Do foliation refraction patterns around buckle folds represent finite strain?

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I. Summary

Axial plane foliation associated with geological folds may exhibit a divergent or convergent fan. To test the hypothesis that the foliation orientation coincides with the major principal finite strain, numerical finite-element simulations of single-layer buckle folding are performed. Four different strain measures are considered: (1) finite strain (recording the entire strain history), (2) infinitesimal strain (instantaneous strain), (3) incremental strain (recording the strain history from a certain shortening value until the end), and (4) initially layer-perpendicular passive marker lines. Since all strain measures result in similar divergent fan patterns in the matrix at the outer arc of the fold, these patterns do not necessarily reflect the finite strain. In the stronger layer, differences of the convergent fans between the different strain measures can be identified. The main difference is associated with a 90°-switch of the major principal strain from a layer-perpendicular to a layer-parallel orientation at the outer arc, which was also observed in one of the studied natural folds (near Ribadeo and Luarca, NW Spain). However, because in natural folds a bedding-parallel foliation is challenging to identify as it may coincide with sedimentary structures, also the convergent foliation fan pattern in natural folds is not very well suited for strain estimates.

II. Geological field area

Field work took place in the Paleozoic metasediments of the Westasturian-Leonese Zone (WALZ), NW Spain (Fig. 1 & 2), which represents the external part of the hinterland of the Variscan orogeny.

The particular outcrops were found along the coast near the village Luarca (Fig. 2).

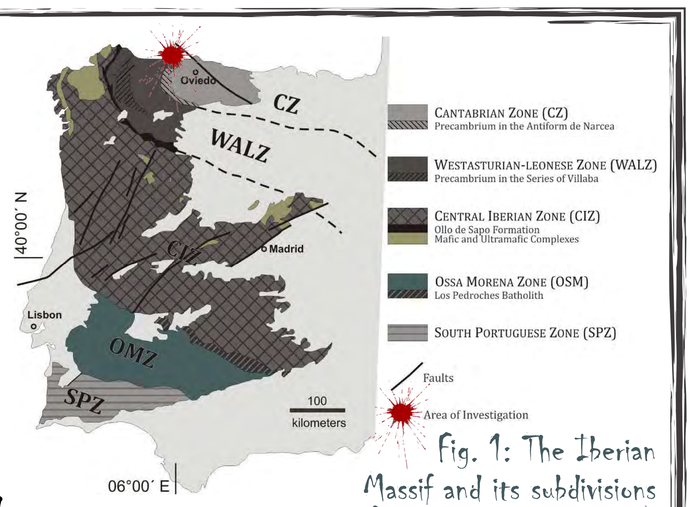


Fig. 1: The Iberian Massif and its subdivisions (Bastida & Aller, 1995)

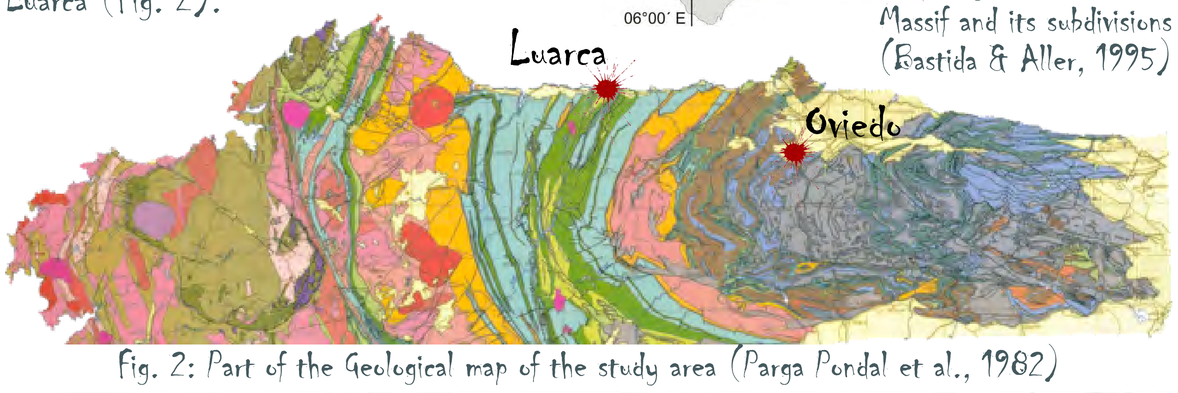
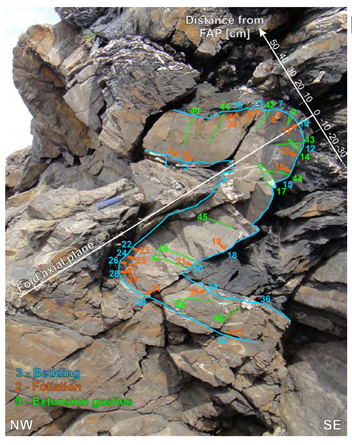
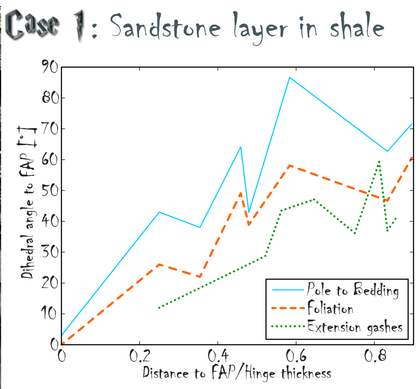


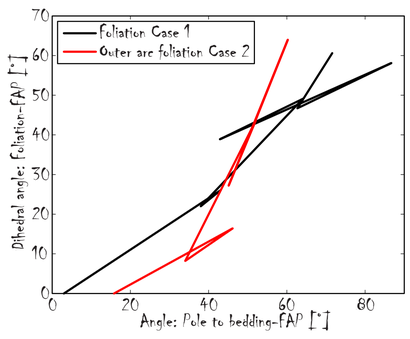
Fig. 2: Part of the Geological map of the study area (Parga Pondal et al., 1982)

III. Field examples

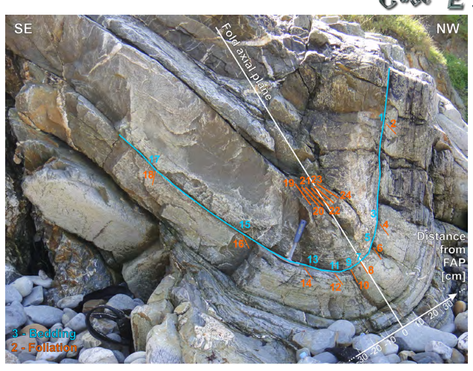


Case 1: Sandstone layer in shale





Case 2: Sandstone multilayers



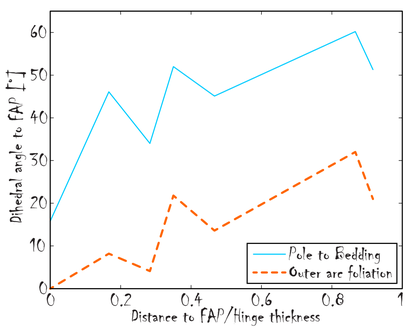
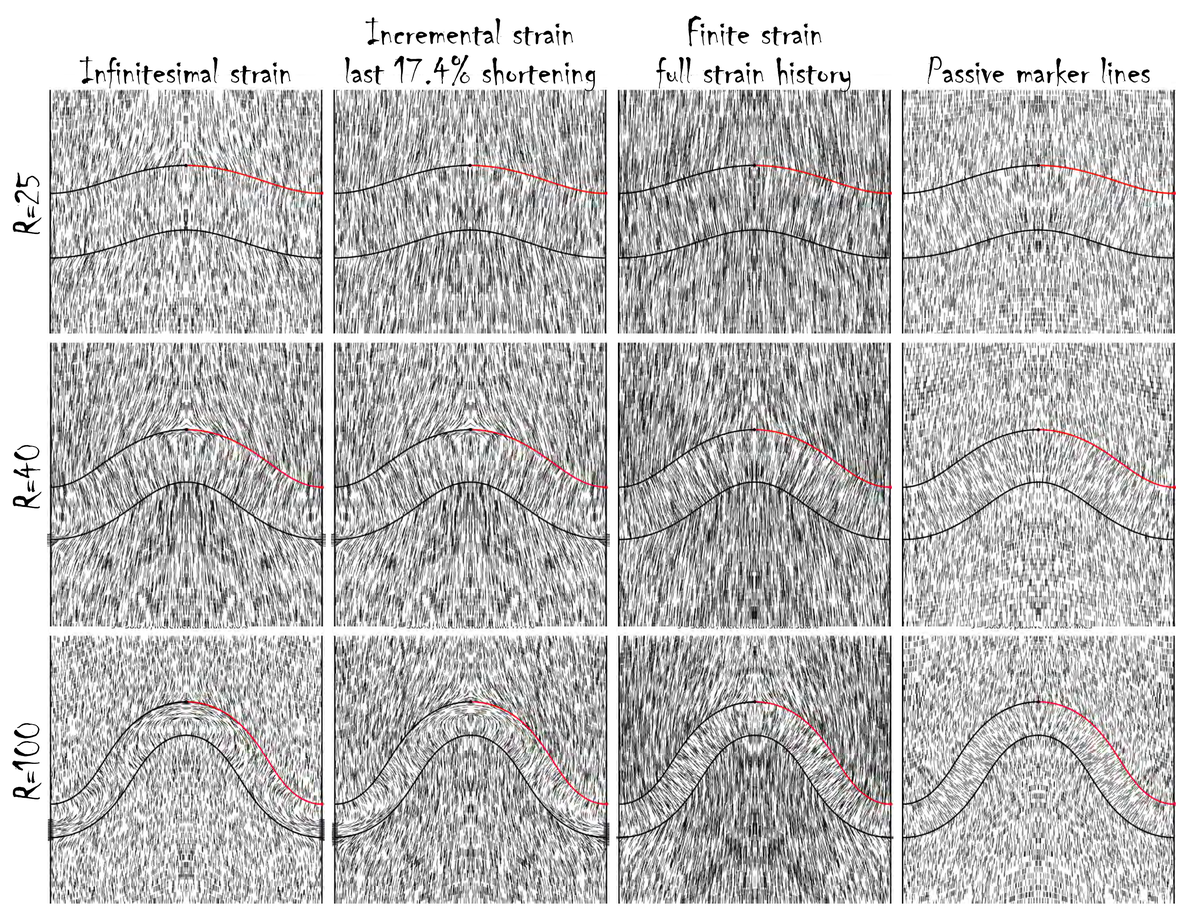


Fig. 3: Left: Outcrop pictures with measurement points.
Middle: Bedding interface, foliation, and extension gashes orientation vs. distance to the fold axial plane (FAP).
Right: Foliation orientation vs. Bedding orientation.

IV. Numerical simulations

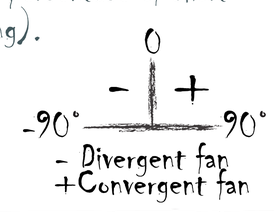
Fig. 4: FE simulations of dominant wavelength folding for different viscosity ratios R and initial amplitude-to-thickness ratio of 0.1 after 38.8% shortening. Lines are long strain ellipse axes recording different amounts of strain or passive marker lines.

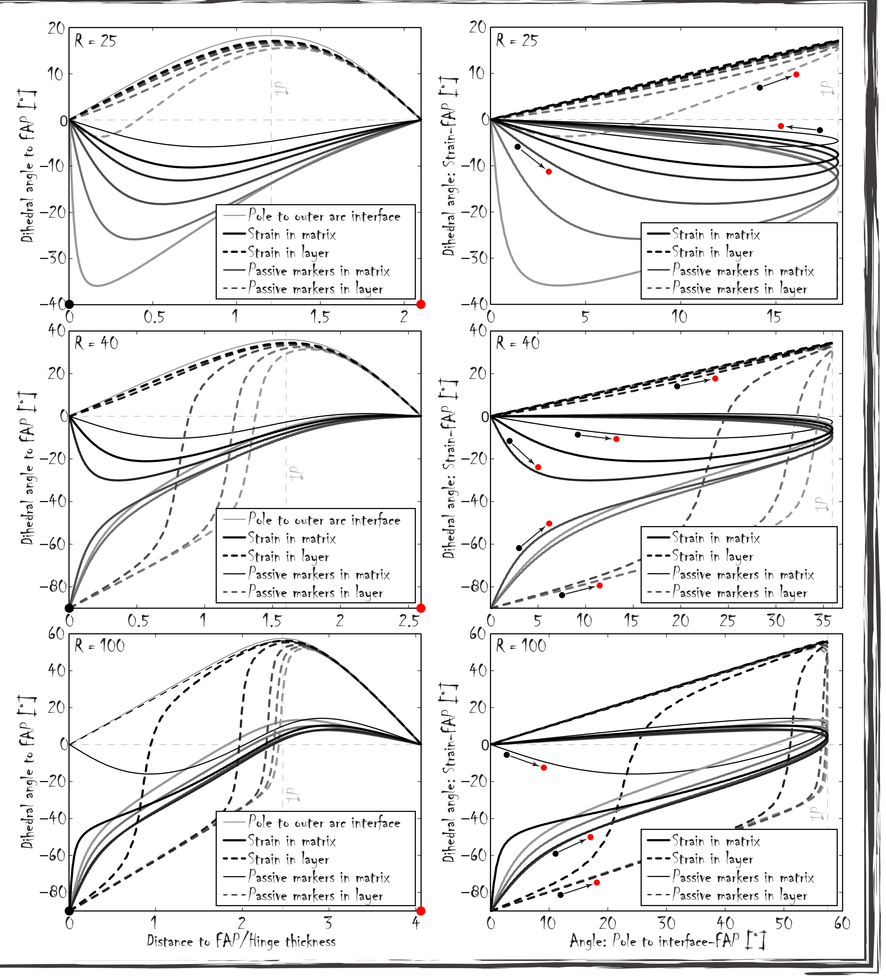


V. Analysis of numerical results

i = 38.8 | 27.9 | 17.4 | 8.2 | 0 %

Fig. 5: Orientations of the long strain ellipse axes and passive marker lines after 38.8% shortening (Fig. 4) just above (matrix) and below (layer) the red line in Fig. 4. Small arrows point from the black to the red dot in Fig. 4.
Different line colors correspond to different strain measures (i=0%: infinitesimal strain; i=38.8%: finite strain; i=intermediate: incremental strain recording the given last percentage of shortening).





VI. Conclusions

- Strain measures recording different amounts of strain result in similar refraction patterns.
- Particularly the divergent fan in the matrix is nearly insensitive to the amount of recorded strain.
- The convergent fan in the layer exhibits an almost sudden 90°-switch in orientation close to the fold axial plane, which depends on the amount of recorded strain and bulk shortening.
- Both divergent and convergent fans depend on the viscosity ratio between layer and matrix.
- The foliation orientations in the natural fold examples exhibit some features of the strain orientation patterns of the numerical simulations, but they are difficult to interpret.

References

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