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Comparing porphyroblasts and plate motions in the Betic Cordillera

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Abstract: A systematic study was undertaken of the geometry and orientation of inclusion trails in 36 samples of garnet schist from the Nevado-Filabrides (Betic Cordillera). A coherent structural pattern emerges from this data that is compared with previously collected data for successive fold generations and related fabrics in the same tectonic unit. A two-stage orogenic evolution is deduced characterized by quite different crustal shortening directions. These directions are shown to be compatible with reconstructions of the Tertiary relative plate motions of Iberia, Africa, Eurasia and Adria.

Keywords: porphyroblast, inclusion trails, Alpine tectonics, oroclinal bending, plate kinematics.

Research during the past twenty years has shown that relic foliations preserved within metamorphic porphyroblasts (inclusion trails), commonly, have consistent orientations across individual folds; shear zones but also large metamorphic terranes. This phenomenon has been attributed to a particular mechanism of deformation partitioning in metamorphic rocks that does not require rotation of undeformable elements like porphyroblasts (e.g. Aerden, 2005). The recognition of this process led to a major re-interpretation of rotational inclusion trails (e.g. snowball garnets), but more importantly, has also furnished an important new tool for deciphering the tectonic evolution of metamorphic belts. This tool exploits the possibility to recognize and obtain the original orientations of successively formed tectonic fabrics, which became preserved within progressive stages of porphyroblast growth. By using this approach, the limitations imposed by reorientation and transposition of early-formed fabrics during the generation of younger ones are overcome. We have applied this tool for the first time in the Betic Cordillera. The plate kinematics underlying this orogen is relatively well known, hence providing an opportunity to assess the tectonic significance of inclusion trail patterns.

Superposition of two sets of (micro-) structures

Thirty-six precisely oriented samples of garnet micaschists were studied from the Nevado-Filabride Complex (Fig. 1a), a high-pressure tectonic unit situated at the base of the Betic nappe stack. Garnet porphyroblasts in these samples preserve two sets of inclusion trails with distinctive NE-SW vs. NW-SE to N-S geographic trends (Figs. 1b and 1c). The occasional inclusion of both trends in core vs. rim zones of individual porphyroblasts allows their relative timing to be established (Fig. 2). NE-SW to N-S inclusion trails are consistently older than NW-SE trending ones. This data was compared with a comprehensive compilation of more than 8,000 field measurements of various generations of folds and associated lineations recognized

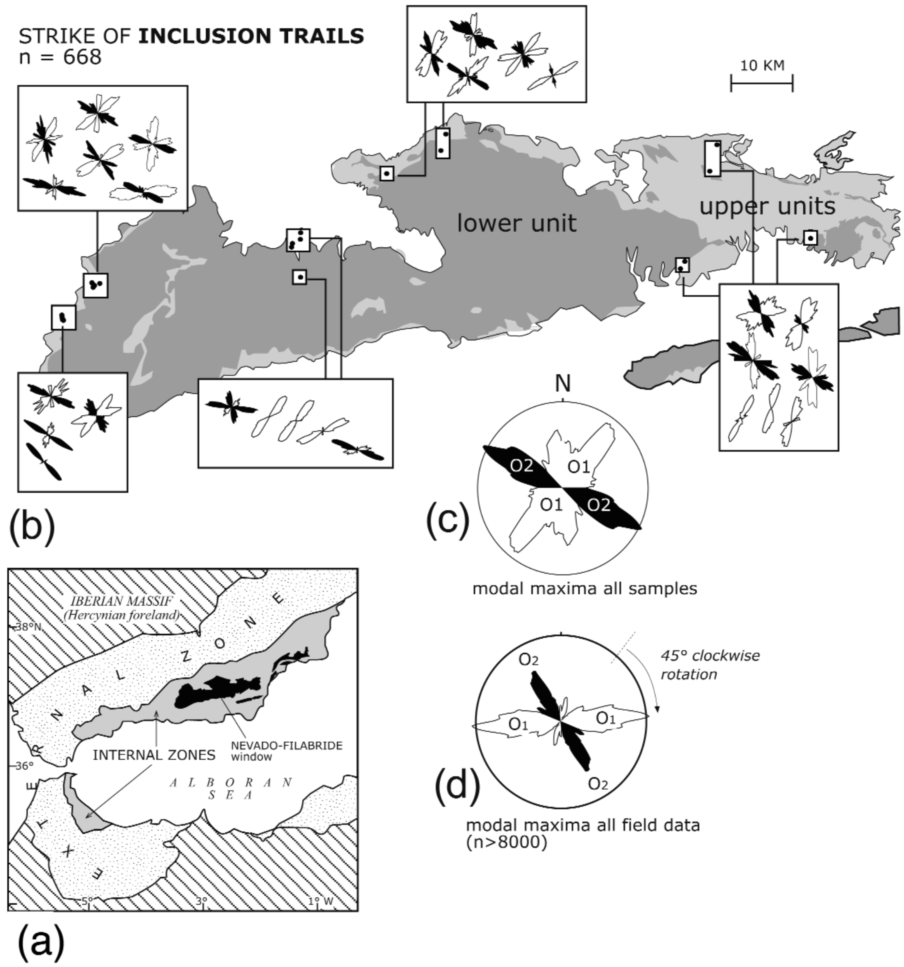

Figure 1. (a) Geological setting of the Nevado-Filabride Complex in the Betic-Rif orogeny, (b) location of 36 studied samples (dots) and moving-average rose diagrams for the strike of inclusion trails in these (n=668), (c) plot of all modal peaks exhibited by the rose diagrams shown in (a), (d) synthetic plot of fold- and fabric-trends in the study based on a compilation of over 8,000 field measurements from previous workers.

by previous Spanish, Dutch and German workers in the Nevado-Filabrides. This analysis also revealed two principle sets of structures with different trends (Fig. 1d) and similar relative timing as the two inclusion trail sets. We interpret this in terms of two orogenic stages (O1 and O2) that were characterized by different directions of crustal shortening or "tectonic transport". During the O2 stage, O1 related fabrics and structures experienced heterogeneous clockwise reorientations from originally NNE-SSW towards WNW-ESE trending. This explains the angle between O1 inclusion trails and O1 elements in the matrix. A smaller angle between O2 preserved in porphyrpoblast rims vs. O2 in the matrix could be due either due to the effects of a third O3 stage (see further) that could have reoriented O2 elements in the matrix but not porphyroblats, or alternatively, a gradual (clockwise) rotation of shortening directions during O2.

Alternating contraction and gravitational collapse

Analysis of vertical thin sections with variable strikes reveals complex inclusion trail geometries including internal truncation surfaces with orthogonal (vertical and horizontal) preferred orientations. The latter is similar as found in many other orogens around the world. It can be interpreted in terms of polyphase deformation histories resulting from alternating crustal shortening and gravitational collapse (Aerden, 2005 and references therein). A consistently horizontal least principal stress axis (σ3), while σ1 and σ2 periodically switched between vertical to horizontal, explains the generation of multiple homoaxial fold generations with axes parallel to the stretching lineation. As described in the preceding section, the presence of two sets of such homoaxial structures with different trends indicate two orogenic stages O1 and O2 each of which included multiple second-order deformation phases. Additional details will be presented in a forthcoming paper (Aerden and Sayab, *in press.*).

From porphyroblasts to plate tectonics?

A change from approximately NW-SE to NNE-SSW directed crustal shortening deduced from

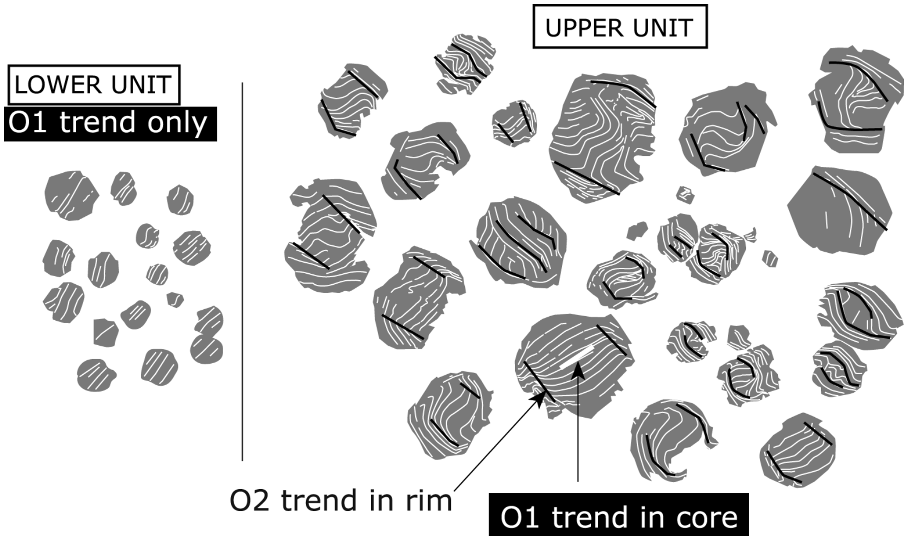

Figure 2. Representative inclusion trails geometries from which the relative timing of NE (white lines) vs. NW (black lines) trending internal foliations can be deduced. Samples from the lower subunit of the Nevado-Filabrides only include O1.

above described data can be tentatively linked with the plate-tectonic evolution of the Mediterranean Alpine system (Fig. 3). Prior to about 35 Ma, orogenic activity in the Betics appears to have been driven by NW-SE directed convergence between Adria, Eurasia and Iberia, while Africa-Iberia relative motion was mainly transcurrent (Azores transform). A NE-SW trending orogen developed bordering "Greater Iberia", including the Sardinia-Corsica bock, and probably continuing as the Brianconais Domain in the Alps (Michard *et al.*, 2002). A second orogenic stage initiated around 35 Ma with the onset of head-on Africa-Iberia convergence in NNE-SSW direction. This convergence subparallel to a pre-existing mountain belt induced heterogeneous rotations in the orogen (clockwise in the Betics) accompanied with the development of NW-SE trending structures and fabrics, and oroclinal bending. We speculate that the waning of SE-NW stresses originally transmitted by Adria and their substitution by SW-NE directed stresses transmitted by Africa triggered subduction roll-back and the ensuing Miocene extension responsible for the opening of the western Mediterranean basin. This extension would have been oriented sub-perpendicular to

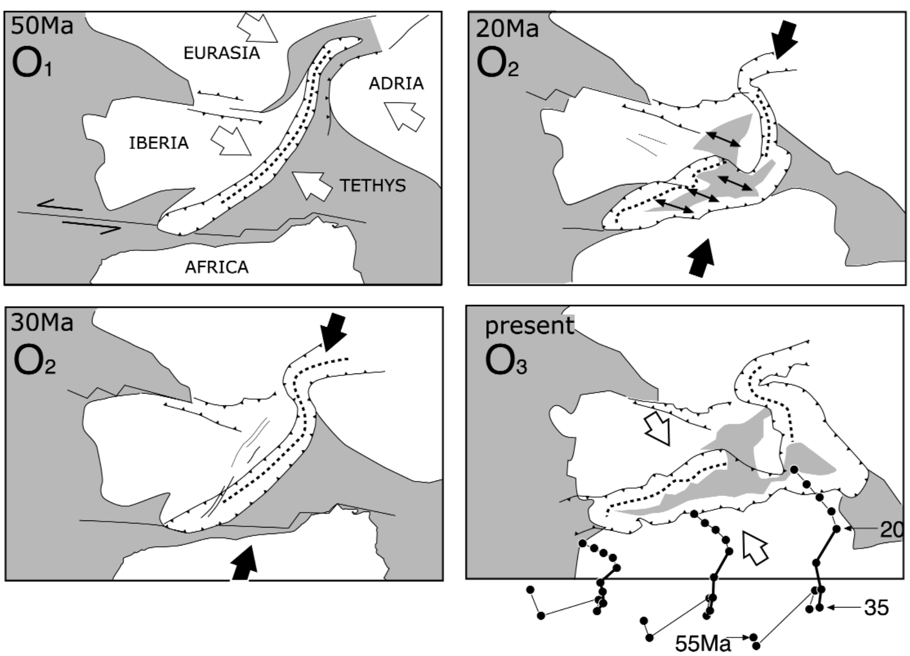

Figure 3. Plate-tectonic evolution of the western Mediterranean with indication of the trajectories of three points on the North-African margin relative to Iberia. A change from NW directed Adria-Iberia convergence to NNE-SSW Africa-Iberia convergence is proposed that took place abound 35 Ma.

NNE-SSW convergence. At about 15 Ma a second change to NW-SE directed Iberia-Africa convergence occurred which postdates porphyroblast growth (stage O3). It may be recorded by late subvertcial crenulation cleavages with NE-SW strike.

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