A Permo-Carboniferous U-Pb age for part of the Guanta Unit of the Elqui-Limarí Batholith at Río del Tránsito, Northern Chile

Robert J. Pankhurst

Ian L. Millar

British Antarctic Survey, c/o NERC Isotope Geosciences Laboratory, Keyworth, Nottinghamshire, NG 12 5GG, U.K.

Francisco Hervé

Departamento de Geología, Universidad de Chile, Casilla 13518, Correo 21, Santiago, Chile

ABSTRACT

A U-Pb zircon age of 285.7±1.5 Ma is presented for granodiorite from the Chanchoquín pluton of the Guanta Unit, Elqui Superunit of the Elqui-Limarí Batholith. This is the first U-Pb zircon age reported from this batholith and is interpreted as dating emplacement of part of its oldest unit, very close to the time of the Carboniferous-Permian boundary. The age is similar to published Rb-Sr ages for the Palaeozoic batholiths of the Coast Range in Central Chile, in the Algarrobo and Nahuelbuta areas, indicating a widespread episode of plutonic activity along the Gondwana margin of Northern and Central Chile. If the new age were applicable to the whole of the Guanta unit, the other units of the Elqui Superunit (Cochiguas and El Volcán units) would have been emplaced during Permian or later times. A new Rb-Sr whole-rock isochron of 256±10 Ma for the Cochiguas Unit in Río Los Molles, at the southern end of the batholith, is in agreement with this, although previous evidence for the Cochiguas Unit in its type section indicated a Carboniferous age. This suggests either that the Rb-Sr system in Los Molles has been reset, or that the mapped units of the batholith, although lithologically similar in different areas, are not contemporaneous. Further U-Pb dating is needed to resolve these questions.

Key words: Geochronology, U-Pb zircon, Rb-Sr, Granite, Palaeozoic, Chile.

RESUMEN

Edad U-Pb permo-carbonífera para parte de la Unidad Guanta del Batolito Elqui-Limarí en Río del Tránsito, norte de Chile. Se presenta una nueva edad (U-Pb en circón de 285,7±1,5 Ma) para una granodiorita del plutón Chanchoquín de la Unidad Guanta (Superunidad Elqui del Batolito Elqui-Limarí). Representa la primera determinación de U-Pb en circón del batolito, y se interpreta como la edad de cristalización de parte de la unidad más antigua, muy próxima al límite Carbonífero-Pérmico. Es, además, muy similar a las edades obtenidas en los batolitos paleozoicos de la Cordillera de la Costa de Chile, en las localidades de Algarrobo y Nahuelbuta, verificando, por lo tanto, una intensa actividad magmática a lo largo del margen gondwánico del norte y centro de Chile. Si la nueva edad pudiera interpretarse como de toda la Unidad Guanta, las restantes unidades de la Superunidad Elqui (unidades Cochiguas y El Volcán) deberían haberse emplazado durante el Pérmico o más recientemente. Una nueva isócrona Rb-Sr en roca total de 256±10 Ma para la Unidad Cochiguas en Río Los Molles, en el extremo austral del batolito, está de acuerdo con esto, aunque evidencias previas de la Unidad Cochiguas en su sección tipo indican una edad carbonífera. Se sugiere que los sistemas Rb-Sr en el área de Río Los Molles, se han ajustado o que distintas unidades mapeadas del batolito, aunque coherentes litológicamente, no son contemporáneas. Se requieren dataciones U-Pb adicionales para resolver estas interrogantes.

Palabras claves: Geocronología, Circón U-Pb, Rb-Sr, Granito, Paleozoico, Chile.

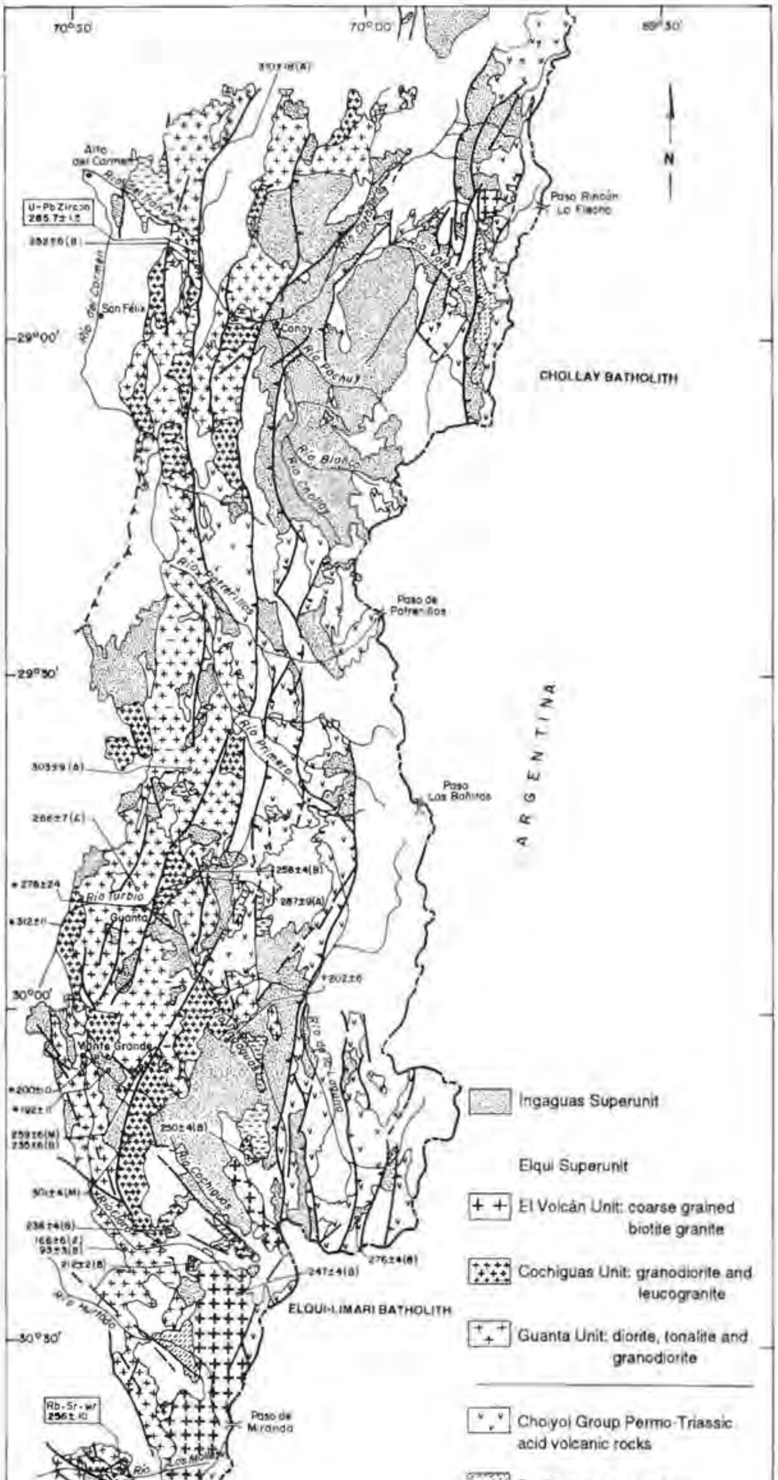

FIG. 1. Location map and distribution of the Elqui Superunit of the Elqui-Limarí Batholith, modified from Mpodozis and Kay (1990). Radiometric ages (Ma) are plotted from the literature (see text for references) and this paper. The asterisk indicates previously published Rb-Sr whole rock isochron ages. Those of Rex's (1987) have been recalculated. Previously published K-Ar ages in amphibole (**A**), biotite (**B**) and muscovite (**M**) taken from Mpodozis and Kay (1990). New ages (this paper) are indicated in rectangles.

INTRODUCTION

The Late Palaeozoic to earliest Mesozoic Elqui-Limarí Batholith constitutes the most extensive geological unit of the High Andes between latitudes 28 and 30°S (Fig. 1). The Elqui-Limarí Batholith is composed of two main suites, the Elqui and Ingaguas superunits (Nasi *et al.*, 1985), which differ in age, petrography, structure, and tectonic setting of emplacement. The Chollay Batholith also indicated in figure 1, lies east of the Elqui-Limarí Batholith in the upper reaches of Río del Tránsito drainage system and is devoid of rocks of the Elqui Superunit.

Mpodozis and Kay (1990; 1992) described the Elqui Superunit as the product of subduction-related magmatism that took place along the continental margin of Gondwana after the docking of the Chilenia terrane in Devonian times (Ramos *et al.*, 1986). The Ingaguas Superunit is thought to have been generated in Permo-Triassic times, mostly by crustal anatexis within a thickened crust resulting from the mid-Permian San Rafael orogenic phase (Llambías and Sato, 1990). Mpodozis and Kay (1990, 1992) considered the Ingaguas Superunit to have been contemporaneous and cogenetic with the Permo-Triassic rhyolites of the Choiyoi Group, which are extensive throughout Northern Chile and Western Argentina.

The Elqui and Ingaguas superunits are subdivided on the basis of mappable suites of distinctive lithological character and consistent age relationships. The Elqui Superunit, in the area shown in figure 1, is composed of the Guanta, Cochiguas and El Volcán units. Field relations indicate that the rocks of the Guanta Unit are intruded by those of the Cochiguas Unit, whereas the latter is considered to be coeval with the El Volcán Unit (Nasi *et al.*, 1985). The Guanta Unit is thus the oldest recognized plutonic unit in the batholith.

GUANTA UNIT

The Guanta Unit is mainly composed of foliated hornblende-biotite tonalites and granodiorites, which constitute elongated plutons with a north-south orientation (Nasi *et al.*, 1985). In some localities the plutons of the Guanta Unit have been intruded into metamorphic rocks of supposed Carboniferous (? or Devonian) age (El Cepo Complex and Hurtado Formation; Mpodozis and Cornejo, 1988). Minor gabbros, migmatitic (?) plutons and mylonitic zones also occur within the Guanta Unit.

In the area near El Tránsito (Huasco Valley, at 28°45'S), the Guanta Unit consists of two plutons, Chanchoquín and Dadín (Fig. 1). The Chanchoquín pluton is considered the equivalent of the Guanta pluton, in the type locality of the unit. It intrudes the El Tránsito metamorphic complex, which is interpreted as part of an accretionary prism, possibly of Carboniferous age (Ribba, 1985; Ribba *et al.*, 1988). The Dadín pluton intrudes the La Pampa gneisses, of Silurian age (Ribba, 1985; Ribba *et al.*, 1988), which represent the only known outcrop of the allochthonous Chilenia terrane.

COCHIGUAS UNIT

The Cochiguas Unit is characterized by uniformly more leucocratic rock types than those of the Guanta Unit and consists mostly of two-mica granodiorites and monzogranites. This unit is also composed of several individual plutons, aligned roughly north-south, but to the east of the Guanta Unit (Fig. 1). In numerous localities, the granitoids of the Cochiguas Unit are seen to intrude those of the Guanta Unit.

GEOCHRONOLOGY

Age determinations by the K-Ar and Rb-Sr methods have been reported for various parts of the Elqui-Limarí Batholith by Parada *et al.* (1981); Ribba (1985); Nasi *et al.* (1985); Brook *et al.* (1986); Rex (1987); Ribba *et al.* (1988); Mpodozis and Cornejo (1988); Parada *et al.* (1988) and Nasi *et al.* (1990). The data relevant to the Elqui Superunit are summarized in figure 1. From this database, Mpodozis and Kay (1990) concluded that the crystallization of the Elqui Superunit occurred during late Carboniferous to early Permian times.

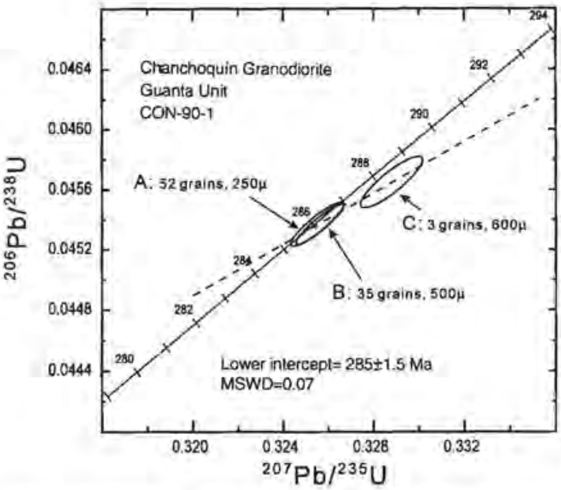

FIG. 2. Concordia diagram showing the three analysed zircon fractions dated in sample CON-90-1, from the Chanchoquín pluton of the Guanta Unit, west of El Tránsito. Error on the inferred age is 2σ.

U-Pb GEOCHRONOLOGICAL DATA

A sample of Guanta Unit granodiorite was collected from the road cutting immediately west of El Tránsito, within the mapped area of the Chanchoquín pluton. The rock is a coarse-grained hornblende-biotite granodiorite, which in outcrop shows considerable variation in the proportion of mafic minerals and in degree of foliation. Micro-slickensides and epidote veining indicate post-crystallization shearing. The sample (CON-90-1) is fresh, relatively unfoliated, and has a sugary (cataclastic?) texture.

Analytical data are shown in table 1 and plotted in figure 2. Two of the three fractions analysed are concordant within analytical error, with $^{207}Pb/^{206}Pb$ ages of 286.8±2.9 Ma and 287.8±2.4 Ma. Data for the third fraction, consisting of three large grains of zircon, are slightly discordant ($^{207}Pb/^{206}Pb$ age of 295.0±3.9 Ma) and suggest minor inheritance relative to the two concordant points. Accordingly, the data have been fitted to a reverse discordia, which yields a precise lower intercept age of 285.7±1.5 Ma (2σ error). This is interpreted as the time of crystallization with a very small degree of inherited zircon from older crust, probably in the cores of these large zircon crystals. Minor inheritance would be consistent with initial $^{87}Sr/^{86}Sr$ ratios close to 0.706 reported for rocks of the Guanta Unit in the Río Elqui section (Parada *et al.*, 1981; Brook *et al.*, 1986; Rex, 1987). The upper intercept (960±530 Ma) is essentially meaningless.

RB-SR GEOCHRONOLOGICAL DATA

Granitoids of the Cochiguas Unit crop out in Río Los Molles, approximately 50 km east-southeast of Ovalle (Mpodozis and Cornejo, 1988). A set of whole-rock samples for Rb-Sr analysis was collected from continuous exposure of about 1 km, *ca.* 30°44.3'S, 70°29.5'W, along the dynamited construction road for the aqueduct that carries water to the hydroelectric plant at Central Los Molles. The principal rock-type is a medium-grained quartz monzogranite, commonly with a saccharoidal texture and cut by apparently cogenetic aplites and pegmatites. Muscovite is ubiquitous, often more abundant than biotite, and is of both primary and secondary origin. Feldspar phenocrysts up to 1 cm vary from fresh to cloudy with sericitic alteration. Evidence of shearing and secondary mica growth increases beyond the western limit of the sampled section. Also at the western end, in roadside outcrops, the granodiorite is seen to intrude sheared lenses of Guanta Unit tonalites belonging to the Panguecillo pluton.

The data for the nine samples are presented in table 2 and plotted in an isochron diagram in figure 3. The fit to a straight line is reasonably good, but shows some excess scatter, with MSWD=6.4. Errors have therefore been enhanced by the square-root of the MSWD, yielding an errorchron age of 256±10 Ma (Middle Permian to earliest Triassic at the extremes of the error range) and an initial $^{87}Sr/^{86}Sr$ ratio (IR) of 0.7089±0.0002.

TABLE 1. U-Pb DATA FOR THE GUANTA UNIT GRANODIORITE.

Concentrations [2]						Atomic ratios						
No.	**Fraction**[1]	**Weight (mg)**	**U (ppm)**	**Pb (ppm)**	**Common Pb (pg)**	$^{206}Pb/^{204}Pb$[3]	$^{208}Pb/^{206}Pb$[4]	$^{206}Pb/^{238}U$[4]	$^{207}Pb/^{235}U$[4]	$^{207}Pb/^{206}Pb$[4]	$^{207}Pb/^{206}Pb$ **Age (Ma)**	**Rho**
Guanta granodiorite, sample CON-90-1												
1A	250µ, NM, A	0.1060	248.5	13.1	26.0	2357	0.269	0.0454±1	0.3255±10	0.05203±7	286.8±2.9	0.90
2A	500µ, NM, A	0.1173	177.8	9.1	14.0	2896	0.241	0.0454±1	0.3256±9	0.05205±5	287.8±2.4	0.92
2B	600µ, NM, A	0.0459	109.9	5.6	4.4	1350	0.219	0.0457±1	0.3288±11	0.05223±8	295.0±3.9	0.87

[1] Average grain size, and magnetic properties of zircon fractions on a Frantz LB-1 Magnetic Barrier Separator. **NM**- non-paramagnetic at 2° side-slope, non-diamagmatic at -2° side-slope. **A**- abraded until all crystal faces were removed.

[2] Errors on sample weights, and consequent systematic errors on U and Pb concentrations, but not on U/Pb ratios, are approximately 20%. Common Pb is after correction for assumed blanks.

[3] Measured ratio corrected for fractionation and spike.

[4] Corrected for fractionation, spike, laboratory Pb and U blanks, and initial common Pb (for 290 Ma according to Stacey and Kramers, 1975). Blanks estimated at 6.5 pg for Pb and 2 pg for U (assumed Pb blank composition is: $^{206}Pb/^{204}Pb$=18.30; $^{207}Pb/^{204}Pb$=15.56; $^{208}Pb/^{204}Pb$=37.63). Ages were calculated using the decay constants recommended by Steiger and Jäger (1977). Errors are quoted at 2σ level, and refer to the last digits of isotopic ratios and ages. Data were reduced using the method of Lüdwig (1989, 1990); errors on measured ages propagated through the reduction were ±2 standard errors of the mean.

[5] Correlation coefficient of $^{207}Pb/^{235}U$ to $^{206}Pb/^{238}U$ is calculated using the procedures and algorithm of Lüdwig (1989, 1990).

TABLE 2. Rb-Sr WHOLE ROCK ANALYTICAL DATA FOR THE COCHIGUAS UNIT IN RIO LOS MOLLES.

Sample	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Tun 1	106	261	1.1818	0.71339
Tun 2	97	289	0.9662	0.71230
Tun 3	89	303	0.8538	0.71209
Tun 4	95	305	0.9052	0.71237
Tun 5	181	136	3.8429	0.72280
Tun 7	145	142	2.9720	0.71960
Tun 9	111	153	2.1127	0.71683
Tun 10	86	330	0.7454	0.71150
Tun 12	77	309	0.7204	0.71124

Rb-Sr concentrations by X-ray fluorecence spectrometry at the British Geological Survey; isotopic measurements on VG 345 mass-spectrometer at NERC Isotope Geosciences Laboratory. Errors on Rb/Sr and $^{87}Sr/^{86}Sr$ estimated at 0.5% and 0.01% (1σ), respectively.

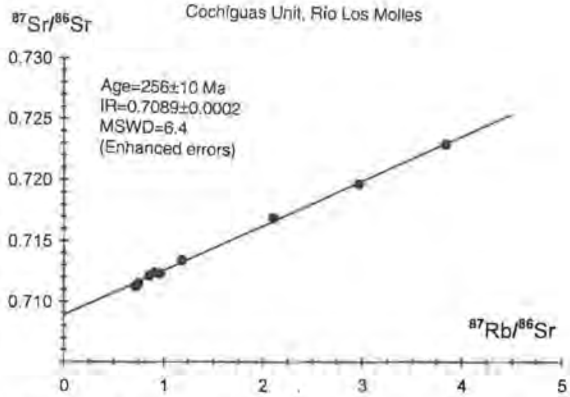

FIG. 3. Rb-Sr isochron diagram for nine samples of the Cochiguas Unit in the aqueduct section of Río Los Molles. Error on the inferred age is 2σ (enhanced).

DISCUSSION

The new U-Pb zircon age of 285.7±1.5 Ma for the Chanchoquín pluton points to an emplacement age very close to the Carboniferous-Permian boundary for this part of the Guanta Unit. Most current estimates for the age of this boundary fall between 286 Ma (Palmer, 1983) and 290 Ma (Harland *et al.*, 1989). Such an age is in agreement with the field relations of the Guanta Unit in the area, and sets a minimum limit to the age of the metamorphism of the El Tránsito metamorphic complex, which is intruded by Guanta Unit granitoids.

Comparison with previously published ages from the Guanta Unit (Fig. 1) shows that two K-Ar amphibole ages appear to be slightly older than the zircon age (only in the case of the K-Ar ages presented by Mpodozis and Cornejo (1988) is it stated clearly that the quoted errors are 2σ, so that the authors cannot be sure of the significance of this difference). All the K-Ar biotite ages and two other amphibole ages are much younger, and can be interpreted as reset or cooling ages in different parts of the Guanta Unit, probably due to the continued plutonic activity represented by the Ingaguas Superunit (Nasi *et al.*, 1985), or possibly by the younger units of the Elqui Superunit itself.

Attempts at Rb-Sr dating of the Guanta Unit have been largely unsuccessful. The result reported by Parada *et al.* (1981) is essentially based on a two-point fit dominated by a single high Rb/Sr sample. Rex (1987) presented further Rb-Sr data that suggested an errorchron age of 310±8 Ma (also cited by Mpodozis and Cornejo, 1988, and Mpodozis and Kay, 1992) for five samples from the Guanta area and one from the Río Ingaguas section; exclusion of the latter sample gave a preferred age of 278±10 Ma. However, values for the associated Mean Square of Weighted Deviates (MSWD) of 31 and 6.0, respectively, show that the data do not adequately fit an isochron model in either case. Enhancement of the errors by the square-root of the MSWD, to allow for the excess scatter beyond analytical error, gives more realistic results of 310±44 and 278±24 Ma that are imprecise, but compatible with the U-Pb zircon age. The present authors also have unpublished analytical data for a further 12 samples of the Guanta unit, but these similarly fail to yield a definitive isochron either alone or in combination with the data of Rex (1987).

A further constraint on the age of the Guanta Unit is provided by the Cochiguas Unit. The latter unit has yielded a similar wide range of K-Ar age determinations to the Guanta Unit (Nasi *et al.*, 1985; Mpodozis and Cornejo, 1988; Nasi *et al.*, 1990). Rex (1987) also presented an Rb-Sr errorchron age for samples from the Río Turbio section, quoted as 312±3 Ma, but again no allowance was made for the scatter of data points (MSWD=8.5). The authors' recalculation of these data with error enhancement as above gives an age of 312±11 Ma, which is significantly older than the authors' U-Pb result from the Guanta Unit. These Rb-Sr systematics may be biased as a result of the high level of crustal input to the magma, indicated by its peraluminous composition (Mpodozis and Kay, 1992) and the high initial $^{87}Sr/^{86}Sr$ ratio of 0.7101±0.0009: both are atypical of subduction-related magmatic arc rocks.

The new Rb-Sr age for the Cochiguas Unit granites in Río Los Molles, at the southern end of the Elqui-Limarí Batholith, is consistent with its intrusive relationship to the Guanta Unit rocks and the new U-Pb zircon age reported here. Comparable ages of ~250 Ma are common amongst the K-Ar data for the Cochiguas and El Volcán units (Mpodozis and Cornejo, 1988) and in the pre-batholithic basement rocks. Radiometric ages for the Ingaguas Superunit are generally in the range 200-230 Ma (Brook *et al.*, 1986; Rex, 1987; Parada *et al.*, 1988); although Mpodozis and Cornejo (1988) reported two older K-Ar biotite ages of 238±4 Ma and 276±4 Ma. Clearly, resetting of Rb-Sr systems is a potential problem in the interpretation of these data, although it is not obvious what event (or events) might be responsible, nor why the K-Ar mica systems should not be equally affected. It is also notable that the initial $^{87}Sr/^{86}Sr$ ratio in the Los Molles area is lower than that determined by Rex (1987) in Río Tubio, although still above the values that could be taken as representing an uncontaminated mantle-derived magma. This, in itself, disallows explanation of the new Rb-Sr isochron for the Cochiguas Unit by Permian resetting of Rb-Sr systems similar to those of the Río Turbio section, unless large-scale open-system behaviour is also invoked.

Alternatively, it is possible that rocks mapped as Guanta and Cochiguas units in different parts of the batholith are not contemporaneous, or that each unit contains a variety of plutonic rocks of different ages. Acceptance of the new U-Pb age of the Chanchoquín pluton as representative of the Guanta Unit as a whole would mean that the Cochiguas and El Volcán units of the Elqui Superunit could be assigned to the Permian period, or younger. These problems can only be properly resolved by further U-Pb dating of all units of the batholith in different areas.

The Permo-Carboniferous age determined for part of the Guanta Unit is very similar to previous ages for Palaeozoic intrusive rocks farther south in the Coast Range of Chile. Hervé *et al.* (1988) reported Rb-Sr ages and initial $^{87}Sr/^{86}Sr$ ratios of 292±2 Ma (0.7061±0.0001) for the Algarrobo area and 294±24 Ma (0.7070±0.0005) for the Nahuelbuta area. The initial $^{87}Sr/^{86}Sr$ ratio of 0.706 for the Guanta Unit (Parada *et al.*, 1981; Brook *et al.*, 1986; Rex, 1987) is also comparable with these previous determinations. A voluminous and widely distributed burst of plutonism in the Gondwana margin is thus indicated very close to the time of the Carboniferous-Permian boundary.

ACKNOWLEDGEMENTS

Part of the field work was done under a Conicet-Argentina-Conicyt-Chile agreement, which involved also C. Rapela, C. Cingolani, L. Dalla Salda (Universidad de La Plata) and M.A. Parada and F. Munizaga (Universidad de Chile), whom the authors thank for their valuable collaboration in unforgettable field trips. Collection of material for the Rb-Sr dating was carried out with the support of Servicio Nacional de Geología y Minería, and the assistance of C. Nasi (CDE Chilean Mining Corporation) and R. Moscoso (SERNAGEOMIN). M. Martin (SERNAGEOMIN) was one of the referees and kindly provided some of his own unpublished data for comparison. J. Vargas (Universidad de Chile) and A. Wood (NIGL) very ably concentrated the zircons, and S.R. Noble (NIGL) gave helpful advice. This paper is registered as NIGL Publication No. 155, and is a contribution to IGCP Projects 345 'Andean Lithospheric Evolution' and 376 'Laurentia-Gondwana connections'.

REFERENCES

Brook, M.; Pankhurst, R.J.; Shepherd, T.; Spiro, B. 1986. Andchron: Andean geochronology and metallogenesis. *Overseas Development Administration, Open File Report*, No. WI/IG/86/1. *British Geological Survey*, 83 p. Nottingham, U.K.

Harland, W.B.; Armstrong, R.L.; Cox, A.V.; Craig, L.E.; Smith, A.G.; Smith, D.G. 1989. A geologic time scale 1989. *Cambridge University Press*, 263 p. Cambridge, U.K.

Hervé, F.; Munizaga, F.; Parada, M.A.; Brook, M.; Pankhurst, R.J.; Snelling, N.J.; Drake, R. 1988. Granitoids of the

Coast Range of central Chile; geochronology and tectonic setting. *Journal of South American Earth Sciences*, Vol. 1, No. 2, p. 185-194.

Lüdwig, K.R. 1989. PBDAT for MS-DOS: a computer program for IBM-PC compatibles for processing raw Pb-U-Th isotope data, version 1.06. *U.S. Geological Survey, Open-File Report*, No. 88-542, 37 p.

Lüdwig, K.R. 1990. Isoplot: a plotting and regression program for radiogenic isotope data, version 2.03. *U.S. Geological Survey, Open-File Report*, No. 88-557, 45 p.

Llambías, E.J.; Sato, A.M. 1990. El batolito de Colanguil (29-31°S), Cordillera frontal de Argentina: estructura y marco tectónico. *Revista Geológica de Chile*, Vol. 17, No. 1, p. 89-108.

Mpodozis, C.; Cornejo, P. 1988. Hoja Pisco Elqui, Región de Coquimbo. *Servicio Nacional de Geología y Minería, Carta Geológica de Chile*, No. 68 (1:250.000), 164 p.

Mpodozis, C.; Kay, S.M. 1990. Provincias magmáticas ácidas y evolución tectónica de Gondwana: Andes chilenos (28-31°S). *Revista Geológica de Chile*, Vol. 17, No. 2, p. 153-180.

Mpodozis, C.; Kay, S.M. 1992. Late Paleozoic to Triassic evolution of the Gondwana margin: evidence from Chilean Frontal Cordilleran batholiths (28°S-31°S). *Geological Society of America, Bulletin*, Vol. 104, No. 8, p. 999-1014.

Nasi, C.; Mpodozis, C.; Cornejo, P.; Moscoso, R.; Maksaev, V. 1985. El Batolito Elqui-Limarí (Paleozoico Superior-Triásico): características petrográficas, geoquímicas y significado tectónico. *Revista Geológica de Chile*, No. 25-26, p. 77-111.

Nasi, C.; Moscoso, R.; Maksaev, V. 1990. Hoja Guanta, Región de Coquimbo. *Servicio Nacional de Geología y Minería, Carta Geológica de Chile*, No. 67 (1:250.000), 141 p.

Palmer, A. (Compiler). 1983. The Decade of North American Geology 1983 geologic time scale. *Geology*, Vol. 11, No. 9, p. 503-504.

Parada, M.A.; Munizaga, F.; Kawashita, K. 1981. Edades Rb-Sr roca total del batolito compuesto de los ríos Elqui-Limarí a la latitud 30°S. *Revista Geológica de Chile*, No. 13-14, p. 87-93.

Parada, M.A.; Rivano, S.; Sepúlveda, P.; Hervé, M.; Hervé, F.; Puig, A.; Munizaga, F.; Brook, M.; Pankhurst, R.J.; Snelling, N.J. 1988. Mesozoic and Cenozoic plutonic development in the Andes of Central Chile (30°30'-32°30' S). *Journal of South American Earth Sciences*, Vol. 1, No. 3, p. 249-260.

Ramos, V.; Jordan, T.E.; Allmendinger, R.W.; Mpodozis, C.; Kay, S.M.; Cortés, J.M.; Palma, M.A. 1986. Paleozoic terranes of the central Argentine-Chilean Andes. *Tectonics*, Vol. 5, No. 6, p. 855-880.

Rex, A.J. 1987. The geology, geochemistry and mineralization of the North Chilean High Cordillera. Ph.D. Thesis (Unpublished), *University of Leicester*, 213 p. England.

Ribba, L. 1985. Geología regional del Cuadrángulo El Tránsito, Región de Atacama. Memoria de Título (Inédito), *Universidad de Chile, Departamento de Geología*, 203 p.

Ribba, L.; Mpodozis, C.; Hervé, F.; Nasi, C.; Moscoso, R. 1988. El basamento del valle del Tránsito, Cordillera de Vallenar: eventos magmáticos y metamórficos y su relación con la evolución de los Andes chileno-argentinos. *Revista Geológica de Chile*, Vol. 15, No. 2, p. 129-149.

Stacey, J.S.; Kramers, J.D. 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. *Earth and Planetary Science Letters*, Vol. 26, No. 2, p. 207-221.

Steiger, R.H.; Jäger, E. (Compilers). 1977. Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letters*, Vol. 36, No. 3, p. 359-362.

Vaughan, A.; Millar, I.L. (In press). Syn-magmatic deformation and extension at Creswick Peaks, NW Palmer Land, Antarctic Peninsula. *Journal of South American Earth Sciences*.

Manuscript received: October 16, 1995; accepted: May 16, 1996.

APPENDIX

ZIRCON ANALYTICAL PROCEDURES

Zircons were separated for U-Pb analysis using standard crushing and heavy mineral separation techniques. Fractions were hand-picked under methanol, and only clear grains with no visible cracks or cores were selected for analysis: all fractions were abraded, and then washed in 4N HNO_3 and H_2O. A mixed ^{205}Pb+^{235}U isotopic tracer was added prior to digestion and ion exchange separation. For details, refer to Vaughan and Millar (in press). U and Pb were loaded together onto outgassed single Re filaments with silica gel. Isotope analyses were performed on a VG 354 mass spectrometer, using an ion-counting Daly detector, at the NERC Isotope Geosciences Laboratory, Keyworth.