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GEOLOGY OF THE SAGRABERD SITE OF VEDI OPHIOLITES: NEW DATA AND REVIEW

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Abstract

The article provides new details on a small area of Sagraberd ophiolite lavas outcropped on the right bank of the Vedi River within the Vedi Ophiolite complex. Due to the long-term lack of research, for the first time, we referred to the coverage of geological-structural, petrographic, and, partly, geochemical issues of this ophiolite outcrop. Pillow lavas are mainly characterized by amygdaloidal, often brecciated structures. The texture of the rocks is plagioclase-porphyritic, the main matrix is intersertal, doleritic (spilitic), hyalopilitic, and variolitic. According to the contents of the major elements, the analyzed sample corresponds to the alkaline type of basalts. The given characteristic oxide values are sufficient to attribute the rocks to OIB-type, excluding their spreading (MORB-like) origin. The age of the pink "cementing" limestones occurring in the form of small lenses or pockets in the pillow lavas, based on the foraminifera *Globotruncana* and *Globigerina* genera enclosed in them, was tentatively determined as Late Cretaceous. In parallel, we referred to the unsolved problem of diatreme tuffs. Based on field observations and microscopic studies, we exclude the existence of recently discovered diatreme here, arguing with the dominance of terrigenous formations. In addition, we see a problem of "harmony" between the geological position of another diatreme in the upper stream of the Vedi River and the age of the zircons determined in it, the explanations of which need serious revision.

Keywords: Tethyan belt; Lesser Caucasus; Armenia; Vedi ophiolite; pillow lava; diatreme; foraminifera

1. Introduction

The petrologic-geochemical issues of rocks in Armenian ophiolite complexes and their (magmatic and sedimentary) age inferring are of primary importance not only in the context of the correct understanding of the tectonic evolution of the territory of the Republic of Armenia (RA) or the Lesser Caucasus region but also for restoration of the history of the geological evolution of the Alpine-Himalayan folded belt. The Vedi ophiolite complex,

which has been the center of attention of Armenian and foreign geologists since the 50s of the last century, has an important role in this scope. Here, the early bio-stratigraphic, lithological-structural, and general geological works (e.g., Yeghoyan, 1955; Aslanyan, 1958; Paffenholtz, 1959; Rengarten, 1959; Hakobyan, 1970) were followed by researches carried under the new "Theory of Plate tectonics" (starting with Knipper, 1975; Knipper, Sokolov, 1976; Sokolov, 1977; Lomize, 1970, 1983). The latter shed new light on the autochthon, the ophiolitic allochthon, and olistostroma horizons, as well as the neo-autochthon units of the Vedi region.

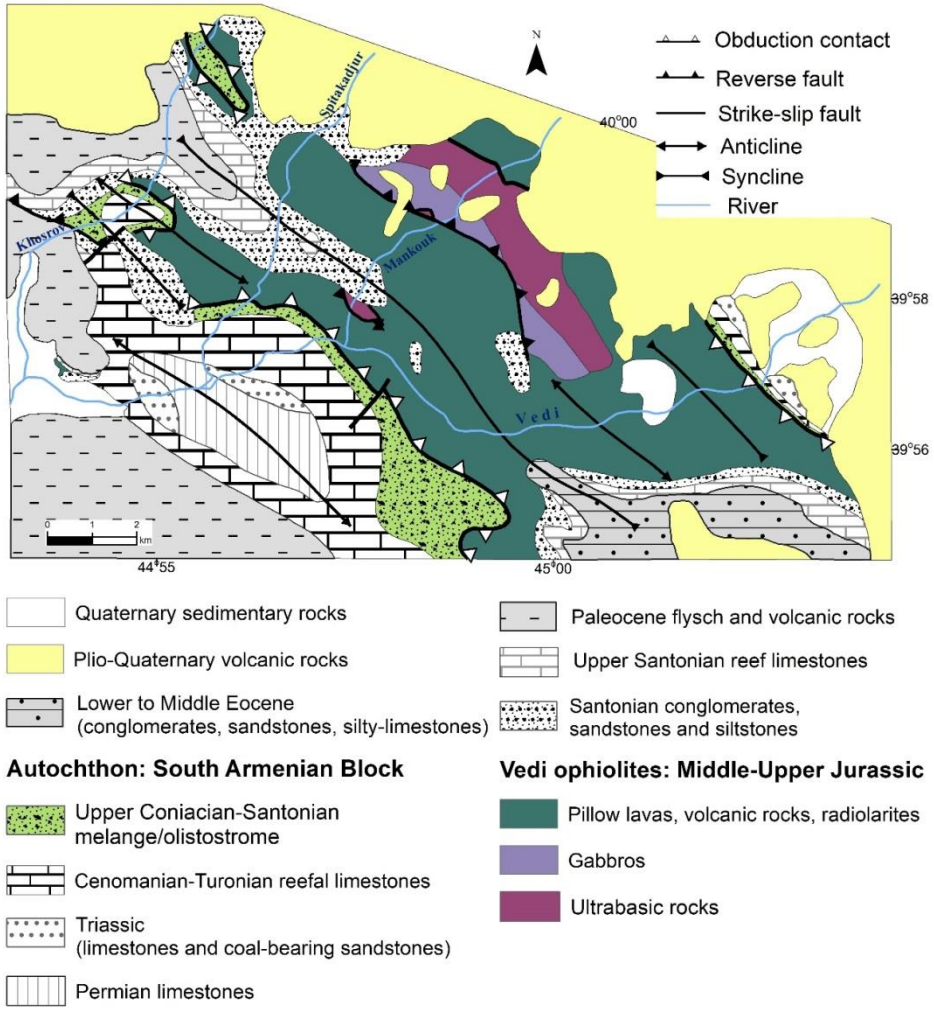

Fig.1. Geological map of the Vedi ophiolites, modified/supplemented according to Galoyan (2008), which was compiled as a result of joint Armenian-French research, also using the maps of Mkrtchyan, Sokolov, Harutyunyan, Satian, and others.

In the following years, lithologic-petrologic, as well as biostratigraphic and structural geological questions of the ophiolite association rocks became the

subject of wide attention (e.g., Abovyan, 1981; Zakariadze et al., 1983; Satian, 1984; Aslanyan et al., 1987; Satian et al., 2005; Galoyan, 2008; Danelian et al., 2008, 2010; Rolland et al., 2010; Sosson et al., 2010). Despite the thoroughness and modernity of recent works, the small area of Sagraberd ophiolitic lavas, on the right bank of the Vedi River, was left out of the attention of authors of the Armenian-French group, to which we are referring for the first time (fig.1,2). In 2013 accidentally "discovered" the outcrops of the pillow lavas, during the next field visits we highlighted the position of the lavas and their relationship with the surrounding rocks. In the laboratory work, we have found out their petrological and chemical composition, and also determined the age of the suite based on the limestone "cementing material". Based on the importance of the recently discovered diatreme (Sahakyan et al., 2022) near the mentioned lavas, we also examined the question of the existence of these "mysterious" tuffs.

2. General geological-stratigraphic setting

In the Vedi River basin, the Upper Cretaceous sediments form a synform structure that extends from the northwest to the southeast, where the ophiolite complex occupies the central or core part (fig.1). Structurally, Sokolov (1977) distinguished autochthonous, allochthonous, and neo-autochthonous complexes here.

The oldest rocks in the region are the Upper Paleozoic and Lower Mesozoic sediments, which are part of the South-Armenian block or microcontinent (e.g., Dercourt et al., 1986; Kazmin et al., 1987) and are the core of the Spitakajur (Aghsu) anticline that borders the Vedi syncline from the southwest.

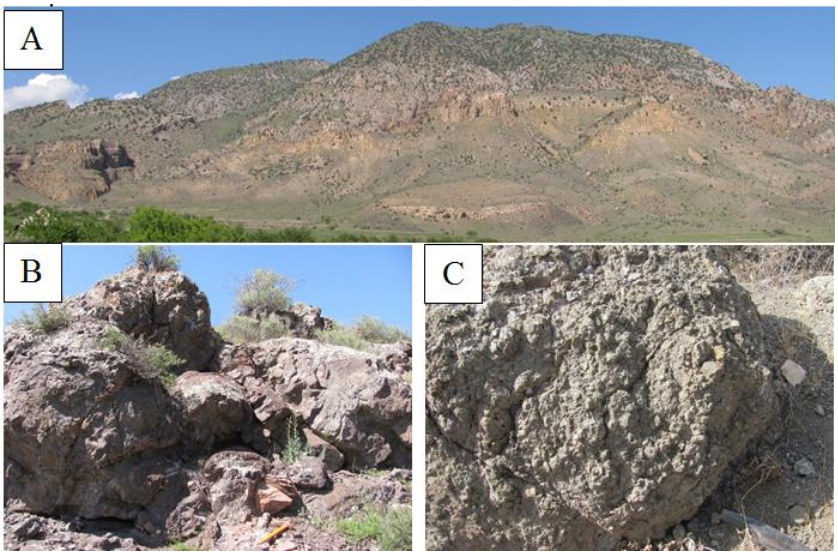

Fig.2. A panoramic view of Mount Khosrovasar from its southwestern foothills: the two gray-brown hills lowermost in the middle correspond to pillow lavas (A); sampled pillow lavas and pink limestone lens next to the hammer (B); fragile conglobreccias as "tuffs" (C). See Figure 3 for the geological description of the slope.

At the site of Spitakadjur (a right tributary of the middle stream of the Vedi River), to the west of it, as well as to the east (towards the Mankuk River, another right tributary) in the core of the anticline of the same name (around 2*4 km^2) and of the northwest distribution, the Middle–Upper Permian, then the Lower Triassic carbonate formations are exposed. This anticline is the main and most spectacular tectonic structure, in the core of which the Middle Permian dark and gray bituminous limestones with vertical dips pass into the Upper Permian light yellow-pink limestones. The hinge of the anticline "plunges" very steeply to the north-northwest (Yeghoyan, 1955).

Light gray limestones of the Lower Triassic Indian stage are exposed in the southwestern and northeastern flanks of the Spitakadjur anticline. And to the northeast of the Vedi synform, in the Djermanis anticline, the carbonate deposits of the Olenekian stage of the Lower Triassic and the Carnian–Norian coal-bearing-terrigenous sediments of the Upper Triassic are exposed (e.g., Grigoryan, 2003).

Permian and Triassic formations are sharply and unconformably overlain by Upper Cretaceous sediments, the base of which is presented with the carbonate suite. It is composed of organogenic, organogenic-detrital limestones, which alternate with massive gray limestones, calcareous sandstones, marls, siltstones, and conglomerates. Detrital material is represented by quartzites, various limestones, granites, gneisses, and metamorphic slates. According to the researchers, the rock fragments of the ophiolite complex are missing in them (e.g., Yeghoyan, 1955; Sokolov, 1977; Hakobyan, 1978). In the southwestern wing of the Vedi syncline, the thickness of the carbonate suite reaches about 300m, and in the northeast – about 50 m, with Cenomanian–Turonian and only Turonian stages, respectively (Hakobyan, 1976; Rengarten, 1959). New age data based on benthic foraminifera gave a Cenomanian age (Danelian et al., 2014) in the uppermost part of the carbonate suite on the right bank of "Coral Valley".

The carbonate terrigenous sediments are placed on the carbonate suite and are represented by a rhythmic flyschoidal alternation of calcareous argillites, sandstones, marls, sandy limestones, and limestones. The thickness of the flyschoid series is 50-150m (Sokolov, 1977). The Lower Coniacian age of the suite was restored by the discovery of numerous faunal remains (Yeghoyan, 1955; Rengarten, 1959; Hakobyan, 1970, 1976). Based on the nannofossils, it was attributed to the Coniacian–Santonian interval (Sosson et al., 2010).

In the upper horizons of the Lower Coniacian section, the first fragments of ophiolites appear, and the flyschoid suite passes to olistostroma formations (with mixed olistoliths) or to tectonic mélange (Sosson et al., 2010). Within the boundaries of this synclinal structure, the olistostrome suite is covered by an allochthonous complex which has long been known as "Khosrov's suite" (Yeghoyan, 1955). It occupies a significant area in the basins of the upper stream of the Vedi River and its Khosrov right tributary, as well as along the southern and western slopes of the Yerakh mountain massif and in the Baberd site.

Northeast of “Coral Valley”, the olistostrome suite is covered by a tectonic contact with rocks of the ophiolite association (these form the base of the nappe *sense*), between which the contact is not always clearly defined (Sokolov, 1977, Galoyan, 2008). The allochthonous complex, based on the rocks that make it up, was divided into two parts: lower effusive-radiolarite and upper gabbro-serpentinite (Sokolov, 1977).

The effusive-radiolarite cover consists mainly of spilitic basalts, spilites, diabases, albitophyres, and various clayey-limestone and carbonate rocks, including radiolarites. The petrologic-geochemical features of the volcanic and plutonic formations of the ophiolite complex are discussed in Zakariadze et al. (1983), Aslanyan et al. (1987), and in the later works of the Armenian-French group (Galoyan, 2008, Rolland et al., 2010).

To the west, in the valley of the Khosrov River (another right tributary of the Vedi River), the basaltic lavas are dominated by rare sublayers of siliceous rocks. The spilitic basalts are often found with spectacular spheroidal textures, in which the interstices of the spheroids are filled with red micritic limestones. In places, the carbonate material becomes significant, so the fragments of spilites are included in the limestones. These are also known (Yeghoyan, 1955) as a “series of porphyrites and carbonate mandelsteins”.

The sediments that cover the ophiolites (i.e., the “neo-autochthonous complex” of Sokolov (1977)) are transgressively placed on the previous two complexes and begin with the Late Coniacian limestone-terrigenous suite. The base of the section is formed by conglomerates, from 1 to 20-25 m thick. These are characterized by clear layering, good sorting of detrital material, and a decrease in the size and number of boulders in the upper parts of the section. The composition of the debris is highly variable. They are made of rocks that correspond to the basement and surroundings of that area. The emplacement contact with the lower (underlying) allochthonous formations is sharp and highly transgressive, while no significant unconformities are observed with respect to the underlying olistostroma and flyschoid strata of the ophiolite cover. Therefore, it is obvious that during the creation of the cover series, the ophiolites were complexly deformed, and the autochthonous, allochthonous, and neo-autochthonous complexes have appeared in the synclinal structure at a later time (Sokolov, 1977, Galoyan, 2008) as a result of the collision of the Arabian and Eurasian plates (Sosson et al., 2010).

3. Description of the Sagraberd site

Sagraberd ruined village site (some time ago also called Karabakhlar) is located on the right bank of the Vedi River, at the southwestern foot of the Khosrovasar mountain, where the pillow shape basaltic composition lavas of our interest are exposed near the ruins of one of the ancient Armenian churches (south-eastern one that is of 5-6 centuries). The actual effusive body is exposed in the vicinity of the following coordinates (N 39.955539°, E 44.881907°) and

extends to the east, with a general extension from northwest to southeast, on an area of about 250*70 m^2, in the form of twin hills (fig.2A).

Yeghoyan (1955) described this section in detail. According to whom, the oldest is "the suite of porphyrites and carbonate mandelsteins, which have gray and purple-gray coloring, with red "sunburn" in the cracks and the bottom of which is not exposed". He assigned this formation to the Upper Turononian–Lower Coniacian age, which is a part of the Khosrov suite. A thin package of red and yellow marls and pelitomorphic limestones is placed on top of the pillows. The color is uneven: the red coloring of the lower half passes through the zones and lenses to the upper half. Marls and pelitomorphic limestones are massive, hard, thick-bedded, and sometimes irregularly platy-like. Among these carbonate formations *Inoceramus seitzi* var., *In. pseudolamarcki* var. nov., *In. involitus* Woods, *In. subercynicus* sp. nov., *In. crassus* Petraschek, *In. wandereri* And., *In.* aff. *schoenbachi* Böhm, *In. inconstant* Woods, *In. koeneni* Müll., *In. humboldti* var. cf. *zeltbergensis* Heinz., *In. gradates* sp. nov., *In. sp. sp.*, *Conulus* cf. *fallax* Lamb., *Echinocorys* cf. *gravesi* Desor have found out. According to this author, the whole complex of fauna described in the section of this package indicates the Late Coniacian age of these reddish marls and limestones.

On the contrary, Rengarten (1959) considered the porphyrites of this locality to be an intrusive body, a sill, placed between the exposed Lower Turonian limestones (below) and the Upper Turonian pink limestones (above). He also stated that the bottom of the "porphyritic intrusion" is not exposed. It should be noted that there are generally subvolcanic (younger) bodies in the region, some of which we will present in another article.

Of course, assigning the "Turonian age" to the reddish sandy and yellow pelitomorphic limestones is not logical. Both of these are characterized by abundant foraminiferal fossils (fig.5d), the modern determinations of which may bring serious clarity to the Late Cretaceous history and sedimentation chronology of this region. Although the lavas of interest are subaqueous in nature and have a prominent pillow appearance with large (average 0.8-1m in diameter, fig.2b) rounded spheres, their intrusive nature has been repeatedly speculated in the past.

In the eastern part of the pillow-lava outcrop, gray-red limestones, with some basal conglomerates, transgressively overlay the black-gray pillows. To the southeast, there are no root lava outcrops and, at some point, the terrigenous formations are exposed (fig.1), with large polished boulders and probably large blocks (perhaps olistoliths?) in places. In particular, the sampled (see sampling points in fig.4) boulder (G22.105) (60*60*60cm^3) and the (G22.107) olistolith-like body (10*30m^2) with a trachytoid texture are aphyric spiltite-like rocks, while the other boulder (G22.105A) is a micro-amygdaloidal, micro-porphyritic diabase, which is brecciated. It is obvious that radiolarites are either absent in the area of interest (we did not see them) or they may be rarely encountered.

About 650m southeast of the above-mentioned coordinates, the Khosrov diatreme was recently described as discovered for the first time (Sahakyan et

al., 2022). Satian (1984, p.42) also referred to this geological section of the southern slope of Mount Khosrovasar, noting that "toward the east, spherical (i.e., pillow) lavas alternate with volcanic breccias with limestone lenses, and the roof consists of thin keratophyre flows". Then, he continues, "as in other parts of this region, here too, the vulcanites are overlain by ophiolitoclastic graywackes and siltstones, with underlying basal conglomerates, which complete the uneven surface of the volcanic suite". Deciphering the scheme of the geological structure presented by this author, we see that the lava breccias and pillow lavas were formed *in situ*, due to the ejection from the volcanic channel, before the Late Coniacian. Moreover, Dr. Satian himself mentioned the "spilitic porphyrites and trachybasalts" and "cutting them small bodies of the 'Khosrovites'-type tuffs" in the explanation of the cross-section. Therefore, the "tuffs" were "revealed" on this site long ago.

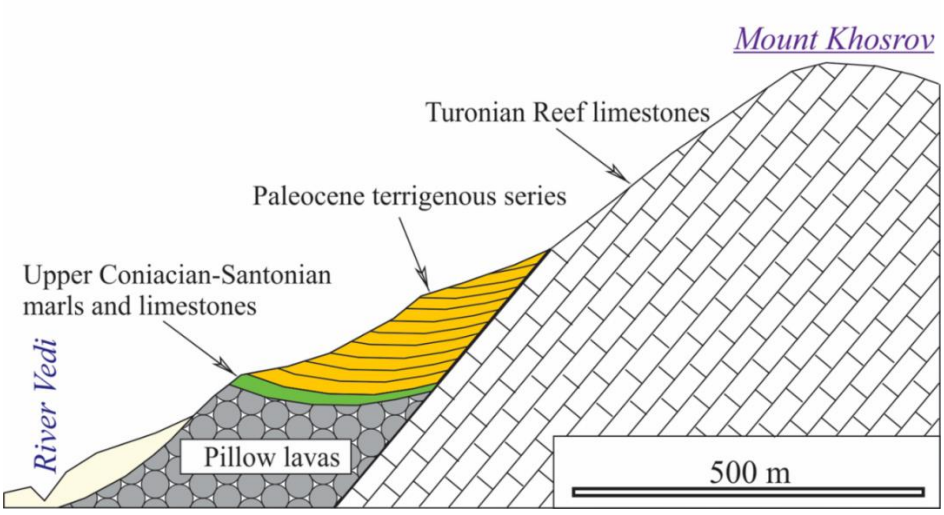

Fig.3. Geological cross-section of the southwestern slope of Mount Khosrovasar. The pillow lavas were obducted over the Turonian limestones.

During fieldwork in 2022, we found out that morphologically, there is no such a cylindrical structure (e.g., oval shape: with 150 vs. 50m axes) that enables one to assume its probable diatreme origin. Indicated in and near the coordinates of Sahakyan et al. (2022), we encountered only terrigenous formations represented by poorly rounded conglomerates or conglobreccias (fig.2c), gravelites (fragile), sandstones, and siltstones. We also did not record the "andesite dyke", which reportedly "cuts the diatreme from the north". Is it possible that the identification of this and other dykes was done incorrectly? For example, Satian et al. (2005, p.29) work mentioned that "... along the northern contact of the diatreme, the dyke of alkaline basalts is located, which has spherical separations in places". Can we doubt that they are talking, rather, about the pillow texture here?

Although rare particles of sedimentary carbonate rock are present in the examined thin sections (fig.5e-f), the dominant detrital material is a basaltic,

volcaniclastic component with rounded-angular, rounded, or angular grains. In addition, the semi-polished conglomerate pebbles, macroscopically, clearly show an amygdaloidal structure, where vesicles are filled with calcite. This also speaks for the pillow lava origin and nature of those fragments. Therefore, the pyroclastic tuffaceous origin (i.e., diatreme) of the particles is unlikely or impossible if their deposition took place in an aqueous environment.

The samples that we took for microscopy from the eastern part of the "body" of interest (fig.4) are represented by micro-conglomerates (G22.104) and fine-grained sandstones (G22.103), which are greyish-green greywackes. The predominant part of the particles and the cementing material (albeit clayey) is the basaltoid component. Here, although the stratification is not clearly expressed, nevertheless, it is possible to measure (probably) the azimuth of the stratigraphic dip to the west, at an angle of 30–40°, between the brecciated sandstones and fine sub-horizons of black argillite.

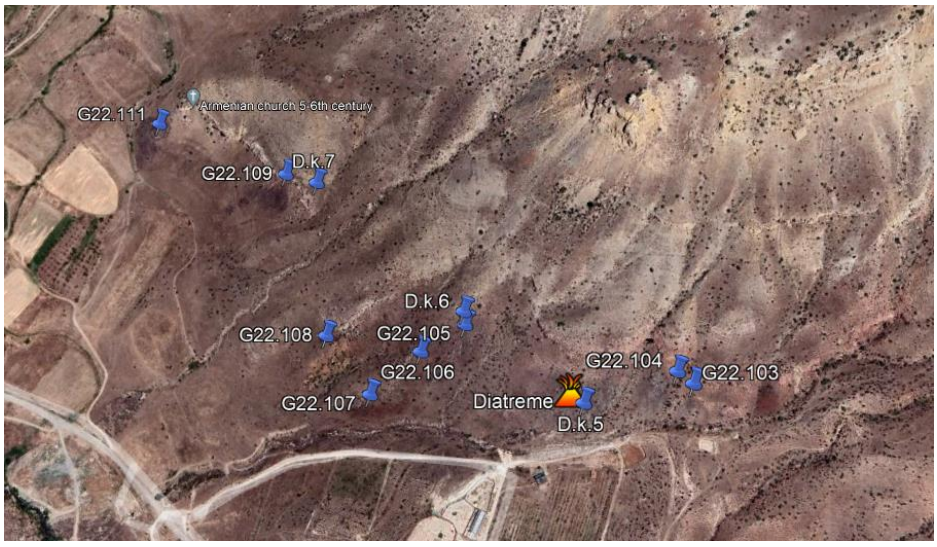

Fig.4. GPS coordinates of the sampling (e.g., G22.103) and observation points (e.g., D.k.5) on the Satellite image of Google Earth.

Moving about 300m to the west (toward the pillows), we did not cross any hot/cold contact and it became apparent that there was a distinct stratification here. In the sorted, gray-chocolate-colored sandstones (G22.106, foraminiferal, calcareous) we have root outcrops with a dip of the azimuth of 235° and an angle of 60°. It was also found that there are no red-gray limestones (i.e., Upper Coniacian) in this part or they were not deposited at that time, and Paleogene terrigenous formations are transgressively deposited directly on these sandstones. If we take the mentioned dip azimuths and dip angles in the terrigenous suite as a basis, it is not difficult to notice that the overlying reddish-gray carbonate sediments (e.g., with a dip azimuth SE-110°, and angle – 45°) have a pronounced angular unconformity, which is strange in terms of time shortness. Therefore, it may be assumed that, prior to the deposition of this

marker horizon of red limestones and marls, these terrigenous formations slid by gravity or tectonically during the obduction of the ophiolitic nappe. Immediately, after the "arrival and re-emplacement" of the ophiolitic components/mega-blocks, the deposition of carbonate material began in the appropriate environment: (a) on the pillow lavas in the west of the study area and (b) on the volcano-terrigenous (i.e., "tuff") formations in the southeast.

4. Pillow Lavas' dating efforts

As we mentioned, the Khosrov volcanic suite in the studied area is represented by pillow lavas of basalt, basaltic andesite composition, in which it is still possible to see and sample (until exhausted) small and rare lenses or pockets of reddish-pink limestones (fig.2b). To determine the age of these lavas, we sampled the largest of those limestone lenses for microfauna. In thin sections of this limestone (e.g., G22.06, G22.111) no radiolarians were observed, but microforaminifera (fig.5c). Among the separated microfauna, it was possible to identify representatives of planktonic foraminifers of the genera of *Globotruncana* and *Globigerina*, which, preliminarily, makes it possible to assign the host volcanic sequence to the Late Cretaceous.

Obviously, the Middle Jurassic age of these lavas is not supported by the fauna gathered in this limestone, which we have assumed beforehand based on the presentation of Sokolov (1977). So far, the only approximate correlation, at the regional level, can be made with the foraminiferal (*Globotruncana*) pink pelagic limestones described in the Khoy ophiolite complex in northwestern Iran (Khalatbari et al., 2004). Accordingly, the Upper Cretaceous, Turonian–Late Campanian *Globotruncanas* were described (in the Goldagh section of Khoy) in the limestones cementing the ophiolitic pillow lavas.

5. Petrography of pillow lavas

The rocks are notable for their mostly amygdaloidal, sometimes massive, often brecciated structures. The texture is porphyritic, and the main matrix is intersertal, spilitic, hyalopilitic, and variolitic (fig.5a-b). In the mineral composition, phenocrysts make up about 25% of the surface, which are represented only by plagioclase. According to the predominant size of grains, they can be divided into two generations (1.5-3mm and 0.5-1mm). They are exclusively represented by tabular and prismatic grains, which are mostly fresh, partly containing (probably) former volcanic glass sieve-like inclusions, which are now replaced, and argillized. Secondary formations in the form of hematite veins are observed. The rocks contain small, rounded, or isometric "grains" filled with a carbonate material and might be former pyroxenes (?), of which no fresher localities have been preserved.

The texture of the main matrix of the rock, with transitions from doleritic to variolitic, is a microlithic fabric of plagioclase, showing small isometric grains, chloritized or carbonatized (perhaps due to a colored mineral), cemented by

partially fresh but mostly devitrified volcanic glass. There are one or two amorphous areas (less amygdaloid-like) and small bubbles that have a chlorite-carbonate composition due to pore refilling. Of the accessories, it is obvious that ore (opaque) mineral is more often found in the form of nests and in volcanic glass in the form of darker areas (due to oxidation of iron). Apatite isn't clearly seen, despite the high content of TiO_2 in the chemically analyzed sample (G22.05).

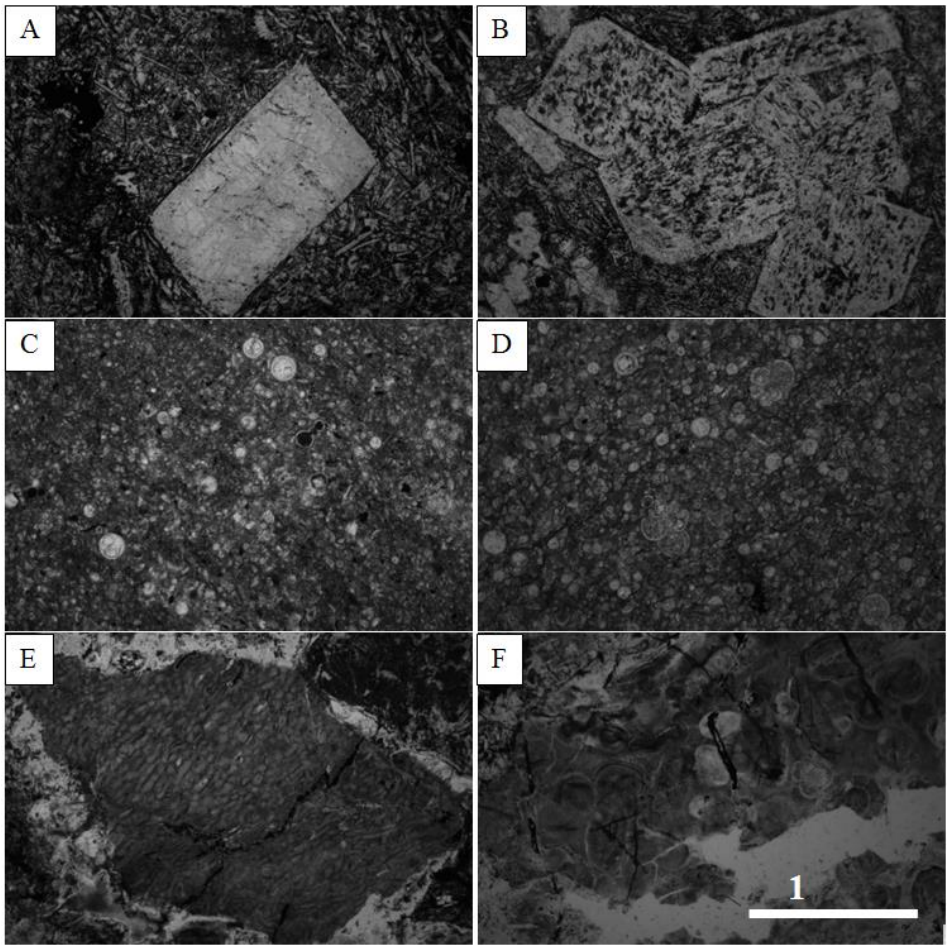

Fig.5. Photomicrographs of thin sections with polarizer only. A and B – fresh and weathered sieve-like phenocrysts of plagioclase in the intersertal and hyalopilitic matrix, C – foraminiferal limestone from a lens included in pillow basalts, D – foraminiferal limestone from red package covering the pillows. Microconglomerate grains: E – algal limestone, F – oolitic limestone.

6. Geochemical characteristics of basalts

In general, the geochemistry of the volcanic rocks of the Vedi ophiolite complex has been addressed in several works. According to MgO, TiO_2, and Na_2O+K_2O values, two horizons of Mg-rich pillow lavas were distinguished: tholeiitic picrodolerites and alkali picrobasalts (Aslanyan et al., 1987).

Picrodolerites are characterized by low TiO_2, Al_2O_3, K_2O, Rb, Sr, Zr, and high MgO, HREE (heavy rare earth elements) values (Satian et al., 2005). In this region, ophiolitic lavas are represented by tholeiitic and alkaline (titanium-rich) basalts, minor trachyandesites, trachytes, andesites, and dacites (Zakariadze et al., 1983). Furthermore, the trachybasalts of the region have been divided into two types, the olivine and the kaersutite group, which are present as both phenocrysts and microlites (Ghazaryan, 2007).

More detailed geochemical work in nine igneous rocks (including plutonic types) of the Vedi complex, also supplemented by microprobe analyses in thin sections, was carried out during joint Armenian-French research (Galoyan, 2008; Rolland et al., 2010). As in other Armenian ophiolite complexes (e.g., Sevan, Stepanavan), here also two distinct series of basaltic lavas: *tholeiitic* and *alkaline* were distinguished, which were formed at different times, from different sources and in tectonic settings. According to these works, these vulcanites are plotted in basalt, trachybasalt, basaltic trachyandesite, and trachydacite fields in the *TAS* classification diagram.

The examined new sample (G22.05) at the Sagraberd pillow lava site corresponds to the alkaline type of basalts according to the contents of the following diagnostic major elements: SiO_2=48.4%, TiO_2=2.3%, P_2O_5=0.345%, Na_2O=3%, K_2O=1.5%. The analyses were carried out in the Chemical laboratory of the Institute of Geological Sciences. Although we do not have thorough trace-element analytical data for this sample, the characteristic oxide values given above are sufficient to rule out a spreading (MORB-like) origin of these lavas, assigning them to OIB-type. Moreover, since we did not see obvious kaersutite amphibole in the new (G22.05, G22.109) thin sections (kaersutites are present, for example, in a diabase boulder G22.105A from the terrigenous suite), we can imagine high titanium content distribution in the main rock matrix and in volcanic glass in the form of rutile. The relatively high content of phosphorus can be interpreted in the same way, despite the small occurrence of apatite from the accessories in the thin section. By the way, these conclusions can only be made based on the analytical data and the experience of Galoyan (2008) on the kaersutite dolerite basalts spread in the Khosrov Valley near this location.

7. Discussion

7.1. Position and age of pillow lavas:

As it was known and mentioned above, the base of the pillow lavas in the Sagraberd site is not outcropped, so it is necessary to consider the issues of their location and age in comparison with the neighboring exposures. It is known from earlier works that the Khosrov suite in the southwestern part of Armenia is represented by effusive lithofacies of “porphyrites, spilites and their mandelstein varieties” (Yeghoyan, 1955). Accordingly, the age limits of this formation are Upper Turonian–Lower Coniacian. The lower limit is determined by the emplacement of vulcanites on the lower Turonian limestones in the

Khosrov River valley. The upper limit is determined by the facial transition of porphyrites to sedimentary layers with *Barroisiceras habertellneri* Hauer var. armenica var. nov. fauna and by their covering with sandstones that are characterized by Lower Coniacian fauna.

Starting with the works of Moscow geologists (Knipper, Sokolov, 1976; Sokolov, 1977), it became obvious that the rocks of the Khosrov suite are allochthonous and are lithofacies of the main marine ejections: due to the nature of the rocks and the conditions of their emplacement, as well as the absence of a significant amount of volcano-sedimentary material. Their origin was later linked to spreading processes at the limit of the northern Neotethys Ocean in a back-arc or fore-arc basin (e.g., Galoyan, 2008; Rolland et al., 2010; Sosson et al., 2010).

Some additional fauna was collected in the Khosrov river valley, *Inoceramus* cf. *sublabiatus* Mull., *In.* cf. *subquadratus* Mull. (determined by M.A. Pergament), which also indicates the Upper Coniacian age of the terrigenous-carbonate suite covering the ophiolites (Sokolov, 1977). Therefore, it is obvious that the obduction of ophiolites took place before the Late Coniacian.

In the upper part of the ophiolitic sequence, the alkaline volcanic series with OIB-type geochemical characteristics was found and confirmed in the sections of each studied complex in the territory of RA (e.g., Galoyan, 2008). At the same time, a late Lower Cretaceous (Aptian) age of 117.3±0.9 Ma was obtained by the $^{40}Ar/^{39}Ar$ method on kaersutite amphiboles in this type of dolerite trachybasalt from the Khosrov valley (Rolland et al., 2009).

Moreover, radiolarites covering mafic vulcanites in the site of Amasia ophiolite, in the far northwest of Armenia, have a Cenomanian age (Danelian et al., 2014), which, according to the authors, indicated the latest volcanic activity and accumulation of radiolarian ooze in the Tetyan domain of the Lesser Caucasus. However, based on our new foraminiferal determinations in a limestone lens of the Sagraberd site, we conclude that the latest marine lava eruptions occurred in the Late Cretaceous, prior to the deposition of the Late Coniacian reddish limestones and marls.

7.2. Returning to the "diatreme tuffs":

More than 24 bodies of "Khosrovite pipes" have been known for a long time in the middle-upper basin of the Vedi River, first separated and described by Mkrtchyan (1970). Later, the studies dedicated to the genesis and mineralization of the "lamprophyre diatremes" described in the Mankuk and Yerakh anticlines in the Vedi region received a new development (e.g., Satian et al., 1997, 2005). According to the latter, a number of diatremes of alkaline lamprophyre tuffs (with up to 70 m, rarely up to 250 m long axis) were separated in the Upper Callovian–Berriasian carbonate-volcanogenic formation, associated in some places with dykes of alkaline basalt and picrobasalt, and, sometimes, of camptonite and monchikite. In general, tuffs consist of aleuro-psammitic fragments of volcanic glass (60-70%), crystalloclasts (~5%,

clinopyroxene, amphibole, etc.), and xenoliths (up to 20%) and calcium carbonate forms porous-contact or, sometimes, basal cement (Sahakyan et al., 2007). According to them, xenoliths in the Khosrov group diatremes are represented by carbonated hyperbasites, harzburgites, trachytes, picrobasalts, calcite carbonatites (yes, you read it right), fine-grained limestones, amygdaloidal basalts, gabbros, etc.

Based on our fieldwork in 2022 in the eastern part of the minor ophiolite site of Sagraberd, we consider the existence of the "new diatreme discovered" by Sahakyan et al. (2022) ("in the Khosrov River Basin", according to these authors) to be doubtful. Here, we encountered terrigenous formations composed essentially of amygdaloidal basalts, which may be Coniacian or older (?) in age. Even if we consider that the rocks we encountered and sampled are not tuffs, but tuffites (e.g., tuff-conglomerate, tuff-sandstone, or tuff-aleurolite/siltstone) formed during submarine volcanism, due to lava material, there is no reason to assume or "to look for" a diatreme-like body or its remnant here (see details above).

Using the REE contents of the alkali-lamprophyre tuffs of the Yerakh and Vedi group from the paper (Sahakyan et al., 2007) and comparing them with his own analytical data, Galoyan (2008) noticed that the normalized REE geochemical patterns of the mentioned lamprophyre tuffs are similar to those of the Alkaline lavas that are known in many (e.g., Vedi and Sevan) ophiolites. Therefore, according to the geochemical data, he concluded that "compared formations could be cogenetic, so there was no need to separate these tuffs from Alkaline lavas, trying to explain their "in situ" emplacement as diatremes, the geometry of which was not well-defined". However, without referring to this thesis of Galoyan (2008), Sahakyan (2022) makes the exact opposite conclusion that those formations are not genetically related. After all, here comes a new conclusion: in general, there was no need "to compare" these rocks with ophiolitic alkaline lavas, if suddenly it is confirmed that all these "tuffs" are of underwater nature or terrigenous origin, the prerequisites of which already exist.

Recently Sahakyan (2022) published the U-Pb zircon age of 182±3 Ma (i.e., Pliensbachian-Toarcian) of another alkali-lamprophyre diatreme exposed on the right bank of the upper stream of the Vedi River, at coordinates N39.944819°, E44.98812°. The author notes that "... all (zircon) grains show broken rimes which suggest that they are affected by explosion". Nevertheless, based on those cathodoluminescence images of zircons, it is not difficult to assume (or observe) that at least six of the eight zircon grains presented in this article are of terrigenous-sedimentary origin. In other words, the grains have "traveled" a sufficient distance, crushing and grinding in several water environments. It would be desirable if Sahakyan presented the absolute values of the 17 experiments of zircons analyzed in her study, depending on which it would be possible to think about the originality of those grains, having probably different ages, and considering their formation from different sources (?). These are questions that need to be addressed in the future. The last statement has prerequisites because, according to the local schematic map drawn by Satian (in

Satian et al., 2005), the "Eastern" diatreme (the same as Sahakyan's 2022) is emplaced in the carbonate-volcanic formation rocks of Callovian–Berriasian (i.e., 165–140 million years). Therefore, there is a problem here: the older (~183 Ma) tuff body cannot cut the younger formation.

In the vicinity of these geographic coordinates, about 100m to the southeast of the last diatreme, radiolarites combined with lavas were described, whose age according to the radiolarians is Middle–Late Oxfordian (i.e., less than 160 million years) or younger (Danelian et al., 2010). The present authors note that "the correlation between the determined volcano-sedimentary formation and the mentioned diatreme is uncertain". About 1.8 km east of the diatreme, again on the right bank of the Vedi River, three red-gray radiolarite horizons mixed with pillow lavas are exposed, the age of which has been determined as Middle Jurassic (Bajocian) (Danelian et al., 2008). By the way, the oldest age in the ophiolites of the Vedi region was obtained in the diorite of the Dashtakar gabbroid massif, where the oldest plateau age of 178.7±2.6 Ma was obtained by the Ar-Ar method on amphiboles (Galoyan, 2008; Rolland et al., 2010). Therefore, based on the last publication on zircon dating, the age of the formation of the Tethyan oceanic crust (i.e., obducted Vedi ophiolite) cannot be younger than the "diatreme" (cutting that crust) or remains of it. Further field observations and sampling of new rocks are needed to verify the validity of the last "diatreme". It remains to clarify the precise location of that "body" in the field. The coordinates mentioned in the text of the paper (Sahakyan, 2022) and the localization of the body in the map given therein (according to Galoyan, 2008) do not match each other. And Satian et al. (2005) monograph states that the "Eastern" diatreme (or "group of small diatremes") is exposed at 1.3km northeast of the ruins of Azizkend village, i.e., not here but about 2km northwest of the indicated coordinates.

Thus, if these "cutting body" rocks are not also sedimentary (or volcano-sedimentary) in origin, but are tuffs, then it's strange their presence in an ophiolite nappe obducted on the SAB, e.g., in Late Coniacian–Santonian (Galoyan, 2008, Sosson et al., 2010). It remains to assume that: either (a) this "diatreme" must be younger than the (host?) rocks around it or (b) these mysterious "tuffs" are just blocks or remnants of a "cutting body" that earlier formed on the oceanic crust and "arrived" here as a result of the obduction.

Conclusion

Within the boundaries of the Vedi ophiolite complex, the small area of Sagraberd ophiolite lavas, on the right bank of the Vedi River, was left out of the attention of authors of the Armenian-French group. Due to the lack of research for several decades, for the first time we addressed the coverage of the geological-structural, petrographic, and, partially, geochemical (based on the contents of the major elements) issues of this ophiolite outcrop. We tried to determine the age of the pink "cementing" limestones, found in the form of

small lenses or pockets in the pillow lavas, based on the foraminifera enclosed in them. In parallel, we referred to the unsolved problem of diatreme tuffs.

During the formation of the ophiolite nappe, these pillow lavas appeared and were placed on the Turonian carbonate suite which is the northern part of the South-Armenian microcontinent, and then were transgressively covered by a thin package of grayish-red and yellow marls and pelitomorphic limestones which have an Upper Coniacian–Lower Santonian age.

Pillow lavas are characterized mainly by amygdaloidal, sometimes massive, and often brecciated structures. The texture of the rocks is plagioclase-porphyritic, the main matrix is intersertal, doleritic (spilitic), hyalopilitic, and variolitic. The analyzed sample (G22.05), according to the contents of the major elements, corresponds to the alkaline type of basalts. The values of the given "characteristic" oxides are sufficient to rule out the spreading (MORB-like) origin of these lavas, assigning them to the OIB-type.

Among the microfauna separated from the limestone that was sampled from the small lens, it was possible to find representatives of planktonic foraminifers of the genera *Globotruncana* and *Globigerina*, on the basis of which the encompassing volcanic sequence is assigned to the Late Cretaceous.

In the course of recent fieldwork, we found that, morphologically, there is no cylindrical-shaped structure here, which would suggest its probable diatreme origin. In the indicated coordinates and in their vicinity, we encountered only terrigenous formations that are represented by poorly rounded conglomerates or conglobreccias, gravellites, sandstones, and siltstones. In the thin section of the microconglomerate examined microscopically, there are isolated particles of sedimentary carbonate rocks and the predominant detrital material is the volcanomictic component with grains rounded of varying degrees. The diatreme(s) described in the upper stream of the Vedi River is(are) also problematic; its described geological position and U-Pb age are disputed and are in need of serious revision.

References

Abovyan S.B. 1981. The mafic-ultramafic intrusive complexes of the ophiolite belts of the Armenian SSR. Publishing house: NAS Arm.SSR, Yerevan, 306p. (in Russian)

Aslanyan A.T. 1958. Regional geology of Armenia. Publishing house: "Haipethrat", Yerevan, 430p. (in Russian).

Aslanyan A.T., Satian M.A., Mnatsakanian A.Kh., Khanzadian H.A. 1987. High-Mg pillow lavas of the Minor Caucasus Vedi ophiolite zone. Izvestia AS Arm. SSR, Nauki o Zemle, N1, p.9–16. (in Russian)

Danelian T., Asatryan G., Sosson M., Person A., Sahakyan L., Galoyan G. 2008. Discovery of Middle Jurassic (Bajocian) Radiolaria from the sedimentary cover of the Vedi ophiolite (Lesser Caucasus, Armenia). C. R. Palevol 7 (General Paleontology), Issue 6, p.327–334.

Danelian T., Asatryan G., Sahakyan L., Galoyan G., Sosson M. and Avagyan A. 2010. New and revised radiolarian biochronology for the sedimentary cover of ophiolites in the Lesser Caucasus (Armenia). Geological Society, London, Special Publications, v. 340, p.383–391.

Danelian T., Zambetakis-Lekkas A., Galoyan G., Sosson M., Asatryan G., Hubert B., Grigoryan A. 2014. Reconstructing Upper Cretaceous (Cenomanian) paleoenvironments in Armenia based on Radiolaria and benthic Foraminifera; implications for the geodynamic evolution of the Tethyan realm in the Lesser Caucasus. Palaeogeography, Palaeoclimatology, Palaeoecology 413, p.123–132.

Dercourt J., Zonenshain L.P., Ricou L.-E., Kazmin V.G., LePichon X., Knipper A.L., Grandjacquet C., Sbortshikov I.M., Geyssant J., Lepvrier C., Pechersky D.H., Boulin J., Sibuet J.-C., Savostin L.A., Sorokhtin O., Westphal M., Bazhenov M.L., Lauer J.P. and Biju-Duval B. 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamir since the Lias. Tectonophysics 123, p.241-315.

Galoyan G. 2008. Etude Pétrologiques, Géochimiques et Géochronologiques des Ophiolites du Petit Caucase (Arménie). Ph.D. thesis, University of Nice-Sophia Antipolis. 287p.

Ghazaryan H.A. 2007. Island-arc volcanism of Armenia's ophiolite zones. Izvestia NAS RA, Nauki o Zemle, N2, p.11–20. (in Russian)

Grigoryan A.G. 2003. Some problems of the Triassic stratigraphy in the Jermaniss coal deposit in Armenia. Izvestia NAS RA, Nauki o Zemle, v.56, N3, p.40–45. (in Russian)

Hakobyan V.T. 1970. Cretaceous system. In: Geology of USSR, vol. 43, Arm. SSR., p.80–113. (in Russian)

Hakobyan V.T. 1976. The Late Cretaceous Gastropods of Armenia. Publishing house: AS Arm. SSR, Yerevan, 441p. (in Russian)

Hakobyan V.T. 1978. Biostratigraphy of the Upper Cretaceous deposits of Armenian SSR. Publishing house: AS of Arm. SSR, Yerevan, 285p. (in Russian)

Joachimski M.M., Alekseev A.S., Grigoryan A., and Gatovsky Yu.A. 2019. Siberian Trap volcanism, global warming and the Permian-Triassic mass extinction: New insights from Armenian Permian-Triassic sections. Geological Society of America Bulletin, 132, №1-2, p.427–443.

Kazmin V.G., Sbortshikov I.M., Ricou L.-E., Zonenshain L.P., Boulin J., Knipper A.L. 1987. Volcanic belt-indicators of the Mesozoic-Cenozoic active outskirts of Eurasia. In: Monin A.S., Zonenshain L.P.; History of the Tethys Ocean. Academy of Sciences of the USSR, P.P. Shirshov Institute of Oceanology, Moscow, p.58–74. (in Russian)

Leven E.Ya. 2009. Upper Carboniferous and Permian of Western Tethys: Fusulinids, stratigraphy, biogeography. Proceedings of Geol. Institute, Moscow, ed. "GEOS", 237 p. (in Russian)

Lomize M.G. 1970. Ophiolitic suture of Vedi (Lesser Caucasus). Bulletin of Geology 6, p.145. (in Russian)

Lomize, M.G. 1970. On the place of ophiolites in the tectonic structure of east Anatoly and Transcaucasia. Proceedings of higher educational institutions, Geology and prospecting 11, p.32-41. (in Russian)

Lomize M.G. 1983. Tectonic settings of geosynclinal volcanism. Moscow, "Nedra", 194p. (in Russian)

Khalatbari M., Juteau T., Bellon H., Whitechurch H., Cotton J., Emami H. 2004. New geological, geochronological and geochemical investigations on the Khoy ophiolites and related formations, NW Iran. Journal of Asian Earth Sciences 23, p.507–535.

Knipper A.L. 1975. The oceanic crust in the structure of the Alpine folded belt (South Europe, Western part of Asia and Cuba). Publishing office: "Nauka", 208 p. (in Russian)

Knipper A.L., Sokolov S.D. 1976. Vedi ophiolites (Armenia) autochton or allochton? Geotektonica 4, p.54–66. (in Russian)

Knipper A.L. and Khain E.V. 1980. Structural position of ophiolites of the Caucasus. Ofioliti, Spec. Iss. 2, p.297–314.

Mkrtchyan K.A. 1970. Intrusives of Vedi river basin. In: Geology of USSR, vol. 43, Arm. SSR., p.286–292. (in Russian)

Morkovkina V.F., Harutyunyan G.S., Gavrilova S.I. 1977. Some questions of petrogenesis of the ophiolitic association of the Lesser Caucasus. In: Magmatic formations of the Caucasus and south of Eastern European platform. Moscow "Nauka", p.183–213. (in Russian)

Paffenholtz K.N. 1959. Geological history of the Caucasus. Publishing house: AS Arm.SSR, 506p. (in Russian)

Rengarten V.P. 1959. Stratigraphy of the Cretaceous deposits of the Lesser Caucasus. Regional stratigraphy of USSR. Publishing house: AS of USSR, Moscow, 537p. (in Russian)

Rolland Y., Galoyan G., Bosch D., Sosson M., Corsini M., Fornari M., Verati C. 2009. Jurassic back-arc and Cretaceous hot-spot series in the Armenian ophiolites – Implications for the obduction process. Lithos 112, Issues 3-4, p.163–187.

Rolland Y., Galoyan G., Sosson M., Melkonyan R. and Avagyan A. 2010. The Armenian Ophiolite: insights for Jurassic back-arc formation, Lower Cretaceous hot spot magmatism

and Upper Cretaceous obduction over the South Armenian Block. Geological Society, London, Special Publications, v. 340, p.353–382.
Sahakyan L. 2022. The age of Vedi alkaline lamprophyre diatreme (Armenia). Proceedings NAS RA, Earth Sciences, v.75, N2, p.16–28.
Sahakyan L.H., Satian M.A., Stepanyan J.H. 2007. To geochemistry of Mesozoic alkaline-lamprophyre pipe tuffs of the Vedi zone (Armenia). Proceedings NAS RA, Earth Sciences, v.60, N2, p.28–35.
Sahakyan L., Stepanyan Zh., Avagyan A., Saakov A., Hayrapetyan A. 2022. Finding a new diatreme at Khosrov reserve (Armenia). Proceedings NAS RA, Earth Sciences, v.75, N1, 5–13.
Satian M.A. 1984. Mesotethys ophiolite depressions. Publishing house: AS Arm.SSR, Yerevan, 195p.
Satian M.A., Vardanyan A.V., Stepanyan Zh.H., Tayan R.N., Mnatsakanyan A.Kh., Haroutyunyan M.A., Nisanyan G.B. 1997. On the geological structure and minerallogeny of lamprophyric diatremes of the Vedi ophiolite zone. Izvestia NAS RA, Nauki o Zemle, N1-2, p.14–24. (in Russian)
Satian M.A., Stepanyan J.H., Sahakyan L.H., Mnatsakanyan A.Kh., Ghukasyan R.Kh. 2005. The Mesozoic lamprophyric diatremes of Vedi zone (Armenia). Yerevan, Publishing house: "Nairi", 148p. (in Russian)
Sokolov S.D. 1977. The olistostroms and ophiolitic nappes of the Lesser Caucasus. Publishing house: "Nauka", Moscow, 92p. (in Russian)
Sosson M., Rolland Y., Müller C., Danelian T., Melkonyan R., Kekelia S., Adamia S., Babazadeh V., Kangarli T., Avagyan A., Galoyan G. and Mosar J. 2010. Subductions, obduction and collision in the Lesser Caucasus (Armenia, Azerbaijan, Georgia), new insights. Geological Society, London, Special Publications, v. 340, p. 329–352.
Yeghoyan V.L. 1955. The Upper Cretaceous deposits of the southwestern part of Armenian SSR. Publishing house: AS Arm.SSR, Yerevan, 270p. (in Russian)
Zakariadze G.S., Knipper A.L., Sobolev A.V., Tsameryan O.P., Dmitriev L.V., Vishnevskaya V.S., Kolesov G.M. 1983. The ophiolite volcanic series of the Lesser Caucasus. Ofioliti 8, p.439–466.

ՎԵԴԻԻ ՕՖԻՈԼԻՏՆԵՐԻ ՍԱԳՐԱԲԵՐԴԻ ՏԵՂԱՄԱՍԻ ԵՐԿՐԱԲԱՆՈՒԹՅՈՒՆԸ. ՆՈՐ ՏՎՅԱԼՆԵՐ ԵՎ ՎԵՐԱՆԱՅՈՒՄ

Գալոյան Ղազար, Գրիգորյան Արայիկ, Աթայան Լուսինե, Ամիրաղյան Սոնա, Պետրոսյան Ժաննա

Ամփոփում

Հոդվածում ներկայացվում են նոր մանրամասներ Վեդիի օֆիոլիտային համալիրի սահմաններում՝ համանուն գետի աջ ափին մերկացող Սագրաբերդի օֆիոլիտային լավաների փոքրիկ տեղամասի վերաբերյալ: Հետազոտությունների երկարատև բացակայությունից դրդված՝ առաջին անգամ անդրադարձել ենք օֆիոլիտների այս տեղամասի երկրաբանական-կառուցվածքային, պետրոգրաֆիական և, մասամբ, երկրաքիմիական հարցերի լուսաբանմանը: Փիլոու լավաներին բնորոշ է, հիմնականում, նշաքարային, հաճախ էլ բրեկչիացված տեքստուրաները: Ապարների ստրուկտուրան պլագիոկլազ-պորֆիրային է, հիմնական զանգվածը՝ ինտերսերտալ, դոլերիտային (սպիլիտանման), հիալոպիլիտային և վարիոլիտային: Ըստ գլխավոր էլեմենտների պարունակությունների՝ հետազոտված նմուշը համա-

պատասխանում է բազալտների ալկալային տիպին: Բերված բնութագրական օքսիդների արժեքները բավարար են ապարները վերագրելու OIB-տիպին, բացառելով նրանց սպրեդինգային (MORB-նման) ծագումը: Նախնական որոշվել է փիլոու լավաներում փոքրիկ ոսպնյակների կամ գրպանների տեսքով հանդիպող վարդագույն «ցեմենտացնող» կրաքարերի հասակը՝ նրանցում պարփակված ֆորամինիֆերների *Globotruncana* և *Globigerina* ցեղերի հիման վրա՝ իբրև ուշ կավճի: Զուգահեռաբար, անդրադարձել ենք դիատրեմային տուֆերի չարչրկված խնդրին: Դաշտային դիտարկումների և միկրոսկոպիկ հետազոտությունների հիման վրա բացառում ենք այստեղ դիատրեմի գոյությունը՝ ելնելով տերիգեն առաջացումների գերակայությունից: Բացի այդ, Վեդի գետի վերին հոսանքի մեկ այլ դիատրեմի երկրաբանական դիրքի ու նրանում ցիրկոնների հասակի «ներդաշնակության» խնդիր ենք տեսնում, որոնց հարցերը լուրջ վերանայման կարիք ունեն:

ГЕОЛОГИЯ САГРАБЕРДСКОГО УЧАСТКА ВЕДИЙСКИХ ОФИОЛИТОВ: НОВЫЕ ДАННЫЕ И ОБЗОР

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Резюме

В статье приводятся новые сведения о небольшом Сагрaбердском участке офиолитовых лав, обнажающихся на правом берегу р. Веди в составе ведийского офиолитового комплекса. В связи с длительным отсутствием исследований, мы впервые обратились к освещению геолого-структурных, петрографических и частично геохимических вопросов данного офиолитового участка. Подушечные лавы в основном характеризуются миндалекаменными, часто брекчированными текстурами. Структура пород плагиоклазово-порфировая, основная масса интерсертальная, долеритовая (спилитовая), гиалопилитовая, вариолитовая. По содержанию главных элементов анализируемый образец соответствует щелочному типу базальтов. Приведенные значения характеристических оксидов достаточны для отнесения пород к OIB-типу, исключая их спрединговое (MORB-подобное) происхождение. Возраст розовых «цементирующих» известняков, залегающих в виде мелких линз или карманов в подушечных лавах, по заключенным в них фораминиферам родов Globotruncana и Globigerina был предварительно определен как позднемеловой. Параллельно мы коснулись нерешенной проблемы диатремовых туфов. На основании полевых наблюдений и микроскопических исследований мы исключаем существование здесь диатремы, учитывая преобладание терригенных образований. Кроме того, мы видим проблему «гармонизации» между геологическим положением другой диатремы в верхнем течении реки Веди и ее возрастом, установленным по цирконам, объяснения которой нуждаются в серьезной доработке.