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Modelling compression along an extended plate boundary; the influence of along-strike mantle strength variation on subduction polarity

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A series of analogue mechanical experiments built from layers of sand and silicone putty was performed and analysed to potentially highlight how crustal density contrasts, strength and geometries have affected deep structures along the Iberian – Eurasian plate boundary. The current understanding of the deep structure of the Pyrenean – Cantabrian Orogeny is that a northerly-directed subduction took place in the Pyrenean (eastern) part, whereas the configuration of the Cantabrian and Bay of Biscay (western) subduction is less well constrained and understood. The transitional area near Pamplona, Spain is of particular interest, as a range of secondary structures is expected to have developed where the deformational styles meet.

The lithospheric structure as incorporated in the model design is based on published work and geological maps. Sand layers represent layers with brittle behaviour during deformation, whereas silicone putty layers represent ductile deformation. The models were built in a container where sand and silicon putty layers float on a substrate of sodium polytungstate liquid, representing the mantle. Layers were designed to match the assumed lithospheric geometries, density contrasts and strength-viscosity profiles along the Iberian – Eurasian suture zone. Keeping geometric and physical (strength profile) conditions identical for each experiment, a computer-controlled jackscrew then shortened the models to a pre-set value at a set rate while time-lapse images were recorded. Upon completion, the deformed layers were saturated with water and frozen, thus allowing for sectioning and profile inspection.

The experiments demonstrate how simultaneous synthetic (northerly dipping) and antithetic (southerly dipping) segments of subduction, as seen along the strike of the collision front, can be produced by subtle changes of the strength/density profiles and plate boundary geometries. The eastern segment, where a thin and narrow silicone layer corresponding to exhumed "upper mantle" separated the two plates with "continental" plate characteristics, was characterized by a symmetrical pop-up structure with associated piggy-back foreland basins.

In contrast, the western segment, where the "continental" plate in the south was in direct contact with the "oceanic" plate to its north, developed a series of geometries including south-directed and north-directed subduction and obduction in different experiments. The experiments highlight how the upper mantle strength influences initiation and positioning of a subduction zone where a strong continental plate and relatively weaker oceanic plate converge in the western part of the model. Upper mantle strength appears to be proportional to the distance from plate boundary to subduction zone in the direction of the weaker oceanic plate. Obduction occurs within the oceanic plate when the upper mantle strength is equal to or less than that of the oceanic crust.

For the central segment, various types of uplifted accommodation zones were produced, largely governed by the deformation style farther "west" in the model, but influenced by a head-on style of collision between two continental plates. The opening angle for the Bay of Biscay controls the scissor-like closure rate for the transition zone and must be considered in order to accurately represent a realistic scenario.