

# A tectonic model for the volcanic province of Olot (NE Spain)

## *Un modelo tectónico para la provincia volcánica de Olot (NE de España)*

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### RESUMEN

Las fallas de dirección NW-SE, pertenecientes a una zona de tipo «transfer» del rifting neógeno del NE de España, han proporcionado los conductos de salida del magmatismo profundo de la región de Olot. Este magmatismo se puede explicar como procedente de una ondulación amplia de la litosfera y la consiguiente fusión parcial de manto subyacente. Un régimen tectónico compresivo de poca intensidad controla la distribución de los centros de emisión.

**Key words:** Neogene-Quaternary volcanism, NE Spain, compressive regime, lithospheric swell, transfer zone.

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### Introduction

Since its ascription to a generalized rifting by Vegas *et al.*, (1980), the Neogene-Quaternary volcanism of NE Spain has been vaguely related to the opening of the Valencia Trough and Gulf of Lions by many workers, yet a precise tectonic setting for this volcanism, here referred as the volcanic province of Olot, has not been propounded. In fact, geochronological and regional

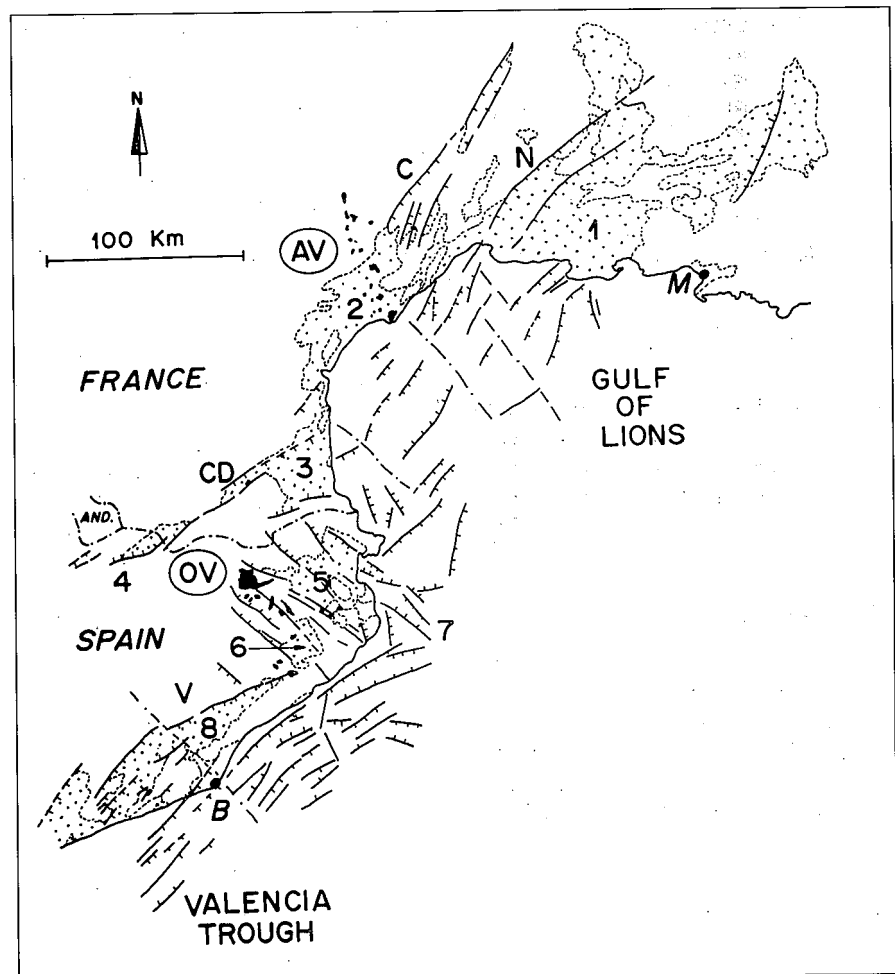
tectonic data (Donville, 1976) indicate that it is younger than the main rifting episode, and linked to NW-SE faults which are perpendicular to the horst and half-graben system of the Catalan rifted margin. Moreover, the magmatism res-

possible for this volcanism seems to extend regionally along a peripheral arch spanning the Alps and Betics.

An attempt is made in this paper aiming to relate surface structures, tectonic behaviour, and deep-seated magma-

Fig. 1.— Neogene rifting features in southeastern France and northeastern Spain. Stippled: Neogene onshore basins, 1, Lower Rhone; 2, Languedoc; 3, Roussillon; 4, Cerdagne; 5, Ampurdan; 6, La Selva; 7 (unornamented, offshore) Rosas and Bagur; 8, Vallés-Penedés. Main border faults: C, Cevennes; CD, Cerdagne; N, Nimes; V, Valles. Black patches: Neogene-Quaternary volcanics: AV, Adge; OV, Olot. Discontinuous lines: Transfer alignments. M, Marseilles and B, Barcelona are shown for location. Based on Anadón *et al.*, (1979), Lefebvre(1980), Roure *et al.*, (1992), and Vazquez *et al.*, (1993).

Fig. 1. — Estructuras del rifting neógeno del sureste de Francia y del noreste de España. En punteado: cuencas neógenas en tierra, 1, Bajo Ródano; 2, Languedoc; 3, Rossellón; 4, Cerdaña; 5, Ampurdán; 6, La Selva; 7 (en blanco en mar), Rosas y Bagur; 8, Vallés-Penedés, Fallas principales de borde; C, Cevennes; CD, Cerdaña; N, Nimes; V, Vallés. En negro: volcanismo neogeno-cuaternario, AV, Adge; OV, Olot. Líneas de trazos: alineaciones de zonas de fallas transfer. M, Marsella; B, Barcelona. Basado en Anadón *et al.*, (1979), Lefevre (1980), Roure *et al.*, (1992) y Vazquez *et al.*, (1993).



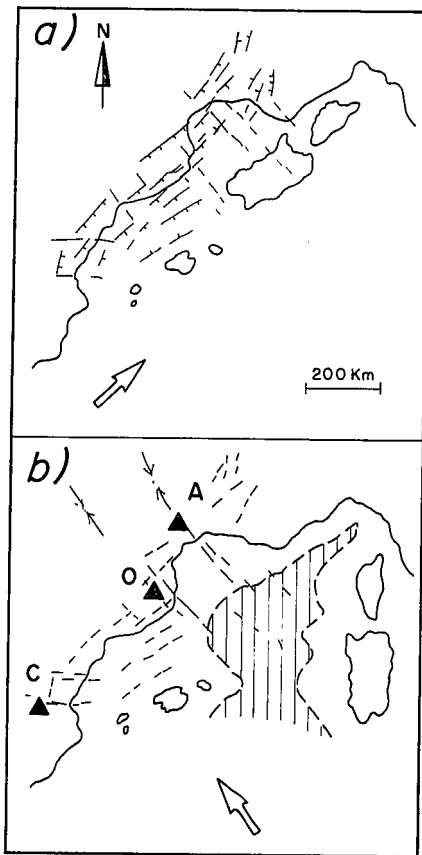


Fig. 2.— Schematic diagram showing the evolution of the Gulf of Lions and Valencia Trough margins in relation to the direction of the Africa-Europe plate convergence. a) Lower Miocene rifting. b) Uppermost Miocene-Present compressive phase, after cessation of opening of the Ligurian Sea. Black triangles: volcanic provinces, A, Adge; C, Cofrentes; O, Olot. Opposite thin arrows: azimuth of maximum horizontal compressive stress. Blank arrows: azimuth of Africa-Europe plate convergence.

Fig. 2.— Diagrama esquemático de la evolución del Golfo de León y el Surco de Valencia en relación con la dirección de la convergencia entre las placas de África y Europa. a) Rifting mioceno inferior; b) Fase compresiva del Mioceno Superior hasta la actualidad, tras el cese de la apertura del Mar Ligur. Triangulos negros: provincias volcánicas, A, Adge; C, Confrontes; O, Olot. Flechas finas opuestas: dirección del esfuerzo compresivo máximo horizontal. Flechas en blanco: dirección de convergencia África-Europa.

tism within the frame of the Africa-Europe plate convergence. In this sense, the Neogene faults and related volcanic outcrops, the regional stress field onset since early Miocene, as well as the regional deformation of the lithosphere causing the localization of the volcanism, will be considered.

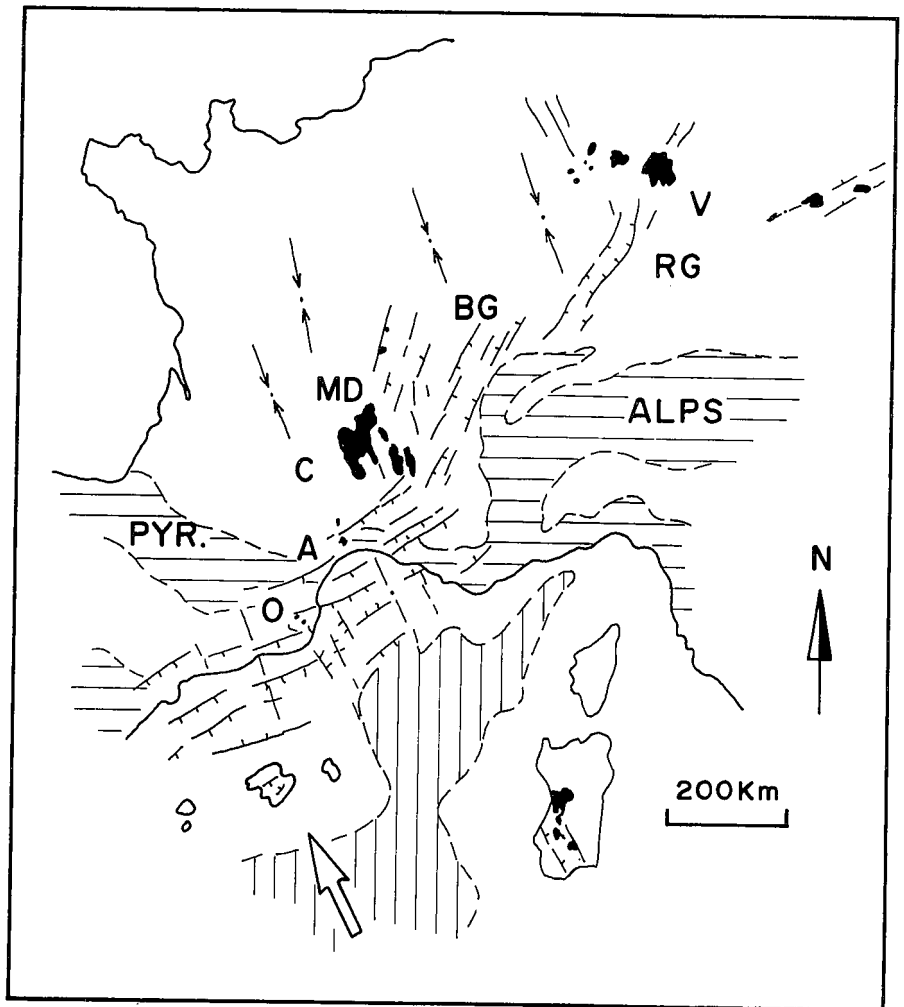


Fig. 3.— Situation of the Neogene-Quaternary alkaline volcanism in central Europe in relation to the Oligocene-Lower Miocene rifting. Black patches: volcanic outcrops; A, Adge; C, Cantal; MD, Mont Doré; O, Olot; V, Vogelsberg; BG, Bresse Graben; RG, Rhine Graben; PYR, Pyrenees. Thin opposite arrows: azimuth of the Uppermost Miocene-Present maximum horizontal stress. Blank arrow: sense of the Africa-Europe relative motion since the Uppermost Miocene. Horizontal lines indicate orogenic regions; vertical lines indicate areas of oceanic or extremely thinned crust.

Fig. 3.— Situación del volcanismo alcalino neógeno-cuaternario de Europa central en relación con el rifting oligoceno-mioceno inferior. A, Agde; C, Cantal; O, Olot; V, Vogelsberg; BG, Fosa de Bresse; RG, Fosa del Rhin; PYR, Pirineos. Flechas finas opuestas: dirección del esfuerzo horizontal compresivo desde el Mioceno más superior hasta la actualidad. La flecha en blanco indica la dirección de convergencia entre África y Europa para el mismo periodo de tiempo. El rayado horizontal indica las regiones orogénicas y el rayado vertical las áreas oceánicas o de corteza continental extremadamente adelgazada.

### Neogene faulting

The Neogene faulting in NE Spain corresponds to a generalized rifting that started in the early Miocene in connection to a southward propagating intraplate rift zone in central Europe. This rifting caused ultimately the formation of the Gulf of Lions, the Ligurian Sea and the Valencia Trough (Vegas *et al.*, 1980; Vegas, 1990). Regionally, it corresponds to NNE-SSW normal faults (Cevennes, Nimes, Cerdagne and Vallés faults) that bound well develo-

ped half-grabens (Lower Rhone, Languedoc, Roussillon, Cerdagne and Vallés-Penedés basins). To these NNE-SSW trending features, some NW-SE transfer-like faults and related basins must be added. These later seem to connect and delimitate the different segments of the rift zone (fig.1). The volcanic province of Olot lies at the transition of the Gulf of Lions to the Valencia Trough, where some transverse offshore basins drawn a transform zone (Vázquez *et al.*, 1993). Clearly, these basins have their onshore counterpart in

the transverse basins of La Selva and Ampurdán. The volcanic outcrops are aligned along the border of these topographic depressions and along some NW-SE faults in the topographic high of La Garrotxa. This transverse zone of basins and NW-SE faults can be defined as a synthetic overlapping transfer zone (Morley *et al.*, 1990), if the southward propagation of the rifting and the overlapping of the Cerdagne and Vallés graben systems are considered (fig. 1). This transfer zone has played an important role in the evolution of the Catalan margin, when drifting ceased in the Gulf of Lions. The new direction of plate convergence (Dewey *et al.*, 1989) induced renewal of tectonic activity localized in the extinct transfer zone (fig. 2).

It can be thus concluded that the onset of the volcanism ought to be placed in this Upper Miocene change of plate convergence. Also worth of mention is that the same conclusion can be made for the volcanism of Adge, linked to a transform alignment described by Lefebvre (1980), and for the volcanism of Cofrentes and Picasent, related to a transform-like fault mentioned by Vegas (1990), as depicted in figure 2.

### Stress field

Besides the vertical faults interesting the entire crust, intraplate volcanism requires an appropriate tectonic behaviour in such a way that magmatism can reach the surface. This is best accomplished when either  $\sigma_1$  or  $\sigma_2$  is vertical (Cas and Wright, 1987). Since the Upper Miocene, in the area here concerned, the most likely stress field configuration points to a weak contractional regime ( $\sigma_1$  and  $\sigma_3$  horizontal) derived from the slow Africa-Europe convergence. This stress-field configuration leads to local strike-slip regimes along conveniently oriented, preexisting fractures. This seems to occur in the volcanic province of Olot, where  $\sigma_1$  (or locally  $\sigma_2$ ) is horizontal and parallel to both the direction of plate convergence and the former transfer zone (fig. 2). This weak compressive stress field can be defined by the alignment of dikes

and volcanic centers that correspond to the direction of the maximum horizontal stress (Nakamura, 1977).

### Deep-seated volcanism

As stated in the preceding paragraphs, the volcanic province of Olot does not correspond actually to a crustal rift. Moreover, it cannot be linked to a stationary mantle plume in absence of a clear decrease of the age of the eruptions along a linear trend. Its alkaline nature and its precedence from an anomalous region in the mantle (López Ruiz y Rodríguez Badiola, 1985) could be related to some sort of lithospheric swell leading to pressure release and partial melting in the underlying mantle. The existence of such a buckling of the lithosphere has been proposed by Wright (1973) for several magmatic provinces not related to stationary mantle plumes. This scenario is even more plausible when considering the volcanism of Olot as part of a vast magmatic province situated in southwestern Europe (fig. 3). The gentle buckling of the continental lithosphere may result in the transmission of horizontal stresses from the Africa-Europe plate interaction. The contractional behaviour for the SW Europe volcanism can be also inferred from the high angle of the volcanic front and the alignment of volcanic centers (fig. 3). This angular relationship has been used by Nakamura (1977) as a clear indicator of a contractional tectonic area.

### Tectonic model and implications

The arguments presented in this paper allow to propose the following conclusions for the volcanic province of Olot: 1) The deep-seated origin of the volcanism can be fixed in a gentle buckling of the lithosphere, an intraplate response to horizontal stresses derived from the Africa - Europe convergence. This causes partial melting in the underlying mantle. 2) A weak, NW contractional stress field creates locally favourable conditions for magmatic eruptions along vertical faults. 3) The

faults serving as channelways for magma extrusion correspond to strike-slip ones resulted in a Lower Miocene transfer zone.

This tectonic model is obviously applicable to the coeval volcanism of Cofrentes and Adge (fig. 2). A similar tectonic behaviour could be proposed for the volcanic province of Campos de Calatrava in central Spain. There, the Alboran collision provided the appropriate lithospheric deformation, while the overall NW-SE elongation of the province is controlled by the weak Upper Miocene-Present compressional tectonic regime. Nevertheless, conspicuous faults related to volcanic centers have not been described. This is the case of some zones of the French Massif Central.

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