Granitic pluton of Gorkhi with crystal-bearing miarolic pegmatite

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Geological setting

The pluton is situated on the eastern bank of the Tuul river. Structurally it is related to the Khentei variscian synclinorium, filled by siliceous-terrigenous the Khentei series of the Devonian-Carboniferous age (Fig.1). The host rocks are represented by up to 4000 m thick Devonian Gorkhi suite, belonging to the lower part of the Khentei series. This series is composed of four concordant strata. The lower is 1000 m thick and is composed of fine and medium-grained graywakes which are in the upper part represented by silica siltstones and aleurosandstones. The second strata, 700 m thick, is composed of sandstones, siltstones, aleuropelites, and minor-jaspers. The third strata, composed of sandstones, tuff stones, is 1500-1600 m thick and have a lot of horizons of jaspers and jasper-quartzites. The last fourth strata is 400 m thick dark-grey silica tuff stones, tuffites and siltstones.

Devonian rocks form a large (about 30 km x 10 km) complicated linear Gorkhi syncline, and Gorkhi pluton is located within the I most plunged central part. Synclinal slopes are varied; the western slope is narrow, formed by monoclyne with 50-70 angles of dip become complicated: it is adjoins the western contact of Gorkhi pluton, with longitudinal conformable fault. The eastern slope is broader and has a complicated structure. With systems of narrow linear synclines and anticlines approximately by 0.5 km amount of slopes with 60°-70° angles of dip. Strike of fault axes follows contact line and changes from sublatitudinal line to longitudinal. Along the line, it coincides with the northern contact of pluton, the undulation of fold bend will appear to the north of it the fold bends are plunged by 45°-70°, south plunge of fold bends is 10°-15°. The contact line is quite visible, weakly twisted, sometimes with apophyses into host rocks. Pluton contacts are irruptive with high dipping (75°-80°). The western contact coincides with the fault zone. The southern contact plunges under the host rocks at an angle of 70°-75°. The northern and southern contacts cut off the folded structure of host rocks. The folded deformations clothed the pluton along the western and eastern contacts.

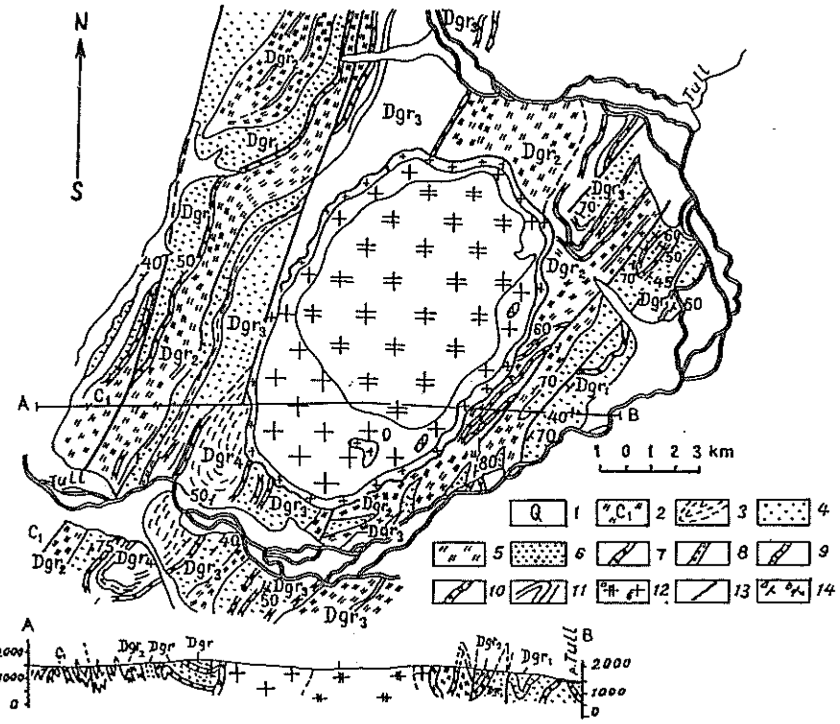

Fig. 1 Geological map in Gorkhi (by Philippova and Antipin)
1.Quaternary; 2-11.Khentiin Group, 2.Carboniferous flysh strata; 3.Gorkhin Formation-fourth; 4.Gorkhin Formation-third; 5.Gorkhin Formation-second; 6.Gorkhin Formation-first; 7. jasper (chert); 8.siltstone; 9.sandstone; 10. conglomerate; 11.rock strata interpreted; 12. Granitic pluton of Gorkhi, a. coarse-grained porphyritic facies ; σ .coarse-grained equigranular facies; b. granite porphyry; 13. fault; 14. strike and dip, a.normal; b.reverse.

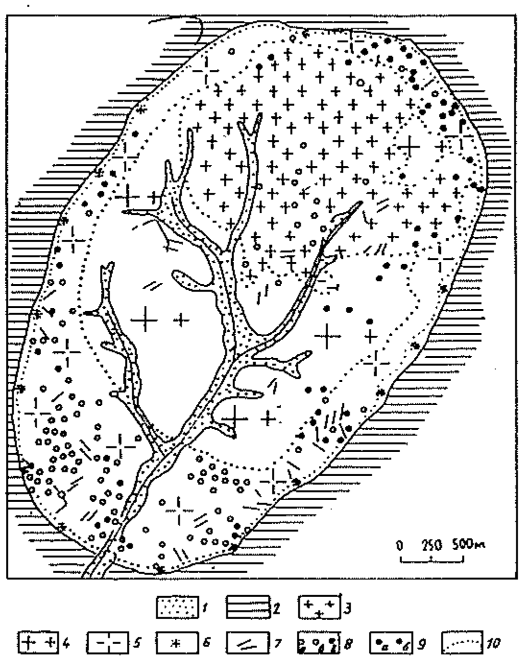

Fig. 2 Detailed geological map of the Gorkhi pluton
(by Kazakov, Sharak, Mikhailov and Mikhailov, 1993)
1. alluvium; 2. hornfels; 3-5. granites, 3. medium-grained porphyritic; 4. coarse-grained porphyritic; 5. coarse-grained equigranular; 6. granite porphyry; 7. aplitic dykes; 8. non-miarolic pegmatite, a. columnar shape; b. isometric; 8. other and non-distinguished; 9. miarolic pegmatite, a. columnar; b. isometric; 10. lithologic boundary.

The contact zone of hornfels of up to 1 km width was formed by exocontact metamorphism of host rocks. The Gorkhi pluton contour is oval in shape (9 km x 15 km) with its longer axis aligned with the folded host rock trend. The pluton has a zonal structure; the central core is composed of coarse-grained porphyritic biotite granite, minor hornblende-biotite granites. The phenocryst's dimensions change and the groundmass becomes a medium-grained in the northern part of the central core. The granites with clear porphyritic structure are rimmed by the either coarse-equigranular zone or weakly porphyritic biotite granites. The thickness of the zone increases from few meters to 30 m in the southern part of the pluton. The endocontact zone (chilled contact zone) is composed of granite-porphyries which are mineralogically similar to granites.

Granite-porphyries bodies occur at the points of highest elevation . The transition among various types of rocks is gradual, indicating the short time of granite formation. The most recent rocks are veined granites, aplites and various bodies of miarolic pegmatites (veins, pipe-like, lenses, etc.). Most of the miarolic pegmatites are distributed within the external zone of pluton, which consists of the coarse-equigranular granites (Fig 2). The veined granites, aplites and inclusions of granitized rocks with large porphyroblasts of alkali feldspar are concentrated in the core of pluton.

Petrography and mineralogy.

There are three petrographic types of granites: porphyritic coarse-grained biotite granites, equigranular medium-grained granites, and granite-porphyries. The porphyritic biotite granites are characterised by phenocrysts of feldspar (Or_{66-72} Ab_{28-34}), plagioclase (An_{24-26} to An_{36} in core of zonal crystals) and quartz. Feldspar forms large (up to 2cm x 5 cm) prismatic crystals with wide irregularly distributed perthites. Structurally, these belong to intermediate triclinic orthoclase (2V=66°-73°; Δp = 0.0-0.2). 2V varies from 66° in the core of crystals to 73° in the marginal part (Tab.1). Plagioclase with rhythmic and spot zonality (with resorption of more basic core) is distinguished. Phenocrysts of above mentioned minerals are cemented by coarse-medium grained groundmass, containing crystals of feldspars (Or_{73-81}, Ab_{19-27}, Plg-An_{14-18}), quartz, Fe-biotite and accessories; orthite, sphene, zircon, fluorite, magnetite, ilmenite, apatite, cyrtolite and scheelite.

Table 1

FELDSPARS FROM GORKHI GRANITIC PLUTON

N	Rocks	Number of samples	Fsp shape	Average content of Fsp	Rb	Ba	Sr	Pb	K/Rb	Δ p	2V°	Tempera - ture (°C)
1	Porphyritic biotite granites	32	Fsp phenocryst	$Ort_{69}Ab_{31}$	334	2240	256	46	286	0.0-0.2	68 - 73	580
		10	Fsp in matrix	$Ort_{77}Ab_{23}$	565	805	150	42	192	0.0-0.3	-	540
2	Granite-porphyries	10	Fsp phenocryst	$Ort_{64}Ab_{36}$	370	800	150	42	239	0.0	66 - 67	550
		4	Fsp in matrix	$Ort_{79}Ab_{21}$	520	400	100	45	213	0.0	80	520
3	Equigranular granites	25	large grains	$Ort_{68}Ab_{32}$	405	810	190	-	212	0.1-0.4	68 - 72	570
4	Veined granites	5	fine - xenomorphic grains	$Ort_{77}Ab_{23}$	725	130	48	53	140	0.0-0.7	-	530
			graphical	$Ort_{70}Ab_{30}$	550	45	24	11.6	167	0.5-0.8	-	550
5	Pegmatites	9	structure of large crystals	$Ort_{73}Ab_{27}$	1080	144	20	18.1	83	0.5-0.8	80	535
6	Xenolytes within granites	9	porphyroblast	$Ort_{73}Ab_{27}$	465	1125	258	37	204	0.0-0.2	-	565

Table 1a

FELDSPARS FROM GRANITES OF JANCHIVLAN PLUTON

Rocks	Number of samples	Content of Fsp			Rare element content in feldspar (ppm)						K/Rb	Ba/Sr	ΔP
		K	Na	Ort+Ab	Rb	Li	Ba	Sr	Pb	Tl			
Alaskites	6	9.9	2.3	$Ort_{73}Ab_{27}$	1150	26	246	46	86	9.0	87	5.3	0.1-0.8
Amazonite-albite granites	8	11.4	1.6	$Ort_{82}Ab_{18}$	2425	14	32	18	156	11.3	47	1.7	0.4-0.9
Albite-lepidolite granites	4	11.8	1.1	$Ort_{87}Ab_{13}$	4855	91	24	27	40	23.1	24	0.9	0.4-0.8

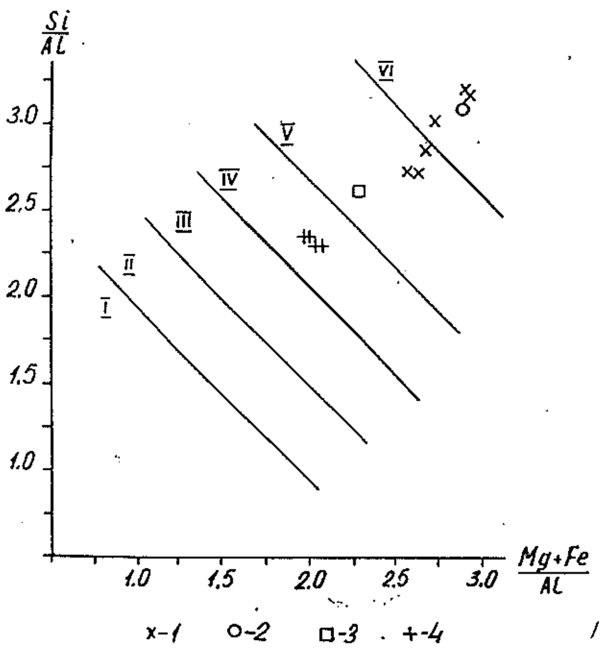

Fig. 3 Composition of biotites from granites of the Gorkhi pluton (by Antipin et al., 1976)

1. coarse-grained porphyritic granite; 2. medium-grained porphyritic granite; 3. granite porphyry; 4. equigranular granite, 5. pegmatite

Biotite forms comparatively large pleochroic from light-yellow to dark brown plates. Plagioclase has the most idiomorphic crystals. The texture of porphyritic granites is hypidiomorphic-granular. The coarse equigranular biotite and leucogranites are composed of intermediate triclinic orthoclase (2V = 68°-72°; Δp=0.0-0.4) Ort_{61-76} Ab_{24-39}, plagioclase An_{18-28} with normal zoning, quartz, siderofillite and accessory minerals orthite, apatite, ilmenite, magnetite, monazite and fluorite. Granites contain melanocratic lenses, which are composed of plagioclase An_{34-45} hornblende, biotite and feldspars. Idiomorphism of quartz compared to feldspar is very characteristic. In the endocontact zone of pluton granites are characterised by clear porphyritic texture. Phenocrysts are represented by orthoclase (2V=66-70°, Δp=0.0-0.1) Ort_{64} Ab_{36}, plagioclase An_{20-26} and quartz. The groundmass is medium-fine-grained microgranitic, minor micropoikilitic. The pegmatites are of quartz-microcline type with morione, rauchtopaz, optical fluorite, topaz and beryl. Mica is represented by biotite, muscovite, cinnwaldite, accessory and ore minerals: hematite, zircon, orthit, sphene, rutile, cassiterite, ilmenite, apatite, molybdenite, xenotym, samarscite, chalcopyrite, garnet and magnetite. Pegmatites with fine-grained granitic and graphic texture have high alkalinity (K_2O+Na_2O=8.4-10.6%) and silica (SiO_2=73.91%-77.14%) K-feldspar predominates compare to Na (Gerel,1977; Ivanov et al,1984).

Geochemistry

Geochemical data are shown in Tab.2 and 3. Granites of all types are characterised by high Li, Rb, Be, F and low Ba and Sr. Comparison between veined granites and coarse-grained equigranular granites, which are host rocks for pegmatites and veined granites, shows increasing content of Li, Rb, Cs, Be and F 2 or 3 time, and decreasing of Ba and Sr in veined granites. The coarse-grained porphyritic granites, equigranular medium and coarse- grained granites, and granite-porphyries have very similar contents of rare elements. Therefore these granites are originated during no deep differentiation. Host rocks have a low content of rare elements. Hornfels on the contact are similar to terrigenous host rocks. Xenolites, which are widespread within porphyric granites are characterised by high content of Li, Rb, Be and F. The zonal structure of the Gorkhi pluton is characterized by a regular distribution of feldspar content; the feldspar phenocrysts with more than 30% Ab are spread in the core part of pluton, feldspars with 25-30 % Ab in the transition zone (within the equigranular medium and coarse-grained granites), and feldspars of up to 35% Ab in the endocontact zone. There is correlation between the composition of feldspar and the number of phenocrysts. In the core part with its low number of phenocrysts the composition of the feldspar is more albitic. Assuming that isolines of feldspar content are isolines of paleotemperature of pluton formation one finds that high-temperature phenocrysts are wide-spread in the central core, whereas in the marginal part of pluton one finds comparatively low temperature phenocrysts. The high-temperature feldspars (with high Ab content) occur near the zones of tectonic faults. The triclinity of feldspars in the porphyritic granites varies from 0.0 to 0.2, in the equigranular granites $\Delta p=0.4$ and from 0.4-0.8 in the pegmatites. Porphyroblasts of feldspar from xenolites and phenocrysts in porphyritic granites have a similar triclinity ($\Delta p=0.0-0.2$). The concentration of Rb in feldspars increases during differentiation process, Ba and Sr content decrease, and Rb concentration increases in the feldspars of the groundmass of porphyritic granites and in feldspars of pegmatites.

Table 2

Chemical composition (mass %) of Gorkhi pluton granites

Components	Coarse-grained porphyritic granite	Equigranular-grained granite	Granite-porphyry	Veined granite-porphyry
SiO_2	70.62	74.18	75.44	72.70
TiO_2	0.41	0.24	0.15	0.25
Al_2O_3	14.28	12.9	12.10	13.94
Fe_2O_3	1.58	1.28	1.34	1.24
FeO	1.57	0.85	0.36	1.04
MnO	0.05	0.03	0.03	0.03
MgO	1.26	0.42	0.20	1.24
CaO	1.84	0.83	0.61	0.44
Na_2O	4.01	3.61	3.73	3.79
K_2O	4.17	4.76	4.92	4.28
P_2O_5	0.13	0.06		0.10
H_2O	0.59	0.41	0.42	0.50
Total	100.5	98.72	99.30	99.55
n	11	50	7	2

Table 3

CHEMICAL COMPOSITION OF BIOTITES FROM GORKHI PLUTON AND INCLUSIONS

Components	Porphyritic granite			Granite-porphyry	Equigranular-grained granite			Pegmatite	Inclusions			
	981	1042	1043	1044	1040	1041	1126	123	1041/4	1043/12	1043/13	1050/14
1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	34.95	34.81	35.38	35.22	34.36	35.29	35.80	34.26	36.36	36.69	36.79	36.39
TiO_2	3.74	3.81	3.66	3.30						3.39	3.23	3.66
Al_2O_3	13.88	12.95	14.17	14.84	13.46	14.51	12.50	14.19	12.68	12.56	11.70	11.79
Fe_2O_3	5.90	6.34	2.90	3.01	3.32	3.19	1.96	17.53	5.58	4.58	5.81	5.07
FeO	25.14	21.39	27.48	27.48	27.04	27.12	28.02	16.55	21.19	22.09	21.55	21.37
MnO	0.52	0.60	0.63	0.69	0.70	0.69	0.44	1.80	0.52	0.49	0.61	0.62
MgO	3.41	6.67	4.26	3.10	5.92	3.38	4.57	0.23	6.30	5.67	5.67	6.36
CaO	0.44	1.57	0.18	0.14	0.58	0.20	0.51	0.21	0.88	1.25	1.49	1.05
Na_2O	0.82	0.27	0.62	0.51	0.56	0.40	0.02	0.22	0.13	0.15	0.21	0.27
K_2O	8.07	8.46	8.31	8.91	8.52	8.43	8.33	7.92	8.31	8.40	8.87	8.55
Li_2O	0.17	0.12	0.021	0.026	0.23	0.026	0.15	0.14	0.21	0.22	0.19	0.28
Rb_2O	0.11	0.09	0.011	0.014	0.13	0.012	0.11	0.48	0.13	0.14	0.14	0.16
Cs_2O	0.006	0.009	0.001	0.008	0.008	0.001	0.004	0.036	0.001	0.004	0.006	0.011
P_2O_5	0.35	0.51	0.26	0.24	0.22	0.42	0.48	0.24	0.36	0.31	0.34	0.35
H_2O	1.67	1.60	1.42	1.27	1.80	1.23	1.81	2.12	3.42	2.55	3.00	2.66
F	1.42	0.64	1.50	1.28	0.50	1.50	1.00	2.12	1.62	1.80	1.64	1.78
Total	101.19	99.74	100.8	100.03	100.52	100.4	100.07	100.42	101.17	100.13	100.45	100.37
F - O	0.60	0.26	0.63	0.54	0.21	0.63	0.42	0.89	0.68	0.76	0.69	0.75
Total	99.59	99.48	100.1	99.49	100.31	99.82	99.65	99.53	100.49	99.54	99.76	99.62
Si	2.74	2.71	2.63	2.78	2.70	2.76	2.83	2.72	2.83	2.87	2.89	2.85
Al IY	1.26	1.19	1..24	1.22	1.25	1.24	1.16	1.28	1.17	1.13	1.09	1.09
Ti	-	0.10	0.13	-	0.05	-	0.01	-	-	-	0.02	0.06
Z	4.00	4.000	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Ti	0.22	0.12	0.08	0.20	0.12	0.24	0.25	0.14	0.21	0.20	0.17	0.16
Al YI	.0.03	-	-	0.15	-	0.10	-	0.05	-	0.03	-	-
Fe 3+	0.35	0.37	0.16	0.18	0.20	0.19	0.12	1.05	0 33	0.27	0.34	0.30
Fe 2+	1.65	1.39	1.71	1.81	1.77	1 78	1.85	1.10	1.38	1.44	1.42	1.40
Mn	0.04	0.04	0.04	0.05	0.04	0.05	0.03	0.12	0.03	0.03	0.04	0.04
Mg	0.35	0.77	0.47	0.36	0.69	0.40	0.54	0.03	0.73	0.66	0.66	0.74
Li	0.05	0.04	0.01	0.04	0.07	0.01	0.05	0.04	0.06	0.07	0.03	0.08
Y	2.69	2.73	2.47	2.79	2.79	2.77	2.84	2.53	2.74	2.70	2.65	2.72
K	0.81	0.84	0.79	0.90	0.85	0.82	0.84	0.80	0.82	0.84	0.81	0.85
Na	0.12	0.04	0.09	0.08	0.08	0.06	-	0.03	0.02	0.02	0.03	0.04
Ca	0.04	0.13	0.01	0.01	0.05	0.02	0.04	0.02	0.08	0.10	0.13	0.09
Rb	0.005	-	-	-	0.005	-	0.005	0.02	0.005	0.005	0.005	0.01
X	0.975	1.01	0.89	0.99	0.985	0.90	0.885	0.87	0.925	0.965	0.975	0.99
OH	1.65	1.84	1.65	1.68	1.88	1.63	1.75	0.94	1.60	1.55	1.59	1 56
F	0.35	0.16	0.35	0.32	0.12	0.37	0.25	1.06	0.40	0.45	0.41	0.44
Fe/Fe+Mg	81.9	67.2	79.05	83.8	72.9	82.6	79.6	98.2	80.9	82.5	82.8	80.6
Al 100/Al+Mg+Fe+Si	16.7	15.8	16.8	17.7	16.0	17.5	15.1	17.1	15.4	15.4	14.4	14.6
Ng'	1.682	1.655	1.684	1.679	1.684	1.682	1.679	1.687	1.655	1.652	1.654	1.650
Sn	56.5	62	34	91	45	40			26	35	42	22
Pb	54	31	16.5	,18.3	22.5	31			11.2	15	11.2	10.5
Zn	500	700	580	565	370	420		n.d	400	490	363	485
Be	12.5	6.9	6.2	11.5	6.0	6.9			3.2	2.9	8.3	2.0
B	25.5	25.0	12.0	10.0	15.5	18.0			-	-	-	-

Table 4

CHEMICAL COMPOSITION OF GRANITES FROM GORKHI PLUTON AND HOST ROCKS

N	Rocks	Number of samples	K	Na	Rb	Li	Cs	Be	F	B	Ba	Sr	Sn	Pb	Zn	WO_3	Mo	K / Rb
1	Porphyritic biotite granites	60	4.0	2.6	231	77	9	7.2	0.15	18.7	200	40	3.8	13.1	31,3	2.6	1.1	173
2	Granite porphyry	21	4.1	2.9	259	68	7	7.1	0.17	18.8	150	30	2.0	13.5	14,7	2.3	1.0	158
3	Equigranular-grained biotite granites and leucogranites	50	4.1	2.7	227	66	5	7.2	0.16	19.0	60	15	1.9	10.5	20,7	1.8	3.7	181
4	Veined granite	9	3.9	-2.6	482	130	32	16	0.23	52	45	10	3.7	18.2	57	3.4	0.5	81
5	Host sandstones and siltstones	9	2.8	3.2	92	34	-4	2.0	0.054	49	100	60	2.2	13.8	83	1.0	1.0	304
6	Hornfels	8	3.1	2.6	82	40	4	2.6	0.050	126	70	20	2.2	13.8	63	1.2	2.0	378
7	Inclusions within granites	11	3.8	2.5	230	74	6	6.4	0.20	16	55	18	4.0	13.0	41	1.3	1.1	165

The distributions of the feldspar phenocrysts and of the Rb content of the feldspar coincide. During the crystallisation and differentiation Rb concentration varies in connection (related) to mineral content of granites. By similar level of Rb content in various types of granites, its content in feldspars from equigranular grained granites decreases at the expense of amount of feldspar in the rock some part of Pb with Li, Cs and Be is concentrated in the fluid, coexisted with melt. Feldspars from pegmatite enriched by Rb, comparing to the feldspars of granites. The highest concentration of Ba and Sr are appeared in the phenocrysts from granites of core part of pluton, and a lower concentration of Ba and Sr in the feldspars from veined rocks, and pegmatites. The biotites from granites of the Gorkhi pluton are related to istonite-siderophylite series (Fe-series). They are characterised by higher Al, and higher alkalinity, characteristic for subalkaline rocks. Rare elements content in biotite is similar in all types of granites (Tab 4, Fig 3). The Rb, Li, Cs and F content increase in the equigranular-grained granites.

REE variation in granites of the Gorkhi pluton is insignificant. The total content is varies from 265.9 ppm (in the porphyritic granites) in the core of pluton to 320.1 ppm (in the equigranular-grained granites of marginal part). The increasing of REE content is visible for light REE (LREE) while other elements (HREE) have very similar concentration in all types of granites (Fig.4). The La/Yb ratio increases from 10 in the porphyritic granites to 1.6 in the equigranular-grained granites during the evolution. This variation of REE distribution can be probably explained by concentration of REE mainly in monazite from equigranular-grained granites. The presence of monazite is not characteristic in porphyritic granites. This type of granites is represented mainly by sphene-orthite-apatite assemblage of accessory minerals. All types of granites of the Gorkhi pluton have a distinct and similar Eu-minimum (Fig. 4. This is evidence of the fact that these granites originate from differentiated granitic magma as within the magmatic chamber differentiation processes was not substantial.

By broad variation of total content of REE in Mesozoic cale-alkaline granites of Mongolia (from 21 to 377 ppm) many researchers show various types of normalized REE plots (Kovalenko et al, 1983).

For palingenetic (anatectic) calc-alkaline granites (Baga Khentei batholite, Kherlen pluton) are characteristic asymmetric with visible enrichment of LREE plots, and poorly marked or without Eu-minimum.

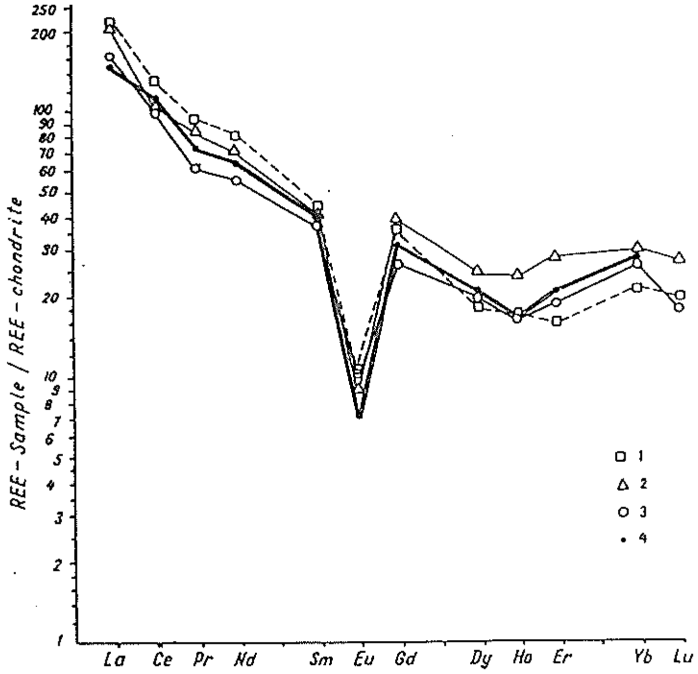

Fig. 4 Chondrite normalized REE abundance pattern in the Gorkhi pluton
1. coarse-grained through pegmatoid biotite granites; 2. granite porphyry; 3. coarse-grained and medium-grained porphyritic biotite granites; 4. inclusions of the country rocks.

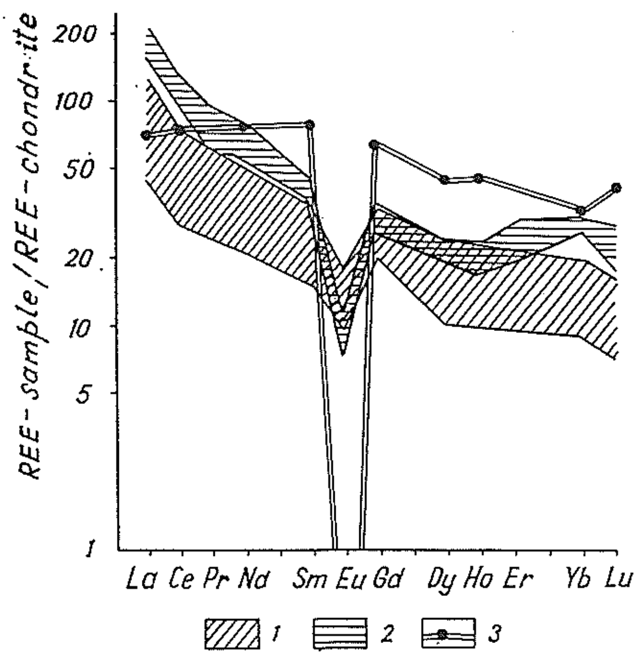

Fig. 5 Chondrite normalized REE abundance pattern in the calc-alkaline granites of north-east Mongolia
1. granodiorite-granite batholith (Baga Khentei and Kherlen plutons); 2. hypabyssal granite intrusions (Gorkhi and Khoshut Uul plutons); 3. amazonite-albite granites (Khentei pluton).

More enriched of LREE and sufficiently marked Eu-minimum plots are characteristic for hypabyssal intrusions of the Gorkhi type. Evolution of this type is finished by the forming of miarolic and seldomly rare metal pegmatites. In Li-F granites (Khentei pluton) with deep Eu-minimum the distribution of REE is relatively symmetric (Fig 5).

REE plots variations in calc-alkaline granites, their genetic features are probably stipulated by processes of granitic magma melting of continental crust substrate, and with processes of magmatic differentiation.

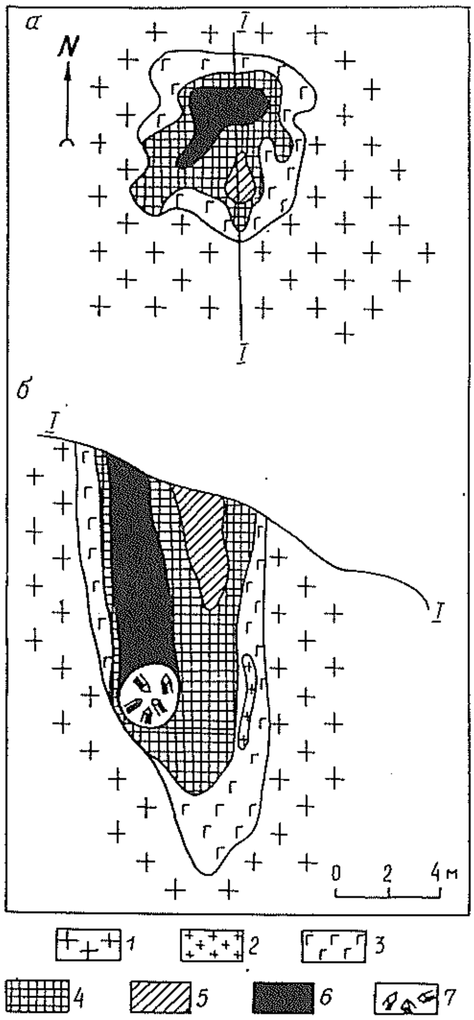

Fig. 6 The medium dimention pegmatite body (by N.N. Senkevich)
1. coarse-grained leucogranite; 2-6. pegmatite zones, 2. aplitic quartz-plagioclase-microcline; 3. graphic quartz-plagioclase-microcline; 4. blocked microcline; 5. quartz ; 6.miarole with crystals of morion and crystal; 7. colunmnar quartz.