# Nanoscale isotopic and chemical zonation of ore minerals

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Ore and gangue minerals often display a nanoscale chemical and isotopic zonation of sectoral or oscillatory, in all types of ore deposits. Recent advances in sample preparation and characterisation at the nanoscale of ore minerals have unlocked previously inaccessible geological archives, providing new insights into the evolution of hydrothermal and related processes.

Here we review and present new results on the nanoscale isotopic and elemental zonation of minerals in various types of ore deposits, including Au placer, Carlin-type, Au-Ag epithermal, porphyry Cu and Cu-Mo, iron oxide-apatite (IOA), iron oxide-copper-gold (IOCG), U roll-front and U hydrothermal deposits.

Discussion of the nanoscale obsservations of the mineral structure, as well as, chemical and isotopic composition is illustrated by: (i) structural and morphological changes in selected, sulfides, spinels, and oxides during incorporation of trace metals and subsequent alteration; (ii) entrapment of nanoscale melt inclusions in oscillatory zoned pyrite; (iii) isotopic nanozoning of $^{185}$Re, $^{187}$Re+Os $^{190,192}$Os in molybdenite and $^{180}$Hf, $^{204,206,207,208}$Pb, $^{232}$Th and $^{238}$U in zircon; (iv) nanoporosity vs. nanozoning; and (v) noble metals (Pd, Ru, Rd) enrichment in Ag-depleted zones during alteration of gold nuggets.

The nanoscale zonation of minerals reveals the physico-chemical evolution of mineral deposits, including processes of metal accumulation, age of the deposit, alteration, origin of the metal-bearing fluids, colling history and alteration of ore deposits.