

DOI 10.51558/2303-5161.2025.13.13.1

Scientific paper

MICROPHYSIOGRAPHY OF SPILITES AND ASSOCIATED ROCKS IN THE SURROUNDINGS OF VAREŠElvir Babajić¹, Alisa Babajić², Alma Imamović³, Maida Tanjić⁴, Selma Ćatić⁵

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Summary

Twelve samples of spilites and associated rocks from the surroundings of Vareš were processed microphysiographically. Based on optical examinations of rocks, structural-textural characteristics, rock color, type and intensity of alteration processes, and respecting the existing classification schemes, different lithotypes were defined. Spilites are the dominant rock type. Taking into consideration textural varieties, ophitic and porphyritic spilites were distinguished. These two varieties are mineralogically similar. The main petrogenic minerals are albite and augite, with a dominating amygdaloidal structure, while the vesicular and fluidal structures are subordinate.

The rocks associated with the spilites are ophitic basalts, rocks of spheroidal jointing, with amygdaloidal and vesicular structure. Both structure and jointing are parameters that distinguish them from similar diabases.

Keywords: ophitic spilites, porphyritic spilites, ophitic basalts, Vareš.

1. INTRODUCTION

The term spilite refers to altered aphyric basaltic rocks that are poor in phenocrysts or to albitized basaltic lavas (*Le Maitre et al. 2002*). Spilites are the most widespread Triassic volcanic rocks in the Dinarides. Initially, they were identified in the vicinity of Sarajevo. Spilites are most widely distributed in the Triassic volcanic area of Zelengora - Treskavica - Igman and along the belt Čevljanovići - Vareš - Borovica. They were also discovered at Krstac near Prozor, in the Vrbas valley and near Čajniče. Spilites near Čajniče are subordinated to the more felsic differentiates (*Pamić, 1957*).

Significative approach to the microphysiography of spilites and associated rocks around Vareš was realized in the 70s of the last century. The results of a modest scope were published more than half a century ago. During the year 2024, as a part of the scientific-research project *Petrological and geochemical characterization of the upper part of the ancient oceanic crust – Vareš surroundings*, the rocks in question were systematically sampled and petrographically defined. A total number of twelve rock samples were examined. Their nomenclature and classification,

according to the standard classification schemes, are based on optical tests of rocks and their structural-textural characteristics, as well as the way they appear in the field.

2. GEOLOGICAL STRUCTURE

Vareš is a town located in Central Bosnia, in the upper course of the river Stavnja. Distance from Sarajevo (north) and Zenica (east) is about 35 km of airline.

In geotectonic terms, the wider area of Vareš belongs to the contact of the central ophiolite zone (northern wing of the Vareš structure) and the zone of Paleozoic schists and Mesozoic limestones (southern wing of the Vareš structure). This structure extends approximately in direction WNW-SE along the Borovica - Ravne section, from where it bends south towards Čevljanovići and Srednje.

This unit also includes elongated volcanic bodies that follow the aforementioned orientation. The most notable in size are the bodies in the immediate vicinity of Vareš (0.4 x 4.2 km, area of about 135 ha) and in the Zubeta - Ravne section (0.3 x 4.4 km, area of about 113 ha).

At the beginning of the Alpine magmatic-tectonic cycle, Vareš area was covered by the sea, and it is assumed that the sedimentary basin was differentiated into a southern and northern part.

The northern development of the Lower Triassic (Scythian - T_1) is represented by quartz sandstones (so-called "Sarajevo sandstones") and sandy clays, while carbonate sediments are completely absent. The southern development of the Lower Triassic is characterized by fine-grained sandstones with a carbonate binder, followed by sandy clays, marls and sandy limestones. The final members of this development are clayey dolomites and tufa limestones (Zellenkalk), which are particularly widespread east of Vareš, in the wider area of Pržići and Dahštansko (Figure 1).

Anisian formations (T_2^1) have been analysed in detail in several localities and well documented paleontologically, which made it possible to separate two Anisian developments. The northern Anisian development (T_2^1) is simple. There usually dark gray crinoid limestones about 60 m thick lie above the white coarse-grained quartz sandstones. Quartz sandstones are conglomeratic in places. Above them are massive and lumpy Han-Bulog limestones, and over them are massive gray dolomitic limestones (Mountain Zvijezda). Limestones are most often recrystallized biosparites and intrasparites, and less frequently microsparites and calcutites. Often, however, Anisian is represented only by massive dolomitic limestones.

In the southern development of Anisian (T_2^1) there is a gradual transition from Scythian to Anisian. Transitional horizon is characterized by clayey dolomites or porous dolomitic limestones, overlain by gray layered dolomites.

Ladinian formations (T_2^2) are widespread in both the northern and southern wings of the Vareš Triassic structure, but with significant lithofacial differences. In many cross-sections, a gradual transition from Anisian to Ladinian is observed. Transitional horizon is characterized by hematite and manganese claystones (Vareš area), or dolomites and dolomitic limestones (Borovica area). The northern development of Ladinian is represented by limestones and dolomitic limestones, while the southern development is characterized by spilites, tuffs, clays, cherts and limestones. Ladinian is paleontologically documented in both developments.

In the northern development Ladinian is developed only in carbonate facies: limestones and dolomitic limestones predominate (mainly pseudosparites and recrystallized biosparites, less frequently recrystallized biomicrites, or dismicrites). In some places, these limestones contain nodules and lenses of cherts. The limestones are massive and most often cannot be separated from the identical Anisian limestones.

Magmatic members of the Ladinian are represented by spilites and tuffs. It is a discontinuous zone of volcanic rocks that occurs from Vareš to Čevljanovići. Spilites appear in the pillow forms or brecciated pillow forms (diameter of pillows 20-70 cm) with enclaves of Anisian limestones, which was one of the reasons for their inclusion in the Ladinian. Pyroclastic rocks, as companions of volcanism, are found only in Ladinian sediments. The lowest position of extrusive rocks is over the limestones of the Anisian zone *Ceratites trinodosus*.

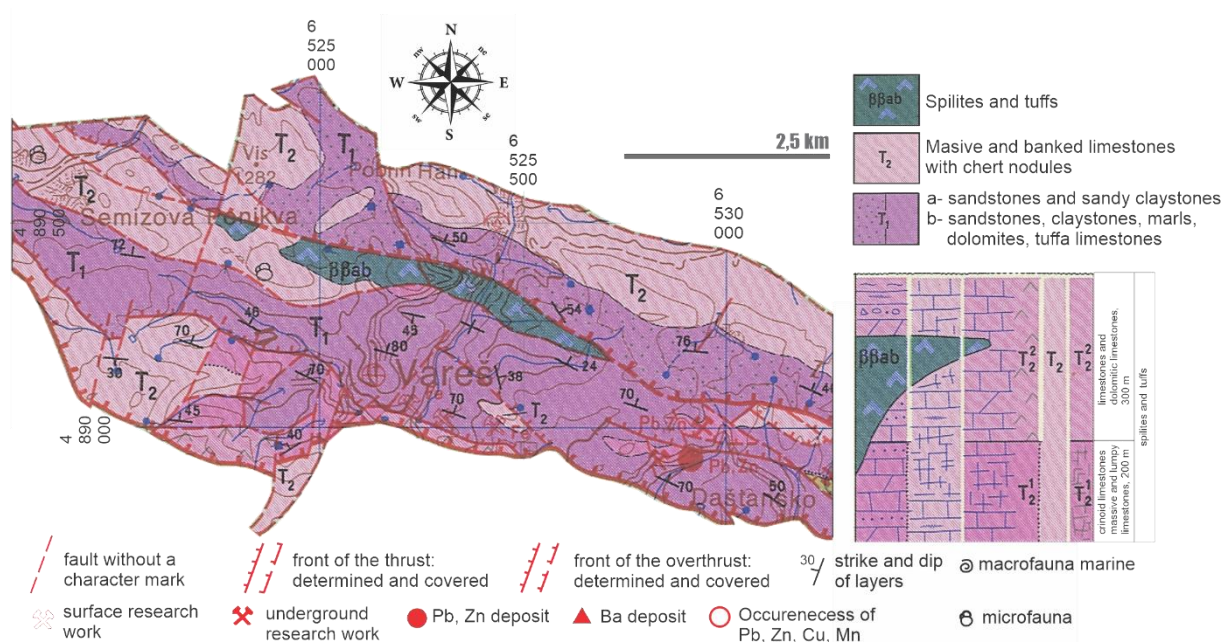


Figure 1 – Geological map of the wider Vareš area (Olujčić et al., 1970).

In the southern development, Ladinian is represented by coloured clays and cherts, and plate limestones (siliceous micrites, less often microsparites and pseudosparites). Mentioned sediments usually alternate and can be layered with tuffs and tuffitic sandstones. Among the igneous rocks, the already shown spilites are the most common. Entire complex is finely folded and meters-long folds are very common. Mentioned folds are often intersected by faults (Olujčić et al., 1970; Pamić et al., 1970).

3. RESEARCH AND TESTING METHODS

During field activities in the surroundings of Vareš (February - March 2024), 25 rock samples were collected on several occasions. After macroscopic determination, the number of samples was reduced to 12 (table 1).

Table 1. Labels and geographical positions of taken rock samples.

sample	N	E	sample	N	E
2	44°10'11.51"	18°19'59.42"	8	44°10'7.56"	18°19'57.14"
3	44°10'13.48"	18°19'55.42"	9	44°10'1.73"	18°19'57.38"
4	44°10'7.36"	18°19'25.47"	10	44°10'2.60"	18°19'58.19"
5	44°10'18.58"	18°19'27.05"	11	44°10'7.74"	18°19'57.21"
6	44°10'19.60"	18°18'47.36"	12	44°10'3.19"	18°19'59.29"
7	44°10'18.10"	18°19'29.32"	13	44°10'7.85"	18°19'57.03"

Samples for petrographic examinations were taken directly from the outcrops discovered in the cuttings and also from the streams. The number of field samples was determined depending on the geological structure of the terrain, its exposure, access, observed mineralogical and structural-textural varieties, and the freshness of the rocks (Figure 2). Thin sections for rock microphysiography were made at the Croatian Geological Institute in Zagreb.

Optical tests were performed on a Leica DM 2500P polarizing microscope at the Faculty of Mining, Geology and Civil Engineering of the University of Tuzla. Microphotographs were taken under orthoscopic conditions, with and without the analyzer on. In order to obtain realistic colors on the microphotographs, with regard to the used light source, a software correction of the white color balance was performed.

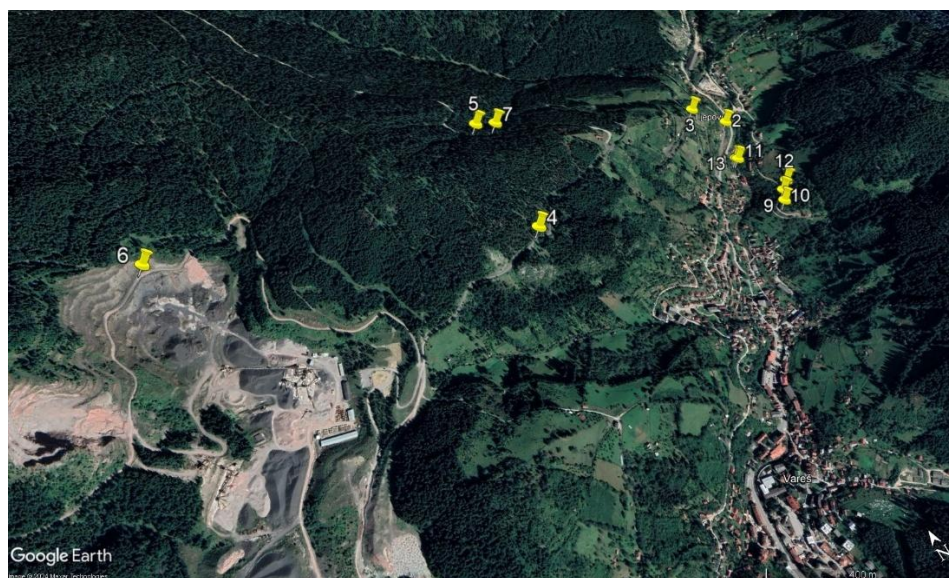


Figure 2 – Geographic positions of taken rock samples.

4. TEST RESULTS

4.1. Macroscopic determination

Textural types are diverse, and among structural types amygdaloidal, vesicular, brecciated and homogeneous structures were found (Figure 3).

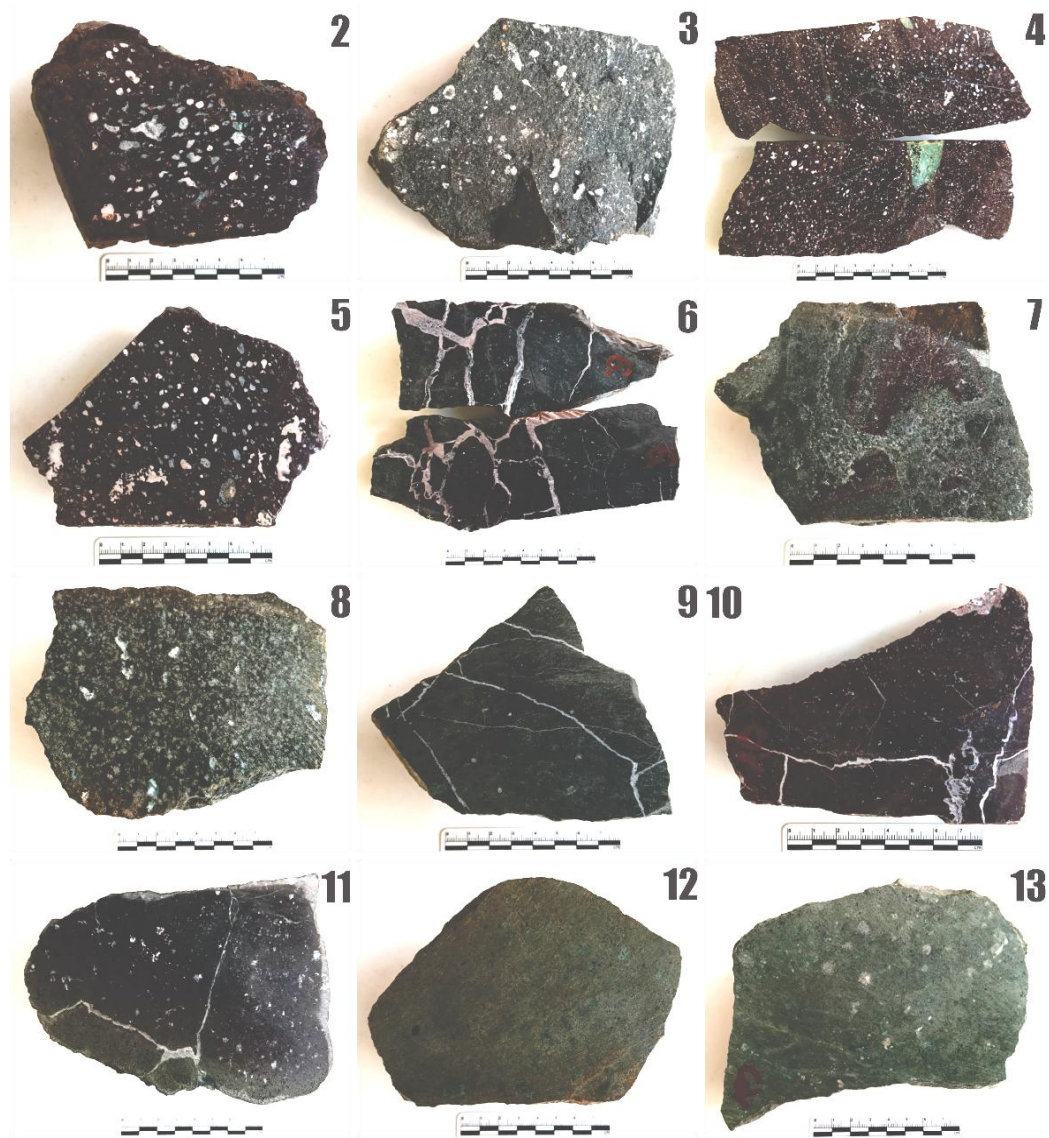


Figure 3 – Macrophotographs of sampled rocks.

Based on the color, presence/absence of amygdaloides and cracks, the following groups of rocks are distinguished:

- purple rocks with amygdaloides, vesicles and cracks. Amygdaloides occupy up to 30% of the rock, and are up to 0.5 cm in diameter. Their filling is white (calcite) and greenish (samples 2, 4 and 5). In samples 6, 9, 10 and 11, cracks dominate over the amygdaloides. The cracks are irregularly oriented, filled with white colored minerals, up to 3 mm in diameter. Amygdaloides appear sporadically, white and greenish in color, up to 1 mm in diameter.
- gray rocks with amygdaloides and cracks. Amygdaloides occupy up to 15% of the rock, and are up to 0.3 cm in diameter. Their filling is white (calcite) and greenish (samples 3 and 8). Along with the amygdaloides, there are irregular piles of pyrite (diameter 2-3 mm), mostly around the edges of the amygdaloides (sample 3).
- greenish colored rocks, with cracks that dominate over sporadic amygdaloides (samples 12 and 13).

According to structural characteristics, sample number 7 stands out. This sample is characterized by brecciated appearance, and is defined as spilitic conгло-breccia. It is built of

polygonal to semi-rounded fragments of ophitic spilites, and the space between the lithoclasts is composed of "glass".

During the field observations, characteristic phenomena of jointing of the rocks in question were observed. The predominant jointing is spherical/pillow-like. The diameters of the pillows range from 20 to 70 cm. Less common is plate-like rock jointing (Figure 4).

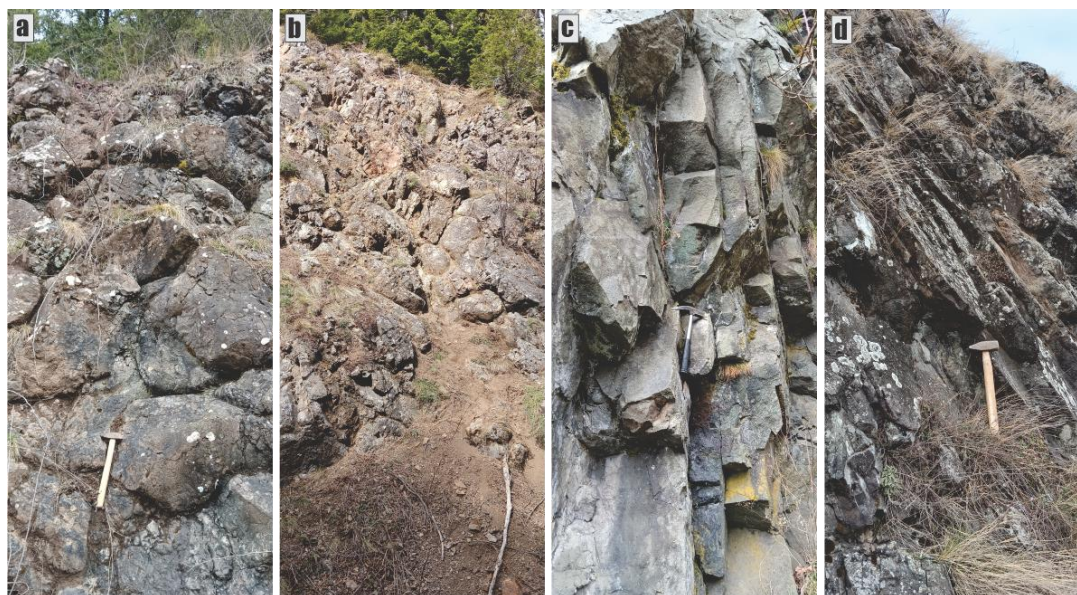


Figure 4 – Jointing of spilites and associated rocks in the Vareš surroundings: a, b) spherical/pillow-like; c, d) plate-like.

4.2 Rocks microphysiography

Spilites

Mineral composition of both structural varieties of spilite (ophitic and porphyritic) is quite uniform (tables 2 and 3). Albite is the most common mineral. It appears as idiomorphic, prismatic or needle-like. The grain length ranges from 0.2 - 0.4 mm. Albite in spilites is rarely fresh, more often it is altered, i.e. suppressed by small secondary minerals: calcite, greenish celadonite, pumpellyite and chlorite (?). According to data from theodolite-microscopic measurements, they usually contain 3-5% of the anorthite component (*Pamić, 1963*).

Plagioclases occur in prismatic forms up to 0.5 mm long. They are irregularly arranged in the rock mass; in some places they form piles, which create the impression of a glomeroporphyric texture. Plagioclases are albitized, blurred and "eroded" by magmatic resorption.

Characteristic feric mineral of spilite is augite, which appears in separate grains of allotriomorphic and hypidiomorphic habit (phenocrysts up to 0.7 mm), then may be branch-like and divergent-rayed. It is rarely fresh, mostly is disintegrated, chloritized and to a lesser extent epidotized. In spilites, which in a ground mass have an elevated content of brown-black isotropic matter, augite may be absent.

Among secondary minerals, celadonite, pumpellyite, chlorite, and accessory ilmenite and magnetite were also detected in the spilites. Pumpellyite appears in the form of fine-grained greenish-brown pleochroitic and dendritic aggregates. It appears in the marginal parts of the

pillows, probably as a result of volcanic glass devitrification during submarine hydrothermal activity, what is indicated by relics of glass around amygdaloids. Celadonite was created by the alteration of feric minerals. Crystals and fine-grained aggregates are green-blue in color. It appears in amygdaloids, cracks and in the ground mass of the rock (Babajić A. *et al.* 2013; Babajić A. *et al.* 2017; Babajić A. and Babajić E., 2023).

Table 2. Mineral composition, texture and structure of ophitic spilites.

sample	mineral composition	texture / structure
2	Ab, Aug, Cal, Cel, G, Ilm	hyalo-ophitic / amygdaloidal, vesicular
3	Pl, Aug, Ab, Cel, Cal, G, Py, Ilm	ophitic / amygdaloidal
4	Ab, Cal, Cel, Chl, Ilm	hyalo-ophitic / amygdaloidal
5	Ab, Aug, Cal, Cel, G, Ilm, Mag	hyalo-ophitic / amygdaloidal
6	Aug, Ab, Cel/Chl	hyalo-ophitic / amygdaloidal
7	Ab, Cal, Cel, Chl, Pmp, G, Ilm	ophitic / brecciated
9	Aug, Ab, Cel/Chl	ophitic / amygdaloidal, fluidal
10	Ab, Cal, Cel, Chl, Pmp, G, Ilm	ophitic / amygdaloidal

(Ab - albite, Aug - augite, Pl - plagioclase, Chl - chlorite, Cal - calcite, Pmp - pumpellyite, Cel - celadonite, Py - pyrite, Ilm - ilmenite, Mag - magnetite, (Warr, 2021)), G - glass (internal mark).

Among the secondary minerals, presence of greenish chlorite was very often emphasized (Pamić, 1963, Pamić and Đorđević, 1966). Subsequent research indicated that it is celadonite and pumpellyite (Trubelja *et al.*, 1976), which was also confirmed in this case. In some of the samples, it was not possible to determine with certainty whether it was chlorite or celadonite, and both of these minerals were taken into account (Cel/Chl).

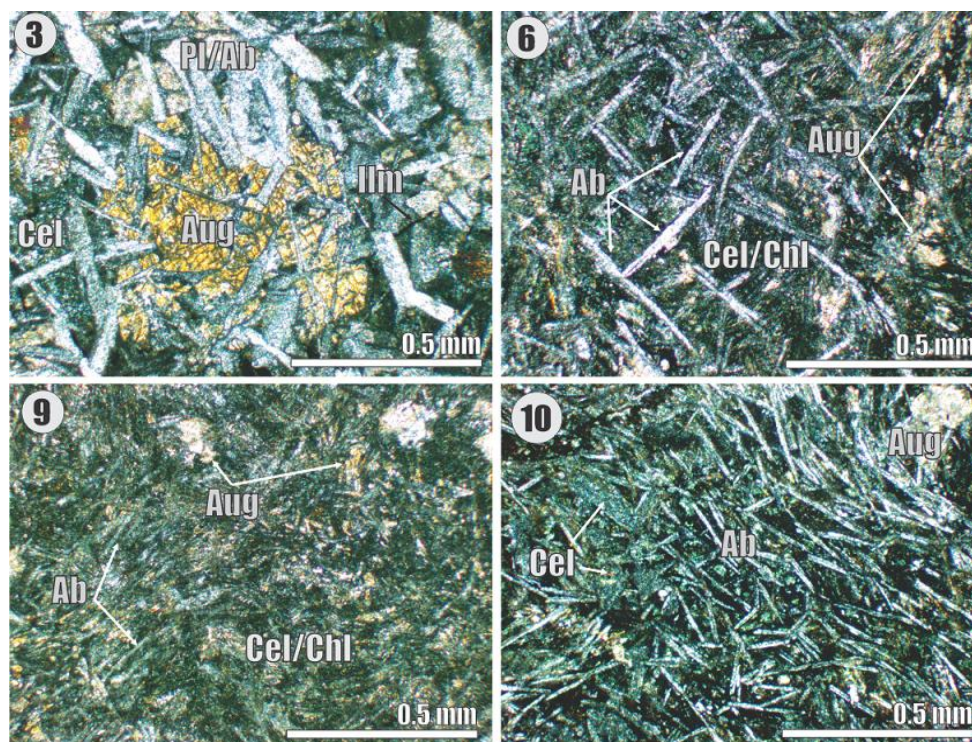


Figure 5 – Microphotographs of ophitic spilites samples. (Ab - albite, Aug - augite, Pl - plagioclase, Chl - chlorite, Cal - calcite, Cel - celadonite, Ilm – ilmenite (Warr, 2021)).

Table 3. Mineral composition, texture and structure of porphyritic spilites

sample	mineral composition	texture / structure
8	Pl, Aug, Ab, Cal, Cel/Chl, Ilm	porphyritic / homogenous
11	Pl, Aug, Ab, Cal, Cel/Chl, Qz, Ilm	porphyritic / amygdaloidal

Pl – plagioclase, *Aug* - augite, *Ab* - albite, *Cel* - celadonite, *Chl* - chlorite, *Cal* - calcite, *Ep* – Epidote, *Ilm* - ilmenite, *Qz* - quartz (Warr, 2021). *G* – glass (internal mark).

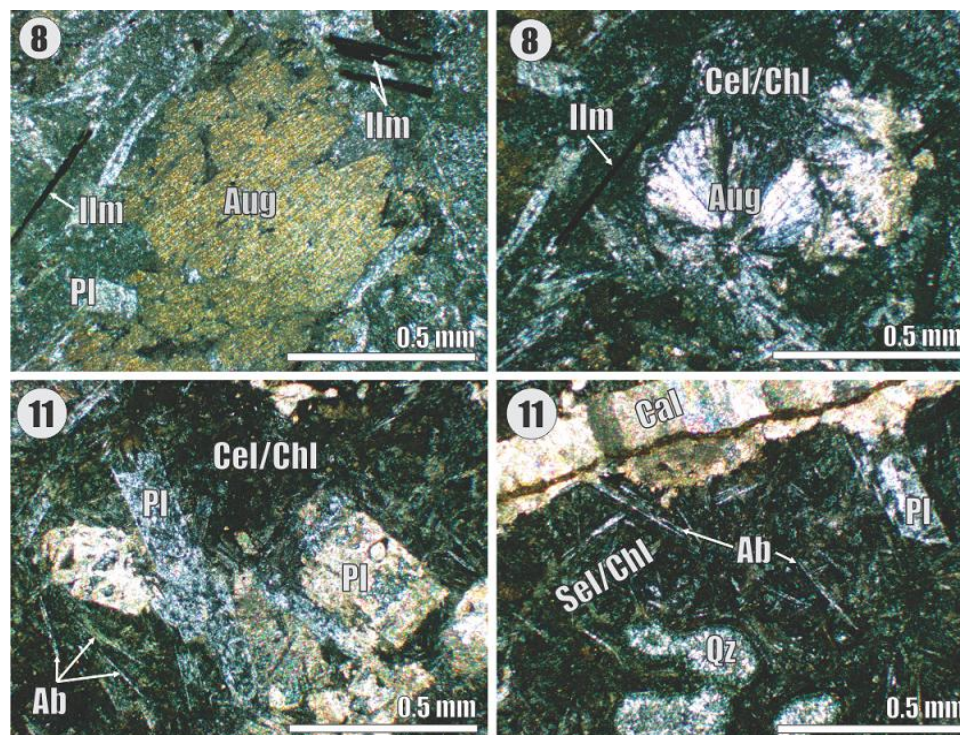


Figure 6 – Microphotographs of porphyritic spilites samples (*Ab* - albite, *Aug* - augite, *Pl* - plagioclase, *Chl* - chlorite, *Cal* - calcite, *Cel* - celadonite, *Prh* - prehnite, *Ilm* - ilmenite, *Qz* - quartz (Warr, 2021)).

Amygdales

Amygdales are a very common occurrence in the subjected rocks. Their presence ranges up to 30% of the rock. Their diameters vary widely, up to 2 cm, most often 0.2-0.5 cm.

Amygdales are most often filled with calcite, chlorite, celadonite, pumpellyite, less often with quartz and chalcedony. In the calcite amygdales, rhombohedral cleavage tracks and radial-divergent aggregates were found. Amygdales with celadonite have a characteristic quartz rim. In the ophitic varieties of spilite around the amygdales, but also in the ground mass of the rock, an isotropic black-brown substance called "glass" is determined (Figure 7).

Previous examinations of "glass" using the X-ray diffraction method indicated the presence of leucoxene and montmorillonite (Pamić, 1982).

Ophitic basalts

Ophitic basalts are often called diabases, because of the ophitic structure. However, ophitic basalts differ from hypabyssal diabases in the geological manner of occurrence (volcanic masses in the form of pillow textures that often appear in association with more felsic

differentials, eg andesites). Another criterion is the presence of amygdaloidal and vesicular structure, which is absent in diabases. Also, ophitic basalts are often interbedded with pyroclastic rocks.

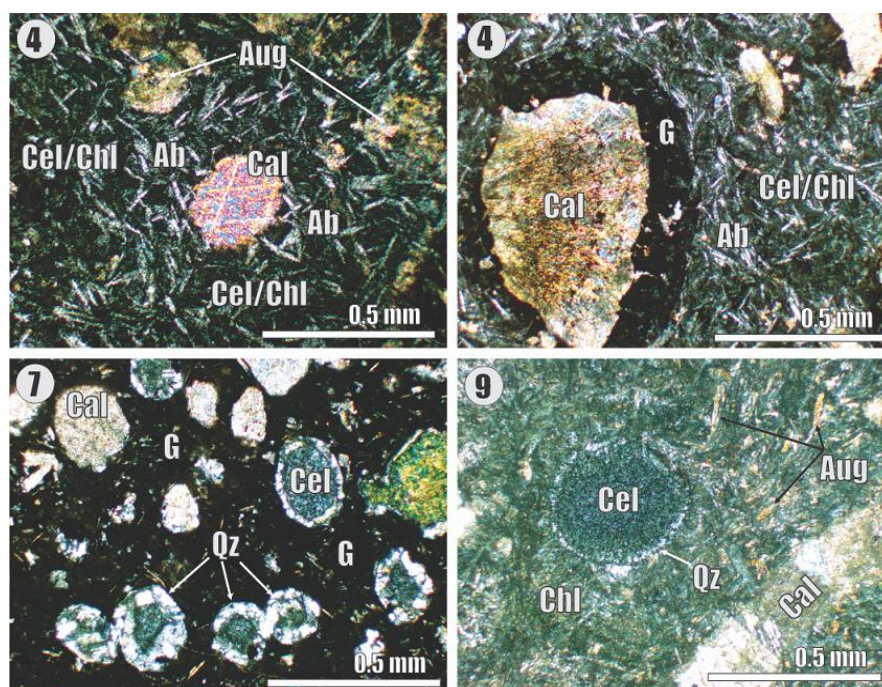


Figure 7 – Amygdales in the ophitic spilites (4 and 9) and spilitic breccias (7) of Vareš (*Ab* - albite, *Aug* - augite, *Pl* - plagioclase, *Cel* - celadonite, *Chl* - chlorite, *Cal* - calcite, *Qz* - quartz (Warr, 2021)), *G* – glass (internal mark).

Extrusive rocks with basic plagioclase and ophitic texture are defined as ophitic basalts, emphasizing the structural variety in accordance with the classification of Streckeisen (1978). The main petrogenic minerals are plagioclase and clinopyroxene. Plagioclase is mainly labrador or bytownite, and the microliths in the ground mass of the rock are more felsic - andesine, less often oligoclase. Clinopyroxene is represented by augite filling the space between plagioclase. Alterations are related to plagioclase, which is suppressed by small secondary minerals, with the separation of albite. Augite is usually fresh, and in this case they are difficult to distinguish from ophitic spilites.

Epidote occurs in prismatic crystals as well as massive to earthy aggregates. It has a characteristic yellow-green to green color. It is a alteration product of the basic plagioclase with the yield of the Fe component (Babajić A. et al. 2017) (table 4).

Table 4. Mineral composition, texture and structure of ophitic basalts.

sample	mineral composition	texture / structure
12	Pl, Aug, Ab, Ep, Cel, Chl, Cal, Ilm	ophitic, homogenous
13	Pl, Aug, Ab, Cel, Chl, Cal, Mag, Ilm	ophitic, amygdaloidal

(*Ab* - albite, *Aug* - augite, *Pl* - plagioclase, *Chl* - chlorite, *Cal* - calcite, *Cel* - celadonite, *Ep* – epidote, *Ilm* - ilmenite, *Mag* - magnetite, (Warr, 2021)).

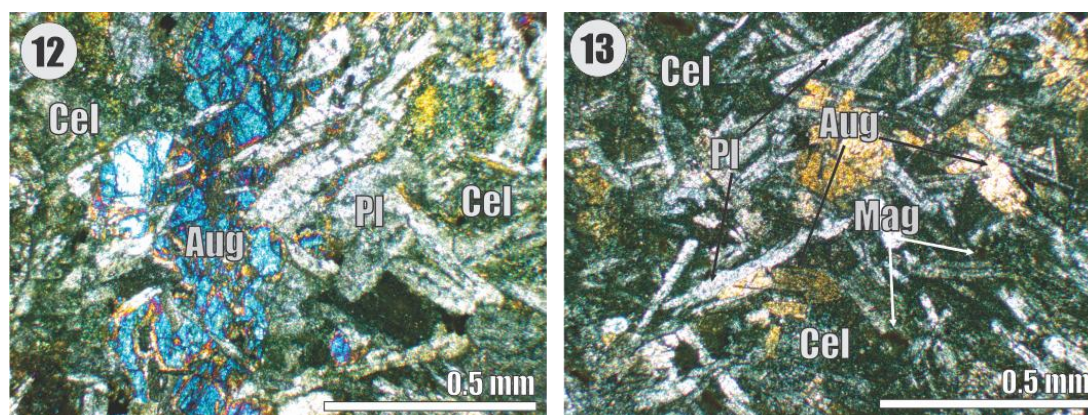


Figure 8 – Ophitic basalts composed of plagioclase (albitized) i clinopyroxene (augite).
(Aug - augite, Pl - plagioclase, Chl - chlorite, Cel - celadonite, Mag – magnetite (Warr, 2021)).

5. CONCLUSION

Spilites are the dominant rock type in the surroundings of Vareš. They most often appear in the pillow forms, which are the result of submarine volcanism. Plate-like type of appearance is more subordinate. Dimensions of the spherical (pillow-shaped) forms of spilite from Vareš range from 20 to 70 cm, rarely larger. Eastern part of the magmatic body (left bank of the river Stavnja) is intensively tectonized and altered, which makes the primary structures poorly visible in the field.

Based on textural characteristics, ophitic and porphyritic spilites are distinguished. Both textural varieties contain a variable amount of amygdaloids, which are most often filled with calcite, celadonite and pumpellyite, less often with quartz. In the ophitic varieties of spilite around the amygdaloids, but also in the ground mass of the rock, an isotropic black-brown substance called "glass" is determined. This mass needs to be further investigated.

Optical tests revealed that the ophitic spilites have an ophitic to hyaloophytic texture, amygdaloidal and less often vesicular or fluidal texture. Petrogenic constituents are plagioclase, augite, albite, celadonite, chlorite, pumpellyite, calcite, ilmenite, magnetite and pyrite.

Porphyritic spilites are amygdaloidal to homogeneous in structure, with the minerals plagioclase, augite, albite, calcite, celadonite, chlorite, quartz and ilmenite.

Associated ophitic basalts have an amygdaloidal and homogeneous structure. The primary minerals are plagioclase (basic) and clinopyroxene augite. A series of secondary minerals consists of albite, calcite, celadonite, chlorite, epidote, along with ilmenite and magnetite.

GRATITUDE

We would like to thank the Office for Scientific and Research Work of the University of Tuzla and the Federal Ministry of Education and Science for financial assistance in the implementation of the scientific and research project: "Petrological and geochemical characterization of the upper part of the ancient oceanic crust - Vareš surroundings" /decision: 01-3840-VI-1/23, dated 23.10.2023/.

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