P-T AND H₂O CONCENTRATION OF MESOZOIC GRANITOID FORMATION IN THE MONGOL-OKHOTSK ZONE, BASED ON MELT INCLUSION INVESTIGATIONS, MONGOLIA, SIBERIA

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ABSTRACT Constraints on the ranges of some parameters of granitoid formation in the Mongol-Okhotsk zone (MOZ) have been determined, based on melt inclusion investigations: temperature from 1235° to 500 °C, pressure -from 8000 to 90 bars, and H₂O concentration -from 13.9 to 0.2 mass %. Increasing value range of temperature, pressure and H₂O concentration in the melt of granitoid magma crystallisation up to the limiting values in the crystal conditions have been found with decreasing depth of granitoid facies occurrences. Values, around the main modal values of corresponding distributions, are common for batholiths. The maximum values are mainly related to small, rare-met al ore-bearing intrusions.

The maximum water pressures and concentrations in the melt are found in rare-met al granitoid massifs. The possibility of forming the rare-met al granitoids by fluid-magmatic differentiation (metamagmatic transformations) of early palingenic granitoid melts, and the participation of fluids with high hydrocarbon content is shown. Fluid-magmatic differentiation is of great importance in the formation of rare-met al ore-magmatic systems.

Key words: granitoid, Mongol-Okhotsk zone, melt inclusions, fluid-magmatic differentiation, granitoid formation

INTRODUCTION The origin of granitoid is still a topical problem in petrology. The study of inclusions of magmatic fluids and melts could provide important data on the main physical-chemical parameters -temperature, pressure and water content -of granitoid magmas crystallisation. Accurate data on the diverse granitic types which occur in space-time zones with in large lithospheric block allows comprehensive comparisons to be made. The Mongol-Okhotsk zone (MOZ), occurring as a wide belt (~ 1000 x 3000 km, Fig. 1) from the Okhotsk Sea into the Asian continent and characterised by a variety of granitoid compositions and facies, is a suitable object for such investigations. A large amount of data is available on geochemistry and geology of MOZ granitoids (Koval 1990). These results are the basis of the geochemical database on MOZ Mesozoic granitoids, created at the Vinogradov Institute of Geochemistry, Siberian Branch of Russian Academy of Science (Koval *et al.* 1997). The "Inclusions" block of this database contains the data from the literature (Bazarov *et al.* 1969, Bakumenko & Kosukhin 1976, Bakumenko *et al.* 1979, 1981 a,b, 1981, Vartanova *et al.* 1979, Galibin *et al.* 1973, Yerokhin *et al.* 1989, Ivanova *et al.* 1985, Kovalenko *et al.* 1990, Kosals 1976, Kosukhin 1977, 1980, Naumov & Ivanova 1980, Naumov *et al.* 1977, 1980, 1982, 1983, 1984, 1987, 1990, Poliveyev & Berzina 1984, Polyansky 1973, Reyf & Bazheyev 1982, Reyf 1990, Sotnikov *et al.* 1979, Tshupin & Matrenitsky 1980, Shapenko 1982, Shapenko & Kharlamov 1977) as well as the authors' data, used to prepare the present paper.

A significant heterogeneity of data both from the parametric viewpoint and in terms of completeness of the descriptions of the granitoid characteristics is an inevitable feature when studying such objects. The creation of "Inclusions" block permitted the evaluation of the completeness of data and to reveal the gaps in information, which is essential when defining the goals of future investigations. Data on some Late Palaeozoic granitoids of the region are used to provide additional MOZ characteristics. Although the data are heterogeneous and incomplete, they are useful for understanding the physical-chemical conditions of formation of different geochemical granitoid types and for development of models of granite formation.

GEOLOGY The MOZ is one of the large-scale examples of intercontinental orogenic areas. It was identified by Fersman (1926) as a geochemical province related to Mesozoic magmatism and mineralization. The MOZ forms an belt up to 1000 km wide stretching from Central Mongolia, to the Sea of Okhotsk over 3000 km east (Fig. 1). The Mesozoic granitoids occupy over 150,000 km² or 5-10% of the area of the zone. The chemically and geochronologically diverse basement includes the Middle-Late Palaeozoic Mongol-Trans-Baikal (Mongol-Okhotsk) fold system, adjacent areas of older ancient folding, and Aldan shield to the north.

Late Palaeozoic and Mesozoic orogenic and rifting structures, i. e. uplifts, and troughs and basins, filled by continental terrigenous and volcanogenic depositions, were formed on this heterogeneous basement. Only at the eastern termination of the Mongol-Okhotsk zone there was a marine Mesozoic trough with a domains of oceanic crust (Yanshin 1989). Thus, by the beginning of the Mesozoic time the greater part of the Mongol-Okhotsk region was an area of continental lithosphere, heterogeneous in composition, structure and degree of maturity.

The tectonic structures and magmatism of the MOZ developed during two main stages - Early Mesozoic (Tr₁J₂) and Late Mesozoic (J₃-K₁) (Koval *et al.* 1989, Yanshin 1983). The largest Early Mesozoic structure of the Mongol-Okhotsk zone is the Dauria-Khentei domal uplift (~1000 x 400-500 km), which occupies the central part of the magmatic area. In the north, east and south it is bordered by the system of intermontane fault troughs mainly filled with continental volcanogenic-terrigenous and molass depositions. In the Late Mesozoic, continuing faulting and block dissection of the preceding structures was accompanied by intense volcanic activity.

Mineralization associated with Mesozoic granitoids of MOZ is very diverse and widespread, including deposits of rare elements (Sn, W, Ta, Li, Nb, Zr, REE), base-met als, molybdenum-copper, gold, fluorite and others.

In terms of plate tectonics, early models proposed that magmatic activity was either related to subduction of the oceanic rift zone under the continent (Kovalenko *et al.* 1984, Zonenshain *et al.* 1976) or to continental collision (Naumov & Ivanova 1984). Later models have been developed which include rifting, subduction and continental collision (Zonenshain *et al.* 1990). In the authors opinion, the most promising model involving collision and mantle diapirism (Koval 1987).

GEOCHEMICAL TYPES AND FACIES OF GRANITOIDS IN

THE MOZ The MOZ is characterised by a variety of granitoids present including analogues of types from active continental margins of Andean type, and from collision and rifting settings (Koval 1990). Based on the geological-geochemical analysis the MOZ granitoids are divided into 13 geochemical types belonging to granitoid proper series (restricted granitoid series) and basite-granitoid (expanded) series (Koval 1990, Koval 1991). The restricted granitoid series, covering more than 90% of total granitoid area include three groups of types: "palingenic" granitoids (series of normal (moderate) alkalinity, subalkaline series, and monzogranitoids); subalkaline and alkaline granitoids of syenite-alaskite intrusions; rare-met al granites of different alkalinity. The latter complement the palingenic and syenite-alaskite series and are considered as their derivatives. The lithium-fluorine facies, wide spread in the MOZ, is one variety of rare-met al plumasitic granites. Granitoids of tholeiitic, trachyandesitic and latitic series form the expanded basite-granitoid associations.

The average composition of the MOZ Mesozoic granitoids is marked by the increased alkalinity and sodium content, enrichment in Ba, Zr, Hf, Sn, Pb, Zn, Co, Ni, Cr, B and depletion in Nb, Ta, REE compared to granitoid clarkes. The "palingenic" geochemical types (batholiths) are predominant and the subalkaline granitoids of syenite-alaskite, "palingenic", rare-met al, latitic and trachyandesitic types are widespread.

The granitoids were divided into three "conventional" facies of depth (Yanshin 1983): mesoabyssal (upper mesozonal - low epizonal), hypabyssal (upper epizonal), near-surface and subvolcanic. The Late Mesozoic intrusions are less-eroded at whole than the early Mesozoic intrusions. A greater variety of granitoid types is characteristic for upper depth facies compared to mesoabyssal one.

Table 1 gives the classification of massifs under discussion into geochemical types and depth facies. As could be expected, all MOZ granitoids have not been characterised. Rare-met al granitoids, which are of great interest to the research workers, are predominant and

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Figure 1 - Area of MOZ Mesozoic magmatism. 1 - granitoid massifs; 2 - 7 - basement complexes: 2 - Archean, 3 - Archean-Proterozoic, 4 - Proterozoic-Early Paleozoic, 5 - Early Paleozoic, 6 - Middle Paleozoic; 7 - main faults; 8 - location and numbers of massifs, for which the inclusions have been studied: 1 - Mariktikan; 2 - Zhirekenskii; 3 - Kara-Chachinskii; 4 - Vershino-Darasunskii (Darasunskii); 5 - Borshchovochnyi; 6 - Balyaginskii; 7 - Zharchikhinskii; 8 - Kunaleyskii; 9 - Bom-Gorhonskii; 10 - Utulik; 11 - Spokoynenskii (Khangilayskii); 12 - Bitu-Dzhidinskii; 13 - Sokuyskii; 14 - Totkhotovskii; 15 - Malokunaleyskii; 16 - Pervomayskii (Gudzhirskii); 17 - Tamirskii; 18 - Bichurskii; 19 - Ary-Bulakskii; 20 - Adunchelonskii; 21 - Sherlovogorskii & Sopka Bolshaya & Sopka Vyisokaya; 22 - Tsagan-Olyevskii; 23 - Kyrenskii; 24 - Balgagolskii; 25 - Narin-Tolburigoyanskii; 26 - Bukhayngolskii; 27 - Erdenetskii; 28 - Baldzhigolskii; 29 - Khusutayskii; 30 - Tsagan-Dabinskii; 31 - Gorikhinskii; 32 - Bayan-Ulanskii; 33 - Ongon-Khairkhanskii; 34 - Baga-Gazryn; 35 - Yugodzyrskii; 36 - Khetsu-Tag & Durbent-Dort-Ula; 37 - Khan-Bogdinskii.

consequently the bulk of the data refers to the granitoids of hypabyssal and shallow facies, while only two massifs belong to the mesoabyssal facies. However, the set of massifs is sufficiently representative for this first summary and comparative analysis.

PROCEDURE TO DETERMINE THE PHYSICAL-CHEMICAL PARAMETERS The paper provides the evaluation of conditions of forming granitoids using the results of individual melt and fluid inclusions. Three parameters are of main interest: homogenisation temperature (corresponding to the temperature of crystallisation of host mineral), pressure (as a rule, water pressure) and water concentration in the melt.

The homogenisation temperature of melt inclusions was determined either by continuous observation during the heating in the thermal stages of different designs or by chilling, which gives better results for acid melts due to their higher viscosity (Naumov 1969).

The pressure of water fluid was evaluated either from the crossing point of isochore and isotherm of the inclusions of fluid, or from the inclusions of water-bearing melt jointly with the assessment of water concentration (Naumov 1979).

RESULTS The selection discussed includes more than 2730 determinations of temperature, more than 740 measurements of pressure and over 980 determinations of water concentrations, obtained for 43 massifs (Tables 2-4). Wide ranges of parameters have been established: temperature from 1235 to 500 °C, pressure from 8000 to 90 bars, water concentration from 13.9 to 0.2 mass %. The presence of silicate melt is confirmed in the majority of inclusions with homogenisation temperatures up to 540°C and more (Bakumenko & Kosukhin 1981, Naumov et. al. 1982). These lower-temperature melts are associated with the presence of elements such as F and Li which reduce the solid temperature of granite.

The available data can be considered from different aspects: geological (age, depth of formation and size of intrusion), geochemical (geochemical granitoid types) and mineralization (ore bearing - barren massifs).

The change of crystallisation temperature with the depth is obvious (Table 5): the widest interval (from 540 to 1235°C) and highest temperature (1235 °C) are found for the shallow granitoids (near-surface and subvolcanic). The temperature interval and maximum significantly decrease in the hypabyssal facies (from 500 to 1110°C). The data for the mesoabyssal granitoids are scarce, but they fit into the 650-550°C interval.

Water pressure in the melt increases with increasing depth, though variation is relatively small (Table 5). The maximum value reaches 8 kb for the Pervomayskiy intrusion, which is the maximum water pressure found in the lithosphere (Naumov & Kovalenko 1986). Only one high value (6 kbar, in the Khan-Bogdinsky massif) is found for near-surface granitoids, while for the majority of them the water pressure does not exceed 5 kbar. The minimum values for the near-surface massifs may be as low as 90 bar while for the hypabyssal facies they may be as low as to 900 b. In case of mesoabyssal massifs two values are from 1110 to 4200 bar.

The determinations of water in the melt gives the similar pattern (Table 5) for near surface and hypabyssal granitoids. Data are not available for the mesoabyssal facies. A wider interval and lower value of the main modal value of shallow granitoids should be noted.

A comparison of batholithic massifs (Kyrenskiy, Borshchovochniy, Bukhayngolskiy, Bichurskiy, Tsagan-Dabinskiy, Gorikhinskiy, Soktuyskiy, Adunchelonskiy, Tables 2-4) with the total populations shows that extreme values of the crystallisation parameters are uncommon, lying close to modal values of temperature and pressure and "saturated" water concentration.

The parameters change little with age, and the differences can be related to differences in facies, and therefore to difference in erosion level. So, the Early Mesozoic granitoids are characterised by lower crystallisation temperature, pressure and water concentration compared to the Late Palaeozoic and Late Mesozoic ones.

In the near-surface facies (Table 5) the maximum and minimum values of temperature, pressure and water concentration are found in rare-met al granites, in particular in the lithium-fluorine facies of rare-met al plumbasic granites and rare-met al apaitic granites. Among other geochemical types the maximum values are found for the granitoids of the trachyandesitic series ($T=1230^{\circ}\text{C}$), while minimum values are typical of monzogranitoids (690°C).

Among the hypabyssal massifs (Table 5) the maximum and minimum values of these three parameters are typical of rare-met al grani-

*Table 1 - Geochemical types and facies of granitoids of the Mongol-Okhotsk zone, considered in this paper. Massif numbers on Fig 1. are given in brackets; * -massifs are located westwards from the area in Fig. 1, within the Mongol-Altai zone.*

Geochemical types (from Koval 1991)	Depth facies of granitoids	
	mesoabyssal (upper meso-zonal - low epizonal M)	Hypabyssal (upper epizonal, (H))
Syenitic-alaskites of alkaline rank		near-surface and subvolcanic (S)
Rare-metal agpaitic granites		Tokhuyatskiy (14) Mabokunalskiy (15) Kunalskiy (8)
Rare metal alaskites		Khakran- Borogolskiy *
Rare-metal granitoids of subalkaline rank		Khan-Bogdinskiy (37) Bayan-Ulanskiy (32)
Syenitic-alaskites of subalkaline rank		Bom-Gorhonskiy (9)
Granitoids of latitic series		Pervomayskiy (Gudzhirskiy) (16) Bim-Dzhidinskiy (12)
Granitoids of trachyandesitic series		Zharchikhinskiy (7) Baga-Garyn (34)
Palingenetic monzogranitoids		Vershino-Darasunskiy (Darasunskiy) (4) Erdeneuin-Obo (27)
Palingenetic granitoids of subalkaline rank		Balyaginskiy (6) Kara-Chachinskiy (3)
Palingenetic granitoids of subalkaline rank		Bichurskiy (18) Tumirskiy (17) Bukhayngolskiy (26)
Palingenetic granitoids of subalkaline rank		Narin-Tolburegskiy (25) Eastern Narin- Tolburegskiy (25) Khusatayskiy (29) Balgolskiy (24)
Rare metal plumbasic granites	Borshchovochniy (5)	Tsagan-Dabinskiy (30) Kyzyl-Tau* (Ulan-Ula) Marikutan (1) Gorikhinskiy (31) Spokoynenskiy (Khangilayskiy) (11) Soktuyskiy (13) Adunchelonskiy (20)
Li-F facies of rare metal plumbasic granites		Yagodzyskiy (35) Sherlovogorskiy (21)
Palingenetic granitoids of normal alkalinity	Kyrenskiy (23)	Baldzhigolskiy (28) Sopka Bolshaya & Sopka Vysokaya (21) Ary-Bulalskiy (19) Khetsu-Teg (36) Ongon-Khairkhanskiy (33) Durbent-Dort-Ula (36) Utulik (10) Zhirkenskiy (2)

toids. It should be noted that the maximum temperature, pressure and water content are in cases observed for one and the same object.

The main fluid component is water, found by all investigators. For the granitoids of the above three main stages the maximum pressures of water fluid and maximum water concentrations in the melt are associated with the rare-met al granitoids (Table 6).

The water phase often contains alkaline chlorides in different concentrations: from a few percent up to 70 mass %, i.e. chlorine is after water the second most widely distributed component in these cases. Some massifs have a dense carbon dioxide phase (Spokoynenskiy massif, Reyf & Bazheyev 1982), Utulik (Yerokhin et. al. 1989). However this problem is not well studied, as the presence of carbon dioxide often is not revealed by the methods available for majority of researchers, and its distribution may be significantly wider. High fluorine concentrations are found in the glass of magmatic melt inclusions of ongonites and rare-met al granites (Naumov et.al. 1990, Kovalenko et. al. 1992).

DISCUSSION The data obtained confirm the significance of volatile and in particular water, in the formation of MOZ granitoids. The water pressure values evaluated from the average MOZ granitoid composition satisfactorily correlate with the thermobarogeochemical data (Fig. 2).

The range of crystallisation parameters increases for the granitoids at shallower erosion levels. As it is expected based on the common viewpoints, the modal values of crystallisation temperature increase while the modal and minimum values of pressure and water content in the melt decrease with the decrease of massif formation depth. However, the opposite tendency is found in a great number of cases: the coordinated growth of parameters in shallow fades to values, which markedly exceed the corresponding lithostatic conditions up to the maximum ones, found for the magmatic and metamorphic rocks (Tables 2-4). It correlates with a wider variety of geochemical granitoid types, observed under the transition from the mesoabyssal to the hypabyssal and the near-surface facies of magmatic areas. It is obvious that the anomalous parameters are not typical of the large batholith massifs (which form at from 980 to 540 °C, from 5600 to 1200 bars, from 8.1 to 2.5 wt. % H_2O), but are associated with the formation of

small stocks, pipe dikes, and subvolcanic structures (from 1230 to 500°C, from 8000 to 90 bars, from 13.9 to 0.2 wt. % H₂O). Taking into account that geochemical types formed during the final stages of main differentiation trends of both granitoid and homodromic basite-granitoid series (rare-met al, trachyandesitic and latitic types) predominant in this case, the increase of physical-chemical parameters range can be inferred on the final stages of main trends of such series.

What is the source of high water pressures which exceed lithostatic pressure but not, of cause, overburden strength in the granitoid melts? One of the possible reason is the increases of fluid pressure (and in particular water) under the crystallisation of granitoid melt from the periphery to the centre of magmatic chambers. However, in its unmodified version, this model is not appropriate for small intrusions and for cases of simultaneous increase of pressure and temperature i.e. it is highly improbable for the objects under consideration. On the other hand, the magmatic melt might be a fluid-conductor, transmitting the pressure of fluids from the deeper zones. In case of extensive magmatic column, the pressure of fluid from the deeper zones might be transmitted into the hypabyssal and even subvolcanic zone. This mechanism as well as the first one might lead to the explosive separation of volatile, enriched in ore components and the formation of ore-magmatic systems. Their productivity for the second variant is significantly higher. The second model is the most appropriate when forming the porphyry deposits.

The cases where high fluid and water pressures are related to maximum crystallisation temperatures (rare-met al granites) and high temperatures couldn't be attributed due to the loss of volatile, may result from a high carbon dioxide content in the fluid, leading to a shift of the solidus shifting to a higher temperatures area (Fig. 3). It may be verified by the position of fields for different granitoid types and in

particular by the finding some points in the area of dry granite solidus. It also can be verified by high CO₂ concentration in the hydrothermal fluid of rare-met al deposits (Reyf & Bazheyev 1982, Reyf 1990). This conclusion is not in variance with experimental constraint of granitoid magmas genesis (Swenson 1979, Clemens 1993, Nekvasil & Carroll 1996).

The majority of high temperature and pressure values were obtained for inclusions in early phenocrysts, which may be the argument to prove the participation of deep high-carbon fluids and significance of fluid-magmatic differentiation ("metamagmatic" according to Korzhinsky 1973) and transformation of early granitoid magmas under the formation of rare-met al granite magmas. It cannot be explained the simple fractional crystallisation of large volumes of palingenic granitoid melts (Kovalenko 1977, Koval 1990). The magmas could start crystallisation before their intrusion into upper crystal levels.

The increase of carbon dioxide/water ratio in the magmatic fluid is also possible due to the preferred loss of carbon acid under the degassing of large "parental" intrusions. The extensive prominences of these (apophysis and dikes) might be the diverted channels of escaping gases. However, in this case the idea on the significance of melt magmatic transformation under the formation of rare-met al magmas is still true. The only problem is the source of fluids, enriched in the carbon acid, though there are may be several sources (outer, crystal and juvenile and inner -automagmatic).

Judging from the data used here, the areas of intensive fluid-magmatic differentiation are the most favourable to host the endogenous mineralization.

The data obtained do not contradict the ideas on two types of granitoid magmas, primary and their derivatives (Tauson 1977, Koval 1990). The first type includes the "palingenic" crustal cotectic magmas

Table 2 - Parameters of forming Late Mesozoic granitoids in the Mongol-Okhotsk zone. Number of studied inclusions is given in brackets'

Geochemical types of granitoids	Massif (numbers as in Fig. 1)	Depth facies	Rock	Temp. °C	H ₂ O P, bar	H ₂ O %	Reference
Li-F facies of rare metal plumbastic granites	Baldzhigolskiy (28)	S	Ongonite	1050-680 (>4)	-	-	Naumov <i>et al.</i> 1982
	Sherlovogorskiy (21)	H	Granite	690-640 (>22)	-	-	Kosukhin 1980
	Sopka Bolshaya & Sopka Vysokaya (21)	S	Granite	1100-700 (>8)	900-800 (>4)	-	Kosukhin 1980
	Ary-Bulakskiy (19)	S	Ongonite	930-580 (27)	-	-	Naumov <i>et al.</i> 1977
		S	Ongonite	1100-620 (>6)	1000-150 (>4)	-	Naumov <i>et al.</i> 1982
		S	Ongonite	700-650 (>4)	1000-800 (>4)	10-8 (>4)	Naumov <i>et al.</i> 1990
	Ongon-Khairkhanskiy (33)	S	Ongonite	1020-920 (17)	-	-	Naumov <i>et al.</i> 1977
		S	Ongonite	1020-540 (>8)	4200-3600 (>4)	8.6-7.2 (>4)	Naumov <i>et al.</i> 1982
	Khutsu-Teg (36)	S	Ongonite	>550 (>2)	3700 (1)	11.7 (1)	Naumov <i>et al.</i> 1987
	Durbent-Dort-Ulat (36)	S	Ongorolite	1180-720 (>8)	2400-600 (>8)	2.3-2.0 (>8)	Naumov <i>et al.</i> 1983
		S	Ongorolite	1200-760 (>20)	1400-90 (>6)	2.3-0.2 (>4)	Naumov <i>et al.</i> 1984
		S	Ongorolite	940-760 (>16)	1400-90 (>6)	2.3-0.2 (>4)	Naumov <i>et al.</i> 1982
		S	Ongorolite	670-620 (>6)	3300-1100 (>4)	7.2 (>2)	Bakumenko & Kosukhin 1981
	Borshchovochuykiy (5)	M	Pegmatite	-	-	-	-
Rare metal plumbastic granites	Khangulayskiy (11)	H	Ongonite	>650 (>2)	4500-3200 (>4)	3.9-3.6 (>4)	Naumov <i>et al.</i> 1982
		H	Ongonite	>650 (>2)	4600 (>2)	4.0 (>2)	Naumov & Ivanova 1980
		H	Granite	825-785 (88)	-	4.8-2.5 (56)	Reyf & Bazheyev 1982; Reyf 1990
	Spokoyenskiy (11)	H	Granite	1025-770 (394)	6200-3600 (155)	6.6-3.2 (210)	Reyf & Bazheyev 1982; Reyf 1990
	Sokruyskiy (13)	H	Granite	800-680 (405)	3200->1400 (243)	6.9-2.7 (243)	Reyf & Bazheyev 1982; Reyf 1990
	Adunchelonskiy (20)	H	Granite	690-620 (>16)	3100 (>2)	-	Bakumenko <i>et al.</i> 1981, 1981b
		H	Granite	690-620 (>16)	-	-	Kosukhin 1980
		H	Granite	640-580 (>10)	3700-3100 (>4)	-	Bakumenko & Kosukhin 1981
		H	Granite	620 (>2)	-	-	Bakumenko <i>et al.</i> 1981, 1981a
		H	Granite	-	-	-	-

Table 3 - Parameters of formation of Early Mesozoic granitoids of Mongol-Okhotsk zone. Number of studied inclusions is given in brackets.

Geochemical types	Massif (number on Fig. 1)	Depth facies	Rock	Temp. °C	H ₂ O pressure, bar	H ₂ O %	Reference
Syenite-alaskites of subalkaline rank	Baga-Gazryn (34)	H-S	Granite	860-800 (7)	3300-1400 (7)	4.4-1.7 (7)	Ivanova <i>et al.</i> 1985
		H-S	Pegmatite	720-640 (7)	-	-	Naumov <i>et al.</i> 1977
		H-S	Ongonite	860-790 (>2)	3300-1400 (>2)	3.4-1.7 (>2)	Naumov <i>et al.</i> 1982
Rare metal plumbastic granites	Tsagan-Dabinskiy (30)	H	Granite	750 (7)	3600-5400 (7)	8.1-4.9 (7)	Ivanova <i>et al.</i> 1985
		H	Granite	750 (>2)	5500 (>2)	6.9 (>2)	Ivanova & Naumov 1980
		H	Pegmatite	600-580 (>6)	3800-3500 (>6)	9.4-7.2 (>6)	Bakumenko & Kosukhin 1981
Syenite-alaskites of alkaline rank	Totkhotskiy (14)	S	Granite	900-700 (>8)	2600-1200 (>4)	-	Vartanova <i>et al.</i> 1979
		S	Norinurkite	890 (>2)	-	-	Vartanova <i>et al.</i> 1979
		S	Syenite	900-670 (>4)	-	-	Vartanova <i>et al.</i> 1979
Palingenic granites of normal alkalinity	Kyrenskiy (23)	M	Pegmatite	560-540 (>8)	-	-	Bakumenko & Kosukhin 1976
		M	Granite	630-550 (>72)	4200-3800 (>4)	-	Kosukhin 1977; Bakumenko & Kosukhin 1981
		M	Granite	-	-	-	-
Palingenic granitoids of subalkaline rank	Bichurskiy (18)	H	Granosyenite	970-800 (>4)	4000 (>2)	-	Vartanova <i>et al.</i> 1979
		H	Granite	600-570 (>4)	4000-2500 (>4)	-	Vartanova <i>et al.</i> 1979
		H	Granosyenite	590-560 (>4)	-	-	Tshupin & Matrenitskiy 1980
		H	Granite	580-560 (>4)	-	-	Tshupin & Matrenitskiy 1980
		H	Granosyenite	660-620 (>2)	-	-	Tshupin & Matrenitskiy 1980
		H	Leucogranite	620-580 (>4)	-	-	Bakumenko <i>et al.</i> 1979
		H	Leucogranite	650-600 (>8)	-	-	Tshupin & Matrenitskiy 1980
Palingenic monzogranitoids	Balagolskiy (Ikhe-Bulaginskiy) (24)	H	Aplitite	620-580 (>4)	-	-	Tshupin & Matrenitskiy 1980
		H	Granite	970-720 (>18)	3500-1700 (>4)	-	Vartanova <i>et al.</i> 1979
		H	Granite	-	-	-	-
Granitoids of trachyandesitic series	Erdenskiy (27)	S	Granite	1230-800 (>18)	-	-	Sonnikov <i>et al.</i> 1979
Rare metal alaskites	Bayan-Ulianskiy (32)	H-S	Granite	>800 (>2)	3500 (>2)	0.5 (>2)	Naumov & Ivanova 1980

Table 4 - Parameters of forming of Upper Paleozoic granitoids of Mongol-Okhotsk zone. Number of studied inclusions is given in brackets. * - massifs located within the Mongol-Altai region

Geochemical types	Massif (number in Fig. 1)	Depth facies	Rock	Temp. °C	H ₂ O P bar	H ₂ O %	Reference
Li-F facies of rare metal plumasitic granites	Bayan-Ulanskiy (35)	H	Granite	900-760 (5)	2200-1800 (5)	5.1-2.1 (5)	Ivanova <i>et al.</i> 1985
		H	Ongonite	650-600 (7)	-	-	Naumov <i>et al.</i> 1977
		H	Ongonite	650-600 (>2)	-	-	Naumov <i>et al.</i> 1982
		H	Granite	860 (>2)	2200 (>2)	3.5 (>2)	Naumov & Ivanova 1980
Rare metal apgraitic granites	Khaldzan-Buregetskiy *	S	Granite	800 (>2)	-	1.5 (>2)	Kovalenko <i>et al.</i> 1990
		S	Granite	1080-700 (>72)	6100-1500 (29)	13.9-0.5 (29)	Naumov <i>et al.</i> 1980
		S	Granite	820-640 (>8)	-	-	Bakumenko <i>et al.</i> 1979
Palingenetic granitoids of subalkaline rank	Narin-Tolburigoykiy (25)	H	Syenite	720-680 (>4)	-	-	Tshupin & Matrenitskiy 1980
		H	syenitegranite	650-570 (>4)	3000 (>2)	8-7 (>4)	Tshupin & Matrenitskiy 1980
		H	Syenite	720-680 (>4)	-	-	Tshupin & Matrenitskiy 1980
Li-F facies of rare metal plumasitic granites	Uruk (10)	S	Granite	>600 (>6)	4000-3000 (>2)	4.7 (>2)	Yerokhin <i>et al.</i> 1989
Rare metal plumasitic granites	Kyzyl-Tau (Ulan-Ula)*	H	Porphyritic granite	800-680 (8)	6100-4700 (8)	13.1-6.3(8)	Ivanova <i>et al.</i> 1985
		H	Granite	1110-840 (721)	1500 (2)	1.0-0.8 (2)	Ryč 1990
		H	Granite	1050-915 (>12)	<1300 (>2)	-	Ryč & Bazheyev 1982
Rare metal granites of alkaline rank	Bihu-Dzhidinskiy (12)	H	Granite	1020-800 (>4)	>1350 (>2)	-	Kosals 1976
		S	syenitegranite	870-820 (13)	-	5.4-4.4 (13)	Ryč 1990

Table 5 - Physical-chemical conditions of formation for granitoids of different depth fades (max-min (average)).

Depth facies	Temperature (°C)	Pressure (bar)	H ₂ O %
near-surface	1230-540 (870)	6100-90 (2200)	13.9-0.2 (4.5)
Hypabyssal	1110-500 (780)	8000-800 (4500)	13.1-0.8 (5.8)
Mesoabyssal	670-540 (600)	4200-1100 (2800)	-

Table 6 - Physical-chemical conditions of origin for groups of geochemical types of granitoids (max-min (average)).

Geochemical types	Temperature (°C)	Pressure (bar)	H ₂ O %
Palingenetic	1230-470 (680)	4800-800 (2700)	11.3-0.6 (4.2)
Rare-metal	1220-500 (940)	8000-700 (3800)	13.9-0.4 (6.1)
Li-F	1200-540 (860)	4200-90 (2200)	11.2-0.2 (2.2)

Figure 2 - The location of the MOZ granitoid compositions on Qz-Ab-Or diagram and Plot - Pmo isobars (James & Hamilton, 1969, Luth *et al.*, 1964, Tuttle & Bowen, 1958). Empty circles - palingenetic granitoids, full circles - rare-metal granitoids (including lithium-fluorine facies).

(palingenetic granitoids and syenite-alaskite intrusions geochemical types) and juvenile basic melts, corresponding to the main stage of granite-formation. Information is still scarce and thus supplementary investigations, in particular of mesoabyssal batholiths, granitisation zones and anatexis are required. The second one involves the anchieutectic (near to eutectic) and apoeutectic (transformed eutectic) magmas of rare-metal geochemical types, as well as differentiates of andesite-basite magmas (granitoids of tholeiitic, trachyandesitic, latitic and

Figure 3 - Variations of the crystallization temperature and fluid pressure (in kbar) for near surface (1) hypabyssal (2), and mesoabyssal (3) depth facies of intrusions. The lines of "dry" liquidus of muscovite granite (4) and solidus for granite -CO₂ (5), granite H₂O (6) and ongonite-H₂O (7) are shown.

alkaline-basaltic series). Such a scheme on the whole corresponds to the observed increase of the variety of geochemical types (from the mesoabyssal to shallow erosion levels). The standard characteristics of different types are reliably determined mainly on the large batholith sections of intrusions. It should be noted that the relationship of rare-metal granitoids with the "palingenetic" ones is confirmed by their spatial association and ratio of total massif areas (Koval 1990), as well as the rare-metal facies in the palingenetic batholiths (Onon massif).

However, as it was shown above, the formation of magmas of rare-metal granitoid types cannot be reduced to different varieties of crystallisation differentiation of "palingenetic" melts. The observed "limiting" T-P characteristics and the levels of accumulation of rare elements require other mechanisms. The metamagmatic transformation of primary magmas by the fluids (fluid-magmatic differentiation) may be considered as one of the probable mechanisms. As to the origin of the fluids, it is not correct to consider only one source, such as the obvious magmatic source. Known examples of rare-metal batholith plutons (Tsagan-Dabinskiy, Egin-Dabinskiy, Borschovochnyi) and the associated granitisation (Egin-Dabinskiy, Borschovochnyi) indicate the large scale of this process, including both the large granite plutons and significant fluid flows in host rocks. The geochemical data on granitoid proper series (restricted crustal granitoid series), indicating the supplementary addition of incompatible elements of the mantle, including the trace elements (Nb, Ta, REE), compatible with the crust, confirms the possible participation of the mantle fluids in the crystal granite-formation. This one of the disputable questions of granite-for-

mation requires a special consideration, mainly from the viewpoint of mass transfer balance.

CONCLUSIONS 1. The crystallisation parameters for MOZ granitoids have been evaluated: temperature from 1235 to 500 °C, pressure from 8000 to 90 bars, water concentration from 13.9 to 0.2 wt. %.

2. The increase of the change range of physical-chemical parameters of the granitoid magmas crystallisation up to the maximum ones in the crystal conditions is found with the decrease of granitoid facies depth. The values, fitting into the area of main modal values of corresponding distributions conform to the batholith sections of intrusions. The limiting values are mainly related to small and ore-bearing intrusions of granitoids of rare-metal geochemical types, formed on the later stages of main granite-formation trends.

3. The possibility of forming granitoids of rare-metal geochemical types due to the fluid-magmatic differentiation (metamagmatic transformation) of early palaeogenic granitoid melts and participation of fluids with relatively high content of carbon dioxide, has been shown. The fluid-magmatic differentiation is of great importance in the formation of ore-magmatic system.

4. The priority of future investigations is to study the physical-chemical conditions of forming granitoids of mesoabyssal facies and facies of the greater depth of all geochemical types.

Acknowledgements Authors are grateful V. I. Kovalenko for stimulating discussions and Ms. Marina Khomutova for assistance in the preparation of the paper. Critical reviews by two anonymous colleagues is highly appreciated. This work was supported by INTAS-92-4 and RFBR-96-05-64941 Projects.

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Manuscript A-1053

Recebido em 12 de Janeiro de 1998

Revisado dos autores em 30 de junho de 1998

Revisao aceita em 10 de julho de 1998