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Heavy-mineral assemblages as a provenance indicator in the Jaca basin (Middle-Late Eocene, southern Pyrenees)

Asociaciones de Minerales pesados como indicadores de procedencia en la cuenca de Jaca (Eoceno Medio-Tardío, sector central surpirenaico)

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ABSTRACT

The Jaca sequence records a major paleogeographic change in the south-central-pyrenean basin, recorded by the replacement of the deep-marine Hecho Group turbidites (Upper Lutetian) by deltaic and alluvials (Bartonian-Priabonian). This work studies the heavy-mineral assemblages of the Eocene clastic systems in the northern Jaca basin, applying optical analysis and Raman spectroscopy. All the clastic systems display impoverished heavy-mineral suites, mainly constituted by titanium oxides, apatite, zircon and tourmaline. Other heavy minerals, as staurolite, weathered pyrite, goethite and hematite, are found in the alluvial systems. Our results show a major heavy-mineral content shift along the transition from turbidites to shallow-water and continental deposits. The turbiditic systems display high content of apatite sourced from the Axial Zone in the eastern Pyrenees, whereas the alluvial systems are characterized by a heavy-mineral suite containing goethite and staurolite. The shift is here interpreted as related to the onset of the Gavarnie thrust, which resulted in the uplift and recycling of the turbidites as well as the exhumation of Paleozoic basement, located to the north of the Jaca basin.

Key-words: *Pyrenees, Jaca basin, heavy minerals, provenance.*

RESUMEN

La secuencia de Jaca registra un cambio paleogeográfico importante en la cuenca surpirenaica central, registrado por la sedimentación marina, representada por las turbiditas del Grupo de Hecho (Luteciense), por ambientes deltaicos y aluviales (Bartoniense-Priaboniense). Este trabajo estudia las asociaciones de minerales pesados de los sistemas clásticos eocenos de la parte norte de la cuenca de Jaca, mediante el análisis petrográfico y la espectrometría Raman. Todos los sistemas muestran asociaciones empobrecidas, constituidas básicamente por óxidos de titanio, apatito, zircón y turmalina. En los sistemas aluviales, en cambio, se identifican otros minerales, como estaurolita, pirita alterada, goethita y hematites. Los resultados muestran un cambio importante en las asociaciones de minerales pesados en la transición desde los depósitos turbidíticos hasta los someros y continentales. Los sistemas turbidíticos muestran elevadas proporciones de apatito, con un área fuente en la Zona Axial de los Pirineos Orientales, mientras que los sistemas aluviales se caracterizan por un contenido elevado en goethita y por la presencia de estaurolita. Se interpreta que el cambio se relacionaría con el inicio del emplazamiento del cabalgamiento de Gavarnie, que provocó el levantamiento de las turbiditas y la exhumación del basamento paleozoico al norte de la cuenca de Jaca.

Palabras clave: *Pirineos, cuenca de Jaca, minerales pesados, procedencia.*

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Introduction

The Jaca sequence (Remacha *et al.*, 1987) records a main paleogeographic change from the deep-marine sedimentation stage, recorded by the Upper Hecho Group turbidites (Upper Lutetian), to the generalization of terrestrial sedimentation in the Priabonian.

Although provenance constraints for these systems have been based on paleocurrents (Puigdefàbregas, 1975; Oms, 1994; Oms and Remacha, 1992; Remacha and Fernández, 2003, Remacha and Picart, 1991) and sandstone petrography (Daza, 2010; Roigé *et al.*, 2013, 2016), their heavy-mineral content remains unknown.

Because of precise conditions of formation, many heavy minerals, provide diagnostic information for provenance interpretation, as well as for tectonic setting, that other studies or provenance tools cannot provide (Mange-Ratgetzky and Murer, 1991; Morton and Hallsworth, 1999).

This paper explores the use of heavy-mineral assemblages as provenance indicators for the clastic systems of the northern Jaca basin. Heavy minerals have been studied by means of optical petrography and Raman spectroscopy.

Geological setting

The study area is located in the Tertiary Jaca Basin (South-Central Pyrenees; Labaume *et al.*, 1985; Canudo y Molina, 1988; Hogan and Burbank, 1996). The studied systems (Figs. 1 and 2) are the Banastón and Jaca turbidite systems, the Sabiñánigo and

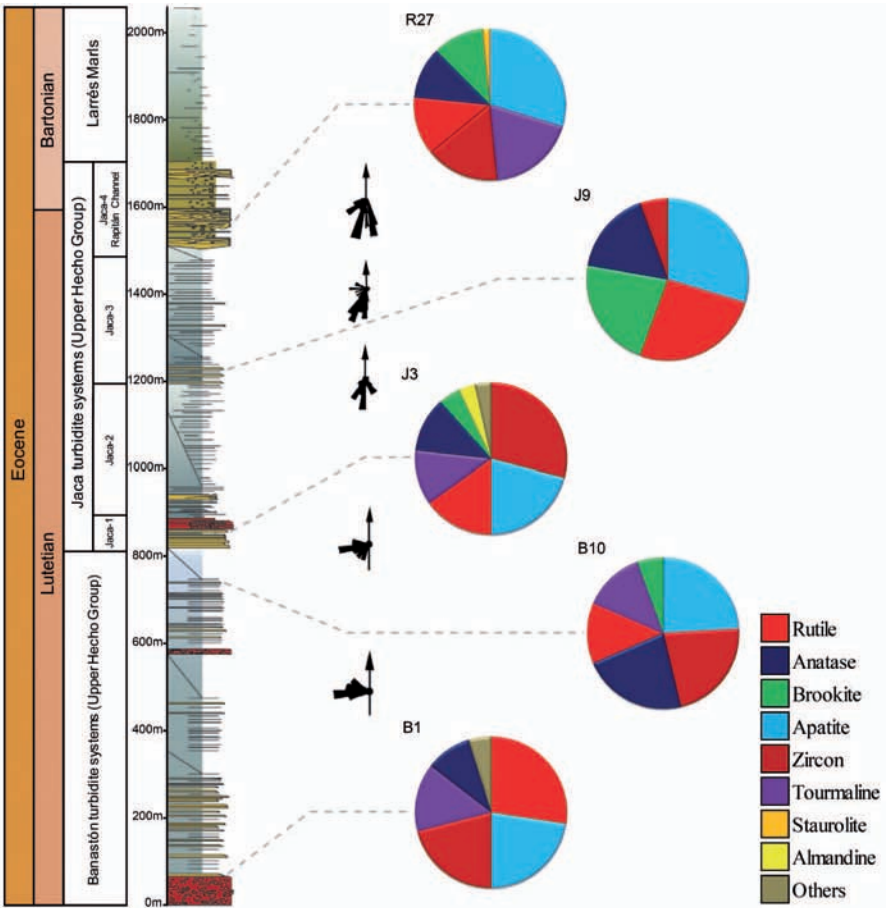


Fig. 1.- Pie charts showing the heavy-mineral assemblages of the turbidite systems. The stratigraphic log is from Roigé *et al.* (2016), where the sample locations can be observed; palaeocurrent data are from Oms, 1994; Oms and Remacha, 1992; Remacha and Fernández, 2003, Remacha and Picart, 1991).

Fig. 1.- Gráficos circulares mostrando las asociaciones de minerales pesados de los sistemas turbidíticos con indicación de la posición de las muestras analizadas. Columna estratigráfica tomada de Roigé et al. *(2016), trabajo en el que se puede apreciar la localización de las muestras; las direcciones de paleocorrientes proceden de Oms, 1994; Oms and Remacha, 1992; Remacha and Fernández, 2003, Remacha and Picart, 1991).*

Atarés delta systems, the Santa Orosia alluvial system and the Canciás alluvial fan.

The Banastón and Jaca turbidite systems belong to the Upper Hecho Group (Remacha and Fernández, 2003). The Banastón system in the study area is constituted by distal turbidites (sandstones and shales) with three interleaved carbonate megaturbidites. Sediments were fed from the east (Remacha *et al.*, 2005), from a source area located in the emerged eastern Pyrenees (Puigdefàbregas *et al.*, 1992; Teixell 1998; Caja *et al.*, 2010).

The Jaca turbidite systems form four composite depositional sequences (CDS 1-4 from Remacha and Picart, 1991). The lower composite depositional sequences (Jaca-1, Jaca-2, Jaca-3) show a composition similar to that of the Banastón systems. By contrast, Jaca-4 (represented by the Rapitán channel-levee complex) displays an increase of sandstone and subvolcanic rock fragments (Roigé *et al.*, 2016). This compositional variation suggests a change of source area related to the Lakora thrust emplacement, which would have created a new source area to the North. The Rapitán channel-levee complex is genetically related to the overlying Sabiñánigo delta, with the turbidites being transitionally replaced by the Sabiñánigo prodeltaic marls (Larrés marls).

The Sabiñánigo Sandstone constitutes a delta system, which prograded towards the SW (Puigdefàbregas, 1975) and comprises prodeltaic and shelfal deposits. Paleocurrent directions suggest sediment input coming from the E and NE, although an additional SE input cannot be precluded (Remacha *et al.*, 1987). This system was fed by two different source areas, located to the north and east, respectively (Roigé *et al.*, 2016). The presence of carbonate extrabasinal clasts and detrital monocrystalline dolomite grains is interpreted to reflect a source area constituted by Mesozoic rocks of the South-Central Pyrenean Unit (Roigé *et al.*, 2013, 2016). The existence of hybrid sandstone clasts is attributed to an early erosion of the turbidite basin (Roigé *et al.*, 2013, 2016).

The Sabiñánigo sandstone is transitionally overlain by the Pamplona marls, which would represent outer shelf deposits and also form the prodelta of the next delta system, the Atarés delta system (Oms and Remacha, 1992).

The Atarés delta systems (Fig. 2) is mostly made of flood-dominated delta front deposits fed from the east (Puidefàbregas, 1975; Oms and Remacha, 1992, Roigé *et al.*, 2016). The Sabiñánigo and Atarés sandstones display the same composition, having the former higher proportions of plutonic and subvolcanic rock fragments (Roigé *et al.*, 2016).

The Santa Orosia fan is characterized by thick conglomeratic beds interlayered with red shales. The source area of this fan is interpreted lie to the N and NE, suggested by a higher proportion of recycled sandstones from the Hecho Group (Roigé *et al.*, 2016). Therefore, a change in the source area occurred between the Sabiñánigo and Atarés delta systems and the Santa Orosia fan, which suggests a major paleogeographic change, which would be related to the onset of the Gavarnie thrust.

The upper Priabonian Santa Orosia alluvial fan marks the beginning of generalized terrestrial sedimentation in the Jaca basin. The continentalization of the basin took place by the diachronic irruption from east to west of the Canciás, Peña Oroel and San Juan de la Peña fans (Late Eocene-Oligocene).

Methodology

Sandstones and conglomerates samples were collected in the Jaca and Yebra de Basa areas. They were crushed, sieved and submitted to vibrating water separation table and to acid digestion with diluted 10% acetic acid (CH_3COOH) prior to heavy mineral separation.

Gravity settling process was done using the none-toxic liquid sodium polytungstate [$Na_6(H2W_{12}O_{40})$]. The recovered heavy minerals of each sample were mounted on slides.

Mineral identification (up to 200 grains per slide) was done under the polarising microscope, whereas opaque, turbid and dubious grains were identified using Raman spectroscopy. This inelastic light-scattering technique is based on the vibrational properties of solids, liquids and gases and the resulting Raman spectra depend on structure and composition. Acquired spectra were compared with reference spectra from several databases and published papers (www.rruff.info; Andó y Garzanti, 2014).

Diagenetic, carbonate and micaceous minerals were eliminated because they do not provide valuable information in provenance analysis.

Results and discussion

Turbidite and deltaic systems are characterized by the highest contents of apatite (Figs. 1 and 2), being higher than 20% in all samples, together with high contents of titanium oxides. Conversely, alluvial systems (Fig. 2) show a very low apatite content (<8%), excepting the Canciás alluvial fan (22,9%, JY36).

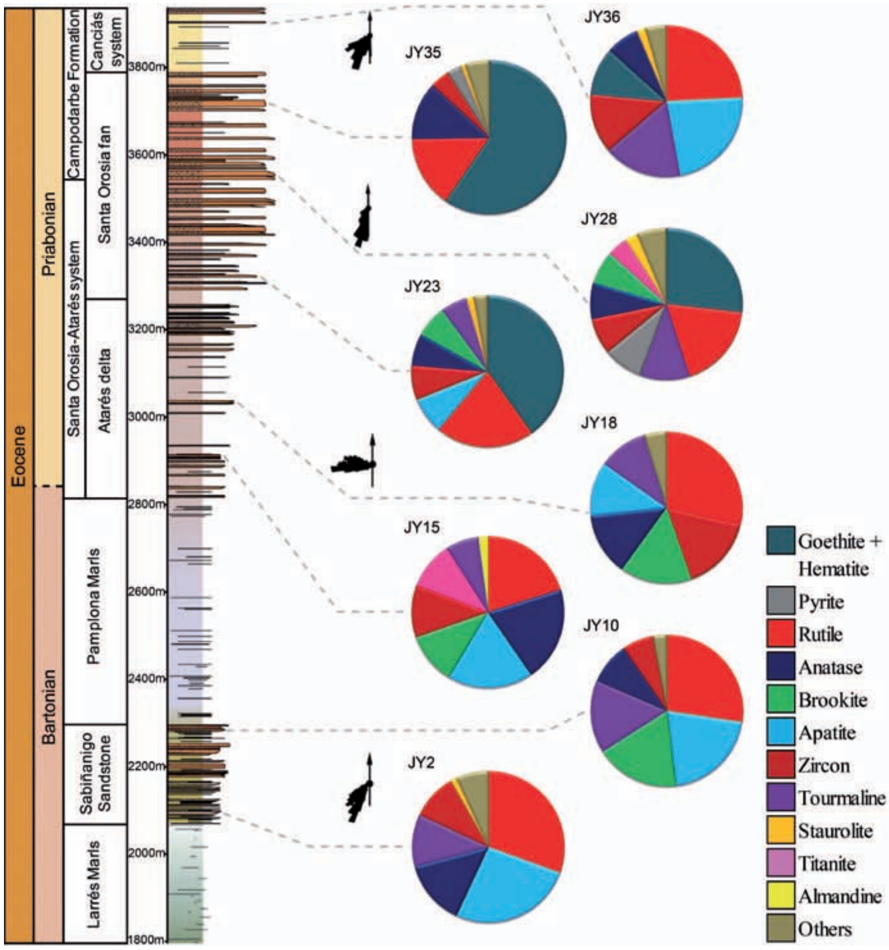
Apatite is commonly an accessory mineral of igneous rocks, most often related to granites. It is a stable mineral under deep burial conditions, so it may have a multicycle origin (Mange-Ratjetzky and Murer, 1991). According to paleocurrents by Remacha and Fernández (2003) and sediment composition (Roigé *et al.*, 2016), the Banastón and Jaca turbiditic systems have an eastern source area. High amounts of feldspar and plutonic rock fragments indicate exhumation of Paleozoic granitoids from the Axial Zone in the eastern Pyrenees (Roigé *et al.*, 2016), which are interpreted as the most likely source for apatite in the present study. Paleocurrents from Remacha y Picard (1991) and the presence of high amounts of carbonate extrabasinal fragments and detrital monocrystalline dolomite grains indicate an eastern origin for these systems (Roigé *et al.*, 2016), which also supports an eastern provenance for apatite. Evidence suggests that apatite is supplied directly from an eastern source area, however its presence in some of the north-sourced deposits (Canciás fan i.e.) must be related to the recycling of the Hecho Group turbidites.

Alluvial systems (Fig. 2), are characterized by very high contents of goethite plus hematite (mainly goethite, up to >60%), which are not present in the former systems. Alluvial fans are also characterized by the lowest contents of apatite (<8%) except for the Canciás alluvial system, where apatite content is higher than 20%. Another characteristic feature of all these systems is the presence of staurolite, which is absent in the former systems but the The Rapitán channel-levee complex (R27) and the lower Sabiñánigo Sandstone (JY2).

The Banastón and Jaca turbidite systems, the Rapitán complex included, display a high content of pyrite grains often related to calcite. Roigé *et al.* (2016) reported the occurrence of foraminifera that are commonly pyritized mainly in the Banastón and Jaca turbidites. Pyritization is a process that occurs in the water-sediment interface where both aerobic and anaerobic bacteria are found. Therefore, a diagenetic origin is deduced for the pyrite of the turbidite and deltaic systems.

Conversely, this diagenetic origin cannot be invoked for pyrite in alluvial fans. The abundance of pyrite in the alluvial systems is low if compared to the turbidite and deltaic systems. On the contrary, these alluvial systems display a high content of hematite and goethite, which display the opposite pattern of abundance. Pyrite oxidation leads to formation of hematite and goethite, therefore, both are interpreted to be derived from pyrite grains and pyrite-bearing bioclasts recycled from turbidite and deltaic deposits, being a clear signal of sediment recycling and a northern provenance.

Staurolite is almost exclusively a product of medium-grade metamorphism. It forms in mica schists derived from argillaceous sediments (Mange-Ratjetzky and Murer 1991) and constitutes a diagnostic mineral of the



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amphibolite grade of metamorphism. Roigé *et al*. (2016) reported the occurrence of metamorphic rock fragments, mainly from schists, in the Santa Orosia and Canciás fans. Puigdefàbregas (1975) documented a northern input for the Santa Orosia and Canciás alluvial fans, based on paleocurrents and facies architecture. A northern provenance has also been suggested for the Santa Orosia fan according to its sandstone composition (Roigé *et al*., 2013, 2016).

The Rapitán complex is the only turbidite, system that records a northern provenance, through a content increase of subvolcanic rocks and sandstone rock fragments, which points to a northern provenance related to the emplacement of the Eaux-Chaudes/Lakora thrust (Roigé *et al*., 2013, 2016). Thus, the presence of staurolite only in systems fed from the north suggests a northern provenance for this mineral. Furthermore, schists of the amphibolite metamorphic facies occur at north, in the Gavarnie and Chiroulet massifs (Barnolas and Chiron, 1996). Therefore, in this work, the presence of staurolite is interpreted as a sensitive indicator of a northen provenance from newly exhumed source areas to the north of the Jaca basin.

Conclusions

Staurolite is an indicator of a northen input and points to a source area constituted by amphibolite facies of metamorphism occurring to the north of the Jaca basin.

Apatite is related to granitic rocks and indicates an eastern provenance related with the Axial Zone in the eastern Pyrenees, where granites were exhumed.

Goethite grains, resulting from pyrite weathering, are clear indicators of sediment recycling.

An eastern provenance for the turbiditic systems of Banastón and Jaca is indicated by their heavy-mineral suites rich in apatite, whereas the first occurrence of staurolite in the Rapitán complex indicates a change in source area. The emplacement of the Eaux-Chaudes/Lakora thrust, which took place at the northern margin of the foreland basin during Rapitán times led to the uplift of new source areas to the north and the exhumation of a Paleozoic basement.

The decrease in apatite content, the presence of staurolite and the high indexes of sediment recycling, evidenced by high contents of goethite, in the Santa Orosia and Canciás alluvial-fan systems indicate a northern provenance with minor input form granitic rocks. This compositional change is related to the onset of the Gavarnie thrust, which again uplifted an area to the north of the Jaca basin. The uplift allowed the erosion of the turbidites producing a heavy-mineral suite rich in recycled pyrite (goethite). Paleozoic basement was also exhumed in some areas and supplied staurolite to the foreland basin.

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