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Slab breakoff: A critical appraisal of a geological theory as applied in space and time

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A R T I C L E I N F O

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A B S T R A C T

The idea that prominent geological phenomena observed in the crust and at the surface may be caused by the detachment of subducting dense lithosphere has been anticipated by tectonic models in the Sixties and Seventies, and imaged with improved geophysical techniques in the Eighties. In the mid-Nineties, the model of slab breakoff was defined formally by Davies and von Blanckenburg. Initially proposed as a thought-provoking working hypothesis, the theory rapidly received wide a priori acceptance and was applied to virtually every mountain range around the world, and even in orogens as old as Paleoproterozoic and Archean, to explain a range of different phenomena. These include magmatic flare-ups, rapid topographic uplift, increasing sediment supply, fast exhumation of metamorphic rocks, ore mineralizations, anomalous distribution of seismicity, changes in stress regimes, and inversion of subduction polarity. Even multiple breakoff events were assumed to have occurred at different times in the same orogenic belt or subduction zone. In the last 20 years, slab breakoff has been invoked in so many settings and time frames that it could have hardly taken place in each and every case in which it was called upon.

This article does not critically examine the theory, but critically examines its use. The extensive review of the vast literature presented here on the subject reveals how the model has been often applied to provide ad hoc explanations for a range of poorly understood observations based on incomplete evidence of deep-seated processes. Our aim is to illustrate a paradigmatic example of how earth scientists, in the face of evidence that challenges our capacity of understanding, often recur to hypotheses based on other hypotheses. Such an approach may induce researchers to look for confirmation in the absence of compelling constraints, or even in the face of conflicting evidence. The faith in models should not lead us to confuse speculative theories with axiomatic truths, and to build upon them theoretical edifices that are vulnerable and exposed to the risk of circular reasoning.

"It is easy to obtain confirmations, or verifications, for nearly every theory - if we look for confirmations."

K.R. Popper, 1963. Conjectures and refutations: the growth of scientific knowledge, p. 36.

"At the foundation of well-founded belief lies belief that is not founded."

L.J.J. Wittgenstein, 1974. On Certainty, #253.

1. Introduction

Slab breakoff, defined as "*the buoyancy-driven detachment of subducted oceanic lithosphere from the light continental lithosphere that follows it during continental collision*" (Davies and von Blanckenburg, 1995; von Blanckenburg and Davies, 1995), is a tectonic model first introduced to explain post-collisional magmatism and exhumation of high-pressure rocks in the European Alps (Fig. 1A). Extensive magmatism in the Alps was ascribed to the rising of the asthenosphere and consequent increase in geothermal gradients after detachment of the oceanic slab formerly attached to the edge of the European continent (Dal Piaz et al., 2003). An analogous process of slab detachment had been illustrated decades before (Fig. 14d in Isacks et al., 1968; Fig. 1B), and subsequently supported by seismic-tomography images (Spakman, 1988; Wortel and Spakman, 2000; Lippitsch et al., 2003; Fig. 1E).

Since its introduction, slab-breakoff theory has received wide consideration and has been applied to virtually every segment of the Alpine-Himalayan orogenic system (Fig. 2). The model has been invoked to explain a variety of phenomena, including magmatic flare-ups (Zhu et al., 2015), rapid topographic uplift (Huang et al., 2010), increasing sediment supply (Sinclair, 1997), fast exhumation of metamorphic rocks (O'Brien, 2001), ore mineralizations (Neubauer et al.,

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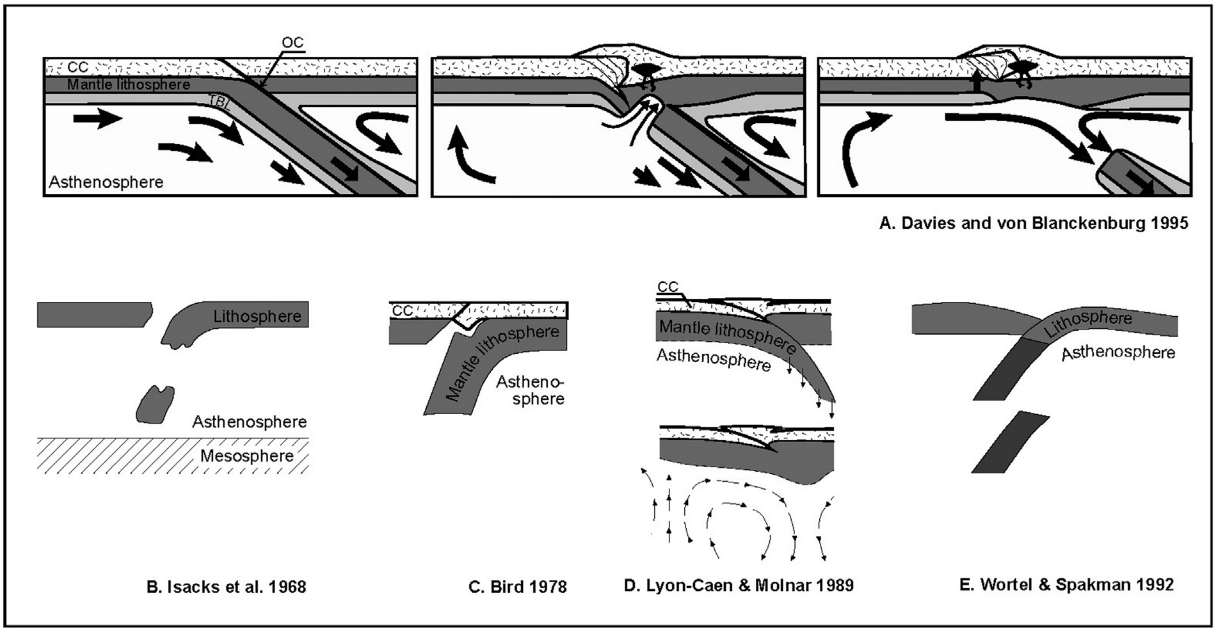

Fig. 1. Different models of slab breakoff, slab detachment and crustal delamination, redrawn from the original sources. A) The slab-breakoff model (Davies and von Blanckenburg, 1995); CC: Continental Crust; OC: Oceanic Crust; TRL: Thermal Boundary Layer. B) A piece of lithosphere becomes detached (Isacks et al., 1968). C) Slab delamination (Bird, 1978). D) Detachment or warming of subducted lithosphere (Lyon-Caen and Molnar, 1989). E) Slab detachment (Wortel and Spakman, 1992).

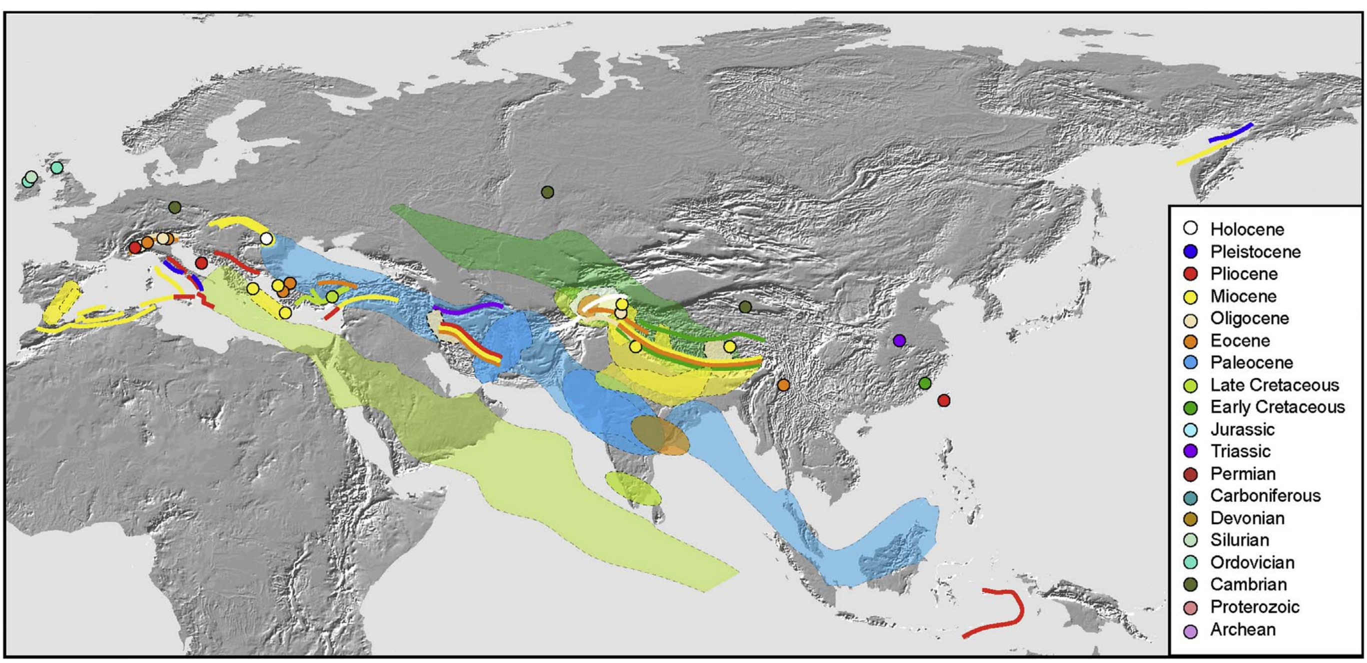

Fig. 2. Slab breakoff in space and time, as proposed by articles cited in the text (circles). Larger areas across the Middle East and central Asia indicate regions of observed tomographic anomalies (Van der Voo et al., 1999) and of slab breakoff inferred from those geophysical data (DeCelles et al., 2002).

2005), anomalous distribution of seismicity (Sperner et al., 2001), changes in the stress regime (Sue et al., 1999), and flipping of subduction polarity (Teng et al., 2000). And even a series of successive breakoff events have been postulated in the same orogenic belt (O'Brien, 2001; Leech et al., 2005).

In this article we examine first the different situations in which slab breakoff has been called upon in various mountain ranges around the world (Section 2), and next appraise critically how the model is rather flexibly applied even in the absence of cogent constraints to provide ad hoc explanations for otherwise unexplained geological facts (Section 3). Finally, we briefly discuss the epistemological problems raised by the limited testability of geological hypotheses and the logical pitfalls induced by the uncritical faith in widely accepted theoretical models (Section 4). Our aim is to illustrate an emblematic example of how earth scientists, in the face of geological evidence that baffles our capacity of understanding, may recur to theories based on other theories. Another case in which a controlling process is situated in the deep Earth beyond the reach of direct observation is the introduction of additional hidden loads to explain foredeep subsidence in excess of what visible loads can account for (Royden and Karner, 1984 p. 710). In this way, to put it in Wittgenstein's (1974, #88) words, "*all enquiry on our part is set so as to exempt certain propositions from doubt, if they were ever formulated. They lie apart from the route travelled by enquiry*". Our purpose here is not to critically examine the theory, but to critically examine its