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The nickel hydrosilicate laterite deposit of the Saxon Granulite Mountains, Germany : Implications for ore and petrogenesis

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رواسب اللاترايت الهيدروسيليكاتية الغنية بالنيكل في جبال الغرانوليت الساكسونية ، المانيا: طبيعة الخام والتكوين الصخري

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Abstract:

In Saxon granulite mountains, significant deposits of hydrosiliceous nickel are characterized by their relevant metal content, average metal concentrations, and thickness. The hydrosilicate deposits are Ni-rich residue, formed by serpentinization process, due to the replacement process of nickel in the immediate vicinity of serpentinites and nickel-bearing ore minerals (e.g., talc, chlorite nontronite, cordierite, nepouite, other oxides and hydroxide magnesium minerals). X-ray and chemical analysis indicate that the study area consists mainly of nickel, magnesium silicates, and hydrosilicate minerals, with concentration of Ni varying from 2% to a few tens of ppm. A variety of lithological compositions are present in these deposits, which are influenced by ultramafic rocks (serpentinite), talc and chloritic clays, etc. The analysis of the mineralogical and geochemical composition of the Ni-ores also evidences that the sources of Ni are ultramafic rocks derived from the mantle and concentration by serpentinitization processes under discrete tectonic and metallogenic events. An important consideration in the economics of these deposits is the mode of occurrence of nickel ores.

Keywords: Saxon granulite mountains, Nickel hydrosilicate, Leaching zone, Serpentinite.

الملخص

تحتوى جبال الجرانوليت الساكسونية، على رواسب الكبيرة من النيكل الهيدروسيليكاتي والتى تمتاز بمحتواها المعدني ، وتركيزاتها المعدنية المتوسطة، وسمكها. تشكلت رواسب الهيدروسيليكات من بقايا غنية بالنيكل، تكونت من خلال عملية السربنتنة، نتيجة لعملية استبدال النيكل في المنطقة المجاورة وبشكل مباشرللصخور السربنتينات والمعادن الخام الحاملة للنيكل (مثل التلك، والكلوريت نونترونيت، والكورديريت، والنيبويت، وأكاسيد أخرى، ومعادن هيدروكسيد المغنيسيوم). تشير التحليلات الكيميائية والأشعة السينية إلى أن منطقة الدراسة تتكون أساسًا من النيكل وسيليكات المغنيسيوم والمعادن الهيدروسيليكاتية، حيث تراوحت تراكيزخام النيكل من 2% إلى بضع عشرات من أجزاء من المليون. توجد مجموعة متنوعة من التركيبات الصخرية في هذه الرواسب، والتي تتضمن الصخور الغنية بالمغنيسيوم (السربنتينيت) والتلك والطين الكلوريتي، إلخ. كما يثبت تحليل التركيب المعدني والجيوكيميائي لخامات النيكل أن مصادر النيكل هي الصخور الفوق القاعدية غنية بالمغنيسيوم والمشتقة من الوشاح والتي تركيزت بواسطة عمليات السربنتينيت تحت أحداث تكتونية ومعدنية منفصلة. تكمن الاهمية الاقتصادية لهذا الخام في طبيعة تواجده وتراكيز خام النيكل.

الكلمات المفتاحية: جبال غرانوليت الساكسونية، هيدروسيليكات النيكل، منطقة الترشيح، السربنتينيت

Introduction

The nickel hydrosilicate in the area of the Saxon granulite mountains (SGM) has been comprehensively reviewed by several studies (e.g., [1];[2];[3];[4];[5];[6],[7]; [8]; and more recently by [9]; [10];[11]. Although preconceived opinions have prevented some practical investigations of nickel ores in serpentinite areas in Germany, due to the political and economic situation during World War II, the carrier rocks, such as 0.2% NiO-bearing serpentinites, are particularly widespread in the Saxon province. [7] initiated a comprehensive investigation of silicate nickel deposits after the discovery of enrichment of silicate nickel ores in a small area on the southern edge of the Saxon Granulite Mountains (SGM).The most common types of nickel ore deposits are found in tropical and subtropical areas [11] and the widespread distribution of the nickel hydrosilicate can also be attributed to weathering processes that took place in tropical climates and as result of weathering and leaching of ultramafic rocks [5]. Furthermore, many stages and mechanisms are involved in the formation of nickel ore, depending on the type of deposit, mainly magmatic, hydrothermal, sedimentary, lateritic, and metamorphic processes. Some of the common processes and conditions involved in the formation of nickel ore deposits, in the SGM area, are related to Paleogene laterite weathering [12]. The aim of this study is to synthesize and discuss its significance for understanding the diagenesis process of nickel-silicate mineral formation based on petrogenetic evolution.

Regional Geology and Tectonic setting

The Saxonian granulite mountain (SGM) is within the Saxo-Thuringian belt of the mid-European Variscides, which constitutes a continental fragment on the north flank of the Variscan orogenic collage. The Saxo-Thuringian represents the hinterland of the Rheno-Hercynian orogen [13] and is characterized by outcrops of rocks of very high metamorphic grade set among very low-grade sediments and volcanic rocks. The main tectonic structures and events in the different parts of the Saxo-Thuringian belt represent the rocks record of early Paleozoic rifting in a Cadomian continental basement, a thermal subsidence stage from the late Ordovician through to the Tournaisian, and a second phase of rifting in Frasnian [14]. The Saxonian Granulites are exposed in a brachyanticlinal structure, overlain by a "schist mantle" of greenschist and very low-grade rocks of Late Proterozoic through early Carboniferous age, they are mainly felsic and are probably derived from magmatic rocks with some sedimentary intercalations. In addition, there are lenses of mafic/ultramafic pyroxene granulites, garnet peridotites, and very few eclogites. [13-14]. The SGM has an elliptical shape that extends from Hohenstein-Ernstthal in a northeasterly direction for about 50 km to Roßwein near Döbeln (Figure 1).

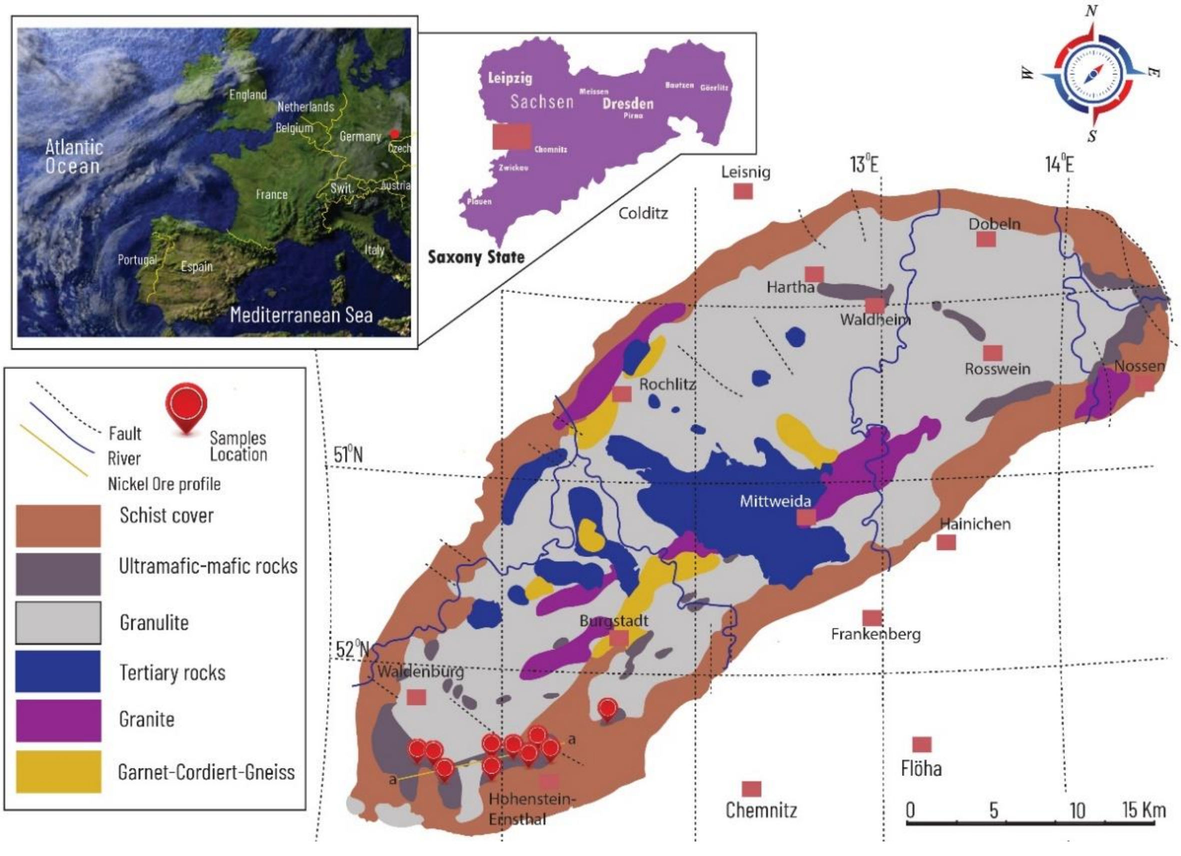

Figure 1. Geological map showing the geological units of the Saxon Granulite Mountains. Modified after [15]

It's approximately 1000 square kilometers in size, and the maximum width is approximately 20 km. The SGM consists mainly of metamorphic rocks of medium- to high-pressure grade, forms garnet-cordierite and serpentine-chlorite assemblages. The location of the study area is near Kiefernberg quarry in Hohenstein-Ernstthal (Figure 2), located north of Hohenstein-Ernstthal in the forest area Goldforst (also known as Oberwald). The nickel silicate deposit facies were found in undisturbed sediments of the lower region (Figure 2; [15]. Furthermore, the source rock for nickel-silicate mineral formation in the SGM is garnet-bearing serpentinite (Figure 3), in the southern part of the SGM, bronzite serpentinites predominate, with garnet serpentinites being found less frequently. An extensive mica schist blanket covers some serpentinite bodies that lie rootless on the granulite block and are covered by biotite schist, and the mineralization of chlorites (or hydrobiotites) is particularly intense in fissures and crevices. It's characterized by massively schistose, dense, dark brown, poorly layered, and appear generally more homogeneous (Figure 3) [16]. Furthermore, the entire serpentinite complex shows turbulent compression, crushing, and shearing, and numerous mineral displacements, which are an expression of mechanical stress with talc and magnesite formations. Additionally, most of the bastitized pyroxene inclusions stand out in the serpentinite fabric. Granulite is fine to medium–grained and enriched in quartz, garnet and charnockite. Moreover, light and dark mica schists, forms hypidioblastic flakes or small xenoblastic patches in the matrix and displays a well-developed schistosity. Bronzite is plate-like, dark with light bands and has a strong foliation, and bronze-colored, and iridescentpyroxene flakes, which are more or less strongly deformed and tailed by mechanical stress and are associated with minerals of the chlorite and talc. (Figure 3).

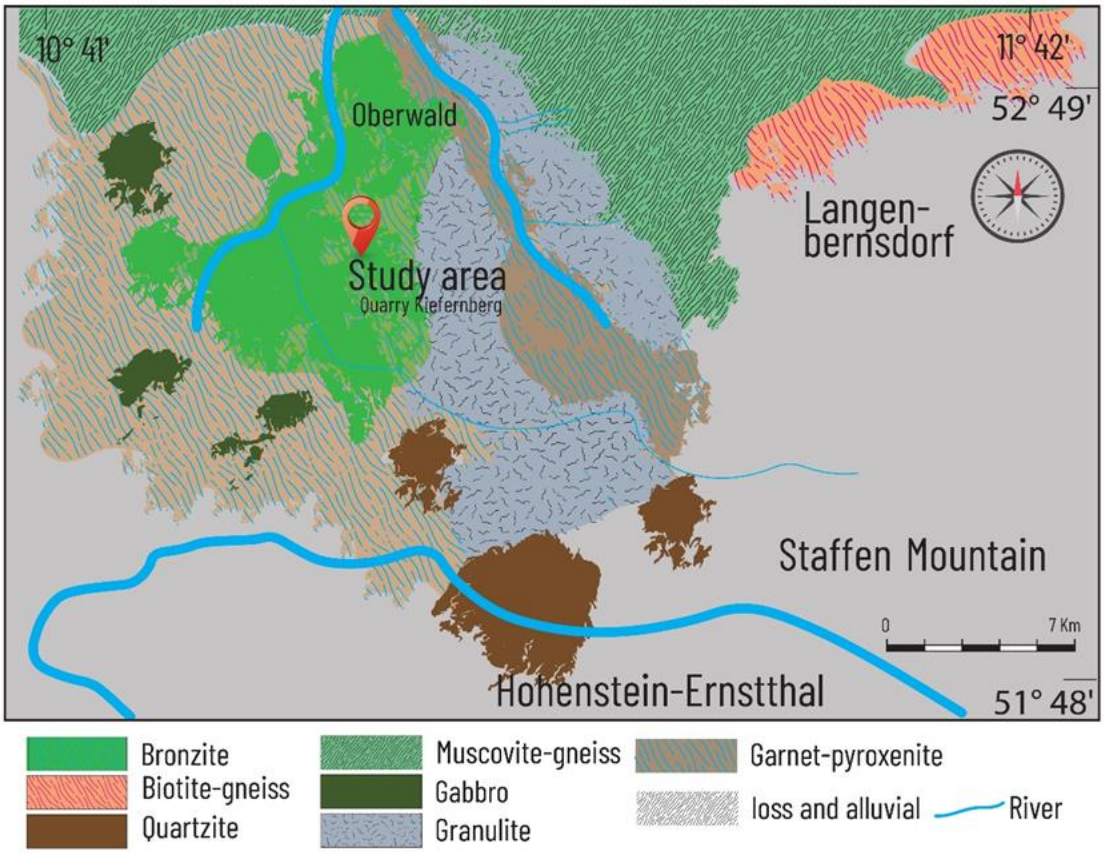

Figure.2. Geological map of study area

Petrographic and petrogenesis of nickel hydrosilicate

The samples (Figure 3) show large variations in total thickness, and continuity of individual zones and in mineralogical and chemical characteristics commonly over short distances (Figure3b). It varies in thickness up to 20m and commonly characterized by a reddish-brown to greenish-gray color, which also includes gravel rock decomposition and bleached serpentinite, is bronze-colored, iridescent pyroxene flakes visible to the naked eye (Ben Sera, 2009). These striking rock masses, up to 20m thick, were examined petrographically, whereas the Ni-content decreases with increasing depth (Figure 3b). The actual nickel silicate ores occur in these mostly magnesium-rich zones, typically cementation zones (Figure 3c). The material balance of the deposit type with the 20-meter-thick extremely Fe-rich decomposition zone as well as the stepped transitions support this conclusion. Nickel enrichment is linked to ascending and descending solutions, whereas material precipitation is dependent on a favorably located environment (such as chemical environment, consolidation and lithification). In addition to the silicate nickel compounds, there are concentrations of iron, which is then present in the form of Fe hydroxides, sometimes in considerable enrichments. Additionally, to the main mass-forming components, chlorite, talc, and hornblende mainly occur in fine layers and layers (Figure 3d). Therefore, the ores occurring in the serpentinites of SGM, are mostly ore formations associated with the serpentinization process and are an earthy weathering product of serpentinite [16]. The source rocks of nickel deposits in SGM are the mylonitic-porphyroclastic bronzite serpentinites (Figure 3e-f). A large part of the bronzite serpentinite was exposed to greater stress in the epizonal area. and stripped under chloritization, whereby the associations were loosened, which favored the following reactions up to the extreme separation of materials. The study area is primarily composed of serpentinized pyroxenite. Petrographically, serpentinite is a A porphyroblast, differing in the associations by their varying mineral composition, with finely platy to banky deposits alternating with one another (Figure 4g-h) are structureless, friable, moderately indurated and porous. The dominant mineralogy comprises Mg-silicates, chlorite and serpentine evident as first-order grey and yellow under the optical microscope (Figure 4). The garnet content in particular can make a decisive contribution to the characterization of the serpentinites (Figure 4a-b). Garnet-pyroxene serpentinites are the almost monomineral composition, which can be joined by magnetite as a secondary mineral (Figure 4c-b), and garnet is small porphyroblastic and patches in thin layers. On the one hand, these conspicuous serpentinites lie in banking alternating layers in the serpentinized pyroxenite association as a rare phenomenon [17]. In other hand, the serpentinites occur in streaky areas. The mineral formation and transformation during the serpentinitization process depends on the original mineral composition, whereas the serpentine minerals are arranged in parallel and give the rock a slaty texture (Figure 4 e-f). Gabbro is coarse grained in general, consist of plagioclase, clinopyroxene, orthopyroxene and hornblende. Quartzite is medium to coarsely crystalline, a compact and hard with granoblastic texture.

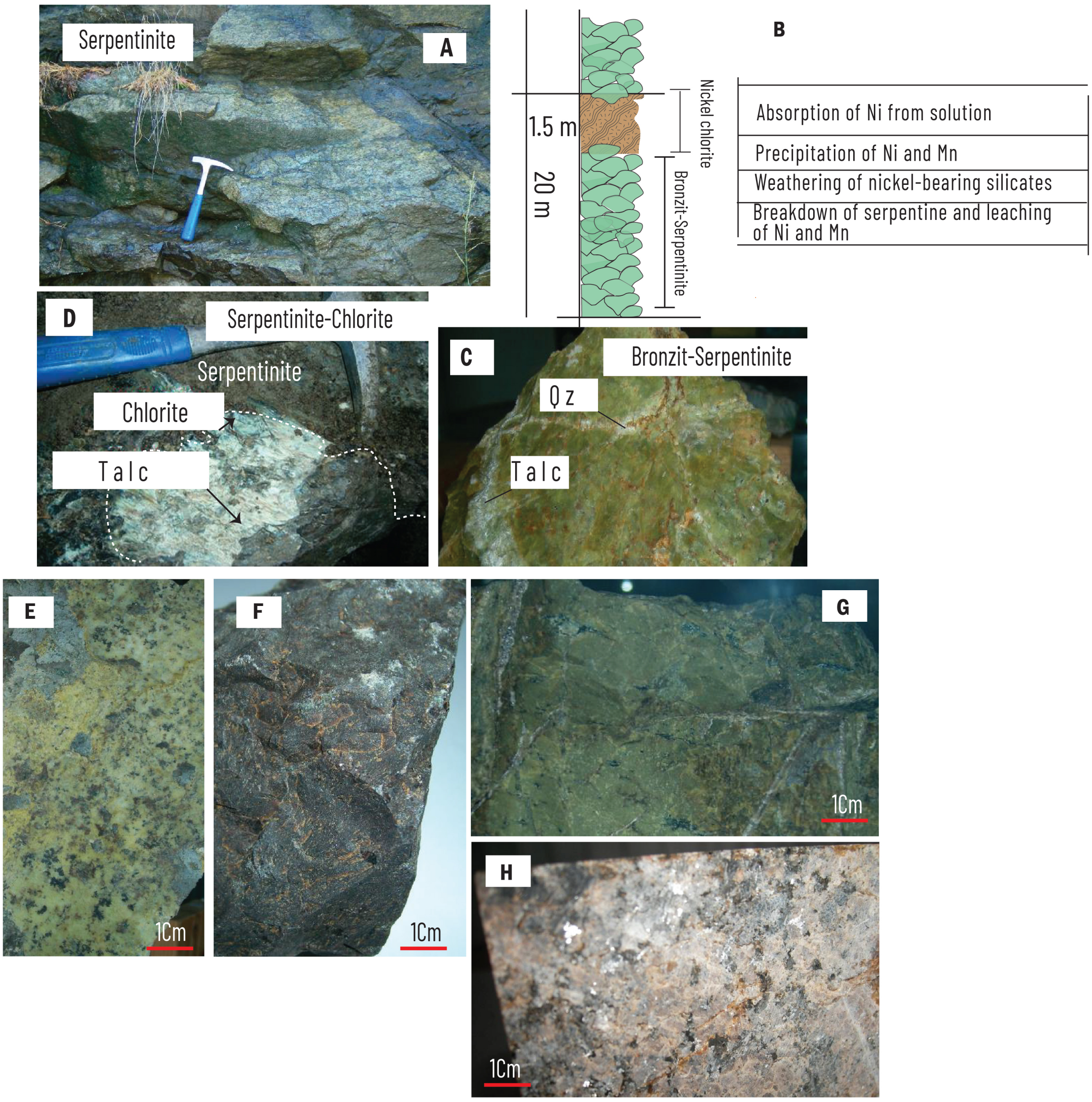

Figure 3. a) Garnet-sepentinite. b) The hydrosilicate deposite profile and horizon thickness. c) Mg-rich Serpentinites with an interspersed quartz vein with talc. d). Bronzite-serpentinite is massive, lenticular, brown-flamed colored, and has a dense structure and slight schistosity. Chlorites (or hydrobiotites) occur in fissures and crevices with talc and magnesite formations. e) Serpentinite with asbestos fissure. f) brown bronzite Serpentine. .g) massive Serpentine is green, aggregates, and white, grey to light brown (h) in color

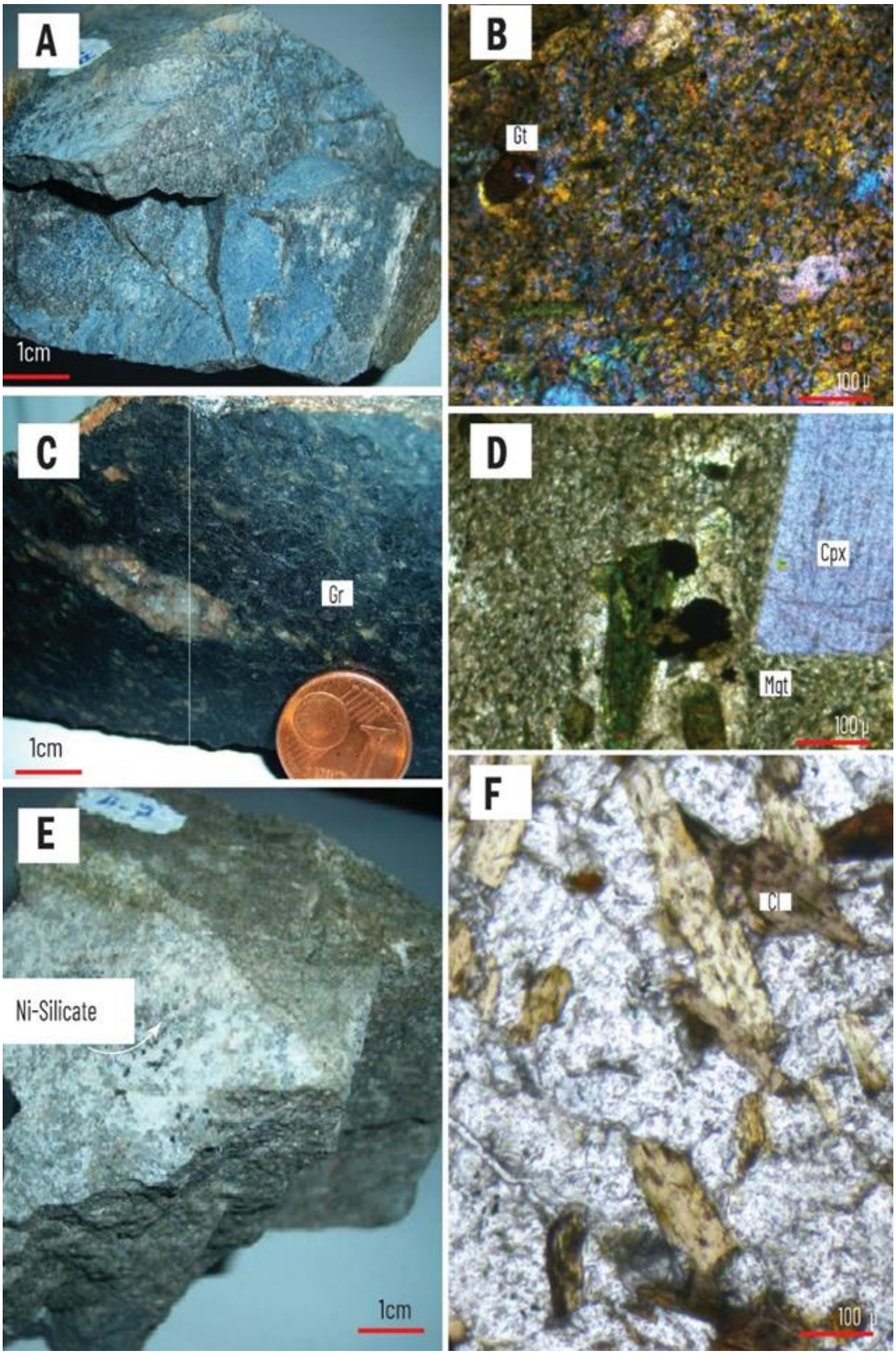

Figure 4. Representative field and cross-polarized light of lithotypes from the study area. (a-b) porphyroblastic garnet in serpentinite. (c-d) garnet-pyroxenite (e-f) serpentinite thickbanking shaly, dark and slaty texture.

Material and methods

A total of ten samples were collected in situ exposed, in the form of either infill veins or exposed coatings surfaces of cracks and fractures, from different types of rocks from two outcrops. The samples were preparation for thin sections and analyses was performed at the geology department, TU Bergakademie Frieberg, Germany. The major oxides (Table 1) and the trace elements were analyzed by meta-borate fusion ICP-OES technique. The analysis was carried out on the new wave NWR-193 excimer laser coupled to a laser coupled to a Themo xseries 2 quadrupole ICP-MS instrument. The total volatiles were determined gravimetrically using the method of loss on ignition (LOI); the weight difference after ignition at 105 C˚ and 1000 C˚. Fresh portions of samples were pulverized using a tungsten carbide or stainless-steel swing mill for 2 minutes. Two grams of the milled sample were mixed with a 66% lithium tetraborate: 34% lithium metaborate flux (5g) weighed to a precision of ±0.0002g. The mixture was fused in platinum crucibles for 10 minutes at 1100°C using a Phoenix VFD automated fusion machine to obtain a homogeneous 32 mm glass disk with a lower surface of analytical quality. The concentrations of major elements were determined by comparison of x-ray intensities for each element with calibration lines constructed from the analysis of known concentrations in 24 international standards of known concentrations. Additionally, the automated Philips X'Pert MPD diffractometer with a post-receiving slit, graphite monochromator, and CuKa radiation to collect XRD patterns is used. An agate mortar and pestle were used for preparation of samples, and powders were backfilled into circular holders with a diameter of 20 mm and depth of 1 mm. 2 s/step, 2h position, was used to get diffraction patterns. With the addition of 1.2 % Calgon solution, 1 to 1.25 grams of gently crushed material were suspended into 1:20 sample solution.

Whole rock Geochemistry

Each of the samples show a quite limited and distinct compositional variation and are dominanted by silica ranging between 55.34 and 29.2 wt%, Ni-content (0.11-2.82; average=1.18 wt%) and high Mg-numbers (Mg# = average 61.87 (Table 1) and (13.03–27.96; average = 20.87 wt%), CaO (0.02–1.21; average = 0.86 wt%) content. Variations in chemistry occur mainly as changes in SiO2, MgO and NiO content. Results and discussion.

Table 1. Chemical analysis of major and trace elements of study samples.

Samples	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Location	Kiefernberg	serpent	serpent	pyroxenite	serpent	Bronzite-serpent	serpent	serpent	serpent	serpent
SiO2	31.45	31	30.14	29.2	44.21	55.34	40.09	35.67	28.56	31.67
TiO2	0.24	0.12	0.05	0.42	1.71	0.22	0.38	0.6	0.77	0.21
Al2O3	10.44	12.62	16.34	16.9	15.8	33.7	14.76	13.56	10.78	12.78
Fe2O3	5.76	9.37	11.61	15.6	9.14	13.4	7.56	10.23	9.08	15.67
FeO	4.6	1.1	0.06	1.07	0.03	0.66	0.78	0.9	4.56	2.64
MnO	0.02	0.05	0.01	0.03	0.2	0.44	0.07	0.04	0.19	0.43
NiO	0.14	0.23	3.61	3.37	0.41	1.24	0.78	0.17	0.76	1.09
MgO	27.96	21.06	13.03	24	20.13	23.72	13.78	21.23	26.32	17.45
CaO	0.55	0.72	1.85	1.21	0.45	3.1	0.02	0.23	0.032	0.45
P2O5	0.8	0.21	0.75	0.86	0.23	0.62	0.12	0.32	0.021	0.23
H2O+	10.02	12.46	14.07	14.5	19.27	7.83	7.89	9.76	10.21	12.09
H2O-	1.12	3.61	1.93	7.81	8.26	2.88	2.31	6.67	2.32	9.76
Si	2.56	2.52	2.45	2.37	3.59	4.5	3.26	2.9	2.32	2.57
Mg	1.69	1.27	0.79	1.45	1.21	1.43	0.83	1.28	1.59	1.05
Ni	0.11	0.18	2.82	2.63	0.32	0.97	0.61	0.13	0.59	0.85
Fe	3.58	0.86	0.05	0.83	0.02	0.51	0.61	0.7	3.54	2.05

X-ray diffraction (XRD) analysis

A majority of these samples contain residual Fe/Mg-silicates as pyroxene in the bulk, along with secondary silicate phases such as chlorite and talc. The complete disappearance of the peak at 7.14–7.26 A˚ after heating at confirms the presence of serpentine in both samples. In addition to X-ray diffraction, chemical analyses confirmed the presence of a serpentine-like phase, with a spacing of 7 A˚ (minor spacing), and a talc-like phase, with a spacing of 14 A˚ (major spacing), containing > 2 Ni (minor spacing) Figure 5. Accordingly, this compositional limit is based on and in agreement with the current arbitrary working limit for Ni-bearing 7 A phases of the serpentine group (e.g., Ni-lizardite and nepouite).

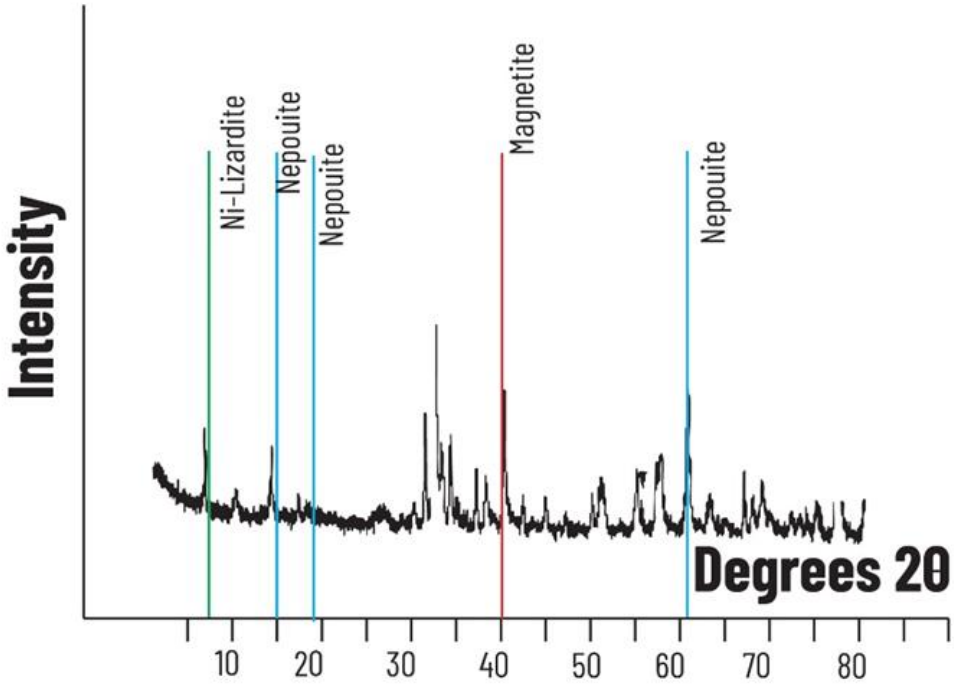

Figure 5. The x-ray fluorescence (XRF) of the sample A4. It contains the highest percentages of nickel

Nepouite (Figure 6) occurs on ridges in fissures and movement zones of serpentinite and as a product of the decomposition of serpentinite in the contact area.

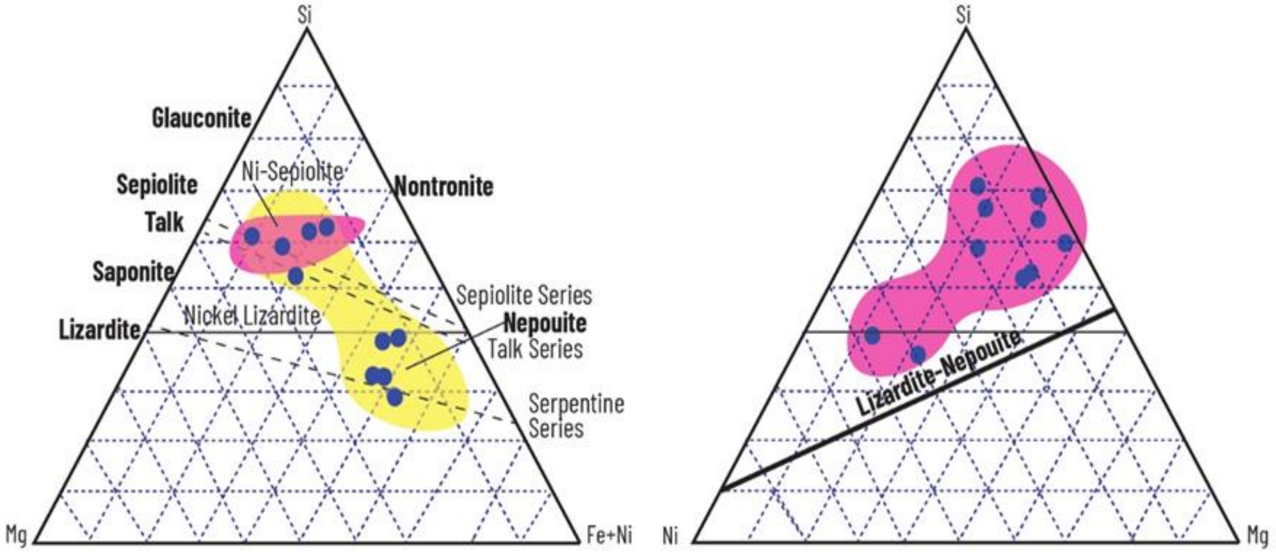

Figure 6. Triangle diagram of paragenetic associations of hydrothermal mineral phases in nickel from SGM. Plotting the relationship between Si, Mg, Fe+Ni with Ni hydrous silicate. Modified from [17].

The stages of dewatering could also be determined from the weight loss curve during static heating. To underline the difference in thermal behavior, the weight loss curves of a Ni and a nickel-containing nepouite chlorite with an irregular alternating layer structure shows endothermic peaks at 625 and 840°C, which can be attributed to the dehydration of the talc layers, while an exothermic peak appears at 860°C and corresponds to the formation of high-temperature phases.

Discussion

Evolution of the nickel hydrosilicate laterite deposit of the Saxon Granulite Mountains

Nickel laterites are the product of intensive weathering of Mg-rich or ultramafic rocks which have primary Ni contents of 0.2-0.4% [18] due to intense weathering of ultramafic rocks at the surface of the earth in humid climatic conditions [19]. The highest grade deposits are concentrated in tectonically active plate collision zones (e.g. Indonesia, the Philippines and New Caledonia) where extensive obducted ophiolite sheets are exposed to aggressive chemical weathering in tropical conditions of high rainfall and warm temperatures, and there is the greatest opportunity for supergene enrichment. The Ni-ore in cratonic settings can be large but tend to be lower in grade (e.g. Murrin in Western Australia). Cratonic shield deposits in West Africa [20] and Brazil [21] are within the equatorial zone, but those in the Balkans (Greece, Albania and former Yugoslavia) [22] and the Yilgarn craton in Western Australia occur at higher latitudes. The analysis of the mineralogical and geochemical composition of the Ni-ores also evidences that the formation of nickel-silicate deposits in the Saxon granulite mountain is not solely due to climatic effects. The important consideration in the economics of these deposits is the mode of occurrence of nickel ores, which indicates that the enrichment of the metal distribution. Wherein, the serpentinisation took place by the magmatogenic processes as a result of the volcanism in the Erzgebirge basin (Lower Cretaceous to Paleogene) and the events of the Variscan ore formation continued in a climate-related, and lateritic to saprolitic weathering took place near-surface rock layers that have been deeply decomposed under the influence of relatively high temperatures and abundant precipitation, which eventually formed the nickel ore deposit. According to [10], serpentinite weathering products are mainly clay minerals like saponite, as well as iron oxides and hydroxides such as hematite and goethite. As a result, Ni is likely to increase with increasing replacement. However, the nickel hydrosilicates are characterised by an absolute enrichment or concentration of Ni in the saprolite zone which comprises altered primary minerals such as secondary serpentine [23]. The occurrence of nepouite is macrocrystalline and is unstable under hydrothermal conditions and partially transform into chlorite, with an additional supply of Mg [24]. The serpentinite body with their metal contents are available to clarify the metal distribution (Figure 7), which indicates that the enrichment is cementative, a dependence on the thickness of the decomposition, and indicates the influence of major tectonic faults (Figure 7). The distribution of Ni grade and their relationship to the Ni-profile are illustrated in (Figure 7). The highest Ni grades occur, particularly in the upper zone, and Ni grades of 1 to 2.

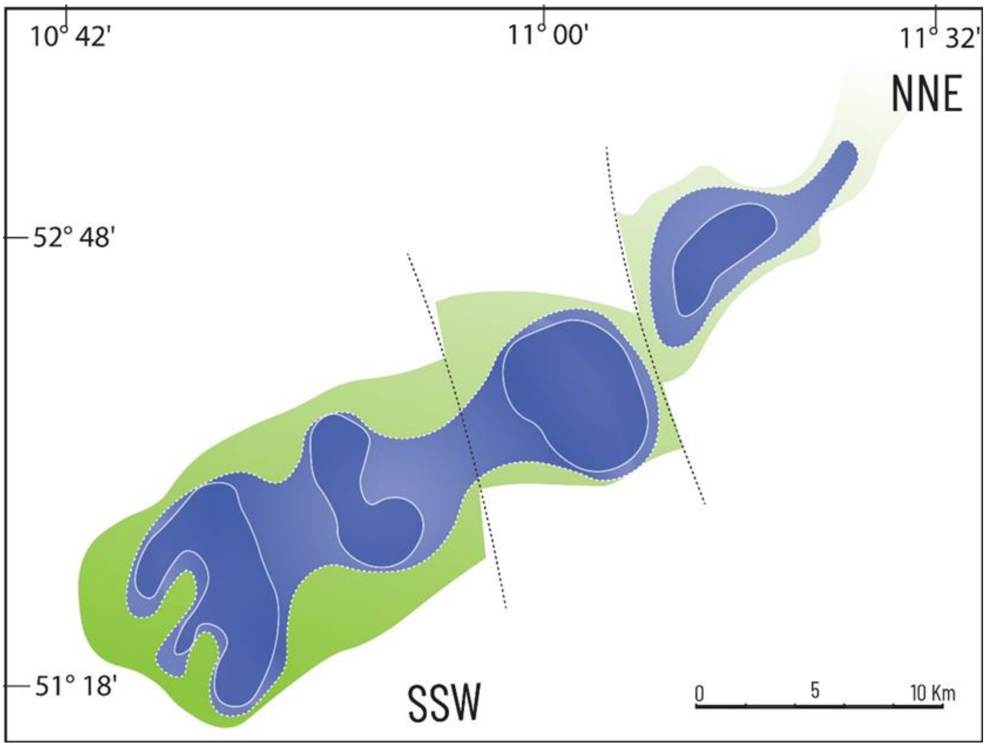

Figure 7. Map of distribution of nickel ore from SMG shows a parallel bedding of the nickel-rich deposits modified after Jubelt (1956). The distribution profile shows clearly enrichment of a different concentrations of Ni (less than 1% and more than 2%). The highest values are more north-south oriented. However, the low values correspond in their areal extent to the general strike of the deposit. The map is based on the distribution of nickel ore concentrations by using the (Surfer 2024 software).

Source rocks of the nickel hydrosilicate laterite deposit of SGM

There is an exothermic hydration known as serpentinization in which water reacts with mafic minerals such as olivine and pyroxene to produce lizardite [24]. As a result, serpentine minerals replace olivine and pyroxene in ultramafic rocks minerals due to the subprocess of serpentinization, namely hydration, serpentine recrystallization, and deserpentinization, which is equivalent in composition to olivine but without of aluminum and chromium [24]. During the change of serpentine, Al and Ni are relatively immobile, thus remaining in their original microstructural site with a predominance of nepouite. Due to the presence of magnetite in serpentine, the amount of iron varies with the abundance of magnetite. Generally, in order to form smectite clays and Nickel is altered in a mildly alkaline environment [17].

Ionic exchange reactions are important in this stage of alteration such as:

Mg serpentine Ni^{+2} = Ni serpentine + Mg^{+2} with continued leaching of Mg+2 in all but stagnant ground-water conditions, smectitec lays (nontronite) may form in a mildly alkaline environment (pH-9), Ni serpentine Ni-rich nontronite+ Mg^{+2}+ silica. The silica may be either precipitated or removed in solution. Nepouite breaks down in more acid conditions and silica lost solution: Ni-rich nontronite = quartz + Si^{+2}+Ni^{+2}. [24]; [17]. The ores occurring in the serpentinite of SGM are mostly the ore formations associated with the serpentinization process (especially magnetite and hematite). A large part of the bronzite serpentinite was exposed to greater stress in the epizonal area and stripped under chloritization (Figure 3b), whereby the associations were loosened, which favored the following reactions up to the extreme separation of materials. In the northern part of the SGM, mainly near Kiefernberg serpentinite body. Individual bodies lie on top of the granulite during the uplift of the schist envelope of SGM with its ultrabasite intrusions on the granulites (Figure 8), which led to granulite and gneiss inclusions in the serpentinite, can also be expected to occur under climatic and hydrothermal conditions.

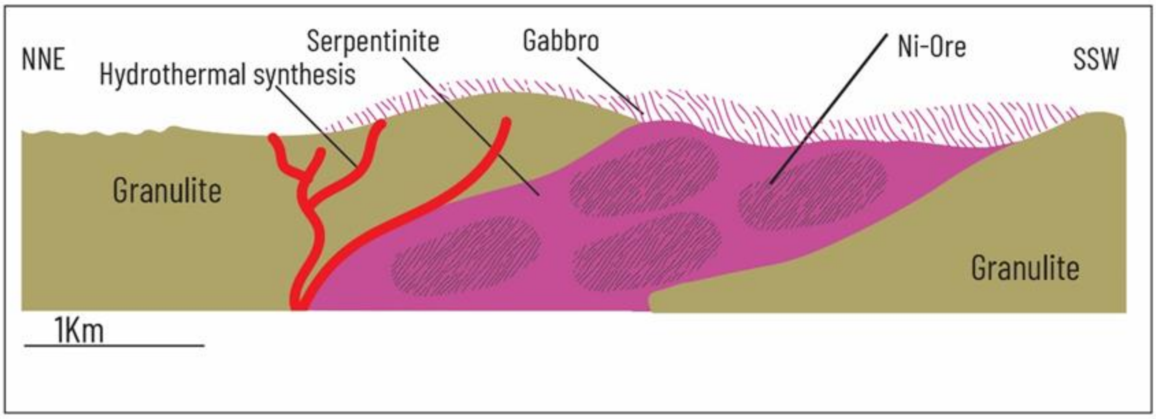

Figure 8. A conceptual cross section of nickel hydrosilicate deposit at the southern margin of the Paleozoic Saxon Granulite through NNE-SSW direction. The section shows how nickel is distributted in the close contact area of source rocks of nickel hydrosilicate.

Conclusion

The Ni-hydrosilicate in SGM shows large variations in total thickness, and in continuity of individual zones and forms part of an extensive belt in the predominantly granulitic and ultramafic terrain as a result of magmatic, hydrothermal, sedimentary, lateritic, and metamorphic processes. The common processes and conditions involved in the formation of nickel ore deposits in the SGM area are related to Serpentinization, which is a process in which anhydrous Fe-Mg silicate is converted to serpentinized Fe-Mg silicate by hydrating ultramafic rocks. As a result of an interaction between fluids and ultramafic rocks, serpentinites are commonly formed by processes such as metamorphism, metasomatism, or hydrothermal alteration in a variety of tectonic environments.The highest Ni grades occur, particularly in the upper zone, and Ni grades of 1 to 2 percent are common.

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Conflict of interest statement

On behalf of the author, the corresponding author states that there are no conflicts of interest.

Data availability statement

The author confirms that the data supporting the findings of this study are available within the article.

References

[1] Jubelt, R. (1953) : Die Nickelhydrosilikatlagerstätten bei Kuhschnappel am Südrand des sächsischen Granulitgebirges.-Wiss.Z.Univ.Leipzig ,math.-nat.R.,III,239-270, Leipzig.
[2] Jubelt, R. (1954) : Die Metabasitkörper des südwestlichen sächsischen Granulitgebirges.-Geologie 3 , Berlin 1954.
[3] Jubelt, R. (1956) : Bemerkungen zu den neuerschlossenen Nickelhydrosilikatlagerstätten am Südrand des sächsischen Granulitgebirges.-Freiberger Forschungshefte , Heft C 5 , 1953.

[4] Korich, D. (1965): Erzminerale in Serpentiniten des südwestlichen Sächsischen Granulitgebirges. Ber. geol. Ges. DDR, 10, 631.
[5] Korich, D. (1980): Über das Vorkommen von Erzmineralen in den Serpentiniten des südwestlichen Sächsischen Granulitgebirges. Fundgrube, 1, 2-7.
[6] Schneider, H. (1970b): Die Bildung von Vermiculit im Serpentinit des westlichen Sächsischen Granulitgebirges. Ber. dtsch. Ges. geol. Wiss., Ser. B 15, 61-66.
[7] Schneider, H., Henning, K.-H. & Benamane, A. (1975a): The nickel hydrosilicate deposit Callenberg on the south-west border of the granulite massif – Formations of weathering on serpentinite, gabbro and acid magmatic rocks. In STÖRR (Hrsg.): Kaolin deposits of the GDR in the northern region of the Bohemian Massif. Univ. Greifswald, 189-206.
[8] Schüller, A. (1956): Die erzbildenden nickelsilikatischen Minerale von Kuhschnappel und ihre röntgenographische Diagnose. Zeitschr. angew. Geologie, 2, 353-370.
[9] Martin, V., Gaëtan R., Stéphane P., Jean-Yves S., Augustin D., Yves V., Olivier N., Yishen Z., -V., Jean-Pierre D., Michel B., Jean-Luc,A. (2023). Ni-rich mineral nepouite explains.
[10] Paul, M. (1993): Die Nickellagerstätte Callenberg: Mineralogie und Genese des Verwitterungsprofils auf Serpentinit sowie Untersuchungen zur Metallextraktion aus Ni-haltigen Phyllosilikaten und Oxiden mit organischen Säuren und heterotrophen Mikroorganismen. Diss. Univ. Greifswald, 142 pp.
[11] Paul, M. (1994): Zur Mineralogie der „Garnierite“ aus der Ni-Lagerstätte Callenberg, Sachsen. Z. geol. Wiss.22(3/4), 397-401.
[12] Leonhardt, H. & Leonhardt W. (1994): Sächsische Nickel-Lagerstätten: Minerale im Serpentinit. Lapis, 3, 13- 19 und 50.
[13] Rötzler, J., (1992. Zur Petrogenese im Sachsischen Granulitgebirge: Die pyroxenfreien Granuliteund die Metapelite, Geotekt. Forsch., 77, 1-100.
[14] Rötzler, J.,Romer., R. Budzinski., H. Oberhaensli., R.(2004). Ultrahigh-temperatur e high-pressure granulites from Tirschheim, Saxon Granulite Massif, Germany: P-T-t path and geotectonic implications. European Journal of Mineralogy 16.pp.917-937.
[15] Reinhardt, J., and Kleemann, U., (1994). Extensional unroofing of granulite lower crust and related low-pressure-high temperature metamorphism the Saxonian Granulite Massif, Germany, Tectonophysics, 238, 71-94.
[16] Ben Sera A., (2009). Die Nickelhydrosilikatlagerstätten des sächsischen Granulitgebirges. Unpublished. Department of Mineralogy. TU Bergakademie Freiburg, Germany.pp 87.
[17] Brand, W., Butt, R. & Elias, M., 1998. Nickel Laterites: Classification and Features. Journal of Australian Geology and Geophysics, 17(4), pp. 81-88.

[18] Golightly, J.P., (1981). Nickeliferous laterite deposits. Economic Geology, 75th Anniversary Volume pp. 710-735.
[19] Elias, M. (2002) Nickel Laterite Deposits-Geological Overview, Resources and Exploitation. Centre for Ore Deposit Research, University of Tasmania, Special Publication, 4, 205-220.
[20] Nahon, D., Paquet, H. and Delvigne, J., (1982). Lateritic weathering of ultramafic rocks and the concentration of nickel in the western Ivory Coast. Economic Geology, 77: pp.1159-1175.
[21] Schobbenhaus, C., 1986. Geologia do niquel. Principais depositos minerals do Brasil, Dnpmcvrd vol II, pp. 251-255.
[22] Valeton, I, Biermann, M., Reche, R. and Rosenberg, F. (1987). Genesis of nickel laterites and bauxites in Greece during the Jurassic and Cretaceous, and their relation to ultrabasic parent rocks. Ore Geology Reviews. 2, pp.359-404.
[23] Pelletier, B., (1996). Serpentines in nickel silicate ore from New Caledonia. In: E.J. Grimsey and I. Neuss (Editors), Nickel '96. Conference proceedings Kalgoorlie, 27-29 November 1996, Australian Institute of Mining and Metallurgy, Publication Series No. 6/96, pp. 197-205.
[24] Hasria, F.,, Masri, A., Muliddin, E., Hasan, L., Sawaludin, L., Salihin, W. (2022). Serpentinization Study On Ultramafic Rock at Morombo Area, Lasolo Islands District, North Konawe Regency, Southeast Sulawesi, Indonesia. Journal of Geoscience Engineering, Environment, and TechnologyVol. 7 (1).pp.15-20 https://doi.org/10.25299/jgeet.2022.7.1.6643.