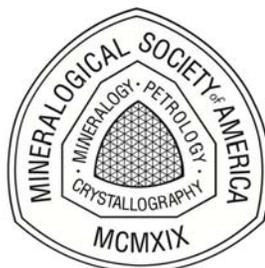




Topaz with schorl, cleavelandite and quartz, Little Three mine, Ramona, California
Carnegie Museum of Natural History, Pittsburgh, PA

The 42nd Tucson Mineral Symposium Tucson Convention Center, Tucson, AZ

Pegmatites: Crystals Big & Beautiful
Saturday, February 10, 2024



The 42th FM-TGMS-MSA Tucson Mineral Symposium

Acknowledgments

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Participants and speakers of the 1982 pegmatite short course. Their photo identification can be found at : http://www.minsocam.org/msa/special/pig/PIG_best_shots/Winnipeg_2.jpg Three of these participants will be speaking at this symposium. Photo courtesy of Richard Bedell. This meeting resulted in a handbook on granitic pegmatites and sharing of ideas by the leading pegmatite advocates.

**The 42th FM-TGMS-MSA Tucson Mineral Symposium,
Theme "Pegmatites – Crystals Big and Beautiful"
Saturday, February 10, 2024, Tucson Convention Center, Tucson, AZ**

10:00 AM	Opening of symposium
10:00-10:15 AM	Introduction by symposium chair, Mark Jacobson
10:15 – 10:45 AM	Michael Wise, Pegmatites: Earth's Most Amazing Rocks
10:45 - 10:55 AM	break
10:55 - 11:25 AM	Michael Menzies, Gem Pegmatites
11:25- 11:35 AM	break
11:35 – 12:05 AM	David London, Gem-Forming Cavities in Pegmatites
12:05 - 1:30 PM	Lunch
1:30 – 2:00 PM	Robert F. Martin, Cleavelandite: Only Crystals Small and Beautiful
2:00 - 2:10 PM	break
2:10 - 2:40 PM	Donald Dallaire, Pegmatite Minerals from New Hampshire's White Mountain Igneous Province
2:40 - 2:50 PM	break
2:50 – 3:20 PM	Peter Lyckberg, Chamber Pegmatites of Volyn, Ukraine
3:20 – 3:40 PM	extended break
3:40 – 4:10 PM	Calvin Mako (speaker) and Carson Richardson, Geochronology of REE-bearing Proterozoic Pegmatites in the Arizona Pegmatite Belt
4:10 – 4:20 PM	break
4:20 – 4:50 PM	Markus Raschke, The South Platte Pegmatite District of Colorado: New Insights into Mineralogy, Petrogenesis, and Rare-earth Element Fractionation
4:50 PM	close of symposium

Pegmatites: Earth's Most Amazing Rocks

Michael Wise

Smithsonian Institution, Washington, D.C.

wisem@si.edu

Granitic pegmatites are extremely complex and enigmatic igneous rocks that are difficult to define in simple terms. Pegmatites are among the world's most mineralogically interesting rock types and have intrigued geologists, mineral enthusiasts, gem and specimen miners, and gemologists since the early 1800's. Pegmatites are best known for their extraordinary development of giant crystals – some of the largest crystals ever recorded were mined from pegmatites – but they are also important sources of rare-elements, industrial minerals, gem material and collectible mineral specimens. When compared to other well-known rock types, such as limestone, sandstone, marble, basalt and even granites, it becomes immediately evident that pegmatites are undeniably some of Earth's most amazing rocks.

Pegmatites form in the Earth's crust in a variety of geologic settings and reside in rocks ranging from 3.9 billion to less than 5 million years old. Although pegmatite bodies may be volumetrically small compared to the large masses typical of other rock types, pegmatites are not uncommon and are found worldwide, generally occurring in groups or clusters consisting of tens to hundreds of bodies. Pegmatite populations may contain not only mineralogically simple bodies consisting of mainly microcline, plagioclase and quartz ± accessory biotite, muscovite, garnet and black tourmaline, but also complex pegmatites that carry rare minerals such as beryl, elbaite, spodumene, or topaz.

Pegmatites owe their origin to a myriad of complex geologic processes and conditions that yet are not completely understood. The fundamental principles of pegmatite formation involves the creation, emplacement, and crystallization of pegmatite melt which can be generated as a residual product of the crystallization of granite magmas or from the direct melting of metamorphic rocks, a process known as anatexis. The chemical composition of the parental magma plays a significant role in determining the mineralogical makeup of the final pegmatite body. Segregation and migration of pegmatite melt from its source occurs at various depths within the middle to upper crust of the earth. The character of the surrounding country rock in which pegmatite melt is injected plays a key role in determining the physical shape of the final pegmatite body. Tabular veins to irregular ovoid or bulbous shapes are direct consequences of the depth of emplacement and the brittle or plastic nature of the country rock in which the pegmatite melt resides prior to final crystallization. The crystallization history of the melt is arguably the most complex portion of the pegmatite-generating process and is largely responsible for (1) the uniform to heterogeneous internal structure of pegmatite bodies, (2) the myriad of textural features that include not only large crystals but also small crystallites, layered features, and miarolitic cavities or pockets, (3) moderate to extreme differentiation and accumulation of rare elements, (4) diverse assemblages of common and rare mineralogical components and (5) post-magmatic alteration of primary mineral phases in the pegmatite and the hosting country rock. Fluctuating crystallization rates and changes in melt and fluid dynamics, work in unison at temperatures from ~ 500° to 150°C under nearly constant pressure conditions to produce the truly spectacular big and beautiful rocks we know as pegmatites.

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Michael Wise - Speaker biography



Michael Wise grew up in a small town in southeastern Virginia where as a child he always had a deep interest in science. A short time after graduating from the University of Virginia with a B.Sc degree in Environmental Sciences (1975) Mike made the decision to attend the University of Manitoba, to study under Petr Cerny, one of the leading pegmatite researchers in the world. As a graduate student Mike became fully immersed in the study of granitic pegmatites thanks to several field seasons investigating the mineralogy and chemistry of niobium, tantalum and tin minerals from pegmatites in the Yellowknife pegmatite field in the Northwest Territories, Canada. Mike received his Ph.D from the University of Manitoba in 1987 and after a one-year post-doctoral position was hired by the Smithsonian Institution. Mike is currently a mineralogist and education officer in the Department of Mineral Sciences at the National Museum of Natural History, Smithsonian Institution in Washington, D.C. His research focuses on the mineralogy, petrology, and geochemistry of granitic pegmatites in order to better understand the geological processes responsible for the genesis, evolution and crystallization of pegmatite melts. Mike has several decades of field-based experience studying pegmatites across the United States and abroad and has long been active in projects related to the classification of different pegmatite types, the regional mineralogical and geochemical patterns of large pegmatite populations and the exploration of critical minerals associated with pegmatite deposits. In addition to his research program on pegmatites, Mike is also highly active in education and outreach activities and is heavily involved in the management of the Smithsonian's Mineral and Gem Collections.

Two recent publications by Michael Wise:

Wise, M. A. ; Müller, S. M. and Simmons, W. B. 2022. A Proposed New Mineralogical Classification System for Granitic Pegmatites. *The Canadian Mineralogist*, Vol. 60, pp. 229-248. DOI: 10.3749/canmin.1800006

Wise, M. A.; Harmon, R. S.; Curry, A.; Jennings, M.; Grimač, Z.; and Khashchevskaya, D. 2022. Handheld LIBS for Li- Exploration: An Example from the Carolina Tin-Spodumene Belt, USA. *Minerals (MDPI)*, v. 12, no. 77, 28 p. <https://doi.org/10.3390/min12010077>.

Gem Pegmatites

Michael Menzies
Calgary, Canada
mike.menzies@telus.net

Pegmatites are produced during the crystallization of the very last remnants of some igneous magmas, typically of granites, but less commonly of other rocks such as syenites or nepheline syenites. They are most commonly recognized by their exceptionally coarse grain size. Those that host gem crystals are rare, representing a very small proportion of the overall pegmatite population, but occur worldwide, typically confined to specific districts. Key characteristics include shallow emplacement depth, which helps to create the required open space (miarolitic cavities) for the crystals to grow.

The most widely accepted classification by Petr Černý (Černý 1991, Černý & Ercit 2005), divides pegmatites into two families, NYF and LCT, named for their characteristic trace elements (Niobium, Yttrium and Fluorine and Lithium, Cesium and Tantalum). But of these elements, only Fluorine & Lithium are important essential elements in gem minerals. Fluorine creates topaz (or less commonly fluorite), and lithium can produce gem tourmaline or spodumene (in particular its gem variety, kunzite). Concentration of these and other essential elements in gem minerals occurs as the pegmatite solidifies inward from the outer margins toward the central core zone in which crystallization of gem minerals is the final stage of pegmatite formation.

Beryllium is another essential element commonly found in both NYF and LCT pegmatites. It is especially important because beryl is commonly the first of the major gem minerals to crystallize, starting as early as in the intermediate zones or core margins and continuing within cavities. Beryl is typically present as aquamarine in NYF pegmatites and morganite in those of the LCT family.

Other important essential elements in gem minerals include and Boron, Phosphorus and Cesium, mainly for LCT pegmatites. Boron (along with lithium) can create gem tourmaline, phosphorus creates phosphate minerals (in particular apatite) and cesium is found in rarer minerals such as pollucite, pezzottaite and londonite.

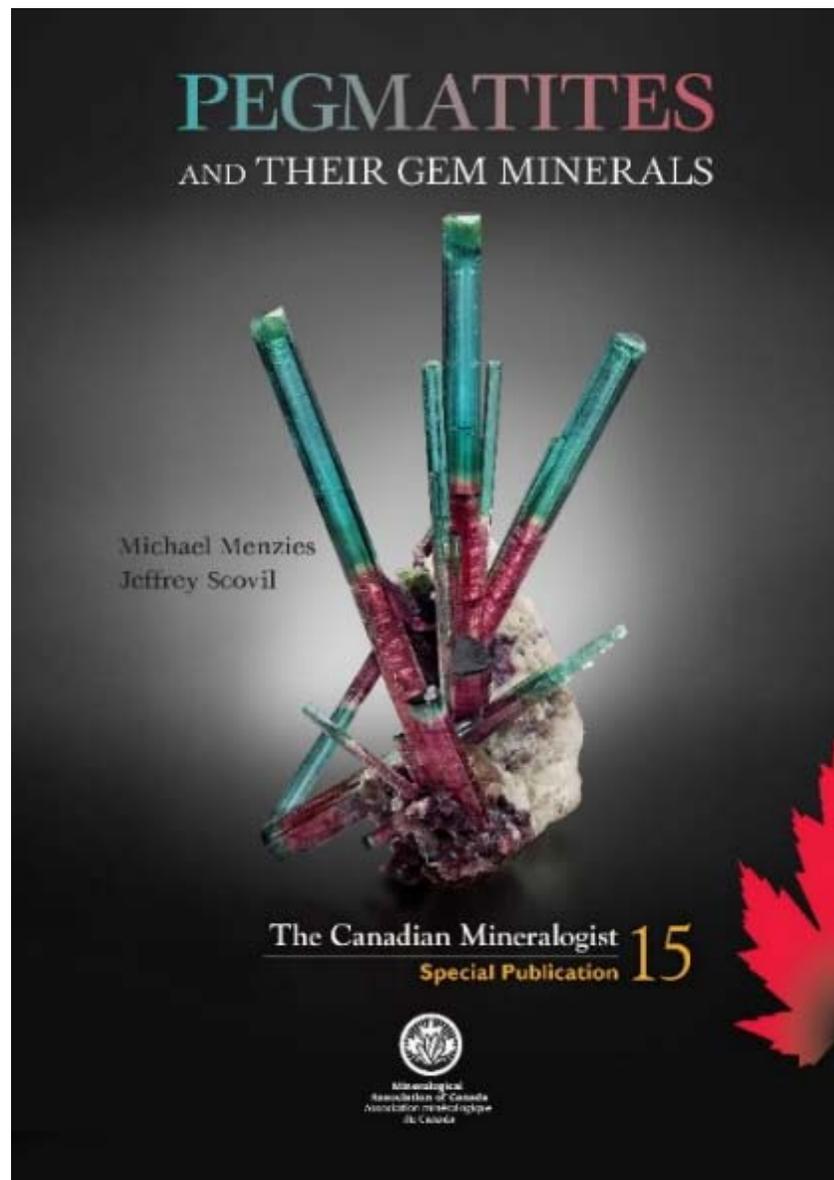
In addition to these differences in the mineralogy, the two pegmatite families have contrasting physical characteristics, in particular the relation to their parent granite, physical form and size, and inner structure. Most NYF bodies have crystallized within their parent granites (typically in the inner margins), vs. LCT pegmatites, which are emplaced within country rocks at varying distances from the parent granite. NYF pegmatites are typically smaller (but with some very striking exceptions) than their LCT counterparts. LCT pegmatites are typically dikes which may show complex inner zoning. In contrast, NYF bodies range from isolated miarolitic cavities (the simplest of all structures) to larger bodies with diverse physical forms and internal structures. Of the two families, NYF pegmatites are typically much less well described in the literature and less well understood than LCT types. A small proportion of NYF pegmatites are, however, exceptionally large and some have produced the world's best and largest crystals of gem minerals.

The suites of minerals found in pegmatite cavities have been well described. But there has been significantly less attention to evolution within the cavity as the pegmatite continues to

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cool. Resulting phenomena seen in gem crystals include etching, corrosion and replacement, color zoning, and changes in mineral species and varieties. Multiple generations of gem crystals are also produced, but are likely under-reported. Secondary minerals are commonly created. Other phenomena include cavity rupture and late-stage hydrothermal alteration of cavity contents.

Worldwide localities for gemstone-bearing pegmatites total more than 120, distributed across more than 35 countries (Menzies & Scovil 2022).



Cover of *Pegmatites and their Gem Minerals*, published in 2022, and reprinted in 2023. This specimen of elbaite tourmaline crystals, with minor albite and lepidolite, 28 cm high, and found in 2004 at the Pederneira mine in the Sao Jose da Safira district, Minas Gerais, Brazil, is one of the finest known elbaite from any locality worldwide. Fine Minerals International specimen, James Elliott photo.

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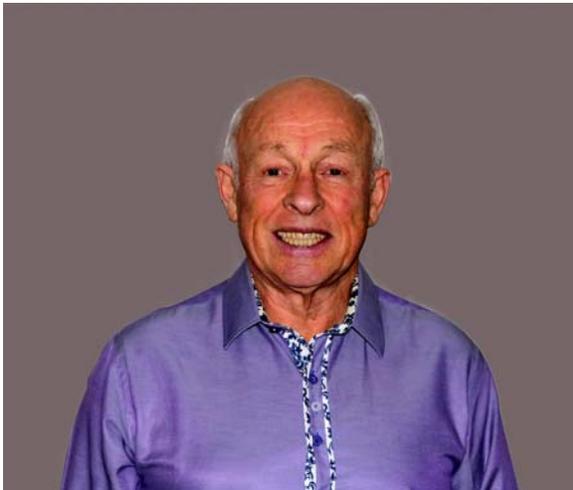
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Mike Menzies - Speaker biography



Mike Menzies was born and grew up in New Zealand. He graduated there as an engineer in 1966 before emigrating to Canada, where he obtained a PhD in Chemical Engineering at McMaster University in Hamilton, Ontario in 1972. After a few years in Montreal, he moved to Calgary in 1976. There he spent the remaining decades of his career in the Alberta Petroleum Industry as an engineer, project manager, and finally a consultant, before he retired in 2010. After moving to Calgary, he became an avid mineral collector, and in subsequent decades has field collected in Alberta and Quebec, Idaho, Montana, Utah, Nevada and California. He has

written for the *Mineralogical Record* on the worldwide occurrence of topaz, and authored locality articles for the *Mineralogical Record* and *Rocks & Minerals*. Since 1990, he has been a speaker at mineral shows and mineralogical symposia in Canada and the USA. His quest for knowledge about pegmatites and their gem minerals has taken him on international trips to Elba and Madagascar for mineralogical symposia and field excursions. In 2022, the Mineralogical association of Canada published his book (co-authored with the photographer, Jeff Scovil), *Pegmatites and their Gem Minerals* as Special Publication 15 of the *Canadian Mineralogist*.

Gem-Forming Cavities in Pegmatites

David London
dlondon@ou.edu

The fine mineral specimens and gem-quality crystals found in pegmatites arise from the final crystallization of a granitic melt. Pegmatites with gem-bearing cavities are exceedingly rare: they constitute less than ~ 0.1% of all known pegmatite bodies.

Depths of pegmatite intrusions. The gem-forming pegmatites, also known as the miarolitic class, used to be considered as the shallow equivalents of the more abundant and massive rare-element pegmatites, most of which are lithium-rich. However, many of the miarolitic pegmatites contain the assemblage of spodumene + quartz, which constrains them to have crystallized at depths greater than 6 km. The massive lithium pegmatites crystallize at depths of 7 to 9 km. What makes a pegmatite form cavities, therefore, depends less on depth of emplacement and more on the retention of H₂O within melt to the final stages of crystallization. That response is favored by rapid cooling and crystallization along the margins of pegmatite-forming dikes that intrude much cooler host rocks.

Temperatures of crystallization. The temperatures of crystallization as recorded by feldspars in the massive portions of thin miarolitic pegmatites are ~ 400°C from the margins, rising to ~ 425°-450°C at centers. These values are ~ 250°-300°C below the temperatures at which crystallization of hydrous granitic melts should begin. The pegmatite-forming melts, therefore, experience a high degree of undercooling before crystallization finally commences. A survey of temperatures recorded by feldspars in a random and unassociated world-wide suite of miarolitic pegmatites indicated that the initial crystallization along the margins of cavities began at ~ 430° (1 σ 68)°C. The growth of pocket feldspars culminated at ~ 360°C (1 σ 64°C). Gem minerals of tourmaline, beryl, spodumene, etc. crystallize over this same interval of cooling. A heat-flow model for two different initial host rock temperatures (160°C and 300°C) predicts that the crystallization of feldspars and associated gem minerals in cavities would have spanned 26 to 183 days.

The pocket-forming environment. The physical features of gem-bearing cavities fall into three morphological types: (1) largely open-space cavities in which crystals line the walls, (2) cavities that are packed with euhedral crystals that are suspended in clay and granular grit of pocket minerals, and (3) cavities that are open at the top but filled with a pile of loose, euhedral crystals at the bottom. Cavities of the first type are akin to geodes: the ratio of crystals to void space is low, and the void space represents the volume of aqueous solution from which the crystals precipitated. The crystals are rooted in the massive pegmatite that surrounds the cavities. Pockets of the second and third types are one and the same: the dense clay, which is an essential part of the gem-forming process, represents the residuum of a flux-rich silicate melt, gel, or glass that devitrified to clay and an aqueous solution at the culmination of the pocket-forming event. Unattached euhedral crystals found floating in the clay formed in a medium that was sufficiently viscous as to support them yet nurture their growth. The subsequent flow of groundwater through cavities upon uplift to the surface erodes the clay gradually, allowing large crystals detached from the top of the cavities to settle gently onto those at the bottom without breakage. In the typical gem cavities of lithium-rich pegmatites, zeolites, including laumontite and stilbite, encrust the coarser primary minerals. The same cooling models predict that cavities in thin

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pegmatite bodies would cool to the temperatures at which zeolites become stable (below 285°C) in months to years. Clay minerals, which become stable below ~ 185°C, would form tens to hundreds of thousands of years later.

The gem-forming medium. The shiny faces of pocket minerals reflect their final crystallization from a fluid that does not adhere to their surfaces, as melt or glass would. Aqueous solutions are likely candidates for that fluid. The solubility of mineral-forming constituents in such fluids, however, is low – less than 10% solids in flux-rich solutions, and less than 2% solids in saline solutions. The small proportion of crystals to open void space in cavities of the first type is a result of that low solubility of solutes. The crystal-packed and clay-filled cavities arise from an entirely different medium, one which is viscous, mostly silicate, and enriched in the elements that are excluded from the ordinary rock-forming minerals: fluxes such as boron, fluorine and sometimes phosphorus, and rare elements including beryllium, lithium, rubidium, and cesium. Fluxes act to lower the final crystallization temperatures of granitic melts; they inhibit the crystallization of minerals that would precipitate on growing crystal surfaces, stunt their growth, and make them cloudy and rough; and they serve to forestall the exsolution of an aqueous solution. When H₂O is retained in the melt, it aids in the rapid diffusion of ions to growing crystal surfaces. Experiments with a flux-rich and hydrous silicate melt indicated that such liquids can deliver ~ 10⁷ times the mineral-forming constituents compared to an equal volume of aqueous solution at rates that are ~ 10⁷ times faster than in flux-poor but hydrous granitic melts. Nonetheless, experiments have shown that even such hydrous and flux-rich silicate liquids are exceedingly viscous at the low temperatures of pocket formation. Hence, gem crystals grow in suspension within that medium before it devitrifies to clay and aqueous solution. Water is the last fluid in contact with the gem crystals, but it is not the principal medium from which they grow.

Exploration. Gem-bearing cavities are generally found in the thickest portions of pegmatites of variable width, or in the thickest portions of horizontal segments near their inflections, also called “rolls”, toward the vertical. Once an aqueous solution has exsolved from the final silicate growth medium, it conveys unconsumed and soluble components outward into hosts, where interactions with common rock types produce a reaction zone of new minerals in close proximity to the exit point from the pegmatite. Most commonly, the loss of boron from the massive cores or miarolitic cavities replaces hosts with dense aggregates of black tourmaline. Such localized zones of tourmalinization can be an indication of tourmaline-bearing cavities within the adjacent pegmatite, as is the case for the gem-bearing pegmatites of San Diego County, California. Holmquistite, a lithium-rich amphibole, in the host rocks is a sure indicator of significant lithium mineralization within a nearby pegmatite. Newly formed micas rich in beryllium, lithium, rubidium, and especially cesium are similarly useful signs of rare-element mineralization within the proximal pegmatite.

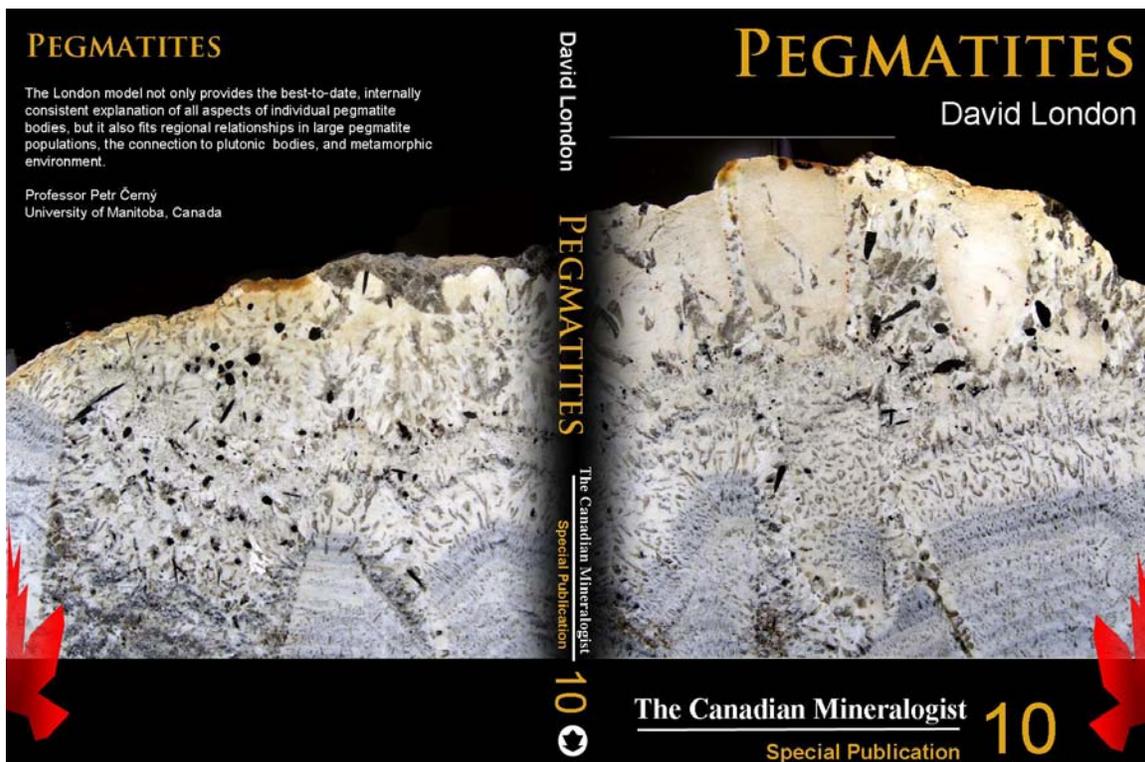
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David London - Speaker Biography



David London obtained his B.A. in geology (1975) at Wesleyan University, Connecticut, after which he mapped for the U.S. Geological Survey (1975-1976) in the high-grade metamorphic terrane of eastern Connecticut, USA. He continued annual summer field mapping in metamorphic rocks of central Connecticut through 1988. London received his M.S. (1979) and Ph.D. (1981) in geology from Arizona State University. His graduate studies included investigations of pegmatites in the White Picacho district, Arizona, and he began laboratory research for his Ph.D. in Washington, D.C., at the Geophysical Laboratory, the U.S. Geological Survey, and the Smithsonian Institution. He returned to the Geophysical Laboratory as a postdoctoral research fellow (1981-1982). London joined the faculty of the School of Geology and Geophysics at the University of Oklahoma (1983-2020), where he held several professorships and a

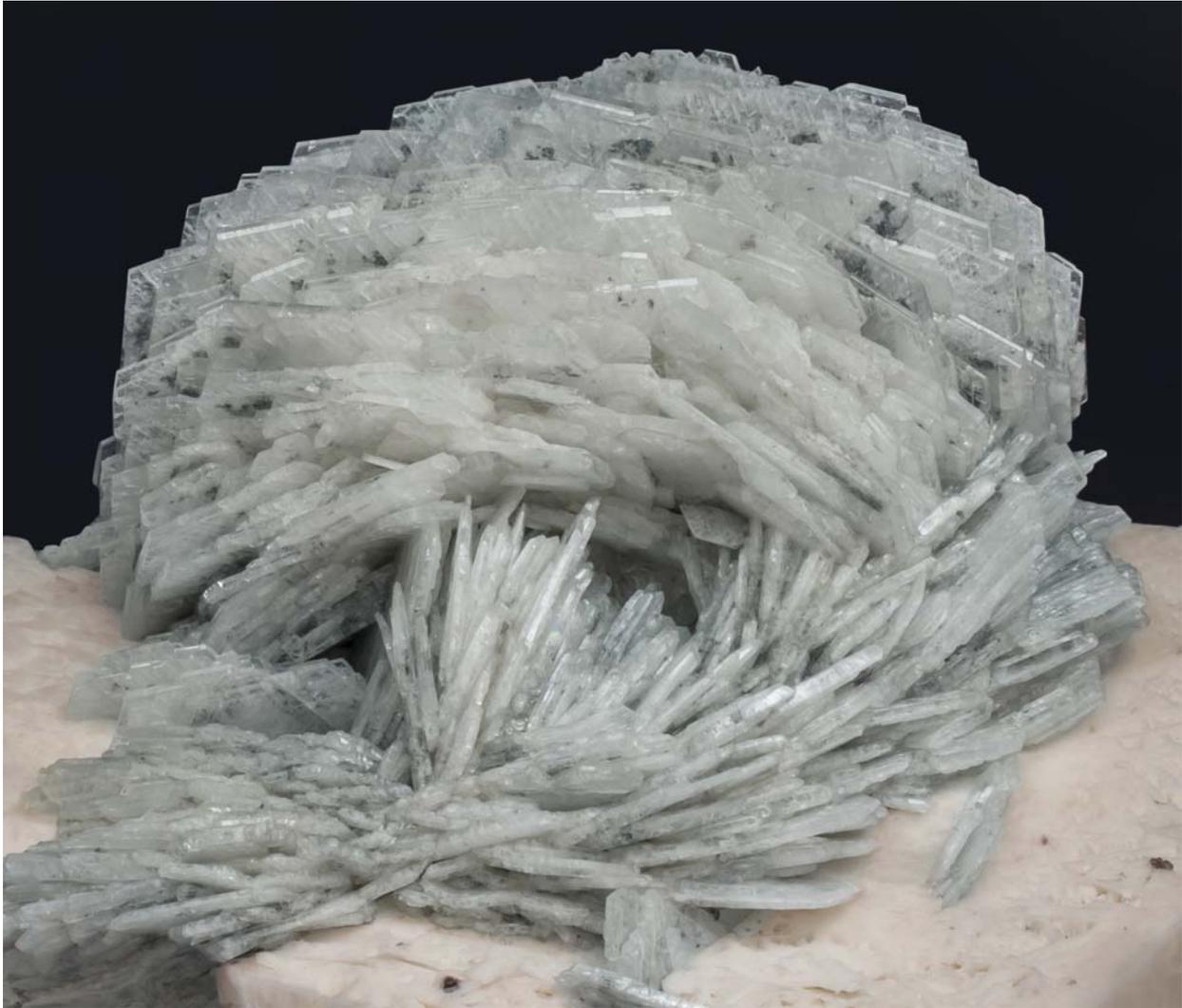
chaired position. He established and directed the University's electron microprobe lab. London is the managing editor of the Pegmatite Interest Group of the Mineralogical Society of America (<http://www.minsocam.org/msa/special/pig/>). His book *Pegmatites* (Canadian Mineralogist, 2008, Special Publication 10, cover below) is the only authoritative monograph on the subject. Londonite, isometric $\text{CsAl}_4\text{Be}_4[\text{B}_{11}\text{Be}]\text{O}_{28}$ (Can. Mineral. 39: 747-755), was named for him in 1999. London has published 146 research articles and has received \$4.4M in funding through 31 grants from the U.S. National Science Foundation and the U.S. Department of Energy.



Cleavelandite: Only Crystals Small and Beautiful

Robert F. Martin

Department of Earth and Planetary Sciences,
McGill University, Montreal, Quebec H3A 0E8, Canada



Cleavelandite, a rosette array of very pale bluish platy crystals on an etched substrate of white microcline. Xanda mine, Virgem de Lapa pegmatite, Jequitinhonha, Minas Gerais, Brazil. The specimen measures $11.8 \times 10.7 \times 4.5$ cm. Photo and specimen : Minerals - Virtual Museum, courtesy of Jordi Fabre.

In a symposium entitled Pegmatites: Crystals Big and Beautiful, I focus instead on cleavelandite, only encountered as small crystals accompanying the big and beautiful crystals. It is relevant to take a look at cleavelandite in this context; it is a morphologically distinctive variety of pure albite that is considered an indicator of gemstone mineralization in granitic pegmatites. It typically consists of a jumbled mass of platy crystals in which the form {010}

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predominates. Curvature of the plates is consistent with relatively rapid growth in a dynamic environment, as is the “house-of-cards” look. The crystals are twinned according to the albite law; the presence of structural discontinuities repeated at each composition plane likely accounts for inefficiency of growth along [010]. Kenneth K. Landes wrote in 1925 that cleavelandite is an unfailing index of the first hydrothermal period in the history of a zoned miarolitic granitic pegmatite. Cleavelandite and lepidolite are both indicators of gemstone mineralization.

Cleavelandite is an accent mineral, and never the center of attention in showy specimens of gem-quality crystals. In peraluminous miarolitic granitic pegmatites of LCT character, which belong to orogenic suites, cleavelandite crystallizes commonly after quartz, tourmaline, topaz, spodumene, and a white mica like muscovite or lepidolite. The K-feldspar present in the pocket environment, well-ordered microcline in general, is generally etched and partially dissolved. In the more alkali-rich NYF granitic pegmatites, members of anorogenic suites, the microcline in pockets is pristine, devoid of signs of dissolution. In the Pikes Peak area, for example, white cleavelandite forms a striking accent mineral next to amazonitic microcline, smoky quartz, goethite and fluorite. There is no sign that the K-feldspar has broken down to a white mica.

Albite dissolves incongruently in H₂O, as does K-feldspar. In both cases, the surface may become coated in an aluminous mineral, a pattern that is well understood in a weathering environment. In the pocket environment in a granitic pegmatite, however, the fluid must be slightly alkaline. The degree of enrichment of Na for albite to grow is significantly greater than that of K for K-feldspar to grow. Thus K-feldspar will normally appear first. As a body of slightly peraluminous LCT pegmatite cools, the microcline is expected to react with H₂O to produce a white mica, either muscovite or lepidolite, with an increase in the concentration of H⁺ in the ambient fluid. In a plot of $\log a(\text{Na}^+/\text{H}^+)$ as a function of temperature, one predicts a transition from microcline + quartz to albite having the cleavelandite habit + white mica + quartz as the system cools. The crystals of cleavelandite probably grow rapidly at first, then more slowly with decreasing supply of Na until the fluid locally becomes acidic. This likely causes a nanolayer of paragonite to poison the growth surfaces. The genesis of cleavelandite is thus considered to involve repeated nucleation and arrested growth. The hypothesis should be testable using high-resolution scanning and transmission electron microscopy.

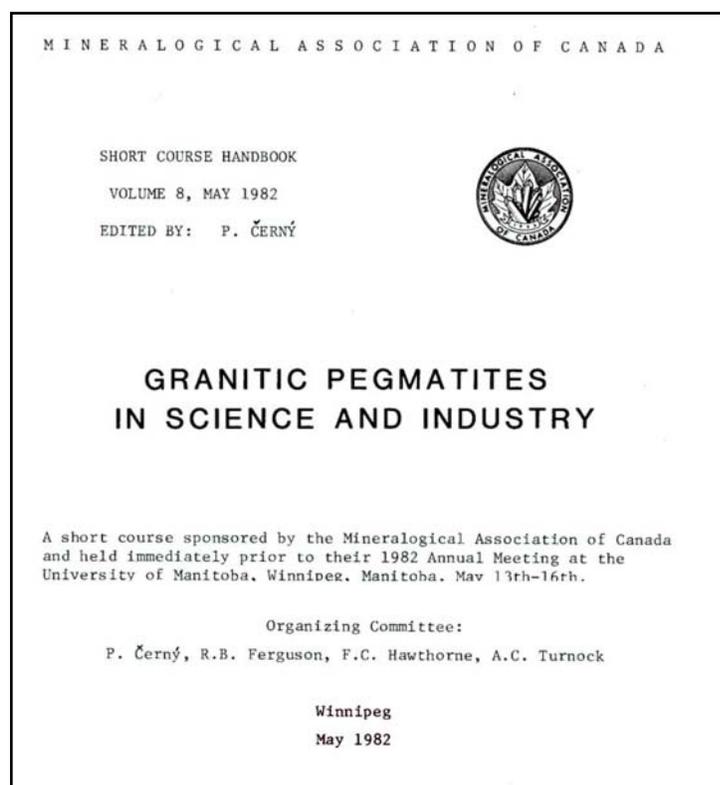
In NYF granitic pegmatites, muscovite and lepidolite do not form. As a result, microcline remains in its field of stability below 375–400°C, and shows no sign of attack by an acidic fluid. With increasing concentration of Na in the fluid, cleavelandite does form. Its presence implies that as the ratio $a(\text{Na}^+/\text{H}^+)$ locally decreases, a tipping point is reached and a nanolayer of paragonite nucleates on the growth surfaces. In more strongly alkaline pegmatites, such as those in silica-undersaturated anorogenic complexes, cleavelandite is absent because no aluminous phase is stabilized to poison the growth surfaces.

The use of variety names is unregulated, which invites misapplications of the label to albite from environments other than miarolitic cavities. Cases of albite replacing microcline do not qualify, as cleavelandite does not replace. Nor does it crystallize from an immiscible sodic melt. Cleavelandite is not an igneous mineral! Such misuse leads to unfortunate confusion.

Robert F. Martin - speaker biography



I hail from Ottawa, Canada, and graduated from the University of Ottawa (B.Sc. Hon. in geology, 1963), the Pennsylvania State University (M.S. in geochemistry, 1966), and Stanford University (Ph.D. in geology, 1969). At Stanford, my advisors were Orville Frank Tuttle, of Tuttle and Bowen fame, and Richard H. Jahns, Mr. Pegmatite. I specialized early on in the mineralogy and petrology of granitic rocks and related pegmatites. In my Ph.D. thesis, I investigated the rate of Al–Si ordering of alkali feldspars. After graduating, I remained at Stanford as a post-doctoral fellow to work on element mobility in polythermal experiments. I also mapped out the solvus in the system $\text{NaAlSi}_3\text{O}_8$ – KAlSi_3O_8 . In 1970, I joined the staff at McGill University, where I spent my entire career. I have focused on anorogenic felsic magmatism, granitic pegmatites, feldspar mineralogy, and related mineralization. In 1978, I was invited to become editor of *The Canadian Mineralogist*, an international journal covering the fields of mineralogy, crystallography, petrology, geochemistry and ore deposits, and served at the helm until 2012, a heroic 35-year stint. I recently edited *Pegmatites and their Gem Minerals* by Michael Menzies and Jeffrey Scovil (2022, reprinted in 2023), published as Special Publication **15** of *The Canadian Mineralogist*. Lately, I have shifted my attention to the anatexis of marble and to carbonatitic and ultrabasic complexes. Martinite, discovered at Mont Saint-Hilaire, is a complex hyperagpaitic Na–Ca borosilicate containing both OH and F. I currently hold the title of Professor Emeritus in the Department of Earth and Planetary Sciences at McGill University, in Montreal.



Left: Cover of the 1982 handbook for the short course on *Granitic Pegmatites in Science and Industry*, edited by Petr Černý. Robert F. Martin authored the chapter “Quartz and the Feldspars”.

Pegmatite Minerals from New Hampshire's White Mountain Igneous Province

Donald Dallaire
Chester, NH
dadallaire@hotmail.com

The New Hampshire White Mountain Igneous Province (WMIP) was emplaced by two failed rifting events. The first occurred in the Jurassic age 200-155Ma and the second during the Early Cretaceous age 130-110Ma. The rifting began after the supercontinent Pangea ceased coalescing 300Ma and began splitting apart. Although the rifting was halted by other geological forces, the crust was thinned allowing magma to rise, emplacing granites and pegmatites.

The pegmatites are anorogenic with a miarolitic NYF (Niobium, Yttrium, Fluorine) signature in Černý and Ercit's (2005) revision of pegmatite classification. They also contain rare earth elements, CO₂, and are water poor.

Pegmatite miaroles are either isolated in the host granite or form where thin pegmatite dikes swell or intersect. The size of most miaroles ranges from a few centimeters to 20 cm but occasionally reach sizes of 5 meters or more. The minerals found exceed 70 species with microcline, albite, and quartz (primary constituents of granite) the most common as well as several uncommon, rare species such as bazzite and milarite. The size of different species also has a wide range from crystals a meter in size to 0.1 mm or less. Quartz crystals by far are the largest found with a few reaching 1 meter. Bazzite crystals on the other hand rarely achieve 0.5 mm.



There are 12 beryllium species found in the WMIP, but beryl is quite rare. In the LCT (Lithium, Cesium, Tantalum) pegmatites in NH, beryl crystals are quite common but not found in pockets unlike the NYF pegmatites where they are uncommon and found in pockets. Topaz crystals first found in 1888 on South Baldface Mountain are relatively common and some have reached 13.5 cm, but most are 2 cm or less. Colors vary from colorless to blue to brown. Many of the crystals were faceted in the past with those from South Baldface Mountain referred to as "Baldface diamonds". The only other gemstone from the WMIP is smoky quartz and faceted examples are known up to several hundred carats.

Figure 1: Quartz, microcline and albite, Moat Mountain, Hales location, Carroll County, NH, 9.3 cm tall. Kevin Downy photo.

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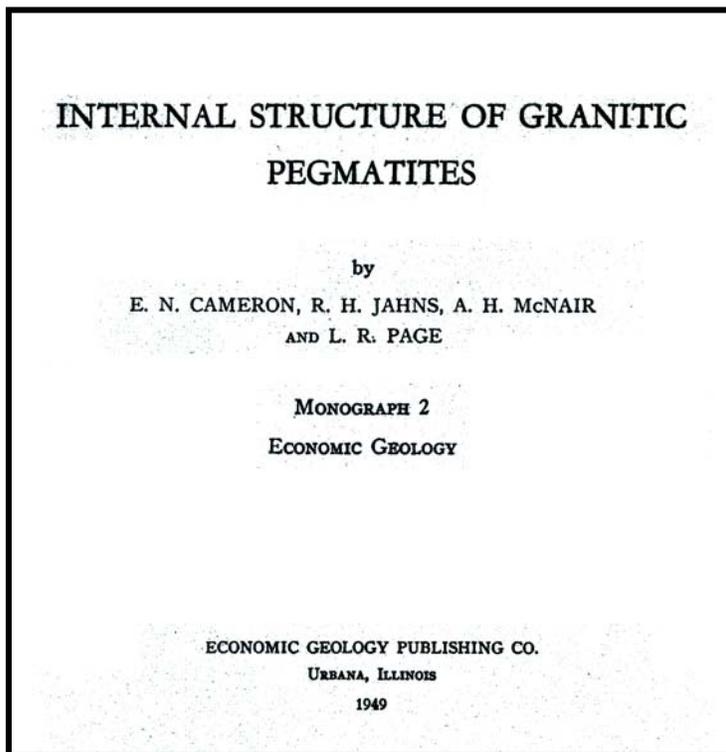
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Don Dallaire – Speaker Biography



Don Dallaire was born in Manchester, New Hampshire and has lived in Chester, New Hampshire since 1971. He received a BA from St. Anselm's college in 1967 and an MBA degree from the University of New Hampshire in 1970. He had a career in banking for 38 years, retiring in 2008 giving more time to devote to his interest in minerals which began in 1971. He has specialized in apatite and New Hampshire minerals. His current collection of 5600 catalogued specimens includes approximately 1000 apatites. Don has field collected in New England, New York, Michigan, California, Arizona, and Eastern Canada. He has written several articles for *Rocks & Minerals* magazine as well as other publications and has given many talks to mineral clubs in New

England. Don is a member of the Board of Trustees for the Maine Mineral & Gem Museum in Bethel.



Cover of the influential monograph documenting the USA efforts during World War II to map and explain the internal structure of granitic pegmatites in the United States. The scientists involved in this work greatly exceeds the authors credited on the cover but are acknowledged in the introduction.

Volyn Gem Chamber Pegmatites, Western Korosten AMCG complex (Ukrainian shield), Ukraine

Peter Lyckberg,
Luxembourg National Museum of Natural History
Lyckbergs@gmail.com

Introduction:

The 1.75 Ga Volyn Chamber pegmatites in the western endocontact of the Korosten Pluton (AMCG complex on the Ukrainian Shield), Ukraine, has produced the largest and most productive crystal cavities on the planet. Access has been highly restricted due to their former strategic importance of producing 75% of former Soviet Unions piezo quartz (Lyckberg 2002) since the start of serious mining in 1931 and later also some of the worlds largest and finest gem crystals of heliodor and topaz (Lyckberg 2002, Lyckberg et al. 2009).

The author has studied these pegmatites in specimens since 1985 and in situ since the first foreign visit (with Professor William B Simmons) in September 1995. In situ studies were continued during several dozen field trips underground while participating in the mining until 2020. During this period mining was overseen sequentially by three Directors and three Chief geologists. The productive area was delineated by core drilling in a 50 m grid over a 22 km north-south distance and 500 to 1500 m wide zone down to 100—600 m depth (Lyckberg et al. 2009). General geology, mineralogy has been outlined by Lazarenko (1973), Pavlishin and Dovgyi (2007), and Lyckberg et al. (2009). Specific details on these pegmatites can be found in the references shown later in the text.

Nineteen hundred chamber pegmatites have been mined to date in this district via numerous giant open pits up to 2 million cubic meters in size, underground workings accessed by six main shafts with access tunnels on three levels and 110 km of tunnels (Lyckberg 2018, 2019), and a number of ‘shurfs’ (meaning shafts 20-80m deep, that reach a small number of or single important pegmatites outside the main areas).

There has been exploration (open pits, shurfs) and drilling of chamber pegmatites also in the southern and eastern endocontact of the Korosten Pluton that encountered other chamber pegmatites with large smoky quartz crystals; however serious mining has not yet started there (A Hmyz and V Chournousenko, personal communication 2007) mainly due to overburden and that it was easier to mine in the Volyn field. The potential for the future is significant.

The position of the pegmatites along the rim of the intrusion, at or below today’s erosion level suggest that similar pegmatites having formed higher inside and towards the roof of the cogenetic rapakivi type granite intrusions, have eroded away. Within the Volyn pegmatite field 10-40m thick kaolinized granite and pegmatite remain covering the bedrock. Much of early piezo quartz crystals to ten tons in weight were recovered in these clays. The sharpest gem heliodor crystals and significant quantities of topaz were also found in the overburden clay. The general structure of the pegmatites is a quartz core with a cavity developed under it. Under the cavity with freely growing crystals, almost always, often collapsed on the floor, is a late stage leached zone (1-36m thick) where quartz has been dissolved and recrystallized in the ceiling and heavy albitization took place. Sometimes this zone contains late stage beryl or topaz.

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2013 research and finds in Shaft 3

During early 2013 shaft 3 which had been sunk, opened, mined in the 1970s and filled by water thereafter was pumped out for renewed mining of quartz and suspected topaz occurrences. In January 2013, while the water was still being pumped out, we started the study of the two levels.

Peter's Dream Pocket

After only a couple of days we encountered in Pegmatite 569 what is perhaps the most spectacular topaz pocket in history. Mine geologist Alexander Hmyz named it "Peters Pocket" (or Peters Dream Pocket, as he said also). The pocket had been accessed by two main tunnels from its bottom. Material from the pocket was now filling much of tunnels due to gravity. We accessed it by walking bent and crawling over an 80 cm boulder covered in its entirety by blue often doubly terminated topaz crystals. Topaz on matrix was only known in rare finds on the dumps, never recorded or known before (Lyckberg 2013). The naming after the author, was just because I had stressed during the past 10 years, that we needed to find a pocket with topaz or beryl crystals still in situ, to better understand these pegmatites. Inside the pocket were large smoky quartz crystals to 80 cm still in original position high on the wall above the entrance. Eight meters across from the entrance the pocket continued over the dump of left over material and continued for additional 5 to 7 meters slightly downwards. To the left up the slope and 10-12 m from the opposite entrance was a small 4 by 4 by 4m deep section in the upper corner of the pocket.

Here is literally a walk in topaz crystal cave: Peters Dream Pocket! It had two entrances separated by a 1m wide, 3 m tall and 1.5 to 2 m thick pillar of ~~non-pocket~~ feldspathic pegmatite covered by cleavelandite, some zinnwaldite and many hundreds of topaz crystals, the latter completely covering several square meters of the wall. Behind the pillar grew a 76cm diameter and 325 kg in weight bi colored sharp wedge shaped (Adun Chelon, Russia or Virgem da Lapa, Brazil type) topaz, the largest ever discovered anywhere. I named it Dedushka after my wife's grandfather and all other grandfathers who saved Europe from Germany during the Second World War.

Before removing it we made sure to photograph and document it properly. The crystal was fractured in several parts. I strongly suggested to mark each section, especially shards; then photograph, so their position and direction (up arrow) would be well known for reassembling and perhaps exhibit in a museum.

Around the pocket walls (also further at the end of the pocket) doubly terminated 5-8 cm mostly blue bi-colored crystals of topaz and large sharp zinnwaldite crystals to 10-15 cm grew upon cleavelandite. The zinnwaldite crystals are the finest known and the combination specimens of zinnwaldite with topaz are also world class although most are a little dull on the surface. Some topaz crystals showed fracturing during growth where parts had been separated a few mm and further growth had formed termination faces on these fractures.

The miners decided to remove this 325 kg topaz crystal without labelling the broken parts, thus one slice in the middle of the crystal was sold by mistake, unknowingly by a clerk not involved in the mining and likely lost forever. That day I decided to sit on a 50.0 kg blue topaz and have my lunch. Not many such opportunities in life. I was also carrying out of the pocket a big corner section of the termination filling both arms and quite heavy (documented by filming). The inner part of the right side tunnel I named Matryoshka after the Russian wooden dolls that nest inside each other, as this was exactly how that section had crystallized. On the left inner part a side with smooth surface and convex curvature. I opened it through a 15 cm hole. Its interior

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was filled with white kaolin clay and on the walls feldspar crystals to 15 cm. The wall to the right was a thin layer opened up by the chief geologist and hiding a single wedge shaped konjak colored gem topaz of incredible beauty and larger than those famous crystals recovered at Urulga in 1850s and now in Kocksharows collection in the Natural History Museum, London.

It should be mentioned also that two small very late stage cognac colored topaz crystals were found growing vertically from the roof with the Ilmen type morphology (elongated with complex termination). At the end of Matryoshka was an exceedingly further rich topaz mineralization producing several large plates to 70cm where blue and bi-coloured topazes sit individually or in small groups on the snow white matrix.

Methane (CH₄) in the cavities within the Chamber pegmatites

These chamber pegmatites are cogenetic with their host rapakivi type granite. They formed as large bubbles during the magmatic phase and grew rather large rapidly over time. As the volume of magma was large and temperature was kept high for an extended period of time, there was a slow multistage crystallization. Chief geologist Chornousenko after years of work in the deposit, studies of old logbooks and interviews with old geologists and miners has presented multiple observations of gas filled chambers encountered by drilling and mining. Methane, CH₄, was believed to be the main component. It is also possible that the methane contributed to the pockets and their sometimes enormous size.

Lyckberg (2020) has speculated that a possible influx of methane and magma mixing during the emplacement of the Korosten igneous event or an influx during later stage events may explain the gas inside the chambers in the pegmatites and as well as the open space at the top of several cavities in pegmatites discovered during drilling and exploration. Natural gas could have entered the system through fractures after the crystallization of the main granite and main chamber material. Another explanation of the open space in the upmost part of a pegmatite cavity could be a vertical collapse of the pegmatite material due to the many extensive contraction/cooling related fissures around the pegmatites roof zones. These open cavities have been studied above large chimney like pockets such as pegmatite 394 Skorkina/Vsevolods Pocket.

Kerite (black fibers of an organic compound now fossilized)

Lyckberg and Chournousenko in 2013 finally discovered after years of search, black fibres of kerite in several chamber pegmatites accessed from shaft 3. Lyckberg (2020) speculated that the strong radiation on methane at the time inside chambers during millions of years created a plethora of other molecules, chemical compounds and further may have lead to life forms. It is well known that there are bacteria living on the energy from radioactivity. Gorlenko and Zhmur (2001) described the fine structure of fossilized bacteria in Volyn kerite.

Possible origin of life inside crystalline rock

Thus it is possible that life first appeared inside crystal cavities-chambers (in crystalline rock). Present were mineral-rich water solutions inside the chambers during hydrothermal conditions lasting for many millions of years. An onset, springing point could include one or a series of special events, with the possible presence and interaction of other elements, compounds and minerals in those cavities. Radiation is proposed to be the key. This is an interesting field which needs to be explored. As a start I sent samples of kerite to Professor of Physics Dr John Jaszczak at the University of Technology in Michigan for SEM Imaging. Fluorite as minute crystals were detected growing on the kerite fibers. Dr Simon Filippo and myself first studied

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Kerite material in SEM at the Luxembourg National Museum of Natural History, Department of mineralogy. We studied also methane/carbon coatings, globules on opal and looked at the various elements present.

Volyn Biota

I brought to Berlin some kerite and opal samples which I had collected in shaft 3 in 2013, as well as some some collected by V Chouornousenko at my request. Professor G Franz and I studied the kerite fibres under SEM and their chemical composition at the SEM facility of the University. Together with Prof Franz, the great majority of follow up work and writing performed by him, we published a few papers on the Volyn biota with age dating as well (see references of Franz (2021, 2022, 2023)). Lyckberg raised the question in 2013 with Chournousenko and presented the hypothesis in letters to Prof Gerhard Franz and at the Volyn Chamber Pegmatite Conference that Lyckberg and Volyn Samotsvety, the mining company, had arranged in 2020. No kerite was ever found in any fissures outside the pegmatite chambers and its wall rock.

Long crystallization period

It is clear that the Korosten pluton and its cogenetic chamber pegmatites and their location (lower rim of intrusion with a high geothermal gradient) suggest a long period of cooling and crystallization. Voznyak et al. (2022) stated that the pegmatites formed by degassing of the magma at a temperature greater than 573°C and where the CO₂-fluids were involved in the crystallization of the late stage quartz from 200°C. They further stated that crystallisation of minerals in the cavities was of long duration from the 1.75 Ga for zircon and uraninite included in topaz crystals (which are very late stage) to 1.39 Ga age of galena inclusions in the late generation of quartz. This later age date suggests a very long crystallization period, or a second revival of the system. Likely the zircon and uraninite may have crystallized early on and later was incorporated into the topaz. These age dates suggest a span of up to 360 Ma which is a very significant long period. The Pb may have been derived from the breakdown of U during this long period when also the activity was significantly higher then it is now.



A just recovered 1.437 kg heliodor/green beryl in the giant chamber of pegmatite 521 being held by Peter Lyckberg.

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Other finds in shaft 3

Several finds of molybdenite were made by myself -- in the granite adjacent to a pegmatite, in the wall zone of the same pegmatite, and also as up to 10 cm crystals on giant orthoclase crystals in an open cavity. With employees of Volyn Quartz – Samotsvety, we mined natural citrine crystals among smoky quartz, feldspar crystals to 1 m, topaz pseudomorphed partly or almost completely to chlorite to 1 m in size with smaller residual or recrystallized bi-colored gem topaz. We also visited and studied the calcite-fluorite pegmatite that had been known since mining in the 1970s where we found blue-green-purple gem crystals to 35 cm of various morphologies. During this visit, we found green to black struverite, and very latest stage outer concentric fracture crystals of goethite, siderite (partly gem crystals 1-3 cm) and fluorite.

Other finds in Shaft 2

In 2015-2020 renewed mining in shaft 2 made studies of many pegmatites in the central district again possible. During several years of mining pegmatite 521 some more gem beryl was found as well as pseudomorphs of a giant topaz 1 kg to 1 ton just under the side of the crystal cavity where quartz to 1.5 m diameter and large euhedral feldspars were found lining the ceiling in its lower excavated limb. This pocket has turned out not only to be the highest production of gem heliodor at 2.5 tons but also the largest gem pegmatite yet discovered with a length of over 85 m; its excavated width was about 20 m, and a height of over 25 m with an the open unfilled cavity up to 15 m in height.

Pegmatite 394 was dug starting at the top of the pocket by chief geologist Vsevolod Chournousenko and his team. This vertical pocket was some 4 m in diameter and 24 m deep with complex side pockets. At 6 m depth Chournousenko started to find topaz. The largest topaz, all of reddish-brown cognac color weighed 295 kg and was named after the mine owner Sergey. A smaller pristine gem crystal was named after his wife Olena. The pegmatite was called Skorkina after the miner who worked alone and in secrecy in the 1990s, which was a time of anarchy; he did not show anyone what he was finding. I named the pocket Vsevolods Pocket, since the Chief geologist of Volyn Quartz - Samotsvety was the one opening it at depth and found the largest cognac colored topaz of the deposit here.

Vsevolod Chournousenko and his miners, here mined more topaz than any other known topaz find in history! Previously the record was 6 ton from a pegmatite in close proximity to 521 at Volyn.

Analogous chamber pegmatites in Finland

The other granite intrusion showing similar chamber pegmatites in rapakivi granite is the Viborg massif in Finland (Lyckberg 2004) where they are located in the roof zone and erosion have yet to expose the peripheral pegmatites near the endocontact as in Volyn. In the Viborg massif, greisen is also present. Lyckberg (2004, 2006) has pointed out that the main pocket's position at the Karelia Beryl Mine, Luumaki was found only 0.5 – 1 m from the contact with the granite. This is a clear anomaly from the main stages of pegmatite formation and suggest a very late stage hydrothermal origin for the pocket. The top of the pocket had a hydrothermally altered 1m mica cap, and most of the pocket had a 20 cm lining of mica which support this observation (Lyckberg 2004). In addition, an irregular hydrothermal overgrowth of beryl was present on the earlier gem beryl crystals. The pocket contained no crystals of quartz, only a thin vein of smoky quartz crossing the pocket as well as a lid to uppermost section consisting of quartz on an albite plate. Beryls were cemented in the pocket by hematite, hydrothermally altered biotite, chlorite,

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muscovite, and microcline. In 2007 he found below the pocket after blasting, the straight thin millimetric inter pegmatitic conductor fissure with its signature hydrothermal white alterations along its walls. This conductor was leading straight to the pocket from below the core of the pegmatite. Michallik et al (2017) verified the hydrothermal origin based on the geochemistry of these late stage beryls compared to the earlier crystals as well as quartz and feldspars. Similar chamber type pegmatites have been mined for piezo quartz (and optical fluorite) in Kazakhstan and in Mongolia.

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Peter Lyckberg – Speaker Biography

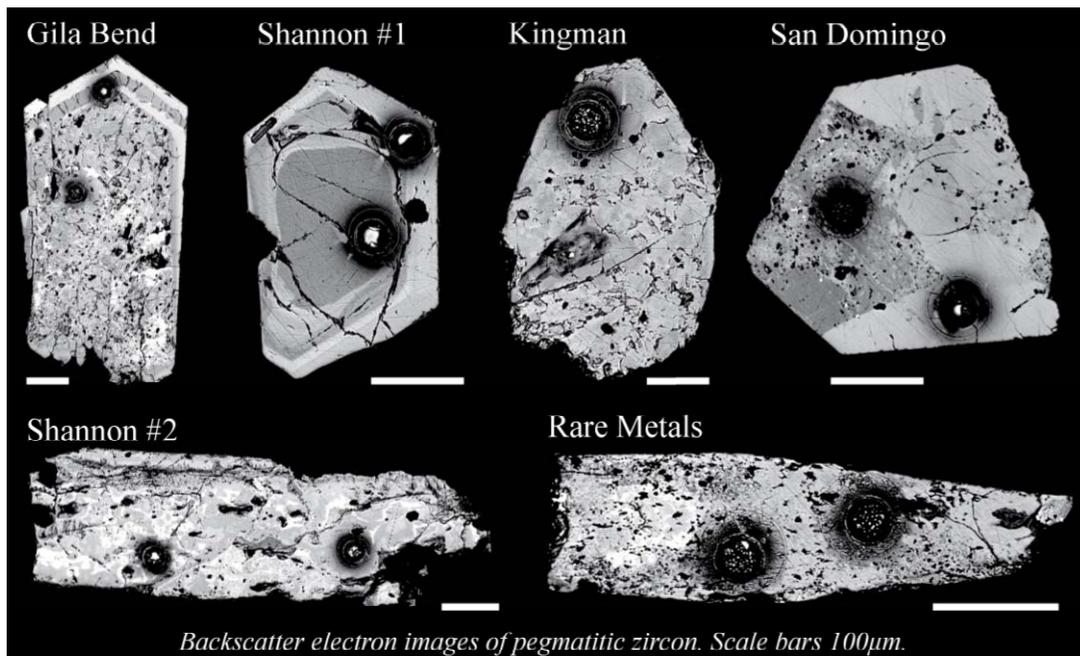
Peter Lyckberg was born 1962 in Göteborg, Sweden, a district rich in pegmatites with various mineralisations which Peter started to study already as a child. At the age of 8 he found his first great pocket in a pegmatite and found plumbomicrolite, a mineral new to Sweden. In the coming years he found, explored many gem bearing pegmatite and mineral deposits, first in Scandinavia, then on other continents. Since 1997, he has been an inspector at the European Commission, General Directorate for Energy from where he retired in 2022. He is an independent researcher on pegmatites, ore and gem deposits. During the years he has been an advisor to institutions, companies, journals, museums, independent miners and collectors all over the world. In 1992 Peter was the first non Soviet scientist since the Russian revolution in 1917 to visit, photograph and study the classic gem pegmatites of Alabashka-Murzinka and the emerald-alexandrite deposits in the Ural Mountains of Russia. Peter was also the first non Soviet scientist to study and have full access to the Volodarsk deposits, Ukraine in situ and underground 1995-2020.

Geochronology of REE-bearing Proterozoic Pegmatites in the Arizona Pegmatite Belt

Calvin Mako (speaker)¹ and Carson Richardson

¹cmako@arizona.edu

A large area of central to northwestern Arizona hosts abundant pegmatites and is known as the Arizona pegmatite belt (APB). Pegmatites are an increasingly important potential source of Li, Rare Earth Elements (REE) and other rare metals. Indeed, at least one pegmatite within the APB is currently being explored as a Li resource. Despite its potential importance the age and tectonic setting of the APB is understudied and few, if any, pegmatites have been dated using modern analytical techniques. We present new geochronology and geochemical data from several pegmatites within and adjacent to the APB. U-Pb-trace element data were collected at the University of Arizona Laserchron Center by laser ablation ICP-MS.



Backscatter electron images, collected by scanning electron microscopy, of typical zircon grains from each of the pegmatitic bodies dated during this study. The textures indicate that some of these zircons record typical growth zoning with variable abundances of included minerals, while some may have experienced fluid mediated dissolution-precipitation reactions after initial crystallization.

Ages have been determined for samples from six pegmatite localities. The following ages are weighted average $^{207}\text{Pb}/^{206}\text{Pb}$ ages of <10% discordant analyses, with uncertainties that include a propagated external uncertainty based on the reproducibility of the secondary standard. Two ages were obtained from different bodies of the Shannon pegmatite in the Hualapai Mountains, 1398 ± 15 and 1370 ± 17 Ma, with substantial inherited detrital cores at 1750-1650 Ma.

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The Rare Metals pegmatite in the Aquarius Mountains yielded an age of 1334 ± 37 Ma. A pegmatitic dike from the Gila Bend Mountains yielded an age of 1340 ± 15 Ma. The San Domingo pegmatite from the Wickenburg Mountains yielded distinct apparent crystallization ages for core and rim domains, 1457 ± 25 and 1377 ± 31 Ma, respectively. It is possible that the core population consists of antecrysts from a plutonic phase of crystallization, and rims grew during pegmatite emplacement and crystallization. The Kingman pegmatite yielded an age of 1542 ± 36 Ma, but we view this age as highly suspect. Individual analyses are significantly spread along concordia and may represent partial resetting of detrital zircon (c. 1750 Ma) during pegmatite emplacement (c. 1350 Ma). In general, the zircon analyzed in this study typically have high U (commonly 1-2 wt%), Hf (commonly 5-10 wt%), and common Pb contents. Many zircons lack the typical oscillatory zoning and instead have irregular, patchy zoning, with strings of voids potentially indicating dissolution-reprecipitation reactions.

The Proterozoic evolution of North America involved the widespread and voluminous intrusion of A-type “anorogenic” granites at c. 1.4 Ga. The pegmatites dated during this study are clearly broadly related to this event. However, known ages of Mesoproterozoic “anorogenic” granites in central-western Arizona and southeastern California are 1440-1400 Ma ($n = 23$). Our ages range from 1400-1335 Ma, almost entirely post-dating the major pulse of Mesoproterozoic magmatism in Arizona. Additionally, the pegmatite bodies of this study are spatially isolated (at the present exposure level) from Mesoproterozoic plutons. Thus, there may not be a direct tectonic or magmatic relationship between the pegmatites and Mesoproterozoic plutons within the APB. We speculate that there are two possible basic explanations for chronologic patterns observed: 1) These pegmatites were emplaced and crystallized during the waning stages of the evolving Mesoproterozoic orogenic-magmatic system; or 2) The recorded pegmatite U-Pb ages reflect late stage fluid-related alteration and resetting rather than crystallization ages as a result of metamictization. Forthcoming Ar-Ar geochronology on micas may shed further light on the interpretation of U-Pb ages.



Calvin Mako is a research scientist and bedrock mapper with the Arizona Geological Survey. His primary interests are in the evolution of ductile shear zones, metamorphic processes, and geochronology. Calvin obtained a bachelor's degree in earth science at the University of Maine, a master's in geology at the University of Massachusetts, and a PhD at Virginia Tech. He has done field work in Arizona, Utah, Scotland, the Appalachians, and Antarctica, and taught undergraduate courses at Virginia Tech, Bates College and Tufts University.

PEGMATITE DEPOSITS OF THE
WHITE PICACHO DISTRICT,
MARICOPA AND YAVAPAI COUNTIES,
ARIZONA

By Richard H. Jahns
California Institute of Technology
Pasadena, California

THE ARIZONA BUREAU OF MINES

Bulletin 162

1952

Reprinted 1969



THE UNIVERSITY OF ARIZONA
TUCSON

This bulletin is the key report on the lithium-bearing pegmatites of the White Picacho pegmatite field, Arizona and includes geologic maps of the major pegmatites. This district contains an abundance of spodumene, eucryptite (altered spodumene), montebrasite, and lithium-iron-manganese phosphates.

The South Platte Pegmatite District of Colorado: new insight into mineralogy, petrology, and rare-earth element fractionation

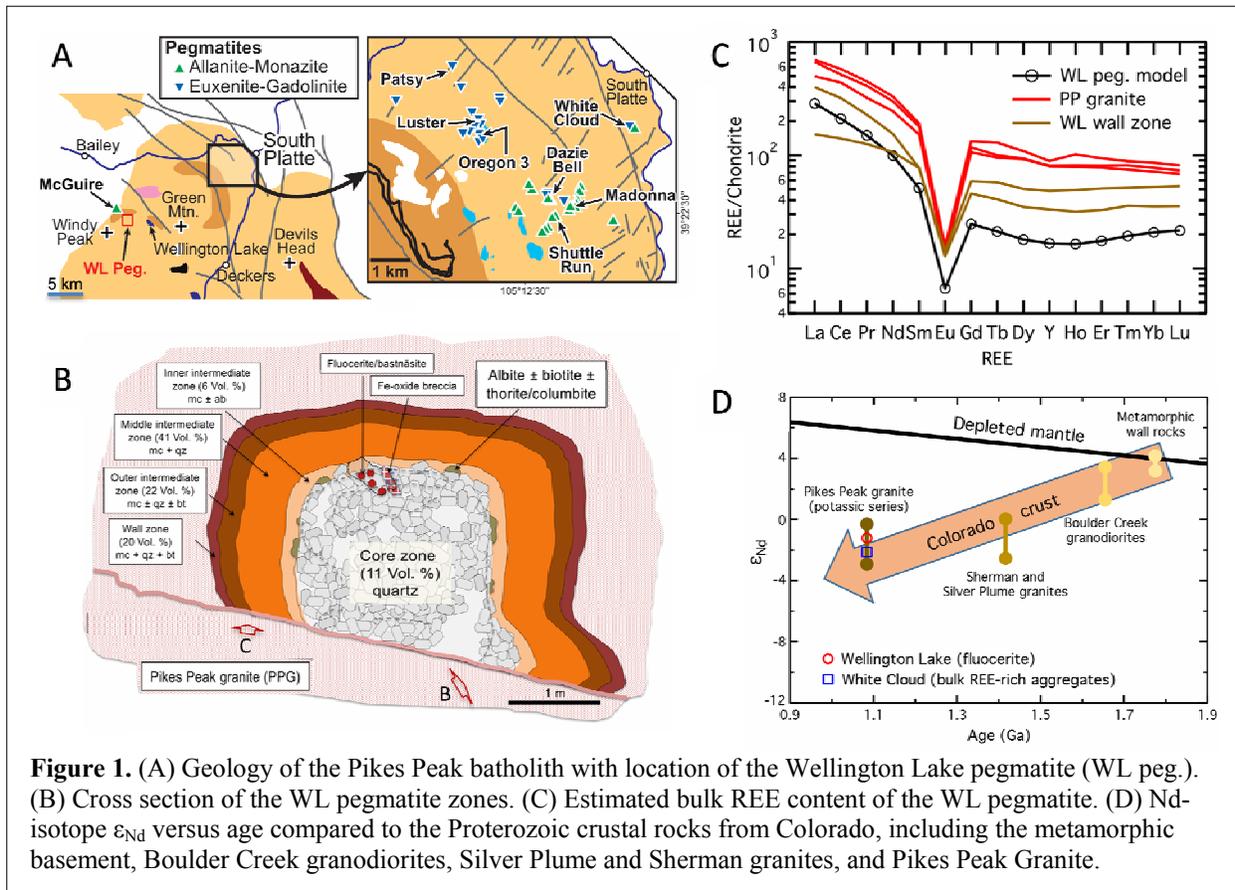
Markus B. Raschke

Department of Physics, and JILA, University of Colorado, Boulder, Colorado, 80309, USA

Email: markus.raschke@colorado.edu, <http://nano-optics.colorado.edu>

The petrogenesis of granitic pegmatites has been a subject of debate to consistently explain their characteristic features, notable textural heterogeneity, inward coarsening, oriented crystal growth, zonation of mineral assemblages, and their mineralogical and geochemical diversity. Few studies have yet systematically addressed the bulk composition of pegmatites, because of the difficulties associated with exposure, internal zonation, and paragenetic heterogeneity. A class of pegmatites of particular interest are those associated with ‘A-type’ (anorogenic) ferroan granites, such as those in the South Platte pegmatite district at the northern end of the 1.08 Ga Pikes Peak granite (PPG) batholith. Many aspects of the formation of the South Platte pegmatites still remain unclear, specifically whether the REE-rich minerals in these pegmatites are the result of an already REE-enriched parental granitic magma, result of extreme fractionation concentrating REE during pegmatite crystallization, or derived from an influx of REE-rich fluids unrelated to the PPG.

We investigated a previously undescribed small lenticular (~5 × 5 × 5 m) pegmatite, located near Wellington Lake in the South Platte pegmatite district (Fig. 1A), which is



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concentrically zoned around a mostly monomineralic quartz core with miarolitic cavities (Fig. 1B). Major constituents of the pegmatite are quartz, perthitic microcline, albite (variety cleavelandite), hematite, and biotite. Accessory minerals include fluocerite, bastnäsité, columbite, zircon (var. 'cyrtolite'), thorite, and secondary U phases. Fluorite is conspicuously absent. Notable for the Wellington Lake pegmatite are a well-developed tabular crystals of fluocerite up to 4 cm in diameter, with epitaxial bastnäsité overgrowths, suggesting formation from F- and CO₂-bearing solutions rich in light rare-earth elements (LREE), with decreasing $a_{F^-}/a_{CO_3^{2-}}$ during the last crystallization phase. An Nd-isotope value of $\epsilon Nd_{1.08Ga} = -1.6$ for the fluocerite is within the range of $\epsilon Nd_{1.08Ga} = -0.2$ to -2.7 of the host coarse-grained, pink K-series PPG, indicating that REE and other pegmatite constituents derived from the parental PPG magma (Fig. 1D).

A calculation of total pegmatite composition based on whole-rock chemistry reveals an overall composition similar to the PPG with respect to Si, Al, Na, and K. Yet the pegmatite is depleted in Fe, Mg, Ca, Ti, Mn, and P, the high-field-strength elements (HFSE; Zr, Hf, Nb, Y, Th), and, most significantly, total REE compared to the PPG (Fig. 1C). Despite containing the REE minerals fluocerite and bastnäsité, the lack of a net overall REE enrichment of the pegmatite compared to the PPG reflects the large amount of REE-poor silicate minerals forming the wall, intermediate, and core zones of the pegmatite. The calculated total pegmatite composition suggests that the pegmatite formed by the separation from the PPG magma of an F-poor H₂O-saturated silicate melt depleted in REE and HFSE compared to the F-rich melts which formed the NYF-type HREE-rich ($La_N/Yb_N < 1$) pegmatites in the South Platte district. Homogenization temperatures of $< 500^\circ C$ for possibly primary fluid inclusions in quartz from the core of the pegmatite are consistent with recent models of pegmatite petrogenesis leading to nucleation controlled mega-crystal growth resulting from supercooling. We therefore postulate, that the Wellington Lake pegmatite formed within the PPG from an H₂O-rich, but F-poor melt that underwent crystallization associated with supercooling. Although the pegmatite melt was derived from the parental PPG magma and had Si, Al, Na, and K contents similar to the PPG magma, it was depleted in REE and HFSE, which have low solubility in F-poor silicate melts and aqueous fluids.

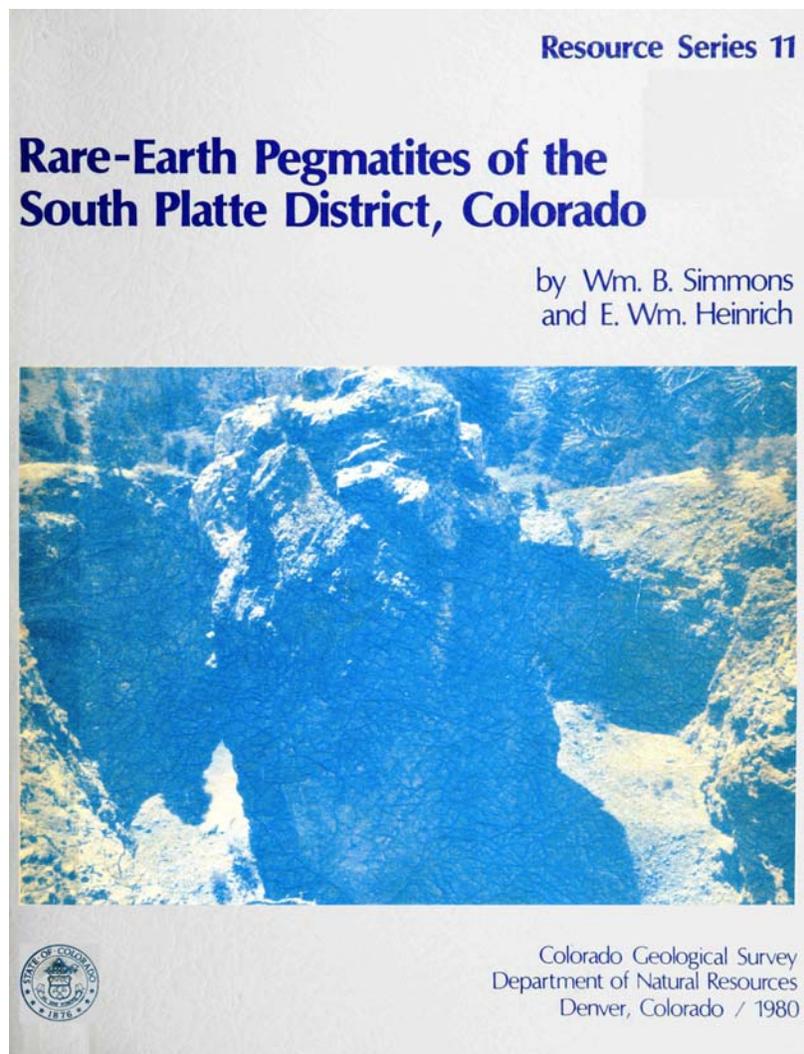
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Markus Raschke is professor at the Department of Physics at the University of Colorado at Boulder. His research is on the development of novel nano-optical spectroscopy and microscopy techniques with applications to single molecules, quantum materials, and fundamental control of light matter interaction. Based on a long personal interest in field collecting minerals his research also ventured into geology and mineralogy, with projects in Washington, Colorado, and the Sichuan Mountains in Tibet/China. He received his PhD in 2000 from the Max-Planck Institute of Quantum Optics and the Technical University in Munich, Germany. Following appointments at the University of California at Berkeley, and the Max-Born-Institute in Berlin, he became faculty member at the University of Washington, followed by his appointment in Boulder in 2010. He is fellow of the Optical Society of America, the American Physical Society, the American Association for the Advancement of Science, and the Explorers Club.



This bulletin describes the pegmatites in the central area of the South Platte pegmatite field and includes geologic maps for each pegmatite. The work is based on William B. Simmons Ph.D thesis.

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