ± 0.6	2

Sources: 1 = Hervé et al., 1979; 2 = determined at SERNAGEOMIN, Chile; 3 = determined at NERC Isotope Geosciences Laboratory, London.

This age is probably related to the intrusion of the North Patagonian batholith.

North Patagonian batholith

Granitoids of the North Patagonian batholith outcrop widely and constitute the highest peaks of the Andes at this latitude. The western margin of the batholith is composed of a 20-km-wide belt, predominantly of monzogranites: in the Futaleufú sector they are leucocratic, quartz-rich, biotite monzogranites, ranging from granodioritic to syenitic in modal composition; farther south, in the Palena sector, they are somewhat less siliceous, transitional to monzonite. These rocks are intruded into Jurassic volcano-sedimentary rocks of the Futaleufú Group (Thiele et al., 1978; Ulloa, 1980) and Neocomian sedimentary rocks of the Palena Group (Hein, 1979; Romero, 1983). They are unconformably covered by the La Cas-

TABLE 3

Sm–Nd data for continental Chiloé

Sample	Sm (ppm)	Nd (ppm)	$^{143}Nd/^{144}Nd$	ϵNd	Tdm (Ma)
Palaezoic schists					
HUI-1	6.954	5.826	0.512154	−6.6	1383
CON89.9B	5.826	31.413	0.512164	−6.0	1263
Cretaceous granitoids					
CH88.36	3.061	14.318	0.512650	+1.1	717
CH88.38	3.952	16.839	0.512633	+0.6	857
CH88.49	5.548	37.378	0.512645	+1.5	514
ESPOLON	3.010	12.256	0.512650	+0.9	897
Pliocene tonalite					
HORN 11	3.432	15.947	0.512632	−0.1	752

Analysed on VG 354 multi-collector mass-spectrometer at NERC Isotope Geosciences Laboratory, London. Errors (1σ) are 0.1% for Sm and Nd and 0.005% for $^{143}Nd/^{144}Nd$. ϵ_{Nd} values are calculated for 300 Ma for the schist samples and the isochron age for the granitoids. Tdm is a model age for separation from a depleted mantle reservoir.

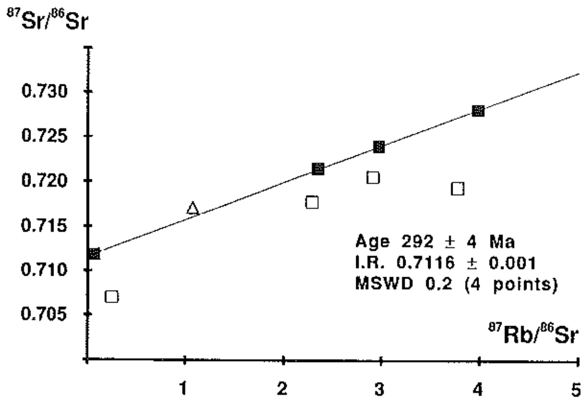

Fig. 2. Rb–Sr isochron plot for metamorphic rocks from Huinay, Fiordo Comau. Open symbols are not included in the regression shown; the triangle is a schist from Isla Pelada.

cada Eocene marine sequence near the town of Futaleufú (Castillo, 1983). These granitoids have yielded three Cretaceous Rb–Sr whole-rock isochrons, in agreement with the stratigraphical constraints on their emplacement. The easternmost road section, within 14 km of Futaleufú, gives the oldest age of 121 ± 4 Ma and the well-defined isochron (Fig. 3a) includes a sample of tonalite from Lago Espolon, considered by Castillo (1983) to be possibly Palaeozoic in age. Six samples from the section between Río Futaleufú and Puerto Ramírez also yield a good isochron (Fig. 3b), with an age of 110 ± 3 Ma. Finally, nine samples from the Puerto Ramírez–Palena section, 20 km farther south, give an isochron age of 104 ± 5 Ma (Fig. 3c). These isochrons appear to represent discrete intrusive episodes between around 120 Ma (Barremian) and 100 Ma (Albian). The initial $^{87}Sr/^{86}Sr$ ratios of these isochrons of 0.7044, 0.7041 and 7042, respectively, indicate that the granite magmas were derived by melting of a relatively primitive source, with little contamination by recycled upper crustal materials.

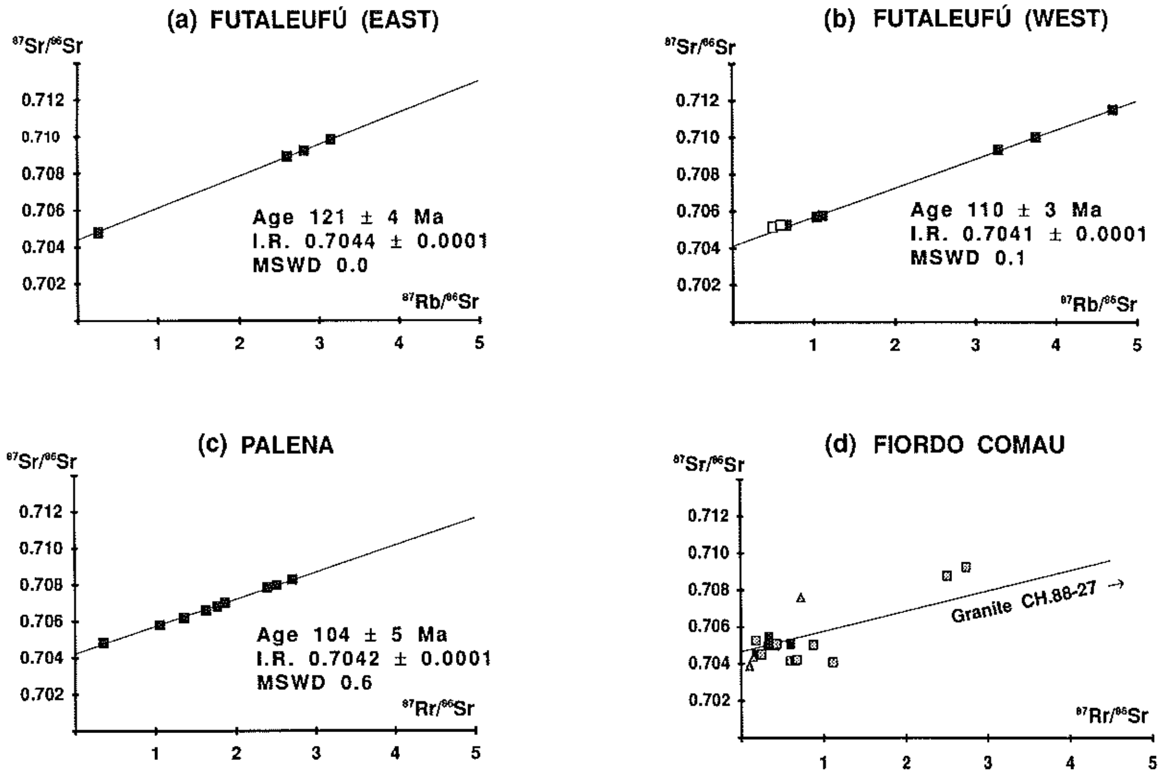

Fig. 3. Rb–Sr isochron plots for granitoids from the eastern margin of the North Patagonian batholith. (a) Northeast section of the Futaleufú granite. (b) Southwest section of Futaleufú, with open squares indicating two diorites from Lago Yelcho. (c) Palena granite. (d) Fiordo Comau, with solid squares representing the Estero Cahuelmó and Fiordo Quintuhuepu granites (one point off scale), open squares representing the Fiordo Comau tonalites, and triangles granitoids from the Isla Llancahue area.

The central and western lithologies of the batholith are mainly intermediate-to-mafic plutonic igneous rocks. Two samples of diorite from Lago Yelcho (Fig. 1) fall very close to the isochron for the adjacent western Futaleufú monzogranites (Fig. 3b), their inclusion only causing an increase in the MSWD from 0.9 to 2.7. Thus these appear to be part of a cogenetic Cretaceous suite. Farther west, tonalites, diorites and gabbros seen in the coastline of Fiordo Comau and around Chaitén are generally of indeterminate age. Rb–Sr isotopic data on 13 whole rocks along Fiordo Comau (Table 1) do not yield any well-defined age: the extreme scatter of the data must indicate either variable crustal contamination or severe post-crystallization disturbance. Rb–Sr data on two muscovites and one biotite from an outcrop of granite with pegmatitic segregations on the eastern shore near Estero Cahuelmó indicate Cenozoic mineral–whole-rock ages (45, 30, 18 Ma). This variation could be explained by Eocene igneous activity and Miocene resetting of biotite, perhaps during uplift. However, the data for the muscovites and biotites alone are collinear at around 20 Ma, and are thus consistent with Early Miocene crystallization of the pegmatites from a fluid phase with radiogenic Sr, in this case without isotopic equilibration with the host rocks. This 20-Ma age is also apparent in K–Ar data for micas from localities from eastern Fiordo Comau (Table 2).

The westernmost outcrops have also yielded rather variable Cenozoic K–Ar ages (Table 2), which may date emplacement rather than recrystallization. This is certainly the case around Cholgo, east of Llancahue Island, where a coarse-grained hornblende-biotite tonalite and associated finer-grained diorites and aplites, define a 4.7 ± 0.6 Ma Rb–Sr isochron with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7047 (Fig. 4). These rocks were intruded directly into the late Palaeozoic metamorphic complex, where a 4-km-wide contact aureole with andalusite, cordierite and sillimanite is developed in the pelitic units. The areal dimensions of this Pliocene pluton are not known. Cembrano (1990) suggests, on the basis of a study of rock fabrics, that it was syntectonically emplaced in a dextral shear zone that corresponds to the LOFZ.

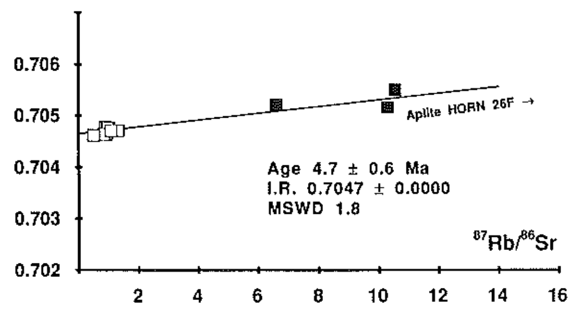

Fig. 4. Combined Rb–Sr isochron plot for the Cholgo tonalite (open squares) and Pichanco granodiorite (filled squares: one aplite point far off-scale).

La Silla formation

South of Lago Yelcho, horizontal lacustrine sediments several hundred metres thick crop out, called La Silla strata by Araya (1979). The sediments were deposited over the main trace of the LOFZ, filling a depression probably excavated on the softer cataclastic rocks which result from the fault movements and thus appear to post-date all movement of the LOFZ in this particular segment. Not even small faults were observed in the finely laminated siltstones that make up the bulk of the deposit.

A basaltic flow near the top of the sequence was dated by the K–Ar whole-rock method at 1.2 ± 0.6 Ma (Table 2), which suggests that the crustal blocks on either side of the LOFZ have not experienced significant differential movements in this area during Pleistocene times. Regional uplift is suggested by the height of the deposits, 600 m above the present-day level of Lago Yelcho.

Discussion and comparative geological evolution

The studied segment of the Andes was an important part of the proto-Pacific margin of Gondwana. Each phase of its geological evolution records interaction between oceanic and continental plates, dominated, at least in Mesozoic and Cenozoic times, by subduction. However, detailed comparison reveals the different processes that occurred during different periods.

During middle and late Palaeozoic times, a broad accretionary complex began to develop along the west coast of southern Chile (Forsythe, 1982). Continental Chiloé, together with the Chonos region to the south, contains the oldest known parts of this complex (which may consist of multiple sedimentary packages), identified as of Devonian age by their extremely rare fossil record. Intercalated volcanic rocks of tholeiitic composition (J. Cembrano, unpublished data) and sparse ultramafic bodies are also known in the Chiloé–Chonos region and may represent slices of the ocean floor over which the pelitic and sandy sedimentary sequences were deposited. Low- to medium-grade metamorphism was associated with accretion, as represented in the Huinay schists with their relatively high initial $^{87}Sr/^{86}Sr$ ratio of 0.7116.

The similar fore-arc accretionary complex of the Antarctic Peninsula (Hyden and Tanner, 1981) started to form later than in Chile: it is, at least in part, of late Palaeozoic to Early Jurassic age (Thomson, 1975; Dalziel et al., 1981). The possible Late Carboniferous to Early Permian Rb–Sr age for the Huinay schists is compatible with one of 281 ± 16 Ma reported for slaty greywackes at the northern end of the Antarctic Peninsula (Pankhurst, 1983) and another of 287 ± 48 Ma for amphibolite-grade mica-schists from the South Orkney Islands (Hervé et al., 1991), although the lower initial $^{87}Sr/^{86}Sr$ ratios (0.707) of both of these appear to signify a less evolved provenance and/or a briefer pre-history. A Carboniferous magmatic-arc source existed for parts of the accretionary complex of the Antarctic Peninsula (Miller et al., 1987) but this has not been specifically identified in southern Chile.

Subsequent Mesozoic re-juvenation of the Chilean fore-arc assemblage is reflected in Jurassic Rb–Sr isotope systematics for the most deformed rocks in the Chonos region (Davidson et al., 1987; Hervé et al., 1988). At this time there was continued deposition in the Antarctic Peninsula fore-arc, which has yielded a Jurassic macrofauna (Thomson and Tranter, 1986) and Cretaceous Radiolaria (Holdsworth and Nell, 1992). Radiometric evidence suggests renewed fore-arc accretion in the Scotia arc region through Cretaceous times (Trouw et al., 1990). As yet, Mesozoic fore-arc deposition has not been positively identified in southern Chile.

In continental Chiloé, as throughout much of the Chilean Andes and the Antarctic Peninsula, a mid-Jurassic volcanic arc and marine back-arc basin developed within the continental margin east of the late Palaeozoic accretionary complex. The unconformity associated with this event in the Antarctic Peninsula region, and the change from accretion to arc-based tectonics that it represents, has been correlated by Storey and Garrett (1985) with uplift during the break-up of Gondwana. Alabaster and Storey (1990) have redefined the tectonic environment of the so-called "back-arc" basins of the Andean margin, suggesting that they were more commonly pull-apart basins associated with strike-slip movement (e.g. Gulf of California). Thus the mid-Jurassic could very well have been the time of primary development of the Liquiñe–Ofqui fault zone, roughly following an ancient margin between the Palaeozoic accretionary complex and the pre-existing continental block of Patagonia.

The intrusion of voluminous monzogranitic magmas into the volcano-sedimentary basin sequences during mid-Cretaceous times marks another tectonic change associated with initial emplacement of the North Patagonian batholith. This homogeneous leucocratic unit persists along the eastern margin of the batholith over a distance of at least 200 km (43°–46°S): numerous Rb–Sr and K–Ar mineral ages of 100–120 Ma have been recorded from granodiorites, adamellites and monzonites to the south (see summary in Niemeyer et al., 1984; Bartholomew and Tarney, 1984) and it probably extends northwards into unmapped territory. Generally, similar subduction-related leucogranitoids are well-developed throughout the Andean margin at this time, e.g. in the coastal batholith of Peru, northern Chile and the Antarctic Peninsula.

The Cretaceous–Tertiary Andean granitoids are also surprisingly uniform in having initial $^{87}Sr/^{86}Sr$ ratios of 0.7040–0.7045 in Peru (Beckinsale et al., 1985), northern Chile (Hervé and

Marinovic, 1989; Rogers and Hawkesworth, 1989) and southern Chile (present work). In the Antarctic Peninsula, the mid-Cretaceous granitoids have slightly higher initial $^{87}Sr/^{86}Sr$ ratios of up to 0.7055, but a fall to about 0.7040 occurs in Late Cretaceous–Paleocene times (Pankhurst et al., 1988). Low initial $^{87}Sr/^{86}Sr$ ratios are reinforced by ϵ_{Nd} values for the Chiloé leucogranites of +0.5 to +1.5 (Table 3), well within the range given for the other late Mesozoic Andean granitoids. These isotopic characteristics are clearly distinct from those of the Palaeozoic schists and the Palaeozoic–Jurassic granitoids of the same margin, which have a more evolved isotope signature (e.g., Pankhurst, 1990). They suggest an ultimate source that had undergone only minor depletion in lithophile elements (relative to that beneath mid-ocean ridges) and which has been interpreted as long-lived lithospheric mantle. The extensive tapping of such a source signifies crustal extension along the continental margin, associated with the establishment of the Andean subduction-related tectonic regime that has continued essentially until recent times. This is also a period of rapid continental drift as Gondwana finally fragmented and the South Atlantic Ocean was formed.

In the studied area, the latest Cretaceous to early Cenozoic history is not well constrained, although it might be represented by the tonalites and diorites of the central belt of the North Patagonian batholith, which we have not yet been able to date with any certainty, and which are lithological similar to parts of the "plutonic complex" of the Patagonian batholith defined in the Aysén district by Bartholomew and Tarney (1984). It seems that this was a period of rapid uplift and erosion of the Andean mountain chain; the youngest sedimentary rocks in the High Cordillera are Neocomian, after which the next known inundation of the margin is recorded by marine Eocene transgressive deposits overlying the granitoids in the western part of the area (Thiele and Hein, 1979).

The locus of plutonic activity shifted to the west during Cenozoic times, and until the Pliocene was located near the trace of the Liquiñe–Ofqui fault zone. A similar Tertiary shift of the magmatic arc towards the trench has been documented in the Aysén district (Bartholomew and Tarney, 1984) and in the Antarctic Peninsula (Pankhurst, 1982), where it has been ascribed to roll-back of the subduction hinge (Pankhurst et al., 1988). It seems that a similar tectonic scenario applied throughout the southeastern Pacific continental margin at this stage. This contrasts with the progressive eastward migration noted in north-central Chile, leading to the position of the present volcanic line above a shallow-dipping subduction zone.

The nature and timing of the movement on the LOFZ are little known in the studied area, but an early strike-slip regime was responsible for creating Eocene–Miocene basins, in which the abundant acid volcanic detritus of the Ayacara formation (Fuenzalida, 1979) was deposited. Acid volcanism of broadly similar age has been reported from Chiloé Island, west of the area, by Valdivia and Valenzuela (1981), and Bartholomew and Tarney (1984) proposed the formation of a Miocene extensional basin in association with trondhjemite–tonalite intrusions in the Aysén district.

During Pliocene times, further rapid uplift took place throughout the area, particularly east of the LOFZ (> 1 km/Ma), where the Cholgo and Pichanco granitoids and contact metamorphic rocks, which formed at depths of at least 4 km, are now exposed. Rb–Sr and Sm–Nd isotope data for these rocks confirm a mantle source region at least as depleted as that of the Cretaceous granitoids, with no evidence for significant interaction with continental crust (Table 3). Differential movements along the main lineament of the LOFZ in this area had apparently ceased by 1.2 Ma as indicated by the undeformed sequences which seal the fault zone south of Lago Yelcho. The modern andesitic to basaltic volcanic chain (Onuma and Lopez-Escobar, 1987) is located along the LOFZ, monogenic basaltic volcanic cones being situated directly over the main lineament (see Fig. 1 and Cingolani et al., 1992).

The exposed geology of the continental Chiloé segment of the Andean margin developed episodically throughout Phanerozoic time, in a tectonic scenario controlled by interaction with the Pan-

Thalassic/Pacific ocean floor, but with significant variations in geodynamic processes and their effects. During Palaeozoic time, the predominant effect was marginal accretion in a continental-shelf basin; low-to-medium-grade metamorphism suggesting burial and deformation associated with compressive forces. However, no associated igneous arc can be identified until Early Mesozoic times, when Jurassic silicic volcanism was followed by the formation and emplacement of the North Patagonian batholith. This was the period during which Gondwana broke up and the fragments began to drift apart. Further emplacement of subduction-related granitoid magmas occurred, intermittently, until Pliocene times. Throughout these "Andean" magmatic episodes, structural control was exerted by strike-slip faulting, exemplified by the major Liquiñe–Ofqui fault zone. Crustal extension, rather than shortening, was also important. In many of these respects, the evolution of this portion of the Andean margin has more in common with that of the Antarctic Peninsula (Storey and Garrett, 1985; Alabaster and Storey, 1990) than with central and northern South American segments.

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