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IDENTIFICATION OF METASOMATIC FAMILIES IN GEOBLOCKS OF UKRAINIAN SHIELD

(Reviewed by the editorial board member V. Shevchuk)

The paper is aimed to refer metasomatites of Ukrainian Shield (USh) to the specific metasomatic families (formations) using the unified system of definitions and terms and to recognize distinctive features of metasomatic rocks for the separate megablocks of the shield. Summarizing the all available data, it can be concluded that restricted list of metasomatic families are identified for the whole of USh. In particular, within USh nearsurface families are not known at all; subvolcanic families are presented in Middle-Dniprean megablock only; but families merely of hypabyssal and abyssal depth levels are shown in other megablocks. Additionally, it has been found that alkaline metasomatic families are evidently prevailing relatively to acid and magnesian-calcian families as well as almost all metasomatic rocks of USh are early or middle Proterozoic. As well it has been found that the separate megablocks of USh are characterized by the specific features of prevalence for different types of metasomatic families. It was concluded that above features of metasomatic rocks distinguish the USh from other Precambrian shields of the world. The authors emphasize that conditionality of hydrothermal-metasomatic processes with general geologic, petrogenetic and tectonic events can give a key knowledge for application of hydrothermaly altered rocks as important petrology and metallogenic indicators.

Introduction

Long since hydrothermally altered (metasomatic) rocks are making good use as significant criterion for exploration of mineral deposits. Investigation of metasomatites allows getting multifarious and often unique information concerning geologic and physicochemical conditions of ore formation. This defines an applied significance of metasomatic rocks. However, it is well known that metasomatic processes are genetically coupled with other endogenous events such as igneous, metamorphic and ultrametamorphic processes, which to a considerable degree assign composition and metallogenic specialization of metasomatites. Therefore in-depth study of hydrothermally altered rocks has a high petrology profile to analyze rock forming conditions within certain geologic unit or region.

Several approaches of hydrothermally altered rock classification were developed since beginning of 20th century [1-3 etc]. However, the concept of metasomatic families approach come as the most general and geologically based way for metasomatic systematics [4, 5]. Concept of metasomatic families (‘metasomatic formations') was first proposed in 1950 decade [6,7] based on ideas of Dmitry Korzhinskii [8], and thereafter it was advanced in the Former Soviet Union and post soviet countries [9-14 etc.]. The authors [4] have summed up these efforts and generalized principal statements of family analysis for metasomatic rocks. In general the recommendations by the IUGS (International Union of Geological Sciences) Subcommission on the systematics of metamorphic rocks concerning metasomatites [5] are based on these statements.

Numerous publications including special books were dedicated to investigation of metasomatites discovered within the Ukrainian Shield (USh) [11, 12, 15-17 etc]. Still there are very restricted numbers of generalized works given up the systematics of metasomatic rocks of USh. Except publications summarizing data on specific groups of hydrothermaly altered rocks (e.g. [11,13,15]) and publications on metasomatites of separate area of USh [11,15,17], there are a few works which anyhow analyze metasomatites for USh as a whole [18, 19, 20]. It has to be noted that all above references date from1970-1980. During last decades considerable volume of new information on metasomatites of USh has been obtained. Moreover this time holistic theoretical and applied approaches of metasomatic systematics based on the family principles have been developed [4, 5].

In particular classification of metasomatic families ("formations") has been proposed in [14]. This attempt was built upon the physicochemical grounds where main class parameters were temperature and acid-base properties of hydrothermal solutions. Besides metasomatites of Siberia, Middle Asia, Ural and other regions, several metasomatic occurrences of USh have been evaluated in [14]. However geologic level of consideration was not introduced in Scherban`s systematics [14]. Vice versa in [4] geologic and petrologic family approach was applied to the only typical metasomstites of USh namely to uraniferrous sodium alkaline metasomatites.

This paper is aimed to refer metasomatites of USh to the specific metasomatic families using the unified system of definitions and terms and to recognize distinctive features of metasomatic rocks for the separate megablocks of the shield.

Main definitions and terms of metasomatic family analysis

It is of importance to fix the meaning of some principal notions as well as relationships between ones before to classify metasomatites on the ground of the family approach. The author's understanding of the terminology of the family analysis for metasomatic systematics as the system of definitions, terms and practical rules is setting out below. Most of cited notions as such are not original. They are formulated in special publications (e.g. [4, 5, 9 etc]) and widely spread in metasomatic petrology. The problem is that part of them has various meaning in different publications and others still were not directly incorporated in the metasomatic family analysis.

Understanding of metasomatic process (metasomatism) is taken in accordance with formulation [4], which defines that metasomatic transformation of the parent rock is occurred at remaining part of the rock in a solid state and with alteration of chemical composition as a result of the interaction between the rock and aqueous endogenic fluids (solution). The most characteristic feature of metasomatic products is their zonation pattern. Therefore the subject of consideration for the family analysis is only endogenic altered rocks. Product of weathering and other products of interaction between rocks and exogenic solutions are not regarded as metasomatites. Rocks formed during interaction of fluids with melts are not related to metasomstites because solid state condition fails. Furthermore, hydrothermal filling veins, which generated by direct crystalliza-

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tion from solution, are not metasomatites as such, whereas substitution veins, which form as a consequence of hydrothermal transformation of parent rocks, refer to metasomatic product. Nevertheless, filling vein just as substitution veins have to be the subject of family analysis because of close spatial and genetic relationships between both vein types and metasomatites.

In general the family (formation) is paragenetic association of the rocks. Thus, definition of certain family has to be based on deducing of genetic unity of the rocks involved in this family. It means that definition criteria for different genetic types of rocks (sedimentary, igneous, metamorphic etc) have to account specific origin conditions. In particular definition of metasomatic family supposes application of the notions which show properties of metasomatism as rock forming process. Within these notions the basic one is metasomatic column which represents horizontal zonation as a general property of metasomatites. It is the certain sequence of zones, consisting of metasomatic rocks (paragenesises). The complete column is formed as result of interaction between parent rock and solution (fluid) at certain conditions (temperature, pressure, chemical composition of parent rock and acted fluid) [4, 21]. It follows from this that metasomatic column is paragenetic association of rocks or metasomatic facies [9].

Metasomatic family is defined [4] as a set of metasomatic facies (columns) which were formed by alteration of rocks of different chemical composition under an action of solutions of certain petrogenetic type. This definition includes the term "solutions of certain petrogenetic type", that is complicated in practice since common genetic character of solutions does not immediately follow from data obtained by direct geologic, mineralogical and petrography methods.

Authors of this paper suggest that metasomatic family i.e. paragenetic association of rocks has to be regarded taking into account such notions as vertical zonation, metasomatic phase and metasomatic stage. Vertical zonation is a regular changing of metasomatic columns (facies) mainly caused by changing of depth and hence by appropriate changing of temperature and chemical properties of solutions during metasomatic replacement of parent rocks under action of single hydrothermal flow [9]. Then it is accepted that metasomatic phase is a period of time when replacement of parent rocks of different chemical composition depth-independently takes place under action of single hydrothermal flow. Consequently in general case vertical zonation is formed during one metasomatic phase. Metasomatic stage can include some phases, which are distinguished with conditions and chemical directivity of alteration, but they are related to single hydrothermal process. And eventually certain metasomatic family includes rocks which were formed over one metasomatic stage. In general location and geologic age do not matter for assignment of certain metasomatic family.

In Table 1 schematic presentation of metasomatic family is shown. It is apparently that metasomatic family constitutes the whole complex of rocks generated as result of single metasomatic process of certain petrogenetic type. The vertical zonation, i.e. set of metasomatic columns (facies) has been formed during prograde phase of this process. Each column differs from another owing to various chemical composition of parent rocks (1, 2, ...k), or because of different depth (h_1, h_2, h_N) and consequently varied TP conditions (PT_1, PT_2, ... PT_N). Additionally, metasomatic family includes products of connected phases. These mineral products can be formed by the way of removal and redeposition of some chemical components (e.g. SiO_2 removal and secondary quartz precipitation caused by alkaline metasomatose), or by mineral precipitation in consequence of solutions oversaturation at temperature and/or pressure decreasing (e.g. formation of secondary carbonates).

Table 1

Schematic presentation of metasomatic family

Single metasomatic process of certain petrogenetic type	Stage, phases		Depth	TP onditions	Products of single metasomatic process				
					$(Parent\ rock)_1$	$(Parent\ rock)_2$	$(Parent\ rock)_K$	Metasomatic columns (facieses) which are included in vertical zonation	METASOMATIC FAMILY
					Metasomatic columns (facieses)				
	Stage	Prograde phase	h_1	PT_1	$facies_{1,1}$	$facies_{1,2}$	$facies_{1,K}$		
			h_2	PT_2	$facies_{2,1}$	$facies_{2,2}$	$facies_{2,K}$		
			h_N	PT_N	$facies_{N,1}$	$facies_{N,2}$	$facies_{N,K}$		
		Connected phases	$h^{\sim}$	$PT^{\sim}$	New formed mineral associations caused by: - removal and redeposition of chemical components; - T and P decreasing, solution oversaturation and precipitation of chemical components				

Family belonging criteria for metasomatic rocks

On the whole family analysis for metasomatic rocks has to be regarded as achievement of two interdependent objectives. There are substantiation of certain metasomatic family (first objective) and referring some metasomatic rocks to certain metasomatic family (second objective).

First objective expects solution of main problem of family analysis that is substantiation of paragenetic unity for rock association. This fulfillment has to be based on results of direct geologic observations and analytical studies as well as on data deducing from these direct results (mass balance calculation, analysis of paragenesises, analysis of metasomatic zonation, estimation of physico-chemical conditions, including temperature, pressure and chemical specialization of solutions). Both direct and deducing data have to be theoretically evaluated and by this way qualitative or quantitative petrogenetic model has to be developed. Therefore final result of these coupled investigations is as firstly, formulation of petrogenetic entirety for the metasomatic rocks relating to certain family and secondly, ascertainment (identification) of geologic, geochemical and petrology characteristics for the rocks of this metasomatic family. Such characteristics, in other words family belonging criteria, have to be based on results of direct observations and measurements as well as on data deducing immediately from geological and geochemical information.

Second objective of family analysis means an investigation of metasomatic rocks with the aim to ascertain the characteristics which are belonging criteria to certain metasomatic family. Taking into account the experience of family analysis [4, 9, 10, 21 etc] the principal family belonging criteria are presented by results of:

a) direct geologic observations (morphology and geologic location of metasomatic bodies, spatial and time relationship of metasomatites with tectonic structures, igneous complexes and rock sequences of different origin etc).

b) mineralogical studies and geochemical measurements (mineral associations, macro and trace element composition of rocks and minerals)

c) formalized geochemical and petrology processing of direct mineralogical and analytical data (typical mineral paragenesises and metasomatic columns, metallogenic and geochemical specialization, chemical feature of solutions, estimates of temperature and pressure).

The most useful method for derivation of the last group of data is analysis of metasomatic zonation.

Identification of metasomatic families for Ukrainian Shield

The identification of metasomatic families was carried out on the base of family systematics presented in [4]. The metasomatic families of this classification are divided among three groups: acid, alkaline and magnesian-calcian. For each family the principal characteristics are given including geochemical and petrologic ones. There are following geochemical characteristics in [4]: typical paragenesises of inner zones in metasomatic columns, metallogenic specialization and mineral associations of connected metasomatites. Petrology characteristics include depth level of origin and relationship between metasomatic and igneous rocks. Moreover an essence of paragenetic unity of rocks for most metasomatic families is formulated as well as geologic examples, descriptions of metasomatic columns and other typical characteristics are given in [4]. "Depth levels" have to be considered as generalized characteristics of thermobaric conditions. They are [4]: nearsurface (NS), subvolcanic (SV), hypabyssal (HA) and abyssal (AB) depth levels. To refer the metasomatites of USh to certain family, available data (see tables 2,3) were compared with family formulations and descriptions by [4]. The identification of metasomatic families has been worked out for separate megablocks of USh: Volyn (V), Dnister-Boug (DB), Ros-Tykych (RT), Kirovograd (K), Middle-Dniprean (MD), Azovian (A). The boundaries between the megablocks were taken from [22].

The results of family identification are presented in Table 2. Having a single meaning metasomatic families are marked by "+". The sigh "?" denotes that there are not sufficient information in accessible data sources for confident referring of the metasomatic rocks to the given family. The albite-aegirine family (family of alkaline sodium metasomatites) has been established for K and V megablocks of USh, however in K megablock this family is represented by uraniferrous metasomatites (marked as "+") and within V megablock uranium ores were not discovered in these metasomatic rocks (marked as "{+}"). For comparison and family identification, besides the publications pointed out in the Table 2, a lot of other data sources were used. In most cases they are cited in publications indicated by "*".

Other metasomatic families of Ukrainian Shield

There are above (Table 2) metasomatic families of USh which appeared in the classification [4]. However despite of this, at least two else families within USh can be substantiated on the base of available information – subvolcanic quartz-carbonate (SQC) family and hematite-calcite-chlorite-orthoclase (HCCO) family. Brief description of these families follows below including general model formulations of paragenetic unity for related rock association, as well as geological, geochemical and petrology family belonging criteria.

The SQC family joins metasomatic rocks which were investigated in detail within Sura greenstone complex (MD geoblock of USh) and described mainly by Victor Monakhov and coauthors [17, 23-25 etc]. Moreover in these publications there are cited works on similar metasomatic rocks discovered in other greenstone complexes of the MD geoblock (Verkhvtsevo, Chortomlyk) as well as in greenstone complexes of Baltic, Australian and Brazilian shields. Generalizing the available data the following family model formulation is accepted: the SQC family includes mesothermal metasomatic rocks which were formed within Precambrian greenstone complexes as result of post magmatic hydrothermal process related to intrusion of subvolcanic porphyritic rocks. Acted hydrothermal solutions are characterized as sodium, considerable carbonate, low acid or near neutral and reduced.

Table 2

Identification of metasomatic families in geoblocks of Ukrainian shield based on systematics [4]

Metasomatic family	Depth level				USh megablocks						Data sources
	NS	SV	HA	AB	A	MD	K	RT	DB	V	
ACID											
Propylites						+					[17*], [25]
Beresites						+					[17*], [25]
Quartz-tourmaline-chlorite family						?					[17]
Greisens					+		?		?	+	[12], [22*], [30], [31*], [32*]
Quartz-feldspar family					+?					?	[12], [31], [32]
ALKALINE											
Apogranites (albitised granites)							?			+	[12], [16], [30], [31]
Albitites within aureole of nepheline syenites					+						[11], [12]
Fenites					+						[33*]
Two feldspar family							?			+	[16], [31]
Microcline-biotite family										?	[34]
Albite-aegirine family							+			{+}	[4*], [9], [11*], [14*], [22*]
MAGNESIAN-CALCIAN											
Carbonate-chlorite family						?					[17]
Amphibole-chlorite family						?					[17]
Phlogopite family										?	[12]
Calc-skarns					+?		+?	?	+?	+	[13*]
Magnesian skarns							?	?	+?	?	[13*]

In this family depending on composition of parent rocks, two distinct groups of facie are separated. Mineral composition essentially tells one group of facies from another. For this reason formerly they were described as two individual groups of metasomatic rocks. First group of SQC metasomatites are represented by zoned aureoles formed as result of hydrothermal alteration of aluminosilicate rocks with composition from acidic to basic. In this case central parts (zones) of metasomatic columns consist mainly of albite with changeable amounts of carbonate (calcite) and quartz [23].

Second group of SQC facies includes vein-type quartz-carbonate-tremolite metasomatites, which replace mainly low thickness bodies of silica-magnesia-calcian rocks (ultrabasic rocks or quartz-carbonate veins) [24]. Zonation of vein-type metasomatites appears more or less distinctly depending on thickness and composition of parent rock [24]. Geo-

logic position, metallogenic specialization and petrology parameters are coincided for both groups of SQC. It is usual occurrence of low thickness tremolitic metasomatites within wide aureole of essentially albitic altered rocks.

Geologic evidences for belonging of metasomatic rocks to SQC family are spatial relation to subvolcanic bodies of porphyritic rocks and especially placement within local tectonic zones in exocontact area of such bodies. Vein-shaped metasomatic bodies or zoned aureoles of thickness from several centimeters to a few meters are morphologic characteristics of SQC metasomatites. Pattern of metasomatic columns for metasomatites of this family depends essentially on composition of parent rock. Vertical zonation of SQC metasomatites is not observed [23, 24]. Inner zones of metasomatic columns are composed of distinctive mineral associations; those are albite+calcite±quartz or tremolite+calcite+quartz. There is typically that secondary mineral associations of connected metasomatic phase (ankerite+biotite+pyrite or ankerite+chlorite+pyrite or ankerite+cericite+pyrite) are locally applied to minerals of inner zones in metasomatic columns of SQC metasomatites. This secondary mineralization is accompanied with gold as well as with following metallogenic associations: Fe-As-Au ±Cu, Fe-Cu-Au, Au-Cu-Mo, Au-Ag-Bi-Te-Pb [25].

Taking into account geochemical characteristics, the SQC metasomatites are distinguished from other resembling altered rocks. In particular, aceites have another (uranium) metallogenic specialization, contain ferrian minerals and are not accompanied with ankerite-biotite(chlorite, cericite)-pyrite secondary mineralization. Uraniferrous albite-aegirine metasomatites (albitites) differ from SQC rocks in the same characteristics as well as in the presence of alkaline amphiboles and pyroxenes. Tremolitic composition of amphibole is a specific sign for SQC family in comparison with another amphibole bearing metasomatites.

The HCCO family is described in detail within Kirovograd megablock of USh [26, 27]. Generalizing the available data the following family model formulation is accepted: HCCO family includes metasomatic rocks which were formed during late Proterozoic tectonic-hydrothermal activity period within tectonic zones without certain relationship with some type of magmatism or complex of igneous rocks. HCCO alteration took place at hypabyssal and low temperature conditions by the action of potassium, essentially carbonate, alkaline and oxidized solutions.

Geologic setting of HCCO metasomatites is defined by area of fractured rocks within lengthy linear fault zones. Separate metasomatic bodies are clearly zoned, but vertical zonation on a level of mineral associations is not observed. Facial varieties of HCCO family depend merely on composition of parent rocks. The typical mineral paragenesis of inner zones in metasomatic columns of HCCO metasomatites is hematite + calcite + chlorite + orthoclase which often are supplemented with net of thin vein composed of secondary chlorite and calcite. Metallogenic specialization of this family is specifically uranium. The HCCO metasomatites are distinguished from other resembling altered rocks by geochemical characteristics. For instance, aceites contain sodium feldspar instead of orthoclase, and gumbeites besides potassium feldspar contain quartz and sulfides.

Metasomatites of USh with uncertain family belonging

Variety of metasomatic rock within USh is far from limited by the list of identified metasomatic families. There is a lot of publications on numerous occurrences of another metasomatites but a scope of information in the accessible sources keeps from substantiation of family self-dependence for some metasomatites or their belonging to certain family. The examples of metasomatites with uncertain family belonging, which were discovered within megablocks of USh and described in referred sources are given in the Table 3.

Table 3

Metasomatic rocks within megablocks of USh with uncertain family belonging

Metasomatites and metallogenic (geochemical) specialization of them		Megablocks of USh						Data sources
		A	MD	K	RT	DB	V	
ACID								
Quartz-microcline metasomatites	U, Mo, Bi, TR						+	[28]
Epidote-actinolite-quartz metasomatites	(Au,As)			+				[29]
Quartz-muscovite metasomatites	Sn, W	+		+			+	[29], [30], [32]
Quartz biotite metasomatites	Au			?		+		[22*], [35], [36*]
Quartz-feldspar metasomatites (within area of pegmatites)	Li, Nb, Ta	?		+			?	[22*],[37]
	(Mn, B)	?		+			?	[22*],[29]
ALKALINE								
Albitites	Zr	+						[38]
Aegirinites	Mo	+						[39]
MAGNESIAN-CALCIAN								
Bazavlukites			+					[40*]
Prenite metasomatites				+				[41]
Scarnoids	W	+		+	+	+	+	[13*], [29]

Conclusion

Summarizing above review, it can be concluded that restricted list of metasomatic families included in [4] are identified for Ukrainian Shield in whole. In particular, within USh nearsurface families are not known at all; subvolcanic families are presented in MD megablock only; but families merely of hypabyssal and abyssal depth levels are shown in other geoblocks.

Moreover, alkaline metasomatic families are evidently prevailing in comparison with acid and magnesian-calcian families as well as almost all metasomatic rocks of USh are early or middle Proterozoic, excluding Archean altered rocks in MD geoblock and Riphean HCCO metasomatites in K megablock. On the other hand the separate megablocks of USh are characterized by the specific features of prevalence for different types of metasomatic families. For instance the distinctive metasomatites are: hypabyssal alkaline altered rocks with zirconium, rare-earth, molybdenum and apatite mineralization within A megablock; subvolcanic acid metasomatites with golden and molybdenum mineralization for MD megablock; abyssal family of uraniferrous sodium alkaline metasomatites (albite-aegirine family) with distinctive vanadium and scandium metallogenic specialization for K megablock; hypabyssal and abyssal magnesian-calcian metasomatites for RT and DB megablocks; hypabyssal alkaline me-

tasomatites with beryllium and tin mineralization as well as varieties of sodium alkaline metasomatites uncontained uranium ores for V geoblock.

These features of metasomatic rocks distinguish the USh from other Precambrian shields of the world that indicate on a specific geologic history of USh as a whole and the geoblocks of it in particular. The example of USh shows that conditionality of hydrothermal-metasomatic processes with general geologic, petrogenetic and tectonic events can give a key knowledge for application of hydrothermaly altered rocks as important petrology and metallogenic indicators.

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ВИЗНАЧЕННЯ МЕТАСОМАТИЧНИХ АСОЦІАЦІЙ У ГЕОБЛОКАХ УКРАЇНСЬКОГО ЩИТА

Метою даної статті є ідентифікація належності метасоматитів Українського щита (УЩ) до певних метасоматичних формацій на основі єдиної системи понять і термінів формаційного аналізу метасоматичних порід, а також встановлення специфіки проявів метасоматозу в окремих мегаблоках УЩ. На основі існуючої інформації зроблено загальний висновок про те, що для УЩ в цілому впевнено ідентифікується обмежений перелік метасоматичних формацій. Зокрема, на УЩ не ідентифіковано приповерхневі метасоматичні формації, субвулканічні представлені лише в межах Середньопридніпровського мегаблоку, а в інших регіонах УЩ розповсюджені тільки гіпабісальні і абісальні формації. Крім того, можна говорити про те, що на щиті в цілому лужні метасоматичні формації суттєво переважають над кислотними і магнезіально-кальцієвими, а у віковому відношенні практично всі метасоматити УЩ є ранньо- або середньопротерозойськими З іншого боку, окремі мегаблоки УЩ характеризуються своїми специфічними особливостями з точки зору розповсюдження окремих типів метасоматичних формацій. Встановлені закономірності відрізняють УЩ від інших докембрійських щитів. Авторами підкреслюється що, поглиблений аналіз обумовленості гідротермально-метасоматичних процесів загально геологічними, петрогенетичними і тектонічними явищами є актуальною задачею, спрямованою на удосконалення використання метасоматичних порід як ефективних петрологічних і пошукових індикаторів.

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ОПРЕДЕЛЕНИЕ МЕТАСОМАТИЧЕСКИХ АССОЦИАЦИЙ В ГЕОБЛОКАХ УКРАИНСКОГО ЩИТА

Целью данной статьи является идентификация принадлежности метасоматитов (УЩ) к определенным метасоматическим формациям на основе единой системы понятий и терминов формационного анализа метасоматических пород, а также выяснение специфики проявления метасоматоза в отдельных мегаблоках УЩ. Общий вывод, полученный на основе имеющейся информации, состоит в том, что для УЩ в целом уверенно идентифицируется только ограниченный перечень метасоматических формаций. В частности, на УЩ не идентифицированы приповерхностные метасоматические формации, субвулканические формации представлены только в пределах Среднеприднепровского мегаблока, а в других регионах УЩ распространены только гипабиссальные и абиссальные формации. Кроме того, можно утверждать, что на щите в целом щелочные метасоматические формации существенно преобладают над кислотними и магнезиально-кальциевыми, а в возрастном отношении практически все метасоматиты УЩ являются ранне- или среднепротерозойскими. С другой стороны, отдельные мегаблоки УЩ характеризуются своими специфическими особенностями с точки зрения распространенности определенных типов метасоматических формаций. Установленные закономерности отличают УЩ от других докембрийских щитов. Авторами подчеркивается, что углубленный анализ обусловленности гидротермально-метасоматических процессов общегеологическими, петрогенетическими и тектоническими явлениями является актуальной задачей, направленной на усовершенствование использования метасоматических пород в качестве эффективных петрологических и поисковых индикаторов.