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Timing of the Arabia-Eurasia continental collision - Evidence from detrital zircon U-Pb geochronology of the Red Bed Series strata of the NW Zagros hinterland, Kurdistan region of Iraq

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ABSTRACT

One of the major debated aspects of the Zagros orogenic system is the timing of onset of continental collision between Arabia and Eurasia. The Zagros hinterland in the Kurdistan region of Iraq contains a ca. 2 km-thick clastic depositional sequence of the Red Bed Series (RBS) that rests unconformably on the Arabian foreland and structurally below the Main Zagros Fault, which carries the allochthonous volcaniclastic rocks of the Walash-Naopurdan groups. Detrital zircon (DZ) U-Pb geochronology constrains both the depositional age and the provenance of the RBS and pinpoint the timing of initial arrival of Eurasian sediment on the Arabian plate. The youngest DZ U-Pb ages for the laterally-extensive (ca. 150 km) basal RBS (Suwais unit) imply a middle Oligocene (ca. 26 Ma) maximum depositional age. The provenance data reveal dominant DZ U-Pb age modes of late Paleocene (~55-60 Ma) and middle Eocene (~37-44 Ma) and, importantly, presence of ca. 10-15% DZ grains that are unequivocally derived from Eurasia, incl. Jurassic (150-200 Ma) and late Paleozoic (270-380 Ma) DZ age modes. These data suggest that the RBS deposits were mainly sourced from forearc/arc-related terranes along the SW margin and hinterland of Eurasia. We advocate that by ca. 26 Ma Neotethys oceanic crust had been consumed and that Arabia-Eurasia continental collision well was underway as indicated by deposition of strata with Eurasian provenance on the Arabian margin. These DZ U-Pb data from the RBS highlight the significance of provenance data from synorogenic deposits in revealing the timing of initial continent collision by document the earliest arrival of upper-plate sediment on the lower plate.

Keywords: Zagros, continental collision, U-Pb geochronology, detrital zircon, provenance, Red Bed Series

INTRODUCTION

The Zagros collisional zone is one of the most prominent and recent collisional segments of the Alpine-Himalayan orogenic system and formed in response to the northward subduction of the Neo-Tethys oceanic crust beneath the Eurasian continental plate, culminating in the continent-continent collision between the Arabian and Eurasian plates (e.g., Alavi, 1994; Hessami, 2001). The initiation of Arabia-Eurasia continent-continent collision remains highly debated, due to the complex along-strike nature, poor preservation the early synorogenic structural and depositional orogenic record, and the complicated tectonic phases that included Late Cretaceous ophiolite obduction and island and/or volcanic arc collisions prior to the continent-continent collision. Whereas studies had suggested a possible pre-Cenozoic onset of continental collision, it is now well understood that Late Cretaceous to early Cenozoic ophiolite obduction and arc accretion, recorded in the proto-Zagros foreland basins, were not related to the continental collision and not yet involve Eurasia (Homke et al., 2009; Saura et al., 2011). Timing constraints for the Cenozoic Zagros continent-continent collision vary considerably and range between Eocene to Miocene (e.g., Horton et al., 2008; Fakhari et al., 2008; Homke et al., 2009; Gavillot et al., 2010; Agard et al., 2011; Ballato et al., 2011, McQuarrie and van Hinsbergen, 2013; Zhang et al., 2016; Pirouz et al., 2017; Barber et al., in press). Constraining the inception of the Arabian and Eurasian plates collision is vital for the understanding of initial continental collision as well as the broader tectonic and geodynamic evolution of the Middle East, including the relationship between rifting in

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the Gulf of Aden/Red Sea system and collision in the Zagros-Bitlis system. This study focuses on the earliest synorogenic deposits of the Red Bed Series (RBS), that rests unconformably on the Arabian foreland and structurally below a low-angle thrust - the Main Zagros Fault (MZF) –that carries the allochthonous volcaniclastic rocks of the Walash-Naopurdan groups and the Sanandaj-Sirjan Zone (SSZ) in its hanging wall (Al-Barzinjy, 2005; Jassim and Goff, 2006; Hassan et al., 2014). Over ca. 150 km along-strike, the RBS is irregularly truncated by the MZF, providing a synorogenic sedimentary record during allochthonous thrust sheet emplacement (Figs. 1 and 2). In this paper, we present new DZ U-Pb age data to elucidate the timing of deposition and characterize the provenance of the RBS and discuss the implications for the timing of the continental collision between Arabia and Eurasia.

THE RED BED SERIES STRATA

The Red Bed Series (RBS) is a Cenozoic siliciclastic sequence deposited in a laterally extensive (ca. 150 km) depositional system in the interior of the NW Zagros fold-thrust belt, on the Arabian side of the suture zone in the footwall of the MZF (Fig. 2). These deposits rest unconformably on deformed Cretaceous rocks of the Arabian platform (Karim et al., 2011; Hassan et al., 2015). Along strike, the RBS basin deposits define several NW-SE oriented discrete depocenters with a composite total preserved stratigraphic thickness of ca. 2 km (Al-Barzinjy, 2005). In the study area, NW of the Dukan Lake, the RBS has a thickness of ca. 1400 m (Fig. 3) and consists of alternating mudstone and sandstone as well as conglomerates and limestone beds with calcareous sandstone. These deposits can be subdivided into three major units: Suwais, Govanda, and Merga units, which were deposited in estuarine, fluvial, and alluvial environments (Jassim and Goff, 2006; Alsultan and Gayara, 2016; Abdula et al., 2018).

METHODS AND SAMPLING

Detrital zircon (DZ) U-Pb geochronology has been shown to be a powerful tool for identifying the provenance of sedimentary basins and constraining the timing of maximum depositional ages (MDA) in volcanically active convergent belts (Fedo et al., 2003; Dickinson and Gehrels, 2009). In this study, we present 679 new DZ U-Pb ages from six Red Bed Series samples (Fig. 3): three from Suwais unit (CH17S10, SH17S4, MT17S5) and three from Merga unit (CH17M6, CH17M5, CH17M4). Four samples are from the same section (CH-) and two Suwais unit samples are from along-strike localities (SH-, MT-) (Fig. 1). All ages were obtained using the Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) following procedures outlined in Hart et al. (2016) at the University of Texas at Austin UTChron Geo- and Thermochronometry laboratories. See GSA Data Repository[1] item for detailed analytical procedures and all analytical data.

RESULTS

All Red Bed Series samples show major DZ age components that cluster in the late Paleocene and the middle Eocene. The three Suwais unit samples (SH17S4, CH17S10, MT17S5) display two major age peaks at 56-58 (late Paleocene) and 37-45 Ma (middle Eocene). Samples from the Merga unit (CH17M6, CH17M5, CH17M4), which are stratigraphically younger, show correlative DZ age signatures of 37-44 Ma (middle

Eocene) and 55-60 Ma (late Paleocene), except for sample CH17M4 that show only a major middle Eocene peak (Fig. 4; GSA Data Repository[1]). In addition to these two dominant DZ U-Pb age components, the RBS samples exhibit notable subsidiary Late Cretaceous (65-120 Ma), Jurassic (150-200 Ma), late Paleozoic (270-380 Ma), and Precambrian (500-700 Ma) DZ age components. The three youngest zircon grains from the basal Suwais unit yielded a mean age of 26.0 ± 0.9 Ma (n=3, MSDW=4.7) and from the stratigraphically higher Merga a mean age of 34.8 ± 0.6 Ma (n=3, MSDW=1.6).

DISCUSSION

Detrital zircon provenance

The late Paleocene and middle Eocene dominant DZ U-Pb age components encountered in the Red Bed Series (RBS) samples suggest a provenance from (i) the Walash-Naopurdan Groups that are thrusted on top of the RBS, (ii) the magmatic portions of the SSZ, and (iii) the Urumieh-Dokhtar magmatic zone (UDMZ), which are all associated with the Eurasian plate (Figs. 1 and 4). The Walash-Naopurdan Groups of the Zagros Suture Zone are likely the equivalent of the Gaveh-Rud Domain forearc deposits in the Iranian Zagros farther to the SE in the Lorestan salient (Sadeghi and Yassaghi, 2016). Reported ages for volcaniclastic forearc/arc-related sequences are middle Eocene (Agard et al., 2005; Homke et al., 2009; Aswad et al., 2014) and late Eocene (Ali et al., 2013). As for the upper-plate hinterland, the metamorphosed SSZ contains several igneous intrusions, incl. the Piranshahr and Kamyaran massifs that span the time interval between the late Paleocene-early Eocene and the middle Eocene ages (Mazhari et al., 2009; Azizi et al., 2011). Farther to the NE, the Andean-type UDMZ continental arc is dominated by voluminous intrusive and extrusive rocks with a peak magmatism age of 55-37 Ma (Verdel et al., 2011; Chiu et al., 2013).

Among the minor DZ U-Pb age components of the RBS, the Jurassic (150-200 Ma) and the late Paleozoic (270-380 Ma) are unequivocally indicative of sources from the SSZ and the broader Eurasian hinterland and have not been reported from the Arabian plate. The 150-200 Ma DZ ages are sourced from numerous plutons in the SSZ (Chiu et al., 2013), while the 270-380 Ma age component is linked to Hercynian magmatic sources (Stampfli et al., 2013). Based on these provenance data, the RBS detritus, unconformably deposited on Arabia, was derived from the convergent southwestern margin and orogenic hinterland of Eurasia.

Timing of deposition

The age of the youngest DZ grains from samples from the bottom of the Suwais unit within the lower part of the RBS strata, suggest that the RBS deposition started sometime during the middle Oligocene. Each of the three Suwais samples, geographically 10s of kilometers apart along strike, contained a single young grain that combined yielded a mean age of ca. 26 Ma, implying a middle Oligocene depositional age for the Suwais unit. This MDA is significantly younger than published Paleocene-Eocene ages for the Suwais unit based on the planktonic foraminifera (Al-Barzinjy, 2005 and Hassan, 2012). These conflicting biostratigraphic and isotopic ages likely point to reworking of the Paleocene-Eocene microfossils – a hypothesis supported by a dominant Paleocene-Eocene DZ age peak. The sparse, but consistent youngest middle Oligocene DZ U-Pb ages support a laterally synchronous onset of lower Suwais deposition over ca. 150 km along strike. Regionally, the basal Suwais unit unconformably overlies folded Triassic-Cretaceous Qulqula Formation or Cretaceous Bekhma and Shiranish Formations. While Karim and others (2011) and Hassan and others (2014) proposed an apparent conformable contact between the RBS and the Maastrichtian Tanjero Formation, the ~26 Ma MDA for the Suwais unit implies a hiatus of ~40 m.y. and a disconformable contact between the RBS and the Tanjero Formation.

Timing of the Arabia-Eurasia continental collision

The Red Bed Series in NE Iraqi Kurdistan is characterized by an unequivocally Eurasian DZ U-Pb provenance signature, a middle Oligocene maximum depositional age of ~26 Ma, and widespread regional unconformity with a 40 m.y. hiatus prior to RBS deposition. These observations provide clear evidence for the minimum age for the Arabia-Eurasia continental collision during the middle Oligocene. These new timing constraints support an earlier timing for the onset of continent-continent collision by the middle Oligocene. These findings are in general agreement with estimates on basis of plate circuit reconstructions and foreland basin sedimentation patterns (e.g., Saura et al., 2015; McQuarrie and van Hinsbergen, 2013; Pirouz et al., 2017; Zadeh et al., 2017). They, however, do not preclude an Eocene inception of collisional deformation (e.g., Ballato et al. 2011, Mouthereau et al., 2012; Barber et al, in press).

CONCLUSIONS

Our new DZ U-Pb age data along with the structural and stratigraphic setting of the RBS deposits, in the present-day interior of the Zagros fold-thrust belt, indicate the minimum

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age for the Arabia-Eurasia continent-continent collision in the middle Oligocene at ca. 26 Ma. The basal RBS, which is structurally truncated by the MZF low-angle thrust and buried by allochthonous thrust sheets, was unconformably deposited on the Arabian plate. The basal RBS deposits of the Suwais unit yielded a middle Oligocene (ca. 26 Ma) maximum depositional age and exhibits provenance data indicative of derivation from forearc and arc-related terranes and the hinterland along the southwestern margin of the Eurasia. These data argue for an onset of continent-continent collision and arrival of the Eurasia-sourced sediment on the Arabian plate by at least the middle Oligocene.

FIGURE CAPTIONS

Figure 1. Left: Regional tectonic map of the Middle East showing the Main Zagros Fault (MZF) that separates Arabia and Eurasia, as well as the Arabian plate motion velocities and directions, which are relative to Eurasia (Koshnaw et al., 2017 and references therein). The black rectangle represents the outline of the geologic map to the right. Right: Simplified geologic map of the study area (Koshnaw et al., 2017 and references therein) depicting the location of the rock samples that used in this study. The blue dashed line represents the international border.

Figure 2. Schematic cross-section illustrating the structural and stratigraphic settings of the Red Bed Series deposits in the NW Zagros fold-thrust belt, and the apparent locations of the sample. MDA: maximum depositional age.

Figure 3. Generalized composite stratigraphic column of the Red Bed Series illustrating the key lithostratigraphic units and the apparent location of the dated rock samples in the NW of the study area. Stratigraphic data are from Jassim and Goff (2006), Alsultan and Gayara (2016), Abdula et al., (2018) and fieldwork from this study.

Figure 4. Top: Detrital zircon U-Pb age distribution plots of samples from the Suwais and Merga units that show significant probability density peaks (histograms bin size is 20 Ma; Vermeesch, 2012) during Paleogene. Bottom: Percentages of the potential source components from the Suwais unit samples.

[1]GSA Data Repository item 201Xxxx, U-Pb data of the newly analyzed zircon grains are available online at www.geosociety.org/pubs/ft20XX.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

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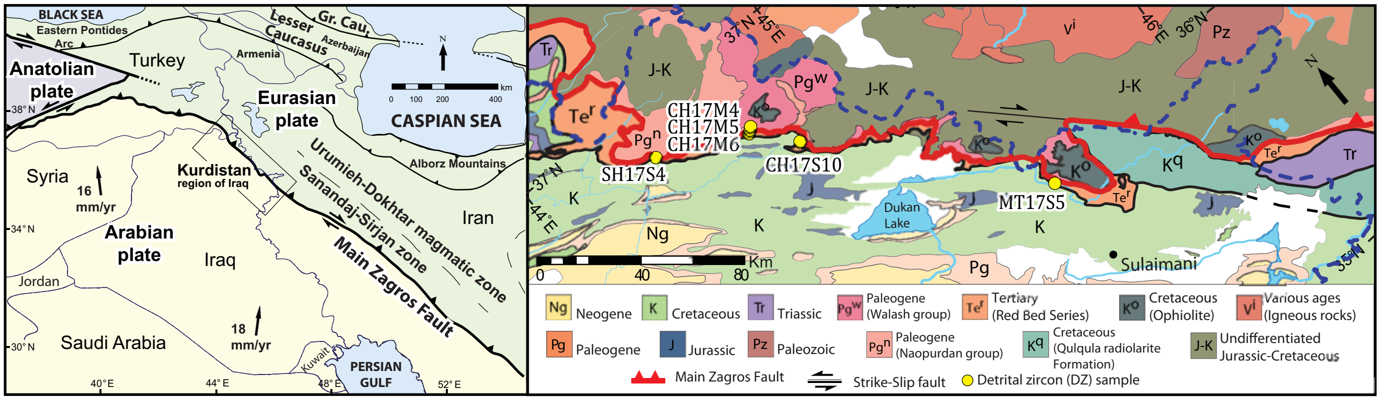
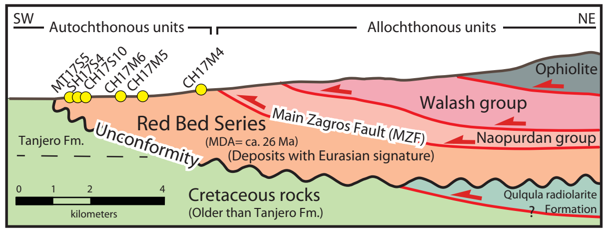


BLACK SEA
Eastern Pontides Arc
Lesser Caucasus
Gr. Cau.
Azerbaijan
Armenia
Turkey
Anatolian plate
Eurasian plate
CASPIAN SEA
Alborz Mountains
Syria
16 mm/yr
Kurdistan region of Iraq
Urumieh-Dokhtar magmatic zone
Sanandaj-Sirjan zone
Main Zagros Fault
Iran
Arabian plate
Iraq
Jordan
Saudi Arabia
18 mm/yr
Kuwait
PERSIAN GULF
38° N
34° N
30° N
40°E
44° E
48° E
52° E
0 100 200 400 km
CH17M4
CH17M5
CH17M6
CH17S10
SH17S4
MT17S5
Dukan Lake
Sulaimani
0 40 80 Km
Ng Neogene
K Cretaceous
Tr Triassic
Pg Paleogene
J Jurassic
Pz Paleozoic
Pgw Paleogene (Walash group)
Pgn Paleogene (Naopurdan group)
Ter Tertiary (Red Bed Series)
Ko Cretaceous (Ophiolite)
Kq Cretaceous (Qulqula radiolarite Formation)
Vi Various ages (Igneous rocks)
J-K Undifferentiated Jurassic-Cretaceous
Main Zagros Fault
Strike-Slip fault
Detrital zircon (DZ) sample

Figure 1



SW
Autochthonous units
Allochthonous units
NE
MT1755
SH1754
CH17510
CH17M6
CH17M5
CH17M4
Ophiolite
Walash group
Red Bed Series
Main Zagros Fault (MZF)
Naopurdan group
(MDA= ca. 26 Ma)
Tanjero Fm.
Unconformity
(Deposits with Eurasian signature)
0 1 2 4
kilometers
Cretaceous rocks
(Older than Tanjero Fm.)
Qulqula radiolarite Formation
?

Figure 2

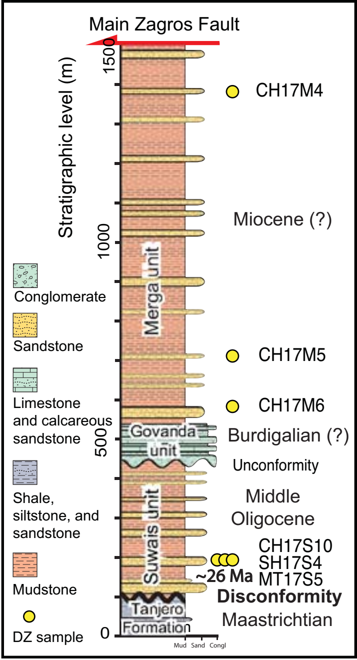
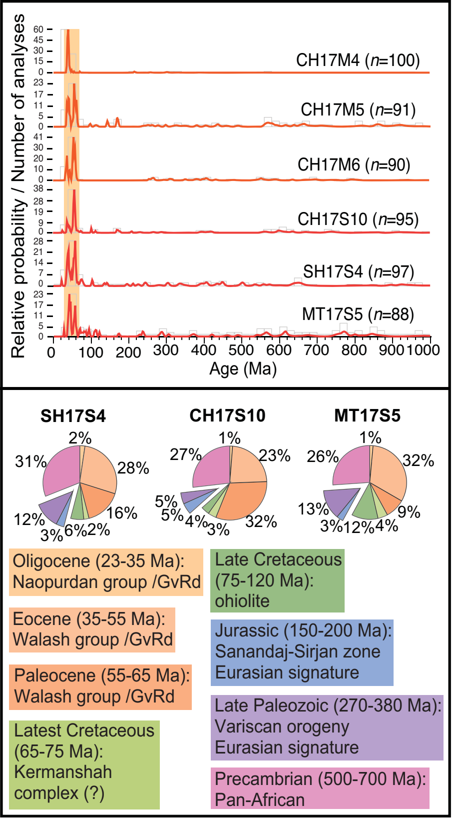

Main Zagros Fault
Stratigraphic level (m)
1500
1000
500
0
Conglomerate
Sandstone
Limestone and calcareous sandstone
Shale, siltstone, and sandstone
Mudstone
DZ sample
Merga unit
Govanda unit
Suwais unit
Tanjero Formation
CH17M4
Miocene (?)
CH17M5
CH17M6
Burdigalian (?)
Unconformity
Middle Oligocene
CH17S10
SH17S4
MT17S5
~26 Ma
Disconformity
Maastrichtian
Mud
Sand
Congl

Figure 3



Relative probability / Number of analyses
CH17M4 (n=100)
CH17M5 (n=91)
CH17M6 (n=90)
CH17S10 (n=95)
SH17S4 (n=97)
MT17S5 (n=88)
0 100 200 300 400 500 600 700 800 900 1000
Age (Ma)
SH17S4
2% 28% 16% 2% 6% 3% 12% 31%
CH17S10
1% 23% 32% 3% 4% 5% 5% 27%
MT17S5
1% 32% 9% 4% 12% 3% 13% 26%
Oligocene (23-35 Ma): Naopurdan group /GvRd
Eocene (35-55 Ma): Walash group /GvRd
Paleocene (55-65 Ma): Walash group /GvRd
Latest Cretaceous (65-75 Ma): Kermanshah complex (?)
Late Cretaceous (75-120 Ma): ohiolite
Jurassic (150-200 Ma): Sanandaj-Sirjan zone Eurasian signature
Late Paleozoic (270-380 Ma): Variscan orogeny Eurasian signature
Precambrian (500-700 Ma): Pan-African

Figure 4