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COMENDITES, PANTELLERITES, ALKALI GRANITES OF MONGOLIA

(Figs. 14, Tabs. 5)

Abstract: In Mongolia, agpaitic acid magmatic rocks occur within Late Paleozoic rift zones. They are developed in volcano-plutonic associations comprising basalts, trachytes, comendites, pnatellerites and alkali granitoids of similar age. Various geological relations indicate genetic links of alkali rhyolites and granites with basaltoids. Analysis of major and trace element behaviour as a function of the degree of differentiation (f) of initial basaltic melt is indicative of the leading role of crystallization differentiation in the evolution of riftogenic magmatic series. It may be supposed that of some importance in the formation alkaline acid melts were processes of partial melting of metasomatically altered mantle.

Резюме: Агпаитовые кислые магматические породы на территории Монголии распространены в пределах позднепалеозойских рифтовых зон. Они проявлены в вулкано-плутонических ассоциациях, объединяющих близкие по возрасту базальты, трахиты, комендиты, пантеллериты и щелочные гранитоиды. Разнообразные геологические соотношения указывают на генетические связи щелочных риолитов и гранитов с базальтоидами. Анализ поведения главных и редких элементов в зависимости от функции дифференциации (f) исходного базальтового расплава указывает на ведущую роль кристаллизационной дифференциации в эволюции рифтогенной магматической серии. Допускается, что определенную роль в образовании щелочно-кислых расплавов сыграли процессы частичного плавления метасоматически измененной мантии.

Comendites, pantellerites, alkaline granites belong to agpaitic acid magmatic rocks or to acid magmatic rocks of the alkaline series (Magmatic rocks . . ., 1983). They are rather rare rocks. But recently, such have been identified in many localities at the territory of Mongolian People's Republic (Yarmolyuk, 1983; Vladykin et al., 1981; Goreglyad et al., 1980). Overwhelming majority of them were formed during Late Paleozoic including the time interval from C_3 to P_2 (Fig. 1), although alkaline granites are also known among Mesozoic magmatic rocks. The following description touches upon only Late Paleozoic rocks.

Classification of the rocks under consideration has been adopted in accordance with views of Soviet scientists (Magmatic rocks . . ., 1983): pantellerites and alkali granites are acid agpaitic magmatic rocks with SiO_2 content less than 73 %, comendites and alkali leucogranites are rocks with higher silica content (Fig. 2).

This paper considers not only a new huge region of development of agpaitic acid magmatic rocks and their petrochemical characteristics, but also the "longest" in an evolutionary sense series of magmatic rocks with participation

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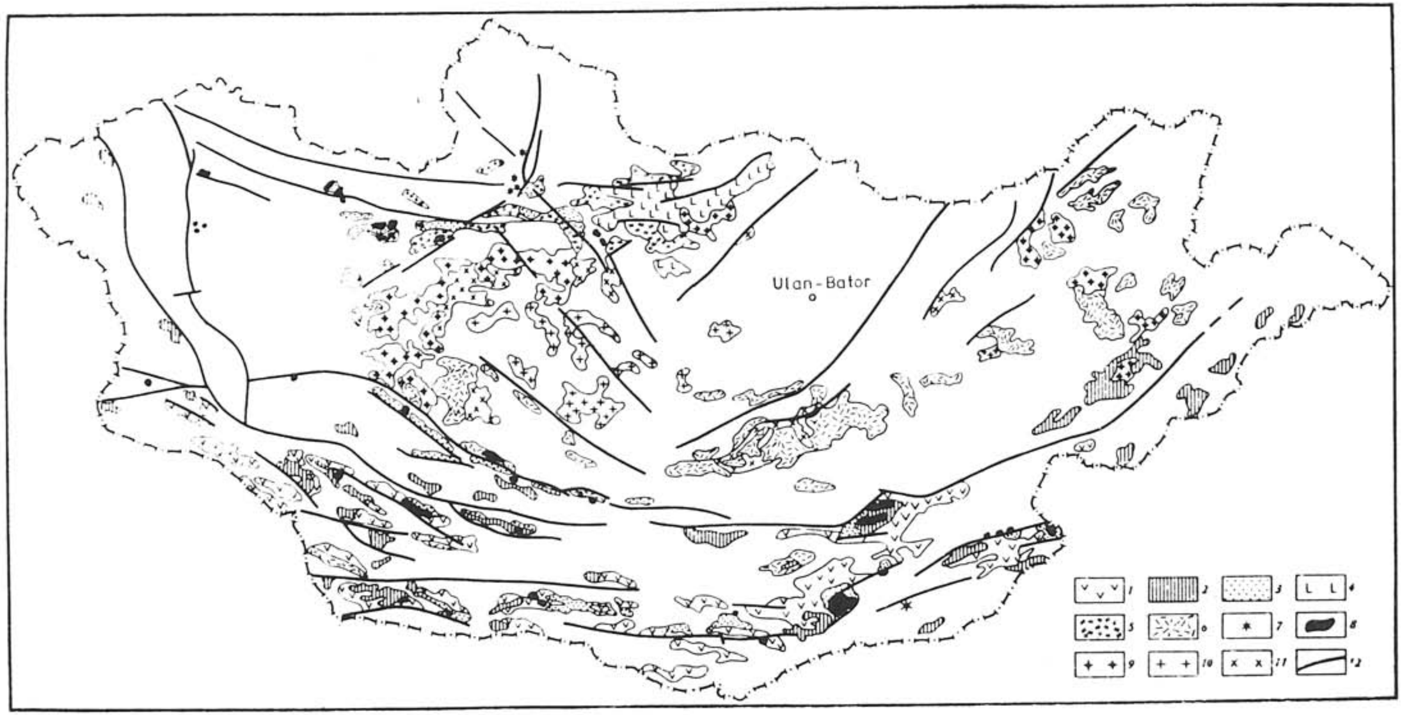


Fig. 1. A scheme of distribution of Late Paleozoic magmatic formations in Mongolia.
Explanations: 1—2 — Carboniferous formations of calc-alkaline series: 1 — volcanics; 2 — granitoids: 3—6 — Permian volcanic associations: 3 — bimodal (trachybasalts-trachydolerite-comendite); 4 — trachybasaltic; 5 — calc-alkaline of increased alkalinity of subalkaline (trachyandesitobasalt-trachyandesite-trachydacite-trachyrhyolite); 6 — calc-alkaline of normal alkalinity (andesitobasalt-andesite-rhyolitic); 7—11 — Permian intrusive formations: 7 — syenitic with feldspations; 8 — alkali granitic; 9 — granite-leucogranitic; 10 — granodiorite-granitic, granitic; 11 — gabbro-diorite-granodioritic, diorite-granodioritic; 12 — major faults.

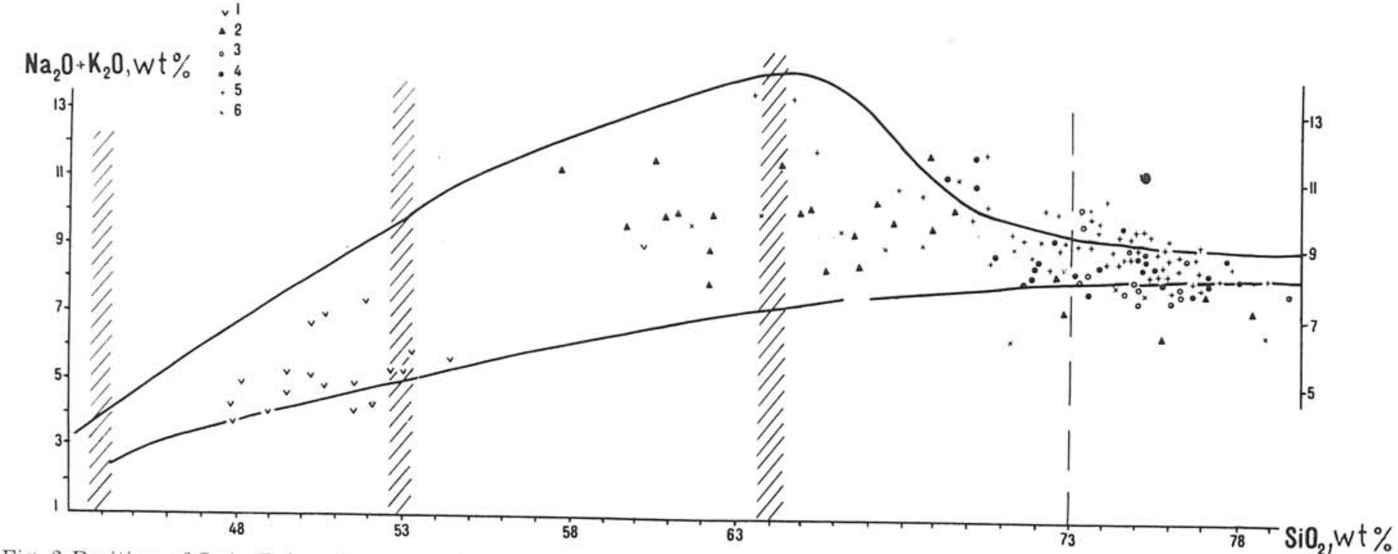


Fig. 2 Position of Late Paleozoic magmatic rocks compositions of Southern Mongolian bimodal series in the classification diagram SiO_2 — ($Na_2O + K_2O$).

Explanations: 1 — basic rocks (basalts, andesitobasalts); 2 — intermediate and acid rocks (trachytes, trachyandesites, trachydacites): 3 — comendites; 4 — pantellerites: 5 — alkali leucogranites of early phases; 6 — alkali granites of late phases.

of agpaitic volcano-plutonic complexes: from basalts to comendites and pantellerites, then alkali leucogranites and, finally, to alkali rare-metal granites. This sufficiently amplifies, from the point of view of general petrology and geochemistry, potentialities of analysis of evolution of magmatic systems with participation of agpaitic acid melts as compared to those described in literature (Barbert et al., 1975; Villari, 1975; Peralkaline ..., 1975).

Geological position of agpaitic acid magmatic rocks

Agpaitic acid magmatic rocks in the territory of Mongolia form single volcano-plutonic association in which basalts, trachytes, comendites, pantellerites subalkaline rhyolites, alkali granitoids are closely associated spacially and temporally (Yarmolyuk et al., 1981). Also, it has been found that such volcano-plutonic associations are confined to extensive elongated sublatitudinal belts controlled by fault zones (Gobi-Tien-Shan, North Mongolian, Major Mongolian) (Fig. 1).

These belts may also be identified in Late Paleozoic by occurrences of continental and shallow marine terrigenic deposits of molassa type, interlayered with thick volcanogenic sequences intruded by bodies of plutonic rocks.

Starting from the Carboniferous — Permian boundary when first agpaitic acid rocks appear, the structures under consideration have undergone at least episodically considerable horizontal tear faulting (tens of km) evidenced by the formation of thick dike belts (Fig. 3). Along with the alkaline character of magmatism this indicates a riftogenic nature of the belts of agpaitic acid magmatic rocks.

As a whole, spacial distribution pattern of agpaitic rocks in Mongolia is symmetrical (Fig. 1): they are broadly developed in the north and south, whereas in the centre of the country magmatic rocks of the calc-alkaline series occur (Kovalenko et al., 1981).

However, such a symmetry originated in the end of Late Paleozoic, and dynamics of the evolution of Late Paleozoic volcanism in Mongolia is rather complicated (Kovalenko et al., 1983; Yarmolyuk, 1983).

Formation of Late Paleozoic magmatic area apparently began with a gradual closing (Late Devonian—Early Carboniferous) of Late Paleozoic ocean basin of Paleothetys, with Eurasian (South Mongolian) marginal volcanic belt superimposed on Hercinides of Southern Mongolia being formed along its northern boundary. In Late Permian this process caused an approach of Northern Eurasia and Catasia continents and resulted in an exchange of plant species between them (Meyen, 1969; Mossakovsky, 1975) which did not take place in Carboniferous.

The zone of plate interaction was characterized by intensive compression under conditions of which calc-alkaline volcanites C_{1-2} of the South Mongolian volcanic belt were generated. The increase in their potassium content indicates that the Zavaritzky—Benyoff zone dipped northwards under the Eurasian continent.

In the first half of the Early Permian calc-alkaline volcanites of the South-Mongolian belt are changed without a substantial structural discontinuity by bimodal basalt-trachyrhyolite-comendite series which, as it was mentioned, was closely associated spatially with extensive dike belts (Yarmolyuk et al., 1981) and developed in Gobi-Tien-Shan zone and the zone of Major Mongolian lineament.

At the same time in central Mongolia magmatic rocks of calc-alkaline series, and in Northern Mongolia those of subalkaline series were formed.

In the end of Early Permian and in the beginning of Late Permian the bimodal association with agpaitic rocks shifts to the north (the south of central Mongolia). In the end of Permian — beginning of Triassic this association shifts farther to the north to Ider-Orkhon-Selenga zone. At the same time Paleothetys as a sedimentary basin of the Mediterranean type stopped its existence.

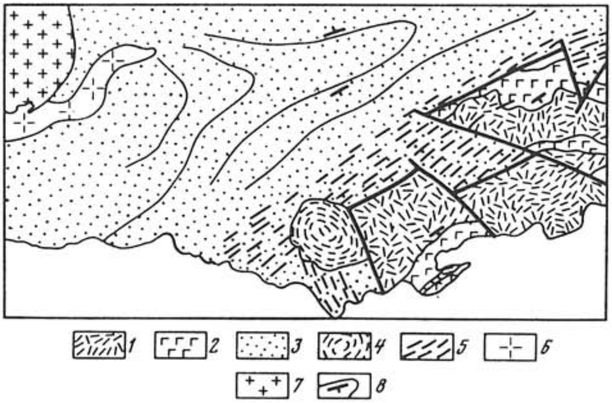


Fig. 3. A scheme of geological structure of south-eastern part of Tost ridge. *Explanations:* 1 — comendites and trachyrhyolites; 2 — basalts; 3 — Carboniferous volcanogenic-sedimentary sequences; 4 — a vent of comendite-basaltic volcano; 5 — dikes; 6 — alkali granites; 7 — biotitic granites, 8 — lines showing the strike of cover formations and dip direction of layers.

Thus magmatic associations including agpaitic rocks were formed in riftogenic structures that came into being at certain stages under conditions of collision of two lithospheric plates. Spreading conditions in zones of riftogenesis which sometimes followed general compression during collision we explain either as a result of 1) successive passage of the Eurasian plate over the rift system of Paleothetys (Kovalenko et al., 1983) as it is the case in western USA; or 2) formation of secondary riftogenic structures at the flanks of the rise with the axis in central Mongolia (Kovalenko et al., 1981), and the formation of the rise itself is connected with tectonic piling up of continental crust out its intensive melting, probably, over a buried system of oceanic rift.

Petrografical and petrochemical characteristics of magmatic rocks

Detailed description of volcanic sections and massives including agpaitic acid rocks has been given in special papers (Goreglyad et al., 1980; Yarmolyuk, 1983; Vladykin et al., 1981). Here we shall note only that the composition of the bimodal series is characterized by interlayering in sections of covers of olivine basalts and lense-like bodies of trachytes, subalkaline rhyolites and comendites and pantellerites. In most cross-sections volume ratios of basic and acid volcanites range from 2 : 1 to 3 : 1. Thickness of volcanic sections reaches 2.0—2.5 km. As a rule, all intermediate between basic and acid varieties of rocks are present in sections, but their alternation is contrast, with basalts often being followed by rhyolites and comendites and vice versa. Ignimbrites predominate among volcanic rocks.

In southern and central Mongolia dominant agpaitic volcanites, are comendites, and in northern Mongolia — less studied pantellerites. Also, in northern Mongolia two generations of agpaitic volcanites and subvolcanic dikes can be outlined: older pantellerites and younger comendites.

Massives of alkaline granitoids are spacially close to agpaitic volcanites as they are located mostly in root parts of paleovolcanic apparatuses. It has been frequently noted that hypabyssal bodies of alkali granitoids passed through subvolcanic dike complexes to volcanic agpaitic covers. The massives often have a ring form (Vladykin et al., 1981). In apical parts of cupola outcrops of the massives, later bodies of alkali granites and pegmatites enriched with rare elements (rare-metal) occur.

Volcanites of bimodal series in Mongolia are represented by olivine basalts, andesitobasalts, trachytes, trachydacites, trachyrhyolites, comendites and pantellerites.

As phenocrysts (up to 10 %) in basalts occur clinopyroxene, olivine, more rarely orthopyroxene and plagioclase. Groundmass consists of glassy aggregate with microlites of plagioclase and clinopyroxene.

In more acid non-agpaitic rocks, phenocrysts of plagioclase are ubiquitous, less frequently potassium feldspar (trachydacites, trachyrhyolites), quartz, clinopyroxene occur.

Comendites contain phenocrysts of quartz (up to 7.1 %) alkaline feldspar (up to 19 %) and less frequently of alkaline amphibole (cataphorite and arfvedsonite). The groundmass is felsitic, rarely half-glassy, fluidal, sometimes vesicular. It is enriched with alkaline amphibole and aegirine. Vugs are filled with quartz and dark-coloured alkaline minerals. Comenditic ignimbrites are comendite fragments cemented by tuffaceous material with typical fiamme and other signatures of their explosive origin.

Pantellerites differ from comendites first by absence of quartz phenocrysts, presence of one mineral phenocrysts, more abundant phenocrysts of alkaline amphibole.

Alkali granitoids have been described by us earlier (Kovalenko, 1977). Dominant among them are numerous varieties of monofeldspar leucogranites with arfvedsonite, cataphorite, aegirine. Later rare-metal granites and pegmatites are microcline-albitic with alkaline amphibole, aegirine, sometimes with polylithionite, armstrongite, elpidite, mongolite, fluorite and various rare metal minerals. These rocks are enriched with dark-coloured alkaline minerals as compared to earlier ones. Typical for them are inhomogeneous banded, patched and other inhomogenous structures with schlieren alkali granitic pegmatoids. The latter often contain giant (up to 1 m in length) crystals of alkaline amphiboles and some rare metal minerals.

Table 1

Chemical composition of rocks of the bimodal basalt — comendite — alkali granite association PZ_3 in Mongolia

	1	2	3	4	5	6	7
	ChB 4025/3	ChB 4025/4	ChB 4025/8	ChB 4025/13	ChB 4025/14	ChB 4025/15	ChB 4025/17
SiO_2	51.94	60.54	68.81	49.37	69.54	68.79	43.35
TiO_2	0.99	1.25	0.56	1.67	0.47	0.68	1.64
Al_2O_3	16.39	16.54	15.52	16.90	14.13	11.89	16.80
Fe_2O_3	4.32	4.54	1.84	5.42	2.69	5.14	6.67
FeO	3.50	1.08	0.27	4.58	0.10	1.35	4.85
MnO	0.10	0.10	0.04	0.14	0.02	0.10	0.13
MgO	3.78	0.96	0.17	4.14	0.22	0.12	5.22
CaO	6.29	1.74	0.43	9.12	0.55	0.86	9.15
Na_2O	4.34	5.36	4.88	3.53	4.35	5.58	3.41
K_2O	2.78	6.08	6.80	0.94	6.00	3.89	0.68
P_2O_5	0.02	0.01	0.01	0.02		0.07	0.01
F	0.08	0.06	0.40	0.08	0.06	0.23	0.06
F~O	0.03	0.02	0.17	0.03	0.02	0.09	0.02
a. c.	4.68	1.40	0.64	4.24	1.28	1.16	7.44
ppp	0.62	0.93	0.99	0.40	0.97	1.12	0.37
Sum	99.20	99.65	100.19	100.15	99.40	99.77	99.40
D. I.	50.8	87.1	95.6	38.4	92.8	85.1	26.2
$f = C_{Ce}/C^{\circ}_{Ce}$	0.71	0.33	0.27	0.75	0.27	0.35	0.81

1st continuation of Tab. 1

	8	9	10	11	12	13	14
	ChB 4025/22	ChB 4025/30	ChB 4025/33	ChB 4025/36	N— 4025/2	N— 4135/3	N— 4135/4
SiO_2	64.34	76.26	73.38	77.01	66.66	74.60	65.74
TiO_2	0.47	0.27	0.25	0.30	0.82	0.27	1.10
Al_2O_3	15.00	11.02	11.59	10.90	15.00	9.75	14.18
Fe_2O_3	4.67	3.22	3.00	2.61	4.40	5.71	6.23
FeO	0.12	0.25	0.54	0.63			
MnO	0.16	0.01	0.04	0.03	0.12	0.16	0.18
MgO	0.41	0.14	0.04	0.09	1.32	0.10	1.05
CaO	1.79	0.51	0.16	0.23	2.10	0.52	1.85
Na_2O	5.26	4.21	3.64	3.64	5.90	3.56	5.99
K_2O	6.12	3.72	5.98	4.55	1.36	4.20	2.30
P_2O_5	0.01	0.02		0.02	0.12		0.20
F	0.10	0.27	0.06	0.32			
F~O	0.04	0.11	0.02	0.13			
a. c.	1.36	0.98	0.60	0.62	1.62	0.52	0.88
ppp	1.01	0.99	1.08	1.01	0.75	1.07	0.87
Sum	99.77	100.50	99.28	100.50	99.42	99.39	99.70
D. I.	87.5	94.6	91.8	95.7	79.1	89.3	81.9
$f = C_{Ce}/C^{\circ}_{Ce}$	0.42	0.35	0.23	0.28	0.68	0.21	0.49

2nd continuation of Tab. 1

	15	16	17	18	19	20	21
	N— 4135/5	N— 4135/8	N— 4135/12	N— 4135/16	N— 4135/17	N— 4135/20	ChB 4115
SiO_2	72.55	75.00	66.64	60.17	50.17	50.17	78.09
TiO_2	0.26	0.34	0.55	1.50	1.90	2.70	0.20
Al_2O_3	13.60	9.00	14.75	15.60	16.63	15.56	9.50
Fe_2O_3	3.36	6.54	5.60	7.48	10.77	11.56	1.91
FeO							2.03
MnO	0.07	0.16	0.13	0.15	0.26	0.11	0.09
MgO	0.22	0.30	1.08	1.90	4.26	4.46	0.04
CaO	0.73	0.35	0.73	2.88	7.20	8.25	0.20
Na_2O	6.70	2.73	3.87	5.17	4.69	3.72	3.40
K_2O	1.52	5.16	4.50	3.62	1.86	1.29	4.68
P_2O_5	0.01		0.06	0.49	0.45	0.62	0.24
F							0.10
F~O							0.04
ppp	0.58	0.14	2.16	0.78	2.38	1.68	
Sum	99.60	99.72	99.07	99.74	100.57	100.12	
a. c.	0.93	1.15	0.73	0.80	0.59	0.48	
D. I.	91.8	87.8	83.1	74.4	47.3	43.3	
$f = C_{Ce}/C^{\circ}_{Ce}$	0.39	0.17	0.30	0.60	0.65	0.94	

Petrochemistry (major element chemistry)

General description: Chemical composition of agpaitic acid rocks of Mongolia and especially granitoids has been considered by the authors earlier (Goreglyad et al., 1980; Yarmolyuk, 1983; Vladykin et al., 1981). Representative chemical compositions of typical rocks from volcanic sections and alkali granitoid massifs is shown in Table 1. We would like to emphasize that, in general, basalts and andesitobasalts most often fall into the field of subalkaline rocks (Magmatic rocks ..., 1983), and judging from their $Na_2O + K_2O$ content prove to be somewhat more alkaline than basalts of the Aerta Ale center in Ethiopia (Barbert et al., 1975). The major petrochemical feature of the acid rocks, naturally, is their oversaturation by alkalies with respect to aluminium, that is agpaitic character.

Below, distribution of major and rare elements (Tabs. 3—5) in agpaitic acid rocks will be considered in terms of behaviour of elements in the course of a succesive differentiation of initial magma (or magmas). To this end, it is necessary first to select a parameter governing differentiation of the magmas under consideration.

Magmatic differentiation index: Usually either SiO_2 content or Torntone differentiation index (D. I.) is used to estimate the degree of differentiation of magmas. The both parameters describe quite satisfactorily differentiated magmatic series from basalts to acid rocks. For example, the

3rd continuation of Tab. 1

	22	23	24	25	26	27	28	29
	ChB— 4021	N— 4123	N— 4135/1	U—N 1648	N— 4192	N— 4192/2	N— 4192/3	N— 4195
SiO_2	74.83	73.39	71.90	71.78	71.49	72.04	71.60	73.54
TiO_2	0.78	0.56	0.78	0.43	0.48	0.55	0.48	0.38
Al_2O_3	11.54	9.78	10.08	10.00	10.00	10.20	10.00	9.80
Fe_2O_3	3.38	2.16	2.56	2.92	2.70	2.60	2.70	4.51
FeO	0.10	3.97	4.28	3.95	4.05	3.96	4.05	1.71
MnO	0.04	0.27	0.28	0.20	0.25	0.20	0.22	0.21
MgO	0.02	0.05	0.08	0.34	0.34	0.24	0.20	0.20
CaO	0.17	0.39	0.50	0.76	0.86	0.69	0.56	0.39
Na_2O	4.16	3.96	3.76	4.05	3.78	4.43	4.40	3.62
K_2O	4.82	4.33	4.69	4.09	4.19	4.19	4.12	4.12
P_2O_5	0.01				0.48	0.42	0.67	0.51
F	0.06	0.11	0.11	0.12	0.08	0.12		0.10
F-O	0.02	0.04	0.04	0.05	0.03	0.05		0.04
CO_2		0.28		0.12			0.32	0.05
Cl			0.04	0.04				
ppp	0.52			0.75	0.93	0.78	0.71	0.32
H_2O		0.42	0.48	0.48				
Sum	100.41	99.64	99.53	99.58	99.59	100.27	99.71	99.37
a. c.	1.04	1.15	1.12	1.11	1.08	1.16	1.17	1.06
D. I.		83.6	83.3	85.3	87.9	86.2	85.5	89.0
$f = C_{Ce}/C^{\circ}_{Ce}$				0.15	0.19	0.18		

major element content as well as that of SiO_2 is clearly dependent on D. I. (Fig. 4) which will be discussed below.

However, the most interesting for us compositions of acid agpaitic rocks can not be discriminated using these indicators as the considered parameters in them even decrease in residual melts (Kovalenko, 1977). For these compositions the growth of agpaitic index in residual melts is outlined so that the agpaitic coefficient (a. c. = $\frac{Na_2O + K_2O}{Al_2O_3}$, at. ratio) values may be used as a differentiation index. A diagram for the rock-forming components of this kind is shown in Fig. 5.

It is inconvenient to use this diagram due to a narrow range of a. c. variations and also because of artificial separation of possible general evolution of a single magmatic series into two parts: by D. I. and a. c. It seems more reasonable to use a single parameter describing differentiation of the whole series.

In this study we selected for this purpose a relative portion of residual melt calculated using the method proposed by Barbert et al. (1975). Residual melt fraction can be estimated from the ratio C/C_0, where C is the concentration of element in magma (rock), and C_0 is the concentration of the same element in initial melt. For this purpose the so-called "residual" elements are used for which partition coefficient is very low and even close to zero. Distinctive feature of behaviour of such residual elements in the process of crystallization differentiation is a linear correlation of their concentrations. As for other basalt-pan-

Table 2

Chemical composition and major petrochemical characteristics of alkali granitoids of Southern Mongolia

	1	2	3	4	5	6	7
	EGM—4022	EGM—4024	EGM—4028	EGM—4025	EGM—4029	EGM—4026	ChB—1800
SiO_2	63.55	65.38	64.56	73.56	73.56	70.35	74.45
TiO_2	0.60	0.77	0.86	0.02	0.02	0.35	0.16
Al_2O_3	16.89	15.87	15.87	12.41	12.26	12.76	11.62
Fe_2O_3	2.04	2.59	3.70	2.69	1.64	2.79	1.90
FeO	1.30	1.26	0.09	0.10	1.26	0.58	2.43
MnO	0.10	0.10	0.11	0.05	0.08	0.07	0.15
MgO	0.42	0.42	0.45	0.12	0.11	0.27	0.03
CaO	0.91	0.87	0.83	0.39	0.29	0.69	0.05
Na_2O	6.61	6.03	6.70	4.98	4.98	6.03	4.61
K_2O	6.93	5.78	6.72	4.89	4.97	5.73	4.59
P_2O_5	tr.	0.01	0.01	tr.	tr.	0.01	
F	0.10	0.06	0.06		0.06	0.10	0.13
F~O	0.04	0.02	0.02		0.02	0.04	0.05
ppp	0.36	0.48	0.20	0.08	0.46	0.24	
H_2O							0.06
CO_2							
ZrO_2							
Sum	99.86	99.62	99.14	99.29	99.67	99.93	100.13
a. c.	1.07	1.01	1.14	1.09	1.10	1.26	1.08
$f = C_{Ce}/C^{\circ}_{Ce}$	0.54	0.40	0.30	0.27	0.30	0.20	0.38

1st continuation of Tab. 2

	8	9	10	11	12	13	14
	ChB—1801	ChB—1808	ChB—1804	ChB—1806	ChB—1825	ChB—1820	U—ChB—551
SiO_2	73.84	76.90	74.83	74.87	74.79	73.76	71.90
TiO_2	0.18	0.18	0.33	0.28	0.22	0.25	0.42
Al_2O_3	11.35	12.10	10.29	10.34	10.62	10.77	8.58
Fe_2O_3	2.10	0.65	2.51	2.13	2.10	2.43	8.30
FeO	2.25	1.35	1.88	2.60	2.07	1.98	0.27
MnO	0.18	0.08	0.13	0.13	0.10	0.20	0.16
MgO	0.02	0.01		0.01	0.02	0.40	0.45
CaO	0.06	0.05	0.04	0.08	0.05	0.58	5.14
Na_2O	4.61	4.31	4.41	4.76	4.46	4.93	3.53
K_2O	4.80	4.69	4.69	4.69	4.59	4.77	
P_2O_5						tr.	
F	0.08	0.04	0.07	0.08	0.16	0.13	
F~O	0.03	0.01	0.03	0.03	0.06	0.05	
ppp						0.52	0.98
H_2O	0.14	0.22	0.26	0.10	0.34		
CO_2	0.08		1.11	0.39	0.36		
ZrO_2							
Sum	100.40	100.57	100.53	100.43	99.82	100.67	99.73
a. c.	1.11	1.00	1.19	1.25	1.17	1.22	1.65
$f = C_{Ce}/C^{\circ}_{Ce}$	0.39	0.25	0.125	0.20	0.125	0.15	0.075

2nd continuation of Tab. 2

	15	16	17	18	19
	U–ChB–549	U–ChB–1792	U–ChB–552	ChB–1816	ChB–1817
SiO_2	71.28	67.40	72.75	71.96	66.20
TiO_2	0.44	0.66	0.51	0.36	0.87
Al_2O_3	8.55	5.36	4.14	9.04	4.17
Fe_2O_3	7.67	5.28	11.72	5.94	12.00
FeO		4.76		0.27	0.89
MnO	0.28	0.47	0.30	0.21	0.31
MgO	0.28	0.01	0.22	0.03	0.02
CaO	0.58	0.16	0.42	0.07	0.16
Na_2O	5.04	4.17	4.82	5.32	5.54
K_2O	3.95	4.69	3.56	3.99	3.90
P_2O_5	tr.		0.03		
F		0.34		0.18	0.03
F~O		0.14		0.07	0.01
ppp	1.32		1.36		
H_2O		1.90		0.90	1.95
CO_2		0.11			0.20
ZrO_2		5.40		1.06	5.14
Sum	99.34	100.57	99.83	99.26	101.31
a. c.	1.73	2.22	3.37	1.44	3.17
$f = C_{Ce}/C^{\circ}_{Ce}$	0.091	0.15	0.015	0.042	0.05

Table 3

The content of fluorine (wt. %) and some rare elements (ppm) in rocks of basalt — comendite — alkali granite association of Southern Mongolia

	1	2	3	4	5	6	7
	ChB–4021	ChB–4025/30	ChB–4025/36	N–4123	N–4135/3	N–4195	N–4192/1
Li	3	11	9	23	15	83	15
Rb	140	108	160	98	91	76	72
Be	3.7		3.9	5.8	3.1	9.5	7.9
F	0.02		0.02	0.04	0.02	0.19	0.10
B	10.5		13	21	12	11	21.5
Pb	33		31	38	30	17	24
Zn	65		49	294	210	79	91
Sn	5.6		4.8	13	8.5	6.6	6.8
Ba	150		160	85	83	110	120
Sr	27		30	47	80	47	48
Cr	6.5	16	22	25	40	3	32
Ni	1.1	5.5	2.5	12	11	5.4	9.6
Co	—		2	3.3	1	1	1
Si	4.0	8	16	10	8.7	2.8	4.2
V	5.0	14	6.9	8.3	5.6	7.3	11
K/Rb	287	283	255	369	385	450	483
$f = (C_{Ce}/C^{\circ}_{Ce})$	0.23	0.35	0.28				0.18

1st continuation of Tab. 3

	8	9	10	11	12	13	14
	N— 4192/2	N— 4192/3	ChB— 4025/3	ChB— 4025/4	ChB— 4025/8	ChB— 4025/13	ChB— 4025/15
Li	9	10					
Rb	74	74					
Be	8.6	8.7	4.1	5.1	2.3	1.4	4.5
F	0.17	0.15	0.15	0.04	0.06	0.04	0.05
B	18	18	10	8	12	7	17
Pb	26	33	9	13	16	5	22
Zn	86	126	54	58	63	72	112
Sn	6.3	8.7	1.2	2.5	2.9	1.8	4.5
Ba	90	140	1500	1600	1900	400	130
Sr	46	42	1200	270	88	440	35
Cr	46	37	230	11	10	160	—
Ni	17	20	55.0	5.2	1.7	52.0	1.1
Co	2.0	1.0	32.0	6.0	2.7	56.0	1.0
Si	7.5	18	63	5	2	79	3
V	10	6.7	200	42	25	29	3
K/Rb	470	462					
$f = (C_{Ce}/C^{\circ}_{Ce})$	0.18	0.18	0.71	0.33	0.27	0.75	0.35

2nd continuation of Tab. 3

	15	16	17	18	19	20	21
	ChB— 4025/17	ChB— 4025/22	ChB— 4025/33	ChB— 4025/39	ChB— 4025/20	N— 4135/2	N— 4135/3
Li							
Rb							
Be	1.1	2.4	3.9	4.0	1.6	3.1	3.1
F	0.09	0.07	0.02	0.06	0.06	0.10	0.02
B	8	13	13	10	20	10	12
Pb	6	16	31	20	7	10	30
Zn	89	51	49	85	178	115	210
Sn	2.1	1.8	4.8	4.7	3.0	2.3	8.5
Ba	270	120	160	140	600	500	83
Sr	500	40	30	33	900	180	80
Cr	210	16	15	16	50	32	40
Ni	120.0	1.7	7.2	6.3	50.0	6.6	11.0
Co	63.0	1.0	2.0	—	35.0	4.6	0.8
Si	100	7	8	6	46	5	9
V	250	4	5	6	250	36	6
K/Rb							
$f = (C_{Ce}/C^{\circ}_{Ce})$	0.81	0.42	0.23	0.32	0.94	0.68	0.21

3rd continuation of Tab. 3

	22	23	24	25	26	27	28
	N— 4135/4	N— 4135/5	N— 4121	N— 4122	N— 4122/9	N— 4122/11	N— 4122/13
Li							
Rb							
Be	2.7	0.7	7.2	8.7	4.6	3.6	4.4
F	0.02	0.03	0.04	0.12	0.04	0.02	0.01
B	11	9	63	14	55	10	13
Pb	13	22	38	42	20	13	16
Zn	105	138	200	172	132	158	230
Sn	2.6	6.3	11.5	14.0	11.5	6.9	9.6
Ba	600	400	100	51	220	470	100
Sr	240	90	63	52	66	140	53
Cr	66	66	25	25	72	32	50
Ni	25.0	26.0	7.9	6.3	18.0	12.0	12.0
Co	7.9	8.0	2.4	3.3	3.2	3.3	3.2
Si	18	21	10	5	14	8	10
V	50	21	4	3	8	16	6
K/Rb							
$f = (C_{Ce}/C^{\circ}_{Ce})$	0.49	0.39	0.19	0.21	0.21		0.20

4th continuation of Tab. 3

	29	30	31	32	33	34	35	36
	N— 4122/15	b/n	b/n	b/n	b/n	b/n	b/n	b/n
Li		20	27	41	75	161	143	120
Rb		100	120	66	180	209	189	228
Be	2.6	4	5		6	7	6	15
F	0.01	0.04	0.18	0.17	0.09	0.22	0.21	0.13
B	16	11	34		20			
Pb	8	29	26		28	18	20	94
Zn	41	94	110		113	128	176	333
Sn	6.9	6.5	7.6		10.2	18.1	7.1	23.0
Ba	69							
Sr	44							
Cr	33							
Ni	23.0							
Co	2.5							
Si	16							
V	9							
K/Rb								
$f = (C_{Ce}/C^{\circ}_{Ce})$	0.62	0.30	0.17	0.06	0.22	0.023	0.03	0.019

Table 4

Rare earth elements and yttrium distribution in volcanic rocks of Tost-Nuroo ridge (in ppm)

	1	2	3	4	5	6	7
	N– 4135/20	N– 4135/2	N– 4135/3	N– 4135/4	N– 4135/5	N– 4135/8	N– 4135/12
La	14	18	77	35	50	66	79
Ce	32	44	140	61	77	180	100
Nd	20	27	75	43	46	82	79
Sm	5.0	6	17	9	12	17	10
Eu	2.0	2.0	2.5	4.3	1.2	2.4	3.7
Gd			20	14	15	27	19
Dy			30	14	16	33	20
Ho			7.2	1	3.8	7.6	4.8
Er			15	5	8	12	12
Yb		3.6	20	5	8.2	21	12
Lu							
Y	23	40	120	48	65	110	88
Eu/Eu			0.433	1.232	0.283	0.358	0.850
La/Yb		5.0	3.9	7.0	6.1	3.1	6.6
D. I.	43.3	79.1	89.3	81.9	91.8		83.1
f	0.94	0.68	0.21	0.49	0.39		0.30

1st continuation of Tab. 4

	8	9	10	11	12	13	14
	N– 4135/16	N– 4135/17	ChB– 4025/3	ChB– 4025/4	ChB– 4025/8	ChB– 4025/13	ChB– 4025/14
La	36	22	26	52	55	20	70
Ce	50	46	42	90	110	40	110
Nd	45	32	18	42	60		61
Sm	6	6	5.2	10.2	12		11
Eu	2.5	2.0	1.1	2.1	3.0	2	1.1
Gd			4.2	7.4	4.5		18
Dy			2.8	7.2	7		14
Ho			0.68	1.2	1		2.5
Er			1.7	3.9	3		7
Yb	4.6	2.9	1.4	4.2	3.2	3.1	
Lu			0.15	0.40	0.3		0.9
Y	42	31	13	47	35	28	70
Eu/Eu			0.733	0.724	1.071		0.25
La/Yb	7.8	7.6					
D. I.	74.4	47.3	50.8	87.1	95.6	38.4	92.8
f	0.60		0.71	0.33	0.27	0.75	0.27

2nd continuation of Tab. 4

	15	16	17	18	19	20	21
	ChB– 4025/15	ChB– 4025/17	ChB– 4025/22	ChB– 4025/30	ChB– 4025/33	ChB– 4025/36	ChB– 4021
La	47	21	40	70	75	74	100
Ce	86	37	71	95	130	150	130
Nd	50	22	40	57	75	72	100
Sm	17	7.5	15	17	17.5	17	17
Eu	2.0	2.5	0.95	0.47	0.38	0.46	1.0
Gd	11	6.2	12	13	20		10
Dy	12	6.0	10	14	17	18	15
Ho	2.2	0.93	2	2.6	3.6	3.5	3
Er	6.5	3.1	6.6	7.3	6.0	5.8	12
Yb	7.5	2.9	5.2	5.7	9.0	6.0	9.3
Lu	0.92	0.42	0.67	0.73	0.23	0.55	
Y	51	34	44	60	86	84	89
Eu/Eu	0.435	1.136	0.22	0.097	0.065		0.225
La/Yb							
D. I.	85.1	26.2	87.5	94.6	91.8	95.7	93.6
f	0.35	0.81	0.42	0.35	0.23	0.28	0.23

telleritic series (Barbert et al., 1975), in this case lanthanum, zirconium, hafnium, cerium posess such properties (Fig. 6). Further we will use for these purposes cerium. To estimate the C^{Ce}_{0} value we used, as in the work Barbert et al. (1975), plots of Ce contents versus Ni and Cr as elements with high values of partition coefficient (Fig. 7). Because of high values of partition coefficient for nickel and chromium in the beginning of fraction this curve is very steep. Extrapolating the cerium concentration value to the vertical position of the curve in Fig. 7 we obtain the value of C^{Ce}_{0}. Below we use the value of $f = C^{Ce}/C^{Ce}_{0}$ as such an index of differentiation for the whole series of rocks.

Distribution of rock-forming components

Fig. 8 shows behaviour of rock-forming components as a function of relative position of residual melt (f).

As a whole, the pattern of variation of chemical composition of melt (rock) as a function in many aspects resembles the picture for the series modelling crystallization differentiation in the Boina Centre, although with some destructions. General for the both series is the increase of SiO_2 and K_2O content, agpaitic coefficient values, decrease of CaO, MgO, FeO* content on transition from basalts to comendites. Common for the two series under comparison is also the presence of maximum and minimum points in concentration diagrams indicating the changing regime of magmatic crystallization (appearance and disappearance of minerals, abrupt changes of ratios of crystallizing minerals etc.). However, position and character of these critical points is different for sections in Mongolia and Ethiopia.

Table 5

Rare earth elements and yttrium distribution in alkali granitoids of Southern Mongolia (in ppm)

	1	2	3	4	5	6	7	8	9	10
	GIF	DK	Kv–EG	A–Kv	DK	Elp–Arms	U–N–1648	N–4192/1	N–4192/2	N–4192/3
La	64	657	2400	9400	487	2900	78	74	72	72
Ce	138	1280	4450	1300	577	3700	190	160	170	170
Pr	12	203	953	1900	53	560	15	18	18	18
Nd	58	687	1933	5700	303	1700	57	61	59	53
Sm	19	203	308	1000	80	370	20	15	16	15
Eu	—	—	—	25	—	—	2.3	2.2	1.8	1.9
Gd	15	177	230	5200	109	240	24	20	23	23
Tb	—	—	—	—	—	—	2.4	2.5	2.5	1.9
Dy	17	237	148	450	131	210	17	17	18	16
Ho	2	47	26	79	33	33	5.5	4.2	4.3	6.5
Er	10	53	54	170	64	77	13	12	15	18
Yb	21	267	73	195	150	93	20	19	20	19
Lu	—	—	—	—	—	—	2.4	2.3	1.6	—
Y	63	733	918	2500	593	1200	100	97	100	100
(TR + Y) %	0.04	0.45	1.10	2.80	0.26	1.10	0.055	0.05	0.052	0.051
Eu/Eu^{+}	—	—	—	0.023	—	—	336	41	0.300	0.330
La/Yb	3.0	2.5	32.9	48.2	3.2	31.2	3.9	3.9	3.6	3.8
D. I.				0.023			0.16	0.19	0.18	0.18
$f = (C_{Ce}/C^{\circ}_{Ce})$	0.22	0.023	0.0067		0.052	0.0081				

Thus, for rocks from Mongolia two major compositional changes in variational diagrams are outlined that fix three major stages of evolution of the magma: 1) in the field of f ~ 0.65; 2) in the field of f ~ 0.25—0.30. The first one is due to the FeO*, Al_2O_3, SiO_2, CaO, MgO and agpaitic coefficient behaviour the second due to FeO*, Al_2O_3, SiO_2, K_2O.

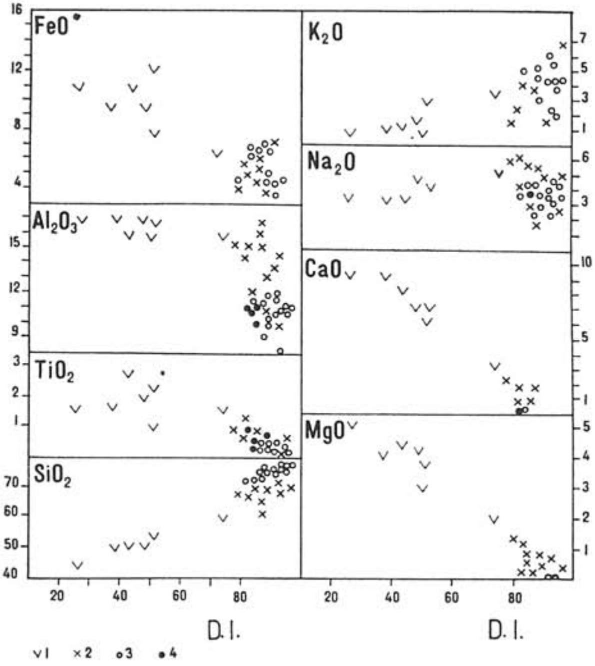


Fig. 4. Major oxide content (wt. %) in volcanic rocks of the bimodal series (P_3) of Southern Mongolia as a function of Tornton differentiation index (D. I.). *Explanations:* 1 — basalts and andesito-basalts; 2 — subalkaline trachydacites-trachyrhyolites; 3 — comendites. Here and below FeO* is total iron calculated as FeO.

Rare element geochemistry

Fig. 9 illustrates the behaviour of rare elements as a function of f (residual melt fraction in volcanic rocks of the bimodal series of Mongolia). As degree of magma differentiation increases (f decreases) such elements as nickel, chromium, zirconium, hafnium, zinc, cobalt qualitatively behave in the same way as in volcanites of the model series of Boina complex (Barbert et al., 1975), that is concentrations of nickel, chromium, cobalt decrease and those of zirconium and hafnium increase. Behaviour of strontium is similar to the behaviour of the iron group elements, and it differs from strontium behaviour in the model series Boina in its monotonous decrease. In doing so, the minimum concentration of the elements considered is reached at f > 0.65 and bends of the

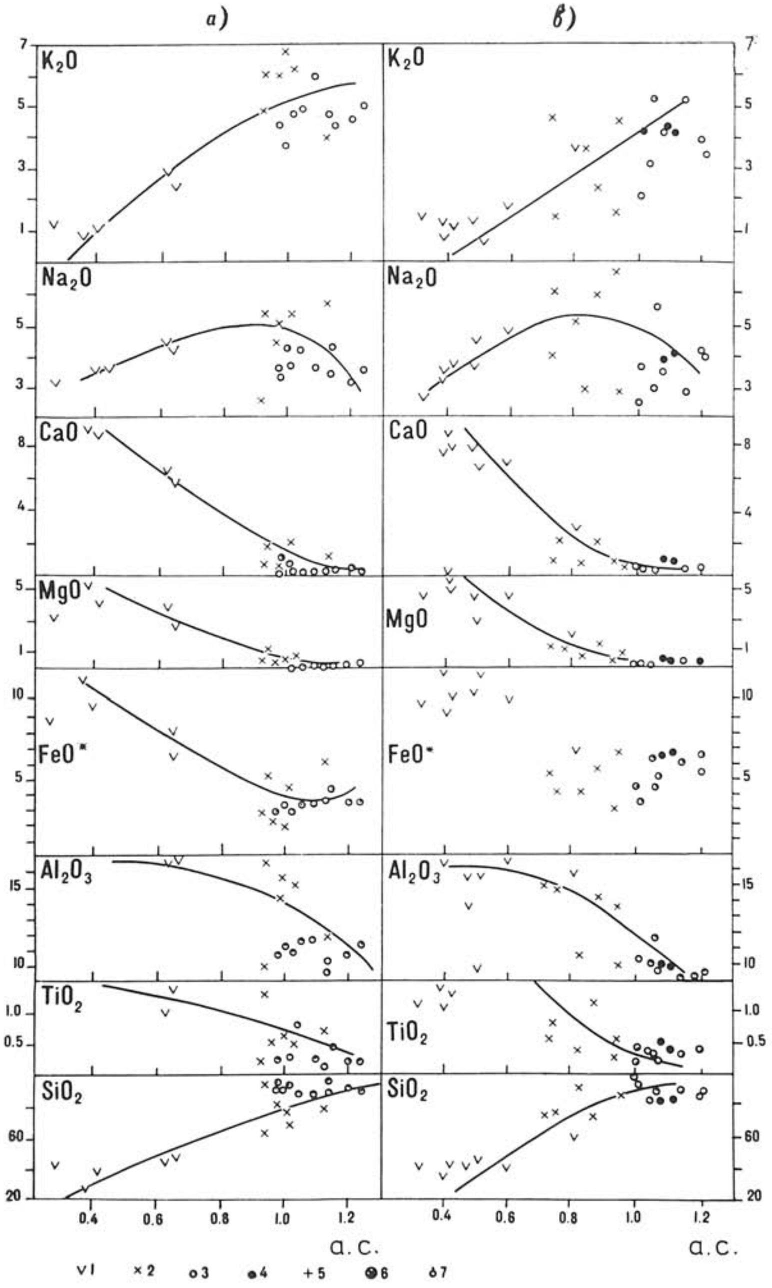

a)
б)
K₂O
Na₂O
CaO
MgO
FeO*
Al₂O₃
TiO₂
SiO₂
7
5
3
1
8
4
10
15
1.0
0.5
60
20
0.4
0.6
0.8
1.0
1.2
a.c.
a.c.
v1
×2
o3
●4
+5
⊗6
ȯ7

Fig. 5a.

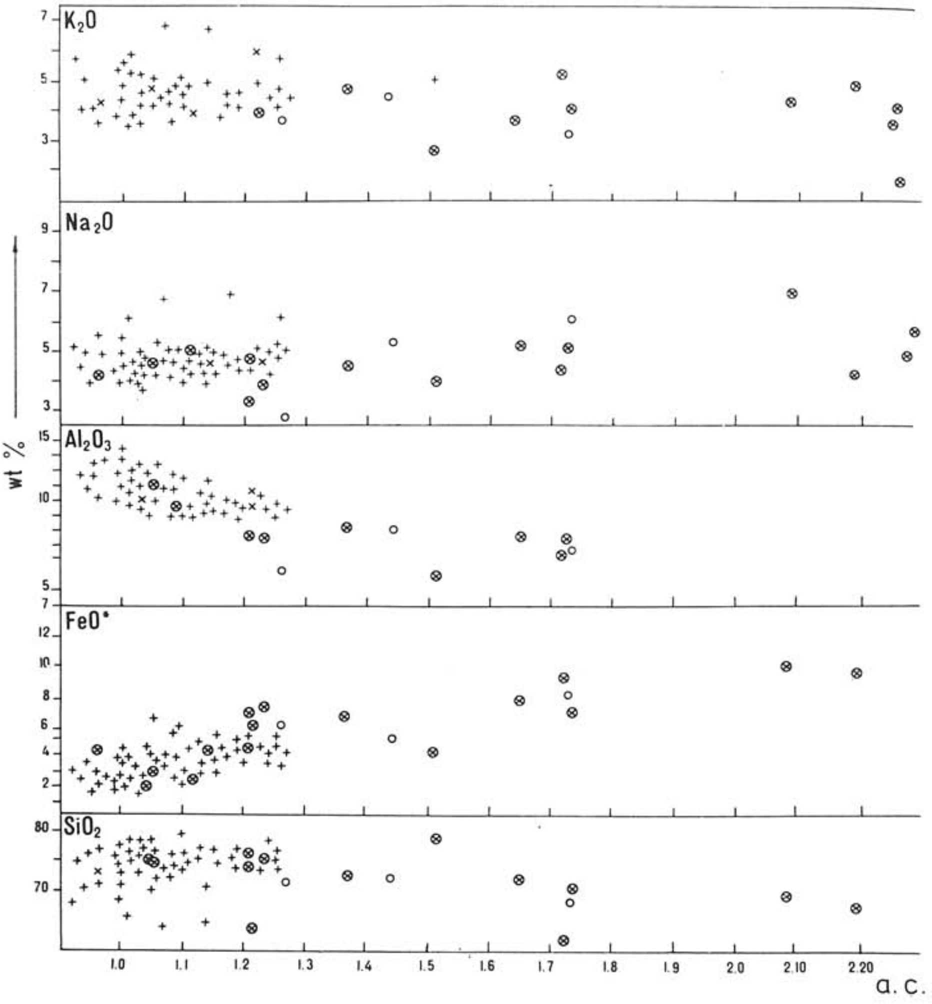


Fig. 5b.

Fig. 5. Major oxide content (wt. %) in volcanic rocks of the bimodal series (P_3) of Southern Mongolia (a — Han-Bogd region, b — Tost-Nuroo ridge region) as a function of the agpaitic coefficient (a.c. = $(Na_2O + K_2O)/Al_2O_3$ at. %).
Explanations: 1 — basalts and andesitobasalts; 2 — subalkaline trachydacites - trachyrhyolites; 3 — comendites; 4 — pantellerites; 5 — leucogranites of early phases; 6 — granites of late phases; 7 — pegmatites.

corresponding curves may be identified in the field of f ~ 0.65. For nickel and chromium a slight increase of concentrations in the field of f = 0.3 — 0.2 (comendites) may be outlined. At the above mentioned values of f zirconium variation curve also bends. Behaviour of niobium and tantalum is close to the behaviour of zirconium and hafnium. Behaviour of zinc is more complicated: its concentration goes through two minima and one maximum located at f = 0.2 — 0.3. Lead has a similar behaviour (Fig. 9a).

Behaviour of tin, beryllium and fluorine is similar: their concentrations are constant or slightly vary in the range of f > 0.2 — 0.3 and sharply increase in comendites.

Most of REE (except Eu), as well as zirconium, increase with the decrease of f but with such distinctions as the appearance of possible concentration minimum at f = 0.2 — 0.3 for some heavy REE (Fig. 10).

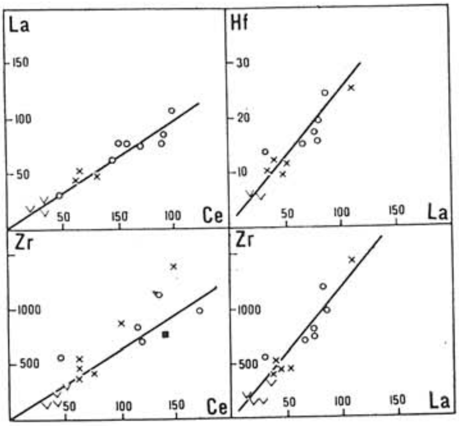


Fig. 6. A correlation between the content (in ppm) of "residual" elements in volcanic rocks of bimodal series (P_3) of Southern Mongolia. Symbols as for Fig. 5.

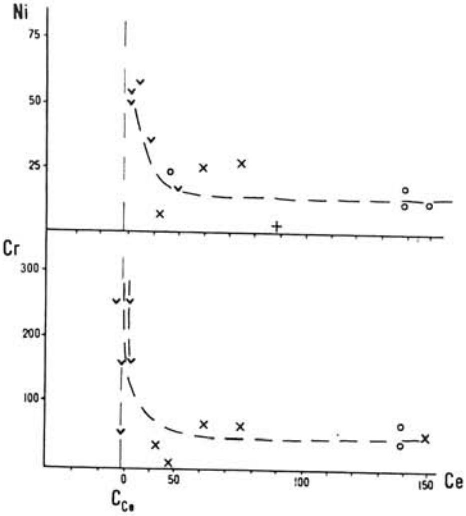


Fig. 7. Cerium content in primary magma (C_{Ce}) estimated by correlation between chromium and nickel and cerium contents (in npm) in volcanic rocks. Symbols as for Fig. 5.

As a whole, position of critical points in rare element variation curves is consistent with those outlined for the major element data (1) f ~ 0.65; 2) f ~ 0.2—0.3). Behaviour of elements in the field of f < 0.2—0.3 (agpaitic field) should be considered taking into account plutonic rocks.

It is worthwhile noting that comendites are very close to alkaline leucogranites of early phases with similar values of f in their content of cobalt, nickel, chromium, vanadium, copper, lead, tin, zinc, fluorine, beryllium, rubidium, lithium, strontium, barium, zirconium, hafnium, niobium, tantalum and rare earth elements. Volcanites only are slightly depleted in fluorine and associated with it beryllium and lithium. This suggests that judging from major and trace element data alkaline leucogranites of early phases are formed from comenditic magma.

As f decreases, evolution of magmatism (transfer from early phases of alkali granitoids to late ones) continues the tendencies in behaviour of most rare elements.

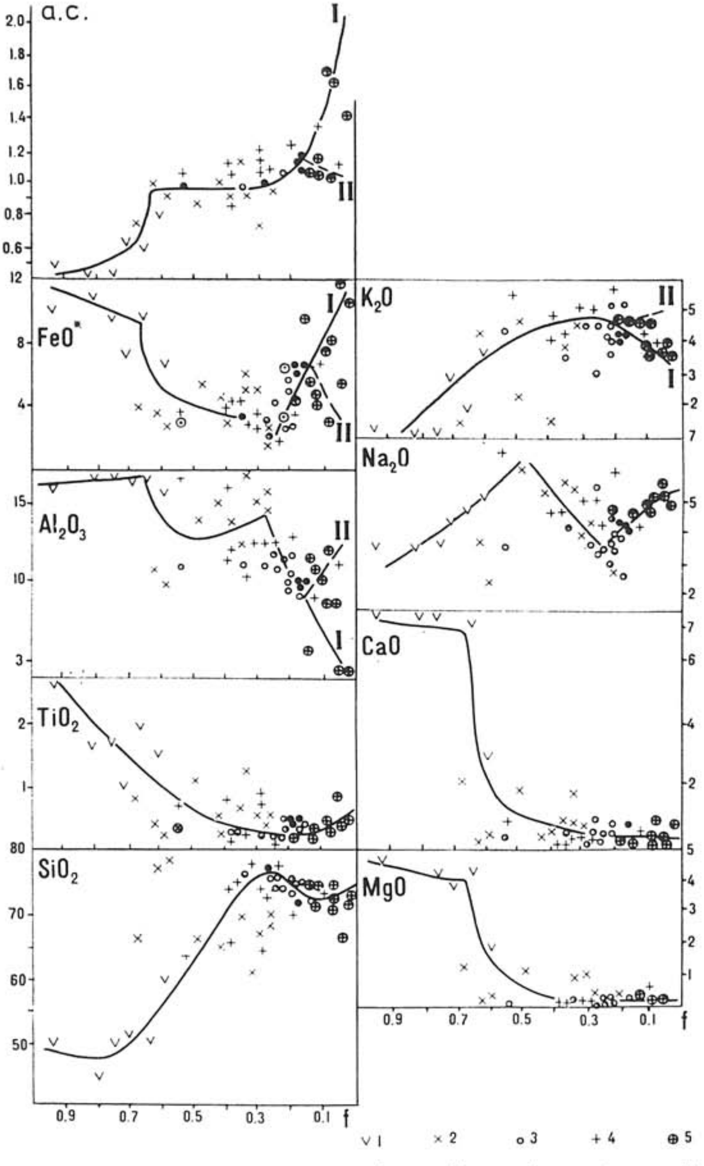


Fig. 8a.

Let us note also a linear in general correlation between logarithms of element concentrations and logarithm of f, which is outlined for a number of elements for all compositions (Fig. 12).

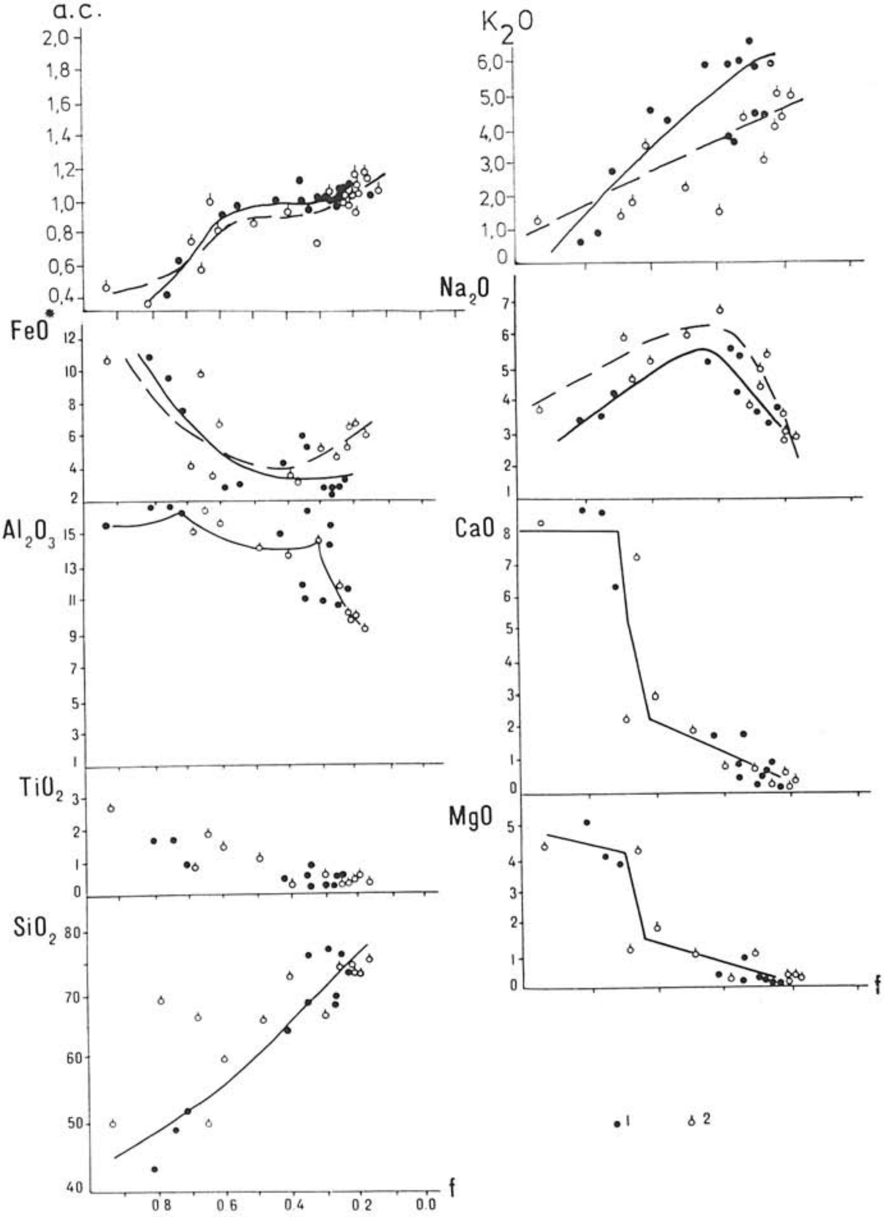


Fig. 8b.

The origin

The most well-founded in terms of physical chemistry model of origin of agpaitic acid magmatic rocks still is crystallization differentiation with its various

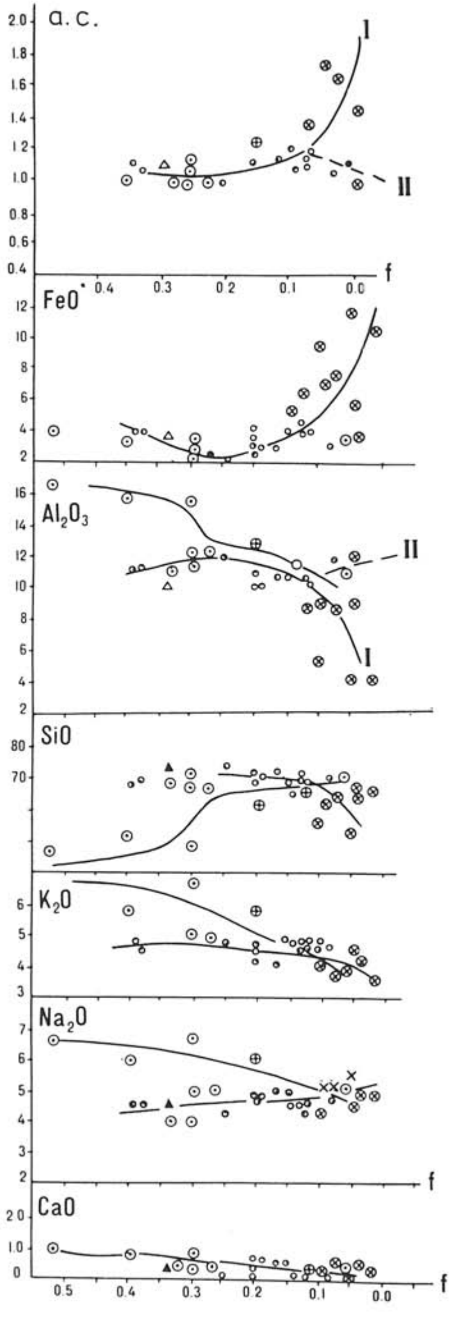


Fig. 8c.

Fig. 8. Major oxide content in rocks (wt. %) as a function of residual melt fraction (f) in the whole series (a), in volcanic rocks (b) and in plutonic rocks (c).
Explanations: 1 — basalts and andesitobasalts; 2 — trachydacites and trachyrhyolites; 3 — comendites; 4 — alkali leucogranites of early phases; 5 — alkali granitoids of late phases; 6—7 — for volcanics (6 — Han-Bogd region, 7 — Tost-Nuroo ridge region); 8—11 — for plutonic rocks (8, 9, 11 — granites of early phases of various regions; 10 — granites of late phases of Han-Bogd region).

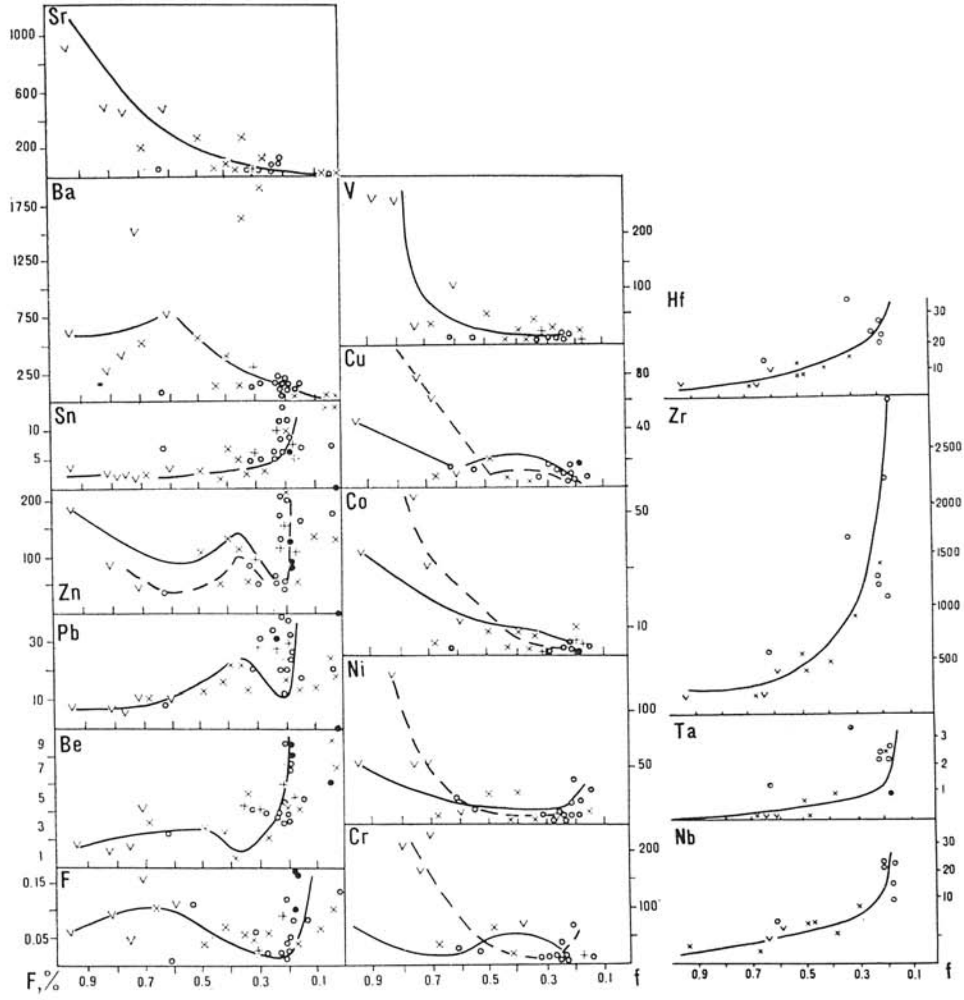


Fig. 9. Selected rare element content (ppm) in Southern Mongolian bimodal series volcanic rocks as a function of residual melt fraction (f). Symbols as for Figs. 4 and 5. Solid lines shows trend for Tost-Nuroo ridge region, doteed line for Han-Bogd region.

modifications. Let us consider applicability of this model to the origin of agpaitic acid magmatic rocks in Mongolia.

Crystallization differentiation

As shown above, all major and trace element characteristics of the Mongolian bimodal series with agpaitic acid rocks is similar to the model crystallization differentiation of the Boine series (Barbert et al., 1975). This is evidenced by the following.

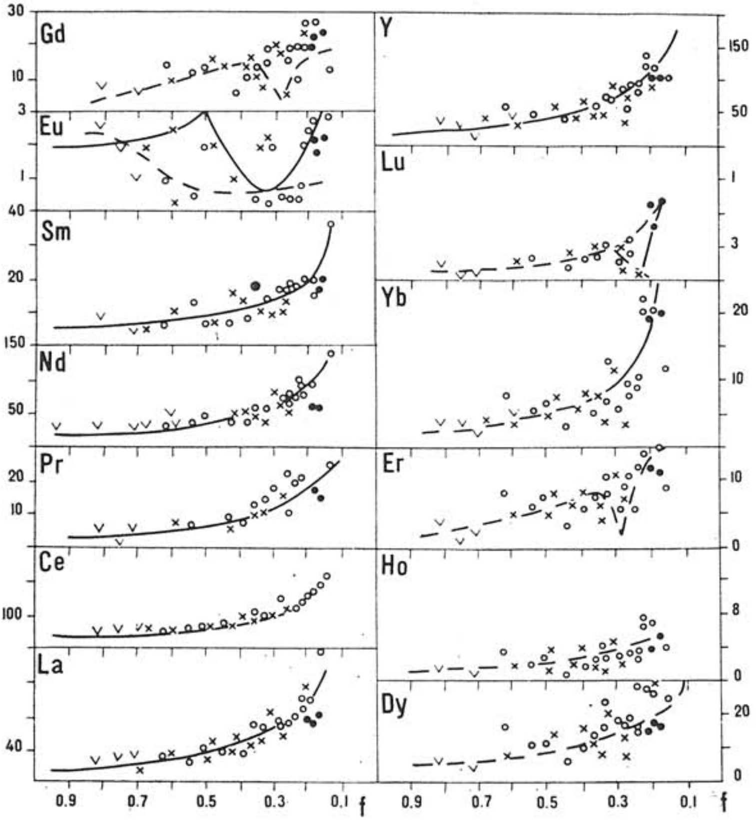


Fig. 10. REE content (ppm) in Southern Mongolian bimodal series volcanic rocks as a function of residual melt fraction. Symbols as for Fig. 9.

1. The presence of a distinct petrochemical trend in variation diagrams suggesting the existence of genetic link between separate members of the series and a common origin of all these rocks during differentiation of basaltic magma.

2. All rocks of the series participate in single tectonic structures and volcano--plutonic complexes. In particular, comendites and pantellerites occur in single stratigraphic sections with basalts and intermediate rocks and also in single dike belts and paleovents of volcanos (Yarmolyuk et al., 1981). In the latter in cases of sufficient erosion transitions from volcanic rocks to plutonic are outlined.

3. The presence of a linear correlation between concentrations of "residual" elements (Fig. 6) that was discussed above and may develop according the data of Treuil (1973); Ferrara—Treuil (1975), only in rocks formed in the process of fractional differentiation.

4. Development of distinct trends of behaviour of rare elements as a function of f (Figs. 9—12), with "residual" elements being characterized by linear (in logarithmical scale) growth of concentrations as f decreases.

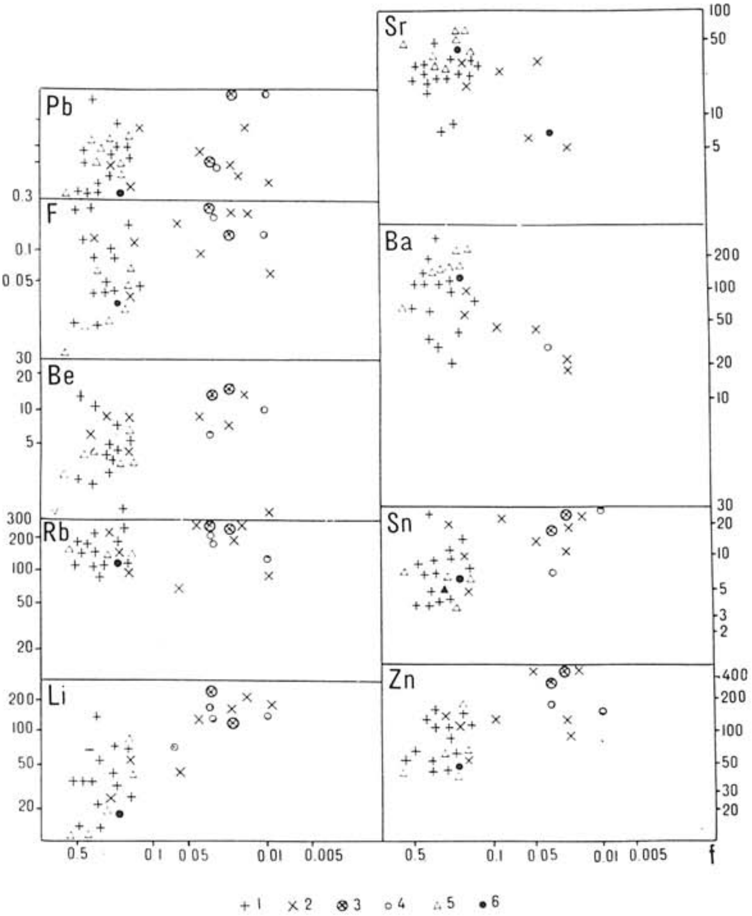


Fig. 11a.

Let us estimate, fractionation of which phases could lead to the transition of basaltic magmas into comendites, naturally, taking into account real composition of phenocrysts in rocks.

At the first stage of differentiation (f > 0.65) melt composition in fact is within basaltic field ($SiO_2 \sim 50\ \%$), but it is somewhat enriched with potassium, sodium and "residual" elements. The change in melt composition may be the result of fractionation of dark-coloured minerals from it (primarily olivine), and also some ferro-titanic oxides removing from the melt iron group elements (nickel, titanium, chromium, cobalt, copper, vanadium, europium). This stage is much less determined than later ones due to a small number of analysed rocks.

At the second stage of differentiation (f = 0.65—0.25) concentrations of FeO*, CaO, MgO, Eu, Sr, in the beginning of the stage of Al_2O_3 decrease sharply indicating separation of clinopyroxene and plagioclase from the melt.

Fig. 11. Selected rare element content (ppm) in plutonic agpaitic rock of Southern Mongolia as a function of residual melt fraction (f).

Explanations: 1 — alkali leucogranites, granosyenites of early phases; 2—4 — alkali granites of late phases (2-echerites, 3-rare-metal microcline-albitic alkali granites, 4-pegmatites); 5 — comendites; 6 — pantellerites.

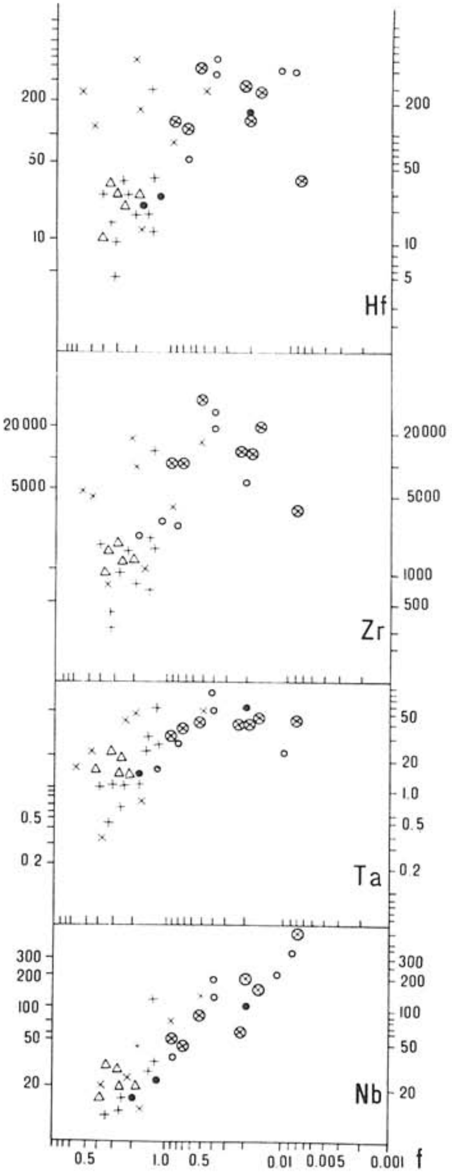


Fig. 11b.

Concentrations of titanium and the iron group elements continue to diminish in melt characteristic of the fractionation of minerals phases of the first stage. Sodium content goes through maximum which is apparently due to fractionation of more and more sodium plagioclase. Minimum sodium content is reached in the end of this stage when fractionation of acid plagioclase is completed.

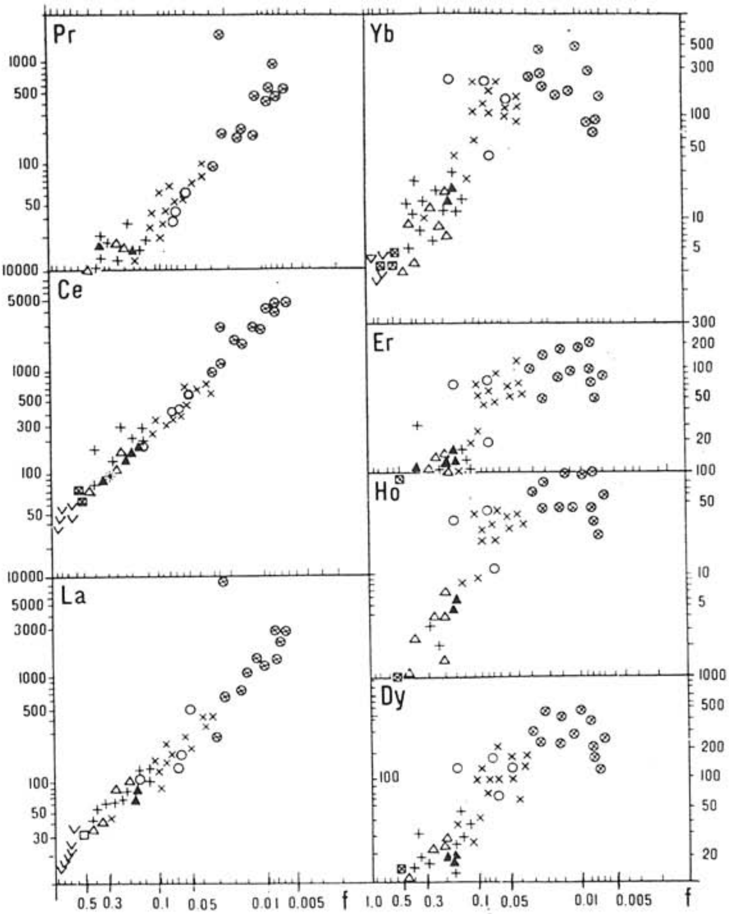
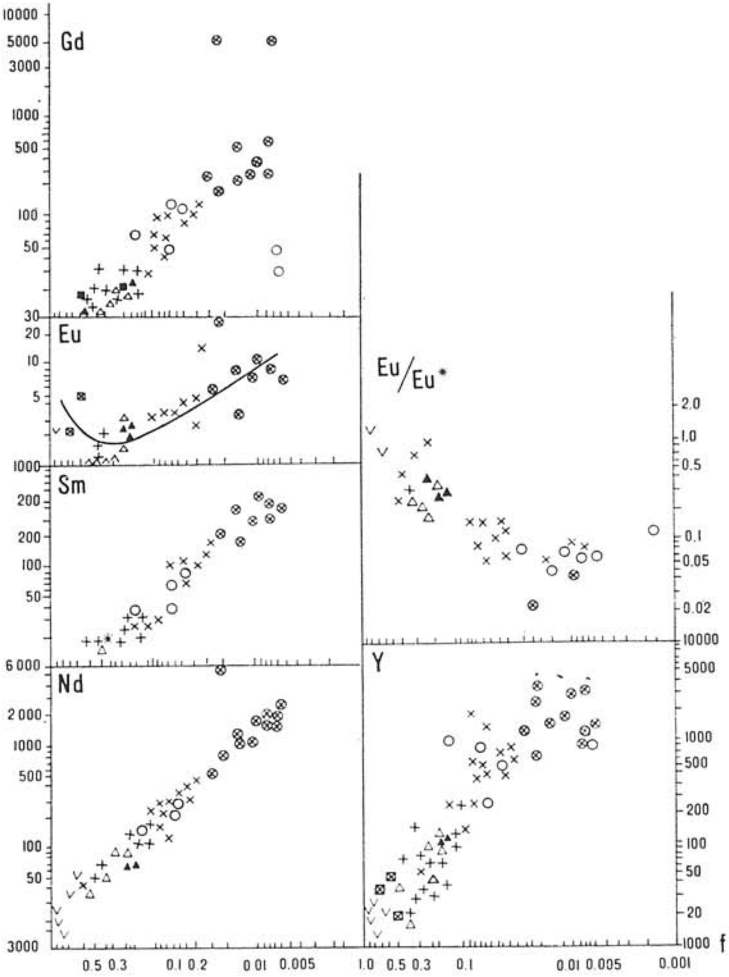


Fig. 12. Logarithms of REE content (in ppm) as a function of residual melt fraction logarithm. Symbols as for Fig. 5.

By the end of the stage potassium content reaches its maximum. In the middle part of this stage some fluorine enrichment in melt occurs followed by its depletion, probably, due to participation of amphibole or biotite in fractionation. By the end of this stage a.c. in the melt passes through unity may be due to the anorthitic efect at which in calcium plagioclase Na_2O/Al_2O_3 ratio is always lower than in melt. It is at this stage that a transition from basalts to comendites occurs. By the end of the stage quartz starts to take part in fractionation.

In the third stage of differentiation (f < 0.2—0.3) fractionation is determined first by separation of alkaline feldspar and quartz. It is with this fact that slight decrease of potassium, silica and sharp decrease of alumina content is connected.

At this stage namely acid agpaitic melt evolves with progressively growing agpaitic coefficient. Usually potassium-sodium feldspar is crystallized so that



Continuation of Fig. 12

bulk partition coefficient of sodium proves to be less than unity, and this element progressively accumulates in residual melt.

At the same differentiation stage in early alkaline leucogranites an opposite tendency in rock-forming component behaviour shows up (Fig. 8a) which is due to the accumulation in rocks of alkaline feldspar and, possibly, quartz. Apparently, the tendency II may be attributed to a cumulative one.

"Residual" elements at this stage accumulate extremely intensively (by logarithmic law) including REE with europium (Fig. 12) up to the formation of rare-metal granitoid melts (Kovalenko, 1977). However, as in other differentiated series, europium accumulates slower than other REE which results in deepening of negative europium anomaly in residual melts, and the Eu/Eu* value progressively decreases. At the very end of this stage heavy REE content decreases, apparently, due to a saturation of melt by these elements and zirconium and precipitation of their own phase (zirconium minerals and others). It is not accidental that some late alkaline granites with similar to early leucogranites f values are enriched with zirconium as compared with the later (Fig. 11), probably as a result of cumulative accumulation of zirconium and REE minerals in them.

The role of water and other volatile components. It is absolutely evident that accepting crystallization differentiation model as a leading one for the process of formation of agpaitic acid magmas from a basaltic melt, one must not ignore the role of volatile components especially because plutonic rocks participate in the series under consideration.

This role can be estimated from studies of melt inclusions in agpaitic volcanic and plutonic rocks in Mongolia (Naumov et al., 1980). Water concentration and fluid pressure in melt at the time of quartz crystallization have been estimated by crystallized microinclusions with separate fluid phase. As seen from the absence of liquid water phase in melt inclusions water content in melt at the moment of quartz crystallization did not exceed 0.5 mass % for volcanites, for alkali leucogranites of early stages was 2.6—6.7 mass % (P_{fl} = 2.0—3.2 kb), for alkali granites of late phases was 2.4—13.9 mass % (P_{fl} = 1.5—6.1 kb). Respectively, homogenization temperature for melt inclusions in quartz amounts: comendites — 1010—860 °C, early alkali leucogranites — 930—800 °C, late alkali granites — 820—700 °C and even 550 °C.

Hence, the following conclusions can be made.

1. Plutonic rocks with the same f values were formed at considerably higher water content than vlocanic rocks. In this case, if only we do not accept not enough founded by all the data mentioned above suggestion about different magma sources for comendites and alkali granites in Mongolia, or about special mechanism of water influx namely to magmas of plutonic rocks, it is necessary to admit that water content in common for comendites and granites magma was not less than in the melt of early alkali leucogranites in which it was kept due to external pressure of plutonic chamber. In erupting to the surface comenditic lavas this water was lost during a dramatic drop of pressure. Not accidentally, many comendites form ignimbrites characteristic of explosive eruption conditions.

2. The loss of water (and other volatile components) during formation of comendites, probably, inhibited further differentiation of magma. In plutonic conditions when water preserved in magma the latter underwent further differentiation to form finally residual, low-temperature (up to 550 °C), very water-rich melts of rare metal microcline-albitic alkali granites. The presence of water sharply decreased viscosity of acid melt which also was favourable for its extreme crystallization differentiation.

3. Knowing f for alkali granitic magmas and their H_2O content it is possible to estimate water concentration in initial basaltic magma, assuming, naturally, that water is a typical "residual" component. This concentration is 0.5—0.8 mass %, that is rather much for basaltic magmas.

4. Judging by comparison of distribution of elements in volcanic and plutonic rocks with similar f values, the presence of water and other volatile components favoured magmatic differentiation during which of most importance was distribution of elements in accordance with crystal $\rightleftarrows$ melt distribution. Trans-

porting role of fluid can be noted only for lithium, beryllium, tin, fluorine in which comendites are depleted due to the loss, probably, of fluid as already discussed above. The presence of single for volcanic and plutonic rocks trends of element behaviour supports an assumption of a single mechanism governing their variations in favour of crystallization differentiation.

Volume ratios of rocks of various compositions in the bimodal series of Mongolia

It was mentioned above that volume ratios of basic and acid rocks in volcanic sections ranges from 2 : 1 to 3 : 1. Taking into account plutonic alkali granitoids it will be even less, indicating approximately equal volumes of basic and acid rocks at modern erosional level. At the same time, judging by the f value at which acid rocks appear, this ratio could not be less than 3 : 1 — 5 : 1. Moreover, basic rocks must be more voluminous than intermediate rocks and intermediate more voluminous than acid rocks. But in reality, intermediate between basic and acid rocks occur in volcanic sections in smaller amounts than basic and acid rocks.

Can this picture be reconciled with the model of crystallization differentiation of basaltic magma?

Let us note at once that the increase of portion of acid rocks in continental geodynamic environments is a typical phenomenon occurring not only in continental rifts. For example, for calc-alcaline series of island arcs and Andian type active continental margins a linear correlation is outlined between the fraction of acid magmas and thickness of continental crust (Gill, 1981). This is why solution of this problem is important not only for the bimodal series of Mongolia and even for continental rifts.

In this particular case that we consider, as in general, two explanations for these ratios can be given: 1) due to effect of physical properties of continental crust; 2) due to effect of chemistry of continental crust.

In the first case it is assumed that lower density of continental crust resulted in slower movement of the column of "dense" basaltic magma and, consequently, its more deep differentiation to give only cumulates and residual acid magmas in the extreme case. In doing so, upper parts of such magmatic columns must be enriched with less dense acid melts. In this case ratios between rocks with different silica content may be close to those observed in Mongolia because heavy basic and intermediate rocks "got stuck" in lower parts of the crust.

Similar mechanism has been suggested for the Cenozoic bimodal series with comendites in western USA (Noble—Parker, 1975) and it has been substantiated by the presence of large positive gravitational anomalies in this region. It cannot be excluded that similar picture developed and in Late Paleozoic in Mongolia.

In the second case crustal source of agpaitic acid magmas is assumed in addition to those formed during crystallization differentiation of basaltic melt. It is obvious that to preserve trends of crystallization differentiation model considered above it is necessary that crustal palingenic agpaitic melts to possess analogous compositional characteristics. This seems possible if interaction of a large volume of fluid in equilibrium with residual comenditic magmas with crustal material to give metasomatic transformation of the latter (alkaline granitization) and its subsequent melting is assumed. Zones of such alkaline granitization at Precambrian structural level are known, presence of water (fluid) in alkali granitic magmas and also probability of its loss during upward transportation of magmas have been shown above. It is possible that mantle fluids enriched also with other volatile components take part in the process. It is

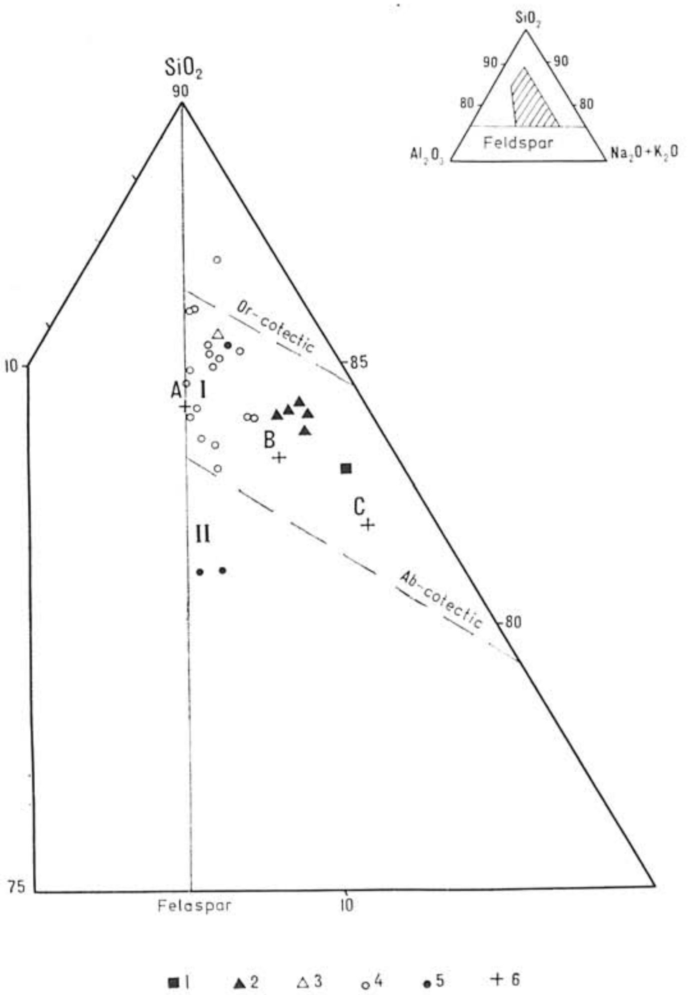


Fig. 13. Position of agpaitic acid volcanics of Mongolia in the diagram SiO_2—Al_2O_3—$(Na_2O + K_2O)$ taken from (21).

Explanations: 1 — pantellerite, Pantelleria; 2 — comendite, Major, New Zealand; 3 — comendite, Sardinia; 4 — comendite, S. Mongolia; 5 — pantellerite, S. Mongolia; 6 — position of the temperature minimum in the system Ab-Ort-2Q-H_2O with 4.5 % a.c. + 4.5 % (B), 8.3 % (a.c.) + 8.3 % (c) taken from (21). Field I — continental agpaitic obsidians, field II — the same for oceanic ones taken from (23).

not accidental that fluids ($H_2O + CO_2$) in equilibrium with mantle minerals have agpaitic rich in silica composition. In any case this hypothesis implies larger amounts of agpaitic silicaceous rocks at the expence of addition of crustal agpaitic rocks to residual rocks.

In conclusion of this division we would like to note the probability of separation at this or other stage of differentiation of chambers of basic and acid magmas with which the "contrast" character of the series that is alternation of eruptions of sharply different in composition magmas is connected.

Let us note that basaltic magmas in Mongolia are more rich in $Na_2O + K_2O$ as compared with basalts of Pantelleria and the Boina Centre (Barbert et al., 1975), but the both as a rule do not contain normative feldspathoids and refer to intermediate (in our classification to subalkaline) between alkaline and tholeiitic basalts. It is such liquids appear to be able to give agpaitic acid residual melts, whereas even in schematic diagram He-Di-SiO_2 alkali basalts must give undersaturated in silica residual melts and calc-alkaline basalts — normal rhyolitic magmas.

Taking into account experimental data (Carmichael — Mackenzie, 1967; Thomson — Mackenzie, 1967) in Fig. 13 broadly used by various investigators, it has been shown that agpaitic compositions of Mongolian series under consideration are situated in fields of "continental" and "oceanic" comendites according to Baily (1970), althoug both of them were formed in

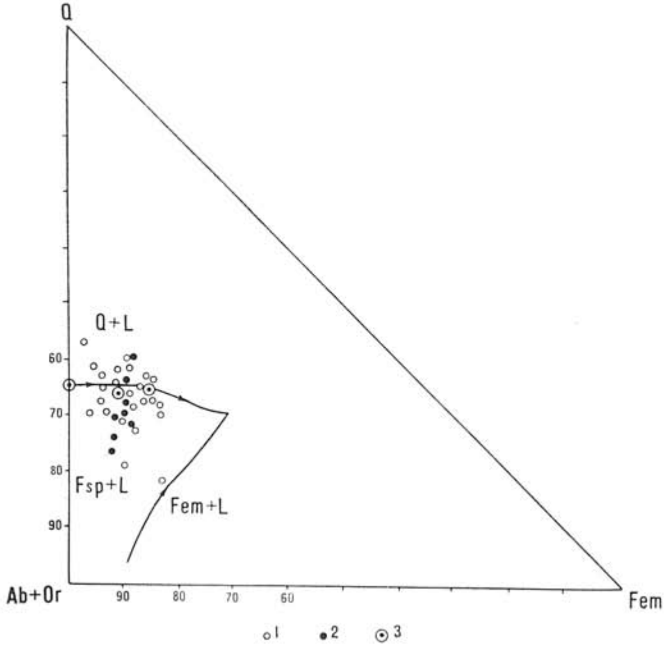


Fig. 14. Position of agpaitic acid magmatic rocks compositions in the schematic melting diagram Q-AFs-Fem (17).

Explanations: 1 — volcanics; 2 — granitoids; 3 — position of boundary line Q + AFs + + melt in the system Q + Ort + Ab + a.c. (21).

continental geodynamic environments. Compositions of less alkaline series referring to "continental" comendites prove to be very close to granitic minimum with addition of Na_2SiO_3 and may indeed, as discussed above, be connected with anatexis of continental crust.

Fig. 14 constructed by us basing on the succession of crystallization of minerals in agpaitic felsitic melts and experimental data, shows that all differentiation trends of agpaitic magmas may be considered in the frame of changing composition of residual melt during fractionation of alkaline feldspar in the field of AFs + melt. When the composition of melt reaches cotectic curves, pairs of minerals start to crystallize. Comendites or pantellerites rarely differentiate along cotectic lines, possibly, due to a loss of water limiting differentiation. However, in plutonic conditions this process goes on in the direction of growing agpaitic coefficient connecting temperature minima of granitic system with increasing alkalinity according to experimental data (Carmichael—Mackenzie, 1967; Thompson—Mackenzie, 1967) to a single trend.

Conclusion

Summing up all the above said, let us note that bimodal basalt-comendite-alkali granitic association is broadly distributed among Late Paleozoic volcanic rocks in Mongolia. It is an indicator of geodynamic regime of continental riftogenesis that is due to the processes of lithosphere spreading when passing of continental plate above buried mid-ocean rift or other processes. As in other environments of continental riftogenesis, under moderate depth conditions in the mantle, probably, metasomatically altered, at the expanse of partial melting and diapirism basaltic magmas of subalkaline series (intermediate between tholeiitic and alkaline basalts) were generated. Emplacement of these magmas in the lithosphere and its extensive crystallization differentiation resulted in formation of residual comenditic and alkali-leucogranitic magmas and development of bimodal volcano-plutonic association. Magmatic source regions undoubtedly were differentiated in vertical direction, its upper parts being enriched with less dense silicaceous melt. Later source regions for basic and acid magmas could be segregated. This differentiation process appears to have been accompanied with segregation of fluids from magmas promoting alkaline granitization and subsequent melting of continental crustal materials due to their effect, probably, to add also anatectic melts to the residual comenditic melts. When water was preserved in comenditic magma its crystallization differentiation continued up to formation of low-temperature (550 °C) water-rich (to 14 % H_2O) melts of rare-metal alkaline microcline-albitic granites and pegmatites.

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