Timing of rodingitization at the Ronda peridotites (Betic Cordilleras, Spain)

Edad del proceso de rodingitizacion en las Peridotitas de Ronda (Cordilleras Béticas, España)

J. J. Esteban (1*), J. Cuevas (1†), D. Seward (2), J. M. Tubía (1)

2) Corresponding author e-mail address: gobsesg@alh.ahu.es
3) Geologisches Institut, ETH Zentrum, a.p. 8092, Zurich

ABSTRACT

This work reports the timing of the rodingitization process of granitic dykes intrusive into the Ronda Peridotites. Representative fission-track ages on zircon and apatite from rodingitized dykes, in combination with cooling rates suggested for the Alpujarride Complex (Monié et al., 1994; Sánchez-Rodríguez, 1998; Sossen et al., 1998) point to a minimum age of 16.8 ± 1.8 Ma for the rodingitization process. By extrapolating to the timing of formation of the highest stability limit of the serpentine minerals (500°C) we propose that the serpentinization of Ronda peridotites was a continuous process lasting at least for 2.2 Ma, from 19.1 to 16.9 Ma.

RESUMEN

Este trabajo proporciona la edad del proceso de rodingitización obtenida en el conjunto de diques graníticos intrusivos en las peridotitas de Ronda. Las edades relativas obtenidas mediante trazas de fisión en circones y apatitas, en combinación con las diferentes tasas de exhumación calculadas para el complejo Alpujarride (Mónié et al., 1994; Sánchez-Rodríguez, 1998; Sossen et al., 1998) proporcionan una edad mínima de 16.8 ± 1.8 Ma para el proceso de rodingitización. La extrapolación de la edad de comienzo de la serpentinización a partir del límite superior de estabilidad de los minerales de la serpentina (500°C), nos hace proponer que la serpentinización en las peridotitas de Ronda fue un proceso continuo con una duración mínima de 2.2 Ma, desde unos 19.1 Ma hasta 16.9 Ma.

Key words: Rodingite, fission track analysis, Cooling ages, Ronda, Betic Cordilleras.

Geogaceta, 34 (2003), 23-26
ISSN:0213683X

Introduction

Rodingites are end products of Ca-metasomatism acting on a great variety of protoliths as a complementary process of serpentinization in nearby ultramafic rocks (e.g. O'Hanley, 1996). The occurrence of rodingites in peridotite massifs reflects the production of Ca-rich fluids owing to the inability of crystal lattices of serpentine minerals to lodge the calcium released from pyroxenes during the serpentinization of peridotites (Schandl et al., 1989, 1990). Other rocks in contact with the ultramafics take in such Ca-rich fluids and are then transformed to assemblages with calcium silicates including hydrogrossular, epidote, idocrase, diopside and pectolite.

The first description of rodingites within the Ronda peridotites has been reported by Esteban et al. (2001), who recognised pectolite associated with xenotlite and hydrogrossular in granitic dykes intrusive into the Ronda peridotites. Esteban et al. (2003), deduced a temperature range between 300° to 350°C as the beginning of the rodingitization process based on the mineral parageneses of the dykes and the surrounded serpentinites. Retrograde alteration at lower temperature conditions has occurred since then, producing aragonite. Thus the rodingitization process has been continuous since the rocks passed through 350°C and continued until near surface temperatures.

Most of the radiometric studies performed on metamorphic rocks of the Alpujarride Complex since the 1980's have yielded evidence for very high cooling rates during Early to Middle Miocene times (Zeck et al., 1989; Menié et al., 1994; Zeck, 1996; Sossen et al., 1998; Sánchez-Rodríguez and Gebauer, 2000). However, the conclusions proposed by these authors disagree in the magnitude of the temperature fall and on the time span required by the cooling process, varying between a cooling rate in the range 100°-350°C/Ma for an age bracket of 20-19 Ma (Monié et al., 1994) and 500°C/Ma within the period 22-17 Ma (Zeck, 1996). A subsequent stage of cooling at lower rates, from below 350°C, has been also detected by some authors (Andriessen and Zeck, 1996; Zeck, 1996; Sossen et al., 1998; Sánchez-Rodríguez, 1998). We report here
Apatite and zircons were extracted from 5-6 kg of initial rock of rodantitized granitic dykes, from an outcrop (Fig. 1C) along the Malaga-Campillos road (A-357), using conventional methods including crushing and Wilfly table/heavy liquids/magnetic separation steps. Both, apatite and zircon were prepared for fission track analysis by the external detector method, using the usual procedures of the ETH laboratory (Seward, 1989). All the samples were irradiated at the ANSTO facility (Australia). Zeta values of 100.5 ± 2.7 for CNI/zircon and 293.1 ± 10.9 for CNI/apatite were used (JJE). Tracks were counted using a ZEISS microscope with magnifications of 1250X for the apatite and 1600X (oil) for the zircon. All the ages are presented as central ages with 2σ errors, following the method by Galbraith (1981).

Results

The studied samples yielded one apatite and two zircon fission-track ages (Table 1). The high values obtained in the chi-squared test (PX; Table 1) indicate that all of the crystals form a single population in each sample, as it is expected in rapidly cooled rocks.

The zircon ages are 16.8 ± 1.8 and 16.7 ± 1.8 Ma (Fig. 2B & C), both with 2σ errors. These ages are in agreement with those calculated by Andriessen and Zech (1996) for the Torrox gneisses (17 ± 2.5 Ma) and Sánchez-Rodríguez (1998) from Los Reales nappe in the Western part of the Betic Chain (17.1 ± 1.9 Ma). The apatite fission-track age is 16.9 ± 3.0 Ma (Table 1, Fig. 2A). This apatite age also concurs with previous results from Andriessen and Zech (1996), Sokson et al. (1998) and Sánchez-Rodríguez (1998).

As the fission-track ages obtained for zircon and apatite are nearly coincident, this implies that fast cooling as seen in the early stages, was also maintained during the lower temperature evolution of the Alpujarride Complex.

It is accepted that at high cooling rates the closure of the radiometric systems takes place at higher temperatures. Yamada et al. (1995) showed that with the fanning model the upper bounding temperature for initiation of annealing can be as high as 390°C, with a mean closure temperature of 240°C for zircons. Foster et al. (1996) determined zircon closure temperatures for a range of cooling rates, estimating a closure temperature of 260° ± 25°C for a cooling rate of 50°C/Ma, while for higher rates the closure temperature was...
increased. Foster et al. (1996) state that for cooling rates between 200° and 500°C/Ma the effective closure temperatures are "extraordinarily high" and not resolvable because in their study the ages were concordant with other methods such as 40Ar/39Ar on hornblende, biotite and K-feldspar. Green et al. (1996) clearly showed that temperatures greater than 250° are required for significant annealing and from a study in the Southern Alps suggest at least 300°C. Finally, Rahn (personal communication) estimate a closure temperature of between 330 and 350°C for a cooling rate of 100-200°C/ Ma in an annealing study of zero damage zircons - a state which is compatible with the zircons in the Ronda. Thus we take here an effective closure temperature for zircon at 300 ± 50°C which covers the range of those listed above but would caution to the higher side.

Estimates for the closure of apatite fall in the range 75-125°C for cooling rates between 1 and 100°C/ Ma (Wagner and Reimer, 1972; Haack, 1977; Gleadow and Lovering, 1978). The upper level of 125°C was used in this study.

Thus, we may conclude that the rodigratinization process, beginning at 300° to 350°C (Esteban et al., 2003), falls within the range of closure of zircon and apatite for extremely high cooling rates (Fig. 3) in the granitic dykes in the Ronda peridotites. Therefore, the mean zircon fission-track age obtained in this work (16.8 ± 1.8 Ma) corresponds to the timing of rodigratinization, in Miocene times, during the extensional collapse of the Beti Cordilleras.

Monié et al. (1994) reported an age of 18.7 ± 0.2 Ma on biotites of granitic dykes at Sierra Alpujata Massif with cooling rates ranging from 100-350°C/ Ma. As the cooling ages for the closure temperature of the 40Ar/39Ar system (350°C or higher in the case of such rapid cooling) and the highest stability limit of the serpentine minerals (500°C) are nearly coincident considering a cooling rate of 350°C/ Ma (Monié et al., 1994), it is possible to estimate the age that would correspond to this upper limit of 500°C.

Thus, an age of 19.1 Ma would correspond to the beginning of the serpentinization. In contrast, the apatite-fission track age obtained in this work (16.9 ± 3.0 Ma), points to a minimum stability limit of the serpentinization similar to the closure temperature of the apatites in this case probably greater than 120°C. Therefore, these age restrictions lead us to suggest that the homogeneous serpentinization imprinted in all the ultramafic masses, was a process lasting 2.2 Ma at least, from the upper stability limit of the serpentine to the closure temperature of the apatites.

Conclusions

The ages reported in this work in the rodigratinized dykes from the Carratra Massif, obtained through fission-track analysis, are in complete agreement with the previous cooling ages at the Beti Cordillera, suggesting a geologically quasi-instantaneous cooling, between the closure temperatures of zircons and apatites. The mean zircon and apatite

<table>
<thead>
<tr>
<th>Sample</th>
<th>Irradiation</th>
<th>Mineral</th>
<th>Altitude (m)</th>
<th>N° of grains</th>
<th>( p_b ) (N%)(10^8/cm²)</th>
<th>( p_s ) (N%)(10^3/cm²)</th>
<th>( p_s ) (N%)(10^3/cm²)</th>
<th>U (ppm)</th>
<th>( P_X ) (%)</th>
<th>Var (%)</th>
<th>Central age (Ma)</th>
<th>±2σ (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ-14</td>
<td>Eth-230-5</td>
<td>Apatite</td>
<td>269.0</td>
<td>14</td>
<td>1.270 (7422)</td>
<td>0.362 (144)</td>
<td>3.969 (1581)</td>
<td>38.1</td>
<td>98.0</td>
<td>0.00</td>
<td>16.9 ± 3.0</td>
<td></td>
</tr>
<tr>
<td>AZ-9</td>
<td>Eth-231-18/17</td>
<td>Zircon</td>
<td>269.0</td>
<td>20</td>
<td>0.3462 (2175)</td>
<td>3.642 (783)</td>
<td>3.763 (809.5)</td>
<td>455.3</td>
<td>56.3</td>
<td>3.49</td>
<td>16.8 ± 1.8</td>
<td></td>
</tr>
<tr>
<td>AZ-14</td>
<td>Eth-231-23</td>
<td>Zircon</td>
<td>269.0</td>
<td>19</td>
<td>0.3130 (2175)</td>
<td>3.785 (760)</td>
<td>3.661 (715.0)</td>
<td>455.1</td>
<td>77.6</td>
<td>2.73</td>
<td>16.7 ± 1.8</td>
<td></td>
</tr>
</tbody>
</table>

\( p_b \) : Density of tracks in the glass dosimeter. (N\%): Number of tracks counted in the glass dosimeter.

\( p_s \) : Spontaneous track density (N\%): Number of spontaneous tracks counted.

\( p_s \) : Induced track density. (N\%): Number of induced tracks counted.

\( P_X \): Probability of obtaining \( X \)-values for \( l \) degrees of freedom, where \( l \) (number of crystals -1).

Var: Variación

All ages are central ages (Galbraith, 1981). Apatite ages are calculated using dosimeter CNS with a \( t \)-factor of 203.13 ± 10.87. Zircon ages are calculated using dosimeter CNS with a \( t \)-factor of 100.48 ± 2.71. Irradiations were performed at the ANSTO nuclear reactor, Lucas Heights, Australia.

Table 1- Fission track data from the granitic dykes of the Ronda peridotites.

Table 1- Datos analíticos de las trazas de fisión de los diques graníticos de las peridotitas de Ronda.
fission-track ages obtained during this work indicate that the serpentinization and rodinigization in the Carrañacca massif were active at least during a time span between 19.1 to 16.8 Ma.

Acknowledgements

This work has been supported from the projects PB96-1452-CO3-03, BTE2001-0634, UPV0001.310-14478/2002 and GI18/99. It is part of the Doctoral Thesis of J.J. Esteban supported by the Basque Government. We are very grateful to the members of the “Fission Track Group” of the ETH, Zurich, especially to A. Kunov and M. Wipf, for their cooperation on the laboratory work.

References