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LATE NEOPROTEROZOIC-EARLY CAMBRIAN, LATE PALEOZOIC AND LATE JURASSIC GRANITOID MAGMATISM ON THE NORTHERN ACTIVE MARGIN OF GONDWANA, TSAGHKUNYATS ANTICLINORIUM OF LESSER CAUCASUS (CENTRAL-NORTHERN ARMENIA)

Galoyan Gh.L.[1*], Chung S.-L.[2], Melkonyan R.L.[1], Lee Y.-H.[3], Atayan L.S.[1], Ghukasyan R.Kh.[1], Khorenyan R.H.[1], Grigoryan A.G.[1], Sahakyan S.S., Avagyan N.A.[1]

[1]*Institute of Geological Sciences NAS RA; 24a M. Baghramian Ave., Yerevan 0019, Republic of Armenia*
[2]*Department of Geosciences, National Taiwan University, Roosevelt Rd., Taipei 106, Taiwan*
[3]*Department of Earth and Environmental Sciences, National Chung Cheng University, 168 University Rd., Chia-Yi 62102, Taiwan*
[*]*Corresponding author E-mail : ghazar.galoyan@gmail.com*
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Abstraet

Tsaghkunyats antielmorium or Crystalhne basement in Armenia is a unique geoteetonie strueture eharaeterized by its multistage magmatism, metamorphism and orogeny. Numerous investigations have been earried out on the granitoids present here and dated from Preeambrian to the Upper Cretaeeous (Jurassie), while the issues of their petrogenesis, geodynamics and emplaeement ages remained eontroversial. After a revision of those issues we present new field observations, bulk roek geochemistry and U-Pb zircon geochronology to assess the age and the teetonie setting of various granitoids eropping out in the Lesser Caueasus Preeambrian basement of Tsaghkunyats as a part (eore?) of Gondwana-derived South Armenian mieroplate (SAM). New zircon U-Pb erystalhzation ages range from Late Neoproterozoie to Early Cambrian (~545–530Ma) for the granitie gneisses; from Middle to Late Permian (~270–250Ma) for the plagiogranites (trondhjemites); and from Late Jurassie to Early Cretaeeous (~155–140Ma) for the tonalite formation roeks. Geoehemieally, these various aged granitoids are eale-alkaline, peraluminous and are eharaeterized by enriehment of LILEs and Th, with pronouneed minimums of Nb-Ta and Ti, and high LREE/HREE ratios indieating subduetion-related magmatie events. As for the geodynamie setting, all these granitoids are geoehemieally eontinental arc-type and their presenee may suggest southward subduetion episodes of Proto-, Paleo- and Neotethys under SAM aetive margin of northern Gondwana during above-mentioned time intervals.

Keywords: Tethyan belt; Lesser Caucasus; Armenia; Tsaghkunyats crystalline basement; granitoid magmatism; geodynamics; geochemistry; geochronology

Introduction

The NW–SE trending Amasia-Sevan-Hakari suture zone (Galoyan and

Melkonyan, 2011) in Lesser Caucasus represents a major Neotethyan suture zone (e.g., Galoyan et al., 2009; Rolland et al., 2009; Sosson et al., 2010; Hassig et al., 2013) separating the Eurasian and Gondwanan continental margins (e.g., Knipper and Khain, 1980) in the central part of Alpine-Himalayan orogenic belt. Located in the south of this suture zone Tsaghkunyats crystalline basement (or Massif) or Tsaghkunyats anticlinorium is the oldest geological unite in Armenia (fig.1), which is generally considered as a part (namely core) of South Armenian microplate (henceforth SAM) derived from Gondwana.

Many researchers have addressed and clarified the issues of geology, tectonics, stratigraphy, petrology and ore mineralization of the area of Tsaghkunyats antichnorium especially since 1930s, until the end of 1980s with a downward trend of interests. Particularly, their findings are summarized in works of V.N. Kotlyar, K.N. Paffenholtz, V.P. Rengarten, A.T. Aslanyan, G.P. Baghdasaryan, R.A. Arakelyan, A.H. Gabrielyan, S.A. Balasanyan, A.R. Harutyunyan, H.E. Nazaryan, V.A. Aghamalyan, A.A. Belov and S.D. Sokolov, B.M. Meliksetyan, R.Kh. Ghukasyan, Z.H. Chibukhchyan, R.H. Khorenyan, Sh.V. Khachatryan and many others. After the latest fundamental a few monographs (i.e., Khorenyan, 1982; Chibukhchyan, 1985), single works focused on the petrology and age issues of the granitoids that are present here (e.g., Aghamalyan et al., 1997; Hassig et al., 2015). Therefore, for the first time after a relatively break of more than thirty years, an attempt is made to refer to the older granitic rocks constituting a significant part of the oldest Precambrian-Paleozoic basement of Armenia (fig.2).

The purpose of this study is to revise the general geological, petrologic, geochemical and geochronological issues of a number of granitoid intrusions exposed within the limits of the Tsaghkunyats anticlinorium. Particularly, it refers as to the *plagiogranites* (trondhjemites) and *granite-gneisses* being the oldest (?) magmatic rocks in the antichnorium and generally in the boundaries of Armenia, whose age is/was considered Precambrian-Upper Proterozoic (see below for details), as well as to several intrusions of *tonalitic formation* (quartz diorite-tonalite-granodiorites) of Lower Cretaceous (formerly dated as Neocomian and younger).

The importance of research is the detailing/solution of existing stratigraphic, petrological, geochronological, and geodynamic problems in accordance with the modern ideas and more realistic geodynamic models. What's the *scientific novelty* of this study? The intended complex researches, and U-Pb dating in various aged granitoid rocks will allow the revealing of: (1) the pecuharities of their material composition; (2) the geochronology of various aged intrusions; (3) the possible genetic hnk or absence between different facies; (4) the geodynamic setting of the formation of these intrusions; as well as (5) their connection with the adjacent Paleozoic-Mesozoic geological complexes (e.g., Lesser Caucasus ophiolites; carbonate-slope deposits of Gondwana). Obviously, it is impossible to give an exhaustive answer to all the questions raised in one work.

Hence, the study involves a wide range of issues that relate to the aforementioned goals and to their implementation solutions. Particularly, in this paper important attention will be given to the various aged granitoid formations cropping out in the Kotayk, Aragatsotn and partially Lori provinces of the Republic of Armenia, which are part of the Tsaghkunyats anticlinorium of Hankavan-Zangezur tectonic zone (Gabrielyan, 1974). This anticlinorium geographically includes the Tsaghkunyats mountain range and the central and western regions of the Pambak range bordering on the north. It is also bordered with Hankavan (or Marmarik) fault zone from Paleogene Sevan-Shirak synclinorium to the north. Marmarik fault coincides with the axis of Marmarik river valley and is represented by several intrusive massifs of the Alpine tectonic stage, from which the younger intrusions, starting from the Middle Eocene ages, will not be reconsidered within the scope of this project. Below we will present the setting, tasks, new data and descriptions with the analysis and interpretation of the results.

Brief stratigraphy

According to studies of the above-mentioned authors, Tsaghkunyats (or Miskhana-Arzakan, or Arzakan-Spitak) anticlinorium (or horst-anticlinorium) consists of the oldest Upper Proterozoic-Paleozoic (?) to the Quaternary aged various formations, whose total thickness exceeds 5000m (Aslanyan, 1958; Kotlyar, 1958; Paffenholtz, 1959; Gabrielyan et al., 1968; and many others). H. Nazaryan (1964) described the internal structure of the anticlinorium in detail. The geological section has the following general look.

The earliest formations are represented by the metamorphic rocks of the Precambrian-Lower Paleozoic crystalline basement, namely various schists, amphibolites, schistosed and dismembered gabbro-peridotites, marbles, phyllites, quartzites, gneisses, etc. In the geological sequence these are known as suites of “Arzakan”, about 500m thick; of “Bjnuyal”, about 400m, and of “Dzoraglukh”, up to 1000m (Arakelyan, 1957, 1959). Detailed information about these rocks, after the monograph of V. Kotlyar (1958), is summarized in V. Aghamalyan’s fundamental work (Aghamalyan, 1998). In the structure of Tsaghkunyats Massif, two Precambrian terranes of Arzakan (of ensialic nature) and of Hankavan (of ensimatic nature) are separated by Aghamalyan (2004). In recent years a partial assessment of the P-T-t conditions of metamorphism in this massif of the crystalline basement of Tsaghkunyats is also done (Lorsabyan, 2013; Hassig et al., 2015). Metamorphic rocks are cut off by a number of granitoid bodies, based on the oldest Rb-Sr isochrone ages of which the oldest Late Proterozoic age of this metamorphic complex had been confirmed. However, this question will be discussed in the following sub-section.

Jurassic (?) formations are represented by weakly metamorphosed or relatively fresh volcanic, volcano-sedimentary formations that are mainly cropped out in the western part of the anticlinorium (fig.2), and are known as: “Aghveran suite” of Ordovician (?) (800m thick; Arakelyan, 1957), an “Ancient volcanic series" of Lower Paleozoic (600m thick; Kotlyar, 1958) or Lower Silurian (Aslanyan, 1958), or "Aparan series" of Lower-Middle Devonian (Gabrielyan et al., 1968) or Lower-Middle Jurassic (more than 6 km thick; Aghamalyan, 1987). The latter includes also terrigenous sedimentary rocks (e.g., Saralanj village region), which, according to V. Aghamalyan, are comparable with the similar formations of Lower-Middle Jurassic of the Shamshadin anticlinorium in Northern Armenia (Magm. and metam. form. ArmSSR, 1981). Stratigraphic and petrographic issues of these formations have been thoroughly studied by Belov and Sokolov (1973), who attributed the age of this series to the Lower-Middle Mesozoic era without specifying. According to these authors, Aparan series does not lie discordantly on older formations, on the contrary, the metamorphic complex is trusted over it along a gentle tectonic surface. The explanation of the petrological issues of a part of these volcanic rocks is also summarized in Khorenyan's (1982) monograph. A. Grigoryan (2014) among the olistoliths of the Melikgyugh (village) member of the Tukhmanuk suite of the Aparan series discovered a rich microfaunistic complex of conodonts, fish scales and their teeth. The age of hmestone ohstohths, according to the identified conodonts of the genus *Palmatolepis* and *Siphonodella*, is determined as Late Famennian. Without going into new details, let's just emphasize that the issues of the composition and the age of "Aparan series" remain problematic, and will be addressed in a separate study.

Cretaceous formations. Though actually the Lower Cretaceous formations (i.e. Aparan series) are shown in some geological maps, in fact they are missing here. Upper Cretaceous formations begin with Upper Turonian-Lower Coniacian terrigenous sediments (sometimes up to 200m thick), which are transgressive, and overlie the previous series with an angular unconformity. These are overlain by Upper Coniacian-Lower Santonian again terrigenous formations (about 100m thick), which are replaced in the section with Santonian marly limestones of 200m thick (Kotlyar, 1958). In particular, on the right bank of the Hrazdan river, near the village of Bjni, the metamorphic schists of the oldest Arzakan suite are transgressively and with sharp discordance covered by the pinkish-gray calcareous sandstones, light gray terrigenous limestones and siltstones of Upper Coniacian (Hakobyan, 1978). Upwards they are covered with various limestones and siltstones of Santonian-Maastrichtian; their total thickness is about 90m. According to this author, to the north of the study area (fig.2), on the left bank of Marmarik River (norther of Hankavan village) the Aparan series and metamorphic rocks are unconformably covered by Lower Coniacian calcareous siltstones (30m) and Upper Coniacian terrigenous-carbonate thicker (160m) sediments.

Paleogene formations. Volcanogenic-sedimentary formations of Eocene that are about 2000m thick, with the conglomerates of base, are spread in the northeastern parts of the antichnorium, which make up the thick Sevan-Shirak synclinorium of Paleogene (Sarkisyan, 1966), in which the volcanic formations of the Middle Eocene dominate. Meanwhile, Nummulitic limestones of lower Eocene have been preserved in the nuclei of local synclines in the Hrazdan

River valley. Miocene-Pliocene thick series (about 300m) of intermediate and acid composition lavas and tuffs occupies the highest relief areas in this anticlinorium, covering almost all previous formations (Kotlyar, 1958). Metamorphic rocks of this anticlinorium along mainly the valley of Hrazdan River (or Hrazdan fault) are confined from the east by the Quaternary lava flows (Gabrielyan et al., 1968). Thus, although a number of stratigraphic questions also need to be revised, they are out of the scope of this paper; some may be partly solved in parallel and we will address these questions later.

Granitoid plutonic manifestations and their age issues

Granitoids play a significant role in the Tsaghkunyats anticlinorium where they are represented with several large and numerous smaller intrusive bodies (Geology of ArmSSR, v.3, 1966; Magm. and metam. form. ArmSSR, 1981). According to the composition, these are grouped into granite-gneisses (also known as "migmatite-granites"), plagiogranites (or leucocratic granites or trondhjemites; in honor of Kotlyar, we also prefer to use the term of plagiogranite) and tonalitic formation rocks (quartz diorite-tonalite-granodiorite). The age subdivision of these intrusions with direct geological observations presents considerable complications considering: (1) the absence of continuous stratigraphic section of the region, (2) the different grade of metamorphism of present rocks, (3) the absence of exact age(s) of the metamorphism, and (4) the tectonic complexity of the region. Still in 1958, V. Kotlyar by principle of analogy with the other Lesser Caucasus massifs of Georgia attributed the plagiogranites to the Paleozoic age, and A. Aslanyan did the same for the Arzakan-Bjni massif of the granite-gneisses. By the way, R. Arakelyan (1959) was one of the first, who mentioned that the plagiogranites cut some gabbro massifs in the Tsaghkunyats anticlinorium, whose age also remains uncertain here. In another paper, we will focus on the problem of mafite-ultramafites as well.

Plagiogranites make up tens to hundreds of small bodies (the larger ones, up to 5-6, rarely 10-12km^2; Chibukhchyan, 1985), especially, in amphibolites and amphibole schists of Hankavan-Aparan series (Baghdasaryan, Ghukasyan, 1961): Most of the bodies are outcropped at the interfluves of Marmarik and Kasakh rivers. These granites are represented by lens-like, dyke-like, often stock-shaped, as well as stratal intrusions of very different sizes (from a few cm to a several meters thick), and intrusive contact relationship with the host rocks can be easily observed. Their intrusion has often accompanied with the granitization and migmatitization processes of hosting metamorphic rocks (Magm. and metam. form. ArmSSR, 1981). Most of plagiogranite bodies have a chaotic spread, though the larger ones are characterized by a sub-latitudinal strike (Chibukhchyan, 1985) that is consistent with the heredity of the region's main tectonic structures. Macroscopically these are light gray (with a white surface), fine-medium to coarse-grained rocks that do not exhibit any variety of mineral composition (see details below section of petrography). Based on field observations, we also share the view of Aghamalyan et al. (1997) that the intrusion of trondhjemite magma occurred at the final stage of folding and metamorphism of the hosting amphibolite stratum, when the latter was still sufficiently heated (i.e. was in a plastic state) that causes the mostly conformal occurrence of plagiogranite bodies and the absence of quenching contacts.

Granite-gneiss formation is known especially by the largest Arzakan-Bjni massif ($12km^2$), and other smaller bodies, which is exposed between the villages of Arzakan and Bjni (Baghdasaryan, Ghukasyan, 1961; Paffenholtz, 1959, 1970) and is exclusively emplaced within the metamorphic series, where the Coniacian-Santonian sediments cover the intrusion and hosting metamorphic rocks. Latter both are cut by several thin diabase dikes of unknown age. It should be noted that, unlike the plagiogranites, the impact of metamorphism on these rocks is considerable, at least their gneissification with an augen texture is a visible fact in the field. These rocks reveal strong foliation and mineral hneation, and, in places, they are massive and preserve their original magmatic fabric. Macroscopically these are light to darker gray (with a pinkish-red surface), medium- to coarse-grained rocks. Unlike of the former group of granites the alkali feldspar is a main mineral phase here.

Tonalitic formation intrusions are known in this antichnorium with the names of Aghveran, Hankavan (including Artavaz (Takarlu) one), Guegharot and Mirak, all of which are included in this study. The massifs of Aghveran ($25km^2$) and Hankavan ($40km^2$) cut the various series of metamorphic schists. In addition, the latter also cuts the aforementioned plagiogranites in some places. The Guegharot massif ($30km^2$), which is emplaced in the north-western edge of the study area, is intruded in the slightly metamorphosed "porphyrites" of the Spitak Pass (Baghdasaryan, Ghukasyan, 1961), and the lesser Mirak intrusion is localized in the main "Aparan series" north of the city Aparan (Fig. 2). In terms of petrography, these intrusions are compositionally quite close to each other and are similar to those of the same composition (diorite-quartz diorite-tonalite-granodiorite-veined leucogranite series) intrusions of the Somkheto-Karabagh tectonic belt of NE Lesser Caucasus.

By comparing the "gneissic granites" with other Georgian older massifs, Paffenholtz (1970) concluded that these are Cambrian-Precambrian (old-Caledonian orogenic phase) in age. Kotlyar (1958) attributed plagiogranitic intrusions age presumably to the Paleozoic (undivided), and Paffenholtz connected their intrusion with the "Sudeten" tectonic phase (the end of the Early and the beginning of the Middle Carboniferous) of Hercynian folding. Baghdasaryan and Ghukasyan (1961) attributed the origin and intrusion of plagiogranites to major orogenic movements. By using the K-Ar method, these authors obtained ages ranging from 130 to 164Ma for both rocks and minerals (plagiogranites and muscovites in them). Later, the researchers obtained 283Ma and younger ages (57Ma), so based on the varying degree of rocks alteration, i.e. "argon rejuvenation" due to loss of radiogenic argon, the plagiogranites was attributed an age of at least 261±14Ma (Magm. and metam. form. ArmSSR, 1981).

Though, mainly with Rb-Sr isotopic dating the intrusion ages of 610 ± 36Ma for granite-gneiss (Baghdasaryan, Ghukasyan, 1983) and the oldest of 685 ± 77Ma for trondhjemite (plagiogranite) massifs (Aghamalyan et al., 1997) were given, the problem can't be considered resolved. Over time, the research laboratories of advanced countries are striving for the acquisition and using of reliable and accurate analytical equipment for any rock dating. Accordingly, to double check these ages for consistency, we applied U-Pb dating on zircons, since in recent decades, this method is considered as more reliable for dating metamorphic and magmatic units, rather than Rb-Sr method.

In recent years, the isotopic ages of many magmatic formations on the territory of Armenia and partly of Karabagh are revised as part of Armenian-Taiwanese scientific cooperation. Particularly, thanks to the support of Taiwanese universities (namely Isotope laboratories of National Taiwan and National Chung-Cheng universities) we acquired new U-Pb ages in zircons from this area (table 1). U-Pb isotopic analyses were performed by the laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) method, following the procedures in (Chiu et al., 2009). It is noteworthy that new U-Pb dating does not confirm the mentioned ages of granite-gneisses at the Bjni village area. In three representative rock samples we received new ages of around 545-530Ma which corresponds to the boundary of latest Neoproterozoic (Late Ediacaran) and Early Cambrian periods in the *International Chronostratigraphic Chart* (2020). At the same time, during one of the quickly done field observations, a question arose in our mind about the considered "oldest" in Armenia plagiogranites (trondhjemites), depending on their field appearance. In contrast to the orthogneisses (granite-gneiss) of Bjni, no deformation phenomena are present (there is almost not stress influence macroscopically) in plagiogranites, which doubted us to compare them with the Middle Jurassic plagiogranites of the Somkheto-Karabagh zone (e.g., Haghpat massif). Although our new U-Pb dating results of ~270-250Ma (average of two samples)

Table 1

Sampling site coordinates and U-Pb ages of the granitoids from Central-Northern Armenia

Sample	*Name of rock*	*Latitude (°)*	*Longitude (°)*	*Ma (2σ)*	*Name of Massif*
BJ-08	granite-gneiss	40.47123	44.64305	532.7±5.6	Bjni
ARM11-2A	granite-gneiss	40.46822	44.64504	554±14	Bjni
ARM12A	granite-gneiss	40.47119	44.64299	545±14	Bjni
ARM01A	plagiogranite	40.68445	44.48699	255±7	Hankavan
ARM08A	plagiogranite	40.57685	44.68398	268±10	Marmarik
ARM03A	tonalite	40.65280	44.47489	159±5	Hankavan
ARM06A	tonalite	40.61178	44.57734	156±4	Artavaz
BJ-16	tonalite	40.51728	44.56438	154.7±1.4	Aghveran
ARM14A	leucogranite	40.51203	44.56774	161±4	Aghveran
ARM18-1A	tonalite	40.73493	44.19888	140±4	Guegharot
ARM18-2A	leucogranite	40.73493	44.19888	143±4	Guegharot
6377	tonalite	40.62298	44.34125	141.6±1.4	Mirak

have shown that these plagiogranites were relatively older (i.e., Middle-Upper Permian) than Jurassic presumed, however they became much younger than considered Neoproterozoic (Precambrian) age determinations were (Rb-Sr, 685 ± 77Ma; Aghamalyan et al., 1997).

In the tonalitic formation, the K-Ar ages from Lower (137-120Ma) to Upper Cretaceous (105-75Ma) were brought for the above-mentioned intrusions (Baghdasaryan, Ghukasyan, 1985). Later, the Rb-Sr age revision of Guegharot massif yielded an age interval between the latest Jurassic and Early Neocomian (147 ± 11Ma; Baghdasaryan, Ghukasyan, 1990). The only older and reliable pubhshed age, in recent years, is that of granodiorite-leucogranites of the Aghveran massif (155-150Ma; Hassig et al., 2015) for the entire anticlinorium, which corresponds to the Late Jurassic epoch. In addition, application of U-Pb method to date tonalite-granodiorite±granite series rocks yielded new ages of 147-140Ma for Guegharot and Mirak intrusions, of 164-152Ma for Hankavan massif and of 165-154Ma for Aghveran massif. Generalizimg the magmitude of the error (2σ) we can take 156-140Ma, as a single age interval of Late Jurassic-Early Cretaceous for tonalite formation that coincides well (though slightly younger) with other intrusions (e.g., Shnogh-Koghb, Chochkan, Mehmana) from Somkheto-Karabagh magmatic belt of Jurassic (Galoyan et al., 2013, 2018).

Petrography

Petrographic issues have been addressed by almost all previous researchers. It is already obvious that gramtes described in this study fall mto three age groups. The oldest granite-gneisses are characterized by hypidiomorphic-granular texture, where acidic plagioclase, quartz and alkali feldspar (generally microcline), minor muscovite and biotite (these two latter are partly secondary) are main minerals, while sericite, epidote, chlorite and pelitic minerals are secondary. Accessories are represented by apatite, zireon and opaque mineral(s). The (modal) compositional plot of QAP diagram (of Streckeisen, not shown) classifies the rocks as monzogranite and a few samples as granodiorite.

Plagiogranites are represented by fine- and medium-, rarely coarse-gramed, occasionally porphyritic varieties, with the hypidiomorphic- to allotriomorphic-granular textures. Mineral composition is very simple, represented by acid plagioclase as a dominant mineral and quartz (together 90-95vol.%), sometimes hornblende, biotite and muscovite (two latter are partly secondary). The secondary minerals are sericite, chlorite and epidote, while the accessories are apatite, opaque minerals, zireon and rarely tourmaline (secondary (?), metasomatic).

Tonalitic formation intrusions are compositionally represented with the diorites (started from several gabbro to gabbro-diorite darker enclaves, except metamorphic host-rock ones), quartz diorites, tonalites, granodiorites that are related facially, except the veined and dike-hke pinkish granite-aplites that are

Table 2

Chemical compositions of the granitoids from Central-Northern Armenia (the major elements in wt%, other elements in ppm, LOI is not defined). *Mg# = 100*Mg/(Mg+Fe2+); ogns – orthogneiss, tdhj – trondhjemite, Q dior. – quartz diorite, leucogr – leucogranite.

U-Pb age	***Precambrian***			***Middle-Upper Permian***					
Sample	BJ-08 Bjn	ARM11-2A	ARM12A	ARM01A	ARM02A	ARM04-2A	ARM08A	ARM08-2A	ARM15A
Name	ogns	ogns	ogns	tdhj	tdhj	tdhj	tdhj	tdhj	tdhj
N°(40.)	*.47123*	*.46822*	*.47119*	*.68445*	*.66844*	*.63787*	*.57685*	*.57685*	*.61302*
E°(44.)	*.64305*	*.64504*	*.64299*	*.48699*	*.47206*	*.50037*	*.68398*	*.68398*	*.41186*
SiO2	76,30	72,35	81,41	71,19	73,53	71,84	71,09	71,84	70,19
TiO2	0,19	0,65	0,05	0,15	0,13	0,10	0,20	0,10	0,11
Al2O3	14,03	12,91	10,48	16,17	15,81	16,76	18,90	17,17	17,22
Fe2O3	1,63	3,20	1,02	0,95	0,90	0,88	1,02	0,23	0,69
MnO	0,02	0,06	0,01	0,02	0,02	0,02	0,00	0,01	0,02
MgO	0,25	1,70	0,38	0,75	0,59	0,56	0,23	0,29	0,74
CaO	0,52	1,91	0,31	1,26	1,49	0,93	0,23	0,99	1,99
Na2O	3,31	3,97	3,57	6,64	6,12	6,57	4,54	5,79	6,67
K2O	4,38	1,25	3,47	1,92	0,96	1,83	2,71	1,84	0,77
P2O5	0,06	0,21	0,06	0,08	0,08	0,07	0,03	0,08	0,06
Total	**100,7**	**98,2**	**100,7**	**99,1**	**99,6**	**99,6**	**98,9**	**98,3**	**98,5**
*(Mg#)**	*25*	*54*	*44*	*63*	*59*	*58*	*33*	*73*	*70*
Rb	133,8	47,0	103,7	30,3	22,9	53,1	93,5	32,8	17,9
Sr	112	95	77	234	306	203	110	332	329
Y	29,3	29,0	14,4	3,2	3,5	2,5	3,5	2,8	1,8
Zr	142	232	55	71	71	46	67	53	48
Nb	8,7	10,9	3,1	1,0	1,1	0,7	1,00	0,9	1,10
Ba	760	256,0	375	364	229,0	333	195	273	140
Hf	4,47	5,8	2,16	2,07	2,0	1,47	2,01	1,68	1,49
Ta	1,197	0,923	0,772	0,077	0,082	0,055	0,074	0,063	0,099
Pb	7,3	16,3	4,2	5,74	13,3	11,5	11,6	2,95	4,3
Th	21,37	9,8	14,27	0,81	1,0	0,49	0,71	0,20	0,2
U	1,84	1,49	0,9	0,38	0,41	0,15	0,15	0,14	0,09
V	15,09	67,36	15,30	11,12	7,28	4,37	23,9	11,6	6,68
Cr	47	86	145	54	181	54	28	36	30
Co	2,3	9,1	1,6	3,0	2,9	2,0	1,3	2,7	2,9
Ni	23	35,0	74	29,3	88,5	21	18	20	18
Cu	5,0	26,13	6,75	3,48	6,79	3,4	3,2	7,2	2,5
Zn	15,9	43,3	8,5	13,9	13,6	10,5	17,1	10,1	21,9
La	30,7	32,2	14,4	2,8	3,5	1,5	1,3	1,0	0,8
Ce	67,5	64,0	34,7	6,4	7,3	2,9	2,2	2,3	1,5
Pr	6,59	7,42	3,35	0,84	0,92	0,397	0,37	0,31	0,21
Nd	22,5	27,7	11,7	3,4	3,7	1,5	1,5	1,3	0,9
Sm	4,38	5,75	2,58	0,86	0,83	0,39	0,39	0,37	0,28
Eu	0,718	1,287	0,311	0,293	0,275	0,196	0,148	0,271	0,174
Gd	3,94	5,41	2,2	0,81	0,77	0,45	0,47	0,45	0,32
Tb	0,679	0,826	0,375	0,107	0,106	0,071	0,085	0,073	0,047
Dy	4,35	4,99	2,38	0,60	0,60	0,41	0,54	0,47	0,27
Ho	0,982	1,023	0,521	0,109	0,118	0,081	0,111	0,095	0,057
Er	2,87	2,81	1,52	0,29	0,31	0,22	0,31	0,25	0,14
Tm	0,476	0,420	0,253	0,044	0,046	0,034	0,045	0,038	0,024
Yb	3,20	2,59	1,72	0,28	0,33	0,21	0,31	0,25	0,18
Lu	0,481	0,383	0,269	0,044	0,050	0,035	0,049	0,038	0,027
ΣREE	149,3	156,8	76,3	16,9	18,8	8,4	7,9	7,3	4,9
Eu/Eu*	0,53	0,71	0,40	1,07	1,05	1,43	1,06	2,03	1,78
(La/Sm)n	4,52	3,62	3,60	2,10	2,72	2,48	2,15	1,74	1,84
(La/Yb)n	6,88	8,92	6,01	7,17	7,61	5,12	3,01	2,87	3,19
Dy/Yb	1,36	1,93	1,38	2,14	1,82	1,95	1,74	1,88	1,50
Ba/Rb	5,68	5,45	3,62	12,00	10,01	6,27	2,09	8,34	7,83
Rb/Sr	1,19	0,49	1,35	0,13	0,07	0,26	0,85	0,10	0,05

	Upper Jurassic-Lower Cretaceous								
ARM1 6A	ARM0 3A	ARM05 A	ARM 06A	BJ-16 Agv	ARM13 A	ARM 14A	ARM18 -1A	ARM 18-2A	6377 Mrk
tdhj	tonalit e	Q dior.	tonalit e	tonalite	Q dior.	leucog r	tonalite	leucog r	tonalite
.61407	*.65280*	*.62928*	*.6117 8*	*.51728*	*.51395*	*.5120 3*	*.73493*	*.7349 3*	*.62298*
.41560	*.47489*	*.53695*	*.5773 4*	*.56438*	*.56790*	*.5677 4*	*.19888*	*.1988 8*	*.34125*
70,88	65,94	63,68	64,63	63,93	61,45	76,97	63,00	77,44	63,94
0,13	0,59	0,68	0,59	0,67	0,82	0,19	0,68	0,08	0,68
17,31	16,34	16,57	16,59	17,17	16,62	13,18	17,41	12,64	18,12
0,84	3,80	4,22	4,07	4,32	5,37	1,09	4,24	0,34	4,78
0,04	0,07	0,06	0,07	0,07	0,09	0,02	0,07	0,00	0,09
0,61	2,14	2,79	2,82	2,99	3,59	0,62	2,40	0,12	2,27
3,29	2,60	4,71	4,26	4,69	5,52	1,04	4,63	0,81	4,70
5,27	4,56	4,65	4,28	4,05	4,51	4,69	4,54	2,93	3,92
0,95	2,05	1,07	2,17	1,66	1,14	2,24	1,65	5,27	1,75
0,07	0,22	0,26	0,23	0,24	0,25	0,06	0,19	0,04	0,20
99,4	**98,3**	**98,7**	**99,7**	**99,8**	**99,4**	**100,1**	**98,8**	**99,7**	**100,4**
61	*55*	*59*	*60*	*60*	*59*	*55*	*55*	*43*	*51*
28,0	62,0	31,4	68,5	48,5	28,1	43,9	27,3	69,4	46,4
355	579	649	547	577	616	322	427	102	462
3,2	13,9	10,6	11,2	10,8	17,4	4,1	17,7	8,5	15,2
70	185	154	138	120	170	55	153	72	158
1,10	14,4	12	13,60	10,900	15,3	7,80	13,40	13,00	14,1
168	675	270	537	413,00	420	411,0	337	304	450,0
1,75	4,34	3,49	3,3	2,750	4	1,83	3,50	2,85	3,620
0,080	1,084	0,773	0,995	0,637	1,09	0,968	0,964	2,812	0,932
11,0	12,0	10,51	28,44	7,830	36,18	12,11	4,1	6,2	3,12
0,57	9,90	7,66	9,8	6,7600	8,53	21,76	4,45	17,58	3,680
0,14	2,62	1,82	1,66	1,200	1,41	2,44	0,84	5,24	0,99
3,0	70,92	77,99	74,49	73,8	99,02	20,23	79,34	5,3	77,31
16	118	63	66	133	110	51	63	30	57
1,7	11,0	12,0	12,0	13	16	3	10,8	0,9	12
9	67	37	44	75,2	59	25	38,6	17	35
4,10	15,10	16,4	9,79	17,9	18,1	5,6	88,48	5,40	4,5
13,2	52,8	62,7	49,9	53,2	56,3	15,3	32,8	46,9	46,5
2,2	33,4	26,6	29,7	24,1	29,5	33,3	16	23,3	22,7
4,7	62,3	45,9	52,0	43,70	54,6	46	31,5	36,9	40,30
0,597	6,99	5,03	5,56	4,931	6,10	3,74	3,71	3,36	4,466
2,4	24,8	18,11	19,3	17,83	21,9	9,9	14,2	9,6	16,22
0,56	4,36	3,26	3,44	3,110	4,14	1,20	3,05	1,44	3,08
0,230	1,278	0,973	1,032	0,963	1,19	0,49	0,971	0,394	1,06
0,52	3,68	2,79	2,93	2,470	3,69	1,09	3,11	1,33	2,84
0,077	0,451	0,351	0,366	0,351	0,512	0,116	0,467	0,189	0,438
0,47	2,48	1,91	2,01	1,930	2,99	0,6	2,97	1,24	2,56
0,101	0,470	0,375	0,39	0,377	0,612	0,129	0,62	0,288	0,532
0,3	1,28	0,99	1,04	0,980	1,66	0,39	1,73	0,94	1,47
0,049	0,183	0,143	0,150	0,139	0,251	0,061	0,264	0,173	0,225
0,36	1,23	0,89	0,99	0,900	1,64	0,45	1,75	1,37	1,47
0,059	0,184	0,137	0,151	0,141	0,248	0,074	0,272	0,240	0,229
12,6	143,1	107,5	119,1	101,9	129,0	97,5	80,6	80,8	97,6
1,30	0,98	0,99	0,99	1,06	0,93	1,30	0,96	0,87	1,10
2,54	4,95	5,27	5,57	5,00	4,60	17,91	3,39	10,45	4,76
4,38	19,48	21,44	21,52	19,21	12,90	53,08	6,56	12,20	11,08
1,31	2,02	2,15	2,03	2,14	1,82	1,31	1,70	0,91	1,74
6,00	10,89	8,60	7,85	8,51	14,96	9,36	12,35	4,38	9,70
0,08	0,11	0,05	0,13	0,08	0,05	0,14	0,06	0,68	0,10

posterior series (second phase). The rocks are characterized mainly by hypidiomorphic-granular, sometimes porphyraceous textures. Main minerals of these rocks are represented by various proportion of medium to acid plagioclase, quartz, potassium feldspar (in granite-granodiorites) minerals, as felsic, and pyroxene, mainly amphibole and biotite as well as mafic minerals. Accessories are opaque (mainly magnetite) minerals, apatite, zireon, rarely sphene and rutlle. Secondary minerals are represented by sericite, pellte, carbonate, chlorite, epidote and hmomite.

In the normative anorthite–albite–orthoclase (An–Ab–Or) ternary diagram (O'Connor, 1965), these granitoids plot in granite, trondhjemite and tonalite (with few granodiorites) fields, respectively (fig.3A).

Geochemistry

A total of 19 samples from three different groups of granitoid intrusions from the studied antichnorium (fig.2) have been selected for major, trace and rare earth element analysis that are determined at the Chemical laboratory of Department of Geosciences of National Taiwan University (NTU). Particularly, the major oxide determinations were done by X-ray spectrometry (XRF), and rare earth and other trace-elements by the method of inductively-coupled plasma Mass spectrometry (ICP-MS). Geochemical composition of the granitoids is shown in (table 2).

Major elements. All studied rocks are characterized by the normal-alkaline chemistry (i.e. sub-alkaline series) and according to TAS diagram (total alkali vs. silica, not shown) plot to mainly dacite and rhyolite fields with a few quartz diorites that are in the andesite field. The studied granitoids are sub-alkaline with well-developed calc-alkaline trend on the AFM diagram (fig.3B). The granite-gneisses are more felsic in composition, their SiO_2 content range between 72-81wt.% and they have relatively low Al_2O_3 contents of 10-14wt.%. The plagiogranites reveal lower SiO_2 contents (70-74wt.%) and increase of the Al_2O_3 contents between 16-19wt.%. In the tonalitic formation rocks SiO_2 contents are 61-66wt.% and around 77wt.%, and Al_2O_3 contents are 16-18wt.% and around 13wt.%, respectively, in the first phase quartz diorite-tonahtes/granodiorites and pimkish leucogranites (granite-aphte) of second phase. Based on geochemical classification for granitic rocks (Frost et al., 2001) these samples are *peraluminous* with the aluminum saturation index (ASI = Al / (Ca – 1.67P + Na + K)) of 1.0-1.9 (i.e. are corundum-normative), which means that they have more Al than can be accommodated in feldspars and that they must have another aluminous phase present (fig.3C). There are no clear differences between the various aged series in the modified alkali-lime index (MALI = Na2O + K2O – CaO) vs. Si diagram (fig.3D) that classified rocks into alkalic, alkali-calcic, calc-alkahc, and calcic groups (Frost et al., 2001). In the K2O versus SiO2 diagram (Le Maitre et al., 1989; not shown) all granitoid samples plot in the low- and medium-K fields. The Mg # (Mg-number) varies from 25 to 54, from 33 to 73 and from 43 to 60 for granite-gneiss, plagiogranite and tonalitic series, respectively.

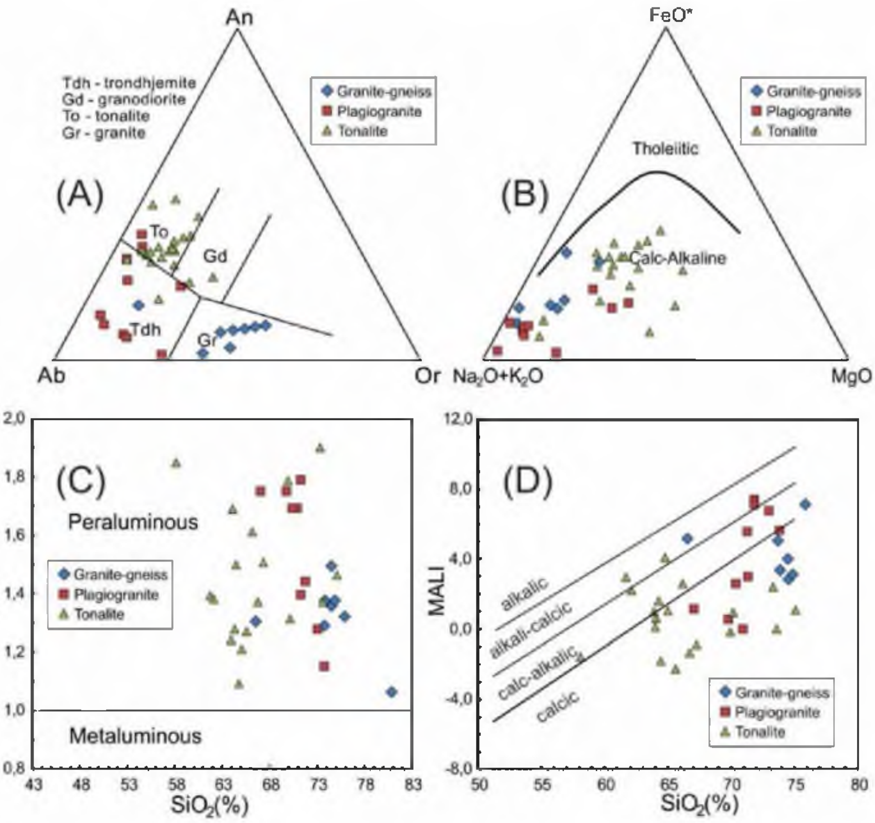

Fig.3. A – Normative anorthite-albite-orthoclase compositions of the units (after O'Connor, 1965); B – AFM (total alkali – total FeO* – MgO) plot for studied rocks of the study area. The boundary line for field discrimination of calc-alkaline and tholeiitic rocks is after Irvine and Baragar (1971); C – Plot of ASI (aluminum saturation index) vs. silica, and D – Plot of MALI (modified alkali-lime index) vs. silica diagrams of (Frost et al., 2001, 2008). Five analyses of granite-gneisses from literature (Chibukhchyan, 1985) have also been included in these diagrams.

Trace elements. In normal Mid-ocean ridge basalt (N-MORB) normalized (Sun and McDonough 1989) multi-element diagrams the patterns of various granitoids are characterized by increase in Ba, Rb, K large-ion lithophile elements (LILE) and Th, and by decrease in Nb-Ta, P (except plagiogranite samples) and Ti (fig.4) that is characteristic of the subduction-related magmatism in the active continental margins (e.g., Taylor and McLennan, 1985; Sun and McDonough 1989; Pearce and Peate, 1995). With the exception of LILEs, the content of almost all the trace elements is around one order lower in the plagiogranites compared to granite-gneisses and tonalite series. In the plagiogranites are observed expressed P (not always) and Zr positive anomalies.

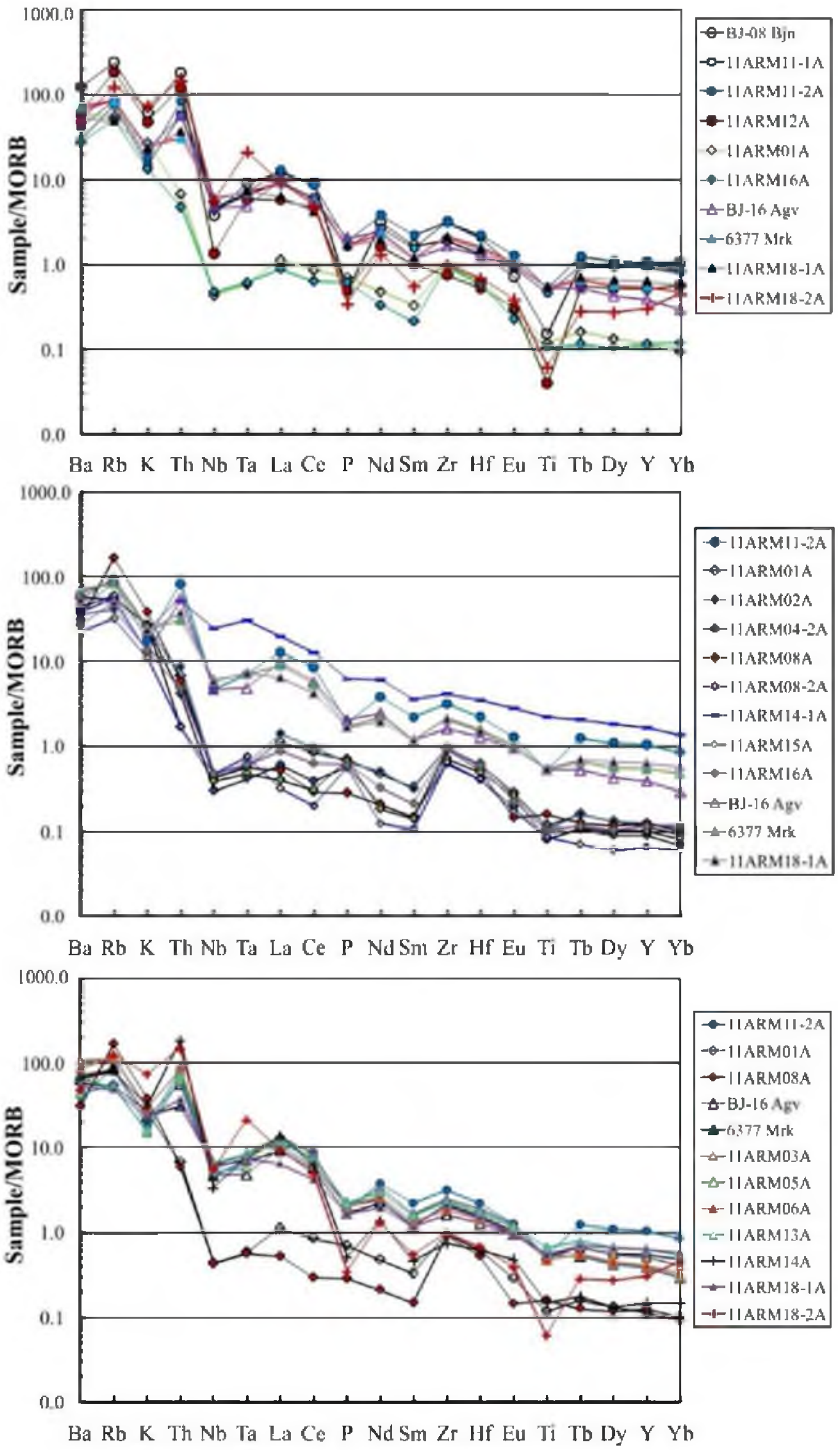

Fig.4. N-MORB normalized (Sun and McDonough, 1989) spider diagrams for studied various aged granitoid. K, P and Ti values are after XRF analyses, sample name description and ages are brought in the table 2.

Some differentiation (discrimination) diagrams have been proposed to determine the tectonic settings of granitoids (e.g., Pearce et al., 1984), though Frost et al. (2001) believed 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, according to those discrimination diagrams all studied samples plot in volcanic arc granite (VAG- type) field (fig.5). In Ta–Yb diagram two leucogranites (pinkish granites of second phase) of Upper Jurassic plot in syn-collisional (Syn-COLG) field. The only exception is the Nb vs. Y diagram, where the Syn-COLG and VAG fields are not delimited. In general, these three groups of rocks are not distinct in terms of their geochemical signature.

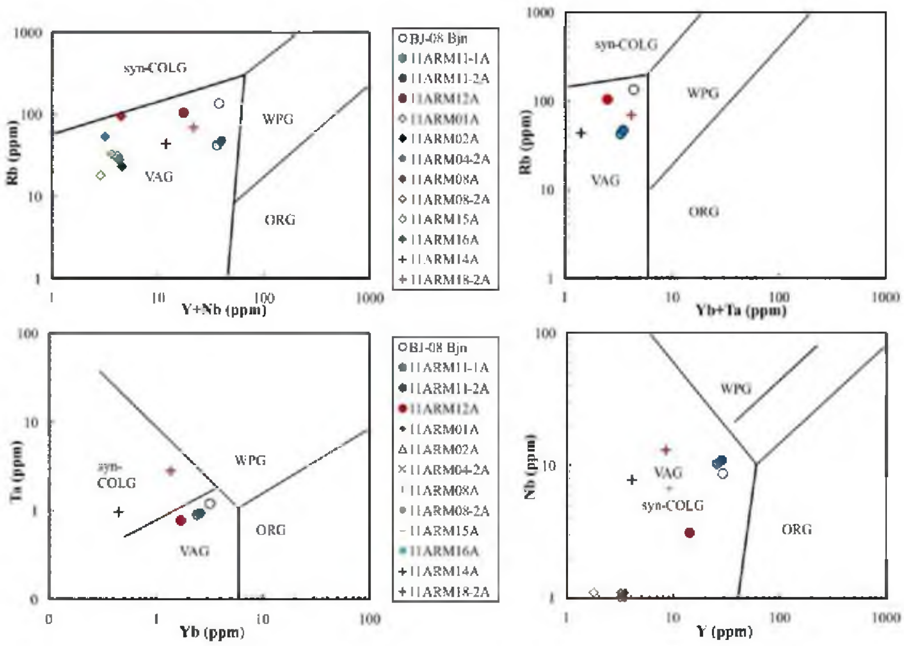

Fig.5. The tectonic discrimination diagrams: (a) Rb *vs.* (Y+Nb), (b) Rb *vs.* (Yb+Ta), (c) Ta *vs.* Yb, and (d) Nb *vs.* Y, for different age granitic rocks (after Pearce *et al.* 1984).

Rare earth elements (REE) distribution in the studied rocks also indicates different levels of their content (table 2). Accordingly, the poorest are the plagiogranites (ΣREE = 5-19ppm), while in the granite-gneisses and tonalite series the REE sums are comparable, 76-157ppm and 81-143ppm, respectively. However, their Chondrite-normalized REE spectra remain parallel to each other, and moderately light-REE (LREE) enrichment is obvious (fig. 6). The significant enrichment of LREE compared with the medium-REE (MREE) ((La/Sm)n = 5-18) and heavy-REE (HREE) ((La/Yb)n = 7-22, rarely 53 in a granite-aplite) is characteristic for tonalite series, while the same ratios in granite-gneisses (3.5-4.5 and 6-9) and plagiogranites (2-3 and 3-8) are comparable. Though all studied samples are with LREE > HREE, marked negative and positive Eu anomalies are characteristic for granitic gneisses

(Eu/Eu* = 0.4-0.7) and plagiogranites (Eu/Eu* = 1-2), respectively, with almost no Eu anomalies (Eu/Eu* ~ 1) in tonalites (fig.6).

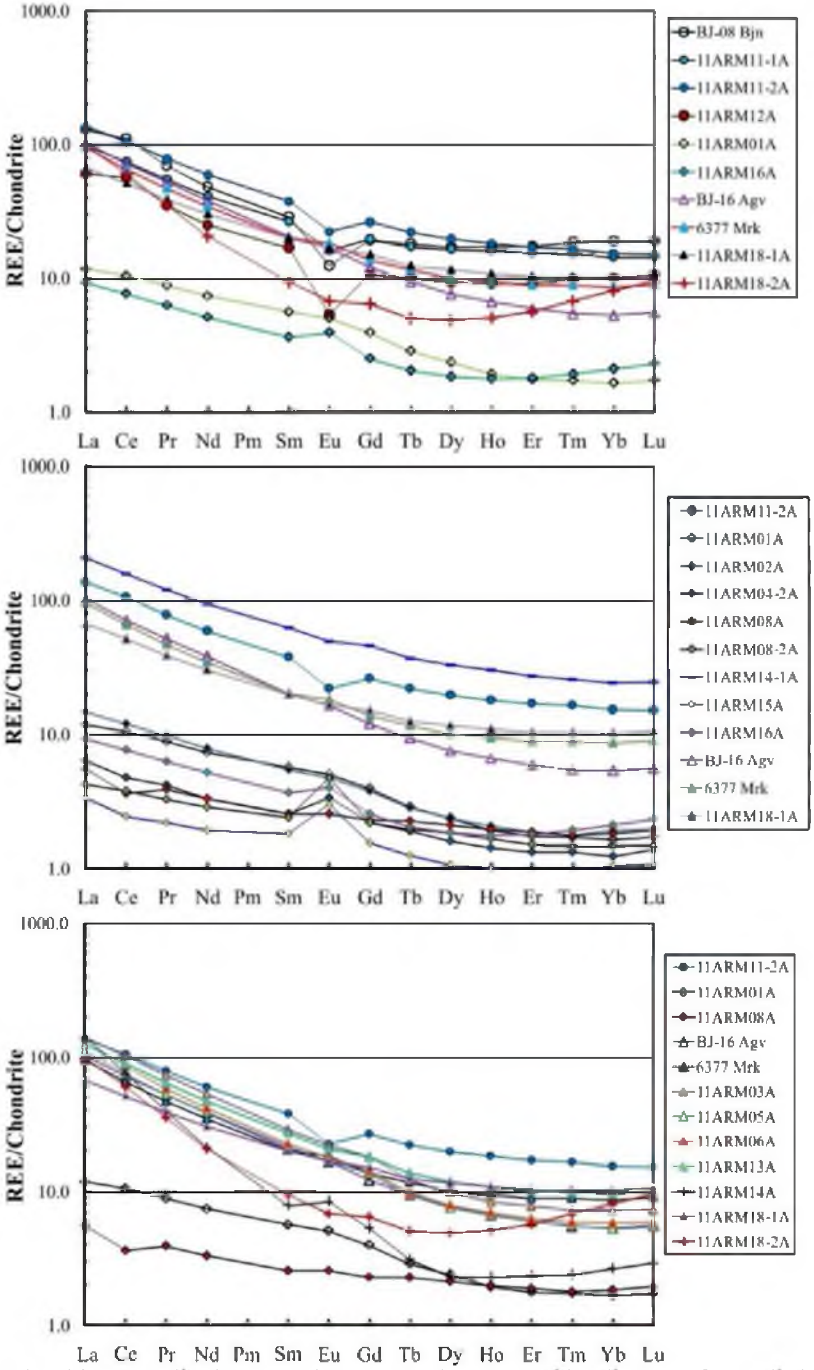

Fig.6. Chondrite-normalized (Sun and McDonough, 1989) spider diagrams for studied various aged granitoid. Sample name description and ages are brought in the table 2.

Discussion

The research relevance is conditioned by the use of modern scientific-theoretical methods and analytical possibilities to obtain the newest and reliable geochemical data and U-Pb isotopic ages, which were mostly absent in previous studies. These are necessary, especially, for elucidation of geological evolution, lithology and tectono-stratigraphy of the Precambrian-Paleozoic metamorphic soles cropping out within the micro-continents in the Arabian and Eurasian plates collision zone.

According to field observations and geological maps, except granitoid massifs emplacement into the SAM's crust, there are no clear indications about the (southward) subduction process among the available data during Late Neoproterozoic or Late Paleozoic, while both plutonic and volcanic activity confirms subduction regime under Tsaghkunyats continental massif during at least Middle-Late Jurassic, lasting up to Early Cretaceous.

It is known that granitic melts can result as from partial fusion of continental crustal rocks in low pressure conditions, as well as from extensive fractional crystallization of basaltic magma that derived from the partial melting of mantle peridotites. The experimental studies have shown that melting of metasedimentary rocks generates also peraluminous silica-rich melts (Patino Douce and Harris, 1998). However, in this paper, we will limit the discussion of petrological and especially granitic magma petrogenesis issues that need additional and detailed research. Below two subsections the timing of granitoid magmatism and the tectonic imphcation in a regional context are discussed.

Regional comparisons and magmatism age constraints.

Before the advent and adoption of Plate tectonics theory all geological problems of the Lesser Caucasus were compared/parallelized, analyzed and discussed with those of the Greater Caucasus. These were widely used in the works of all or by the majority of previous researchers, up to the 1980s. Meanwhile, comparisons with lateral, regional geological units (in Anatolia and Iran) and geo-events are more effective and informative at present. Zircon age dating has shown that there are two different magmatic series in Dzirula Massif of Georgia: (1) the older Lower Cambrian mostly of tonalitic composition, and (2) the younger (~ 330Ma, corresponding to Variscan orogenic phase) gabbro-diorite series, with mostly tonalite-granodiorite type of rocks (Mayringer et al., 2011).

The U-Pb dating has revealed that the crystalline basement of the Sanandaj-Sirjan, the Central Iran and the Alborz terranes (blocks or zones) in Iran consists of the continental parts of Gondwanan origin, which are characterized by a wide spread of subduction related granite-granodiorite intrusions of Late Neoproterozoic–Early Cambrian (average 550Ma) period (Hassanzadeh et al., 2008). According them, an active Peri-Gondwanan continental margin best explains the distribution of these granitoids in Iran. Balaghi Einalou et al.

(2014) and Moghadam et al. (2016), who studied upper Neoproterozoic granites and granite-gneisses in the Biarjmand region of Central Iran, came to a similar conclusion on the ages (i.e. Late Ediacaran and Early Cambrian) and the geodynamic setting of Central Iran as a *continental magmatic arc*. Besides, new zircon U-Pb ages of granitoids from NW Sanandaj-Sirjan (Marand area) and Central Iran (Saghand area) showed Late Neoproterozoic (565-556Ma) and Early-Middle Cambrian (518-510Ma) intervals, respectively (Chiu et al., 2017). Let's briefly mention that according to Lechmann et al. (2018) these two Precambrian terranes were separated from each other by a continental rifting that is reflected in a dioritic-granitic magmatism in Khoy area during Late Jurassic (159-154Ma).

In Turkey, Central Anatolian Crystalline Complex (CACC, known also Kirshehir Massif) is a large region of metamorphic rocks (gneisses, schists, marbles, quartzites, etc.), cut by the Upper Cretaceous granites (isotope ages 95-70Ma; Okay, 2008 and references therein). The Menderes Massif consists of a Precambrian core of micaschists, gneiss and minor granulite and eclogite, which are intruded by large metagranites of latest Precambrian ages (~550Ma) (Candan et al., 2001). In the Precambrian basement of the Biths Massif (south-west of Lake Van), as a part of the Taurides-Anatolides, again the metamorphic rocks (gneiss, amphibohte, schist and eclogite) are intruded with leucocratic granitoids (Okay, 2008), but we have no ages (?). U-Pb zircon dating of the Mutki granite from Bitlis Massif and a nearby granitic dyke yielded crystallization ages of 545.5±6.1Ma and 531.4±3.6Ma, respectively (Ustaömer et al., 2009). Besides, in the Karacahisar dome in the southern-central Taurides, the intrusion of dacitic dyke swarms yielded a U–Pb zircon age of 544±4Ma, coeval with the magmatism in other Cadomian basement units in the Taurides (e.g., Sandıklı and Menderes massif; Abbo et al., 2015).

At the Strandja Massif in the southern Balkans (NW Turkey) the Variscan crystalline basement, made up of predominantly quartz-feldspathic gneisses, is intruded by Late Carboniferous and Early Permian (257±6Ma) granitoids (Sunal et al., 2006). Although Permian ages coincide well with our results, those granites are distinguished for their high content of K-feldspars (35-45%), unlike our plagiogranites. Besides, Permo-Carboniferous granitoids with Jurassic high temperature metamorphism are described also in Central Pontides of Northern Turkey with U-Pb zircon ages of 316-252Ma (Gücer et al., 2016). According to these authors, this calc-alkaline arc-type granitoid magmatism resulted from the *northward subduction* of Paleotethys oceanic lithospherc under Laurasia.

Recently, Candan et al. (2016) showed the presence of Carboniferous (331-315Ma, U-Pb method) metagranite plutons in the Afyon zone, at the northern margin of the Anatolide-Tauride Block, which is made up of the latest Neoproterozoic to Late Cretaceous units. Petrographically these are normal (sub-alkaline) granites with the predominance of K-feldspar (~45%), and geochemical characteristics argued their subduction origin in a continental arc setting.

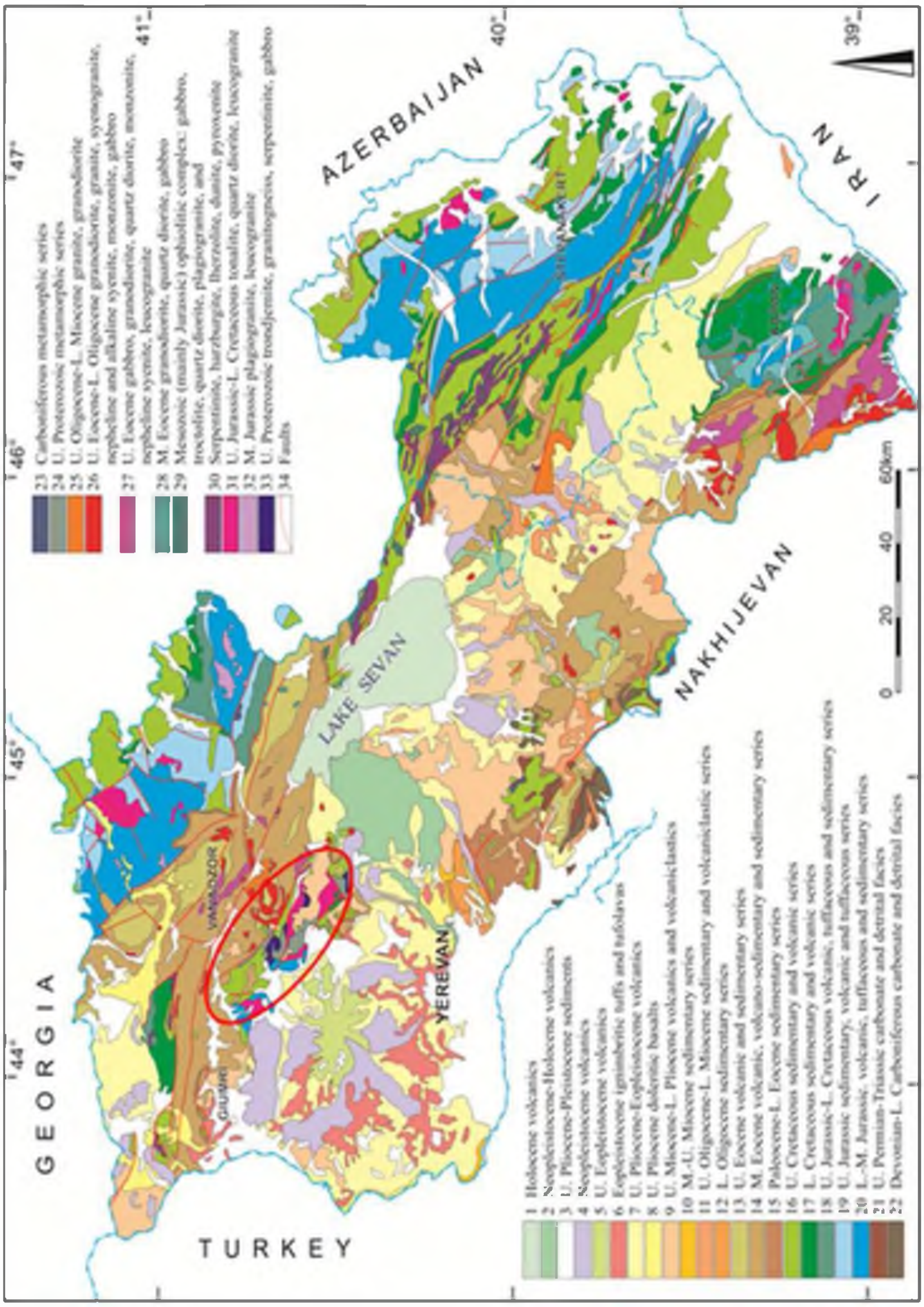

Fig.1. Schematic geological map of Republics of Armenia and Karabagh after (National Atlas of Armenia, 2007, pp. 26-27), modified by Gh. Galoyan. Red circle corresponds to the study area (fig.2).

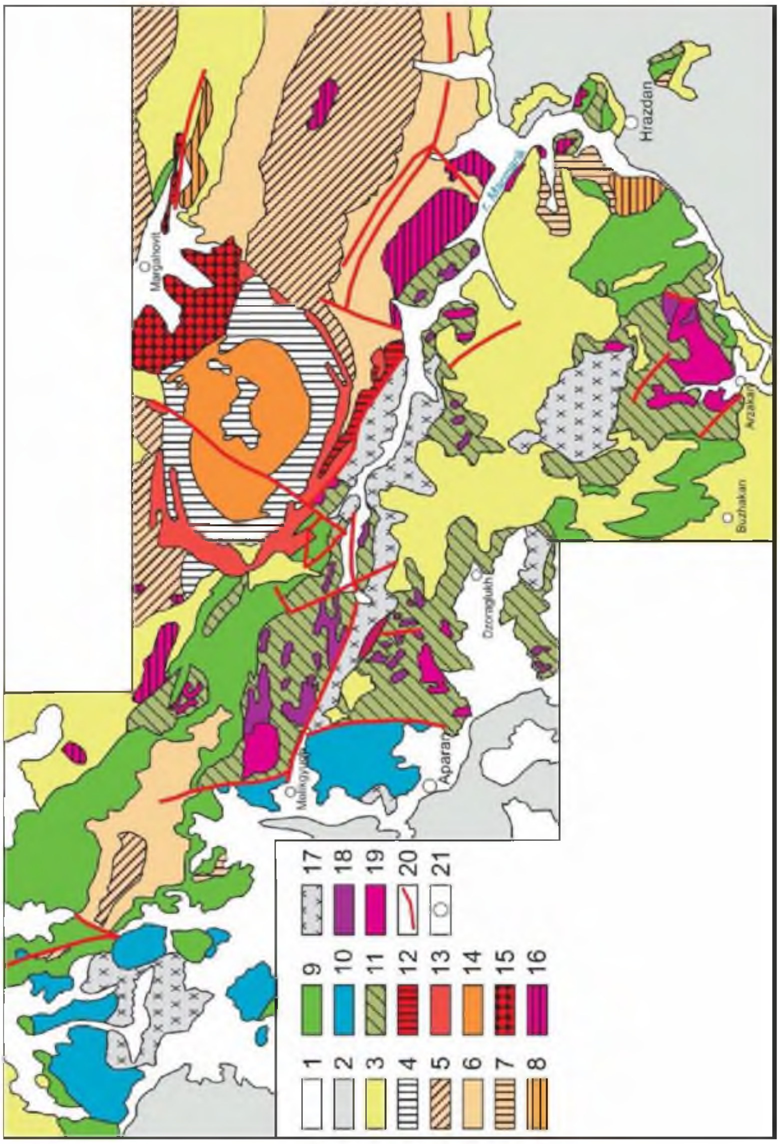

Fig.2. Schematized geological map of Tsaghkunyats anticlinorium after Arakelyan (1973), modified by Galoyan. Note: 1 - Quaternary deposits; 2 – Quaternary basalts, basaltic andesites and tuffs; 3 – Miocene-Pliocene various andesites, rhyolites, breccias and tuffs; 4 – Upper Eocene trachyandesites, trachydacites, leucite porphyries; 5 – Upper Eocene basalts, andesites, rhyolites, pyroclastics; 6 – Middle Eocene basalts, andesites, dacites, rhyolites, tuffs, tuffites, sandstones; 7 – Lower-Middle Eocene conglomerates, limestones, sandstones, basalts, andesites, dacltes; 8 – Paleocene-Lower Eocene limestones and marls; 9 – Upper Cretaceous conglomerates, sandstones, marls, limestones and shales; 10 – Middle Jurassic (?) or Upper Paleozoic (?) pillow basalts and andesitic series; 11 – Upper Proterozoic-Lower Paleozoic (?) metamorphic complex; Upper Eocene intrusions (12-16): 12 – porphyric granites; 13 – alkaline syenites; 14 – pseudoleucite and nepheline syenites; 15 – porphyric granosyenites; 16 – monzonites, quartz monzonites and syenites, diorites, granodiorites; 17 – Upper Jurassic tonalite formation; 18 – Middle-Upper Permian plagiogranites; 19 – Neoproterozoic-Lower Cambrian granite-gneiss; 20 – faults; 21 – settlements.

The geochemical signatures of Guegharot, Mirak, Hankavan and Aghveran tonalite intrusions from the present study are similar to those of tonalites from intrusions of Jurassic Somkheto-Karabagh belt (Galoyan et al., 2013, 2018), whose subductive nature is no longer in doubt. Given the assumption that these intrusions are part of the Spitak-Kapan zone of Galoyan et al. (2013), the rejuvenation of the age of intrusion(s) of tonalite formation is noticed towards the south-east, i.e. in Kapan area. Here the rocks of voluminous Tsav pluton yielded Lower Cretaceous zircon U-Pb ages (~138-130Ma; Mederer et al., 2013 and Melkonyan et al., 2016), which is the result of subduction-related magmatism as well.

Being composed of Precambrian various metamorphic rocks sequences (mainly with the terrigenous protoliths) and intruded by Late Ediacaran–Early Cambrian granitic rocks, the Tsaghkunyats basement resembles other Cadomian terranes in the region, including those in Iran and Turkey. Thus, it is evident that studied oldest (from Precambrian to the Early Cretaceous) granitoid intrusions are one of the most commonly occurring plutonic formations in our region, and the problem of their petrologic and geodynamic synthesis (comparison) and the geochronological generalization remains one of the most important in the regional context.

Issues concerning to the regional geodynamic setting.

From the point of view of petrologic issues and, in particular, of geodynamics the granitoid formations (similarly to basalts) have extremely important significance. The geodynamic evolution of Eastern Pontides–Lesser Caucasus–Iran orogenic belt remains a subject of debates mainly because of the rarity or often absence of systematized geological, geochemical, and thoroughly geochronological data on various geological formations, and especially, on the abundant magmatic complexes. Additionally, the reconstruction of history of the geodynamic evolution of any region, based on the analysis of its magmatism, is one of the most effective methods. Taking into consideration the geochemical features of studied granitoid intrusions, it is obvious that the majority of features assigned them to the *subduction-related* tectonic settings.

Though it is commonly assumed that Tsaghkunyats crystalline massif is a part of the South-Armenian micro-continent (microplate or block), as a *basement* of Caledonian consolidation, nevertheless, the view remains unjustified. This has already been mentioned also in (Sosson et al., 2010). The problem is caused, on one hand, by the buried boundary of the crystalline massif or core (?) complex along with the Upper Paleozoic carbonate shelf formations from its south, and, on the other hand, by the rarity or absence of reliable and modern deep geophysical (e.g., seismic reflection, gravity and magnetic anomalies, and seismic tomography) research data. Similarly, Kirshehir Massif (or CACC) in Turkey is an extensive terrane, represented by metamorphic and plutonic rocks of the Upper Cretaceous, and the question of whether it belongs to Anatolides-Taurides is still controversial (e.g., Okay, 2008).

In last two (or three) decades, there is no deficiency of schemes and models regarding to the tectonic evolution of the Lesser Caucasus during Jurassic (e.g., Melkonyan et al., 2000; Galoyan et al., 2009, 2013, 2018; Rolland et al., 2009; Sosson et al., 2010; Mederer et al., 2013; Hassig et al., 2015). However, the same can't be said about the geological situations and processes that existed before Jurassic, tough these issues have also been addressed in several studies (e.g., Aghamalyan, 2004; Gamkrelidze and Shengelia, 2007; Rolland, 2017). Here, uncertainties are much more than clarities. Finally, it is difficult to achieve a realistic solution to the problem based only on (1) the study of the Tsaghkunyats anticlinorium (or crystalline basement) or (2) the granitoid intrusions emplaced therein. In this sense, regional comparisons and synthesis are inevitable on the way of finding explanations that are more logical and realistic.

From the above-mentioned (section 6.1) age data follows that there is no doubt about the long extended (~45Ma) Andean-type subduction of the Prototethys beneath the northern margin of Gondwana, which produced the massive Cadomian arc-type magmatism during the Late Neoproterozoic to Early Cambrian exposed in Turkey (Candan et al., 2001; Ustaömer et al., 2009), southern Georgia (Zakariadze et al., 2007), Iran (Ramezani and Tucker, 2003; Hassanzadeh et al., 2008; Balaghi Einalou et al., 2014; Moghadam et al., 2015, 2016; Chiu et al., 2017) and Armenia (this study). Moreover, the Cadomian belt stretches from Iberia through central and southeast Europe into Turkey and Iran and may continue into the Qingtang terrane of Tibet (Moghadam et al., 2016 and references therein). This subduction is suggested to have ceased around 450–400 Ma, due to continental or oceanic plateau collision (Ustaömer et al., 2009), while this time interval coincides to the opening (rifting) of Paleotethys Ocean corresponding to Iranian part of Gondwana (reconstruction in Moghadam et al., 2015).

"Mystery" of the Paleotethys Ocean. Location of the suture line of Paleotethys Ocean in the Caucasus has been debated for a long time. According to Gamkrelidze and Shengelia (2007), this line sits between the Black Sea-Central Transcaucasian and Baiburt-Sevanian (corresponds to Eastern Pontides-Lesser Caucasus belt of others) terranes, i.e., along the northern periphery of the Somkheto-Karabagh belt (a *sub-terrane* according them). They supposed the existence of serpentinite mélange in the eastern periphery of the Loki Massif (southern Georgia) as an ophiolite suture, and considered the existence of the Proto-Paleotethys basin to be continuous until the Late Jurassic. Based on their original results and critical analysis of literature data, Galoyan et al. (2018) suggested a south-dipping subduction model in the Paleotethyan ocean, which have led to formation of the Somkheto-Karabagh island(?)-arc (i.e. ensimatic) structure and to the opening of Lesser Caucasian Neotethyan rear basin corresponding contemporary Amasia-Sevan-Hakari suture zone (Galoyan and Melkonyan, 2011).

Aghamalyan (2004) presented a model covering the longest period from mid-Proterozoic to Quaternary for this region. According to his reconstruction, Paleotethys inherited from Prototethys that functioned between Proto-Africa and Laurentia continental masses. However, this model can't work anymore for the simple reason that the ages of granite-gneisses and, especially, plagiogranites were "exaggerated" (see section 3), while the geodynamic interpretations, in the early stages of the Caucasian earth's crust formation, were based on these timing.

Similarly, the possible location or existence of the Paleotethys suture in Turkey has been the subjects of a long-lasting debate (e.g., Şen, 2007; Dokuz et al., 2017; Candan et al., 2016 and references therein). Moreover, the tectonic setting of the northern continental margin of Gondwana during the late Paleozoic remains controversial (Candan et al., 2016 and references therein). It is especially about the issues of active or passive nature of continental margin and the polarity of Paleotethys subduction. Based on original results of widespread Early to mid-Carboniferous metagranites from the Afyon zone and the analysis of a large amount of literature data (for a review see Candan et al., 2016), these authors concluded that the presence of Carboniferous subduction-accretion complexes and arc-type (meta)granites on the northern margin of the Anatolide-Tauride Block suggest southward subduction of Paleotethys under Gondwana. Besides, they concluded that these granites are not related to the Variscan orogenic event that was characteristic to the southern margin of Laurasia. Dissimilarly, in their preferred southward subduction model of Dokuz et al. (2017), the Paleotethys Ocean was to the north of Sakarya zone (or Pontides) constituting a part of the northern margin of Gondwana. According them, starting from Permian the subduction resulted to the back-arc extension and breaking up of the Sakarya zone from Gondwana in the Late Triassic and closing the Paleotethys ocean during the Late Jurassic. Similarly, to the opinion of Gamkrelidze and Shengeha (2007) for Caucasus, these authors "located" the Paleotethys suture along the northern border of Sakarya zone.

On the basis of a review of geological data from the literature from NE Anatolia, Caucasus and NW Iran, a reconstruction of the evolution of the Eurasian margin from Proterozoic to the present was proposed by Rolland (2017). According him, the Pontides-Transcaucasus belt, as an elongated continental tectonic block, rifted away from the NE margin of Gondwana between 450-350Ma (e.g., Adamia et al., 2011), leading to further opening of Paleotethys as a consequence of the southward subduction of Rheic Ocean lithosphere. Similarly, in their tectonic model Okay and Nikishin (2015) suggested the southward subduction of Rheic Ocean under a ribbon-shaped continental block (including Rhodope, Sakarya Zone and Caucasus) that led to development of *a continental arc* and the Late Carboniferous collision of it with the southern margin of Laurasia. On the contrary, Dokuz et al. (2011) proposed Early Devonian rifting and Paleotethys opening as a result of northward subduction of the Rheic Ocean below Laurasia. Putting the existing opinions together, Candan et al. (2016) came to a view that the geological evidence favors dual subduction both under Laurasia and Gondwana for the Paleotethys during Late Paleozoic. Because we have already put forward the idea of a tectonic model of southward subduction (Galoyan et al., 2019), therefore Paleotethyan southern subduction under Anatolide-Tauride Block of Early-Late Carboniferous (331-315Ma; Candan et al. 2016) could have continued very likely in the east under SAM during Middle-Late Permian (270-250Ma and earlier, this study). Moreover, in the current context of scientific information, we cannot exclude the view of Zakariadze et al. (2007) that Transcaucasian Massif underwent a period of extensive crustal growth during 330–280Ma through the emplacement of microcline granite plutons as part of a magmatic arc system above a Paleotethyan northward subduction zone dipping beneath the southern ınargin of Eurasia.

For the Caucasus, Khain (1975) assumed the first that closnre of Tethys (Meso- or Neo-) during Jurassic-Early Cretaceous occurred as a result of dual subduction: (1) to the north, under the Artvino(Soınkheto)-Karabagh zone and (2) to the south, under the Kapan zone; about latter testify the volcanism of Kapan zone and the granitoid intrusions of the Jurassic-Early Cretaceous age of both Kapan zone and the Arzakan (i.e. Tsaghkunyats) massif. Analogous opinion, on the basis of the results of their own studies adhere also Zaseyev and Abramovich (1993) and Melkonyan et al. (2000). Without stopping on details or different aspects of the paleo-geodynamic reconstruction of the Lesser Caucasus during Mesozoic, to which are recently devoted many special studies (e.g., Galoyan et al., 2009, 2013, 2018; Rolland et al., 2009; Sosson et al., 2010; Mederer et al., 2013; Hässig et al., 2013, 2015; and references therein), let us note that only fewer (Galoyan et al., 2013; Melkonyan et al., 2016) proposed to consider the Kapan block as an independent structure from the Somkheto-Karabagh belt. Moreover, Galoyan et al. (2013) considered the second belt (zone) of subduction origin to the south of Armenian ophiolite belt and, on the basis of its geographical position, named it *Spitak-Kapan* zone of Jurassic-Cretaceous. It should be noted that views of the southward subduction of Northern Neothetys hthosphere beneath the SAM (Hässig et al., 2015) or the Spitak-Kapan zone (Galoyan et al., 2018) are also well-reasoned in Middle-Late Jurassic. In all mentioned other (also previously proposed) tectonic models, this segment is represented as *a passive margin* of Tethys.

Thus, the new petrologic-geochemical studies and U-Pb isotope age dating of the older granitoids on the boundaries of the Tsaghkunyats antichnorium will facihtate and clarify our understanding about the whole Anatolia–Lesser Caucasus–Iran orogenic belt. In case of successful and complex works in the near future, the geographical-tectonic position of the Tsaghkunyats crystalline basement towards both the Late Paleozoic terrigenous carbonate shelf of the SAM (from south) and the Lesser Caucasus ophiohtic basin (i.e., Paleo- or Neotethys, from the north) can be clarified during the Jurassic and preceding periods.

Conclusion

This study is presenting general geological, new petrologic-geochemical and zireon U-Pb geochronological data on the older granitoids from Tsaghkunyats antichnorium or crystalline basement comprising present day Central-Northern Armenia. It provides age precisions about the Precambrian and Late Jurassic magmatic events and new constraints on the Late Paleozoic (Permian) magmatic activity in SAM that has not previously been reported. Thus, obtained new U-Pb zireon crystallization ages are ranging from Late Neoproterozoic (Late Ediacaran) to Early Cambrian (~545-530Ma) for the granitic gneisses; from Middle to Late Permian (~270-250Ma) for the plagiogranites; and from Late Jurassic to Early Cretaceous (~155-140Ma) for the tonalite formation rocks. Deformation traces are present only in granite-gneisses as a result of regional metamorphism.

We also present new constraints on a regional scale for the geodynamic evolution of the northern margin of SAM as a part of Gondwana. Namely, Andean-type subduction of the Prototethys beneath the northern margin of Gondwana produced the massive Cadomian arc-type magmatism during the Late Neoproterozoic to Early Cambrian exposed in Turkey, southern Georgia, Iran and Armenia, etc.

Geochemically, Middle-Upper Permian granitic rocks have features that are partially different (poor content of REE) from those of Precambrian and Mesozoic granitoids. All these various aged granitoids are calc-alkahne, peraluminous and are characterized by enrichment of LILEs and Th, with pronounced mimimums of Nb-Ta and Ti, and high LREE/HREE ratios which are typical of subduction-related magmas. As for the geodynamic setting, all studied granitoids are are-type and their presence may suggest *southward subduction* events of Proto-Paleo-, and Neotethys oceans under SAM of Gondwana during above-mentioned time intervals.

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ՈՒՇ ՆԵՈՊՐՈՏԵՐՈԶՈՅԱՆ-ՎԱՂ ՔԵՄԲՐԻ, ՈՒՇ ՊԱԼԵՈԶՈՅԱՆ ԵՎ ՈՒՇ ՅՈՒՐԱՅԻ ԳՐԱՆԻՏՈԻԴԱՅԻՆ ՄԱԳՄԱՏԻԶՄԸ ԳՈՆԴՎԱՆԱՅԻ ՀՅՈՒՍԻՍԱՅԻՆ ԱԿՏԻՎ ԾԱՅՐԱՄԱՍՈՒՄ՝ ՓՈՔՐ ԿՈՎԿԱՍԻ ԾԱՂԿՈՒՆՅԱՑ ԱՆՏԻԿԼԻՆՈՐԻՈՒՄ (ԿԵՆՏՐՈՆԱԿԱՆ-ՀՅՈՒՍԻՍԱՅԻՆ ՀԱՅԱՍՏԱՆ)

Գալոյան Ղ.Լ., Չունգ Ս.-Լ., Մելքոնյան Ռ.Լ., Լիի Յ.-Հ., Աթայան Լ.Ս., Ղուկասյան Ռ.Խ., Խորենյան Ռ.Հ., Գրիգորյան Ա.Գ., Սահակյան Ս.Ս., Ավագյան Ն.Ա.

Ամփոփում

Հայաստանում Ծաղկունյաց անտիկլինորիումը կամ բյուրեղային հիմքը բացառիկ լեռնածալքավոր կառույց է, որը բնորոշվում է իր բազմափուլ մագմատիզմով, մետամորֆիզմով և լեռնակազմությամբ: Բազմաթիվ հետազոտություններ են կատարվել այստեղ առկա հնագույն գրանիտոիդների վրա, որոնք հասակագրվել էին մինչքեմբրից մինչև վերին կավիճ (իրականում՝ յուրա), սակայն դրանց պետրոգենեզիսի, երկրադինամիկայի և տեղադրման հասակների հարցերը շարունակում են մնալ հակասական: Սույն հարցերի վերանայումից հետո ներկայացված են նոր դաշտային դիտարկումների, ապարների համախառն երկրաքիմիական անալիզի և U-Pb ցիրկոնային երկրաժամանակագրության տվյալներ՝ գնահատելու համար տարբեր գրանիտոիդների հասակը և տեկտոնական իրավիճակը, որոնք մերկանում են Ծաղկունյաց մինչքեմբրիան հիմքում՝ իբրև գոնդվանական ծագման Հարավ-հայկական միկրոսալի (SAM) մաս (միջուկ ?): Նոր U-Pb ցիրկոնային բյուրեղացման հասակները տատանվում են ուշ նեոպրոտերոզոյանից մինչև վաղ քեմբրիան (~545–530Ma)՝ գրանիտագնեյսների համար, միջինից մինչև ուշ պերմիան (~270–250Ma)՝ պլագիոգրանիտների (տրոնդյեմիտներ) համար և ուշ յուրայից մինչև վաղ կավիճ (~155–140Ma)՝ տոնալիտային ֆորմացիայի ապարների համար: Երկրաքիմիական առումով, այս տարահասակ գրանիտոիդները կրաալկալային են, պերալյումինային (peraluminous) և բնորոշվում են խոշորաիոն լիթոֆիլ տարրերի (LILE) ու Th հարստացմաբ, Nb-Ta և Ti հստակ արտահայտված մինիմումներով և LREE/HREE բարձր հարաբերություններով, որոնք մատնանշում են սուբդուկցիայի հետ առնչվող մագմատիկ իրադարձություններ: Ուսումնասիրված գրանիտոիդները երկրաքիմիապես հանդիսանում են ցամաքային աղեղային տիպի (Անդիան տիպ) առաջացումներ, որոնց ներկայությունը մատնանշում է Պրոտո-Պալեո- և Նեոթետիս օվկիանոսային ավազանների հարավ ուղղված սուբդուկցիայի էպիզոդները հյուսիսային Գոնդվանայի Հարավ-հայկական միկրոսալի ակտիվ ծայրամասի տակ վերոնշյալ ժամանակային միջակայքերում:

НОЗДНЕНЕОНРОТЕРОЗОЙСКИЙ-РАИНЕКЕМБРИЙСКИЙ, НОЗДНЕПАЛЕОЗОЙСКИЙ И НОЗДНЕЮРСКИЙ ГРАНИТОИДНЫЙ МАГМАТИЗМ СЕВЕРНОЙ АКТИВНОЙ ОКРАИНЫ ГОНДВАНЫ ЦАХКУНЯЦКОГО АНТИКЛИНОРИЯ МАЛОГО КАВКАЗА (ЦЕИТРАЛЬНАЯ-СЕВЕРНАЯ АРМЕНИЯ)

Галоян К.Л., Чунг С.-Л., Мелконян Р.Л., Лии Ю.Х., Атаян Л.С., Гукасян Р.Х., Хоренян Р.А., Григорян А.Г., Саакян С.С., Авагян Н.А.

Резюме

Цахкуняцкий антиклинорий или кристаллический фундамент в Армении является уникальным геотектоническим сооружением, характеризующимся многостадийным магматизмом, метаморфизмом и орогенией. Многочисленные исследования были нроведены на обнажающихся здесь гранитоидах, датированных от докембрия до верхнего мела (в действи-

тельности юрского пернода), одиако вопросы их петрогенеза, геодинамики н возраста залегаиия оставались спорными. После пересмотра этих вопросов представлены результаты новых полевых наблюдений, валовая геохимия пород и U-Pb геохронология цирконов, с целью оцеики возраста и тектонической обстановки различиых гранитоидов, сформированных в докембрийском фундаменте Цахкуняца как части (ядро?) Южноармяиской микроплиты (SAM) Гондваны. Новые U-Pb возраста кристаллизации циркона варьируют от позднего неопротерозоя до раниего кембрия (~545–530Ma) для грапитогпейсов; от средней до поздней перми (~270–250Ma) для илагиограпитов (трондьемитов); и от поздней юры до раниего мела (~155–140Ma) для пород тоналитовой формации. Геохимически, эти разновозрастные гранитоиды являются известково-щелочными, пералюминиевыми и характеризуются обогащением LILE элементами и Th, с выраженными минимумами Nb-Ta и Ti, высоким соотношением LREE/HREE, указывающим на магматические события, связанные с субдукцней. Изученные граннтоиды геохимически являются образованиями типа континентальных дуг, и их присутствие указывает на эпизоды южно-направленной субдукцнн Прото-, Палео- и Неотетис океанов под актнвную окраину SAM северной Гондваны в течение вышеуномянутых временных интервалов.