

## **Estimativas geotermobarométricas e percursos P-T de migmatitos dos Farilhões, arquipélago das Berlengas, Oeste de Portugal**

### *Geothermobarometric estimates and P-T paths for migmatites from Farilhões Islands, Berlengas archipelago, W Portugal*

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**RESUMO:** Os ilhéus dos Farilhões apresentam metassedimentos metaluminosos com uma paragénese metamórfica prógrada  $M_1$  a  $P = 8.6 \pm 1$  kbar e  $T = 915 \pm 50$  °C, seguida de uma paragénese  $M_2$  representativa do pico térmico a  $T = 950 \pm 50$  °C durante descompressão até  $P = 6 \pm 1$  kbar. Os subsequentes estágios retrógrados levaram a P e T inferiores, desde  $M_3$  ( $T \approx 720$  °C e  $P \approx 5$  kbar) a  $T \approx 630$  °C e  $P \approx 3.5$  kbar. Os metassedimentos peraluminosos presentes nos Farilhões apresentam uma paragénese prógrada com pico metamórfico a  $T \approx 720$  °C e  $P \approx 5.5$  kbar ( $M_3$ ) e um estágio retrógrado a  $T \approx 600$  °C e  $P \approx 4.5$  kbar.

**PALAVRAS-CHAVE:** Berlengas, migmatitos, percurso P-T, metamorfismo de alto grau, geotérmica crustal anormal.

**ABSTRACT:** The Farilhões islets show metaluminous metasediments with an  $M_1$  prograde metamorphic paragenesis at  $P = 8.6 \pm 1$  kbar and  $T = 915 \pm 50$  °C, followed by an  $M_2$  paragenesis representative of the peak temperature at  $T = 950 \pm 50$  °C during decompression to  $P = 6 \pm 1$  kbar. Progressive retrogressive stages implied lower P and T from  $M_3$  ( $T \approx 720$  °C and  $P \approx 5$  kbar) to  $T \approx 630$  °C and  $P \approx 3.5$  kbar. The peraluminous metasediments from Farilhões show a prograde paragenesis that defines a metamorphic peak at  $T \approx 720$  °C and  $P \approx 5.5$  kbar ( $M_3$ ) and a retrogressive stage at  $T \approx 600$  °C and  $P \approx 4.5$  kbar.

**KEYWORDS:** Berlengas, migmatites, P-T path, high-grade metamorphism, abnormal crustal geotherm.

## **1. INTRODUCTION**

The Berlengas Archipelago is located W of the Portuguese continental shore. The Berlenga island and the Estelas islets are mainly composed of a coarse-grained biotitic granite (with rare K-feldspar phenocrysts) whereas the Farilhões islets (10km to NW) are composed of a medium

to fine-grained two-mica gneissic granitoid and paragneissic migmatites. Observations on the migmatites reveal they are commonly deformed and retrogressed, showing a granolepidoblastic texture and a wide compositional variation from slightly peraluminous (at sea level – 250m south of the lighthouse) to metaluminous (in small metric pockets, 100m south of the lighthouse).

## 2. PETROGRAPHY AND GEOTHERMOBAROMETRY

The peraluminous rocks are broadly composed of a plagioclase + K-feldspar + quartz + biotite ± muscovite ± garnet ± sillimanite ± graphite mineral assemblage, whereas the metaluminous are composed of a plagioclase + quartz + biotite + amphibole ± garnet ± clinopyroxene ± ilmenite ± sphene assemblage.

The metaluminous metasediments present an  $M_1$  (~483 Ma – Valverde Vaquero et al., 2010) prograde metamorphic paragenesis composed of plagioclase ( $X_{An} = 0.94$ ) + quartz + type-1 grossular-rich garnet ( $X_{Ca} = 0.75 - 0.76$ ; Fe/Mg = 8.5 – 16.2) + clinopyroxene (Fe/Mg = 0.55 – 0.58) that define P-T conditions consistent with the baric peak ( $P = 8.6 \pm 1$  kbar and  $T = 915 \pm 50$  °C) followed by an  $M_2$  paragenesis composed of plagioclase ( $X_{An} = 0.90$ ) + quartz + type-1 grossular-rich garnet ( $X_{Ca} = 0.72 - 0.81$ ; Fe/Mg = 22.9 – 28.1) + clinopyroxene (Fe/Mg = 1.5 – 2.0) representative of the establishment of the metamorphic peak temperature at  $T = 950 \pm 50$  °C during decompression to  $P = 6 \pm 1$  kbar. After reaching metamorphic peak conditions, migmatites underwent further decompression. Progressive retrogressive stages also implied cooling with subsequent paragenetic evolution and reequilibration to lower P and T.  $M_3$  (~377 Ma – Valverde Vaquero, 2010) assemblages show plagioclase ( $X_{An} = 0.98$ ) + quartz + biotite + type-2 almandine-rich garnet ( $X_{Ca} = 0.23 - 0.33$ ;  $X_{Mn} = 0.12 - 0.15$ ; Fe/Mg = 5.0 – 7.5) ± amphibole ± ilmenite ± clinopyroxene relics (Fe/Mg = 0.86 – 0.89) to  $T \approx 720$  °C and  $P \approx 5$  kbar. Continuous exhumation stage and thermal readjustment followed to  $T \approx 630$  °C and  $P \approx 3.5$  kbar (P-T estimates on the rims of type-2 almandine-rich garnet and clinopyroxene), depicting very high thermal flux at shallow depths. Increasing  $a_{H_2O}$  during retrogression provided a lower P-T assemblage with plagioclase + biotite + amphibole + ilmenite ± sphene.

The peraluminous metasediments present a prograde paragenesis composed of plagioclase ( $X_{An} = 0.29 - 0.33$ ) + K-feldspar + quartz + type-3 almandine-rich garnet ( $X_{Ca} = 0.046 - 0.074$ ; Fe/Mg = 5.4 – 6.3) + biotite (Fe/Mg = 1.08 – 1.27) ± sillimanite that define a metamorphic peak of  $T \approx 720$  °C and  $P \approx 5.5$  kbar and a retrogressive stage of  $T \approx 600$  °C and  $P \approx 4.5$  kbar (P-T estimates on the rims of type-3 garnet and nearby matrix biotite), very close results to the  $M_3$  metamorphic stage of the metaluminous rocks. The peraluminous rocks underwent lower P-T conditions (amphibolite facies) than the metaluminous rocks and were probably put together during the final exhumation stage, coeval with the  $M_3$  metamorphic stage (Fig. 1).

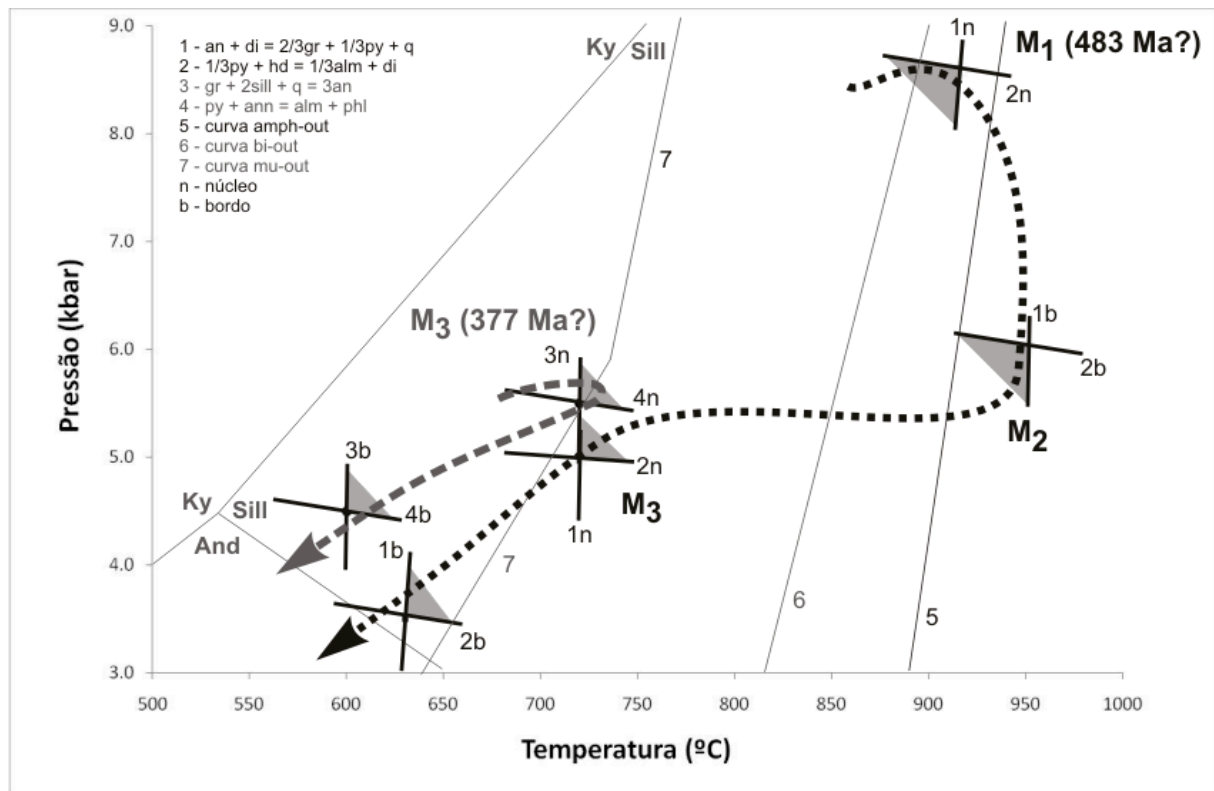


Figure 1 – Summarized P-T-t evolution for the studied samples. In grey is shown the evolution and the most important chemical reactions for the peraluminous rocks, whereas black is for the metaluminous. The dotted line defines the metamorphic evolution for the metaluminous rocks, whereas the dashed line defines the possible metamorphic evolution of the peraluminous rocks. It can be seen that these two rock types, although geographically close presently, had very distinct metamorphic evolutions and were only juxtaposed, probably, during the last metamorphic event ( $M_3$ ) at 377 Ma ago (Valverde Vaquero et al., 2010). The geothermobarometric estimates for the  $M_1$  and  $M_2$  events are interpreted as maximum T and P, whereas for  $M_3$  they are minimum T and P. Mineral abbreviations are as in Powell et al. (1998).  $Al_2SiO_5$  triple point and muscovite (7) and biotite (6) dehydration-melting curves are as in Spear et al. (1999), whereas amphibole dehydration-melting curve (5) follows Patiño Douce & Beard (1995).

### 3. DISCUSSION AND CONCLUSIONS

Overall, the new results indicate a prograde metamorphic trajectory well into granulite facies conditions for the metaluminous rocks, reaching amphibole-dehydration melting curve at higher geothermal gradients than normally present at the lower crust (Fig. 1). External heat input, probably from upwelling of asthenospheric mantle and magma underplating, must be considered to explain the obtained P-T evolution and sustainment of an abnormal crustal geotherm during the best part of the burial – heating – exhumation – cooling stages of the clockwise P-T path of these rocks.

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