Age and origin of nodular ('grey') monazite from the Matamulas placer deposit (Ciudad Real, Spain)

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Palabras Clave: Monacita, Edad U-Pb, Tierras Raras Ablación Láser, Placer. **Key Words:** Monazite, U-Pb age, Rare Earth Elements, Laser Ablation, Placer.

INTRODUCTION

Monazite and bastnaesite are the main sources of rare earth elements (REE), which are essential for many high technology applications. Unlike the magmatic yellow monazite, the nodular or grey monazite presents low contents of thorium and uranium. The formation of grey monazite is poorly understood and it is generally related to diagenesis or low-grade metamorphic processes that would liberate the lanthanides initially adsorbed on clays. The Matamulas (Ciudad Real) placer deposit is made of nodular grey monazite within unconsolidated alluvial sand and clay layers. The source area for the nodules is likely the middle Ordovician black slates from the surroundings as nodular monazite has been recognized in analogous formations within the Central Iberian and West Asturian Leonese zones (Luarca, del Rio, Pochico, with Calymene, etc. slates; e.g. Windle 1994). Previous studies of the Matamulas placer deposit have revealed its high economic potential due to the richness in monazite that make it the main of Europe in its class and one of the richest in the world in praseodymium and neodymium (cf. Vergara Espuelas 2019, for more information). In order to determine the age and conditions of formation of the nodules of grey monazite we have carried out a petrological and geochronological study whose main results are presented below.

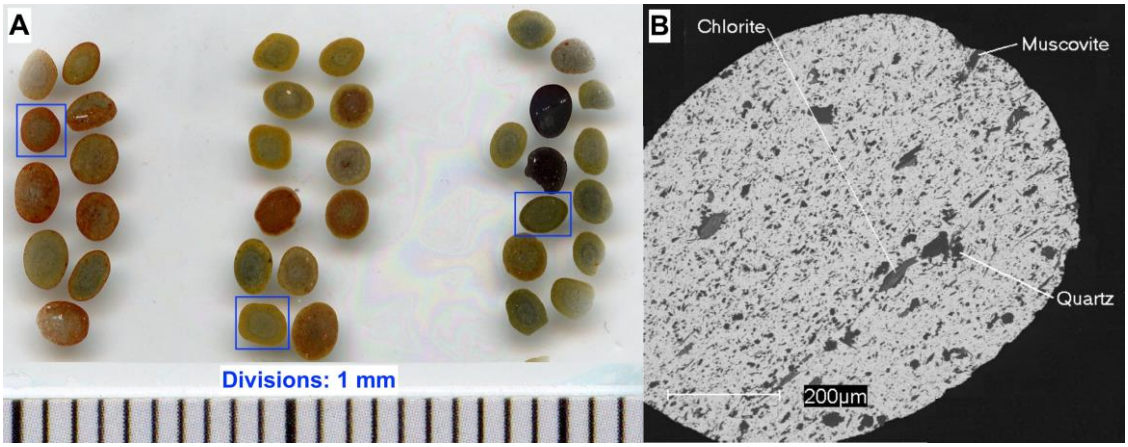

Fig 1. A. *Monazite nodules of different colors showing elliptical to subrounded XY sections and macroscopic concentric color zoning. Nodules in blue boxes (left, ochre-red; center, ochre-yellow; right, grey) were analysed for U-Pb determinations.* ***B.*** *Aligned inclusions of phyllosilicates in monazite nodule.*

PETROLOGY AND GEOCHRONOLOGY OF NODULAR MONAZITE

The nodules of grey monazite from Matamulas are 0.1 m to 2 mm in size, display lenticular to subspherical shapes and concentric color zoning. They present a variety of colors that allow to establish three main types: (ochre) red, (ochre) yellow and grey (Fig. 1A). Minute inclusions of other minerals are abundant and have been identified by XRD and EPMA as quartz, chlorite, muscovite, goethite and clay minerals. The inclusions of phyllosilicates often display a preferred orientation (Fig. 1B). Temperature estimates for chlorite included in monazite are ca. 165-230

°C (Lanari et al., 2014 formulation). Rare earth element distribution was checked on three nodules macroscopically different in colour: red, yellow and grey. They all show distinctly Nd enriched cores (up to 24 wt % Nd_2O_3), La and Ce increase towards the rims of the nodules (up to 21 wt % and 34 wt % La_2O_3 and Ce_2O_3, respectively) and no significant difference among the three types of nodules distinguished (Fig.2). One nodule of each type (cf. Fig. 1A) has been analysed by means of LA-ICPMS at the Karlsruhe Institute of Technology using an Analyte Excite+, Teledyne excimer laser and a ThermoScientific ElementXR ICPMS. Approximately 50 U-Pb spot analyses were performed on each nodule. The results obtained in the three types of nodules are within the uncertainty of each other: red nodule 402 ± 2 Ma, yellow and grey nodules 399 ± 2 Ma.

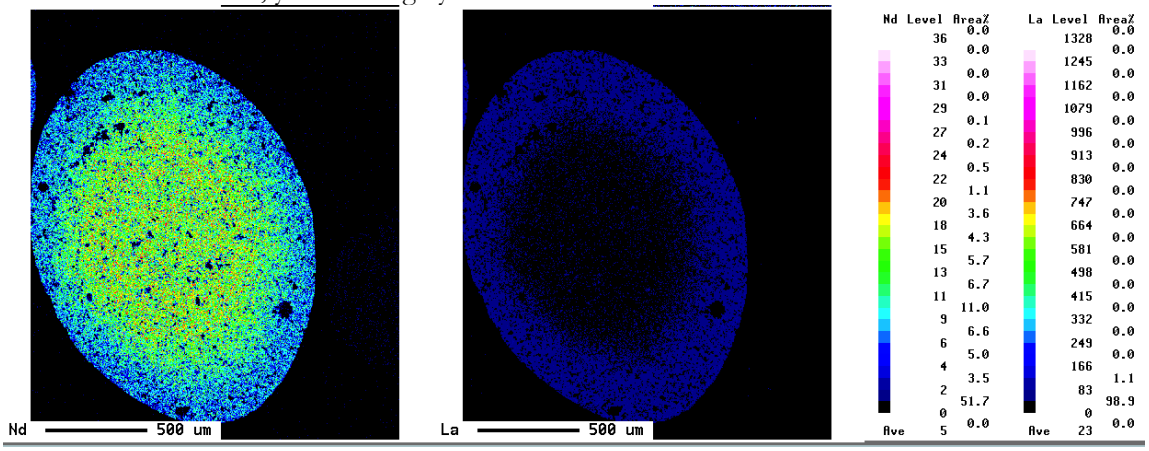

Fig 2. *Compositional zoning in grey monazite nodule (Fig. 1A) with rich Nd core and La increase from core to rim (microprobe X-ray images).*

INTEPRETATION

The ages of ca. 400 Ma obtained for the monazite nodules imply that their formation took place well after the deposition of the source rock units, the slates with Calymene considered as of Llanvirn age (472-464 Ma; Gutiérrez-Marco et al., 1984). Likewise, the age of ca. 400 Ma is too old to be considered that of a regional Variscan tectonothermal event, which would not be older than Carboniferous (≤ 359 Ma; Cohen et al., 2013). It would reflect therefore the age of a distinct event, likely related to the diagenesis or burial metamorphism of the black shale protoliths. This would be in agreement with similar findings elsewhere in the Variscan foldbelt of Europe where ages around 400 Ma have been established for nodular monazite, e.g. in Wales (Evans et al., 2002) and in Brittany (Tuduri et al., submit.). However, the preferred orientation of inclusions often observed within the monazite nodules still poses problems in the interpretation. According to the canonical understanding these would be remnants of stratification (S_0) variably flattened during the diagenesis/burial metamorphism of the sediments. Nonetheless, the fact that the inclusions may represent a mineral lineation within XY planes calls for some caution and more information for a definitive interpretation.

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