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GEOLOGICAL POSITION AND AGE OF TUXEN-RASMUSSEN LAYERED GABBROID INTRUSION (WEST ANTARCTICA)

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Abstract. The latest geological research carried out during seasonal work in 2017 revealed that metamorphosed layered gabbroids, which partially outcrop along the Antarctic Peninsula Coast on Cape Tuxen and Rasmussen Island, compose sheet-like intrusive body of total dimensions more than 3 km^2. Significant part of the Tuxen-Rasmussen Gabbroid Intrusion (TRGI) is submerged under Waddington Bay. **Main objectives** of the study were the identification of geological position of the TRGI and the clarification of its geological age. In addition to the field **methods** of the geological research the samples collected during this and the previous years were studied using optical and electron microscopy techniques in order to identify petrographic and mineralogical features of the gabbroids. **Results** of the studies confirmed previous observation that TRGI was embedded in Upper Jurassic Volcanic Group (UJVG) of Antarctic Peninsula and it was responsible for contact metamorphism of the UJVG and suffered contamination by volcanic material. Gabbroids and volcanic rocks were later intruded by granites of Late Cretaceous age, which belong to the Andean Intrusive Suite (AIS) of Graham Land. Authors define geological age of TRGI as Early Cretaceous. Previous U-Pb isotope datings of the gabbroids are believed to be "rejuvenated". It was discovered that TRGI strikes in northeastern direction and dips steep in northwestern direction. It is assumed that intrusive body continues underwater and can outcrop at the northern shore of the Waddington Bay and at Barros Rocks direction to the southwest. Petrographical researches showed that gabbroids underwent metamorphic alteration in conditions of epidote-amphibolite facies. They bear, nevertheless, relict structural-textural features and mineral associations of mafic igneous rocks. Authors drew a **conclusion** that geological position and petrographical peculiarities of TRGI correspond to hypabyssal level of crystallization. Primary igneous origin is proved for the microrhythmic layering of the gabbroids. Relict mineral associations allow to identify the rocks as olivine gabbro-norites. Potential Fe-Ti-V ore specialization is emphasized according to the revealed patterns of crystal fractionation and accumulation of ilmenite and magnetite.

Key words: geology of Antarctica, Andean Intrusive Suite, layered intrusions, gabbroids.

ГЕОЛОГІЧНА БУДОВА ТА ВІК РОЗШАРОВАНОЇ ГАБРОЇДНОЇ ІНТРУЗІЇ ТУКСЕН-РАСМУСЕН (ЗАХІДНА АНТАРКТИКА)

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Реферат. Новітні геологічні дослідження 2017 року показали, що метаморфізовані шаруваті габроїди, які фрагментарно відслонюються вздовж узбережжя Антарктичного півострова в районі мису Туксен та острова Расмусен, складають пластоподібне інтрузивне тіло загальною площею не менш ніж 3 км^2. Значна частина габроїдної інтрузії Туксен-Расмусен (ГІТР) знаходиться під водами затоки Вадінгтон. Головною **метою** досліджень було з'ясування умов залягання та особливостей будови ГІТР, а також уточнення її геологічного віку. Крім польових геологічних **методів** досліджень, зразки гірських порід, які були зібрані у цей та попередні роки, вивчалися з використанням методів оптичної та електронної мікроскопії для з'ясування мінералого-петрографічних особливостей габроїдів. **Результати** виконаних досліджень підтвердили спостереження попередників, які засвідчили, що ГІТР вкорінена у орогенні утворення верхньо-юрської вулканічної групи Антарктичного півострова, спричинила їх контактовий метаморфізм та зазнала контамінації вулканоген-

ним матеріалом. Габроїди і вулканіти, у свою чергу, інтрудуються гранітоїдами пізньо-крейдяного віку, що належать до Андійської інтрузивної серії Землі Греяма. Геологічний вік ГІТР визначається авторами як ранньо-крейдяний, попередні U-Pb ізотопні датуванні цирконів з габроїдів вважаються «омолодженими». Виявлено, що ГІТР має північно-східне простягання та стрімке північно-західне падіння. Виходячи з умов залягання, припускається продовження інтрузивного тіла на північному узбережжі затоки Вадінгтон, а також у напрямку на південний захід у бік островів Барос Рокс. Петрографічні дослідження показали, що габроїди ГІТР підлягають метаморфічнічним перетворенням в умовах епідот-амфіболітової фації. Тим не менше, вони зберігають реліктові особливості будови та мінеральні парагенезиси основних магматичних порід нормального ряду лужності. Автори роблять **висновок** про те, що умови залягання та структурно-текстурні особливості габроїдів ГІТР свідчать про гіпабісальний рівень їх кристалізації. Для тонкої ритмічної шаруватості габроїдів доводиться первинно-магматичне походження. Реліктові мінеральні парагенезиси дозволяють ідентифікувати серед них олівінові габро-норити. З огляду на виявлені ознаки кристалізаційної диференціації, що супроводжувалася кумуляцією ільменіту та титаномагнетиту, звертається увага на потенційну Fe-Ti-V спеціалізацію габроїдів ГІТР.

Ключові слова: геологія Антарктиди, Андійська інтрузивна світа, розшаровані інтрузії, габроїди.

ГЕОЛОГИЧЕСКОЕ СТРОЕНИЕ И ВОЗРАСТ РАССЛОЕННОЙ ГАББРОИДНОЙ ИНТРУЗИИ ТУКСЕН-РАСМУССЕН (ЗАПАДНАЯ АНТАРКТИКА)

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Реферат. Последние геологические исследования 2017 года показали, что метаморфизированные расслоенные габброиды, которые фрагментарно обнажаются вдоль побережья Антарктического полуострова в районе миса Туксен и острова Расмуссен, слагают пластоподобное интрузивное тело общей площадью не менее 3 км^2. Значительная часть габброидной интрузии Туксен-Расмуссен (ГИТР) находится под водами залива Ваддингтон. Главной **целью** исследований было выяснение условий залегания и особенностей строение ГИТР, а также уточнение ее геологического возраста. Кроме полевых геологических **методов** исследования, образцы горных пород, собранные в этот и предыдущие годы, изучались с использованием методов оптической и электронной микроскопии для определения минералого-петрографических особенностей габброидов. **Результаты** выполненных исследований подтвердили наблюдения предшественников, согласно которым ГИТР внедрена в орогенные образования верхнеюрской вулканической группы Антарктического полуострова, обусловила их контактовый метаморфизм и подверглась контаминации вулканогенным материалом. Габброиды и вулканиты, в свою очередь, интрудируются гранитоидами позднемелового возраста, относящимися к Андийской интрузивной серии Земли Греяма. Геологический возраст ГИТР определяется авторами как раннемеловой, предыдущие U-Pb изотопные датировки габброидов считаются «омоложенными». Установлено, что ГИТР имеет северо-восточное простирание и крутое северо-западное падение. Исходя из условий залегания, предполагается продолжение интрузивного тела на северном побережье залива Ваддингтон, а также в направлении на юго-запад в сторону островов Барос Рокс. Петрографические исследования показали, что габброиды ГИТР подверглись метаморфическим преобразованиям в условиях эпидот-амфиболитовой фации. Тем не менее, они сохраняют реликтовые особенности строения и минеральные парагенезисы основных магматических пород нормального ряда щелочности. Авторы делают **вывод** о том, что условия залегания и структурно-текстурные особенности габброидов ГИТР свидетельствуют об гипабиссальном уровне их кристаллизации. Для тонкой ритмической расслоенности габброидов доказывается первично-магматическое происхождение. Реликтовые минеральные парагенезисы позволяют идентифицировать среди них оливиновые габбро-нориты. Ввиду выявленных признаков кристаллизационной дифференциации, сопровождаемой кумуляцией ильменита и титаномагнетита, обращается внимание на потенциальную Fe-Ti-V специализацию габброидов ГИТР.

Ключевые слова: геология Антарктиды, Андийская интрузивная свита, расслоенные интрузии, габброиды.

1. Introduction

Mafic intrusive rocks attract lots of attention among the igneous rocks that are widespread in the vicinity of Ukrainian Antarctic Akademik Vernadsky station (Vernadsky station). Unlike predominant granitoids and volcanic rocks, gabbroids do not cover large territories. Nonetheless, small separate outcrops of gabbroids are detected at numerous islands of Wilhelm Archipelago as well as at the adjacent Antarctic Peninsula coast. Due to inaccessibility of the scarce outcrops, it is natural that morphology of separate gabbroid bodies, their geological position, age and ore-bearing potential are still insufficiently studied.

Cape Tuxen, which is situated at the western coast of Graham Land to the south of Waddington Bay, was discovered and recorded in 1898 by Belgian expedition under Adrien de Gerlache command. This expedition named Cape Rasmussen, which allegedly limited entrance to the Waddington Bay from the North. Data from the subsequent aerial survey refuted existence of visible land ledge in the area. Hence, according to the United Kingdom Antarctic Place-Names Committee decision, Rasmussen Island name stuck to one of the small islands near the northern shore of Waddington Bay since 1959. R. Curtis (1966) carried out brief petrographic study of Cape Tuxen gabbros and referred them to the Andean Intrusive Suite (AIS) of Graham Land (Curtis,1966). In his opinion the AIS formation included time span from Late-Cretaceous to Early-Tertiary. Obvious flaw of Cape Tuxen geological map represented in the paper is absence of rocks bedding features. Isotopic dating results on Cape Tuxen and Rasmussen Island can be found in following papers (Pankhurst, 1982; Tanggeman et al., 1996; Bakhmutov et al., 2013). Gladkochub et al

(2011-12) provided geochemical data on Cape Tuxen gabbros, which assume subduction lithospheric source of magma generation for the rocks studied. Artemenko et al. (2013) came to conclusion that rhythmic layering was formed due to minerals crystallization in conditions of rapid moving magma. Magnetites of Cape Tuxen demonstrate high V concentrations (Artemenko et al., 2011).

During seasonal work in 2017 field geological research of Cape Tuxen and Rasmussen Island gabbroids took place. The research revealed that layered intrusive body, which is further regarded as Tuxen-Rasmussen Gabbroid Intrusion (TRGI), lies in this region. Further lab research of the samples taken yielded fundamentally new data on structural-textural features and matter composition of TRGI. Research conducted was supported by State Institution National Antarctic Scientific Center, Ministry of Education and Science of Ukrainee in terms of target scientific-technical program of State Special-Purpose Research Program in Antarctica for 2011-2020. The research aims the identification of geological position, age, petrographical and mineralogical features of TRGI.

2. Methods and materials

Field research in the area of Cape Tuxen and Rasmussen Island, which was conducted by Mytrokhyn O.V. and Bakhmutov V.G. during seasonal works in 2017, included studying of petrographic diversity of the rocks, their bedding and contact relations, outcrops examination and sampling. Further laboratory research was implemented in Taras Shevchenko National University of Kyiv (Institute of Geology). Mytrokhyn O.V. and Mytrokhyna T. V. studied thin-sections using polarized light microscopes. Quantitative mineralogical analysis was performed using Andin integration table. Electron microscopy and electron-microprobe investigations of rock-forming and Fe-Ti oxide-ore minerals were conducted by Mytrokhyn O.V., Gavryliv L.I. and Aleksieienko A.G. Raster electron microscope REMMA-202M equipped with energy-dispersion X-ray spectrometer «Link systems» was used.

3. Results and discussion

3.1. Bedding, contact relations and age of TRGI

Cape Tuxen (65°16’ S, 64°07’ W) is a small rocky cape at the western coast of Antarctic Peninsula. The cape is situated at 6.9 km distance to the east from UAS at Galindez Island, from which it is separated by Penola Strait (Fig.1).

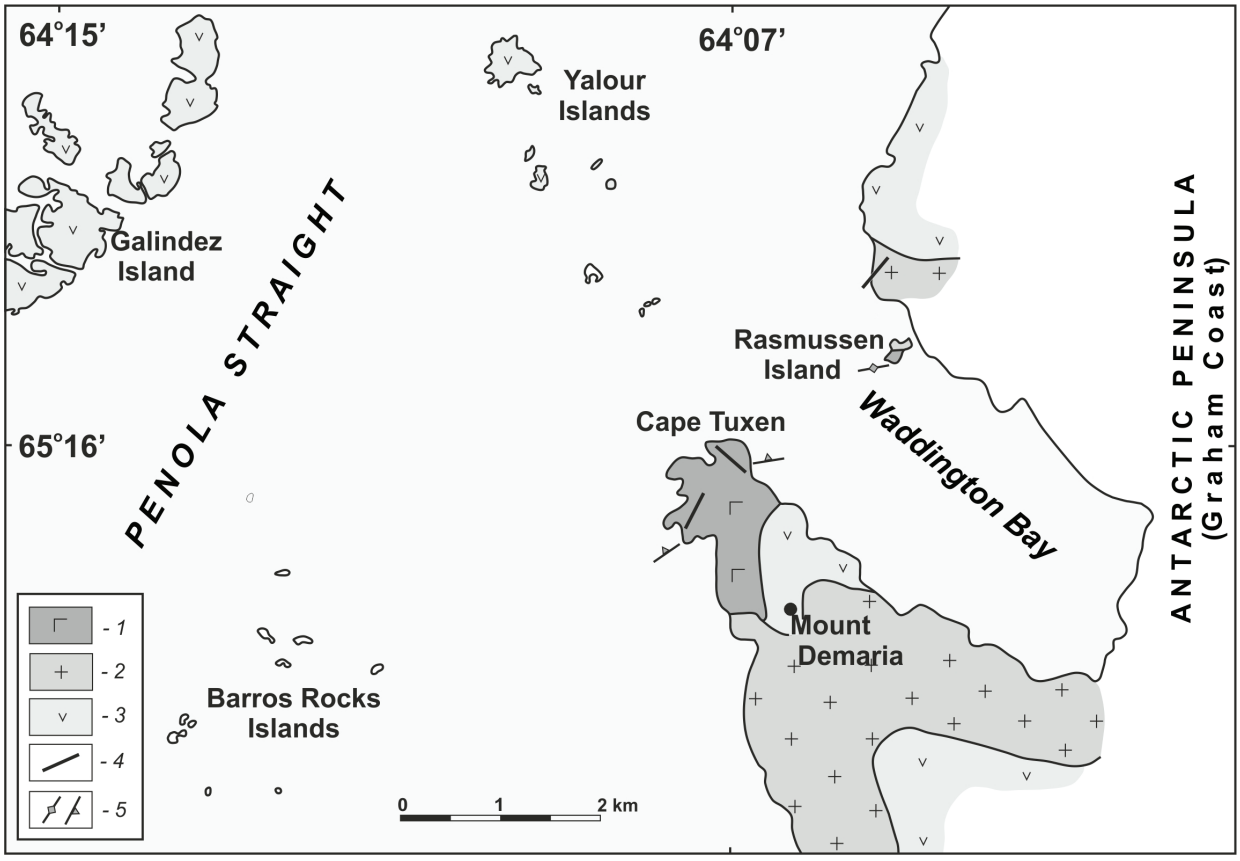

Fig.1. Geological position of Tuxen-Rasmussen Gabbroid Intrusion. Legend: 1 – TRGI gabbroids; 2 – AIS granitoids; 3 – UJVG volcanites; 4 – mafic dikes; 5 – strike of the magmatic layering with bedding features respectively. The map was compiled using (Curtis, 1966) with author’s corrections and additions.

Cape Tuxen is limited by Waddington Bay from the north. Its central part is occupied by Mount Demaria 638 m high. Lumiere Peak 1066 m is situated to the east of it. Collins Bay cuts into the coast to the south of Cape Tuxen.

Gabbroids compose most northwestern ridge of Cape Tuxen and are traced for more than 1.5 km along its western coast (Fig.2). East of Mount Demaria steep slopes gabbroids contact with volcanic rocks, which are traditionally referred to Upper Jurassic Volcanic Group (UJVG). South of Mount Demaria gabbroids and volcanic rocks are intruded by granitoids, which are described as a part of Andian Intrusive Suite (AIS) of Graham Land. During 2017 seasonal works gabbroid outcrops were also detected at Rasmussen Island, which is situated in Waddington Bay 2 km north the northernmost point of Cape Tuxen. Similarities in the bedding of Cape Tuxen and Rasmussen Island gabbroids as well as their petrographic identity suggest that they belong to a large single intrusive body, main part of which is submerged under Waddigton Bay. The intrusive body might possess flattened form, northeastern strike and steep northwestern dip. Tuxen-Rusmussen gabbroid intrusion (TRGI) is at least 3-4 km long and 1-1.5 km wide. More accurate estimation of dimensions requires further outcrops research of the northern Waddington Bay shore and Barros Rocks Islands.

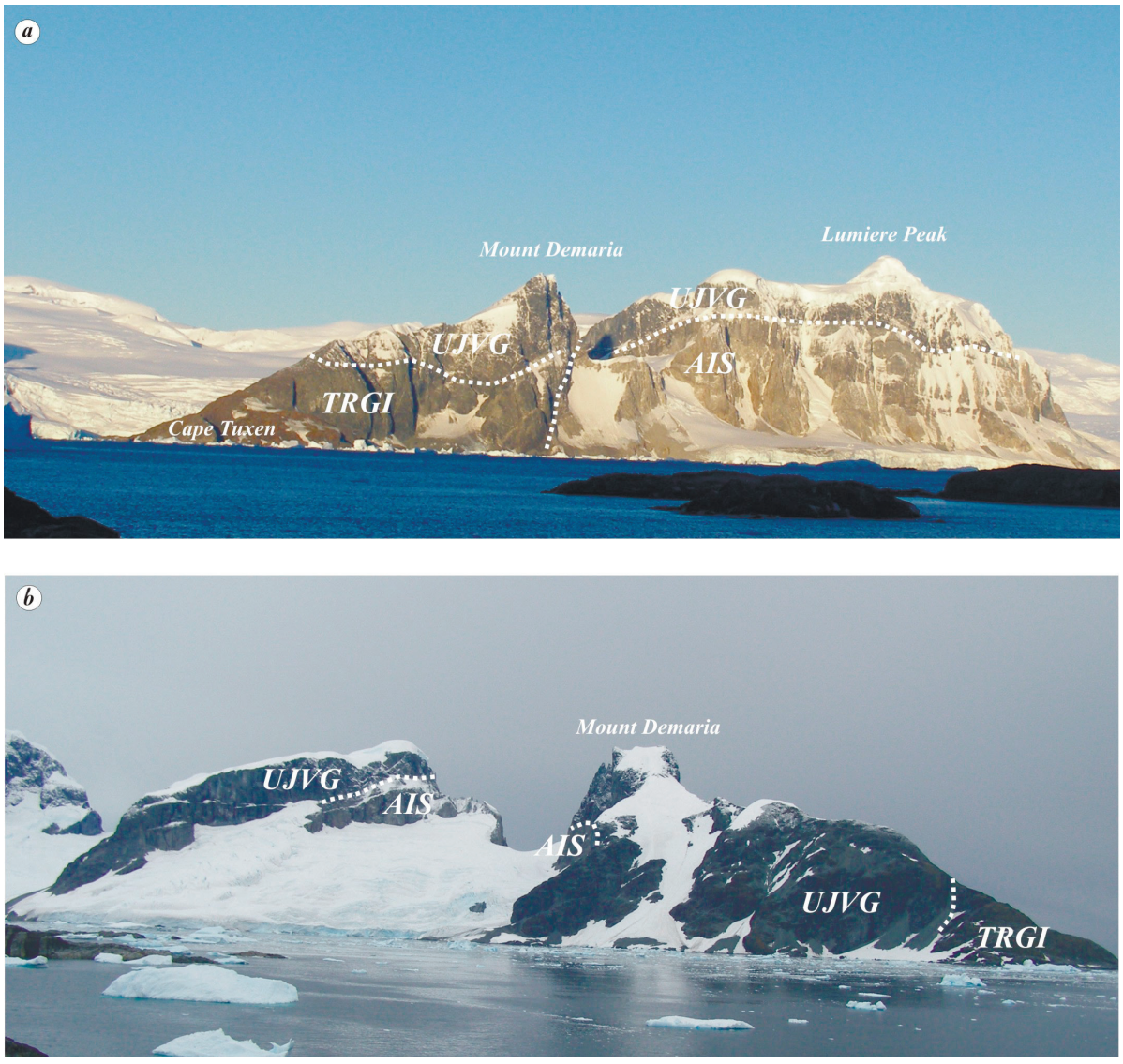

Fig.2. Bedding of the Cape Tuxen rocks: a – look from the west from Penola Straight; b – look from the north from the Waddington Bay. Legend: TRGI – Tuxen-Rasmussen Gabbroid Intrusion; UJVG – Upper Jurassic Volcanic Group; AIS – granitoids of the Andean Intrusive Suite.

Characteristic feature of TRGI is its original igneous layering (Fig.3). Layered structure is distinguished by variation of 10-20 cm thick layers, which differ by mafic and sialic minerals ratios and texture. Medium-grained mesocratic gabbroids with hypidiomorphic cumulate texture are dominant. Layers of leucocratic gabbroids have larger grain size sometimes show porphyritic texture. Tabular phenocrysts of plagioclase and elongated mafic minerals demonstrate weak orientation pattern parallel to layering surface. At the most northwestern point of Cape Tuxen TRGI outcrop (65°16’3,4” S, 64°06’56,2” W) gabbros layering strikes NE80° and dips NW at angle of 65°. Farther south at the Mount Demaria slopes layering strike changes to NE55°, NW dip at 55° angle. Layered gabbroids from southern part of Rasmussen Island (65°15’29,6” S, 64°04’48,3” W) strike NE75-80° and dip subvertical, which correlates with Cape Tuxen gabbroids.

Fig.3. Layered structures of TRGI gabbroids: a – Cape Tuxen, most northwestern point; b – Cape Tuxen, northern slope of Mount Demaria, layered gabbroids near the contact with UJVG; c – Rasmussen Island, microlayered gabbroids intruded by aplite vein.

At several outcrops on Cape Tuxen thin porphyritic and diabase dikes intrude the gabbroids (Fig.4a). Such dikes rarely exceed 20-30 cm in thickness, strike NE25° or NW310° and dip subvertical. Dikes have sharp intrusive contacts with angular unconformity with gabbro layering. Chilled margins that are composed by aphanitic diabase are common, which suggests significantly younger age for the dikes in relation to TRGI. Some of the dikes are even younger than granite veins that cut gabbroids.

Geological data suggests the Mesozoic age of TRGI. Lower age limit is based on intrusive contact between Cape Tuxen gabbroids and UJVG. Xenoliths of UJVG in gabbroids as well as contact metamorphism of volcanic rocks at the contact with gabbroids described by R. Curtis (1966) prove Post-Jurassic age of TRGI. Upper age limit for TGRI formation is controlled by aforementioned AIS granitoid intrusion inside TRGI. Numerous granite dikes and veins intrude gabbroids along the western shore of Cape Tuxen at the steep slopes of Mount Demaria (Fig.4b-c). One of the biggest dikes was studied at 65°16’24,1’’S, 64°07’37,1’’W outcrop. Gabbroids demonstrate microrythmical layering that strikes NE25° and dips NW at 75° angle. 1 m thick granite dike strikes NE81° and dips SE at angle of 80°. The dike has sharp straight cutting contacts with gabbro layering. Central part of the dike has slightly better crystallinity relatively to the peripheral aplite parts, which, probably, indicates that granite magma intruded in completely cooled gabbroids. Granitic apophysises intrude gabbros at both sides of the dike and form thin aplite veins 1-10 cm thick. Numerous xenoliths of gabbro are presented in this and in other aplite veins and sometimes form eruptive breccia.

According to Tanggeman et al. (1996), U-Pb age of zircons from Mount Demaria granitoids is 84.5±0,9 Ma, which corresponds to Upper-Cretaceous period. Two samples of amphibolized gabbroids from Cape Tuxen and Mount Demaria that were mistakenly named quartz-diorites (Tanggeman et al., 1996) yielded almost identical results of U-Pb dating 85,2±0,7 Ma – sample AP90-11H and 84,8±0,5 Ma – sample AP90-11J. One can easily identify those as gabbros according to published chemical analysis data (Tanggeman et al., 1996). Close to the mentioned U-Pb isotope data was obtained for zircons of Cape Tuxen gabbroids (Bakhmutov et al., 2013). Nevertheless, despite of seeming evidence of the isotope datings Upper-Cretaceous age of the TRGI is doubtful. First, numerous geological observations prove older age of gabbroids relatively to granitoids, which doesn’t demonstrate isotope dating. Second, petrographic research points out metamorphic alteration of TRGI, which has certainly affected isotope ratios and reduced the age. At last, granites of Rasmussen Island, which demonstrate post-gabbro geological age, yielded 117,0±0,8 Ma using U-Pb zircon dating (Tanggeman et al., 1996) and 128,0±3,0 Ma – Rb-Sr whole-rock estimations (Pankhurst, 1982). Hence, the most probable age of TRGI is Early Cretaceous or even Late Jurassic.

Fig.4. Dikes and veins in TRGI gabbroids: a – Cape Tuxen gabbroids are intruded by vertical NE-striking diabase dike; b – numerous granite veins in gabbroids on Mount Demaria slope; c – NE-striking granite dike intrudes Cape Tuxen gabbroids.

3.2. Petrographic characteristic of TRGI gabbroids

Characteristic feature of TRGI gabbroids is metamorphic alteration these rocks underwent in different limits. Nevertheless, all of the samples studied preserve relicts of original structural-textural features and mineral associations, which make it possible to use igneous plutonic rocks classification and nomenclature. Gabbroids from Rasmussen Island underwent minimum metamorphism. The most "fresh" sample 17-118A-1 was identified as gabbronorite. It is unevenly striped gray with microrythmic structure that is formed by 0.5-4 cm thick layers, which differ in mafic minerals content. Two thin layers represent leucogabbronorite, other – mesocratic. Texture is phanerytic, equigranular, medium-grained, grain orientation is identified only in thin sections. Tabular plagioclases 1-2 mm in size are more idiomorphic than mafic minerals. Under binocular loupe dark-gray pyroxene, greenish columnar amphibole and steel-gray magnetite are easily distinguished among mafic and ore minerals. In thin sections TRGI gabbroids demonstrate hypidiomorphic granular gabbro-ophitic texture (Fig.5), which is characterized by subhedral plagioclase relatively to the mafic minerals. Mineral composition: plagioclase (46-89%), amphiboles (20-47%), pyroxenes (0-12%), Fe-Ti oxides (4-5%), quartz (1-2%). Biotite, chlorite and talk were present in some samples. Accessory minerals are represented by apatite, sphene, zircon and baddeleyite. The last two were diagnosed using REMMA.

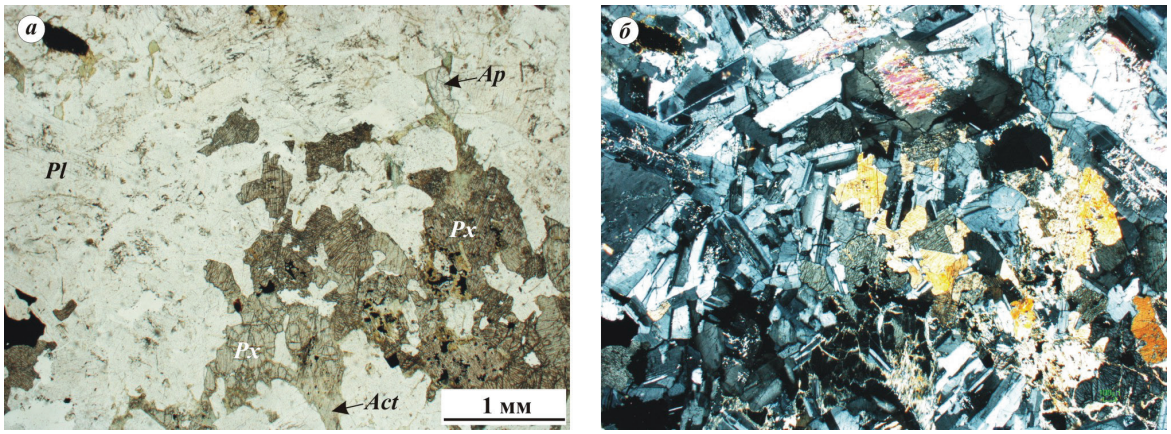

Fig. 5. Microscopic features of Rasmussen Island gabbronorite, sample 17-118A-1 in thin section under polarized microscope. Main rock-forming minerals are represented by plagioclase and pyroxenes. Plagioclase demonstrates idiomorphism in relation to pyroxenes. Pyroxenes form small cumulative aggregates up to several grains. Parallel-fibrous actinolite replaces partly pyroxene grains.

Calcium plagioclase is the main primary magmatic mineral of all studied samples. It crystalizes as chaotic-oriented tabular grains 0.5-2 mm size. In polarized light the plagioclases demonstrate both simple and polysynthetic twinning, in some places it has zonned extinction. Block extinction and other signs of brittle deformations can also be found. At high magnification rate one can distinguish numerous oriented inclusions of opaque minerals within plagioclases. Some grains underwent mild sericitization. Electron microprobe analysis of the least altered 17-118A-1 sample yielded bytownite-anorthite An_{72-93} for the core parts and andesine An_{39-45} at the rims. Less basic plagioclases that are found in more altered TRGI samples probably have secondary genesis. Secondary genesis is also suggested for quartz, which crystallizes in small anhedral grains and granoblastic aggregates between plagioclases.

Fibrous amphiboles are the most common metamorphic minerals of the studied rocks. They are mostly represented by pale-green actinolite or sometimes by colorless cummingtonite, precise diagnostics of which were performed using REMMA. The amphiboles usually crystalize as parallel-fibrous aggregates that pseudomorphicaly replace original pyroxenes. Less common are matted-fibrous aggregates. Dimensions of the aggregate reach 2-3 mm with single fibers 1-2 mm thick. Pyroxenes that are undoubtedly typical igneous minerals can be found only in the least altered samples of TRGI. They are represented by both clinopyroxene and orthopyroxene. According to the electron microprobe analysis in 17-118A-1 sample clinopyroxenes are represented by diopside $Wo_{46-47}En_{40-41}$, when orthopyroxenes are enstatites $Wo_{2-3}En_{66-67}$. Pyroxenes usually crystalize as euhedral grains 1-4 mm size or form cumulate aggregates. Inside the biggest pyroxene grains magnetite-talc aggregates can be found, which are likely to be fully pseudomorphosed olivines that preserve previous "bay-like" configuration of crystals. In some cases these pseudomorphoses are altered into fibrous amphiboles.

Fe-Ti-oxide ore minerals of TRGI gabbroids are present both as primary magmatic, and secondary metamorphic varieties. Primary ones are represented by ilmenite and Ti-magnetite, which occur in both individual grain and cumulate aggregate 1-2 mm in size forms (Fig.6). Such aggregates are rare but form sideronitic-like texture when present. Primary magmatic ilmenites crystallized earlier than Ti-magnetite and usually are more euhedral. Such ilmenites form tabular crystals that include lamellar exsolution inclusions of hematite parallel to the (0001) crystallographic plane. Some of the ilmenite grains also contain numerous sphene inclusions or demonstrate slight leucoxenization. On the contrary, primary Ti-magnetite graines are anhedral. They contain tabular exsolution inclusions of ilmenite that are oriented parallel to the (111) crystallographic plane. Microprobe analysis of Ti-magnetites demonstrated 1-6% of TiO_2 and 0.7-0.9% V_2O_3. Except primary magmatic Ti-magnetites secondary metamorphic magnetites are present in examined rocks. Their dusty grains are located within fibrous amphibole aggregates. The secondary magnetites contain no ilmenite inclusions as well as any other chemical impurity of TiO_2.

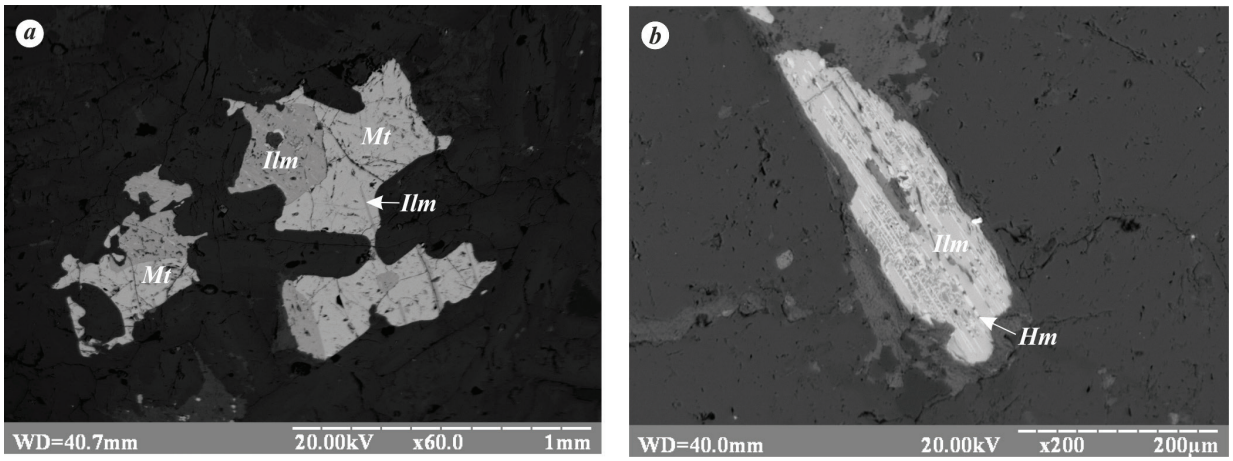

Fig.6. Fe-Ti-oxide ore minerals of TRGI gabbroids under electron microscope: a – cumulate aggregate of Ti-magnetite and ilmenite, sample 17-118A-1; b – individual ilmenite grain with exsolution inclusions of hematite, sample 16-2.

Anhedral laths and scaly aggregates of red-brown biotite are unevenly distributed in the studied rocks. They grow around Fe-Ti-oxide ore minerals or at the mafic mineral to plagioclase margins. Microprobe analysis detected significant TiO_2 and Cl impurities. Biotite is often replaced by chlorite with "drops" surplus titanium as fine sphene. Microcrystal aggregates of sphene are also found within fibrous amphiboles. The most significant accessory mineral of TRGI gabbroids is apatite. It is crystalized as small elongated-prismatic crystals 0.1-0.3 mm in size, which commonly tend to the mafic minerals aggregations. Microprobe analysis detected high content of Cl in the apatites.

4. Conslusions

On the basis of conducted research following conclusions concerning bedding, geological age and petrographic features of the studied rocks were made.

1. Metamorphosed gabbroids that fragmentary crop out on Cape Tuxen and Rasmussen Island form sheet-like intrusive body at least 3 km^2. Tuxen-Rasmussen Gabbroid Intrusion intruded into orogenic rocks of Upper Jurassic Volcanic Group, metamorphosed them and underwent contamination by volcanic material itself. Gabbroids and UJVG rocks were subsequenty intruded by Upper Cretaceous granites of Andean Intrusive Suite. Geological age of

TRGI is estimated as Lower Cretaceous. Previous U-Pb isotope datings of zircon from the gabbroids are believed to be "rejuvenated".

2. TRGI strikes NE and dips steep in SW direction. Authors suggest that intrusive body continues underwater and can crop out at the northern shore of the Waddington Bay and in Barros Rocks direction to the southwest. Microrythmic layering of TRGI gabbroids has original igneous origin. Cryptic layering, which implies variation in the chemical composition of rock-forming minerals with stratigraphic height in a layered sequence, is possible and requires additional research.

3. TRGI gabbroids underwent metamorphism in epidote-amphibolite facies. The most common alteration process is amphibolization. They preserve, nevertheless, relict structural-textural features and mineral associations of mafic igneous rocks. Geological position and petrographical features of TRGI correspond to hypabyssal level of crystallization. Relict mineral associations allow to identify the rocks as olivine gabbro-norites. Potential Fe-Ti-V ore specialization is emphasized according to the revealed patterns of crystal fractionation and accumulation of ilmenite and magnetite.

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