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URANIUM, THORIUM AND POTASSIUM CONTENTS AND HEAT PRODUCTION IN THE RÍO VERDE BATHOLITH, SOUTHERN OAXACA, MEXICO—PRELIMINARY STUDY

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SUMMARY

Determinations of uranium, thorium and potassium contents in five samples from three plutonic bodies (Río Grande, Río Verde and Jamiltepec) of the Río Verde batholith, Oaxaca continental margin, southern Mexico, are reported. These measurements have been obtained by two different methods, using: (1) passive gamma-ray spectroscopy with a Ge (Li) detector, and (2) Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Results for the two methods show discrepancies larger than the analytical uncertainties, with the first method giving larger concentrations.

The contents of the radioactive elements are used to calculate the radiogenic heat production for the three plutons. The radiogenic heat production estimated for data obtained by gamma-ray spectroscopy is 10-25 % larger than that obtained for the ICP-MS method. Th/U ratios estimated for the first method range from 3.56 to 4.83, whereas for the second method they display larger variations, between 3.59 to 9.75. It should be emphasized, however, that the small number of samples analyzed does not permit any statistical inferences concerning the methods.

Determinations of radioactive element contents and corresponding heat production obtained by gamma-ray spectroscopy are considered representative for the Río Verde batholith. The radiogenic heat production estimates for the batholith range from 1.81 to 2.51 μW/m. The data set available for Mexico on radiogenic heat production and heat flow is still very small, and more studies are needed before inferences on regional tectonics, crustal structure and petrogenesis of plutonic terranes can be derived.

Key words: Radioactive elements, heat flow and production, plutonic rocks, Río Verde batholith, Oaxaca State, southern Mexico.

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INTRODUCTION

The Pacific continental margin of southern Mexico is characterized by abundant batholithic bodies that intrude metamorphic, sedimentary and volcanosedimentary terranes. In the sector of Puerto Escondido-Juchatengo-Huatulco-Puerto Ángel, the Xolapa complex is mainly composed of amphibolites, migmatites, paragneisses, schists and ortogneisses. In this paper, the authors present results of a reconnaissance study of the contents of radioactive elements and the radiogenic heat production in three intrusive bodies (Río Grande, Río Verde and Jamiltepec granitoids) of the Río Verde batholith (Figure 1).

Heat flow studies have long suggested that the upper continental crust, comprising the first 5 to 10 km, is enriched of radioactive elements which are important in generating a significant component of the heat flow in continental areas (Roy *et al.*, 1968; Morgan *et al.*, 1987). The distribution of these elements in the upper crustal rocks is variable and models ranging from constant abundance within a given sector, linear decrease and exponential decrease with depth, are used for thermal modeling (Lachenbruch, 1970; Morgan *et al.*, 1987). Magmatic processes can concentrate the radioactive elements that are strongly lithophile and partial melting and source composition affect melt partitioning and degree of fractionation (*e. g.*, Tilling *et al.*, 1970; Collins *et al.*, 1982). Vertical variations and processes are not yet well documented, and measurements on igneous rocks from shallow plutonic environments are needed to understand the spatial variability (Morgan *et al.*, 1987).

The southern Mexico continental margin, which has been subjected to major uplift and subsidence related to plate convergence and subduction of the Cocos plate and margin erosion and truncation processes (Morán-Zenteno *et al.*, 1994), extensively exposes the crust and abundant plutonic bodies at various levels. In the region, perhaps some 15 km of the upper crust have been uplifted and removed. The abundant intrusive bodies represent relatively shallow and intermediate plutonic environments and constitute promising targets for studies of the abundance and distribution of radioactive elements.

GEOLOGIC SETTING AND SAMPLING

The Río Verde batholithic complex is composed of three plutons (Figure 1), which can be distinguished by their main

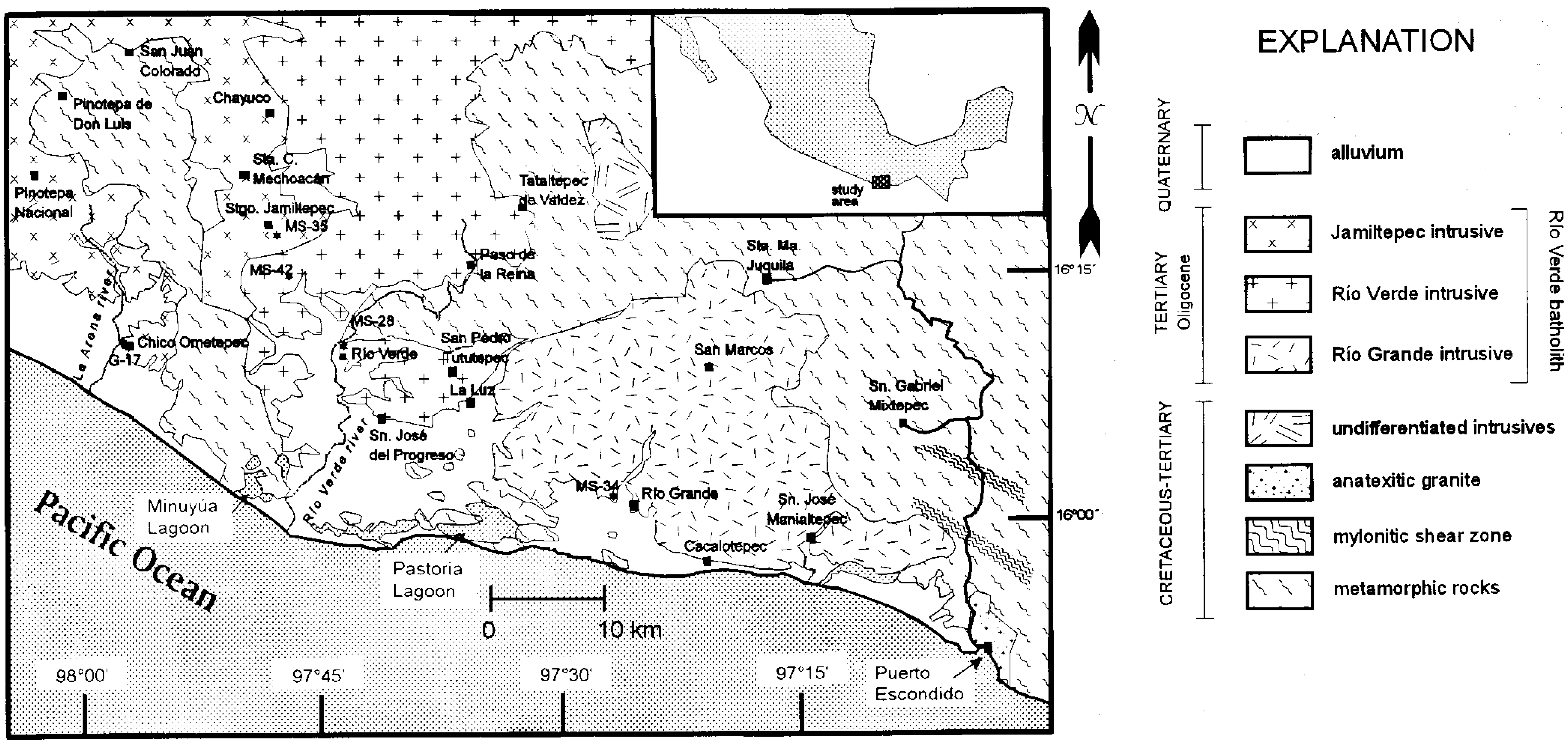

Figure 1. Schematic geological map of the Río Verde-Puerto Escondido region, Oaxaca, showing the distribution of plutonic bodies and sampling localities.

accessory minerals and geochemistry. It has been recently studied by Hernández-Bernal (1995), who has reported results of detailed mapping, petrography, geochemistry of major oxides, trace elements and rare earths, and isotopic studies. The Río Grande pluton contains biotite, with compositions ranging from granite, granodiorite to tonalite. Other accessory minerals include hornblende, apatite, zircon and sphene. It is fine grained and with equigranular texture. In some portions, particulary towards the eastern contact with the gneissic sequence, micas show an incipient foliation. The Río Verde pluton shows biotite and hornblende as major accessory minerals (in varying proportions). Composition corresponds to granodiorite-tonalite with biotite and hornblende, with other accessory minerals such as apatite, zircon and sphene. Grain size ranges from medium (0.1-0.5 cm) to coarse (0.5-1.0 cm). In the San Pedro Tututepec region (Figure 1), the contact with the metamorphic sequence shows a gradual increase in xenolith and hornblende abundance, a subtle foliation and intense fracturing. The Jamiltepec pluton shows hornblende as the major accessory mineral and a tonalite-monzodiorite-granodiorite-granite composition. Also present are biotite, zircon and apatite. Grain sizes are larger than in the other two plutons (0.5-1.0 cm). Jamiltepec displays a marked foliation in its western limit with the gneissic sequence. Exposures extend over an area of some 800 km.

K-Ar dates on hornblende and biotite concentrates for the three plutons range from 23.5 to 29.9 Ma. The cooling rates, in the range 530 to 300° C, estimated for the Jamiltepec and Río Verde plutons are 104.5°C/Ma and 69.7°C/Ma, respectively (Hernández-Bernal, 1995).

Selected samples for determination of U, Th and K were collected from the three plutons (Figure 1). Samples MS-28 (biotite granodiorite) and MS-42 (hornblende tonalite) come from the Río Verde pluton; samples G-17 (biotite granite) and MS-35 (hornblende tonalite) come from the Jamiltepec pluton; and sample MS-34 (biotite granodiorite) comes from the Río Grande pluton.

METHODS AND RESULTS

Samples were crushed and powdered to -100 mesh. Determination of U, Th, and K was completed with two different methods. The first method is by passive gamma ray spectroscopy (Lewis, 1974). Powdered samples of 330 g are packed in a Martinelli beaker and analyzed using a liquid-nitrogen cooled Ge (Li) detector that has an approximate 35% efficiency. Also included for each sample is the corresponding counting error in percentage. The second method uses an Inductively Coupled Plasma Mass Spectrometer (ICP-MS). ICP-MS analyses use 0.025 g of powdered sample, which are digested by HF and HNO_3 in teflon and steel jackets at 150°C during a week. Digested samples are treated with HCl and H_3BO_3 to remove insoluble fluorides. The standard solutions are made with SPEX plasma standard solutions and a trace spike of In and Re. Analytical control is also provided by analysis of the rhyolitic rock standard RGM-1.

Results using both methods are summarized in Tables 1 and 2. U and Th contents are given in ppm and for K in percentage. The differences, expressed in percentages, of the two data sets are included in Table 3. Radiogenic heat production (in $\mu W/m^3$) is calculated using the method and conversion factors given by Wollenberg and Smith (1987). The estimates of radiogenic heat production are summarized in Tables 1 and 2.

Table 1. Summary of radioactive elements and radiogenic heat production by gamma-ray spectroscopy.

Sample	Lithology	U [ppm]	Th [ppm]	K [%]	Th/U	E [%]	RHP
Jamiltepec Pluton							
MS-35	Hornblende tonalite	1.90	7.83	1.91	4.12	3.5	1.81
G-17	Biotite granite	2.28	10.4	2.97	4.56	5.1	2.51
Río Verde Pluton							
MS-28	Biotite granodiorite	1.82	6.47	2.88	3.56	3.6	2.08
MS-42	Hornblende tonalite	2.33	8.55	2.70	3.67	4.2	2.29
Río Grande Pluton							
MS-34	Biotite granodiorite	1.27	6.13	2.69	4.83	4.83	1.84

E: counting error [%]
RHP: Radiogenic heat production [$\mu W/m^3$]

DISCUSSION

The concentrations determined with the two different methodologies show differences, larger than the estimated analytical uncertainties. The results obtained with gamma-ray spectroscopy (Table 1) give higher values than those obtained with the ICP-MS method (Table 2). The corresponding estimates of radiogenic heat production are 10-25 % higher using the first data set (Table 3). The Th/U ratios for the first data set range from 3.56 to 4.83 (Table 1), whereas for the second data set the range is 3.59 to 9.75 (Table 2).

Results obtained with gamma-ray spectroscopy are considered representative for the plutons studied. The radiogenic heat production estimated for the plutons ranges from 1.81 to 2.51 $\mu W/m^3$ (Table 1). These two values come from the Jamiltepec pluton, and were determined in samples of hornblende tonalite and biotite granite, respectively. The Río Verde pluton gives estimates of 2.08 and 2.29 $\mu W/m^3$, and for the Río Grande pluton the estimate is 1.84 $\mu W/m^3$ (Table 1).

Heat production estimates for the plutons are lower than average values quoted for intermediate igneous rocks or the upper continental crust. For instance, Taylor (1977) estimated a value for the upper continental crust of 2.5 $\mu W/m^3$, and Wollenberg and Smith (1987) a value of 2.9 $\mu W/m^3$ (with a value for intermediate igneous rocks of 2.6 $\mu W/m^3$). Ronov and Yaroshevsky (1967) also estimated a value of 2.9 ± 2.5 $\mu W/m^3$.

Table 2. Summary of radioactive elements and radiogenic heat production by ICP-MS.

Sample	U [ppm]	Th [ppm]	K [%]	Th/U	RHP [$\mu W/m^3$]
Jamiltepec Pluton					
MS-35	1.52	5.46	2.00	3.59	1.58
G-17	1.42	13.82		9.75	
Río Verde Pluton					
MS-28	0.84	3.24	3.00	3.87	1.65
MS-42	1.51	6.32	3.31	4.18	2.16
Río Grande Pluton					
MS-34	0.53	2.33	2.86	4.40	1.45

RHP: Radiogenic heat production.

Table 3. Percentage differences between data obtained by gamma spectroscopy and by ICP-SM.

Sample	U [ppm]	Th [ppm]	K [%]	Th/U	RHP [%]
Jamiltepec Pluton					
MS-35	19.90	30.27	-4.71	12.96	12.62
G-17	37.81	-32.90		113.73	
Río Verde Pluton					
MS-28	36.44	49.86	- 4.17	-8.78	20.84
MS-42	35.15	26.07	-22.59	-13.98	5.51
Río Grande Pluton					
MS-34	58.35	62.04	-6.32	8.87	21.29

Additional studies of radioactive element contents and distribution in these plutons are being planned. They will permit investigation of the influence of magma composition and degree of fractionation (*e. g.*, Tilling *et al.*, 1970; Collins *et al.*, 1982). The role of magma source, *e. g.*, I-type (igneous) and S-type (sedimentary) of Chappell and White (1974) and A-type (anorogenic) and M-type (mantle) (*e. g.*, Collins *et al.*, 1982), appears particularly interesting. Also, it is important to document how single plutons (such as Jamiltepec pluton) or compositionally similar plutons can show large variations in trace elements and fractionation trends. Apparently, even for strongly lithophile elements like U, Th and K, source compositions and partial melting conditions can play an important role in melt partitioning and relative vertical enrichment.

Despite its critical importance for understanding the tectonic and crustal structure of the continental margin-subduction zone, there are no heat flow data available for this sector of the margin. Limited data for the Acapulco region (Ziagos *et al.*, 1985) and measurements for central Oaxaca, to the north of the Río Verde area (Urrutia-Fucugauchi and Schildnecht, in preparation), suggest that the margin and the Precambrian and Paleozoic terranes are characterized by low heat flow (2 mW/m^2). The Oaxaca sector of the continental margin-subduction zone shows several characteristics that deviate from "classical" models. Calc-alkaline arc magmatism is apparently absent in this sector, and even if the Tuxtlas alkaline center in the Gulf of Mexico coast is linked to plate subduction, the trench-arc gap seems anomalously large. Subduction dip is shallow and perhaps there is little or no mantle wedge beneath central Oaxaca. Significant uplift and erosion have characterized the entire region. In central Oaxaca, the granulite facies rocks and anorthosites, representing the lower crust are extensively exposed. In southern Oaxaca, deep crustal levels are also exposed, and recent estimates from geobarometry studies (Morán-Zenteno *et al.*, 1994) indicate that exposed plutons were emplaced at depths of 15 to 20 km.

Differential uplift and erosion have been an important process during the past 30-25 Ma.

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