Geometric analysis and scaling properties of calcite e-twins in the Cameros Basin (NW Iberian Chain, Spain)

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ABSTRACT

One dimensional geometric analysis has been carried out in several scan lines from 885 measures of twins in calcite grains to determine grain width (in microns) and twin density (number of twins.mm-1) distributions. Grain width and twin density have a good fit to the log-normal frequency distribution. Twinning in calcite implies intracrystaline deformation mechanism with low shear stress. When the process begins low grain width and calcite twins are developed with a probably random distribution what could be supported by a negative exponential distribution tendency. The twinning process continues until a "critical" value of grain width and density which is going to influence in the scaling process, and becoming the distribution to log-normal type. But some data also conform to a power-law (fractal) frequency distribution from determined range or sizes (300 to 1000 mm) and density (2 to 10 twins.mm-1) with some superimposed random (negative-exponential) elements, possible due to the irregularities at grain scale, but also because this systems show multifractal behavior.

Key words: *calcite, e-twins, geometry, fractal, scaling.*

INTRODUCTION

Recent awareness of fractals and the development of techniques to measure fractal dimensions give rise to new applications in vein distribution and vein properties studies (e.g. Gumiel *et al.* 1995; Roberts *et al.* 1999). In this sense, has been investigated the possible fractal geometry of calcite e-twins from grains that fill microveins in two areas of the Iberian Chain (Sierra del Alto Tajo and Cameros Basin, Fig. 1), a straight NW-SE trending fold and thrust belt located between the Ebro, Duero and Tajo Tertiary basins, in the eastern part of the Iberian Peninsula. The Iberian Chain was built up mainly during the Paleogene in response to the compressional tectonics then occurring on the active margins of the Iberian Plate (e.g. Salas and Casas, 1993).The deformation history of the area is preserved in the calcite e-twins (e.g. González-Casado and García-Cuevas, 1999, 2002). Then more than 100 veins were collected from the Lower Jurassic and Upper Cretaceous limestones in order to study the possible fractal geometry of e-twins. In each sample were analysed more than 40 grains. The twin index (twin/mm), grain size (mm2) and the twin geometry (Burkhard, 1993) were measured.

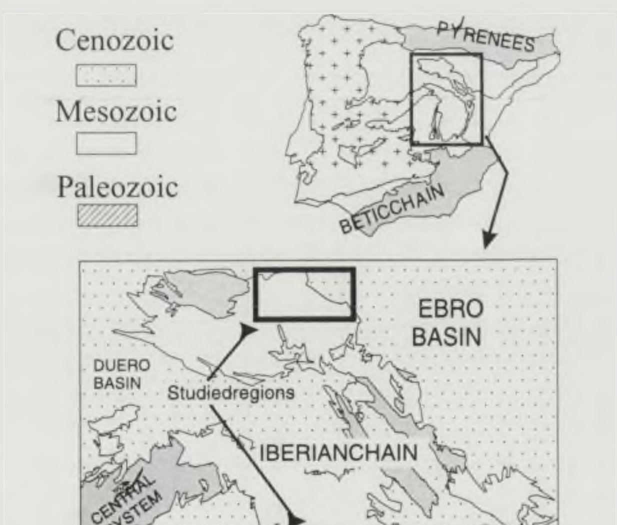

FIGURE 1. *Location of the studied regions on the Iberian Chain.*

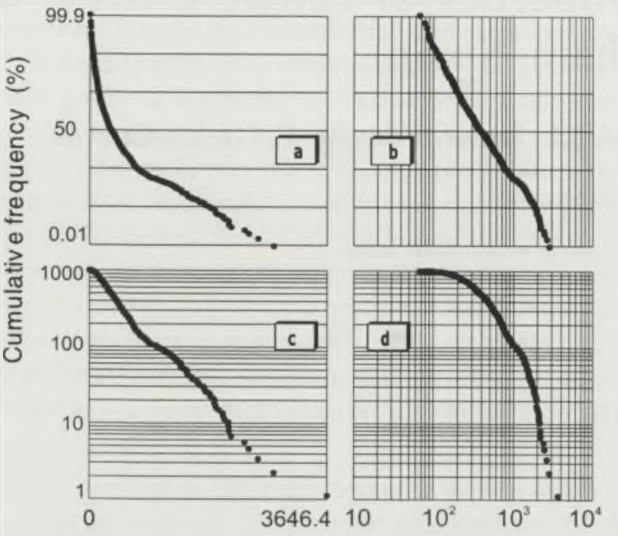

FIGURE 2. *Cumulative frequency plotted against grain width. Four models are plotted: a) normal distribution, b) log-normal, c) negative exponential and d) power-law.*

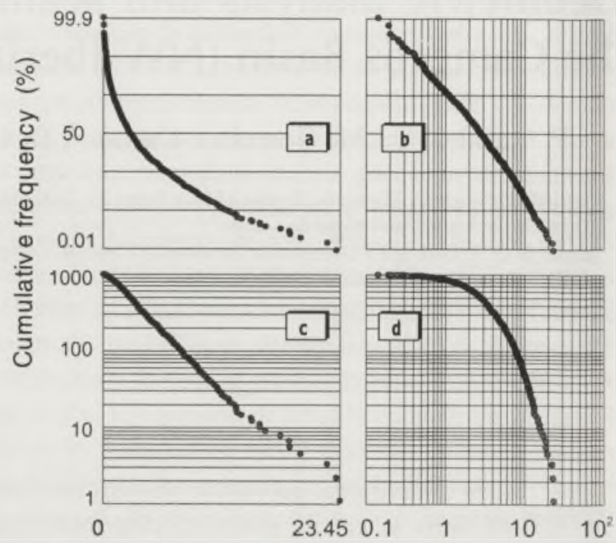

FIGURE 3. *Cumulative frequency plotted against twin density. Four models are plotted: a) normal distribution, b) log-normal, c) negative exponential and d) power-law.*

ANALYSIS OF FREQUENCY DISTRIBUTION OF CALCITE TWINS

In this work, one dimensional analysis has been carried out in calcite twins to determine grain width (in microns) and twin density (number of twins.mm^{-1}) distributions. The scan line data from 885 measures of twins in calcite grains can be used to validate theoretical techniques for utilizing twin-data distribution and evolution. Cumulative frequency log (*N*)-log (*grain width*) and log (*N*)-log (*twin density*) plots have been utilized to verify if grain width and twin density conformed to a power-law distribution, of the form: $N \propto C\, g^{-D}$ (1) or $N \propto C\, \delta^{-D}$ (2), where *N* is the number of grains, or number of twins.mm^{-1} –density-, with a size $\geq g$ or δ. *C* represents the frequency of grains/twins $\geq$ unit size (g/δ), and $-D$ is the slope of the log-log plot respectively (Fig. 2d and Fig. 3d).

Data from e-twins generally do not conform to a power-law distribution. Some of the departure from the power-law distribution, (i.e. a straight line relationship on the log-log plots, can be attributed to two effects: truncation –the under sampling of the lowest grain size (< 67.5 microns) and the lowest twin density (< 0.14 twin.mm^{-1}), and censoring –the low probability of larger grains / twins-, due to finite-size effect. The latter effect would produce a characteristic downturn or steeping of slope at the high width/density end of the log-log plots, usually affecting the widest twins (over 500 microns), and the highest twin density (over 4 twins.mm^{-1}). Truncation and censoring have been corrected following Pickering *et al.* (1995).

To select the best model for twin distribution least-squares regressions have been fit to the segments of grain width and density distribution in the log-log plots. Grain width distribution shows two slopes; the lower with a dimension (D_{g1} = 0.61, r^2 = 0.96) and the steeper with a dimension (D_{g2}=1.25, r^2=0.93). Data conform to a power-law distribution for a grain size interval ranging between 300 and 1000 microns with a generalized grain size dimension (Dg = 1.31). This power-law regression shows a correlation coefficient (r^2=0.93). Twin density follow a similar behavior showing also two slopes; the lower with a dimension ($D_{\delta 1}$=0.46, r^2=0.92), and the steeper with a dimension ($D_{\delta 2}$ = 1.52, r^2 = 0.95). Data also conform to a power-law distribution for a twin density interval ranging from 2 to 10 twins.mm^{-1} with a generalized density dimension ($D\delta$= 0.99). This power-law regression shows a correlation coefficient (r^2=0.87).

Comparing pairs of variables (e.g. twin density-grain width, and strain-grain width), there are not any lineal correlation (r^2 =-0.28 and r^2 =-0.41 respectively), however considering their logarithms (log density-log grain width, and log strain-log grain width) both are highly correlated (r^2 =0.98), what is also confirmed using a cross-correlation log function. Thus all data strongly support that grain width and twin density do not conform power-law distributions, however, both parameters have a good fit to the **log-normal** distribution which can be better seen when compared with the normal (gaussian), log-normal, negative-exponential and power-law distributions by using cumulative frequency plots (Figs. 2 and 3).

These plots provide a graphical representation of the data in a form suitable for visual estimation of the fit to the distribution models. In the case of normal (Figs. 2a and 3a) and log-normal (Figs. 2b and 3b) distributions, the cumulative frequency is plotted against grain width or twin density (Figs. 2a and 3a respectively), or log (grain width) / log (twin density) –Figs. 2b and 3b-, using normal probability scaling. A straight line plot indicates conformity in the normal (or log-normal) frequency distribution. For a negative-exponential distribution a plot of log (cumulative frequency of grain width or twin density, Figs. 2c and 3c) against grain width or twin density is a straight line, whereas for a power-law distribution log (cumulative frequency of grain width or twin density, Figs. 2d and 3d-) against log (grain width or twin density) yields a straight line.

INTERPRETATION AND DISCUSSION

The behavior of grain size and twin density is similar with a characteristic downturn or steeping of slopes at the high grain width and density ends of the log-log plots, usually affecting the widest twins (over 500 microns), and the highest twin density (over 4 twins.mm^{-1}). The meaning of this is complex, but can be interpreted as follows: twinning in calcite implies intracrystaline deformation mechanism with low shear stress. When the process begins, low grain width and calcite twins are developed with a probably random distribution what could be supported by a negative exponential distribution tendency in this low values. The twinning process continues until a "critical" value of grain width and density which is going to influence in the scaling process, and becoming the distribution to log-normal type. Most of data from calcite twins have a good fit to log-normal distribution, which is related to a characteristic grain size or density, best described by the arithmetic mean (grain size mean= 528.2 microns, and twin density = 3.73 mm^{-1}). These values can be considered as "critical" values to influence the scaling law. The use of the log-normal model allows further statistical analysis. But some data also conform to power-law cumulated frequency distribution of e-twins in calcite what is interpreted as a fractal geometry from determined range or sizes (300 to 1000 mm) and density (2 to 10 twins.mm^{-1}), with some superimposed random (negative-exponential) element, possible due to the irregularities at grain scale, but also because this systems show multifractal behavior.

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REFERENCES

González Casado, J.M. y García-Cuevas, C. (1999): Calcite twins from microveins as indicators of deformation history. *Journal of Structural Geology*, 21: 875-889.

Gumiel, P., Campos, R., Sanderson, D.J. y Roberts, S. (1995): Geometría y fractalidad de los sistemas filonianos de la mina de La Parrilla (Cáceres), Conectividad y Percolación. *Boletín Geológico y Minero*, 106 (4): 16-37.

Pickering, G., Bull, J.M. y Sanderson, D.J. (1995): Sampling power-law distributions. *Tectonophysics*, 248: 1-20.

Roberts, S., Sanderson, D. J. y Gumiel, P. (1999): Fractal Analysis and Percolation Properties of Veins. En: *Fractures, Fluid Flow and Mineralization* (K.J.W. Mc Caffrey, L. Lonergan y J.J. Wilkinson, Eds.). Geological Society of London, Special Publication 155: 7-16.

Salas, R. y Casas, A. (1993): Mesozoic extensional tectonics, stratigraphy and crustal evolution during the Alpine cycle of the eastern Iberian Chain. *Tectonophysics*, 228: 33-55.