| 1  | Timing of the Arabia-Eurasia continental collision -   |
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| 2  | Evidence from detrital zircon U-Pb geochronology of the  |
| 3  | Red Bed Series strata of the NW Zagros hinterland,   |
| 4  | Kurdistan region of Iraq   |
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# 22 ABSTRACT

23 One of the major debated aspects of the Zagros orogenic system is the timing of 24 onset of continental collision between Arabia and Eurasia. The Zagros hinterland in the 25 Kurdistan region of Iraq contains a ca. 2 km-thick clastic depositional sequence of the 26 Red Bed Series (RBS) that rests unconformably on the Arabian foreland and structurally 27 below the Main Zagros Fault, which carries the allochthonous volcaniclastic rocks of the 28 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 29 30 of Eurasian sediment on the Arabian plate. The youngest DZ U-Pb ages for the laterally-31 extensive (ca. 150 km) basal RBS (Suwais unit) imply a middle Oligocene (ca. 26 Ma) 32 maximum depositional age. The provenance data reveal dominant DZ U-Pb age modes of 33 late Paleocene (~55-60 Ma) and middle Eocene (~37-44 Ma) and, importantly, presence 34 of ca. 10-15% DZ grains that are unequivocally derived from Eurasia, incl. Jurassic (150-35 200 Ma) and late Paleozoic (270-380 Ma) DZ age modes. These data suggest that the 36 RBS deposits were mainly sourced from forearc/arc-related terranes along the SW 37 margin and hinterland of Eurasia. We advocate that by ca. 26 Ma Neotethys oceanic crust 38 had been consumed and that Arabia-Eurasia continental collision well was underway as 39 indicated by deposition of strata with Eurasian provenance on the Arabian margin. These 40 DZ U-Pb data from the RBS highlight the significance of provenance data from 41 synorogenic deposits in revealing the timing of initial continent collision by document the 42 earliest arrival of upper-plate sediment on the lower plate.

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44 Keywords: Zagros, continental collision, U-Pb geochronology, detrital zircon,

45 provenance, Red Bed Series

#### 46 INTRODUCTION

47 The Zagros collisional zone is one of the most prominent and recent collisional segments 48 of the Alpine-Himalayan orogenic system and formed in response to the northward 49 subduction of the Neo-Tethys oceanic crust beneath the Eurasian continental plate, 50 culminating in the continent-continent collision between the Arabian and Eurasian plates 51 (e.g., Alavi, 1994; Hessami, 2001). The initiation of Arabia-Eurasia continent-continent 52 collision remains highly debated, due to the complex along-strike nature, poor 53 preservation the early synorogenic structural and depositional orogenic record, and the 54 complicated tectonic phases that included Late Cretaceous ophiolite obduction and island 55 and/or volcanic arc collisions prior to the continent-continent collision. Whereas studies 56 had suggested a possible pre-Cenozoic onset of continental collision, it is now well 57 understood that Late Cretaceous to early Cenozoic ophiolite obduction and arc accretion, 58 recorded in the proto-Zagros foreland basins, were not related to the continental collision 59 and not yet involve Eurasia (Homke et al., 2009; Saura et al., 2011). Timing constraints 60 for the Cenozoic Zagros continent-continent collision vary considerably and range 61 between Eocene to Miocene (e.g., Horton et al., 2008; Fakhari et al., 2008; Homke et al., 62 2009; Gavillot et al., 2010; Agard et al., 2011; Ballato et al., 2011, McQuarrie and van 63 Hinsbergen, 2013; Zhang et al., 2016; Pirouz et al., 2017; Barber et al., in press). 64 Constraining the inception of the Arabian and Eurasian plates collision is vital for the 65 understanding of initial continental collision as well as the broader tectonic and 66 geodynamic evolution of the Middle East, including the relationship between rifting in

the Gulf of Aden/Red Sea system and collision in the Zagros-Bitlis system. This study 67 68 focuses on the earliest synorogenic deposits of the Red Bed Series (RBS), that rests 69 unconformably on the Arabian foreland and structurally below a low-angle thrust - the 70 Main Zagros Fault (MZF) -that carries the allochthonous volcaniclastic rocks of the 71 Walash-Naopurdan groups and the Sanandaj-Sirjan Zone (SSZ) in its hanging wall (Al-72 Barzinjy, 2005; Jassim and Goff, 2006; Hassan et al., 2014). Over ca. 150 km along-73 strike, the RBS is irregularly truncated by the MZF, providing a synorogenic sedimentary 74 record during allochthonous thrust sheet emplacement (Figs. 1 and 2). In this paper, we 75 present new DZ U-Pb age data to elucidate the timing of deposition and characterize the 76 provenance of the RBS and discuss the implications for the timing of the continental 77 collision between Arabia and Eurasia.

78

#### 79 THE RED BED SERIES STRATA

80 The Red Bed Series (RBS) is a Cenozoic siliciclastic sequence deposited in a laterally 81 extensive (ca. 150 km) depositional system in the interior of the NW Zagros fold-thrust 82 belt, on the Arabian side of the suture zone in the footwall of the MZF (Fig. 2). These 83 deposits rest unconformably on deformed Cretaceous rocks of the Arabian platform 84 (Karim et al., 2011; Hassan et al., 2015). Along strike, the RBS basin deposits define 85 several NW-SE oriented discrete depocenters with a composite total preserved 86 stratigraphic thickness of ca. 2 km (Al-Barzinjy, 2005). In the study area, NW of the 87 Dukan Lake, the RBS has a thickness of ca. 1400 m (Fig. 3) and consists of alternating 88 mudstone and sandstone as well as conglomerates and limestone beds with calcareous 89 sandstone. These deposits can be subdivided into three major units: Suwais, Govanda,

90 and Merga units, which were deposited in estuarine, fluvial, and alluvial environments

91 (Jassim and Goff, 2006; Alsultan and Gayara, 2016; Abdula et al., 2018).

92

#### 93 METHODS AND SAMPLING

94 Detrital zircon (DZ) U-Pb geochronology has been shown to be a powerful tool for 95 identifying the provenance of sedimentary basins and constraining the timing of 96 maximum depositional ages (MDA) in volcanically active convergent belts (Fedo et al., 97 2003; Dickinson and Gehrels, 2009). In this study, we present 679 new DZ U-Pb ages 98 from six Red Bed Series samples (Fig. 3): three from Suwais unit (CH17S10, SH17S4, 99 MT17S5) and three from Merga unit (CH17M6, CH17M5, CH17M4). Four samples are 100 from the same section (CH-) and two Suwais unit samples are from along-strike localities 101 (SH-, MT-) (Fig. 1). All ages were obtained using the Laser Ablation Inductively 102 Coupled Plasma Mass Spectrometry (LA-ICP-MS) following procedures outlined in Hart 103 et al. (2016) at the University of Texas at Austin UTChron Geo- and Thermochronometry laboratories. See GSA Data Repository<sup>1</sup> item for detailed analytical procedures and all 104 105 analytical data.

106

#### 107 **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

| 113 | Eocene) and 55-60 Ma (late Paleocene), except for sample CH17M4 that show only a               |
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| 114 | major middle Eocene peak (Fig. 4; GSA Data Repository <sup>1</sup> ). In addition to these two |
| 115 | dominant DZ U-Pb age components, the RBS samples exhibit notable subsidiary Late               |
| 116 | Cretaceous (65-120 Ma), Jurassic (150-200 Ma), late Paleozoic (270-380 Ma), and                |
| 117 | Precambrian (500-700 Ma) DZ age components. The three youngest zircon grains from              |
| 118 | the basal Suwais unit yielded a mean age of $26.0 \pm 0.9$ Ma (n=3, MSDW=4.7) and from         |
| 119 | the stratigraphically higher Merga a mean age of $34.8 \pm 0.6$ Ma (n=3, MSDW=1.6).            |

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#### 121 **DISCUSSION**

#### 122 Detrital zircon provenance

123 The late Paleocene and middle Eocene dominant DZ U-Pb age components encountered 124 in the Red Bed Series (RBS) samples suggest a provenance from (i) the Walash-125 Naopurdan Groups that are thrusted on top of the RBS, (ii) the magmatic portions of the 126 SSZ, and (iii) the Urumieh-Dokhtar magmatic zone (UDMZ), which are all associated 127 with the Eurasian plate (Figs. 1 and 4). The Walash-Naopurdan Groups of the Zagros 128 Suture Zone are likely the equivalent of the Gaveh-Rud Domain forearc deposits in the 129 Iranian Zagros farther to the SE in the Lorestan salient (Sadeghi and Yassaghi, 2016). 130 Reported ages for volcaniclastic forearc/arc-related sequences are middle Eocene (Agard 131 et al., 2005; Homke et al., 2009; Aswad et al., 2014) and late Eocene (Ali et al., 2013). 132 As for the upper-plate hinterland, the metamorphosed SSZ contains several igneous 133 intrusions, incl. the Piranshahr and Kamyaran massifs that span the time interval between 134 the late Paleocene-early Eocene and the middle Eocene ages (Mazhari et al., 2009; Azizi 135 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).

138 Among the minor DZ U-Pb age components of the RBS, the Jurassic (150-200 139 Ma) and the late Paleozoic (270-380 Ma) are unequivocally indicative of sources from 140 the SSZ and the broader Eurasian hinterland and have not been reported from the Arabian 141 plate. The 150-200 Ma DZ ages are sourced from numerous plutons in the SSZ (Chiu et 142 al., 2013), while the 270-380 Ma age component is linked to Hercynian magmatic 143 sources (Stampfli et al., 2013). Based on these provenance data, the RBS detritus, 144 unconformably deposited on Arabia, was derived from the convergent southwestern 145 margin and orogenic hinterland of Eurasia.

146

#### 147 **Timing of deposition**

148 The age of the youngest DZ grains from samples from the bottom of the Suwais unit 149 within the lower part of the RBS strata, suggest that the RBS deposition started sometime 150 during the middle Oligocene. Each of the three Suwais samples, geographically 10s of 151 kilometers apart along strike, contained a single young grain that combined yielded a 152 mean age of ca. 26 Ma, implying a middle Oligocene depositional age for the Suwais 153 unit. This MDA is significantly younger than published Paleocene-Eocene ages for the 154 Suwais unit based on the planktonic foraminifera (Al-Barzinjy, 2005 and Hassan, 2012). 155 These conflicting biostratigraphic and isotopic ages likely point to reworking of the 156 Paleocene-Eocene microfossils – a hypothesis supported by a dominant Paleocene-157 Eocene DZ age peak. The sparse, but consistent youngest middle Oligocene DZ U-Pb 158 ages support a laterally synchronous onset of lower Suwais deposition over ca. 150 km

159 along strike. Regionally, the basal Suwais unit unconformably overlies folded Triassic-160 Cretaceous Qulqula Formation or Cretaceous Bekhma and Shiranish Formations. While 161 Karim and others (2011) and Hassan and others (2014) proposed an apparent 162 conformable contact between the RBS and the Maastrichtian Tanjero Formation, the ~26 163 Ma MDA for the Suwais unit implies a hiatus of ~40 m.y. and a disconformable contact 164 between the RBS and the Tanjero Formation.

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#### 166 Timing of the Arabia-Eurasia continental collision

167 The Red Bed Series in NE Iraqi Kurdistan is characterized by an unequivocally Eurasian 168 DZ U-Pb provenance signature, a middle Oligocene maximum depositional age of  $\sim 26$ 169 Ma, and widespread regional unconformity with a 40 m.y. hiatus prior to RBS deposition. 170 These observations provide clear evidence for the minimum age for the Arabia-Eurasia 171 continental collision during the middle Oligocene. These new timing constraints support 172 an earlier timing for the onset of continent-continent collision by the middle Oligocene. 173 These findings are in general agreement with estimates on basis of plate circuit 174 reconstructions and foreland basin sedimentation patterns (e.g., Saura et al., 2015; 175 McQuarrie and van Hinsbergen, 2013; Pirouz et al., 2017; Zadeh et al., 2017). They, 176 however, do not preclude an Eocene inception of collisional deformation (e.g., Ballato et 177 al. 2011, Mouthereau et al., 2012; Barber et al, in press).

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#### 179 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

182 age for the Arabia-Eurasia continent-continent collision in the middle Oligocene at ca. 26 183 Ma. The basal RBS, which is structurally truncated by the MZF low-angle thrust and 184 buried by allochthonous thrust sheets, was unconformably deposited on the Arabian 185 plate. The basal RBS deposits of the Suwais unit yielded a middle Oligocene (ca. 26 Ma) 186 maximum depositional age and exhibits provenance data indicative of derivation from 187 forearc and arc-related terranes and the hinterland along the southwestern margin of the 188 Eurasia. These data argue for an onset of continent-continent collision and arrival of the 189 Eurasia-sourced sediment on the Arabian plate by at least the middle Oligocene.

190

#### 191 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.

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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.

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| 205 | Figure 3. Generalized composite stratigraphic column of the Red Bed Series illustrating          |
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| 206 | the key lithostratigraphic units and the apparent location of the dated rock samples in the      |
| 207 | NW of the study area. Stratigraphic data are from Jassim and Goff (2006), Alsultan and           |
| 208 | Gayara (2016), Abdula et al., (2018) and fieldwork from this study.                              |
| 209 |  |
| 210 | Figure 4. Top: Detrital zircon U-Pb age distribution plots of samples from the Suwais and        |
| 211 | Merga units that show significant probability density peaks (histograms bin size is 20           |
| 212 | Ma; Vermeesch, 2012) during Paleogene. Bottom: Percentages of the potential source               |
| 213 | components from the Suwais unit samples.   |
| 214 |  |
| 215 | <sup>1</sup> GSA Data Repository item 201Xxxx, U-Pb data of the newly analyzed zircon grains are |
| 216 | available online at www.geosociety.org/pubs/ft20XX.htm, or on request from                       |
| 217 | editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO                   |
| 218 | 80301, USA.  |

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Figure 1



Figure 2



Figure 3



Figure 4