

# Origin of Green Clinopyroxene Cores of Lavas from the Garrotxa Volcanic Field (Spain)

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## INTRODUCTION.

Volcanism of the Garrotxa area is part of the Neogene volcanism of NE Spain (NE Spain volcanic province, NESVP). This volcanism is a manifestation of the magmatic activity consequence of the rift-type extensional tectonics that affect the eastern margin of Iberia since late Oligocene and that involved the opening of the Valencia trough. Volcanic activity in the NESVP started weakly in the Cadaqués zone 15 Ma ago, (C. Lewis, personal communication), followed by the Empordà (9 to 12 Ma in Alt Empordà, 6 Ma in Baix Empordà), La Selva field (5 to 7 Ma) and the Tordera fault system (2 Ma). Finally, activity took place at the Garrotxa volcanic field (GVF) from 300,000 to 10,000 years ago, with an eruptive episode every 15,000 to 20,000 years approximately (C. Lewis personal communication).

Evolution of the NESVP was highly influenced by the evolution of the Neogene extensional fracturation which generated a complex system of horst and graben structures and allowed the upwelling of magmas generated by decompression in the upper mantle in the three main volcanic fields (Empordà, Selva and Garrotxa). Geophysical data show that the area containing the NESVP is characterized by a crustal thinning and high thermal gradient, with a thinned lithosphere of 60-70 km, and a maximum crustal thickness of about 28 km.

The NESVP is mainly characterized by alkaline basaltic rocks — basalts and basanites — both potassic and sodic in affinity, with the only known exception of Vilacolum and Arenys d'Empordà trachytes (Gimeno, 1995; Diaz et al., 1996, Gisbert Pinto, 2008). Mineralogical composition of rocks is simple. In most cases small olivine, clinopyroxene and plagioclase crystals are found inside a glassy matrix, usually

rich in iron oxides. At some selected localities the alkaline basaltic rocks of these regions contain xenoliths of several types: mantle xenoliths, crustal magmatic xenoliths, with widespread accidental sedimentary xenoliths incorporated during the opening of the vents. The mantellic sources of magmas have been interpreted as the result of a two-fold mantle metasomatism process (Bianchini et al., 2007).

## PETROGRAPHY AND MINERAL CHEMISTRY.

### Petrography.

Rocks are aphanitic, light to dark grey, with some small (mm) phenocrysts and xenoliths (up to cm). Microscopic texture is porphyritic, hipohyaline to holocrystalline, with phenocrysts, microcrysts and xenocrysts of clinopyroxene, olivine and plagioclase. Matrix between microcrysts is made of opaque minerals and feldspars, and locally leucite.

Olivine is mainly present as phenocrysts, but also as microphenocrysts, frequently with skeletal or elongated growing. Evidences of resorption can be found (probably corroded xenocrysts).

Plagioclase is found as clear and fresh idio- to hipidiomorphic microlites with albite twinning; phenocrysts are scarce. Xenocrysts of rounded allotriomorphic morphologies, with internal sieve texture and a thin skeletal overgrown rim can be found.

Clinopyroxene shows the widest range of composition, morphologies and origins of all minerals. It is mostly present as phenocrysts and microphenocrysts, either free or in glomerules and agglomerates, but also as xenocrysts and in xenoliths. The bigger ones tend to have a core of rounded shape and sharp boundary mantled by clinopyroxene in

equilibrium with the melt, which gives a final idiomorphic shape to the crystals, in some cases with some degree of skeletal growing. There are several typologies of core; the main ones are: slightly-pleochroic green cores (Fig. 1), brown cores and pinkish brown cores. Cores can be either intact or present some degree of corrosion (in sieve texture). Small crystals usually do not show core. Microphenocrysts are mainly idiomorphic of equidimensional or short prismatic habit. Clinopyroxene in equilibrium with the melt (which forms the mantle over cores, phenocrysts without core, and microphenocrysts) is zoned and its color changes from brown at the centre to pinkish brown at the edges. Zonation is more dominant at the edges, being in some cases oscillatory.

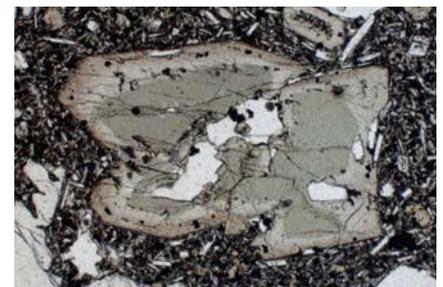


fig 1. Example of pyroxene with green core. The crystal is 2 mm wide.

### Mineral chemistry

Olivine phenocrysts show a composition of  $FO_{88-72}$ , being chemically homogeneous in most of their volume, with the Fo content only decreasing in a thin band by the edge.

Plagioclase microlites are mainly labradorite, with minor bytownite, ( $An_{71-54}(Or_{1-3})$ ). Average composition ( $An_{65}$ ) is the same for all rock compositions.

Opaque minerals are Fe-Ti oxides of the magnetite-ulvospinel series, containing also Al and Mg. FeO ranges from 47 to

**palabras clave:** Campo volcánico de la Garrotxa, Xenocristales, Piroxenos.

**key words:** Garrotxa Volcanic Field, Xenocrysts, Pyroxenes.

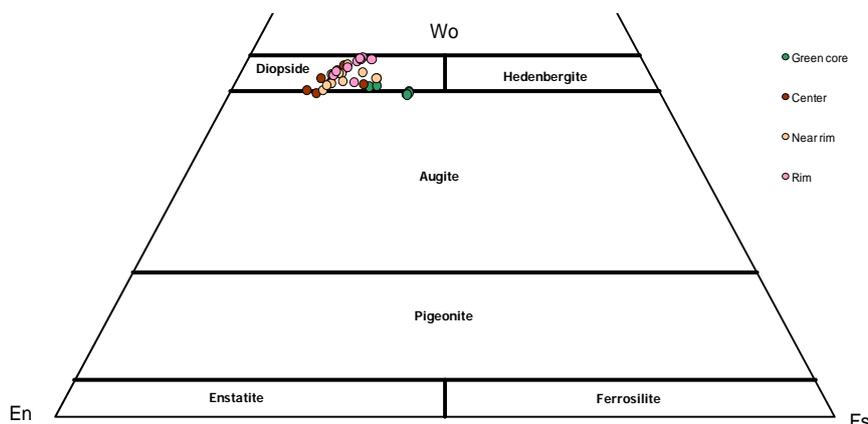


fig 2. Projection of pyroxenes from one sample in the En-Fs-Wo classification diagram (Morimoto et al., 1989).

64 wt% and TiO<sub>2</sub> from 7 to 23 wt%. Al<sub>2</sub>O<sub>3</sub> ranges from 2 to 16 wt%, and MgO from 2 to 8 wt%.

Most of the analysed pyroxenes have diopside composition whereas few plot in the hedenbergite and augite fields (Fig. 2). Chemical analyses reveal that brown cores have the same composition as centres of non-cored phenocrysts. Pinkish-brown cores show higher Al<sub>2</sub>O<sub>3</sub> contents, as well as more FeO<sub>t</sub> and less MgO and CaO, resembling the composition of rims. Green cores show higher contents of FeO<sub>t</sub>, Na<sub>2</sub>O and MnO, and are depleted in MgO, TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>. Despite the higher content in Na<sub>2</sub>O, this is not enough to claim diopside/hedenbergite/augite to be sodic. Cores are in most cases chemically homogeneous. Mantle compositions are the same as those of the non-cored phenocrysts: from core to rim SiO<sub>2</sub> and MgO decrease, while TiO<sub>2</sub> and FeO<sub>t</sub> increase. The transition from core to overgrowing implies in most cases a sharp increase (more or less marked depending on the type of core) of the MgO content (reverse zoning), and from there to the edge of the crystal a steady decrease. TiO<sub>2</sub> shows an opposite behaviour.

#### WHOLE-ROCK GEOCHEMISTRY.

Rocks from the GVF are basalts, basanites and traquibasalts in composition. Regular chemical trends can be observed in major element versus SiO<sub>2</sub> or MgO binary diagrams showing that the magmatic events occurring in the GVF underwent similar magmatic evolutionary processes. These trends can be explained in terms of fractional crystallisation of olivine, pyroxene and opaque minerals of the

magnetite-ulvospinel series.

#### DISCUSSION AND CONCLUSIONS.

Reversely zoned clinopyroxenes found in GVZ have also been observed in other alkali basalts related to the opening of the Miocene European Rift (e.g. Eiffel, Duda and Schmincke, 1995) and in other alkali provinces (e.g. Canary Islands, Aulinas et al., 2010). The different origins proposed for such reverse zonation include a genetic relationship between cores and mantle-rims, considered cognate phases. According to this model, the inverse zonation may be caused by an increase of fO<sub>2</sub> conditions (i.e. oxidation) or by sinking of the crystal into a convecting crustal magma chamber in which crystals settle in hotter, Mg-rich, lower portions (Borely et al., 1971). Another explanation of the origin of such inversely zoned phenocrysts is the interpretation of green cores as accidental xenoliths related to wall rock debris entrained by the rising magma (Barton & Bergen, 1981). Finally, the green clinopyroxene cores could be interpreted as cognate xenocrysts produced during crystallisation of an evolved magma that subsequently interacted with a more primitive hot magma (Brooks and Printzlau, 1978).

In our case, the rounded shape of the green cores, the sharp optical and chemical boundary between green cores and mantles, the high Fe/Mg ratios of cores, and the coexistence of normally and reversely zoned clinopyroxene in a single sample cannot be explained by a change in the melt composition. Consequently, these petrographic features require a xenocrystic origin of the green cores.

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