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Geochemical and age data on the Bajgan Complex metaophiolites (Makran Accretionary Prism, SE Iran): New evidence for their magmatic formation in a Cretaceous oceanic domain

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2- Why to investigate the Bajgan Complex

3- Field evidence and a few words on matamorphism and metamorphic evolution

4- Geochemistry, age and petrogenesis of the magmatic protoliths

5- Regional comparisons and conclusions

Part 1

1- Introduction: Previous studies and our investigations, the Geology of Makran, and the importance of the Bajgan Complex

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Previous works

After the pioneering works of McCall, Samimi-Namin, Eftekhar-Nezhad, Desmons, Platt, & co-workers in the 1980s, in the last two decades, increasing extensive research has been carried out in the Makran.

Among others:

Kopp et al., 2000;
Kananian et al. 2001;
Ghazi et al., 2004;
Engdahl et al., 2006;
Grando and McClay, 2007;
Burg et al., 2008, 2013;
Dolati, 2010;
Dolati and Burg, 2013;
Hunziker, 2014;
Hunziker et al., 2015, 2017;
Moslempour et al., 2015;
Delavari et al., 2016;
Mohammadi et al., 2016, 2017;
Dorani et al., 2017;
Entezar-Saadat et al., 2017;
Saccani et al., 2018;
Burg, 2018;
Penney et al., 2017;
Esmaeili et al., 2020a, 2020b, 2121;
Barbero et al., 2020a, b, 2021a, b;
Barbero, 2021;
Monsef et al., 2019;
Pandolfi et al., 2021
Sepidbar et al., 2020
Motaghi et al., 2020
…. and others…*

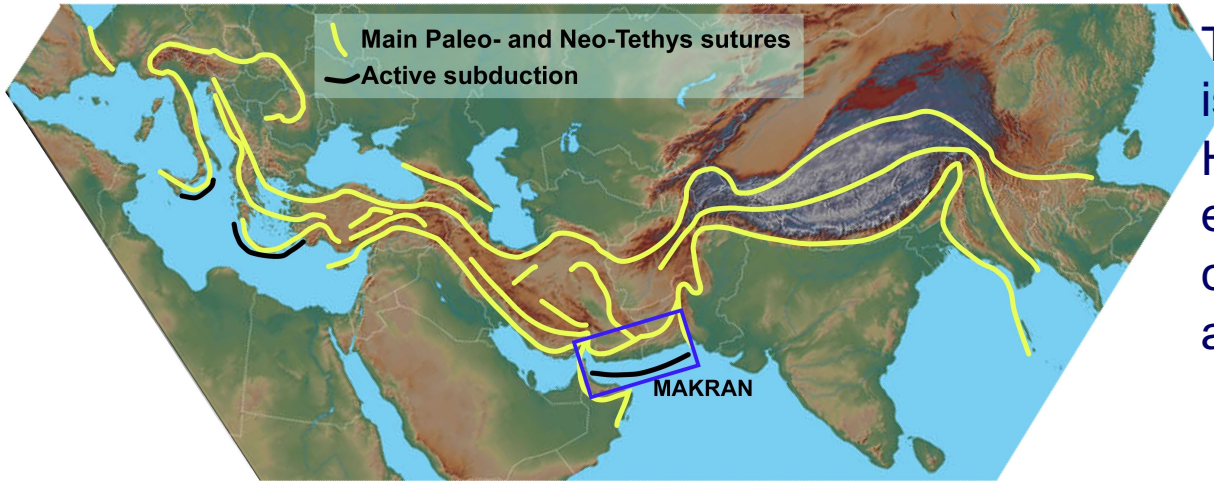
(*sorry if I forgot some contributions…)

Our investigations

Our research team made a massive work in the North Makran area. This presentation is only a little part of this work.

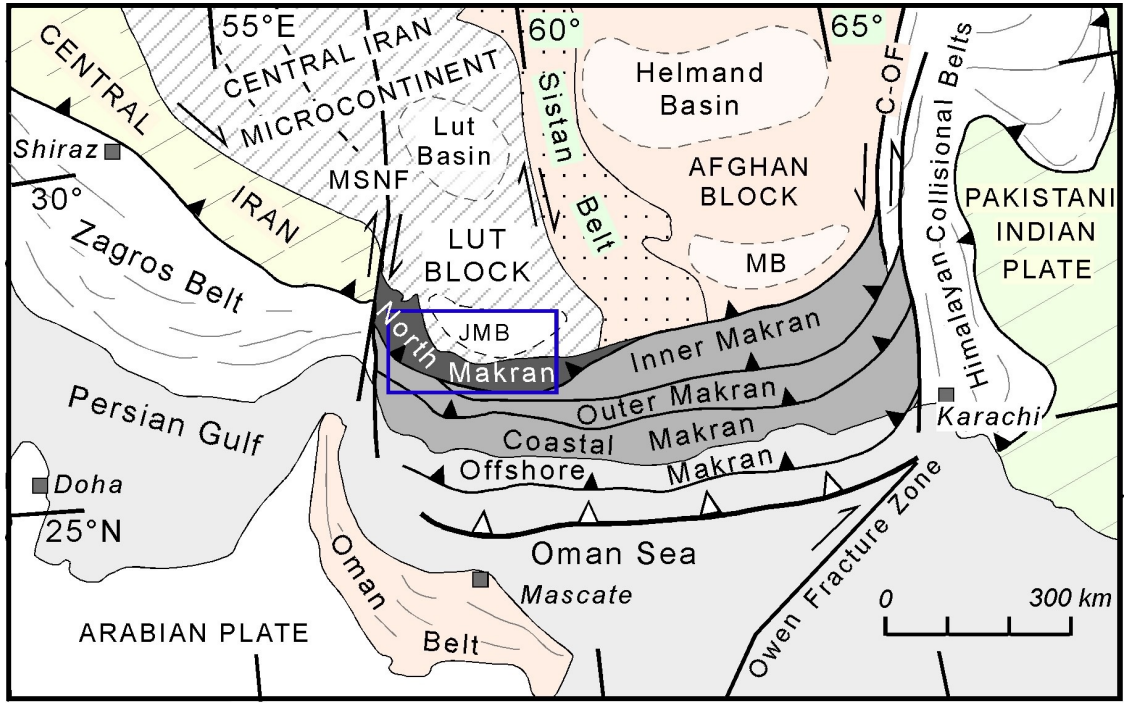
- Several field trips from 2016 to 2020
- More than 1000 samples collected and analysed for many purposes
- About 20 researchers from different Institutions and differet skills involved:
  - A. Dolati, M. Delavari, L. Vahedi (Kharazmi University, Iran)
  - M. Marroni, L. Pandolfi, M. Di Rosa, C. Frassi (Pisa University, Italy)
  - R. Catanzariti, M. Chiari, A. Langone (NRC, Pisa, Florence, Pavia, Italy)
  - E. Saccani, E. Barbero, V. Luciani (Ferrara University, Italy)
  - F. Zaccarini (Montan University, Leoben, Austria)
  - S. Gorican (Slovenia); S. Bybee (Southafrica); and others…

The Makran geology

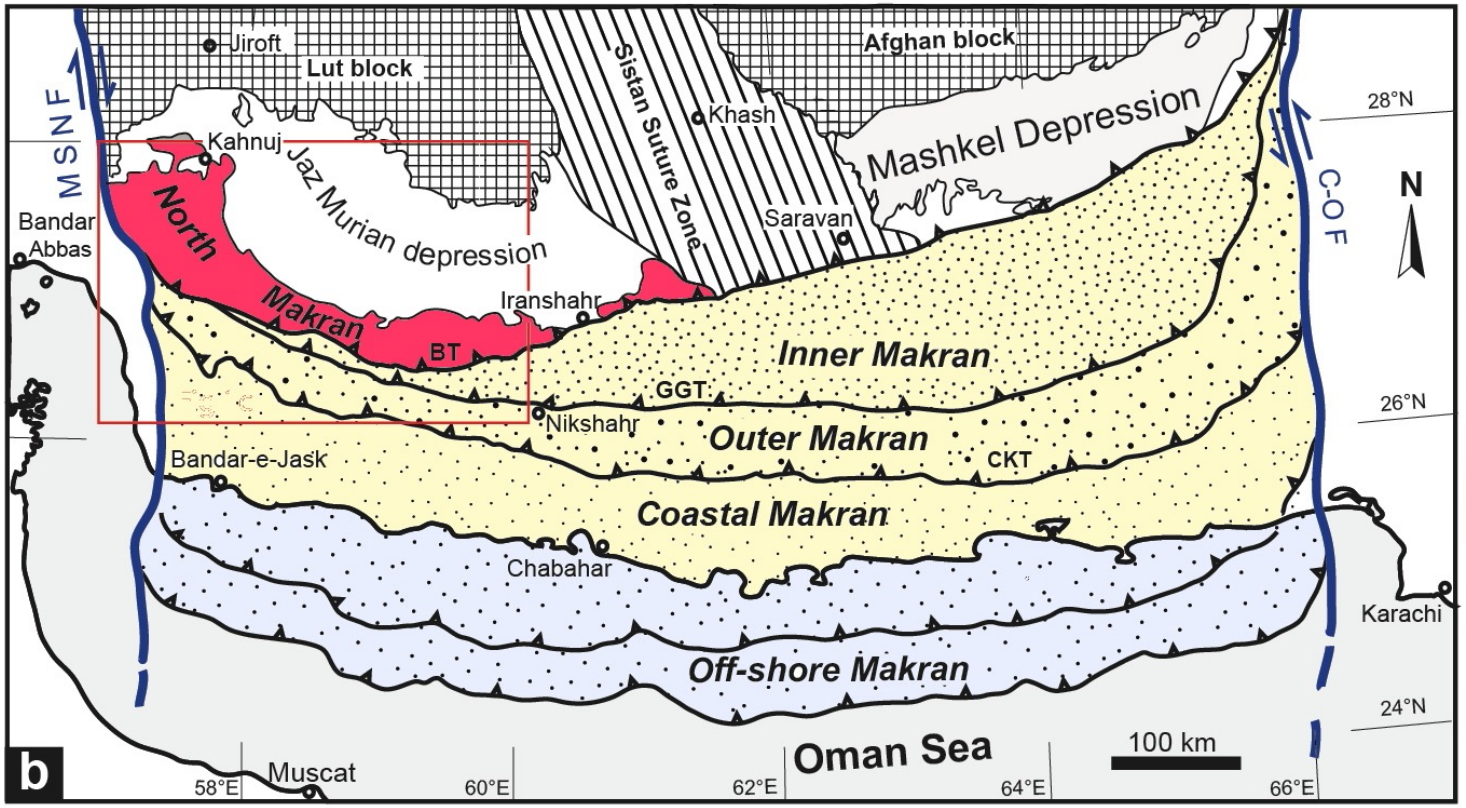


The Makran Accretionary Prism is the only sector of the Alpine-Himalayan belts, which did not experienced continental collision and subduction is still active.

The Makran Accretionary Prism represents the link between the Zagros and the Himalayan Collisional belts

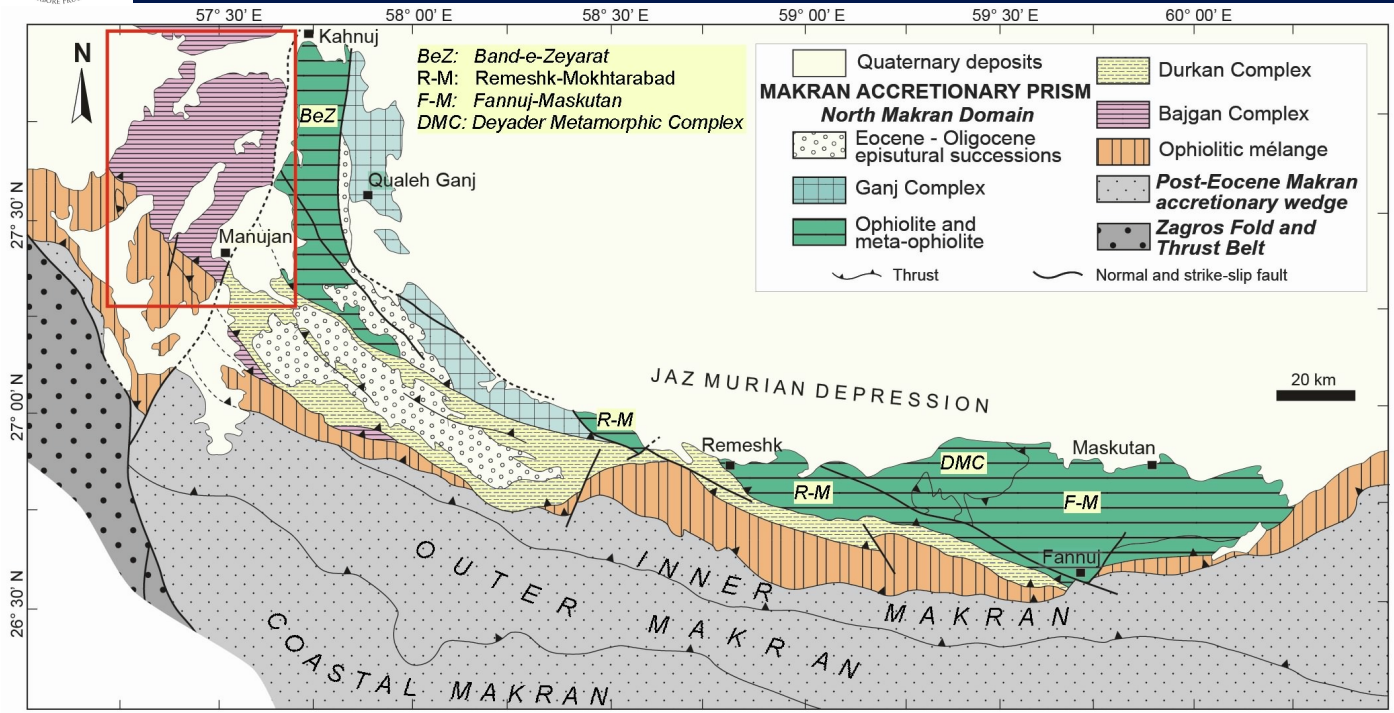


The Makran geology

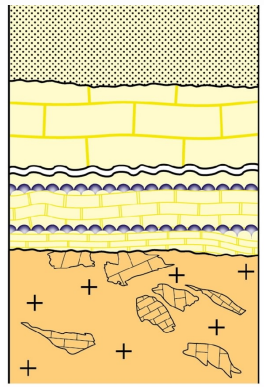


The formation of the Makran Accretionary prism started in the Cretaceous (North Makran), continued throughout Cenozoic (Inner, Outer, and Coastal Makran), and it is still active (Offshore Makran).

The classic view of the North Makran geology



The North Makran consists of several tectonic units:



Bajgan-Durkan continental basement-platform pair

(from: Burg, 2018, Earth Sci. Rev.)

TOP

BOTTOM

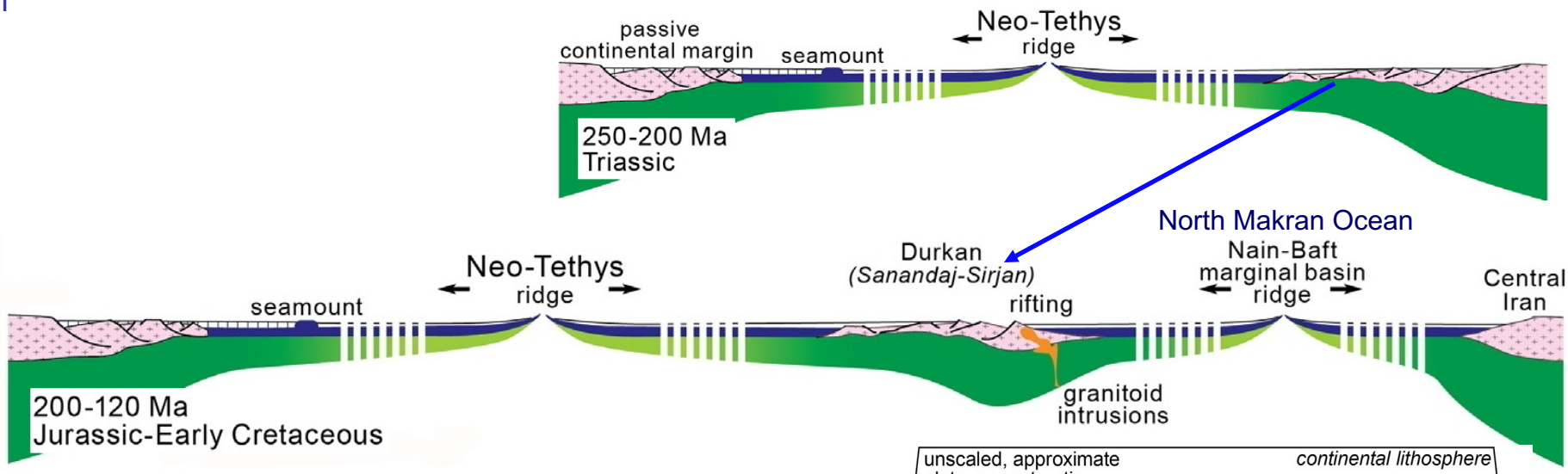
Episutural successions

Ganj Complex	Volcanic arc
Ophiolites	Oceanic domain
Durkan	Continental platform
Bajgan	Continental basement
Sorkh Band	Intra-oceanic arc
Coloured Mélange	Trench tectonic mélange

------ Bashakerd Thrust -----

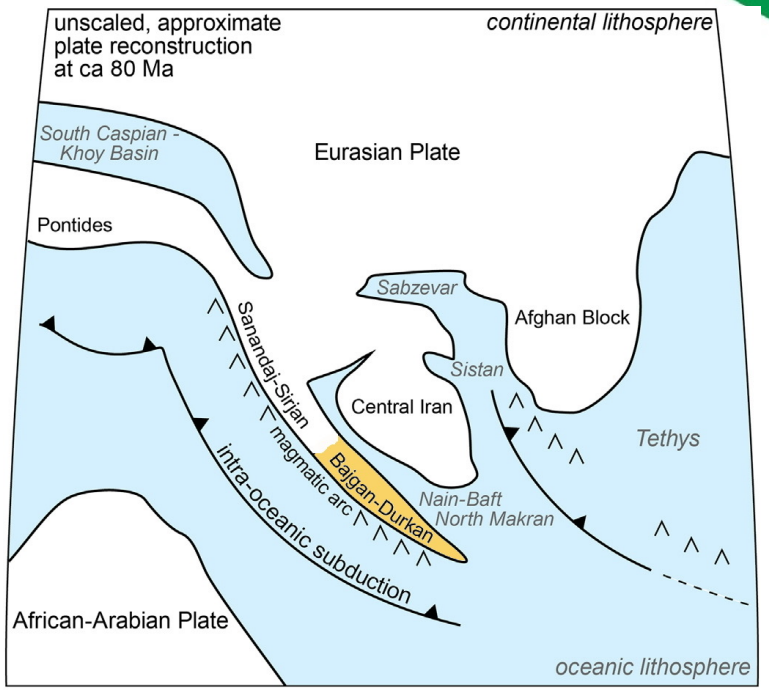
Post-Eocene Accretionary Wedge

Classic geodynamic interpretation of the North Makran



The geodynamic reconstructions, from the 1980s to now, of the Makran area have been strongly influenced by the interpretation of the Bajgan-Durkan pair as fragments of a continental domain

(e.g., McCall & Kidd, 1982; Burg, 2018).



(from: Burg, 2018, Earth Sci. Rev.)

Part 2

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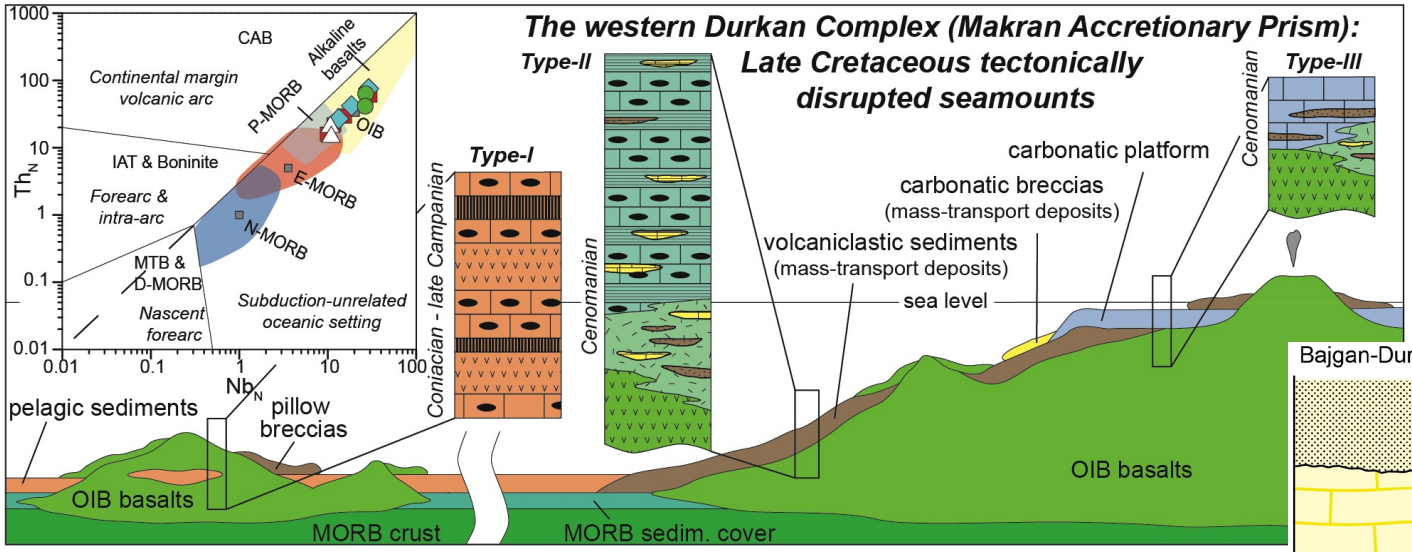
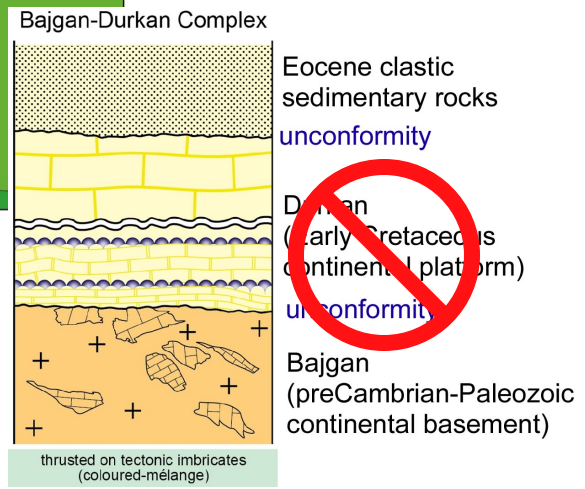
New evidence from the Durkan Complex



Barbero et al. (2021) Goscience Frontiers

Barbero et al. (2021) Lithos

Barbero et al. (2021) Tectonophics, in progress



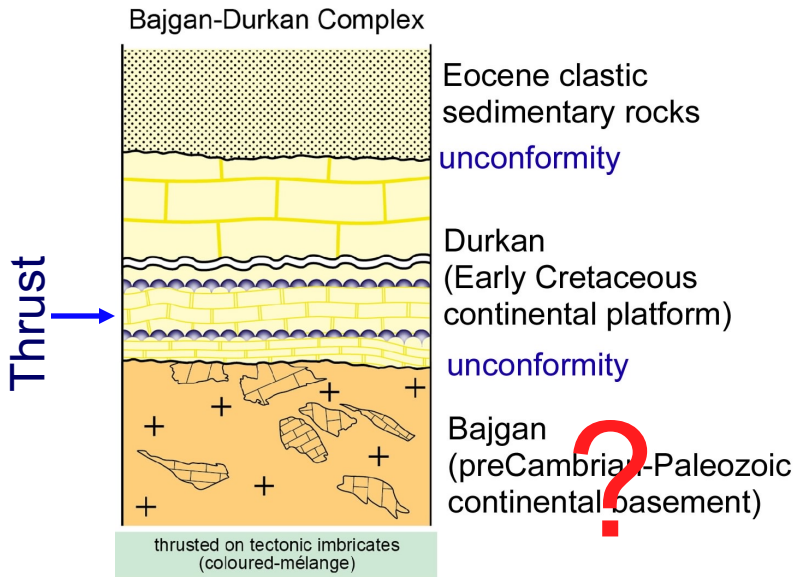
Basalt geochemistry (alkaline ocean island basalts)
Detailed stratigraphic reconstructions
Radiolarian, foraminifera, and nannofossil datings
Foraminifera paleo-ecology
Volcanic rock textures
Tectonic evidence, etc… etc…
Show that:
The Durkan Complex consists of tectonic slices representing successions formed in distinct parts of two or more Late Cretaceous seamounts

The question is:
If Durkan is not the continental platform of the Bajgan continental block, are we sure that the Bajgan itself is really a continental block?

New field evidence from the Bajgan Complex

Preliminary field investigation allowed us to identify tectonic slices representing metamorphosed ophiolitic sequences.

The same observations were already made by H.S. Moghadam, R. Esmaeili and co-workers (possiby other researchers I don't know?)



The question is still the same:
If the Bajgan Complex includes metaophiolitic sequences, are we sure that it really represents a continental block?

This problem needed to be investigated in detail. Age, geochemistry, and petrogenesis of the magmatic protoliths can tell us if this Complex formed in a continental or oceanic domain.

Part 3

1- Introduction: Previous studies and our investigations, the Geology of Makran, and the importance of the Bajgan Complex

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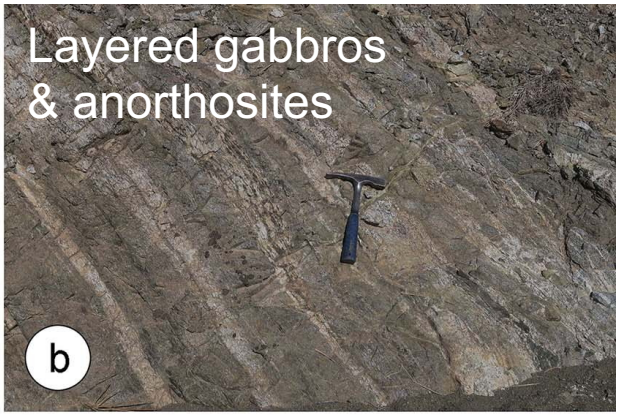
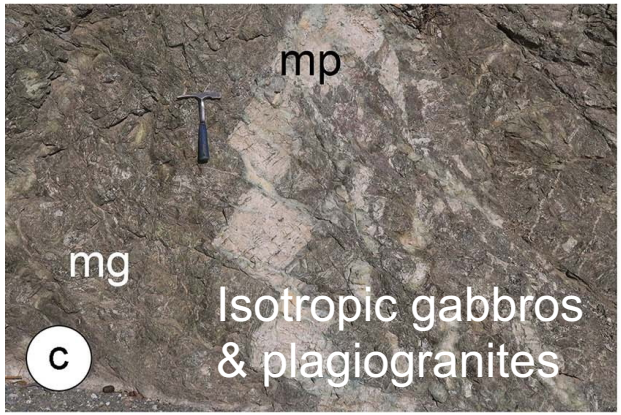
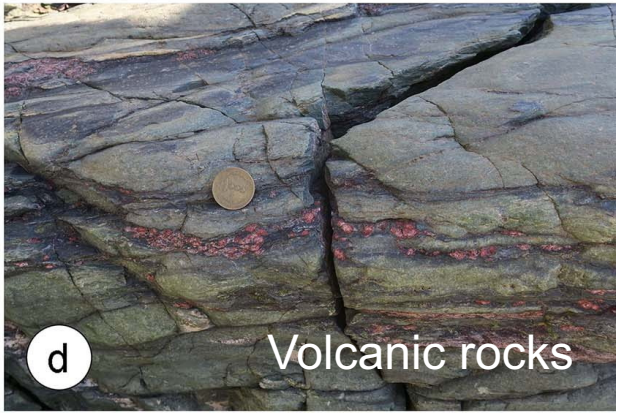
Field evidence from the Bajgan Complex

Ophiolitic protoliths consists of:





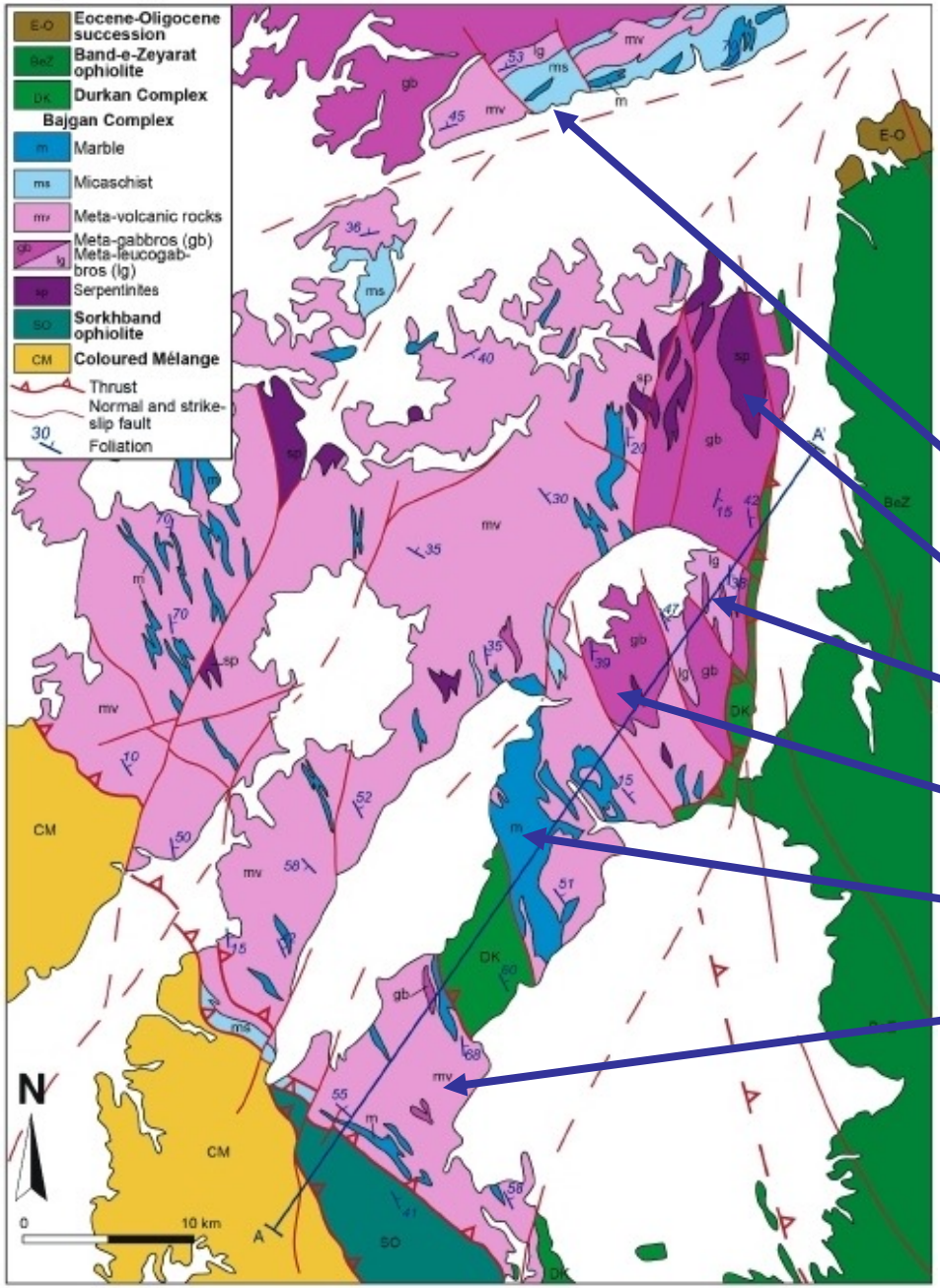


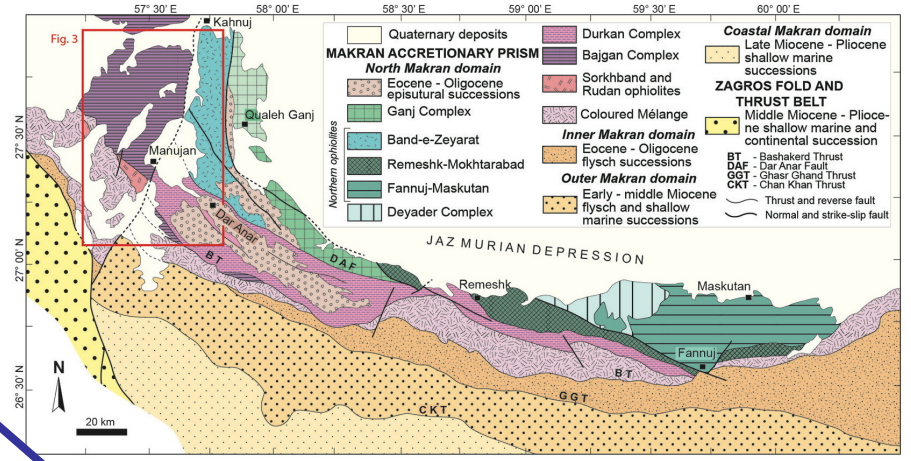
DETAILED FIELD INVESTIGATION showed that the Bajgan Complex largely consists of tectonic slices representing incomplete ophiolitic sequences metamorphosed to various facies conditions. Continental-type rocks are very rare, of uncertain interpretation (e.g., garnet-micaschists), and occur as disrupted tectonic slices of single lithologies

Plus:

- oceanic pelagic sedimentary rocks (limestones, marls, mudstones)
- Minor peridotites (mantle peridotites?)
- Minor volcaniclastic rocks

Geological map of the Bajgan Complex





micaschists

metaultramafic cumulates

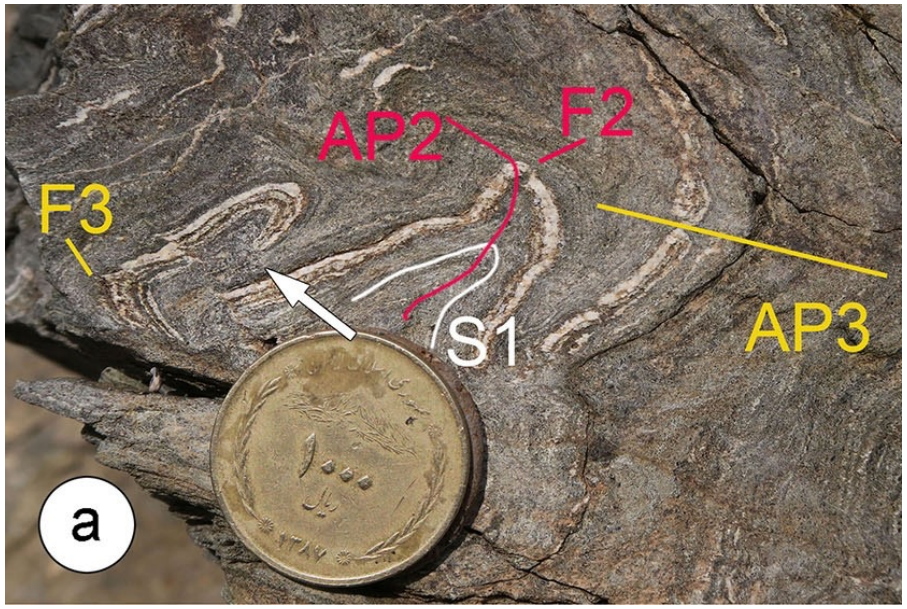
metaleucogabbro

metagabbro

marbles

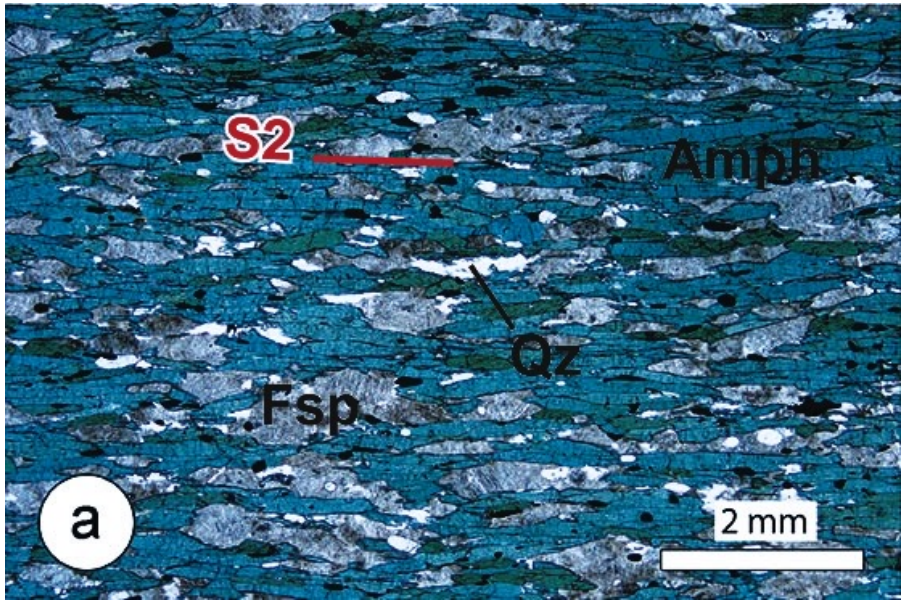
metavolcanic rocks

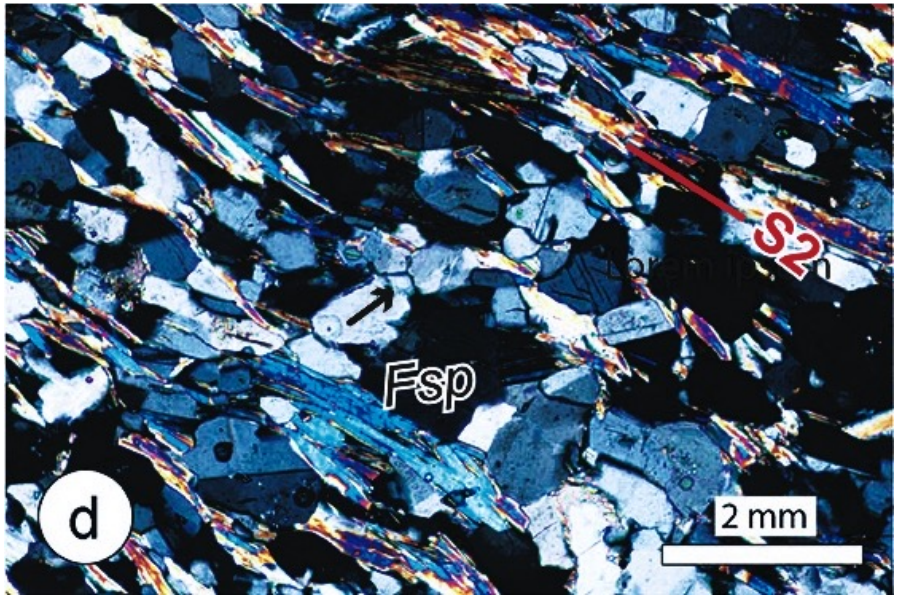
Metamorphism and metamorphic evolution



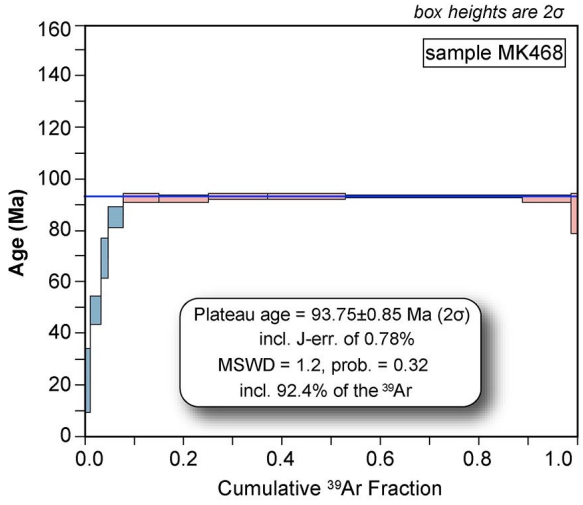
Typically, three distinct deformation phases can be recognized. Foliation S1 is folded by a D2 phase, which is, in turn deformed by a D3 phase

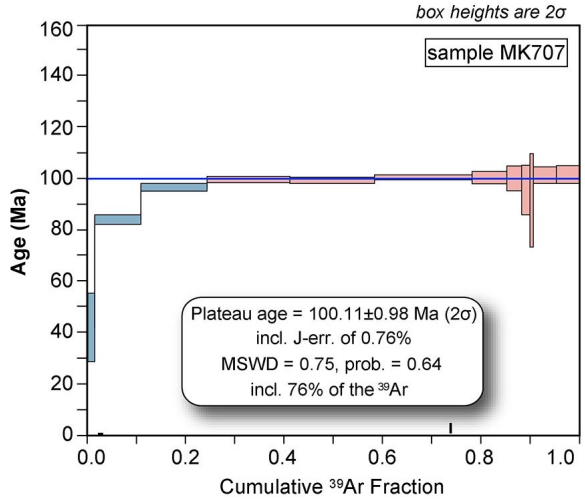
The main foliation that can be seen in both field and thin-section in all rock-types is the S2 foliation.
Metagabbro/metavolcanic rocks (left); metasedimentary rocks (right).





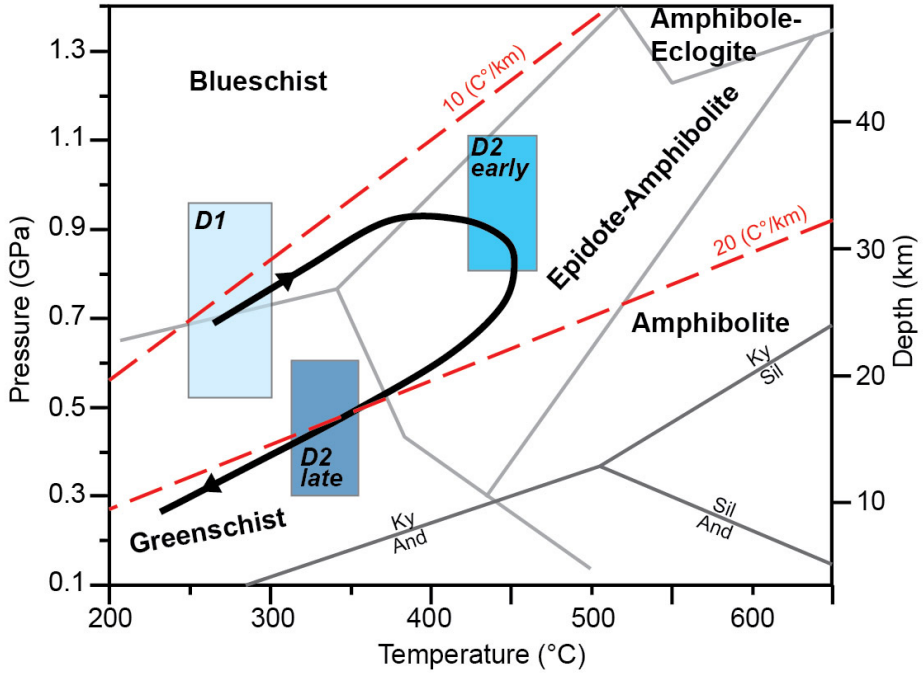
Metamorphism and metamorphic evolution





Ages of the metamorphic peak estimated using 40Ar-39Ar ages range from 93 to 100 Ma

The clockwise P-T path estimated using phengite-chlorite and amphibole testifies for typical metamorphic evolution along a subducion slab



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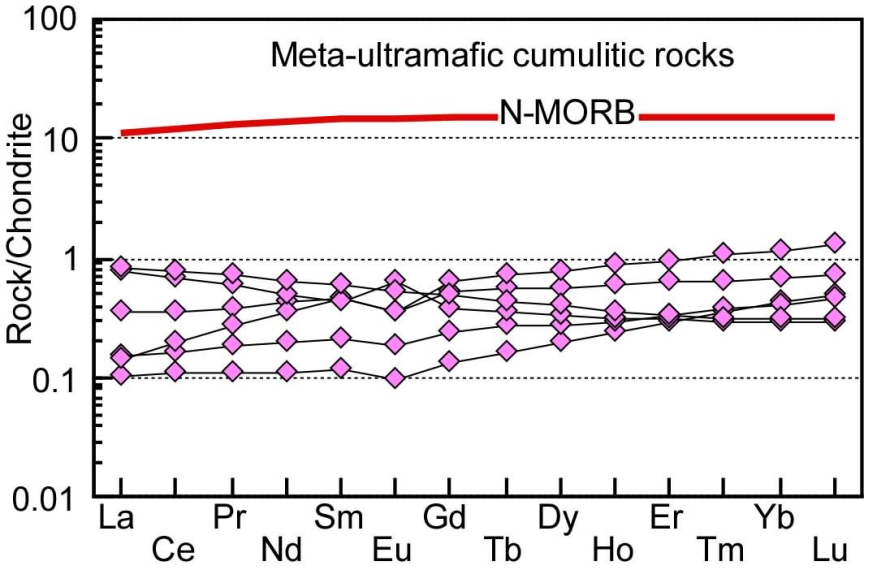
Geochemistry - general classifications

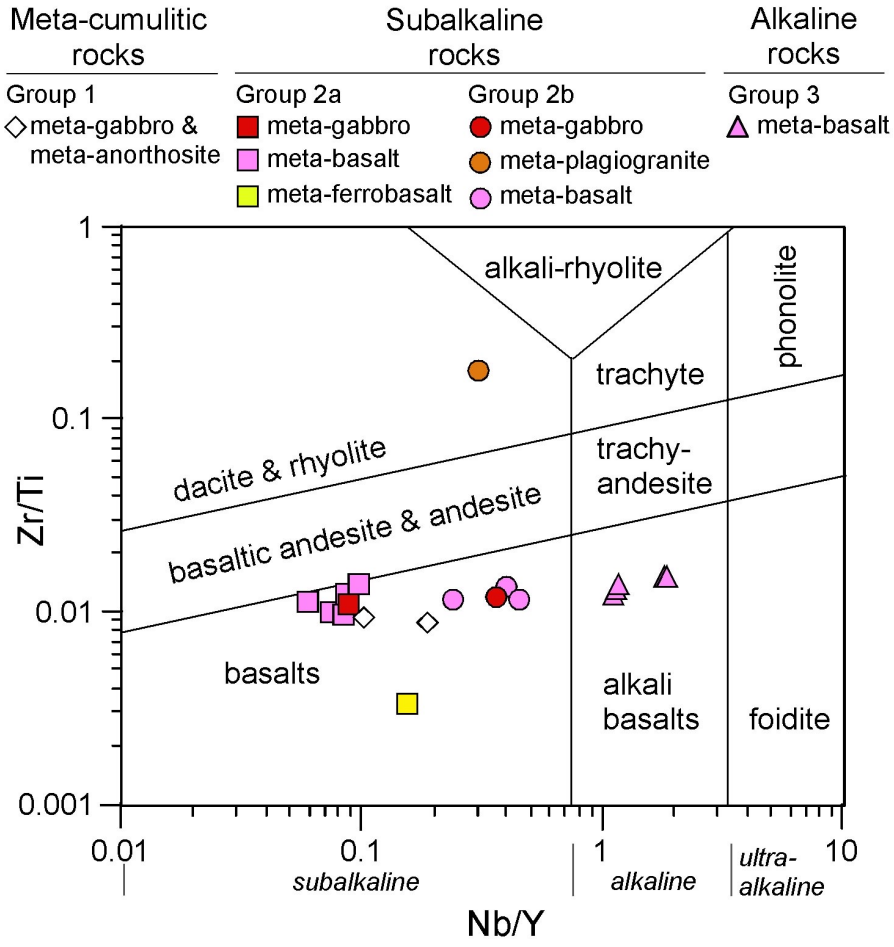
Ultramafic protoliths are difficult to be interpreted because the original texture was obliterated by metamorphic deformation. They are interpreted as ultramafic cumulates based on:

- Common layering in the field
- Variable chemical compositions (MgO=27-41 wt%, Cr=650-3500 ppm, V=29-265 ppm)
- Chondrite-normalised REE patterns

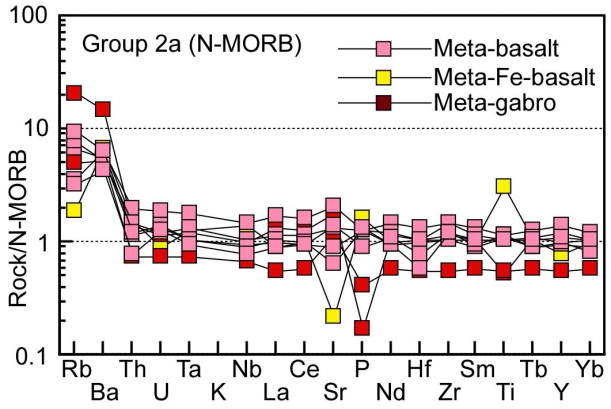


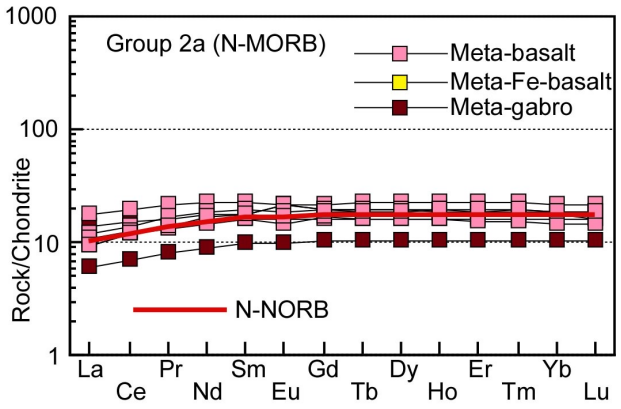
Normalization values from Sun & McDonough (1989)

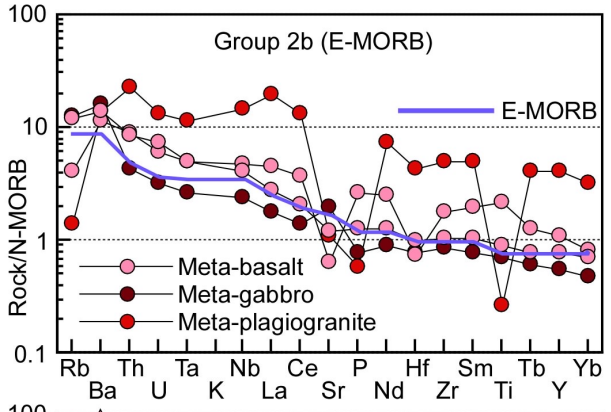
Mafic, intermediate, and acidic protoliths (i.e., upper crust rocks) are subdivided in:

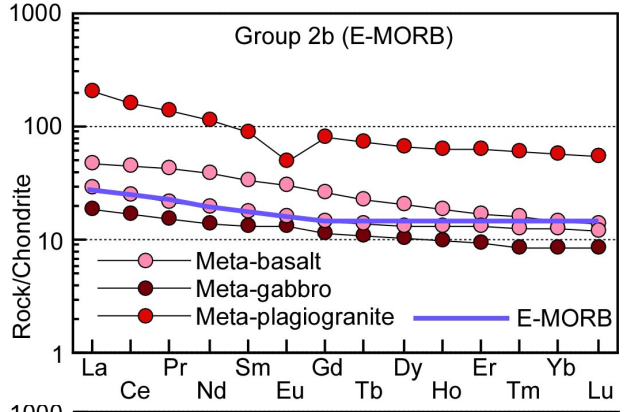


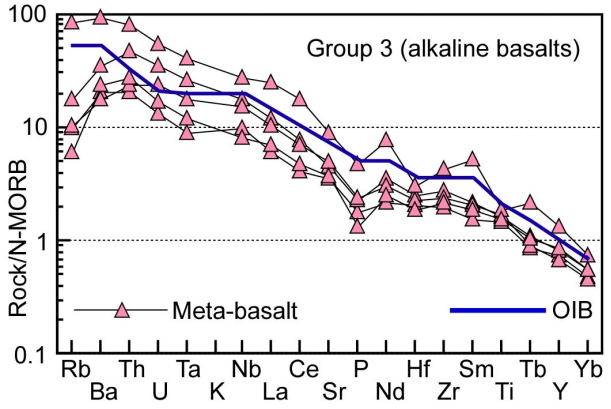
Geochemistry - upper crust rocks

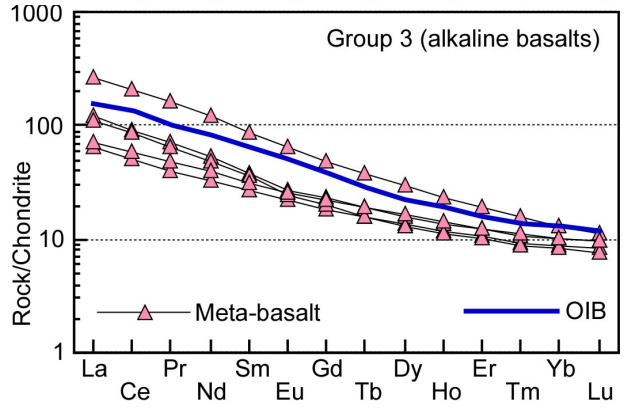












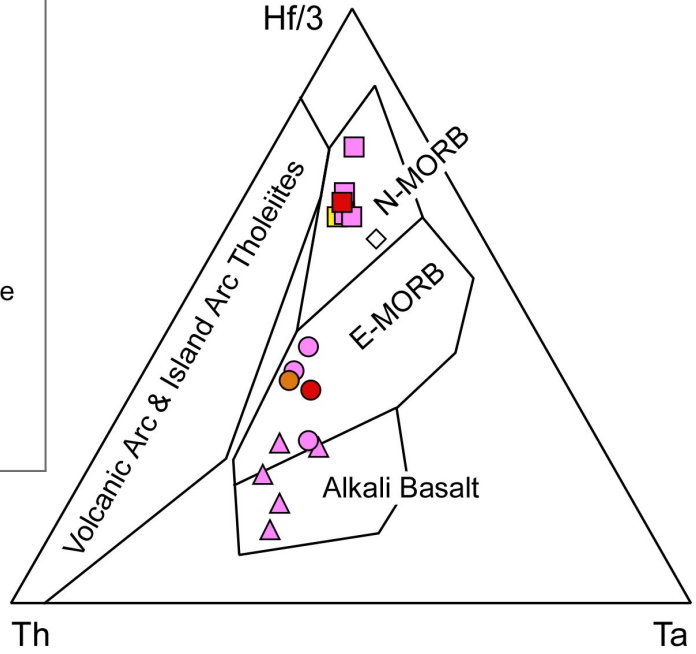
Normalization values, N-MORB, E-MORB, and OIB compositions are from Sun & McDonough (1989) GSL Sp. Vol. 42: 313-345

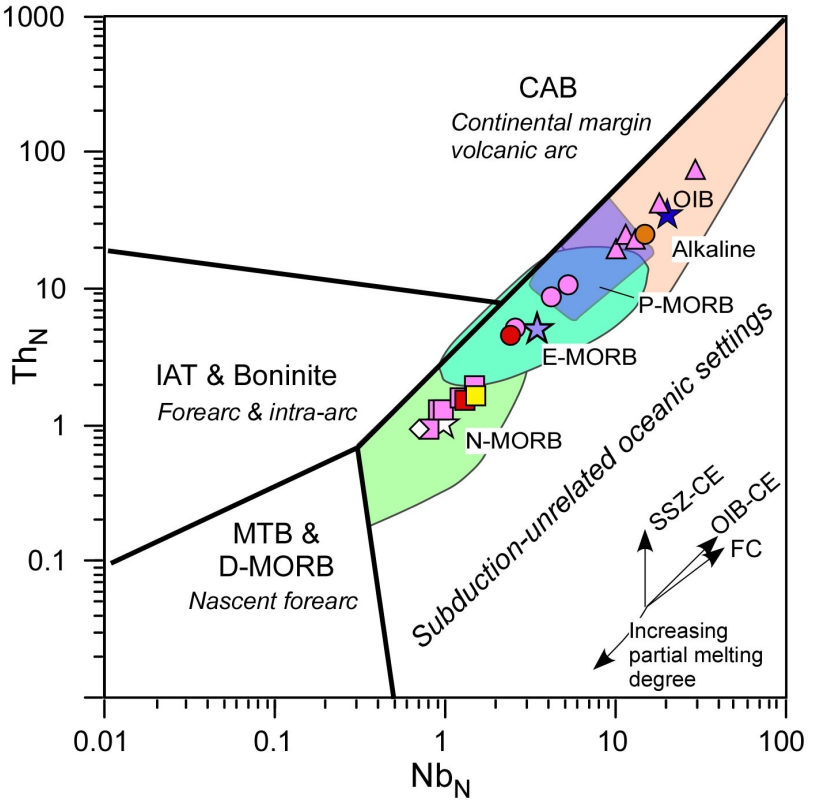
Tectono-magmatic interpretation

Mafic cumulitic rocks
Group 1
◇ meta-gabbro

Subalkaline rocks
Group 2a
■ meta-gabbro
■ meta-basalt
■ meta-ferrobasalt
Group 2b
● meta-gabbro
● meta-plagiogranite
● meta-basalt

Alkaline rocks
Group 3
▲ meta-basalt



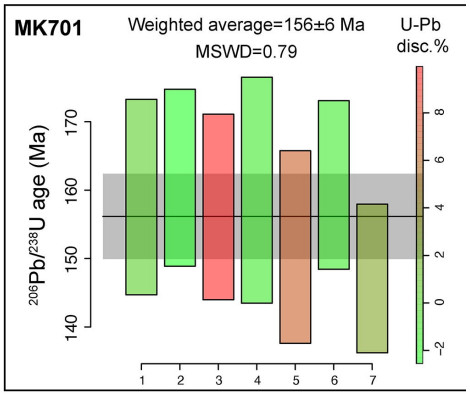


The magmatic protoliths of the Bajgan meta-ophiolites were formed in a SUBDUCTION-UNRELATED OCEANIC SETTINGS either in:

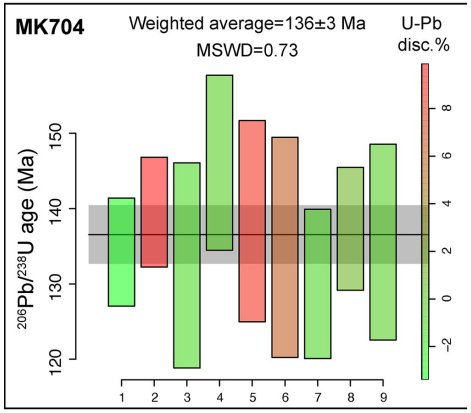
- Normal-type mid-oceanic ridge
- Plume-influenced (plume proximal) mid-oceanic ridge
- Oceanic within-plate settings (seamounts)

Normalization values are from Sun & McDonough (1989) GSL Sp. Vol. 42: 313-345

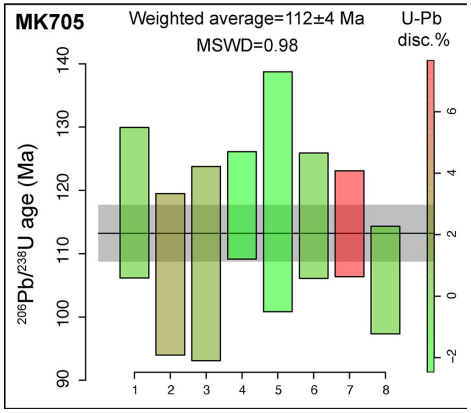
LA-ICP-MS U-Pb zircon magmatic ages



Meta-plagiogranite
E-MORB (?)
156±6 Ma
(Late Jurassic)

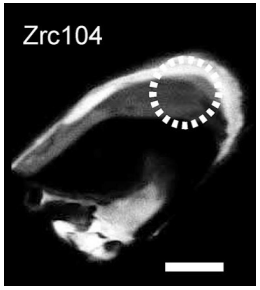


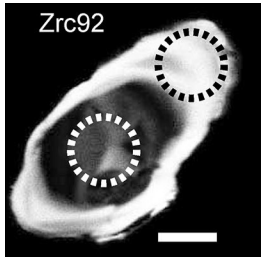
Meta-anorthosite
MORB
136±3 Ma
(Early Cretaceous)

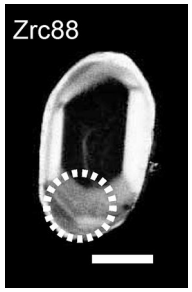


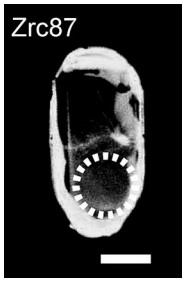
Meta-gabbro
N-MORB
112±4 Ma
(Early Cretaceous)

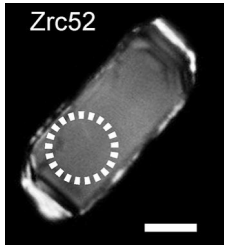
Examples of magmatic zircons





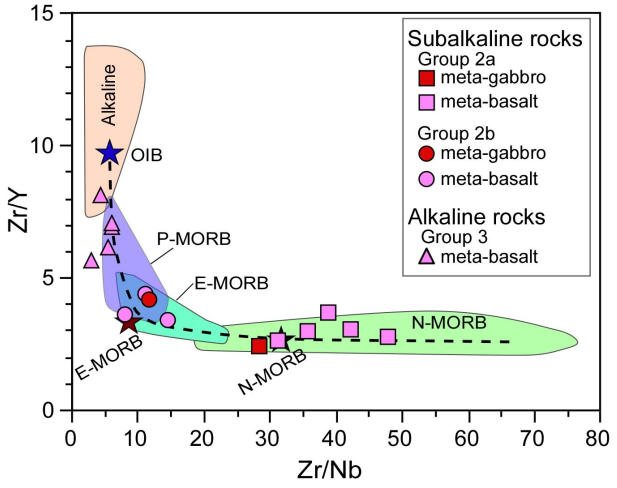


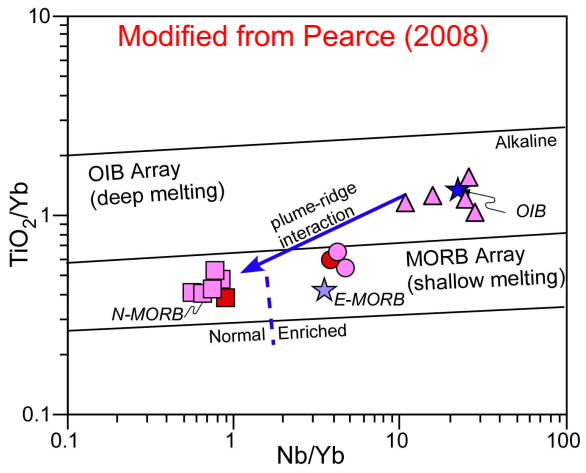




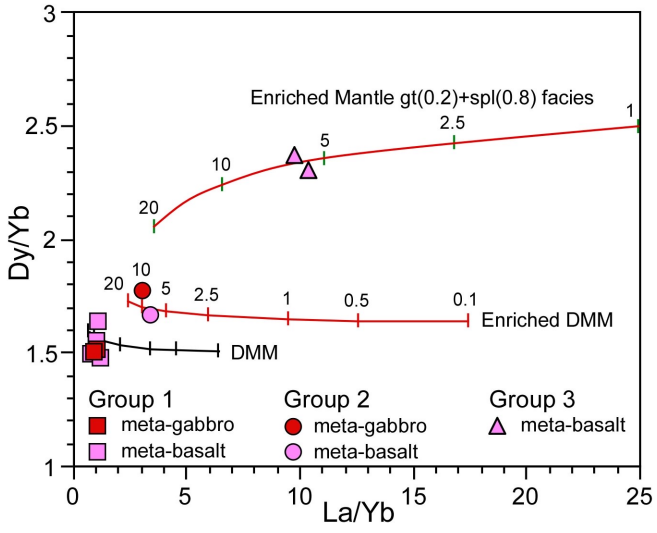
From: Pandolfi et al. (2021) Journal of Asian Earth Sci., in press

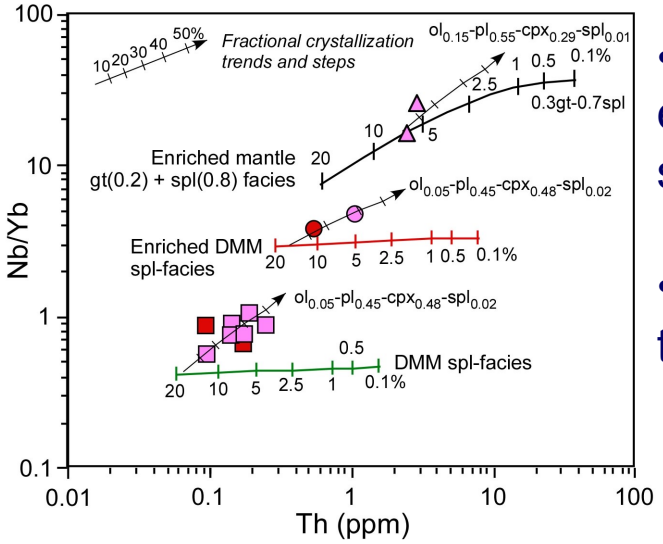
Petrogenesis of magmatic protoliths





- Plume-ridge interaction in the mantle sources is testified by many incompatible element ratios
- The chemistry of Group 3 basalts indicates residual garnet in the mantle source





- La, Th, Nb ⇒ enrichment the mantle sources (plume influence)
- Yb ⇒ residual garnet in the mantle source

- DMM: La=0.222, Dy=0.55, Yb=0.353, Th=0.0089, Nb=0.16
- E-DMM: La=0.64, Dy=0.58, Yb=0.353, Th=0.09, Nb=1.20
- EM: La=0.75, Dy=0.42, Yb=0.347, Th=1.675, Nb=1.52

DMM composition from Workman & Hart (2005)

Part 5

1- Introduction: Previous studies and our investigations, the Geology of Makran, and the importance of the Bajgan Complex

2- Why to investigate the Bajgan Complex

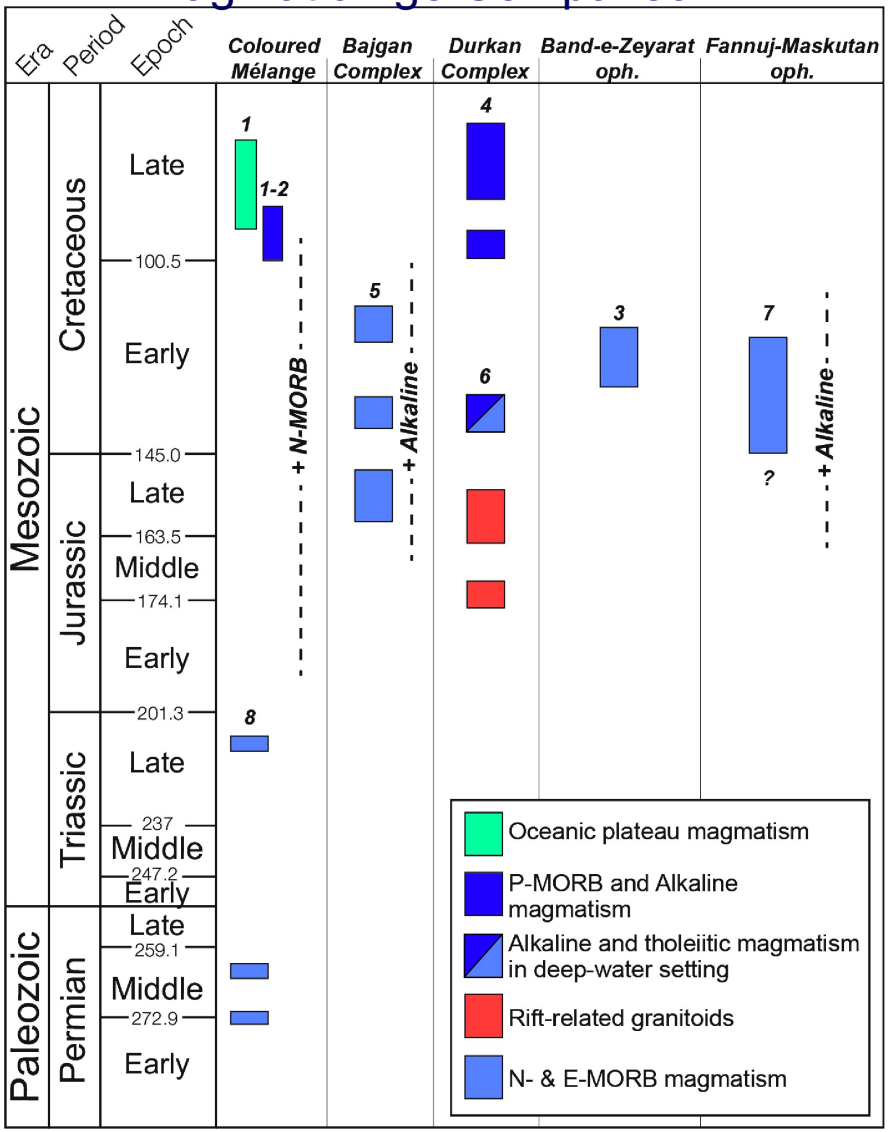
3- Field evidence and a few words on metamorphism and metamorphic evolution

4- Geochemistry, age and petrogenesis of the magmatic protoliths

5- Regional comparisons and conclusions

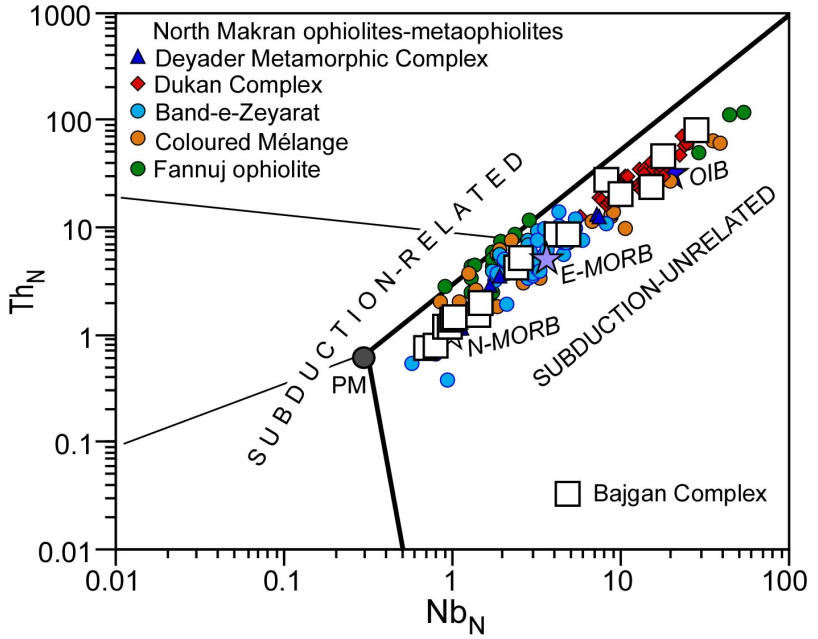
Regional comparison

Magmatic Age Comparison



(1) Saccani et al., 2018; (2) Esmaeili et al., 2019; (3) Barbero et al., 2020; (4) Barbero et al., 2021; (5) Pandolfi et al., 2021; (6) Hunziker et al., 2015; (7) Dolati, 2010; (8) Esmaeili et al., 2021.

Geochemical Comparison



- Magmatic protoliths of the Bajgan metaophiolites share ages and chemical compositions with all the other ophiolites and metaophiolites in the North Makran (including the Durkan Complex)
- Compared with other North Makran ophiolites and metaophiolites, the Bajgan Complex show different metamorphic imprinting (but the Deyader Metamorphic Complex)

Conclusions

• Similar to other North Makran ophiolites and metaophiolites (Durkan Complex, Band-e-Zeyarat, Fannuj-Maskutan, Coloured Mélange), the Bajgan Complex consists of metaophiolites ranging in composition from N-MORB to E-MORB and Alkaline basalts.

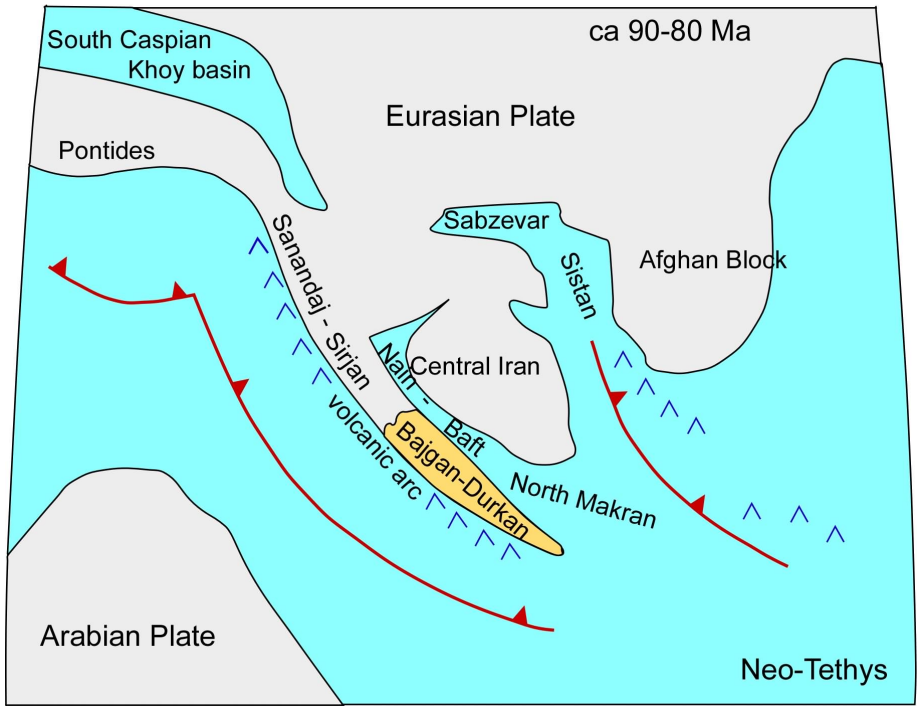
•Similar to other North Makran ophiolites and metaophiolites, they represent remnants of an oceanic basin characterized by plume activity and plume-ridge interaction.

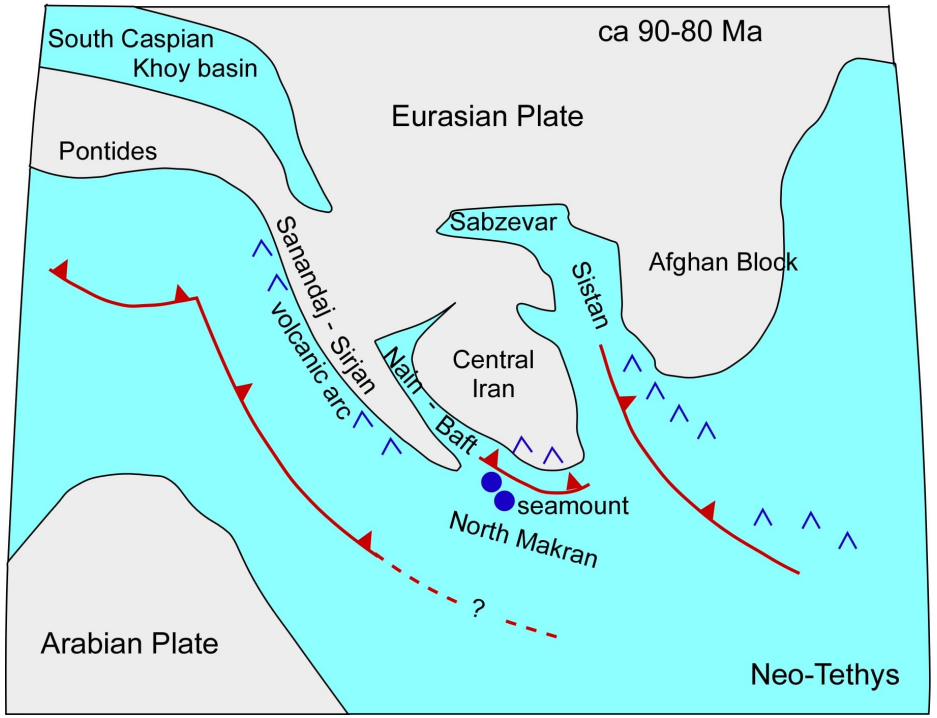
Conclusions

• The interpretation of the Bajgan Complex as a continental ribbon fragment should, therefore, be deeply revised, if not abandoned.

•The Bajgan Complex consists of a tectonic assemblage of metaophiolites representing portions of the late Jurassic - Early Cretaceous North Makran Ocean

•This new interpretation should be taken into account for future geodynamic reconstruction of the North Makran.





Thank you very much for your attention

UNIVERSITÀ DEGLI STUDI DI FERRARA
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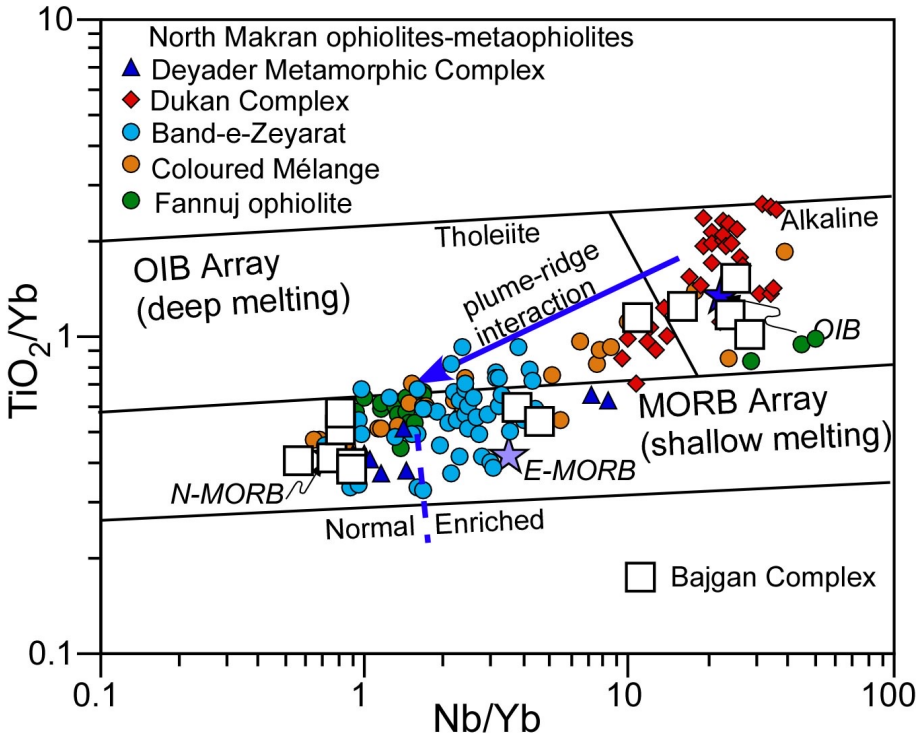
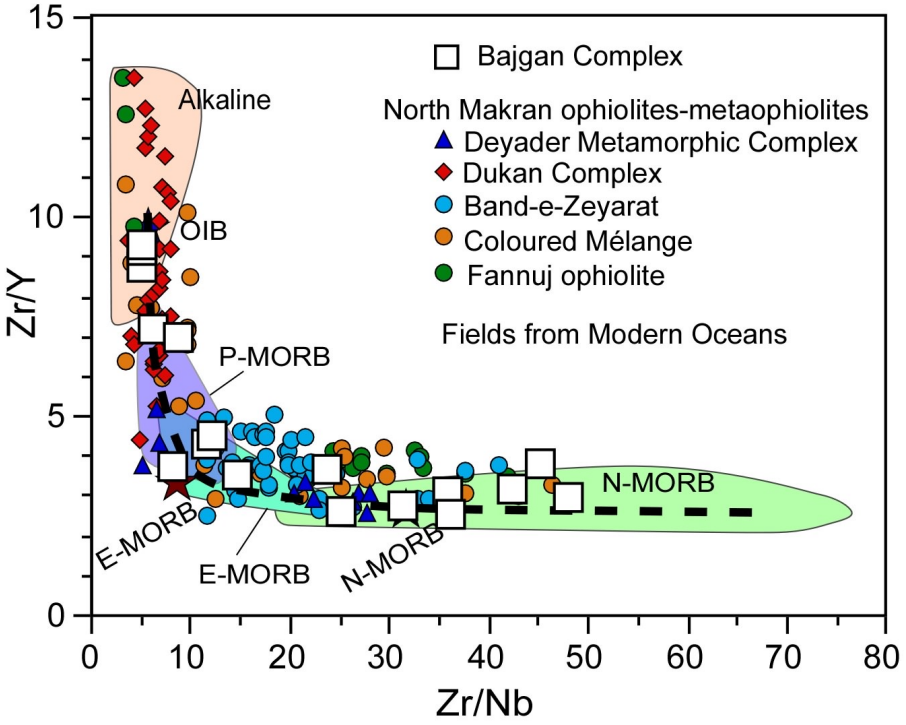
EX LABORE FRUCTUS

Supplementary material





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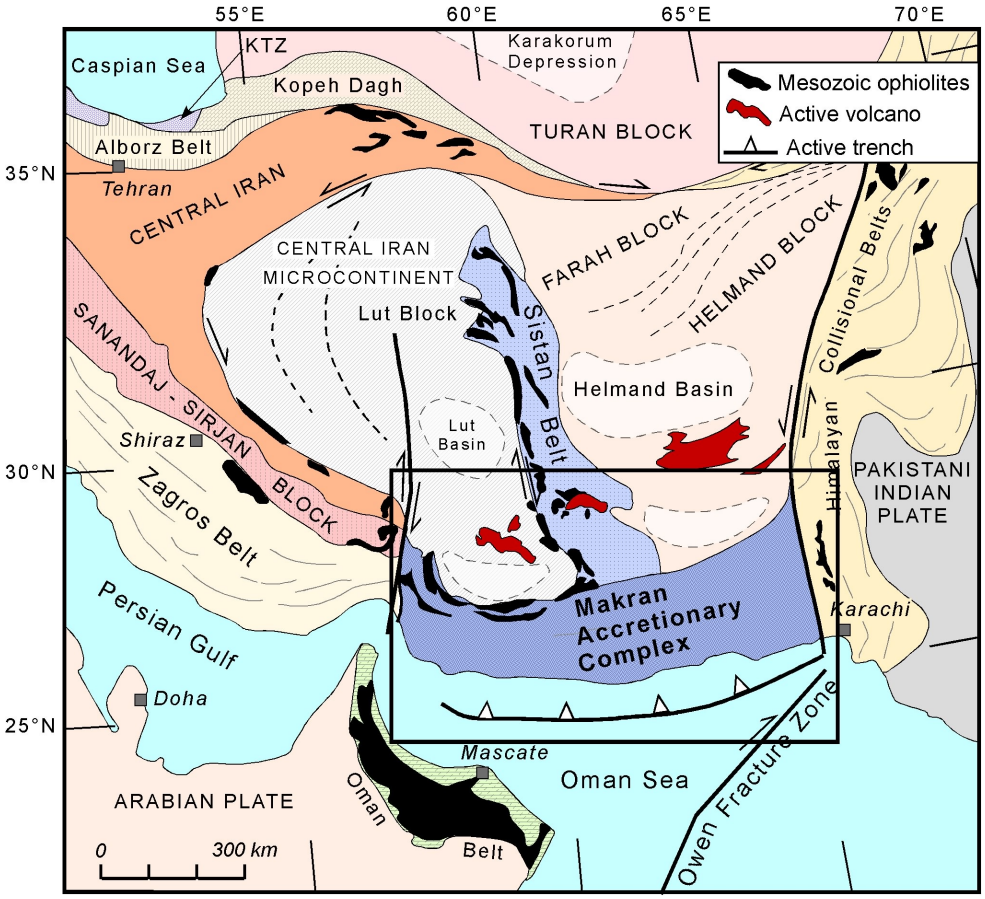

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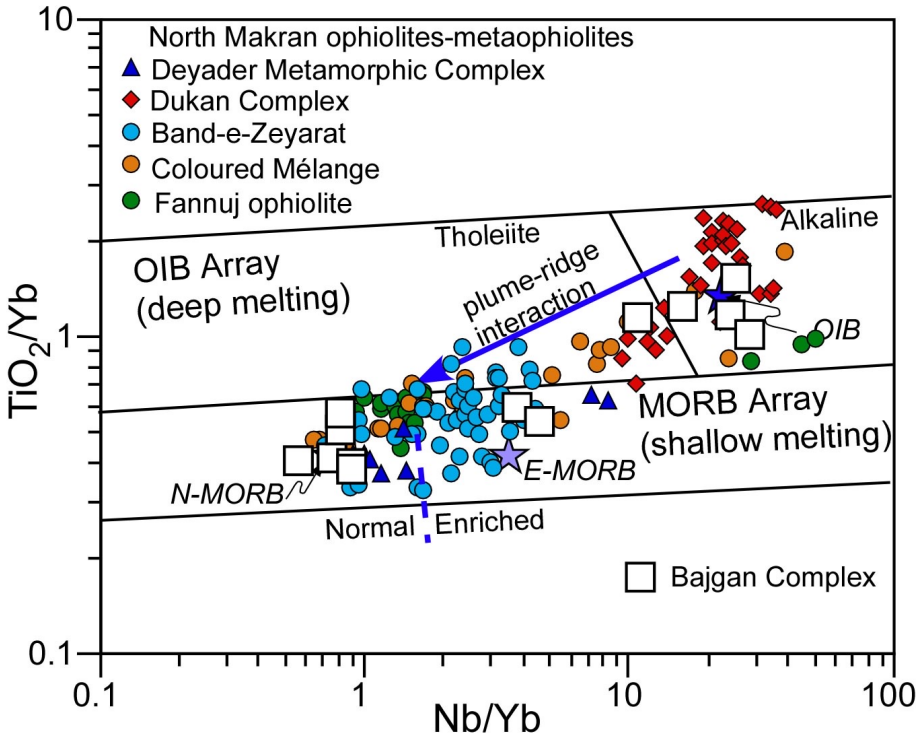

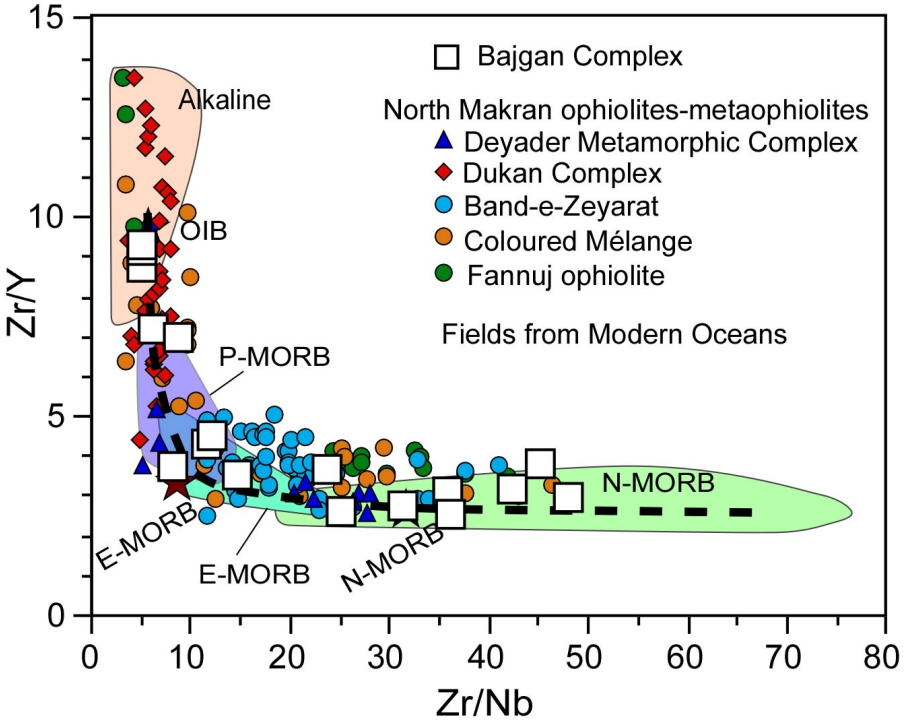

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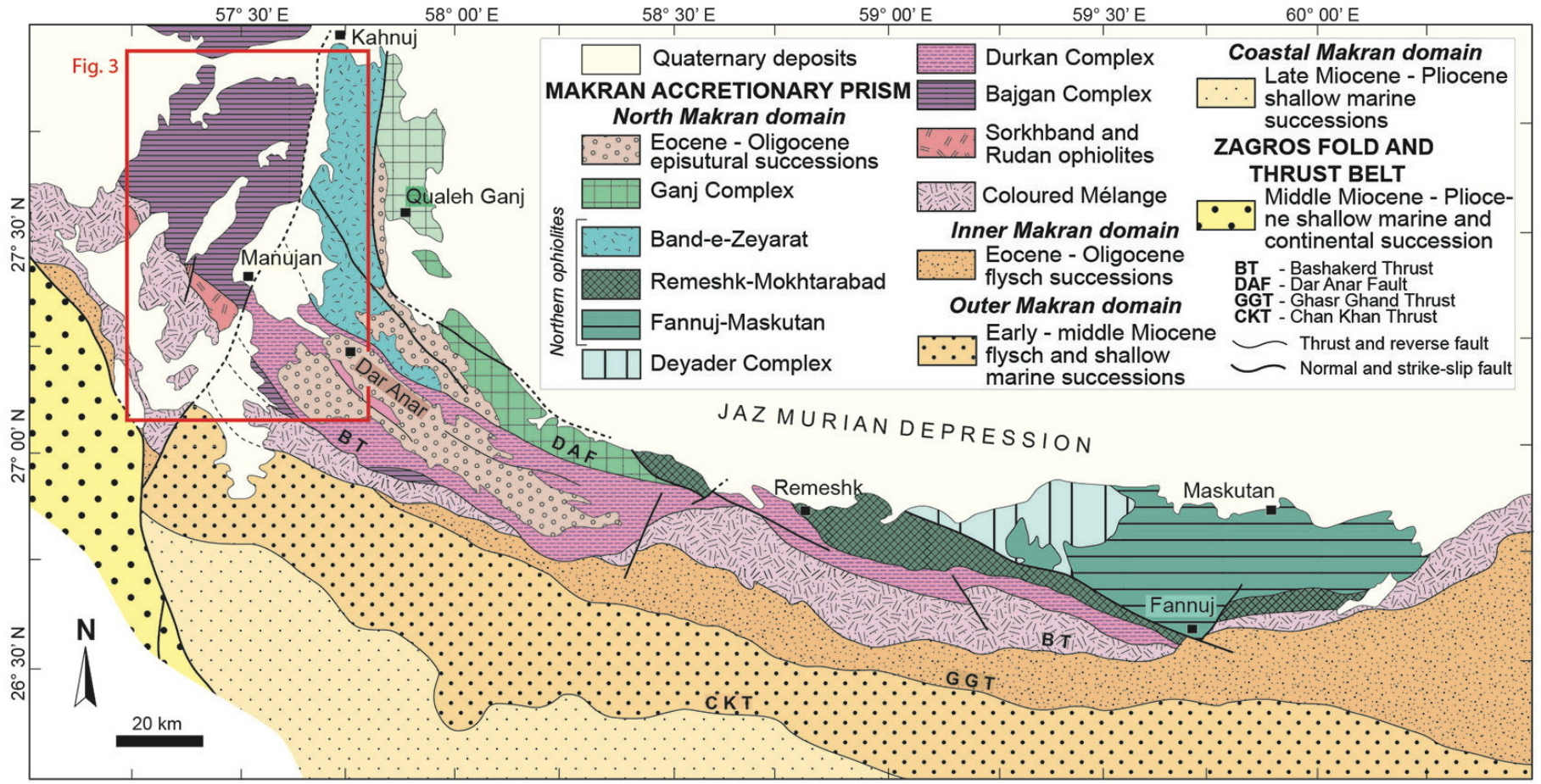

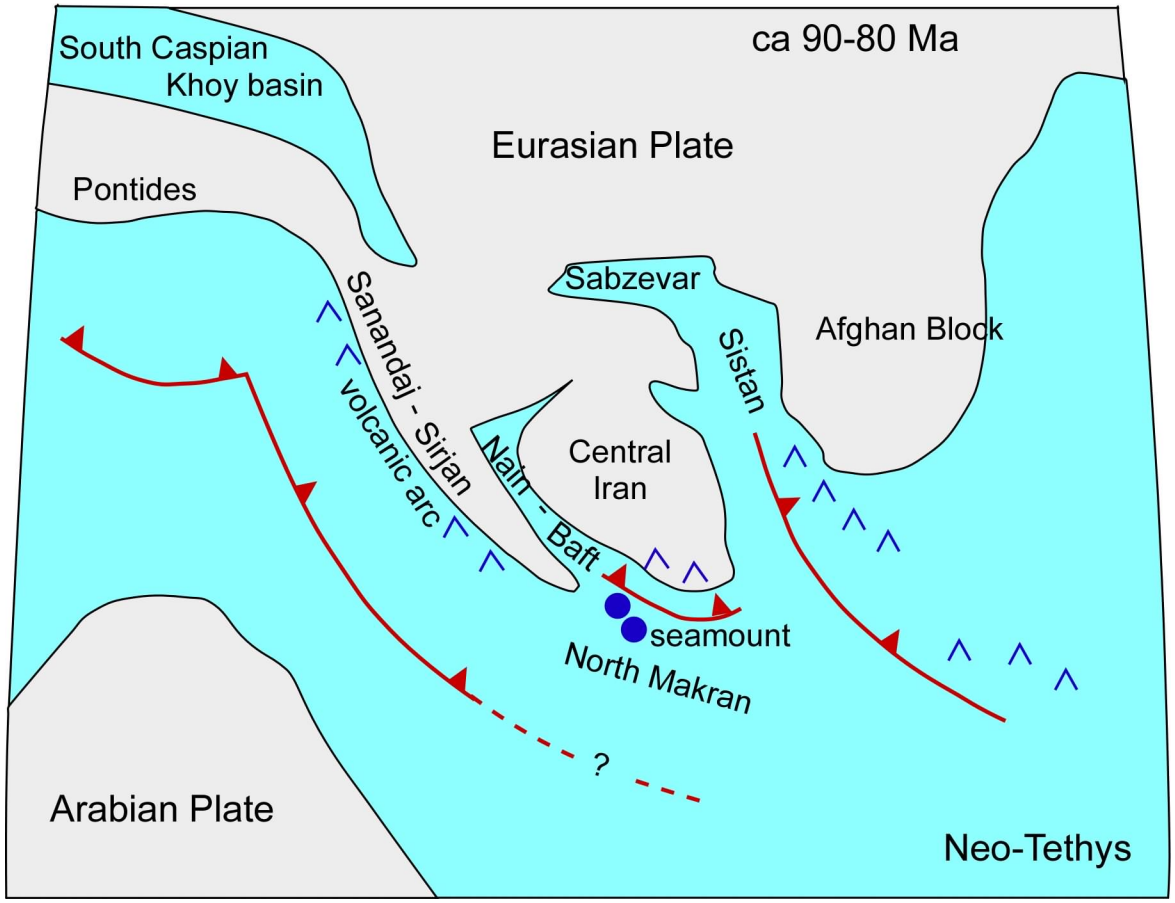
ca 90-80 Ma
South Caspian
Khoy basin
Eurasian Plate
Pontides
Sabzevar
Afghan Block
Sistan
Sanandaj - Sirjan
volcanic arc
Nain - Baft
Central
Iran
seamount
North Makran
?
Arabian Plate
Neo-Tethys

Supplementary material