NEW AGES AND CHEMICAL ANALYSIS ON LOWER JURASSIC VOLCANISM CLOSE TO THE DORSAL DE HUINCUL, NEUQUÉN

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ABSTRACT

New single zircon ages from hydrocarbon well cores in the A-1 Norte de la Dorsal and Anticlinal Campamento area of the Neuquén basin indicate that 199.0 ± 1.5 Ma andesite lava flow and 203.75 ± 0.26 Ma dacite breccia overlie a 286.5 ± 2.3 Ma granodiorite and 284.0 ± 1.3 Ma andesite dike. The Lower Jurassic volcanics were deposited on a regional erosion surface affecting the Permian rocks. In the studied area there is no record of Middle to Upper Triassic volcanics as in other areas of the basin. Exotic zircon crystals gave ages of Mesoproterozoic, Middle Cambian, Early Devonian and Early Carboniferous, suggesting a poliphasic basement. Chemical analyses of three selected samples show a calc-alkaline signature, supporting the existence of a volcanic arc at the Early Jurassic as it has been proposed for the center of the basin.

Keywords: *Neuquén basin, Precuyano cycle, Early Jurassic, Calc-alkaline volcanics.*

RESUMEN: *Nuevas edades del volcanismo Jurásico Inferior de la cuenca Neuquina en la dorsal de Huincul.* Se dan nuevas edades U/Pb en cristales únicos de circón de muestras de corona de pozos exploratorios en el área petrolera A-1 Norte de la Dorsal y Anticlinal Campamento de la cuenca Neuquina. Estas edades permiten acotar un volcanismo Jurásico Inferior apoyado directamente sobre un basamento ígneo del Pérmico Inferior. Una muestra de andesita arrojó una edad de 199,0 ± 1,5 Ma y una de dacita 203,75 ± 0,26 Ma. El basamento está constituido por una granodiorita de 286,5 ± 2,3 Ma intruida por diques de andesita con 284,0 ± 1,3 Ma, ambas rocas están cortadas por una superficie de erosión de carácter regional labrada durante el Triásico, posiblemente Medio. En las perforaciones estudiadas no se han encontrado rocas triásicas. Los circones exóticos hallados indican la existencia de un complejo basamento con edades del Mesoproterozoico, Cámbrico Medio, Devónico Temprano y Carbonífero Temprano. Los análisis químicos muestras una filiación calco-alcalina que apoya la hipótesis de la existencia de un arco volcánico Jurásico Temprano en el centro de la cuenca Neuquina.

Palabras clave: *Cuenca Neuquina, Ciclo Precuyano, Jurásico Temprano, Volcánicas calco-alcalinas.*

INTRODUCTION

The Neuquén Basin is part of an extensional system along the active margin of South America. During the Triassic to Early Jurassic times, many hemigrabens were generated because the extensional system described above. Those hemigrabens, related to the rifting stage (Vergani *et al.* 1995), were filled by volcanic and sedimentary sequences (Franzese and Spalletti 2001, Pángaro *et al.* 2002, Franzese *et al.* 2007, Llambías *et al.* 2007) with variable thickness, ranging from zero up to a few thousand meters. The rifting stage was followed by the Early Jurassic transgressive inundation of the Cuyo Group, thus changing from localized rifting to a generalized subsidence (Legarreta and Uliana 1999).
In a wide sense, these sequences were grouped in the Precuyano cycle (Gulisano *et al.* 1984) or in the syn-rift sequences (Franzese *et al.* 2007). In most of the sections the Precuyano units overlie the volcanic and plutonic complexes of Permian to Lower Triassic age, known as the Choiyoi Group (*sensu* Rolleri and Criado Roque 1970). Occasionally the Precuyano can be deposited over metamorphic rocks of Devonian to Carboniferous age (Franzese 1995). In spite of the geological and economic importance of the deposits related to the Precuyano cycle, their ages are still unknown, although they are stratigraphically constrained between Late Triassic and Early Jurassic. In the studied area the volcanic rocks consist of highly altered andesites, dacites and rhyolites, with minor basalts. On account of the intense alteration dating must be carried out in minerals resistant to changes, like zircon. In this research we dated the rocks by the U/Pb methods in single zircon crystals.
The results obtained in the study of core samples of two wells Anticlinal Campamento and Cerro Guanaco, close to the Dorsal de Huincul (Fig. 1), show the existence of an active volcanism during the Early Jurassic. The chemical features of the analyzed samples show that they are part of a volcanic association similar to a volcanic arc, as suggested by Ber-

múdez *et al.* (2002) and Llambías *et al.* (2007) for the center of the basin.

GEOLOGICAL BACKGROUND

The basement of the Neuquén basin consists of the paleozoic Colohuincul and Piedra Santa metamorphic formations, the sedimentary Upper Carboniferous Andacollo Group and the Permian to Early Triassic volcano-plutonic assemblages of the Choiyoi Group *sensu* Rolleri and Criado Roque (1970). This nomination differs from the Choiyoi concept proposed by Groeber (1946), when he described the Upper Triassic volcanics of the Cordillera del Viento, which has been included in the Precuyano cycle by Gulisano *et al.* (1984).

In most of the Neuquén basin the Precuyano volcano-sedimentary sequences were deposited over an erosion surface of regional extension, the Huarpic (= intra-Triassic) unconformity, carved on the plutono-volcanic complexes of the Choiyoi Group (Llambías *et al.* 2007), which in many places constitutes the basement of the Neuquén basin. In the wells studied this Group consists of granodiorite and comagmatic andesític dikes.

The Precuyano units underlie the Cuyo Group (Pliensbachian to Bathonian) composed mainly by the Los Molles Formation (Pliensbachian to Callovian) and the Lajas Formation (Bajocian to Callovian). In the Ñireco area and northern of Dorsal de Huincul, the Los Molles Formation usually starts with a silicified limestone, named the Chachil Limestone, it thickness ranges from a couple of meters to forty meters, and underlies a thick sequence of shales and sandstones deposited in a deep marine environment, attaining a thickness of more than 3000 m (Gulisano *et al.* 1984).

STRATIGRAPHIC RELATIONS

During the exploration process in the A-

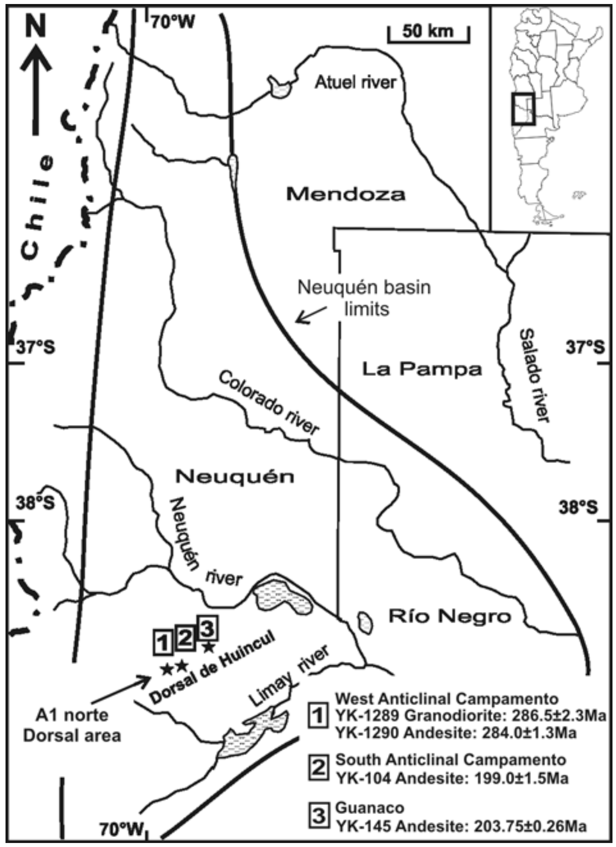

Figure 1: Location map of the samples studied in the A-1 norte de la Dorsal and Anticlinal Campamento, Neuquén province.

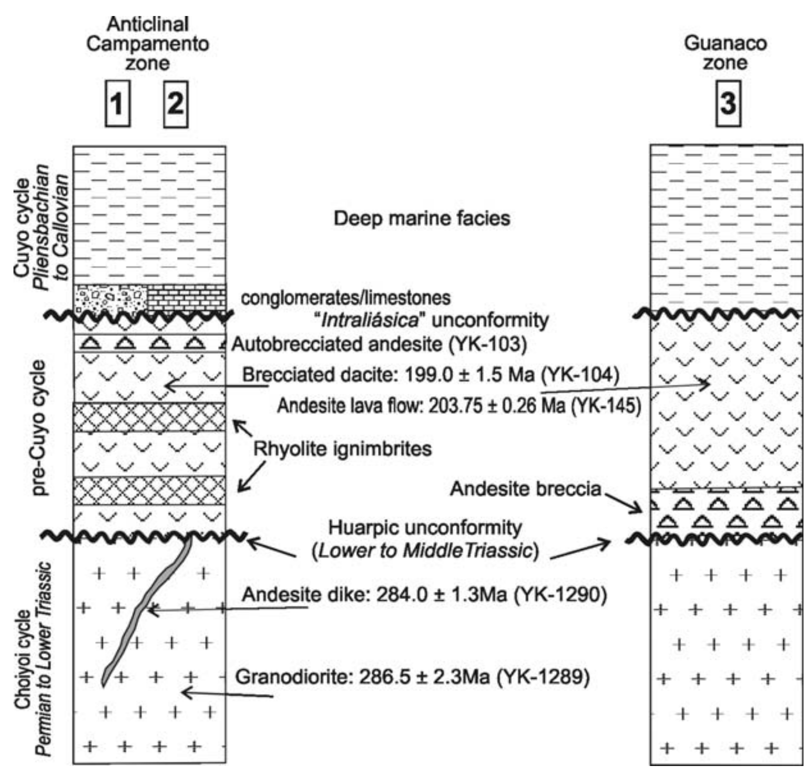

Figure 2: Columnar sections, not to scale, summarizing the stratigraphy of the studied samples. In the Anticlinal Campamento and Guanaco area the Lower Jurassic volcanics overlie the Lower Permian plutonic rocks. The dated Jurassic volcanics belong to a single eruptive event.

1, Norte de la Dorsal and Anticlinal Campamento areas (Fig. 1), it was planned to study the volcanic formations underlying the Los Molles Formation. The exploration program included drilling of several wells and the analysis of core and cutting samples.

Rotated samples and core samples were obtained from several wells in order to adjust the stratigraphic and lithological interpretation of this portion of the Neuquén basin. The samples were subsequently analyzed and described in detail. Geochronological data were attempted to obtain in several samples, and in all of them zircon crystals were separated except in YK-103. In addition, three chemical analyses were carried out, including trace and rare elements.

In the Anticlinal Campamento and Guanaco wells (Figs. 1 and 2) the rocks underlying Los Molles Formation consist of andesitic block and ash and lava flow deposits, dacitic to rhyolitic ignimbrites and lavas and silicic ash fall deposits. It is also important to point out the strong propylitic alterations, mainly of hydrothermal origin, overprinted the original composition and textures of the rocks.

The thickness of the volcanic sequence is highly variable, ranging from zero up to more than 450 meters. In some wells of the Anticlinal Campamento and Guanaco area there is no record of deposition, and the Cuyo Group overlies the plutonic rocks of the Choiyoi Group (*sensu* Rolleri and Criado Roque 1970). Based on the seismic data of this area, a total thickness of over 1000 meters has been estimated. The volcanic sequences, which may be correlated with the Precuyano cycle, were deposited over a massive granodiorite intruded by coeval andesite dikes. The granodiorite has an altered cap of about 15 m thick. The Early Permian age of the granodiorite and the andesite dikes allow to include them in the Choiyoi cycle.

A possible stratigraphic correlation of the igneous and sedimentary deposits analyzed in this paper is shown in Fig. 2.

GEOCHRONOLOGY

Five core samples from the A-1 Norte de la Dorsal and Anticlinal Campamento areas (Fig. 1) were analyzed for geochronology. Dating was obtained using U-Pb method on single zircon crystals by Activation Laboratories Ltd. Analytical data are shown in Table 1. Correlation between isotopical and stratigraphic ages was made according to the geologic time scale of Gradstein *et al.* (2004). No zircon crystals were obtained in an andesite lava flow (YK-103).

Three zircon crystals were selected from each sample (six crystals for YK 145). The outer zone of the crystals was removed by abrasion. The ages obtained in each of the crystals from the sample are not homogenous and only the ages which plot in the concordia and are coherent with the stratigraphic location have been reproduced in Figs 3-4. The remaining ages, always older, are interpreted as exotic zircons coming from possible contamination.

Two groups of ages have been obtained which are compatible with the local stratigraphic column: 1) Permian ages, related to the Choiyoi cycle (*sensu* Rolleri and Criado Roque 1970) and 2) Early Jurassic ages corresponding to the Precuyano cycle (*sensu* Gulisano *et al.* 1984).

Choiyoi Cycle: Three zircon crystals were analyzed from a granodiorite sample (YK -1289) and other three from an andesite dike (YK-1290) intruding the granodiorite (Table 1, Fig. 3). The granodiorite consists of 50 % plagioclase (An_{12-25}), 25 % of K-feldspar, 20 % of quartz, and 5 % of biotite with scarce alteration to chlorite and sericite. The best age is the upper intercept of the concordia at 286.5 ± 2.3 Ma.

The andesite is fine-grained and consists of sericitized and kaolinitized plagioclase, fine-grained interstitial granular amphibole, prismatic biotite, chlorite and fine-grained carbonate. Sericite (or illite), chlorite, carbonate and quartz are secondary minerals, partly replacing plagioclase and biotite. Two out of three zircon crystals analyzed plot on the concordia and the weighted mean $^{207}Pb/^{206}Pb$ age is 284.0 ± 1.3 Ma.

The similar ages of andesite and granodiorite suggest a cogenetic origin, a relationship which is common in the Choiyoi cycle of the Cordillera Frontal (Sato and Llambías 1993, Llambías and Sato 1995), conforming a plutono-volcanic association. The Lower Permian age of both rocks correlates with the lower section of the Choiyoi Group. No exotic zircons have been found in these samples.

Precuyano Cycle: Two samples yielded meaningful results: YK-104, from Anticlinal Campamento area and YK145 from Guanaco area.

YK-104 is a brecciated phenoandesite with glomeroporphyritic texture, and is chemically classified as dacite (Table 2, Fig. 5). Phenocrysts (20 %) are of plagioclase (An_{40}) altered to sericite, kaolinite and chlorite. The groundmass (80 %) has intersertal texture composed of partially recrystallized volcanic glass and plagioclase needles with moderate orientation by magmatic flow. Submicroscopic, irregular vesicles are filled with quartz. Several microfissures cross cut the sample, they are totally or partially filled with chlorite and/or quartz.

The three zircon crystals dated from sample YK-104 gave different ages (Table 1, Fig. 4a): 1140-1175 Ma, 517-522 Ma and 199.0 ± 1.5 Ma. We only consider the youngest one as the age of the andesite crystallization, which corresponds to the Sinemurian. The other two ages correspond to xenocrystals suggesting the presence of a basement with Grenvillian age and possible igneous bodies from the Middle Cambrian.

The YK-145 sample is a greenish gray andesite with porphyritic texture. The chemical analysis suggests an andesitic composition close to the field of dacites (Table 2, Fig.5) Prismatic and oriented plagioclase (An_{35}) phenocrysts (25%) show an intense alteration to sericite, kaolinite, epidote and calcite. The pilotaxic texture of the groundmass is composed of acicular plagioclase and interstitial

TABLE 1: Analytical data for zircons from A1, Norte dorsal, Anticlinal Campamento and Guanaco zones.

Concentrations											Ratios		Age (Ma)			
Sample fractions	Weight (µg) (a)	U (ppm)	Pb (ppm)	Pb(c) (pg) (b)	206 Pb 204 Pb (c)	208 Pb 206 Pb (d)	206 Pb 238 U (e)	err (2σ%)	207 Pb 235 U (e)	err (2σ%)	207 Pb 206 Pb (e)	err (2σ%)	206 Pb 238 U	207 Pb 235 U	207 Pb 206 Pb	corr. coef.
YK-104																
z1	1,80	114	23,2	1,6	1616,3	0,120	0,193538	0,20	2,11174	0,28	0,07914	0,18	1140.5+2.3	1152.6+3.2	1175.5+2.1	0,754
z2	2,50	93	9,5	0,9	1364,7	0,359	0,083511	0,17	0,66536	0,35	0,05778	0,29	517.0+0.9	517.9+1.8	521.6+1.5	0,561
z3	3,10	82	3,2	1,1	477,9	0,364	0,031353	0,75	0,21650	1,01	0,05008	0,64	199.0+1.5	199.0+2.0	198.8+1.3	0,777
YK-145																
z1	0,61	333	26,1	0,5	1864,6	0,360	0,064387	0,18	0,48655	0,30	0,05481	0,23	402.3+0.7	402.6+1.2	404.3+4.0	0,638
z2	0,61	203	15,5	0,3	1621,0	0,323	0,064404	0,19	0,48650	0,36	0,05479	0,30	402.4+0.8	402.5+1.4	403.5+4.3	0,568
z3	0,45	765	41,2	0,4	3304,9	0,149	0,052067	0,09	0,39012	0,14	0,05434	0,11	327.2+0.3	334.5+0.5	385.3+3.1	0,629
z4	3,10	133	11,1	0,6	2819,7	0,441	0,065220	0,15	0,49614	0,23	0,05517	0,17	407.3±0.6	409.1±0.9	419.3±1.1	0,672
z5	1,50	261	9,2	0,3	2915,6	0,217	0,032108	0,09	0,22231	0,17	0,05022	0,15	203.7±0.2	203.8±0.3	205.0±0.4	0,547
z6	1,50	70	5,6	0,3	1706,4	0,376	0,065201	0,16	0,49325	0,37	0,05487	0,32	407.2±0.6	407.1±1.5	406.8±1.6	0,527
YK-1289																
z1	2,00	608	28,6	0,6	5753	0,153	0,045340	0,06	0,32525	0,12	0,05202	0,10	285.9±0.17	285.9±0.34	286.4±0.29	0,520
z2	2,20	989	41,7	0,6	10438	0,112	0,042160	0,05	0,30202	0,09	0,05196	0,07	266.2±0.13	268±0.24	283.5±0.20	0,590
z3	1,90	810	37	0,8	5878	0,131	0,044950	0,07	0,32235	0,15	0,05201	0,13	283.4±0.20	283.7±0.42	285.9±0.37	0,500
YK-1290																
z1	3,70	711	32,8	0,9	8395,0	0,138	0,045010	0,05	0,32249	0,09	0,05196	0,07	283.8±0.14	283.8±0.26	283.7±0.20	0,630
z2	2,80	405	18,9	1,8	1860,5	0,154	0,045080	0,13	0,32306	0,24	0,05198	0,20	284.2±0.37	284.3±0.68	284.5±0.57	0,590
z3	1,80	518	24,7	0,7	3726,0	0,188	0,044700	0,09	0,32038	0,17	0,05199	0,14	281.9±0.25	282.2±0.48	284.9±0.40	0,570

(a) Sample weights are estimated by using a video monitor and are known to within 40%. (b) Total common-Pb in analyses. (c) Measured ratio corrected for spike and fractionation only. (d) Radiogenic Pb. (e) Corrected for fractionation, spike, blank, and initial common Pb. Mass fractionation correction of 0.15%/amu ± 0.04%/amu (atomic mass unit) was applied to single-collector Daly analyses and 0.12%/amu ± 0.04% for dynamic Faraday-Daly analyses. Total procedural blank less than 0.5 pg for Pb and less than 0.1 pg for U. Blank isotopic composition: 206Pb/204Pb = 19.10 ± 0.1, 207Pb/204Pb =15.71 ± 0.1, 208Pb/204Pb = 38.65 ± 0.1. Corr. coef. = correlation coefficient. Age calculations are based on the decay constants of Steiger and Jäger (1977). Common-Pb corrections were calculated by using the model of Stacey and Kramers (1975) and the interpreted age of the sample.

glass with abundant iron oxide. Submicroscope vesicles filled with chlorite, opaque minerals and calcite are common. The microfractures are filled with calcite, and in some rare cases with pyrite. Six zircon crystals have been dated with different ages (Table 1, Fig. 4b), suggesting the presence of exotic zircons. The youngest age, 203.75 ± 0.26 Ma, is interpreted as the crystallyzation age of the andesite, in agreement with the stratigraphic relations shown by the well analysis. It is comparable to the Hettangian stratigraphic age and does not differ from the andesite of the YK-104 sample, thus indicating the existence of an important Early Jurassic volcanism. Four crystals out of the remaining five indicate ages of 404.0 ± 4.0Ma suggesting the existence of possible igneous activity at the Early Devonian, on account that the grains are euehedral (Table 1).

An additional sample of andesite lava (YK-103) is located 85 m higher than the YK-104 in the stratigraphic column. Unfortunately, no zircon crystals were found, therefore it could not be dated. It is an autobrecciated-andesite (Table 2, Figs. 2-5) with porphyritic to glomeruloporphyritic texture and groundmass composed of plagioclasa needles immersed in glass. The plagioclase (An_{35}) phenocrysts and the mafic minerals are intensely altered to chlorite, epidote and calcite.

CHEMICAL CHARACTERISTICS

Three chemical analyses of well core samples from A-1, Norte de la Dorsal and Anticlinal Campamento areas have been carried out. All of them were performed at Activation Laboratories Limited. The results are shown in Table 2. Major elements and Sc. V and Cr were analyzed by sample fusion and measured with induction by argon plasma (ICP-fusion). The remaining elements were analyzed by fusion and quantified in a mass spectrometer (MS-fusion).

The analyzed samples have high values of LOI (loss on ignition) therefore no graphs with major elements have been used. We consider that the Winchester and Floyd (1977) diagram based on immobile elements (Fig. 5) shows the classification of alterated rocks more accurated than the TAS diagram. The samples plot in the andesite and dacite field, in a similar manner as the samples of the La Primavera (Pliensbachian) and Milla Michico Formations (Upper Triassic-Lower Jurassic) of Chacay Melehue area (Llambías *et al.* 2007).

The Mg# value (Mg/Mg+Fe2+ assuming F3+/Fe2+ = 0.15) of the analyzed samples is moderately high, ranging from 43.4 to 51.9. This range coincides with the samples from Chacay Melehue. In contrast, the values of Cr, Co and Ni are

TABLE 2: Chemical analysis from Anticlinal Campamento and Guanaco zones.

	YK-103	YK-104	YK-145
SiO_2	53,13	69,10	49,90
TiO_2	0,67	0,31	1,17
Al_2O_3	15,16	15,54	17,15
Fe_2O_3	5,53	2,14	8,21
MnO	0,10	0,03	0,11
MgO	1,82	0,99	3,04
CaO	8,29	0,92	3,95
Na_2O	3,66	4,77	2,80
K_2O	2,90	4,13	5,80
P_2O_5	0,24	0,10	0,49
LOI	8,55	2,07	7,40
TOTAL	100,03	100,08	100,03
	Trace elements, ppm		
Cs	1,18	3,52	5,21
Rb	58,80	130,58	198,26
Ba	1040	2190	1060
Th	4,16	12,35	10,62
U	0,98	2,19	3,15
Nb	3,99	6,81	9,01
Sr	334,82	212,61	196,86
Hf	3,85	5,26	7,79
Zr	145,01	209,34	305,83
Y	21,86	16,35	28,82
V	106,88	20,25	170,62
Cr	<20	35,27	26,09
Co	16,48	3,14	17,99
Ni	7,77	1,30	34,60
Ga	18,17	16,35	22,04
Tl	0,98	0,97	3,05
Pb	19,13	18,15	16,85
Sc	14,00	4,00	15,00
Ta	0,19	0,46	0,44
	Rare earth elements, ppm		
La	25,07	27,53	39,91
Ce	54,41	57,45	86,86
Pr	6,17	5,90	10,09
Nd	23,78	20,21	39,24
Sm	4,54	3,59	7,86
Eu	1,23	0,89	2,07
Gd	3,95	2,86	6,50
Tb	0,65	0,48	1,00
Dy	3,52	2,60	5,21
Ho	0,73	0,52	1,04
Er	2,30	1,73	3,27
Tm	0,36	0,29	0,48
Yb	2,37	1,96	3,08
Lu	0,36	0,31	0,44
Mg#	43,40	51,90	46,30

Mg# = Mg/Mg + Fe^{2+} (assuming Fe^{3+}/Fe^{2+} = 0.15

low (Table 2), showing differences in the composition of the source, in the fusion grade or in the subsequent differentiation processes.

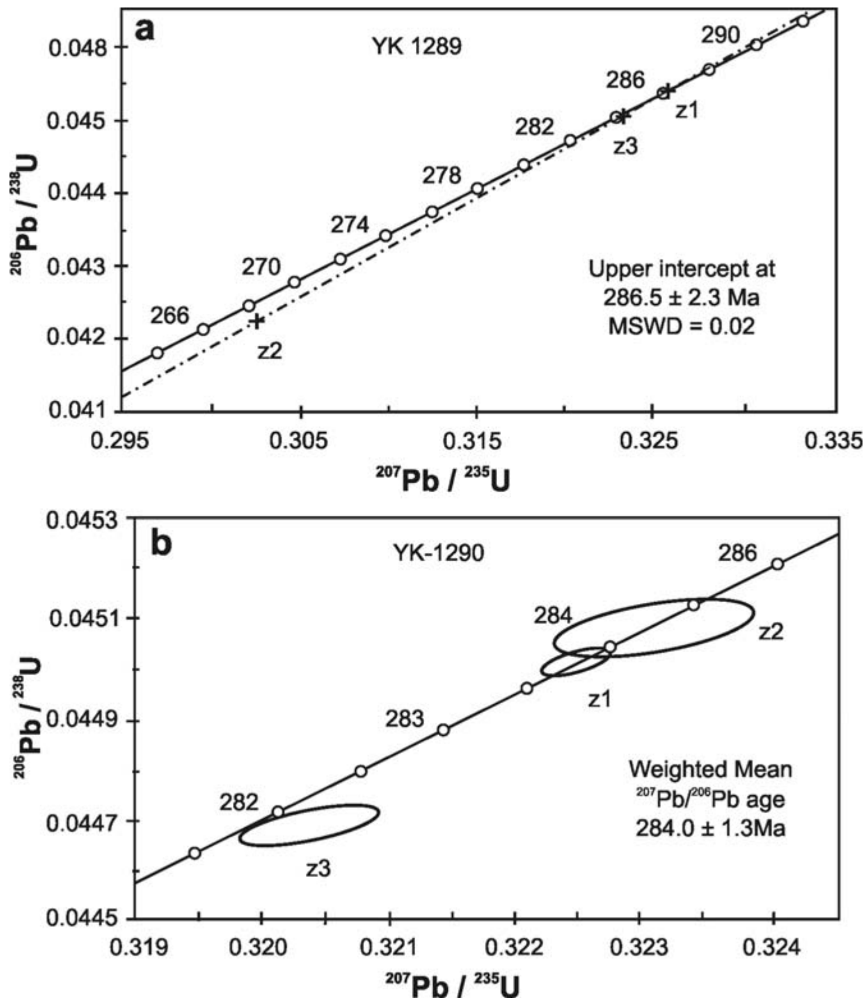

Figure 3: a: U/Pb concordia-discordia plot of the granodiorite from the basement of West Anticlinal Campamento area. b: U/Pb concordia plot of an andesite dike intruded into the granodiorite.

Fig. 6 shows the expanded diagrams of the trace elements of the three analyzed samples. There is little variation among them. Regarding the La Primavera and Milla Michico Formations, the analyzed samples show a similar trend but with greater enrichment.

The behavior of rare earth elements (Fig. 6b) is also typical of the calc-alkaline suites, with a moderate slope in the light rare earth elements and a weak horizontality in the heavy ones. The absence of the Eu depression could reflect a poor differentiation process of the magmas in the crust, probably because the rise of the magma through the crust was fast, without the emplacement of large magmatic chambers. Regarding the Milla Michico and La Primavera Formations, once again, a similar trend occurs but with a major enrichment of the light rare earth elements.

In the Harris *et al.* (1986) and Pearce *et al.* (1984) discrimination diagrams, the samples plot in the field of the volcanic arcs (Figs 7a-7b) in agreement with the rare and trace elements trends.

To sum up, the three analyzed samples have the signature of a volcanic arc. They do not differ from those samples from the Planicie Banderita well (Bermúdez *et al.* 2002) and Chacay Melehue area (Llambías *et al.* 2007), therefore it is probably that this volcanic arc had a regional distribution at the center of the Neuquén basin.

DISCUSSION AND CONCLUSIONS

The ages indicated by the single zircon crystals from core samples in the northern section of the A-1 Norte de la Dorsal and Anticlinal Campamento show the existence of an important magmatic activity during the Hettangian and Sinemurian, according to the geologic time scale of Gradstein *et al.* (2004). The new Early Jurassic isotopic ages confirm the Hettangian-Sinemurian stratigraphic ages assumed by Groeber (1958), Stipanicic *et al.* (1968), Gulisano and Pando (1981) and Gulisano *et al.* (1984) for the Sañicó, Piedra del Águila and Lapa Formations, all of them included in the Precuyano cycle. However, more studies are needed to clarify the age of Lapa Formation, which based on its flora content was related to Upper Triassic by Spalletti *et al.* (1991).

This is the first time that the existence of an intense magmatic activity during the Early Jurassic in the Neuquen basin is documented by the U-Pb age in zircon single crystals. The volcanic rocks analyzed are placed below the "*intraliásica*" unconformity that separates the beginning of the Cuyo transgressive inundation from the volcanic deposits related to the rifting phase. This unconformity has a regional meaning because it represents the transition of the rifting phase to a greater amplitude subsidence (Legarreta and Uliana 1999). The new ages suggest that this unconformity is constrained to the Sinemurian-Pliensbachian limit.

Our research in the Anticlinal Campamento and Guanaco area shows that between the Choiyoi Group and the Precuyano volcanics dated herein, there is a maximum hiatus of 82 Ma suggesting a long period of erosion in this sector of the Dorsal de Hincul that favored the exhumation of the plutons of the Choiyoi Group during the Triassic. The hiatus between the Precuyano cycle and the first sediments of the Cuyo cycle would be approximately 4 Ma. The fact that the conglomerates at the base of the Los Molles Formation include volcanic pebbles similar to the rocks of the Precuyano cycle suggests that they had a subair exposure at the beginning of the marine inundation.

In another localities of the Neuquén basin, the hettangian and sinemurian volcanic activity continued along the Pliensbachian and Toarcian, as it is shown at the base of the Cuyo Group in the Chacay Melehue area by the volcano-sedimentary "Unnamed Unit" (Gulisano and

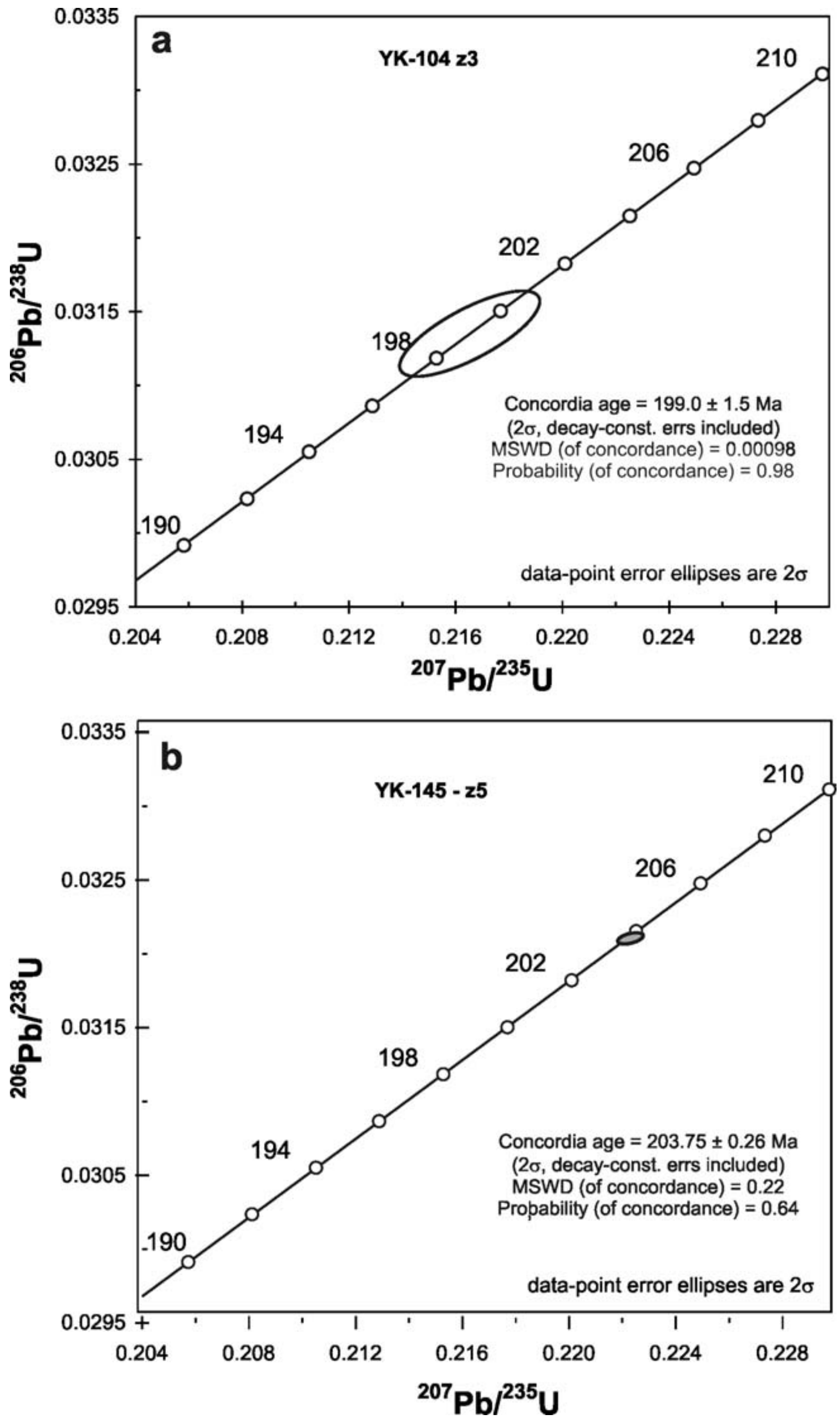

Figure 4: a) U/Pb concordia plot of single zircon crystal of andesite from South Anticlinal Campamento area. b) U/Pb concordia plot of single zircon crystal of andesite from Guanaco zone.

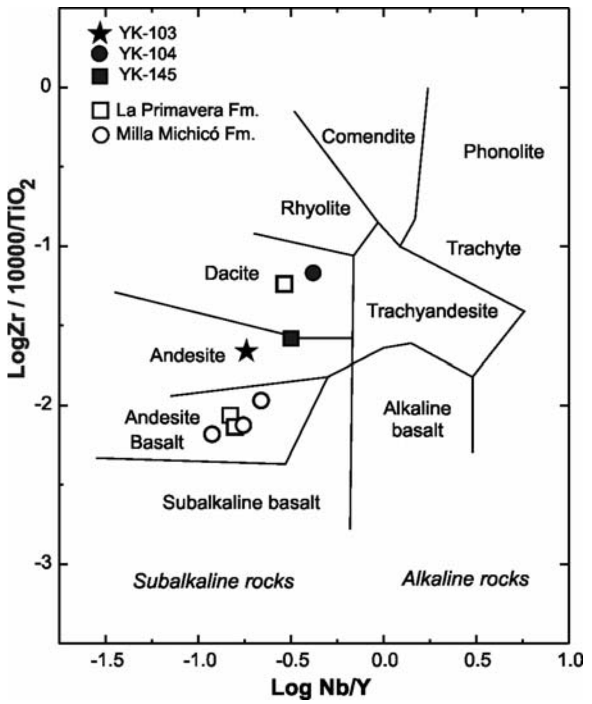

Figure 5: Classification of the volcanic rocks according to the Winchester and Floyd diagram. For comparison are included samples from La Primavera and Milla Michicó Formations (data from Llambías *et al.* 2007).

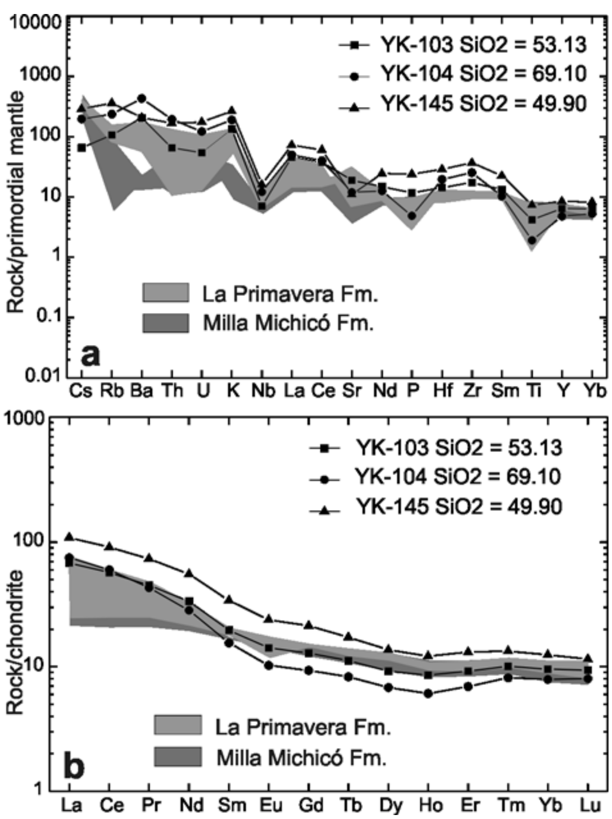

Figure 6: Abundance diagrams of trace elements: a) and rare earth elements; b) normalized to primordial mantle and chondrite respectively, after Taylor and McLennan (1985).

Gutiérrez Pleimling 1995) -subsequently called La Primavera Formation by Suarez and De La Cruz (1997)- dated by marine fossils as Pliensbachian to Toarcian by Damborenea and Manceñido (in Gulisano and Gutiérrez Pleimling 1995). In addition, the hyper-dense gravity flows of andesitic composition (laharic deposits) intercalated in the turbiditc black shales and sandstones of the Los Molles Formation suggest the existence of andesitic strato-volcanoes during that period (Llambías and Leanza 2005). Another indication that there was a considerable volcanic activity during the Pliensbachian is the presence of abundant piroclastic material on the base of the Los Molles Formation, as evidenced by the Sierra de Chacaico Formation (Leanza 1992). At the center of the Neuquen basin, the volcanic activity diminishes dramatically during the Middle Jurassic, but along the west border of the basin it had a remarkable development (Suárez *et al.* 1988, Suárez and Emparán 1997).

In the studied area the basement of the Lower Jurassic volcanics is formed by the Choiyoi Group (*sensu* Rolleri and Criado Roque 1970). According to the age of the granodiorite, 286.5 ± 2.3 Ma and the andesite dike, 284.0 ± 1.3 Ma (Fig. 1), these rocks correlate with the lower section of the Choiyoi Group (Llambías *et al.* 1993).

The ages determined in the exotic zircon crystals reveal that the Choiyoi Group evolved over a basement formed by rocks with zircons of grenvillian age of uncertain provenance and devonian and cambrian igneous bodies. With these ages, we confirm the presence of a crystalline basement formed by successive igneous and metamorphic events, as stated by Linares *et al.* (1988), Franzese (1995) and Varela *et al.* (2005).

The chemical composition of the Jurassic volcanics analyzed in this paper shows a magmatic arc signature, similar to that proposed by Bermúdez *et al.* (2002) for the Planicie Banderita depocenter, in the northern portion of the Dorsal de Huincul, and by Llambías *et al.* (2007) for the southern part of the Cordillera del Viento in northern Neuquén. According with the new ages at the Dorsal de Huincul, this volcanic arc was still active during the Early Jurassic in the center of the Neuquén basin.

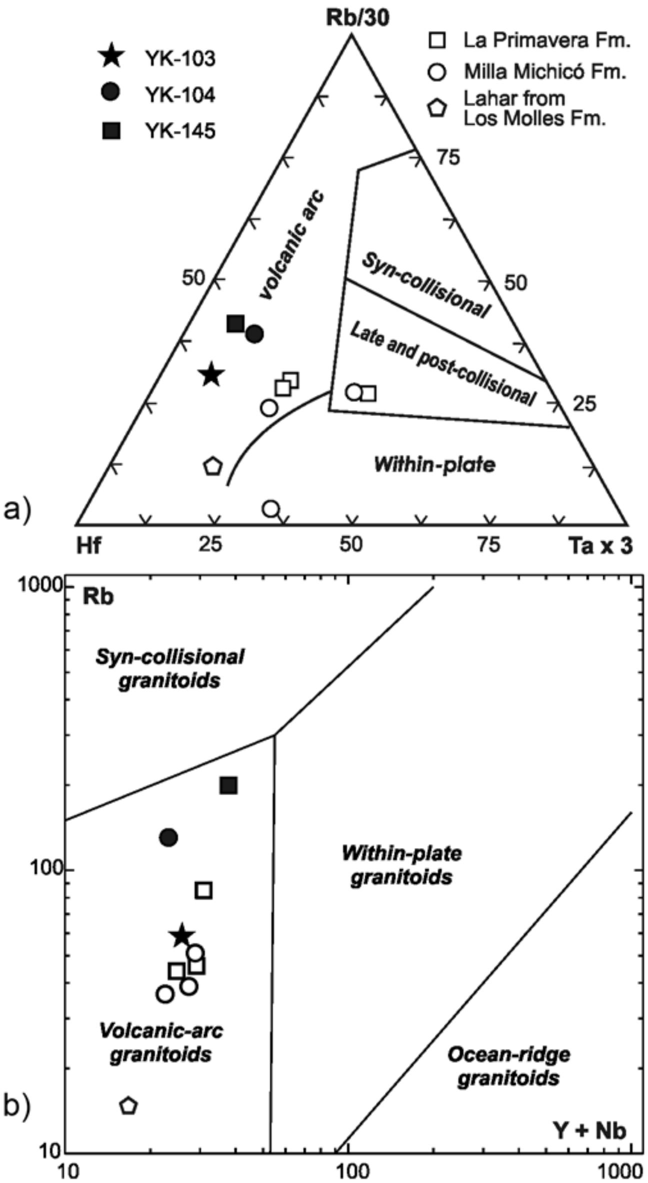

Figure 7: Discrimination diagrams: a) after: Harris *et al.* (1986); b) after Pearce *et al.* (1984). The signature of volcanic arc of the anlaysed samples is clear in both diagrams.

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WORKS CITED IN THE TEXT

Gradstein, F.M., Ogg, J.G., Smith, A.G. *et al.* 2004. A Geological Time Scale, Cambridge University Press.

Bermúdez, A., Delpino, D. and Pángaro, F. 2002. Volcanismo de arco asociado a procesos de subducción - extensión durante el Triásico Superior - Jurásico Inferior (Precuyano). Área Cerro Bandera, Cuenca Neuquina, Argentina. 5º Congreso de Exploración y Desarrollo de Hidrocarburos. Trabajos Técnicos. Versión CD ROM. Mar del Plata.

Franzese, J. 1995. El complejo Piedra Santa (Neuquén, Argentina): parte de un cinturón metamórfico de edad neopaleozoica del gondwana suroccidental. Revista Geológica de Chile 22 (2): 193-202.

Franzese, J.R and Spalletti, L.A. 2001. Late Triassic-Early Jurassic continental extension in southwestern Gondwana: tectonic segmentation and pre-break-up rifting. Journal of South American Earth Sciences 14: 257-270.

Franzese, J.R, Veiga, G.D., Muravchik, M., Ancheta, M.D. and D´Elía, L. 2007. Estratigrafía de 'sin-rift' (Triásico Superior-Jurásico Inferior) de la Cuenca Neuquina en la sierra de Chacaico, Neuquén, Argentina. Revista Geológica de Chile 34(1): 49-62.

Groeber, P. 1946. Observaciones geológicas a lo largo del meridiano 70°. 1. Hoja Chos Malal. Revista de la Asociación Geológica Argentina 1(3): 177-208. Buenos Aires.

Groeber, P. 1958. Acerca de la edad del Sañicolitense. Revista de la Asociación Geológica Argentina 11(4): 281-292, Buenos Aires.

Gulisano, C.A. and Gutiérrez Pleimling, A. 1995. Field guide: The Jurassic of the Neuquén Basin. a) Neuquén province. Asociación Geológica Argentina, Serie E 2: 1-111, Buenos Aires.

Gulisano, C.A. and Pando, G.A. 1981. Estratigrafía y facies de los depósitos jurásicos entre Piedra del Águila y Zanco, Departamento Collón Cura, provincia del Neuquén. 8° Congreso Geológico Argentino (San Luis), Actas 3: 553-577.

Gulisano, C.A., Gutiérrez Pleimling, A. and Digregorio, R. l984. Esquema estratigráfico de la secuencia jurásica del oeste de la provincia del Neuquén. 9° Congreso Geológico Argentino, Actas 1: 236-259. Buenos Aires.

Harris, N.B.W., Pearce, J.A. and Tindle, A.G. 1986. Geochemical characteristics of collision zone magmatism. In: Coward, M.P. y Reis, A.C. (eds.), Collision Tectonics. Geological Society of America, Special Paper 19: 67-81.

Leanza, H.A. 1992. Estratigrafía del Paleozoico y Mesozoico anterior a los Movimientos Intermálmicos en la comarca del cerro Chachil, provincia del Neuquén. Revista de la Asociación Geológica Argentina 45(3-4): 272-299, Buenos Aires.

Legarreta, L. and Uliana M.A. 1999. El Jurásico y Cretácico de la Cordillera Principal y la Cuenca Neuquina. 1. Facies Sedimentarias. In: Geología Argentina. Instituto de Geología y Recursos Minerales, Anales 29 (16): 399-432, Buenos Aires.

Linares, E., Cagnoni, M.C., Do Campo, M., and Ostera, H.A. 1988. Geochronoloy of metamorphic and eruptive rocks of southeastern

Neuquén and nothwestern Río Negro provinces, Argentine Republic. Journal of South American Earth Sciences 1(1): 53-61.

Llambías, E.J. and Leanza, H.A. 2005. Depósitos laháricos en la Formación Los Molles en Chacay Melehue, Neuquén: evidencia de volcanismo jurásico en la cuenca Neuquina. Revista de la Asociación Geológica Argentina 60(3): 552-558.

Llambías, E.J. and Sato, A.M. 1995. El batolito de Colangüil: transición entre orogénesis y anorogénesis. Revista de la Asociación Geológica Argentina 50(1-4): 111-131.

Llambías, E.J., Kleiman, L.E. and Salvarredi, J.A. 1993. El magmatismo Gondwánico. 12º Congreso Geológico Argentino y 2º Congreso de Exploración de Hidrocarburos (Mendoza). En: Ramos, V.A. (ed.), Geología y Recursos Naturales de Mendoza, Relatorio I(6): 53-64.

Llambías, E.J., Leanza, H.A. and Carbone, O. 2007. Evolución tectono-magmática durante el Pérmico al Jurásico Temprano en la cordillera del Viento (37°05´S - 37°15´S): nuevas evidencias geológicas y geoquímicas del inicio de la cuenca Neuquina. Revista de la Asociación Geológica Argentina 62(2): 217-235.

Pángaro, F., Corbera, R., Carbone, O. and Hinterwimmer, G. 2002. Los Reservorios del "Precuyano". En: Schiuma, M., Hinterwimmer, G. and Vergani, G. (Eds.): Rocas reservorio de las Cuencas Productivas de la Argentina, 5° Congreso de Exploración y Desarrollo de Hidrocarburos (Mar del Plata), Actas: 229-254.

Pearce, J.A., Harris, N.B.W. and Tindle, A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology 25: 956-983.

Rolleri, E.O. and Criado Roque, P. 1970. Geología de la provincia de Mendoza. Cuartas Jornadas Geológicas Argentinas 2: 1-60.

Sato, A.M. and Llambías, E.J. 1993. El Grupo Choiyoi, provincia de San Juan: equivalente efusivo del Batolito de Colangüil. 12º Congreso Geológico Argentino y 2º Congreso de Exploración de Hidrocarburos, Actas 4: 156-165.

Spalletti, L.A., Arrondo, O.G., Morel, M. and Ganuza, D.G. 1991. Evidencias sobre la edad triásica de la Formación Lapa en la región de Chacaico, provincia del Neuquén Revista de la Asociación Geológica Argentina 46(3-4): 167-172.

Stacey, J.S. and Kramers, J.D. 1975. Approximation of terrestrial lead isotopes evolution by a two-stage model. Earth and Planetary Science Letters 26: 207-221.

Steiger, R.H. and Jäger, R. 1977. Convention on the use of decay constants in Geo- and Cosmochronology. Earth and Planetary Science Letters 36(3): 359-362.

Stipanicic, P.N., Rodrigo, F., Baulíes, O.L. and Martínez, C.G. 1968. Las formaciones presenonianas en el denominado Macizo Nordpatagónico y regiones adyacentes. Revista de la Asociación Geológica Argentina 23(2): 67-98.

Suárez, M. and De La Cruz, R. 1997. Volcanismo pliniano del Lías durante los inicios de la cuenca de Neuquén, Cordillera del Viento, Neuquén, Argentina. 7º Congreso Geológico Chileno, Actas 1: 266-270.

Suárez, M. and Emparán, C. 1997. Hoja Curacautín, Regiones de la Araucanía y del Bío Bío, escala 1: 250.000. Servicio Nacional de Geología y Minería, Carta Geológica de Chile 71, 105 p., Santiago.

Suárez, M., Emparan, C. and De La Cruz, R. 1988. Lavas submarinas, rocas piroclásticas y turbiditas jurásicas en los Andes de Lonquimay (Latitud 38° - 39° S). 5º Congreso Geológico Chileno, Volumen Especial Resúmenes [Comunicaciones 39: 39], Santiago.

Taylor, S.R. and McLennan, S.M. 1985. The continental crust: its composition and evolution. Blackwell Publications, 312 p., Oxford.

Varela, R., Basei, M.A.S., Cingolani, C.A., Siga, O. and Passarelli, C.R. 2005. El basamento cristalino de los Andes norpatagónicos en Argentina: geocronología e interpretación tectónica. Revista Geológica de Chile 32(2): 167-187.

Vergani, G.D., Tankard, A.J., Belotti, H.J. and Welsink, H.J. 1995. Tectonic evolution and Paleogeography of the Neuquén basin, Argentina. En Tankard, A.J., Suárez, R. and Welsink, H.J. (eds.) Petroleum basins of South America. American Association of Petroleum Geologists, Memoir 62: 383-402.

Winchester, J.A. and Floyd, P.A. 1977. Geochemical discrimination of different magma series and their differentiation products using inmobile elements. Chemical Geology 20: 325 -343.

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