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GEOCHRONOLOGY OF PORTUGUESE GRANITOIDS: A CONTRIBUTION

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SUMMARY.— Geochronological data (Rb-Sr method, $\lambda 87_{Rb} = 1.42 \times 10^{-11}$/y) relative to eight granitoid bodies, of which five form part of a zoned pluton (Castro Daire area, Northern Portugal), show this pluton as a multi-pulse intrusion and define four age groups (ca. 280, 290, 305, 322My). Published data refering to granitoids from other areas of Portugal (Central Iberian zone mostly) may be included in these and in other two Hercynian age groups (ca. 345, 380My) and also in three Caledonian groups (ca. 435, 482, 515My), the Caledonian granitoids occurring along the suture Central iberia-Ossa Morena geotectonic zones.

Seven of the granitoids have intermediate initial $^{87}Sr/^{86}Sr$ ratios (.707 ± .002 for six units of the zoned pluton and .711 ± .002) and one has a high initial ratio (.722 ± .008). These data suggest that all the granitoids are of the S-type, the possible mechanisms of magma genesis being discussed.

RESUMO.— Dados geocronológicos (método Rb-Sr, $\lambda 87_{Rb} = 1,42 \times 10^{-11}$/ano) relativos a oito corpos de granitóides, dos quais cinco fazem parte de um plutão zonado (Castro Daire, Norte de Portugal), mostram que o plutão é uma intrusão multi-fase e definem quatro grupos de idade (ca. 280, 290, 305, 322Ma).

Dados disponíveis relativos a granitóides de outras áreas de Portugal, na sua maioria da zona Centro-Ibérica, podem ser incluidos naqueles grupos e ainda noutros dois (ca. 345 a 380Ma) tambén de idade hercínica; e ainda em três grupos de idade Caledónica (435, 482), 515Ma), ocorrendo os granitóides destes últimos ao longo da sutura zona Centro-Ibérica-zona Ossa Morena.

Sete dos corpos têm razões iniciais $^{87}Sr/^{86}Sr$ intermédias (seis das unidades do plutão zonado com 0,707 ±0,002 e uma outra com 0,711 ±0,002), apresentando o oitavo uma razão inicial alta (.722 ± .008). Estes dados sugerem que se trata de granitóides tipo-S com vários mecanismos possíveis de génese magmática.

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I. INTRODUCTION

1.1. The need for abundant and reliable radiometric age data related to the granitoids that make up a large segment of the Portuguese crust has been strongly felt by many geologist concerned with the pre-Mesozoic geology of Portugal. This is due to two main reasons: a) the radiometric approach to the problem of the age of those granitoids has shown to be more informative than the stratigraphic or the tectonic/structural approaches (see, for instance, TEIXEIRA, 1976; NEIVA, 1972; RIBEIRO, 1974); b) there are strong implications of the isotopic data not only in many aspects of the geology of the country (see also OEN, 1970; THADEU, 1977; SOUSA, 1978; TEIXEIRA et al., 1979; SCHERMERHORN, 1981) but also on the characterization of the Hercynian orogeny in the Iberian Peninsula. MENDES, 1967/68 and PRIEM et al., 1970, have served as main references for age data on Portuguese rocks. Several other determinations have been made during the 1970's (see below) and the total number of sites in which granitoid samples have been collected for dating purposes is estimated at not less than 250 (Rb-Sr, K-Ar and U-Pb methods).

1.2. Unpublished isotopic data (PINTO, 1979) used in this paper relate to eight granite units occurring in the Castro Daire area (fig. 1). This area is particulary appropriate for geochronological investigations since it has been very well mapped on the 1/50.000 scale (SCHERMERHORN, 1956; 1980; SLUIJK, 1963; SERVIÇOS GEOLOGICOS DE PORTUGAL,1977; 1981; PEREIRA et al., 1980) and has also many other references to various aspects of its geology that are relevant to Northern Portugal (FLEURY, 1922/24; WESTERWELD et al., 1956; OEN, 1960; 1962; BONHOMME et al., 1961; MENDES, 1961; 1967/68; SCHERMERHORN, 1962; BERGER and PITCHER, 1970; FERNANDES, 1970; FLOOR et al., 1970; OEN, 1970; FERREIRA, 1972; 1980; GODINHO and JALECO, 1973; 1974; 1975; ARTHAUD and MATTE, 1975; SANTAREM and CONDE, 1976; BOISSAVY-VINAU et al., 1978; 1979; 1980; OLIVEIRA and PEREIRA, 1980; PINTO 1982).

2. BROAD GEOLOGIC SETTING

This section and fig. 1 is a summary of the geology of the area, focusing on the age of the rock units under consideration. The geology is described in detail in the above references, particulary SCHERMERHORN, 1956 and SLUIJK, 1963.

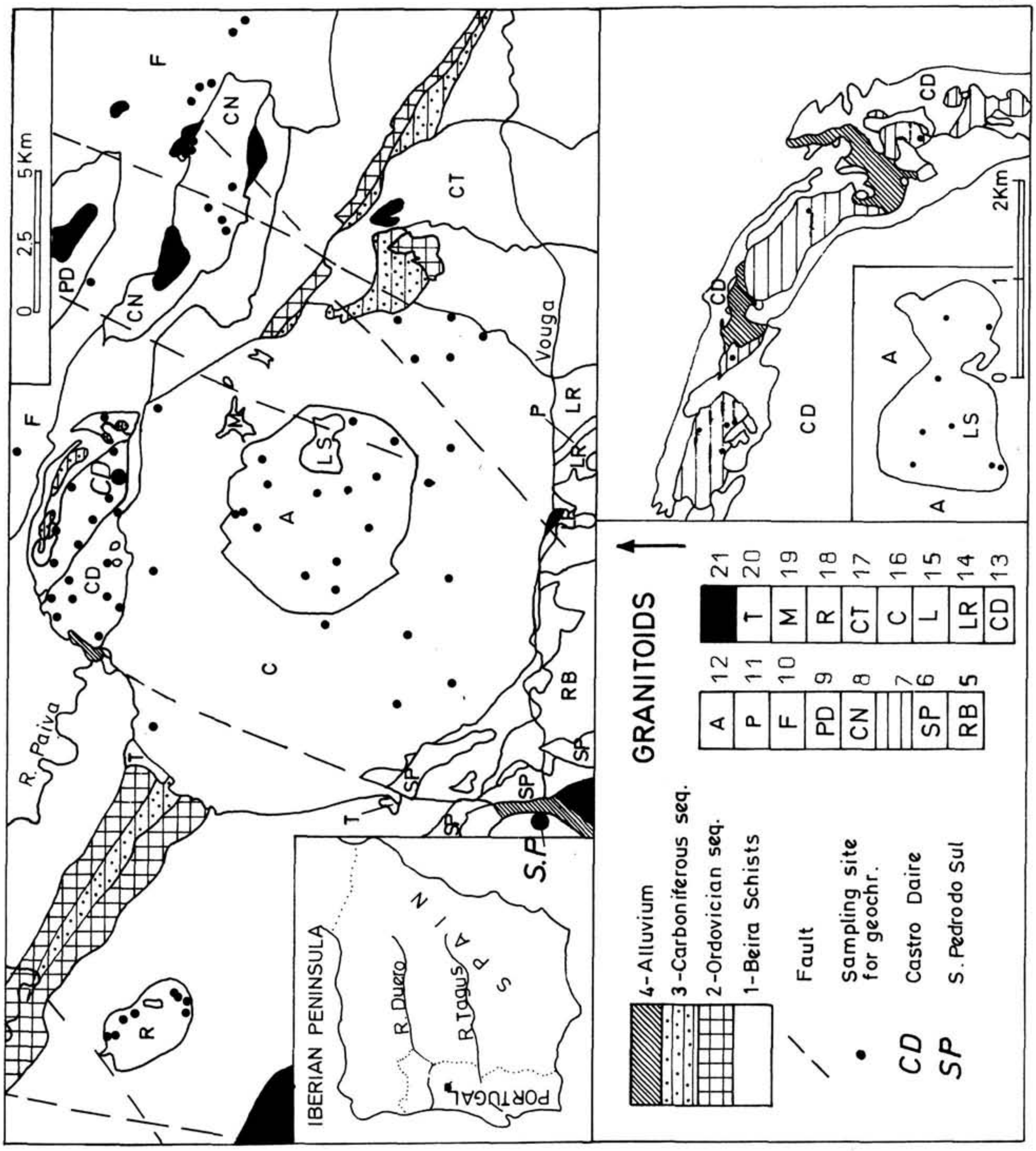

FIG. 1.— Simplified geological map of the Castro Daire area (Northern Portugal) (See text for source references).

1.- Beira Schists
2.- Ordovician seq.
3.- Carboniferous seq.
4.- Post-Paleozoic cover
5.- Ribafeita gr (II γ_6)
6.- S. Pedro Sul gr (VII γ_2)
7.- Lamelas grd (V_γ)
8.- Canado gr ($II_{\gamma 2}$)
9.- Pendilhe gr ($II_{\gamma 1}$)
10.- Frágoas gr ($IX_{\gamma 1}$)
11.- Póvoa gr ($II_{\gamma 7}$)
(Simbols as in SCHERMERHORN, 1956).
12.- Alva gr ($II_{\gamma 4}$)
13.- Castro Daire gr ($VII_{\gamma 1}$)
14.- Lordosa gr (VII γ_3)
15.- Lamas gr (I γ_7)
16.- Calde gr (IX γ_2)
17.- Cota gr (IX γ_3)
18.- Regoufe gr
19.- Mões aplg (X_γ)
20.- Tourmaline gr ($VIII_\gamma$)
21.- Other granites

The area shown in fig. 1 is primarily a domain of metasedimentary and granitic rocks (s.l.) with minor acid and basic intrusives.

The «Beira Schists» (or «Complexo xisto-grauváquico ante-ordoviciano») is a pre-Ordovician sequence believed to be either of Cambrian age or late Precambrian-Cambrian.

Ordovician (Skiddavian and llanvirnian-Landeilian) and Carboniferous rocks lower Stephanian-C, according to L. SOUSA, person. comun.) form a north-westerly trending belt (Esposende-Satao sinclinal structure) that extends outsidê the area.

The granitoid units form plutons that vary in terms of petrography, shape, size, internal structure, structural relationships with country rocks and associated metamorphism. They have been considered to be of Hercynian age: Older Hercynian granites, with a 309 ± 10Ma age and Younger Hercynian granites, with 290 ± 11 age [1], for the Younger ones, a regular intrusion sequence has been admitted from fine-to coarse-grained and to porphyritic; some of the plutons intrude metasedimentary rocks of known age; in certain cases the relative ages of the plutons are known; some of them are spatially associated with Sn-W mineralizations.

Samples were taken from these units:

— the Regoufe muscovite-albite porphyritic granite (K-feldspar phenocrysts) (SLUIJK, 1963) forming the roughly oval-shaped Regoufe stock intruding the Beira Schists (contact metamorphism);

— the Canado medium —to coarse— grained biotite-granite with variable content of muscovite (unit II_{γ_2} in SCHERMERHORN, 1956) that forms a nothwesterly trending elongate concordant pluton east of Castro Daire; it intrudes and metamorphoses the Beira Schists and it is cut and veined by the Frágoas granite;

— the Frágoas porphyritic (K-feldspar phenocrysts(biotite-granite with some muscovite (unit IX_{γ_1} in SCHERMERHORN, 1956; «Touro granite» in BOODER, 1965) forming an elongated pluton which largely extends outside the area shown in fig. 1 and intrudes the Beira Schists;

— the Lamelas fine-grained hornblende-biotite granodiorite (unit V_{γ} in SCHERMERHORN, 1956) that forms a discontinuous belt of some 12 small bodies N, NE and E of Castro Daire, at the margin of the Castro Daire zoned pluton; it is intrusive in the Beira Schists;

[1] These are recalculated 298 ± 10My and 280 ± 11My ages using $\lambda\ ^{87}Rb = 1{,}42 \times 10^{-11}$/year (STEIGER and JÄGGER, 1977).

— the Castro Daire biotite-granite with little muscovite (unit VII_{γ_1} in SCHERMERHORN, 1956) that occurs in several separate bodies and forms the northernmost margin of the zoned pluton; it cuts the Lamelas granodiorite;

— the Calde two mica porphyritic (K-feldspar phenocrysts) granite (unit IX_{γ_2} in SCHERMERHORN, 1956) which is the largest member of the zoned pluton, forming a ring-shaped body; it intrudes and metamorphoses rocks of the Beira Schists, and of the Ordovician and Carboniferous sequences; it is younger than the Castro Daire and the Alva granites as shown by field evidence; a 282 ±7My age (recalculated: 292 ±7My) for a biotite separated from this granite is given in BONHOMME et al., 1961 and in MENDES, 1967/68: it was used for the Carboniferous time scale (FRANCIS and WOODLAND, 1964; LAMBERT, 1971).

— the Alva two mica porphyritic granite (unit II_{γ_4} in SCHERMERHORN, 1956) which is surrounded by the Calde granite and shows decreasing abundance of k-feldspar phenocrysts towards the centre;

— the Lamas fine-grained biotite-muscovite granite (unit I_{γ_7} in SCHERMERHORN, 1956) making up the innermost unit of the zoned pluton.

The Castro Daire pluton (Castro Daire complex or Castro Daire composite batholit) includes many other, mostly marginal, phases some of them of restricted outcrop.

3. EXPERIMENTAL PROCEDURES

Fresh rock samples collected from each of the eight units were subject to a sequence of cleaning, comminution (weight of crushed sample: 2-5Kg depending on grain size) halving and quartering procedures that produced a -120 mesh powder for XRF and isotope analysis.

Rb and Sr samples with appropriate Rb/Sr ratios were determined using a Philips PW 1212 automated X-ray fluorescence spectrometer on pressed powder pellets, broadly along lines described in PAMNKHURST and O'NIONS, 1973. To assess accuracy and precision, 10 and 12 replicate analyses of reference samples GSP1 and NIMG respectively were carried out over the period of the geochronological work. Means and confidence intervals at the .95 significance level obtained —251 ± 1ppm and 232 ± 1ppm respectively for Rb and for Sr in GSP1 and 324 ± 1pp, and 10 ± 3ppm in NIM-G compare favourably with «usable»values in ABBEY (1978) and with «recommended» values in STEELE et al. (1978).

Sample dissolutions for Sr isotope analysis were performed in teflon beakers using $HF + HNO_3$ and HCl acids. Sr separation included the use of Bio AG × 850 w quartz columns. Blanks were sufficient low (10 ng Sr and 2 ng Rb) to provide negligible corrections.

Sr isotope analysis of microsamples loaded on outgassed single Ta filaments (fused quartz beads) made use of a Vg - Micromass 30 mass spectrometer equipped with a 30 cm radius, 90° - sector analyser tube and Faraday collector. Fast peak switching, short counting times and data processing were controlled by an on-line microprocessor. Replicate measurements on the NBS 987 reference material gave an average value of .71029±00008 (2o error) for the normalized $^{87}Sr/^{86}Sr$ ratio. Thirty duplicate $^{87}Sr/^{86}Sr$ measurements on unknown samples were made over that period; a pooled standard deviation of 010% was obtained. Experimental errors assigned to $^{87}Rb/^{86}Sr$ and to $^{87}Sr/^{86}Sr$ present day ratios: 1.0% and .010% respectively.

For spiked biotite samples: clean biotite (magnetic separation and hand picking)y, added of mixed (^{84}Sr + ^{87}Sr) spike, was digested using $HClO_4 + HF$ (teflon crucible at 105°C) and HCl. Rb (eluted before Sr from the ion-exchange column) was analysed using a modified Associated Electric Industries MS 5 mass spectrometer equipped with a 30 cm radius, 90° - sector analyser tube and Faraday collector.

All isochron ages were calculate through a computer programme which combines the statistical treatment of variances of present day isotope ratios by G. McINTYRE et al. (1966) with York's generalized regression treatment of these ratios with uncorrelated errors (YORK, 1969).

Constants in use are given in STEIGER and JÄGGER, 1977, namely $\lambda^{87}Rb$ = $1,42 \times 10^{-11}$/year.

4. RESULTS AND DISCUSSION

The Regoufe granite.- Eight whole rock samples define a 280±9My isochron with r_i = .7222±.0080 (MSWD = 1.05) (fig. 2; Table I). All samles show very high Rb/Sr ratios.

The Canado granite.- Isotopic data for seven whole rock samples define a 324 ± 11My isochron with r_i = .7110 ± .0024 (MSWD = .67) (fig. 3; Table II).

The Frágoas granite.- Seven whole rock samples define a 320 ± 10My isochron with r_i = .7069 ± .0006 (MSWD = 1,21) (Table III; fig. 4).

These results should not be extrapolated for the whole pluton as it is shown, for instance, in the 1972 edition of the Geological Map of Portugal (SERVIÇOS GEOLÓGICOS DE PORTUGAL, 1972).

The Lamelas granodiorite.- Seven samples collected in four of the small rock bodies define a 322 ± 15My isochron with r_i = .7063 ± .0002 (MSWD = 1,34) (fig. 5; Table IV).

The C. Daire granite.- Isotopic data for seventeen whole rock samples define a 303 ± 12My isochron with r_i = .7078 ± .0011 (MSWD = .20) (fig. 6; Table V).

Inclusion of isotopic data from a biotite (spiked sample) separated from sample from sample F1 sharply reduces the 2σ interval affecting data and r_i, and a 305 ± 6My isochron is obtained with r_i = .7077 ± .0005 (MSWD = .15). This inclusion seems justifiable on the grounds of a quiet geological history of the pluton after crystallization and of a primary nature of the biotite in the granite.

The Calde granite.- Fifteen whole rock samples have isotopic data that define a 282 ± 5My isochron, with r_i = .7093 ± .0011 (MSWD = 1,25) (table VI; fig. 7).

Inclusion of the isotopic data from a biotite published in MENDES, 1967/68 gives a 285 ± 5My isochron with r_i = .7087 ± .0010 (MSWD = 1,59).

The Alva granite.- Fourteen whole rock samples define a 304 ± 7My isochron with r_i = .7061 ± 0012 (MSWD = 1,79) (fig. 8; Table VII).

About half of the samples have been collected from the border zone of the pluton in which the effects of post-consolidation alkali metasomatism caused by the emplacement of the Alva unit can be seen, according to SCHERMERHORN (1956).

The Lamas granite.- Eight samples define a 291 ± 10My isochron with r_i = .7075 ± .0013 (MSWD = 1,04) (Table VIII; fig. 9).

Available field evidence confirms isochron dates (Table IX) as ages of crystallization of the granitoids, as shown by: a) the relative ages of the pairs «Lamelas-C. Daire», «C. Daire-Calde», «Calde-Alva» and «Canado-Frágoas» from field evidence; b) the lower limit of age emplacement of the Calde granite that intrudes and metamorphoses Stephanian-B rocks; (the boundary Autunian-

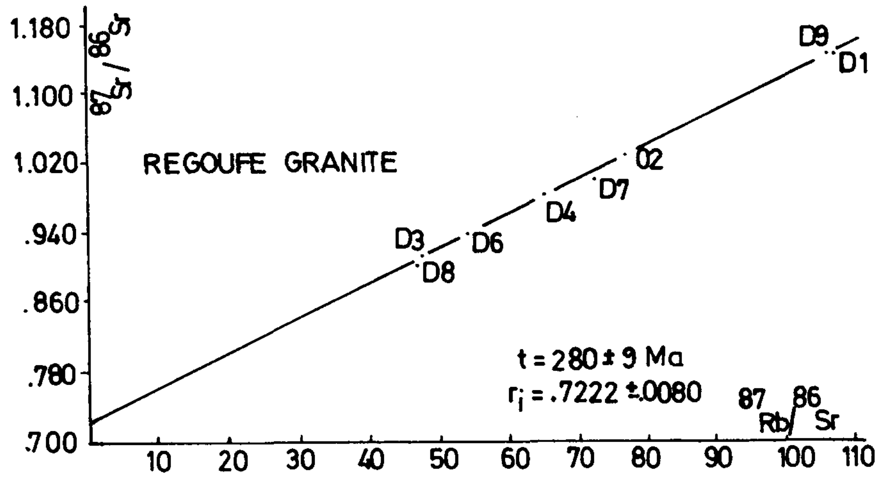

Fig. 2

Table I - Rb-Sr isotope data. Regoufe pluton (whole rock unspiked samples).

Sample No.	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
D_1	869.5	24.6	35.346	106.5	1.14437
D_2	731.7	28.1	26.039	76.89	1.02910
D_3	928.2	58.0	16.003	47.16	.91204
D_4	857.2	39.1	21.923	65.17	.98404
D_6	696.9	37.2	18.734	54.26	.94026
D_7	777.2	32.1	24.212	72.05	1.00662
D_8	742.3	46.7	15.912	46.89	.90619
D_9	779.8	22.3	34.969	105.4	1.14461

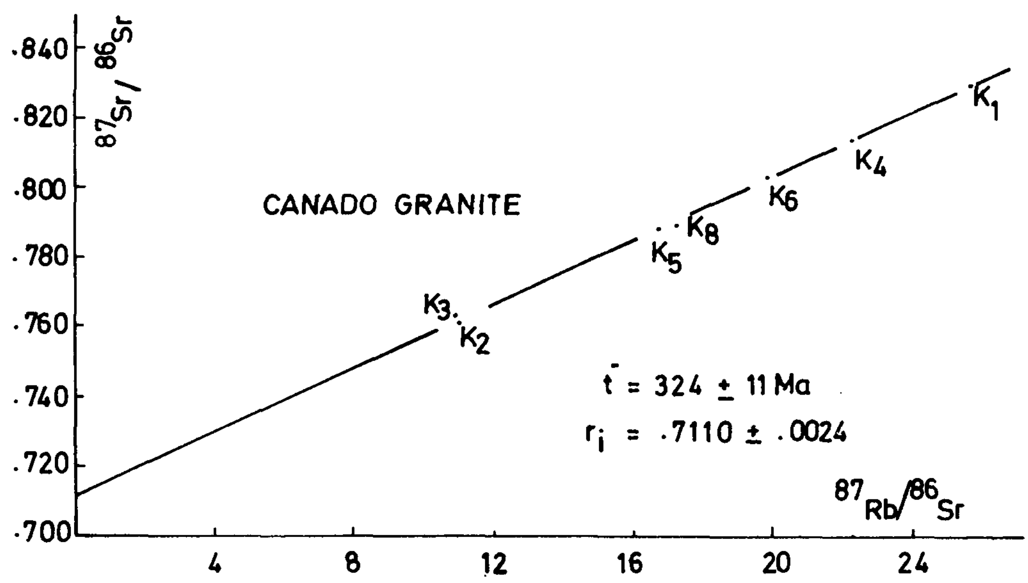

Fig. 3

Table II - Rb-Sr isotope data. Canado granite (whole rock unspiked samples).

Sample No.	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
K_1	325.2	37.2	8.742	25.59	.82913
K_2	241.3	63.3	3.812	11.08	.76165
K_3	245.3	64.9	3.780	10.99	.76234
K_4	347.0	45.7	7.593	22.19	.81343
K_5	326.5	57.0	5.728	16.69	.78789
K_6	243.0	35.9	6.788	19.81	.80297
K_8	326.9	55.8	5.858	17.06	.78920

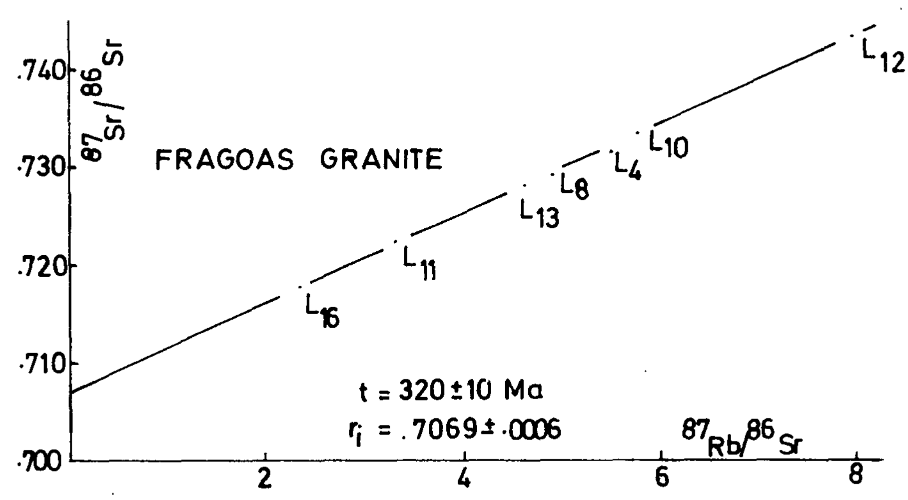

Fig. 4

Table III - Rb-Sr isotope data. Frágoas granite (whole rock unspiked samples).

Sample No.	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
L_4	304.0	161.1	1.887	5.472	.73138
L_8	313.9	185.2	1.695	4.913	.72897
L_{10}	289.4	145.5	1.989	5.769	.73342
L_{11}	273.2	237.5	1.150	3.332	.72212
L_{12}	312.1	114.6	2.723	7.905	.74320
L_{13}	343.3	219.7	1.563	4.529	.72757
L_{16}	256.7	322.0	.797	2.308	.71742

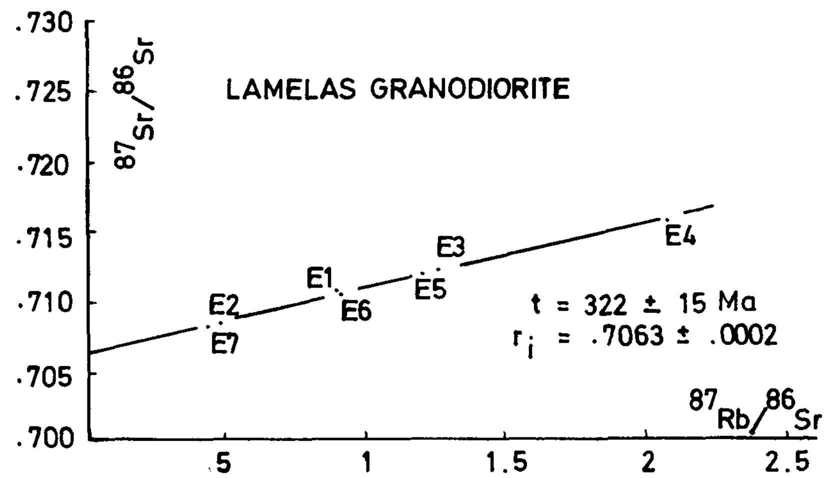

Fig. 5

Table IV - Rb-Sr isotope data. Lamelas granodiorite (whole rock unspiked samples).

Sample No.	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
E_1	105.9	340.8	.311	.8996	.71056
E_2	50.1	285.9	.175	.4750	.70845
E_3	102.5	236.6	.433	1.252	.71211
E_4	145.2	199.2	.729	2.110	.71583
E_5	115.6	276.6	.418	1.209	.71196
E_6	85.5	285.9	.313	.9058	.71041
E_7	41.2	280.0	.147	.4266	.70823

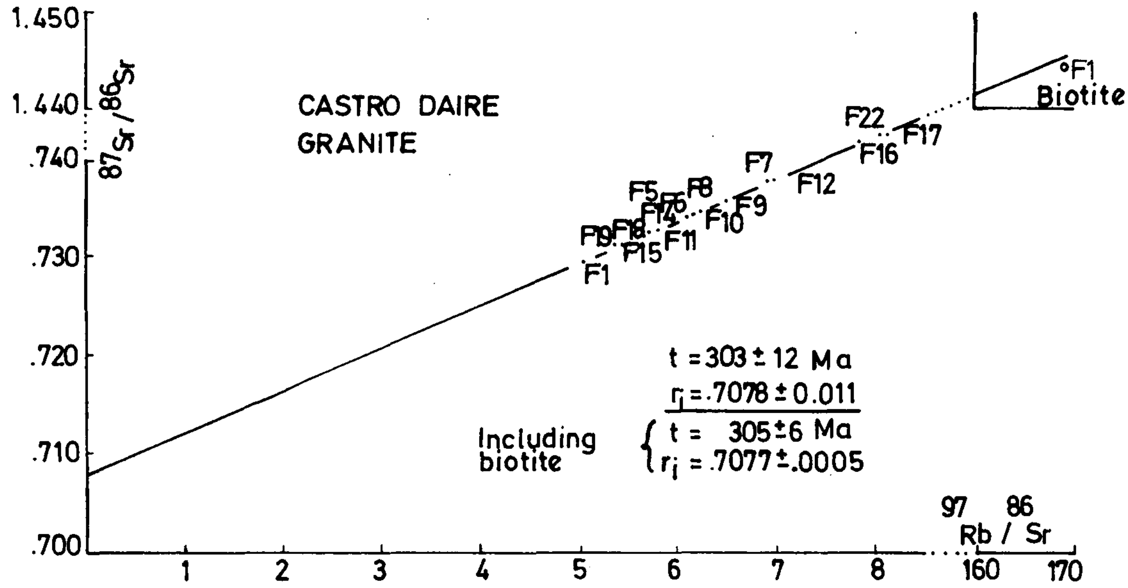

Fig. 6

Table V - Rb-Sr isotope data. Castro Daire granite (whole rock unspiked samples; spiked mineral separates).

Sample No.	^{87}Rb μ mol/g	Rb ppm	^{86}Sr μ mol/g	Sr ppm	Rb/Sr	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
F_1		213.1		122.1	1.745	4.059	.72958
F_1* Biotite	1.420674	436.4229	.008376	7.442		169.612	1.44446
F_4		228.9		114.5	1.999	5.800	.73274
F_5		224.5		114.1	1.968	5.713	.73259
F_6		215.4		101.9	2.114	6.132	.73440
F_7		244.3		102.0	2.395	6.948	.73788
F_8		217.8		103.4	2.106	6.112	.73417
F_9		216.0		96.1	2.248	6.522	.73591
F_{10}		234.9		109.0	2.155	6.251	.73465
F_{11}		214.6		107.6	1.994	5.781	.73269
F_{12}		251.6		104.2	2.415	7.007	.73823
F_{14}		224.1		113.5	1.974	5.724	.73254
F_{15}		224.3		119.3	1.880	5.452	.73121
F_{16}		226.5		83.6	2.709	7.864	.74186
F_{17}		250.8		89.3	2.809	8.155	.74294
F_{18}		210.8		107.3	1.965	5.697	.73235
F_{19}		185.8		100.2	1.855	5.378	.73109
F_{22}		224.3		80.5	2.786	8.086	.74234

*Indicates spiked sample.

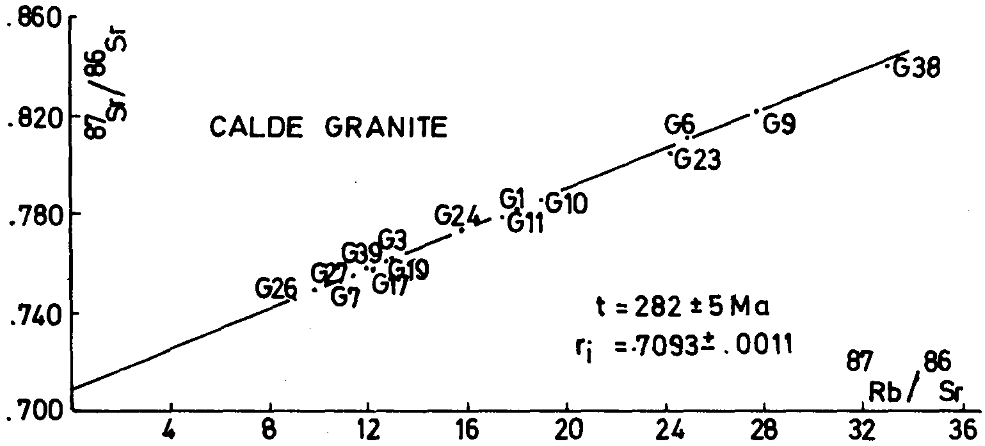

Fig. 7

Table VI - Rb-Sr isotope data. Calde granite (whole rock unspiked samples).

Sample No.	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
G_1	299.5	48.6	6.163	17.95	.78082
G_3	300.5	67.6	4.445	12.92	.76071
G_6	380.8	44.6	8.538	24.95	.81096
G_7	303.4	89.7	3.382	9.822	.74909
G_9	302.5	32.0	9.453	27.65	.82091
G_{10}	320.6	49.1	6.530	19.03	.78610
G_{11}	374.7	62.4	6.005	17.49	.77912
G_{17}	296.4	70.4	4.210	12.23	.75777
G_{19}	291.2	66.3	4.392	12.77	.76023
G_{23}	298.6	36.0	8.294	24.22	.80513
G_{24}	308.6	56.5	5.462	15.90	.77397
G_{26}	321.5	103.4	3.109	9.026	.74522
G_{27}	291.3	74.3	3.920	11.39	.75493
G_{38}	370.3	32.8	11.290	33.08	.83989
G_{39}	284.7	69.4	4.102	11.92	.75782

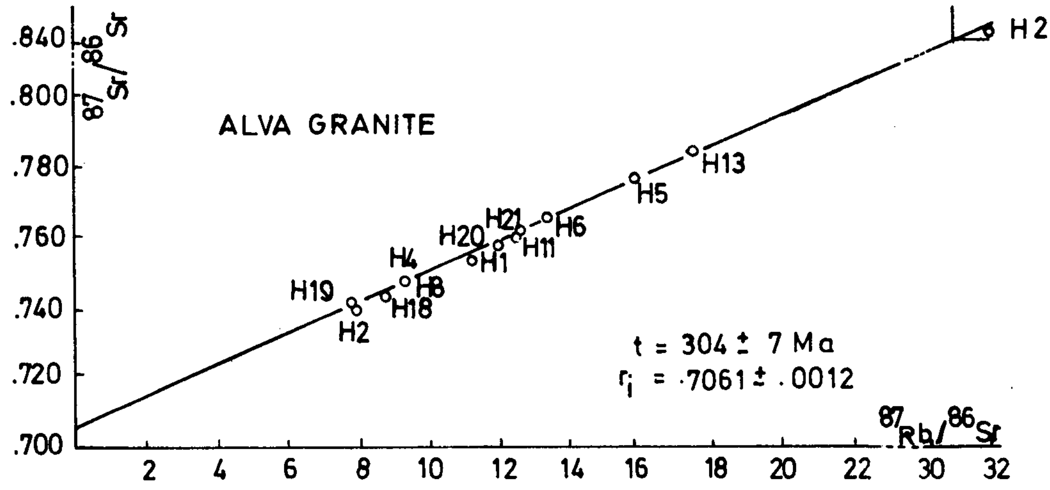

Fig. 8

Table VII - Rb/Sr isotope data. Alva granite (Whole rock unspiked samples).

Sample No.	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
H_1	319.4	84.0	3.802	11.04	.75343
H_2	262.9	96.2	2.732	7.92[illegible]	.74021
H_6	261.1	56.4	4.629	13.46	.76475
H_8	276.3	85.6	3.228	9.375	.74699
H_4	276.0	85.7	3.221	9.355	.74684
H_{11}	314.2	72.6	4.328	12.58	.76092
H_{13}	359.9	59.5	6.049	17.62	.79201
H_{18}	277.7	92.9	2.989	8.675	.74298
H_{19}	290.11	107.3	2.704	7.849	.74050
H_{20}	306.2	73.3	4.177	12.14	.75810
H_{21}	331.0	75.7	4.373	12.72	.76200
H_5	306.6	55.7	5.504	16.02	.77562
H_{26}	316.2	28.8	10.979	32.18	.84219
H_{30}	331.2	41.8	7.923	23.14	.80551

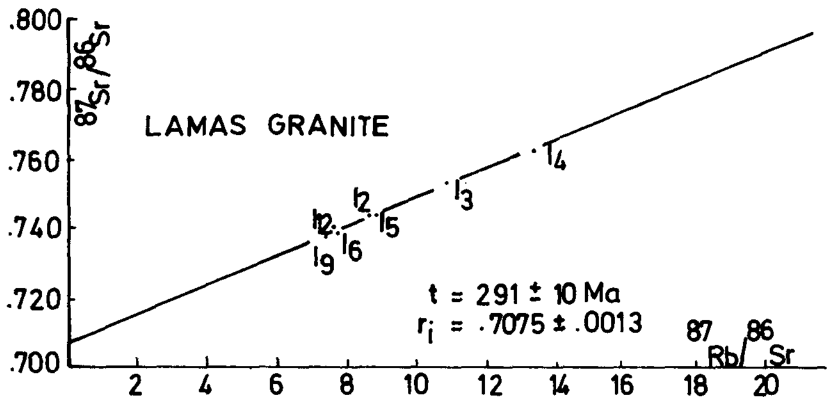

Fig. 9

Table VIII - Rb-Sr isotope data. Lamas granite (whole rock unspiked samples).

Sample No.	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
I_1	309.1	43.0	7.188	20.96	.79379
I_2	274.0	92.2	2.972	8.627	.74333
I_3	277.3	74.8	3.707	10.77	.75303
I_4	323.6	70.7	4.577	13.31	.76262
I_6	258.2	97.8	2.640	7.659	.73887
I_7	286.7	95.1	3.015	8.752	.74355
I_9	230.9	90.7	2.546	7.388	.73823
I_{12}	241.6	91.6	2.638	7.656	.73933

Stephanian is 286My according to HARLAND et al. (1983); c) the lower limit of age of emplacement of all plutons intruding the Beira Schists (Late Precambrian/Cambrian).

TABLE IX.- Isochron datas (My) of the units of the Castro Daire area.

Regoufe granite	280 ± 9
Calde granite	282 ± 5
	285 ± 5 (1)
Lamas granite	291 ± 10
Alva granite	304 ± 7
Castro Daire granite	303 ± 12
	305 ±6 (2)
Frágoas granite	320 ± 10
Lamelas granodiorite	322 ± 15
Canado granite	324 ± 11

(1) Whole rock data plus biotite determination in MENDES 1967 /68 (see text).
(2) Whole rock-biotite isochron.

The Lamas granite now deserves special attention because it has been considered to be older than the Alva granite. SCHERMERHORN (1956, p. 426) points out that the contacts between the Lamas and the Alva granites are sharp and irregular and states that the Lamas granite is «... surrounded and penetrated by the Alva granite». The Lamas granite is included by that author in his group of Older granites, based on a definite pre-Calde granite age; he also admits that the Alva granite might be included in either the older or the Younger group, these groups being defined on the grounds of petrographic and field evidence.

On the grounds of geochronological evidence its is believed that: a) the Calde granite in fact post-dates the Alva granite; b) the Lamas granite has a crystallization age between the Calde and the Alva geanites, being apparently closer to the age of the former, but nevertheless defining a specific isochron.

It should be stressed that the deuteric metasomatism affecting the Regoufe granite (SLUIJK, 1963) and the alkali metasomatic effects on the Alva granite —which, according to SCHERMERHORN (1956), were due to emplacement of the Calde granite— did not disturb the Rb-Sr system in the granites after crystallization, or if it did, it was not to the point to cause the samples to scatter and not to fit an isochron.

5. SOME IMPLICATIONS

5.1. *Sequence of intrusion in the Castro Daire area.*— Ages of crystallization of granitoids of the Castro Daire area show similarities (Table IX) and it seems reasonable to form with them four groups: 280 ± 5My (Regoufe, Calde), 290 ± 5My (Lamas) 305 ± My (Alva, Castro Daire) and 322 ± 5My (Frágoas, Lamas, Canado).

It must be stressed that units within each group cannot be considered rigorously coeval in the sense that each one corresponds to an isochron, the respective age differences in the case of the Canado and the Frágoas granites faithfully reflecting the fact that the former is older than the latter, as shown by the intrusive nature of the contacts.

However it is obviously not possible to differenciate between, on the one hand, the 322 ± 15My of the Lamelas granodiorite and the 320 ± 10My for the Frágoas granite and, on the other, between 324 ± 11My for the Canado granite and the mentioned age for the Lamelas rocks.

Taking into account field evidence and other data, an attempt is made to decipher the sequence of intrusion of most of the granitoids shown in fig. 1, within the framework provided by that clustering of ages (Table X).

It can be seeen that the Castro Daire zoned pluton is a multi-pulse intrusion made up of gregarious granitoid stocks that have been emplaced at different Carboniferous-Permian times within a time span of at least 40 million years.

Two other points should be stressed in relation to Table X: a) a chemical 321 ± 31My age of uraninites of the S. Pedro do Sul granite has been reported in BASHAM et al., 1982; b) tourmaline granites are here considered to post-date the Calde granite, to which they are adjacent, on the grounds of their similarity to the Regoufe granite (SLUIJK, 1963). In SCHERMERHORN, 1956, they are considered to be slightly earlier intruded granites relative to the Calde unit.

5.2. *Age groups of granitoids of Portugal.*— A survey of radiometric ages and dates of pre-Mesozoic granitids of Portugal shows that they cluster around certain values, as shown in Tables XI and XII, the age groups of Table X being maintained.

These compilations deal with radiometric values that have been determined in several laboratories, using various methods, on different materials sampled according to different criteria and therefore a comparison of such values is always difficult. Apart from that, there is always the temptation of putting divisions where they might not exist.

TABLE X- Sequence in intrusion of granitoids, Castro Daire area .

?	322±5Ma	305±10Ma	290±5Ma	280±5Ma	?
Ribafeita (IIγ_6)	S. Pedro do Sul (VIIγ_2)			Regoufe	
		Alva (IIγ_4)	Lamas (Iγ_7)	? Cota (IXγ_3)	Tourmaline gr (VIIIγ)
	Lamelas (Vγ)	C.Daire (VIIγ_1)		Calde (IXγ_2)	Mões aplg (Xγ)
	Canado (IIγ_2)				
	Frágoas (IXγ_1)				
	? Pendilhe (IIγ_1)				
	? Pòvoa (IIγ_7)	?Lordosa (VIIγ_3)			

? Indicates uncertainity in group assignment

↔ Indicates two granites in contact

Symbols as in SCHERMERHORN, 1956

Underlined units: Castro Daire complex

TABLE XI- Age groups of Hercynian granitoids of Portugal.

Age group (Ma)	Age (Ma)	Method	Locality	Reference
280±5 EARLY PERMIAN	280±9	Rb-Sr Wr	Regoufe gr	PINTO, 1979
	282±5	Rb-Sr Wr	Calde gr	PINTO, 1979
	281	Rb-Sr biot	Hercynian gr/Group I	MENDES, 1967/68
	283±5	K-Ar biot	Marofa-Satão orthogneisses	MACEDO and FERREIRA, in press
	284	K-Ar biot	Older Hercynian gr	PRIEM et al., 1970
	284±5	K-Ar biot	Pinhel gr	MACEDO, 1979
290±5 STEPHANIAN	290±11	Rb-Sr Wr	Younger Hercynian gr	PRIEM et al., 1970
	296 - 297	Rb-Sr musc, biot	Younger Hercynian gr	PRIEM et al., 1970
	291	K-Ar biot	Younger Hercynian gr	PRIEM et al., 1970
	291±10	Rb-Sr Wr	Lamas gr	PINTO, 1979
	292	Rb-Sr biot	Hercynian gr/Group II	MENDES, 1967/68
	291	K-Ar biot, musc	Gardunha gr	FERREIRA et al., 1977
	296	K-Ar musc	Panasqueira	CLARK, 1970
305±10 WESTPHALIAN	304±7	Rb-Sr Wr	Alva gr	PINTO, 1979
	303±12	Rb-Sr Wr	Castro Daire gr	PINTO, 1979
	305±6	Rb-Sr Wr biot	Castro Daire gr	PINTO, 1979
	309±10	Rb-Sr Wr	Older Hercynian gr	PRIEM et al., 1970
	289-304-316	Rb-Sr musc. biot	Older Hercynian gr	PRIEM et al., 1970
	301	Rb-Sr biot	Hercynian gr/Group III	MENDES, 1967/68
	304	Rb-Sr biot	Hercynian gr/Group I	MENDES, 1967/68
	306	Rb-Sr biot	Hercynian gr/Group IV	MENDES, 1967/68
	309±7	K-Ar biot	Marofa-Satão orthogneisses	MACEDO and FERREIRA, in press
	305	K-Ar biot	Fundão pluton	FERREIRA et al., 1977
	311±7	K-Ar biot	Aregos grd	ALBUQUERQUE, 1971
322±10 NAMURIAN	320±10	Rb-Sr Wr	Frágoas gr	PINTO, 1979
	322±15	Rb-Sr Wr	Lamelas grd	PINTO, 1979
	324±11	Rb-Sr Wr	Canado gr	PINTO, 1979
	316±4	Rb-Sr Wr	Granitic intrusions, Viana dos Castelo	BARR and AREIAS, 1980
	329	Rb-Sr biot, musc	Porto gr/Group II	MENDES, 1967/68
	320±8	K-Ar musc	Marofa-Sátão orthogneisses	MACEDO and FERREIRA, in press
	314±7	K-Ar bi	Aregos gr	ALBUQUERQUE, 1971
	321±31	Chemical uraninite	S. Pedro do Sul	BASHAM et al., 1982
345±5 VISEAN	344,8±4,3	Rb-Sr Wr	Porto gr	ABRANCHES et al., 1979
	344±2	K-Ar biot, musc	Pala (Pinhel) orthogn.	MACEDO and FERREIRA, in press
379±12 MD/LATE DEVON	379±12	Rb-Sr Wr	O. Azemeis gr-gneiss	PINTO, 1979; in press

All Rb-Sr and K-Ar ages recalculated to new constants (STEIGER and JÄGER, 1977) when necessary.

Time-scale according to HARLAND et al., 1982.

TABLE XII- Age groups of Caledonian plutonic rocks of Portugal.

Age group (Ma)	Age (Ma)	Method	Locality	Reference
402 GEDINNIAN	402±15	Rb-Sr Wr	Penhascoso-Mação-Belver gr	ABRANCHES and CANILHO, in press
435 ASHGILL	440±6	Rb-Sr Wr	Portalegre gr	ABRANCHES et al., 1979
	433±27	Rb-Sr Wr *	Pedrógão Grande gr	ABRANCHES and CANILHO, in press
482 ARENIG	482±79	Rb-Sr Wr *	Rossio Sul Teho gr	
	482±12	Rb-Sr Wr	Alto Alentejo rocks	PRIEM et al., 1970
	482±16	U-Pb zircons	A. Pedroso alk. orthgn	LANCELOT and ALLEGRET, 1982
	485±9	K-Ar musc	Casal Zote gr	PEREIRA and MACEDO, in press
500 TREMADOC	506±14	Rb-Sr Wr	Villa Nova and Coentral gr	ABRANCHES and CARRILHO, in press
	499±9	K-Ar musc	Figueiro Vinhos gr	PEREIRA and MACEDO, in press
515 LATE CAMBRIAN	514±9	K-Ar biot		
	512±19	Rb-Sr Wr	Junqueira-tonalitic orthgn	PINTO, 1979; in press

* ERRORCHRON

All Rb-Sr ages recalculated to new constants (STEIGER and JÄGER, 1977) When necessary.

Time-scale according to HARLAND et al., 1982.

Despite that, it is believed that the age groups represent episodes of (mostly) acid plutonism in Caledonian and mainly in Hercynian times. In fact, the model for the latter is one of long lasting (Devonian-Parmian) recurrent magmatism that has imprinted on the Portuguese crust, at a regional and, in cases, local scale (e.g. Castro Daire pluton), a complex pattern of intrusion ages. Such a model may provide an explanation for many of the mineral dates that have been determined.

The mainly syntectonic character of the O. Azemeis granite-gneiss relative to an early (Middle/Late Devonian) Hercynian deformation phase (GONÇALVES, 1974); PEREIRA et al., 1980; RIBEIRO et al., 1980) makes it the oldest dated (379 ± 12My) Hercynian granitoid; on the other extreme, the Regufe granite is the youngest dated (280 ± 9My) Hercynian granitoid; it belongs to the 280 ± 5My age group, but a still younger group, waiting for radiometric dating, will probably be defined (Mões aplogranite, tourmaline granites?).

Granodiorites and granites share several of, and possibly all, the Hercynian groups.

Most of these granitoids and many others units do occur in the Central Iberian zone (JULIVERT et al., 1974) in which time-relations between Hercynian deformation phases are subject to conflicting views (ANDRADE, 1979; RIBEIRO et al., 1980; SCHERMERHORN, 1981; MACEDO and FERREIRA, in press). Such time relations may eventually be better understood within the framework of granitoid ages shown in Table XI.

As a broad picture, one might stress that, apart from the early phase to which the O. Azemeis orthogneiss has been related, the 322 ± 10 and the 305 ± 10My groups should possibly be related to an intra-Westphalian phase (F_2?) and the younger groups (290 ± 5 and 280 ± 5My) may be considered late —to post tectonic relative to it. The 345 ± 5My group is possibly related to a pre-Visean phase (F1?). In the Central Iberian zone the existence of two important Hercynian deformation phases is generally accepted (see for instance CAPDEVILA et al., 1973) but no general agreement about their exact characterization has yet been reached.

The O. Azemeis orthogneiss and the Caledonian rocks (Table XII) occur close to the boundary of the Central Iberian and the Ossa Morena geotectonic zones (fig. 10).

Evidence is growing for extensive Caledonian magmatism in Portugal, in time, space and character (tonalitic-granitic-and alkaline rocks have been dated).

Apart from the 482My and 515My age groups, a 500My one seems to be forming. As more radiometric data are obtained, surely a better definition of ages groups will follow, stimulating more debate about the nature of the Caledonian deformation and magmatism in Portugal.

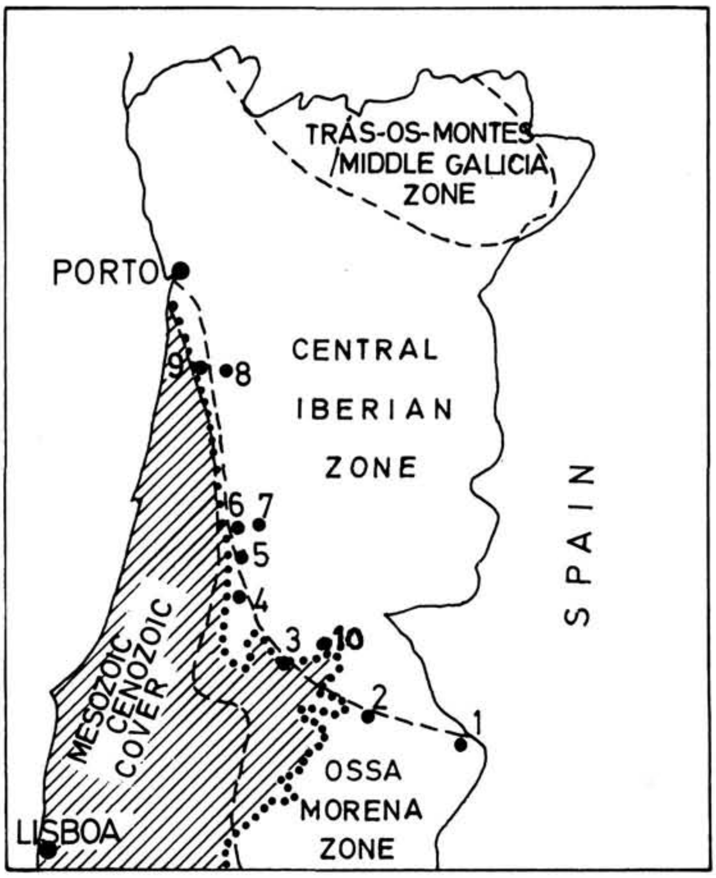

FIG. 10.— Hercynian geotectonic zones in Northern Portugal, showing location of oldest dated plutonic rocks.

1/2/3/4- Alto Alentejo (Cevadais and Alter Pedroso), Rossio ao Sul do Tejo and Casal do Zote rocks (482Ma)

5/8- Figueiró dos Vinhos and Junqueira rocks (515Ma)

6/7- Vila Nova and Coentral rocks (500Ma)

9- O. Azemeis rocks (380Ma)

10- Penhascoso-Mação-Belver (435Ma)

11/12- Portalegre and Pedrógao Grande rocks (435Ma)

5.3. *Initial* $^{87}Sr/^{86}Sr$ ratios and granitoid genesis.— Table XIII lists the initial ratios of the dated units of the Castro Daire area.

TABLE XIII.— Initial $^{87}Srf/^{86}Sr$ ratios of granitoids of the Castro Daire area.

Unit	Initial ratio	Unit	Initial ratio
Regoufe	.7222 ± .0080	Lamas	.7075 ± .0013
Canado	.7110 ± .0024	Frágoas	.7069 ± .0006
Calde	.7093 ± .0011	Lamelas	.7063 ± .0002
C. Daire	.7077 ± .0005 (1) .7078 ± .0011	Alva	.7061 ± .0012

(1) Whole rock - mineral isochron.

Fig. 11 represents that region of the diagram used by FAURE and POWELL (1972) where the initial ratios of the magmatic rocks from Central and Western Europe concentrate (VIDAL, 1977) and where the Castro Daire area and other rocks from Portugal do plot; a general trend of age decrease with increasing initial ratios is seen for the latter rocks.

The Regoufe granite forms a xenolithic, small, late to post-tectonic epizonal pluton (SLUIJK, 1963) with high initial $^{87}Sr/^{6}$ Sr ratio. It has crystallized from a magma with a significant crustal history derived either: a) from a melt of low initial ratio of upper mantle or lower crust derivation that underwent strong contamination in its ascent to a high crustal level of emplacement; b) or from partial melting of mesocrustal material.

The Canado granite has an intermediate $^{87}Sr/^{86}Sr$ initial ratio that is high as compared with the other intermediate r_i granitoids. It forms an elongate, concordant, non-xenolithic pluton that most probably has derived from mesocrustal material by partial melting.

The Castro Daire pluton units have low intermediate initial ratios (.707 ± .002) that suggest an original melt (or melts) most probably derived by dry fusion of low crust contaminated with mantle material; this mechanism may be also envisaged for the Frágoas granite melt, which has an age and a initial ratio close to the Lamelas granodiorite, but contrary to it, is xenolithic (crustal contamination).

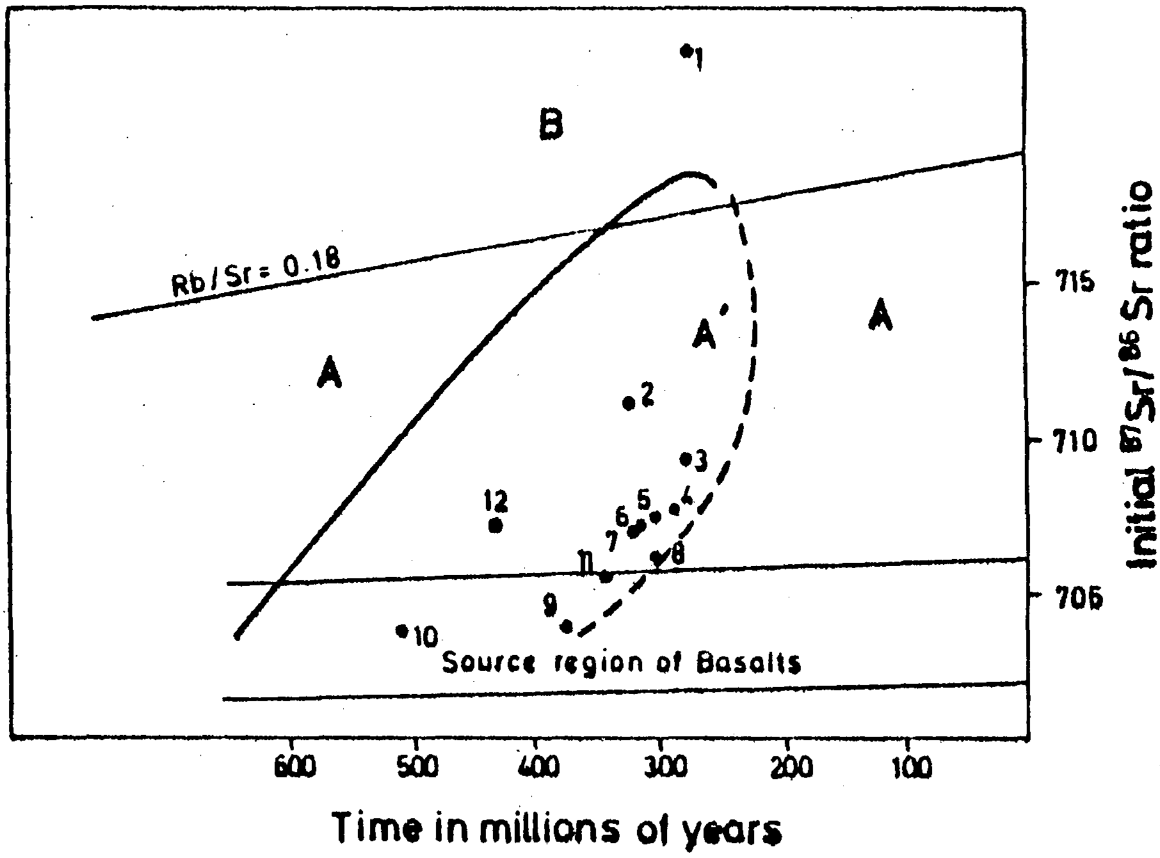

FIG. 11.— Plot of granitoids of Portugal in the time-r_i diagram (After FAURE and POWELL, 1972). (Data for units 11 and 12 from ABRANCHES et al., 1979).

1- Regoufe
2- Canado
3- Calde
4- Lamas from central and Western
5- C. Daire
6- Frágoas
7- Lamelas
8- Alva
9- O. Azemeis
10- W of Junqueira
11- Porto
12- Portalegre

B- Field of granites with high initial ratios
A'- Region of Field A where rocks

Europe plot (VIDAL, 1977)
A- Field of granites with intermediate initial ratios.

The Castro Daire, Alva, Lamas and Calde granites are also xenolithic and contamination of a single melt with radiogenic strontium from crustal origin during ascent may explain the observed variations in initial ratios. Differentiation by fractional crystallization and gregarious emplacement of the differentiated (units) at different times and at different crustal levels (originating different degrees of contamination with radiogenic strontium) has been envisaged as the mode of formation of the pluton (PINTO, 1982).

Initial ratios of these units suggest that they are S-type granitoids.

Fig. 11 shows granitoids in the «basalt field», their initial ratios suggesting an origin either by partial meltings of upper mantle material or by differentiation of basalt magma.

It is noteworthy that the O. Azemeis and the Junqueira units have the same initial ratios (= .704) indicating a common source; their age difference is of some 130 million years and the tectonic context of their emplacement is probably different (orogenic for O. Azemeis, onorogenic (?) for Junqueira). Their low initial ratios suggest an I-type granitoid derivation, but both rocks have S-type geochemical characteristics (PINTO, in press).

Portuguese granitoids as a whole thus have initial $^{87}Sr/^{86}Sr$ ratios from high to low and a variety of magmatic mechanisms seem to have been in their origin, which is in accordance with geochemical and other evidence (see for instance CAPDEVILA et al., 1973; ALBUQUERQUE, 1978; NEIVA, 1981).

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