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Fault patterns in complex extensional strain fields

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Complex patterns of normal faults, characterised by variable strike orientations and non-systematic crosscutting relationships, have been observed in different settings (e.g. the Hoop Fault Complex in the SW Barents Sea, the Afar region, the polygonal faults in the northern North Sea and the canyon systems of Noctis Labyrinthus on Mars). These fault patterns could be related to complex strain fields, characterised by simultaneous or non-coeval multidirectional extensions. Recognizing and differentiating the extensional structures resulting from the occurrence of these complex strain fields could have major implications in terms of interpretation of plates kinematics and tectonics.

In this work, three complex extensional strain fields were reproduced using 2-layers analogue models and the obtained geometries of normal faults were compared with selected natural examples. Specifically, we deformed brittle-ductile models in 1g conditions, and simulated (1) radial extension, (2) simultaneous bidirectional extension and (3) multiphase extension, with two successive phases of extension at 90° one to the other. Set-up (1) was characterised by a circular model in which extension was the same along each radius, inducing radial extension of the brittle-ductile model. In this case, numerous, closely spaced normal faults formed without a dominant strike, intersecting at different angles and defining polygonal fault blocks in plan view. Set-up (2) consisted in a square model deformed by simultaneously applying two dominant extensional directions orthogonal to the model sides. In this experiment, two fault sets - perpendicular one to the other and orthogonal to the two dominant extensional directions - developed contemporaneously in the central part of the model. The faults of one set generally terminated against the faults of the other, producing T-shaped intersections. However, next to the vertices of the square model, the two extensional directions interacted, resulting in more complex fault patterns typically characterised by Y-shaped fault geometries. Finally, in set-up (3), a square model was deformed by successively applying extension in two directions, orthogonal to the model sides and at 90° one to the other. In this case, two distinct fault systems - intersecting at 90° and perpendicular to each extensional direction - developed successively during the two different extensional phases. Differently from model (2), the later faults in this experiment did not terminate against earlier structures; rather they typically tended to cut the pre-existing faults.

Our results suggest that the discrimination between radial, simultaneous bidirectional and non-coeval bidirectional extension is possible. Indeed, the similarity between the geometries observed in the models and the natural examples suggests that complex strain fields can occur in nature and account for the geometries observed in several extensional settings.