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Ultramafic Varėna Suite in the Precambrian crystalline basement of the Southern Lithuania – implications for the origin

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Abstract The Varėna Suite comprises a set of ultramafic rocks: olivinic, pyroxenic, magnetitic, dolomitic, and apatite bearing rocks, which form complex bodies of few sq. km in the Precambrian crystalline basement near the Varėna town in Southern Lithuania. Occurrences of few mineral commodities are related to the Varėna Suite. Magnetitic rocks contain essential resources of high grade iron ores. Phlogopite, apatite, REE and Th mineralization is related to the Varėna Suite. The assessment of the potential for these commodities is primarily dependent on the origin of Varėna Suite, which is still disputed. The models of metasomatic (skarn), and igneous (layered intrusion) origin are proposed earlier. The article presents an overview and reinterpretation of the recent data on the Varėna Suite, its petrographic and geochemical characteristic, as well as the arguments for igneous origin of the Varėna Suite, as the polyphase intrusion with subsequent metasomatic alteration, with alkaline trend.

Keywords *• Precambrian • ultramafic rocks • magnetite rocks • metasomatosis*

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INTRODUCTION

Varėna Suite (VS) embraces olivinic, pyroxenic, magnetitic, dolomitic, and apatite bearing rocks, which appear in the Precambrian crystalline basement near the Varėna town in Southern Lithuania. These rocks are united in the suite, presuming that they are genetically related and roughly coeval. VS rocks form complex bodies, which size on the surface of the crystalline basement reach few sq. km. These bodies appear on the area of about 300 sq. km, which have no certain tectonically or otherwise expressed borders. Primarily this lithological association was named "Varėna Complex" having similar meaning as "Varėna Suite", while the area of their distribution – "Varėna iron ore area" (Motuza *et al*, 1976).

The magnetitic rocks being part of the VS present high grade iron ores. Occurrences of LREE, thorium, apatite, and phlogopite are spatially related to the VS and deserve industrial interest. The assessment of the potential for those commodities requires understanding of the genesis of VS, what still is disputable and requires further investigation. This article presents a state–of–art of the recent data on the VS and, their reinterpretation, testing the hypothesis on the igneous origin of the VS and its tentative relation to alkaline magmatism.

DATA OF PREVIOUS RESEARCHES

Main portion of data on VS have been acquired in course of mapping and exploration of iron ores. The rocks of the VS are met in 30 boreholes (Fig. 1). In several other boreholes metasomatic alteration of country rocks was fixed, manifested in bands and veins of carbonates, albite, K-feldspar, scapolite, quartz, enriched in monazite, tourmaline, titanite, alanite.

The exploration drilling was focused on magnetite ore deposits, manifested by magnetic anomalies. Investigation of particular anomalies in most cases was limited by single borehole, therefore, mainly magnetitic, and spatially related rocks of the VS were characterised. Exception is Varėna iron deposit where 13 exploration boreholes have been drilled in the realms of same complex body characterising its composition and internal structure. The depth of boreholes in to the crystalline basement varies from few tenths up to 800 meters (bh. 20176).

Primary characteristic of the lithology of the VS is provided in manuscript reports by G. Motuza *et al.* (1976), S. Marfin *et al.* (1988), S. Marfinas *et al.* (1996) which are stored in the Archives of the Geological Survey of Lithuania (http://www.lgt.lt/). Scientific interpretation was given in the manuscript reports by G. Motuza and G. Skridlaitė (1988), the doctoral theses by G. Skridlaitė (1993), and a few published papers (Motuza *et al.* 1976; Kornilov *et al.* 1983; Percev, Kulakovski 1988; Motuza *et al.* 1989).

The views on the origin of the VS are contradictive. In most of works mentioned above, the VS rocks are regarded as skarns, comparable with those in iron ore deposits of the Aldan Shield (Sakha Republic, Russian Federation), particularly Tajozhnoje, Dios, Leglier. Some authors considered igneous genesis of VS rocks and compared them with lithology of Kiruna type deposits (Kornilov *et al.* 1982), or layered intrusions, such as Bushveld sill (Kepežinskas, Šliaupa 1994; Kepežinskas 2001).

The purpose of this work is to provide general characteristic of the VS rocks analysing existing petrological and geochemical data and reveal features implying certain model of the origin of VS. These data not necessary are conclusive, but reflect most essential features of the VS rocks and can be used for the strategy of further research, applying modern analytical methods and concepts.

MATERIAL AND METHODS

In this research were used primary data presented in the reports for the mapping and exploration of iron ores carried out in the research area in 1973–1996 (Motuza *et al.* 1976; Motuza *et al.* 1979; Marfin *et al.* 1988; Marfinas *et al.* 1996). These data include analyses of rocks for major chemical elements performed by the method of wet chemistry in the laboratory of the Complex Geological Expedition, and mineralogical analyses using X-Ray diffractometry, performed by enterprise "Mechanobr" in Sankt-Petersburg (Russia). Also drill cores have been examined preserved in the Drill Core Storage of the Geological Survey of Lithuania. For the petrographic investigation and photography thin sections where used, collected at the Department of Geology and Mineralogy of Vilnius University.

GEOLOGICAL SETTING

The research area is located in the western side of the East European Craton, in the East Lithuanian Domain (ELD), which is regarded as accretionary terrane, formed along the eastern margin of the West Lithuanian Domain (Motuza 2008, 2005, 2004) (Fig. 1). The predominant supracrustal rocks in ELD are amphibolites – primary basalts and diabases. They are interbedding with biotite–quartz–feldspar gneisses, predominantly metapsammites, concentrated in certain beltiform areas extended to NNE parallel to the margin of the West Lithuanian Domain.

In the area of Varėna iron deposit along with metapsammites appear felsic gneisses with relic porphyry texture, which composition corresponds to dacite or andesite. The amphibolites and metapsammitic gneisses are characterised in published papers (Motuza 2005; Linnemann *et al.* 2008), while metaporphyries in previous works were not identified as primary volcanic rock and here are characterised in more detail.

Metaporphyries are fixed in the seven out of 13 boreholes drilled in Varėna iron deposit (bh. Varėna-981; 982; 20158; 20171; 20172; 20176; 20181). In all cases these rocks appear in deepest position as the horizon of supracrustals serving as footwall for the VS. Mineral composition of gneisses is: biotite, clinopyroxene, hornblende, microcline, quartz, and plagioclase, the later being the predominant phase. The texture of rock is relic porphyry, formed by phenocrysts of plagioclase up to 5 mm in diameter, euhedral, some with simple twins, often zoned, with fine epidote crystals in the centre, some phenocrysts are granulated in different degree and looks like agglomerates of fine crystals of plagioclase, the matrix is granoblastic very fine (<0.3 mm) to fine grained (0.3–1 mm), polygonal, the structure is gneissic (Fig. 2).

Chemical patterns of the metaporphyry gneisses are reflected on the diagrams (Fig. 3). On the Total Alkali vs. Silica diagram, all analyses reveal elevated alkalinity and plot in the field of trachidacites. Total content of alkalis is up to 16%, but content of both K_2O, and Na_2O varies irregularly, and do not show correlation with SiO_2. On the diagram Normative Albite vs. Na_2O, part of analysis composes straight line showing very strong positive correlation, but the other part of analysis is spread irregularly. These samples contain normative acmite, what indicates that excess of Na might be concentrated not only in albite, but also other minerals, presumably pyroxenes and amphiboles.

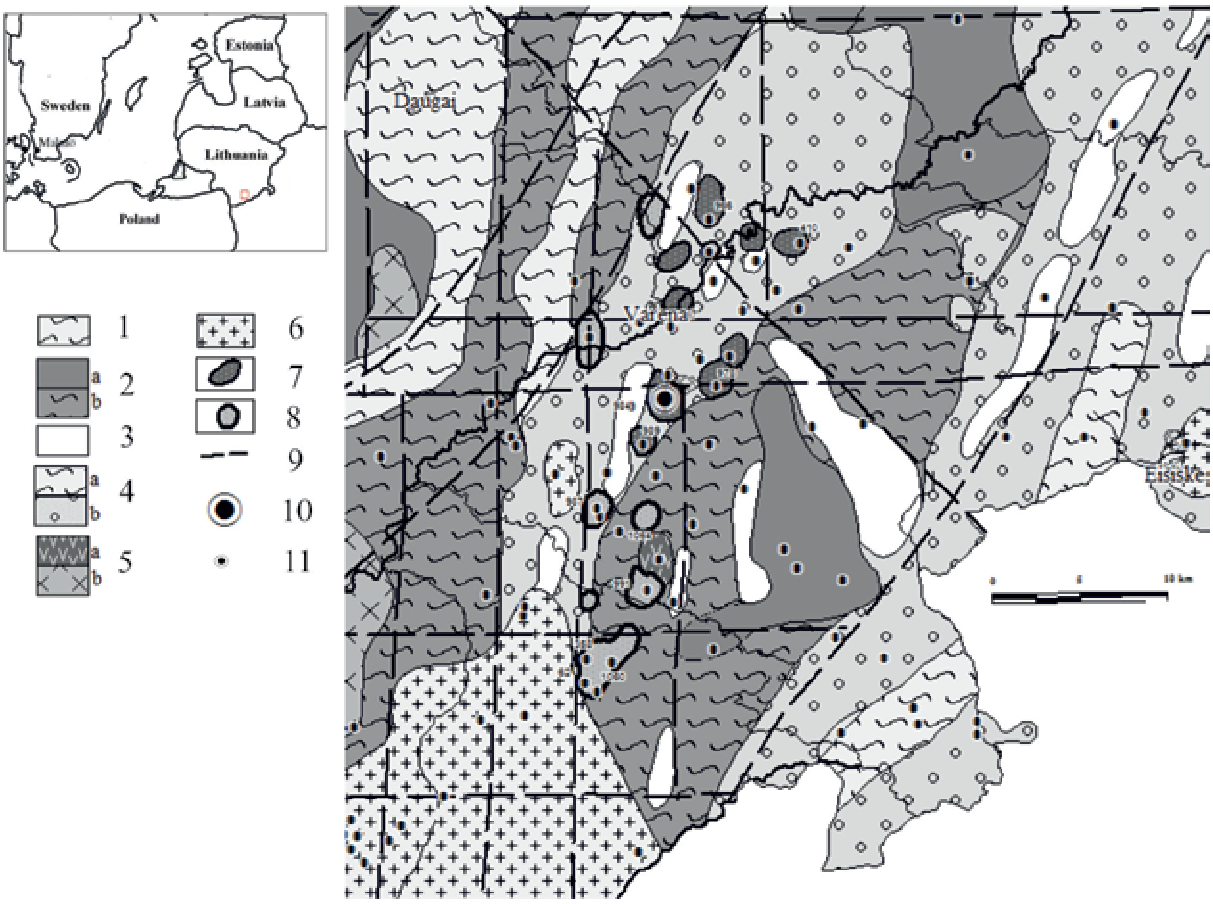

Fig. 1 Geological position of the Varėna Suite in the crystalline basement of Southern Lithuania (after G. Motuza). Supracrustal rocks: 1 – Hbl-Cpx-Opx-Pl granulite, primary basalt or diabase; 2a – amphibolite, primary basalt; 2b – amphibolite migmatised; 3 – Bt-Qtz-Pl±Kfs gneisse, primary psammite and felsic volcanics. Migmatites: 4a – with relics of amphibolites; 4b – with relics of amphibolites and felsic gneisses. Intrusive rocks: 5 – Randamonys Suite (1.840–1.80 Ga): a – gabbro; b – diorite and granodiorite; 6 – Kabeliai granite intrusion (1.5 Ga). Varėna Suite: 7 – olivinic association; 8 – pyroxenic association. 9 – faults; 10 –group of boreholes of the Varėna iron deposit; 11 – single borehole

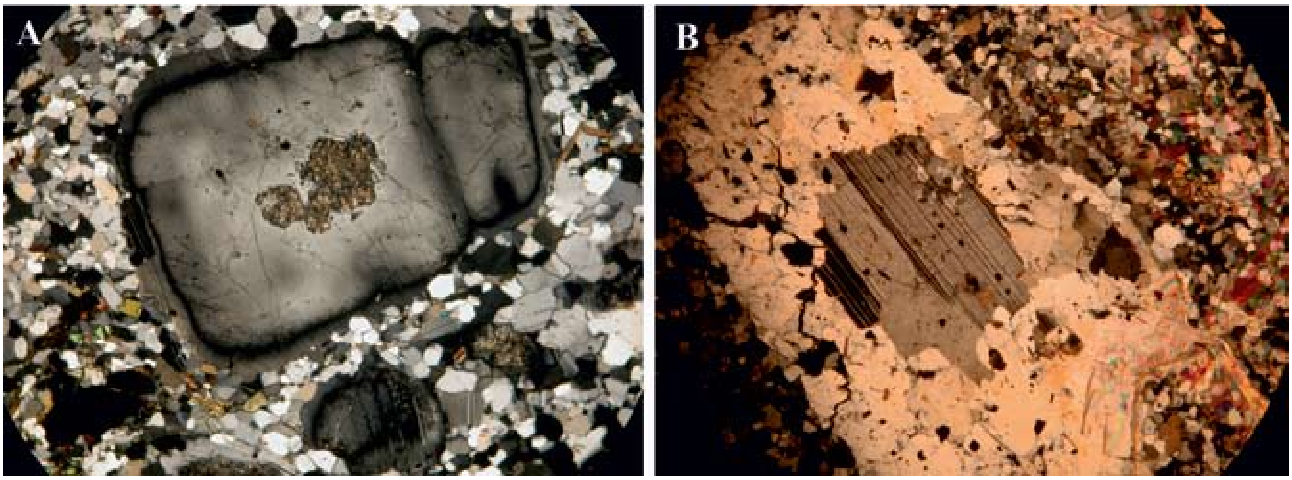

Fig. 2 Metaporphyry gneisses from the Varėna iron deposit. A – zoned phenocryst of plagioclase; bh. 20158, int. 861.3 m, base of the picture – 5 mm; B – plagioclase phenocryst partly granulated; bh. 981, int. 959.1 m; base of the picture – 5 mm

Varėna deposit is the only known location of the dolomite marble in Southern Lithuania. The origin of this dolomite rock is not clear, and it is characterised below as plausible member of the VS, but its sedimentary origin is not excluded. Syn-orogenic intrusive rocks are represented by Randamonys suite, which forms a large Randamonys intrusion and smaller satellite bodies composed by gabbro, diorite

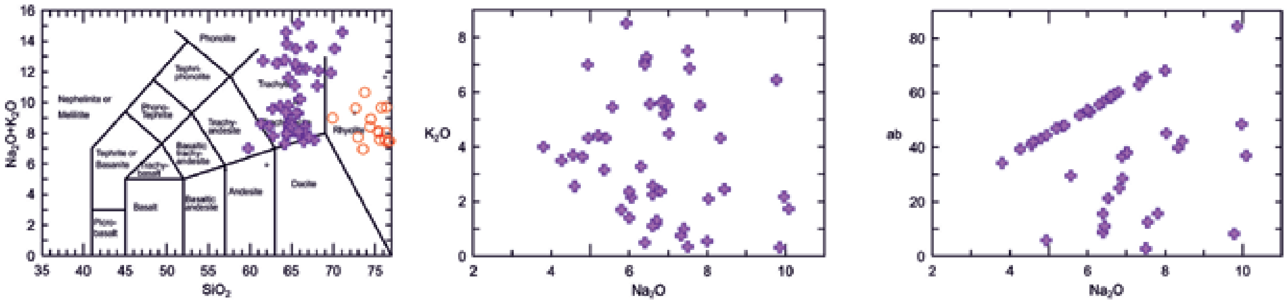

Fig. 3 Diagrams demonstrating chemical patterns of the metaporphyries: Total Alkali vs. Silica; K_2O vs. Na_2O; Normative Albite (ab) vs. Na_2O. Symbols: blue crosses – metaporphyries; red circles – metapsammites

Table 1 Average composition of ultramafic rocks in the Varėna iron deposit

Rocks	Number of analysis	SiO_2	Al_2O_3	FeO_{tot}	MgO	CaO	Na_2O	K_2O
Olivinic and magnetitic olivinic	66	35	2.2	17.2	32.7	0.9	0.49	1.07
Pyroxenic-olivinic	20	44.8	5	8.9	25.6	5.6	1.4	1.9
Clinopyroxenic	55	51.6	2.7	9	18.7	14	1.02	0.57
Orthopyroxenic	6	50	1.2	14.8	27.5	1.8	0.3	0.6

and granodiorite. These intrusions have been formed in few pulses between 1840 and 1800 Ga (Bogdanova *et al.* 2015). Granitic rocks form an anorogenic Kabeliai intrusion and probably few smaller bodies in the southern part of the area, which age is 1.5 Ga (Sundblad *et al.* 1994).

CHARACTERISTIC OF THE VARĖNA SUITE ROCKS

To the VS are attributed rocks composed by olivine, pyroxene, magnetite, dolomite, and apatite bearing rocks. These rocks are associated and usually form composite bodies with variable content of particular lithologies mentioned above. The primary rocks are altered by the later metasomatic processes which changed essentially mineralogical and partly chemical composition of rocks. Therefore characterising those rocks and reconstructing their possible protholith both mineralogical, and chemical composition were taken into account (Table 1).

Olivinic rocks

Olivinic rocks are composed predominantly by forsterite. Essential minerals are magnetite which amount might increase up to few tenths of percent. Green spinel (hercynite), apatite, and pyroxene appear often. Secondary minerals are serpentine, almost completely substituting olivine, hornblende, substituting pyroxene and phlogopite, formed at the expense of both olivine and pyroxene. Spinel in places is altered to hydrotalcite.

The texture of olivinic rocks is fine (0.3–1 mm) to middle (1–5 mm) grained, structure is massive (Fig. 4). The rocks with higher content of magnetite have sideronitic texture (Fig. 4C,D), which is characteristic to igneous rocks formed as cumulus in the magma chamber or by mingling of silicate and iron oxide magma separated by the liquation process (Zhou *et al.* 2013).

High content of MgO–30–40%, and low of SiO_2<40% is characteristic for olivinic rock. Content of other major elements (Al, Ca, Ti), and FeO_{tot} in olivinic rock varies (Fig. 5). The geochemical patterns of the olivinic and magnetitic-olivinic rocks differ little up to amount of FeO_{tot}=20%. The magnetitic-olivinic rocks with higher content of FeO_{tot}=20–40% slightly differ from pure olivinic rock, by lover content of MgO and alkalies, and might be regarded as subtype of olivinic rock. The compositional gap exists between magnetitic-olivinic rock and magnetitic rock (FeO_{tot}>60%). It means that rocks with FeO_{tot}=40–60% are practically absent. Corresponding gap appears also in MgO variation – there are no fixed rocks with MgO between 18 and 25%. This feature might indicate a different way of formation of olivinic and magnetitic rocks (Fig. 5).

Peculiarity of the olivinic rock is variable, often high alkalinity – up to 6%, mainly due to potassium amount, which is expressed by presence of normative feldspatoids, in some analysis. The high variability might be indication of secondary origin of the alkalinity, which might be related to phlogopitisation. Remarkable feature of these rocks is very low content of chromium (tenths of ppm), cobalt (tenths of ppm), and nickel (hundreds of ppm). However in some boreholes (bh. Varėna-989 and Merkinė-348) intervals of serpentinite (serpentinised olivinic rock) with much higher concentration of Cr up to 0.5–2% are fixed.

Magnetitic rocks

To this group are attributed rocks, which contain >60% of FeO_{tot} in form of magnetite (Fig. 4D; 5). Mag-

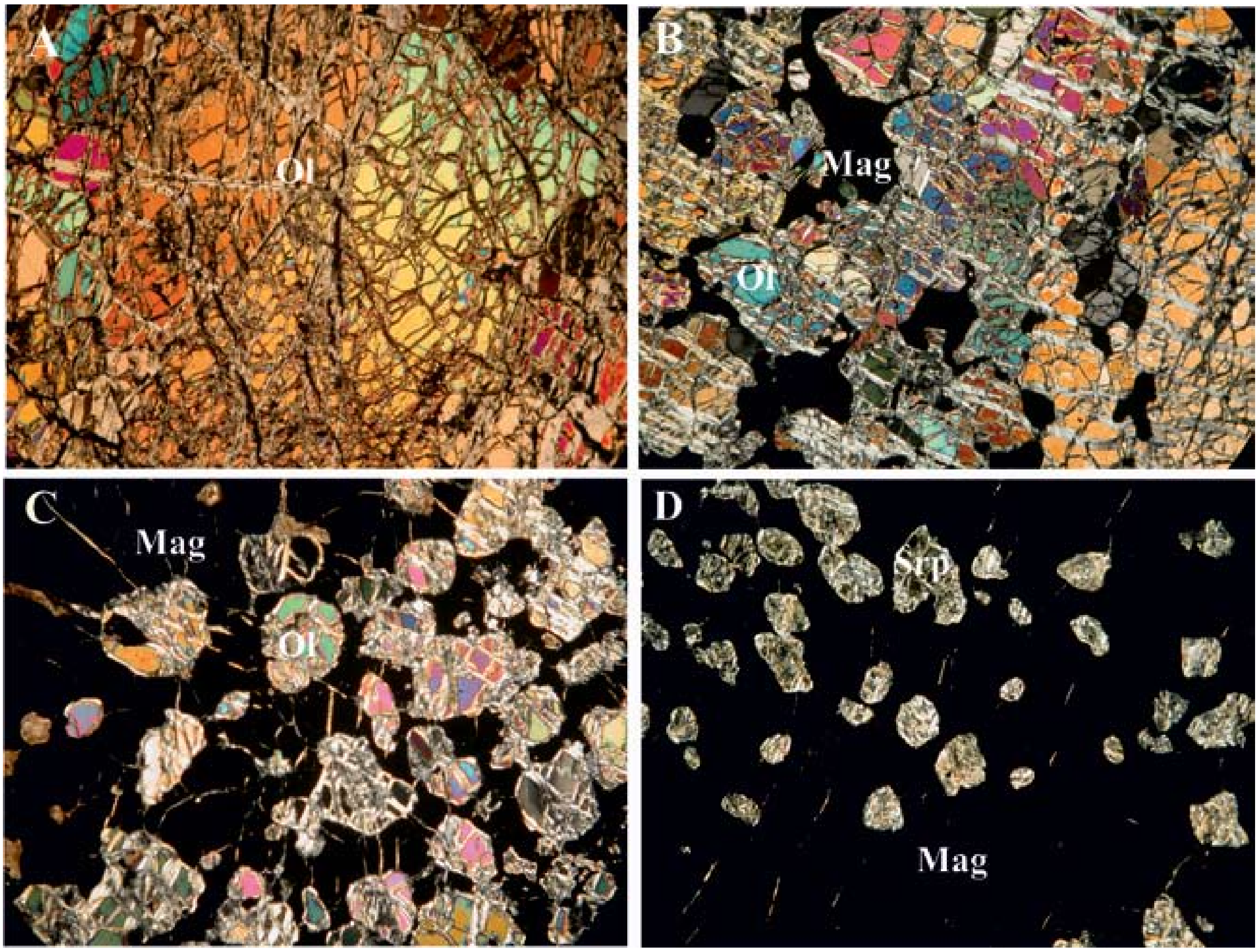

Fig. 4 Olivinic rocks and magnetitic-olivinic rocks: A – bh. Varėna-982, int. 734.7 m; B – bh. 20183, int. 971.3 m; C – magnetitic-serpentinic rock with sideronitic texture, bh. 20171, int. 488.6 m; D – serpentinic-magnetitic rock with sideronitic texture bh. 20179, int. 848.5 m. Base of the pictures 4 mm

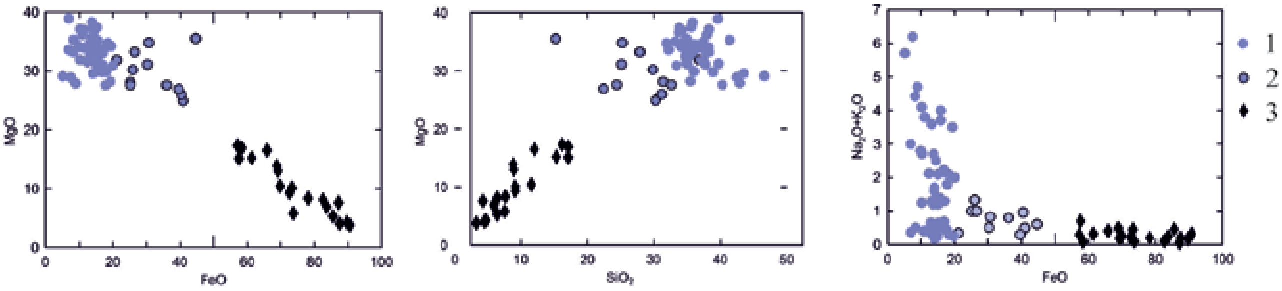

Fig. 5 Chemical composition of olivinic and magnetitic rocks: 1 – olivinic rocks; 2 – magnetitic-olivinic rocks; 3 – magnetitic rocks

netitic rocks are fixed in many boreholes, especially because these rocks where the target of exploration, manifested by intensive magnetic anomalies. The thickness of magnetitic rocks, visible in boreholes is up to 354 m (bh. 981, int. 536.9–891.2 m), and 308 m (bh. 20171, int. 409–716.8 m) including small intervals of subordinated pyroxenic, and carbonate rocks. Along with the magnetite, the rocks contain olivine (mainly serpentinised), more rarely pyroxene, amphibole, spinel, and apatite. The characteristic texture of rocks is sideronitic (Fig. 4).

Pyroxenic-olivinic rocks

These rocks are composed by primary olivine and pyroxene, which are mainly altered to serpentine and amphibole, correspondingly. The magnetite, phlogopite, hercynite and apatite are obvious, but in minor amount (Fig. 6). The texture of rocks is fine and middle grained, the structure is massive or patchy, because of irregular distribution of minerals. These rocks are rear and fixed mainly in the marginal parts of the bodies of the olivinic rocks. The thickest body of olivinic-pyroxenic rock is fixed in the borehole 20157 – 68 m (int. 378–446 m), but most often their bodies are just a few meters thick.

For these rocks high content of MgO – 26% in average is characteristic, but, as compared to olivinic rocks, they have higher content of CaO – 5.6% and Al_2O_3 – 5.2 (Table 1). On the TAS diagram part of analyses plot in the field of high alkalinity rocks and those rocks contain normative foids (Fig. 7). Alkalinity is positively related to Al_2O_3, what is indicating, that alkalis are concentrated in the aliumosilicates.

Pyroxenic rocks

Pyroxenic rocks are composed of clinopyroxene (mainly diopside) or orthopyroxene (enstatite). Apatite, hercynite, magnetite, allanite are present in small amounts in these rocks. In the borehole Varėna-987 (int. 363.1–366.5; 431.5–433.5 m), garnet of andradite type appears in clinopyroxenic rock represented by salite. The amount of garnet is around 10%. The texture is euhedral or hypidiomorphic, the size of grains varies from parts of mm up to few cm (Fig. 8). Clinopyroxenic rocks often are substituted in various degrees by hornblende or actinolite.

Clinopyroxenic rocks are widespread and forms intervals of few tenths up to 90 meters thick. Orthopyroxenic rock is fixed just in few boreholes (Varėna-978; 981; 20171; 20172; 20173; 20176). In borehole Varėna-978 the thickness of particular orthopyroxenic bodies exceeds 44 m (int. 767–811.1 m), in borehole 20176 – 10 m (int. 855.8–864.3 m), while in other boreholes it is just few metres. It is composed of magnesium variety of pyroxene - enstatite or bronsite with addition of serpentine (after olivine), in places apatite and magnetite. The grain size is variable, predominantly few, in places more than 50 millimetres. Orthopyroxene is partly substituted by tremolite, and talc. This process is nearly isochemical. Phlogopite appears as a secondary mineral, which formation proceeds with addition of potassium. Major element content in the pyroxenic rocks is given in the Table 1. The orthopyroxenic rocks as compared to clinopyroxenic differ essentially in higher amount of MgO and lover – CaO, while alkalinity is low in the rocks of both types (Fig. 9).

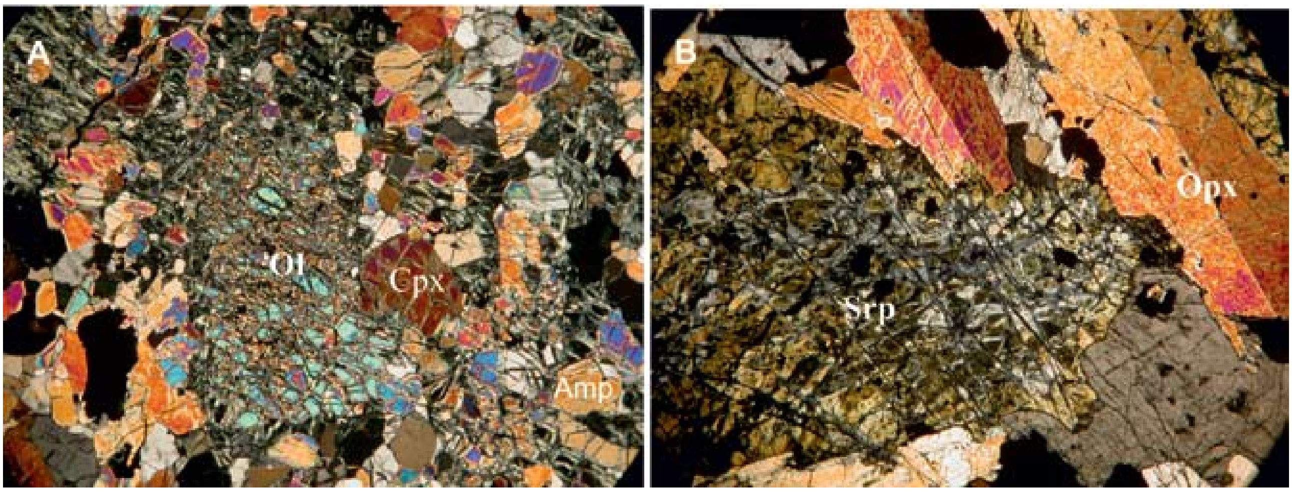

Fig. 6 Clinopyroxenic-olivinic rocks with secondary amphibole, bh. 20183, int. 855.5 m (A), and orthopyroxene-serpentinic rock, bh. Varėna-978, int. 661 m (B). Base of picture – 4 mm

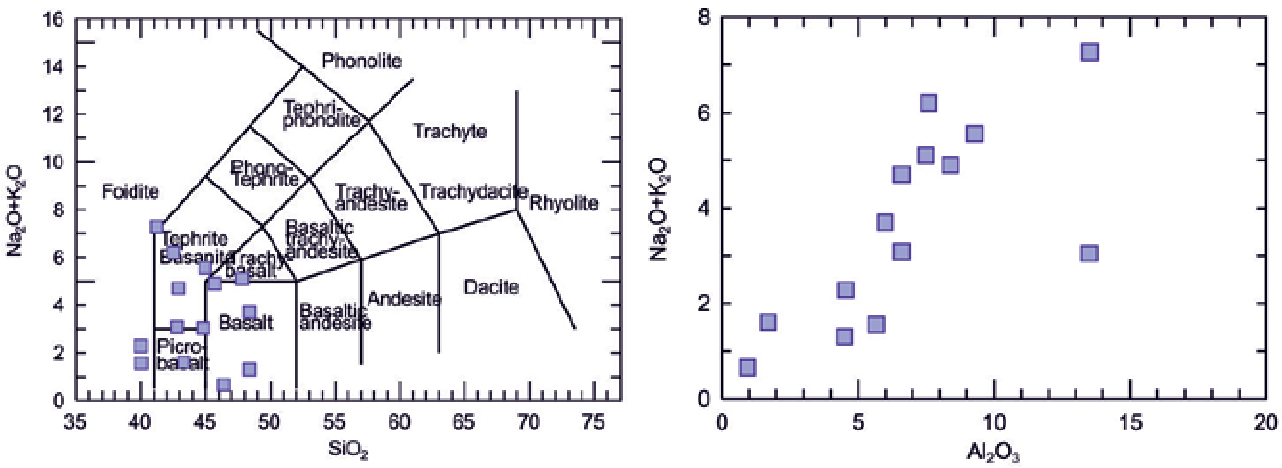

Fig. 7 Chemical, diagrams of the pyroxenic-olivinic (amphibolised and serpentinised) rocks

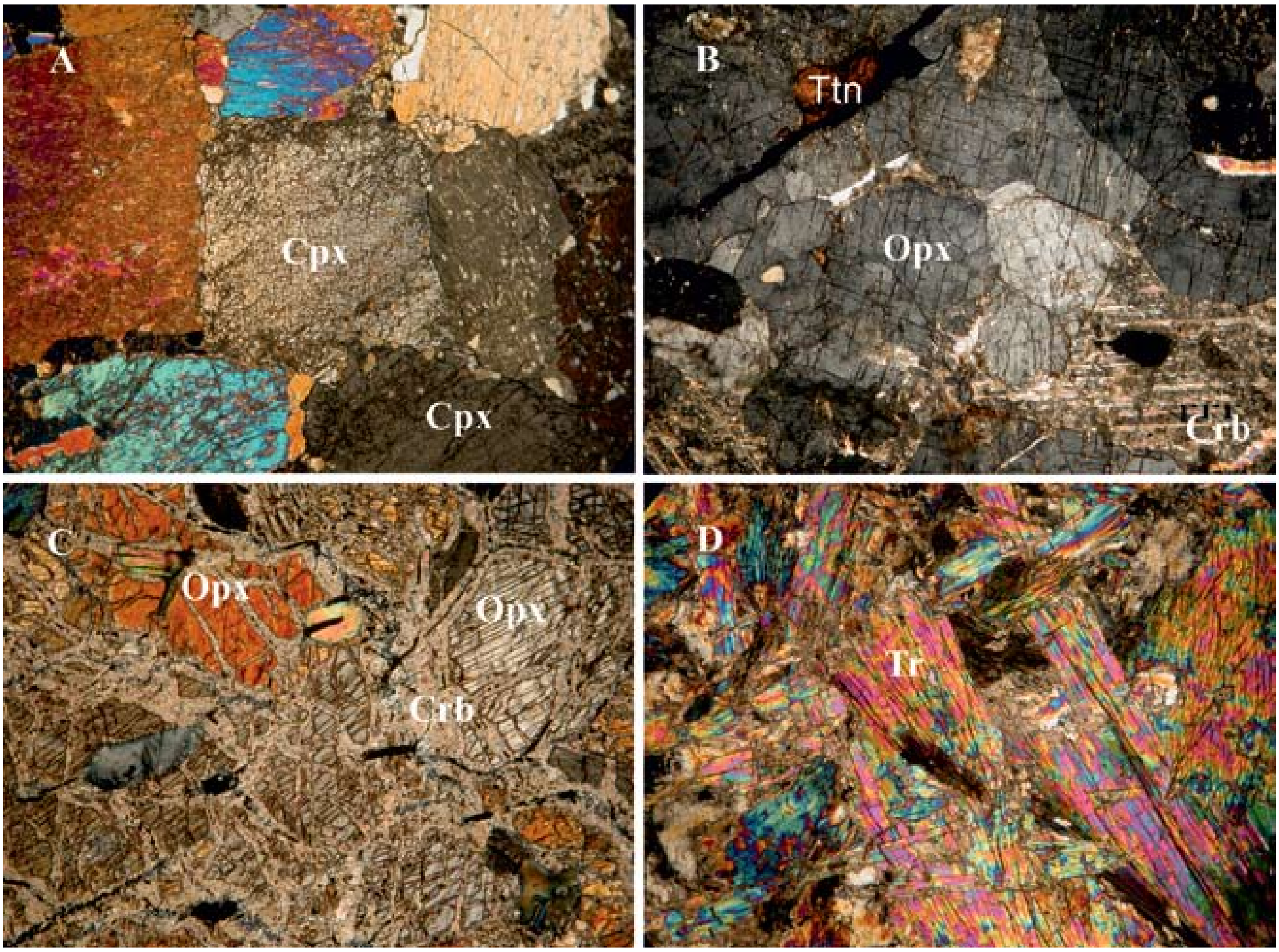

Fig. 8 Pyroxenic rocks: A – diopsidic rock, bh. 20157, int. 848.3 m; B – orthopyroxenic rock with calcite, bh.Varėna-978, int. 799 m; C – orthopyroxenic rock carbonatised, bh. Varėna-978, int. 809 m; D – tremolitic rock formed at the expense of orthopyroxenic rock; bh. Varėna-978 int. 774.2 m

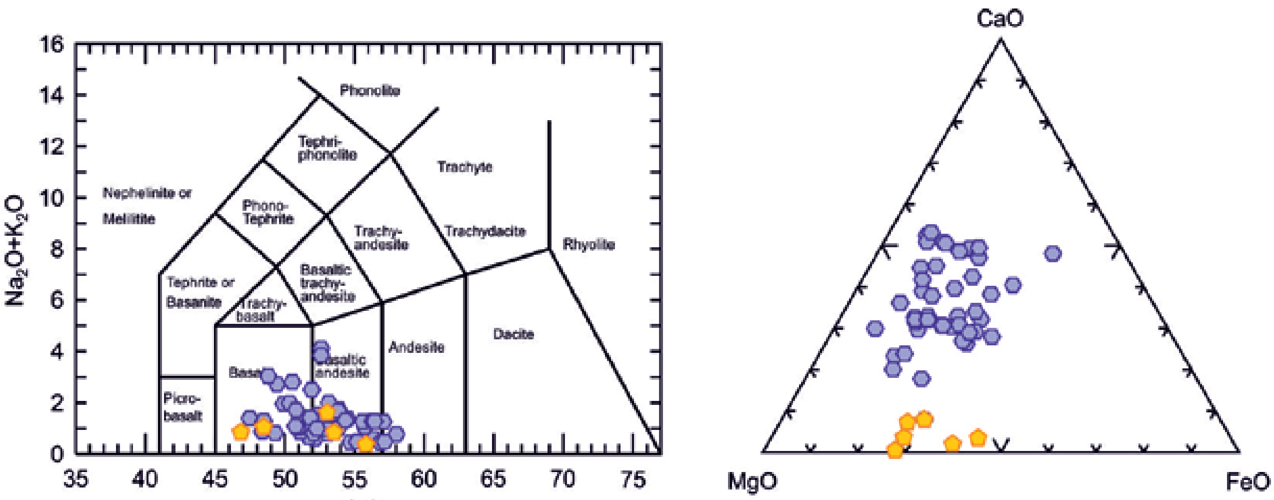

Fig. 9 TAS and MgO-CaO-FeO diagrams for pyroxenic rocks of the Varėna Suite. Blue polygons – clinopyroxenic rocks; yellow polygons - orthopyroxenic rocks

Carbonate rocks

Carbonate rocks are fixed only in the Varėna deposit, and just in two boreholes (bh. Varėna-982 and 20179). The thickness reaches 210 m (bh. 20179, int. 378–588.6 m), including 28 m thick body of magnetitic rock and few thinner intervals of pyroxenic rocks. In two other boreholes (Varėna-981 and 20177) carbonate rocks form small intervals up to 5 meters thick. Rocks are composed of dolomite with addition of olivine, pyroxene, apatite, magnetite, and hercynite which are distributed irregularly and concentrated in bands or patches. The texture of carbonate rocks is middle to coarse grained, structure massive in places banded or patchy (Fig. 10). The five ICP-AES analysis of dolomitic rocks, produced in the Geological Survey of Norway reveal very low content (average in ppm) of Sr – 33, Ce – 7.6, La – 5, Zr <2; Nb <5.

Apatite bearing rocks

To this group are attributed rocks, where apatite content is >10%. They are fixed in many boreholes (bh. Merkinė-358; Barčiai-410; Varėna-966; 980; 981; 20157, 20158; 20171; 20173; 20183). Apatite forms nearly monomineralic veins up to 10 cm thick, or is dispersed in form of fine grains or patches in various rocks: olivinic (serpentinite); magnetitic, pyroxenic, phlogopitic, amphibolic (actinolitic-tremolitic) (Fig. 11). There are cases when rock contains magnetite, olivine, and apatite and thus correspond to phoscorite.

Highest estimated apatite concentration is fixed in the serpentinic rock in the borehole Varėna-966, int. 530-548 m – 27% P_2O_5. In some boreholes (bh. Merkinė-358, int. 329.0–329.6 m; 20183) veins of

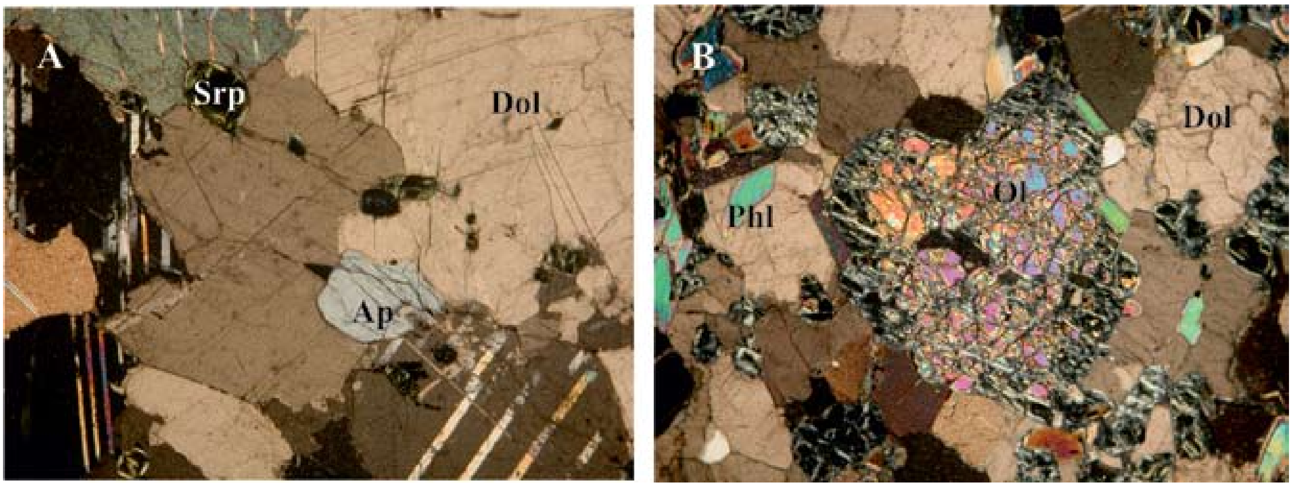

Fig. 10 Dolomitic rocks: A – with apatite (bh. 20179, int. 402.1 m); B – with olivine (bh. 20179, int. 627.2 m)

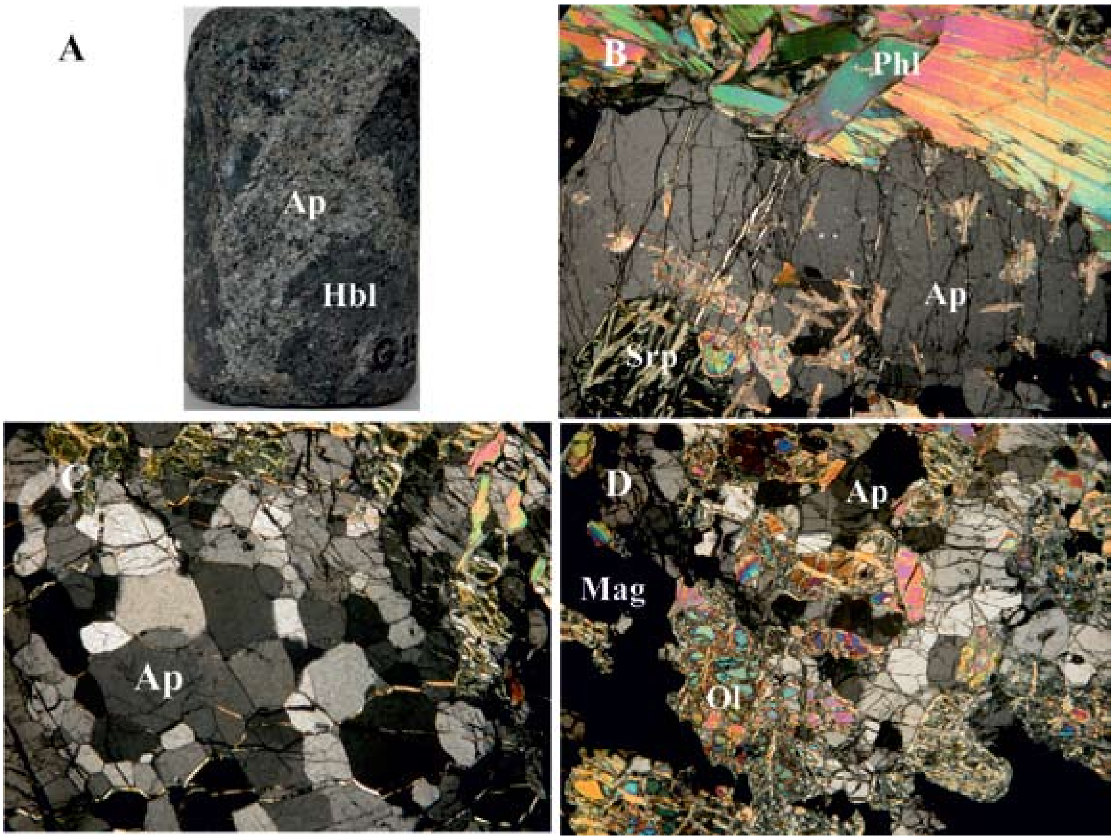

Fig. 11 Apatite bearing rocks: A – apatite vein in amphibolic rock, bh. Merkinė-358, int. 320.6–329.3 m; B, C – apatitic rocks, bh. 20157, int. 994 and 992.1 m; D – magnetitic-olivinic-apatitic rock, bh. 20183, int. 971.3 m

apatite few decimetres thick appear, where its concentration, is few tenths of percent (Fig. 11). Apatite often is host mineral of the LREE, particularly La and Ce, which concentration in apatite bearing rocks is up to a few percents.

Other types of rocks

Rocks of sienitic composition, consisting predominantly of K-feldspar are fixed in few boreholes, cutting bodies of other VS rocks or hosting rocks (Merkinė–360; Varėna–967; 987; 1060; 1064; 20158). Usually such bodies are a few metres thick, and consist of microcline, sodic plagioclase, biotite, amphibole. The texture is middle grained, in places very coarse grained, the structure massive, sometimes patchy formed by agglomerations of amphibole. The contacts of bodies are usually sharp, with recrystallisation rims in hosting rock (Fig. 12A). Presence of nepheline in the sienitic rock in the borehole 987 (int. 472 m) was reported by (Donskoy *et al.* 1990). But this finding was not confirmed by other researches and remains doubtful.

METASOMATIC ALTERATION OF VARĖNA SUITE AND HOSTING ROCKS

The characteristic feature of the VS is intensive metasomatic alteration, which affected both rocks of proper VS and the hosting rocks. Metasomatic alteration is manifested by the substitution of olivine by serpentine; clinopyroxene by hornblende, actinolite; orthopyroxene by tremolite, leeding to formation of bodies or bands of predominantly amphibole rocks. In olivinic, pyroxenic and carbonate rocks phlogopite is formed. Phlogopite rocks often are very coarse grained, where size of particular phlogopite crystals exceeds few centimetres (Fig. 13). The phlogopitisation is related to the influx of potassium.

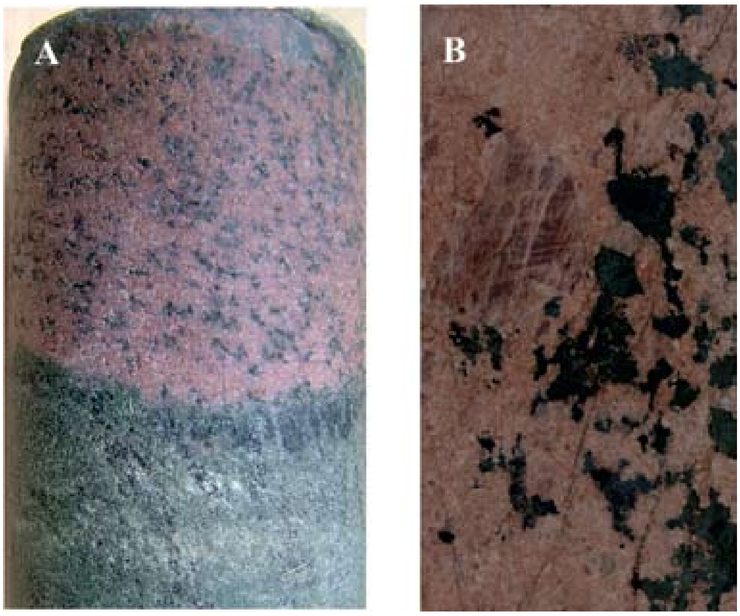

Fig.12 Sienitic rock and its contact with pyroxenic rock, bh. Varėna-987, int. 393.4 m

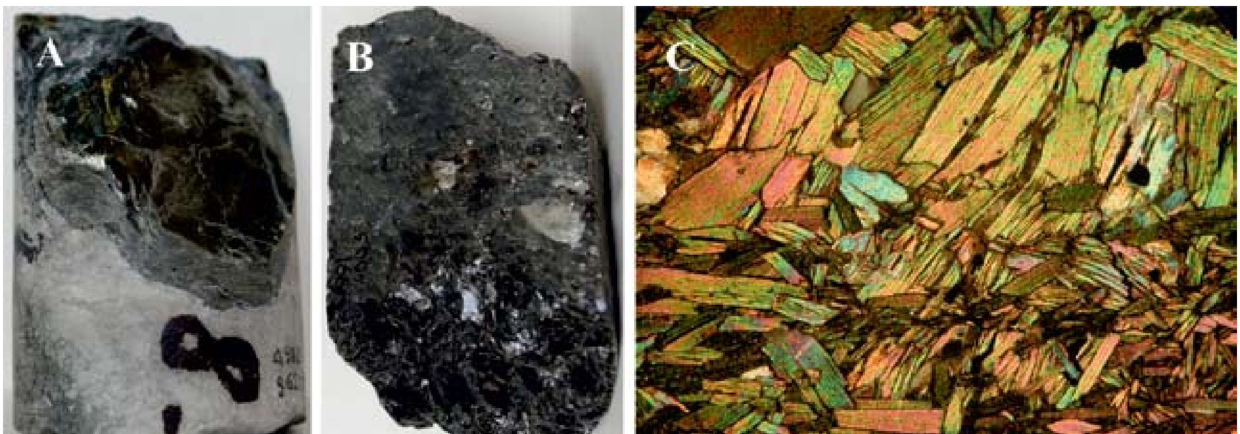

Fig. 13 Phlogopitic rocks: A – bh. Varėna-982, int. 621.9 m; B – bh. Varėna-991, int. 400.3 m; C – band of phlogopite in pyroxenic rock under the microscope, bh. Varėna-980, int. 650.1 m

The strong metasomatic alteration can "hide" some types of primary rocks. Thus in Kovdor alkaline-carbonatitic intrusion, where main types of rocks are similar to the VS, primary melilitic rocks are metasomatically transformed into carbonat-diopside-hastingsitic rock, and further to phlogopitic rock.

Metasomatic processes affecting both VS and hosting rocks often reveal the alkaline trend. By mineralogical analysis there are fixed small amounts of pyrochlore (in magnetitic rock, bh. Varėna-981, int. 545–666 m), riebeckite (in serpentinite, bh. Varėna-982, int. 734 m), ferrorichterite (in pyroxenic rock, bh. 20158, int. 559; 705–710 m; olivinic rock, int. 710 m) (Marfinas *et al.* 1996).

In hosting amphibolites hornblende is substituted by clinopyroxene, which contains higher amount of sodium, what is indicated *inter alia* by normative acmite. In places (bh. 20158) richterite and spodumene appears. Scapolitisation of plagioclase is widespread. Amphibolite affected by these processes contains various amounts of clinopyroxene and scapolite, formed at the expense of hornblende and plagioclase correspondingly (Fig. 14). In places in altered amphibolites ferrorichterite appears (bh. 20158, int. 559; 705; 710; 724; 766; 807; 854 m). On the TAS diagram a high bulk alkalinity of amphibolites situated near the VS bodies is evident – most of analyses plot in the fields of phonotefrite and phonolite, and in some sam-

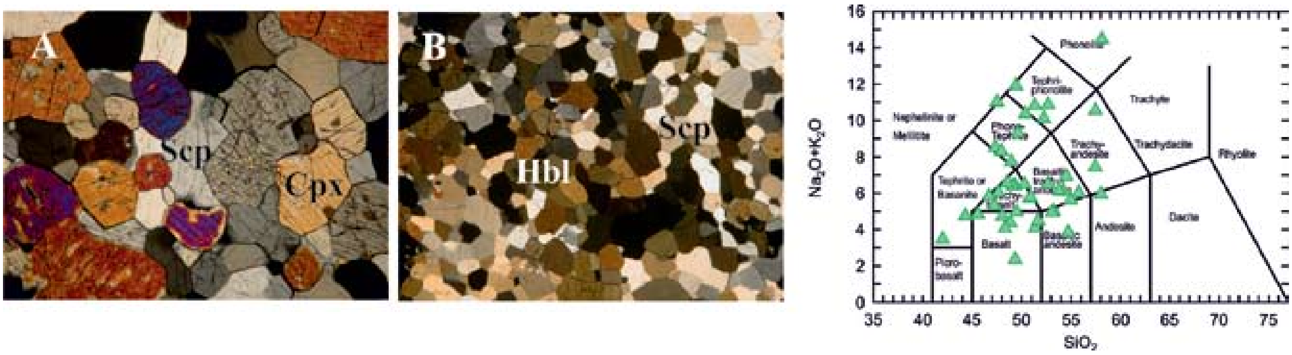

Fig. 14 Amphibolite altered by metasomatosis: A – clinopyroxene-scapolite rock, bh. 20158, int. 796.7 m; B – scapolite-hornblende rock, bh. 20171, int. 819.4 m. TAS diagram for amphibolites hosting Varėna Suite

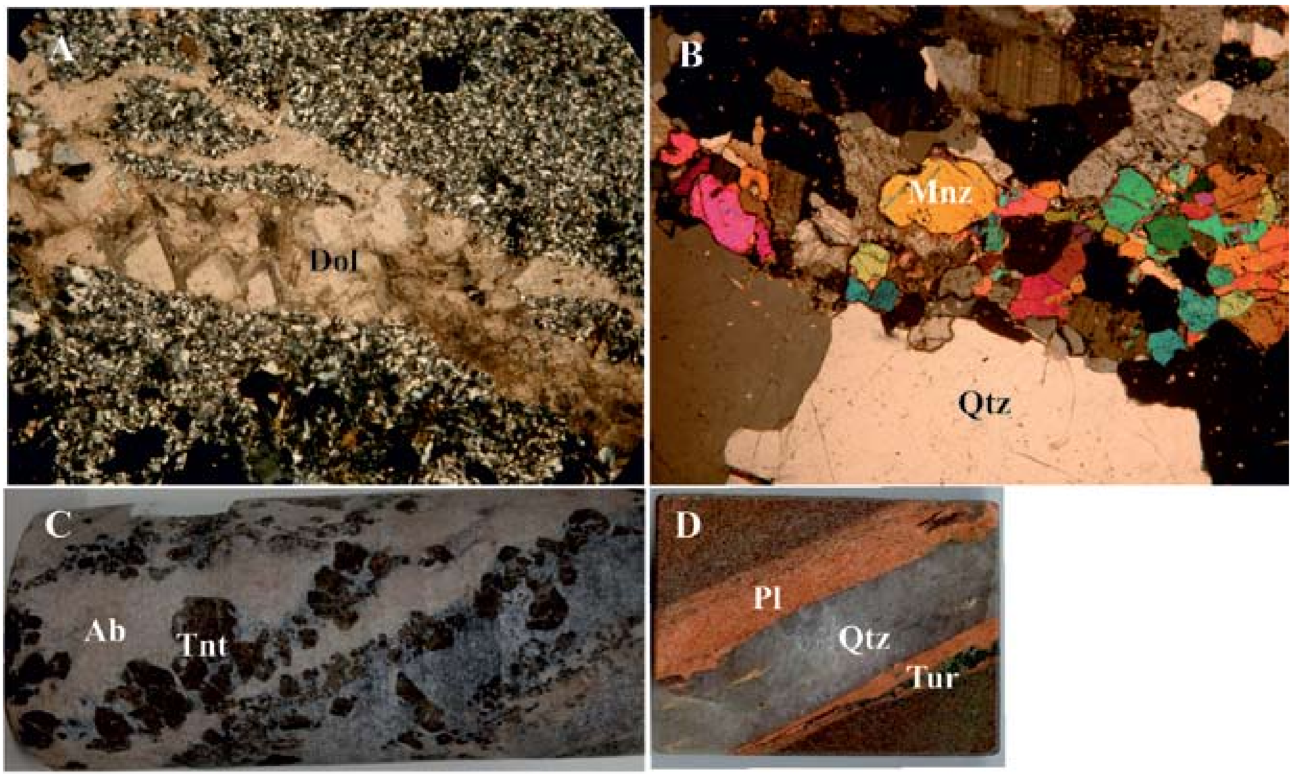

Fig. 15 Metasomatic alteration of metapsammitic gneisses: A – vein of dolomite, bh. 20158, int. 373 m; base of picture - 4 mm; B – vein of monazite, bh. Varėna-984, int. 461.5 m; base of picture – 4 mm; C – zone of albitisation with tourmaline, bh. Varėna-984, int. 461.2–461.3 m, diameter of core – 4 cm; D – zone of albitisation and quartzitisation; black stripe – tourmaline; bh. Barčiai-421.

ples normative foids are fixed (Fig. 14). Alkalinity is predominantly caused by high content of sodium.

Biotite-quartz-feldspar gneisses (metapsammites) are affected by albitisation, microclinisation, phlogopitisation of biotite, formation of carbonate or quartz veins, cutting or substituting gneisses. In zones of metasomatic alteration by mineralogical analysis are fixed (in ppm): allanite – 94; bastnesite – 0.28; apatite – 1204; spodumene – 252.6; tourmaline, pirochlore, aegirine (bh. Merkinė-360, int. 367–444.4 m) (Marfin *et al.* 1988). In places high concentration of monazite, and titanite also anomalous concentration of REE (up to few percent of La and Ce), Nb (500-630 ppm) are revealed (Fig. 15). As it was mentioned above, gneisses of metavolcanic origin with relic porphyry texture are also alkaline in different degree, which might be the result of alteration (see Fig. 3).

SHAPE OF BODIES OF THE VARĖNA SUITE ROCKS

The VS rocks form complex bodies, composed of few types of rocks. There are two principal associations of the VS. One contains olivinic (serpentinic) rocks, along with pyroxenic, magnetitic and dolomitic (see Fig. 1). Another type of association is limited by clinopyroxenic rocks and derivative amphibolic and phlogopitic rocks. Magnetitic rocks also appear in this association, but contain hornblende, phlogopite and do not form so big and so concentrated bodies as compared to olivinic (serpentinic)-magnetitic rocks. The bodies of different associations occupy separate areas (see Fig. 1). The area of olivinic association is nearly isometric, while the area of the pyroxenic association is beltiform and embraces the former area from the western and southern sides.

It is to mention, that most of boreholes were drilled for the exploration of iron ores, and bodies of the VS rocks containing magnetitic rocks and manifested by magnetic anomalies have been investigated, but there might be bodies do not containing magnetitic rocks and therefore not encountered. The bodies of the VS are composite, formed by rocks of various types, but certain types usually are predominant, forming intervals up to few hundred meters of visible thickness (Fig.16). The bodies of these rocks usually contain inclusions (veins, bands, fragments) of other rocks of decimetre to few meters thick, particularly numerous along the margins. The rocks of primary association often are substituted by secondary metasomatic rocks.

The structure of the composite bodies of VS is demonstrated by the map and cross-sections of the Varėna iron deposit (Fig. 16), which is characterised by 13 boreholes, some drilled up to 900 m into the basement. Seeking to present the principal structural features of the bodies we showed generalised data, omitting small (up to few metres) intervals of particular rocks. Moreover, there are shown presumable primary rocks do not taking into account secondary metasomatic alteration, it is olivinic rocks are shown

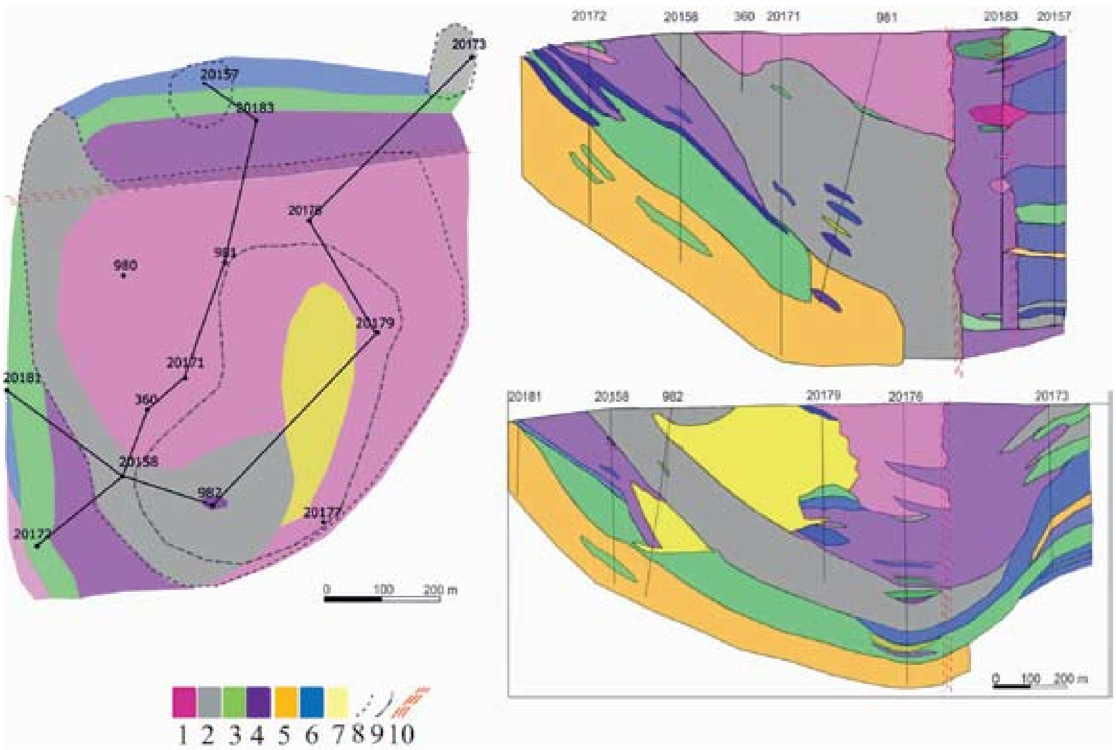

Fig. 16 Generalised geological map and sections of the Varėna ore deposit: 1 – metapsammitic gneiss; 2 – magnetitic rock; 3 – amphibolite; 4 – serpentinite; 5 – metaporphyry; 6 – pyroxenic rocks; 7 – dolomitic rock; 8 – presumable limits of bodies of magnetitic rock; 9 – presumable limits of bodies of dolomitic rock; 10 – faults

instead of serpentinite; pyroxenic rocks shown do not taking into account amphibolisation; hosting amphibolites – ignoring scapolitisation etc.

In the Varėna deposit in the lower section of many boreholes two types of the hosting rocks appear – hornblende-biotite-quartz-feldspar gneiss (primary andesitic-dacitic porphyry), and amphibolite (primary basalt), forming footwall of the VS rocks. In some section these layers are continuous and might be correlated, in other they are partly or completely missing. In upper part of the sections of most boreholes, metapsammitic gneiss appears above the package of the VS rocks, as hanging wall of the VS, but in some boreholes it is absent.

The principal feature of the bodies of VS is their irregular shape and variability of parameters. Often the sections of adjacent boreholes are quite different and inconsistent. For example, the borehole Varėna-981 penetrated very thick body of the magnetitic rock, exceeding 300 m, while in borehole 20183, located on the distance just 250 m, magnetitic rocks are absent and the serpentinised olivinic rock is predominant in the section, exceeding 500 m of total thickness.

Bodies of the dolomitic rocks are particularly variable; they reveal indications of flow, and allochthonous position, what was noticed also by other researches (Percev, Kulakovskij 1988). Such indications are: irregular shape; cutting contacts with serpentinite and magnetitic rocks; fragments of these rocks of angular shape appearing close to the contacts (possibly xenolites?) (Fig. 17). These authors presume that dolomitic rock was flowing in the solid state, but similar features might appear also by intrusion of magma.

Fig. 17 Fragment (xenolith?) of the magnetitic rock in the marginal part of the dolomite rock, close to the contact with serpentinite, bh. 20177, int. 628 m

THE GENESIS AND THE AGE OF THE VARĖNA SUITE

There are proposed two principle models of formation of the VS – metasomatic (skarn) (Motuza *et al.* 1989) and intrusive (layered intrusion) (Kepežinskas 2001). The skarn hypothesis is based primarily on specific geochemical properties of rocks – low Ti, Cr and Co content in olivinic rocks (and serpentinites) is explained by formation of olivinic rocks as a skarn after dolomite, inheriting their geochemical properties. The pyroxenic rocks have higher concentration of the elements listed above, which is explained by their formation after amphibolites, inheriting their geochemical properties.

Another argument for skarn type is the similarity of the VS with magnetite deposits and associated rocks in Central Aldan Shield, particularly Tajozhnoje, Dios, and Leglier, regarded as skarn type (Motuza *et al.* 1989; Percev, Kulakovskij 1988). However the last authors emphasised difficulties explaining metasomatic origin of rocks in these iron deposits, particularly large amount of homogeneous serpentinite with relics of olivine. They presumed, that serpentinite was primarily intrusive olivinite. These authors also admit that source of iron concentrated in the magnetitic deposits of Aldan Shield is unknown. They also noticed allochthonous position and irregular shape of the dolomite rocks but explained it by plastic flow of their material in solid state. Same features and problems are characteristic to the VS rocks. Thus the skarn hypothesis cannot explain their origin.

It is to notice, that in VS the serpentinised olivinic or magnetite-olivinic rocks very rarely contain carbonate inclusions, what might be expected in case of formation of olivinic rocks after carbonates as it is presumed by skarn hypothesis. There are not known large granitic bodies to be sufficient source of fluids producing skarns, particularly magnetitic. The variation of ultramafic rocks in the section of boreholes was interpreted as layered intrusion by K. Kepežinskas (Kepežinskas 2001; Kepežinskas, Šliaupa 1994), based on alternation of rocks of different types in the sections of boreholes.

Analysing and reconsidering existing data on the VS, the features supporting the hypothesis of the magmatic origin of the VS, and subsequent metasomatic alteration by fluids derived from alkaline magmas have been proposed:

- Association of rocks composing VS (olivinic, pyroxenic, dolomitic, magnetitic, apatite bearing) are characteristic for suites of ultramafic-alkaline-carbonatitic intrusions.

- The principal texture of olivinic-magnetitic rocks is sideronitic, characterised by olivine or other silicate crystals suspended in oxides, which by many scholars is regarded as magmatic texture, suggesting either a cumulus silicate-intercumulus oxide, or a liquid immiscibility relationship (Zhou *et al.* 2013).
- The geochemical patterns of VS rocks (low content of Cr, Ni, Co, Ti) are not characteristic to ultramafic rocks in general, but appear in the varieties of ultramafics related to alkaline suites.
- The metasomatic alteration of VS and hosting rocks with strong alkaline trend implies relation to alkaline magmatism.
- The shape, size, and composition of the bodies of the VS are irregular and variable. On the contacts, are noticed fragments of rocks of different types, of angular shape, looking like xenolites (see Fig. 17). Such variability is characteristic for polyphase alkaline and carbonatite intrusions, caused by interaction between rocks of different phases, assimilation and contamination, formation of xenoliths, activity of volatiles, provoking intensive metasomatosis.
- The hosting rocks (supracrustal gneisses, amphibolites), are affected by metasomatic alteration which might be the case of fenitisation, typicall for alkaline intrusions.

Following the presumption of the magmatic genesis of the VS rocks their original types might be interpreted as olivinite, peridotite, pyroxenite, magnetitite, beforsite and phoscorite. The only age estimations for rocks of the VS are acquired by Ar–Ar method (Bogdanova *et al*. 2001). Two hornblende samples from the borehole Varėna-982 were dated, named by authors as "metasomatic amphibolite" (int. 470.6 m), and "metaandesite dike" (int. 771.5 m). According to our data the first sampled rock is diopside–hornblende rock, it is pyroxenic rock partly substituted by hornblende. The second rock is scapolite–diopside–plagioclase rock, presumably amphibolite, altered metasomatically. The acquired dates of samples are 1620±10 Ma, and 1420±6 Ma correspondingly. Interpreting these dates as the time of cooling of hornblende below 500^{o}C the older data implies, that the formation of the VS probably took place at, or close to the orogenic period, at 1800–1840 Ma. But comparing both dates appears very big difference in the age of the samples situated at the distance just 300 m, what requires explanation.

CONCLUSIONS

The presumption on the origin of the VS as polyphase intrusion, subsequently affected by metasomatic processes is based on certain arguments and must be considered as plausible genetical model, along with alternative hypothesis (metasomatic skarn type, or layered intrusion).

The metasomatic rocks formed at the expense of VS and host rocks are of alkaline trend. Fluids, responsible for this process, as well as REE, Th, apatite mineralisation, might be regarded as manifestation of alkaline magmatism.

The recent state of knowledge is not sufficient to prove any hypothesis explaining the origin of the VS rocks, but provide the base for further researches looking for convincing models backgrounded by modern analytical tools.

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