

## PETROLOGY AND GEOCHEMISTRY OF GRANITIC INTRUSIONS IN THE VIANA DO CASTELO AREA, NORTHERN PORTUGAL<sup>1</sup>

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### ABSTRACT

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Granitic intrusions in the Viana do Castelo map-area in northern Portugal are part of the Hercynian plutonic belt of the Iberian peninsula. They consist predominantly of muscovite-biotite granite of varied textures with minor granodiorite and quartz monzonite. Chemically they exhibit typical calc-alkalic differentiation trends and appear to represent a co-magmatic suite. They are peraluminous and show typical characteristics of S-type granites. An age of  $316 \pm 4$  Ma was obtained from a Rb-Sr whole-rock isochron.

### INTRODUCTION

Hercynian plutonic rocks of varied petrologic types underlie nearly half of northern Portugal (TEIXEIRA, 1972). Two groups have generally been distinguished: (1) syntectonic or late syntectonic 'Older Granites' consisting mainly of medium- or coarse-grained two-mica granites and granodiorites, in places with porphyritic, gneissose or schistose character; and (2) post-tectonic 'Younger Granites' which are predominantly biotite-rich and either porphyritic with abundant microcline, or fine- to medium-grained equigranular (WESTERVELD, 1956; SCHERMERHORN, 1956; OEN, 1960, 1970; PRIEM ET AL., 1967). OEN (1970) described the 'Older Granites' as being essentially concordant, mesozonal alkaline granites, whereas the 'Younger Granites' are alkaline to calc-alkaline, discordant, and epizonal. The distribution of these granitoid rocks in northern Portugal is shown in figure 1.

This paper describes the petrography, geochemistry, and age of granitoid rocks from the Viana do Castelo area of northern Portugal (Fig. 1). Sampling was done during August, 1977 using Folha 5A (Scale 1:50,000) of Carta Geologica de Portugal (1970) and the accompanying report by TEIXEIRA ET AL. (1972) as a guide to the distribution and field relations of the plutons. Samples from localities shown on figure 2 were examined in thin section. On the basis of petrographic studies,

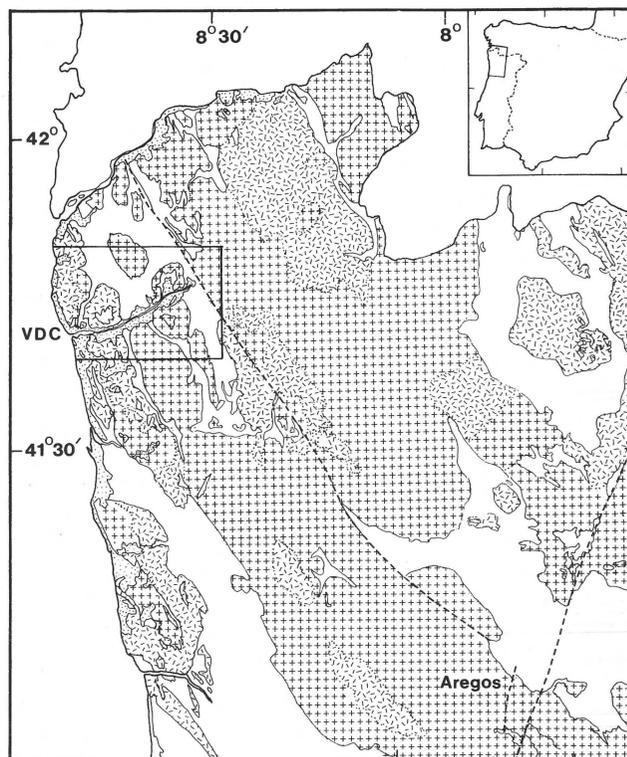


Fig. 1  
Distribution of Hercynian plutonic rocks in northern Portugal. The Viana do Castelo map-area is outlined. Modified from Teixeira, 1972. Legend: Metamorphic rocks, white; older granites, line pattern; younger granites, crosses; Pleistocene and Recent, stippled.

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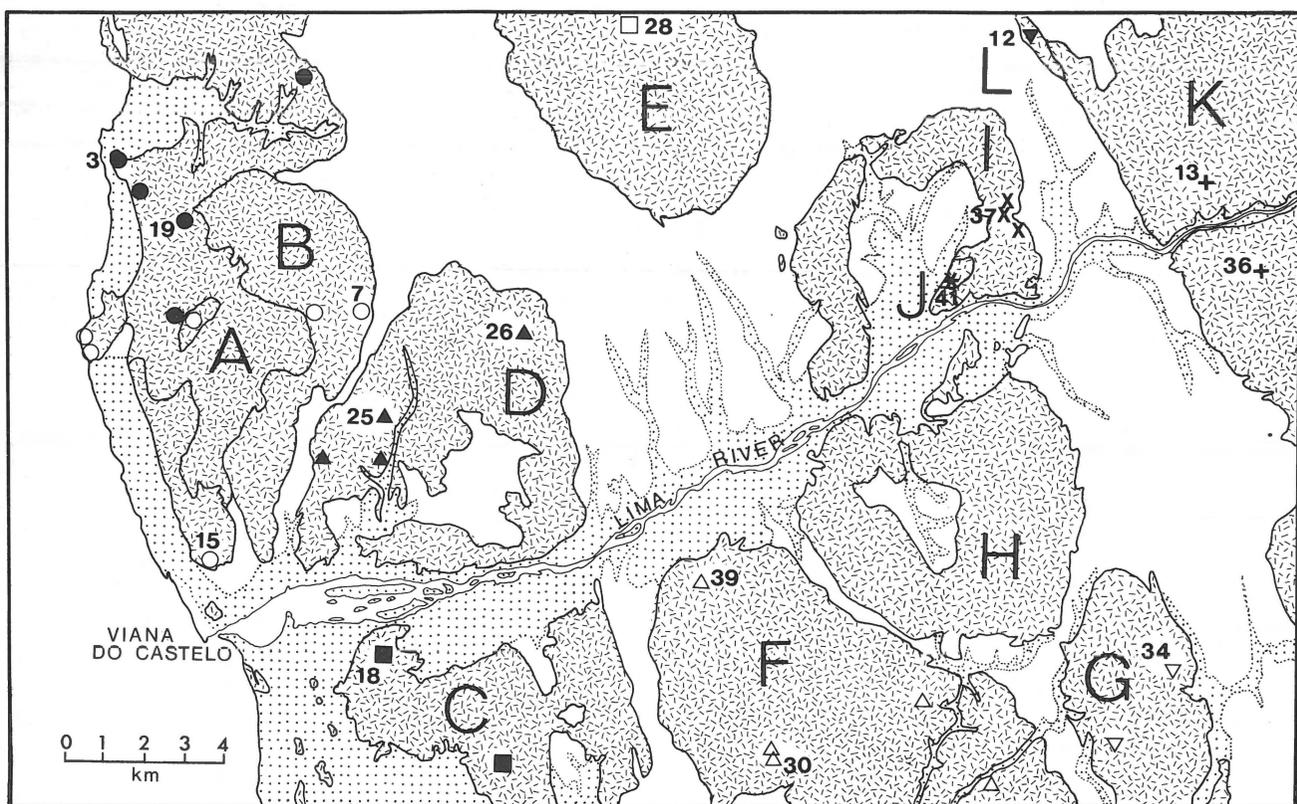


Fig. 2 Distribution of granitoid plutons in the Viana do Castelo map-area, showing locations of samples collected during this study. Numbered symbols indicate analyzed samples. Modified from Teixeira et al., 1972. Legend: Metamorphic rocks, white; plutonic rocks, line pattern; Pleistocene to Recent, stippled.

fifteen representative samples were selected for whole-rock analyses of major elements and selected trace elements. Five samples with suitable Rb/Sr ratios were used to obtain a Rb-Sr whole-rock isochron. Analyses of alkali feldspars, plagioclases, and biotites in seven samples were obtained by electron microprobe.

#### PETROGRAPHY AND MINERALOGY

Twelve granitoid bodies were sampled (Fig. 2) but not mapped in detail. However, on the basis of our reconnaissance mapping and descriptions by TEIXEIRA ET AL. (1972) each body appears to be relatively homogeneous and so the samples are considered to be representative. As some bodies are very similar petrographically and chemically, it is likely that they are part of one pluton and/or igneous phase. However, for the purposes of this study, each of the twelve bodies is considered as a separate pluton. Their petrographies based on samples collected during this study are summarized in table 1. Mineral analyses discussed below and presented in tables II, III and IV were obtained by electron microprobe using an Ortec energy dispersive analyzer at Dalhousie University, Halifax, Nova Scotia.

Most of the bodies are composed of muscovite-biotite granite, characterized by the presence of abundant quartz and microcline with well-developed 'cross-hatch' twinning. In plutons A, C, D, E, G and I textures are equigranular to inequigranular whereas plutons B, F and H are porphyritic, with perthitic microcline forming phenocrysts up to 3 cm or more in length. Analyses of 8 microcline crystals from 4 samples indicate that the microcline is nearly pure potassium feldspar (Table II). Zoned sodic plagioclase is present in varying amounts. Compositions of 13 crystals from 7 samples determined by microprobe range from albite to sodic andesine (Table III). Muscovite and biotite are present in approximately equal amounts. Opaques, apatite, and zircon, the latter commonly occurring as inclusions in biotite with well-developed pleochroic haloes, are ubiquitous accessories. Several of the plutons show foliation as a result of flow alignment of phenocrysts and/or mica.

The large pluton, K, in the eastern part of the study area (Fig. 2) contains less quartz than the other bodies, and perthitic orthoclase phenocrysts instead of microcline. Analyses of the orthoclase indicate between 11 and 24% Ab component (VDC-13, 36; Table II). The rock contains very little muscovite and large amounts of plagioclase (oligoclase-andesine; Table III) and is classified as a quartz monzonite.

Table I

Compilation of petrographic descriptions of plutons in the Viana do Castelo area. Locations of samples on which these descriptions are based are shown in figure 2.

Map Symbol	Dominant Lithology	Texture	Modal Mineralogy	
			%	Major Minerals
A	Muscovite-biotite granite	Fine- to medium-grained, allotriomorphic inequigranular; foliated (alignment of micas).	35-40 30-35 7-10 10-15 5-10	Quartz Microcline Oligoclase Biotite Muscovite
B	Porphyritic muscovite-biotite granite	Medium-grained, hypidiomorphic inequigranular with perthitic microcline phenocrysts; foliated (alignment of phenocrysts and micas).	30-35 30-45 5-15 5-10 5-15	Quartz Microcline Oligoclase Biotite Muscovite
C	Muscovite-biotite granite	Fine- to medium-grained, allotriomorphic granular; foliated (alignment of micas).	45 35 5 8 7	Quartz Microcline Oligoclase Biotite Muscovite
D	Muscovite-biotite granite	Medium- to coarse-grained, hypidiomorphic inequigranular	20-35 40-60 5-10 5-10 5-10	Quartz Microcline Oligoclase Biotite Muscovite
E	Muscovite-biotite granite	Medium- to coarse-grained, hypidiomorphic inequigranular	30 50 5 8 7	Quartz Microcline Oligoclase Biotite Muscovite
F	Porphyritic muscovite-biotite granite	Fine- to medium-grained, hypidiomorphic inequigranular with perthitic	25-35 25-55 5-30 5-15 5-10	Quartz Microcline Oligoclase Biotite Muscovite
G	Muscovite-biotite granite	Medium- to coarse-grained, hypidiomorphic inequigranular	30 25 30-35 5-10 5-10	Quartz Microcline Oligoclase Biotite Muscovite
H	Muscovite-biotite granite	Medium- to coarse-grained allotriomorphic granular, in places porphyritic with microcline phenocrysts.	30-40 30-40 15-20 5-10 5	Quartz Microcline Oligoclase Biotite Muscovite
I	Biotite-muscovite granite	Medium- to coarse-grained, hypidiomorphic inequigranular with weak foliation (alignment of micas).	25-35 35 10-20 5 10-15	Quartz Microcline Oligoclase Biotite Muscovite
J	Muscovite-biotite granocliorite	Fine-grained, hypidiomorphic granular	35 10 30 20 5	Quartz Orthoclase Oligoclase- andesine Biotite Muscovite
K	Muscovite-biotite quartz monzonite	Fine- to medium-grained, hypidiomorphic inequigranular with perthitic orthoclase phenocrysts; gneissose foliation.	15 35-50 28-36 5-10 < 2	Quartz Orthoclase Oligoclase- andesine Biotite Muscovite
L	Muscovite-biotite granite	Fine- to medium-grained, allotriomorphic inequigranular; foliated (alignment of micas).	30 27 28 10 5	Quartz Orthoclase Oligoclase Biotite Muscovite

Table II  
Analyses of microcline and orthoclase in samples from the Viana do Castelo map-area.

Pluton Sample	Microcline Analyses								Orthoclase Analyses					
	B		D		F		K		L					
	VDC-7	VDC-25	VDC-30	VDC-39	VDC-13	VDC-36	VDC-12							
SiO <sub>2</sub>	63.4	63.7	63.0	63.7	63.0	63.3	63.5	63.6	64.2	63.4	63.4	63.7	63.9	64.0
Al <sub>2</sub> O <sub>3</sub>	18.6	18.8	18.6	18.3	18.4	18.3	18.1	18.6	18.7	18.5	18.5	18.7	18.7	18.6
CaO	n.d.	n.d.	n.d.	n.d.	0.1	n.d.	0.1	0.1	0.1	n.d.	n.d.	0.0	0.2	0.1
Na <sub>2</sub> O	n.d.	0.2	0.2	0.5	0.5	0.1	n.d.	0.1	2.5	1.1	1.1	1.2	1.3	1.5
K <sub>2</sub> O	15.6	15.1	15.3	14.6	14.8	15.5	15.7	15.5	12.0	13.8	13.9	13.5	13.6	13.5
Total	97.6	97.8	97.1	97.1	96.8	97.2	97.4	97.9	97.5	96.8	96.9	97.1	97.7	97.7
Si	12.0	12.0	11.9	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Al	4.1	4.2	4.2	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Ca	0.0	0.0	0.0	0.0	<0.1	0.0	<0.1	<0.1	<0.1	0.0	0.0	0.0	<0.1	<0.1
Na	0.0	0.1	0.6	0.2	0.2	<0.1	0.0	<0.1	0.9	0.4	0.4	0.4	0.5	0.9
K	3.8	3.6	3.7	3.5	3.6	3.7	3.8	3.7	2.8	3.3	3.3	3.2	3.3	3.2
O	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
Or	100.0	98.3	98.4	95.3	94.8	99.5	99.3	98.8	75.3	89.0	89.1	88.3	86.7	85.0
Ab	0.0	1.7	1.6	4.7	4.8	0.5	0.0	0.5	24.3	11.0	10.9	11.7	12.5	14.4
An	0.0	0.0	0.0	0.0	0.5	0.0	0.7	0.7	0.5	0.0	0.0	0.0	0.8	0.6

Table III  
Analyses of plagioclase in samples from the Viana do Castelo map-area.

Pluton Sample	B		D		F		K		L				
	VDC-7	VDC-25	VDC-30	VDC-39	VDC-13	VDC-36	VDC-12						
SiO <sub>2</sub>	66.1	67.0	67.8	64.9	59.8	59.4	60.0	64.4	60.9	60.6	60.5	66.6	66.6
Al <sub>2</sub> O <sub>3</sub>	21.5	21.3	20.1	22.2	25.3	25.2	25.4	22.3	24.3	24.6	25.1	21.1	21.2
CaO	2.1	1.6	0.8	2.8	6.6	6.7	6.9	3.3	5.6	6.1	6.6	1.7	1.7
Na <sub>2</sub> O	10.5	10.7	11.2	10.2	7.6	7.3	7.2	9.5	7.9	8.1	7.5	10.7	10.6
K <sub>2</sub> O	0.3	0.4	0.2	0.2	0.3	0.2	0.2	0.4	0.3	0.3	0.2	0.3	0.3
Total	100.5	101.0	100.1	100.3	99.6	98.8	99.7	99.9	99.0	99.7	99.9	100.4	100.4
Si	11.6	11.7	11.9	11.4	10.7	10.7	10.7	11.4	10.9	10.8	10.8	11.7	11.6
Al	4.4	4.4	4.1	4.6	5.3	5.3	5.3	4.6	5.1	5.2	5.3	4.3	4.4
Ca	0.4	0.3	0.1	0.5	1.3	1.3	1.3	0.6	1.1	1.2	1.3	0.3	0.3
Na	3.6	3.6	3.8	3.5	2.6	2.5	2.5	3.2	2.8	2.8	2.6	3.6	3.6
K	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1
O	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
Or	1.5	2.1	1.0	1.0	1.4	1.3	1.0	2.2	1.9	1.6	1.2	1.4	1.5
Ab	88.6	90.6	95.5	86.1	66.7	65.5	64.7	81.9	70.4	69.4	66.4	90.6	90.5
An	9.9	7.3	3.5	12.9	32.0	33.2	34.3	15.9	27.7	28.9	32.2	8.0	8.1

Table IV  
Analyses of biotite in samples from the Viana do Castelo map-area.

Pluton	B		D		F		K		L				
	VDC-7		VDC-25		VDC-30		VDC-39		VDC-13		VDC-36		VDC-12
SiO <sub>2</sub>	37.2	37.0	36.5	36.4	36.4	36.6	35.9	36.1	35.5	35.9	36.6	35.9	36.6
TiO <sub>2</sub>	3.1	2.7	2.3	2.3	3.2	2.8	2.9	3.6	3.2	3.8	1.3	3.0	2.4
Al <sub>2</sub> O <sub>3</sub>	18.4	19.4	20.2	19.9	18.7	18.6	19.1	18.9	19.9	19.6	20.7	19.3	20.5
FeO <sup>T</sup>	22.1	22.6	22.8	23.7	23.4	23.2	24.7	25.5	22.8	22.8	22.1	23.5	24.5
MgO	6.3	6.2	6.1	5.8	7.1	7.3	6.0	5.7	6.8	6.3	8.0	6.7	5.0
K <sub>2</sub> O	9.5	9.1	8.7	8.8	9.6	9.6	9.4	9.5	8.8	9.5	9.6	9.1	9.3
Total	96.6	97.0	96.6	96.9	98.1	98.1	98.0	99.3	97.0	97.9	102.3	101.3	98.3
Si	5.6	5.6	5.6	5.5	5.4	5.5	5.4	5.4	5.4	5.4	5.4	5.4	5.5
Al	3.3	3.4	3.5	3.6	3.3	3.3	3.4	3.3	3.5	3.7	3.6	3.4	3.6
Ti	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.2	0.3	0.3
Fe	3.4	2.8	2.9	3.0	2.9	2.9	3.1	3.2	2.9	2.9	2.7	3.0	3.1
Mg	1.2	1.4	1.4	1.3	1.6	1.6	1.4	1.3	1.5	1.4	1.8	1.5	1.1
K	1.8	1.8	1.6	1.7	1.8	1.8	1.8	1.8	1.7	1.8	1.8	1.8	1.8
H	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
O	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Fe/Mg	2.8	2.1	2.3	2.3	1.8	1.8	2.3	2.5	1.9	2.1	1.5	2.0	2.7

Table V  
Chemical analyses and CIPW normative mineralogies.

PLUTON	A		B		C		D		E		F		G		I		J		K		L								
	SAMPLE VDC		3		7		15		18		25		26		28		30		39		34		37		41		36		12
SiO <sub>2</sub>	72.8	72.6	70.9	68.8	71.2	70.3	71.5	71.0	67.3	71.0	78.8	70.2	65.6	70.6	72.6														
TiO <sub>2</sub>	0.17	0.17	0.47	0.59	0.21	0.27	0.23	0.29	0.69	0.66	0.49	0.42	1.01	0.37	0.22														
Al <sub>2</sub> O <sub>3</sub>	14.5	15.3	15.8	15.5	14.8	16.2	15.8	15.5	15.6	14.4	15.6	15.6	15.5	15.0	14.6														
Fe <sub>2</sub> O <sub>3</sub>	0.07	0.18	0.61	0.87	0.22	0.66	0.38	0.21	0.83	0.71	0.69	0.46	1.00	0.38	0.58														
FeO	0.92	0.72	1.6	1.89	0.72	0.77	0.89	1.17	2.61	2.86	1.83	1.15	3.94	2.08	0.76														
MnO	0.03	0.02	0.03	0.03	0.01	0.02	0.03	0.03	0.05	0.06	0.05	0.02	0.09	0.05	0.02														
MgO	0.23	0.22	0.83	1.15	0.25	0.38	0.38	0.46	1.17	1.00	0.98	0.52	1.87	0.76	0.25														
CaO	1.05	0.61	0.59	0.25	0.18	0.43	0.28	0.49	1.57	1.35	0.88	0.28	2.31	1.35	0.52														
Na <sub>2</sub> O	3.5	3.3	1.8	0.6	2.7	3.0	2.9	2.8	3.0	2.9	3.3	2.4	2.6	3.1	3.3														
K <sub>2</sub> O	4.7	5.1	5.4	5.9	5.6	5.8	5.5	5.1	4.6	4.2	4.3	5.6	4.9	4.6	5.3														
P <sub>2</sub> O <sub>5</sub>	0.20	0.26	0.23	0.21	0.30	0.28	0.27	0.34	0.32	0.35	0.20	0.38	0.31	0.24	0.34														
LOI	1.4	1.8	2.4	3.7	2.2	2.4	2.3	1.7	1.4	1.3	1.9	2.5	1.4	1.3	1.8														
Total	99.6	100.3	100.7	99.5	98.4	100.5	100.5	99.1	99.1	100.8	99.0	99.5	100.5	99.8	100.3														
Q	32.3	33.0	38.0	41.6	34.3	30.4	32.8	34.4	27.0	32.9	30.1	34.6	22.8	30.2	32.7														
Or	28.3	30.4	32.4	36.5	34.6	34.8	33.3	30.8	27.6	25.1	26.2	34.3	29.1	27.9	32.0														
Ab	30.2	28.5	15.3	5.7	24.0	25.8	25.4	24.7	26.4	24.7	28.9	21.0	22.3	27.0	28.2														
An	4.0	1.3	1.4	--	--	0.3	--	0.2	5.8	4.4	3.1	--	9.5	5.0	0.4														
Hy	2.0	1.5	3.8	4.9	1.5	1.4	2.0	2.8	6.1	6.2	4.6	2.4	9.6	4.9	1.2														
Mt	0.1	0.3	0.9	1.3	0.3	1.0	0.6	0.3	1.2	1.0	1.0	0.7	1.5	0.6	0.9														
Il	0.3	0.3	0.9	1.2	0.4	0.5	0.5	0.6	1.3	1.3	1.0	0.8	1.9	0.7	0.4														
Ap	0.5	0.6	0.5	0.5	0.7	0.7	0.6	0.8	0.8	0.8	0.5	0.9	0.7	0.6	0.8														
C	2.3	3.9	6.6	8.3	4.4	5.0	5.0	5.3	3.7	3.4	4.5	5.7	2.5	2.9	3.4														
Rb	273	275	530	316	290	280	304	322	275	300	214	500	243	229	370														
Sr	176	108	80	116	90	94	72	81	160	124	448	66	200	252	58														
Ba	325	282	371	641	353	375	312	432	684	535	778	338	776	801	258														
La	18	14	44	92	23	21	13	19	70	61	62	53	79	62	15														
Ce	36	25	104	192	44	45	34	36	136	124	112	120	164	112	31														
Zr	94	92	202	347	132	130	97	124	332	267	190	233	367	172	107														
Nb	6	10	18	17	11	13	12	13	19	22	13	16	21	13	11														

A small body (L) of deformed gneissic granite was sampled in the northeastern corner of the map-area (Fig. 2). It occurs along a major fault zone (TEIXEIRA, 1972) and could be a deformed portion of pluton K.

A small body (J) of granodiorite occurs within granite body I (Fig. 2). It contains abundant quartz, plagioclase (andesine) and biotite, and lesser amounts of orthoclase and muscovite. Its relationship to the surrounding granite is not known.

The sampled plutons include both 'Older' and 'Younger' Granites as extrapolated from better studied areas to the south by TEIXEIRA (1972). However, no systematic petrographic differences were observed in the present study between plutons designated as 'Older' (A, C, D, L) and 'Younger' (B, E, F, G, H, I, J, K). Both groups are predominantly two-mica granites characterized by the presence of microcline and thus show petrographic characteristics of both granite series. Biotite compositions are very similar in all plutons analyzed (Table IV) and are characterized by high Fe/Mg and low contents of water.

### GEOCHEMISTRY

Fifteen samples were selected for major- and trace-element analyses. Major-element analyses were done by Atomic Absorption Spectrophotometry (Si, Al, Ti, Fe, Mg, Mn, Ca) and Flame Photometry (Na, K) at Acadia University employing a modification of the method of BUCKLEY & CRANSTON (1971). Ferrous iron was determined by volumetric analysis using a standardized potassium permanganate solution as the oxidizing agent (MAXWELL, 1968). Phosphorous was determined by a spectrophotometric technique at Dalhousie University. Loss on ignition was obtained by heating the sample powders in a muffle furnace for 1 hour at 1000 °C. All major-element analyses were done in duplicate. Standard granite, granodiorite and andesite powders from the USGS and the Japanese Geological Survey were used for standardization of the working curves.

Trace elements Rb, Nb, Sr, Zr, Ba, La, and Ce were determined using an INAX Instruments Energy Dispersive X-Ray Fluorescence Analyzer at the Department of Geology, St. Mary's University, Halifax, N.S. Accuracy for these analyses is  $\pm 10\%$ .

Major- and trace-element data, together with CIPW normative mineralogies, are compiled in table V. Twelve of the analyzed samples are classified as granite on the basis of petrography, and this is confirmed by their geochemistry and normative mineralogies. The quartz monzonite (VDC-36) is chemically similar with somewhat lower silica and higher lime and total iron. The granodiorite (VDC-41) is the least felsic sample analyzed.

Silica variation diagrams (Fig. 3) show typical trends for calc-alkalic rocks (NOCKOLDS & ALLEN, 1953) with  $\text{TiO}_2$ ,  $\text{FeO}^T$ ,  $\text{MgO}$ ,  $\text{MnO}$ , and  $\text{CaO}$  decreasing with increasing  $\text{SiO}_2$ .  $\text{K}_2\text{O}$ ,  $\text{P}_2\text{O}_5$  and  $\text{Na}_2\text{O}$  show considerable scatter and no definite

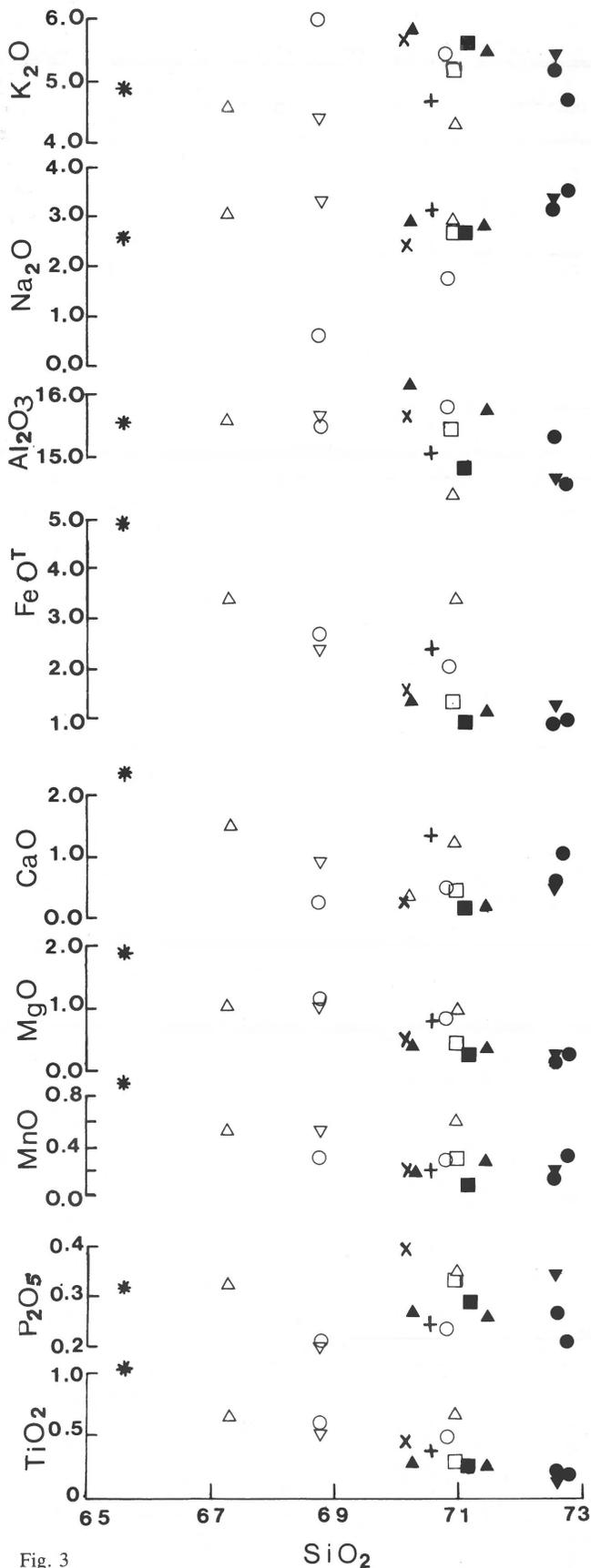


Fig. 3 Silica variation diagrams for major oxides. Symbols as in figure 2.

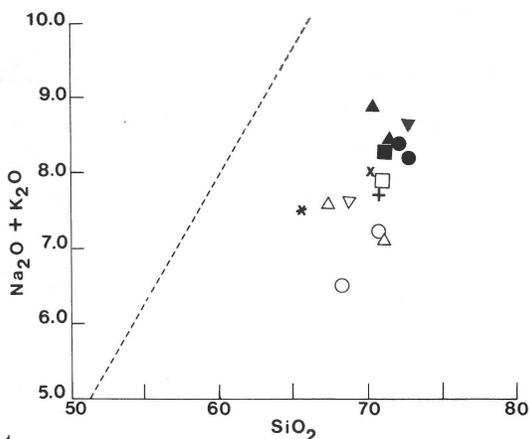


Fig. 4  
Alkalies-silica diagram for granitoid rocks of the Viana do Castelo map-area. Alkalic/subalkalic field boundary after Irvine & Baragar (1971). Symbols as in figure 2.

trends with increasing  $\text{SiO}_2$ , which may reflect the narrow  $\text{SiO}_2$  range of the analyzed samples, or the mobility of these elements during weathering.

The calc-alkalic character of the rocks is confirmed by an alkalies-silica diagram on which the samples plot in the subalkalic field (Fig. 4).

The AFM diagram (Fig. 5) is typical of a single magma series which underwent fractionation of plagioclase and mafic minerals and is similar to AFM diagrams for other calc-alkalic plutonic rocks. Differentiation is also indicated by the  $\text{Na}_2\text{O}$ - $\text{K}_2\text{O}$ - $\text{CaO}$  diagram (Fig. 6) which shows a trend typical of a single magma which underwent plagioclase fractionation removing  $\text{CaO}$ , followed by depletion of  $\text{Na}_2\text{O}$  in later stages of crystallization.

All analyzed samples are peraluminous, with normative corundum ranging from 2.3 to 8.3%.

Trace elements generally show typical calc-alkalic trends with Nb, Zr, Ce, La, Ba and Sr generally decreasing and Rb increasing with increasing  $\text{SiO}_2$  (Fig. 7). However, there is considerable scatter.

## AGE RELATIONS

As most of the plutons occur as separate bodies (Fig. 2), age relations between plutons are not clear. In order to obtain evidence concerning the absolute age of the plutons, five samples with suitable Rb/Sr ratios were selected from plutons F (2 samples), G, I and K for dating by the Rb-Sr isochron method. The analytical work was done by R. F. Cormier at the Department of Geology, St. Francis Xavier University, Antigonish, Nova Scotia, using routine isotope dilution methods and mass spectrometry. The analytical data are presented in table VI. The resulting isochron, constructed using the method of YORK (1966), indicates an age of  $316 \pm 4$  Ma for these plutons (Fig. 8).

According to TEIXEIRA (1972) these four plutons belong to

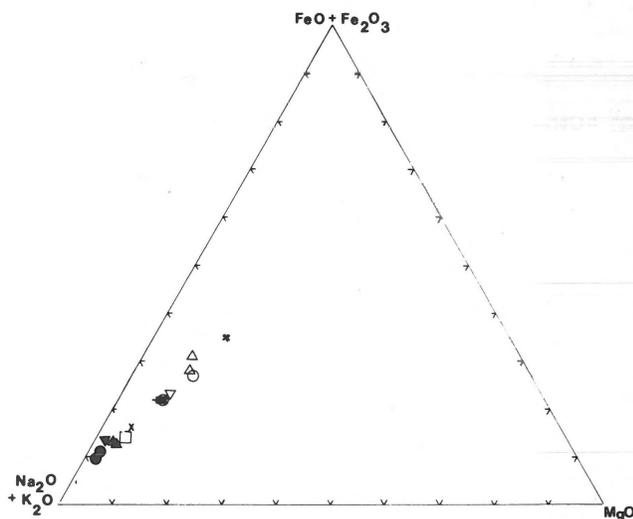


Fig. 5  
AFM diagram for granitoid rocks of the Viana do Castelo map-area. Symbols as in figure 2.

the Younger Hercynian Granites. Unfortunately the use of samples from separate plutons of uncertain relationship leaves the validity of the isochron age open to some question. However, all data points fall very close to the isochron, and exclusion of sample VDC-37 (which could act as pivot for the line) does not significantly change the slope of the line.

Previous Rb-Sr age determinations (PRIEM ET AL., 1967) indicated ages of 317 to 286 Ma for granites from central northern Portugal, with the 'Older Granites' yielding somewhat older ages (317 to 301 Ma) than the 'Younger Granites' (296 to 286 Ma), although in fact the error limits of the two groups show considerable overlap. PRIEM ET AL. (1970) cited ages of  $298 \pm 10$  Ma for the 'Older Granites' and  $280 \pm 11$  Ma for the 'Younger Granites'. Recalculation of these ages using currently recom-

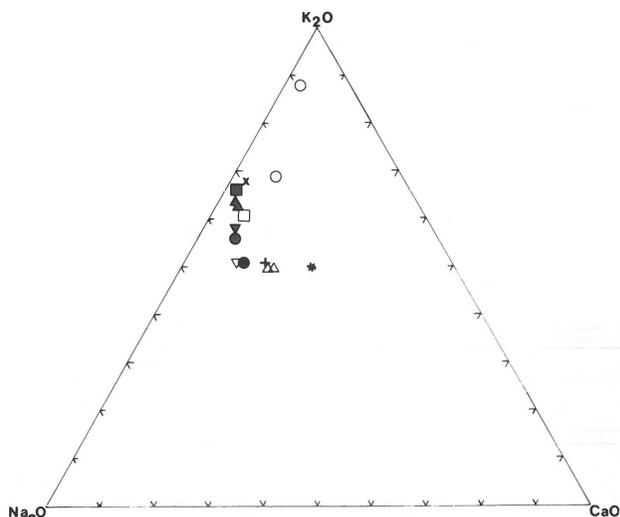


Fig. 6  
 $\text{Na}_2\text{O}$ - $\text{K}_2\text{O}$ - $\text{CaO}$  diagram for granitoid rocks of the Viana do Castelo map-area. Symbols as in figure 2.

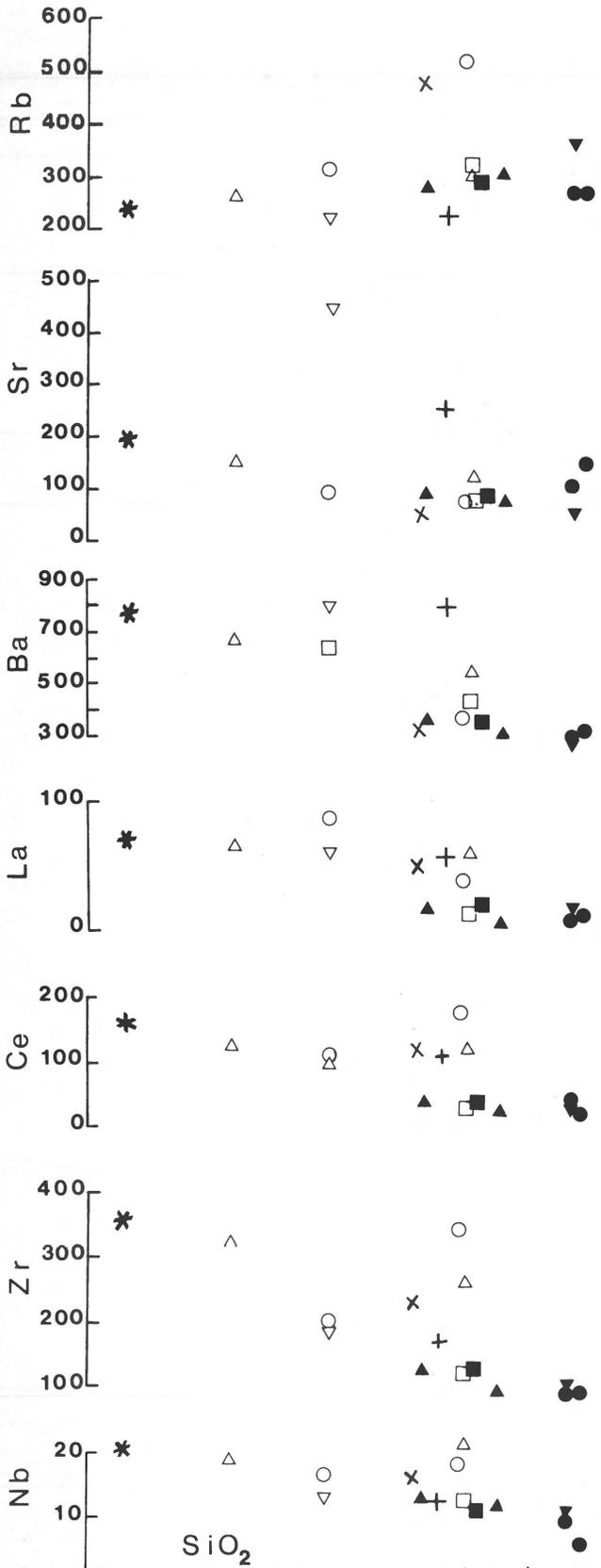


Fig. 7 Silica variation diagrams for trace elements. Symbols as in figure 2.

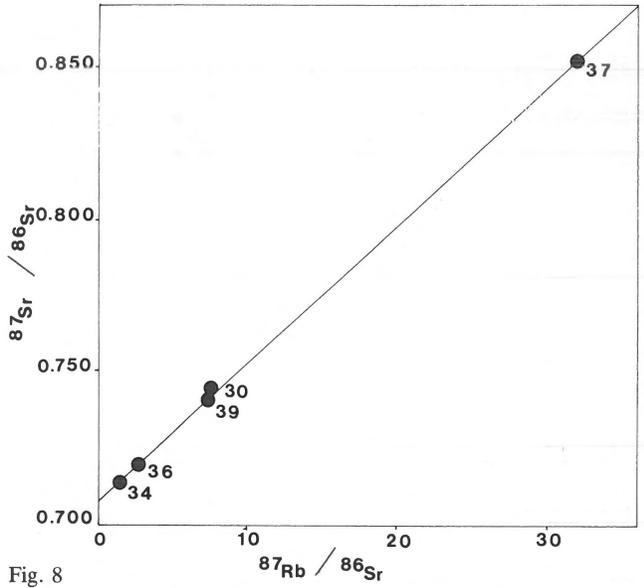


Fig. 8 Rb-Sr isochron for 5 whole-rock samples from granitoid plutons in the Viana do Castelo map-area. <sup>87</sup>Rb decay constant: 1.42 x 10<sup>-11</sup>a<sup>-1</sup>. Errors at 95% level of confidence.

mended constants for the Rb-Sr method (STEIGER & JAGER, 1977) would increase these ages by about 10 Ma.

Thus the age obtained in this study is older than the range of ages previously established for the 'Younger Granite' and is as old as the oldest of the 'Older-Granite' ages. However, it is similar to K-Ar ages of 298 ± 6, 305 ± 7, and 308 ± 7 Ma reported by DE ALBUQUERQUE (1972) for biotites from the 'Younger Granites' of the Aregos region of central northern Portugal (Fig. 1).

PETROGENESIS

The geochemical trends suggest (but cannot prove) that the analyzed plutons form a co-magmatic suite formed by differentiation of a calc-alkalic parent magma.

The granites show strong characteristics of S-type granites, as defined by CHAPPELL & WHITE (1974), indicating derivation from anatexis of meta-sedimentary rocks in the lower crust. These include: (1) peraluminous mineralogy in which biotite and muscovite dominate and hornblende is absent; (2) pelitic meta-sedimentary xenoliths; (3) high normative corundum; (4) a limited range of felsic compositions; (5) initial <sup>87</sup>Sr/<sup>86</sup>Sr = 0.7072 ± 0.0007 (Fig. 8).

Table VI Rb-Sr analytical data for 5 samples from the Viana do Castelo map-area (after R. F. Cormier, 1979, written communication).

PLUTON	SAMPLE	Rb (ppm)	Sr (ppm)	<sup>87</sup> Rb/ <sup>86</sup> Sr	<sup>87</sup> Sr/ <sup>86</sup> Sr
F	VDC-30	353	133	7.68	0.7427
F	VDC-39	306	118	7.50	0.7405
G	VDC-34	223	420	1.54	0.7135
I	VDC-37	524	48.1	32.0	0.8524
K	VDC-36	245	261	2.72	0.7191

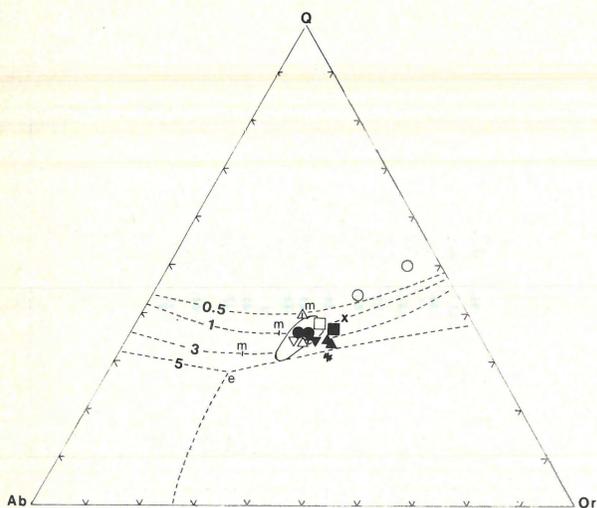


Fig. 9 Ternary diagram for Q-Ab-Or for analyzed granitoid samples from the Viana do Castelo map-area. Isobaric minima from Tuttle & Bowen (1958).

The presence of primary muscovite and the plot of Q-Ab-Or (Fig. 9) infer a  $P_{H_2O}$  of about 2 Kb, implying epizonal emplacement, in agreement with generally discordant nature of the plutons and their well-developed contact aureoles (TEIXEIRA ET AL., 1972).

### CONCLUSIONS

Granitoid plutonic rocks in the Viana do Castelo map-area appear to belong to a co-magmatic calc-alkalic suite on the basis of major- and trace-element geochemistry. They consist predominantly of muscovite-biotite granite, characterized by the presence of microcline. They exhibit the characteristics of S-type granites, derived from anatexis of the continental crust. There is no petrographic or geochemical evidence for grouping the plutons into 'Older Granites' and 'Younger Granites' as extrapolated from elsewhere in northern Portugal. Furthermore a Rb-Sr isochron for samples from 4 plutons indicates an age of  $316 \pm 4$  Ma which is significantly older than ages previously suggested for the 'Younger Granites' and as old as those found for the 'Older Granites' in other areas. These data suggest that the plutons of the Viana do Castelo area belong to the 'Older Granites'. Alternatively the 'Younger Granites' may show wider ranges in age than previously cited and the two series may overlap in petrographic and chemical characteristics.

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