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In memoriam
Professor Josep Maria Fontboté i Mussoles († 13. 9. 1989)

Alpine tourmaline-bearing muscovite leucogranites, intrusion age and petrogenesis, Betic Cordilleras, SE Spain

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With 2 figures and 1 table in the text

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Abstract: Rb–Sr muscovite-WR dating of three samples of a leucogranitic dyke suite from the Alpine Belt in southern Spain yields tie lines indicating ages of 18.8 ± 0.4, 18.8 ± 0.4 and 20.4 ± 0.7 Ma, respectively. Considering the difference between isotopic closure temperatures and magmatic crystallization temperatures, the best estimate for the intrusion age of the leucogranites is thought to be 20 ± 1 Ma (Late Aquitanian). A published older age of 50 ± 3 Ma is discarded.

The intrusive leucogranitic magma is thought to have been formed by contact anatexis in the crust under the influence of material intruded from the mantle. The HT–LP metamorphism which characterizes the schists harbouring the leucogranitic dykes is thought to be roughly contemporaneous with the melting which would have taken place at a somewhat deeper level. A similar petrogenetic scenario is seen unfolded in the "erupted migmatite" from the Cerro del Hoyazo (ca. 25 km to the SW) and in connection with the intrusion of the HT Ronda peridotite body in the S^a Bermeja (ca. 250 km W).

Introduction

In the south-eastern part of the S^a Cabrera, N of Carboneras (Almería), thin, fragmented leucogranitic dykes occur within schists of the Alpujárride nappe complex. An intrusive age of 50 ± 3 Ma was claimed (Westra, 1969). However, Bellon et al. (1983) on the basis of K–Ar WR determinations suggested the much younger age of 21.7 ± 0.7 Ma.

Very similar leucogranitic intrusives occur in the S^a Bermeja, S of Ronda, where they are thought to represent contact anatectic melts formed under the influence of the HT Ronda peridotite intrusion (Loomis, 1972 a, 1975). Analytical radiometric ages connected to these processes range from 18 to 81 Ma (Loomis, 1975; Priem et al., 1979). Contact anatexis of crustal material under the influence of intruding material from the mantle has also been suggested to explain much more voluminous, Neogene volcanic rocks in the south-eastern

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part of the Betic domain (ZECK, 1968, 1970, 1972; LOOMIS, 1975; MUNKSGAARD, 1984). And, mantle diapirism has been invoked in orogenic models for the Betic chain (BEMMELEN, 1933; LOOMIS, 1975; TORRES-ROLDÁN, 1979).

Therefore, the leucogranitic dykes in the S^a^ Cabrera, though very modest in size, are of some importance for the understanding of the orogenic evolution and magma generation in the Betic Cordilleras, and it was thought worth while to try and solve the dating incongruity concerning these rocks. The present paper reports the results of muscovite-WR Rb–Sr determination of three carefully selected samples. A Rb–Sr WR survey comprising more samples was judged less suitable because the lithological variation within the bodies is minimal. Combining material from several bodies would extend the lithological variation, and therewith the Rb/Sr range, but carries the danger of combining material with different initial isotopic Sr ratios.

Field relations and petrography

The S^a^ Cabrera in the eastern part of the Betic Cordilleras forms an NE–SW oriented mountain ridge, delimited towards the N and S by post-orogenic Neogene basins (Fig. 1). It is made up mainly of Alpujárride and Nevado-Filábride nappe units. Its south-eastern margin consists of an imbricated zone in which steep, NE striking faults juxtapose narrow sheets of rocks of widely differing age and geological history. The area was investigated by WESTRA (1969), who described in great detail the plurifacial development of the graphite micaschist/quartzite sequence of the Alpujárride nappe complex. This sequence shows composite mineral assemblages which according to WESTRA (1969) comprise partly relict, upper greenschist parageneses of pre-Alpine age, and Alpine parageneses of Barrovian type amphibolite facies overprinted by HT–LP parageneses which indicate increasing metamorphic grade towards the SE. Within 100–200 m from the steep, NE striking fault contact with the Neogene, muscovite becomes unstable and is replaced by sillimanite and K-feldspar. It is in these high grade rocks that the leucogranites have been found. They form a few m large pods and discontinuous dykes, the intrusive character of which is not in doubt. The rocks are non-schistose, but are broken up to a variable degree by later, brittle tectonics.

The samples which were dated, were taken from the fragmented dykes on hill 296, SE of the Cerro del Marqués (cf. WESTRA, 1969). The ca. 2–3 kg large samples represent the central parts of carefully selected, coherent blocks bounded by joint faces. The only macroscopic sign of alteration consists in minute intergranular films of brown Fe-rich impregnations; these could not be avoided in the sampling.

In thin section the rocks reveal a monzogranitic composition and a typical hypidiomorphic granular, granitic texture comprising crystals of plagioclase,

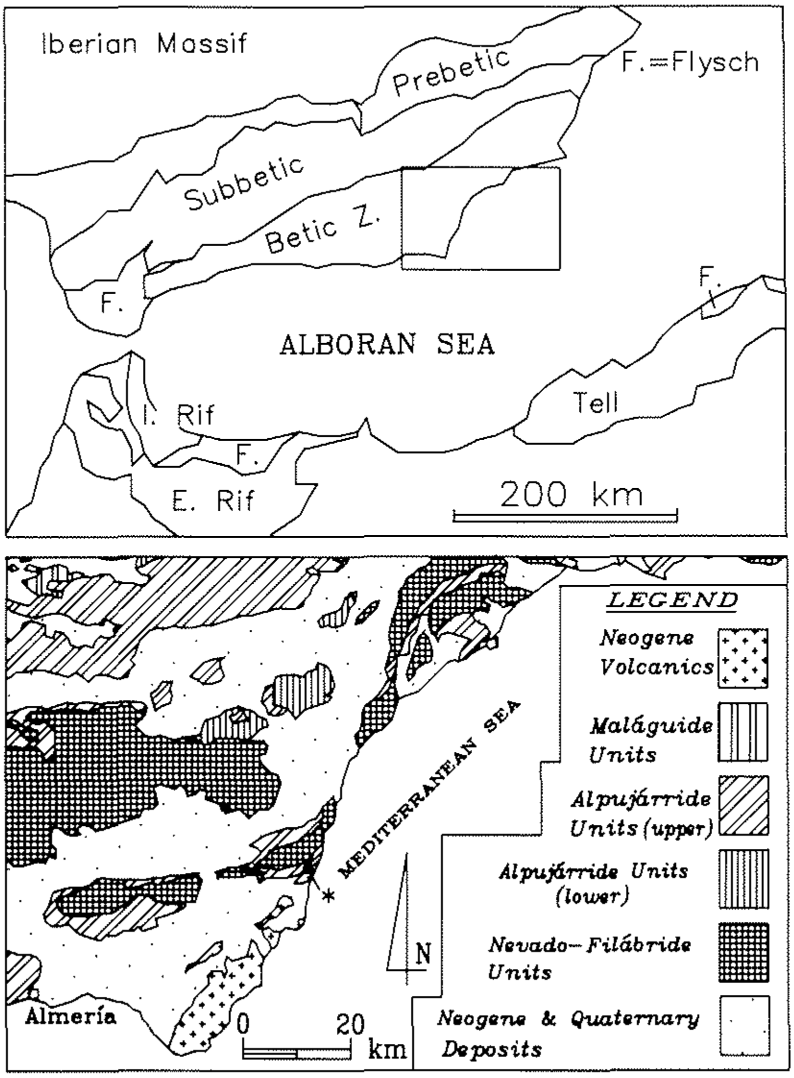

Fig. 1. Location of the samples investigated (*) in the Betic Cordilleras.

K-feldspar, quartz, muscovite and tourmaline. Apatite is a rare accessory. Magnetite, hematite and cassiterite occur in a few crystals. *Quartz* (∅ = 0.2 – 2 mm) forms rather small, euhedral dipyramids as well as larger anhedral crystals and intergranular fillings, indicating an extended crystallization traject. *Plagioclase* is in subhedral crystals (∅ = 0.5 – 3 mm) with a sodic composition (ca. An_5).

K-feldspar forms more anhedral crystals, perthitic and strongly clouded. *Tourmaline* occurs in euhedral crystals (∅ = 0.2 – 2 mm), zoned from coulourless to predominantly yellow-brown (blue cores were seen in a few crystals). *Muscovite* is mostly in large crystals which are clearly part of the magmatic texture. Very fine white mica – which was not included in the dated fraction – has replaced K-feldspar along small cracks and crystal margins, and also parts of some tourmaline crystals, and it forms some sericite within plagioclase;

Table 1. Rb – Sr analytical data.

Sample No.	Type of sample[a]	Rb ppm	Total Sr ppm	^{86}Sr µ mol/g	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$[b]
CAZ25	WR	674	30.9	0.035	63.46	0.7463 ±2
	mu	3673	3.24	0.0033	3623	1.780 ±6
CAZ26	WR	630	34.3	0.038	53.37	0.74292±5
	mu	4118	3.99	0.0041	3247	1.5943 ±1
CAZ27	WR	612	27.7	0.031	64.25	0.74750±6
	mu	3486	2.81	0.0029	3971	1.7909 ±1

[a] WR = whole rock, mu = muscovite.
[b] $^{87}Sr/^{86}Sr$ normalised to $^{86}Sr/^{88}Sr$ of 0.1194; ±2 σ error in last digit.

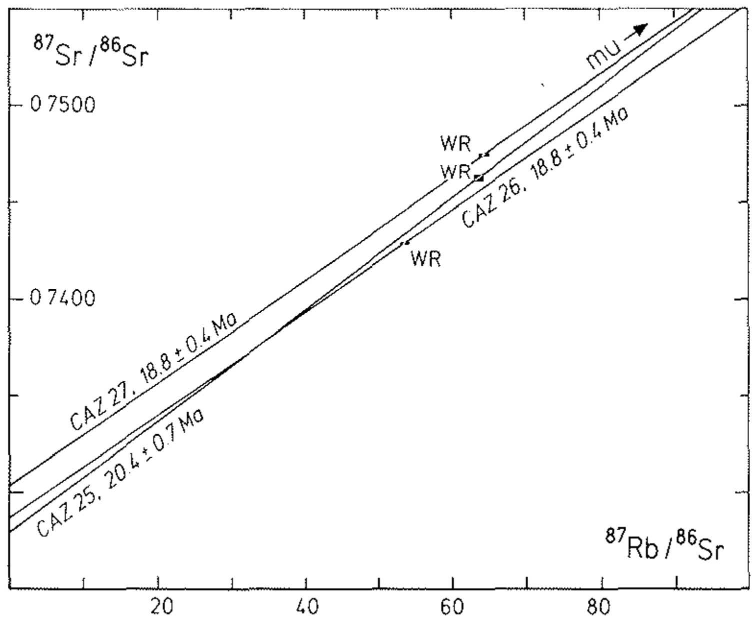

Fig. 2. Nicolaysen diagram presenting the analytical results for the leucogranitic rocks from the S[a] Cabrera. The slope of the isochron lines represents the closure age of the muscovite Rb – Sr isotopic systems.

it is clearly later than the other minerals which form an extended, sliding paragenesis.

Analytical procedures and results

For sample preparation and analytical procedures see ZECK & HANSEN (1988). Before crushing the samples were cleaned in an ultrasonic bath. Muscovite was separated in the 125–200 μm size fraction. The separates have only a few tenths of a per cent impurities (mainly small inclusions of biotite and opaque material). The analytical results are given in Table 1 and Fig. 2. The least squares method of YORK (1969) was used for the calculation of the regression line; error on $^{87}Rb/^{86}Sr$ is 1%, on $^{87}Sr/^{86}Sr$ the 2σ error of the run mean (Table 1). Errors given on the ages are at the 2σ level.

Discussion and conclusions

Three age determinations by three different methods, from three different isotope laboratories, are available on the leucogranitic intrusions from the south-eastern part of the S^a Cabrera:

- 50 ± 3 Ma, Rb–Sr WR (WESTRA, 1969), ZWO Laboratory for Isotope Geology, Amsterdam;
- 21.7 ± 0.7 Ma, average of 20.80 ± 1.05, 21.50 ± 1.05 and 22.70 ± 1.15, K–Ar WR (BELLON et al., 1983), Laboratoire de Géochimie, Brest;
- 19.0 ± 0.5 Ma, weighed average of 18.8 ± 0.4, 18.8 ± 0.4 and 20.4 ± 0.7, Rb–Sr muscovite-WR (present paper), Zentrallaboratorium für Geochronologie, Münster.

The good agreement between the K–Ar WR and the Rb–Sr muscovite-WR results indicates that the 50 ± 3 Ma age reported by WESTRA (1969) is erroneous. The reason for this has to remain unexplained as analytical data were not given. Provided that the dated K–Ar WR systems remained closed after the magmatic crystallization and excess Ar is not involved, their average analytical age of 21.7 ± 0.7 Ma would represent the age of intrusion.

Interpretation of the 19.0 ± 0.5 Ma muscovite-WR age is less straight forward. Data compiled by DODSON & MCCLELLAND-BROWN (1985) suggest a closure temperature of 500 ± 50 °C for the muscovite Rb–Sr isotopic system (at a cooling rate of 30 °C/Ma). The intrusion temperature of the leucogranitic rocks is estimated at 700 °C (cf. WINKLER, 1979). The geological interpretation of the 19 ± 0.5 Ma analytical age thus hinges on the question of how much time elapsed between intrusion and the cooling through the closure temperature of muscovite. Due to the small size of the intrusive bodies their effective cooling rate is identical to that of their host rock complex; cooling to ambient temperatures of intrusions so small is very fast (JAEGER, 1957).

WESTRA (1969) interpreted the intrusive leucogranitic melts as late fractionation products of magmas formed by large scale partial melting of metapelitic material. Melting would have taken place at greater depths than their level of emplacement and enrichment in incompatible elements was considered to be the result of crystal fractionation. It was suggested that intrusion took place in close connection to the HT–LP metamorphic culmination, and high ambient temperatures might still have been present at the time of intrusion. The fact that the intrusions only occur within the narrow zones of highest metamorphic grade supports this. If ambient temperatures were ca. 700 °C at the time of the intrusion, and the regional cooling rate was ca. 200 °C/Ma (ZECK et al., in press) the muscovite Rb–Sr system might have closed ca. 1 Ma after intrusion of the leucogranitic magma. Obviously, these considerations are of a speculative nature and consequently the error on the estimate of the age of a geological entity such as the leucogranitic intrusion is considerably larger than the analytical error. In keeping with this, it is suggested that the best estimate for the age of intrusion is 20 ± 1 Ma.

The leucogranites in the S^a Cabrera have been compared to those occurring in the S^a Bermeja, S of Ronda (BELLON et al., 1983). Texture, mineralogy, chemistry and geological setting are quite similar. In the S^a Bermeja the leucogranites form small dykes and pods predominantly at the contact of the HT peridotite body of Ronda. LUNDEEN (1978) presented proof that the peridotite body forms the 1–1.5 km thick base of a gently S dipping major thrust sheet, the Los Reales peridotite nappe (TUBÍA & CUEVAS, 1986). The peridotite is underlain by a thick series of blastomylonites which forms the top of the Blanca/Ojén Unit and which documents static recrystallization temperatures of more than 700 °C (LUNDEEN, 1978), suggesting "hot" lateral emplacement. The peridotite sheet would represent the northerly displaced top of a mantle diapir which LOOMIS (1972 b, 1975) suggested intruded into upper crustal levels in the Alborán Sea area. It was further proposed (LOOMIS, 1972 a, b) that the present western contact of the peridotite body represents the steeper diapiric contact with a high-grade contact aureole which was developed during the rise of the diapir and was modified by later static re crystallization. The metamorphic development in the prograde contact aureole is similar to the development in the graphite mica-schist/quartzite sequence which harbours the leucogranitic dykes in the S^a Cabrera. It is tempting therefore to correlate the readily observed setting in the S^a Bermeja with the unexposed, deeper parts of the S^a Cabrera.

PRIEM et al. (1979) reported WR Rb–Sr isochron dating results on the leucogranitic intrusives from the S^a Bermeja: 22.6 ± 4.7 and 22.0 ± 8.2 Ma, weighed average 22.4 ± 3.9 Ma. This age confirms the younger age of leucogranite formation and the proposed correlation with the S^a Cabrera leucogranites.

It is concluded that the leucogranitic dykes in the S^a Cabrera are contemporaneous with similar intrusive bodies in the S^a Bermeja. Their radiometric ages are statistically undistinguishable. This confirms previous suggestions by BELLON et al. (1983). The geological setting of these intrusives in the two areas is quite similar and it is suggested that also in the Sª Cabrera intrusion of mantle derived material was responsible for the HT event of which the leucogranitic melt production is a result (WESTRA, 1969). In accordance with suggestions by LOOMIS (1972 a, 1975), the Sª Cabrera leucogranites are interpreted as one of the many HT–LP metamorphic-anatectic expressions in S Spain and N Africa of large bodies of mantle derived material intruded into high level crust in the Alborán Sea area. Other examples are (cf. LOOMIS, 1975; WESTERHOF, 1977): (1) the "erupted migmatite" of the Cerro Hoyazo; and other Neogene volcanic rocks in south-eastern Spain (ZECK, 1968, 1970, 1972; MUNKSGAARD, 1984; TORRES-ROLDÁN, 1979), and (2) the regional occurrence of late HT–LP metamorphic imprints usually characterized by andalusite- and sillimanite-bearing parageneses (TORRES-ROLDÁN, 1974, 1979).

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