Compositional signatures of the Cenozoic sedimentary successions of the Malaguide Complex (Betic Cordillera, Spain)

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ABSTRACT

The studied Cenozoic sedimentary successions consist of deposits from continental/shallow-water to deep-marine environments of the Malaguide Complex (Betic Cordillera) outcropping in the Sierra Espuña area (SE Spain). The aim of this study is to characterize the composition, source area(s) provenance and weathering processes of these sedimentary successions from the pre-orogenic (Paleocene-Early Oligocene) to the syn-orogenic (Late Oligocene-Early Miocene) stage using petrological and geochemical methodologies. The studied sandstones are mainly quartzolithic with abundant metamorphic and sedimentary lithic fragments. In particular, the composition of samples from the pre-orogenic cycle is mainly carbonate with important siliciclastic components that occur within the medium to fine grained arenites. The composition of samples from the syn-orogenic cycle is characterized by a sharp change from carbonate to siliciclastic terms. Thus, the composition of the overall sandstone samples is very heterogeneous and suggests a source area mainly characterized by the Malaguide basement and lower units of the Internal Betic Zone, that partially compose the Mesomediterranean Microplate. The geochemical proxies suggest a provenance mainly from felsic source area with a minor supply from mafic rocks in some samples of the syn-orogenic stage. Furthermore, palaeoweathering indices indicate low to moderate weathering conditions for the sources. The Cenozoic sedimentary successions of the Malaguide Complex played an important role in the geodynamic evolution of the Betic Cordillera that represents the key tectonic element of the western domains of the Mesomediterranean Microplate.

KEY WORDS: Betic Cordillera, composition, Malaguide Complex, mudrock, provenance, sandstone.

INTRODUCTION

The Sierra Espuña area belongs to the Internal Betic Zone and is located to the west of the Murcia province in SE Spain (Fig. 1A). The Internal Betic Zone mainly consists of three stacked tectonic complexes (Fig. 1B), which in ascending order are: the Nevado-Filabride, Alpujarride and Malaguide Complexes (*e.g.*, Guerrero and Martín-Martín, 2014 and references therein). The tectonic stacking of the Internal Betic Zone is related to the continental collision of the Mesomediterranean Microplate against the South Iberian Margin. In particular, the Malaguide Complex is composed of a Paleozoic basement unconformably covered by a thick,

continuous, unmetamorphosed and complete Meso-Cenozoic sedimentary successions (*e.g.*, Guerrero & Martín-Martín, 2014 and references therein).

The chemical and minero-petrographical features of the sandstone and mudrock samples are considered to be dependent on sedimentary processes, including source rocks, weathering, sorting and tectonic setting (*e.g.*, Arribas *et al.*, 2000; Critelli *et al.*, 2003; Perri *et al.*, 2011, 2014). By combining the information deduced from the petrography and chemistry it is possible to decipher the sedimentary evolution and geological processes affecting sediments and, thus, the relationships between the source area and the sedimentary

Fig. 1 – (A) Geological sketch map of the Internal Zones in the Central-Western Mediterranean region. (B) Schematic geological map of the Betic Cordillera, with indication of the study area. Modified from Vera (2004).

basin (*e.g.*, Critelli *et al.*, 1990; Critelli & Le Pera, 1995; Perri, 2014; Perri & Ohta, 2014).

This work is aimed to a better understanding of the composition, provenance and weathering signatures of the Cenozoic sedimentary successions belonging to the Malaguide Complex (Betic Cordillera) in relation to the later evolution of the westernmost Mediterranean Alpine regions.

GEOLOGICAL SETTING

The Sierra Espuña s.s., structured as an antiformal stack (Espuña Fold), and the Mula-Pliego Basin, arranged as a syncline with several minor folding and thrusting structures, characterize the study (Martín-Martín & Martín-Algarra, 2002).

The Sierra Espuña area is composed of several tectonic units (Alpujarride and Malaguide units). In particular the Malaguide upper units develop a thin Paleozoic basement covered by Triassic to Tertiary sedimentary successions (Martín-Martín et al., 2006).

The Tertiary succession of the Sierra Espuña area (Sierra Espuña s.s. and the Mula-Pliego Basin) is composed of several formations evolving from continental to deep marine sediments. This Tertiary succession is divided into two sedimentary main cycles (pre-orogenic and syn-orogenic, respectively) (e.g., Martín-Martín & Martín-Algarra, 2002; Martín-Martín et al., 2006 and references therein). The pre-orogenic cycle (Paleocene to Early Oligocene) is made up by the Paleocene (Mula Formation), Cuisian-Early Lutetian (Espuña Formation and Valdelaparra Formation), Middle Lutetian-Priabonian (Malvariche Formation and Cànovas Formation) and Early Rupelian (As Formation) depositional sequences. The syn-orogenic cycle (Late Oligocene to Early Miocene) is made up by the Chattian-Late Aquitanian (Bosque Formation and Rio Pliego formation) and the Burdigalian p.p. (El Niño Formation) depositional sequences. Several sandstone (25) and mudrock (25) samples were collected along these Cenozoic formations of the Sierra Espuña area to cover the entire Tertiary succession.

PETROLOGICAL AND DETRITAL MODES

The composition of samples from the pre-orogenic cycle is mainly carbonate with important siliciclastic components that occur within the medium to fine grained arenites (Fig. 2). The samples from the Mula Fm are mainly composed by bioclastic limestones with grainstone, packstone and locally rudstone texture. Siliciclastic component is present in fine-grained sandstones and siltstones and is characterized by subrounded to angular quartz grains and micas (biotite and muscovite). The samples from the Espuña Formation are mainly characterized by basal mixed carbonate and siliciclastic arenites (Zuffa, 1980; Critelli et al., 2007) followed by bioclastic limestones with packstone textures. In particular, the lower layers of the Espuña Fm area is characterized by sandstone samples having a quartzarenitic composition (Fig. 2). The intrabasinal carbonate component (CI) is more abundant and largely increases toward the top (Fig. 2). The samples from the Malvariche Fm are mainly made of calcirudite/calcarene and siltstones. The samples from the As Fm mainly show a quartzarenitic composition (Fig. 2). Such arenites include monocrystalline quartz grains and rare polycrystalline quartz, phaneritic metamorphic lithic and chert fragments. Carbonate component is mainly of extrabasinal origin (CE) and is mainly composed by Paleocene-Eocene bioclasts (Fig. 2).

The composition of samples from the syn-orogenic cycle is characterized by a sharp change from carbonate to siliciclastic terms. The carbonate rocks are only present in the samples from the Bosque Fm that are mainly composed of bioclastic calcarenites. Siliciclastic component is very scarce and is only represented by fine-sand size monocrystalline quartz grains. These calcarenites are poor sorted and several grains are characterized by grain contacts indicating a strong mechanical consolidation. The increase of siliciclastic content is recorded starting from the upper part of the Bosque Fm samples enriched in quartz and micas. The overlying samples from the Rio Pliego Fm are mainly siliciclastic and composed of alternating fine-grained and coarse-grained sandstones and siltstones with minor micro-conglomerates. Sandstones of the lower portions of the Rio Pliego Fm are quartzarenite to

Fig. 2 – Ternary plots of NCE (noncarbonate extrabasinal) - CE (carbonate extrabasinal) - CI (carbonate intrabasinal) and Qm (monocrystalline quartz) - F (feldspars) - Lt+CE (total lithic fragments and carbonate extrabasinal) of the studied samples.

quartzolitic (Fig. 2). They mainly include both monocrystalline and polycrystalline quartz grains; metamorphic lithic grains are also abundant and include rounded and flattered phyllite, slate and secondary fine-grained schist grains and rare metarenites.

The samples from the El Niño Fm are mainly characterized by fine-medium grained sandstones with an average quartzarenitic to quartzolitic composition (Fig. 2). These sandstones have an equal siliciclastic versus carbonate component with a sharp predominance of siliciclastic elements. Quartz grains are the most abundant component, whereas aphanitic metamorphic lithic fragments, represented by few slate and phyllite grains, are strongly depleted respect to the samples of the underlying Rio Pliego Fm.

PROVENANCE AND SOURCE-AREA WEATHERING

The mudrocks of syn-orogenic successions (in particular the El Niño and Rio Pliego formations) are characterized by narrow compositional changes for Si, Al, K and Ca, whereas the mudrocks of pre-orogenic successions show a similar composition with higher concentration of Ca and Sr than the samples of the syn-orogenic successions.

The heterogeneous composition of the studied samples suggests that the Tertiary succession of the Malaguide Complex is related to multiple source areas composed of metamorphic, siliciclastic and carbonate rocks, with a minor

supply of mafic rocks. The basement rocks of the Malaguide Complex mainly consist of a pre-Ordovician to Late Carboniferous siliciclastic, siliceous and metasedimentary (slate, phyllite, carbonate and quartzite) succession including thin carbonate lenses and conglomerate bodies with some clasts of acid plutonic rocks (Vera, 2004). The composition of the pre-orogenic cycle rocks is dominantly carbonatic, as highlighted by both petrographical and chemical data. The beginning of the syn-orogenic cycle (i.e. Bosque Fm) is marked by a continuous carbonate debris supply from the early Tertiary units of the Malaguide Complex. The strong increase of siliciclastic component starting from the Rio Pliego Formation indicates a marked change of the source area from the Late Palaeozoic to early Mesozoic metamorphic and

Fig. 3 – (A) Cr+Ni vs. Fe+Mg diagram of the studied mudrocks, showing the provenance from mixing source rocks. (B) Y/Ni vs. Cr/V diagram of the studied mudrocks, showing the mixing trend between mafic and felsic sources.

terrigenous basement of the Morrón de Totana unit (e.g., (Martín-Martín & Martín-Algarra, 2002; Martín-Martín et al., 2006).

Chemical data of the mudrock samples show that some samples of the Rio Pliego and El Niño formations are enriched in Fe+Mg and Cr+Ni suggesting a mafic contribution for the syn-orogenic samples (Fig. 3A). Furthermore, the distribution

of the samples of the Rio Pliego and El Niño formations in the Y/Ni vs. Cr/V confirms a mafic supply for the syn-orogenic samples (Fig. 3B). Such formations probably recorded a provenance signal from volcanic or ophiolitic members of the Alpujarride or Alpujarride-Malaguide units (Martín-Martín et al., 2006).

The source rocks are generally affected by weathering

Fig. 4 – Ternary A-CN-K diagram. Legend: Ms, muscovite; Ilt, illite; Kln, kaolinite; Chl, chlorite; Gbs, gibbsite; Smt, smectite; Bt, biotite; Kfs, K-feldspar; Plg, plagioclase; A, Al_2O_3 ; CN, $\text{CaO}+\text{Na}_2\text{O}$; K, K_2O ; CIA, Chemical Index of Alteration (Nesbitt & Young, 1982).

processes that can be evaluated and quantified by the chemical index of alteration (CIA; Nesbitt & Young, 1982) with the A-CN-K (Al_2O_3 , $\text{CaO}+\text{Na}_2\text{O}$, K_2O) diagram, where CaO^* represents Ca in silicate minerals only.

The studied mudrocks show low to moderate CIA values (from 53 to 69 for the samples of the pre-orogenic cycle; from 54 to 71 for the samples of the syn-orogenic cycle). The mudrocks are plotted in the A-CN-K triangular diagram in a wide group following a trend toward the illite-muscovite point of the A-K join (Fig. 4). This trend indicates a source area with low to moderate weathering in non-steady-state conditions that change from the pre-orogenic to the syn-orogenic cycle. Furthermore, this pattern is typical of a source area where active tectonism allows erosion of all weathering profile developed on source rocks. The geodynamic evolution of the Sierra España area is characterized by several uplift and erosional processes related to the active tectonism of the studied area, during the Paleocene-Early Miocene and, thus, during the transition from the pre-orogenic to syn-orogenic cycle.

CONCLUDING REMARKS

The tectonic evolution of the Malaguide Complex during the Paleocene to Miocene is complex, particularly in the Sierra España area, and is marked by different structural stages that strongly influenced the provenance, composition and source-

area weathering of sediments deposited in the Mula-Pliego basin (e.g., Martín-Martín et al., 2006).

The composition of sandstones from the pre-orogenic cycle (Paleocene-Early Oligocene) is mainly carbonate with important siliciclastic components that occur within the medium to fine grained arenites. The composition of samples from the syn-orogenic cycle (Late Oligocene-Early Miocene) is characterized by a sharp change from carbonate to siliciclastic terms. Thus, the heterogeneous composition of the overall sandstone samples indicates a multiple source area mainly characterized by the Malaguide basement and the lower units of the Internal Betic Zone. These features in term of provenance are also confirmed by the geochemical proxies that suggest a provenance mainly from felsic source area with a minor supply from mafic rocks in some samples of the syn-orogenic stage. The paleoweathering index (CIA) indicates a source area with low to moderate weathering in non-steady-state conditions, characterized by active tectonism in the studied area, that changes from the pre-orogenic to the syn-orogenic cycle. The geodynamic evolution of the Sierra Espuña area experienced several uplift and erosional processes related to the active tectonism of the studied area, during the Paleocene-Early Miocene and, thus, during the transition from the pre-orogenic to synorogenic cycle.

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