COMMENT

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Comment on 'Tectono-sedimentary evolution of lower to middle Miocene halfgraben basins related to an extensional detachment fault (western Crete, Greece)' by M. Seidel, E. Seidel and B. Stöckhert

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Exhumation of a high-pressure, low-temperature metamorphic unit on the island of Crete occurred between *c.* 24–21 and *c.* 10 Ma (Jolivet *et al.*, 1996; Thomson *et al.*, 1998; van Hinsbergen and Meulenkamp, 2006). This exhumation process has been suggested to have occurred partly syn-orogenically by e.g. extrusion or buoyant rise within a subduction channel and partly post-orogenically by N–S extension (Thomson *et al.*, 1998; Jolivet *et al.*, 2003; Rahl *et al.*, 2005). The relative importance of these two exhumation phases can be assessed by establishing the age of the oldest Cretan supra-detachment basin sediments, which mark the onset of crustal scale, post-orogenic N–S extension. The supra-detachment basin formed by tectonic break-up of the hangingwall (Pindos and Tripolitza nappes) of the Cretan detachment. Van Hinsbergen and Meulenkamp (2006) dated the formation of this basin at 12–11 Ma, well after the deposition of the oldest Neogene sedimentary unit of western Crete – the Topolia breccias, which have occurrences in the north and south of western Crete (Fig. 1a). These breccias do not contain any metamorphic debris and form isolated extensional klippen above the extensional detachment. This date of the oldest detachment basin and thus of the beginning of post-orogenic N–S extension suggests a relatively minor role of post-orogenic extension in the exhumation history of the Cretan metamorphic rocks consistent with the earlier suggestions of Rahl *et al.* (2005). In their recent paper, Seidel *et al.* (2007) arrive at a much older date of 20–15 Ma (corresponding to their estimate for the age of the Topolia breccias) for the onset of N–S extensional desintegration of the hangingwall based, in our view, on an erroneous interpretation of the depositional environment of the Topolia breccias and basin geometry. Their arguments and interpretations can be summarized as follows:

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First, Seidel *et al.* (2007) state that 'detailed geological mapping (...) shows that each of the [northern and southern] basins is bound by a W–E trending (high-angle) normal fault, thus displaying a typical half-graben geometry'. They then analyse the northern and southern sub-basins of the Topolia breccias. For the northern outcrops, they argue that the fault they interpret as the basin boundary formed during deposition based on sedimentary characteristics of the Topolia breccias: a northward decreasing sedimentary thickness away from the fault, and decreasing grainsize and increasing roundness of the pebbles away from the fault. Thus, they argue that north-western Crete formed a half-graben during the deposition of the Topolia-breccias, which were shed from a horst on central western Crete (where nowadays only metamorphic rocks are exposed). Seidel *et al.* (2007) interpret the southern occurrences of the Topolia breccias near Lissos as a fan delta, again with debris derived from a horst on central western Crete, showing interfingering of the terrestrial Topolia breccias with marine marls and mass flow deposits (although they did not report any fossils indicating a marine depositional environment).

We object to these interpretations for several reasons. The main faults bounding the present occurrences of the Topolia breccias both in the north and in the south juxtapose these breccias against metamorphic units and Seidel *et al.* (2007) agree with the earlier works (Kopp and Richter, 1983; van Hinsbergen and Meulenkamp, 2006) that the Topolia breccias contain no trace of metamorphic debris. These main faults therefore certainly have been active after sedimentation and lithification of the Topolia breccias. Proving that these faults were also active during sedimentation then entirely relies on sedimentology and stratigraphic relationships. Their claim of northward decreasing sedimentary thickness of the Topolia breccias away from the fault has no relevance in this context as the breccias are everywhere unconformably overlain by Neogene sediments or not overlain at all. Because time-stratigraphic correlations within these breccias are illusive, the present thicknesses have no meaning for the original basin geometry. Seidel *et al.* (2007) describe the sedimentary trends concerning roundness and size of the breccias suggesting northward sediment transport in very general statements without showing documentation, but neither we nor Kopp and Richter (1983) observed such trends. Indeed, an exposure of Topolia breccias along the northern coast near the harbour of Kastelli

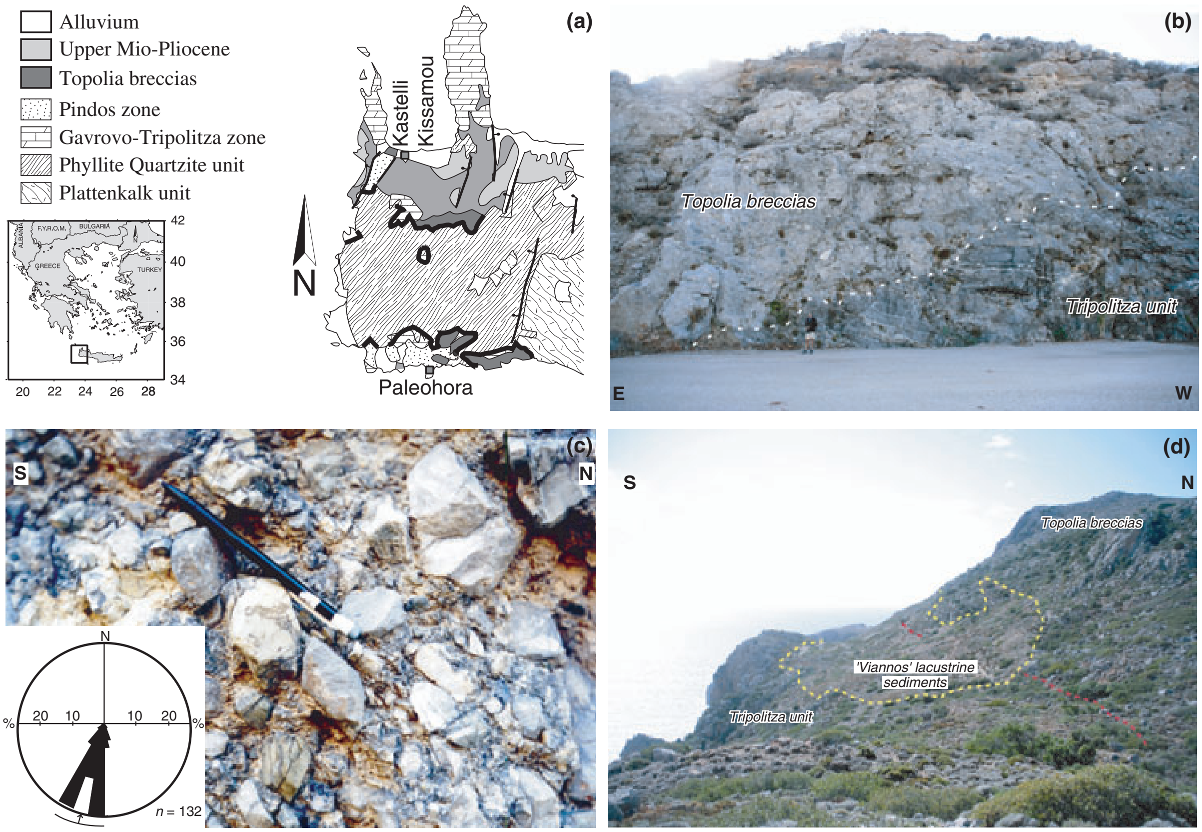

Fig. 1 (a) Geological map of western Crete, modified after Bornovas and Rontogianni-Tsiabaou (1983); (b) unconformity between the Tripolitza unit and very coarse, angular Topolia breccias along the northern coast, near the harbour of Kastelli Kissamos; (c) example of imbricated pebbles from the Topolia breccias in the gorge of Topolia indicating southward palaeoflow. Inset shows a rose diagram based on 132 palaeocurrent readings from imbricated pebbles exposed in the Topolia gorge, showing SSW palaeocurrent directions; (d) westward view on the south coast of Cape Elides, illustrating that the lacustrine deposits of the Males–Viannos fluvio-lacustrine system were unconformably deposited against a palaeorelief in the Tripolitza unit and unconformably overlying Topolia breccias.

Kissamos reveals breccias just as coarse and rounded – if not more proximal – as in the Topolia gorge 10 km to the south (Fig. 1b).

Moreover, van Hinsbergen and Meulenkamp (2006) already mentioned southward palaeoflow directions obtained from the Topolia gorge at the southern margin of the inferred basin of Seidel *et al.* (2007). In Fig. 1c, we show the documentation of the directions of van Hinsbergen and Meulenkamp (2006) and some additional ones as well as examples of the imbricated pebbles on which these southward directions are based. These palaeocurrent readings show that the basin geometry and southerly position of the catchment area inferred by Seidel *et al.* (2007) are not consistent with the reality. There is no evidence that the northern occurrences of the Topolia breccias were deposited in a half-graben.

In south-western Crete, where Seidel *et al.* (2007) infer a fan-delta with interfingering of the Topolia breccias with deep-marine mass-flow deposits, indeed clays, sandstones and mass-transported breccias and limestones are exposed on the western, southern and eastern side of Cape Elides. The thinly-bedded limestones contain gyrogonites of *Charaphyta* and representatives of the fresh-water gastropods *Melanopsis* and *Terebralia* together with abundant plant remains. These fossils together with wave ripples point to a shallow lake environment for these deposits and definitely not a deep-marine environment as inferred by Seidel *et al.* (2007). The lithology, stratigraphic position and depositional environment of these deposits at Cape Elides suggest that they belong to the distal part of the large westward flowing river system first described by Fortuin (1977) as the Males drainage system and given a 12–11 Ma age by van Hinsbergen and Meulenkamp (2006). We did not encounter any marine deposits [nor can we confirm the presence of shallow marine deposits at the base of the Topolia breccias reported by van Hinsbergen and Meulenkamp (2006)]. Moreover, these deposits do not interfinger with the Topolia breccias: the lacustrine deposits of Cape Elides unconformably overlie both the abundantly outcropping Tripolitza unit along the southern coast [not indicated in the map of Seidel *et al.* (2007), but present in the map of Kopp and Richter (1983)], as well as against the Topolia breccias, which unconformably cover the Tripolitza unit here. Thus, the lacustrine deposits were deposited in front of a palaeo-relief (Fig. 1d), cut through the Topolia breccias into the Tripolitza unit. They certainly do not form a marine interfingering equivalent of the Topolia breccias. Indeed, deep marine marls and turbidites are found along the south-western coast near Palaeochora, but these form the equivalent of the Skinias Formation which, in central Crete, conformably overlies fine-grained sediments of the Males drainage system [assigned to the Viannos Formation (IGME, 1994)].

The southward palaeoflow directions reported here and in van Hinsbergen and Meulenkamp (2006), together with the absence of evidence for major syn-sedimentary, basin-bounding faults during the deposition of the Topolia breccias, rather suggests that they were deposited in a single alluvial to fluvial basin, with a sediment source north of the present-day island prior to the structural disintegration of the hangingwall exposed on the modern island, consistent with earlier conclusions of Kopp and Richter (1983). Van Hinsbergen and Meulenkamp (2006) tentatively suggested that the deposition of the Topolia breccias may have been triggered by the formation of a break-away fault south of the island, but this remains a speculation. The first indications for break-up and subsidence of basins on the hangingwall to the Cretan detachment are marked by the formation of an E–W trending basin accommodating the Males–Viannos river system, i.e. around 12–11 Ma (van Hinsbergen and Meulenkamp, 2006), as opposed to the age of 20–15 Ma suggested by Seidel *et al.* (2007). The unconformable relationship between the lacustrine sediments of the Males–Viannos fluvio-lacustrine system deposited in a palaeovalley in the Topolia Breccias and Tripolitza rocks shows that the structural disintegration of the west Cretan hangingwall followed lithification and erosion of the Topolia breccias. This difference is important in the determination of the onset of N–S stretching of the lithosphere in the Cretan segment of the Hellenic arc and the assessment of the role of post-orogenic extension in the exhumation of the high-pressure, low-temperature metamorphic rocks of Crete.

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