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PETROGRAPHY OF LAMPROITES FROM THE VILLAGE MRZEN, NORTH MACEDONIA

Ivan Boev[1]
[1]*Faculty of Natural and Technical Sciences, University "Goce Delcev", Stip*
**Corresponding author: ivan.boev@ugd.edu.mk*

Abstract

The paper presents detailed petrographic research using optical microscopy on lamproite rocks around the village of Mrzen, North Macedonia. Detailed microscopic examinations of 5 specimens show that the rocks have typical porphyritic structures and in some places they also show sub-rounded textures with cavities filled with secondary calcite. Phenocrystals that have idiomorphic forms are represented by olivine, clinopyroxene, orthopyroxene, plagioclase, and magnetite. In some places there are changes - alterations in phenocrystals that are represented by iddingsite, smectite-chlorite-goethite), clay and/or zeolites, and calcite. Microscopic examination shows that they are lamproites.

Key words: *lamproites, petrography, phenocrystals, idiomorphic*

INTRODUCTION

The geological structure of North Macedonia consists of several tectonic units that have a northwest-southeast extension within the Balkan Peninsula. The western part of Macedonia belongs to the Dinarides-Helenides belt that was formed in the process of collision between the continental margin of the Adriatic and the Eurasian plate [1-3]. In the central part of Macedonia, it is built of two tectonic units: the Pelagonides and the Vardar Zone. The Pelagonides are built of highly metamorphic rocks of Precambrian age, and they extend northward to the line Skutari-Peja, i.e., Drina-Ivanjica meta-metamorphic terrain [4-10]. The Pelagonides are part of the passive margin of the Adriatic plate [9] (Figure 1). The Vardar zone occupies the central part of Macedonia and it consists of the western ophiolite belt [9] or the Dinaric ophiolite sequence [8] and the eastern ophiolitic belt. Within the eastern ophiolitic belt there is the massif Demir Kapija-Gevgelija as well as the ophiolitic complex of Klepa within which the alkaline rocks of the locality Mrzen appear.

The eastern part of Macedonia belongs to the Serbian-Macedonian massif, which stretches from Serbia through Macedonia to Greece (Figure 1).

This crystalline terrane comprises high- to medium-grade metamorphic units that were separated from Gondwana during a Triassic rifting episode that led to the formation of a branch of the Neotethys Ocean (Vardar-Meliata Ocean) [11-15]. They are of both MORB and subduction-related affinity [11]. Rb/Srand K/Ar age data suggest metamorphism during a Palaeozoic orogen (48819 Ma), with Variscan and younger metamorphic overprints at 275 and 160-127Ma, respectively [11].

In the Vardar zone in Macedonia and Serbia there is occurrence of potassium and ultrapotassium rocks whose age ranges from Miocene to Pleistocene (1.47 Ma) [16] (Figure 1).

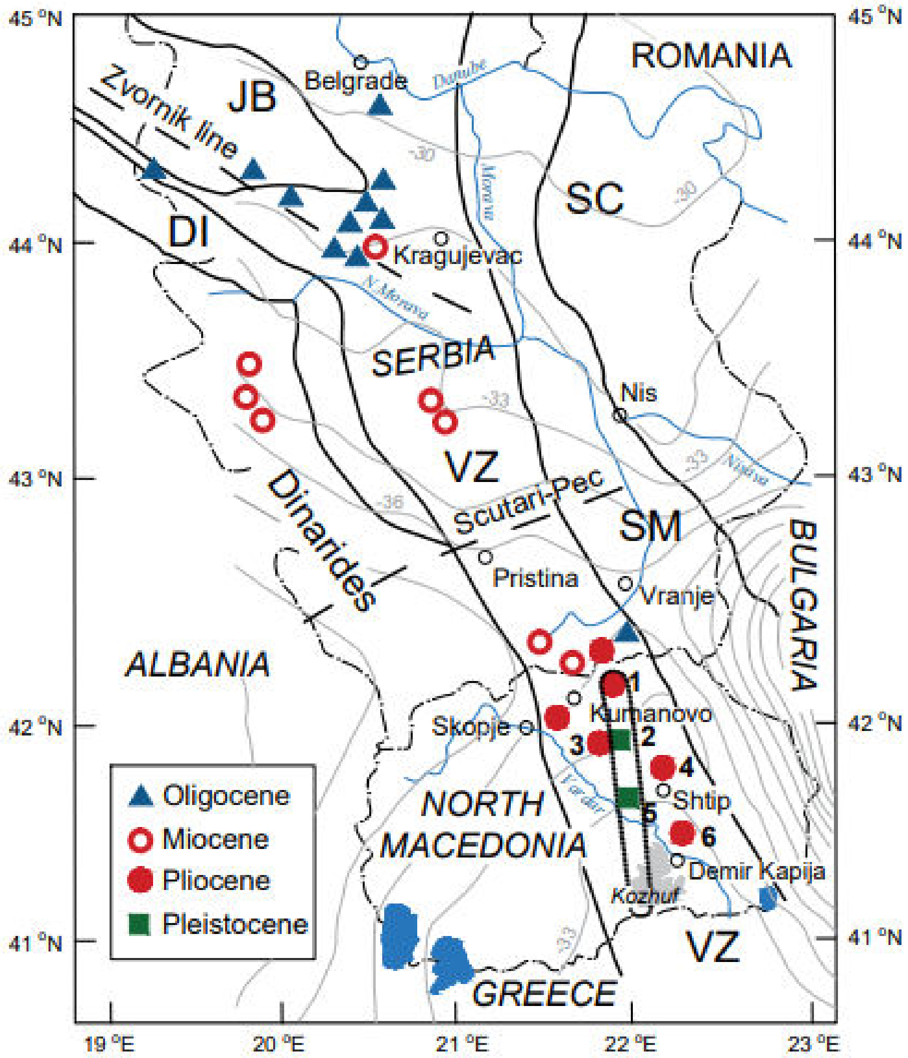


Figure 1. Potassium and ultrapotassium rocks in the Vardar Zone.

MATERIAL AND METHODS

The present "Petrographic Descriptions" provide the following information about each sample:

i. the petrographic rock classification;
ii. microstructural description;
iii. a table with the modal percentage and average grain size for each mineral;
iv. description of the minerals in decreasing order of abundance.

Samples were cut and prepared as ~20 × 40 mm polished thin sections.

The petrographic classification follows the recommendations of Gillespie and Styles (1999) [17].

The microstructural terminology used in this report follows the recommendations and definitions of [18], Some of the petrographic and microstructural terms are defined in the glossary (Table 1).

Table 1. Glossary of Microstructural and Petrologic Terms Used in the Text

Term	Description
amoeboid	With strongly curved and lobate interlocking grain boundaries; like an amoeba.
anhedral	Describes irregular grains showing no crystal-face boundaries.
cleavage domain	Layer or lens with a relatively high content of elongated grains (such as micas or amphiboles) and low content of equidimensional grains (such as quartz, feldspar, or carbonate). Together with microlithons, they make up a spaced foliation. Micas in cleavage domains commonly have a preferred orientation parallel to or at a small angle to the domain.
euhedral	Describes a mineral with crystal faces.
foliation	Planar microstructural element that occurs penetratively on a mesoscopic scale in a rock. Primary foliation includes bedding and igneous layering; secondary foliations are formed by deformation-induced processes.
groundmass	Aggregate that is distinctly finer-grained than the phenocrysts in an igneous rock.
interstitial	Describes a mineral occupying angular cavities or interspace fillings between other minerals.
matrix	Aggregate that is distinctly finer-grained than the crystals, clasts, and lithic fragments in a metamorphic and volcaniclastic rock. The usage is similar to that of "groundmass" in an igneous rock.
phenocryst	Crystal (commonly euhedral) that is distinctly larger than the other minerals around it.
pleochroism	A property of certain crystals of absorbing light to an extent that depends on the orientation of the vector of the light with respect to the optic axes of the crystal.
Poikilitic / poikiloblastic	Describes a crystal with numerous, randomly oriented inclusions of other minerals.
porphyroblast	Crystal that is distinctly larger than the other minerals in a metamorphic rock.
relic (residual structure)	Structure remaining after a deformation or a metamorphic event, such as a porphyroclast in a mylonite, a phenocryst in a metamorphosed volcanic rock, or a partially replaced porphyroblast in a retrograde metamorphic rock. "Relict" is sometimes used as a synonym for "residual."

Polished thin sections (PTS) were examined using a petrographic microscope, under both transmitted and reflected light. Both techniques use the properties of polarized light as it travels through, or reflects off of, the mineral sample, respectively.

Within transmitted light petrography, one can look at a sample in either 'plane polarized light' (ppl), or 'crossed polars' (xp). Plane polarized light is when the light coming through the microscope is traveling in only one direction. This state most closely resembles what the naked eye would see, just magnified. Some minerals show a slight difference in color as the microscope stage is rotated under ppl, and this is called 'pleochroism'. It happens because the light travels faster along one of the three axial planes in the mineral compared to another. Some minerals show a high degree of pleochroism (such as amphiboles), while others are not pleochroic at all.

When a second polarizer is inserted into the light path at the right angle to the first polarizer, the incoming light is now polarized in two directions. This other polarizer is called the 'analyzer', and this state is called 'crossed polars' (or 'xp' for short). The colors that we now see down the microscope are the result of the refraction of two light paths coming through the mineral, and the interaction or 'interference' between them. One light ray comes through the mineral faster than the other, and that is why the colors are called 'interference colors'. They are only seen under a petrographic microscope, and in many cases provide diagnostic information to identify minerals. When there is a large difference between the speeds of the two light rays coming out of the mineral, we can say that there is a high degree of 'birefringence', and therefore higher 'orders' of interference colors will result. This is particularly true for minerals such as carbonates that display anomalously high orders of interference colors, almost resembling a rainbow.

Opaque minerals such as sulfides and oxides appear black in transmitted light and are identified instead under 'reflected light'. This is achieved using the same petrographic microscope, in reflected mode, where the light is now shining on the sample, instead of through it. A mineral is said to be highly 'reflective' if it appears light white or light yellow. A good example of this reflectance is arsenopyrite (white) and pyrite (light butter yellow). Other sulfides are distinguished mainly by their reflectance, from brassy yellow (chalcopyrite), to a golden yellow color (native gold). Pentlandite has a slightly more pinkish reflectance.

Oxides such as hematite and magnetite have a light grey reflectance. Silicates are usually dark grey under reflected light and only the crystal shapes and maybe cleavage traces are visible.

Specific tests are performed using both optical techniques with high powered objectives (2.5x, 5x, 10x, 20x, 50x, and 100x), and specialized petrographic accessories to identify all mineral phases present to the best of the ability of the petrographer. Note that the oculars (eyepieces) also apply a magnification of 10x, therefore the total magnification is the objective magnification multiplied by 10. Images displaying most of the pertinent mineral phases and overall textures are captured using a digital camera mounted on top of the microscope. Scale bars are included in each image, and this scale is calibrated to a micrometer prior to analysis.

RESULTS AND DISCUSSION

Petrography

For the purpose of this paper, five polished tin sections (PTS) were made from several samples of lamproites and they were examined using a petrographic microscope, under both transmitted and reflected light. The results from the conducted examinations are presented further.

Sample M1: Alkali feldspar-altered clinopyroxene-olivine-orthopyroxene-lamproite

Fine-grained laths of plagioclase and subordinate phenocrystals of clinopyroxene, olivine, probable orthopyroxene, and biotite are randomly oriented within a very fine-grained unresolved groundmass. The fine-grained porphyritic microstructure is heterogeneously overprinted by alkali feldspar alteration.

Alteration: alkali feldspar: moderate; **iddingsit**e: moderate to strong after olivine

Figure. 2 Thin section of sample M1

Table 2. Modal mineralogical composition of silica lamproite

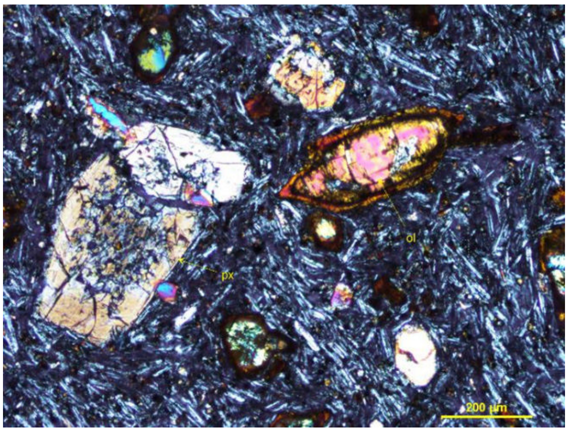
Mineral	*Alteration and Weathering Mineral*	*Modal %*	*Size Range (mm)*
phenocrystals			
olivine	iddingsite: smectite-chlorite-goethite	3–4	up to 0.4 long
clinopyroxene		2–3	up to 0.5 long
orthopyroxene		1.5–2	up to 0.2
groundmass			
plagioclase		59–61	up to 0.1
	alkali feldspar	30–35	up to 0.02
magnetite		2–4	up to 0.05

Plagioclase occurs as subhedral laths (up to 0.1 mm long), which are randomly oriented within the porphyritic microstructure. The plagioclase crystals show Albite twinnings and are relatively fresh. In some of the laths, polysynthetic twinnings and relic growth zoning are observed. While the plagioclase laths are homogeneously distributed, and in some cases show a weak magmatic foliation, the staining color is heterogeneous and forms small patches around some of the phenocrystals or cavities. I interpret this as evidence of the occurrence of plagioclase as fine-grained laths and the **alkali feldspar** as a very fine-grained replacement within the unresolved groundmass. This hypothesis needs to be tested by electron optic analysis.

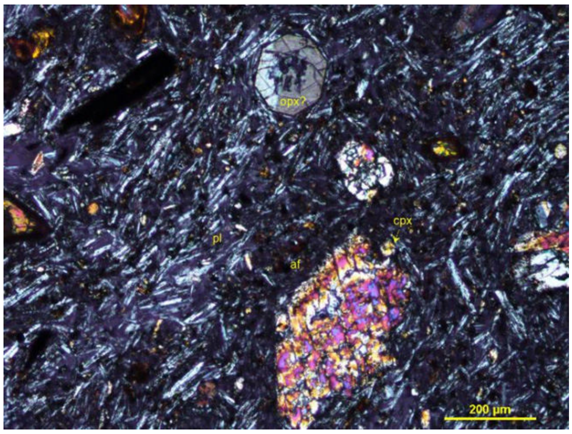
Olivine occurs as fine-grained subhedral to anhedral phenocrystals moderately to strongly altered by iddingsitic (smectite-chlorite-goethite) products.

Clinopyroxene forms subhedral to anhedral phenocrystals (up to 1 mm long) immersed within the fine-grained groundmass dominated by the plagioclase. The plagioclase is distinguished by its high relief, oblique extinction, and extinction angles up to 40°. In some cases, anhedral crystals showing moderate birefringence are tentatively interpreted as **orthopyroxene**, and in some cases, clinopyroxene and orthopyroxene form glomerophenocrystals.

Very fine to fine-grained subhedral crystals of **magnetite** are homogeneously dispersed within the groundmass, and it is not clear if the magnetite is a primary mineral or it is an alteration mineral.



Photomicrograph 1a. Subhedral phenocrystals of pyroxene (px) and olivine (ol) are immersed within a fine-grained groundmass dominated by plagioclase (pl) and patchy aggregates of very fine-grained alkali feldspar. Crossed polarizers transmitted light.



Photomicrograph 1b. Anhedral phenocrystals of clinopyroxene (cpx) are distinguished from subhedral crystals of orthopyroxene (opx). The phenocrystals are immersed within a fine-grained groundmass of plagioclase (pl), which was overprinted by very fine-grained replacement patches of alkali feldspar (af). Crossed polarizers transmitted light.

Sample M2: Alkali feldspar-altered olivine lamproite

Fine - to medium-grained subhedral phenocrystals of olivine are randomly oriented within a fine-grained groundmass dominated by plagioclase laths. The plagioclase shows a weak preferred dimensional orientation defining a weak magmatic foliation.

Alteration: alkali feldspar: weak; **iddingsite**: moderate to strong after olivine; **clay and/or zeolites**: subtle to weak.

Figure. 3 Thin section of sample2 M

Table 3. Modal mineralogical composition of silica lamproite

Mineral	*Alteration and Weathering Mineral*	*Modal %*	*Size Range (mm)*
phenocrystals			
olivine	iddingsite: smectite-chlorite-goethite	10–15	0.1–0.4
groundmass			
plagioclase		81–82	up to 0.1
	alkali feldspar	5–10	up to 0.01
magnetite		1.5–2	up to 0.03
	clay and/or zeolites	1–2	<0.01

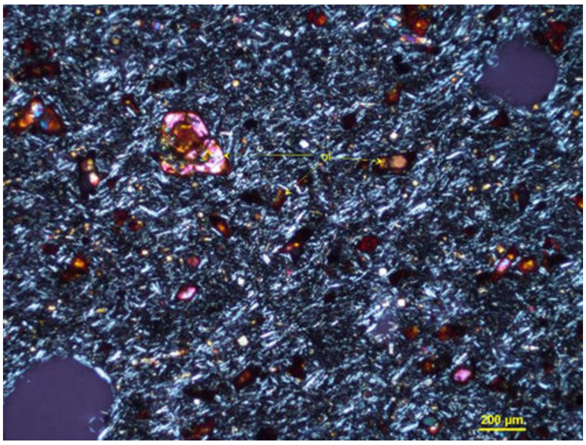
Plagioclase occurs as fine-grained laths (up to 0.1 mm long) preferentially iso-oriented in the groundmass (Photomicrograph 2). The plagioclase crystals are fresh and show Albite twinnings.

Probable alkali feldspar weakly overprinted the groundmass, and in some cases, coated the internal surface of the vugs.

Olivine is homogeneously dispersed within the groundmass as fine-grained subhedral crystals and rare medium-grained (up to 0.4 mm across) phenocrystals. In most of its occurrences, the olivine is moderately altered by iddingsite (smectite-chlorite-goethite). Only in rare cases, the olivine shows its typical high birefringence and straight extinction.

Very fine-grained crystals of magnetite (up to 0.03 mm across) are homogeneously dispersed within the groundmass.

Sub-rounded cavities are filled in by a powdery and creamy white material (clay or zeolites), which in most cases were removed during the polished thin section preparation. The nature of this material would need to be determined by spectroscopic analysis on the billet or hand sample.



Photomicrograph 2. Inequigranular phenocrystals of variably altered olivine (ol) are dispersed within a weakly foliated groundmass dominated by plagioclase. Crossed polarizers transmitted light.

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Sample M3: Alkali feldspar-altered olivine lamproite

This sample is similar to Sample 2. Fine-grained laths of plagioclase dominate the composition of the groundmass, in which fine-grained phenocrystals of olivine and thin prisms of clinopyroxene are dispersed.

Alteration: alkali feldspar: weak; **iddingsite**: weak to moderate after olivine; **clay and/or zeolites-calcit**e: subtle to weak.

Figure. 4 Thin section of sample M3

Table 4. Modal mineralogical composition of silica lamproite

Mineral	*Alteration and Weathering Mineral*	*Modal %*	*Size Range (mm)*
phenocrystals			
olivine	iddingsite: smectite-chlorite-goethite	10–15	0.1–0.4
groundmass			
plagioclase		78–79	up to 0.1
clinopyroxene		4–5	
	alkali feldspar	4–8	up to 0.01
magnetite		1–1.5	up to 0.03
	clay and/or zeolites	1–2	<0.01
	calcite	0.1–0.2	up to 0.2

Very fine to fine-grained laths of plagioclase (up to 0.1 mm long) are randomly oriented and define an isotropic groundmass. The plagioclase crystals are relatively fresh and show Albite twinnings.

Very fine-grained replacement aggregates of alkali feldspar weakly overprinted the plagioclase-rich groundmass. It must be noted that the alkali feldspar was not positively distinguished under the microscope and its occurrence is interpreted based on the pale-yellow staining observed on the billet.

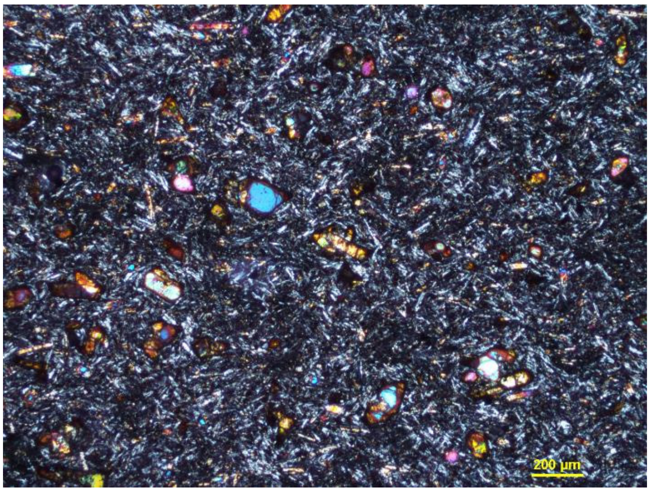
Olivine occurs as fine-grained phenocrystals (up to 0.2 mm long). The fine-grained anhedral to subhedral crystals are weakly to moderately altered by iddingsite (smectite-chlorite-goethite) and are randomly oriented within the groundmass.

Clinopyroxene forms thin prisms (up to 0.2 mm long), which are dispersed and randomly oriented within the plagioclase-rich groundmass.

Sub-rounded vesicles are heterogeneously dispersed within the fine-grained magmatic rock. Some of the vesicles are filled in by vitreous light unresolved material. This material was detected on the billet and it was removed during the preparation of the thin section. I interpret the material as clay and/or zeolites fillings.

Very fine-grained anhedral crystals of magnetite (up to 0.05 mm across) are homogeneously dispersed within the groundmass.

Rare replacement patches of calcite are dispersed within the groundmass.



Photomicrograph 3. Mostly anhedral phenocrystals of olivine (highly birefringent) are randomly oriented within the plagioclase-rich groundmass. Plane-polarized / Crossed polarizers transmitted / reflected light.

Sample M4: Alkali feldspar-altered olivine lamproite

Irregular replacement patches of alkali feldspar overprinted a fine-grained porphyritic microstructure compositionally and microstructurally similar to Sample 2 and 3.
Fine-grained laths of plagioclase are randomly oriented and host fine-grained anhedral phenocrystals of olivine and fine-grained prismatic crystals of clinopyroxene.

Alteration: alkali feldspar:weak; **iddingsite**:weak to moderate after olivine; **calcite**: subtle.

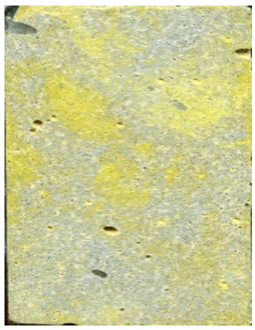


Figure. 5 Thin section of sample M4

Table 5. Modal mineralogical composition of silica lamproite

Mineral	*Alteration and Weathering Mineral*	*Modal %*	*Size Range (mm)*
phenocrystals			
olivine	iddingsite: smectite-chlorite-goethite	10–12	0.1–0.4
groundmass			
plagioclase		77–78	up to 0.1
	alkali feldspar	10–15	up to 0.01
magnetite		1–1.5	up to 0.03
	calcite	0.5–1	up to 0.2

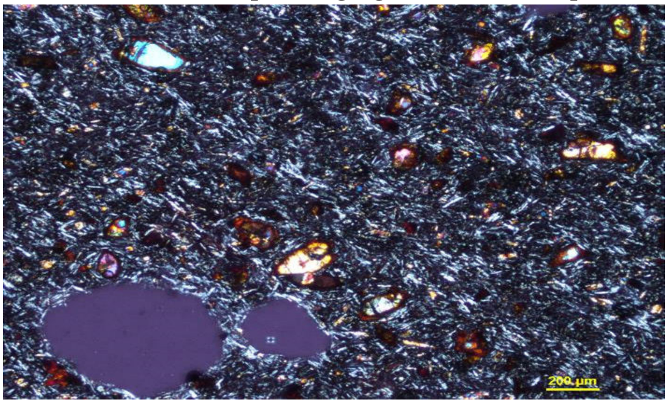
Plagioclase is very fine- to fine-grained (up to 0.1 mm long) and prevails over a very fine-grained unresolved earthy aggregate. I interpret this aggregate as alkali feldspar because of the yellow color of staining shown on the billet. The staining's patchy distribution indicates that the alkali feldspar post-dated the magmatic assemblage, and I interpret it as an alteration mineral.

Olivine is fine-grained anhedral to subhedral, and its crystals are randomly oriented within the groundmass. Similar to the other samples (sample 1–3), olivine is weakly to strongly altered by iddingsite, and in some cases, the pseudomorphs after the olivine show a brown color under plane-polarized transmitted light.

Fine-grained elongated prisms of clinopyroxene are dispersed within the groundmass and are distinguished by their high birefringence and oblique extinction.

Very fine-grained crystals of magnetite are homogeneously dispersed within the groundmass.

Calcite filled in amygdules up to 1.5 mm in diameter. In most of the cases, the vesicles are empty and show sub-rounded shapes ranging from 0.3 mm up to 1.5 mm in diameter.



Photomicrograph 4. Sub-rounded vesicles (in the lower left part of this photomicrograph) are dispersed within the fine-grained plagioclase-rich groundmass hosting sparse crystals of olivine. Crossed polarizers transmitted light

Sample M5: Alkali feldspar-altered pyroxene-olivine lamproite.

Subhedral to anhedral phenocrystals of clinopyroxene and anhedral to subhedral phenocrystals of olivine are immersed within a fine-grained groundmass dominated by plagioclase laths and heterogeneously overprinted by very fine-grained alkali feldspar.

Alteration: alkali feldspar: moderate; **iddingsite**: weak to moderate after olivine; **iron oxides:** strong after biotite.

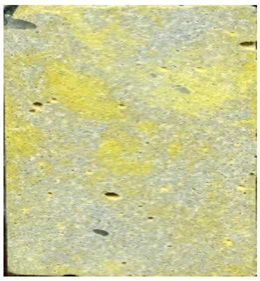


Figure. 6 Thin section of sample M5

Table 6. Modal mineralogical composition of silica lamproite

Mineral	*Alteration and Weathering Mineral*	*Modal %*	*Size Range (mm)*
phenocrystals			
olivine	iddingsite: smectite-chlorite-goethite	8–10	0.1–0.4
clinopyroxene		2.5–3	up to 0.5 long
orthopyroxene		2–2.5	up to 0.4
[biotite]	iron oxides	0.5–0.6	up to 0.35 long
groundmass			
plagioclase		71–72	up to 0.1
	alkali feldspar	12–15	up to 0.01
magnetite		2–4	up to 0.03

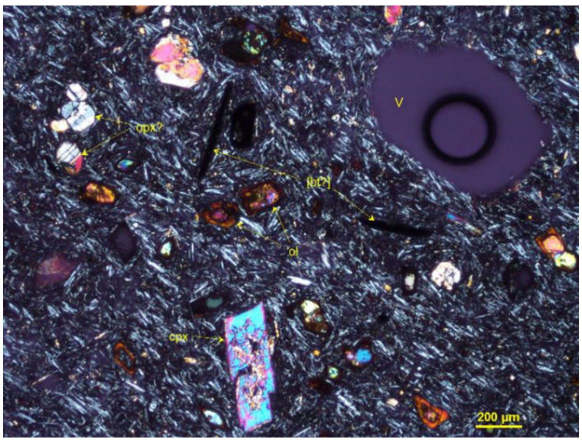
Plagioclase occurs as fine-grained laths (up to 0.1 mm long), dominating the composition of the groundmass. The plagioclase crystals are relatively fresh and show Albite twinnings. In some cases, the plagioclase laths are preferentially iso-oriented and define a weak magmatic foliation in the groundmass. Very fine-grained replacement aggregates of **alkali feldspar** are heterogeneously dispersed within the groundmass. Similar to the other samples, the alkali feldspar was not positively distinguished under the microscope. Its occurrence is deducted by the yellow staining color observed on the billet. The alkali feldspar needs to be determined by electron optic analysis.

Olivine forms fine-grained anhedral to subhedral crystals dispersed within the groundmass. The olivine is weakly to strongly altered by a brown and unresolved iddingsitic material (probable smectite-chlorite-goethite). Only in some cases, the olivine shows high birefringence and straight extinction.

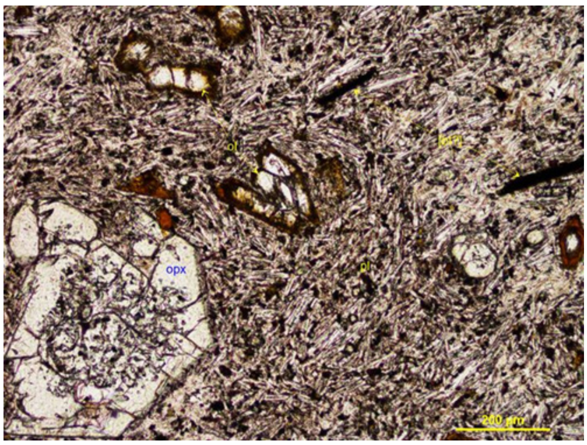
Subhedral to anhedral phenocrystals of clinopyroxene are randomly oriented within the groundmass and are distinguished by their high relief, oblique extinction, and extinction angle up to 40°. Probable orthopyroxene phenocrystals are up to 0.35 mm across and show moderate birefringence colors (Photomicrograph 5a and 5b).

Very fine-grained anhedral crystals of magnetite are homogeneously dispersed within the plagioclase-rich groundmass.

Elongate alteromorphs after biotite (Photomicrograph 5a and 5b) are completely replaced by iron oxides. In some cases, the alteromorphs are oriented parallel to the magmatic foliation.



Photomicrograph 5a. Irregularly shaped to subrounded vesicles (V), subhedral phenocrystals of clinopyroxene (cpx), orthopyroxene (opx?), olivine (ol) and elongated alteromorphs after biotite [bt?] are immersed within a fine-grained groundmass dominated by plagioclase laths. Crossed polarizers transmitted light.



Photomicrograph 5b. Subhedral phenocrystals of orthopyroxene (opx), fine-grained crystals of olivine (ol) and alteromorphs after biotite [bt?] are dispersed within a plagioclase-rich groundmass (pl). Plane-polarized transmitted light

CONCLUSION

Detailed microscopic examinations of 5 specimens show that the rocks have typical porphyritic structures and in some places they also show sub-rounded textures with cavities filled with secondary calcite. Phenocrystals that have idiomorphic forms are represented by olivine, clinopyroxene, orthopyroxene, plagioclase, and magnetite. In some places there are changes - alterations in phenocrysts that are represented by iddingsite, smectite-chlorite-goethite), clay and/or zeolites and calcite. Microscopic examination shows that they are lamproites.

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ПЕТОГРАФИЈА НА ЛАМПРОИТИТЕ ОД ОКОЛИНАТА НА СЕЛОТО МРЗЕН, СЕВЕРНА МАКЕДОНИЈА

Иван Боев[1]
[1] *Факултет за Природни и Технички науки, Универзитет "Гоце Делчев" Штип*
*Контакт автор: *ivan.boev@ugd.edu.mk*

Резиме
Во трудот се прикажани деталните петрографски истражувања со примена на оптичка микроскопија на лампроитските карпи од околината на селото Мрзен, Северна Македонија. Деталните микроскопски испитувања на 5 примероци покажуваат дека карпите имаат типични порфирски структури а на места покажауваат и мандолести текстури при што мандолите (шуплините) се исполнети со секундарен калцит. Фенокристалите, кои имаат идиоморфни облици се преставени со: оливин, клинопироксен, ортопироксен, плагиокласи и магнетит. На некои места се забележуваат промени, алтерации по фенокристалите а кои се преставени со: идингсит-смектит, хлорит-гетит, глини, зеолити и калцит. Микроскопските испитувања покажуваат дека станува збор за силициски лампроити.

Клучни зборови: *лампроити, петрографија, фенокристали, идиоморфни*