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GEOCRONOLOGIA DEL EXTREMO SURESTE DEL MACIZO DE AREQUIPA

GEOCHRONOLOGICAL RESULTS FROM THE SOUTHEASTERN PART OF THE AREQUIPA MASSIF

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The Arequipa Massif plays an important role in the tectonic evolution of the Central Andes, because it constitutes a large and ancient region, from which radiometric ages as old as Lower Proterozoic have been obtained. It has been interpreted as the westernmost portion of an ensialic basement of the Andean orogen, physically contiguous with the Brazilian Shield, or alternatively, as an allochtonous terrane, welded onto South America in a collisional event near the end of the Paleozoic, or even in early Mesozoic times. Vicente (in press) demostrated the existence of nappes and large faults at the northern edge of the Arequipa massif, which affected sedimentary rock as late Cretaceous. These nappes can be traced over more than 300 km.

The available geochronological data on the so called "basement" rocks are quite varied. The oldest results were obtained by Lancelot et al. (1976), as well as Dalmayrac et al. (1977), by the U-Pb method on zircons. They determined reliable ages of 1910 Ma, a value which was confirmed by Shackleton el al. (1979), by the whole rock Rb-Sr isochron method on some gneisses in the Mollendo area. Cobbing et al. (1977) presented a reference isochron for gneisses in the region between Mollendo and Quilca, with an age of around 1800 Ma. Younger results were found in other units, some Late Precambrian (600 Ma), and others early Paleozoic (Atico event at about 450 Ma, and Marcona event at about 390 Ma).

Stewart et al. (1974) obtained two K-Ar apparent ages of 680 and 640 Ma. for gneisses at Cerro Verde, near Arequipa, and Wilson (1975) reportes K-Ar results of 430 Ma. for the San Nicolas batholith. Other Rb-Sr and/or K-Ar results given in the references just cited are less reliable in terms of geologic significance, but they do serve to demostrate the complex history for the development of the different "basement" units in the Arequipa massif.

Regarding the Meso-Cenozoic evolution, some K-Ar ages were reported by Stewart et al. (1974), for the Arequipa Batholith. Two age-groups were considered as geologically significant, and related to magmatic pulses, one at 77 Ma, and the other at about 58 Ma.

The radiometric ages obtained in the basement rocks cannot be directly correlated with the tectonic provinces of the western part of the Brazilian Shield. In the appropriate area, Rondonia state of Brazil and northeastern Bolivia, mid to late Proterozoic ages predominate (Cordani and Brito Neves, 1982). Also within other Precambrian areas of the Andean Cordillera, radiometric ages around 1000-1200 Ma. are common, as is also the case for the Belen schists (Pacci et al. 1980).

RESULTS AND DISCUSSION

The samples from the Precambrian Basement, essentially gneisses and related rocks, were collected near the Cerro Verde mine, south of Arequipa, and along the Panamerican Highway, near the Cochendo tunnel and the Rambo River (fig 1).

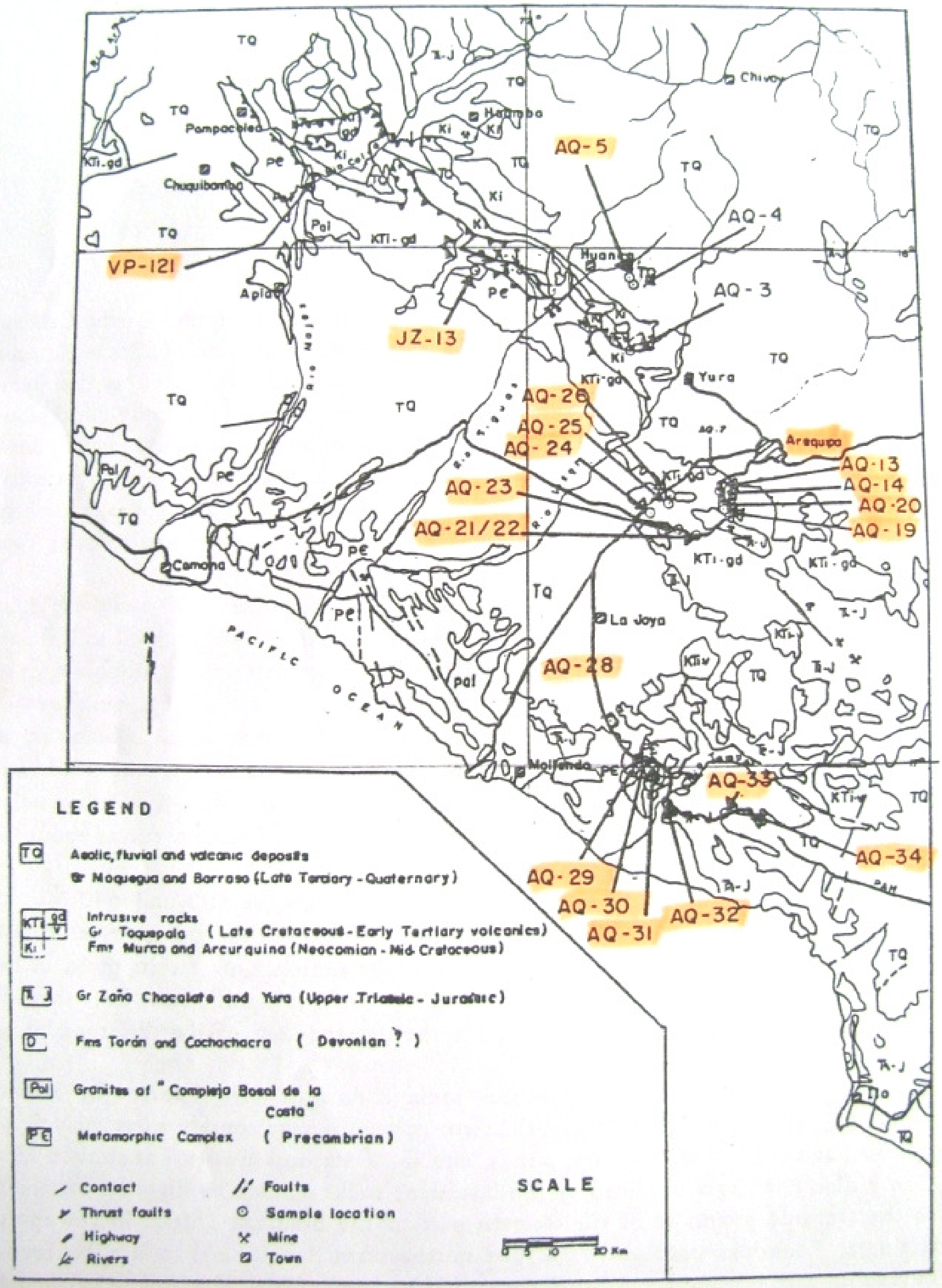

Fig. 1. Geological map of sotheastern Peru, showing locations of dated samples

Fig. 1 Mapa Geológico del sureste del Perú en el que se indica la ubicación de las muestras datada.

The samples from the Cachendo tunnel, are from three different outcrops (AQ-20, 30 and 31) located a few miles apart. They are high grade gneissic rocks located within a major fault zone, and exhibit mylonitic structure and intense shear deformation. The petrographic study revealed strong hydrothermal alteration with significant quantities of secondary minerals such as chlorite, sericite and carbonate. No phases suitable for separation and dating by the K-Ar method were found.

In the isochron diagram of Figure 2 the analytical points exhibit a great dispersion: in particular samples from outcrop AQ-31 look more like a cloud than a straight line. A tentative reference isochron was traced, passing close to the points from outcrop AQ-29, and to some of the points (B,D,E) from outcrop AQ-31; the resulting apparent age is 1330 Ma, with an initial Sr^{87}/Sr^{86} ratio of 0.712.

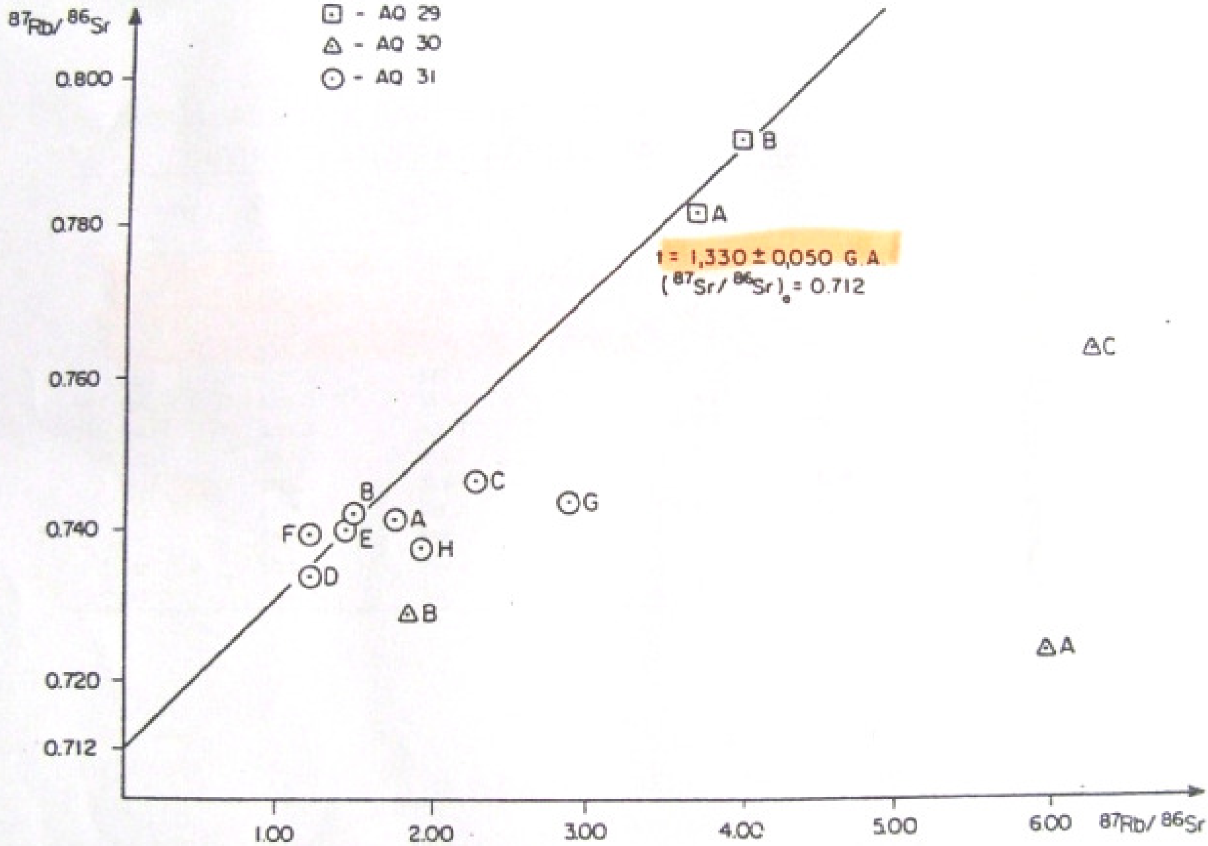

Fig.2. Rb-Sr whole-rock isochron - Arequipa Massif.
Fig. 2. Isócrona Rb-Sr en roca total - Macizo de Arequipa.

There is a tendency for the more hydrothermally altered samples to be the more discordant. All the samples are gneisses with garnet and sillimanite, but AQ-30B and C, as well as AQ-31 A, H,C and G, exhibit large amounts of chlorite, carbonate, and secondary sericite, the presence of which may be related to the a process which shifted these points towards the right side of the isochron diagram, through the chemical mobility of Rb and Sr, and increase of the Rb/Sr ratio.

Sample AQ-30 is an aplitic dyke with granitic composition, and its apparent Rb-Sr age of 220 Ma, calculated with an assumed initial ratio of 0.705 (Table 1), could be geologically meaningful. The other apparent ages included in Table 1 can only be considered as indications of a probable Mid-Proterozoic age for the high-grade terrain. Regional metamorphism may have occurred somewhere between 1300 and 1700 Ma, and the rocks suffered at least one younger event of retrogression, associated with hydrothermal alteration, possibly as young as Mesozoic.

From the Cerro Verde area, the available samples (AQ-19 and 20) were not suitable for Rb-Sr dating, but some of their minerals were analysed by the K-Ar method (Table 2). The nearly concordant apparent K-Ar ages obtained on the amphiboles from samples AQ-19A and B, are close to 1050-1100 Ma. These should be considered as minimum ages for the basement rocks of the Cerro Verde outcrop, which could then correlate with similar ages reported by Pacci et al. (1980) for the Belen schists, in northern Chile. The K-Ar apparent ages obtained in the pegmatitic biotite AQ-19C (517 Ma), and those on the feldspars AQ-19B and AQ-20 (around 450 Ma.), could also be geologically significant, and possibly related to a strong tectonothermal reactivation, the Atico event proposed by Schackleton et al. (1979).

TABLE 1

VALORES Rb-Sr DE MUESTRAS DE ROCA TOTAL DE UNIDADES DEL BASAMENTO
Rb-Sr DATA OF WHOLE-ROCK SAMPLES FROM BASEMENT UNITS

Sample	Rock	Lab.Nº	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Apparent age (m.y.)
AQ-31F	sill.gneiss	6704	71,4	165,5	1,253	0,7395	1910
AQ-31B	gr.sill gneiss	6703	62,9	120,1	1,521	0,7417	1680
AQ-31E	sill.gr.gneiss	6013	70,5	137,0	1,494	0,7400	1630
AQ-31D	sill.gr.gneiss	6012	50,9	117,3	1,259	0,7338	1590
AQ-29B	gr. gneiss	6007	174,7	125,6	4,059	0,7917	1490
AQ-29A	gr. gneiss	6701	171,4	132,7	3,766	0,7818	1420
AQ-31A	sill.gr.gneiss	6702	62,2	100,1	1,816	0,7412	1390
AQ-31C	musc.gneiss	6011	71,9	89,8	2,326	0,7461	1230
AQ-31H	sill.gr.gneiss	6015	43,6	63,7	1,987	0,7371	1130
AQ-31G	sill.musc.gneiss	6014	69,5	68,9	2,930	0,7433	915
AQ-30B	gr. gneiss	6009	70,1	107,2	1,897	0,7292	890
AQ-30C	gr.sill.gneiss	6010	91,6	42,0	6,347	0,7638	650
AQ-30A	aplite	6008	172,8	83,1	6,028	0,7242	220

* assumed initial ratio $(^{87}Sr/^{86}Sr)_o = 0,705$

Rb^{87} Decay constant $1,42 \times 10^{-11}\ yr^{-1}$

TABLE 2

DETERMINACIONES DE EDAD K-Ar
K-Ar DETERMINATIONS

Sample	Rock	Mineral	Lab.Nº	%K	Radiogenic ^{40}Ar (ccSTP/g)x10^{-6}	Atmospheric ^{40}Ar (%)	Apparent mineral age Ma
AQ-19B	granodiorite	amphibole	5668	1.0731	62.43	2.1	1090 ± 23
		plagioclase	5669	1.0412	20.85	6.4	454 ± 11
AQ-19A	amphibolite	amphibole	5666	0.9627	52.20	1.6	1034 ± 28
AQ-19C	pegmatite	biotite	5670	2.8527	66.20	5.3	517 ± 27
AQ-20	augen-gneiss	potash-feldspar	5680	3.4254	65.16	2.7	433 ± 14
AQ-34	qz.monzonite	pyroxene	5678	0.7088	7.98	7.3	269 ± 10
VP-121	granite	biotite	5370	4.7604	36.78	24.9	189 ± 11
AQ-28	qz.monzonite	biotite	5403	3.4031	26.23	8.3	189 ± 13
JZ-13	granite	biotite	5371	3.3685	21.33	21.3	157 ± 14
AQ-33	adamellite	biotite	5679	3.6213	22.62	20.9	154 ± 9
AQ-32B	basic dyke	amphibole	5671	0.9194	5.18	19.3	140 ± 7
AQ-3	andesite	whole-rock	5339	3.7427	1.38	70.5	9.5 ± 1.2
AQ-4	andesite	plagioclase	5653	0.4614	0.15	71.1	8.4 ± 2.6
AQ-5	andesite	whole-rock	5343	1.8760	0.50	80.8	6.9 ± 1.3

The Meso-Cenozoic samples were collected in three main localities (fig 1): in the region near Arequipa (samples AQ-3,4 and 5, as well as samples AQ-21, 22, 23, 24, 25 and 26), along the Tambo river (AQ-28, 32, 33 and 34), and near the Majes river (J2-13 and VP-121).

Some of samples collected near Arequipa belong to the Late Tertiary volcanic sequences of the Moquegua Group. They are andesites, which yielded K-Ar ages between 6 and 10 Ma, characterizing an Upper Miocene volcanic phase (Table 2).

TABLE 3

DATOS Rb-Sr DE ROCAS ERUPTIVAS MESO-CENOZOICO
Rb-Sr DATA FORM MESO-CENOZOIC ERUPTIVE ROCKS

Sample	Rock	Lab.Nº	Rb(ppm)	Sr(ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$(^{87}Sr/^{86}Sr)_i$*
AQ-21	quartz-monzonite	6698	64.4	480.7	0.388	0.7076	0.7072
AQ-22	granodiorite	6002	96.2	392.1	0.710	0.7096	0.7088
AQ-23A	granite	6699	180.6	336.8	1.552	0.7063	0.7046
AQ-24	quartz-monzonite	6004	337.7	173.0	5.651	0.7107	0.7046
AQ-25	granitic	6005	188.4	262.2	2.079	0.7072	0.7050
AQ-26	granodiorite	6006	74.6	453.3	0.476	0.7071	0.7066
AQ-28	quartz-monzonite	6700	90.4	418.8	0.625	0.7060	0.7053
AQ-32A	granite	6705	94.0	375.2	0.725	0.7058	0.7050

* Corrected to 76 Ma.

Rb^{87} Decay constant: $1,42 \times 10^{-11}$ yr^{-1}

One other group of samples, collected in an area about 20 km SW of Arequipa, belong to the Arequipa batholith, a differentiated plutonic complex, including gabbros, as well as diorite, tonalites, granodiorites, granites.

Samples AQ-23A and AQ-24 are related to the same quartz-monzonitic unit, and define a line with an apparent Rb-Sr age of 76 Ma. This result is concordant with some of the K-Ar ages reported by Stewart et al. (1974), and is taken as probably significant and related to the age of the intrusion. The value of 76 Ma. was employed to correct the present day $Sr^{87}/^{86}Sr$ ratios, in order to obtain the initial ratios of Table 3. The corrected results were between 0.704 and 0.709, indicating some sort of crustal contamination affecting the original magmas.

Pitcher (1978) suggested an initial ratio of 0.704 for several units of the Coastal batholith, and considered a predominantly primitive mantle source for the plutonic rocks. The Sr isotopic results indicating some component of crustal contamination may suggest that, during the emplacement of the Arequipa batholith, the continental crust was already long established in the area. This implies that, if the Arequipa massif is indeed allochtonous, its welding to South America occurred prior to the Late Cretaceous.

The K-Ar determinations for the Majes and Tambo rivers (Table 2) should be considered as minimum ages for the formation and intrusion of the corresponding granitic bodies. The oldest results is the ca 270 Ma. for the Aq-34 quartz-monzonite which was obtained in a pyroxene separate. Four other K-Ar dates, obtained on biotite samples, indicated apparent ages around 190 Ma, and around 155 Ma. suggesting the existence of Jurassic magmatic activity, similar to the age pattern further South. in

Chile. Another apparent age of 140 Ma. obtained on the amphibole from sample AQ-32B, a basic dyke cutting through a granitic intrusion, is also Jurassic.

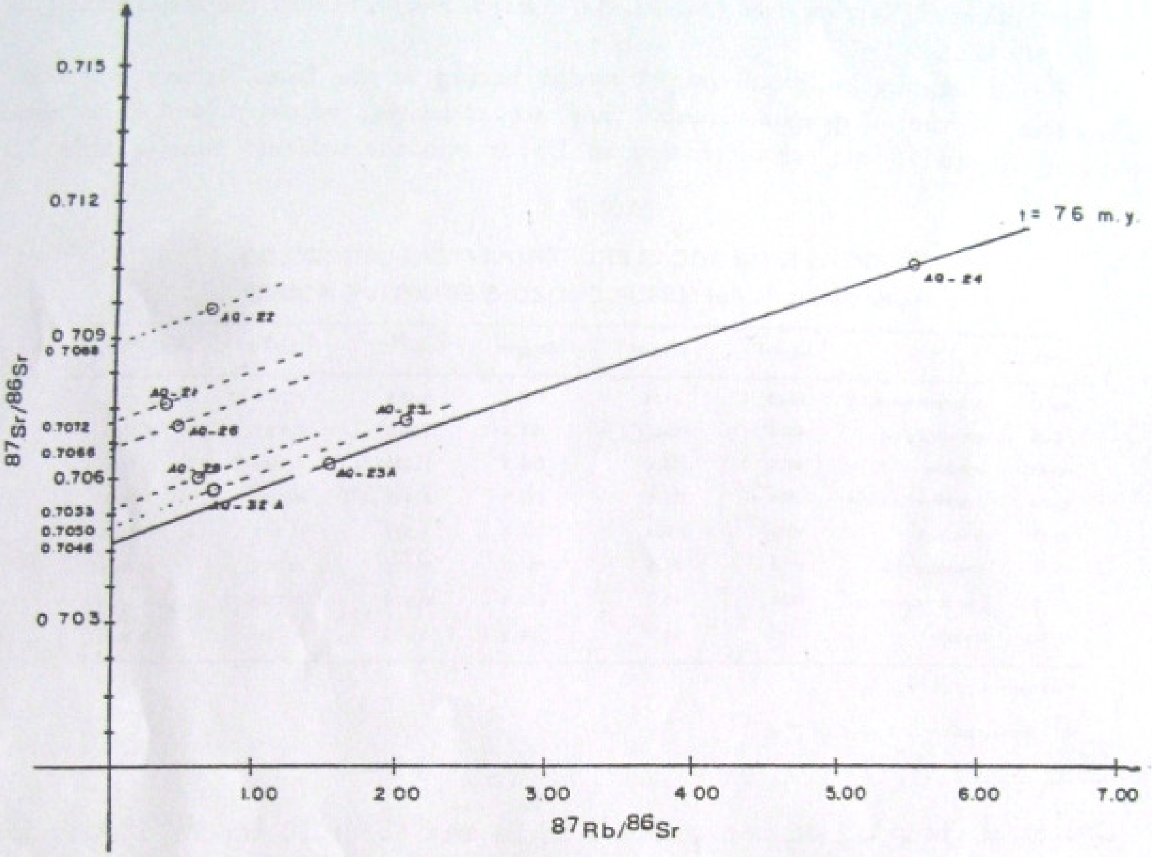

Fig. 3. Rb-Sr Whole-rock isochron - Mesozoic intrusive rocks.
Fig. 3. Isocrona Rb-Sr en roca total - Intrusivos Mesozoicos.

CONCLUSIONS

The geochronological data here reported confirm the chronological heterogeneity of the basement rocks of the Arequipa massif, indicating that it is formed by different units, and its evolution is complex. Moreover, it does not correlate easily with the tectonic province which occur is the western part of the Brazilian Shield Some correspondence can be found between the ages at Cerro Verde and those of the Belen schists, in Northern Chile, which might possibly be considered as a southern extension of the massif.

Taking into account the tectonic reactivations of Paleozoic age, which are conspicuos in some of the basement rocks, speculation abouth the possible influence of an Hercynian episode could be presented. In this case, the Arequipa massif should have been presented along the western coast of South America at least since early Paleozoic times. In addition, the Meso-Cenozoic tectomagmatic processes, starting at least in Jurassic times, can be easily correlated with similar events defined in Chile, where numerous granitic rocks occur along elongated and parallel plutonic belts. At the same time, the Cretaceous ages and Sr^{87}/Sr^{86} initial ratios between 0.704 and 0.709 here reported for the Arequipa batholith are fully compatible with the available results found elsewhere, within the Coastal Cordillera of Peru.

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