The composite Sierra Bermeja Pluton (southern Iberian Massif): science, heritage and geoconservation

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ABSTRACT

The Sierra Bermeja Pluton (~60 km² surface area) exemplifies a type of controversial granites of the Iberian Massif (European Variscan Belt), the cordierite-bearing ‘Serie Mixta’ (mixed series) monzogranites. The pluton is included almost completely in the Cornalvo Natural Park (Badajoz, Spain), a relevant target area in Roman times. The geological mapping summarised in the presented map at 1:10,000 scale has revealed a complex intrusive assemblage. Three main cordierite-bearing monzogranite types that show local varieties constitute most of the massif. Monzogranite intrusions are younger towards the centre of the pluton and gave rise to outstanding mappable mingling/mixing zones in some areas. A NE-SW trending reduced dyke complex composed by vaugnerite series rocks, lamprophyres, aplites and quartz dykes, completes the lithological assemblage of the pluton. An inventory of Geologic Points of Interest to promote the geological knowledge of this remarkable protected area and its geoconservation is also presented.

1. Introduction

Precise geological maps constitute the basis of studies such as those applied in resources exploration, civil engineering, environmental geosciences and natural hazards (Lisle, Brabham, & Barnes, 2011). Indeed, their accuracy is decisive to prevent severe economic and/or human losses, and the progress of the scientific knowledge requires as well accurate maps. This is the case of the Igneous Petrology, where detailed mapping of granitic areas is essential. Granitic rocks dominate the upper continental crust and, since the crust records the evolution of the Earth through time, their study provides essential information about major geological processes (Bonin, Azzouni-Sekkal, Bussy, & Ferrag, 1998; Hawkesworth et al., 2010; Rudnick & Gao, 2014). Igneous intrusions often form large adjacent arrays of multiple plutons (batholiths), in many cases up to several thousands of km² in surface area (e.g. Strathbogie Batholith in the Lachlan Fold Belt, Sierra Nevada Batholith in the Cordilleran Belt, Gangdese Batholith of Himalaya, Spanish Central System in the Iberian Variscan Belt, etc.), where the study of discrete magma batches is feasible (Pitcher, 1997; Villaseca & Herreros, 2000). In such extensive batholiths, a regional scale mapping could be the best initial approach (e.g. Casini et al., 2015; Martínez Catalán et al., 2007; Porquet et al., 2017). However, as a result of the usual complex assemblage of different magma pulses, detailed maps are mandatory for specific researches (e.g. Cobbing, 2000; Díez Fernández, Martín Parra, & Rubio Pascual, 2017; Díez Fernández, Rubio Pascual, & Martín Parra, 2018, in press; Sarrionandia et al., 2013).

The interest of mapping granitic areas furthermore transcends the purely scientific realms. Granitoids have been highly exploited through History (e.g. Barral I Altet, 1991; Sureda, 1991). In the Egyptian, Greek and Roman Civilisations, granites represented an essential construction material in dams, aqueducts, temples, circuses and other monumental buildings due to their durability (Barral I Altet, 1991; Sureda, 1991; Wilson Jones, 2000). While this use as building or dimension stone still remains, granites are currently prospective targets of maximum interest since modern technologies require granite-related ore deposits for the increasing demand of Rare Earth Elements (REE), precious and critical metals (Chakhmouradian & Zaitsev, 2012; Linnen, Lichtervelde, & Černý, 2012; Sial, Bettencourt, De Campos, & Ferreira, 2011).

Since geology is part of all natural systems, the care for geological heritage is undeniably essential for an
effective nature conservation (Brilha, 2002). The preservation of geological entities involves the protection of the space where those objects or entities are found (Carreras & Druguet, 2000). In this sense, protected areas such as National Parks or Natural Reserves play an important role, not only in preserving habitats, ecosystems and species, but also safeguarding landscape features and rock exposures (Dingwall, 2006). In terms of geoconservation (Brocx & Semeniuk, 2007), the recognition of Geoparks (UNESCO Earth-Sciences Division) and the Global Geosites Project (International Union of Geological Sciences, IUGS) are valuable frameworks for the governmental management (e.g. Carreras & Druguet, 2000; Wimbledon et al., 2000). According to IUGS procedures, geological map sheets, at least at scale of 1:50,000, are needed in order to display, among others, the location and extent of a Geosite (Wimbledon et al., 2000).

In this contribution we present a detailed geological map at 1:10,000 scale of a composite granitic pluton, the Sierra Bermeja Pluton, which is encompassed in part within a protected area of remarkable natural and historical interest, the Cornalvo Natural Park (Badajoz province of Spain). Despite the relatively small surface area (~60 km²), the resulting map reveals a complex igneous architecture consequence of several magma intrusions. The purpose of this contribution is twofold. On one hand, the map constitutes the base for specific contributions on the petrogenesis of the Sierra Bermeja Pluton, and since this pluton is representative of the controversial cordierite-bearing granites of the Iberian Massif, it is intended to serve as reference for upcoming mapping of such granites there and elsewhere. The map also includes a thorough inventory of noticeable geological (Geological Point of Interest, GPI; Table 1) and of other nature sites of interest (Main Map) aimed to be taken into account by the Cornalvo Natural Park administration in terms of geoconservation and geological heritage.

2. Geographical and geological setting

The Sierra Bermeja Pluton (731773.6–746353.8; 4322473.8–4331664.5; UTM zone 29N) is located 15 km northeast of the City of Mérida, at the border of Cáceres and Badajoz provinces (Spain). The main accesses to this pluton depart from the villages of Aljucén, Mirandilla and Trujillanos (Figure 1). This area is encompassed within the Guadiana Basin, south of the Sierra de San Pedro and Montánchez Ranges, and immediately north of the Sierra Bermeja Range (Main Map). The climate is temperate with dry and hot summers (Agencia Estatal de Meteorología de España, AEMET & Instituto Portugués do Mar e da Atmosfera, IPMA, 2011) characterised in the studied area by low humidity (60–65% as average) and rainfall values (450–550 mm per year as average), not very cold winters (hardly ever < 0°C) and specially dry and hot summers, often above 40°C (AEMET, 2012). The landscape is characterised by a sparse forest (‘dehesa’; Main Map, G-1) composed by a variety of holm oak and cork oak groves that cover a smooth topography (250–350 m.a.s.l) sprinkled with formations of large rounded granitic boulders (‘berrocal’; Main Map, G-2, G-3, G-4). The drainage system of the mapped area is governed by the Aljucén and Albarregas Rivers. This hydrographic network, defined by a roughly dendritic pattern, includes minor streams (Fresneda, Muelas, San Pablo and Gamo) and the Cornalvo and Muelas major reservoirs (Main Map, G-5).

The granitic massif is almost completely included within the Cornalvo Natural Park (Decree 27/1993, on 24 February 1993; Law 7/2004, on 19 November 2004). Also, since the year 2000 the area is included in the European network Natura 2000 and is regulated as Protected Area for Birds (ZEPA; Directive 79/409/CEE, on 2 April 1989), Places of Community Interest (LIC, Directive 92/43/CEE, on 19 July 2006) and Area of Special Conservation (ZEC, Decree 110/2015, on 19 May 2015). This region has been occupied since the Antiquity, standing out the uncountable Roman remains related to the colony of Emerita Augusta (current Mérida). In fact, the granitic rocks were used by the Romans for the construction of roads and bridges (Camino de la Plata/Vía de la Plata), monumental buildings of Emerita Augusta (e.g. the amphitheatre or the theatre), and structures for water supply such as the Cornalvo and Proserpina Dams or the Los Milagros Aqueduct (Álvarez Martínez & Nogales Basarrarte, 2014; Gil Montes, 2004; Nogales Basarrarte, 2007; Pizzo, 2004).

In geological terms, the Sierra Bermeja Pluton is located in the southern Iberian Massif (Figure 2) that is at the innermost part of the Variscan Foldbelt characterised by large granitic batholiths (e.g. Bea, Montero, & Zinger, 2003; Castro et al., 2002; Corretgé, Ugidos, & Martinez, 1977; Roda-Robles et al., 2018; Villaseca, Barbero, & Rogers, 1998; Villaseca & Herreros, 2000). Among these batholiths, stand out the cordierite-bearing monzogranites of the so-called ‘Serie Mixta’ (mixed series), whose origin sits between hybrid (crustal + mantle) and exclusively crustal (e.g. Alonso Olazabal, Carracedo, & Aranguren, 1999; Castro et al., 1999; Castro et al., 2002; Corretgé et al., 1977; Corretgé, Castro, & García-Moreno, 2004; García-Moreno, Corretgé, & Castro, 2007; González Menéndez, 2002). In this sense, the Sierra Bermeja Pluton is suitable for the study of the genesis of these particular granitoids.

At the local scale, the pluton locates in the middle of the Variscan Nisa-Alburquerque–Los Pedruecos Magmatic Alignment (Figure 2, Main Map), close to one of the major suture zones of the SW Iberian Massif (e.g. Bandrés et al., 2004; García-Lobón et al., 2014; Martín Parra et al., 2006). In the studied area, two Oroogenic Cycles are recognised: the Cadomian Orogeny, better discerned south of the suture zone, and the Variscan Orogeny, the most notorious one north of the
Table 1. Inventory of Geological Points of Interest (GPI).

| N° GPI | Coord. (UTM zone 29N) | Description |
|--------|------------------------|-------------|
| GPI-01 | 731395.7 432597.4      | Neoproterozoic dioritoids |
| GPI-02 | 746049.3 432670.9      | Paleozoic shales, slates and quartzites |
| GPI-03 | 744905.3 432260.1      | Intrusive contact between monzogranites and host rocks |
| GPI-04 | 738039.9 432433.1      | Andalusite spotted hornfels |
| GPI-05 | 735972.8 432266.7      | Cenozoic cover |
| GPI-06 | 744876.8 432266.7      | Intrusion of MU into the OU (The Rugidero Berrocal) |
| GPI-07 | 744593.7 432285.2      | OU main type |
| GPI-08 | 744842.8 432270.5      | K-feldspar phenocrysts large accumulations (The Rugidero Berrocal) |
| GPI-09 | 741257.0 432902.0      | K-feldspar phenocrysts large accumulations |
| GPI-10 | 740653.9 432377.4      | Microgranular mafic magmatic enclaves |
| GPI-11 | 745493.0 432583.4      | OU local variety |
| GPI-12 | 745190.2 432599.7      | Sheet-by-sheet intrusions between the main type of the OU and its local variety |
| GPI-13 | 744208.3 432652.5      | Intrusion of MU into the OU |
| GPI-14 | 740363.8 432718.0      | Mixing/mingling relations between the MU and IU |
| GPI-15 | 736734.4 432762.6      | Mixing/mingling relations between the MU and IU |
| GPI-16 | 740774.4 432487.5      | MU main type |
| GPI-17 | 741751.6 432503.7      | MU main type |
| GPI-18 | 745440.4 432436.7      | MU local variety |
| GPI-19 | 743868.0 432399.6      | MU local variety |
| GPI-20 | 738828.1 432798.5      | IU main type |
| GPI-21 | 735853.5 432869.4      | IU main type |
| GPI-22 | 743934.1 432516.2      | IU local variety |
| GPI-23 | 743830.8 432835.9      | Vaugnerite series rocks |
| GPI-24 | 737667.2 432734.2      | Vaugnerite series rocks |
| GPI-25 | 742424.8 432398.4      | Lamprophyre dyke |
| GPI-26 | 743902.8 432479.9      | Lamprophyre dyke |
| GPI-27 | 744399.3 432480.0      | Aplite dyke |
| GPI-28 | 738511.4 432783.5      | Quartz dyke |

Published maps that include the Sierra Bermeja Pluton were developed in the frame of regional scale geological projects. For this reason, in these maps the terminology and spatial distribution of granitic units within this pluton are confusing. The first maps (1:50,000 scale) date back to 1946 and 1949 and were conducted by the Geological and Mining Institute of Spain (IGME) during the first MAGNA series (Marín y Bertrán de Lís, 1946; Roso de Luna & Palacios, 1949). These maps were later updated in a second MAGNA series (Del Olmo Sanz, Matia Villarino, Olivé Davó, & Huerta Carmona, 1992; López Sopena, Matia Villarino, del Olmo, & Ortega Ruiz, 1990). Previously to the second MAGNA series, Gonzalo (1987) proposed a geological scheme for the area of Mérida (1:2,50,000 scale) distinguishing a biotite-bearing porphyritic granite in the outermost sector of the pluton, and a two-mica cordierite-bearing granite in the centre. Afterwards, Sarrionandia, Carracedo, Eguíluz, and Apalategui (2004) proposed another geological scheme (1:2,50,000 scale) of the Sierra Bermeja Pluton dividing the two-mica-cordierite-bearing granite of Gonzalo (1987) in two new units. Since 2004, the IGME is providing the Continuous Geological map of Spain (GEODE) at 1:50,000 scale but the detailed cartographic information of the Sierra Bermeja Pluton still remains unsolved in that continuous map.
4. Methods

Preliminary research was made by means of the interpretation of Light Detection And Ranging (LIDAR) images of 5 m resolution and orthophotographs of the National Plan of Aerial Orthophotography (PNOA, 2009, 2011, 2013). Image analysis allowed the location of the main outcrops, planning of field itineraries and delineation of the contact between granites and host rocks. This preliminary map design was at 1:25,000 scale, using the Mirandilla (0752-IV), Carmo- nita (0752-II) and Conquista del Guadiana (0753-III) sheets of the Topographic Map of Spain (MTN).

The fieldwork scale was 1:5000, establishing 447 observation stations (7–8 station/km²) that were georeferenced by a Geographical Positioning System (GPS) receiver. During 42 days of fieldwork the outcrops were described in detail in terms of rock structure, texture,
fabric and mineralogy. In order to determine the different rock types that constitute this pluton, a series of criteria were defined. Rocks classification in each observation station following these criteria allowed to establish the rock types with a high level of detail in the map. Additionally, detailed field observations allowed to establish the spatial and timing relations between the different rock types. Finally, an inventory of 28 Geological Point of Interest (GPI; Table 1) and 5 sites of interest (Main Map) was generated in order to contribute in the Geological Heritage.

Afterwards, 137 rock-samples (~2 sample/km²) were collected for complementary petrographic studies in thin section using a polarising microscope Leica DMLP model fitted with a CCD camera in the Mineralogy and Petrology Department of the University of the Basque Country (UPV/EHU). The proportions of monzogranite rock-forming minerals were determined by point-count modal analyses (Table 2). Finally, for the drawing of the presented map, the cartographic standards for geologic maps (Federal Geographic Data Committee, 2006) were followed, as much as possible.

5. Map description

The Sierra Bermeja Pluton is a 59.75 km² elongated trapezoidal-shape intrusion (5.0–7.0 km width; 9.5–12.0 km length), with the long axis oriented N120°E. This massif encompasses several cordierite-bearing monzogranite lithotypes that can be grouped into three main units, which according to their roughly spatial concentric arrangement have been termed as Outer Unit (OU), Middle Unit (MU) and Inner Unit (IU). The contacts between the OU and MU are sharp and curvilinear, whereas those between the MU and IU are complex, resulting on a 100–400 m width belt of heterogeneous monzogranitic masses. This pluton includes also a reduced dyke complex mostly represented by vaugnerite series rocks and calc-alkaline lamprophyres trending NE–SW. The dyke complex of the Sierra Bermeja Pluton includes also minor amounts of aplite and quartz dykes.

The Sierra Bermeja Pluton intrudes into Neoproterozoic dioritoids (GPI-01; Bandrés et al., 2004) and a Paleozoic (Ordovician–Carboniferous) metasedimentary sequence constituted by slates, slates and quartzites (GPI-02; Palacios et al., 2013). This sequence exhibits N120–140E strike and a low-grade regional metamorphism. The intrusive contacts with the host rocks are sharp (GPI-03), but only visible in the North and South edges of the pluton where some faults have been inferred. The intrusion generated a contact metamorphism aureole in the Paleozoic sequence constituted by andalusite spotted hornfels in a 400–600 m width band (GPI-04), whereas in the Neoproterozoic dioritoids there are no apparent effects. By contrast, in the East and West areas the cordierite-bearing monzogranites are hidden under thick alluvial and colluvial deposits (Cenozoic cover; GPI-05).

6. Cordierite-bearing monzogranites of the Sierra Bermeja Pluton

6.1. Outer Unit (OU)

This unit extends along the outermost areas of the pluton, subparallel to the northern and southern limits of the massif in three separated sectors encompassing 20.03 km² (33.5% of the total area of the pluton; t.a.p.). Outward, it limits with the host rocks showing sharp intrusive contacts (Figure 3(a)) that appear segmented by decametre-scale displacements (up to 250 m) along N-NE trending faults, and inward with the MU. The temporal emplacement relation between both units is deducible in several areas of the pluton, standing out the outcrop of the Rugidero Berrocal (GPI-06), where a dyke of the MU intrudes the OU (Figure 3(b); Main Map).

The OU is constituted by white monzogranites that show a massive or homophanous structure and a planar/linear fabric. This fabric is defined by fairly oriented (N100–170E, subhorizontal) K-feldspar phenocrysts that can reach up to 12 cm in length. The concentration of these phenocrysts is markedly high (150–350 crystals/m²; 10–35% vol.), which confers a porphyritic texture to these rocks and constitutes the most characteristic feature of this unit (Figure 3(c); GPI-07). The phenocrysts are included in a holocrystalline phaneritic (medium- to coarse-grained) biotite-rich granodioritic groundmass, constituted by euhedral plagioclase (up to 15 mm), globular quartz (up to 11 mm), K-feldspar (up to 10 mm), biotite (up to 3 mm) and cordierite (up to 6 mm). Besides the K-feldspar phenocrysts, at the outcrop scale this unit is also characterised by the relative abundance of globular quartz and biotite, and the relative scarcity of cordierite as compared to the other units (Table 2). Larger accumulations of phenocrysts (up to 750 crystals/m²; GPI-08; GPI-09), tonalitic microgranular mafic magmatic enclaves (Figure 3(d); GPI-10), rare felsic-microgranular enclaves and pelitic xenoliths, and biotite schlieren are found sparsely in the OU. Also, in several outcrops pegmatite, aplite and aplopegmatite veins are observed, all of them on the order of centimetres in width.

Within the OU stands out a fine-grained variety characterised by a greater abundance of biotite, and lower amounts of cordierite and globular quartz (Table 2; GPI-11). The size of the K-feldspar phenocrysts is also smaller in this variety (up to 6 cm long) that crops out in three small irregular masses representing 4.8% of the OU surface area (0.97 km²). These masses are located in the eastern sector of the pluton in contact with the medium- to coarse-grained
monzogranites of the OU, the host rocks and the MU (Main Map). The timing relation between this local variety and the medium- to coarse-grained monzogranites of the OU is deducible from the observed sheet-by-sheet intrusion relationships (GPI-12) that indicate their coetaneous emplacement.

### 6.2. Middle Unit (MU)

This unit is located between the aforementioned OU and the IU covering a surface area of 24.49 km² (41.0% t.a.p.). The external limits of this unit are sharp and curvilinear, which may be regarded as a consequence of its intrusion into the host rocks and the monzogranites of the OU (GPI-13). On the contrary, the relation with the IU is defined by a 100–400 m width heterogeneous belt that covers an area of 5.38 km² (9.0% t.a.p.; Main Map). This belt is constituted by rocks with intermediate characteristics between those of the MU and IU, besides the sheet-by-sheet intrusion zones between both units (GPI-14; GPI-15). This evidences that mixing and mingling processes occurred between the MU and IU.

The MU is constituted by apparently undeformed white monzogranites showing a massive or homophanous structure. Only in some outcrops a planar/linear fabric is observable related to local metre-scale shear zones. These rocks exhibit a medium- to coarse-grained hypidiomorphic seriated texture and are constituted by globular quartz (up to 19 mm), plagioclase (up to 15 mm), K-feldspar (up to 16 mm), euhedral cordierite (up to 18 mm) and biotite (up to 2 mm). K-feldspar phenocrysts (up to 6 cm) are scarce (<5 crystals/m²) and are usually found close to the OU–MU contact. The monzogranites of this unit differ from those of the OU because of their drastic lower K-feldspar phenocryst and markedly higher cordierite contents (Figure 3(e); GPI-16: GPI-17). Besides that, biotite amounts are lower in the MU (Table 2). Small accumulations of K-feldspar phenocrysts (20–50 crystals), as well as rare pegmatite, aplite and aplopegmatite veins/segregates are observed in this unit too.

Locally within the MU a subtype of monzogranite can be discerned (GPI-18; GPI-19). It crops out in two distinct areas of the pluton (Main Map) covering a surface of 5.66 km² (23.1% of the MU). This variety is distinguished from the main type by the greater abundance of biotite and markedly lower cordierite content (Table 2). The relation between both monzogranites of the MU is controversial. Nevertheless, the observed variations in texture within this subtype, close to the main monzogranite type, points to their coeval emplacement.

### 6.3. Inner Unit (IU)

This unit extends along the pluton axis covering a surface area of 9.38 km² (15.7% t.a.p.). It appears dismembered in eight heterometric masses, standing out a ∼5 km long and ∼2 km width mass located in the westernmost zone of the pluton (Main Map). All these masses are enclosed by the mixing/mingling belt that separates the IU and MU.

The IU is constituted by yellowish monzogranites with massive or homophanous structure and isotropic fabric that, in the westernmost areas, exhibit a well-developed N40–60E trending joint system (GPI-20; GPI-21). Their texture is fine- to medium-grained hypidiomorphic seriated, with low colour index (generally <5) that allows to consider them as leucogranites (Figure 3(f)). Their main mineralogy consists of globular quartz (up to 10 mm), plagioclase (up to 9 mm), K-feldspar (up to 8 mm), muscovite (up to 3 mm), euhedral cordierite (up to 9 mm) and biotite (up to 2 mm). The distinctive features of this unit are the fine crystal-size and the relatively high content of muscovite (Table 2). As in the other monzogranite units, K-feldspar phenocryst clusters (20–50 crystals) and pegmatite, aplite and aplopegmatite veins/segregates are observable (Figure 3(g)).

In the easternmost masses, the cordierite content decreases markedly whereas that of biotite increases (Table 2; GPI-22), which allows to differentiate a local variety within the IU (0.34 km²; 3.6% of IU). Moreover, the mixing/mingling belt around this variety

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**Table 2.** Key features of monzogranite types of the Sierra Bermeja Pluton.

| Enclaves | Main type | Local variety | Main type | Local variety | Main type | Local variety |
|----------|-----------|---------------|-----------|---------------|-----------|---------------|
| Kfs (groundmass) | Mafic and felsic magmatic; pelitic | – | Occasional | – | Occasional | – |
| Groundmass crystal-syenite | Medium to coarse | Fine to medium | Medium to coarse | Fine to medium | Medium to coarse | Fine to medium |
| Quartz | 27–35% | 26–38% | 31–40% | 33–39% | 32–41% | 31–38% |
| Kfs (groundmass) | 15–28% | 14–27% | 24–33% | 25–32% | 22–30% | 24–31% |
| Plagioclase | 33–42% | 34–45% | 26–35% | 25–33% | 24–32% | 25–32% |
| Cordierite | 1–5% | 1–3% | 5–10% | 1–5% | 2–7% | 1–3% |
| Biotite | 6–11% | 9–14% | 3–6% | 5–7% | 1–4% | 3–7% |
| Muscovite | 0–1% | 0–1% | 0–2% | 0–2% | 2–8% | 2–4% |
| Accessory minerals | Ap, Mnz, Zrn, Xtm, Tur, Ilm | Ap, Mnz, Zrn, Xtm, Tur, Ilm | Ap, Mnz, Zrn, Xtm, Tur, Ilm | Ap, Mnz, Zrn, Xtm, Tur, Ilm | Ap, Mnz, Zrn, Xtm, Tur, Ilm | Ap, Mnz, Zrn, Xtm, Tur, Ilm |

| Main type | Local variety | Main type | Local variety | Main type | Local variety |
|-----------|---------------|-----------|---------------|-----------|---------------|
| Mafic and felsic magmatic; pelitic | 150–350/m² | 150–250/m² | 35% 25 | 39% 32 | 38% 31 |
| Mafic and felsic magmatic; pelitic | – | – | – | – | – |
| Occasional | Occasional | Medium to coarse | Medium to coarse | Fine to medium | Fine to medium |
| Medium to coarse | Medium to coarse | – | – | – | – |
| Fine to medium | Fine to medium | – | – | – | – |

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*Main type and Local variety in mm.*

| Enclaves | Main type | Local variety | Main type | Local variety | Main type | Local variety |
|----------|-----------|---------------|-----------|---------------|-----------|---------------|
| Mafic and felsic magmatic | – | – | – | – | – |
| Mafic and felsic magmatic | – | – | – | – | – | – |
| Occasional | Occasional | Medium to coarse | Medium to coarse | Fine to medium | Fine to medium |
| Medium to coarse | Medium to coarse | – | – | – | – |
| Fine to medium | Fine to medium | – | – | – | – |

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*Main type and Local variety in mm.*
contacts only with the monzogranite subtype of the 
MU (Main Map).

7. Vaugnerite series rocks and lamprophyres of the Sierra Bermeja Pluton

7.1. Vaugnerite series rocks

These rocks are restricted to a 4 km long and up to 150 m width, N30–45\E trending linear belt. It covers a 0.13 km\(^2\) (0.2% t.a.p.) surface area in the middle-western sector of the pluton (Main Map). At the outcrop scale, this belt is defined by sinuous alignments of decimetre in size, rounded, dark-coloured rock blocks. These blocks do not constitute continuous masses and show variable spacing between them (0.5–3 m) that increases progressively towards the tips of each alignment, up to finally disappear (GPI-23; GPI-24). The timing relation with the host monzogranites is deducible at the cartographic scale with vaugneritic alignments cross-cutting the contacts between the monzogranite units (Main Map). Yet, their sinuous trends, the absence of chilled margins, the necking of the alignments and their dismembered
terminations suggest that they would correspond to syn-plutonic dykes.

These mesocratic rocks show a massive or homophanous structure and present a medium-grained, hypidio-idiomorphic, inequigranular seriated texture. Their main mineralogy includes variable amounts of plagioclase, amphibole, clinopyroxene, biotite, K-feldspar, and quartz. In detail, these mesocratic rocks can be subdivided in two subtypes, which, depending on the modal composition, are here termed as ‘biotite-rich’ and ‘biotite-poor’. Following the IUGS recommendations (Le Maitre et al., 2002) these rocks are classified as diorites, quartz diorites and quartz monzodiorites, but on account of their mineralogy and whole-rock geochemical composition are considered as a whole within the vaugnerite series rocks (see Errandonea-Martín, Sarrionandia, Carracedo-Sánchez, Gil Ibarguchi, & Eguíluz, 2018).

7.2. Lamprophyres

These rocks appear distributed throughout the whole pluton covering a 0.11 km² surface area (0.2% t.a.p.). At the outcrop and map scale lamprophyres exhibit characteristics fairly similar to those of vaugnerite series rocks above described. Nevertheless, they usually constitute straight and narrow (<5 m) alignments with NE–SW trends (Main Map). Host monzogranite enclaves are found in some lamprophyres, suggesting the late- to post-intrusive character of these dykes respect to the monzogranites.

These rocks are constituted by homophanous aphanitic mesocratic rocks with porphyritic texture (GPI-25; GPI-26). They are characterised by the presence of clinopyroxene phenocrysts (up to 2 mm), occasionally accompanied by biotite (up to 2 mm) and amphibole (up to 2 mm), included in a microcrystalline groundmass. This aphanitic groundmass is constituted mainly by the same mineralogy as the phenocrysts plus plagioclase (up to 5 mm), muscovite (up to 2 mm) and tourmaline (up to 3 mm).

Quartz dykes form marked positive linear prominences up to 450 m long and 50 m width (Main Map; GPI-28). They show straight N35–45E trends and are constituted by white (locally reddish) quartz crystal aggregates. The host monzogranite close to these dykes shows pervasive hydrothermal alteration.

9. Conclusions

The detailed geologic map of the Sierra Bermeja Pluton presented in this contribution has revealed a complex intrusive assemblage. Three main monzogranite types (showing local varieties) plus a reduced dyke complex composed by vaugnerite series rocks, lamprophyres, aplites and quartz dykes constitute this Variscan massif. Besides, mingling/mixing areas have been mapped for the first time in this type of cordierite-bearing monzogranites of the Iberian Massif. Field relationships indicate that (1) monzogranite pulses are younger towards the centre of the pluton, (2) vaugnerite series rocks form syn-plutonic dykes, and (3) lamprophyres, aplites and quartz dykes intruded after almost the complete consolidation of monzogranites. These outcomes will constitute the basis for forthcoming contributions related to the genesis of these controversial monzogranites.

Additionally, exhaustive fieldwork has allowed to summarise an inventory of relevant sites that comprise several Geologic Points of Interest (GPI), most of them located in the Cornalvo Natural Park. These points of interest, together with the new geologic map produced of the Sierra Bermeja Pluton, should be considered by the relevant institutions in terms of geoconservation and geological heritage. It is hoped that the map will constitute a robust tool in the diffusion and educational objectives for the Cornalvo Natural Park Interpretation Centre.

Software

Garmin Basecamp 4.7.0 was used for: (1) create tracks for the fieldwork, and (2) manage georeferenced points. Esri ArcGIS 10.3 was used for: (1) gathering and visualisation of underlying data, (2) construction of high-resolution digital terrain models, (3) management of field data, (4) digitisation and editing of geologic data layers, and (5) production of the map layout.

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