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Identification the tectonic setting of granite using geochemistry and trace elements: implication for the granites in the Syrostan massive (Southern Ural)

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Abstract

Relevance and the purpose of the work. The use of trace element to differentiate granite types and tectonic setting is a well-established method in geology and mineral exploration. The aim of the paper is to determine the tectonic environment of the granite in the Syrostan massive using trace elements and geochemistry which lead to significant outcome and revealed of related deposits.

Methods of research. X-ray spectral fluorescence analysis was used to determine the concentrations of petrogenic oxides and trace elements in the samples, while trace element and rare earth element (REE) contents were measured using (ICP-MS).

Results of the work. Sericite and muscovite are discovered after plagioclase. Plagioclase exhibits sericitization and epidotization as a result of hydrothermal activity. Accessory minerals (zircon and apatite), include opaque minerals are distinguished. The trace element geochemistry of intrusion is reflected in the YbN vs. $(La/Yb)_N$ ratio, which is typical of magmas found in island arcs. Granite and granodiorite formation is a segment of the island arc formed as a result of the post-subduction or syn-collision tectonic setting. indicating that the intrusion associated with the Dark Kingdom Marble deposit can be considered a part of the Syrostan massive with the same general characteristics.

Conclusion. These findings imply that the granite formed in a volcanic arc tectonic environment. Finally, these results present the characteristics and tectonic environment of granitic rocks, which can provide valuable insight into related mineralization and rare element concentration.

Keywords: Trace elements, geochemistry, sericitization, epidotization, tectonic environment, island arc, Southern Ural.

Introduction

It is known that trace element has significance implication for identification rocks type and tectonic setting. Recent geochemistry of igneous rocks demonstrates that ratio of trace and rare elements in magma indicating tectonic environment [1, 2]. Increasing and decreasing concentration of trace elements decipher formation of minerals enriched in rare earth elements such as allanite, monazite, and zircon that could revealed hydrothermal rare earth element mineralization [3]. Because of their resistance to weathering and metamorphism, the geochemical tracers used to identify fractional crystallization such as La/Sm ratio. They are also helpful since they prefer to stay in solid solution together as the magma or lava cools and crystallizes because they are compatible elements [4]. Understanding a region's geology and its economic potential for mineral development can both benefit from the use of geochemistry and trace elements to discriminate between different types of granite and their tectonic setting [5]. The benefit of such classification, it may both show the tectonic setting and represent the unique features of the magma source [6]. Despite, several studies have previously been conducted on the Syrostan massive to investigate its petrogenesis, geochronology, tectonic evolution, and mineralization potential [7–10], however they did not cover the entire area of the Syrostan massive. Therefore, the purpose of this paper to identify the tectonic setting of the apical part of Syrostan granite using petrological model based on trace element, and general characteristic of granite based on geochemical information and petrography investigation. From this point of view, we compare these findings to previous one that conducted in the south and middle part of the massive, to examine the similarities and the contamination possibilities in the apical part of the massive.

Geological characteristic of the Syrostan massive. The Syrostan massif is surrounded by metabasites and shales of diverse compositions, as well as pieces of metamorphosed oce-

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anic crust and the crust of the Ural paleocean's passive border, southwest of Miass City in the zone of the main Ural deep fault (fig. 1). In the lower Carboniferous epoch, a polyphase structure developed. Granodiorite and quartz diorite are the initial phases, followed by double feldspar, plagiogranite, and a vein complex as the second and third [11, 12]. Granodiorite makes up the majority of the isometric huge body's composition. Its root zone was found in the southern part of the massive, which was made up of migmatized gabbroid and anatectic granodiorites and developed at a depth of more than 20 km. The middle and northern portions of the massive are composed of granite and granodiorite [7, 13].

The majority of the massive is made up of biotite granodiorites, adamellites, and granites, with some migmatized gabbros in the southwest. The primary ratio of gabbro and granitoids is 87Sr/86Sr = 0.703, which corresponds to MORB. 335 ± 4 Ma zircon has been discovered in gabbroid with traces of partial melting and anatectic granodiorites, while 327 ± 4 Ma zircon has been discovered in the youngest undeformed granites. Furthermore, cores in granite zircons date back to 1816 27 Ma, indicating a diverse source of rocks, including blocks of oceanic and ancient continental crust [14].

In the Syrostan granitoid massive, samples were collected from granitoid intrusions of the Dark Kingdom and Marble Deposit. The study area is located in the Chelyabinsk region of the southern Ural, about 15 kilometers northwest of Miass. The study area is made up of a metamorphic complex, a marble body shaped like lenses, and diorites. A magmatic complex is also exposed in the marble quarry's north-to-northwest section. The complex includes quartz diorites, granodiorites, biotite granites, and leucogranite [11].

Geological field observation of the study area. Diorites and plagiogranite are examples of igneous rocks. Quartz diorites are common igneous complex constituents and can be found embedded in xenoliths such as marbles. Xenoliths can range in size from one centimeter to tens of meters, with thicknesses ranging from one centimeter to five meters. Their shape can also vary, from isometric to elongated. A xenolith is a piece of rock that differs from the rock in which it is found in diorite (fig. 2, *a*). In the context of diorite, a xenolith is a piece of rock that is distinct from the diorite in which it is found. This can be any type of rock, such as granite, basalt, or limestone, and it can range in size from small fragments to large blocks. Xenoliths in diorite can be formed through a process known as magma mixing, which involves the mixing and solidification of magma from various sources.

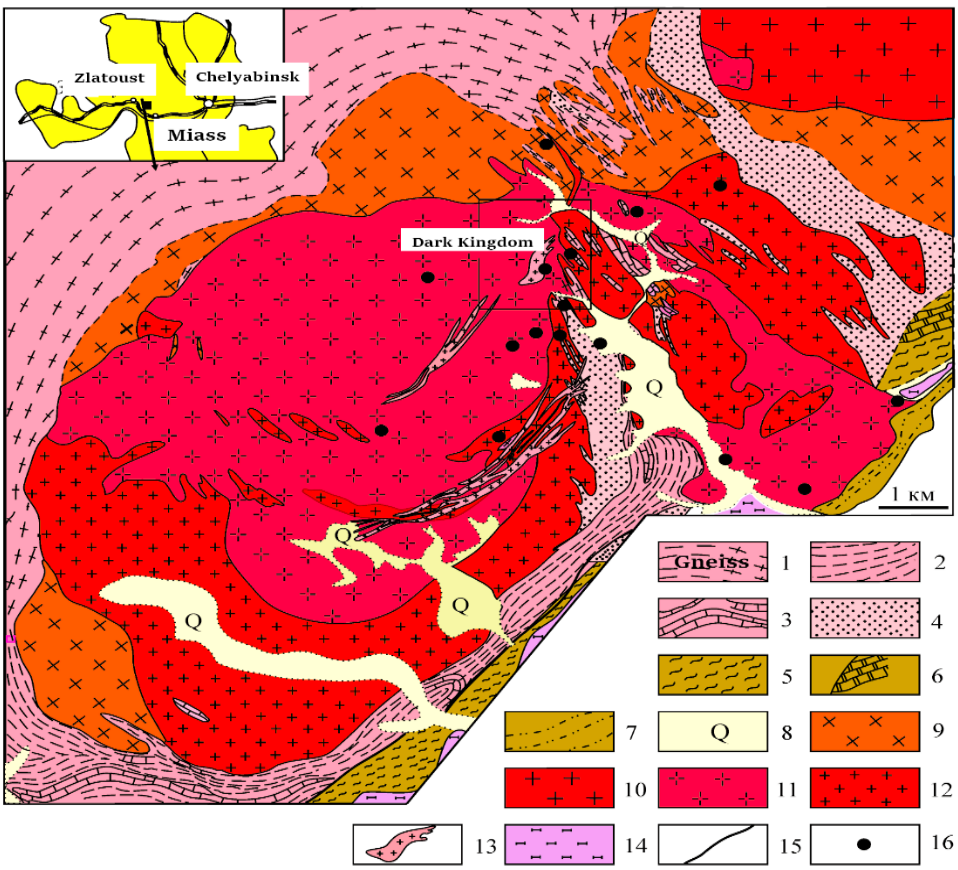

Figure 1. A modified geological map of the Syrostan massive, which includes Marble Deposit the Dark Kingdom (after Makagonov and Muftahov, 2015): *1* – Gneiss; *2* – Mica Quartz Schist; *3* – Marble Limestone; *4* – Quartzite; *5* – Shale; *6* – Marble; *7* – Carbonaceous shale; *8* – Quaternary Sediments; *9* – Granodiorite, Quartz diorite, Diorite; *10* – Porphyric Biotite Granites; *11* – Pink Porphyric Biotite Granites; *12* – Veined Granite and Plagiogranite; *13* – Pegmatites; *14* – Serpentinites; *15* – Tectonic faults; *16* – Occurrence of Niobium

Рисунок 1. Модифицированная геологическая карта Сыростанского массива, включающего месторождение мрамора Темное царство (по Макагонову и Муфтахову, 2015): *1* – гнейс; *2* – слюдяной кварцевый сланец; *3* – мраморный известняк; *4* – кварцит; *5* – сланец; *6* – мрамор; *7* – углеродистый сланец; *8* – четвертичные отложения; *9* – гранодиорит, кварцевый диорит, диорит; *10* – порфировые биотитовые граниты; *11* – розовые порфировые биотитовые граниты; *12* – прожилковые граниты и плагиограниты; *13* – пегматиты; *14* – серпентиниты; *15* – тектонические разломы; *16* – залежи ниобия

Plagiogranites are rocks that form as a result of the partial melting of granitic rocks. Microgranites, quartz veins, and basic and intermediate dikes make up the northern part of a quarry.

In a plagioclase granitoid rock formation, pegmatite and microgranite veins have been discovered. Pegmatite veins are thin, reaching a maximum thickness of 10 cm. Microgranite veins run along weakened zones at the diorite-marble-granodiorite boundary (fig. 2, *b*), and they penetrate the diorite complex and marble xenoliths partially.

Granitization processes are observed on microgranites and manifest in the appearance of large-scale muscovite up to 1 cm in size. This process can result in the formation of large-scale muscovite and the feldsparization of granites, which can transform microgranites into coarse-grained rocks.

The lower pit's southern end is being documented. Large blocks of marble up to 2–3 m in length is exposed in the center of the observation point, with vein formations of microgranites and pegmatite visible (fig. 2, *c*). The residential complex is about 10 cm thick. Contact with marbles is painful. Separate changes occur in the vein's selvedges, where small inclusions of dark green pyroxene appear. These inclusions form clumps as well as scattered clusters. Fine-grained white microgranites with a grayish and, on occasion, pinkish tint (1 mm). In the southern part, where marbles predominate, a vein complex of black rocks, presumably a dike, was discovered. Its potency varies. The size ranges from 10–15 cm to 0.5 m. The dike (vein) body cuts through the diorites and marbles. Biotite schist xenoliths were discovered during a thorough examination of the samples (fig. 2, *d*).

Materials and Methods

Rock samples were collected during the field trip for petrographic and geochemical analysis. Following a thorough examination of numerous thin sections under a microscope (Altami). For the bulk-rock major geochemical composition, nine samples were chosen (three samples representative microgranite, three leucogranite, two biotite granite, and one sample of diorite). X-ray spectral fluorescence analysis (XRF) on a sequential vacuum spectrometer (with wavelength dispersion), model Axios mAX manufactured by PAN alytical, was used to determine the concentration of petrogenic oxides and some trace elements in the samples (Netherlands). The analysis was carried out at the IGEM RAS's Center for Collective Use in Moscow (Russia). In the "IMGRE" lab, trace element and rare earth element (REE) contents were measured using inductively coupled plasma mass spectrometry (ICP-MS) on four rock samples (Russia). Using

Figure 2. Outcrops from the geological field observations: *a* – diorite with large xenoliths; *b* – Granodiorite dyke in Marble fracture; *c* – Marble block with pegmatite vein; *d* – Crack filled with dark-colored rock (biotite schist)

Рисунок 2. **Обнажения геологических полевых наблюдений:** *а* – диорит с крупными ксенолитами; *б* – дайка гранодиоритов в мраморном разломе; *в* – мраморный блок с пегматитовой жилой; *г* – трещина, заполненная темноцветной породой (биотитовый сланец) the Agilent Series 7500, this experiment was carried out to detect and quantify rare earth elements (REE) and trace elements.

Results and discussion

Petrographic investigation. Petrographic surveys are important in observing general features of igneous rocks and determining major minerals, which provide information about rock alteration, minerology, and deformation. Several analyses will be performed based on the petro-graphic survey to confirm the type of alteration and dominant minerals, which could reflect specific conditions and potential mineralization.

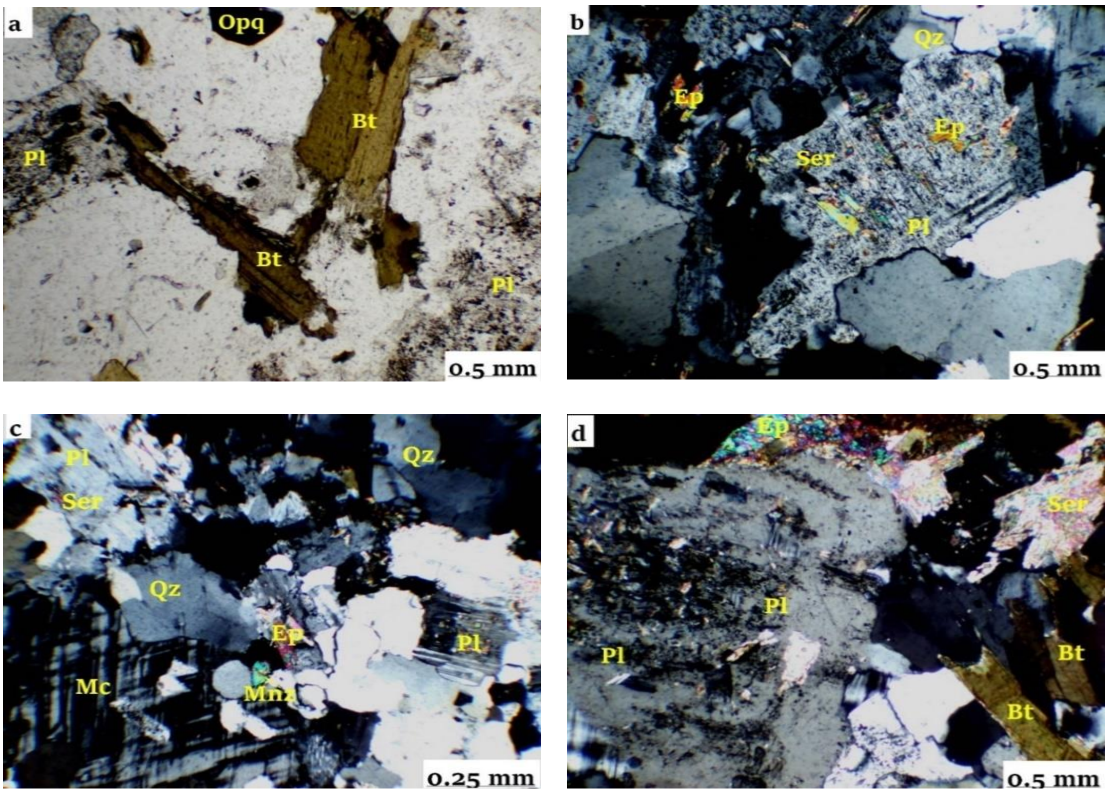

Figure 3. A microscopic examination of microgranite: *a* – granitic rocks with plagioclase, biotite, and opaque mineral (analyzer out); *b* – plagioclase grain partially mixed with a sericite aggregate and epidote, and quartz (analyzer in); *c* – monazite mineral in thin sections, sericite, epidote, microcline, and plagioclase (analyzer in); *d* – plagioclase, biotite, sericite, and epidote. Mineral abbreviations: Qz – quartz; Pl – plagioclase; Mc – microcline; Bi – biotite; Ep – epidote; Ser – sericite; Mnz – monazite

Рисунок 3. Микроскопическое исследование микрогранита: *а* – гранитные породы с плагиоклазом, биотитом и непрозрачным минералом (без анализатора); *б* – зерно плагиоклаза, частично смешанное с серицитовым агрегатом, эпидотом и кварцем (с анализатором); *в* – минерал монацит в шлифах, серицит, эпидот, микроклин и плагиоклаз (с анализатором); *г* – плагиоклаз, биотит, серицит и эпидот. Сокращения наименований минералов: Qz – кварц; Pl – плагиоклаз; Mc – микроклин; Bi – биотит; Ep – эпидот; Ser – серицит; Mnz – монацит

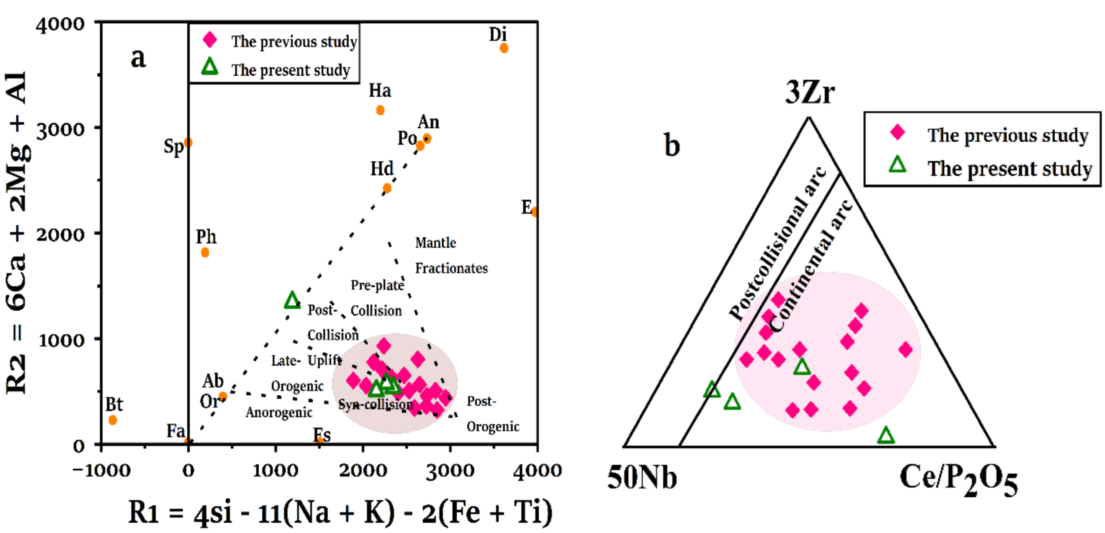

Figure 4. Tectonic discrimination diagrams: *a* – rocks tectonic discrimination based on multication proportions and the parameters R1 and R2 [16]; *b* – 50Nb-3Zr-Ce/P2O5 [17]; with data from previous study

Рисунок 4. Тектонические дискриминационные диаграммы: *а* – тектоническая дискриминация пород по соотношению мультикатионов и параметрам R1 и R2 [16]; *б* – 50Nb-3Zr-Ce/P_2O_5 [17]; с данными предыдущего исследования

According to the structural relationships of igneous rocks in the Miass region, geo-chronological information, and the current petrographic survey, the information about the geodynamic setting of the formation of the volcanic island arc, which consists primarily of micrgranite, biotite granite, leucogranite, and diorite, is revealed. The petrographic descriptions of these rocks are provided in the following paragraphs.

Granites are defined as either deformed (gneiss) or massive. They are made up of large bodies confined to the central part of the massif, as well as dikes and veins.

Granites include biotite, two-mica, and microcline (pink). Granite is commonly gray or pink in color. Pink granites have fine- to medium-grained granitic structures that are occasionally porphyritic (with development K-feldspar mega crystals among plagioclase-quartz-K-feldspar-biotite groundmass). The mineral composition of the above granite varieties of the Syrostan massif is very similar.

Granite is composed primarily of quartz (15–25%) is represented by light gray xenomorphic grains with a wavy mosaic fading. Some grains have a diameter of 2 mm. microcline

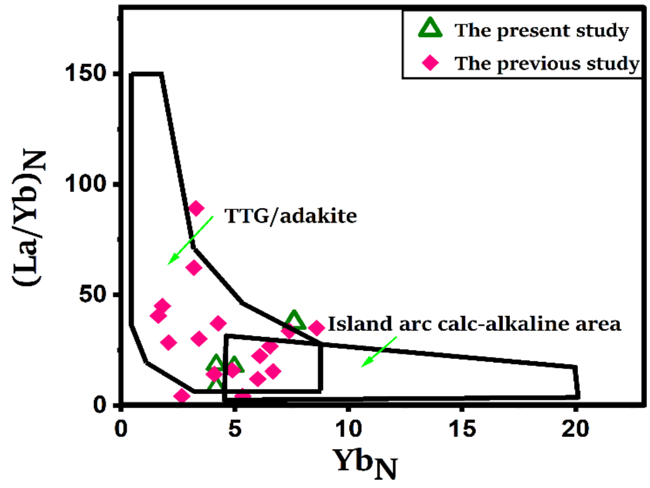

Figure 5. Yb_N vs. $(La/Yb)_N$ plotting for the data of present and previous study [18]

Рисунок 5. График зависимости Yb_N vs. $(La/Yb)_N$ для данных настоящего и предыдущего исследования [18]

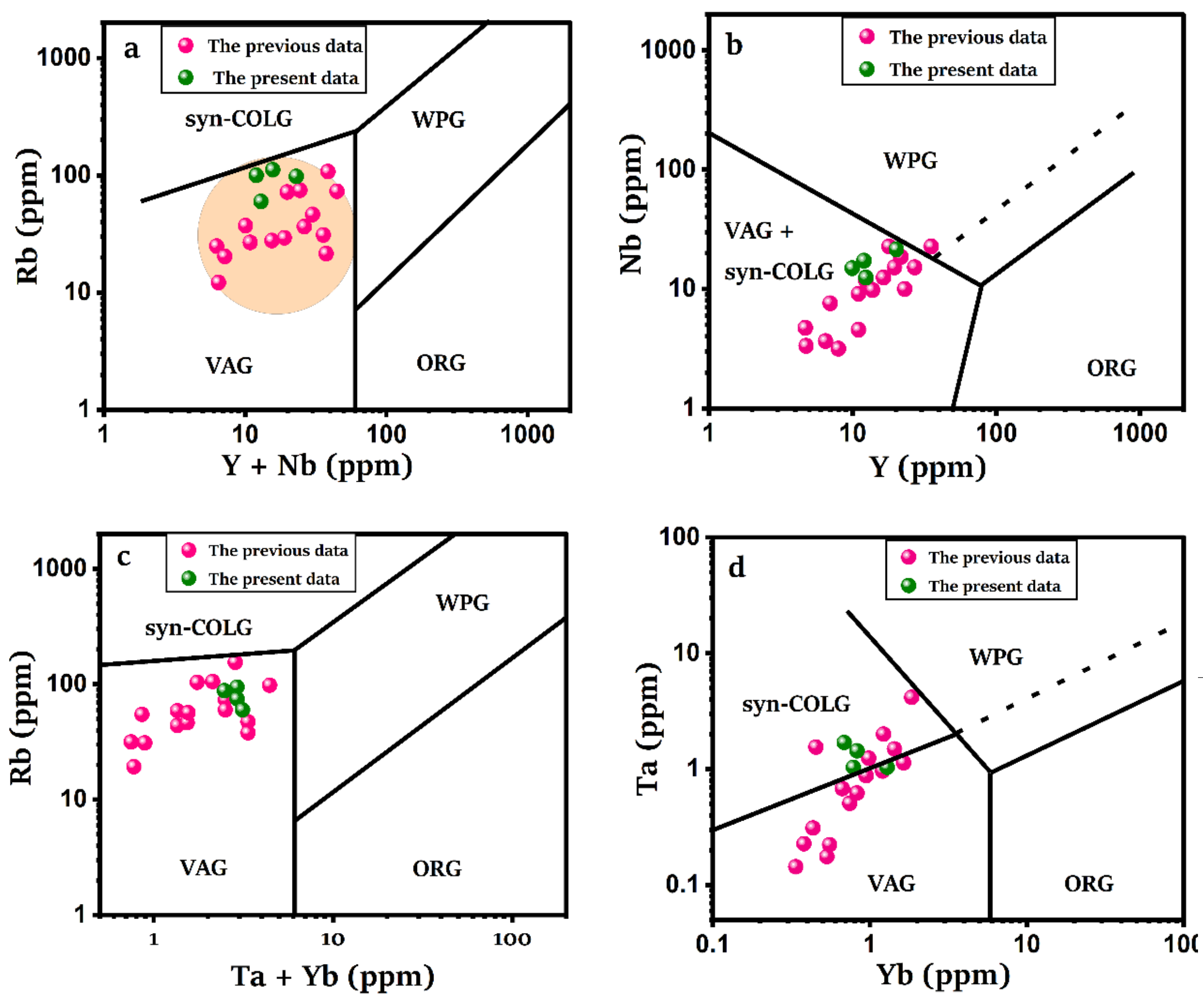

Figure 6. Discrimination diagrams for granitic rocks for the present and the previous data (*a–d*) and tectonic discrimination diagrams for intrusive rocks after [19]: VAG: volcanic arc granites; Syn-COLG: syn-collision granites; ORG: oceanic ridge granites; WPG: within plate granites

Рисунок 6. Дискриминационные диаграммы гранитных пород по настоящим и предыдущим данным (*а–г*) и тектонические дискриминационные диаграммы интрузивных пород [19]: VAG: граниты вулканической дуги; Syn-COLG: синколлизионные граниты; ORG: граниты океанических хребтов; WPG: внутриплитные граниты

(20–50%), plagioclase (20–40%) Plagioclase forms twinned zonal hypidiomorphic to euhedral grains and is located in the form of perthites in K-feldspar. The Grains are intensively changed in central part. Myrmekite is abundantly developed. Antiperthites and apatite inclusions are rarely present. Sericite and muscovite are discovered after plagioclase. Plagioclase exhibits sericitization and epidotization as a result of hydrothermal activity. Plagioclase zoning shows epidote and sericite from core to rim, and biotite (5–10%) and has a medium to coarse grained texture. Recrystallized quartz has two generations. This indicates that there has been deformation. Furthermore, chlorite, epidote, and calcite are secondary minerals. Accessory minerals (zircon and apatite), include opaque minerals. The major, secondary, and accessory minerals found in microgranite are shown in (fig. 3, *a–d*).

Tectonic setting of granite in the Syrostan massive. Our results massively rely on unpublished geochemical data from previous research conducted by [15] in the south and middle part of the Syrostan massive, to compare the present findings from the apical part to previous study, to examine the similarities, and the contamination possibilities in the apical part of the Syrostan massive.

The R1-R2 plot (fig. 4, *a*) after [16], showed granitic samples of intrusions formed by syn-collision tectonic setting. The granite plotted into the continental arc on the ternary discrimination plot 50Nb-3Zr-Ce/P_2O_5 (fig. 4, *b*) after [17].

According to geochemistry, granite rocks are the result of crystallization differentiation of a calc-alkaline magma with pyroxene, biotite, and amphibole playing a role. The trace element geochemistry of samples collected from the intrusion is reflected in the YbN vs. (La/Yb)N binary diagram (fig. 5) [18], which is typical of magmas found in island arcs. The formation of granite and granodiorite is a segment of the island arc that occurred as a result of the Syrostan massive as a post-subduction or syn-collision tectonic setting.

Furthermore, plotting previous data revealed the same tectonic environment as the current study (fig. 6, *a–d*). Indicating that the intrusion associated with the Dark Kingdom Marble deposit can be considered a part of the Syrostan massive with the same general characteristics, but the intrusion associated with the Dark Kingdom Marble Deposits shows enrichment in some rare and trace elements than other parts of the massive from previous studies (such as Ta, W, and Sn).

Conclusion

According to the structural relationships of igneous rocks in the Miass region, geo-chronological information, and the current petrographic survey, the information about the geodynamic setting of the formation of the volcanic island arc, which consists primarily of microgranite, biotite granite, leucogranite, and diorite, is revealed. The tectonic discrimination diagram of the investigated samples suggests that the dominant tectonic setting is volcanic arc granite. These results indicate that the volcanic arc granite is a tectonic environment in which magma from the continental crust is involved.

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Declaration of the Competing Interest

The author declare that they have no know competing financial interests or personal relationships that could have appeared to influence the work in this paper.

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Определение тектонической обстановки гранитов с использованием геохимии и микроэлементов на примере гранитов Сыростанского массива (Южный Урал)

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Аннотация

Актуальность и цель работы. Использование микроэлементов для разделения типов гранитов и тектонических структур является хорошо зарекомендовавшим себя методом в геологии и разведке полезных ископаемых. Целью статьи является определение тектонической обстановки гранитов Сыростанского массива с использованием микроэлементов и геохимии, изучение которых приводит к значительным результатам и выявлению сопутствующих месторождений.

Методы проведения работы. Рентгеноспектральный флуоресцентный анализ использовался для определения концентрации петрогенных оксидов и микроэлементов в образцах, а содержание микроэлементов и редкоземельных элементов (РЗЭ) измерялось с помощью ИСП-МС.

Результаты работы. По плагиоклазу обнаружены серицит и мусковит. Плагиоклаз проявляет серицитизацию и эпидотизацию в результате гидротермальной деятельности. Различают акцессорные минералы (циркон и апатит), в том числе непрозрачные минералы. Геохимия редких элементов интрузии отражается в соотношении Yb_N vs. $(La/Yb)_N$, что типично для магм, обнаруженных в островных дугах. Гранито-гранодиоритовая формация представляют собой сегмент островной дуги, образовавшийся в результате постсубдукционной или синколлизионной тектонической обстановки. Это указывает на то, что интрузия, связанная с месторождением мрамора Темное царство, может считаться частью массива Сыростан с такими же общими характеристиками.

Выводы. Эти данные предполагают, что гранит образовался в островодужных условиях вулканической дуги. Наконец, эти результаты представляют характеристики и условия образования гранитных пород, которые могут дать ценную информацию о связанной с ними минерализации и концентрации редких элементов.

Ключевые слова: микроэлементы, геохимия, серицитизация, эпидотизация, тектоническая обстановка, островная дуга, Южный Урал.

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