Peralkaline rocks in the Late Cretaceous Del Salto Pluton, Eastern Patagonian Andes, Aisén, Chile (47°35'S)

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ABSTRACT

The Late Cretaceous Del Salto Pluton is one of the four Late Jurassic to Late Miocene intrusives that are recognized *ca.* 60 km inboard from the eastern limit of the Patagonian Batholith, close to the Chilean-Argentinian border. The pluton is a fluorite-bearing biotite syenogranite, except for part of its northeastern sector, where an alkali feldspar granite contains a typical peralkaline assemblage composed of relict augite and aegirine, together with arfvedsonite, ferrorichterite, astrophyllite, pyrochlore and zektzerite. Most of these minerals had not been recognized previously, making this the first example of an alkaline intrusion with a local peralkaline facies in this southern part of the continent. These mineral assemblages are unusual for a subduction-related margin in which subalkalic magmatism is characteristic. Judging from its trace element composition and rare earth element patterns, the pluton probably reflects the end product of extreme fractionation in a within-plate to post-collisional environment. The lack of clear-cut contacts between the rock that contains the peralkaline assemblage and the biotite syenogranite argues in favor of podiform bodies in which F-rich solutions have induced alkalic metasomatism.

Key words: Alkalic mineral assemblage, Patagonian Andes, Post-collisional Cretaceous granites.

RESUMEN

Rocas peralcalinas en el Plutón Del Salto del Cretácico Superior, Andes patagónicos orientales, Aisén, Chile (47°35'S). El Plutón Del Salto, de edad Cretácica tardía, aflora en las inmediaciones del límite chileno-argentino como uno de cuatro intrusivos del Jurásico Superior al Mioceno Superior reconocidos aproximadamente a 60 km del borde oriental del Batolito Patagónico. El intrusivo es petrográficamente hetereogéneo, compuesto principalmente por un sienogranito de biotita y fluorita. En su extremo nororiental se ha reconocido un granito de feldespato alcalino con augita y aegirina relicta, arfvedsonita, ferrorichterita, astrofilita, pirocloro y zektzerita. La mayoría de estos minerales no habían sido descritos con anterioridad en esta zona, haciendo de éste el primer caso de una intrusión alcalina con una facies peralcalina local. Esta asociación mineralógica es inusual para un márgen de subducción activo, donde un

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magmatismo subalcalino es característico. Considerando la composición de sus elementos traza y el patrón de tierras raras, el plutón podría reflejar el producto final de un fraccionamiento extremo en un ambiente de intraplaca a postcolisional. La ausencia de contactos definidos entre la asociación peralcalina y el sienogranito de biotita, argumenta a favor de cuerpos podiformes en los cuales soluciones ricas en flúor han inducido un metasomatismo alcalino.

Palabras claves: Asociación mineralógica alcalina, Andes Patagónicos, Granitos cretácicos postcolisionales.

INTRODUCTION

A cluster of small to medium size intrusive bodies occurs near the Chilean-Argentinian border, *ca.* 60 km inboard from the eastern limit of the Jurassic to Miocene Patagonian Batholith (Fig. 1). Recent studies have discussed its petrography, geochemistry and geochronology (Welkner, 1999, 2000). Based on K-Ar biotite and amphibole, and $^{40}Ar/^{39}Ar$ biotite and K-feldspar dating, it has been subdivided into the following four plutons and one dyke complex, ranging in age from Late Jurassic to Late Miocene (Table 1, Fig. 2):

- The Sobral Pluton, which extends for 70 km^2 and is 143 to 138 Ma old, corresponds to a coarse grained amphibole-tonalite that crops out in the southeastern part of the cluster.
- The Calluqueo Dyke Complex is a 121 Ma old amphibole-biotite diorite to granodiorite swarm with a NNW trend that crops out north of the Sobral Pluton and extends for 15 km up to the Glaciar Calluqueo. The thickness of individual subvolcanic andesitic and dacitic dykes is close to 3 m.
- The Tranquilo Pluton, with an area of 50 km^2 and 90 to 84 Ma old, is an intrusive complex that crops out in the northern part of the cluster. It is made up of marginal brecciated gabbro (89±3 Ma), quartz-syenite and syenogranite surrounding a quartz-monzonite to monzogranitic core.

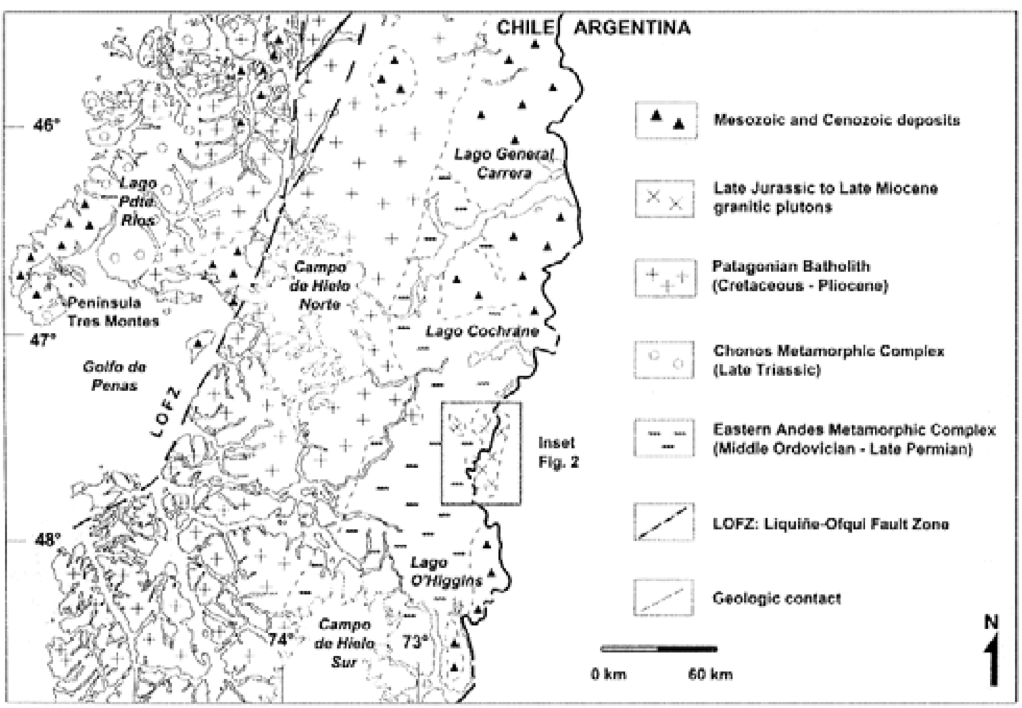

FIG. 1. Geologic map of the Patagonian Andes of southern Chile showing the setting of Late Jurassic to Late Miocene granitic plutons. The area represented in figure 2 is outlined with a box.

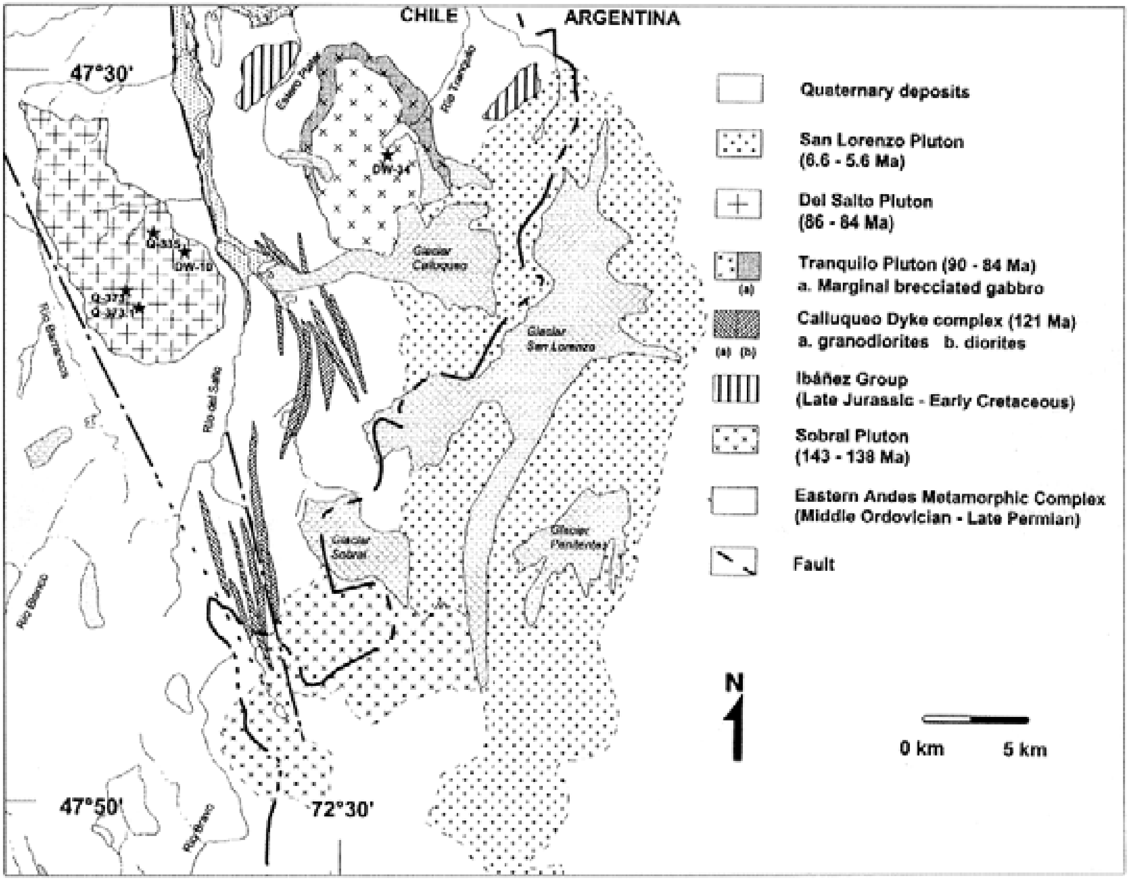

FIG. 2. Geologic map of the study area and location of the Del Salto Pluton samples.

- The Del Salto Pluton, with an extension of 75 km^2 and 86 to 84 Ma old, corresponds to the western intrusive of the cluster. It is mainly composed by a syenogranite but towards its eastern margin an alkali feldspar granite which hosts the peralkaline minerals studied in this paper was recognized.
- The San Lorenzo Pluton was named after Mount San Lorenzo 3,706 m, the second highest mountain in Patagonia. With an area of 320 km^2 and 6.6 to 5.6 Ma, it is made up mainly of syenogranite that towards its northern part encloses a monzogranitic mafic inclusion-rich facies. However, an 89 Ma old granodiorite (D. Welkner, unpublished data) of unknown extension has been sampled in its southeastern 'Argentinian' section. Therefore, depending on the areal extension of such Late Cretaceous intrusion, the size of this Miocene unit may be considerably reduced.

All the plutons listed above are epizonal and emplaced in a Middle Ordovician to Late Permian metaturbiditic complex (age based on SHRIMP U-Pb dating of detrital zircons, Thomson *et al.*, 2000) that is part of the Eastern Andes Metamorphic Complex of Hervé (1993) and Hervé *et al.* (1998). The northern part of the San Lorenzo Pluton also intrudes into conglomerates, tuffs and both andesitic and rhyolitic lavas of Late Jurassic to Early Cretaceous age assigned to the Ibañez Group (Welkner, 1999).

Microprobe data from the alkalic minerals found in one of the samples from the Del Salto Pluton, mostly previously unknown in Chile, are presented in this paper. A brief discussion on the geotectonic significance of this highly differentiated and compositionally unusual magmatism follows.

TABLE 1. K-Ar AND $^{40}Ar/^{39}Ar$ AGES FOR THE LATE JURASSIC TO LATE MIOCENE INTRUSIVE ROCKS.

Sample	Rock type	Mineral	K-Ar Age (Ma ± 2σ)	$^{40}Ar/^{39}Ar$ WMPA* (Ma ± 2σ)	TFA** (Ma ± 2σ)	II*** (Ma ± 2σ)	Data source
Sobral Pluton							
DW-60.2	Tonalite	Biotite		143.21 ± 0.76	122.98±0.64	143.04±1.27	Welkner (2000)
DW-60.2	Tonalite	Biotite	143 ± 5				Welkner (1999)
DW-60	Tonalite	Amphibole	138 ± 8	-	-	-	Welkner (1999)
Calluqueo Dyke Complex							
DW-16	Granodiorite porphyry	Biotite	121 ± 3	-	-	-	Welkner (1999)
Tranquilo Pluton							
DW-34	Quartz monzonite	Biotite	90 ± 2				Welkner (1999)
DW-34	Quartz monzonite	Biotite		84.30 ± 0.40	82.88 ± 0.39	-	Welkner (2000)
DW-32.1	Gabbro	Biotite	89 ± 3	-	-	-	Welkner (1999)
Del Salto Pluton							
Q-373	Syenogranite	Biotite	86 ± 2	-	-	-	Welkner (1999)
DW-10	Alkali feldspar granite	Amphibole	84 ± 4	-	-	-	Welkner (1999)
San Lorenzo Pluton							
Q-379	Monzogranite	Biotite	6.6 ± 0.5	-	-	-	Welkner (1999)
DW-38	Syenogranite	Biotite	6.4 ± 0.4				Welkner (1999)
DW-38	Syenogranite	Biotite		6.20 ± 0.12	6.19 ± 0.12	6.23 ± 0.16	This paper
DW-38	Syenogranite	K-feldspar		5.76 ± 0.09	6.21 ± 0.12	5.59 ± 0.92	Welkner (2000)

*WMPA: Weighted Mean Plateau Age; ** TFA: Total Fusion Age; ***II: Inverse Isochron Age. K-Ar age determinations were obained at the Geochronological Laboratory of the Servicio Nacional de Geología y Minería by C. Pérez de Arce. The $^{40}Ar/^{39}Ar$ analyses were performed at Stanford University by M. Mc Williams.

THE DEL SALTO PLUTON

The Del Salto Pluton is a NNW elongated pluton composed dominantly of equigranular to porphyritic biotite-syenogranite. It crops out between the Del Salto and Barrancos valleys, a few kilometers southwest from the coeval Tranquilo Pluton (Figs. 2 and 3).

PETROGRAPHY

Samples Q-373 and Q-373.1 were collected on the eastern shoulder of the Barrancos glacial valley in the western half of the pluton (Fig. 2). The first sample, dated in 86±2 Ma (K-Ar; biotite), is a biotite-poor, fluorite-bearing, coarse grained, porphyritic syenogranite. The second sample is finer-grained, biotite-rich and has two varieties of perthitic feldspars, one of which displays deformation lamellae. The groundmass of both granites contains abundant embayed quartz and its texture often resembles a graphic intergrowth.

A somewhat more heterogeneous lithology is exposed in the eastern half of the pluton, where a 84±4 Ma K-Ar sodic amphibole age was obtained

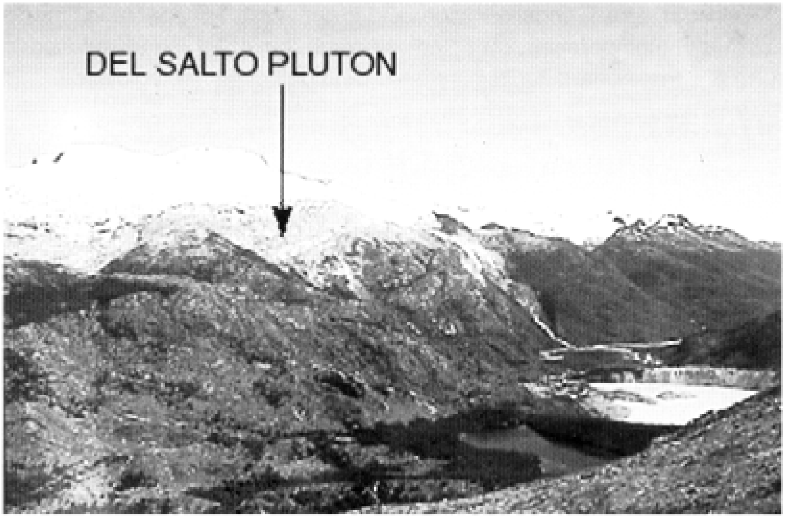

FIG. 3. View from the southeast of the Del Salto Pluton.

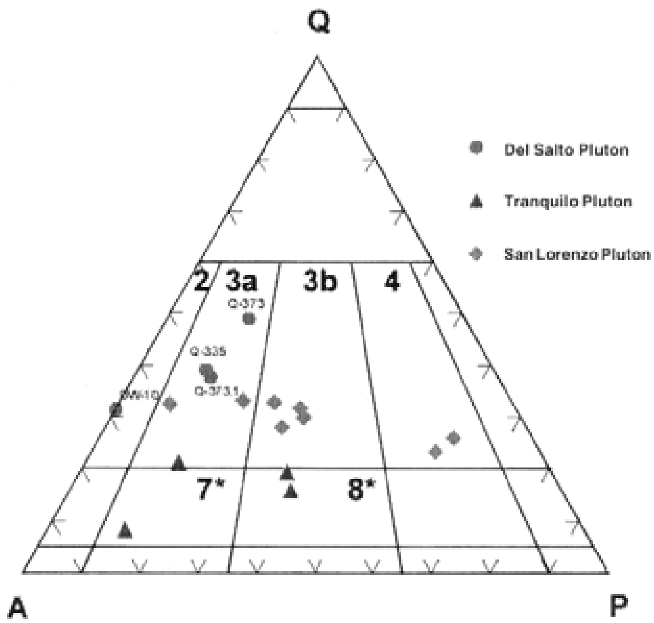

FIG. 4. QAP diagram (based on Le Maitre *et al.*, 1989) of the Tranquilo, Del Salto and San Lorenzo plutons. The corners of the triangle are **Q**=quartz; **A**= alkali feldspar and **P**=plagioclase. Field numbers are: **2**=alkali feldspar granite; **3a**=syenogranite; **3b**=monzogranite; **4**= granodiorite; **7***= quartz syenite and **8***= quartz monzonite.

for sample DW-10, the arfvedsonite-ferrorichterite-aegirine alkali feldspar granite with seriate texture (0.1-4 mm) described here in detail. Sample Q-335, on the other hand, is a fine-grained, fluorite-bearing syenogranite in which feldspar and biotite show advanced alteration to sericite and chlorite respectively. Its texture is similar to Q-373.1.

Whole rock chemical analyses of the four Del Salto samples have been plotted, together with data from the Tranquilo and San Lorenzo plutons, in a Q-A-P diagram (Fig. 4). The Del Salto Pluton trend broadly shows a decrease in quartz and plagioclase with increase of K-feldspar. The Tranquilo Pluton, on the other hand, while contemporaneous with the Del Salto Pluton, has a trend characterized by a lower quartz/feldspar ratio. The San Lorenzo Pluton trend shows the usual K-feldspar-quartz enrichment and decrease in plagioclase.

MINERALOGY

The following minerals have been identified in the alkali feldspar granite (DW-10): quartz (29%), perthitic K-feldspar (48%), albite (16%), arfvedsonite and ferrorichterite (6%), augite (<1%), aegirine, (<1%), astrophyllite (<1%), pyrochlore (<1%) and zektzerite (<1%). Selected microprobe analyses from the first 5 mafic minerals are shown in table 2.

Aegirine is present as scarce small (0.3 mm) green crystals fringed by arfvedsonite. Its formula was calculated to be:

$$(Na_{.97}Ca_{.03})_1(Fe^{+3}_{.82}Fe^{+2}_{.10}Ti_{.08})_1(Si_{1.99}Al_{.01})_2O_6$$

Another relict pyroxene, more abundant and forming 1 mm thick crystals, has an **Al-poor augitic** composition:

$$(Ca_{.85}Na_{.02}Mn_{.03}Fe^{2+}_{.00})_{1.01}(Fe^{2+}_{.85}Fe^{3+}_{.08}Mg_{.06}Ti_{.01})_1(Si_{1.97}Al_{.01}Fe^{3+}_{.02})_2O_6$$

Ferrorichterite partially overgrows all the pyroxene crystals and most of the arfvedsonite (Fig. 5). The following formula was calculated for this light green mineral:

$$(Na_{.52}K_{.27})_{.79}(Ca_{.7}Na_{1.30})_2(Ti_{.14}Fe^{3+}_{.53}Mg_{.18}Fe^{2+}_{4.18}Mn_{.08})_{5.11}(Si_{7.69}Al_{.26}Fe^{3+}_{.06})_{8.01}O_{22}(OH_{1.98}Cl_{.02})_2$$

Arfvedsonite, the main mafic mineral, is strongly zoned with a core that has the following formula:

$$(Na_{.4}K_{.29})_{.69}(Ca_{.2}Na_{1.8})_2(Ti_{.18}Fe^{3+}_{.96}Mg_{.06}Fe^{2+}_{3.75}Mn_{.06})_{5.03}(Si_{7.85}Al_{.11}Fe^{3+}_{.04})_8O_{22}(OH_{1.96}Cl_{.04})_2$$

The structural formula of its pleochroic brown-bluish to dark blue wide rim (Fig. 6) is:

$$(Na_{.69}K_{.30})_{.99}(Ca_{.38}Na_{1.62})_2(Al_{.06}Ti_{.19}Fe^{3+}_{.32}Mg_{.02}Fe^{2+}_{4.32}Mn_{.08})_{4.99}(Si_{7.87}Al_{.13})_8O_{22}(OH_{1.99}Cl_{.01})_2$$

The major crystal-chemical difference between rim and core corresponds to the presence of Al^{VI} in the former. According to Strong and Taylor (1984), arfvedsonite in this paragenesis points to a rather reducing environment.

Astrophyllite is present as abundant late stage small, tabular to platy, brown to yellow crystals, usually filling fractures in arfvedsonite (Fig. 6). The

TABLE 2. SELECTED MINERAL ANALYSES FROM THE ALKALI FELSPAR GRANITE OF THE DEL SALTO PLUTON: SAMPLE DW-10.

Mineral Classification	Structural Formula	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	BaO	Na_2O	K_2O	Total
Ferrorichterite	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	47.51	1.01	1.35	35.28	0.60	0.29	3.91	0.00	5.74	1.45	97.25
Ferrorichterite	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	47.53	0.97	1.33	35.18	0.58	0.32	4.25	0.07	5.77	1.26	97.31
Ferrorichterite	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	47.22	1.59	1.35	35.04	0.65	0.15	3.97	0.00	5.87	1.24	97.12
Arfvedsonite (core)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	48.81	2.42	0.43	35.11	0.34	0.18	1.22	0.04	7.02	1.01	96.58
Arfvedsonite (core)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	48.40	0.96	1.22	35.61	0.39	0.37	1.54	0.06	7.03	1.63	97.25
Arfvedsonite (core)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	50.12	0.36	0.12	35.85	0.50	0.50	0.78	0.02	7.19	1.66	97.11
Arfvedsonite (rim)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	48.28	1.58	1.02	34.13	0.56	0.04	1.95	0.03	7.27	1.48	96.39
Arfvedsonite (rim)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	49.13	1.52	0.92	33.69	0.69	0.13	1.88	0.02	7.43	1.42	96.86
Arfvedsonite (rim)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	48.52	1.49	0.91	33.88	0.60	0.09	1.98	0.04	7.46	1.59	96.59
Arfvedsonite (rim)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	47.66	1.76	1.26	34.01	0.59	0.17	2.78	0.04	6.86	1.56	96.74
Arfvedsonite (rim)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	48.01	1.51	1.08	34.34	0.62	0.07	2.85	0.04	7.13	1.13	96.82
Arfvedsonite (rim)	$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$	48.58	1.41	0.81	34.66	0.60	0.06	1.67	0.06	7.70	1.47	97.09
Al-poor Augite	XYZ_2O_6	47.89	0.27	0.19	29.44	0.77	0.95	19.00	0.05	0.88	0.03	99.46
Aegerine	XYZ_2O_6	51.81	2.71	0.12	28.45	0.27	0.02	0.78	0.06	12.95	0.00	97.20
Astrophyllite	$W_3X_7Y_2Z_8O_{31}$	39.42	0.06	4.89	39.16	0.36	0.86	2.70	0.10	0.08	0.21	87.90

Leake *et al.* (1997); Morimoto *et al.* (1988) and Deer *et al.* (1992) were used for the classification of amphiboles, pyroxenes and astrophyllite, respectively. Microprobe analyses were performed at Rühr Universität, Bochum, with a CAMECA SX50 Microprobe.

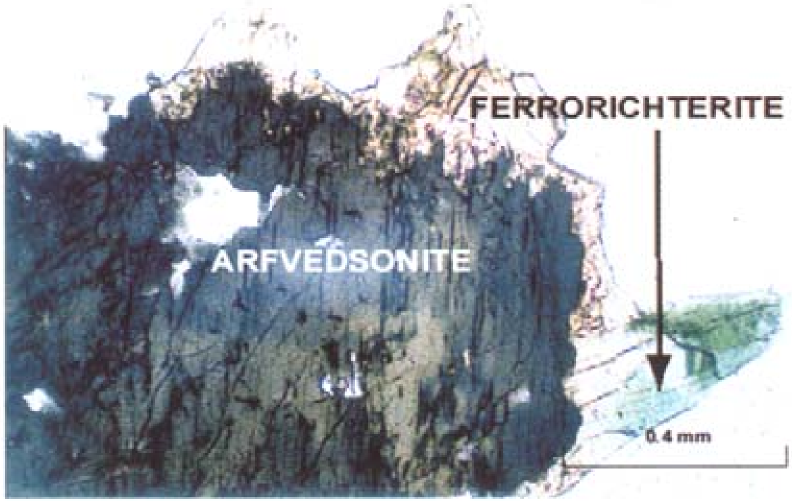

FIG. 5. Photomicrograph showing arfvedsonite with a ferrorichterite overgrowth. PPL, 10x.

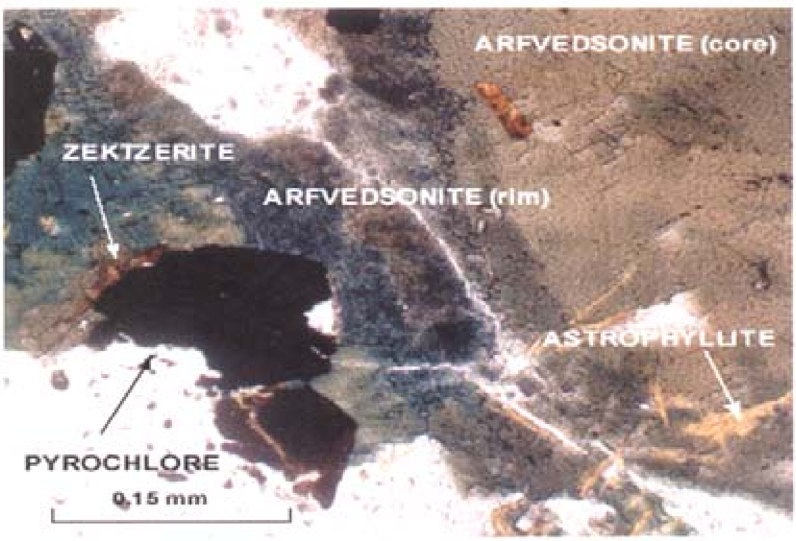

FIG. 6. Photomicrograph showing arfvedsonite, astrophyllite, pyrochlore and zektzerite. XPL, 20x.

formula presented (best total 87.9% out of four analyzed points) is incomplete because the mineral was originally misidentified as stilpnomelane, so that Cs, Nb and *Zr* were not considered. The mineral may thus probably correspond to a cesium-rich astrophyllite:

$$(Cs_{2.34}?Ca_{\ldots}Na_{\ldots}K_{\ldots})_{\ldots}(Fe_{\ldots}Mn_{\ldots})_{\ldots}(Ti_{\ldots}Al_{\ldots}(Zr,Nb)_{\ldots}?)Si_{\ldots}O_{\ldots}(OH)$$

Pyrochlore, a cubic multiple oxide containing niobium, tantalum and titanium, is found as small (150 µm) crystals (Fig. 6). The best of the 9 analyses gives the following composition:

F	La_2O_3	Na_2O	CaO	TiO_2	FeO	Nb_2O_5	SiO_2	CeO_2	Nd_2O_3	Ta_2O_5	Total
4.87	2.29	7.77	9.22	10.43	0.32	43.60	4.63	7.32	2.91	2.99	96.34

According to this composition, the formula of this particular pyrochlore, based on 6.5 oxygens is:

$$(Na_{.94}Ca_{.61}Ce_{.32}Nd_{.06}La_{.09}Fe_{.02})_2(Nb_{1.23}Ti_{.48}Si_{.29}Ta_{.09})_{2.06}O_6(OH,F_{.96})$$

It is a Si-Ti-Ta rich Ca-Nb poor variety, similar to species such as **Ellsworthite** or **Hatchettolite** quoted in Dana and Dana (1944).

A mineral with extreme blue cathodoluminescence surrounds some of the pyrochlore crystals (Fig. 6). Both its X-ray pattern and its composition match that of **Zektzerite**, a double chain silicate with a period of six ('Sechser-Doppelkette'). Its formula: **Li, Na(Zr,Ti,Hf)Si_6O_{15}** may be considered **Tuhualite** (**$(Na,K)_2Fe_2^{2+}Fe_2^{3+}Si_{12}O_{30}$ H_2O**) and, more distantly, a member of the **Osumilite Group**. The authors' Li-free analysis is close to the one reported by Dunn *et al.* (1977) (Table 3).

Scarce, high relief, brownish, high birefringent minerals with a botryoidal habit may be either **Xenotime** or **Yttrialite**.

TABLE 3. PARTIAL CHEMICAL COMPOSITION OF ZEKTZERITE FROM THE DEL SALTO PLUTON COMPARED WITH THAT FROM THE GOLDEN HORN BATHOLITH (DUNN *et al.*, 1977).

Oxide	Del Salto Pluton	Golden Horn Batholith
Na_2O	4.83	5.9
SiO_2	67.13	68.24
ZrO_2	21.41	21.84

GEOCHEMISTRY AND PETROGENESIS

Chemical composition of the Del Salto and Tranquilo Pluton granitoids are shown in table 4.

In figure 7 sample DW-10 plots in the peralkaline field, consistent with its mineralogy and high REE abundance. As seen in table 4, its $\acute{Y}REE_{DW-10}$(505.6 ppm) is roughly twice to three times greater than the other Del Salto Pluton samples. The Q-335 syenogranite plots in the peraluminous field, compatible with alteration of feldspar to clay minerals and the consequent loss of alkalis (Na_2O=2.04 wt% and K_2O=2.53 wt%), while the two western syenogranites (Q-373 and Q-373.1) fall in the metaluminous field, together with the Tranquilo and San Lorenzo intrusives.

Figure 8 shows the REE pattern from the Del Salto Pluton samples, in which a major difference is observed in both the LREE and Eu contents. A moderate $(La/Yb)_N$ ratio of 10.02 is recognized in sample DW-10, together with the highest LREE enrichment and a moderate Eu/Eu* negative anomaly (0.17). Samples Q-335 and Q-373.1 show similar $(La/Yb)_N$ ratios (8.17 and 7.57, respectively), slightly lower than DW-10. The former exhibit a weak Eu/Eu* negative anomaly (0.70), while in the latter it reaches a very low value (0.06). The syenogranite Q-373 shows a flat pattern with a $(La/Yb)_N$ ratio of 1.01 and the most pronounced Eu/Eu* negative anomaly from all the Del Salto samples (0.01).

According to Clarke (1992), 'because granitoid magmas are slow to ascend and probably undergo polybaric/polythermal fractional crystallization en route, and because they almost certainly have become contaminated with country rocks, they are no longer primary and no amount of investigation of their phase relations is going to help determine the nature of their source'. Despite these strong drawbacks the authors will try to advance some comments on the genesis of the Del Salto Pluton, based on its geochemistry.

The extremely low Ba (12-50 ppm) and Sr (5-24 ppm) contents of the Del Salto Pluton granitoids DW-10, Q-373.1 and Q-373 are compatible with extense plagioclase and K-feldspar fractionation, an interpretation strongly supported by their negative Eu anomalies. Both the Q-335 and the Tranquilo Pluton DW-34 samples have, on the other hand, higher Ba and Sr contents as well as a more discrete negative Eu anomaly, which is consistent with less feldspar fractionation. Such high Ba and Sr values have been explained by Hildreth and Moorbath (1988) in the Central Volcanic Zone by means of assimilation of Andean crustal material.

In the Rb-(Y+Nb) diagram for discriminating the tectonic setting of granites (Fig. 9; Pearce *et al.*, 1984) DW-10 and the two western samples plot well inside the Within-Plate Granites field (WPG), Q-335 and the San Lorenzo syenogranites lie in the Volcanic Arc Granites field (VAG), while the Tranquilo samples plot on the boundary between the Within Plate and Volcanic Arc Granites fields. According to Pearce (1996), most of the authors' analyses also plot in the

TABLE 4. CHEMICAL COPOSITIONS OF REPRESENTATIVE SAMPLES FROM THE DEL SALTO AND TRANQUILO PLUTONS.

	Analyses	Q-373 Del Salto Puton	Q-373.1 Del Salto Pluton	Q-335 Del Salto Pluton	DW-34 Tranquilo Pluton	DW-10 Del Salto Pluton
wt %	SiO_2	76.98	75.39	72.94	69.01	74.23
	Al_2O_3	12.39	12.35	11.67	14.91	11.37
	TiO_2	0.09	0.19	0.52	0.39	0.20
	Fe_2O_3	0.69	0.97	0.55	1.06	1.41
	FeO	0.24	0.86	2.87	1.70	2.13
	CaO	0.39	0.34	1.61	1.35	0.43
	MgO	0.02	0.13	1.33	0.57	0.03
	MnO	0.01	0.03	0.05	0.06	0.05
	Na_2O	4.25	3.30	2.04	4.62	5.03
	K_2O	4.66	5.96	2.53	5.11	4.50
	P_2O_5	0.05	0.05	0.18	0.15	0.05
	LOI	0.12	0.21	3.49	0.69	0.44
	Total	99.90	99.77	99.78	99.62	99.87
ppm	Ba	12	35	383	484.00	50
	Rb	287	308	109	182.00	250
	Sr	5	24	85	206.00	15
	Y	100	56	28	26.00	83
	Zr	149	132	258	296.00	1010
	Nb	96	55	11	38.00	116
	Th	x	x	8	20.00	30
	Pb	21	15	14	24.00	18
	Zn	37	65	33	58.00	202
	Cu	3	5	22	10.00	5
	Ni	2	2	19	2.00	2
	V	5	5	8	24.00	5
	Cr	24	6	58	8.00	12
	Co	2	2	10	2.00	2
	Sc	2	2	9	4.00	2
	La	14.05	60.65	32	47.00	106
	Ce	44.5	109	72	98.00	235
	Pr	5.77	13	x	x	x
	Nd	28.7	48.9	33	32.00	95
	Sm	9.81	10.7	6.11	5.57	17.74
	Eu	0.05	0.19	1.27	1.03	0.97
	Gd	11.85	9.66	5.09	4.31	16.57
	Tb	2.29	1.79	x	x	x
	Dy	15.75	9.93	5.24	4.42	16.03
	Ho	3.25	1.95	1	0.96	3.3
	Er	9.58	5.54	2.55	2.66	6.92
	Tm	1.41	0.71	x	x	x
	Yb	9.31	5.34	2.61	2.61	7.05
	Lu	1.28	0.77	0.39	0.41	1.04
	ΣREE	148.13	262.63	161.26	198.97	505.62
	$(La/Yb)_N$	1.01	7.57	8.17	12.01	10.02
	Eu/Eu*	0.01	0.06	0.70	0.65	0.17

Major and trace elements, including REE from samples Q-373 and Q-373.1, were analyzed in the chemical laboratory of the Servicio Nacional de Geología y Minería by F. Llona, using both AAS (Perkin Elmer 4000) and ICP-AES. Rare earth elements from DW-10, DW-34 and Q-335 (Welkner, 1999) were analyzed at the Department of Geology of the University of Chile by J. Martínez with a Perkin Elmer P-400 ICP-AES. ΣREE considers only La, Ce,Nd, Sm, Eu, Gd, Dy, Ho, Er, Yb, Lu. x: not measured.

field defined as Post-collision Granites (post-COLG), a type for which a great range of source materials has been proposed.

Figure 10 highlights the decrease on $(La/Yb)_N$ and Eu anomaly, related to plagioclase and K-feldspar fractionation in a DW-34, Q-335, Q-373.1

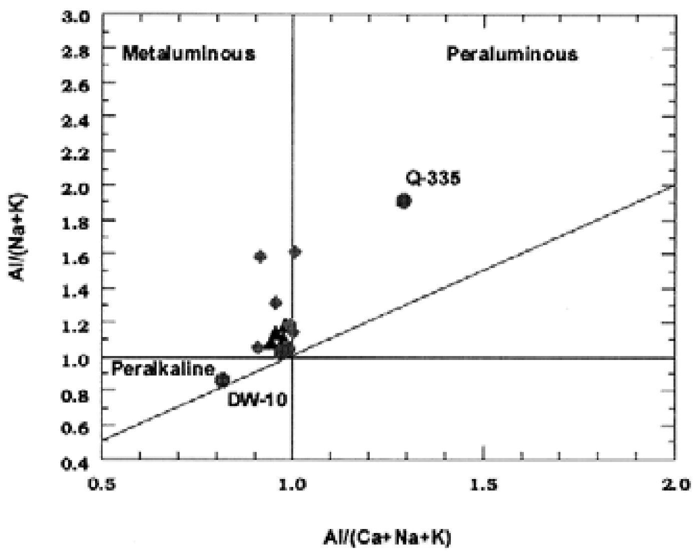

FIG. 7. Alkalinity index *versus* alumina saturation index of the Tranquilo (▲), Del Salto (●) and San Lorenzo (◆)

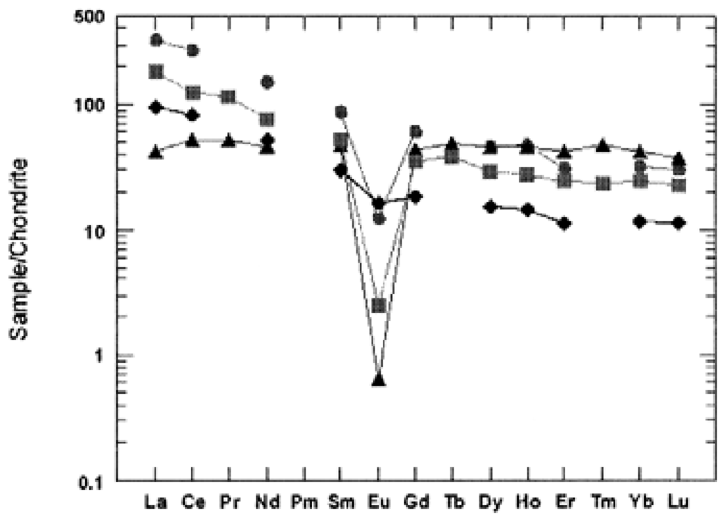

FIG. 8. REE plot of samples DW-10 (●), Q-335 (◆), Q-373.1 (■) and Q-373 (▲), from the Del Salto Pluton. Values normalized to the average chondrite of Nakamura (1974) with additions from Haskin *et al.* (1968), quoted in Rollinson, 1993.

to Q-373 differentiation sequence for the Tranquilo and Del Salto samples. The authors' K-Ar data (from 90±2 to 86±2 Ma, Table 1) support this sequence as constituting a progressive temporal differentiation trend. The neighbour Tranquilo Pluton quartz-monzonite, however, has an $^{40}Ar/^{39}Ar$ age of 84.3±0.4 Ma, which is considered more reliable, and hence may point to a younger age for the entire series. The $(Y)_N$ increase in the sequence may be explained by a lack of amphibole fractionation.

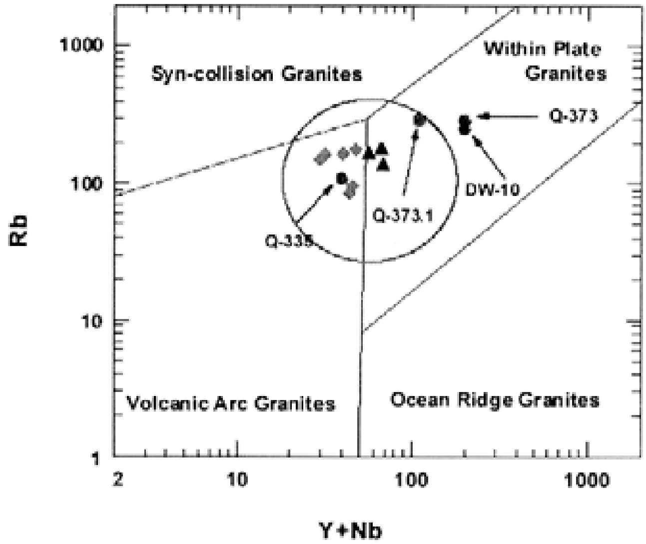

FIG. 9. Rb *versus* (Y+Nb) diagram (Pearce *et al.*, 1984) of the Tranquilo (▲), Del Salto (●) and San Lorenzo (◆) plutons. The ellipse corresponds to the Post-collision Granites field of Pearce (1996).

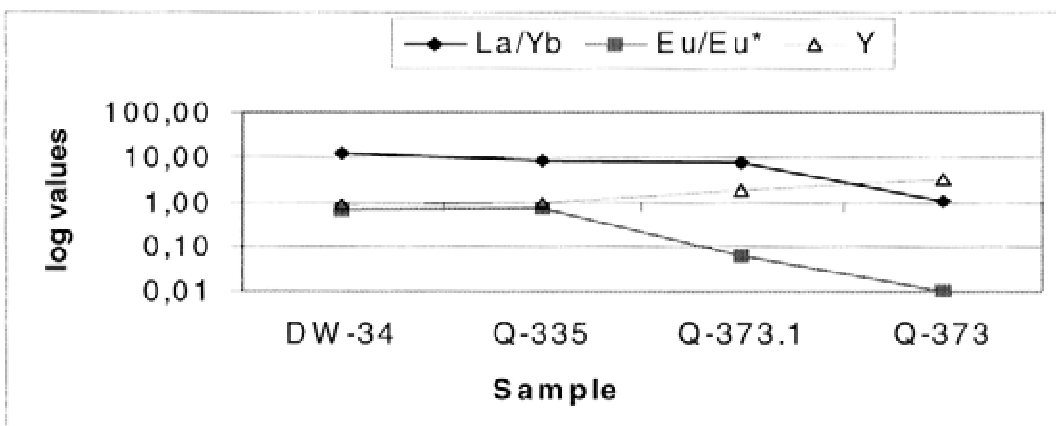

FIG. 10. Logarithmic diagram of the Tranquilo (DW-34) and Del Salto (Q-335, Q-373.1, Q-373) pluton samples showing the $(La/Yb)_N$, Eu/Eu* and $(Y)_N$ variations linked to an increase on plagioclase and K-feldspar fractionation.

DISCUSSION

The Late Cretaceous Del Salto Pluton is the first example of an alkaline intrusion with a local peralkaline facies described in southern Chile. Its partially peralkaline composition and alkalic mineral assemblages are unusual for a subduction-related margin in which subalkalic magmatism is characteristic.

The alkali feldspar granite hosting the alkalic minerals may have formed as a podiform roof coarse-grain facies, later amalgamated during cooling with the syenogranitic main mush, thus no sharp contacts were observed. Both the Tranquilo and particularly the Del Salto Pluton are fluorite bearing and, according to the authors quoted in Clarke (1992), fluorine is held responsible for complexing REEs and other HFS elements. The authors thus interpret that enrichment in these elements was more effective in the latter pluton. Considering that the alkali fedspar granite may have been originated due to this special F-driven process, it was not taken into account in the magmatic differenciation trend of figure 10.

Cretaceous plutons from the Patagonian Batholith were emplaced in a crust that underwent a fast post-intrusion cooling, followed by a decrease in the rate of denudation which ceased at *ca.* 12-8 Ma (Thompson *et al.*, 2001). According to these authors, this process could be linked to a slow and extremely oblique plate convergence at that time. The Late Cretaceous within plate to post-collision granites of the San Lorenzo area may have been emplaced during the early relaxation stage that followed Mid-Cretaceous Andean crustal thickening and marginal basin closure. Suárez and de la Cruz (1997) recognized Late Cretaceous bimodal volcanism north of the area, which they interpreted as emplaced in a back-arc extensional tectonic environment. The Miocene San Lorenzo Pluton bears a post-collision character related to ridge subduction (Cande and Leslie, 1986) and its volcanic arc signature may correspond to an extensive interaction between mantle-derived magmas and the crust.

This Late Jurassic to Late Miocene cluster of small to medium size satellite intrusive bodies, *ca.* 60 km inboard from the eastern limit of the coeval Patagonian Batholith, reflects a long-lived deep seated control. Magmatic activity that fills the Paleogene gap in both the Patagonian Batholith as well as the San Lorenzo cluster has been recognized east of the area. This magmatism, extending from the Paleocene to the Pliocene, includes mafic alkaline subintrusives, mainly zeolite-rich teschenites and essexites (Ardolino *et al.*, 1999). Though all the authors agree on their anorogenic character, whether they were emplaced along a Paleogene rift or in a transition sector between the Andean Orogen and the 'Patagonia Passive Zone' is debated (Bitschene *et al.*, 1991).

The three unaltered the Del Salto granitoids and all the Tranquilo syenitoids (Le Maitre *et al.*, 1989) plot in the WPG to post-COLG field of the Rb-(Y+Nb) discriminant diagram and may thus be interpreted as extensional types. As post-tectonic granites are the most difficult to classify due to their source variability, these results should be considered as preliminary. Further support to these propositions will be possible, once isotopic data become available.

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