Do foliation refraction patterns around buckle folds represent finite strain?

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

universität wien

Marcel FREHNER Geological Institute, ETH Zurich, Switzerland (marcel.frehner@erdw.ethz.ch)
Ulrike EXNER Department for Geodynamics and Sedimentology, University of Vienna, Austria

I) INTRODUCTION

Buckle folds commonly feature a characteristic syn-deformational foliation, which is sub-parallel to the fold axial plane; hence axial plane foliation. As the foliation is not perfectly parallel to the axial plane, it may exhibit either a divergent or convergent fan around the fold. Convergent fans most commonly occur in the mechanically stronger rocks while divergent fans rather occur in the mechanically weaker rocks. The foliation orientation is usually thought to reflect the long axes of the finite strain ellipses, a hypothesis that we investigate in our study.

We use the finite-element (FE) method to simulate two-dimensional single-layer viscous buckling. The numerical simulations allow calculating the strain evolution during folding and visualizing its distribution and orientation around the fold. We use different measures of strain: (1) the finite strain, (2) the infinitesimal strain, (3) the incremental strain (recording the strain history from a certain moment of the simulation until the end), and (4) initially layer-orthogonal passive marker lines. The first three strain measures are tensor fields that are used to calculate and visualize the orientation of the long axis of the strain ellipses around the fold.

We find that all strain measures result in a divergent fan in the mechanically weak matrix at the outer arc of the fold of almost equal geometry for all strain measures. For the case of the incremental strain, the divergent fan hardly depends on the moment from which the incremental strain is calculated. Therefore, the geometry of the divergent fan does not reflect the orientation of the long axes of the finite strain ellipses, but can reflect anything from finite to infinitesimal strain. In contrast, the convergent fan in the mechanically strong layer takes very different shapes for the different strain measures. The convergent fan is well developed in the case of the finite strain and the passive marker lines, but it is strongly influenced by the migration of the neutral line through the fold in the case of the incremental and the infinitesimal strain.

II) 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).

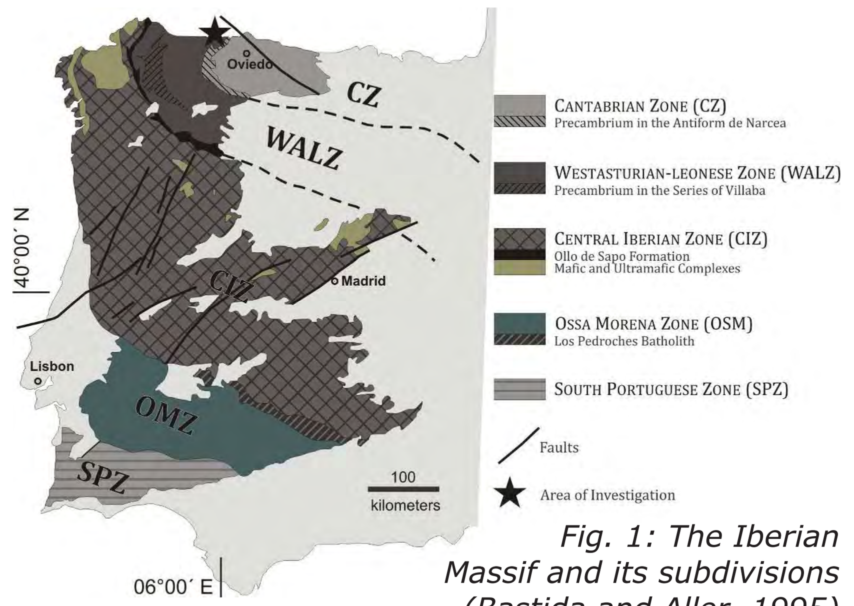


Fig. 1: The Iberian Massif and its subdivisions (Bastida and Aller, 1995)

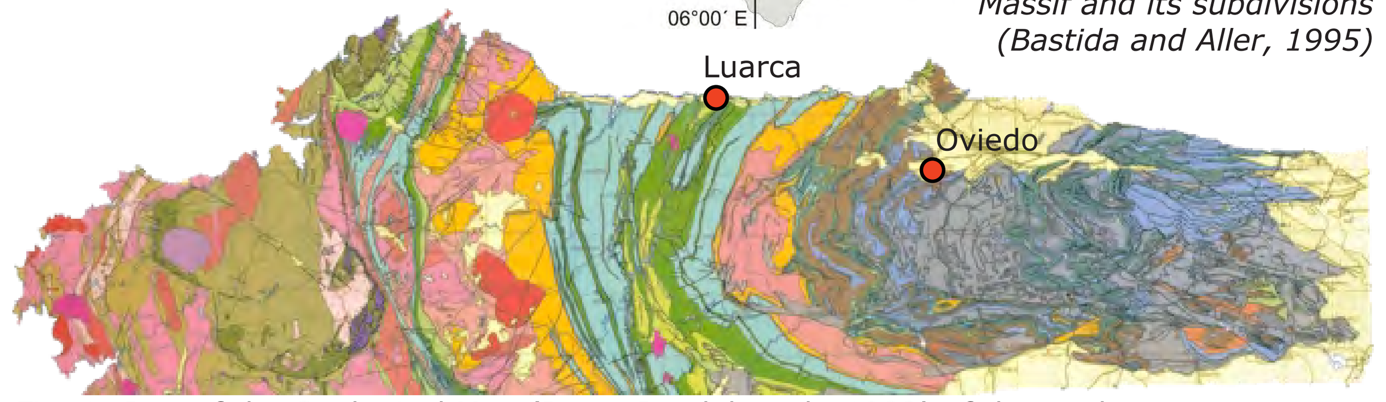


Fig. 1: Part of the Geological Map (Parga Pondal et al., 1982) of the study area.

III) FIELD EXAMPLE 1

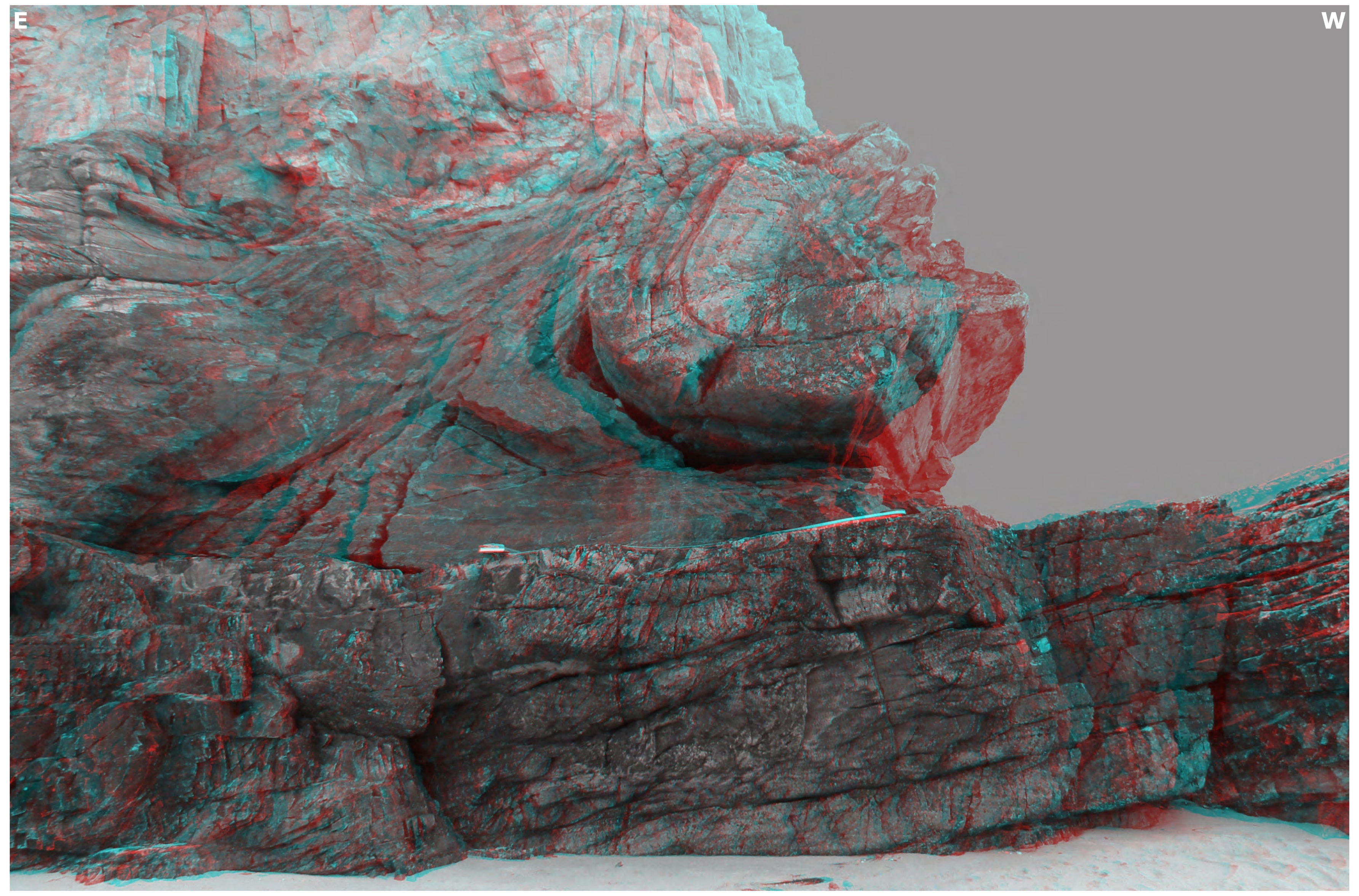


Fig. 3: 3D anaglyph of the outcrop.

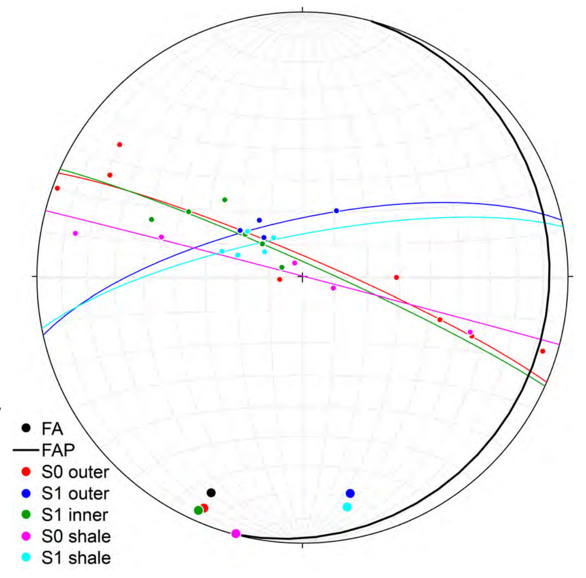


Fig. 4: Lower-hemisphere equal area projection of measured bedding (S0), foliation (S1), fold axis (FA), and axial plane (FAP) orientations in the inner and outer layer and in the thin shale layer in between.

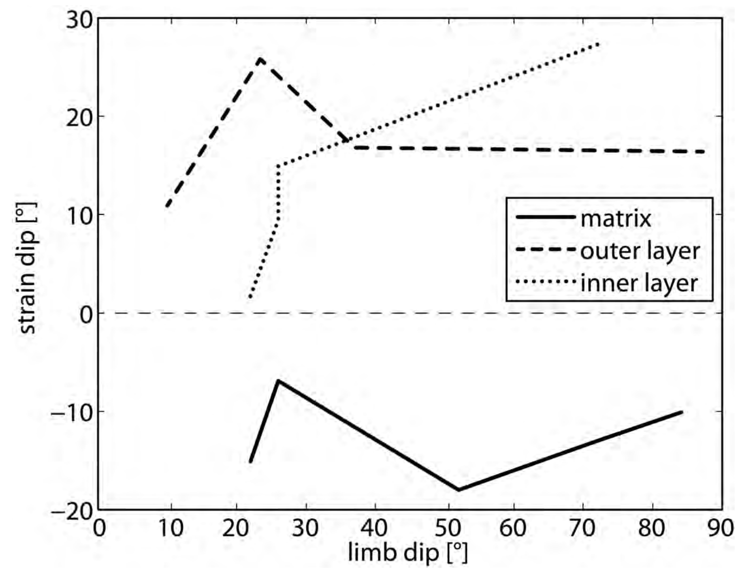
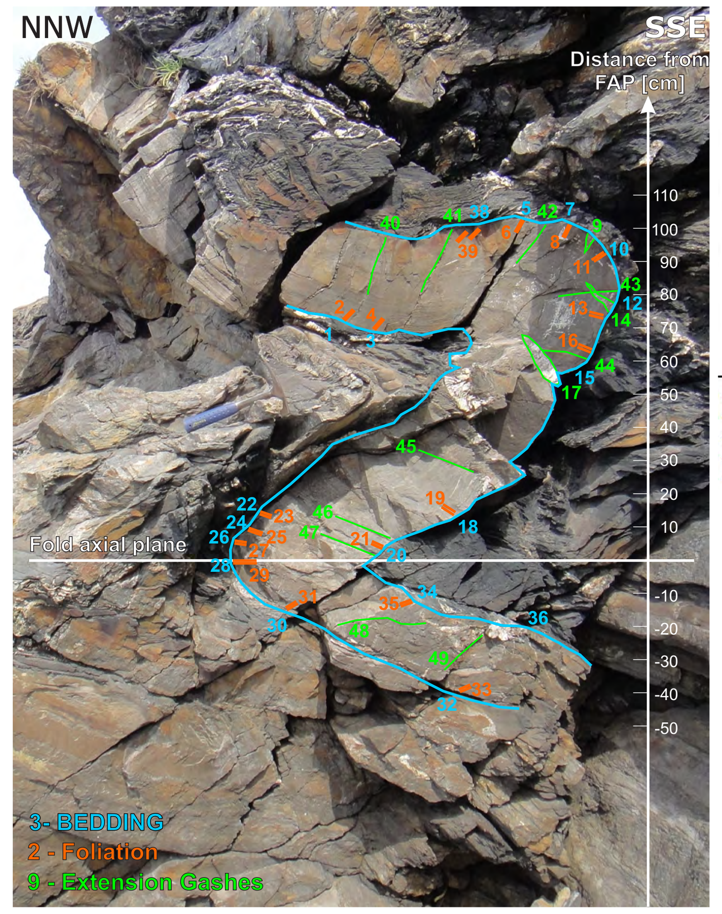


Fig. 5: Foliation (strain) vs. bedding orientation. Both are measured with respect to the FAP.

IV) FIELD EXAMPLE 2

Fig. 6: Outcrop with measurement points.



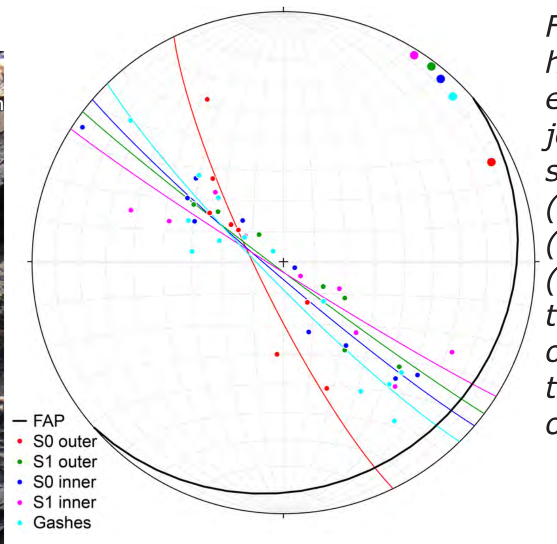


Fig. 7: Lower-hemisphere equal area projection of measured foliation (S1), bedding (S0), axial plane (FAP), and extension gashes orientations at the inner and outer arc.

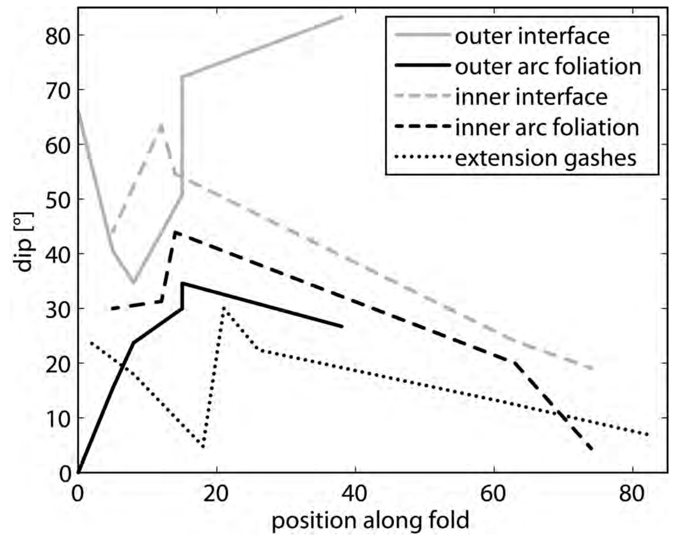
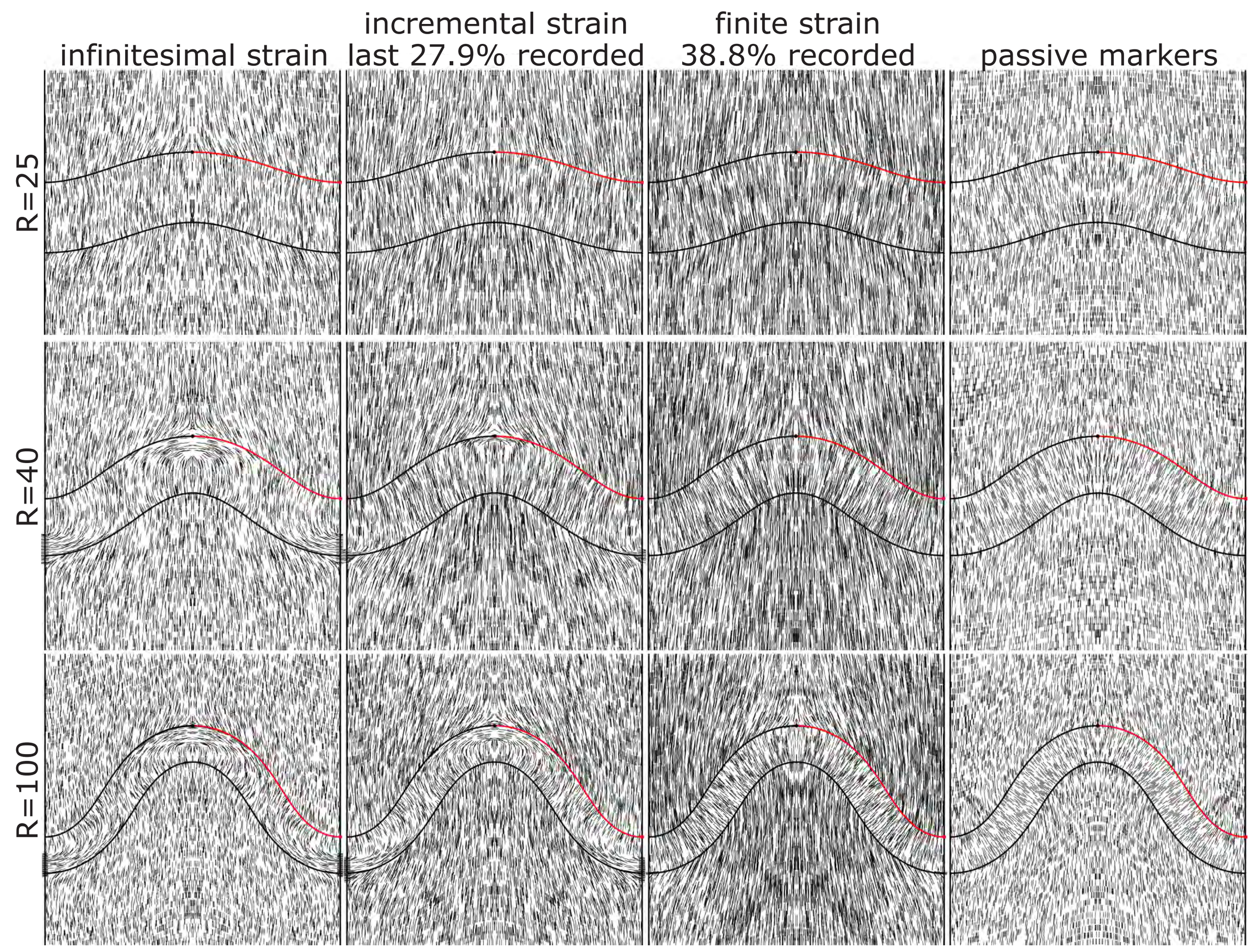


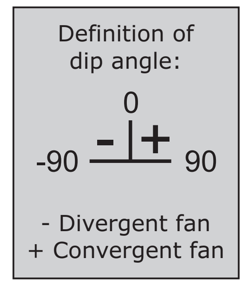
Fig. 8: Bedding interface, foliation, and extension gashes orientation vs. distance from the FAP. All orientations are measured with respect to the FAP.

V) NUMERICAL SIMULATIONS

Fig. 9: FE simulations of dominant wavelength folding for 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.



VI) ANALYSIS OF NUMERICAL RESULTS



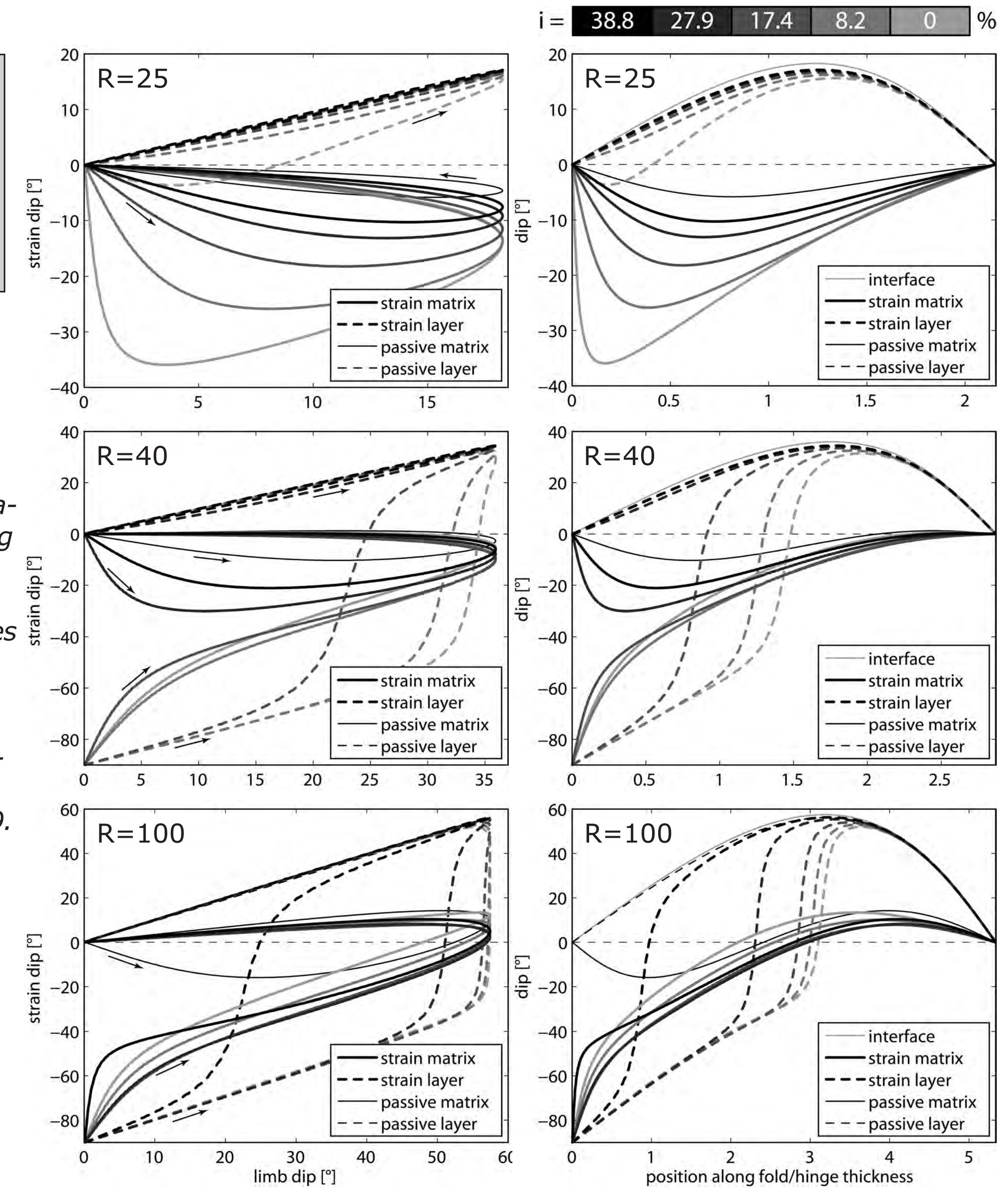


Fig. 10: Orientations of the long strain ellipse axes and passive marker lines after 38.8% shortening (Fig. 9) just outside (matrix) and inside (layer) the red line in Fig. 9. Small arrows point from the black to the red dot in Fig. 9.

VII) CONCLUSIONS

From the numerical simulations, several observations can be made:

- For low viscosity ratios, both the divergent and convergent fans of finite strain are similar to the fan of the passive marker lines.
- The convergent fan in the buckling layer depends much stronger on the recorded strain than the divergent fan in the surrounding matrix.
- Both the divergent and convergent fans strongly depend on the viscosity ratio between the buckling layer and the surrounding matrix.

Therefore, the interpretation of observed divergent foliation fans can be almost anything between finite and infinitesimal strain. However, the convergent fan geometry may help determine the recorded amount of strain. The overall geometry of both foliation fans may be used to infer the viscosity ratio between layer and matrix.

Only very general features of the angular relationships of the strain orientations is mimicked by the studied natural folds. Further investigation is necessary to better understand the kinematic meaning of different types of foliation fans.

References:

Bastida F. and Aller J., 1995: Rasgos geológicos generales, *in*: C. Aramburu and F. Bastida (eds): Geología de Asturias, Ediciones Trea, 27-34

Parga Pondal I., Parga Peinador X.R., Vegas R. and Marcos A., 1982: Mapa Xeológico do Macizo Hespérico, Publicacións da Area Xeoloxía e Minería do Seminario de Estudios Galegos, Ediciós do Castro, La Coruña, Scale 1:500.000

Acknowledgement:

FWF Der Wissenschaftsfonds