An Introduction to Calc-alkaline lamprophyres (Spessartites) at Saghez Area

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Abstract

Introduction: Lamprophyres are a group of alkaline rocks which usually observed as sub-volcanic intrusions. They include abundant foliated minerals such as mica or amphibole. Spessartite is a type of lamprophyres that usually includes hornblende, pyroxene, albite, alkali feldspar and rarely quartz, also its plagioclase content is more than alkali feldspar's. Spessartite bodies are usually observed around diorite and granitoid intrusions.

Aim: introducing petrographical and geochemical characteristics of sub-volcanic spessartite bodies in Saghez area (NW Kurdistan Prov.) which intruded within cretaceous volcanic rocks with lithology of andesite and basaltic andesite.

Materials and methods: during a study on cretaceous volcanic rocks in Saghez area, sometimes sub-volcanic bodies of spessartite (usually in dyke form) observed. Their characteristics in field studies are green color, foliated structure (which usually named dia-schistic) and brecciation and oxidation of host rock. After field study and sampling, 10 thin sections prepared for petrographical studies and 9 specimens were analyzed by geochemical methods (XRF and ICP-MS).

Results: during petrographical study, special pan-idiomorphic texture observed which formed by pyroxene phenocrysts and small automorphic hornblende grains within a background of plagioclase (albite), sometimes alkali feldspar, chlorite and calcite. Weak alteration (chloritization and carbonatization) usually affected these rocks also their fractures frequently filled by calcite, chlorite, albite and/or epidote. Based on particular classification of lamprophyres using light color minerals, the studied samples were named as spessartite (a calc-alkaline type). According to geochemical study, the analyzed samples located at the field of alkaline rocks. Also, rare earth elements' diagrams show high concentration of LREEs. Moreover, high content of Ti and P in these rocks is considerable.

Conclusion: Due to high content of plagioclase (albite) and hornblende (magnesio-hornblende) and spatial relations of studied bodies with granitoid and diorite plutons, lamprophyre rocks in Saghez area could be named as appinitic spessartites; while they show geochemical properties of spessartites and lamproites (extrusive lamprophyres). High concentration of LREEs in these rocks seems to happen due to low degree partial melting at mantle source, but we can't forget possible crustal contamination of ascending magma.

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Keywords**:** Saghez area, Sanandaj - Sirjan Zone, Lamprophyre, Cretaceous volcanic rocks.

Introduction

Studied area located between 46° 02' – 46° 30' E and 36° 10' – 36° 26' N around Saghez City (Kurdistan Prov.). The area belongs to Sanandaj – Sirjan zone that is a magmatic metamorphic belt.[1] Figure 1 is a simplified map of the area, which prepared based on GSI[1] geological maps. [2, 3] Figure 2 is a land-sat 7-band image with marked sampling sites.

Most parts of studied area covered by cretaceous limestones, shales and volcanic rocks; also outcrops of late Paleozoic sandstones and limestones (Ruteh Formation), Triassic dolomites, Jurassic shales and sandstones (Shemshak Formation), Miocene limestones and marls (Ghom Formation) and quaternary alluviums observed. A Large porphyry diorite body (Cenozoic) outcropped (Banafsheh Mount) at the southwest (figure 1).

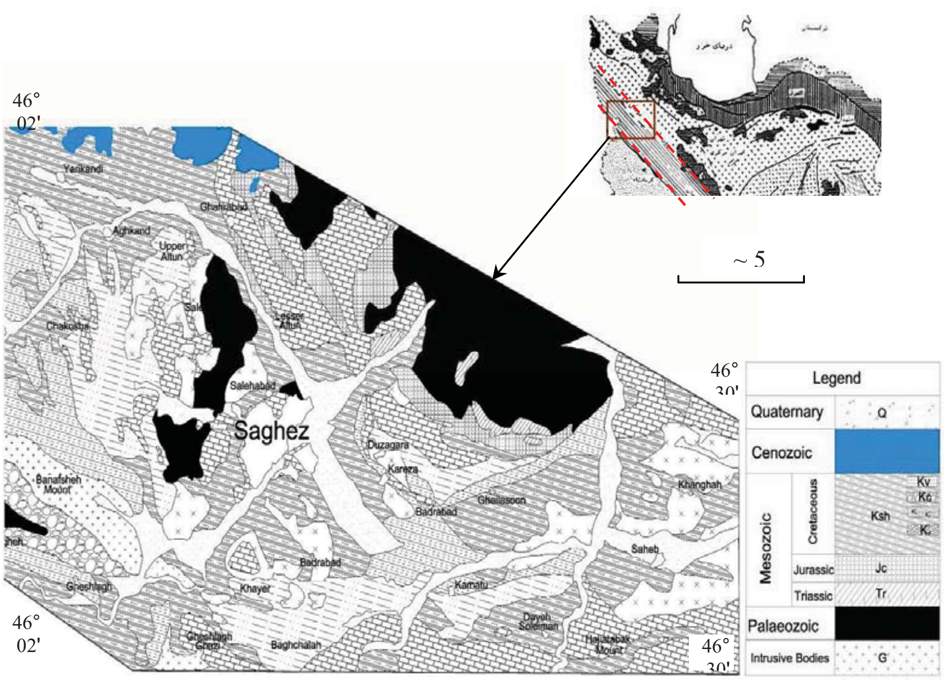


Figure 1 - Simplified geological map of the area, which prepared based on GSI geological maps.[2, 3] A large diorite sill observed at southwest. Red dashed lines on the small country map (up right) show Sanandaj – Sirjan geological-structural zone.[1] Lithologcal units introduced in above text.

[1]- Geological Survey of Iran.

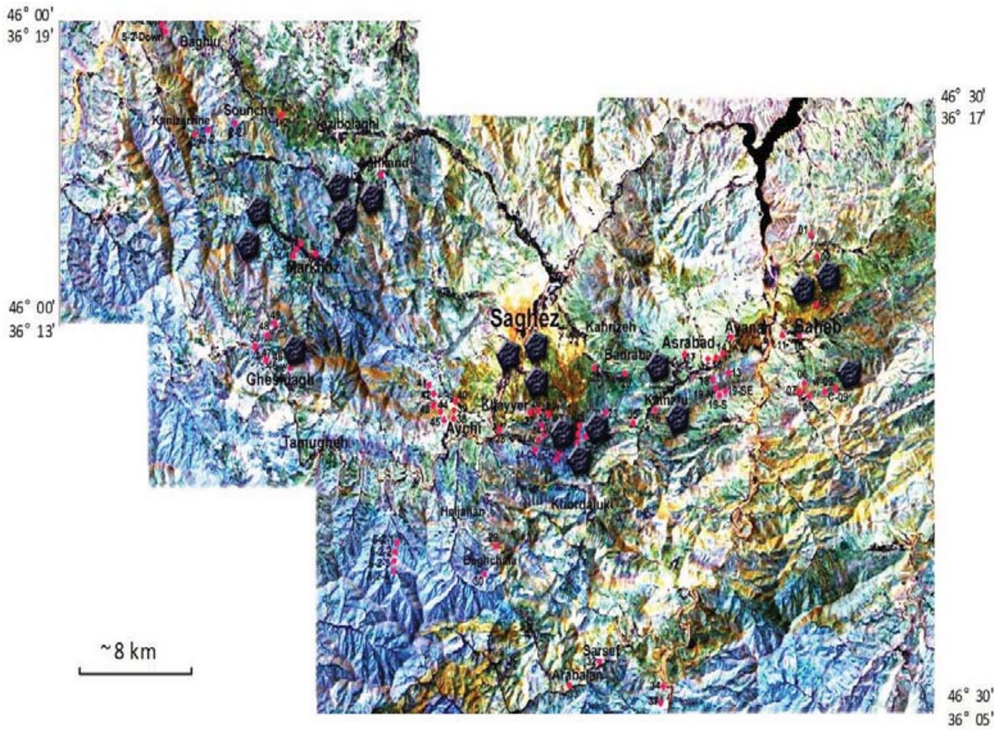


Figure 2 – “Landsat” image (color bands: 3 – 5 – 7) of studied area; sampling sites of our study on cretaceous volcanic rocks observed as red points [4]. Polygons show locations of lamprophyre samples.

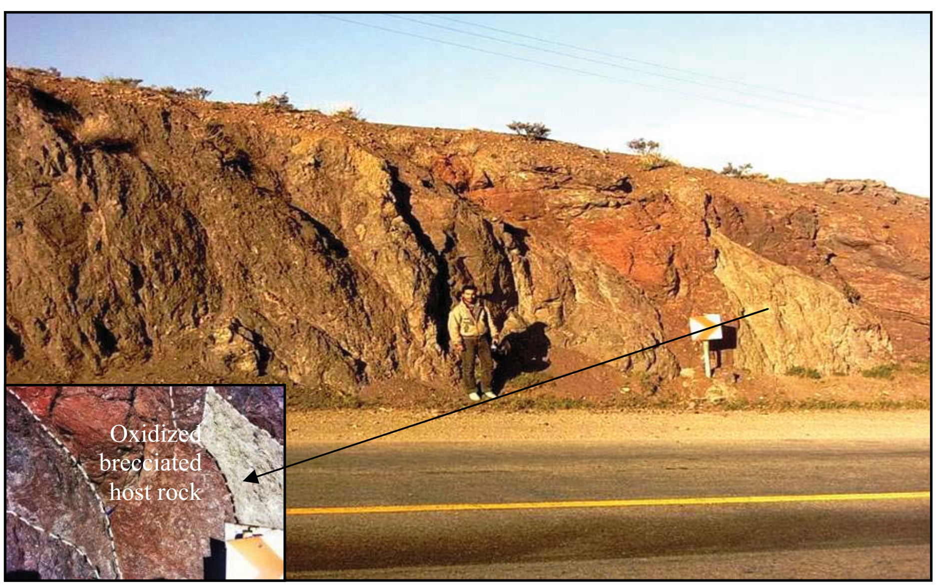


Figure 3 –lamprophyre intrusions recognized by their green color and foliated (dia-schistic) structure versus oxidized brecciated host rock (20th km Saghez – Sanandaj road, northward view).

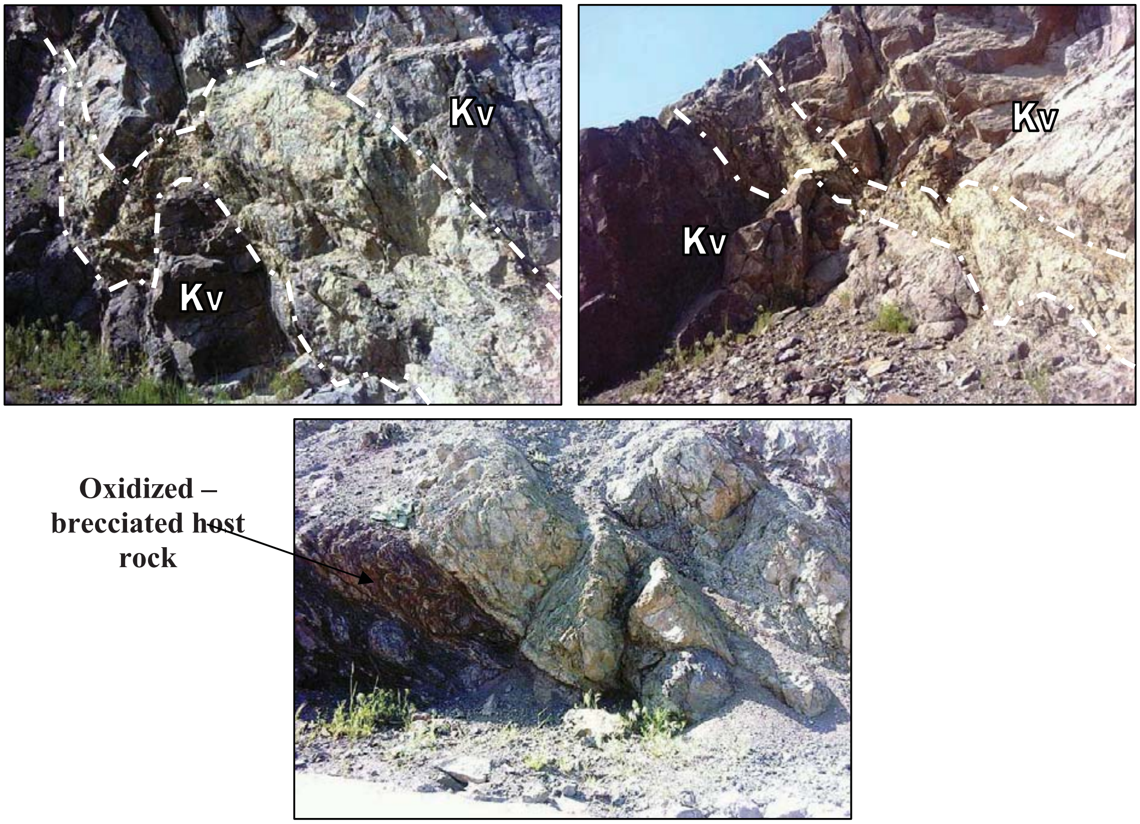


Figure 4 – Lamprophyre dykes with foliated structure within cretaceous volcanic unit (Kv), oxidized – brecciated host rock obviously observed in lower picture (South of Saghez, near Sanandaj road, eastward view).

Before this study, some geological and geochemical maps were prepared by GSI in the area[2, 3] also some explorative studies on indications and deposits of Au, Cu, Fe and SiO_2 performed in several sites which especially located within Cretaceous volcanic unit.

During our collegiate studies on the cretaceous volcanic – sedimentary [4] unit, sometimes, we saw small intrusive bodies (usually in dyke form) with green color and foliated structure (figures 3 and 4). There is a close relationship between those bodies and large granitoid plutons (that intruded within different rock units at the area [2, 3]) as the number of them increased by approaching the plutons.

Microscopic studies

During petrographic studies on samples of the intrusive bodies [5, 6] (figure 2), a special (which known as pan-idiomorphic [7]) texture usually was perceived (figure 5). It included automorphic hornblende[1] grains (e.g. figure 5) sometimes with pyroxene cores (figure 9a, b), large rounded (sometimes as xenocrysts) quartz grains (figure 9a, b), pyroxene (figure 8a, b) pseudo-morphs (formed by Fe-oxides and chlorite, figure 8d, e and f) and rarely olivine pseudo-morphs (formed by chlorite, epidote or calcite) (figure 8 i, l) within a background of plagioclase[2] (sometimes plagioclase crystals show glummero-porphyritic texture [6, 7]) and rarely alkali feldspar.

Also ilmenite grains (which replaced by leucoxene) observed beside abundant sphene and apatite crystals. Large amount of apatite needles implies high P_2O_5 content of these samples (figure 6).

Chlorite observed within all sections as smooth plates and/or windrow needles which sometimes placed instead of large pyroxene phenocrysts (figure 8c, g and j) or it fills intra-grain spaces and rock holes (figure 7) and fractures.

Abundant calcite (sometimes beside secondary microcrystalline SiO2) filled casts of altered crystals (figure 8h, k), open spaces, holes and fractures, which points to large CO_2 content of parental magma.

Sometimes albite observed - within holes (figure 7) or open spaces belong to previous grains - that formed due to hydrothermal fluids operation.
Also, large amounts of epidote (especially clinozoisite [4]) observed within chlorite-filled veins which could refer to the act of such fluids.

Uralitized pyroxene and (sometimes) hornblende crystals may suggest weak metamorphism of some samples in green schist facies.
Opaque minerals such as pyrite, hematite and ilmenite usually observed as disseminated fine-grained fragments (figures 5, 8) or as filled sites of altered pyroxene crystals (figure 8 d to f).

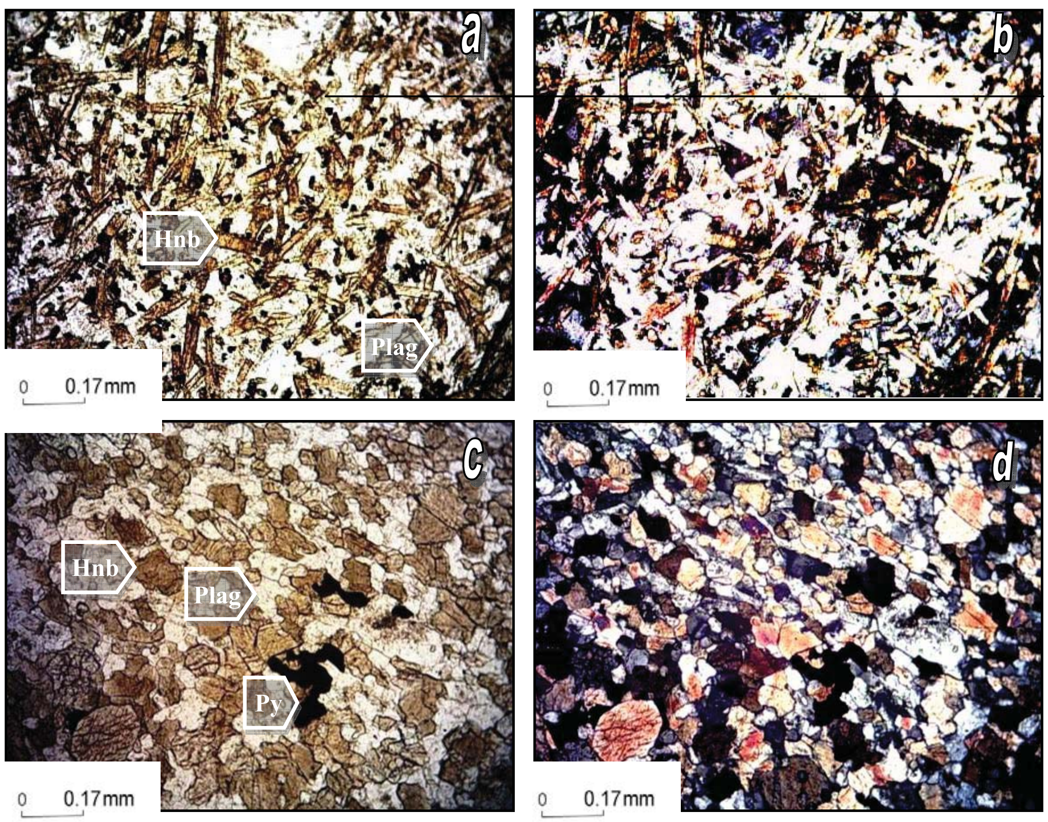


Figure 5 – observed textures in lamprophyre thin sections under the microscope (a and c: PPL; b and d: XPL):

- A and b: needle shape brown hornblende grains inside plagioclase (albite) background observed, fine grains of pyrite and small fragments of jarosite could be observed; XRD analysis for the sample shows magnesio-hornblende, albite, chlorite and calcite.
- C and d: another observed (aplitic) texture that includes brown sheets of magnesio-hornblende beside anhedral albite grains; opaque mineral is ilmenite.

[1] - Based on XRD analysis its composition is magnesio-hornblende $Ca_2(Mg,Fe)_4Al(Si_7Al)O_{22}(OH)_2$ which only observed in lamprophyres.

[2] - Based on XRD analysis its composition is albite $NaAlSi_3O_8$.

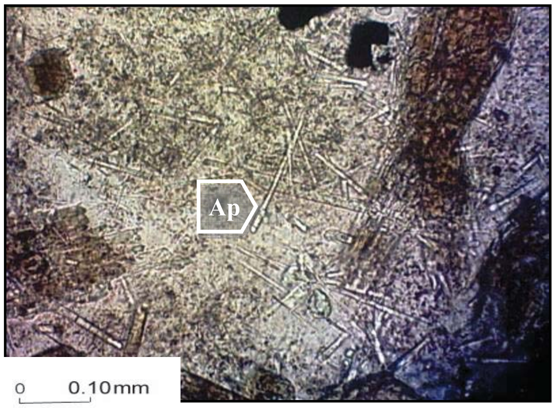


Figure 6 – Apatite needles inside plagioclase (albite) grains show high P_2O_5 content. Pale green color of background appears because of weak chloritization of sample (PPL).

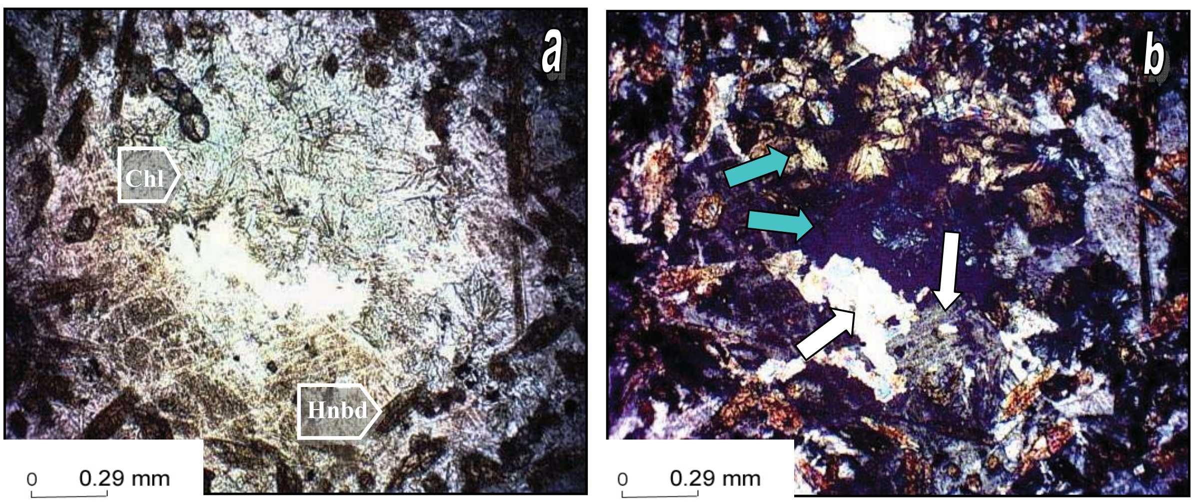


Figure 7 – chlorite (blue arrows) and albite (white arrows) in a filled hole (a: PPL, b: XPL).

Based on mentioned minerals in thin sections and according to lamprophyre classification by their light minerals [7], samples could named as Spessartite (table 1) which usually contains plagioclase (more than alkali feldspar) and rare quartz grains.

Table 1 – classification of lamprophyres based on their light minerals.[7] Colors show different types (yellow: calc-alkaline, red: lamproite, green: Alkaline, blue: Ultramafic and violet: kimberlite). According to the table, the name of our samples is spessartite.

SiO2 decreased →

SiO2 Decreased ↓

Light color minerals	Plagioclase > Alkali Feldspar	Alkali Feldspar > Plagioclase	No feldspar	Without Foids, only melilite observed,
Without Na-Foids or Lucite	Kersantite	Minnette	-	-
May have little quartz	Spessartite	Vogesite	Verites	-
With Lucite, without Na-Foids	-	Jummilites	Orendites	-
With Na-Foids, without Lucite	Camptonite	Sannaite	Monchiquite	Polzenite
Have carbonate and Na-Foids	-	Damkjernite	Ouachitite	Alnoite
Accessory carbonate content, without Foids	-	-	Aillikite Kimberlite	-

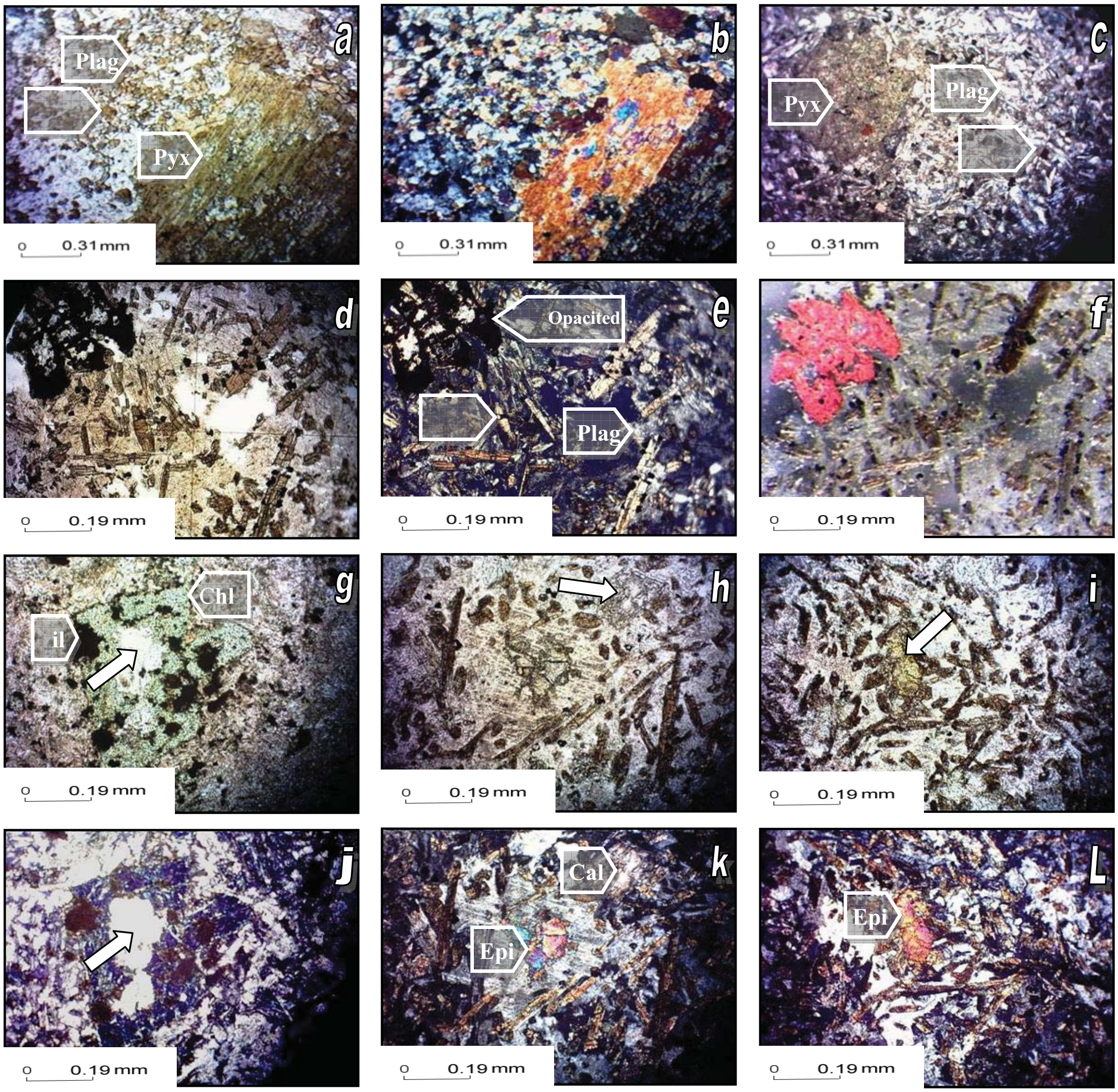


Figure 8 – image comments:

- A and b: Large pyroxene crystal with uralitized edges within plagioclase and hornblende background. (a: PPL, b: XPL).
- C: large chloritized pyroxene grain, plagioclase and hornblende crystals observed (PPL),
- D, e and f: large crystal of completely opacited pyroxene. Image f taken at reflective light shows red iron oxides, fine disseminated opaque mineral is ilmenite. Hornblende needles observed inside chloritized plagioclase background. Apatite in the sample is abundant. In addition, fine-grained calcite observed, (d: PPL, c: XPL).
- G and j: a pyroxene crystal which altered to chlorite, calcite (arrow) and ilmenite (a thin rim of leucoxene observed around ilmenite grains), (g: PPL, j: XPL),
- H, i, k and l: epidote (arrow) formed inside plagioclase crystals. H and k show a pyroxene crystal's cast which completely filled by calcite (arrow), chlorite and opaque phase. I and l show an olivine pseudo morph which formed by epidote. High content of apatite observed in these samples, (h, i: PPL; k, l: XPL).

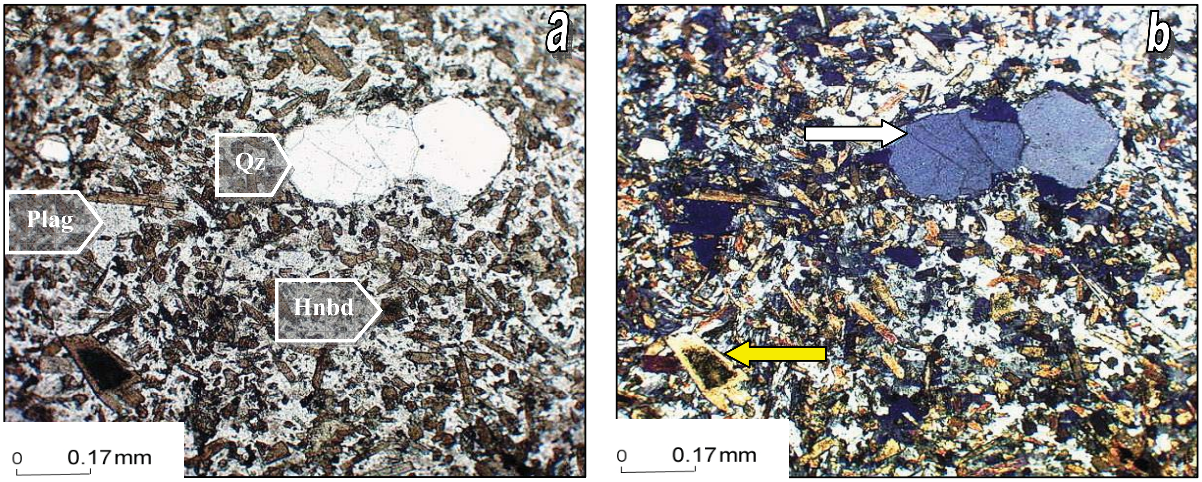


Figure 9 – rounded quartz grains (white arrow) and a hornblende crystal (yellow arrow) with a pyroxene core in a background of hornblende and plagioclase (a: PPL, b: XPL).

Result and Discution

Geochemical studies

Methods

Nine samples selected for XRF, 2 samples for XRD and 2 samples for ICP-MS (REE measurement) analysis. Results presented in tables 2 and 3. For comparison, ICP-MS results for a cretaceous andesite-basalt sample present. Plotted diagrams based on geochemical data observed as figures 10 to 16. In table 4 normative composition of lamprophyre samples observed.

Some XRF and all XRD analysis performed by Kansaran Binaloud Co. and ICP-MS analysis performed by AMDEL laboratories; also other XRF analysis performed by GSI laboratories.

Maps designed by Autocad, landsat image processed by Geomathica, laboratorial results processed and diagrams plotted by MS. Excel and Minpet.

Results:

As it observed in figures 10 and 11, our samples plotted in alkaline field in Total Alkaline – SiO_2 diagrams [9, 10]. These samples placed in both metaluminous – peraluminous areas of Maniar and Piccoli (1989) diagram [10] (figure 12). This bipartisan is in line with high content of CaO at some samples.

Table 2 – Rare earth elements (REE) results prepared by ICP-MS analysis (performed by AMDEL laboratories, Australia). Sample MST-47 is an andesite which belongs to studied area and presented here for comparison. Values presented as part per million (ppm). Average whole rock compositions are from Rock (1991) [7]

Sample	Pr	Nd	Lu	La	Ho	Gd	Eu	Er	Dy	Ce	Sm	Tb	Tm	Yb
Average whole rock composition of calc-alkaline lamprophyres	1.80	0.24	1.10	10.50	11.00	56.0	0.26	53.00	0.90	11.00	3.10	1.60	3.70	110.0
Average whole rock composition of pessartite	1.70	0.19	0.48	7.50	6.80	30.0	0.34	35.00	0.45	4.50	2.20	1.20	2.50	80.0
Mst – 47 (Andesite)	2.37	0.42	0.72	2.97	2.22	10.6	0.35	7.36	0.88	3.47	1.09	2.78	4.56	15.1
Mst - 03	1.57	0.27	0.91	8.69	17.00	59.5	0.25	7.36	0.72	6.21	2.47	2.02	4.31	163.0
T – 2 - 1	1.57	0.29	1.10	13.60	24.40	91.9	0.25	129	0.76	8.46	3.64	2.12	4.98	208.0

Table 3 – Main oxides values resulted by XRF analysis (laboratories of GSI and Kansaran Binaloud Co.), samples Z2 and Z18 belong to Sanandaj lamprophyre samples [8] (laboratory of Shahid Beheshti University). Values presented as percent (%). Average whole rock compositions are from Rock (1991). [7]

Sample	SiO2	TiO2	Al2O3	Fe2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5
Average whole rock composition of calc-alkaline lamprophyres	51.00	1.10	14.00	5.60	2.60	0.13	7.00	7.00	2.70	3.10	0.60
Average whole rock composition of Spessartite	52.20	1.10	15.10	5.80	2.60	0.14	6.80	6.90	3.40	2.10	0.38
Mst - 04	45.00	1.47	12.52	2.97	7.04	0.14	14.30	9.95	1.48	1.98	0.84
mst-03	48.87	1.46	13.04	2.96	6.89	0.15	8.74	8.61	3.07	2.00	0.75
Mst-09-E	49.69	1.17	14.58	2.67	7.78	0.19	4.94	10.97	2.93	1.34	0.48
T-2-1	50.10	1.26	13.01	2.76	3.49	0.16	7.16	9.78	2.58	3.33	1.39
T-3-1	47.62	1.71	14.66	3.21	7.87	0.19	5.23	9.76	2.17	3.43	0.21
T-3-1-UP	48.89	1.57	15.76	3.07	5.73	0.19	8.49	9.65	1.15	1.46	0.26
T-b-6-1	45.39	1.49	15.39	2.99	7.34	0.17	12.52	6.72	2.49	2.45	0.36
Z18	52.28	1.20	16.71	2.70	7.23	0.13	3.04	6.40	3.23	2.99	0.22
Z2	50.97	1.13	16.94	2.63	6.92	0.13	2.98	6.78	3.20	3.11	0.22

Table 4 – normative (CIPW) compositions for lamprophyre samples (calculations performed by Minpet software); (Ab: Albite, An: Anorthite, Wo; Wollastonite, En: Enstatite, Fs: Ferroselite, Fo: Forsterite, Fa: Fayalite).

Sample	Quartz	Orthoclase	Plagioclase		Diopside (Cpx)			Hypersthene (Opx)		Olivine		Magnetite	Ilmenite	Apatite
			Ab	An	Wo	En	Fs	En	Fs	Fo	Fa			
Mst-03	-	12.25	26.88	16.43	9.72	6.55	2.41	2.36	0.87	9.61	3.91	4.45	2.87	1.70
Mst-41	6.13	1.88	24.28	21.53	8.75	4.50	4.03	10.36	9.28	-	-	4.93	3.53	0.81
Mst-42	3.27	1.90	23.51	26.91	5.60	3.18	2.17	16.41	11.19	-	-	3.63	1.81	0.43
Mst-47	-	0.62	21.31	26.60	5.96	4.01	1.49	13.97	5.18	10.86	4.44	3.63	1.74	0.18
T-2-1	-	20.73	22.95	14.78	11.57	9.07	1.19	5.98	0.78	2.65	0.38	4.21	2.52	3.19
T-3-1-Up	4.20	8.97	10.10	34.79	5.59	4.00	1.08	18.06	4.88	-	-	4.63	3.10	0.59
T-7-1-1	10.59	5.00	21.35	24.90	12.24	7.65	3.83	5.72	2.86	-	-	3.62	1.84	0.40

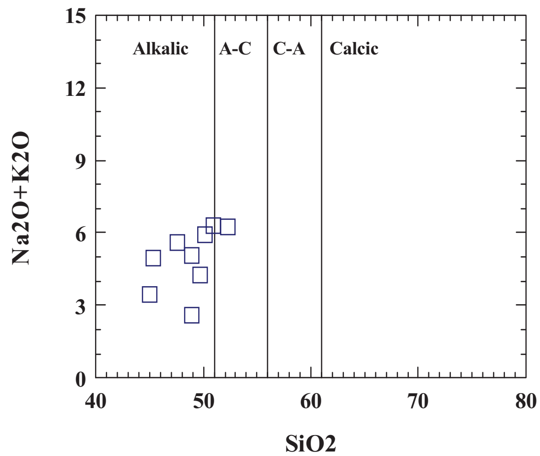


Figure 11 – presenting data in SiO2 versus total alkaline diagram [10].

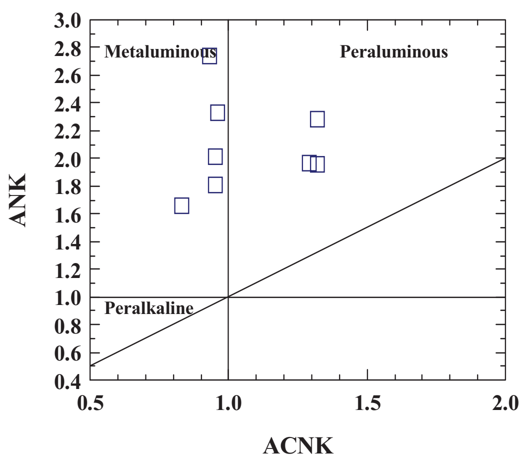


Figure 12 – presenting data on ANK (Al2O3 + Na2O3 + K2O) versus ACNK (Al2O3 + CaO + Na2O3 + K2O) diagram [10]

By comparing REE[1] data prepared by ICP-MS method, we can observe high enrichment in LREEs, which is a special character of such rocks. [7] This enrichment is about 100-400 times above chondorite and mantle standards and 2-4 times above OIB[2] and sialic crust values (figure 13). Such patterns are very similar to calc-alkaline[3] (figure 14) also lamproite patterns which presented by Rock (1991). [7]

He suggested forming of such melts occurred in an enriched source from incompatible elements, and then, the melt suffered crustal contamination through ascending.[7] These processes may be done beneath an active continental margin environment, where an oceanic slab subducted downward a continental plate.

There is a close similarity between our samples' HREEs pattern with samples of cretaceous volcanic unit (which its magma is mantle-derived [4]), so lamprophyre magma is mantle-derived but its lower degrees of melting caused to higher concentration in light REEs (figure 15). Although, crustal contamination process

1-Rare Earth Elements.
2 - Oceanic Island Basalts.
3- Here our aim is Calc-alkaline Lamprophyres

(which caused to more enrichment in LREEs) never could be forget through magma ascending.

Conclusions

During our study on cretaceous volcanic rocks in Saghez area, small bodies with special texture and structure, which led us to name them “Lamprophyre”, observed.

Strong alteration and brecciation of host rock around these bodies also their special foliated (or dia-schistic) structure and green color let us easily recognized them during field studies.

Their texture - which named pan-idiomorphic - under microscope includes automorphic reddish brown hornblende grains (which identified as magnesio-hornblende by XRD analysis) and larger pyroxene – olivine pseudo-morphs and rounded quartz crystals (sometimes as xenocrysts) within a background of plagioclase (albite) and alkali feldspar beside small amounts of chlorite, epidote, calcite, apatite needles and disseminated pyrite grains. In addition, abundant fragments of leucoxene and jarosite observed within the background. These rocks, according to classification of lamprophyres based on their light minerals,[7] named as Spessartite (a calc-alkaline type), although they show intermediate geochemical characteristics between spessartites and lamproites.

In addition, based on microscopic studies, our samples could name as appinitic spessartites (because of their high content of plagioclase and hornblende; also because of their association with large granitoid plutons [4, 7]).

Low degree melting at source (probably upper mantle) as well as later crustal contamination during magma ascending could cause in higher concentration of light rare earth elements (LREEs) against medium (MREEs) and heavy (HREEs) ones.

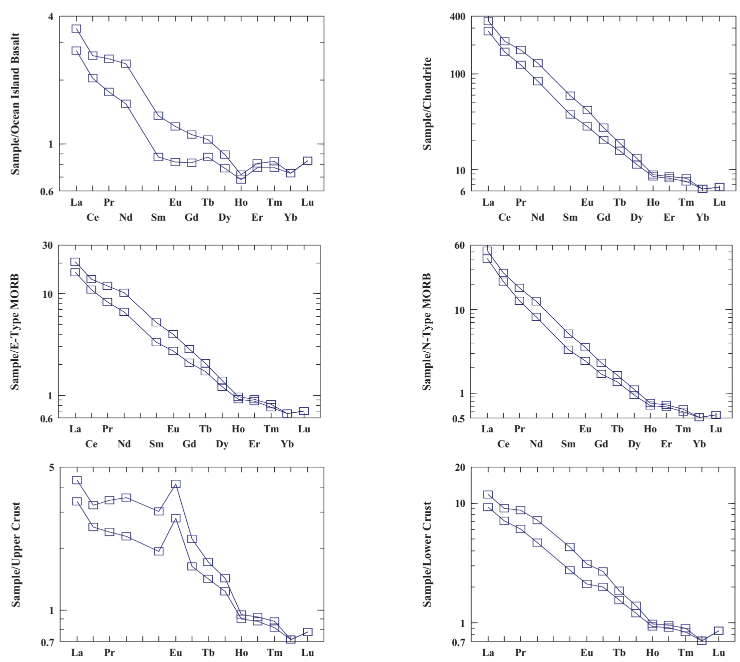
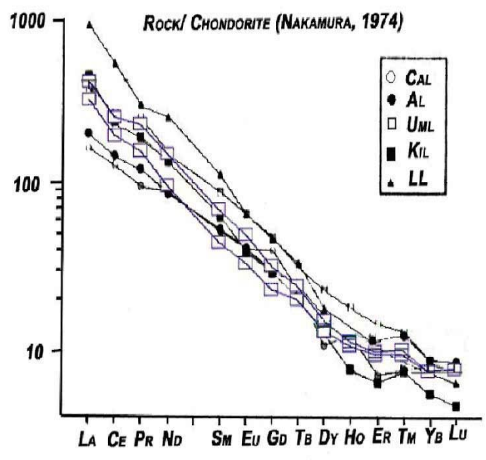
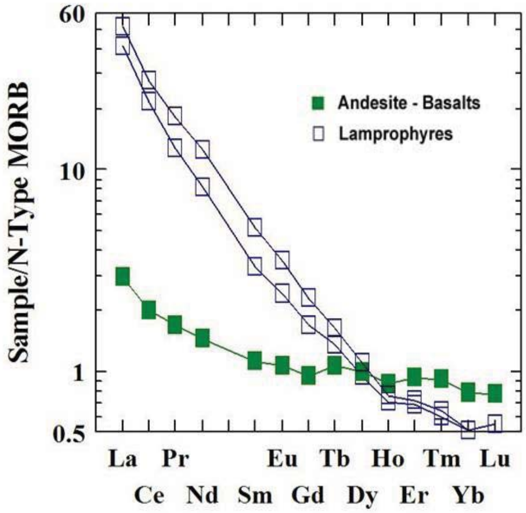


Figure 13 – REE pattern drawn for 2 samples (table 2) which normalized by different standards. Name of each standard observed beside related diagram. There is an obvious enrichment in LREEs.



	Calc-alkaline	Alkaline	Ultramafic	Kimberlite	Lamproite
La	53	66	125	150	310
Ce	110	125	230	200	470
Pr	11	14	29	22	35
Nd	56	54	95	85	157
Sm	10.5	10.8	18	13	23
Eu	3.1	3.1	5	3	5
Gd	11	8.2	13	8	12.7
Tb	1.1	1.2	1.5	1	1.6
Dy	3.7	5.4	7.9	.	6
Ho	0.9	0.9	1.3	0.55	1
Er	1.6	2.7	3.2	1.45	2.3
Tm	0.24	0.38	0.4	0.23	.
Yb	1.8	1.8	1.9	1.2	1.6
Lu	0.26	0.29	0.27	0.16	0.22

Figure 14 – A comparison between our patterns with presented diagram and of Rock (1991). [7] There is a close similarity between our samples and calc-alkaline and lamproite patterns. Average whole rock REE values of lamprophyre types (which presented at above table) are from Rock (1991) [7] (CAL: Calc-alkaline, AL: Alkaline, UML: Ultramafic, KIL: Kimberlite, LL: Lamproite).



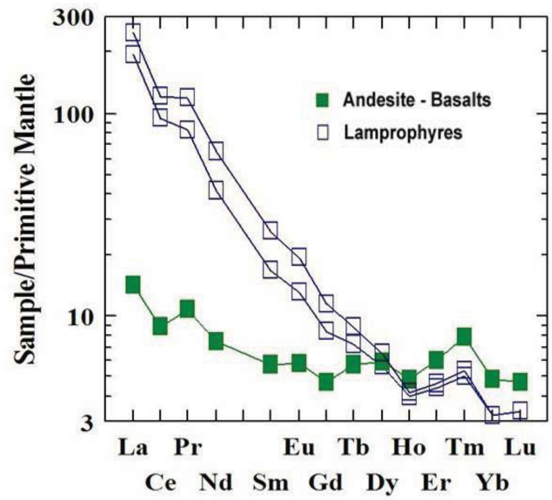


Figure 15 – REE patterns for 2 lamprophyre and 1 cretaceous andesite-basalt samples (table 2). Obvious enrichment in LREEs observed for lamprophyre samples (green squares belong to andesite – basalt sample and hollow squares present lamprophyre values).

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