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PETROLOGY

GENERATION OF LOWER-MIDDLE JURASSIC TRONDHJEMITE SERIES IN THE LESSER CAUCASUS (REPUBLICS OF ARMENIA AND MOUNTAINOUS KARABAGH)

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Abstract

The age and geotectonic history of trondhjemite (plagiogranite) magmatism of Mesozoic is especially important for unraveling the geological/geodynamic evolution of the east-southeastern segment of the Lesser Caucasus (LC). Issues for a more definite and comprehensive interpretation of tectonic implications of the LC ophiolites with adjacent Somkheto–Karabagh and Spitak–Kapan Jurassic–Cretaceous zones have been discussed anew. Evidently, these zones, particularly the geological units in them, are strongly associated with each other both spatially and temporally. U–Pb zircon dating of plagiogranites from Sevan ophiolite (central part of Amasia–Sevan–Hakari: ASH suture zone) and from mentioned zones in LC provides more reliable geochronological constraints on the evolution of Neotethys (?). Obviously, all zircon ages are in the interval of late Early to late Middle Jurassic epoch (~180–165 Ma). Considering these data, the age of the host effusions located actually both south and north of the main ASH ophiolite zone, should possibly be minimum Pliensbachian–Toarcian or older, rather than Bajocian and Bathonian. Based on whole rock geochemistry, the amphibole gabbro, pillow basalt and plagiogranites are co-genetic, suggesting a common melt source in their origin. All plagiogranite samples display variable LILE-enrichment and marked negative HFSE (Nb, Ta and Ti) anomalies typical of subduction-related magmas. Based on the field relationships and petrologic-geochemical features, all five plagiogranite bodies discussed are similar and may be interpreted to have been generated by low-pressure crystal fractionation of a basaltic magma derived from partial melting of the mantle in a subduction (or supra-subduction) zone tectonic setting. Created on the Paleotethys the ASH basin (as northern branch of Neotethys) was probably consumed by either northward or preferred southward double subductions mainly during Early–Middle Jurassic to Late Cretaceous, not excluding the possibility of the existence of a single subduction zone here.

Keywords: Zircon U–Pb dating, trondhjemite, plagiogranite, Sevan ophiolite, geodynamics, Neotethys, Armenia, Mountainous Karabagh, Lesser Caucasus.

1. Introduction

Granitic rocks of different ages are widespread in the Lesser Caucasus (LC) in which various plagiogranites are significantly represented. In particular, plagiogranite intrusions of Lower–Middle Jurassic are well known, which are part of different tectono-magmatic zones. These are especially common in the Somkheto–Karabagh tectonic belt (outcrops in NE Armenia and western Azerbaijan), in the Spitak–Kapan volcanic zone (e.g., in Karabagh territory) and in their intermediate Amasia–Sevan–Hakari ophiolite zone (e.g., in Sevan area).

The Mesozoic ophiolites of LC constitute a part of the Tethyan (Neotethyan) ophiolite belt (e.g., Knipper, 1975; Knipper and Khain, 1980; Adamia et al., 1981; Zakariadze et al., 1983; Galoyan, 2008; Rolland et al., 2009; Sosson et al., 2010), which provide constraints on the geodynamic evolution of the former oceanic domain(s) starting its (their) opening untill the closure and finally obduction of the oceanic lithosphere remnants onto the continental crust as an "ophiolite complex". Sevan ophiolite exposed in northeastern part of Sevan Lake is one of the largest and best-preserved relicts of the ancient oceanic crust of Neotethys in Armenia; therefore, this complex contains important information about that basin evolution.

Unlike of the ophiolites of LC, the geological history and tectonic evolution of the Mesozoic and especially of the most predominant Jurassic magmatic activity in this region are still obscure and debated due to the scarcity of structural, geophysical, modern geochemical and authentic geochronological data. Therefore, a good understanding of this region requires the study, interpretation and integration of the whole geological information from a number of areas across a wide region, which may complete each other reciprocally.

The problem of the origin of granitoid formations is one of the most important in modern petrology. In Somkheto–Karabagh zone, the Middle Jurassic intrusions are represented by the Haghpat, Tavush, Khndzorut (in Armenia) and the Atabek–Slavyanka, Gilanbir (in Azerbaijan) plagiogranite complexes (e.g., Melkonyan, 1989; Sadikhov, Shatova, 2016). For comparison, here we have also discussed the Dali plagiogranite intrusion from Sevan ophiolite. This paper presents a review of field, geochronological and geochemical data from the eastern LC, focusing only on the felsic (plagiogranite=trondhjemite) rocks of Lower–Middle Jurassic and discussing their genetic link, possible origin (formation) and their tectonic setting.

2. Geological setting

The ophiolite complex of Sevan (the map is available e.g., in Galoyan et al., 2009) constitutes part of the Amasia–Sevan–Hakari (ASH; e.g., Galoyan and Melkonyan, 2011; Hässig et al., 2013) or Sevan–Akera (e.g., Knipper, 1975) ophiolite belt that is considered to be a suture zone for half a century (e.g., Milanovski, 1968). The ASH is the largest in the LC belt, which is NW–SE oriented discontinuous arched zone extending for ca. 400 km (with a maximum width of 20–25km), from NW Armenia (Amasia–Stepanavan group of ophiolites) through the East of Sevan Lake to the Karabagh territory (Hakari branch of it).

The ophiolite complex on the eastern shore of Lake Sevan is a dismembered near-complete ophiolite succession, where mantle serpentinites and serpentinized peridotites at the base followed upwards by a layered dunite–wehrlite–troctolite–gabbro sequence, then followed by isotropic gabbros (including amphibole varieties), diorites and plagiogranites, and pillow or massive lavas (e.g., Galoyan et al., 2009 and references therein). These pillow lavas are associated with relatively deep-water sedimentary rocks (mainly cherts and radiolarites); but a well-developed sheeted diabase dyke complex has not been observed. The geological sections here are completely different in different valleys that join to the Lake. Dali section (located in a valley about 4km northwest of Jil village, fig.1) in the Sevan area plays a key role, where numerous field visits have been both by ourselves and with French partners in recent years (see Galoyan, 2020 for details).

Based on the U–Pb new data of Dali plagiogranitic intrusion (~172Ma), a new boundary is "drawn" between the pre-intrusive and post-intrusive basalts, both in pillowed nature (Galoyan, 2020). Accordingly, we suggested that "lower lava" series may have an older age, at least, the beginning of the Middle Jurassic, while the "upper lavas", tectono-stratigraphically covering the main plagiogranite body, have an age of Upper Jurassic–Lower Cretaceous that is based on radiolarites intercalated in them (Asatryan et al., 2012). Lower pillow lavas are host rocks of this intrusion and, unfortunately, no signs of sedimentary rocks were found as cement in them, which would enable their direct dating.

The plagiogranite sample is taken from the largest stock-like felsic intrusive body (< 1km^2) in Dali valley (fig.1), where they are overlain by radiolarites and pillow basalts of different geochemical composition. In the field the plagiogranites display bright, white and yellowish weathered surfaces and often contain mafic enclaves. They are strongly altered in their exocontact parts, mainly epidotized but some fresh parts are still available to study petrologically. Alternatively, plagiogranites have formed discrete and diffused segregations or discontinuous networks of veins with local coarse-pegmatitic texture within and around gabbro-dioritic intrusions.

Geological units of the Middle–Upper Jurassic have a wider distribution in the north-eastern part of the LC that is known as Somkheto–Karabagh tectonic belt (or "anticlinorium", "zone" or "terrane"; for details see references in Galoyan et al., 2013, 2018). It is stretching by a continuous belt over than 350 km (with a maximum width of 35–40km) from the southern Georgia and mainly the Alaverdi–Ijevan regions of northern Armenia on its northwest, then partly passes through the north-western corner of Azerbaijan (Shamkhor–Dashkesan area) to the basins of rivers Tartar and Khachenaget on its southeast (in Karabagh Republic territory). Further, to the southwest formations of Jurassic period are outlined on the left bank of river Hakari (Akera), in Karabagh territory and in basins of rivers Vokhchi and Vorotan (Kapan region, in southern Armenia), which constitute the "Kapan block (or zone)" of Mesozoic age. Located southwest of the main ophiolite zone this "block" was part of the recently distinguished "Spitak–Kapan volcanic zone" (Galoyan et al., 2013) due to the presence of Jurassic–Lower Cretaceous igneous and other complexes in the Tsaghkunyats anticlinorium and to the north of it (near the city of Spitak).

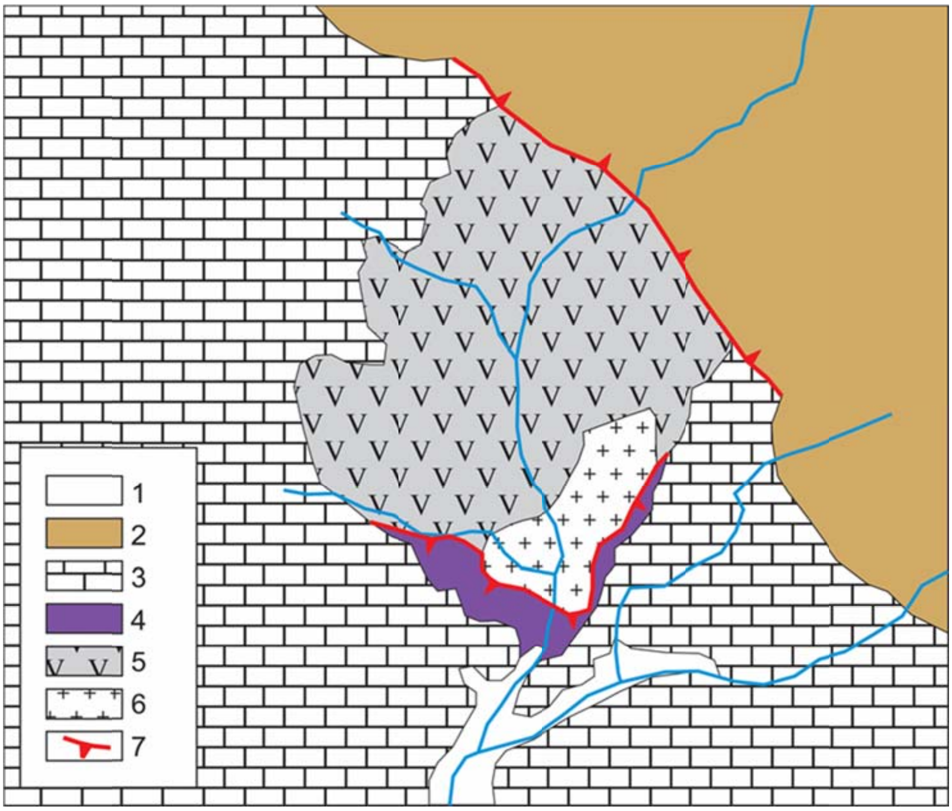

Fig.1. Schematic geological map of the middle valley of the Dali River; by Galoyan (2020). 1 – Quaternary deposits; 2 – Eocene volcanic and sedimentary formations; 3 – Campanian–Maastrichtian pelagic limestones and marls with micro-conglomerates at the base; 4 – Upper series of pillow basalts–radiolarites, 5 – Lower series of pillow basalts, cut by numerous rhyolite dikes, 6 – Dali plagiogranite intrusion of the early Middle Jurassic (~ 172Ma), 7 – thrust.

The presence of felsic granitoid intrusions of Middle and Late Jurassic epochs is common within these volcanogenic–sedimentary zones. According to the literature data (for compiled references in Russian see e.g., Aslanyan, 1958; Abdullayev, 1963; Lordkipanidze, 1980; Melkonyan, 1989; Galoyan et al., 2013) the Middle Jurassic in LC is represented by a great thick (about 3500m) sedimentary–volcanogenic sequence with predominant basalt–andesite series and associated pyroclastic rocks. The most ancient Mesozoic intrusions here are the Middle Jurassic trondhjemite (plagiogranite) massifs included in the “plagiogranitic formation”. In northern Armenia these are represented by several major bodies (Tavush and Khndzorut intrusions, about 50km^2) and a lesser (around 6km^2) massif of Haghpat (e.g., Melkonyan, 1989). In north-western Azerbaijan the intrusions of Atabek (80km^2) and Gilanbir (16km^2) are known (e.g., Sadikhov, Shatova, 2016). In the extreme southeast of the LC the Berdadzor

(Bülülduz) gabbro–plagiogranite massif (< 60km^2) is the main plagiogranite intrusion (Abdullayev et al., 1974; Galoyan et al., 2013).

Recently dated Berdadzor gabbro–plagiogranite massif is elongated and localized in the limits of Berdzor (Lachin) anticlinorium, which is intruded the mainly pillow basaltic volcanic and tuffaceous formations of Middle (?) Jurassic age (fig.2). The stratigraphic base of these formations remains unknown in this area. This intrusion is linearly propagating from northwest to the southeast, cropping out in many isolated localities, including dyke-like bodies (i.e. apophyses) within strongly epidotized basalts. Note also that in main plagiogranite body some dykes (up to 50 cm-thick or scarcely larger) of pinkish leucogranite (aplite) with the clear-cutting contacts are also encountered by us (Galoyan et al., 2013). The plagiogranite (labeled 6552) is sampled from one of the largest outcrops of the Berdadzor intrusion, on the vicinity of the highway between towns Berdzor–Shushi, where they intruded the pillow basalts of so considered Bathonian stage (e.g., Abdullaev et al., 1974 and references therein). The plagiogranite sample is white, medium-grained, and outwardly is fresher and massive.

3. Petrologic-geochemical background of plagiogranites

In general, plagiogranitic rocks are so similar with their texture and petrographic composition in different intrusions that there is no need to present their description separately. Therefore, rocks are briefly described as follows. They are small- to medium-grained hypidiomorphic-granular, sometimes porphyric in texture. Usually, plagioclase (40–70%) and quartz (20–50%) make up more than 90% of these rocks. Amphibole, biotite, magnetite, ilmenite and epidote are present in minor but variable amounts, and the zircon, sphene and apatite are typical accessory minerals. The textures of micro-pegmatitic, graphic to granophyric intergrowth with quartz and plagioclase crystals are not uncommon in them (e.g., Melkonyan, 1989; Galoyan et al., 2013, 2018; Sadikhov, Shatova, 2016). Coleman and Donato (1979) interpreted these kind plagioclase–quartz intergrowths (granophyric–micrographic) as primarily formed textures during eutectic crystallization of a low-K magma. The alterations are represented by chlorite, epidote, actinolite, sericite, carbonate and argillite.

Dali plagiogranite sample is formed from 55–65% plagioclase ($An_{20\text{-}30}$), 25–45% quartz, and minor biotite (<5%), rarely ortho-amphibole (<5%) and accessory phases of titanomagnetite, sphene (titanite), apatite and zircon (Galoyan, 2008; Galoyan et al., 2009).

The plots of Artanish amphibole gabbro (sample AR-03-10; this is used for genetic comparison) and Dali plagiogranite (AR-03-19) samples of Sevan ophiolite show nearly parallel forms in both MORB-normalized trace-element and Chondrite-normalized rare earth element (REE) diagrams (fig.3,4). In MORB-normalized diagram they both show significant enrichment of large-ion lithophile element (LILE) and slight enrichment of light REE (LREE) with respect to heavy (HREE) ones. Clear negative anomalies of Nb, Ta, P and Ti are

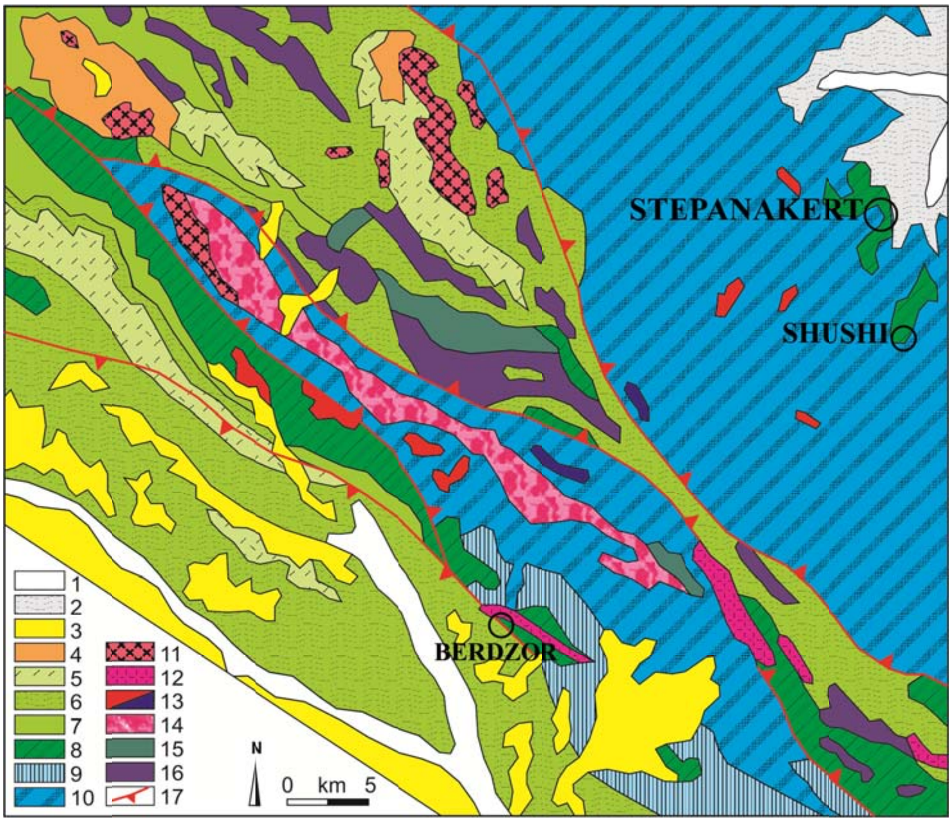

Fig.2. Schematic geological map of the Berdzor anticlinorium area, compiled after (Abdullaev et al., 1974; National Atlas of Armenia, 2007, p.26–27), modified by Galoyan. 1 – Quaternary deposits; 2 – Pleistocene formations; 3 – Upper Pliocene–Pleistocene volcanic, volcanoclastic formations; 4 – Middle–Upper Eocene volcanic, volcanoclastic formations; 5–7 Upper Cretaceous series: 5 – Campanian–Maastrichtian limestones and marls; 6 – Coniacian–Santonian conglomerates, limestones, argillites; 7 – Cenomanian limestones, argillites, tuffites; 8 – Lower Cretaceous, Albian limestones, argillites, marls, sandstones; 9 – Upper Jurassic, Oxfordian–Tithonian sandstones, tuffs, limestones; 10 – Middle Jurassic, Bajocian–Bathonian volcanic, volcanoclastic formations; Intrusive series (11–14): 11 – Upper Eocene, quartz diorites, granodiorites, granitoids; 12 – Upper Cretaceous, quartz diorites, granodiorites, syenites; 13 – Upper Jurassic: (A: red) quartz diorites, granodiorites, granitoids; (B: blue) diorites; 14 – Lower–Middle Jurassic, *Berdadzor* plagiogranite intrusion; Lower–Middle Jurassic ophiolite series (15–16): 15 – gabbroids; 16 – ultrabasites, serpentinites; 17 – thrust.

also seen in them, in contrast to the diorite sample (AR-03-23), where there is no minimum of P, and that of Ti is weakly expressed. In a Chondrite-normalized REE diagram the amphibole gabbro shows slight depletion in LREE, and the plagiogranite sample (as well as diorite) is characterized by slightly concave pattern with negative Eu anomaly (Eu/Eu* = 0.67), reflecting plagioclase fractionation. The similarities of many trace element features (or patterns) argue for a genetic relationship between these two groups (gabbro–granite members) of rocks, and, consequently, the fact of fractional crystallization during the formation of plagiogranites is more probable (or is obvious).

Table

Rock names, geotectonic affiliation, ages, coordinates, and data sources of samples used for geochemical comparisons.

Sample name	***Rock type***	***Geotectonic unit/zone***	***Age (Ma)***	***GPS coordinates***	***References***
AR-03-10	Amphibole gabbro	Sevan ophiolite of ASH belt	170.5 ± 4.4; 165.3 ± 1.7	*N* 40.51119° *E* 45.37227°	*Galoyan et al., 2009*
AR-03-19	Plagiogranite		171.8 ± 2.8	*N* 40.48466° *E* 45.42277°	
AR-03-23	Diorite		–	–	
6551	Pillow basalt	Spitak-Kapan zone	–	*N* 39.66798° *E*4 6.59109°	*Galoyan et al., 2013*
6552	Plagiogranite		176.7 ± 1.7	*N* 39.67687° *E* 46.62931°	
11ARM25A	Plagiogranite	Somkheto-Karabagh zone	165 ± 4	*N* 41.11592° *E* 44.70738°	*Galoyan et al., 2018*
AL-09-05	Plagiogranite		–	*N* 41.11017° *E* 44.71101°	*Mederer et al., 2014*
L3.2	Plagiogranite*		–	*N* 41.08709° *E* 44.70564°	*Neill et al., 2015*
Azb-1	Plagiogranite		180.2 ± 1.8	–	*Sadikhov, Shatova, 2016*

The petrology and geochemical characteristics of Middle and Upper Jurassic magmatic rocks within the Artsakh (Karabagh) territory is summarised recently by Galoyan et al. (2013). According to these authors, the plagiogranite single sample (number 6552) is calc-alkaline, while their hosting pillowed basalt (sample 6551) is tholeiitic in AFM ternary plot. These two samples show nearly parallel patterns in both MORB-normalized trace-element and Chondrite-normalized REE diagrams (figs.3,4). The plagiogranite (sample 6552) is characterized by higher concentration of REEs (is enriched 31–38 times compared with the average chondrite value) than their hosting pillow basalt (sample 6551; is enriched 17–23 times), as well as the amphibole gabbro (sample AR-03-10; enriched 7–9 times) and the plagiogranite (sample AR-03-19; enriched 17–23 times) from Sevan ophiolite, although all of their patterns are similar and more or less parallel to each other. Negative Eu anomalies in all plagiogranites indicate plagioclase involvement during either a fractionation or a melting process (e.g. Floyd et al., 1998). Moreover, in the MORB-normalized spider diagram all plagiogranites have similar patterns and are characterized by variably high concentrations of LILE (Ba, Rb, K) and Th with the negative Nb-Ta and deeper P and Ti anomalies (fig.3).

On the feldspar (An–Ab–Or) normative rock classification diagram of O'Connor (1965) all plagiogranites plot in "trondhjemite field" (not shown here). Therefore, it would be more correct classically to name these rocks *trondhjemite* although the term "plagiogranite" is widely used in Russian literature (since the 1930s). Though Frost et al. (2001) believe that trace element compositions of granitoids are a function of the sources and crystallization history of the melt, and the tectonic environment is secondary, nevertheless, some schemes are in wide use. On the basis of binary discrimination diagrams with respect to Rb, Y, Yb, Nb and Ta values for granitic rocks (Pearce et al., 1984, not shown) the Dali and other plagiogranites plots in the volcanic arc granite (VAG) field while the Berdadzor plagiogranite plots in the ocean ridge granite (ORG) field but closer with the VAG limit. The compositional similarity in terms of major and trace elements and REEs of the Sevan ophiolite Dali plagiogranite with the other intrusions plagiogranites from Somkheto–Karabagh and Spitak–Kapan zones and their lateral vicinity suggests that they may be genetically related with each other. It is not difficult to notice that these structures (i.e. zones), in particular the geological units in them, are strongly associated with each other both spatially and temporally.

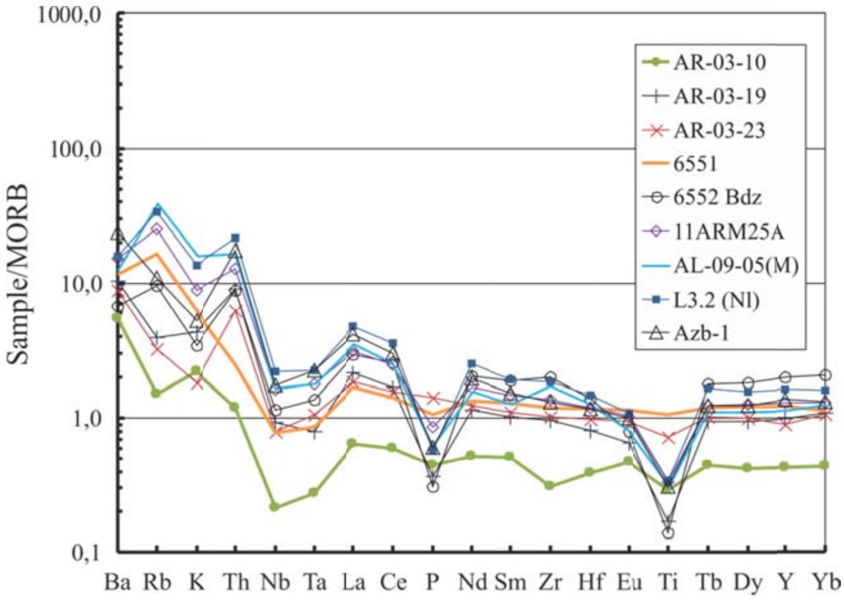

Fig.3. MORB-normalized multi-element (Sun and McDonough, 1989) diagram showing the patterns of amphibole gabbro (AR-03-10), plagiogranite (AR-03-19) and diorite (AR-03-23) from Sevan ophiolite (after Galoyan et al., 2009), Early Jurassic pillow basalt (6551) and plagiogranite (6552) from Kapan zone Berdzor locality (after Galoyan et al., 2013), plagiogranites (11ARM25A, AL-09-05, L3.2) of Haghpat intrusion (respectively, Galoyan et al., 2018; Mederer et al., 2014; Neill et al., 2015) and plagiogranite (Azb-1) from western Azerbaijan (Sadikhov, Shatova, 2016).

Actually, the ophiolite narrower belt here (in Karabagh), on its both NE and SW sides, is tectonically associated or accreted (attached) with the volcanic and volcaniclastic rocks of Lower (?) to Middle Jurassic age (fig.2). Thus, without estimating the volume of the marine crustal contraction here, these plagiogranitic stages of magmatism were developed very closely in space and time during the evolution of the LC crust formation. Besides, though the precise age of pillow basalts (hosting the Berdadzor plagiogranite) and geodynamic context of their formation are still uncertain, MORB- and Chondrite-normalized their patterns are parallel with and belong to the main "ophiolitic series" domain of LC ophiolites (not shown; Galoyan, 2008). In many discrimination diagrams (not shown here) the pillow basalt spans in the field of N-MORB and/or IAT, and its relatively high content of Ti (TiO_2 = 1.3 wt.%) is resulted of involvement of asthenospheric material. Meanwhile, its lower Mg-number (Mg# = 46) evidence the possible derivation from variably fractionated melts but not primitive magmas (Galoyan et al., 2013). The lower Nb content (1.8ppm) of this pillow basalt is characteristic to the Nb content of representative arc tholeiitic basalt (e.g., 1.7ppm, in Pearce, 1982). In terms of geochemistry these features are peculiar for basalts from back-arc basins being transitional in composition between MORB and IAB (e.g., Pearce and Stern, 2006). Therefore, the potential tectonic setting for pillow basalts might also be either fore-arc or back-arc basin regime similar to the main ophiolite volcanic bodies.

Recall that petrologic and especially geochemical studies (major, trace, REE and some isotopes) suggest two distinct lava flow series in the LC ophiolites: (1) a contaminated normal Mid-Oceanic Ridge Basalt (N-MORB or back-arc basin basalt: BABB-type) series evolving from gabbro to plagiogranite and from basalt to basaltic andesite, exhibiting tholeiitic to calc-alkaline features (enrichments in LILE); negative anomalies in Nb, Ta and Ti relative to N-MORB) and (2) an alkaline ocean island basalt (OIB-type) series of lavas evolving from basanite to trachy-andesite that considered to be the expression of a mantle plume event (Galoyan, 2008).

4. Summary data on the age of trondhjemite magmatism

Establishing the precise magmatic ages of rocks is one of the most critical tasks, which is involved in their full characterization. In recent years, except for the plutons of north-eastern Armenia Shamshadin anticlinorium (i.e. Tavush–Khndzorut group), new U–Pb zircon ages have been obtained for plagiogranites of all other massifs under discussion (see table), which we will briefly present below from north to south. Plagiogranites of Haghpat intrusion in northern Armenia have a Bajocian–Bathonian age of 165 ± 4Ma (Galoyan et al., 2018). Towards south-east in the territory of Azerbaijan, the crystallization ages of first phase plagiogranite (180.2 ± 1.8Ma) and of second phase leucoplagiogranite (169.3 ± 1.2Ma) (Sadikhov, Shatova, 2016) are somewhat older. The new age of a sample taken from the Dali plagiogranite intrusion of Sevan ophiolite corresponds to the Aalenian–Bajocian (171.8 ± 2.8Ma) period, in which no inherited zircon grains were found (Galoyan, 2020). Finally, the zircons of the oldest plagiogranite intrusion of Berdadzor from the territory of Artsakh revealed a relatively older age (176.7 ± 1.7Ma) of Toarcian–Aalenian (Galoyan et al., 2013) than was it previously considered (K–Ar, ~156 Ma; Abdullayev et al., 1974). Thus, it is obvious that all ages are in the interval of late Lower to late Middle Jurassic epoch. We have used these data to attain a better understanding of the timing and geodynamic evolution of LC region during middle Mesozoic.

5. Discussion

Having new data accumulated in the literature it seems necessary to make certain adjustments to the understanding of the geodynamic setting of the formation and petrogenesis of various types of plagiogranites. The structure of the entire allochthonous ophiolite domain in the LC belt (mostly in Armenia and partly in Karabagh territory) was unraveled during the last years aimed to identify the setting of that allochthonous units and to timing their generation and emplacement into the thrust pile (e.g., Galoyan, 2008; Galoyan et al., 2009; Rolland et al., 2009, 2010; Sosson et al., 2010; Danelian et al., 2012; Hässig et al., 2013; 2014). We refer readers to use these works and references therein to avoid repetitions here.

After the recent studies of Sevan ophiolite (Galoyan et al., 2009), the plagiogranites (Dali and others) appear to be a most differentiated component of the dioritic intrusions. Either the fractional crystallization of basaltic magma (e.g. Coleman and Peterman, 1975; Coleman and Donato, 1979; Floyd et al., 1998) or the partial melting of a gabbroic source under hydrous conditions (e.g., Gerlach et al., 1981; Pedersen and Malpas, 1984; Koepke et al., 2004; Zi et al., 2012) is largely considered as a responsible process for production of plagiogranitic liquids. In our case, both field and geochemical peculiarities (e.g., Galoyan et al., 2009) suggest their origin by fractional crystallization of wet (amphibolic) gabbroic magma.

The age and tectonic emplacement history of the Sevan–Hakari ophiolite is especially important for unraveling the evolution of the eastern-southeastern segment of the LC ophiolite belt. U–Pb zircon dating of an amphibole gabbro (unpublished yet) and plagiogranite of Sevan ophiolite from the central part of ASH suture zone in LC belt provides new and more reliable geochronological constraints on the evolution of Neotethys (?). At the same time, the late Lower Jurassic age of Berdadzor plagiogranite from adjacent Spitak–Kapan zone is a supporting evidence to emphasize the shortening/closure stage of Tethyan LC basin related to the ongoing subduction (at any convergent plate boundary) or its initiation.

In Sevan area, several “anatectic plagiogranite–migmatites” from Pambak valley are described that have been formed under conditions of epidote–amphibolite facies of metamorphism (Kazaryan, 2006). Unlike it, during our recent studies, no inherited zircons have encountered in a plagiogranite sample of Dali, i.e., there is no evidence for interaction with old crustal materials, which implies their magmatic differentiated origin too. Therefore, we interpret the amphibole gabbro and plagiogranite as having formed by the same source melt, derived from a "sea-floor spreading" likely in a supra-subduction zone setting. We further consider that the age of ~172Ma (Aalenian) for the upper plutonic part of the Sevan ophiolite represents the timing of an intra-oceanic (MOR/BAB setting) plutonism, which was more probably caused by fractional crystallization of a basic magma source. Alternatively, at least, the plagiogranite magma alone might be intruded the gabbroic unit, as we will discuss below, more probably above a subduction zone.

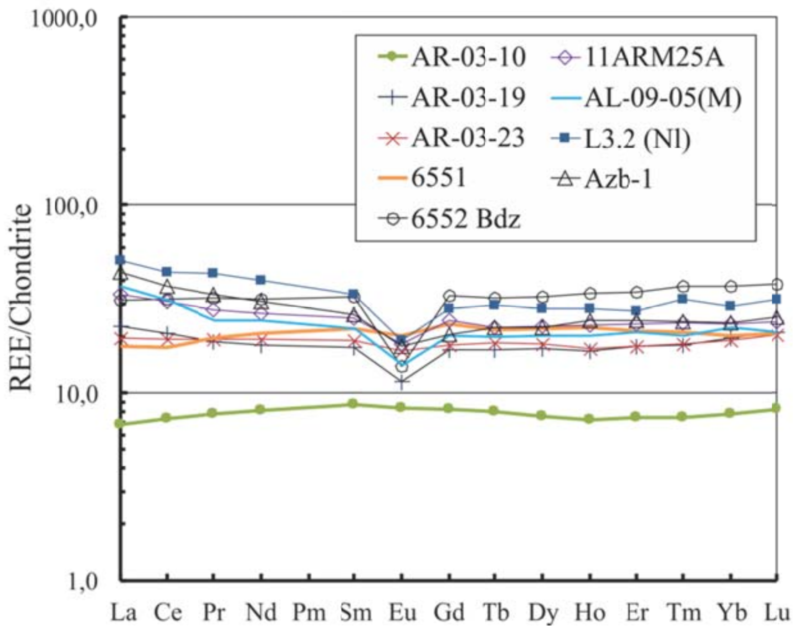

Fig.4. Chondrite-normalized REE (Sun and McDonough, 1989) diagram showing the patterns of mentioned rock samples in Fig.3.

One of the important questions with regard to Tethyan basin evolution is the nature of Somkheto–Karabagh volcanic arc? The analysis of tectonic models in the literature and the details of their own data are summarized in articles (Galoyan et al., 2013, 2018). The facts are in favor of a model of Mariana-type island arc environment. However, controversy still exists regarding to the tectonic setting(s), subduction polarity and the powerful magmatism on both northern and southern alongsides of the ASH suture zone during Jurassic and Cretaceous. Any viable interpretation needs to explain the origin and wider propagation of the arc-type (both volcanic and plutonic) magmatic rocks and ophiolites themselves. Some discussion based on available data of local and regional scale comparison can be useful for this and especially future studies.

In Berdzor anticlinorium (in Karabagh area), the pillow basalts that are hosting the Berdadzor plagiogranite intrusion could not be Bajocian or Bathonian as considered (e.g., Abdullaev et al., 1974), and should possibly be, at least, Pliensbachian–Toarcian, given the new age of ~177Ma (Toarcian; based on a last International chronostratigraphic chart, 2021) of mentioned intrusion. The same picture emerges with the plagiogranite intrusions (~180Ma; Sadikhov, Shatova, 2016) of western Azerbaijan. Therefore, considering these facts, the age of the host effusions located actually both south and north of the main ASH ophiolite zone, should possibly be minimum Pliensbachian–Toarcian or older, rather than Bajocian and/or Bathonian. So, these are new evidences of earliest Mesozoic magmatic activity(ies) being related to any of subduction models within the LC domain, which was unknown (or partially and somehow ignored?) up to present. Alternatively, those pillow basalts in Berdzor anticlinorium might also belong to a pre-existing oceanic crust (e.g., Paleotethys?) that was older than Lower–Middle Jurassic.

Evidently, the trondhjemite intrusions are abundant in the northern segment of Somkheto–Karabagh zone exposed both in Armenian and Azerbaijan parts. While some of the plagiogranite and related pink leucogranite intrusions from NE Armenia are under the laboratory studying process, the U–Pb dating of plagiogranite (Galoyan et al., 2018) from smaller Haghpat intrusion of Alaverdi region (northern Armenia) argue the late Middle Jurassic stage (165 ± 4Ma) of its emplacement. Although petrologically similar, this trondhjemitic sample is about 10 Ma younger than those mentioned above. Here, isotopically analyzed the single sample of plagiogranite yields higher $^{87}Sr/^{86}Sr$ value of 0.70806 (Neil et al., 2015) than those of typical MORB (0.7035–0.7050), which reveals that the Haghpat plagiogranites were not entirely derived from a depleted mantle source but with additional input of some enriched materials (e.g., slab-derived components).

For the first time, fundamental differences were established in the geochemical appearance of ensialic paleo-island arc (i.e., Somkheto–Karabagh) plagiogranites and plagiogranites within the ophiolite association, due to the petrogenetic features of their formation (Melkonyan, 1989). However, geochemically, at least the Dali plagiogranite of the ophiolitic complex do not support this conclusion.

Chondrite-normalized undepleted (i.e., flat) HREE patterns suggest that the trondhjemitic liquids were generated in a low-pressure, garnet-absent field (e.g., Zi et al., 2012). Melting or the fractionation at lower pressures or with lower water contents may produce calc-alkaline liquids as plagioclase replaces garnet as the major Al-bearing phase (Carroll and Wyllie, 1990). Both Sevan and Berdadzor plagiogranites might have been produced by low-pressure crystal fractionation of a MORB source (e.g., Pallister and Knight, 1981; Pedersen and Malpas, 1984; Floyd et al., 1998; Dilek and Thy, 2006), because they generally show flat and unfractionated REE patterns that are similar (sub-parallel) to those of MORB-type parents. At the same time, all these samples display variable LILE-enrichment and marked negative HFSE (Nb, Ta and Ti) anomalies typical of subduction-related magmas. Therefore, based on field relationships and petrologic-geochemical features (especially, positive correlation between REE and SiO_2 contents), all the discussed plagiogranite bodies may be interpreted to have been generated by low-pressure fractional crystallization of a basaltic magma derived from partial melting of the mantle in a subduction (or supra-subduction) zone tectonic setting.

It is already obvious that several of plutons are among the oldest (177–180 Ma) in this area, and it may represent the earliest stage in the magmatic evolution of an “intraoceanic island arc” or an “active continental margin”. Therefore, the earliest major magmatic event recorded in this study, and perhaps the “defining time” in the early Mesozoic evolution of the Lesser Caucasus, is the intense episode of Jurassic intra-oceanic arc magmatism at around 180–165 Ma.

To better understand the structure of the Earth's crust in the LC, we need additional and new data (including those of seismic tomography). The polarity of the subduction and the number of zones (one, two or three?) during Jurassic are still problematic and largely debated in this region (e.g., Rolland et al., 2009; Sosson et al., 2010; Hässig et al., 2015; Galoyan et al., 2009, 2018). If we consider a large Mesozoic sea-basin here, we will need “to propose” two subduction zones, which are responsible for the “creation” of zones Somkheto–Karabagh and Spitak–Kapan (Galoyan et al., 2013).

The first assumption is that only two north-dipping subduction zones might be "drawn" that are “responsible” for both southern and northern magmatic belts of Jurassic period separated by ASH sea-basin (or suture actually). Since, at least, late Early Jurassic (~180 Ma) the northern Neotethys was sinking under the Somkheto–Karabagh belt and the southern Neotethys or a southern brunch (?) of northern Neotethys was subducting beneath the South Armenian microplate (SAM) and, probably, under the older oceanic crust (in the east), to produce the Spitak–Kapan zone. On the contrary, Hässig et al. (2015) considered that north-dipping subduction under the southern margin of SAM is unlikely at that time as it would lead to the convergence of SAM with Gondwana; so, they substantiated their south-facing model of subduction. Alternatively, a model of two south-dipping subduction zones in the Paleotethyan ocean is proposed recently (Galoyan et al., 2018), which led: (1) to the creation of the Somkheto–Karabagh island-arc (*sensu stricto*), (2) to the opening of LC sea-basin (corresponding to ASH ophiolites) behind it and (3) to the formation of the Spitak–Kapan heterogeneous zone due to subduction of Paleotethys beneath the SAM and itself(?). In both hypotheses, the LC ophiolites are creating in a back-arc basin context.

Apparently a more definite and comprehensive interpretation of tectonic implications of the LC Mesozoic ophiolites with adjacent Somkheto–Karabagh and Spitak–Kapan Jurassic–Cretaceous zones during Neotethys evolution and closure requires additional field and laboratory (including detailed geochemical and isotopic) studies and especially geophysical works. Nevertheless, from the results of the recent and present studies, we suggest the second scenario as more likely interpretation. Although it cannot be excluded that all these could have been formed at the same time and over *only one subduction zone*, if we consider that the absorption volumes of the oceanic crust were not large, i.e., there was no wider Sea between these zones (or volcanic arcs). This is a question that can only be answered through additional and detailed paleomagnetic research.

6. Conclusions

The field data, petrological and geochemical results of the plagiogranites and associated mafic rocks (gabbro, pillow basalts etc.) allow us to draw the following conclusions on their ages, petrogenesis and tectonic setting within the Mesozoic tectono-magmatic sections of LC in Alpine–Himalayan orogenic belt.

The ophiolitic remnants within the LC belt represent an oceanic basement evolved between the Eurasian active continental margin [?]) or Somkheto–Karabagh Island-arc terran to the north and the Gondwana-originated SAM to the south during Mesozoic. This “oceanic basin” (named ASH) belongs to the northern branch of Neotethys (created on the Paleotethys) as an eastward extension of the larger Izmir–Ankara–Erzincan Seaway. It was probably consumed by either northward or (preferred) southward double (also having in mind the idea of one zone) subductions mainly during Early–Middle Jurassic to Late Cretaceous.

The amphibole gabbro (from Artanish valley) and the Dali plagiogranite (among others) form the upper plutonic part of the Sevan ophiolite succession of ASH, and display geochemical features that are typical for an arc-related petrogenetic evolution taken place in an intra-oceanic supra-subduction back-arc (or fore-arc?) setting.

Based on petrography and major–trace element abundances, the five trondhjemite (plagiogranite) plutons (including two of them in western Azerbaijan) are similar. Their trace element discrimination diagrams define a volcanic arc granite (VAG-type) setting. Discussed plagiogranite bodies may all be interpreted to have been generated by low-pressure fractional crystallization of a basaltic magma derived from partial melting of the mantle in subduction (supra-subduction) zone tectonic setting.

The plagiogranite samples of larger trondhjemite bodies from magmatic zones surrounding the Sevan–Hakari ophiolite belt to the southwest (in Karabagh) and northeast (in Azerbaijan) have yielded slightly older ages (177–180 Ma) than Dali plagiogranite (~172 Ma). Somewhat younger 165 ± 4 Ma age is obtained for a plagiogranite from westernmost Haghpat intrusion in northern Armenia. The pillow basalts hosting the Berdadzor plagiogranite have “supra-subduction zone” features similar to the LC ophiolites and evidence the earliest, at least, Early Jurassic volcanic activity in this region.

This synchronous magmatic activity along the ASH Seaway and surrounding regions could probably be related to the initiation of subduction(s) of the Neotethys oceanic crust below the SAM and, together with Paleotethys, below either Eurasian (Andean type?) margin or the pre-existing same paleo-oceanic crust (Mariana type subduction).

References

Abdullayev R.N. 1963. Mesozoic volcanism of the north-eastern part of the Lesser Caucasus. Ed.: AS of AzerbSSR, Baku, 228p. (in Russian).

Abdullayev R.N., Gasanov R.K., Mustafayev G.V., Aliyev I.A. 1974. The age-distribution of the intrusions of Lachin anticlinorium of the Lesser Caucasus and some features of their composition. Proceedings of AS of Azerb. SSR, Series of Earth Sciences, N4, p.75–83 (in Russian).

Adamia S., Chkhotua T., Kekelia M., Lordkipanidze M. et al. 1981. Tectonics of Caucasus and adjoining regions: implications for the evolution of the Tethys Ocean. Journal of Structural Geology 3 (4), p.437–447.

Asatryan G., Danelian T., Sahakyan L., Galoyan G., Seyler M., Sosson M., Avagyan A. Hubert B.L.M. and Ventalon S. 2012. Radiolarian biostratigraphic constraints for latest Jurassic–earliest Cretaceous submarine volcanic activity in the Tethyan oceanic realm of the Sevan ophiolite (Armenia). Bull. Soc. géol. France, t.183, N4, p. 319–330.

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

Carroll M.R., and Wyllie P.J. 1990. The system tonalite-H_2O at 15 kbar and the genesis of calc-alkaline magmas. American Mineralogist 75, p.345–357.

Coleman R.G, Peterman Z.E. 1975. Oceanic plagiogranite. Journal of Geophysical Research 80, p.1099–1108.

Coleman R.G., and Donato M.M. 1979. Oceanic plagiogranite revisited. In: Barker, F. (Ed.), Trondhjemites, dacites and related rocks: Amsterdam, Elsevier, p.149–168.

Danelian D., Asatryan G., Galoyan G., Sosson M., Sahakyan L., Caridroit M. and Avagyan A. 2012. Geological history of ophiolites in the Lesser Caucasus and correlation with the Izmir-Ankara-Erzincan suture zone: insights from radiolarian biochronology. Bull. Soc. géol. France, t. 183, N 4, p.331-342.

Dilek Y. and Thy P. 2006. Age and petrogenesis of plagiogranite intrusions in the Ankara mélange, central Turkey. Island Arc 15, p.44–57.

Floyd P.A., Yaliniz M.K., Goncuoglu M.C. 1998. Geochemistry and petrogenesis of intrusive and extrusive ophiolitic plagiogranites, Central Anatolian Crystalline Complex, Turkey. Lithos 42(3–4), p.225–241.

Frost B.R., Barnes C.G., Collins W.J., Arculus R.J., Ellis D.J. and Frost C.D. 2001. A geochemical classification for granitic rocks. Journal of Petrology 42(11), p.2033–2048.

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

Galoyan G. 2020. Oceanic crust or Iskand arc: manifestations of magmatism in the ophiolite section of the Dali river valley on the shore of Lake Sevan. Scientific periodical "Katchar" N1, 16–29 (in Armenian).

Galoyan G.L., Melkonyan R.L. 2011. Ophiolitic association. In the book: "Geology and the mineral resources of Mountainous-Karabagh Republic". Yerevan: Publishing House "Zangak-97", p.99–112 (in Russian).

Galoyan G., Rolland Y., Sosson M., Corsini M., Billo S., Verati C. and Melkonyan R. 2009. Geochemistry and 40Ar/39Ar dating of Sevan Ophiolites (Lesser Caucasus, Armenia): evidences for Jurassic Back-arc opening and hot spot event between the South Armenian Block and Eurasia. Journal of Asian Earth Science 34, p.135–153.

Galoyan G.L., Melkonyan R.L., Chung S.-L., Khorenyan R.H., Atayan L.S., Hung C.-H., Amiraghyan S.V. 2013. To the petrology and geochemistry of Jurassic Island-arc magmatics of the Karabagh segment of the Somkheto–Karabagh terrain. Proceedings of the NAS of the Republic of Armenia, Earth Sciences, v.66, N1, p.3–22 (in Russian).

Galoyan G.L., Melkonyan R.L., Atayan L.S., Chung S.-L., Khorenyan R.H., Lee Y.-H., Amiraghyan S.V. 2018. On the petrology and geochemistry of Jurassic magmatics of the Somkheti segment of Somkheto–Karabagh tectonic zone (Northern Armenia). Proceedings NAS RA, Earth Sciences, 2018, v.71, N1, p.3–27.

Gerlach D.C., Leeman W.P., Ave Lallemant H.G. 1981. Petrology and geochemistry of plagiogranite in the Canyon Mountain Ophiolite, Oregon. Contributions to Mineralogy and Petrology 77, p.82–92.

Hässig M., Rolland Y., Sosson M., Galoyan G., Muller C., Avagyan A., Sahakyan L. 2013. New structural and petrological data on the Amasia ophiolites (NW Sevan–Akera suture zone, Lesser Caucasus): Insights for a large-scale obduction in Armenia and NE Turkey. Tectonophysics, 588, p.135–153.

Hässig M., Rolland Y., Sosson M., Galoyan G., Sahakyan L., Topuz G., Çelik Ö.F., Avagyan A., Müller C. 2014. Linking the NE Anatolian and Lesser Caucasus ophiolites: evidence for large scale obduction of oceanic crust and implications for the formation of the Lesser Caucasus–Pontides Arc. Geodinamica Acta, 26(3-4), Special Issue: SI, 2013, p.311–330.

Hässig M., Rolland Y., Sahakyan L., Sosson M., Galoyan G., Avagyan A., Bosch D., Muller C. 2015. Multi-stage metamorphism in the South Armenian Block during the Late Jurassic to Early Cretaceous: Tectonics over south-dipping subduction of Northern branch of Neotethys. Journal of Asian Earth Sciences 102, p.4–23.

Kazaryan H.A. 2006. Anatectic plagiogranite-migmatites of gabbro and ultra-basite contact zone (the Sevan ophiolite zone). Proceedings of the NAS of the Republic of Armenia, Earth Sciences, v.59, N1, p.20–26 (in Russian).

Knipper A.L. 1975. The oceanic crust in the alpine belt. Tr. GIN NAS USSR 267, 207p. (in Russian).

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

Koepke J., Feig S.T., Snow J., Freise M. 2004. Petrogenesis of oceanic plagiogranites by partial melting of gabbros: an experimental study. Contributions to Mineralogy and Petrology 146, p.414–432.

Lordkipanidze M. 1980. Alpine volcanism and geodynamics of the Central segment of the Mediterranean belt. Tbilisi, Publishing House "Metsniereba", 162p. (in Russian).

Mederer J., Moritz R., Zohrabyan S., Vardanyan A., Melkonyan R., Ulianov A. 2014. Base and precious metal mineralization in Middle Jurassic rocks of the Lesser Caucasus: A review of geology and metallogeny and new data from the Kapan, Alaverdi and Mehmana districts. Ore Geology Reviews 58, p.185–207.

Melkonyan R.L. 1989. Petrology and mineralization of Mesozoic island-arc granitoid formations of the Lesser Caucasus. Doctor thesis Abstract, Moscow, IGEM, 52p. (in Russian)

Milanovski E.E. 1968. Neotectonics of the Caucasus. Moscow, "Nedra", 484p. (in Russian)

National Atlas of Armenia, Volume A, 2007. Publishing house: "Tigran Mets", Yerevan, 232p. (in Armenian)

Neill I., Meliksetian Kh., Allen M.B, Navasardyan G., Kuiper K. 2015. Petrogenesis of mafic collision zone magmatism: The Armenian sector of the Turkish–Iranian Plateau. Chemical Geology 403, p.24–41.

O'Connor J.T. 1965. A classification for quartz-rich igneous rock based upon feldspar ratios. U.S.G.S. Professional Paper 525B, B79–B84.

Pallister J.S. and Knight R.J. 1981. Rare-earth element geochemistry of the Samail ophiolite near Ibra, Oman, Journal of Geophys. Res. 86(B4), p.2673–2697.

Pearce J.A. 1982. Trace element characteristics of lavas from destructive plate boundaries. In: Thorpe, R.S. (Ed.), Andesites. John Wiley and Sons, p.525–548.

Pearce J.A., Harris N.B., Tindle A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology 25, p.956–983.

Pearce J.A. and Stern R.J. 2006. Origin of Back-Arc Basin Magmas: Trace Element and Isotope Perspectives. Back-Arc Spreading Systems: Geological, Biological, Chemical, and Physical Interactions. Geophysical Monograph Series 166, Published by the American Geophysical Union, p.63–86.

Pedersen R.B. and Malpas J. 1984. The origin of oceanic plagiogranites from the Karmoy ophiolite, Western Norway. Contrib. Mineral. Petrol. 88, p.36–52.

Rolland Y., Galoyan G., Bosch D., Sosson M., Corsini M., Fornari M. and Verati C. 2009. Jurassic Back-arc and Cretaceous hot-spot series in the Armenian ophiolites – implications for the obduction process. Lithos 112, 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.

Sadikhov E.A., Shatova N.V. 2016. Geochemical characteristics and isotopic U-Pb dating of plagiogranite plutonic complex rocks from the Lok-Garabakh zone of the Lesser Caucasus (Azerbaijan). (VSEGEI) Regional Geology and Metallogeny N66, p.67–74.

Sosson M., Rolland Y., Muller 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. In: Sosson M., Kaymakci N., Stephenson R., Bergerat F. and Starostenko V. (Eds.), Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform. Geological Society, London, Special Publications; v. 340, p.329–352.

Sun S.S., McDonough W.F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: Saunders A.D., Norry M.J. (Eds.), Magmatism in Ocean Basins, Geological Society of London, Special Publication 42, p.313–345.

Zakariadze G.S., Knipper A.L., Sobolev A.V., Tsameryan O.P., Dimitriev L.V., Vishnevskaya V.S., Kolesov G.M. 1983. The ophiolite volcanic series of the Lesser Caucasus. Ofioliti 8, p.439–466.

Zi J.-W., Cawood P.A., Fan W.-M., Wang Y.-J. and Tohver E. 2012. Contrasting rift and subduction-related plagiogranites in the Jinshajiang ophiolitic mélange, southwest China, and implications for the Paleo-Tethys. Tectonics 31, TC2012.

ՍՏՈՐԻՆ-ՄԻՋԻՆ ՅՈՒՐԱՅԻ ՏՐՈՆԴՅԵՄԻՏԱՅԻՆ ՍԵՐԻԱՅԻ ԱՌԱՋԱՑՈՒՄԸ ՓՈՔՐ ԿՈՎԿԱՍՈՒՄ (ՀԱՅԱՍՏԱՆԻ ԵՎ ԼԵՌՆԱՅԻՆ ՂԱՐԱԲԱՂԻ ՀԱՆՐԱՊԵՏՈՒԹՅՈՒՆՆԵՐ)

Գալոյան Ղ.Լ.

Ամփոփում

Մեզոզոյան տրոնդյեմիտային (պլագիոգրանիտային) մագմատիզմի հասակն ու երկրատեկտոնական պատմությունը հատկապես կարևոր են Փոքր Կովկասի (ՓԿ) արևելյան–հարավ-արևելյան հատվածի երկրաբանական-երկրադինամիկ էվոլյուցիան բացահայտելու համար: Նորովի են քննարկվել ՓԿ օֆիոլիտների տեկտոնական իրավիճակի առավել հստակ և համապարփակ մեկնաբանման հարցերը հարակից Սոմխեթ-Ղարաբաղի և Սպիտակ-Կապանի յուրա-կավճի գոտիների հետ: Ակնհայտ է, որ այդ գոտիները, մասնավորապես դրանցում առկա երկրաբանական միավորները, սերտորեն կապված են միմյանց հետ տարածականորեն և ժամանակային առումով: Սևանի օֆիոլիտից (Ամասիա-Սևան-Հակարի՝ ԱՍՀ կարային գոտու կենտրոնական մաս) և ՓԿ նշված գոտիներից ստացված պլագիոգրանիտների U–Pb ցիրկոնային թվագրումը ապահովում է առավել հուսալի երկրաժամանակագրական ճշգրտումներ Նեոթետիսի (?) էվոլյուցիայի վերաբերյալ: Ակնհայտ է, որ ցիրկոնային բոլոր հասակները գտնվում են ուշ վաղ և ուշ միջին յուրայի դարաշրջանի միջակայքում (~ 180–165Ma): Հաշվի առնելով այս տվյալները, հիմնական ԱՍՀ օֆիոլիտային գոտուց հարավ և հյուսիս տեղակայված ինտրուզիաները ներփակող էֆուզիվ սերիաների տարիքը, հավանաբար, պետք է լինի նվազագույնը պլինսբախ-տոարի կամ ավելի հին հասակի, քան՝ բայոսի և բաթի: Ապարների երկրաքիմիայի հիման վրա՝ գաբրոային ամֆիբոլը, բարձանման

բազալտը և պլագիոգրանիտները սինգենետիկ են, որը մատնանշում է դրանց ծագման ընդհանուր հալոցքային աղբյուրը: Պլագիոգրանիտի բոլոր նմուշները ցուցադրում են փոփոխական LILE հարստացում և ընդգծված բացասական HFSE (Nb, Ta և Ti) անոմալիաներ, որոնք բնորոշ են սուբդուկցիայի հետ կապված մագմաներին: Ելնելով երկրաբանական և պետրոլոգաերկրաքիմիական առանձնահատկություններից՝ քննարկված բոլոր հինգ պլագիոգրանիտային մարմինները նման են և կարող են մեկնաբանվել, որ դրանք առաջացել են բազալտային մագմայի ցածր ճնշմամբ ֆրակցիոն բյուրեղացման արդյունքում, որը գոյացել է մանթիայի մասնակի հալումից սուբդուկցիոն (կամ սուպրա-սուբդուկցիոն) գոտու տեկտոնական իրավիճակում: Պալեոթետիսում ստեղծված ԱՍՀ ավազանը (որպես Նեոթետիսի հյուսիսային ճյուղ), ամենայն հավանականությամբ, կլանվել է կամ դեպի հյուսիս, կամ հարավ (նախընտրելի է) ուղղված կրկնակի սուբդուկցիաներից՝ հիմնականում վաղ–միջին յուրայից մինչև ուշ կավճի ժամանակ, նաև չբացառելով միայն մեկ սուբդուկցիոն զոնայի հնարավորությունը:

ФОРМИРОВАНИЕ НИЖНЕ–СРЕДНЕЮРСКОЙ ТРОНДЬЕМИТОВЙ СЕРИИ НА МАЛОМ КАВКАЗЕ (РЕСПУБЛИКИ АРМЕНИЯ И НАГОРНЫЙ КАРАБАХ)

Галоян К.Л.

Резюме

Возраст и геотектоническая история мезозойского трондьемитового (плагиогранитого) магматизма особенно важны для раскрытия геологической-геодинамической эволюции восточно-юго-восточного сегмента Малого Кавказа (МК). Вновь обсуждаются вопросы более определенной и исчерпывающей интерпретации тектонического положения офиолитов МК с прилегающими к ним Сомхето–Карабахской и Спитак–Капанской юрско–меловой зонами. Очевидно, эти зоны, в особенности находящиеся в них геологические единицы, прочно связаны друг с другом как в пространственном, так и во временном отношении. U–Pb датирование по циркону плагиогранитов из Севанского офиолита (центральная часть шовной зоны Амасия–Севан–Аакари или АСА) и из упомянутых зон в МК дает новые и более надежные геохронологические реперы в эволюцию Неотетиса (?). Очевидно, что все возрасты цирконов находятся в интервале от позднераннего до позднесреднего юрского периода (~ 180–165 млн лет). Принимая во внимание эти данные, возраст вмещающих эффузий, расположенных на самом деле как к югу, так и к северу от основной офиолитовой зоны АСА, возможно, должен быть минимум плинсбах–тоарским или старше, чем байосским и батским. Основываясь на геохимии пород, амфиболовые габбро, подушечные базальты и плагиограниты являются когенетическими, что предполагает общий источник расплава в их проис-

хождении. Все образцы плагиогранитов демонстрируют переменное обогащение LILE и явно выраженные отрицательные аномалии HFSE (Nb, Ta и Ti), типичные для магм, связанных с субдукцией. Основываясь на геологических и петролого-геохимических особенностях, все пять обсуждаемых тел плагиогранитов похожи и могут быть интерпретированы как образованные при фракционной кристаллизации базальтовой магмы при низком давлении, образовавшейся в результате частичного плавления мантии в субдукционной (или супра-субдукционной) тектонической обстановке. Образовавшийся на Палеотетисе бассейн АСА (как северная ветвь Неотетиса), вероятно, был поглощен либо северными, либо предпочтительно южными двойными субдукциями, в основном в период от ранне–средней юры до позднего мела, не исключая также возможности существования здесь единой зоны субдукции.