Deformation Patterns of Neoproterozoic and Earliest Cambrian Rocks at the Western Sector of the Jabal Akhdar Dome, Central Oman Mountains*

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Abstract

This work aims to improve the understanding of Paleozoic tectonic events that affected the Neoproterozoic and Early Paleozoic rocks of the western part of the Jabal Akhdar Dome in Oman (Central Oman Mountains). This sedimentary sequence forms the oldest cover of the Arabian platform with an age ranging from the Cryogenian to the earliest Cambrian. The weakly metamorphosed rocks are truncated by an angular unconformity and re-covered by Permo-Mesozoic sedimentary rocks of the Arabian passive margin. The younger cover was only deformed under brittle conditions and shows gentle, open folding which differs in style and intensity of deformation of the polyphaser folded Neoproterozoic-Cambrian rocks. In the western part of the Jabal Akhdar Dome (in Wadi Bani Awf and Wadi Sathan), two Paleozoic folding phases/events have been identified.

Evidence for an older Paleozoic deformation (D1) has been identified within black fetid limestone of the Hajir Formation. These rocks have been ductile deformed, as shown by tight to close apparent cylindrical folds (F1). The structural style reconstructions show a uniform vergence to the northeast of the F1 folds, overprinted by a second event (D2). This younger event has refolded the F1 fold axes in open to close folds (F2) with an amplitude of one kilometer. The F2 folds are reclined with fold axes plunging ENE-ward with about 50° and SW-ward with about 30° at the northern and southern side of the Jabal Akhdar Dome, respectively. F2 axial planes dip sub-vertically to steeply inclined to the NNW. F2 folds have been recognized/described by previous authors while the F1 folds are a new result of this study. Towards the east, the folds amplitudes and wavelengths are reduced. In the eastern Jabal Akhdar Dome, only minor (D2) folding can be observed.

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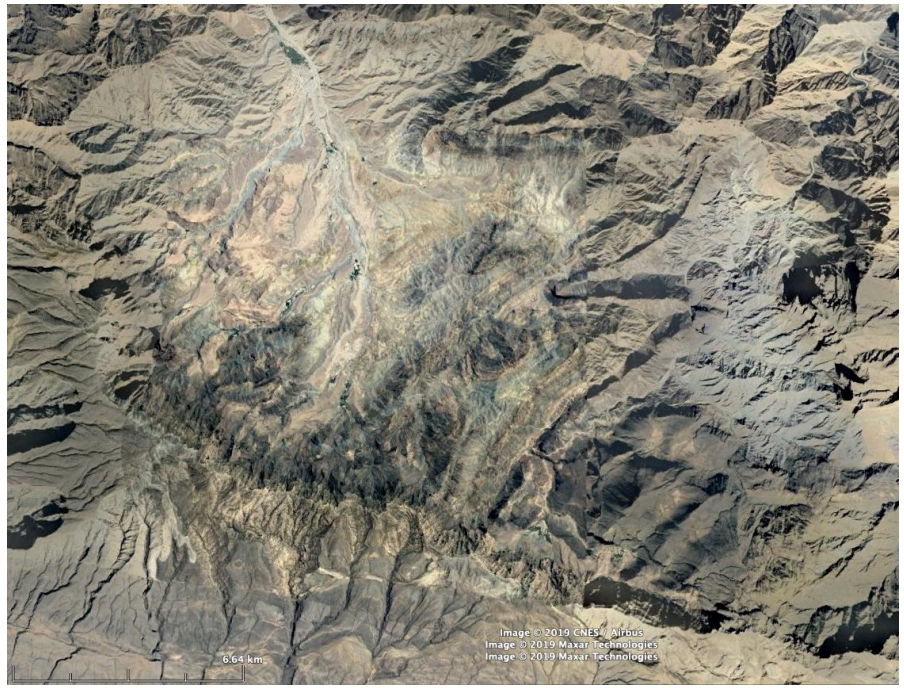

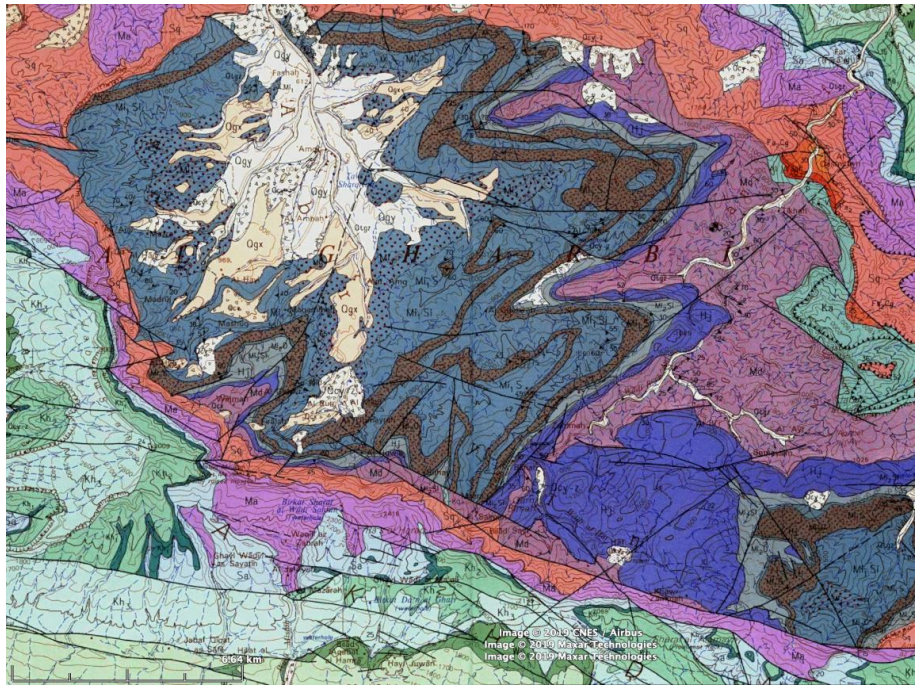

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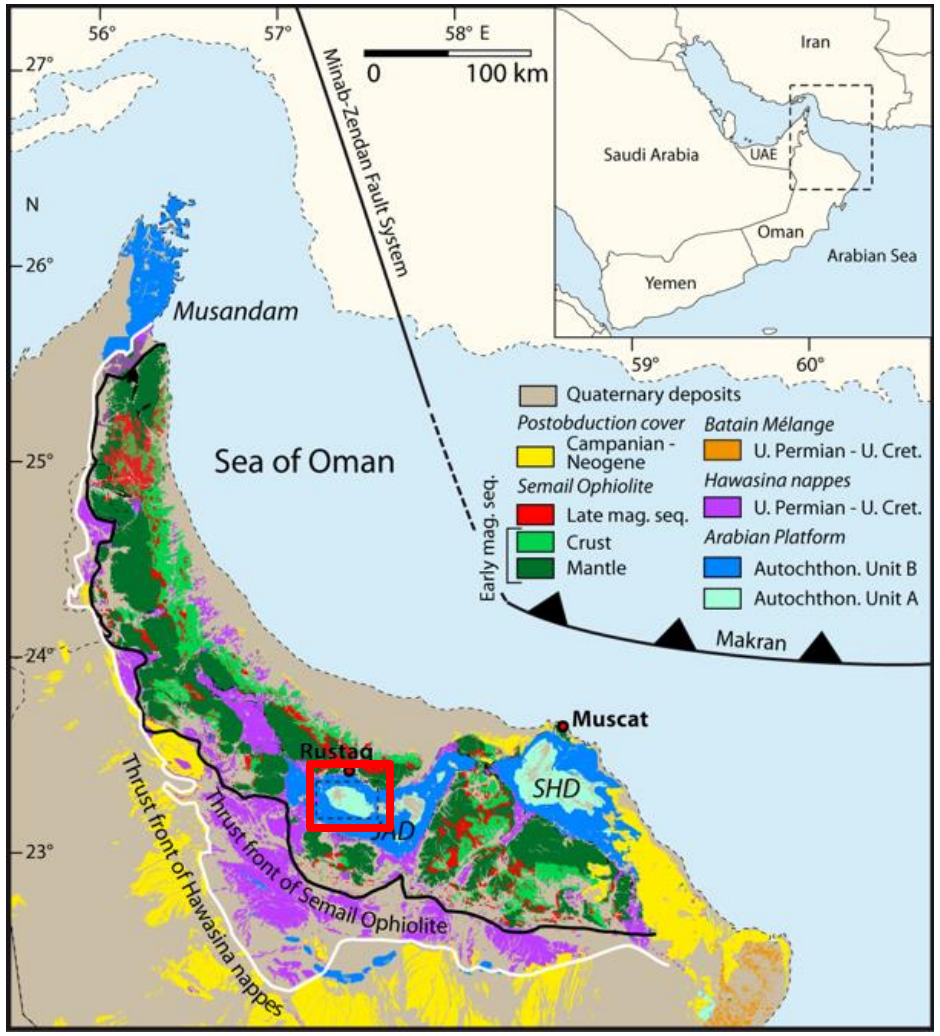
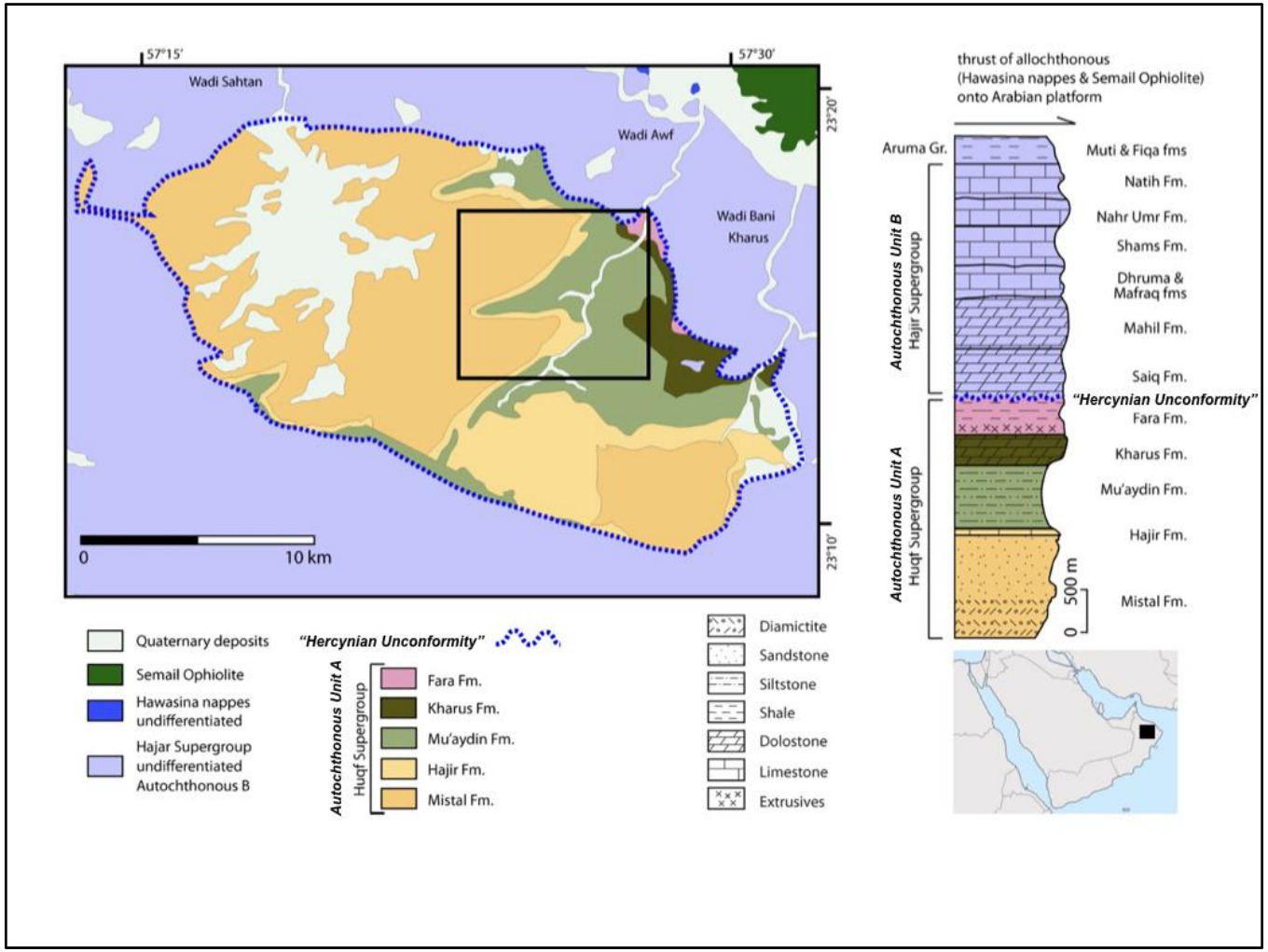




Geological setting

Geological setting

Paleozoic

Permian

Cambrian

Neoproterozoic

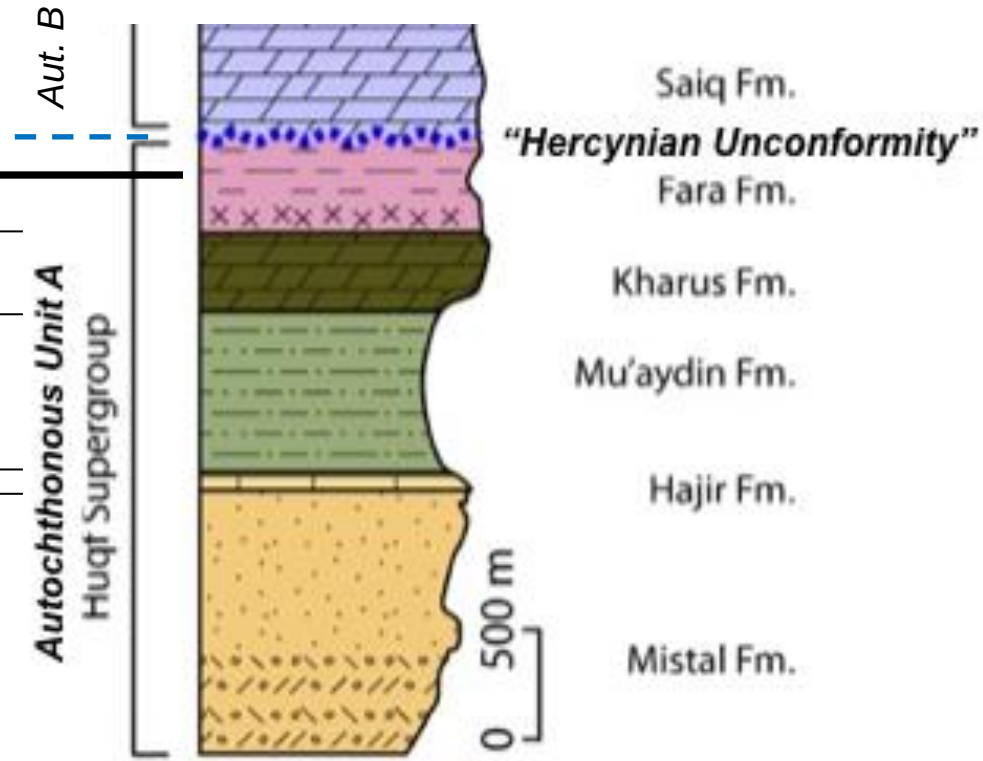
380 m of chert, volcanoclastics, siltstone, sandstone and conglomerate (Beurrier et al., 1986)

up to 245 m of limestone and dolostone

800 m of mainly siltstone with thin carbonate beds (Beurrier et al., 1986)

100 m-thick black fetid limestone (Beurrier et al., 1986)

alternation of siltstone and sandstone with a diamictite in the lower part;
total thickness >1250 m (Beurrier et al., 1986)



Fara Formation age: from ~547 to ~542 Ma (Brasier et al., 2000; Bowring et al., 2007)

Geological setting

A Paleozoic deformation of the Arabian Plate and the JAD has been described by, e.g., Glennie et al. (1974), Beurrier et al. (1986), Rabu et al. (1986) and Mann and Hanna (1990).

Open folds with an amplitude of few kilometers and reverse/thrust faults, revealing a ~NW- or SE-directed compressional interval (e.g., Mann and Hanna, 1990).

Related to the “Hercynian deformation” (e.g., Glennie et al., 1974; Faqira et al. 2009) or “pre-Permian deformation” (e.g., Mann and Hanna, 1990). Beurrier et al. (1986) and Rabu et al. (1986) relate this deformation to either Late Proterozoic or, more likely, “Hercynian movements”.

Previous works: one deformation event.

Geological setting –Hercynian Event

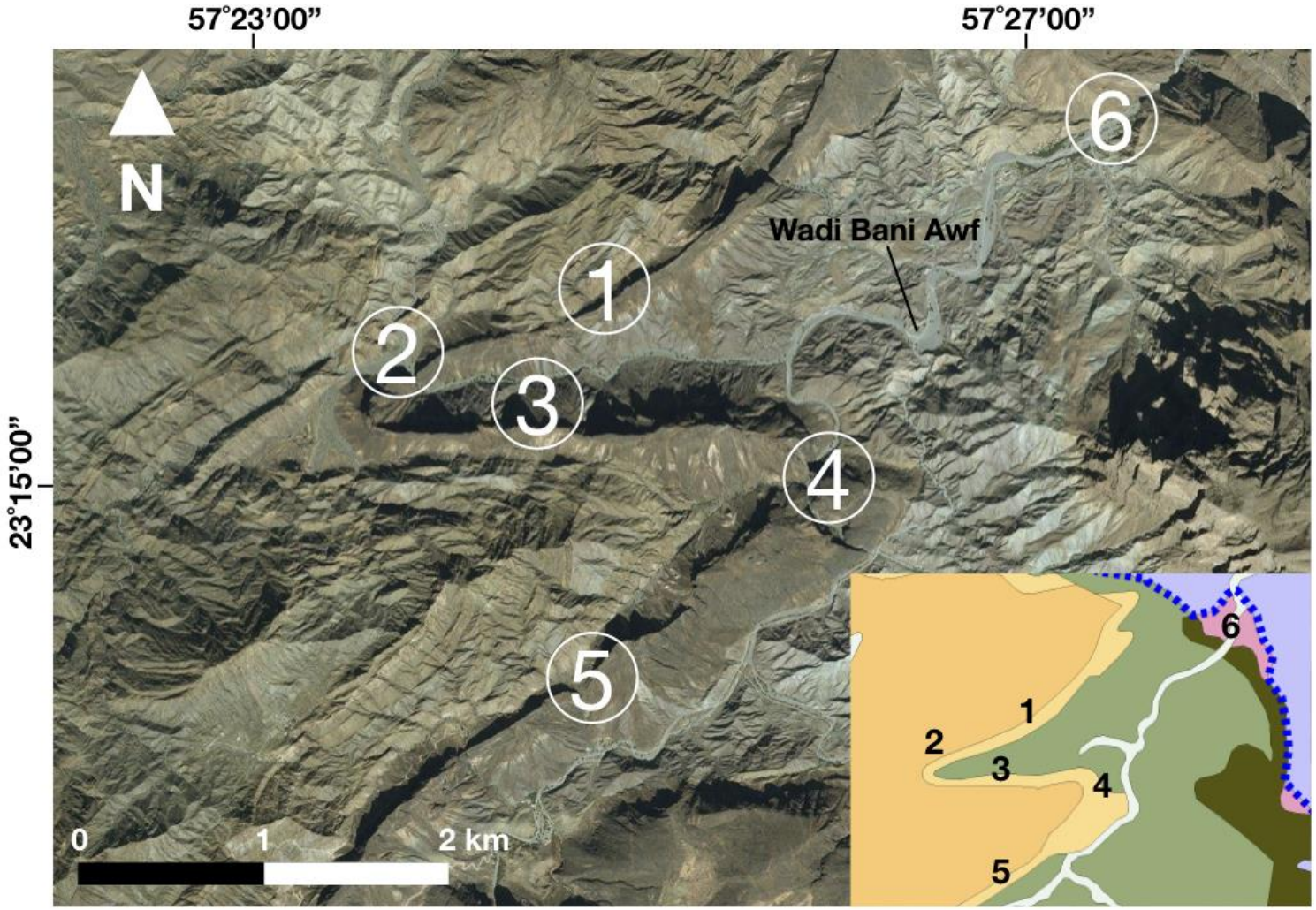
- Unconformity, crystallization ages and the WSW/ENE to SSW/NNE-oriented folds are expression of the “Hercynian Orogeny” (e.g., Beurrier et al., 1986).
- Konert et al. (2001), the “Hercynian Orogeny” affected the Arabian Plate from the Late Devonian to the early Carboniferous.
- Arch formation on the Arabian Peninsula has also been attributed to “Hercynian deformation” (e.g., Rabu et al., 1986, Faqira et al., 2009; Steward, 2016).

BUT

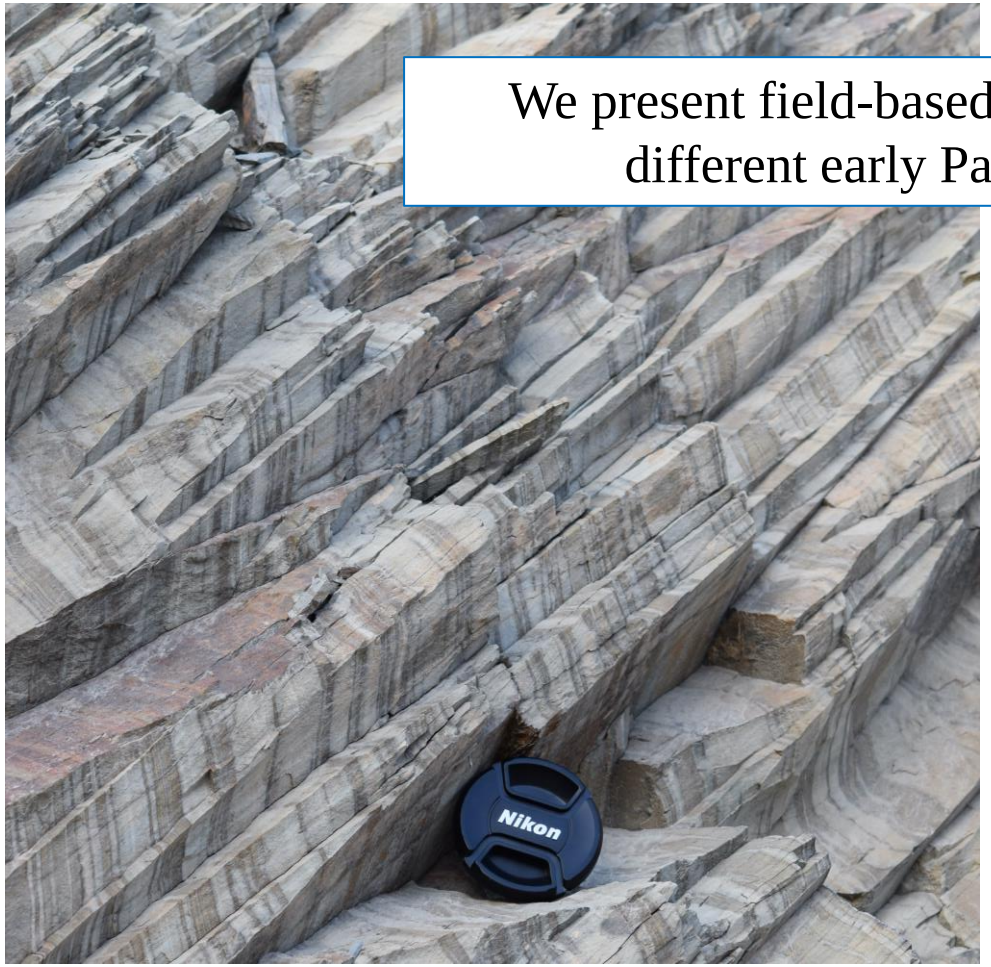
- “Hercynian interpretation” can be questioned because of the significant late Paleozoic distance between the Arabian Plate and the Gondwana-Laurasia collision zone (e.g., Guiraud et al., 2005; Ruban et al., 2007).
- Unconformity and stratigraphic gap could have been caused by the exhumation associated with the breakoff of the Cimmeria Superterrane from Gondwana (Ruban et al., 2007).
- “Hercynian event” has recently been interpreted to be mainly a thermal one as far as northern Africa and Arabia are concerned (Abbo et al., 2018).

SO

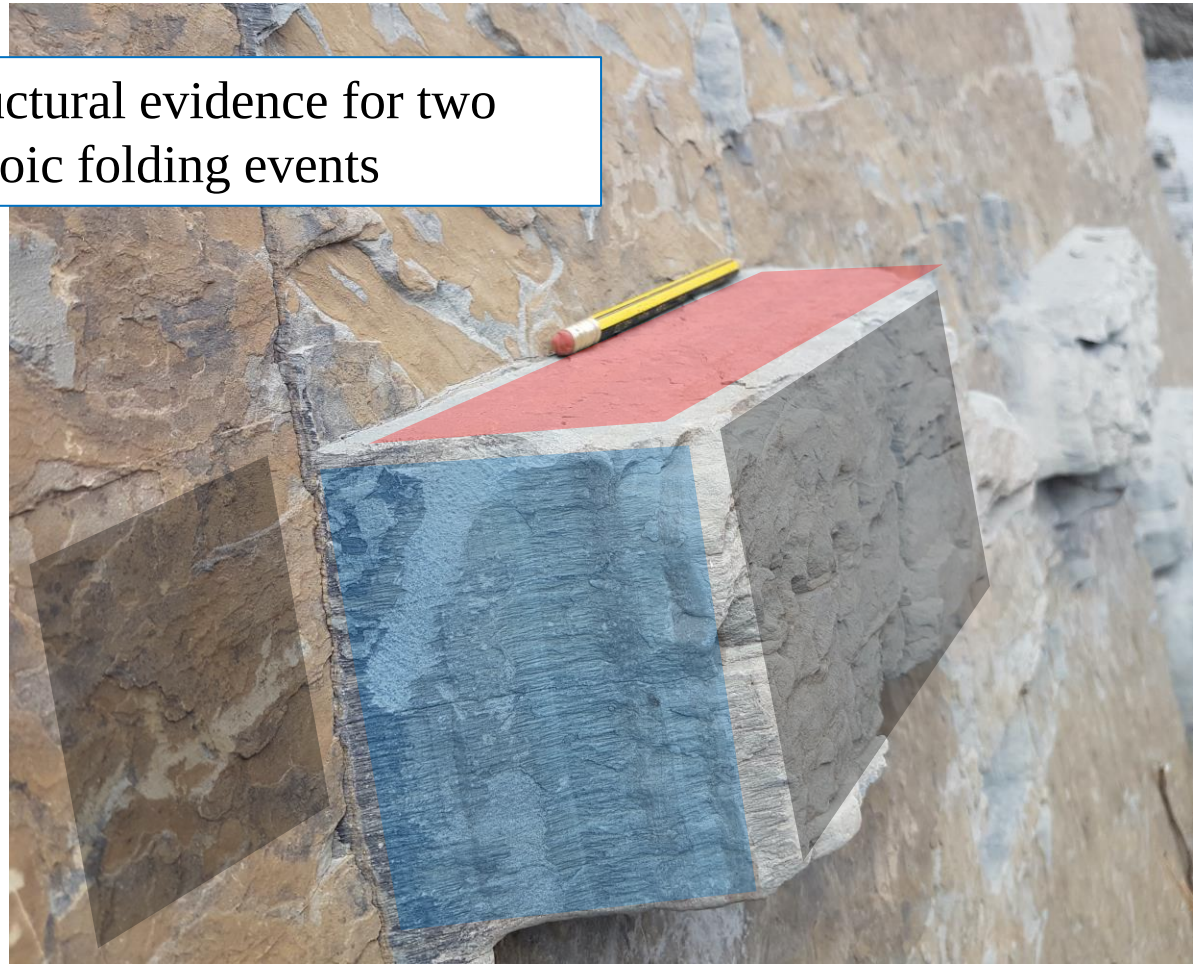
- Absence of “Hercynian deformation” mechanism leaves the folds in the Neoproterozoic rocks unexplained. Folding have to be attributed to a compressional or transpressional episode predating such an “Hercynian event”. Another aspect leading to potentially ambiguous interpretations is the ~NE-SW orientation of structures deemed “Hercynian”, similarly to the trend of the Angudan Orogeny, according to present cardinal directions (e.g., Droste 2014).



Field investigation and results

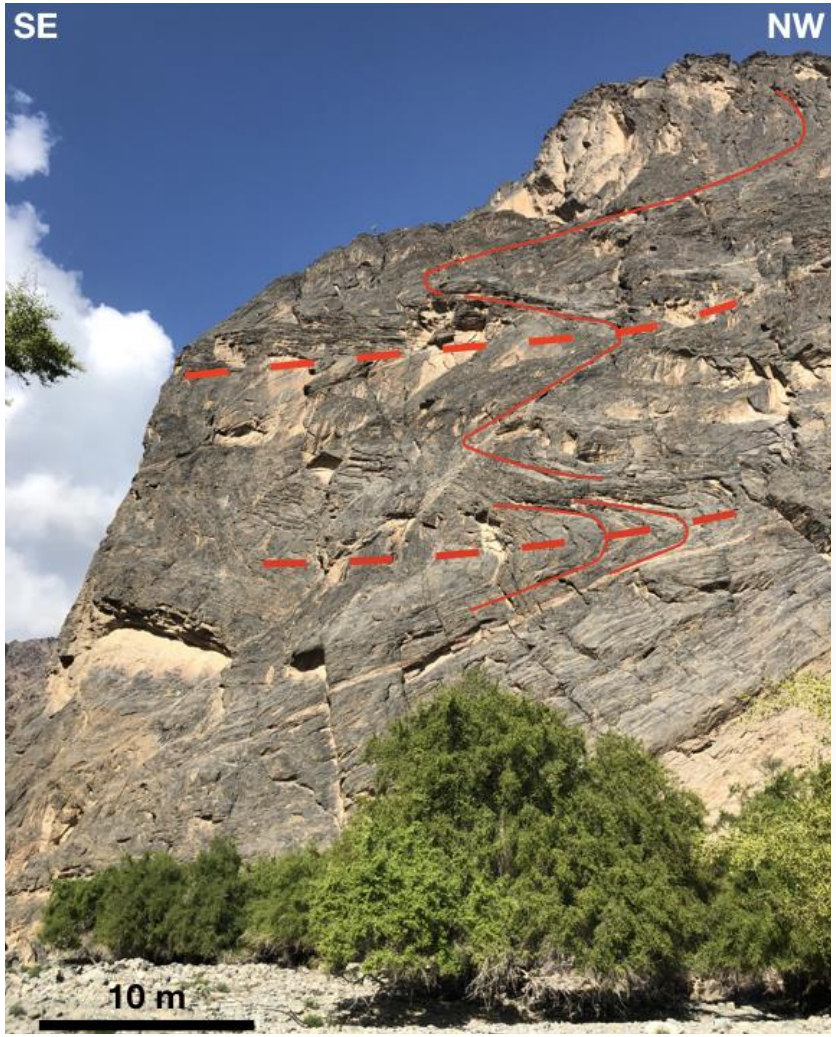


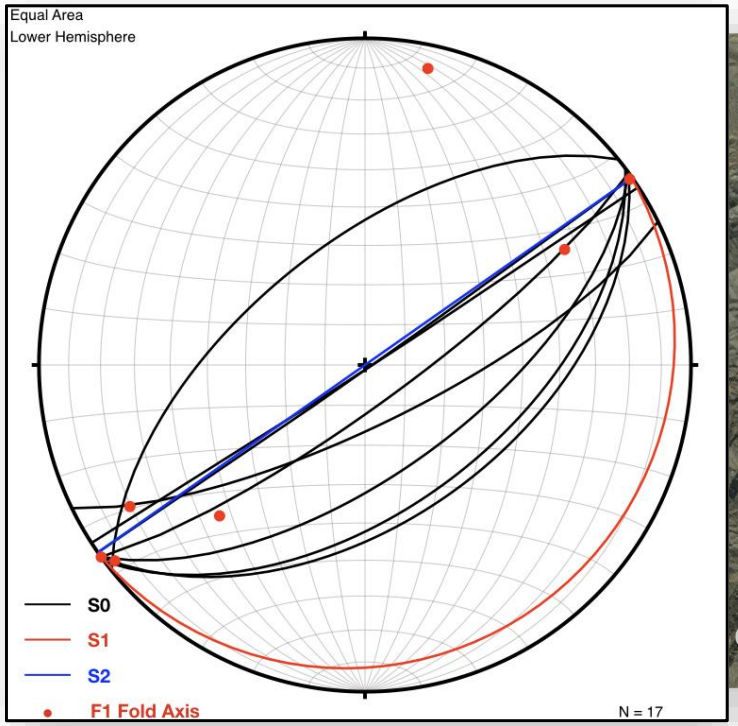
We present field-based structural evidence for two different early Paleozoic folding events

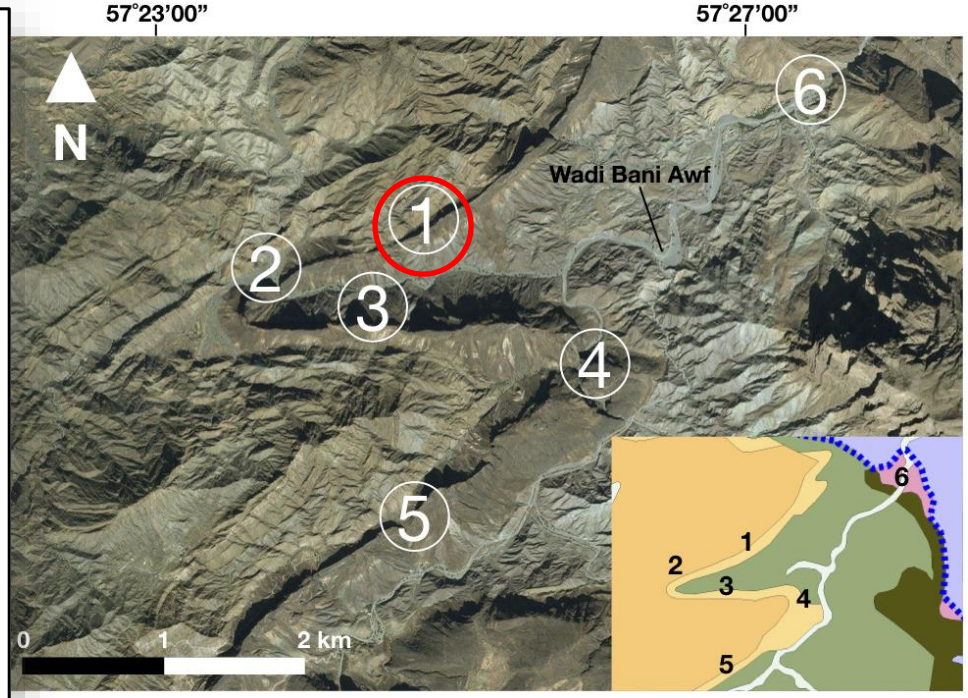


Field investigation and results

Sector 1

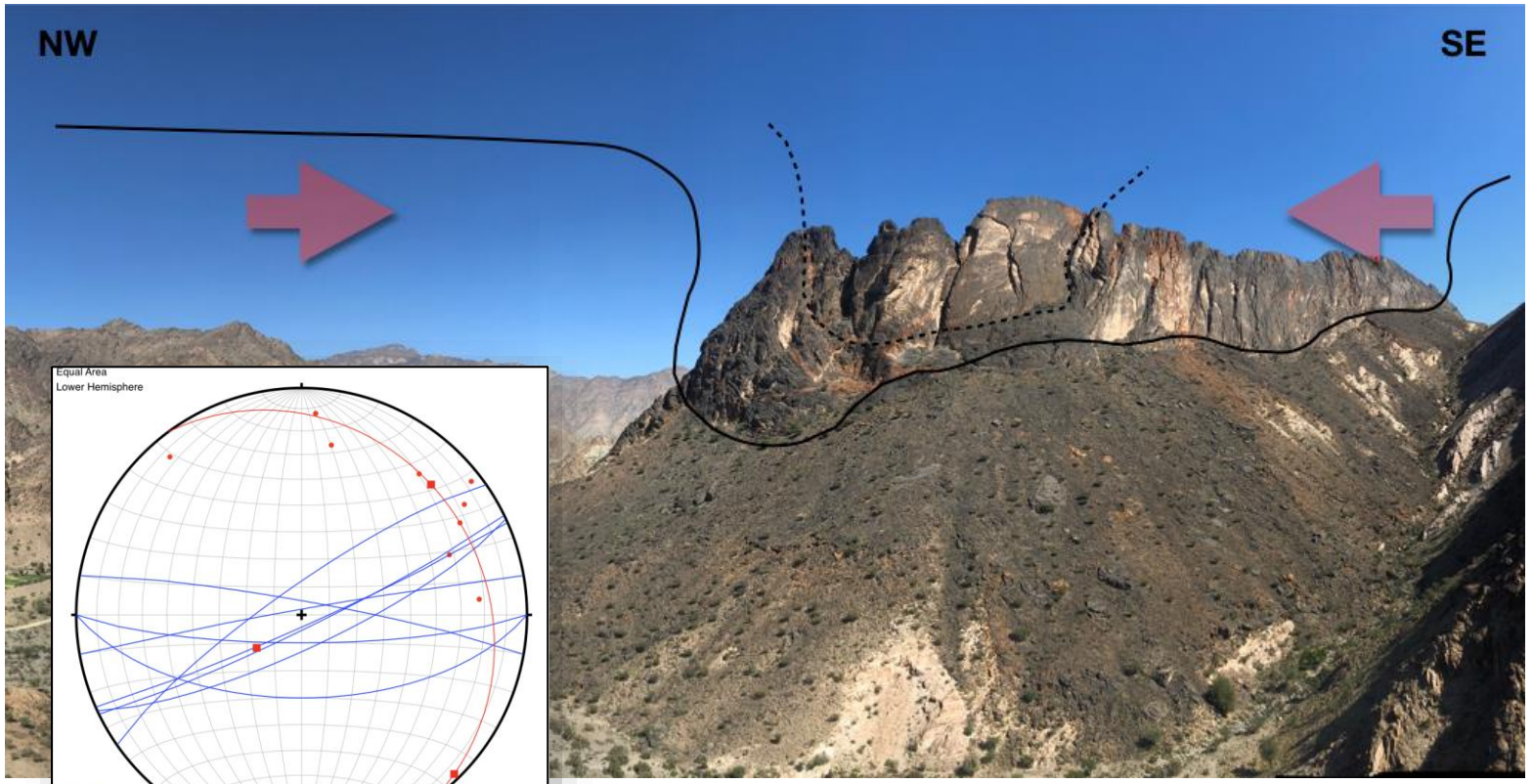


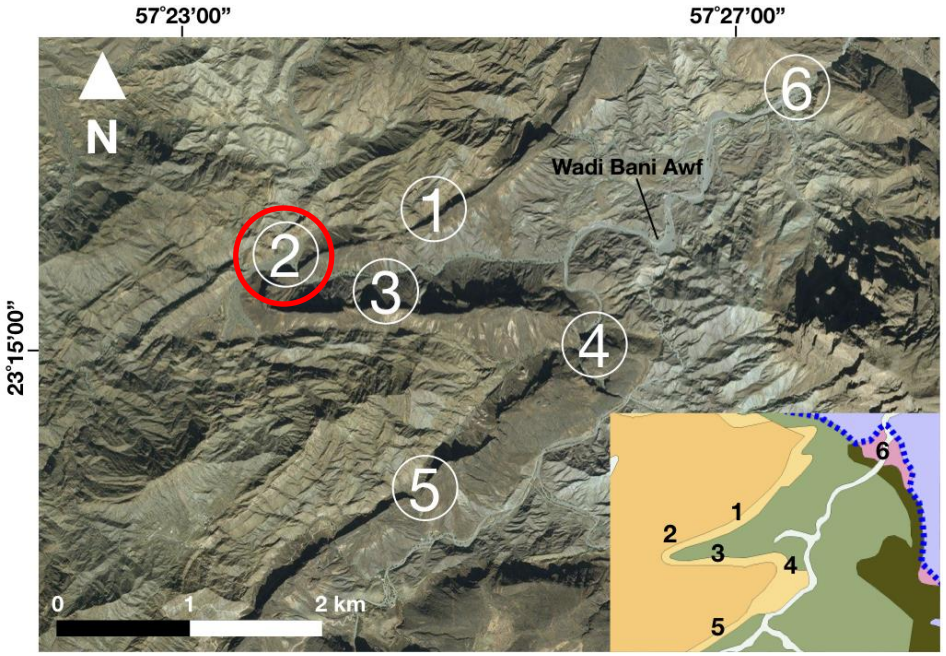




Field investigation and results

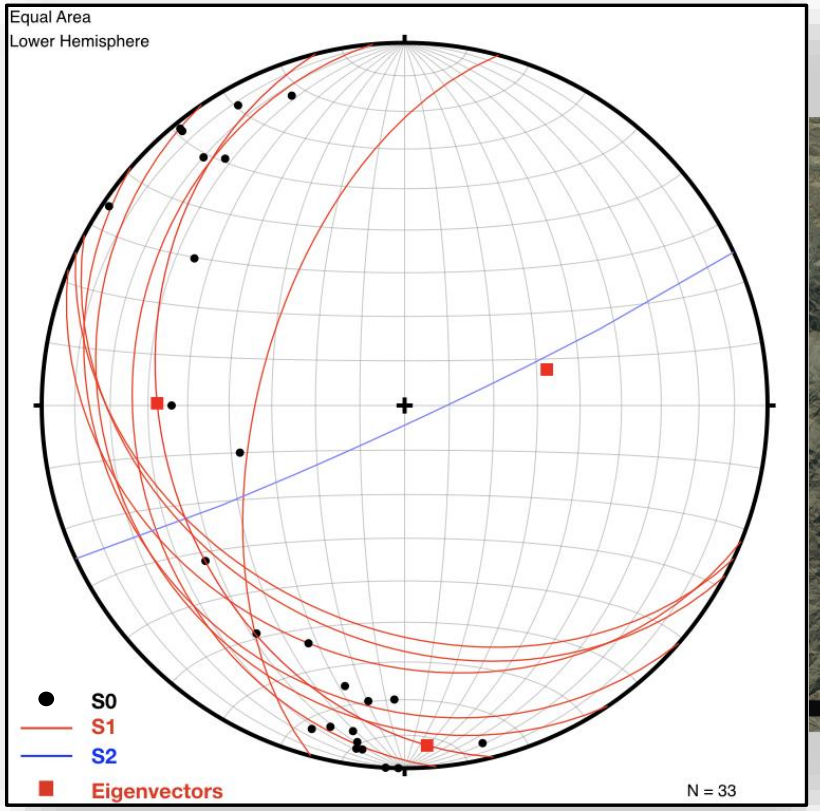
Sector 2

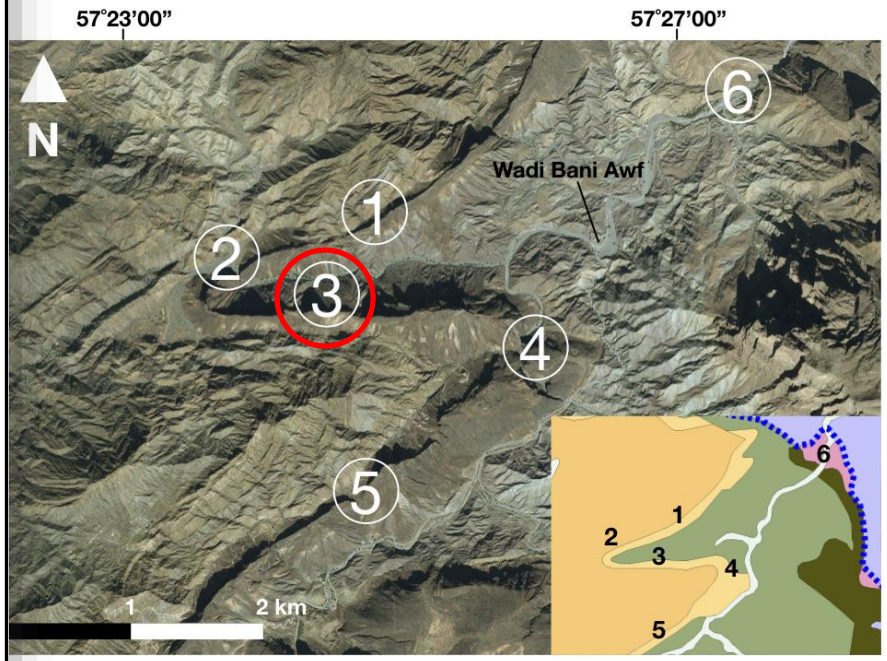




Field investigation and results

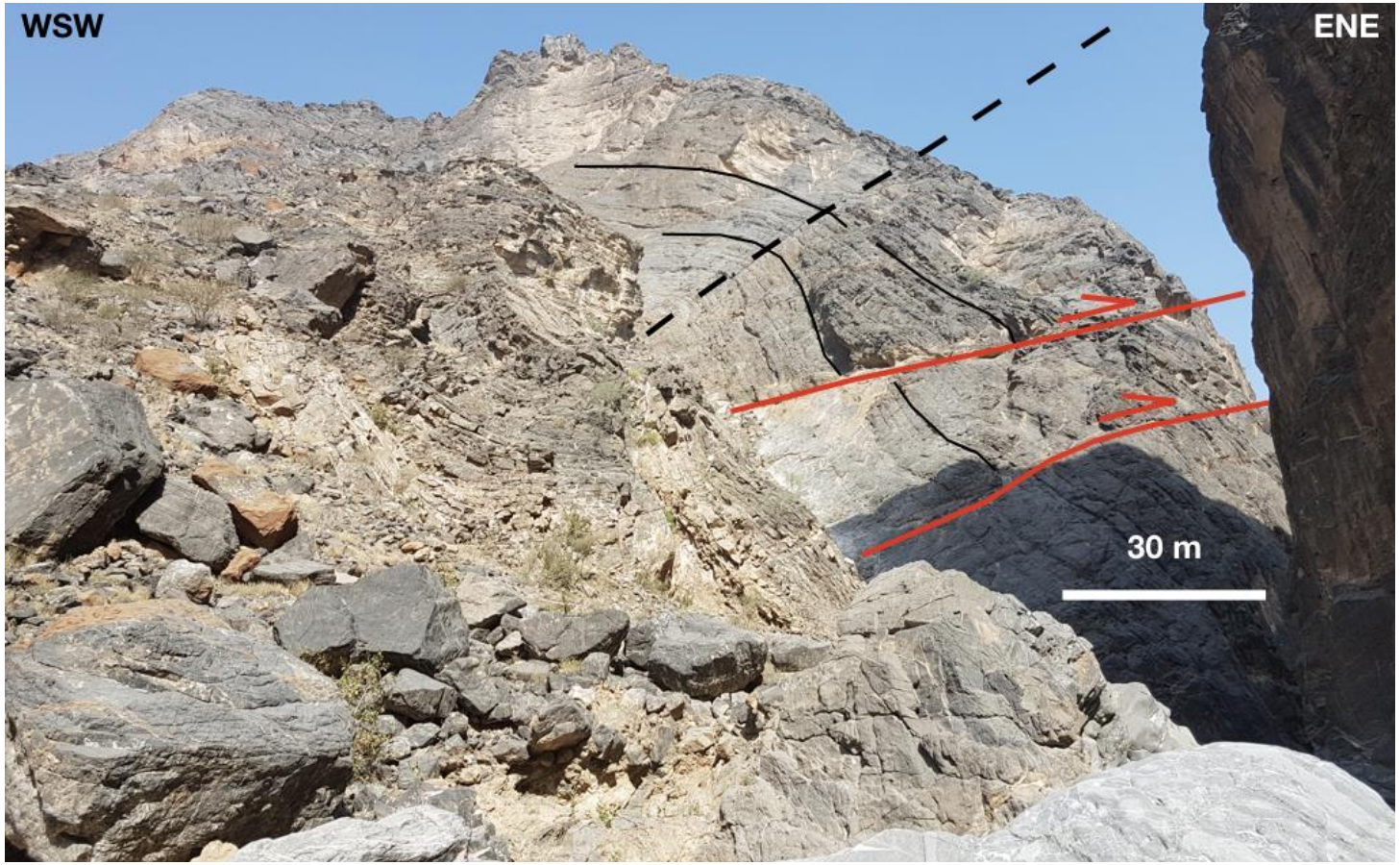
Sector 3

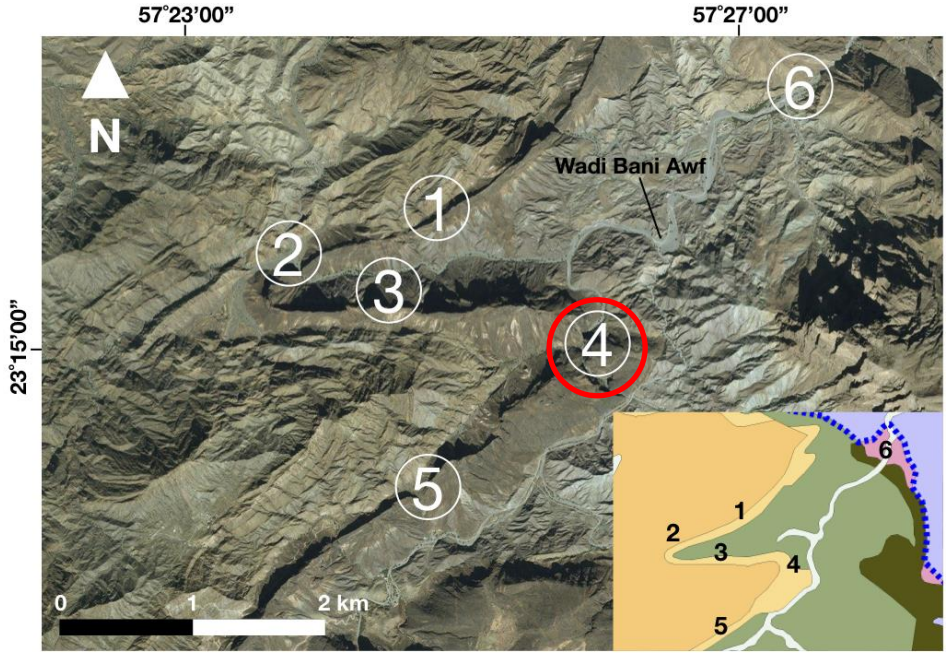




Field investigation and results

Sector 4





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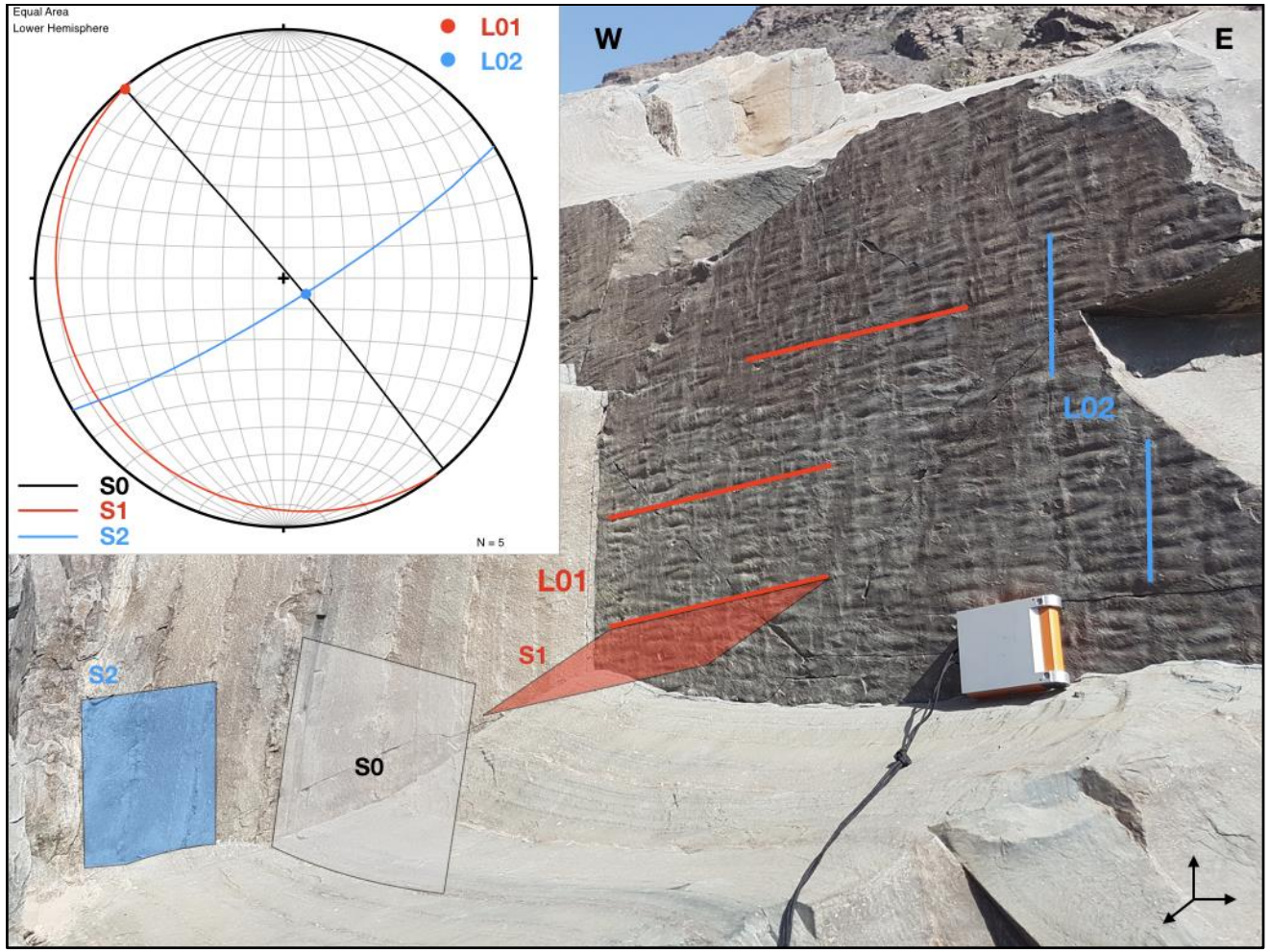
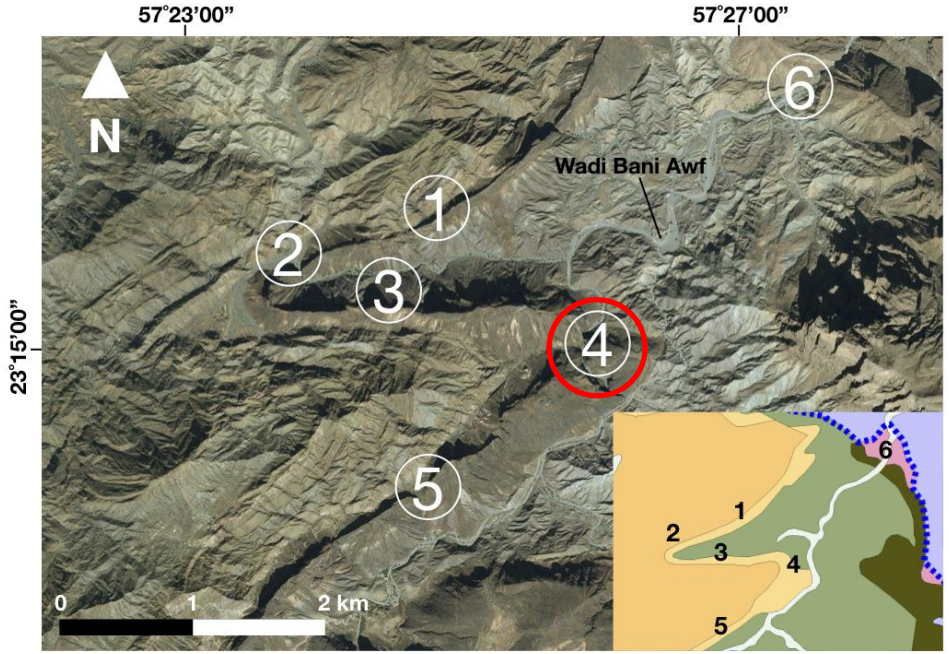
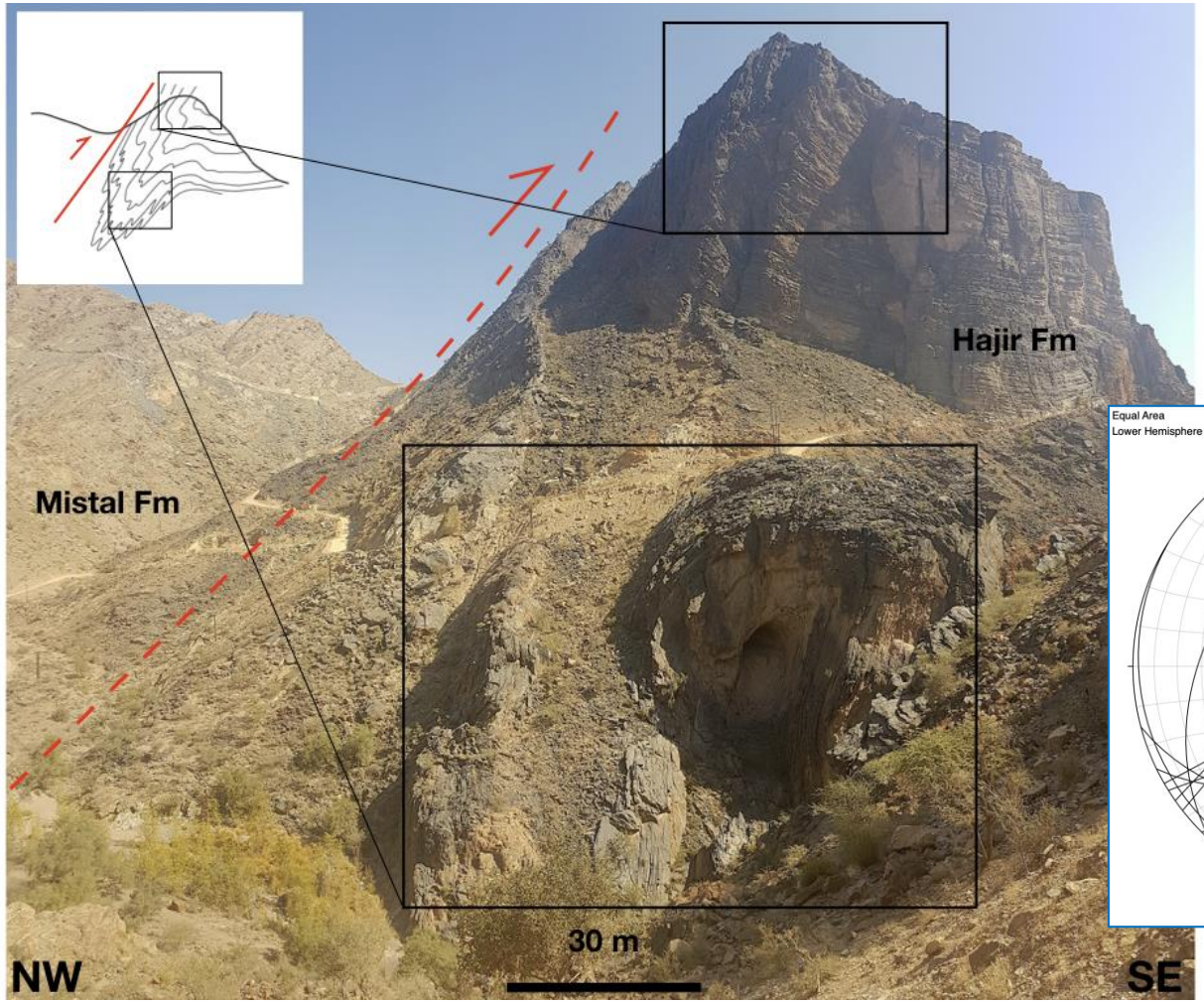
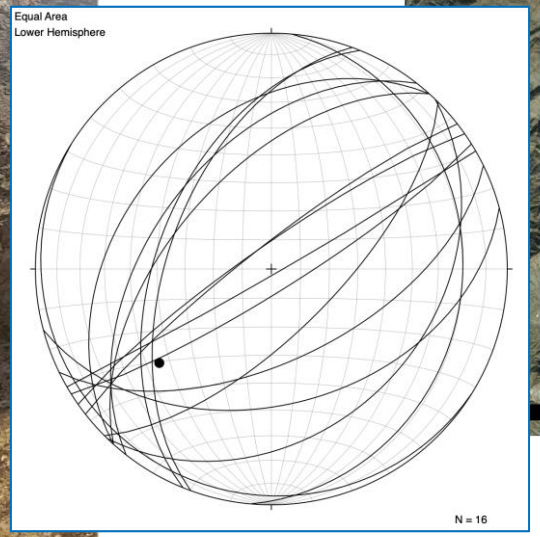


Sector 4

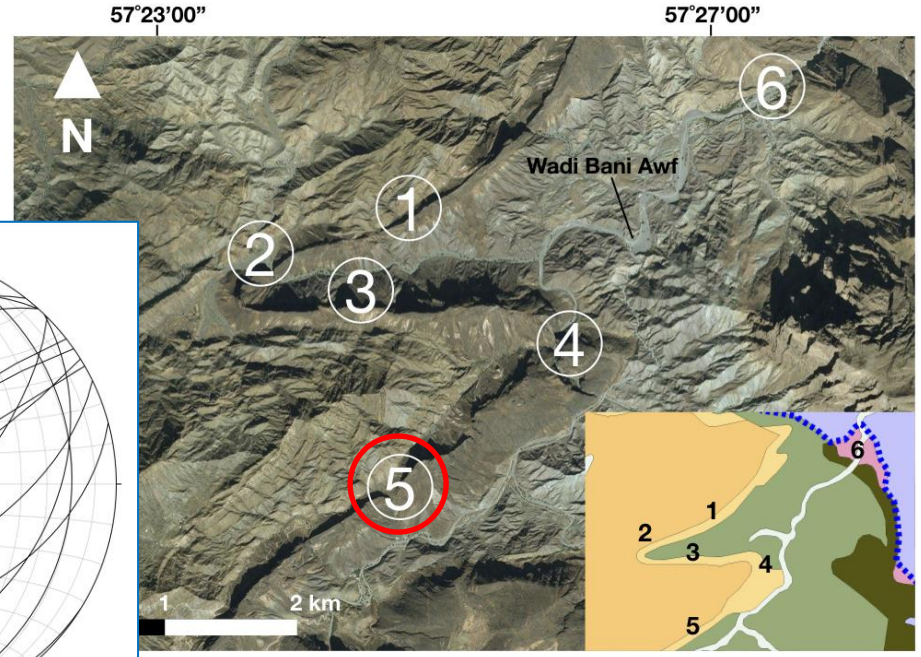


Field investigation and results



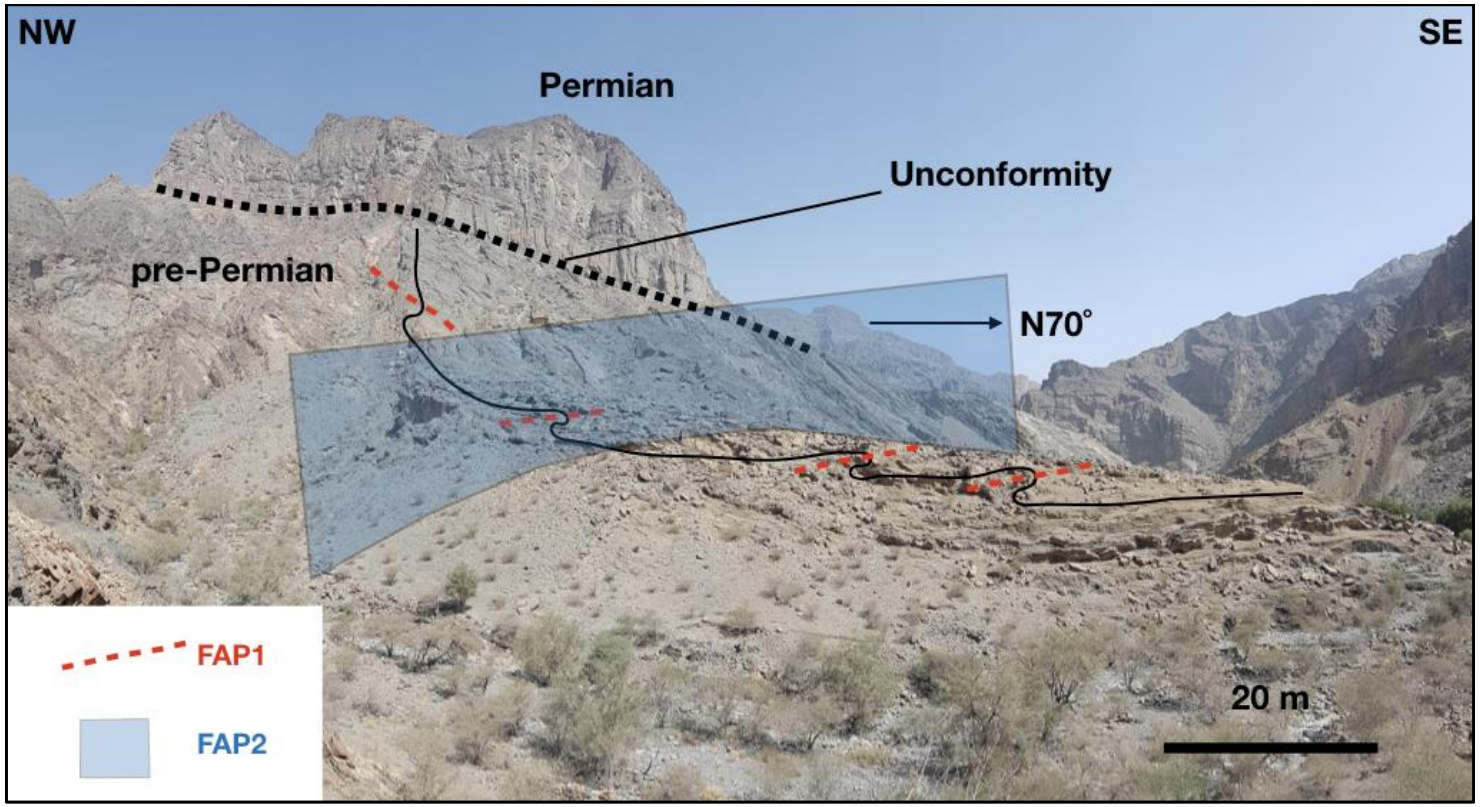


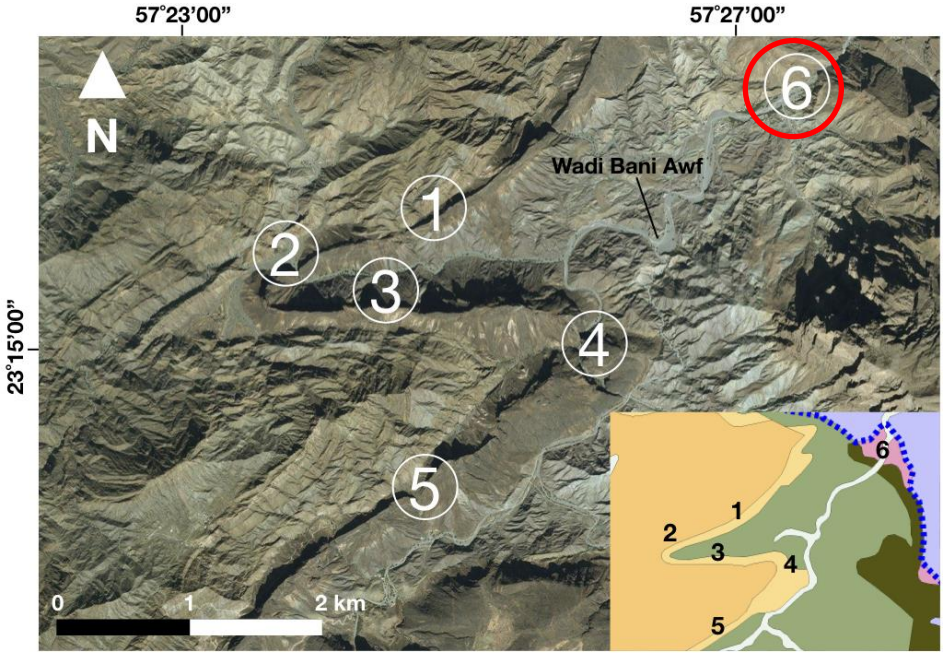
Sector 5

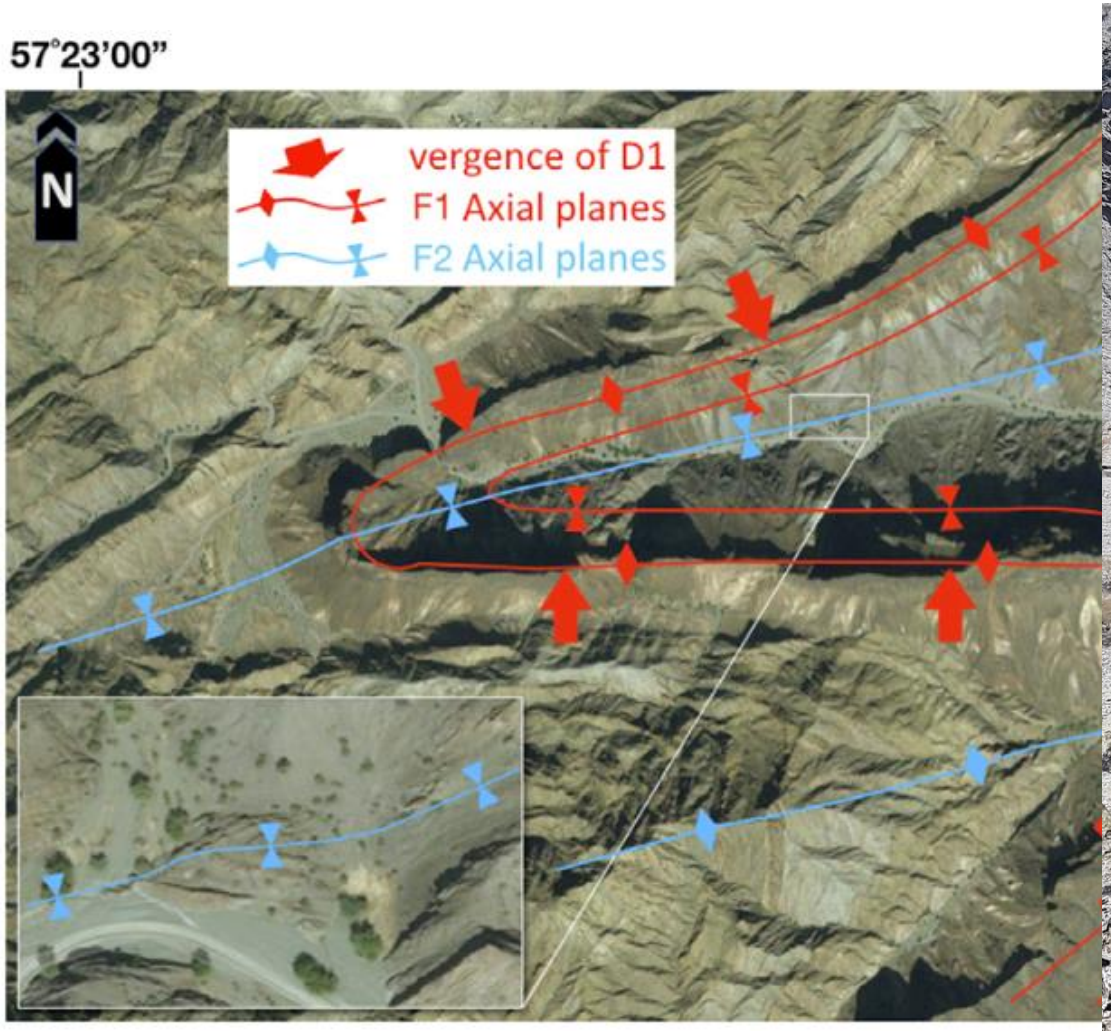


Field investigation and results

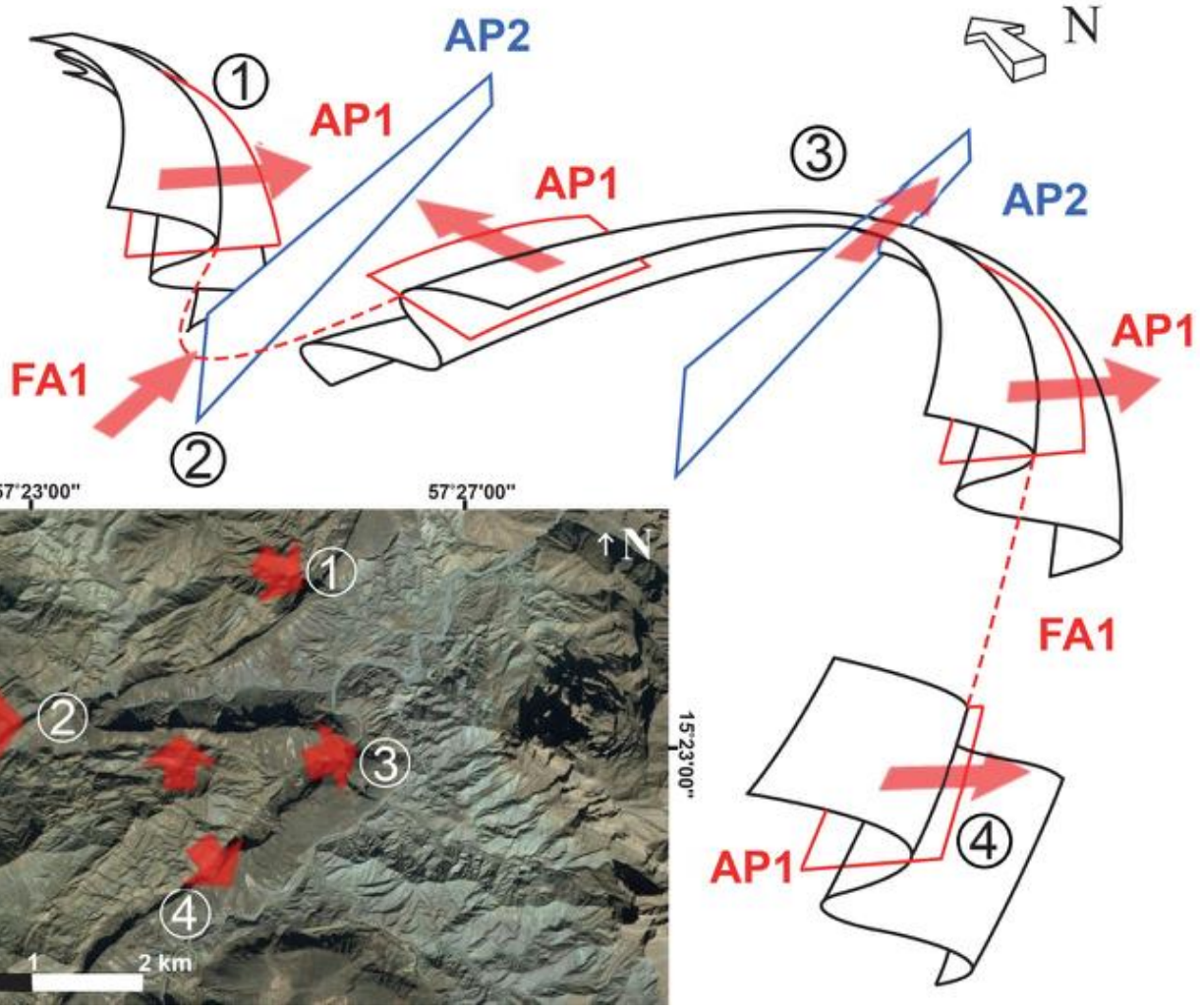
Sector 6


NW
SE
Permian
Unconformity
pre-Permian
N70°
FAP1
FAP2
20 m

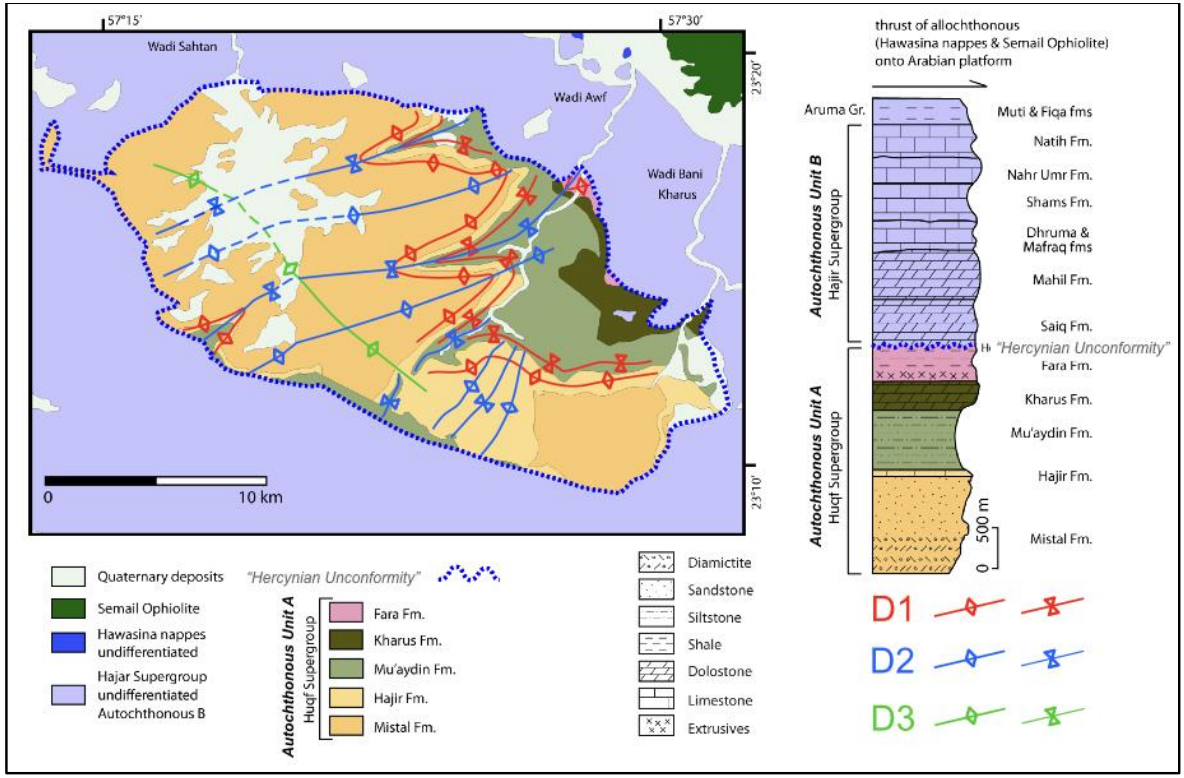

57°23'00"
57°27'00"
23°15'00"
N
Wadi Bani Awf
1
2
3
4
5
6
0
1
2 km



Discussion


AP2
AP1
AP1
AP2
AP1
FA1
FA1
AP1
N
①
②
③
④

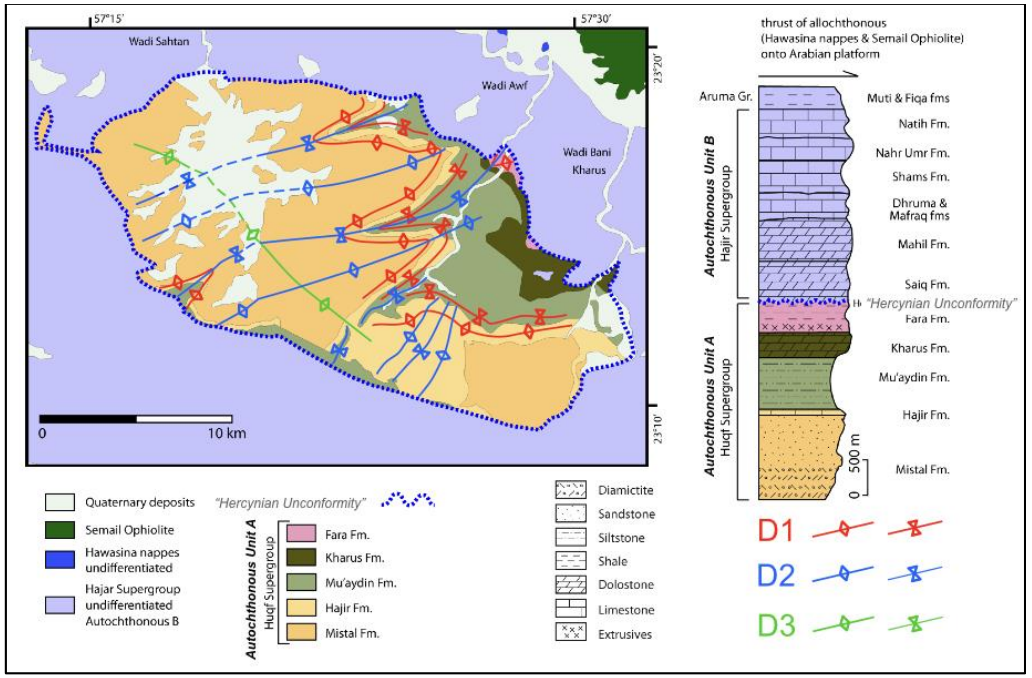
57°23'00"
57°27'00"
15°23'00"
N
①
②
③
④
0
1
2 km


57°15'
57°30'
23°20'
23°10'
Wadi Sahtan
Wadi Awf
Wadi Bani Kharus
0
10 km
Quaternary deposits
Semail Ophiolite
Hawasina nappes undifferentiated
Hajar Supergroup undifferentiated Autochthonous B
"Hercynian Unconformity"
Autochthonous Unit A
Huqf Supergroup
Fara Fm.
Kharus Fm.
Mu'aydin Fm.
Hajir Fm.
Mistal Fm.
Diamictite
Sandstone
Siltstone
Shale
Dolostone
Limestone
Extrusives
thrust of allochthonous (Hawasina nappes & Semail Ophiolite) onto Arabian platform
Aruma Gr.
Muti & Fiqa fms
Natih Fm.
Nahr Umr Fm.
Shams Fm.
Dhruma & Mafraq fms
Mahil Fm.
Saiq Fm.
Autochthonous Unit B
Hajir Supergroup
"Hercynian Unconformity"
Fara Fm.
Kharus Fm.
Mu'aydin Fm.
Hajir Fm.
Autochthonous Unit A
Huqf Supergroup
0
500 m
Mistal Fm.
D1
D2
D3

Discussion

Regional and temporal implications

- Deposition of the Fara Formation lasted until ~542 Ma (Bowring et al., 2007).
- Angudan event dates as 525 ±5 Ma (Al-Husseini, 2014). This major act of deformation is evidenced by NW-SE contraction (Droste, 2014) to which we assign the D2 event.
- The NE/SW-directed event (D1) firstly affected northeastern Oman at some time between ~542 Ma and 525 ±5 Ma.



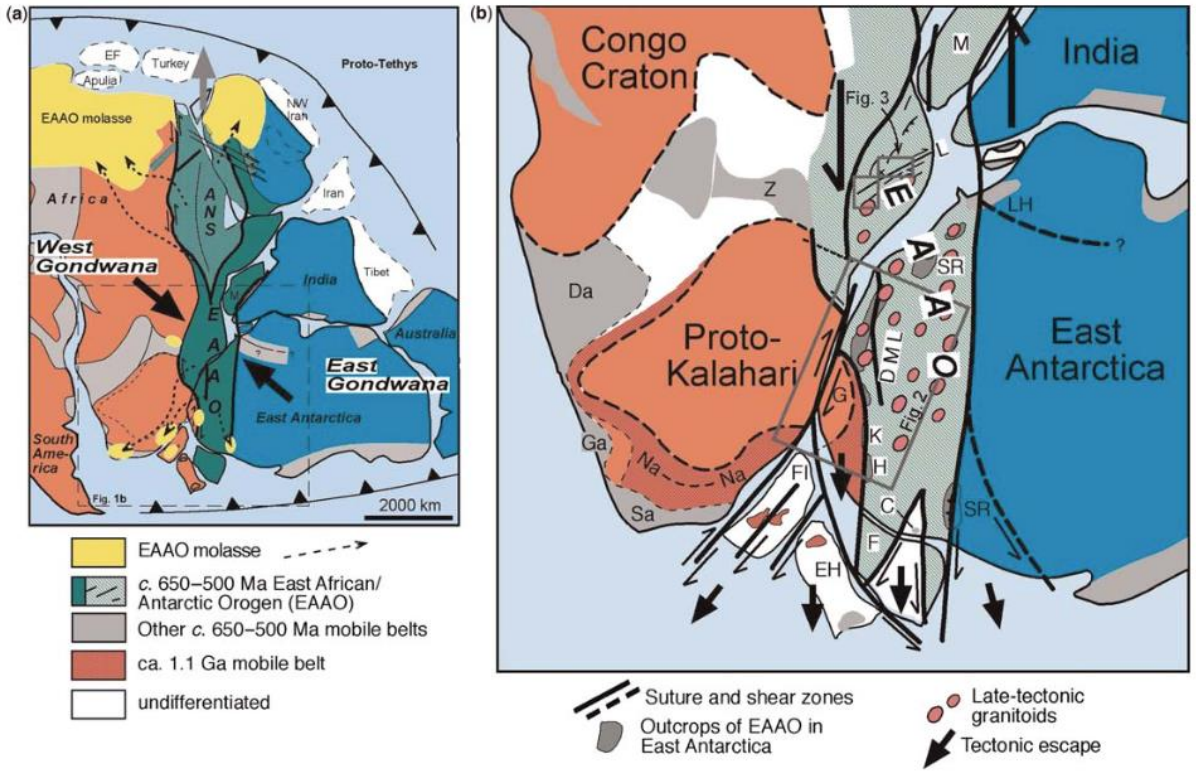
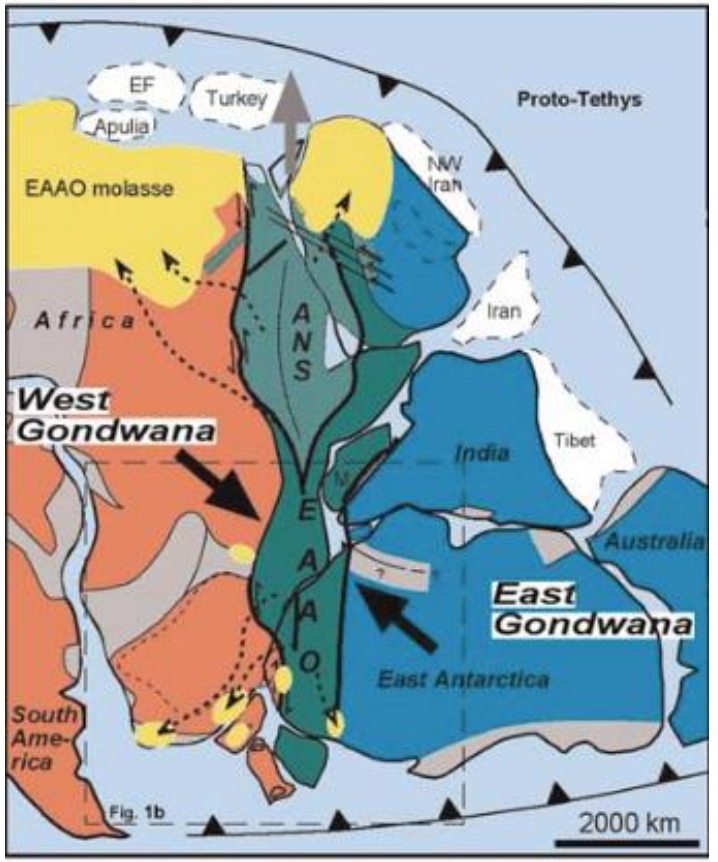
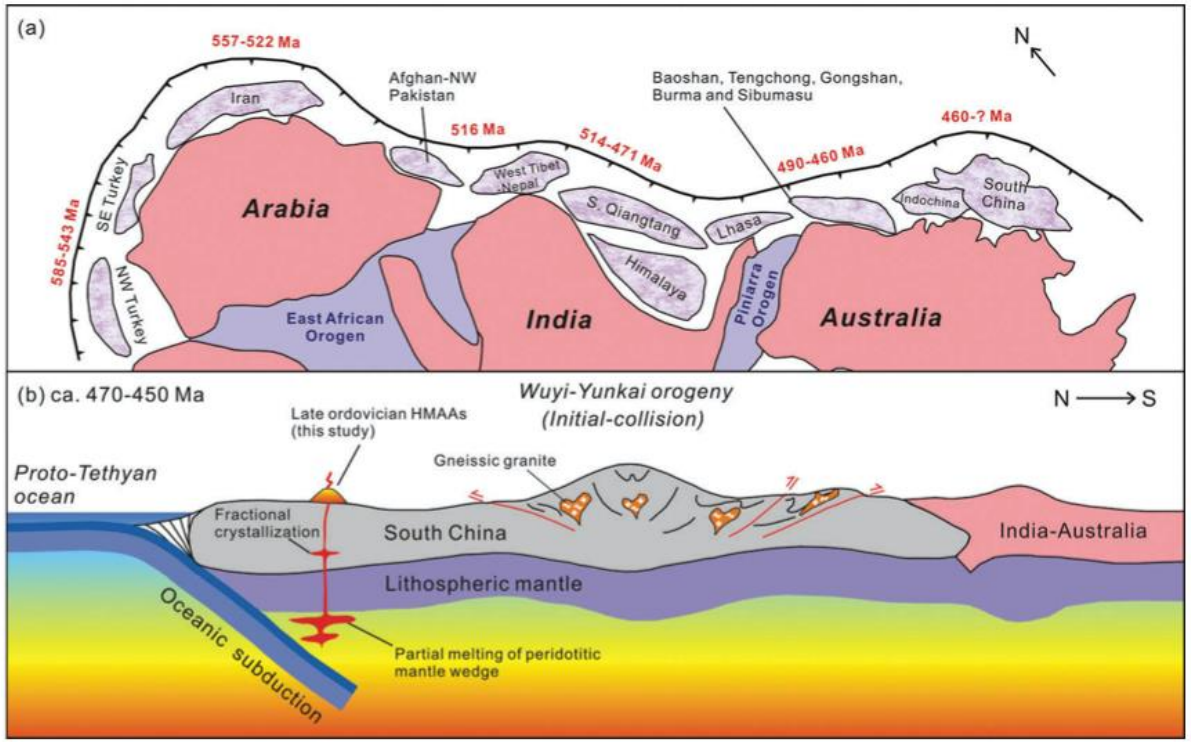


Fig. 1. (**a**) Geological setting of the East African–Antarctic Orogen (EAAO) after Jacobs & Thomas (2004). (**b**) The southern part of the EAAO affected by lateral extrusion and widespread intrusion of late-tectonic granitoids. The latter are largely confined to the EAAO and effectively terminate along the Lurio Belt in northern Mozambique. ANS, Arabian–Nubian Shield; C, Coats Land; DML, Dronning Maud Land; EH, Ellsworth–Haag; F, Filchner block; FI, Falkland Islands; G, Grunehogna; Ga, Gariep Belt; H, Heimefrontfjella; K, Kirwanveggen; L, Lurio Belt; Na---Na, Namaqua–Natal; SR, Shackleton Range; Da, Damara Belt; LH, Lützow-Holm Bay; M, Madagascar; Sa, Saldania Belt; Z, Zambezi Belt.



Jacobs, J., Bingen, B., Thomas, R.J., Bauer, W., Wingate, M.T., Feitio, P., 2008. Early Palaeozoic orogenic collapse and voluminous late-tectonic magmatism in Dronning Maud Land and Mozambique: insights into the partially delaminated orogenic root of the East African–Antarctic Orogen? Geological Society, London, Special Publications 308, 69–90.

Regional and temporal implications



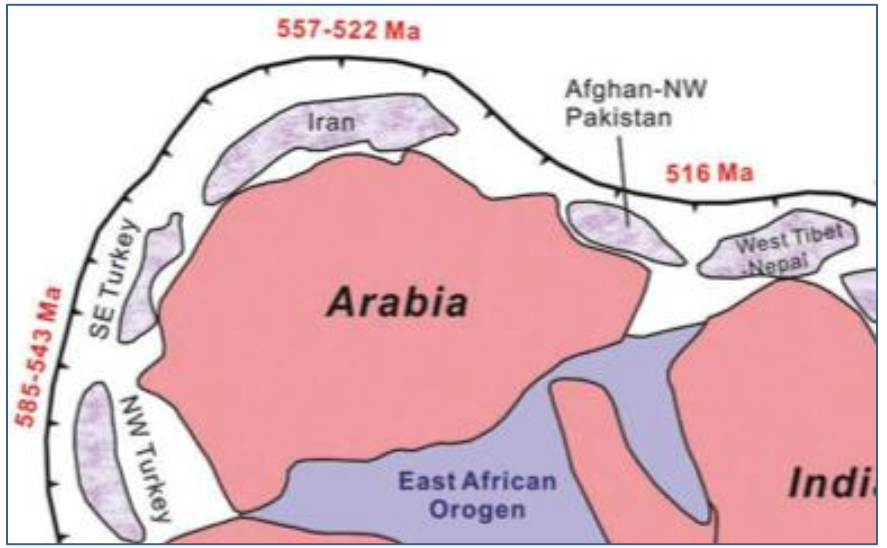
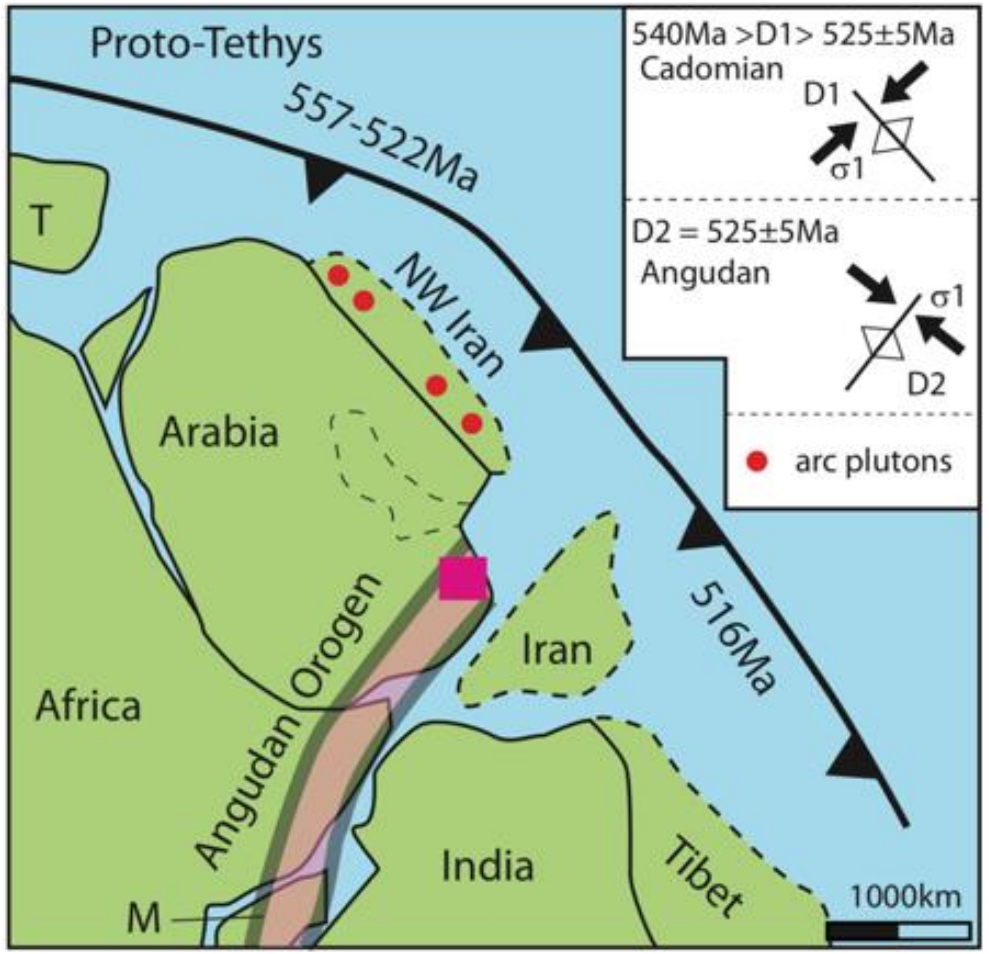


Figure 10. (a) Reconstruction of Gondwana showing the Late Neoproterozoic–Early Palaeozoic Andean-type orogeny along the proto-Tethyan margin (modified from Hu *et al*. 2015; Gürsu 2016). (b) Schematic diagrams illustrating the tectonic evolution of the SCB in the Late Ordovician and the petrogenesis of Shimian andesites.

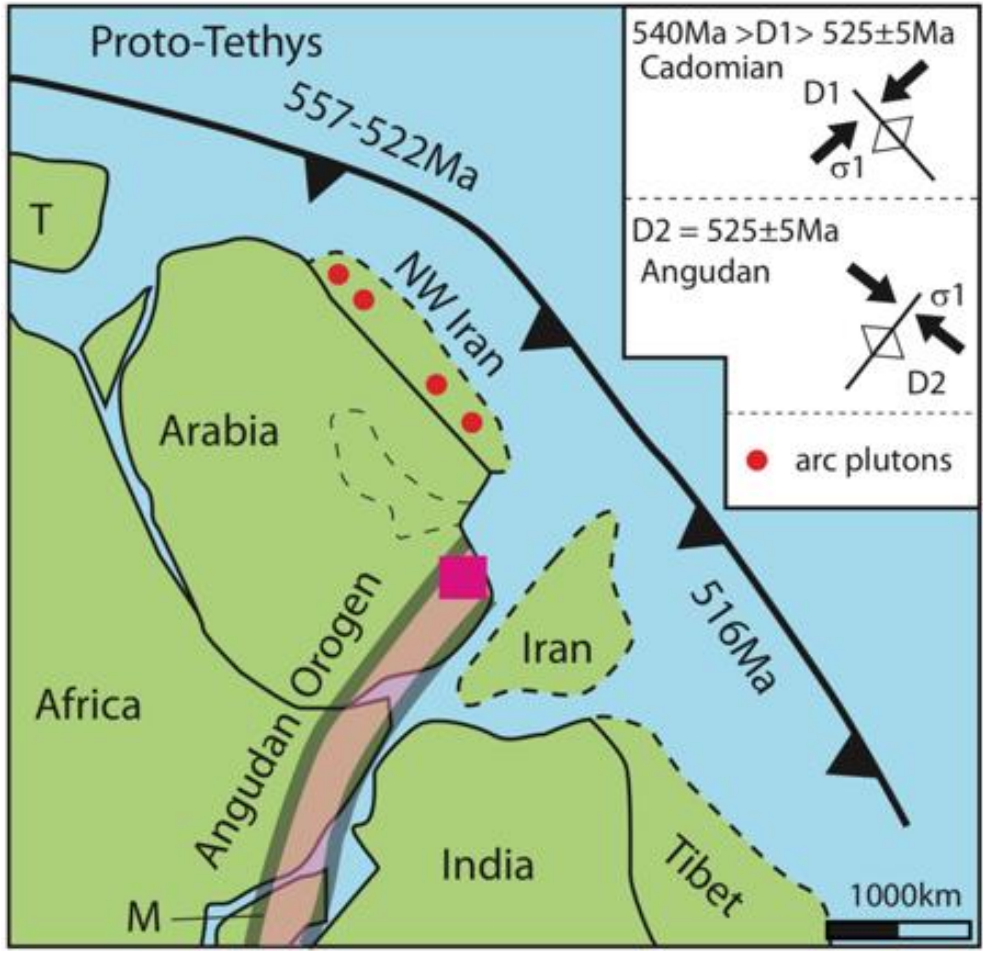
Hu, P., Zhai, Q., Ren, G., Wang, J., Tang, Y., 2018. Late Ordovician high-Mg adakitic andesite in the western South China block: evidence of oceanic subduction. International Geology Review 60, 1140–1154.

- D1 event is a result of the convergence between a microcontinent with Arabia (Jacobs et al., 2008).
- Consumption of Proto-Tethys oceanic lithosphere beneath those microcontinents and Arabia (see Jacobs et al., 2008; Hu et al., 2017).
- The direction of convergence for both scenarios was NE-SW (in present coordinates; e.g., Jacobs et al., 2008), which resulted in the formation of the NW/SE-oriented F1 folds.
- Deposition of the Fara Formation lasted until ~542 Ma (Bowring et al., 2007) and the Angudan event dates as 525 ±5 Ma (Al-Husseini, 2014).
- Major deformation is evidenced by NW-SE contraction (Droste, 2014) to which we assign the D2 event. Therefore, the NE/SW-directed event (D1) firstly affected northeastern Oman at some time between ~542 Ma and 525 ±5 Ma.



Regional and temporal implications

- Occurrences of calc-alkaline magmatism and the associated continental arc setting at the Ediacaran-Cambrian transition (~572 to 528 Ma) have been reported for neighboring Iranian terranes (e.g., Rosetti et al., 2015; Moghadam et al., 2017 and references therein). This tectonic environment is contextual with the Cadomian Orogeny (e.g., Rosetti et al., 2015).
- We relate the D1 NE/SW-directed compressional event, forming the NW/SE-oriented F1 folds which affected northeastern Oman between ~542 and 525 ±5 Ma, to the Cadomian Orogeny. Consequently, the shallow dip and the NW-directed vergence of F1 fold axial planes were acquired in the course of a fold-and-thrust-belt formation during the Cadomian Orogeny.



Regional and temporal implications

Conclusion

- First time relation of two-fold structures within the western part of the Jabal Akhdar Dome to the early Paleozoic.
- F1 folds involves amplitudes of several meters, sub-horizontal fold axes and shallow-dipping fold axial planes, which formed during NE/SW-directed compression.
- D1 structures, fold-and-thrust-belt which formed during the Cadomian event, postdating the deposition of Fara Formation (~542 Ma) and predating the Angudan Orogeny (525 ±5 Ma). The Cadomian deformation is for the first time identified in Oman.
- F1 folds are deformed by large-scale (several kilometers in amplitude) F2 folds. These folds developed ~WSW/ESE-striking sub-vertical axial planes with gently plunging fold axes towards the NE. The fold axes of the F1 folds are parallel to the limbs of the F2 folds.
- The F2 folds formed during the NW/SE-oriented Angudan event.
- We rule out effects of the “Hercynian Orogeny” for the F2 folds because of the significant distance between our study area and the Hercynian collision zone during the Late Paleozoic. The Hercynian event in eastern Arabia was a thermal effect without significant folding.

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Structural Styles of Precambrian, Paleozoic, Mesozoic and Cenozoic Deformation - A Transect Through the Jabal Akhdar Dome

Field Trip Leader: Andreas Scharf, Sultan Qaboos University (SQU)

Date: 12th December

Time: 7.30am – 7pm

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Gondwana accretion tectonics and implications for the geodynamic evolution of eastern Arabia: First structural evidence of the existence of the Cadomian Orogen in Oman (Jabal Akhdar Dome, Central Oman Mountains)

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…in memory of my best friend and extraordinary geologist Giovanni Massa……

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