大陸地殼環境中蛇紋岩型滑石的形成：以波蘭西南部索維山塊 Gilów 礦床為例的岩石學、礦物學、地球化學及氧、氫與氯同位素研究

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摘要

Gilów 礦床位於波蘭西南部中央蘇台德地區的索維山塊(Góry Sowie Massif，屬波希米亞地塊的東北部)。此處的滑石岩與蛇紋岩體共生，蛇紋岩體則與混成片麻岩接觸，並伴隨角閃石化的榴輝岩體以及花崗偉晶岩脈。研究對滑石岩與其母岩進行了岩石薄片觀察、電子顯微探測、地球化學分析，以及穩定同位素(O、H、Cl)和獨居石 Th-U-total Pb 定年等分析。Gilów 礦床的滑石岩可作為雕刻與陶瓷材料使用，但由於含有透閃石與陽起石，且 Cr 與 Ni 含量偏高(Cr： 2121.0–2148.4 mg/L，Ni：1079–1561 mg/L)，限制其在製藥與化妝品領域的應用。氧與氫同位素分析($\delta^{18}O$、δD)顯示該滑石岩屬於貧碳酸鹽型蛇紋岩礦床。礦床所處位置為大型變質地體的一部分，其中包含多期變質與構造事件，顯示此礦床屬於推覆構造與褶皺相關的變質成因滑石礦床。

滑石岩體與蛇紋岩由變質葉綠石岩帶分隔，此區帶中存在兩代獨居石，其 Th-U-total Pb 定年顯示在較早期的定年值為 389.8 ± 11.4Ma，對應蛇紋岩與片麻岩接觸及葉綠石形成。較晚期定年為 365.0 ± 18.2Ma，可能對應角閃岩化、片麻岩混成化及花崗岩侵入。滑石岩中所含的高 MgO(24.27–27.21 wt%)、Fe_2O_3(5.06–5.12 wt%)、Cr、Ni、Co 等來自蛇紋岩；而 SiO_2(57.30–60.46 wt%)、CaO(0.86–4.39 wt%)、Al_2O_3(1.38–3.04 wt%)、TiO_2(0.02–0.04 wt%)、F(197–337 mg/L)等元素則顯著高於母岩，顯示來自片麻岩與花崗偉晶岩的交代流體所引入。這些元素的來源

透過負的 $\delta^{37}Cl$ 值與較高的 $\delta^{18}O$ 值予以證實。滑石岩與母岩蛇紋岩相比，其稀土與微量元素特徵包括是 LREE/HREE 富集、Nb-La 與 Zr-Hf-Sm 呈正斜率，Sr 與 Ti 出現負異常，這些與片麻岩及花崗偉晶岩類似。蛇紋岩向滑石岩的轉化是逐步進行的，伴隨 $\delta^{18}O$ 的升高、δD 與 $\delta^{37}Cl$ 的下降：假晶質蛇紋岩($\delta^{18}O$ = +5.7‰, δD = –64‰, $\delta^{37}Cl$ = +2.0‰)→非假晶質蛇紋岩($\delta^{18}O$ = +7.1‰, δD = –48‰, $\delta^{37}Cl$ = –0.1‰)→滑石岩($\delta^{18}O$ = +8.3‰, δD = –52‰～–48‰, $\delta^{37}Cl$ = –2.6‰～–0.1‰)。此外，來自片麻岩與花崗偉晶岩的流體也可能在角閃岩相退變質過程中影響了榴輝岩，導致角閃石邊緣富含 Cl，且 $\delta^{37}Cl$ 值偏負(–0.5‰)，顯示與地殼流體有關。

關鍵字：滑石、蛇紋岩、穩定同位素、鈦-鈾-總鉛定年、蘇台德山脈。

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Formation of serpentinite-hosted talc in a continental crust setting: Petrographic, mineralogical, geochemical, and O, H and Cl isotope study of the Gilów deposit, Góry Sowie Massif (SW Poland)

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ABSTRACT

The Gilów deposit is located in the Góry Sowie Massif of the Central Sudetes (NE Bohemian Massif, SW Poland). Talcose rocks are associated with serpentinite bodies hosted by country migmatitic paragneiss, in an area where paragneiss also hosts amphibolitized eclogite bodies and granitic pegmatite veins. The talcose rocks and wall rocks were subjected to petrographic examination, electron microprobe study of minerals (including monazite Th-U-total Pb chemical dating), bulk rock chemical examination, as well as stable O, H and Cl isotope analysis. The talcose rocks can be used as a carving material and in ceramics, although the presence of tremolite and anthophyllite, and high Cr and Ni contents, preclude application in pharmacy and cosmetics. High Cr (2121.0–2148.4 ppm), Ni (1079–1561 ppm) and Co (57.4–84.8 ppm) contents, low ΣREE (2.13–13.81 ppm), as well as isotopic composition of O and H, classify the talcose rocks as a serpentinite-hosted type of deposit. Location in the strongly folded metamorphic unit, in the intimate vicinity of several faults and mylonitic zones, implies classification along the thrust-bound and fold-related metamorphogenic deposits. The talcose rocks are separated from serpentinites by the metasomatic chlorite schist, which contains two generations of monazite yielding two, different Th-U-total Pb dates. Older (389.8 ± 11.4 Ma) probably dates serpentinites juxtaposition with country paragneiss and chlorite formation. Younger (365.0 ± 18.2 Ma) likely dates amphiboles and talc formation, as overlaps the ages of amphibolite facies, country paragneiss migmatitization and intrusions of granitic pegmatites, and the talcose rocks contain talc-tremolite-anthophyllite assemblage indicative of the low-pressure mid-amphibolite facies. High MgO (24.27–27.21 wt%), Fe_2O_3 (5.06–5.12 wt%), Cr, Ni and Co contents are inherited from serpentinites. On the other hand, SiO_2 (57.30–60.46 wt%), CaO (0.86–4.39 wt%), Al_2O_3 (1.38–3.04 wt%), TiO_2 (0.02–0.04 wt%) and F (197–337 ppm) contents in the talcose rocks are higher than in host-serpentinites, likely due to a metasomatic introduction by fluids derived from migmatitic paragneisses or intruding pegmatites. Introduction of these elements is evidenced by a negative $\delta^{37}Cl$ and elevated $\delta^{18}O$ of the talcose rocks relative to host-serpentinites that are typical effects of interaction with a felsic crustal material. Interaction with paragneiss- and pegmatite-derived fluids is further evidenced by REE and trace elements patterns of the talcose rocks. The LREE/HREE enrichment, negative Sr and Ti anomalies, and positive Nb-La and Zr-Hf-Sm slopes, of the talcose rocks patterns, are similar as in paragneiss and pegmatite. Serpentinite bodies transformation into the talcose rocks was gradual and associated with increase of $\delta^{18}O$, and decrease of a Cl content, δD and $\delta^{37}Cl$. Pseudomorphic serpentinite, similar to abyssal serpentinites in terms of an isotopic composition ($\delta^{18}O = +5.7‰$, $\delta D = -64‰$, $\delta^{37}Cl = +2.0‰$), recrystallized into non-pseudomorphic serpentinite ($\delta^{18}O = +7.1‰$, $\delta D = -48‰$, $\delta^{37}Cl = -0.1‰$), which, in turn, was replaced by the talcose rock ($\delta^{18}O = +8.3‰$ to $+8.7‰$, $\delta D = -52‰$ to $-48‰$, $\delta^{37}Cl = -2.6‰$ to $-0.1‰$). Moreover, paragneiss- and pegmatite-derived fluids might have interacted with eclogite bodies during amphibolite facies-retrogression. Amphibolitized eclogite has Cl-rich amphibole rims, and negative $\delta^{37}Cl$ (−0.5‰) consistent with a Cl-rich crustal fluid.

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