ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 409A, No. 6, pp. 900–904. © Pleiades Publishing, Inc., 2006.
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GEOLOGY

New Data on Structure, Composition, and Regional Metamorphism of the Tsakhkunyats and Akhum–Asrikchai Massifs, the Lesser Caucasus

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Presented by Academician V. E. Khain November 14, 2005

Received November 23, 2005

DOI: 10.1134/S1028334X06060146

The nappe structure of the Pre-Alpine basement of the Caucasus was established based on identification of large tectonic nappes within the Greater Caucasus and Dzirul and Loksk crystalline massifs [1–6]. Geological data also point to the thrust–sheet (nappe) structure of the Pre-Alpine basement of the Zakhkunyats and Akhum–Asrikchai massifs of the Lesser Caucasus (Fig. 1) [6, 7]. As is indicated by microprobe study of rock-forming minerals, the “formations” of the metamorphic complexes of the Lesser Caucasus are characterized by a different character of metamorphic grade and composition, suggesting their juxtaposition as nappes.

The Zakhkunyats Massif (600 km^2) consists of two structural stages (Fig. 1) [8]. The lower (Middle Proterozoic) stage composes the Arzakan structural zone with sublatitudinal dislocations. According to Agamalyan [8–12], this stage is subdivided into three formations, which were affected by prograde Middle Proterozoic regional metamorphism and Late Proterozoic diaphthoresis. The lower (Bzhni Formation) 715 m thick is made up of mainly quartz–two-mica schists with relicts of porphyroblastic almandine and andalusite. The rock-forming minerals[1] make up the following assemblage[2] (Table 1): $Grt_{89–94}$ + $Bt_{51–59}$+(Ms 0, Phn 97–99, Par 1–3)+Pl^{29} + Andl + Qtz ± Chl_{49}. Garnet (Alm 60–70, Pi 4–8, Spes 4–16, Gros 10–21) shows distinct prograde zoning (Fig. 2) and no diaphthoresis. This is presumably related to the low-pressure character of the late Proterozoic diaphthoresis, which is unfavorable for the growth of high-grossular garnet. The elevated contents of grossular component in garnets and phengite (97–99%) in coexisting white K-mica point to the moderate-pressure regional metamorphism. The temperature regime of prograde regional metamorphism of the Bzhni Formation corresponds to staurolite facies and low-grade biotite–muscovite gneiss facies.[3] The Surpsarkis Formation (610 m) overlying the Bzhni Formation is composed of tourmaline-bearing quartz–chlorite–muscovite schists with horizons of dolomites and micaceous marbles [8]. This formation includes the following mineral assemblages: (Ms 50–53, Phn 37–43, Par 7–9) + Chl_{15} + Qtz ± Kfs, (Ms 38–59, Phn 33–40, Par 6–12) + $Chl_{13–15}$ + Tu_{14} + Qtz. They correspond to biotite subfacies. The Vankidzor Formation (150 m) consists of graphite-bearing andalusite–almandine–quartz–two-mica schists. The key mineral assemblage of the formation (Grt 90–94 + Bt + Andl + Ms + Qtz + C ± Chl_{49}) indicates the temperature conditions of staurolite facies. Garnet ($Alm_{59–74}$, Pi 4–8, Spes 4–16, Gross 10–21) from the Vankidzor Formation, like that from the Bzhni Formation, exhibits prograde zoning (Table 1). Greenschist diaphthoresis occurred only in the Bzhni and Vankidzor formations. This is expressed in the replacement of garnet and biotite by chlorite and phengite, andalusite by phengite, and plagioclase by albite.

Based on detailed investigations, we believe that the Surpsarkis Formation ascribed to the lower structural stage is a nappe overthrusted from the Dallar Group of the upper structural stage (Fig. 3). The temperature regime within the Surpsarkis Formation was not higher than the biotite subfacies, whereas the Bzhni and

[1] Microprobe studies of minerals from metamorphic complexes of the Lesser Caucasus were made on a CamScan-4DV microprobe in the Laboratory of local methods in the Moscow State University.

[2] Mineral abbreviations: (Ab) albite, (Act) actinolite, (Act–Hbl) actinolitic hornblende, (Alm) almandine, (Andl) andalusite, (Bt) Biotite, (C) graphite, (Ca) calcite, (Carb) carbonate, (Chl) chlorite, (Chld) chloritoid, (Ep) epidote, (Hbl) hornblende, (Gros) grossular, (Grt) garnet, (Kfs) K-feldspar, (Ms) muscovite, (Par) paragonite, (Phn) phengite, (Pl) plagioclase, (Rut) rutile, (Qtz) quartz, (Ser) sericite, (Serp) serpentine, (Sph) sphene, (Spes) spessartite, (Tlc) talc, (Tr) tremolite, (Tu) tourmaline.

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[3] The authors follow the facies classification of metamorphic rocks proposed by Korikovsky [13].

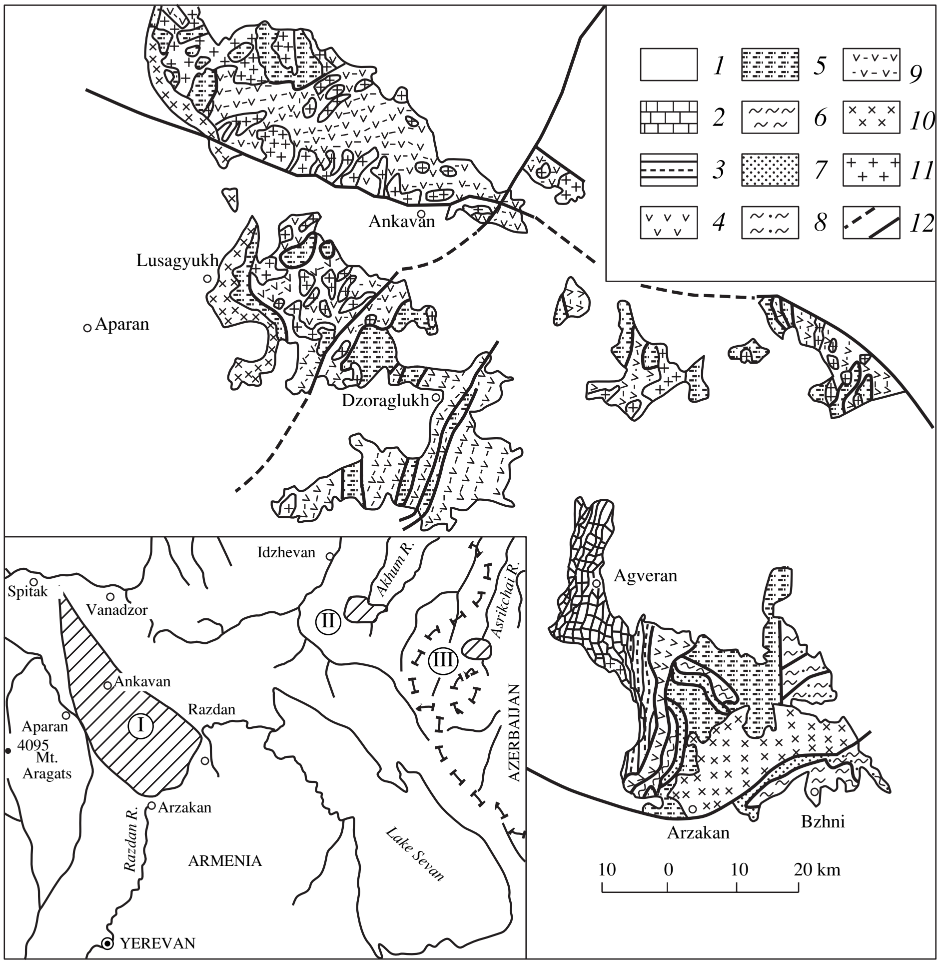

Fig. 1. Scheme of exposures of the (I) Tsakhkunyats, (II) Akhum, and (III) Asrikchai crystalline massifs and geological map of the Tsakhkunyats Massif (modified after V. A. Agamalyan). (*1*) Mesozoic–Cenozoic rocks. Upper Proterozoic: (*2*) Agveran Formation; (*3–6*) nappes: (*3*) Dallar, (*4*) Gguk, (*5*) Surpsarkis, (*6*) Bertitak. Middle Proterozoic: (*7*) Vankidzornappe, (*8*) Bzhni Formation, (*9*) Ankavan and Kasakh metamorphic complexes (undifferentiated). Upper Proterozoic: (*10*) granite gneisses, (*11*) trondhjemites, (*12*) faults.

Vankidzor formations were metamorphosed under staurolite facies and low-grade biotite–muscovite gneiss facies. The Surpsarkis formation has a distinct tectonic contact with the Vankidzor Formation. Dolomites of the Surpsarkis Formation occur as brecciated clasts with size varying from centimeters to a few meters, while the overlying platy schists of the Vankidzor Formation are disintegrated and crushed. At the same time, the Vankidzor Formation overlies various horizons of all underlying formations with a distinct angular and azimuthal unconformity. The nappe structure of the lower structural stage of the Tsakhkunyts Massif indicates that the Arzakan "Group" is a metamorphic complex consisting of the autochthonous Bzhni Formation and allochthonous nappes of the Surpsarkis and Vankidzor formations (Fig. 3).

The upper (Late Proterozoic) structural stage with a submeridional style of deformations is developed in the Arzakan (ensialic Dallar Group) and Aparan–Ankavan (mainly, ensimatic Ankavan Group) structural zones of the massif [8].

The Dallar Group includes the Bertitak, Gguk, Dallar, and Agveran formations [8, 11, 12]. The lowermost (Bertitak) Formation (420 m) is made up of metaarkosic phyllites with marble intercalations. It sharply differs in metamorphic grade from the underlying crystalline schists of the Arzakan metamorphic complex. In particular, the rocks of the Vankidzor Formation are metamorphosed under biotite–muscovite gneiss and staurolite facies, while the Bertitak phyllites immediately resting on them were affected by only biotite subfacies of the greenschist facies. Mineral assemblages of the Bertitak Formation are as follows: Chl_{47}+(Ms 0, Phn 76, Par 24)+Pl^{17} + C + Tu + Qtz ± Grt ± Bt, Ab + Ms + Bt + Chl + Qtz + C ± Tu. The overlying Gguk Formation (590 m) comprises metabasalts of albite–chlorite–epidote–actinolite composition. The typical mineral assemblages of the formation are Act_{31} + $Chl_{33–43}$ +

Table 1. Composition of minerals (wt %) from metamorphic rocks of the Tsakhkunyats Massif

Sample no.	Minerals	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cr_2O_3
Arzakan Complex											
Bzhni Formation											
28-04	Grt m	36.80	0.04	20.77	33.14	1.72	2.01	5.52	–	0.01	n.a.
	c	36.75	0.07	20.79	28.44	5.94	1.08	6.93	–	–	n.a.
	m	36.66	0.06	20.70	26.82	7.41	1.29	6.70	0.25	0.03	n.a.
	Ms (3)	48.64	0.01	31.23	5.25	0.06	3.96	0.02	0.19	10.63	n.a.
	Bt (5)	36.21	1.45	21.02	22.01	0.18	10.67	0.01	0.06	8.39	n.a.
Surpsarkis nappe											
20-02T	Ms (2)	49.99	0.42	34.92	1.50	0.05	1.50	0.04	0.60	10.95	–
	Chl (2)	32.31	0.55	27.09	9.68	0.24	30.33	0.02	0.14	0.02	0.55
23-04	Ms (5)	50.12	0.38	35.87	1.12	0.01	1.43	0.03	0.64	10.39	0.01
	Chl (3)	32.59	0.02	27.22	8.49	0.19	31.20	0.02	0.19	0.01	0.03
Vankidzor nappe											
24-02T	Grt m	36.98	0.10	20.49	28.65	5.43	1.24	7.73	0.39	–	n.a.
	c	36.37	0.13	20.96	26.48	8.54	1.15	6.14	0.17	0.08	n.a.
	m	36.58	–	21.21	33.37	1.91	2.16	4.69	–	0.08	n.a.
	Chl	28.02	0.15	26.05	28.39	0.27	16.70	–	0.31	0.11	n.a.
Dallar Complex											
Bertitak nappe											
11-04	Ms	50.01	0.48	34.89	2.03	0.01	1.46	0.05	0.96	10.11	n.a.
	Chl	28.66	0.05	25.47	27.84	0.36	17.40	0.11	0.12	–	n.a.
	Pl	64.80	–	22.08	0.12	–	0.03	3.42	9.44	0.11	n.a.
Gguk nappe											
32-04	Act	54.68	0.21	2.98	12.80	0.35	16.20	12.21	0.38	0.09	0.08
	Hbl (2)	49.97	1.03	6.68	15.06	0.32	13.93	12.17	1.09	0.10	0.10
	Chl (2)	31.39	0.15	22.40	23.59	0.08	22.03	–	0.09	0.01	0.22
	Pl	60.81	0.06	24.62	0.44	–	–	6.07	7.79	0.04	0.15
117a	Act	57.2	0.05	1.41	9.31	0.16	17.65	12.41	0.14	0.06	0.10
Dallar nappe											
34-04	Ms (5)	48.02	0.55	32.46	6.61	0.13	0.87	0.04	0.47	1.77	0.05
	Chl (4)	27.82	0.28	21.37	43.37	0.54	5.58	0.19	0.36	0.11	0.16
	Pl (2)	65.90	0.02	20.73	0.59	0.005	–	2.42	10.08	0.09	0.06
Agveran Formation											
45-04	Bt (2)	37.02	1.92	20.54	19.43	0.02	11.46	0.04	0.15	9.40	n.a.
	Chl	28.88	0.17	25.89	26.03	0.25	18.79	–	–	–	n.a.
	Pl (2)	68.98	0.08	19.33	0.17	0.02	0.01	1.82	9.54	0.05	n.a.
Ankavan Metamorphic Complex											
48-04	Act	57.95	0.06	0.50	9.22	0.28	18.85	13.14	–	–	n.a.
	Hbl	45.02	0.07	14.71	13.84	0.28	11.62	12.09	1.52	0.27	n.a.
	Chl	30.90	0.09	25.33	18.50	0.20	24.92	0.03	–	0.04	n.a.
	Ab	68.51	–	19.77	0.12	0.01	0.03	0.25	11.24	0.08	n.a.
56-04	Grt (6)	36.73	0.13	20.39	21.18	17.58	1.36	2.28	0.27	0.02	0.03
	Bt (2)	37.51	1.60	17.65	22.96	0.59	9.98	0.23	0.64	8.65	0.15
	Chl (2)	30.58	0.16	22.95	28.42	0.84	16.38	0.15	0.16	0.09	0.19
	Ms (2)	50.15	0.72	34.97	4.09	0.12	1.77	–	0.20	10.33	0.02
	Ab	68.66	0.03	19.44	0.02	–	0.01	0.03	11.58	0.10	0.06
Kasakh Ophiolite Complex											
33-02T	Act-Hbl (2)	53.28	0.24	5.73	11.6	0.28	17.34	10.01	1.29	0.13	0.05
	Hbl (3)	46.68	0.58	11.82	13.51	0.26	13.24	10.98	2.49	0.25	0.14
	Pl (2)	66.13	0.03	21.19	0.13	0.03	0.04	2.08	10.2	0.10	0.05

Note: Numbers in parentheses denote the number of analyses. (m) margin, (c) core.

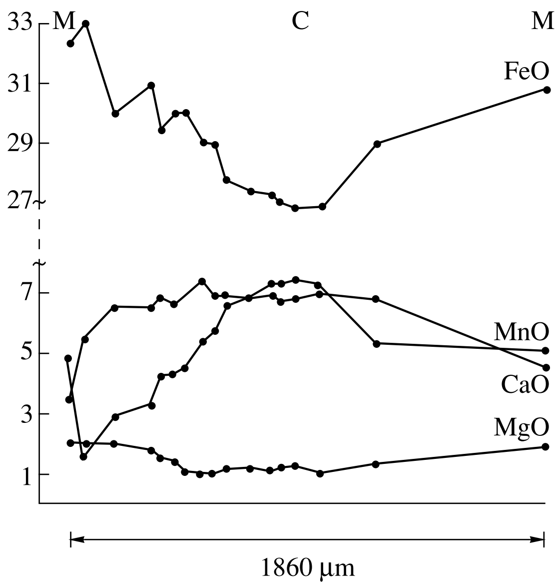

Fig. 2. Microprobe profile of the garnet from the Bzhni Formation. (C) Core, (M) margin.

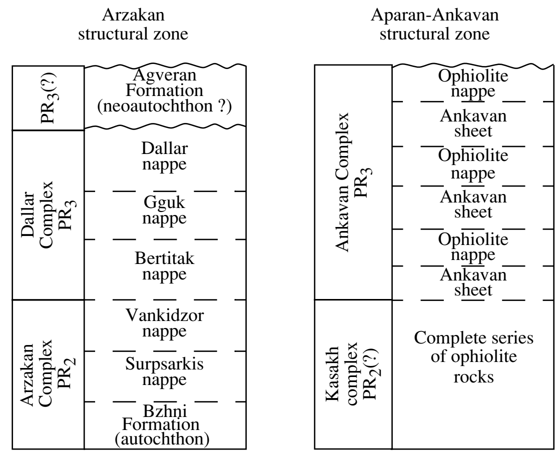

Fig. 3. Interrelations between metamorphic complexes of the Tsakhkunyats Massif (modified after Agamalyan [8]).

Ab+[Act-Hbl$^{6-7}_{35-39}$, Pl^{30}], Ab + Chl + Bt + Qtz ± Ep+[Pl], Ep + Ca + Ab ± Act + [Hbl, Pl] (Table 1). These assemblages correspond to the biotite subfacies.[4] According to our data and [8–10], these rocks have low-K MORB petrogeochemistry.

The Gguk metaophiolite formation is an alien body with respect to the terrigenous and metarhyolite rocks of the Dallar Group. Therefore, we believe that this formation represents a nappe (Fig. 3). The Dallar Formation (310 m) sharply differs from underlying rocks and consists of porphyroid metarhyolites of albite–K-feldspar–chlorite–sericite composition, occasionally with chloritoid porphyroblasts. The mineral assemblages of the formation, Chl$_{50-55}$ + Ab + Kfs + Ms + Qtz ± Bt+[Pl] and Chl$_{79-82}$ + Pl$^{10-15}$ +(Ms 0–55, Phn 36–99, Par 12)+Qtz and Ab + Chl+[Pl], corresponds to the low-grade greenschist facies. The Dallar Group section is crowned by the Agveran Formation (550 m), which consists of thick marble beds intercalated with horizons of metagraywacke epidote–albite–chlorite and quartz–chlorite schists. Their mineral assemblage is Ab^2 + Chl$_{44}$ + Qtz + C ± Ser+[Bt$_{48-50}$, Pl^{16}]. The rocks contain detrital (Bt$_{48-50}$, Pl^{16}, Qtz) and authigenic (Ab^2, Chl$_{44}$, Carb, Ep, ±Ser) minerals. The mineral composition and clastic texture of the rock indicates that the Agveran Formation was formed under anchimetamorphic conditions (more exactly, in the high-temperature part of the epizone).

Thus, the upper stage of the Arzakan structural zone consists of the Bertitak, Gguk, and Dallar nappes and the Agveran Formation, which make up the Dallar metamorphic complex.

The lower part of the Aparan–Ankavan structural zone includes the Kasakh metamorphic complex, while the upper part is composed of the Ankavan Complex [6, 7]. These metamorphic rocks were previously combined into the Ankavan Group consisting of the lower Kasakh and upper Ankavan formations [8]. Agamalyan [8] believed that during the Upper Proterozoic collision, rocks of the Ankavan ensimatic island arc were obducted on the ensialic Arzakan Group with disturbed stratification, which is well expressed in its lower part.

The Kasakh metaophiolite complex (1870 m) is represented by mainly metabasaltic and metagabbro amphibolites, with significant contribution of basaltic komatiites and thin interbeds of metaphthanite garnet–graphite quartzites and serpentinite lenses [8]. The mineral assemblages of the complex correspond to staurolite facies of prograde regional metamorphism ((Hbl$_{bl\text{-}gr}$ + Pl^{16} + Ep, Hbl$_{bl}$ + Pl^{12} + Rut + Sf+[Hbl, Pl])) and greenschist diaphthoresis (Chl + Act + Ab+[Hbl, Pl], Act + Chl + Ab + Rut, Act-Hbl$_{30-35}$ + Ab(Pl^1)+[Pl^{20}, Hbl$_{35-45}$]). The Kasakh Complex can be correlated with the Arzakan Complex based on the similar grade of prograde regional metamorphism (Fig. 3).

In addition to serpentinites, metabasaltic amphibolites, and ferruginous quartzites, he Ankavan Complex (1630 m) contains marbleized interbeds and sequences of albite–chlorite and actinolite–quartz–micaceous schists. The complex also contains amphibolites with staurolite-facies mineral assemblages (Hbl$_{bl\text{-}gr}$ + Pl^{12} + Ep ± Bt, Hbl$_{bl\text{-}gr}$ + Ab + Carb ± Ep+[Hbl, Pl]), and metapelite and amphibole–chlorite schists with mineral assemblages of the low-temperature chlorite–sericite and biotite subfacies of greenschist facies: Grt$_{89-91}$ + Bt$_{55-58}$ + Chl$_{47-52}$+(Ms 0–18, Phn 79–96, Par 3–4)+C + Pl^0 + Qtz, Chl + Ab + Act + Ep ± Carb, Act$^{0.5}_{21}$ + Chl$_{29}$ + Pl^1 + Ep+[Hbl$_{40}$, Pl], Ser + Chl + Ab + Qtz + C. The gar-

[4] Hereinafter, disequilibrium minerals are shown in brackets.

Table 2. Composition of minerals (wt %) from metamorphic rocks of the Akhum and Asrikchai (3226) exposures of the massif

Sample no.	Mineral	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
2751	Chld	26.24	0.01	42.89	27.34	0.77	2.69	0.06	0.00	0.00
	Ms (4)	50.60	0.33	33.84	3.22	–	1.48	0.30	0.70	9.79
	Chl	27.30	0.03	25.54	33.68	0.54	12.58	0.07	0.18	0.09
3226	Ms	51.71	0.37	32.57	2.59	0.00	1.81	0.00	0.28	10.67
	Chl	27.53	0.02	24.84	33.15	0.59	13.51	0.08	0.29	0.00
2795	Act (6)	56.48	0.06	2.33	9.47	0.24	18.42	12.05	0.71	0.13
	Ab	68.63	0.10	19.24	0.14	–	–	0.07	11.73	0.09
	Kfs (2)	65.43	0.18	18.28	0.11	–	0.10	0.08	0.54	15.23

net assemblage was ascribed to the biotite subfacies because small (<0.1 mm) homogenous garnet grains have low-magnesian composition (X_{mg} = 9–11%) with high content of spessartite end member (43%). Since the serpentinite–amphibolite assemblage of the complex is similar to that of the Kasakh metaophiolite complex in terms of composition and metamorphic grade, we believe that the staurolite-facies amphibolite, greenschist quartz–chlorite–sericite schists (Ankavan nappe), and associated serpentinites are nappes (thrust sheets) (Fig. 3).

The Akhum–Asrikchai Massif is represented by the Akhum (3 km^2) and Asrikchai (1.5–2.2 km^2) exposures. They are similar in composition and consist of [8] Lower Paleozoic microgneisses (350 m), chloritoid–muscovite–quartz (250 m) and graphite-bearing quartz–muscovite (150 m) schists, and probably Precambrian metaophiolites represented by albite–epidote–actinolite schists with metapyroxenite lenses (120 m). The metapelites consist of the following mineral assemblages (Table 2): $Chld_{85}$ + Chl_{60}+(Ms 0–4, Phn 42–97, Par 3–17)+Ab + Qtz, (Ms 29, Phn 67, Par 4)+Chl_{35} + Ab + Qtz, Qtz + Ms + Andl, Qtz + Ms + Bt ± Grt, Qtz + Ms + Chl, Qtz + Ms + Chl + Chld. The metaophiolites contain $Act_{20–29}$ + Chl + Ab(Pl^0) ± Ep, Act + Ep + Ab + Sf, Ab + Chl ± Qtz, Tr + Serp + Tlk + Carb (Table 2). The prograde regional metamorphism corresponds to the garnet facies in the metapelites and to the low-pressure pre-biotite greenschist facies in the metaophiolites.

The composition and mineral assemblages of microgneisses, muscovite–quartz, and graphite-bearing quartz–muscovite schists, as well as metaophiolites of the Akhum and Asrikchai exposures closely approximate those of the allochthonous complex of the Loksk Massif [14]. Based on the above data and by analogy with the Loksk Massif, we infer the allochthonous sheeted (nappe) nature of metamorphic complexes of the Akhum–Asrikchai Massif.

ACKNOWLEDGMENTS

This work was supported by INTAS (project No. 01-242).

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