

# **PS Late Lutetian <sup>40</sup>Ar/<sup>39</sup>Ar Age Dating of a Mafic Intrusion into the Jafnayn Formation and its Tectonic Implications (Muscat, Oman)\***

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## **Abstract**

A quartz undersaturated alkali-olivine basalt/camptonite magma intruded the late Paleocene/Early Eocene Jafnayn Formation ~30 km to the WSW of Muscat. This previously undated intrusion has been first mentioned and mineralogically investigated by Al-Harthy et al. (1991). The intrusion occurred 2 km north and in the hanging wall of a regional-scale extensional fault zone – the Frontal Range Fault (FRF; Mattern and Scharf, 2018). This fault zone follows the northern margins of the Jabal Akhdar/Nakhl and Saih Hatat domes and has a throw of few to several kilometers. The camptonite is positioned at the northwestern margin of the Saih Hatat Dome, close to the Jabal Akhdar/Nakhl Dome. Two shear intervals along the FRF have been identified, the first one immediately after emplacement of the Semail Ophiolite (latest Cretaceous to the late Paleocene), the second one probably during the Oligocene. The latter is poorly constrained. The cause for both intervals is gravitational collapse during or slightly after uplift of the two domes. The camptonite intruded the Jafnayn Formation in an extensional regime. The camptonite occurs in the immediate vicinity of a dextral releasing bend, which was active during the second deformation interval along the FRF. The <sup>40</sup>Ar/<sup>39</sup>Ar dating of the whole rock sample of this camptonite was conducted by stepwise heating with continuous CO<sub>2</sub> laser and the noble gas mass spectrometer, MM5400, at the <sup>40</sup>Ar/<sup>39</sup>Ar geochronology laboratory in the University of Potsdam. The age was obtained against the age of Fish Canyon Tuff sanidine, FCs-EK (Morgan et al., 2014), and by the MassSpec software developed by Dr. Alan Deino of the Berkeley Geochronology Center, USA. We obtained a well-defined plateau age of 42.7 ± 0.5 Ma (1 sigma error; late Lutetian). The normal and inverse isochron ages obtained from the plateau steps are also consistent with the plateau age. The age of the camptonite postdates the first interval of the FRF by more than 10 Ma. It is of interest to see how the camptonite age relates to the cooling curve provided by Hansman et al. (2017). Their work indicates an onset of rapid exhumation and cooling of the Jabal Akhdar Dome at 40 Ma and with less intensity in the Saih Hatat Dome (their event II). The error margin of their cooling curve allows for the interpretation that the intrusion occurred at the onset of rapid exhumation and cooling. Furthermore, rapid exhumation and cooling from 49 to 39 Ma for the center of the Jabal Akhdar Dome was determined by Grobe et al. (2019). The proximity of the camptonite to the extensional FRF suggests that magma used an extensional fault of

the FRF Zone for the upper part of the ascent path. For the lower part of the ascent path reactivated Permian rift faults of the Pangea Rift or other preexisting faults may have been used. We suggest that the camptonite intrusion ensued at an early stage of the second deformation interval along the FRF, because (1) the location of the camptonite is near the dextral releasing bend which formed during the second shear interval of the FRF, (2) the coincidence of our  $^{40}\text{Ar}/^{39}\text{Ar}$  age with the exhumation/cooling curves, (3) the camptonite postdates the first interval at the FRF by more than 10 Ma and (4) the fact that only the second deformation interval is poorly time-constrained. Therefore, we conclude that the second deformation interval along the FRF may have started already during the Late Lutetian and lasted into the Oligocene.

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## 2ND EDITION STRUCTURAL STYLES OF THE MIDDLE EAST

### LATE LUTETIAN $^{40}\text{Ar}/^{39}\text{Ar}$ AGE DATING OF A MAFIC INTRUSION INTO THE JAFNAYN FORMATION AND ITS TECTONIC IMPLICATIONS (MUSCAT, OMAN)

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#### Introduction

A quartz undersaturated alkali-olivine basalt/basanite magma intruded the late Paleocene/Early Eocene Jafnayn Formation ~30 km to the WSW of Muscat (Fig. 1). This previously undated intrusion has been first mentioned and mineralogically investigated by Al-Harthi et al. (1991) and later by Nasir et al. (2006). The intrusion occurred 2 km north and in the hanging wall of a regional-scale extensional fault zone – the Frontal Range Fault (FRF; Mattern and Scharf, 2018; Figs. 2 and 3). This fault zone follows the northern margins of the Jabal Akhdar/Nakhl and Saih Hatat domes and has a throw of a few to several kilometers. The basanite is positioned at the northwestern margin of the Saih Hatat Dome, close to the Jabal Akhdar/Nakhl Dome. Two shear intervals along the FRF have been identified, the first one immediately after emplacement of the Semail Ophiolite (latest Cretaceous to the late Paleocene/Eocene; Grobe et al., 2019), the second one probably during the Oligocene (Mattern and Scharf, 2018 with deformation ages after Fournier et al., 2006). The latter is poorly constrained. The cause for both intervals is gravitational collapse during or slightly after uplift of the two domes. The basanite intruded the Jafnayn Formation in an extensional regime. The basanite occurs in the immediate vicinity of a dextral releasing bend, which was active during the second deformation interval along the FRF.

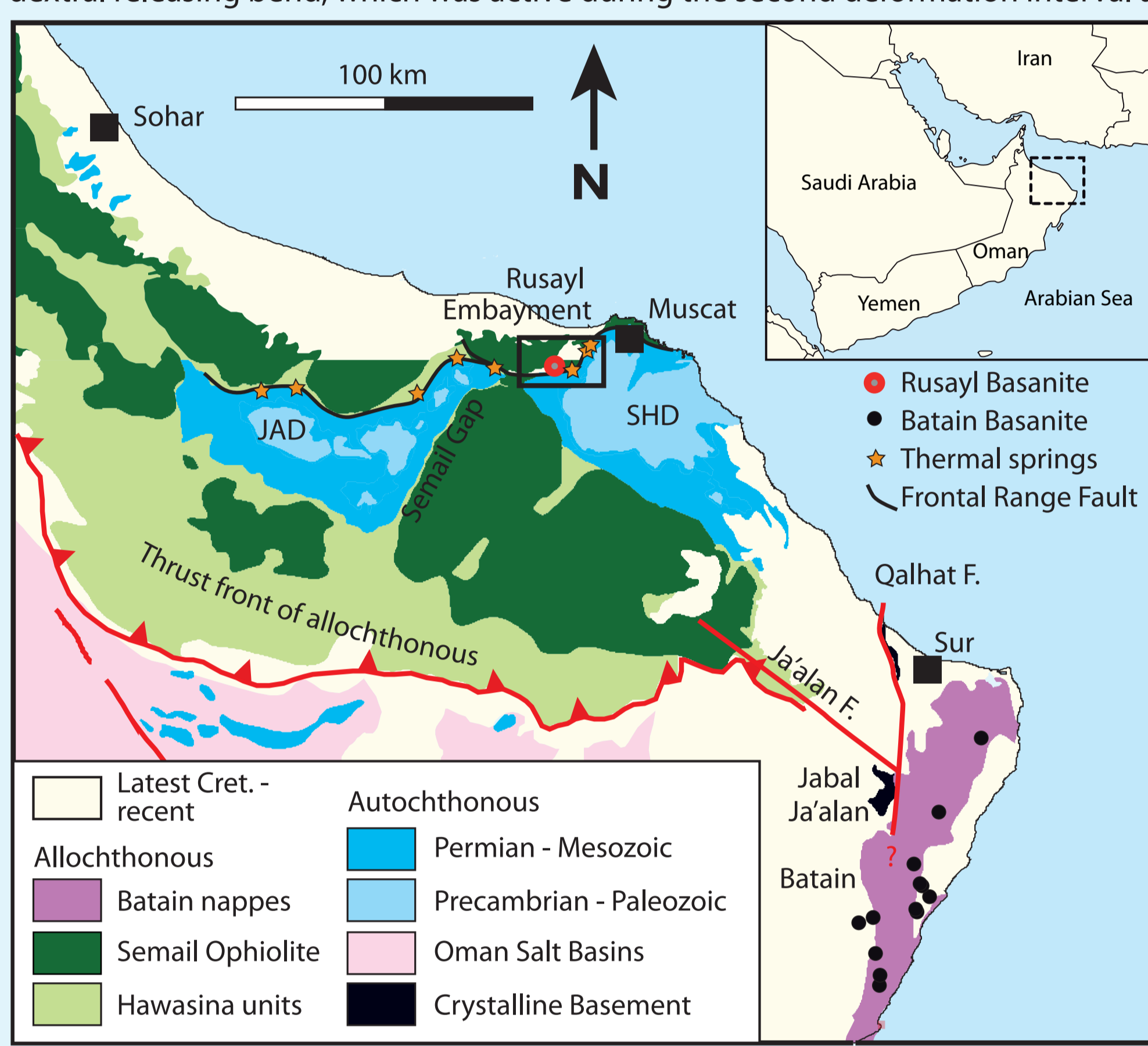


Figure 1. Geological map of the greater study area, modified after Forbes et al. (2010). Note the Frontal Range Fault, thermal springs, listwaenite and the location of the studied basanite. Thermal springs are after Al-Harthi et al. (1991) and Al-Hosni (pers. comm.). Frontal Range Fault after Mattern and Scharf (2018). JAD – Jabal Akhdar Dome; SHD – Saih Hatat Dome. Basanite from the Batain area are taken from Gnos and Peters (2003). Dark box indicates Figure 2. Inset depicts Arabia and its surroundings. Dotted black box shows the greater study area.

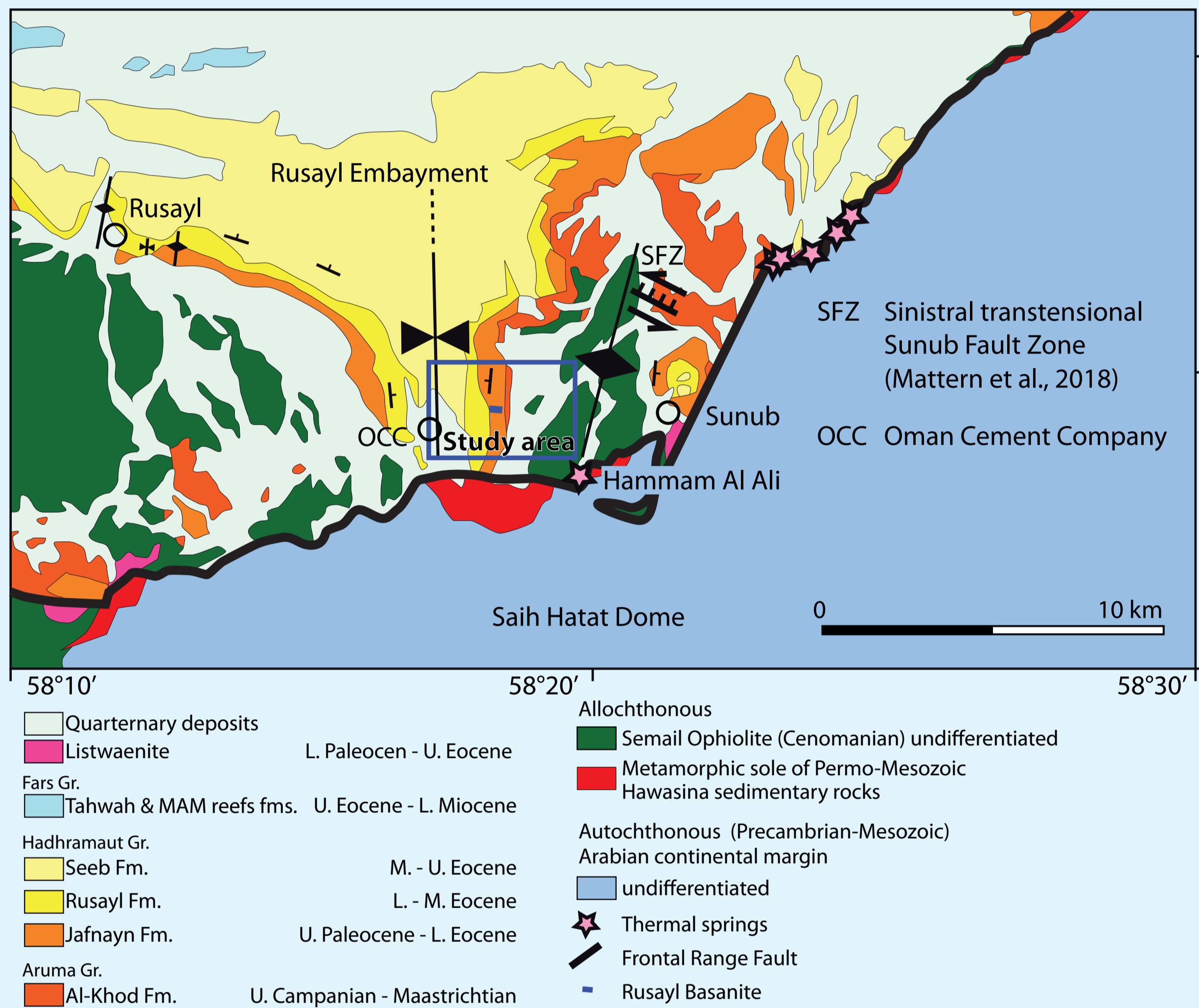


Figure 2. Geological map of the study area after Béchenneq et al. (1992). Note the location of the thermal springs, listwaenite at the Frontal Range Fault. Also note the ~N-S trending folds in the hanging wall of the Frontal Range Fault.

#### The outcrop

The Rusayl Basanite forms a dike and cuts the strata of the basal part of the Jafnayn Formation. The orientation of the Jafnayn Formation is 275/15 while the <75m-long and 10m-wide dike has a strike of 95° and a vertical dip angle. The carbonates of the host rock mostly display a contact aureole of a few centimeters in thickness. This aureole is marked by a slightly orange to reddish color of the carbonates (Fig. 3). Outside the aureole, the weathering color of the carbonates is yellowish. The contact between host rock and igneous rock is sharp, however, at the top/roof of the intrusion it is irregular. The fact that the dike is largely covered by debris makes it difficult to spot the dike by satellite image or from a distance. The basanite contains locally but numerous dark green xenoliths of dunite with a diameter of 1 to 2 cm.



Figure 3. Contact of the basanite at the western upper outcrop. Note the sharp contact between the basanite (right) with the carbonates (left) as well as the reddish contact aureole in the limestone (i.e., near the hammer).

#### $^{40}\text{Ar}/^{39}\text{Ar}$ dating

We analyzed the whole-rock basalt/basanite sample of about 7 mg by stepwise heating using a  $\text{CO}_2$  continuous laser. We obtained a well-defined plateau age of  $42.7 \pm 0.5$  Ma (late Lutetian) from the four steps, which cover 80.1% of the total amount of  $^{39}\text{ArK}$  (Fig. 4). The normal and inverse isochron diagrams (Fig. 4) obtained from the plateau steps show the ages of  $46 \pm 5$  Ma and  $45 \pm 5$  Ma with the initial  $^{40}\text{Ar}/^{39}\text{Ar}$  ratios of  $286 \pm 20$  and  $287 \pm 19$ , respectively. Thus, the initial ratios with errors from the plateau steps agree with the atmospheric value (298.56), and both the isochron ages from plateau steps agree with the plateau age within error. This means that the selection of plateau steps is valid, and the plateau age shows a geological meaningful age.

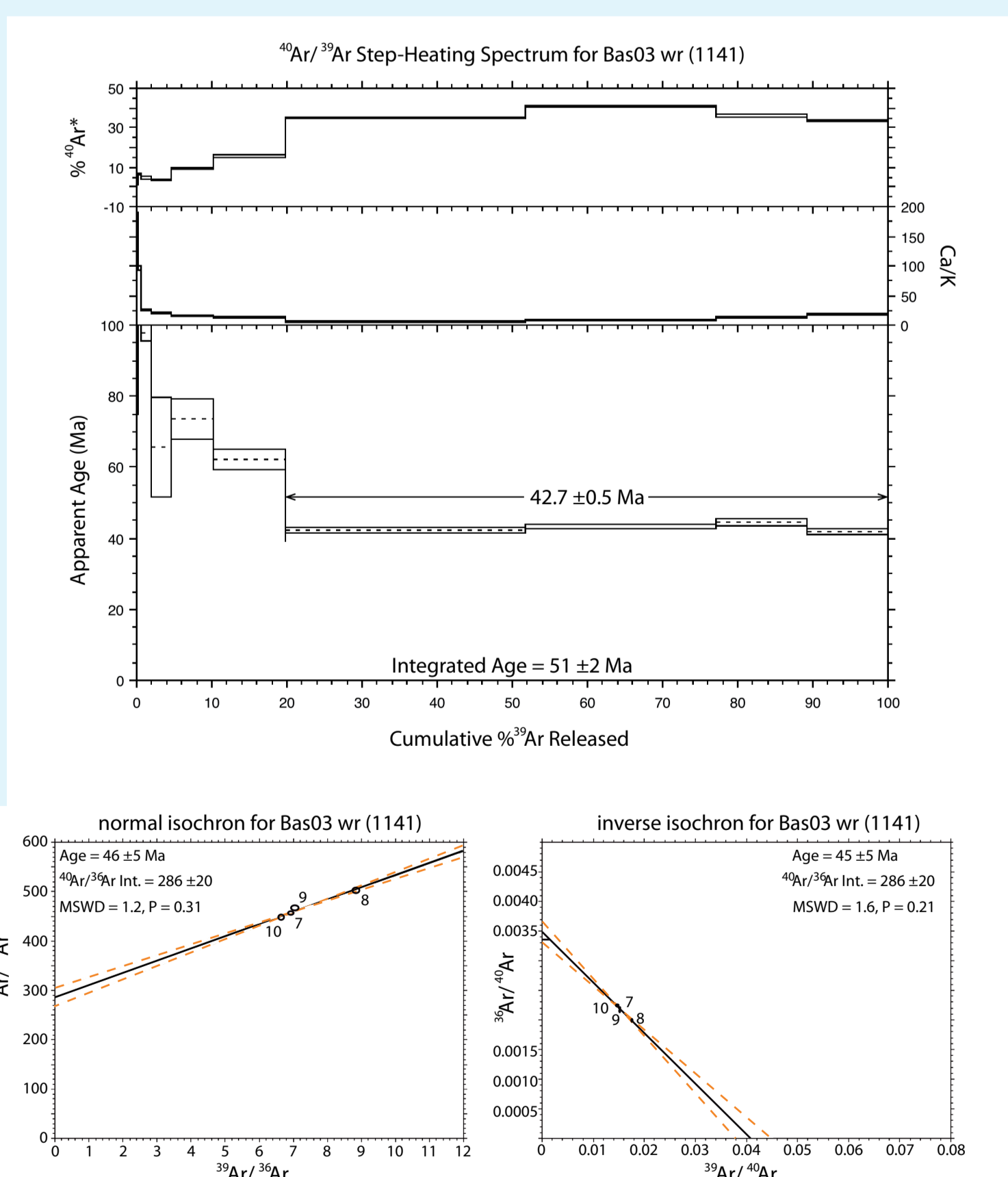


Figure 4. Age spectrum and normal and inverse isochrons from the plateau steps by the  $^{40}\text{Ar}/^{39}\text{Ar}$  analysis of 1141 (Lab ID). All errors indicate 1 sigma error.

#### Tectonic implications

##### 1. Activity of Phase II of the FRF

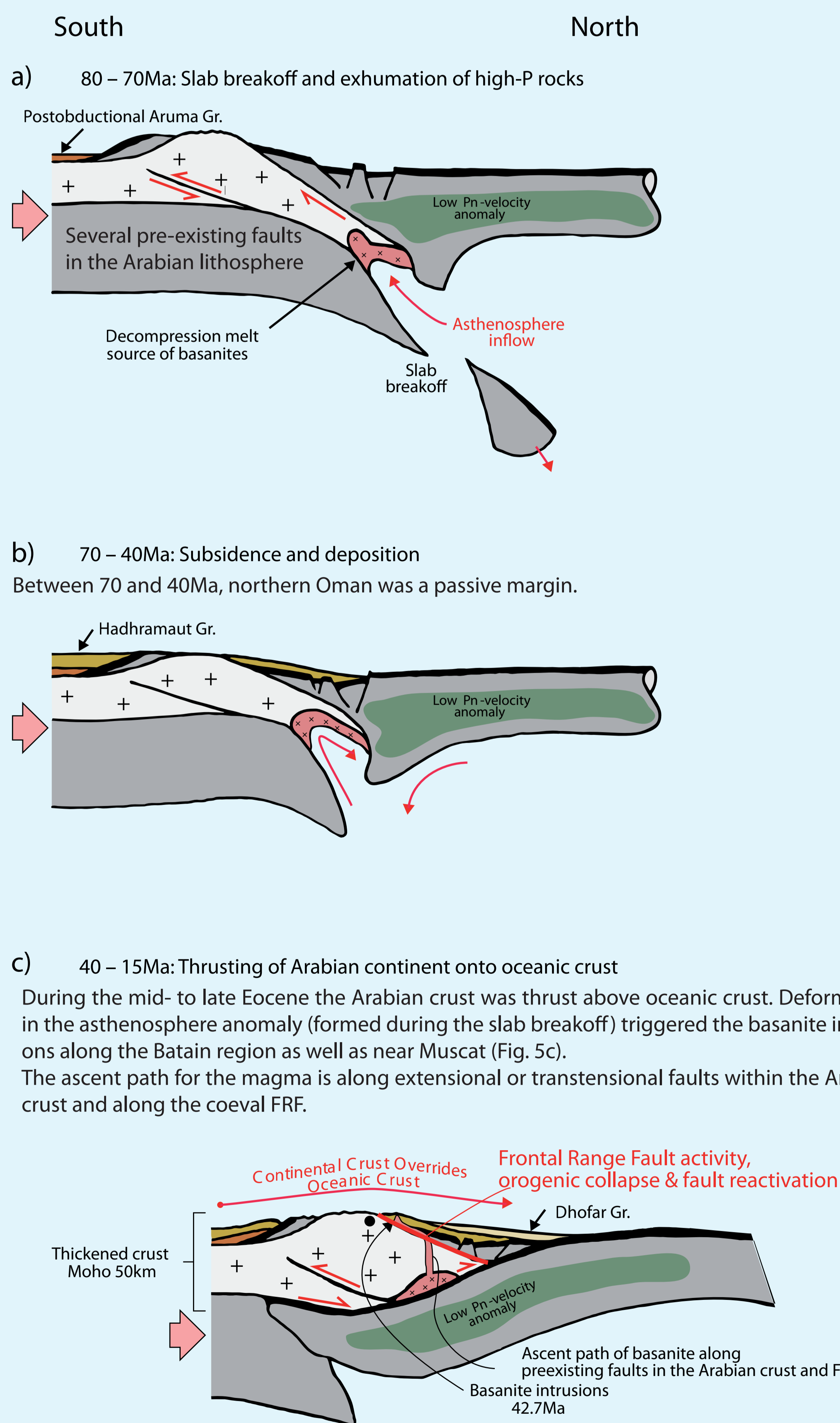
- The FRF has two phases of active (Mattern and Scharf, 2018)
- Phase I lasted from latest Cretaceous to late Paleocene/early Eocene.
- Phase II occurred probably during the Oligocene (previously thought).
- Intrusion took place under extensional or transtensional stress, providing for an ascent path for the magma.

Thus, the intrusion (42.7Ma) correlates with activity of the FRF.

**Phase II of FRF activity started already during the late Lutetian (Eocene) and lasted until the Oligocene**

##### 2. Tectonic setting/origin of intrusion

Hansman et al. (2017) hypothesized that the source of the basanites are decompressional melts originated during the slab breakoff between the continental Arabian lithosphere and the Neo-Tethys Ocean lithosphere during the late Cretaceous (Fig. 5a). Slab breakoff resulted in an asthenosphere inflow (anomaly) between the subducting slab and the exhuming continental lithosphere (Fig. 5a). The following sketches are modified from Hansman et al. (2017, their Fig. 11).



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