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The role of indenter rheology during continental collision

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Introduction

The process of continental collision is generally described with an indenter geometry: A rigid plate is assumed to indent into a softer plate producing a region of thickened crust and elevated topography in front of an undeformed block referred to as the indenter. This geometry has been assumed in analogue models for continental collision (e.g. Tapponnier et al., 1982; Ratschbacher et al., 1991), numerical models (England and Houseman, 1986; Houseman and England, 1993) and has been applied to several orogens (Frisch et al., 2000; Ratschbacher et al., 1989). However, in the European Alps both the Adriatic indenter and the European foreland show significant deformation and elevated topography indicating that the indenting plate cannot be assume rigid. In this study we use the finite element model of Barr and Houseman (1996) to investigate the influence of the indenter rheology on the distribution of deformation between two plates in two dimensional plan view.

Model Results

The partitioning of deformation between two plates is strongly dependent on the viscosity contrast between indenter and foreland, the width of the indenter and the angle of indentation.

The majority of deformation occurs within the indenter, if viscosity of the indenter is small and the width of this low viscosity region is large. In contrast, stresses are transmitted into the foreland if the viscosity contrast is large and the indenter narrow. For indenters that are twice as viscous as their foreland, an aspect ratio of the indenter of 2:1 will cause roughly equal partitioning of crustal thickening between indenter and foreland. This result is largely independent of Argand number (*Ar*) and power law exponent (n).

The angle of indentation alters the thickening and velocity pattern in the foreland significantly. During oblique indentation the distribution of crustal thickening remains roughly symmetric about the oblique indenter front. However, the horizontal velocity field in the foreland becomes highly asymmetric. If the indenter is less than 10 times as viscous as the foreland, it becomes rapidly deformed during progressive deformation so that the thickening and horizontal velocity fields approach that of rectangular indenters after time.

The process of lateral extrusion is interpreted by tracking the maximum horizontal velocity during progressive deformation. This velocity remains roughly constant over time for *Ar* = 0 as lateral escape is not influenced by crustal thickening. However, it increases gradually with higher *Ar* as gravitational extensional collapse provides and increasing contribution to the lateral velocity field. After substantial convergence the gravitational extensional collapse accounts for about 1/3 of of the horizontal velocity at viscosity contrasts of 100 and is less important for smaller viscosity contrasts between indenter and foreland. Areas with significant east-directed lateral motion increase with indenter angle, but the lateral gradient of the lateral velocity is smooth.

Comparison with the India Asia collision zone predicts that the area of eastwards displacement has increased by about 20% since the onset of collision. In contrast, in the European Alps, where the indenter has changed its obliquity over the last 30 my, the area may have increased by about 50% during this time interval. However, if the indenter softened during indentation, then the area increase of the lateral extrusion corridor may not be so dramatic.

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