

Hydraulic brecciation on top of the Alboran Domain and its relationship with Lower Miocene deposits (Western Betics)

Brechificación hidráulica a techo del Dominio de Alborán y su relación con los depósitos del Mioceno inferior (Béticas occidentales)

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RESUMEN

Al oeste de las Cordilleras Béticas, se describen unos cuerpos de brechas dentro del Complejo Maláguide, muy similares a las brechas del Mioceno inferior del grupo Viñuela. La distribución, geometría interna y características petrográficas de dichos cuerpos muestran que pueden haberse formado durante procesos cataclásticos acompañados por fracturación hidráulica. Se sugiere que estos cuerpos de brechas tectónicas nutren las brechas sedimentarias del grupo Viñuela.

Palabras clave: Betics, Alboran Domain, Malaguide Complex, breccia, hydraulic fracturing.

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Introduction

The internal zone of the Betics, the Alboran Domain, is formed by a post-metamorphic nappe-stack, strongly thinned during the Miocene back-arc rifting which produce the development of the Alboran Basin in the Gibraltar Arc hinterland (García-Dueñas *et al.*, 1992, Comas *et al.*, 1992) (Fig. 1A). As a consequence, low-angle normal faults affected the Alboran Domain units and marine transgressive sediments deposited. Good example of the relationship between the metamorphic basement and the oldest sediments deposited during rifting can be observed in an area situated north of Malaga (Fig. 1B). There, the brittle boundaries between the Malaguide and the Alpujarride Complexes, the uppermost Complexes of the Alboran Domain, are sealed by the Viñuela group (Martín-Algarra, 1987), which in turn is situated below the wildflysch-type rocks of the so-called Alosaina Complex as defined by Balanyá and García-Dueñas (1986). While La Viñuela group is well known (Serrano *et al.*, 2006), the origin, nature, and tectonic significance of the Alosaina Complex is still a matter-of-debate.

The aim of this paper is to shed light on the nature of the boundary between the Alboran Domain, the Viñuela group and the Alosaina Complex along the easternmost outcrops of this latter (Fig. 1A). We reveal the presence of breccia

bodies formed by cataclastic and hydraulic fracturing in the upper part of the Malaguide Complex. Their geometry and their relationship with the Viñuela group and the Alosaina Complex suggest that the tectonic breccias could have nourished the Viñuela deposits. By contrast, the described faults are sealed by the Alosaina Complex.

Geological context

In the study area, the Alboran Domain is mainly represented by the Malaguide Complex (Fig. 1B). Only a small outcrop of Alpujarride rocks is present, composed of garnet and andalucite schists. It is situated structurally below the Malaguide Complex, which in turn is characterized by Silurian black phyllites, together with Devonian and Carboniferous phyllites interbedded with carbonatic levels. The boundaries between these formations are frequently low-angle normal faults which affect not only the Alpujarride-Malaguide contact but also the whole Malaguide (Alonso-Chaves *et al.*, 1993). On top of the Malaguide sequence, unmetamorphosed red conglomerates and sandstones of Permo-Triassic age deposited unconformably over the low grade metamorphic rocks.

In the study area, two Miocene sedimentary formations are transgressive over the Malaguide rocks (Fig. 1B). The

most characteristic member of the lower one is a polymictic breccia made of heterometric clasts of Malaguide and Alpujarride origin. It corresponds to the Viñuela group dated as lower Burdigalian (Serrano *et al.*, 2006) and records the initial stages of the rifting of the Alboran Domain. The upper one is an olistostromic complex made up of boulders of internal and external domain rocks in a matrix of marls and sandy sediments, the Alosaina Complex of Balanyá and García-Dueñas (1986) (Neonumidian of Bourgeois, 1978, or Numidoide of Martín-Algarra, 1987). These authors attributed the age of this complex to Middle Burdigalian.

Detailed mapping reveals the presence of two sets of medium to high angle normal faults that affected the unconformity between the Malaguide and Neogene rocks. They are NE-SW and NW-SE directed (see rose diagram in Fig. 1B).

Breccia bodies within the Malaguide: characteristic features

North of Riogordo village, the Carboniferous phyllites interbedded with carbonatic levels from the upper part of the Malaguide complex are highly brecciated. The process of fracturation is so developed that, when the outcrops are poor, they seem to be an avalanche deposit similar to

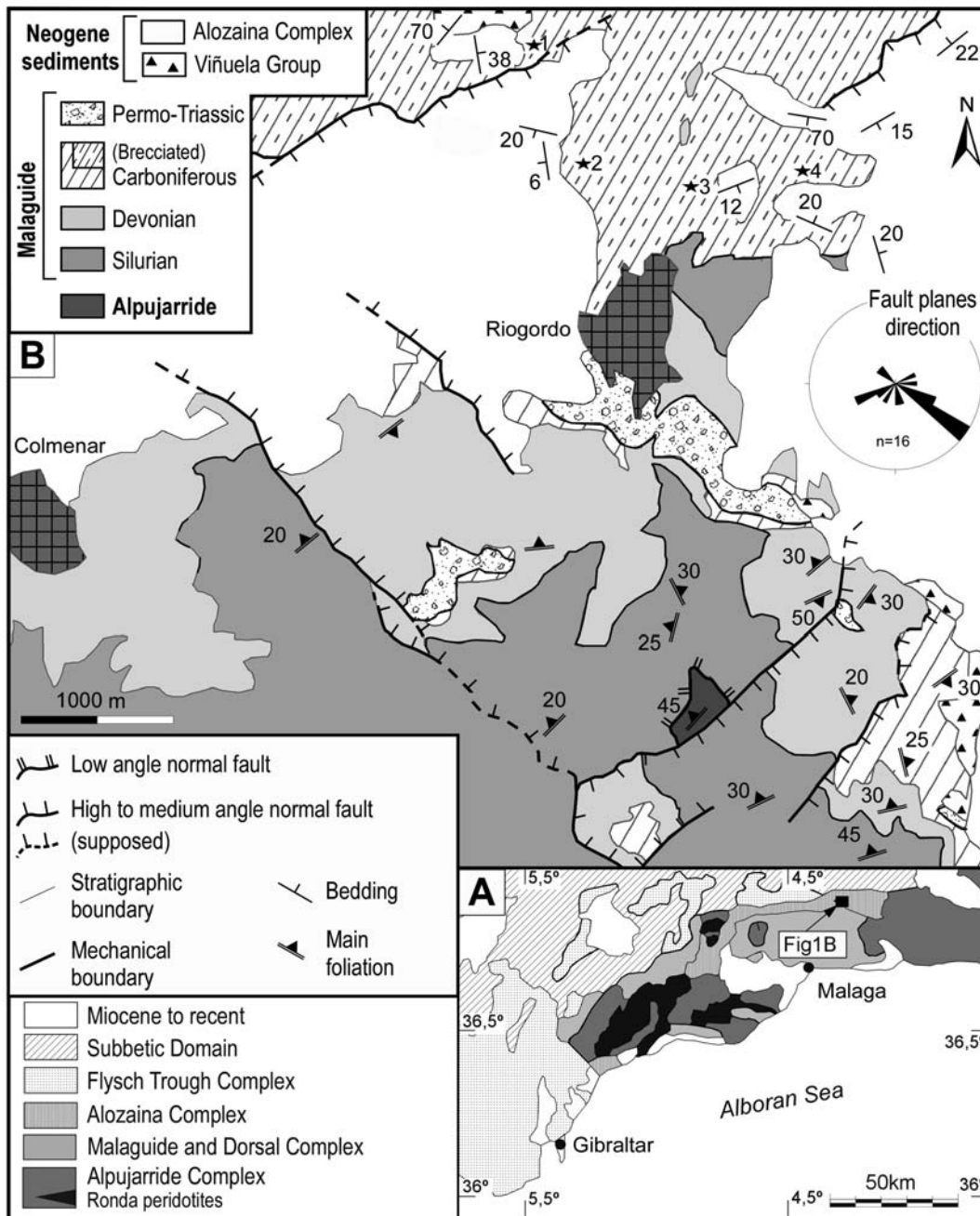


Fig. 1.- A) Main complexes in western Betics. B) Geological map of the studied area, modified from Barba Martín et al. (1979). Stars show the location of the photographs of figures 2 and 3.

Fig. 1.- A) Complejos principales en las Béticas occidentales. B) Mapa geológico de la zona de estudio, modificado de Barba Martín et al. (1979). Las estrellas muestran la localización de las fotografías de las figuras 2 y 3.

the lower member of the Viñuela group. Nevertheless, a careful examination, in particular along road trenches (stars of Fig. 1B), shows that these breccias are in fact discontinuous bodies hosted within the Carboniferous rocks (Fig. 2A). Accordingly, in map of Figure 1B they are differentiated as «Brecciated Carboniferous».

These breccia bodies have variable size, with length ranging from some tens of meters to less than a meter, and width from a few centimeters to a meter. They are frequently parallel to the Malaguide phyllite foliation, mainly subhorizontal north of Riogordo, with a sill geometry (Fig. 2A), or following low-angle normal fault planes. They can also show a branched

or anastomosing geometry, and sometimes crosscut the foliation (dyke geometry). When present, high angle faults cut the breccia bodies (Fig. 2A).

At hand-sample scale, the breccias are clasts dominated (40-70%), although the matrix is always present. The dun-yellowish color of this latter, which contrasts with the greenish tones of the phyllites, is the most distinctive feature of the breccia. The clasts are mainly angular (Fig. 2B) but can also be sub-rounded (Fig. 2C, 3A and 3D) and scarcely well-rounded (Fig. 3B). The breccias are highly heterometric and mono- to polymictic (Figs. 2 and 3). Indeed, the clasts range from a few millimeters to some decimetres, and their composition is similar to that of the host rock (phyllite, carbonate

rocks, monomineralic quartz or greywackes, e.g. Fig. 2B).

The clasts are frequently fractured, with separation and differential rotation between fragments (Figs. 2C and 3A), as evidenced by the foliation marked by the micas inside the clasts. It is frequent to observe how the elongated clasts follow a dominant direction, which in turn is subparallel to the hostwall (Fig. 2C). Finally, a size sorting of the clasts can be observed. It is subperpendicular to the hostwall and shows a higher concentration of the finer portion near of the host wall margins (Fig. 3C).

At thin-section scale, the matrix is made of fine-grained quartz, micas and carbonate minerals, together with a finer portion whose composition has been determined by X-ray diffraction



Fig. 2.- A) Representative breccia body within the Malaguide Complex with a sill geometry. It is cut by a high-angle normal fault. Note the lack of lateral continuity. Location: Star 3 of Fig. 1B. B) Detail of the polymict breccia with heterometric clast population. C) Small subvertical breccia body with angular and sub-rounded clasts. Location: Star 1 of figure 1B.

Fig. 2.- A) Cuerpo de brechas representativo dentro del Complejo Maláguide con geometría tipo sill. Se encuentra cortado por una falla normal de alto ángulo. Nótese la ausencia de continuidad lateral. Localización: Estrella 3 de la Fig. 1B. B) Detalle de la brecha polimictica con clastos heterométricos. C) Pequeño cuerpo de brechas subvertical con clastos angulares y sub-redondeados. Localización: Estrella 1 de la figura 1B.

(dolomite, ankerite, calcite, quartz and phyllosilicates), that suggests a mixed nature between a carbonatic cement and very fine rock fragments. Scarcely, the mica grains of the matrix can draw a cataclastic foliation.

Cement is always present and in some cases can be the only component in the matrix. The cement composition is mainly calcite, although small rhombohedral dolomite crystals of replacement have been observed (Figs. 3D and 3E).

Various generations of veins filled by calcite are present. Narrow rims surrounding the clasts (Fig. 3B) and veins filling intraclasts cracks are characteristic geometries of those identified as the oldest ones. Veins filled by calcite of higher crystal size represent late generations (Fig. 3A).

Discussion and conclusions

The breccias described in the previous paragraph can have originated either during sedimentary or tectonic processes. At the moment, we discard a sedimentary origin. Indeed, the clast transport should have been small, as a) the wall rocks and the clasts show the same composition and b) the breccias are highly heterometric.

Moreover, the sill geometry of the breccia bodies, within the Malaguide Complex host rocks would have implied a transport of the sediments from up to down, through neptunian dykes, which

have not been observed. Finally, no fossils have been found (although this argument does not exclude a sedimentary genesis).

We suggest that the breccias have a tectonic origin, and generated during processes of cataclastic breakage accompanied by hydraulic fracturing. Indeed, they are not simple cataclastic rocks limited to continuous fault planes (Twiss and Moores, 1992), but are distributed as sill-like bodies included within the upper part of the Malaguide Complex (fig. 2A), although the breccias bodies sometimes also mimic the surfaces of low-angle normal faults. Moreover, at smaller scale, cataclastic foliation in the studied breccias is only very scarce and the presence at same time of large rounded and highly angular clasts (Fig. 3B) is incoherent with cataclastic fault breccias (Storti *et al.*, 2007). Accordingly, the roundness of the clasts should be due to a remobilization of the fragments, and it is proposed that this remobilization would have occurred during fluid circulation associated with a mechanism of hydraulic fracturing (e.g. Hulen and Nielson, 1988). This process would also explain the size sorting of the clasts perpendicular to the host wall (Fig. 3C; Chown and Gobeil, 1990), the fabric without cataclastic foliation and the fact that the matrix is sometimes composed only by cement (Katz *et al.*, 2006). In the other hand, dolomite of replacement is also indicative of fluid circulation.

If the breccias were formed as a consequence of both processes, hydraulic and cataclastic fracturing, it is not possible yet to determine their relative chronology. Nevertheless, a possible scenario would be that the faults and fractures in the Malaguide rocks acted as pathways for the fluid circulation and subsequent hydraulic fracturing. This interpretation would explain the existence of different breccia fabrics, in terms of clast shape, presence of cataclastic foliation and composition of the matrix, from one sample to another.

The similarity of the breccias forming bodies in the Malaguide Complex with those of the avalanche deposits of the lowest member of Viñuela group and the fact that the tectonic breccias of Riogordo area are situated immediately below the Viñuela sedimentary deposits (Fig. 1B), suggest that the tectonic breccias could have nourished the sedimentary ones. If so, the tectonic processes that produced the breccia bodies would have been previous to the lower Burdigalian. It is also possible that tectonic and sedimentary processes acted coeval. In this case, brecciation of the uppermost levels of the Malaguide Complex would have occurred at very shallow conditions, but in which the presence of highly pressurized fluids required for hydraulic fracturing would be difficult to explain. Finally, in the studied area,

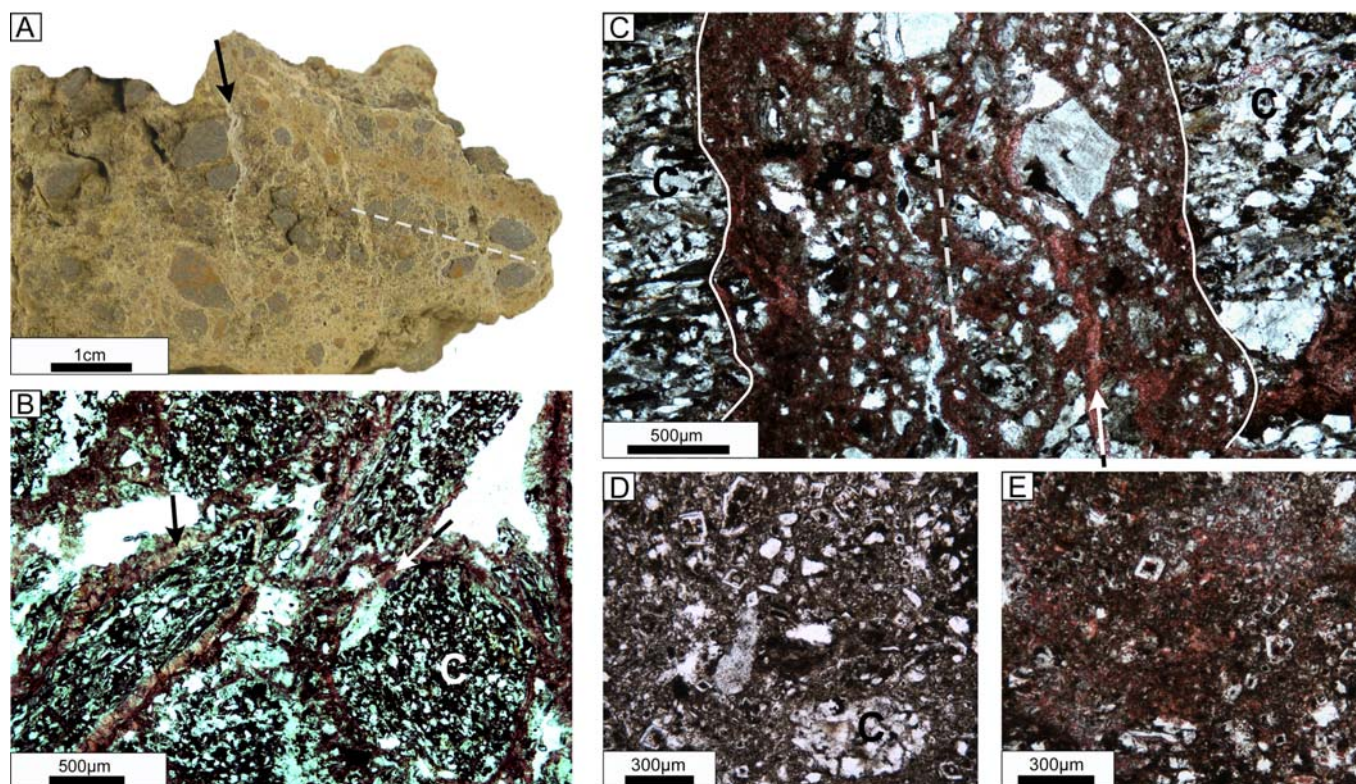


Fig. 3.- A) Hand-sample with grain size sorting. The band of centimetre-scale sub-rounded clasts bounded by microscopic-scale matrix marks a flow direction (dashed line). Note the veins, which cut the band of clasts (arrow). **B)** Clasts surrounded by calcite veins forming narrow rims (arrows). Note the well-rounded clast (C) (tinted thin-section). **C)** Grain size sorting at thin-section scale with smaller clasts in the neighbouring of the host rock walls (continuous lines) and indicating the flow direction (dashed line). The arrow shows a vein aligned with the flow (tinted thin-section). **D and E)** Cement with rhombohedral crystals of replacement dolomite (E: tinted thin-section). Location of hand-sample: Star 4 of Fig. 1B. Location of thin sections: Star 2 of Fig. 1B.

Fig. 3.- A) Muestra de mano con granoselección. La banda de clastos sub-redondeados de tamaño centimétrico y delimitada por una matriz de tamaño microscópico marca una dirección de flujo (línea discontinua). Nótese las venas que cortan la banda de clastos (flecha). *B)* Clastos rodeados de venas de calcita formando delgados anillos (flechas). Nótese el clasto altamente redondeado (C) (lámina delgada teñida). *C)* Granoselección a escala microscópica con los clastos de menor tamaño cerca de la roca encajante (líneas continuas) e indicando la dirección de flujo (línea discontinua). La flecha muestra una vena alineada con el flujo (lámina delgada teñida). *D y E)* Cemento con cristales romboédricos de dolomita de sustitución (E: lámina delgada teñida). Localización de la muestra de mano: Estrella 4 de la Fig. 1B. Localización de las láminas delgadas: Estrella 2 de la Fig. 1B.

Alozaina Complex attributed to Middle Burdigalian seals the relationships between both types of rocks and is affected by normal faulting (medium to high angle faults, Fig. 1B).

Breccias formed with fluid-assisted process have been described by Comas and Soto (1999) in the Alboran Basin. They are very similar to the rocks described in the present paper, and they show the same replacement dolomite habitus observed in Riogordo area, although they developed in the upper Alpujarride Complex. These authors suggest that breccias and fault-gouge zones were an important pathway for fluids that produced dolomitization after the brittle deformation.

Acknowledgments

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