Agència de Gestió d'Ajuts Universitaris i de Recerca

Memòria justificativa de recerca de les convocatòries BCC, BE, BP, CTP-AIRE, DEBEQ, FI, INEFC, NANOS i PIV

La memòria justificativa consta de les dues parts que venen a continuació:
1.- Dades bàsiques i resums
2.- Memòria del treball (informe científic)

Tots els camps són obligatoris

1.- Dades bàsiques i resums

Nom de la convocatòria

BE

Llegenda per a les convocatòries:

BCC	Convocatòria de beques per a joves membres de comunitats catalanes a l'exterior
BE	Beques per a estades per a la recerca fora de Catalunya
BP	Convocatòria d'ajuts postdoctorals dins del programa Beatriu de Pinós
CTP-AIRE	Ajuts per accions de cooperació en el marc de la comunitat de treball dels Pirineus. Ajuts de mobilitat de personal investigador.
DEBEQ (Modalitat A3)	Beques de Cooperació Internacional i Desenvolupament
FI	Beques predoctorals per a la formació de personal investigador
INEFC	Beques predoctorals i de col·laboració, dins de l'àmbit de l'educació física i l'esport i les ciències aplicades a l'esport
NANOS	Beques de recerca per a la formació en el camp de les nanotecnologies
PIV	Beques de recerca per a professors i investigadors visitants a Catalunya

Títol del projecte: ha de sintetitzar la temàtica científica del vostre document.
Analog Modelling of N-S anticlines of the External Sierras (Jaca basin, Southern Pyrenees).

Dades de l'investigador o beneficiari

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Generalitat de Catalunya
Departament d'Innovació, Universitats i Empresa

Agència
de Gestió d'Ajuts
Universitaris
i de Recerca

Número d'expedient
2006 BE-2 0095

Paraules clau: cal que esmenteu cinc conceptes que defineixin el contingut de la vostra memòria.
Analogue modelling, External Sierras, Southern Pyrenees, Pico del Aguila, detachment, ductile deformation, brittle deformation.

Data de presentació de la justificació
22/12/2008

Nom i cognoms i signatura
del/de la investigador/a

Visttiplau del/de la responsable de la
sol·licitud

Generalitat de Catalunya
Departament d'Innovació,
Universitats i Empresa

Agència
de Gestió d'Ajuts
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i de Recerca

Resum del projecte: cal adjuntar dos resums del document, l'un en anglès i l'altre en la llengua del document, on s'esmenti la durada de l'acció

Resum en la llengua del projecte (màxim 300 paraules)

Two series of analogue models are used to explore ductile-frictional contrasts of the basal décollement in the development of oblique and transverse structures simultaneously to thin-skinned shortening. These models simulate the evolution of the Central External Sierras (Southern Pyrenees, Spain), which constitute the frontal emerging part of the southernmost Pyrenean thrust sheet. They are characterized by the presence of transverse N-S to NW-SE anticlines, which are perpendicular to the Pyrenean structural trend and developed in the hangingwall of the Santo Domingo thrust system, detaching on an unevenly distributed Triassic materials (evaporitic-dolomitic interfingerings). Model setup performs a décollement made by three patches of silicone neighbouring pure brittle sand. Model series A test the thickness ratio between overburden and décollement. Model series B test the width of frictional detachment areas. Model results show how deformation reaches further in areas detached on ductile layer whereas frictional décollement areas assimilate the strain by means of an additional uplift. This replicates the structural style of Central External Sierras: higher structural relief of N-S anticlines with regard to orogen-parallel structures, absence of a representative ductile décollement in the core, tilting towards the orogen and foreland-side closure not thrusted by the frontal emerging South-Pyrenean thrust.

Resum en anglès (màxim 300 paraules)

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Resum en anglès (màxim 300 paraules) – continuació -.

2.- Memòria del treball (informe científic sense limitació de paraules). Pot incloure altres fitxers de qualsevol mena, no més grans de 10 MB cadascun d'ells.

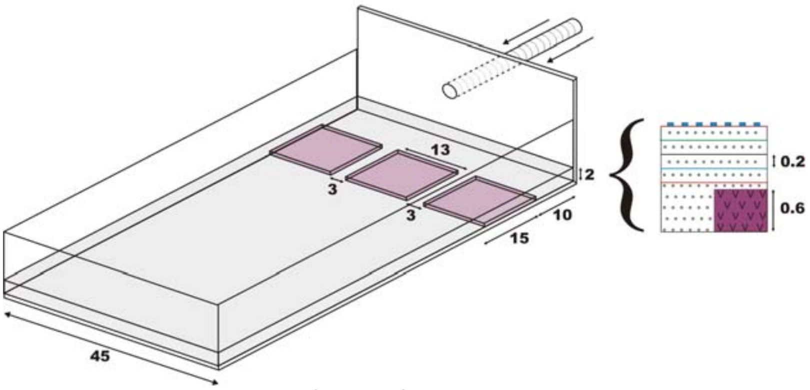
Based on field evidences of inhomogeneous distribution of Triassic materials, the experiments carried out at the HRTL of Uppsala University explore the mechanical contrasts in the basal décollement as a possible factor controlling the generation of oblique and transverse N-S anticlines by applying a homogeneous N-S shortening. In such a way, the aim of this work is to give new insights about the geodynamic evolution of the central sector of the External Sierras (Southern Pyrenees, Spain) by carrying out series of analogue models that explore the mechanical changes in the basal detachment.

The models comprised a colour inter-layered sequence of sand covering an uneven basal level made of three transparent silicone patches (ductile layers) neighbouring pure brittle sand (see Figures of each initial setup). Dry quartz sand sieved to an average grain size of 35 μm was used to simulate the brittle sedimentary cover. The bulk density was 1700 kg m-3 and the cohesive strength was 140 Pa. The detachment level was simulated by means of a Newtonian silicone polymer with a density of 987 kg m-3 and an effective viscosity of 5 x 104 Pa s, neighbouring dry quartz sand. The layers were placed on an aluminium plate. The experiments had a fixed width of 45 cm, an initial length of 60 cm, and a constant detachment thickness of 8 mm. Compression was applied at a rate of 2 cm/h (5.56 x 10-6 m/s) from one side using a motor-driven worm screw (see Figure 1a). The models were shortened up to 20% during a period comprised between 6 and 8h. Before placing the ductile layer, a small amount of sand was glued onto the basal plate to force contrasting friction in the basement, in order to accentuate the frictional contrast between the ductile layers and the sand sequence. The aim of this irregularly distributed detachment level was to test whether lateral contrasts in friction cause the generation of arcuate, oblique and even transverse structures regardless the orientation of the shortening.

A more detailed description of the most relevant experiments is exposed below:

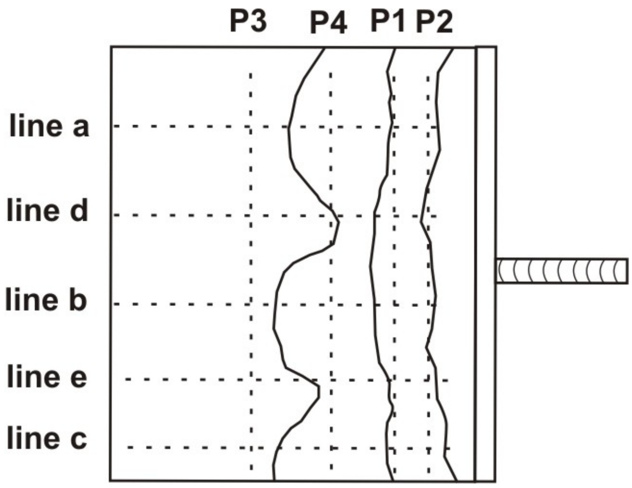
Experiment SExt6. This was the first model in which the separation between silicon patches was only 3 cm. The model was constructed above a high friction basal plate, made by gluing sand onto a metallic plate. The presence of this plate accentuated the difference in behaviour between the ductile layers and the pure brittle areas. This setting produced a very narrow high friction area, featuring much curved thrusts and a well marked differential advance between the pure brittle and the brittle-ductile areas. Two generations of curved thrusts were formed along the length of the silicon patches. Both of them are recorded in the top views and can be internally observed in the cross sections.

SExt6



Initial set up of model SExt6 (all values in cm)

Evolution of the topography was controlled by adding control points on the surface, following an order showed in the next schema:



The model was cut following two different orientations, generating a total number of 40 sections. These orientations are:

- 30 sections parallel to shortening directions (sections A)
- 10 horizontal sections (sections B)

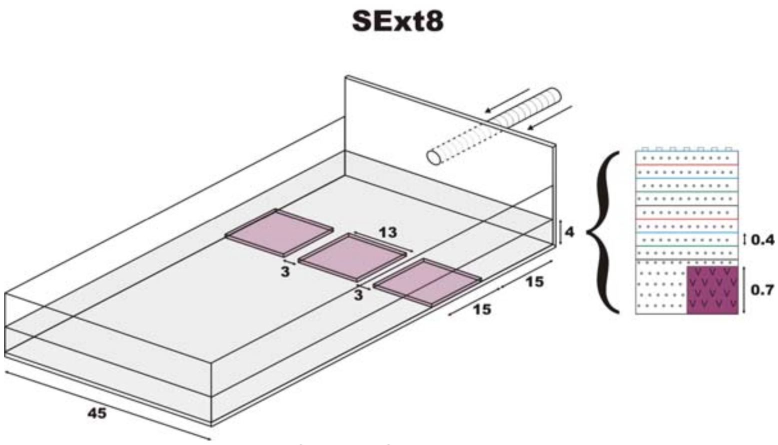
Both types of sections show a rear part featuring straight, frontward and narrowly spaced thrusts.

Sections A give information about the internal structure of the model along the shortening; but they are also giving information about how the structural style changes across the model. In such a way, the transport direction of the thrusts is continuously and progressively varying from the edges to the centre of the ductile layer. This means that thrusts are continuously changing geometry from a frontward thrust in the edge to a back thrust in the centre of the ductile layer and vice versa. In the areas with no ductile layer, the structural style is a typical sequence of frontward thrusts.

Sections B give important insights about the internal evolution of the layers. When comparing some of the horizontal sections with the geological map of the field area, the major geodynamic processes become obvious. Although the thrusts are partitioning the bedding, the geometry of the layers clearly describes an antiformal sequence perpendicular to the backstop. Besides that, the horizontal sections allow to observe the frontal folds associated to the emersion of the straight thrusts developed above the ductile layers. Sections B, therefore, are demonstrating how is it possible to obtain rotated and perpendicular geometries of the layers applying a unique straight compressive episode. Despite of the several repetitions of the sequence, sections B are clearly showing the rotation of the layers, which have been later thrusted and repeated.

Experiment SExt8. Although the results obtained in this model were not fully satisfactory according to the scope of the experiment, its structural evolution helps to constrain the conditions in which the expected structures form.

A high friction basal plate (glued sand) was used to accentuate the differential behaviour between brittle-ductile and pure brittle areas.



Initial set up of model SExt8 (all values in cm)

Evolution of the topography was controlled by scanning the surface of the model every hour. Since the model run during 5 hours, the surface of the model was scanned at 6 stages.

The model was cut following two different orientations, generating a total number of 33 sections. These orientations are:

- 15 sections parallel to shortening directions (sections A)
- 18 horizontal sections (sections B)

In this model there are no big differences between the pure brittle and the brittle-ductile areas. Besides that, sections B are not giving new insights about the geodynamic evolution. The general structure is composed by major frontward and back thrusts, slightly wavy, but mainly straight.

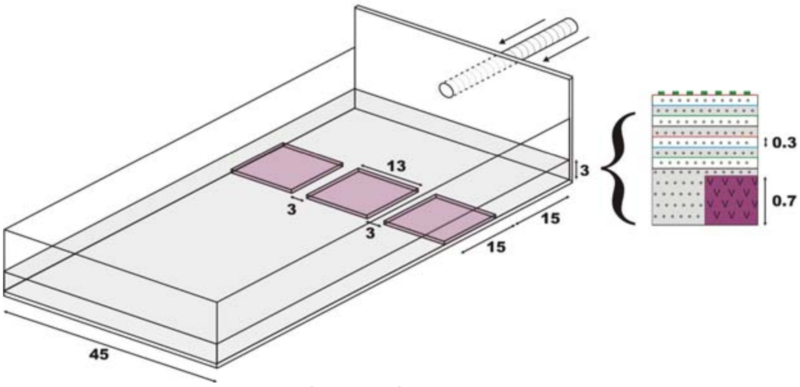
However, this model sheds light about the importance of the ratio "thickness/ductile layer length" in the creation of perpendicular to shortening structures. When observing sections A, one realizes that there is no difference in structural style between the pure brittle and the brittle-ductile areas. Furthermore, it is obvious that the last frontward thrust was developed on the tip line of the ductile layer and, therefore, it was forced to form there because of the frictional contrast between silicon and sand. This fact is providing an idea about the importance of the ratio between thickness of the cover and thrust spacing to generate the structures naturally. Furthermore, the relation between thickness and ductile layer dimensions is definitely a determining factor in the creation and evolution of wavy and perpendicular to shortening structures. In such a way, the spacing between the silicon patches was not enough in relation to the thickness of the sedimentary cover.

To sum up, we have realized that SExt8 did not generate transverse structures because the sequence was too thick in relation to the dimensions and spacing of the ductile layers.

Experiment SExt9. This experiment is providing valuable information about the origin and evolution of the perpendicular to shortening structures. Although the obtained geometries are not the most spectacular in comparison with other models, SExt9 is shedding light about the importance of another parameter: the spacing between ductile layers and therefore, the ratio "cover thickness/pure-brittle width".

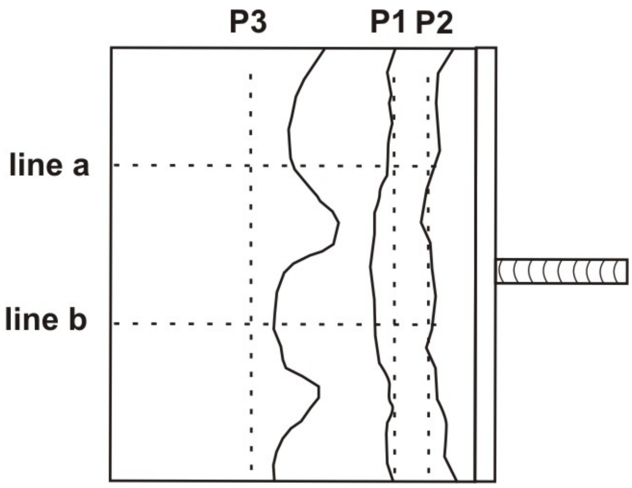
Although perpendicular-to-shortening structures were obtained, they were rather average when comparing to other models.

SExt9



Initial set up of model SExt9 (all values in cm)

Evolution of the topography was controlled by adding control points on the surface, following an order showed in the next schema:



As it was done in previous experiments, two types of sectioning were performed in order to constrain the internal structure:

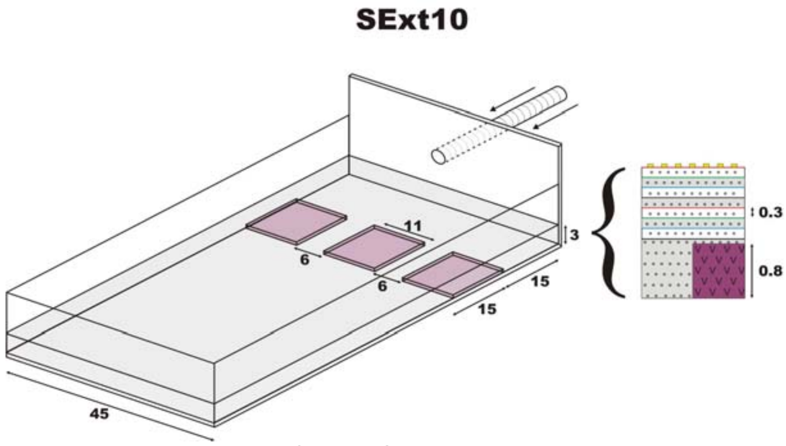
- Sections A: 21 parallel-to-shortening sections
- Sections B: 18 perpendicular-to-shortening sections.

Sections A are pointing out the importance of back thrusts in brittle-ductile areas, whereas in pure-brittle areas frontward thrusts are the major structural pattern. Although back thrusts are present in pure-brittle areas, they are a minor structure, blinded by a frontward thrust or simply almost creating no relief. However, in brittle-ductile areas, back thrusts take much importance, even blinding major frontward thrusts and showing pop-up geometries (section 2).
In this case, the tip line of the ductile layer has not completely worked as a nucleation point for the last frontal thrust, since the main part of the frontal structure has its origin on the inner part of the silicon layer. One recognizes important internal deformation due to the displacement of the silicon layer along the table (notice the thinning of the ductile layer towards the backstop, and the thinning of the sand layers towards the axis of the box and gentle syncline).

Example of Section A for model SExt9

Sections B are not giving new important insights about the perpendicular-to-shortening geometries. However, good lateral ramps can be observed, some of them notably increasing thickness of the silicon and some of them detaching in an intermediate sand level. This is suggesting that the lateral ramps are not such totally lateral ramps but a complex synformal thrust geometry which can be observed as a frontward thrust or as a lateral ramp depending on the orientation of the sectioning procedure (sectioning A or B). Therefore, lateral ramps are not generated in the basal part of the ductile layer, but in the advancing frontward ramp of the parallel-to-shortening thrusts.

Experiment Sext10. The scope of this model was to improve the geometry of the perpendicular-to-shortening structures by increasing the spacing between ductile layers. For this purpose, the distance between silicon patches was increased up to 6 cm.



Initial set up of model SExt10 (all values in cm)

The result was a beautiful generation of the expected structures, as it is showed in both top views and sections. Two different generations of perpendicular structures were formed, besides a set of preliminary straight thrusts.

In SExt10 the structures are beautifully showed by means of 42 sections, separated in 3 different types of sections:

- Sections A: 6 parallel-to-shortening sections to sum up the general structure along the tectonic transport.
- Sections B: 16 horizontal sections to see the internal structure of the model in top view.
- Sections C: 20 perpendicular-to-shortening sections to show the quality of the perpendicular structures of this model.

All the sections are showing the same type of structures than in previous models, but improving very much the quality of the structures.

Sections B and C are especially illustrative showing the geometry of the structures and its progressive variation along and across the shortening direction. Some of the lateral ramps observed in later Sections C are really spectacular and illustrative, even complicating the structure very much (Sections 35, 36, 38, 39, for instance).

Sections B are showing beautifully in top view how the layers have been folded perpendicularly to the shortening, being able to notice the geometry variation along strike, and to compare with the geological map of the field area.

Evolution of the topography was controlled by scanning the surface of the model every hour. Since the model run during 6 hours, the surface of the model was scanned at 7 stages.

Last top view of the model Sext10, after 20% of shortening. See how some areas have reached further (silicon-detached) than others (sand-detached).

Example of Section B taken in model SExt10.

Conclusions

Model results indicate that the geodynamic evolution of a fold-and-thrust belt is controlled by the distribution and mechanical behaviour of the basal detachment level. Therefore, the overburden will show a different structural response depending on the mechanical behaviour of the basal décollement. Areas detached on a ductile décollement show a larger advance of the structures whereas areas detached on a frictional brittle décollement show a higher uplift with regard to neighbouring areas.
Model results provide new insights on the evolution of the Central External Sierras. Based on the uneven distribution of the Triassic detachment level, models simulate the characteristics of the N-S

anticlines of Central External Sierras: higher structural relief with regard to orogen-parallel structures, absence of a representative ductile décollement in the core, tilting towards the orogen and foreland-side closure not thrusted by the frontal emerging South-Pyrenean thrust.

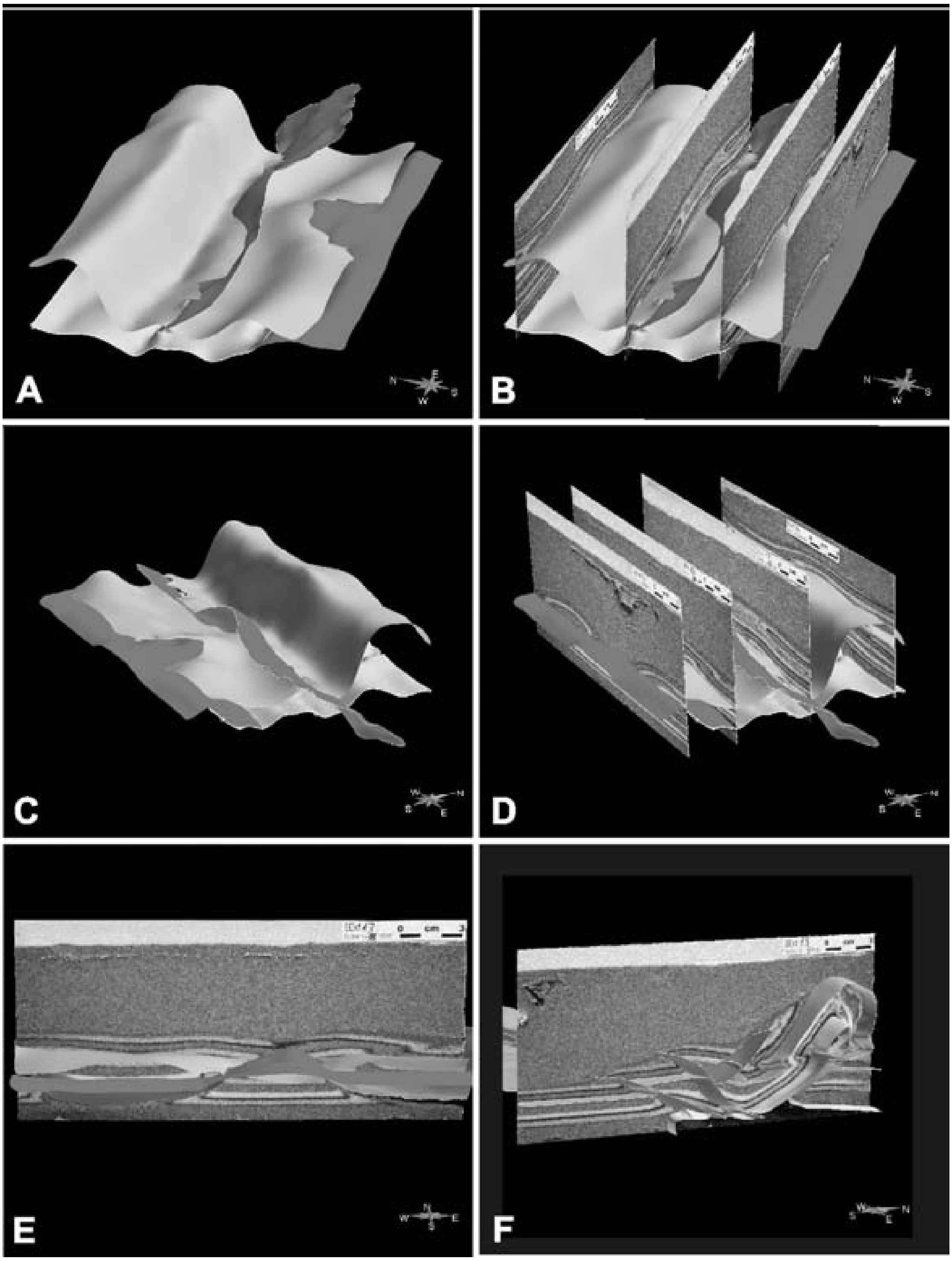
3D Reconstruction of Analogue modelling experiments

Besides the description and interpretation of the models, some of the most outstanding have also been reconstructed in 3D for a better comparison with the 3D geometrical model of the Pico del Aguila from field data and seismic interpretations. 3D Reconstruction of geological structures has become a widespread technique with which to perform a more realistic approach to field or model geometries. The work carried out presents a methodology to reconstruct 3D geometries of analogue modelling experiments without using sophisticated instruments such as Computerized Tomography (CT) scanners. Our approach is based on a 2.5D approach in which sections with different orientations and top views of models are integrated in order to obtain a unique consistent 3D model of the experiment geometries. The main benefit of 3D modelling is that it must agree with nature in all the spatial directions and, therefore, a more reliable result is obtained. In addition, 3D geometries provide an excellent database from which further studies can be performed.

The aim of the experiment presented in this work was to analyze the effect of the initial geometry of the basal detachment level as a contributor on the generation of oblique and transverse structures. The model results were compared to the structure observed in Central External Sierras (Southern Pyrenees, Spain). However, since the present work aims to be essentially methodological, no further discussions about comparisons to nature will be kept. Despite this, a brief description of the initial setup will be exposed for completeness.

A total number of 54 cross sections were taken, organized in two different types of sectioning: 29 parallel-to-shortening sections to observe the internal structure across strike; and 25 perpendicular-to-shortening sections, showing the internal geometry of the transverse structures. In addition, top photographs were taken every 15 minutes, to figure out the structural evolution of the model through time. From all these 2D dataset, we showed up the internal structure of the model by digitizing the silicone-sand boundary, two internal colour markers of the sand cover pack, all the perceptible faults and the topographic profile.

By following the methodology, we were able to reconstruct many different surfaces: the shape of the ductile layer, two internal levels of the sand cover pack corresponding to colour markers, the topographic surface, and several sets of major and minor associated faults affecting the entire sequence.



Several examples of the 3D reconstruction carried out for one of the analogue models conducted in the HRTL of Uppsala University. Notice how the sections fit exactly the position of the reconstructed horizons.

Derived from this works, several publications in international journals and conferences have been carried out:

- Vidal-Royo, O; Koyi, H.; Muñoz, J.A. Effect of mechanical contrasts in the basal décollement in the structural evolution of Central External Sierras (Southern Pyrenees, Spain): insights from analogue modelling. (submitted); Journal of Structural Geology (under revision).

- Vidal-Royo, O; Koyi, H.; Hardy, S.; Muñoz, J.A. Analogue and numerical modelling contributions to the structural evolution of Central External Sierras (Southern Pyrenees, Spain); Bolletino di Geofisica teorica ed aplicata, vol. 49 (2), 295-299.

- Vidal-Royo, O.; Ferrer, O.; Koyi, H.A:; Vendeville, B; Muñoz, J.A; Roca, E.; 3D Reconstruction of analogue modelling experiments from 2D datasets; Bolletino di Geofisica teorica ed aplicata, vol. 49 (2), 524-528.

- Vidal-Royo, O; Koyi, H.; Hardy, S.; Muñoz, J.A; 3-D Structural, Analog and Numerical Modeling Integration Applied to Pico Del Águila Anticline (Sierras Exteriores, Southern Pyrenees); Poster presented at the American Association of Petroleum Geologists General Meeting, San Antonio (TX, USA). 19-23 April 2008. Abstract: http://www.searchanddiscovery.net/documents/2008/08039annual_abst/abstracts/409454.htm