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Nano-mineralogy studies by advanced electron microscopy

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With high-resolution analytical SEM, electron probe and Raman microanalyses, we are now capable to characterize earth and planetary materials easier and faster down to nano-scales. Small but new minerals with important geological significance are being discovered. Nano-features are being discovered in many common minerals and gems, which cause color and other optical effects. Presented here are a few projects demonstrating how nano-mineralogy works and plays a unique role in earth science.

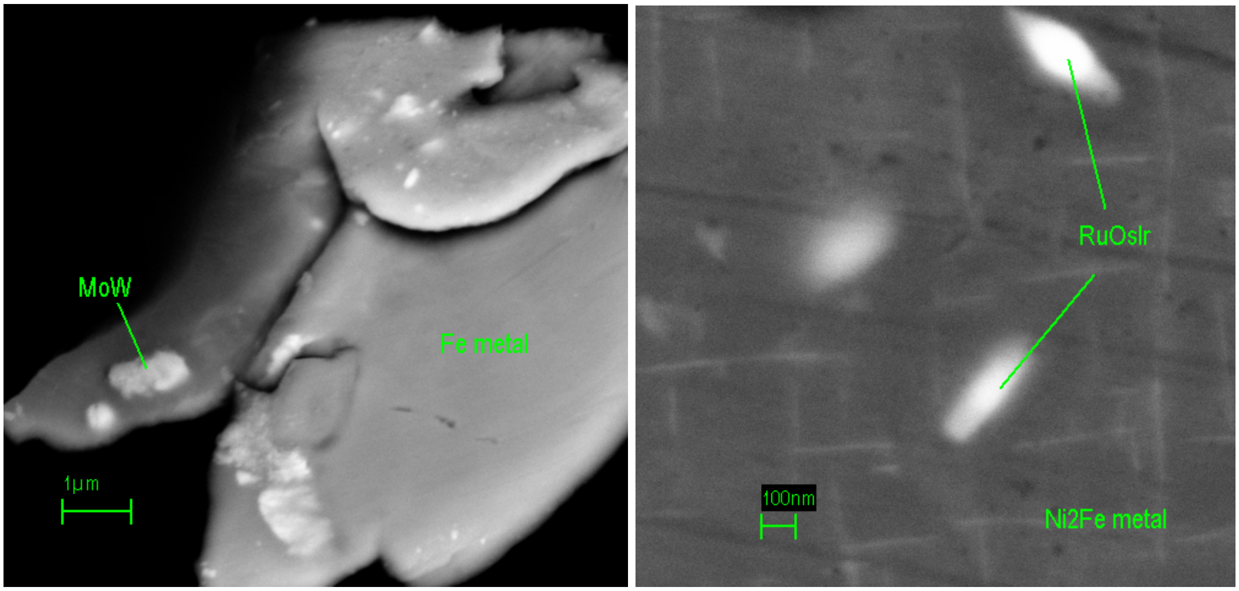
New information on primitive meteorite Our nano-mineralogy investigation of the Allende meteorite has provided new information on the early evolution of the solar system. The findings include [1] a new refractory alloy MoW (with atomic ratio at about 1:1 within an iron metal) (Fig. 1a) that likely formed by high temperature condensation at the beginning stage of the solar nebula or before; [2] unique nanotexture and nano-inclusions of Ru-rich and Os-rich phases observed in the irregular Ni_2Fe metal (Fig. 1b) from a calcium-aluminum-rich inclusion along with euhedral $Ni_{0.9}Fe_{0.1}$ metal, indicating multiple-event formations of the metal phases.

Newly-found Ba-muscovite A barium dioctahedral layer silicate was identified from Oreana, Humbolt County, Nevada, formed by hydrothermal alteration[1]. BSE images reveal extensive domains or zonation of the BaO content with regions of high Ba concentrations from about 100 nm to 15 µm in dimension. Electron microprobe analyses of these domains reveal a composition $(Ba_{0.53}K_{0.37}Na_{0.05})_{\Sigma=0.95}$ $(Al_{2.00}Ti_{0.01})_{\Sigma=2.01}$ $[Al_{1.51}Si_{2.49}O_{10}]$ $(OH)_2$ or, ideally, $(Ba_{0.5}K_{0.5})Al_2(Al_{1.5}Si_{2.5})O_{10}(OH)_2$., which is at the exactly boundary of brittle and true micas. This composition corresponds to the recently described mica, ganterite[2], but it is a purer dioctahedral mica with highest Ba/(K+Na) atomic ratios and very low Na in the structure. Complete solid solutions between muscovite and ganterite were observed.

Nanofeatures in minerals The inclusions in minerals that are commonly observed with an optical microscope occur at a scale of a micrometer or larger. In addition to these inclusions, there is also a multitude of inclusions and features that are larger than individual atoms but are so small that they can not be clearly resolved with optical methods. These features are measured in nanometers. Such features can cause iridescence, opalescence, stars, and turbidity in gem materials. High-resolution SEM allows us to image features on the nano-scale. When images are combined with chemical analysis and electron diffraction patterns, a whole world of previously inaccessible mineralogy becomes available for investigation. Many common minerals and gems familiar to the public are examples of phases that contain nano-scale features that are also the origin of color. For example, rose quartz contains nano-fibers of a dumortierite-related phase[3] (Fig. 2) (not rutile) that is pink, which is the cause of rose color[4] and optical star effects.

References

[1] C. Ma and G.R. Rossman, *American Mineralogist*, 91 (2006) 702-705.
[2] S. Graeser et al., *Canadian Mineralogist*, 41 (2003) 1271-1280.
[3] C. Ma et al., *American Mineralogist*, 87 (2002) 269-276.
[4] J.S. Goreva et al., *American Mineralogist*, 86 (2001) 466-472.



(a) (b)

Fig. 1. (a) The MoW phase. (b) Nanotexture and Ru-Os nano-inclusions in a Ni2Fe phase.

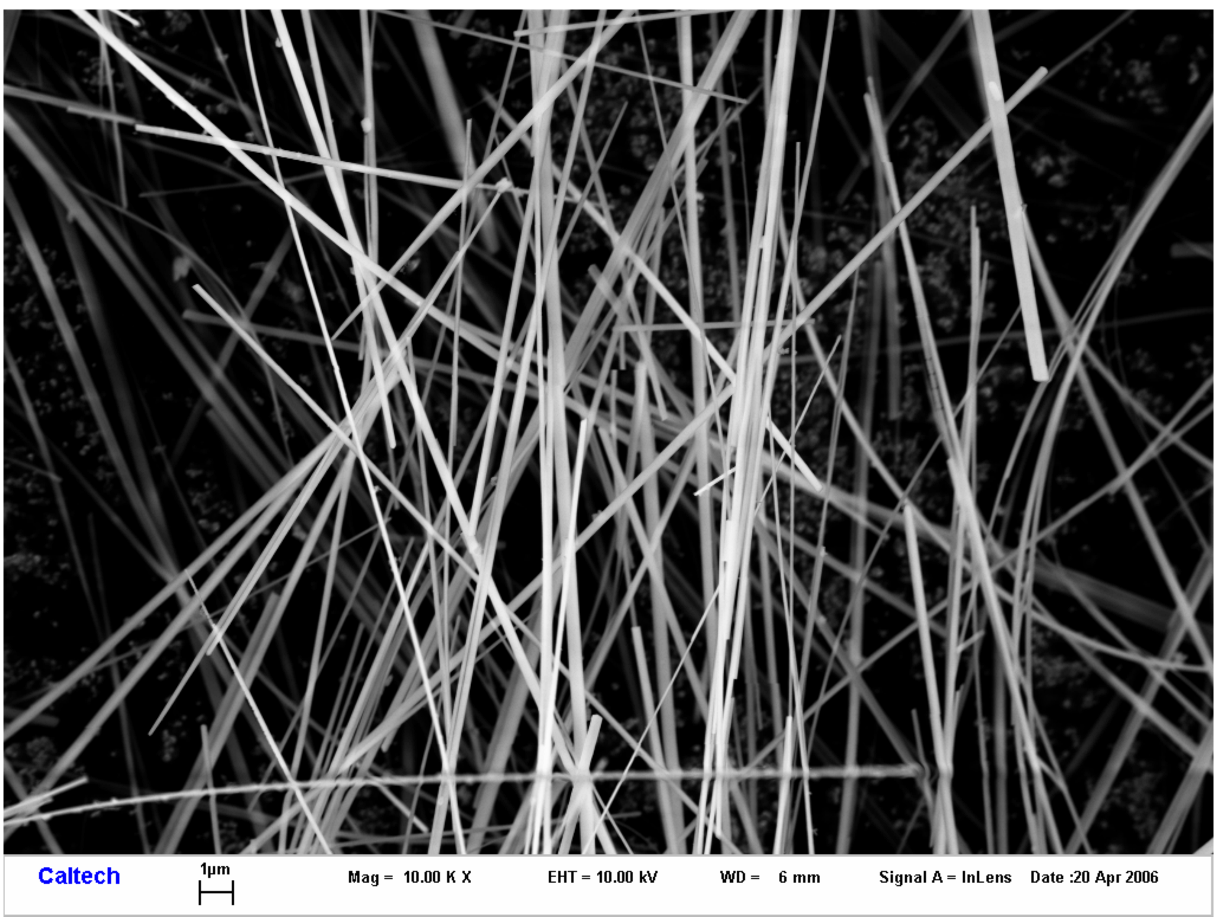


FIG. 2. SE image showing the nano-fibers extracted from rose quartz.