

Reply to comments by Frédéric Mouthereau

General comments

This paper presents 1097 new U-Pb ages and 74 new AHe on zircon providing 74 double dates on key deposits from the Zagros foreland and proto-foreland and sediments from the Zagros (Kurdistan) suture zone. These constraints are used to position the Red Beds Series and decipher between different scenarios of the evolution of the transitional domain stretching between the Arabian margin and the active margin of Eurasia. The paper is generally well written and organised except the introduction that requires shortening and rewriting. This part also contains several unclear statements (see below). My main concern is about the discussion. The discussion indeed implements models of large scale geodynamic reconstructions but unfortunately do not enough present similar constraints (stratigraphy, basin evolution and sparse thermochronological constraints or description of sediments) obtained in other regions of the Zagros including Kermanshah region but also in the Fars. As presented below there are several lines of evidence suggesting the Red Beds Series and the WNK volcanic complex could correlate with deposits identified along the strike of Zagros suture zone. This has obvious implications on the architecture of the suture zone that could argue for a cylindrical margin over more than 2000 km. Also I suggest the Red Beds Series may be part of the Zagros foreland above the obducted units and above the the proto-foreland basin.

Thank you for your comments. The introduction section has been edited and shortened. Potential equivalent formation names in Iran have been added. The Kermanshah region was considered in the context of the Lurestan segment, but for this revised version the Dezful and Fars regions were also included, especially for the presence of the Razak Formation. The concern about the RBS being part of the collisional foreland basin has also been addressed (see details in the next section). We agree that the RBS might have been deposited on top of the obducted ophiolite and the proto-foreland. The geodynamic model figure (13c, d) has been updated to show this aspect more explicitly.

Main comments

The U-Pb/Zr age signature obtained for RBS may be compared to the few AFT data from the base of the Neogene strata (Razak Fm) of the Fars region of the Iranian Zagros (Khadiji et al., 2012) revealing source from a mixture of ophiolitic series (100 Ma) and arc derived rocks (magmatic or erosion events in the range 66-39 Ma) that was emplaced in the inner part of the Zagros and likely covered part of the High Zagros. In this work the base of the foreland deposits (Razak FM), which is found only to the north close to the MZT, share some FT ages (but not U-Pb ages signature) with the early (proto-)foreland deposits of Paleogene age (e.g. Amiran Fm). In the scenario presented the WNK complex would be a possible source of Razak Fm that we never found preserved in the Fars. In terms of terminology and spatial correlation would it be possible that the RBS=Razak Fm ? In this case the RBS could be part of an inner foreland basin as commonly described in the Iranian Zagros rather than intermontane basin. In other words, the Zagros suture zone was the inner foreland during the Neogene. In addition, an erosional event is described in the Eocene in the high Zagros (Mouthereau et al., 2012; Khadiji et al. 2012) in the Lorestan and the Fars. This could correspond to the

unconformity inferred at the base of the Suwais Fm. Although the margin of Arabia was obviously variable along strike such equivalence would make the foreland more cylindrical.

There is a possibility that the RBS and Razak Formations are equivalent, but may vary in facies depending on where they had been deposited. See below new texts from the revised version of the manuscript:

The targeted NW Zagros hinterland deposits are the Red Beds Series (potential equivalent of the Razak Formation in Iran; Etemad-Saeed et al., 2020), below the Main Zagros fault, and the proto-Zagros Tanjero (Amiran), Kolosh (Amiran), and Gercus (Kashghan) Formations in the Kurdistan region of Iraq (Fig. 1b).

Along-strike of the Zagros suture zone toward Iran, the potential equivalent of the RBS, the Razak Formation, appears not to be preserved in the Lurestan segment, but in the Dezful and Fars segments it has been documented (James and Wynd, 1965; Alavi, 2004; Khadivi et al., 2010, 2012; Vergés et al., 2018; Etemad-Saeed et al., 2020). The Razak Formation shows a lithostratigraphy and a possibly timing of deposition that is comparable to the RBS particularly in the hinterland. The stratigraphy includes carbonates and calcareous argillites toward the foreland and shales, siltstones, sandstones and conglomerates toward the suture zone (Alavi, 2004). Available magnetostratigraphic dating, yet between the High Zagros fault and the Mountain Front Flexure and not adjacent to the Main Zagros fault, suggest 19.7 – 16.6 Ma as the time of deposition of the Razak Formation (Khadivi et al., 2010). The older deposits of the Razak Formation closer to the Main Zagros fault might have been eroded due to deformation and exhumation (Alavi, 2004; Khadivi et al., 2012). These characteristics of the lithology and the timing of deposition appear to resemble those of the Govanda Formation and the Merga Group of the RBS. However, unlike the RBS in the Kurdistan region of Iraq, the Razak Formation seems to be more wide spread geographically from the hinterland toward the foreland and in direct contact with the Asamri (Jeribe), Gachsaran (Fatha), and Aghajari (Injana) Formations (Alavi, 1994; Khadivi, 2010; Etemad-Saeed et al., 2020).

This conclusion about the RBS in the NW Zagros in the Kurdistan region of Iraq can also be considered for the Razak Formation in the Dezful and Fars areas of Iran, but with a possible variation regarding the structural architecture of the basin. In the study area, the RBS is structurally bounded by the allochthonous WNK complex toward the NE and by the anticlines of the proto-Zagros fold-thrust belt toward the SW (e.g. Figs. 4 and 5), and it is in direct contact with the Paleogene and older rocks. However in the Dezful and Fars segments of Zagros, where the development of the Paleogene proto-Zagros fold-thrust belt is limited (Hessami et al., 2001), the basin setting of the Razak Formation appears to be less restricted geographically, and the sediments appear in direct contact with the Neogene Zagros foreland basin deposits with no documented unconformities (James and Wynd, 1965; Khadivi et al., 2010; Vergés et al., 2018; Etemad-Saeed et al., 2020). Such a basin setting for the Razak Formation could facilitate a more straightforward interpretation as early foreland basin deposits during the Neogene. In either case, both the RBS and the Razak Formation are representing the deposits of the early stage

collision between the Arabia-Eurasia plates (Khadivi et al., 2012; Koshnaw et al., 2019; Etemad-Saeed et al., 2020).

Moreover, in the southeastern Fars segment of the Zagros belt, the AFT detrital age from the potential equivalent of the RBS, the Razak Formation, yielded ~25 Ma, and it has been interpreted to record the exhumation of the Main Zagros hanging wall in the suture zone (Khadivi, et al., 2012). Such a similarity in the suture zone exhumation during the latest Oligocene and the earliest Miocene across the Zagros ~2000 km-long orogen may suggest a uniform suturing between Arabia and Eurasia, and possibly reduction of the oblique collision effect and onset of the northward motion of Arabia (McQuarrie et al., 2003; Navabpour et al., 2013).

Specific comments

This part is unnecessary long and wordy. It contains disconnected sentences. I suggest to shorten in 2 short sentences.

The text has been shortened as follow: Hinterland basins, such as wedge-top and intermontane basins are valuable archives for the assessment of the exhumation and unroofing history of the adjacent uplifted terranes because of their proximity to the source areas. Nevertheless, well-preserved ancient stratigraphic successions are scarce due to the deformation of sedimentary strata as orogenesis proceeds (Horton et al., 2012; Orme et al., 2015). A possible approach to overcome this drawback is the utilization of geochronologic and thermochronologic records, which are preserved by detrital zircons (e.g. Cawood et al., 2012; Webb et al., 2013; Gehrels, 2014; Colleps et al., 2020).

L55 : No. The Zagros orogen did not form as a result of obduction but due to convergence and most likely collision between Eurasia and Arabia plates.

The text has been edited as follow: This orogenic belt formed during the Late Cretaceous and Cenozoic as a consequence of the Arabia-Eurasia convergence and their collision

L58: Different terranes ? which ones ?

L59: Why uncertainties arise from the amalgamation of different tectonic terranes ? If their geometry and kinematics are simple then the reconstructions can be straightforward.

The text has been edited as follow: This prolonged history of deformation resulted in an amalgamation of different tectonic terranes between the Arabian and Eurasian plates, such as the Bisotoun block, the middle Cretaceous intraoceanic oceanic subduction and back-arc spreading zone, the early Tertiary magmatic domain, overprinting the preceding tectonic configurations (Wrobel-Daveau et al., 2010; Agard et al., 2011; Vergés et al., 2011; Barber et al., 2018, 2019).

An example for uncertainty, defining the length and width of the stretched Arabian margin prior to collision, which might influence the timing and the style of the hard collision.

L61-62: ... Walash Fm.. Red Beds Series. Not yet introduced.

They have been removed.

L108-109: Yes but not only. Acknowledge also older works.

New references have been added (Stoneley, 1975; Koop and Stoneley, 1982; Alavi, 1994)

By the Maastrichtian time the proto-Zagros flexural foreland basin started to form in response to the arrival of the Neotethys intraoceanic subduction zone at the Arabia plate margin, leading to the ophiolite obduction (Stoneley, 1975; Koop and Stoneley, 1982; Alavi, 1994; Homke et al., 2010; Saura et al., 2011; Barber et al., 2019).

L118-121: how do these successions relate to the deep marine to shallow marine transition you mentioned above ?

The text has been edited and the text about the Fatha (Gachsaran) Formation was moved to the next section in the text.

On top of the Pila-Spi Formation, an unconformity has been recorded based on absence of the Oligocene-early Miocene rocks that are linked to the Arabia-Eurasia collision (Fig. 2) (Dunnington, 1958; Ameen, 2009; Lawa et al., 2013).

L127: Would be useful to know how these formations correlate with more familiar stratigraphy of the Iranian Zagros. This could be done in Figure 2.

The potential equivalent formations have been added in the text and Fig. 2.

L235: This is not true. The neogene period is obviously syn-collision.

Edited to be "collision-related"

L236: Tanjero Fm belongs to the obduction phase according to your stratigraphic chart not to the proto-Zagros. This is a lot of names. Wherever possible add the stratigraphic ages.

The stratigraphic ages and potential equivalent formations have been added.

In particular, the provenance data from the Maastrichtian Tanjero (Amiran), the Paleocene-Eocene Kolosh (Amiran), and the Eocene Gercus (Kashghan) Formations

L239: The WNK complex should be defined earlier when you introduce the Walsh-Naopurdan series for the first time.

The WNK has been defined immediately after description of the Naopurdan Group.

The Walsh and Naopurdan Groups were correlated with similar rock units in the adjacent part of the Zagros belt in Iran and named as Walsh-Naopurdan-Kamyaran (WNK) (Ali et al., 2014; Moghadam et al., 2020).

L257: It is not trivial to associate zircon with the expected juvenile composition of magmas on mid-oceanic ridges. the same comment holds when you relate zircon U-Pb age of 100 Ma with the Tethys. Although common in cumulate this is not expected in basalt. Just add a few words perhaps in Chapter 2, to make this point clearer.

L258: Somewhat related to my comment above but this point should address earlier when you present the geology of potential sources.

We agree. The comparison and the age similarities are based U-Pb ages for zircons. The text has been edited as follows: Even though zircon is not a common mineral in the mafic rocks, yet it has been recognized (Grimes et al., 2007 and references therein). The ~240 Ma Triassic age signature in the Amiran and Kashghan Formations has been attributed to the mid-oceanic ridge based on the zircon trace element data (Barber et al., 2019).

L262: Unclear why you need to recycle sediments of this basin which is rich in carbonates.

The sentence has been edited as follow: Such variation in the sediment source for the proto-Zagros foreland basin is in line with the destruction of the Gotnia basin architecture and the input of carbonate materials into the newly formed flexural basin, and the occurrence of some recycled Paleozoic and older zircon grains in the Tanjero Formation

L326-327: This is not what is shown in Fig. 5c.

Fig. 5c. Shows that the RBS (Suwais Group) deposited on the older Upper Cretaceous rocks. The detrital zircon data show similarity of provenance among different samples of the RBS, including the Suwais Group. So, we think and are convinced that it is indeed the case.

L339: Ok there is one finally. So why this is different from Le Garzic et al. 2019 ?

It seems that the Le Garzic et al. considered the RBS to be equivalent to the Kolosh (Amiran) Formation and possibly to the Gercus (Kashghan Fromation) that were deposited during the Paleocene and the Eocene. Such view is common in most of the papers that are dealing with the Zagros belt in Iraq. However, this manuscript considers the onset of the RBS deposition to be of a late Oligocene age. This age assignment is based on a maximum depositional age recorded by detrital zircon minerals (Koshnaw et al., 2019). Additionally, as discussed in the discussion section *Basin dynamic of the NW Zagros Red Beds Series deposits*, the U-Pb and the ZHe data do not support the occurrence of a single basin especially during the Paleocene-Eocene.

L353: But what if RBS have been originally deposited above WNK which series were later emplaced during the Neogene ?

This is unlikely because there is field observation that the RBS was deposited on strata of the Upper Cretaceous Arabian plate (e.g. Figs. 4 and 5). Additionally, so far no thrust fault has been identified between the RBS and the other Arabian plate strata.