

## Direct dating of brittle extensional deformation in the internal zones of the Rif Chain

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We provide for the first time a direct dating of brittle deformation of internal zones of the Rif chain, in the Ceuta peninsula. We report two <sup>40</sup>Ar/<sup>39</sup>Ar illite ages from fault gouge within the orthogneiss from the Monte Hacho Lower Unit ( $12.1 \pm 2.6$  Ma and  $15.9 \pm 1.9$  Ma) in the footwall of the Ceuta Shear Zone and three <sup>40</sup>Ar/<sup>39</sup>Ar illite ages from fault gouge within the granulitic paragneisses from the Ceuta Upper Unit ( $16.0 \pm 1.0$  Ma,  $18.7 \pm 0.3$  Ma and  $18.7 \pm 0.3$  Ma), in the hanging wall. We also report apatite (U-Th)/He ages in rocks from both units that exhibit slightly different cooling history with the footwall cooled down to 40°C slightly before (c. few million years) the hanging wall of the Ceuta Shear Zone.

We interpret the illite ages to date growth of authigenic illite (1Md polytype) during gouge formation at temperatures lower than 60°C. Such low temperatures correspond to the top few kilometers of the earth's surface and were previously reported for illitization processes during the faulting of sedimentary clay-rich wall rocks.

The studied brittle deformation within the internal zones of the Rif-Betic chain revealed that an E-W directed extension, initiated at the ductile-brittle transition at around 21 Ma, lasted until ~16 Ma during the cooling of Sebtide-Alpujarride units through the apatite PRZ. After 16 Ma, the direction of extension shifted to NNW-SSE and only minor steep normal faults occurred at depth < 1 km corresponding to temperatures cooler than 40°C. Thus dated brittle normal faults occurred after a phase of rapid cooling and during the initial stage of slow cooling (~1–2°C/myr) representing exhumation within the uppermost 1-2 kilometers of the continental crust. These two brittle extensional events match well the subsidence pulses evidenced the neighboring Alboran Basin.

**Mots-Clés :** Western Mediterranean, Fault gouge dating, <sup>40</sup>Ar/<sup>39</sup>Ar dating, Low-T thermochronology, Rif belt