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Discussion

Comment on "Structural evolution, metamorphism and restoration of the Arabian continental margin, Saih Hatat region, Oman Mountains" by M.P. Searle et al.

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Searle et al. (2004) in their recent paper reviewing the structure, stratigraphic, metamorphic and geochronologic data in Saih Hatat, NE Oman attempt to present a revised geometry of this part of the Oman margin in the Late Cretaceous, and at the same time highlight the geodynamic model proposed by Searle involving one subduction zone with subduction away from the margin (e.g. Searle et al., 1994, 2004; Searle and Cox, 1999). As part of this review they have attempted to highlight what they consider to be 'differences' between the mapping of Gregory, Gray and Miller as shown in Miller et al. (2002) and their mapping, but at the same time they have misrepresented and misquoted our work. The misrepresentation of our work needs to be addressed.

In their paper, Searle et al. (2004, p. 462) have argued there are three major differences with our work: (1) that we have only mapped one major shear zone (our upper plate–lower plate (UP–LP) discontinuity); (2) that the UP–LP shear zone cannot root towards the mantle to the SW as discussed by Gray et al. (2000); and (3) that we "did not recognize several of the higher shear zones, notably the Al Khuyran and Yenkit shear zones".

We argue that Searle et al. (2004) have either misunderstood or misread our work and, as a result, many of the proposed 'differences' are inconsistent with what we have documented in our detailed structural synopsis in the *Journal of Structural Geology* (Miller et al., 2002). One result of this is that many of the structural and metamorphic findings presented by Searle et al. (2004) are actually similar to Miller et al. (2002) even though they use these structural and metamorphic findings to attack our work. In fact it is interesting to note that Searle et al. (2004) have accepted the basic findings of our structural work, namely the recognition of the Saih Hatat fold-nappe and the UP–LP discontinuity or shear zone, which they have attempted to incorporate into their pseudo-balanced cross-section.

1. Discussion points

1.1. Mapped one shear zone and failed to recognize other shear zones

We dispute this claim and discuss this with respect to three separate but related issues

(i) *Shear zone separating the Hulw and As Sifah units*: Searle et al. (2004) argue that Miller et al. (2002) failed to recognize this shear zone. It is a pity that Searle et al. (2004) did not read our papers more carefully as the structure is clearly shown (designated as a structural break or disrupted zone) in every detailed structural profile of the As Sifah window starting with Gregory et al. (1998, figs. 5 and 6); we also indicated that this shear zone marked the garnet-in isograd. In particular, note section segments 17^3–17^4 of fig. 16, and figs. 17 and 19a of Miller et al. (2002). We point out that fig. 17 of Miller et al. (2002) also highlights differences in amphibole chemistry across the shear zone, clearly indicating the importance of this break. Readers should also be aware that the shear zone is highlighted as SZ2 (shear zone 2) in profiles by Gray and Gregory (2003, fig. 9) and

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Gray et al. (2004b, fig. 1), and has been named the As Sheik Shear Zone in Gray et al. (2004a).

The composite character of the lower plate was firstly identified by, and secondly reflected by, the metamorphic zonation described by El-Shazly et al. (1990) and El-Shazly and Coleman (1990). The structural juxtaposition of these Hulw and As Sifah units within the lower plate clearly predate the upper plate–lower plate break (see Miller et al., 1998). This is highlighted by the differences in structural interpretation of the relationships on Jabal Daud (see (ii)).

(ii) *Structural relations on Jabal Daud, west side of the As Sifah window*: Along the east side of Jabal Daud the prominent structural break, or that most readily recognised, is the structurally higher UP–LP discontinuity/shear zone with Saiq 1 limestones in the hanging wall (see fig. 4b of Miller et al., 2002). What has confused Searle and Cox (1999) and Searle et al. (2004) is that here the lower plate disrupted zone, or As Sheik Shear Zone, is in the immediate footwall to this structure. Both shear zones have subparallel map trends, but the disrupted zone (As Sheik Shear Zone) is clearly truncated by the structurally higher UP–LP discontinuity (see photograph fig. 15b of Miller et al., 2002).

In their interpretation Searle et al. (2004) have our designated UP–LP shear zone as the shear zone separating the Huwl and As Sifah units, but this is not the case (see (i)). Their shear zone (our UP–LP boundary) has been depicted as dipping to the west beneath Jabal Daud (see figs. 11 and 12 of Searle and Cox, 1999), but again what Searle et al. (2004) and Searle and Cox (1999) have not realized is that all structures, including these shear zones are folded across Jabal Daud by N-trending steeply inclined to upright folds (see section segments 16^1–16^4 and 17^1–17^4 of fig. 16 in Miller et al., 2002). Searle and his co-workers have not recognized the overprinting N-trending folds (e.g. Searle and Cox, 1999, fig. 12; Searle et al., 2004, fig. 3) and have interpreted the Saiq Limestone as a homoclinally-dipping fault sliver. The folds, however, are clearly visible in the hills on the back or west side of the Jabal Daud range, and can be viewed from the road in the south end or upper reaches of Wadi Huwl (see photograph in Miller et al., 2002, fig. 15a). The folding and klippen of Saiq Limestone is also depicted in the map pattern as shown on the Quryat 1:100,000 map sheet of Le Métour et al. (1986).

(iii) *Nature and timing of the UP–LP discontinuity*: Field relationships (see (ii) above) clearly demonstrate that the shear zone separating the Huwl and As Sifah units occurs below the UP–LP shear zone and is truncated by it. We have also argued, that “any variation with the metamorphic grade in the lower plate existed prior to the formation of the Upper plate–Lower plate discontinuity” (Miller et al., 2002, p. 382). This is followed in the same section by “The entire lower plate appears to have been at shallower crustal levels (evidenced by the timing of retrograde minerals) prior to juxtaposition with the upper plate”.

It is also difficult to argue that the upper–lower plate contact is a major extensional break when one makes a comparison of the recorded peak minerals occurring in the upper plate rocks and those in the Hulw lower plate window. This is exactly the same reasoning presented by Searle et al. (2004) to discount this break as a major detachment. Furthermore, we actually explicitly state in the abstract of Miller et al. (2002) that the UP–LP discontinuity is a low angle contractional fault (décollement)—a fact overlooked by Searle et al. (2004) when discussing our work.

1.2. Original dip direction of the UP–LP discontinuity

A major issue critical to any tectonic interpretation of the margin is the original dip direction of the UP–LP shear zone (for discussion see Gray et al. (2000) and Gray and Gregory (2003)). The UP–LP boundary is folded as part of the Saih Hatat dome forming event and as a consequence there is a problem in determining which way the structure originally dipped, whether towards the margin or away from it. This is because (1) the surface has been subsequently folded by the later doming event to produce the Hulw and As Sifah subwindows, and (2) has recumbently folded stratigraphy in both the hanging wall and footwall.

Due to the Tertiary doming event, the present overall attitude of the UP–LP shear zone is approximately horizontal. Searle argues that it planes out in Saiq 1 and 2 limestones and descends no deeper than the Hatat Schist to the SW. The mapped relationships (Miller et al., 2002, fig. 5) show that the oldest and youngest units truncated in the hanging wall are the Ordovician Amdeh Quartzite and Permian Saiq 3 carbonates, respectively. Because of the high strain and attenuated nature of the structurally lower limb of the Wadi Meeh/Mayh SW-facing recumbent fold the shear zone may appear to plane out, as it has Saiq 1 and 2 limestones in the hanging wall along almost the entire length of Wadi Meeh/Mayh.

If the cutoff relationships of stratigraphic units in the hanging wall to the UP–LP shear zone are examined in more detail, their overall direction of younging suggests that the UP–LP shear zone originally should dip toward the margin. This is because the stratigraphic units get progressively older to the west or southwest (see also Miller et al., 2002, fig. 10). For the UP–LP discontinuity to dip towards the Neo-Tethys ocean, cutoffs should get progressively older in that direction, which is not the case. However, complexities in both the hanging wall and footwall structures and the possibility of an exotic lower plate may make this interpretation too simplistic. Independent criteria (e.g. geophysical imaging) are clearly needed to specify the original shear zone dip-direction.

1.3. Dominant structure of NE Saih Hatat

Searle et al. (2004) also argue that the present-day structure of the Oman Mountains is determined by four SW-vergent thrusts/shear zones, defining the Yiti, Al Khuyran and Mayh units (thrust sheets); note these were the Yiti, Wadi Mayh–Al Khuyran and Rija units in Searle and Cox (1999, fig. 10) and Searle et al. (1994, fig. 4).

There are two issues related to this. Firstly, the nature of these structural breaks in this part of Saih Hatat, and secondly their importance. We argue that late brittle faults occur in the positions indicated by Searle et al. (1994, 2004) and Searle and Cox (1999), and not major shear zones that control the stacking order. We therefore dispute the claim by Searle et al. (2004) that we "…did not recognise several of the higher shear zones, notably the Al Khuyran and Yenkit shear zones" (section 3.1, last paragraph).

The original delineation of these breaks (Searle et al., 1994) was based on structural work where their map detail in such complexly folded and deformed rocks is solely restricted to bedding strike/dip data (see fig. 5 of Searle et al., 1994). One of the problems with the interpretation of Searle et al. (1994), as shown in this figure, is that they did not subdivide the Saiq stratigraphy into subunits as shown on the published BRGM 1:100,00 map sheets (Le Métour et al., 1986). As a consequence, Searle and his co-workers have failed to recognize upside down stratigraphy as part of major regional recumbent folds that clearly control the map pattern in this region of Saih Hatat (see Miller et al., 2002, figs. 5, 6 and 8d; Gray and Gregory, 2003, fig. 8).

It is also interesting to note that Searle et al. (2004) for the first time, have shown major axial surface traces of regional recumbent folds on their maps of NE Saih Hatat, but that they stop the axial surface traces before they enter this faulted region under discussion (see fig. 3 of Searle et al., 2004). Our mapping indicates that these structures, particularly highlighted by the Wadi Meeh SW-facing synformal closure, continue through to the NE (see fig. 5 of Miller et al., 2002; fig. 8e of Gray and Gregory, 2003). The lower part of the hinge and lower limb of this structure are spectacularly exposed in the wadi walls in the top end of Wadi Meeh/Mayh.

Due to the late, largely brittle nature of Searle's proposed major faults, we have argued that the metamorphic relationships documented by Goffé et al. (1988) are most likely controlled by the position in the folded structure for the UP units (see figs. 5 and 9 of Gray and Gregory, 2003). Searle et al. (1994) on the other hand argue that their fault pattern best explains the metamorphic zonation of Goffé et al. (1988). However, when the metamorphic data 'control' points are plotted in relation to the fault outcrop traces this interpretation may not be as tightly defined (compare with fig. 3 of Goffé et al., 1988).

We refer readers to section 6.2 of Miller et al. (2002, p. 367) for discussion of these shear zones/fault structures that we supposedly did not recognize. The Yenkit shear zone on fig. 3 of Searle et al. (2004), also labelled by these workers as the Wadi Qanu fault (near Ruwi), is shown in fig. 2a of Miller et al. (2002) as a structural break in the same position. We also mark it on section line 7^1–7^3 in fig. 11 as "Fault runs down Wadi Qanu". It is also marked on fig. 19d and f (marked by an arrow labelled 'Wadi Qanu'). Our interpretation, which is different to Searle et al. (2004), is that much of the high strain observed in the Yenkit area adjacent to this structure is due to the fault/high strain zone cutting through the thinly bedded Saiq 3 dolomite into which strain is partitioned.

The Al Khuyrun shear zone is represented by Searle et al. (2004) on their fig. 3 as a dashed line (there is no explanation for this or why other faults are solid lines), and it is structurally below the Yenkit shear zone/Wadi Qanu fault. On p. 369 of Miller et al. (2002) we stated: "These serpentine units require similar structural breaks …below the major break in Wadi Qanu that were not identified by the 1: 25000 mapping". One of these faults is marked in fig. 11 on section line 31–34–41–44 and causes the repetition of the Saiq 2v unit.

2. Other issues

The age of peak metamorphism in the As Sifah eclogites has been controversial, and we refer readers to recently published (Gray et al., 2004b) Sm–Nd garnet–garnet leachate–whole rock isochron ages of 110 ± 9 Ma (5-point isochron) and 109 ± 13 Ma (3-point isochron), and a contrary viewpoint.

3. Conclusions

Tectonic scenarios for Samail ophiolite emplacement as well as the tectonic evolution of the Arabian Peninsula will continue to be debated as part of the scientific process, but we hope that readers of the *Journal of Structural Geology* interested in the structural framework of the Saih Hatat window in Oman will take the time to read Miller et al. (2002), rather than relying on the representation of our work by Searle et al. (2004).

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