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Cenozoic landforms and post-orogenic landscape evolution of the Balkanide orogen: Evidence for alternatives to the tectonic denudation narrative in southern Bulgaria

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ABSTRACT

Continental denudation is the mass transfer of rock from source areas to sedimentary depocentres, and is typically the result of Earth surface processes. However, a process known as tectonic denudation is also understood to expose deep-seated rocks in short periods of geological time by displacing large masses of continental crust along shallow-angle faults, and without requiring major contributions from surface erosion. Some parts of the world, such as the Basin and Range in the USA or the Aegean province in Europe, have been showcased for their Cenozoic tectonic denudation features, commonly described as metamorphic core-complexes or as supradetachment faults. Based on 22 new apatite fission-track (AFT) and 21 helium (AHe) cooling ages among rock samples collected widely from plateau summits and their adjacent valley floors, and elaborating on inconsistencies between the regional stratigraphic, topographic and denudational records, this study frames a revised perspective on the prevailing tectonic denudation narrative for southern Bulgaria. We conclude that conspicuous landforms in this region, such as erosion surfaces on basement-cored mountain ranges, are not primarily the result of Paleogene to Neogene core-complex formation. They result instead from "ordinary" erosion-driven, subaerial denudation. Rock cooling, each time suggesting at least 2 km of crustal denudation, has exposed shallow Paleogene granitic plutons and documents a 3-stage wave of erosional denudation which progressed from north to south during the Middle Eocene, Oligocene, Early to Middle Miocene, and Late Miocene. Denudation initially prevailed during the Paleogene under a syn-orogenic compressional regime involving piggyback extensional basins (Phase 1), but subsequently migrated southward in response to post-orogenic upper-plate extension driven by trench rollback of the Hellenic subduction slab (Phase 2). Rare insight given by the denudation pattern indicates that trench rollback progressed at a mean velocity of 3 to 4 km/Ma. The Neogene horst-and-graben mosaic that defines the modern landscape (Phase 3) has completely overprinted the earlier fabrics of Phases 1 and 2, and has been the prime focus of tectonic geomorphologists working in the region. The new narrative proposed here for linking the geodynamic evolution of SE Europe with surface landform assemblages raises issues in favour of better documenting the regional sedimentary record of existing Paleogene basins, which constitute a poorly documented missing link to the thermochronological evidence presented here.

1. Introduction

Basin analysis is commonly used in Earth science as a proxy for inferring the denudation chronology of adjacent uplands or the controls exerted by tectonic regime on the intensity of debris supply from eroding source areas (e.g., Leeder, 1999). Such is the case in the Rhodope of Bulgaria, where geomorphological research overall remains greatly under-reported in comparison with other similar European regions such as neighbouring Greece or southern Spain, but where regional research on Neogene basins and Quaternary neotectonics has focused accordingly on range-front morphology and basin stratigraphy (e.g., Zagorčev, 1992a, 1992b, 2007; Westaway, 2006).

Other approaches to understanding denudation chronology in regional landscapes involve measuring denudation depths directly in the eroding uplands, typically using methods based on low-temperature

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thermochronology. Precise sediment budgets between source and sink become increasingly difficult to establish with increasing geological age because, as the landscape changes over tens of millions of years and thus potentially over one or more orogenic cycles, spatial patterns of palaeorelief and sediment routing become more indistinct. Matters are further obscured when the sediments are predominantly of clastic origin and their stratigraphy difficult to date precisely—a problem encountered in the Rhodope. As a result, inferred links between sedimentary depocentres and adjacent uplands may lead to spurious conclusions, for example that a sedimentary basin and its adjacent footwall upland have functioned as strictly cogenetic, coupled systems. It may instead be the case, for example, that the upland region has recorded a much longer denudation history than recorded by its nearest depocentre, the latter being a young tectonic feature that has only recorded the more recent period of upland denudation.

The landscape history of complex, post-orogenic mosaics of uplands and basins, i.e. horsts and grabens such as those encountered in the southern Balkan region of Europe (Figs. 1, 2), has been difficult to unravel and has given rise to a number of debated tectonic interpretations (Dumurdzanov et al., 2005; Westaway, 2006; Burchfiel et al., 2008; Jolivet et al., 2013). The choice of this region as a study area is, therefore, motivated by persisting uncertainty regarding its long-term landscape evolution. New insights are gained here by analysing and comparing two independent chronologies—the first based on the chronostratigraphy of existing Cenozoic sedimentary basins, and the second obtained from rock cooling data inferred from four elevated basement uplands situated along a north–south cross-section extending from the External to the Internal Balkanides. The stratigraphic data were compiled from a review of the literature, whereas the thermochronological data were produced for this study. The presence of a high-elevation surface of low erosion, also dated at several sites, provides further important clues towards understanding the long-term evolution of the landscape. We subsequently attempt to reconcile observed discrepancies between the respective stratigraphic, topographic and denudational records by constructing a coherent morphotectonic history of the Balkanic collisional orogeny and its postorogenic history of crustal extension.

Low-temperature thermochronology, which in this study combines apatite fission-track (AFT) with apatite (U–Th)/He (AHe) analysis, is commonly used to constrain the thermal history of rocks in the upper few kilometres of the Earth's crust, and is suited to monitoring the depth and timing of continental denudation over time scales of 1 to 1000 Ma (Gallagher et al., 1998). An apatite sample's measured AFT age and spontaneous track-length distribution together record its

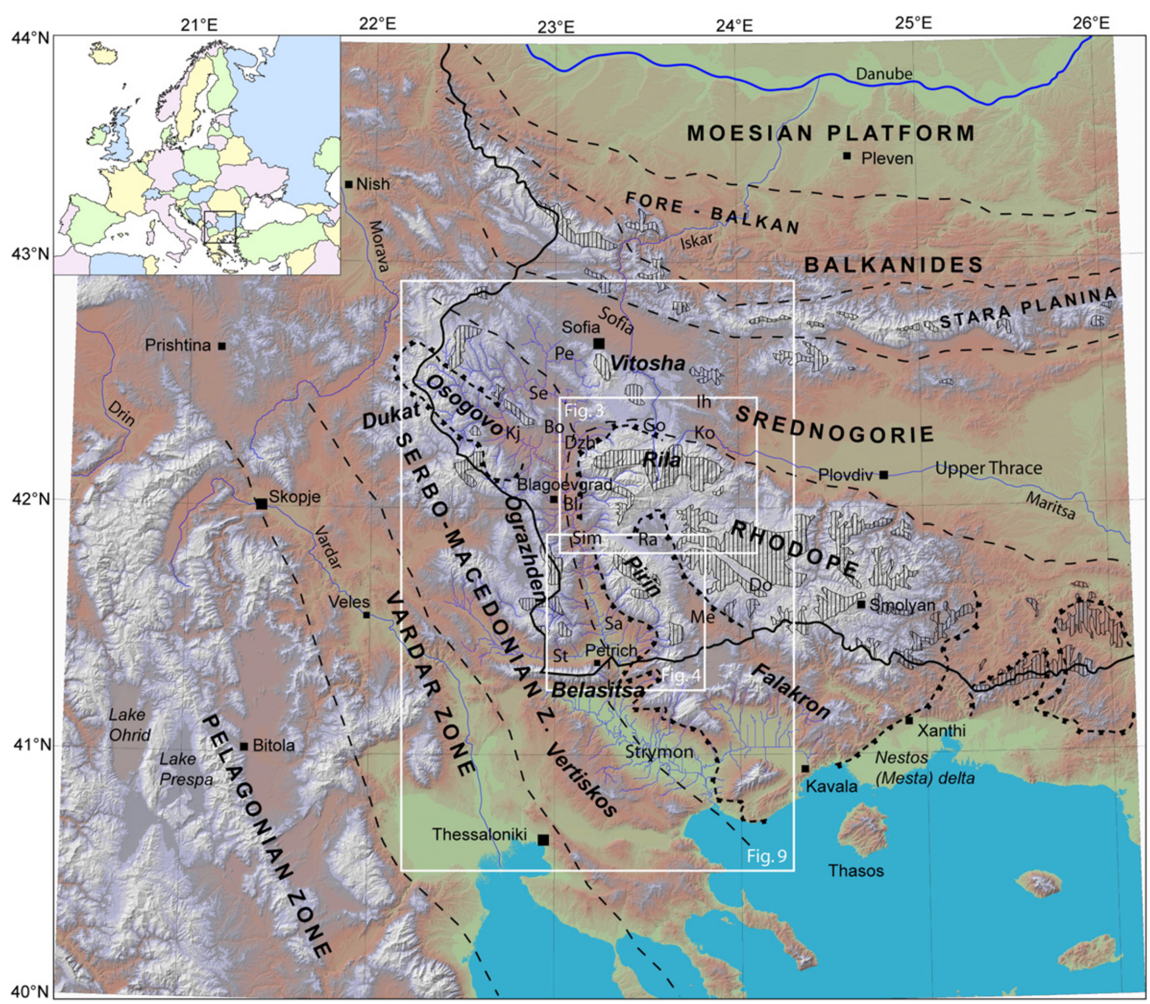

Fig. 1. The Struma watershed in its Balkanic regional context. Massifs named in the text are indicated in italics. Names in capitals define the four main tectonic subdivisions of Bulgaria (long-dash boundaries). Vertical hatch delineates areas containing previously mapped occurrences of a summit surface in the Rhodope province of Bulgaria (after Vaptsarov et al., 1973; occurrences outside Bulgaria not shown). Short-dash barbed contours delineate previously documented Paleogene to early Neogene detachment faults, outlining detachment-fault footwall units in the topography. Note that the footwall units all appear to carry vestiges of elevated planar surfaces. Cenozoic basins: St–Strumitsa; Sa–Sandanski; Si–Simitli; Bl–Blagoevgrad; Dzh–Dzherman; Bo–Bobovdol; Se–Sekirna; Go–Govedartsi; Ko–Kostenets; Ih–Ihtiman; Pe–Pernik; Ra–Razlog; Me–Mesta; Do–Dospat. Topographic source data: SRTM v. 3. Map projection: Transverse Mercator. Solid black line: political boundary of Bulgaria.