Dipartimento
di Scienze della Terra

Sapienza
Università di Roma

PhD in Earth Sciences
Curriculum in Geosciences

Doctoral School “Vito Volterra”
XXXIII cycle – AY 2020-2021

PETROGENESIS OF THE CENOZOIC MAGMATISM IN NORTH-WESTERN IRAN

PhD student: Giulia Salari

Supervisor: Prof. Michele Lustrino, Sapienza University of Rome
Co-supervisor: Dott. Samuele Agostini, IGG-CNR of Pisa

- PhD FINAL REPORT -

1. Research activities (AY 2017-2020)

Aim of the PhD project is the investigation of four volcanic districts in NW Iran (Nowbaran, Tafresh, Bijar-Qorveh and Sahand areas; Fig. 1) in terms of petrographic characterization, major and trace elements and isotopic compositions, with the purpose to better understand the mechanisms governing the petrological evolution of the Cenozoic magmatic system in western Iran.

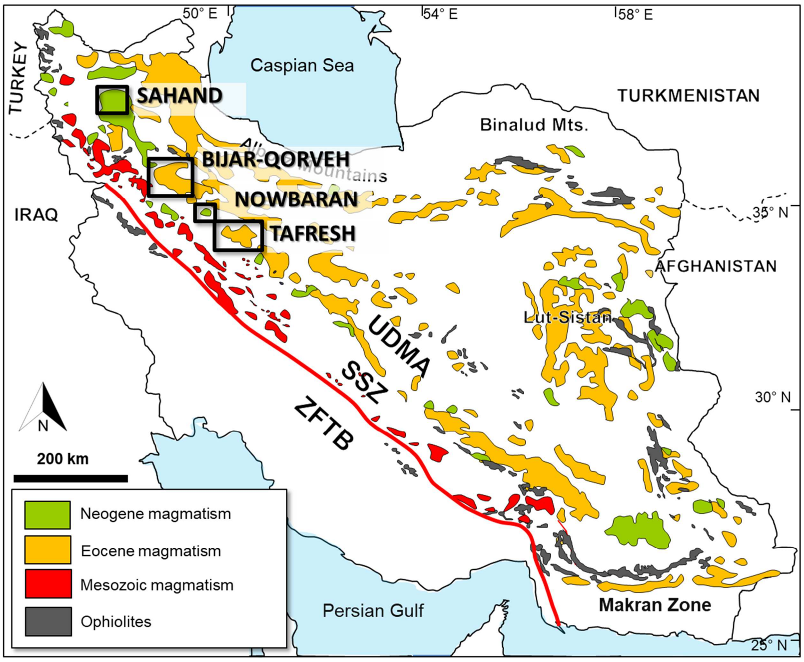


Fig. 1: Simplified geological sketch map of Iran with black rectangles indicating the location of the study areas (Tafresh, Nowbaran, Bijar-Qorveh and Sahand). UDMA = Urumieh-Dokhtar Magmatic Arc; SSZ = Sanandaj Sirjan Zone; ZFTB = Zagros Foldand-Thrust Belt.

The studied areas belong to the so-called Urumieh-Dokthar Magmatic Arc (UDMA; Fig. 1) running from NW to SE along the western margin of Iran, whose volcanism is related to the NE-ward Neotethys Ocean subduction beneath the Iranian plate since Early Cretaceous time, evolved into Arabia-Iran continental collision during early Cenozoic period (Berberian and King, 1981; Alavi 1994; Agard et al., 2005). Despite the crucial role of the study area in understanding the evolution of the Alpine-Himalayan Orogeny, Iran is still poorly studied. Thus the purpose of this PhD project is to give a contribution to the scientific community about the tectono-magmatic framework of the Arabia-Eurasia collision zone.

The first year of my PhD was mostly dedicated to Bijar-Qorveh and Nowbaran volcanic areas. In particular, I started sending powdered samples of both districts (fifty-nine samples from Bijar-Qorveh and twenty-one from Nowbaran) to the Activation Laboratories in Ancaster (Ontario, Canada; www.actlabs.com), where whole-rock major and trace elements analyses were respectively determined by ICP-AES (Inductively-Coupled Plasma Atomic Emission Spectrometry) and ICP-MS (Inductively-Coupled Plasma Mass Spectrometry). In the first semester of the first year I also started the procedure for the preparation of thin sections, followed by a detailed petrographic characterization of these samples. Morphological microstructures and quantification of mineralogical phases (on nineteen selected representative samples from Bijar-Qorveh and nine samples from Nowbaran) were also determined by using the Scanning Electron microscope (SEM) and the Electron Micro-Probe Analysis (EMPA). Moreover, two samples from Nowbaran have been also selected for X-ray powder diffraction (XRPD) at Dipartimento di Scienze della Terra of Sapienza University of Rome, due to their very fine-grained groundmass. Finally, I spent one month (April 16^{th} - May 16^{th}) at CNR-IGG laboratories of Pisa to perform Sr-Nd-Pb isotopic analyses on some selected samples of these districts (see section below "*National research activities"*).

During the second year activities, Tafresh and Sahand volcanic districts have been investigated in terms of petrographic and chemical characterization. More specifically, preparation of thin sections of Sahand area and whole-rock chemical analyses of both areas were carried out during the first trimester of the year. The powders of a total of fifty-two rocks (twenty-six for each district) were sent to ActLabs in Canada for major and trace elements determination.
Spring trimester was committed for the period abroad (see "*International Research activities*") at the Institute of Geochemistry and Petrology at ETH Zürich in collaboration with Prof. Max W. Schmidt, to perform high pressure experiments by using end-loaded piston cylinder. The purpose of the experiments was to try to unravel the magmatic processes that controlled the genesis and the evolution of Nowbaran peculiar melts. The close-to-primary Nowbaran compositions were forced into multiple saturation points with a mantle assemblage (by adding peridotite phases in the capsule) with the aim to saturate the system in olivine, orthopyroxene, clinopyroxene and garnet. In particular, H_2O and CO_2 were added to the average Nowbaran compositions (after excluding the more weathered or less primitive samples) as a carbonated peridotitic mantle source is supposed for these magmas. Then I forced the system into multiple saturation points by varying the mantle phases proportions, the T range and the volatiles content (i.e., H_2O ~3 wt% and CO_2 ~3-5 wt%). Pressure was constrained at 2.7 GPa likely considering i) involvement of amphibole-rich mantle source in the genesis of these ultrabasic magmas (lithospheric pargasitic amphibole is stable up to ~3.0 Gpa) and ii) a garnet-residual source (garnet is frequently assumed to begin breaking down to spinel at ~2.7 Gpa).

The time-schedule of the third year research activity was significantly impacted by the global COVID-19 pandemic outbreak, i.e. planned Ar-Ar dating for age determinations of Nowbaran likely young (< 1 Ma) nephelinites has been cancelled. However, during the first part of my last year I started working on Nowbaran and Tafresh papers. As deep weathering involves Tafresh samples (LOI up to ~9.5 wt%), neither mineral characterization by electron microprobe (EMP) analyses nor isotopic study have been performed on these rocks. Electron microprobe analyses and Sr-Nd-Pb isotopic determinations for Sahand rocks were also scheduled during spring 2020. After globally-adopted lockdown conditions, eight selected samples from Sahand were investigated in term of mineral chemistry (EMPA) whereas nine selected samples were analyzed for Sr-Nd-Pb isotopic ratios at CNR-IGG Laboratories in Pisa.

2. Results

The Bijar-Qorveh obtained results revealed a wide range of volcanic products in terms of age and chemical compositions (Fig. 2), developed as a consequence of the NE-directed subduction of the Neotethyan oceanic lithosphere beneath the Eurasian plate during Early Cenozoic times. Indeed two main volcanic cycles have been recognized in this area, as also confirmed by literature data. More specifically, Miocene compositions (~9.2-8.3 Ma) range from trachy-andesites to trachytes, with minor rhyolitic terms, showing a high-K calcalkaline affinity. They are characterized by LILE-LREE enrichments with Nb-Ta negative anomalies totally resembling subduction-related magmas, and likely represent the final phase of the calcalkaline volcanism occurred during Tertiary period in Central Iran. Pleistocene (~1.3-0.5 Ma) volcanic products are here mostly represented by trachybasalts and tephrites, with lesser alkali basalts, showing quite primitive characteristics (i.e. high Mg#, high Cr and Ni contents) with mixed features of both intraplate-like and subduction-related end members. This certainly indicates hybrid mantle sources, as also confirmed by further subgroups which have been identified within overall Bijar-Qorveh samples, in terms of chemical compositions. Indeed a Quaternary sampling site is characterized by both silica-poor and silica-rich outcrops, with the silica-poor compositions being referred to as *adakites*. This term is still controversial, as the genesis for these geochemical features are not well defined, but these unusual rocks (high La/Yb and Sr/Y with low Yb and HFSE contents) are thought to be originated by melting of lower continental crust ore, more likely, by melting of subducted basalts in eclogite facies (i.e., subducted oceanic slabs) with amphibole and/or garnet as residual phases. According to literature data, Quaternary basic magmatism in this area is to be considered as the expression of regional tensional tectonics or other hypothesis involving a variation in the source mineralogy during melting processes.

On the other hand, Nowbaran Quaternary district shows anomalous compositions as an extremely low SiO_2 (~35.4-41.4 wt%; Fig. 2) is coupled with very high CaO and Al_2O_3 (~13.1-18.3 wt% and ~8.6-11.6 wt%, respectively) contents, leading to ultracalcic compositions. These melanephelinites result by far the most peculiar igneous rocks of the entire Bitlis-Zagros Orogen as feldspars and melilite are totally absent. Moreover, high Mg# along with high Cr and Ni contents suggest a primitive character of these melts, but isotopic ratios and primitive-mantle normalized patterns indicate hybrid features. Such uncommon compositions cannot be derived from a classic four-phase (i.e. C-H-free) peridotitic mantle or from digestion of carbonatic compositions. These small volume melts are rather supposed to derived by carbonated apatite-hornblendite-rich metasomes, which are considered as the products of interaction between peridotitic matrix and partial melts derived from arc cumulates (formed by crystallization of hydrous and CO_2-bearing magmas generated during previous subduction-related arc).

Results of preliminary runs revealed that Nowbaran magmas likely originated from a ~3 wt% H_2O and ~3 wt% CO_2-rich source as these experimental melts show major elements trends and concentrations comparable with investigated nephelinites. However, some discrepancies are observed regarding chemical overall compositions and these could be merely related to the effects due to set of variables. This topic certainly needs further investigations.

The Eocene investigated rocks of Tafresh area include a wide compositional spectrum of rocks, ranging from basaltic-andesites to rhyolitic terms (Fig. 2). Magmatic processes supposed for this area involve first the fractionation of ferromagnesian minerals (mostly clinopyroxene and olivine) and plagioclase, followed by a second removal of plagioclase and lesser amphibole (plus minor clinopyroxene) and eventually, in the most evolved phases, the crystallization of plagioclase with lesser alkali feldspar and minor amphibole. Tafresh rocks define a typical calcalkaline series generated from a subduction-modified mantle wedge, characterized by classical LILE-enriched and HFSE-depleted compositions. Additional lithotypes cropping out in Tafresh area also include strongly evolved rocks which are thought to be derived from crustal anatexis of a meta-sedimentary source. Moreover, one sample shows distinctive adakitic signatures (high La/Yb and Sr/Y ratios, low Yb and HFSE contents) which are interpreted as the product of the melting of a meta-mafic source rock (i.e., subducted oceanic slabs) with residual garnet and amphibole in the source. The association of these magmatic rocks pointing to all such different petrogenetic processes in a relatively limited area is strongly suggestive of emplacement in a post-collisional stage.

Sahand investigated rocks show a wide range of compositions also varying in in terms of space and time. Two different magmatic cycles have been recognized in the area, mainly consisting in Upper Miocene (12-5 Ma) basaltic-andesitic to dacitic rocks with subduction-related calcalkaline affinity and Quaternary andesites showing post-collisional shoshonitic-alkaline affinities (Fig. 2). Indeed, Sahand volcano is located within the northernmost part of Eastern Azerbaijan, a region where oceanic slab break-off seems to lead to NE migration of the sinking slab with consequent volcanism progression (i.e., Saray and Sabalan volcanoes; Ghalamghash et al., 2019). Such processes hence result in composite melting mechanisms of mixed subduction-modified sources, as also suggested by few literature data (i.e., Lechmann et al., 2018; Ghalamghash et al., 2019) which support a compound evolution in a post-collisional context.

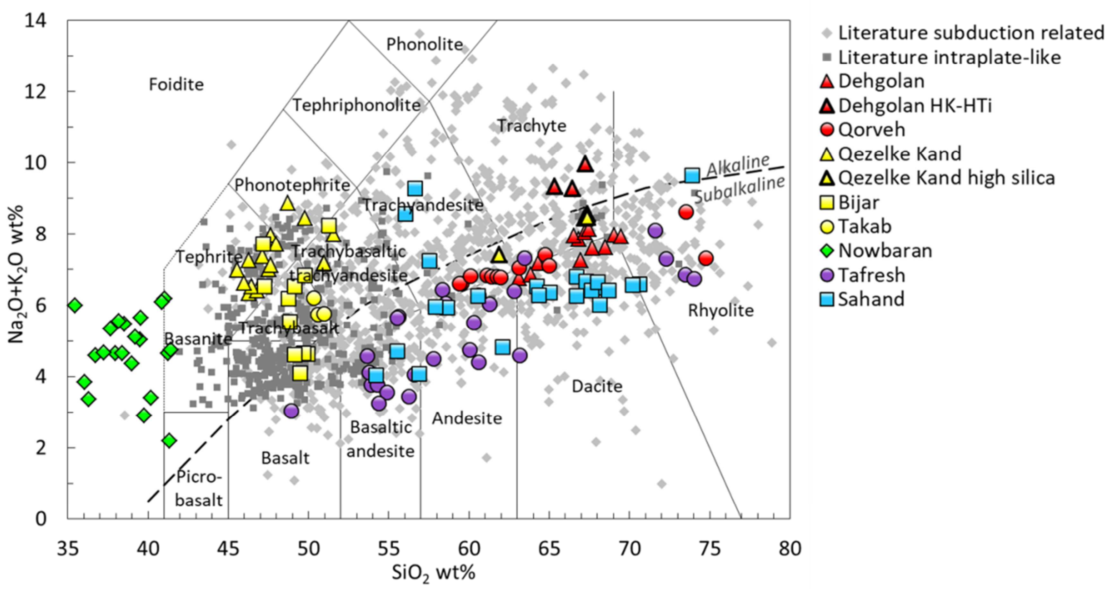
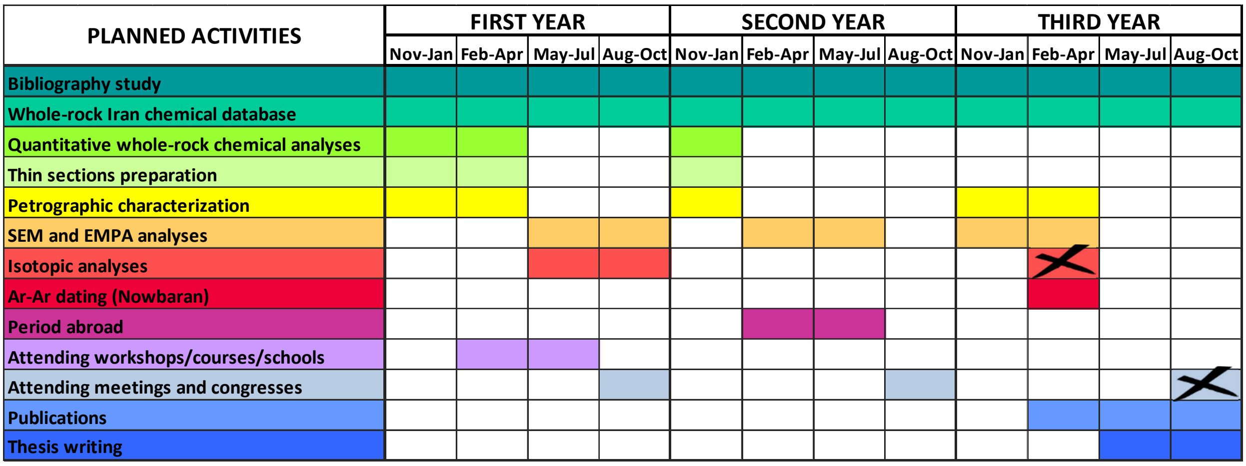


Fig. 2: Total Alkali vs. Silica (TAS; Le Maitre, 2002) diagram for the studied compositions: Bijar-Qorveh (Yellow and red symbols), Nowbaran (green diamonds), Sahand (light blue squares) and Tafresh (purple circles). Dashed line indicates the limit between alkaline-subalkaline fields after Irvine and Baragar (1971).

3. Time Schedule – Gantt Chart



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4. Seminars, courses, workshops and conferences

- 16/11/2020 – Seminar "*Near real-time monitoring and modelling of explosive volcanic eruptions*" - British Geological Survey and University of Bari
- 09/11/2020 – Seminar "*Large-scale experiments on geophysical flows: examples from volcanology*" - British Geological Survey and University of Bari
- 02/11/2020 – Seminar "*The aerodynamic drag of solid particles: applications to volcanology*" - British Geological Survey and University of Bari
- 14-16/09/2020 – "*Workshop on feedbacks between mantle compositions, structure and evolution*" - EGU geodynamics division
- 16-19/09/2019 – SIMP-SGI Congress "*Il tempo del pianeta Terra e il tempo dell'uomo: Le geoscienze fra passato e futuro*" (Parma) - oral session
- 12-14/09/2018 – SIMP-SGI-SOGEI Congress "*Geosciences for the environment, natural hazard and cultural heritage*" (Catania) - oral session
- 26-28/06/2018 – "3rd European Mantle Workshop EMAW" (*poster session*) - University of Pavia
- 04-08/06/2018 – Training course "*Sampling techniques and measurements of volcanic gases*" at Vulcano (Aeolian Islands)
- 19-22/03/2018 – Short Course "*Magma, Eruptions and Risk*" - University of Perugia
- 05-09/02/2018 – Short Course "*Geology of Southern Tethys*" - Roma Tre University

5. Research products

PUBLICATIONS (ISI JOURNALS):

- Lustrino M., **Salari G.**, Rahimzadeh B., Fedele L., Masoudi F., Agostini S. – Quaternary melanephelinites from Nowbaran (NW Urumieh-Dokhtar Magmatic Arc, Iran): origin of ultrabasic-ultracalcic melts in a post-collisional setting. Journal of Petrology, *submitted*.

- **Salari G.**, Lustrino M., Ghorbani M.R., Agostini S., Fedele L. – Petrological characterization of the Cenozoic igneous rocks of the Tafresh district, central Urumieh-Dokhtar Magmatic Arc (Iran). Periodico di Mineralogia. *In press*. doi:10.13133/2239-1002/16620

- Lustrino M., Fedele L., Agostini S., Prelevic D., **Salari G.** (2019) – Leucitites and leucitites within and around the Mediterranean area. Lithos, 324-325, pp. 216-233. doi:10.1016/j.lithos.2018.11.007

NON-ISI JOURNALS:

- **Salari G.**, Rahimzadeh B., Agostini S., Masoudi F. & Lustrino M. – Quaternary ultrabasic volcanic rocks in central Urumieh-Dohktar magmatic arc (Central-Northern Iran): melanephelinites in post-collisional setting. Abstract book 2019 SIMP-SGI-SOGEI Congress (Parma).

- **Salari G.,** Rahimzadeh B., Agostini S., Masoudi F. & Lustrino M. – Neogene ultrabasic volcanic rocks in central Urumieh-Dohktar Magmatic Arc (NW Iran): melilitites and nephelinites in subduction setting. Abstract book 2018 SIMP-SGI Congress (Catania).

6. PhD awards and mobility funds

- 2019 – "Medium" research project founded by Ateneo Sapienza: *Carbon cycle perturbation along the Cenozoic and the role of volcanism: insight from the carbonate sedimentary records and Ca-rich igneous rocks.* Responsible: Prof. Marco Brandano (n° RM11916B506CB674)

- 2018 – "Medium" research project founded by Ateneo Sapienza: *How deep and shallow carbonates can influence the composition and the explosivity of volcanic activity and how volcanic activity can modify the production and evolution of carbonate factories. Case studies from the circum-Mediterranean area.* Responsible: Prof. Michele Lustrino (n° RM118164210D006E)

- 2018 – Grant SIMP (SGI-SIMP Congress "Geosciences for the environment, natural hazard and cultural heritage", Catania)

7. International Research activities

- March 9th - June 21st 2019: Department of Earth Sciences at ETH (Zürich).

  During the second year of my PhD I spent more than three months at the Institute of Geochemistry and Petrology (D-ERDW) at ETH Zürich to perform high pressure experiments by using end-loaded piston cylinder apparatus, in collaboration with Prof. Max W. Schmidt.

- February 17th - February 28th 2019: Fieldtrip in Ethiopia.

  PhD students XXXII and XXXIII cycles spent ten days in Afar Region with the aim of investigating tectono-magmatic processes of the Ethiopian Rift Valley. MIUR funding program "Dipartimento d'Eccellenza 2018-2022"

8. National research activities

- April 16th - May 16th 2018: *TIMS and MC-ICP-MS Isotope Laboratory* at CNR-IGG-Pisa.

  During the first year of my PhD I spent one month at CNR-IGG Laboratories in Pisa performing whole-rock Sr-Nd-Pb isotopic analyses. Eighteen samples from Bijar-Qorveh district and seven samples from Nowbaran volcanic area have been selected for isotopic ratios and the complete procedures were carried out in collaboration with Dott. Samuele Agostini, following the Ion Exchange Chromatography (IEC) technique. Strontium separates were analyzed using a Finnigan MAT 262 Thermal Ionization Mass Spectrometer (TIMS), whereas neodymium and lead were performed with a ThermoFisher Neptune Plus™ Multi-collector Inductively-Coupled Plasma Mass Spectrometer (MC-ICP-MS). Accuracy and high sensitivity of the new Neptune Plus™ permitted to get lower measurement errors with more reliable results, also reducing significantly the response time.

9. SSD and Doctor Europaeus

SSD: GEO/07 Petrology and Petrography

Doctor Europaeus: not requested

10. References

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Lechmann A., Burg J.P., Ulmer P., Guillong M., Faridi M., 2018. Metasomatized mantle as the source of Mid-Miocene-Quaternary volcanism in NW-Iranian Azerbaijan: Geochronological and geochemical evidence. Lithos 304-307, 311-328.