



## Reply to Genç and Yürür's comments on: "Late Cretaceous extensional denudation along a marble detachment fault zone in the Kırşehir massif near Kaman, Central Turkey"

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### 1. Introduction

We appreciate the interest of Dr. Yurdal Genç and Dr. Tekin Yürür in the work we carried out in central Turkey. In our paper, we presented a detailed structural study focused on one single fault zone located in the Kaman area, in the northwestern metamorphic massif of central Anatolia. The aim of our work was to provide clear structural evidence to assess the nature and kinematics of this fault zone, and to test whether it could be held responsible for part of the exhumation of the high-grade metamorphic rocks in the region. We demonstrated that the Kaman fault is an extensional detachment that was active in the late Cretaceous, and concluded that it was contemporaneous with late Cretaceous extension and exhumation of metamorphic rocks of the Central Anatolian Crystalline Complex (CACC) documented previously. This extensional phase has been discussed in numerous works such as the structural and metamorphic analysis from the southern Niğde crystalline massif (Gautier et al. 2002, Whitney et al. 2003, Whitney et al. 2007,

Gautier et al. 2008), structural and geochronological data from discrete shear zones across large magmatic intrusions in the north (Yozgat) and the west (Ağaçören) of the CACC (Isik et al. 2008, Isik 2009), and the tectonic evolution of the large basins surrounding the CACC (e.g. the Tuzgölü and Sivas basins, Çemen et al. 1999, Dirik et al. 1999). Following extension, the region underwent compression during the Paleogene due to the convergence and consequent collision between the CACC and the central Pontides (Görür et al. 1984, Görür et al. 1998, Kaymakci et al. 2000, Kaymakci et al. 2009, Meijers et al. 2010).

In contradiction to the generally accepted tectonic evolution for central Anatolia, Genç and Yürür (2010) recently proposed an alternative model based on inferences from digital elevation data and local field observations. They interpreted the Cenozoic tectonic regime of central Anatolia to be dominated by extension, associated with coeval compressional zones resulting from gravitational movements. Taking that into consideration, Genç and Yürür have in their discussion listed several points that they consider to be "incoherencies".

In this reply, we answer each point addressed in the comment, discussing the validity of our statements and data, and taking the opportunity to clarify the ideas that the authors of the comment may have misunderstood.

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## 2. Answer to Genç and Yürür's comments

(1) Genç and Yürür reject the validity of the Kaman fault being “the first extensional detachment described in the northern CACC”, as we mentioned in the synthesis paragraph (p. 1232) of Lefebvre et al. (2011). They state that it is incorrect to use the term “first” as the presence of such a detachment fault in Kaman has already been evoked in the literature (Okay and Tüysüz 1999). Furthermore, they claim that Genç and Yürür (2010) mapped the Kaman fault as a second-order normal fault dipping towards the WSW, and therefore consider that we are not the first to have described it.

We are fully aware of the previous work in the region, which suggests that late Cretaceous extension in the northern CACC could have been much more important than has so far been considered. We therefore referred to Okay & Tüysüz (1999), Dirik et al. (1999) and Gautier et al. (2008) in the introduction (p. 1222, (Lefebvre et al., 2011)). The aim of our work in the Kaman area was to document the structure of that region in detail, to test the previous speculations on the nature of the Kaman fault. Genç and Yürür (2010) traced the Kaman fault as a lineament, and interpreted it as “second-order normal fault dipping towards the WSW” solely based on digital elevation data without structural observations in the field (or at least they did not mention any in their paper).

The detailed field- and microstructural observations presented in Lefebvre et al. (2011) demonstrate conclusively that the Kaman fault is an extensional structure that juxtaposes non-metamorphic rocks in the hanging wall with metamorphic rocks in the footwall, which led us to interpret that fault as an extensional detachment fault. In doing so, Lefebvre et al. (2011) were the first to provide field-based structural evidence demonstrating that the inferences of others, e.g. Okay and Tüysüz (1999), were correct. The Kaman fault is thereby the first documented late Cretaceous extensional detachment in the CACC north of the Niğde massif.

(2) Secondly, Genç and Yürür argue that the gabbros from the ophiolitic hanging wall of the Kaman fault cannot be distinguished from intrusive gabbros elsewhere in the CACC, and that we can therefore not use them to demonstrate the extensional nature of the Kaman fault. The western ophiolites in the hanging-wall of the Kaman fault belong to the central Anatolian Ophiolites (CAO). The CAO consist of gabbro and hornblendite (i.e. the Karaboğazdere Gabbro or Karakaya Ultramafite), and basalt covered by epi-ophiolitic sediments (the Çiçekdağ Formation) (Seymen 1981, 1982). As we note in the geological setting and the geological map of the Kırşehir massif (Figure 3 (Lefebvre et al. 2011)), there are two types of gabbros in central Anatolia: cumulate and isotropic gabbros belonging to the CAO (Yaliniz and Göncüoğlu 1998), and co-magmatic gabbros occurring as irregular intrusive bodies within the large granitoid plutons (Kadioğlu and Güleç 1996, Kadioğlu et al. 2003). Despite the similar composition of those mafic rocks, which have very different origins, their distinction in the field is rather straightforward, as the intense deformation and penetrative low grade metamorphism of the obducted ophiolitic gabbros strongly differs from the in-situ, little altered intrusive gabbros belonging to the central Anatolian magmatic supersuites (Kadioğlu and Güleç 1996). Despite the claim of Genç and Yürür, there is no debate about the origin of the gabbros west of Kaman.

Genç and Yürür also question why we did not collect structural data from the ophiolitic hanging-wall immediately above the contact with the detachment fault, but from gabbros 10 km away from the fault on the right bank of the Kızılırmak River at the Hirfanlı dam instead. As we clearly state in the paper there are “no

exposures of the ophiolitic sequence closer to the contact with the Kırşehir metamorphics that would allow a further study of its deformation history” (p. 1225). A good illustration of the situation may be observed in the left hand side of the panorama presented in Figure 6a (Lefebvre et al., 2011). The square shaped fields used for agriculture attest clearly that the prevailing degree of exposure does not permit a solid structural and kinematic analysis of any rock-unit to be made. Loose rocks in these fields, as well as in small road cuts, however, clearly demonstrate that this region is underlain by mafic rocks and epi-ophiolitic cover sediments.

(3) Genç and Yürür argue that all brecciated rocks we have studied are karst-related rather than caused by tectonic deformation. Within the metamorphic rocks of the Kaman area, however, we documented two categories of cataclastic marbles as described in the paragraph 3.2.2.6 (p. 1230) of Lefebvre et al. (2011). These two types of brecciated rocks have been distinguished as follows:

- Decimetre- to metre-thick cataclastic joints and micro-breccias which are concentrated near to the contact with the ophiolites. These preferentially developed parallel to the main foliation in the metasediments. They show gradual fragment size reduction from the fault-wall towards the central part of the deformed breccia zones.
- Massive breccias (called “megabreccias”) which are concentrated near steep strike-slip faults crossing the entire Kaman area. They contain decimetre- to metre-scale broken fragments, separated by a fine-grained red matrix (with graded and cross lamination).

It is possible that the authors of the comment missed this important distinction as they wrongly state that we associated the breccias developed parallel to the foliation with the ones called “megabreccias” presenting evidence of fluid circulation within open voids. This distinction is even more important since the “megabreccias” have been found away from the Kaman fault, but in the vicinity of E-NE strike-slip faults cross-cutting the Kaman metamorphics. We did certainly not associate them with the development of the Kaman detachment in our interpretation. There are no grounds to infer that the cataclases developed parallel to the detachment foliation have anything to do with ‘karst breccias’ (see Synthesis p. 1232).

(4) The footwall of the Kaman fault consists mainly of calcareous metasediments. To describe the deformation of the rocks associated with the Kaman fault and their evolution, our approach was to study and provide microstructural data from the deformed marbles. Therefore, we distinguished and characterized 5 types of marble that record different stages of evolution of the metamorphics: protolith, proto-mylonite, mylonite, cataclasite and statically recrystallized marble. For each of those marble types, we studied the fabrics of the calcite rocks under the microscope, and described the textures of the rock, the shape and size of the crystals, and their internal deformation (mainly twinning and extinction). Genç and Yürür commented that the method we used to describe the tectonic evolution of the marbles was not appropriate since the peak metamorphic conditions of the Kaman metasediments reached 700–750 °C (Whitney et al. 2001), whilst temperatures for development of twinning in calcite do not exceed 300 °C (Burkhard 1993).

We fully agree with Genç and Yürür about the statement that the calcite twins formed at low temperatures, and are therefore not representative of the deformation of the marbles at conditions near peak metamorphism. However in our paper, we did not interpret the twinning texture as a marker of deformation of the calcite crystals at high temperature. The only time we interpreted the

calcite twins in term of temperature of deformation is for the protomylonite marble type (p. 1230 and Figure 8C, Lefebvre et al., (2011)). There, the faintly bent and slightly sigmoidal twins present within the large and elongated porphyroclast of calcite have been interpreted as type III twins (according to Burkhard (1993)), which would indicate deformation temperatures above 200 °C and lower than 300 °C, i.e. occurring during exhumation. This is fully compatible with our interpretation that the Kaman fault represents an upper-crustal extensional detachment.

- (5) Based on our field and microstructural data from the marble rich sequence, we illustrated in figure 10 of Lefebvre et al. (2011) our interpretation of the exhumation history of the Kaman-Ömerhacılı area, in four stages. In this area, the evolution of calcite microstructures, also supported by EBSD analysis (Figure 9 of Lefebvre et al., 2011), indicate that the protomylonitic marble, associated with the deformation related to the Kaman detachment, has been statically recrystallized at high temperature in the vicinity of the 75 Ma Baranadağ pluton. This evidence clearly demonstrates that the development of mylonitic structures associated with the activation of the Kaman detachment predated the intrusion of the Baranadağ monzonite. As neither ductile fabrics or brittle horizons have been found within the Baranadağ pluton, we proposed that the intrusion may have marked the end of most of the tectonic activity along the Kaman detachment. This interpretation, based on our observations, is obviously valid at the scale of the Kaman area, as we specified in the paper.

However, Genç and Yürür disagree with our interpretation as they claim to have found detachment-like structures affecting both magmatic and metamorphic rocks from the Kırşehir, Niğde and Yozgat regions (Genç and Yürür 2010). In addition, Genç and Yürür use the example of the discrete ductile shear zones crossing the Yozgat and Ağaören batholiths (Isik et al. 2008, Isik 2009) to argue that the extension was still active after the emplacement of the central Anatolian intrusives in the late Cretaceous, and also suggest that it continues today.

First of all, we clearly stipulated that the observations and interpretations in our Figure 10 are valid for the Kaman area only (pp. 1232–1234). Therefore, our interpretations of the kinematics of the Kaman detachment and its timing cannot be directly transposed to other areas of the CACC. In addition, our own observations in the field at the location of the so-called “Savçlı detachment” described by Yürür and Genç (2006), strongly contradict the proposed existence of such structures which, in our opinion, are more consistent with the original thrust interpretation, as proposed and mapped by Seymen (1981), and recently confirmed by the detailed fieldwork of Isik et al., (2010).

Secondly, it is important to note that the central Anatolian magmatism lasted 20 My (from ~95 to 75 Ma) (e.g. Whitney et al. 2003, Köksal et al. 2004, Boztuğ et al. 2007). The only documented records of ductile deformation affecting the central Anatolian intrusives (Isik et al. 2008, Isik 2009) are located in the older granite supersuite, while the younger monzonite and syenite supersuites are typically represented by plutons unaffected by any ductile deformation (Kadioğlu et al. 2006). The Baranadağ monzonite located to the east of the Kaman fault belongs to the younger magmatic supersuite, and does not contain evidence for ductile deformation, consistent with the regional relationships.

Therefore, we think that the arguments of Genç and Yürür against our tectonic scenario for the Kaman detachment are invalid.

- (6) In the introduction and in Figure 1c of Lefebvre et al. (2011), we present a stratigraphic column showing the general

organization of the metamorphic sequence throughout the CACC. This column is based on local and regional geological maps and numerous studies from the three major metamorphic units of the CACC: the Kırşehir, Akdağ and Niğde massifs. Together, it is generally accepted that the metasediments consists of a coherent sequence, comprising from bottom to top: gneiss, micaschist, quartzite, amphibolite, calcisilicate and marble (e.g. Göncüoğlu 1977, Seymen 1982, Tolluoglu and Erkan 1989). Our own observations in the field are consistent with this general vertical organization of the metasediments.

Genç and Yürür speculate that this vertical organization for the central Anatolian metamorphics is incorrect. Their statement is based on “new” observations on the metamorphic stratigraphy from the Kırşehir massif (that have been only reported in the 56th Geological Congress of Turkey, Extended Abstract Book, (Genç 2003). In this abstract, they claim that the marble sequences (referred to as the Bozçaldağ Formation) should instead represent the lower unit of the stratigraphic pile.

In our paper, we did not consider this unpublished information which is obviously in contradiction with all of the existing published literature.

- (7) In the discussion paragraph of Lefebvre et al., (2011), we mentioned that the term Kırşehir Metamorphic Core Complex (KMCC) has been proposed by Genç (2004) in reference to the inferred detachment fault near Savçlı. Genç and Yürür commented on that, referring that Genç (2004) did not propose any link between the formation of the so-called Kırşehir Metamorphic Core Complex and detachment faulting. If that is the case, we do not clearly understand what justifies the use of the term “core complex”.

### 3. Conclusion

Two of the criticisms made by Genç and Yürür criticized Lefebvre et al. (2011) for not referring to their own previous work. In those cases, we have explained here why we decided not to do so. The other scientific comments mainly concerned issues that Genç and Yürür may have misunderstood and we have taken the opportunity to clarify these in this reply. We note that whilst Genç and Yürür commented on our paper, we infer that they agree with our main conclusion that the Kaman fault is an extensional detachment.

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