THE RADENTHEIN SPARRY MAGNESITE DEPOSIT (MILLSTÄTTER ALPE, CARINTHIA, AUSTRIA), A PRE-ALPINE MAGNESITE MINERALIZATION IN THE MIDDLE AUSTRO-ALPINE CRYSTALLINE BASEMENT ("ALTKRISTALLIN") OF THE EASTERN ALPS

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Abstract: The strata-bound pre-Alpine Radenthein sparry magnesite deposit represents worldwide the type locality of a sparry magnesite mineralization occurring within a silicate crystalline series, in this case within a polymetamorphic crystalline series which exhibits distinct diaphthoresis and a pronounced deficiency of carbonate rocks. This crystalline series and its embedded magnesite deposit have both been subjected to exactly the same succession of tectonic events and metamorphosing processes in pre-Alpine and Alpine time.

Key words: Eastern Alps, crystalline basement, magnesite, pre-Alpine formation.

The Radenthein magnesite deposit of the Millstätter Alpe (Carinthia, Austria) with its estimated total content of 35 million tons of sparry magnesite represents one of the most important sparry magnesite deposits of the Eastern Alps. In contrast to other sparry magnesite deposits of the Eastern Alps, strata-bound embedded in carbonate-dominated series, such as in the "Northern Graywacke Zone", the Radenthein magnesite deposit is characterized by its strata-bound occurrence within a polymetamorphic crystalline complex ("Altkristallin"), namely strata-bound within the "Radenthein mica schist series", which is part of the Middle Austro-Alpine crystalline basement ("Altkristallin") and is distinguished by a nearly total lack of carbonate rocks. The "Radenthein mica schist series" contains the embedded magnesite deposit and consists mainly of garnet-bearing muscovite mica schists (garnet – "mixed almandite" - often displaying zonal arrangements and up to 30 mol-% pyrope) besides amphibolite, graphite mica schist and graphite quartzite, whereas marble is only very subordinate.

In contrast to this, the underlying "Millstätter mica schist series" is characterized by a lack of garnet and a lack of amphibolite, but contains thick marble chains and numerous pegmatitic formations. Although the "Millstätter mica schist series" incorporates thick marble chains, magnesite is nevertheless completely absent in this series.

The hanging "Priedröff gneiss series" likewise contains no magnesite and consists mainly of paragneiss, which is often very quartzitic, some mica schist and intercalations of microcline augengneiss ("Bundschuh orthogneiss").

The Radenthein magnesite deposit is located around 6 km NW of Radenthein at the NE slope of the Millstätter Alpe at about 1250 m to 1870 m above sea level. The magnesite deposit is part of a stratiform, N - S striking and steep towards N dipping deposit chain of approximately 5 km length within the "Radenthein mica schist series". Within the vicinity of the magnesite deposit the "Radenthein mica schist series" is distinguished by garnet-mica schist ("grönnite": extremely rich in garnet, in places even garnetyte) and incorporated amphibolite, hornblende-fascicular schist ("garbenschiefer") and lime marble, as well as dolomitic marble. A peculiarity is radentheinite (coarse-grained rock consisting of garnet, biotite and kyanite, in part also some quartz), which occurs in places at the magnesite contact. A rich zone of magnesite with a thickness of 30 m to 80 m occurs over an extension of about 1.2 km in the northern part. Within the succession, magnesite is accompanied by traces to small amounts of dolomite (marble) and partly overlayed by a magnesite-dolomite (marble) transition zone.

Within the deposit magnesite (sparry magnesite, average contents: 1.65 wt.-% FeO, 0.066 wt.-% MnO, 1.33 wt.-% SiO_2, 20.4 ppm Sr) represents more or less the monomineralic mineral constituent, frequently in relatively large crystal aggregates or as porphyroblasts and idioblasts, up to several cm in length. Petrographically, the magnesite marble present can be divided into several types. Prevailing is white sparry magnesite, in places along with "pignolite magnesite" and also banded magnesite. The pignolite magnesite forms a coarse crystalline, impure, "dirty" magnesite marble, consisting of magnesite porphyroblasts and idioblasts which sprouted within an argillaceous material containing some organic matter (now graphite), pyrite etc., resembling pignolias, or pine seeds. The banded magnesite is characterized by a rhythmic lamination of very regular or periodic layers of white and gray to darker gray magnesite within the range of mm or cm. While the white magnesite layers are somewhat thicker, the gray to darker gray magnesite layers are thin, contain talc, chlorite (clinochlore) and sometimes also traces of graphite as a pigment. The lamination of the banded magnesite is of primary nature and can be traced back to rhythmic successions or sequences and alternations of white pure and impure, mostly gray, partially bituminous and argillaceous material containing carbonate layers in the original sediment. Inclusions of other minerals, frequently carbonates (calcite, dolomite), occur in places within magnesite, as well as in its porphyroblasts and idioblasts and also in the pignolite magnesite and banded magnesite. In places, these inclusions within magnesite are often developed in very fine grains and furthermore can occur in zonal arrangements or also be found even as dusty turbidity. In places, as an inclusion within magnesite, likewise as constituent of the dusty turbidity, even relics of older magnesite can be found.

Strong tectonic stress and regional metamorphic overprinting has affected the magnesite which as a consequence exhibits distinct postcrystalline deformation, cataclasis and even complete recrystallization. In places, relics of cataclastic magnesite show stretching in connection with a certain (flow-) schistosity and are embedded within recrystallized younger magnesite.

Dolomite and/or calcite occur in small amounts and can be found intergrown with magnesite, either replacing the former or itself replaced by younger magnesite generations. Further minor to accessory mineral constituents are talc (in places also more frequent), iron-poor biotite or phlogopite, chlorite (clinochlore), quartz, kyanite (locally several cm in length, frequently replaced and pseudomorphed by talc and clinochlore), Mg-rich amphibole, sulfides (frequently pyrite, locally traces of chalcopyrite, pyrrhotite, sphalerite etc., where pyrrhotite in places exhibits a Co-mineralization, as a peculiarity, namely exsolution of flames of Co-pentlandite and idioblasts of cobaltite, likewise a peculiarity), rutile, tourmaline and graphite. Locally, at the contact distinct enrichments of tourmaline can be found forming a tourmaline rock (“tourmalinite”) and considering the fact that a considerable enrichment of boron took place, which otherwise typically appears in evaporite formations. Magnesite and its associated silicates and graphite represent the occurrence of a metamorphic paragenesis which, with respect to the grade of regional metamorphism, corresponds to that of the surrounding “Radenthein mica schist series” and that of the (pre-Alpine) crystalline basement (“Altkristallin”). Furthermore, the occurrence of graphite indicates euxinic conditions in the original sediment and the appearance of a black-shale facies before this was subjected to (pre-Alpine) regional metamorphism.

Concerning the genesis of the magnesite, the Radenthein deposit points out that the trace element analysis of the rare-earth elements (REE) yields no reliable results and evidence with regard to the genesis of the magnesite. The distribution of REE (average Σ REE without Y: 8.43 ppm) in the Radenthein magnesite reveals a characteristic positive Eu anomaly in nearly all of the samples, and in places a certain loss of Yttric earths can be observed. Furthermore, the REE distribution patterns of magnesite reveal that they differ distinctly from those of accompanied calcite (lime marble) and dolomite (dolomite marble) and partially are masked by foreign material and inclusions within the respective magnesite (samples).

The carbon and oxygen isotope composition of the magnesite exhibits a higher degree of scattering of values both for carbon ($\delta^{13}C$ in ‰ relative to PDB: - 5.22 to + 1.32) as well as for oxygen ($\delta^{18}O$ in ‰ relative to PDB: - 19.85 to - 9.21), characteristic of magnesite which has become distinctly overprinted by regional metamorphism.

Usually, the Radenthein magnesite shows only very small fluid inclusions, mostly in the range of 1 - 3 µm, rarely up to 20 µm. Prevailing are one-phase fluid inclusions (liquid), two-phase fluid inclusions (liquid and vapor) are subordinate, while three-phase fluid inclusions (either liquid, liquid CO_2 and CO_2 vapor or liquid, vapor and crystalline solid) only occur occasionally. Two-phase fluid inclusions which at room temperature under the microscope look rather dark homogenize within a temperature interval of 29.8 °C to 30.9 °C into the liquid phase, that is they contain CO_2 of critical density. Raman-spectroscopic investigations of these fluid inclusions verify that they contain, besides the predominant CO_2 phase, likewise small amounts of CH_4 and N_2. Two-phase fluid inclusions which at room temperature under the microscope look rather bright show final ice-melting temperatures in the range of - 11.2 °C and - 11.6 °C and in the range of - 8.3 °C and - 9.2 °C which corresponds to salinities up to 15 wt.-% NaCl equivalent. The homogenization temperatures of these fluid inclusions scatter around maxima of 235 °C and 305 °C. Leaching analyses of fluid inclusions of the Radenthein magnesite revealed chloride-hydrogen carbonate solutions of alkali and alkaline-earth metals with predominant Na, K and Mg and distinctly reduced contents of Ca and Sr.

The Radenthein sparry magnesite deposit represents worldwide the type locality of a magnesite deposit overprinted by regional metamorphism and especially characterized by its strata-bound occurrence within a silicate crystalline complex which is distinguished by an almost total lack of carbonate rocks. Furthermore, the Radenthein sparry magnesite deposit occurs within a polymetamorphic crystalline series which exhibits distinct diaphthoresis. Originally this pre-Alpine crystalline series, namely the “Radenthein mica schist series”, represented a thick volcanogenic-sedimentary (geosynclinal) series in which the strata-bound magnesite deposit chain was formed within a closed basin. This basin was influenced by volcanic processes, showed formation of saliniferous solutions and contained a black-shale facies (graphite!). A feeding of epigenetic hydrothermal or metamorphogenic-hydrothermal solutions, causing magnesite metasomatism, does not apply for the Radenthein sparry magnesite. The complete volcanogenic-sedimentary (geosynclinal) series including its embedded strata-bound magnesite deposit chain underwent a strongly pre-Alpine progressive regional metamorphism (mesozonal or medium-grade, e. g., staurolite) as well as Alpine diaphthoresis. The Radenthein magnesite deposit exhibits exactly the same tectonic stress and deformation, as well as the various tectonic deformation processes, schistosities and regional metamorphisms as do the adjacent polymetamorphic "Radenthein mica schist series" in which the strata-bound magnesite is embedded. In conclusion, the "Radenthein mica schist series" and its embedded strata-bound Radenthein magnesite deposit jointly underwent the identical entire tectonic, metamorphic and geologic development in pre-Alpine and Alpine time.