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EVOLUCION DE LAS ROCAS IGNEAS DEL TERCIARIO MEDIO A SUPERIOR EN LA CORDILLERA PRINCIPAL DE CHILE (29°-31°S): CORRELACION CON CAMBIOS EN LA GEOMETRIA DE LA SUBDUCCION

EVOLUTION OF MID-LATE TERTIARY IGNEOUS ROCKS IN THE MAIN CHILEAN CORDILLERA (29°-31°S): CORRELATION WITH CHANGES IN SLAB GEOMETRY

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An outstanding feature of the modern Andes is the correlation of the tectonic and volcanic characteristics on the American plate with the geometry of the subducting Nazca plata. Where the modern angle of subduction is subhorizontal, and the asthenosphere is thinned or missing (BARAZANGI and ISACKS, 1976), modern volcanism is essentially absent. One such region in the modern Andes lies between 28°–33°S. Regional mapping and dating, particulary between 29°-31°S (MAKSAEV et al., 1984), has shown, however, that extensive volcanism existed in this region until the Middle Miocene. This volcanism, along with the distribution of younger volcanism to the east (GORDILLO and LINARES, 1982; LEVERATO, 1976), and examination of the topography and tectonism between 22°-33°S has led ISACKS (1985) to suggest that the angle of subduction shallowed in this region as the South American plate overrode the Nazca plate. Petrologic and geochemical characteristics of Tertiary igneous rocks from the main Cordillera in Chile, as well as the Calingasta Valley and the Sierras Pampeanas to the east in Agentina show variations that are in agreement with this model.

The earliest mid-Tertiary volcanism in the region is represented by the Doña Ana Formation, which consists of basaltic andesitic to rhyolitic lavas, pyroclastic breccias and ignimbrites that reach thicknesses up to 2000 m (MAKSAEV et al., 1984). South of the Rio del Medio (Fig. 1), two members occur: a) the lower Tilito member consisting of rhyolitic and dacitic ignimbrites and Flows (Table 1, col. 3) and characterized mineralogically by plagioclase, orthoclase, quartz and biotite, and b) the upper Escabroso member composed of basaltic andesites with mafic phenocryst of olivine and clinopyroxene (col.1) and pyroxene andesites which may have lesser amounts of amphibole (col.2). North of the Rio del Medio, basaltic andesite is dominant. The Infiernillo unit plutons (col. 4) are subvolcanic equivalents to some Doña Ana andesites and contain modal clinpyroxene and amphibole. Eight K-Ar determinations on both members of the Doña Ana Formation show ages between 27.0 and 18.9 m.a (MAKSAEV et al., 1984). One date from the Infiernillo gives 16.7 m.a.

Chemically, the Doña Ana basaltic andesites and rhyolites (Table 1) are broadly similar to basaltic andesites and rhyolites that occur in the modern Southern Volcanic Zone (SVZ) i.e. Laguna del Maule, (Frey et al., 1984) and other centers, (LOPEZ-ESCOBAR,

TABLA 1: ANALISIS QUIMICOS REPRESENTATIVOS DE ROCAS VOLCANICAS NEOGENAS DE LOS ANDES CHILENOS (29–31.5°S)

TABLE 1 – REPRESENTATIVE ANALYSES OF LATE TERTIARY VOLCANIC ROCKS FROM THE CHILEAN ANDES CORDILLERA (29–31.5°S)

	Doña Ana			Infiernillo	Tórtolas	Vallecito	
	Escabroso		Tilito				
	1	2	3	4	5	6	
	NBT10	*164	*162	*I-17	*NBT150	*VLL-2	GSP-1
SiO_2	53.08	57.91	73.63	63.64	63.76	70.94	
TiO_2	1.05	1.07	0.29	0.75	0.70	0.26	
Al_2O_3	19.38	18.62	14.51	16.71	18.87	16.37	
FeO	7.83	5.96	1.42	4.87	3.35	1.32	3.90
MnO	0.123	0.095	0.034	0.077	0.075	0.034	0.65
MgO	4.78	3.07	0.34	2.93	1.26	0.33	
CaO	9.75	6.35	1.64	3.05	5.07	2.30	
Na_2O	3.25	4.98	4.12	4.51	4.32	4.77	2.80
K_2O	0.59	1.65	3.91	3.33	2.23	3.45	
P_2O_5	0.17	0.29	0.10	0.13	0.20	0.21	
Total	100.00	100.00	100.00	100.00	100.00	100.00	
FeO/MgO	1.64	1.94	4.15	1.66	2.65	3.93	
La	10.2	17.1	26.5	26.4	24.9	21.4	184.
Ce	23.3	38.8	52.4	58.1	50.8	43.5	430.
Nd	14.1	19.3	22.0	23.2	22.7	18.9	203.
Sm	3.19	3.90	4.09	4.92	4.14	3.19	26.1
Eu	1.07	1.11	0.694	1.05	1.08	0.741	2.23
Tb	0.448	0.456	0.605	0.564	0.373	0.229	14.3
Yb	1.48	1.30	2.16	1.90	0.973	0.673	1.36
Lu	0.211	0.202	0.335	0.269	0.141	0.088	1.67
La/Yb	6.9	13.2	12.3	13.8	25.6	31.8	0.22
Sc	24.8	10.6	3.80	10.6	7.70	1.93	6.00
Hf	2.7	3.5	4.6	4.3	4.5	3.8	15.7
Ta	0.209	0.371	1.50	0.978	0.735	0.714	0.920
Cr	22.	32.	-	17.	-	-	13.9
Ni	36.	8.	3.	13.	8.	3.	10.5
Co	29.4	16.4	4.90	14.6	11.2	2.26	6.5
Th	1.42	2.8	9.77	23.2	10.1	6.91	107.0
U	0.21	0.67	2.82	4.9	3.5	3.6	2.56
Ba	241.	407.	748.	624.	642.	894.	1313.0
Cs	0.37	0.44	3.2	2.8	8.0	6.8	0.978
Rb		59.	127.	151.	88.	119.	
Sr		558.	135.	420.	621.	542.	

Trace element analyses (except Rb and Sr), Na_2O, and MnO analyses by NIAA at Cornell University (values for USGS standard GSP-1 at right). Concentrations are keyed to sample FeO concentrations (anhydrous values) which were used as an internal flux monitor. Rb and Sr and starred major analyses (normalized to anhydrous values) are from Maksaev et al. (1984). Major element analyses of NBT10 on fluxed powder by electron microprobe at Cornell.

1984) and are consistent with the hypothesis that they formed over a more steeply dipping portion of the Nazca plate. The REE of the Doña Ana are characterized by La/Yb ratios ranging from 6-7 for basaltic andesites and 10-14 for the andesites and rhyolites (Fig. 2). Relative to the basaltic andesites. the andesites show an enrichment in the LREE and the rhyolites show a depletion in the middle REE. The rhyolites have significant Eu anomalies consistent with plagioclase fractionation. Andesites from near Cerro Doña Ana (Fig. 1) and the basaltic andesites have ratios of U, Th and Ta similar to those of the rhyolites suggesting they are related. Derivation of the andesites from the basaltic andesites by shallow level crystal fractionation is difficult as the andesites are high in Sr and do not have Eu anomalies. The characteristic low to moderate La/Yb ratios in the Doña Ana Formation suggest little or no role for garnet in the source region, consistent with high temperatures and a normal subduction zone asthenospheric thickness.

The Infiernillo plutonic rocks and associated volcanic rocks of the Doña Ana Formation (58-67% SiO_2) have La/Yb ratios similar to other Doña Ana andesites and rhyolites. However, their REE levels are equivalent to, and their U and Th contents are up to 3

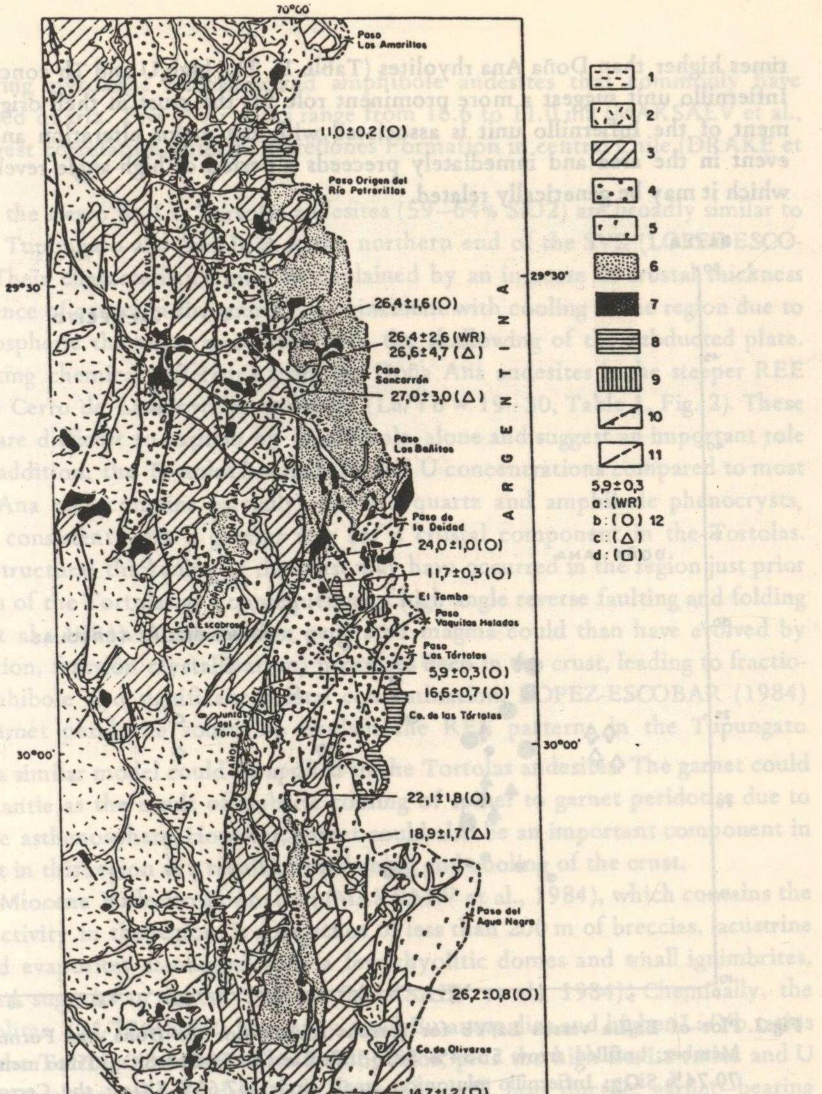

Fig.1. Geological map of the Chilean Main Cordillera between 29°-30°30'S (1) Lower Paleozoic schists; (2) Upper Paleozoic - Lower Triassic acidic volcanics: (4) Jurassic - Cretaceous lavas and sediments; (5-6) Doña Ana Formation (5) Tilito Member; (6) Escabroso Member); (7) Infiernillo unit; (Miocene); (8) Cerro de las Tórtolas Formation; (9) Vallecito Formation; (10) Thrust faults; (11) Normal faults; (12) K-Ar ages a) whole rock, b) biotite, c) plagioclase, d) amphibole. Modified from MAKSAEV et al., (1984).

Fig.1. Mapa Geológico de la cordillera principal de Chile entre 20°-30°30' Lat. S (1) Esquistos del Paleozoico inferior (2) Granitoides del Paleozoico superior (3) Volcanitas ácidas del Paleozoico Superior - Triásico Inferior (4) Lavas y sedimentos Jurásicos y Cretácicos (5-6) Formación Doña Ana 5), Miembro Tilito; 6) Miembro Escabroso (7) Unidad Infiernillo (8) Formación Cerro de las Tórtolas (9) Formación Vallecito (10) Fallas Inversas (11) Fallas Normales (12) Edad K-Ar a) roca total b) Biotita c) plagioclasa d) anfíbola. (Modificado de MAKSAEV et al., 1984).

times higher than Doña Ana rhyolites (Table 1). The high U and Th concentrations in the Infiernillo unit suggest a more prominent role for the crust in their origin. The emplacement of the Infiernillo unit is associated with the major alteration and mineralization event in the area and inmediately preceeds a period of high-angle reverse faulting with which it may be genetically related.

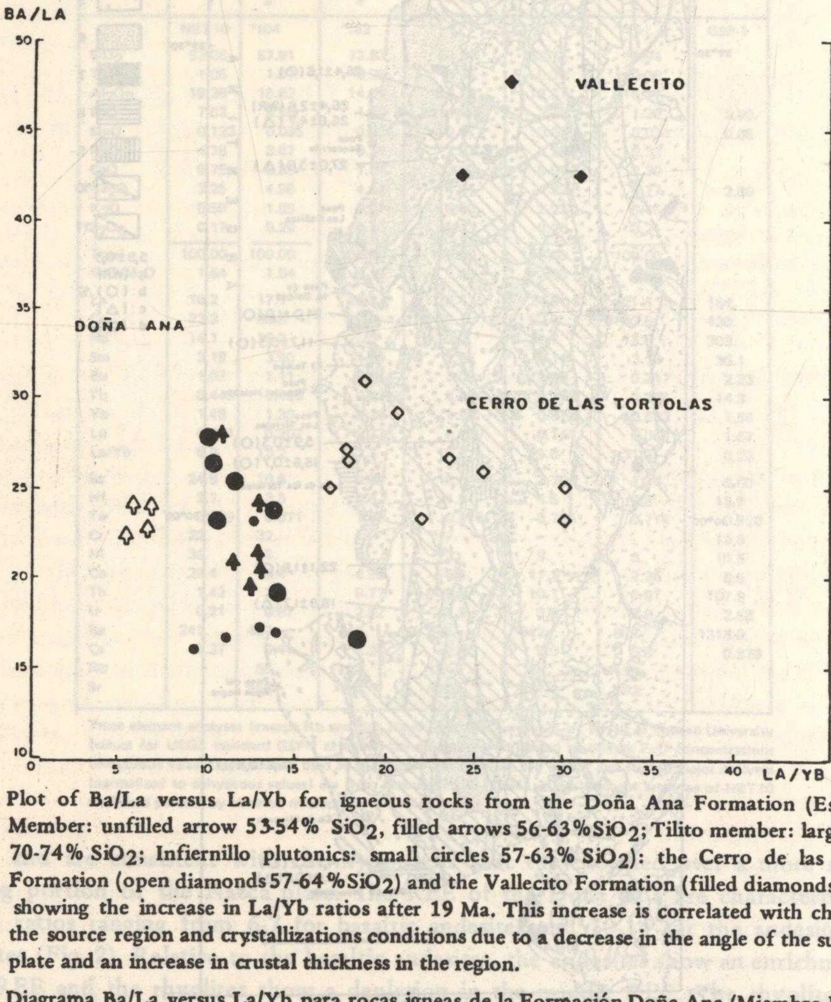

Fig.2. Plot of Ba/La versus La/Yb for igneous rocks from the Doña Ana Formation (Escabroso Member: unfilled arrow 53-54% SiO_2, filled arrows 56-63% SiO_2; Tilito member: large circles 70-74% SiO_2; Infiernillo plutonics: small circles 57-63% SiO_2): the Cerro de las Tórtolas Formation (open diamonds 57-64% SiO_2) and the Vallecito Formation (filled diamonds -70-72%) showing the increase in La/Yb ratios after 19 Ma. This increase is correlated with changes in the source region and crystallizations conditions due to a decrease in the angle of the subducting plate and an increase in crustal thickness in the region.

Fig.2. Diagrama Ba/La versus La/Yb para rocas igneas de la Formación Doña Ana (Miembro Escabroso; flechas vacías 53-54% SiO_2, flechas llenas 56-63% SiO_2; Miembro Tilito: circulos grandes 70-74% SiO_2; Plutonitas Infiernillo: círculos pequeños 57-63% SiO_2); de la Formación Cerro de Las Tórtolas (diamantes vacíos 57-64% SiO_2), y de la Formación Vallecito (diamantes llenos 70-72%) que muestran el aumento en la razón La/Yb después de 19 Ma. Este aumento se correlaciona con cambios en la región de origen de los magmas y de las condiciones de cristalización desbidos a una disminución en el ángulo de subducción y un aumento en el espesor cortical de la región.

The Lower to Middle Miocene Cerro de Las Tortolas Formation uncomformably overlies the Doña Ana Formation and represents the last major volcanic event in this region. The formation consists of lavas, agglomerates and tuffs that reach a maximum thicknes of 1900 m at Cerro de Las Tortolas (Fig. 1). The predominant rock types are amphibole-bearing pyroxene andesites and amphibole andesites that commonly have partially resorbed quartz. Five K-Ar dates range from 16.6 to 11.0 ma (MAKSAEV et al., 1984) and suggest correlation with the Farellones Formation in central Chile (DRAKE et al., 1982).

Chemically, the Cerro de Las Tortolas andesites (59–64% SiO_2) are broadly similar to andesites from Tupungato and San Jose at the northern end of the SVZ (LOPEZ-ESCOBAR, 1984). Their characteristics may be explained by an increase in crustal thickness and the emergence of garnet in the source, coincident with cooling in the region due to a lesser asthenospheric thickness associated with the shallowing of the subducted plate. The most striking chemical difference from the Doña Ana andesites is the steeper REE patterns of the Cerro de Las Tortolas andesites (La/Yb = 19–30, Table 1, Fig. 2). These REE patterns are difficult to explain by amphibole alone and suggest an important role for garnet. In addition, the Tortolas has high Th and U concentrations compared to most of the Doña Ana and contains partially resorbed quartz and amphibole phenocrysts, characteristics consistent with a greater role for a crustal component in the Tortolas. Significantly, structural thickening of the crust may have occurred in the region just prior to the eruption of the Tortolas as a consequence of high angle reverse faulting and folding (MAKSAEV et al., 1984). A subduction generated magma could than have evolved by AFC (assimilation, fraction crystallization) processes deep in the crust, leading to fractionation of amphibole and significant crustal contamination. LOPEZ-ESCOBAR (1984) suggested a garnet peridotite source to explain the REE patterns in the Tupungato andesites and a similar model could be applied to the Tortolas andesites. The garnet could form in the mantle as the result of isobaric cooling of spinel to garnet peridotite due to thinning of the asthenosphere. However, garnet could also be an important component in the lower crust in this region as a result of thickening and cooling of the crust.

The upper Miocene Vallecito Formation (MAKSAEV et al., 1984), which contains the last volcanic activity in the region, is a sequence of less than 200 m of breccias, lacustrine sediments, and evaporites associated with a few rhyolitic domes and small ignimbrites. One K-Ar date suggests an age of 5.9 Ma (MAKSAEV et al., 1984). Chemically, the Vallecito rhyolites (71-72% SiO_2) have very small Eu anomalies and higher La/Yb ratios (27-31) than the Tortolas andesites. The La/Yb ratios, plus the high Ba/La ratios and U and Th concentrations, suggest derivation from the still hot, ductile, garnet–bearing lower crust that remained in this region after the asthenosphere was thinned and when subduction–related volcanism was occuring far to the east in the Sierras Pampeanas.

The pattern and geochemistry of volcanism to the east in the Calingasta Valley and the Sierras Pampeanas lends further support to the hypothesis of the shallowing of the subduction zone concurrent with the eruption of the Tortolas and Vallecito Formations in Chile. Volcanism in the Calingasta Valley is apparently contemporaneous or slightly younger than the Cerro de Las Tortolas Formation (LEVERATTO, 1976) and the REE patterns of the andesites and dacites are characterized by high La/Yb ratios. Post 8 Ma volcanism is concentrated in the Sierras Pampeanas and ranges in age from 5-7 Ma (GORDILLO and LINARES, 1982). The petrology and geochemistry of the Pocho volcanic rocks in the Sierra de Cordoba is described by Kay and Gordillo (1985). While present day volcanism in the main cordillera is inhibited by a thinned or missing asthenosphere, volcanism to the east is inhibited because the slab has lost the volatiles necessary to flux melting in the upper mantle by the time the temperatures are high enough to produce melting in the mantle above the slab.

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