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Notes

Forum

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In our paper (Hollingsworth et al., 2008), we present a model of how the distribution of active faults in northeast Iran might accommodate both the northward motion of Central Iran and the westward motion of the South Caspian region, relative to Eurasia. We suggest the westward expulsion of the South Caspian region is accommodated by slip on the right-lateral Ashkabad and left-lateral Shahrud faults, which results in east-west extension along its eastern margin in the central Kopeh Dagh mountains. We provide a potential mechanism for generating east-west extension in the central Kopeh Dagh mountains, while still allowing the range to shorten in a north-south direction (consistent with the published Global Positioning System [GPS] velocities of Masson et al. [2007]), by invoking the vertical-axis rotation of a series of parallel right-lateral faults within the central Kopeh Dagh (collectively known as the Bakharden-Quchan fault zone [BQFZ], see also Hollingsworth et al. [2006]).

Siame et al. (2009) provide alternative interpretations of some of the geological and geomorphological displacements along the Ashkabad fault. Near Ushak village, they change the right-lateral displacement of an underground irrigation canal (a qanat) by a few meters (from the ~10 m to ~14 m), which increases the slip rate from 4 mm/yr to 5.6 mm/yr (however, it is unclear exactly how Trifonov [1978] assigns an age to this qanat, and so the resulting slip rates should be treated with caution). Furthermore, both Ritz (2009) and Siame et al. argue against the 35 km of cumulative right-lateral displacement in Cretaceous and Neogene bedrock across the Ashkabad fault, favoring a lower value (~9 km in Siame et al.'s case, while Ritz correctly highlights how north-directed thrusting may exaggerate any right-lateral offset). Ritz also proposes lower estimates (by an order of magnitude) for the total left-lateral offset on faults in the Central and East Alborz. Therefore, Siame et al. and Ritz suggest the inception ages for the main strike-slip faults in northeast Iran, which accommodate the westward expulsion of the South Caspian region, may be younger than the 10 Ma we suggested (Hollingsworth et al., 2008). Nevertheless, the wide variation in values preferred by the two authors (ca. 4 Ma for the Kopeh Dagh [after Shabanian et al., 2009a]; ca. 2 Ma for the East Alborz [Ritz et al., 2006]; and even ca. 7 Ma for the West Alborz [Axen et al., 2001]), as mentioned in the Comment by Ritz, highlights the difficulty in estimating fault inception ages even when detailed geomorphic and geological mapping, Quaternary dating, and GPS data are available.

In response to these points, we state in our original paper that the estimate of 10 Ma relies on the assumptions that GPS rates are representative of the longer term, and we even state that the age of initiation could be much younger depending on the validity of these assumptions (we reference several independent studies that suggest ages of less than 10 Ma for initiation of westward motion of the South Caspian relative to its surroundings). We acknowledge both the Shahrud and Ashkabad faults may be significantly younger than 10 Ma, and therefore Ritz and Siame et al.'s reinterpretation of the age of the Astaneh and Ashkabad faults are potentially interesting. Unfortunately, the younger age estimates of both authors rely heavily on their new reinterpretations of fault displacements seen in the geology and geomorphology, and which are not well supported in either author's Comment.

The point raised by Ritz regarding the offset on the Jajarm fault is interesting, since the total offset at first glance does appear to be lower than our 35 km estimate (Hollingsworth et al., 2008). Nevertheless, this estimate has not been corroborated by field observation, and the total left-lateral offset at the longitude of Jajarm must be more than 6 km as significant left-lateral shear occurs both north and south of the Jajarm fault, but within the wider Shahrud fault system (Hollingsworth, 2007). We cannot comment on the details of left-lateral faulting in the Central Alborz, as discussed by Ritz, since we have spent little time in the field looking at these faults. However, we look forward to future publications which will provide a more comprehensive discussion of these offsets. Nevertheless, we find some of the observations of Siame et al., such as the offset qanats in their figures 1A and 1B, and the total offset in their figure 1E unconvincing. Therefore, the data presented by both authors is not detailed enough to convince us, at present, that their new interpretations are correct, and that the age of fault inception of northeast Iran is well constrained to be Pliocene or younger.

Siame et al. then use their reinterpretations, combined with new GPS data (which isn't readily available to the wider scientific community), to argue against our overall model of the tectonics of northeast Iran, alternatively favoring a new model in which the tectonics of northeast Iran is best described by simple northwest translation of material across the Central Kopeh Dagh (discussed in more detail in Shabanian et al. [2009b]). However, two problems remain with this new model: firstly, the observations they present only have an impact on the rates of fault slip and the amount of cumulative displacement on the Ashkabad fault, but not sense of slip. Therefore, their observations have no bearing on whether slip on the Ashkabad or Shahrud faults allows lateral expulsion of the South Caspian region. Observations of the geomorphology, geology, and seismicity along both fault systems are all consistent with the hypothesis that extrusion does occur: westward motion of the South Caspian relative to its surroundings is consistent with published GPS data (Masson et al., 2007), with a small east-west normal component in the strike-slip faults of the Central Kopeh Dagh (Jackson et al., 2002; Ritz et al., 2006), as well as the proposed counterclockwise block rotations and the significant decrease in elevation across the Central Kopeh Dagh suggested by Hollingsworth et al. (2006). Few details are given regarding the new GPS velocities discussed in Shabanian et al. (2009b); in particular, no error ellipses are shown, and therefore the quality of the data is difficult to assess. Velocities of new stations DARG, MAR2, and GARD show consistently higher values relative to older stations in the region published by Masson et al. (2007). In the case of KASH and DARG, the difference in velocity between these two stations requires ~2.5 mm/yr north-south extension across the Kuh-e-Sorkh mountains, for which there is ample seismic, geomorphic, and geological evidence for active north-south shortening, and also ~3.9 mm/yr east-west extension, which is inconsistent with the 2.4 ± 0.3 mm/yr estimate for left-lateral slip on the east-west Doruneh fault (Fattahi et al., 2006). Furthermore, the new GPS data indicates relatively high rates of range-parallel right-lateral shear (3.7 ± 2.0 mm/yr) along the Binalud range, for which there is little evidence in the geomorphology or seismicity.

Secondly, the alternative regional model proposed by Siame et al. conflicts with the geological evidence. They state that vertical axis rotation of the crust within the BQFZ cannot be confirmed by the pattern of regional fold axes. However, inspection of their figure 1C shows that the fold axes (marked in blue) clearly trend differently (by ~20°) within the BQFZ than they do outside it. The authors also state that the post-folding, brittle deformation pattern favors a simple strike-slip faulting mechanism within the Kopeh Dagh, yet they offer no further justification of this far-reaching statement. If the BQFZ is simply translating material across it without vertical axis rotation, we should see a displacement in both the geology and the topography marking the range fronts. The total right-lateral displacement across the three largest faults in the zone amounts to ~40 km (Hollingsworth et al., 2006). However, there is no overall displacement of the fold axes across the Kopeh Dagh (i.e., although the fold axes are locally disrupted within the BQFZ, a line traced along the fold axes east of the BQFZ aligns with the same fold axes west of the BQFZ). This lack of overall displacement is visible in figure 1C of Siame et al., but is clearer in figure 12 of Hollingsworth et al. (2006) who show a more regionally extensive view. The same lack of overall displacement is also apparent in the linear, uninterrupted, northwest-southeast–trending margins of the Kopeh Dagh (see figure 12 in Hollingsworth et al., 2006). Finally, if the BQFZ accommodates simple translation of material across the Central Kopeh Dagh, we would expect to see significantly more shortening (up to 40 km) accommodated along the northern margin of the western Kopeh Dagh when compared with the eastern side. Such an observation is not supported by either the elevation or width of the range, or the age of geological exposure in the western Kopeh Dagh, which is both lower and of relatively similar width compared with the east, and features Cretaceous rocks outcropping at the surface rather than stratigraphically deeper Jurassic rocks seen in the eastern Kopeh Dagh (figure 11 in Hollingsworth et al., 2006). Therefore, as the new kinematic model of Shabanian et al. (2009b) relies heavily on new GPS data, which in places appears inconsistent with the seismicity, geology, and geomorphology, as well as previously published GPS studies, we think Siame et al. are a little too quick to discredit our kinematic model (Hollingsworth et al., 2008).

In summary, both Ritz and Siame et al. provide reinterpretations of several of the sites we investigated, and in the case of Ritz, new observations for the Central Alborz. Although the sparse level of detail with which both authors present their observations prevent us from fully assessing their robustness, if they are correct, their observations will make refinements to our knowledge of the assumed slip-rate and cumulative displacement on the Ashkabad fault. Nevertheless, the observations presented by Siame et al. have little significance for validating the regional model we presented (Hollingsworth et al., 2008). Furthermore, the alternative scenario suggested by Siame et al. does not appear to be well supported by geological and geophysical evidence, and relies too heavily on unpublished GPS data (with no mention of errors). However, the dense network of continuous GPS stations currently operating in northeast Iran will likely better resolve the kinematics of northeast Iran in the near future. Until then, neither model can be absolutely ruled out. Finally, rather than urge caution about the validity of other workers' equally competent data sets, we encourage positive discussion and thought to improve our collective understanding of the tectonics for this complicated region.

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