

# Gold Deposits in Metamorphic Belts: Overview of Current Understanding, Outstanding Problems, Future Research, and Exploration Significance

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## Abstract

Metamorphic belts are complex regions where accretion or collision has added to, or thickened, continental crust. Gold-rich deposits can be formed at all stages of orogen evolution, so that evolving metamorphic belts contain diverse gold deposit types that may be juxtaposed or overprint each other. This partly explains the high level of controversy on the origin of some deposit types, particularly those formed or overprinted/remobilized during the major compressional orogeny that shaped the final geometry of the hosting metamorphic belts. These include gold-dominated orogenic and intrusion-related deposits, but also particularly controversial gold deposits with atypical metal associations.

Orogenic lode gold deposits of Middle Archean to Tertiary age are arguably the predominant gold deposit type in metamorphic belts, and include several giant (>250 t Au) and numerous world-class (>100 t Au) examples. Their defining characteristics and spatial and temporal distributions are now relatively well documented, such that other gold deposit types can be compared and contrasted against them. They form as an integral part of the evolution of subduction-related accretionary or collisional terranes in which the host-rock sequences were formed in arcs, back arcs, or accretionary prisms. Current unknowns for orogenic gold deposits include the following: (1) the precise tectonic setting and age of mineralization in many provinces, particularly in Paleozoic and older metamorphic belts; (2) the source of ore fluids and metals; (3) the precise architecture of the hydrothermal systems, particularly the relationship between first- and lower-order structures; and (4) the specific depositional mechanisms for gold, particularly for high-grade deposits.

Gold-dominant intrusion-related deposits are a less coherent group of deposits, which are mainly Phanerozoic in age, and include a few world-class, but no unequivocal giant, examples. They have many similarities to orogenic deposits in terms of metal associations, wall-rock alteration assemblages, ore fluids, and, to a lesser extent, structural controls, and hence, some deposits, particularly those with close spatial relationships to granitoid intrusions, have been placed in both orogenic and intrusion-related categories by different authors. Those that are clearly intrusion-related deposits appear to be best distinguished by their near-craton setting, in locations more distal from subduction zones than most orogenic gold deposits and in provinces that also commonly contain Sn and/or W deposits; relatively low gold grades ( $\leq 1\text{--}2$  g/t Au); and district-scale zoning to Ag-Pb-Zn deposits in distal zones. Outstanding problems for intrusion-related deposits include the following: (1) lack of a clear definition of this apparently diverse group of deposits, (2) lack of a definitive link for ore fluids and metals between mineralization and magmatism, (3) the diverse nature of both petrogenetic association and redox state of the granitoids invoked as the source of mineralization, and (4) mechanisms for exsolution of the CO<sub>2</sub>-rich ore fluids from the relatively shallow level granitoids implicated as ore-fluid sources.

Gold deposits with atypical metal associations are a particularly diverse and controversial group, are most abundant in Late Archean terranes, and include several world-class to giant examples. Most are probably modified Cu-Mo-Au porphyry, volcanic rock-hosted Zn-Pb-Ag-Au massive sulfide, or Zn-Pb-Ag-Au or Ba-Au-Mo-Hg submarine epithermal systems, overprinted or remobilized during the events in which orogenic gold deposits formed, but there is lack of consensus on genesis. Outstanding problems for these deposits include the following: (1) lack of a clear grouping of distinctive deposits, (2) lack of published, well integrated studies of their characteristics, (3) generally a poorly defined timing of mineralization events, and (4) lack of assessment of metal mass balances in each stage of the complex mineralization and overprinting events.

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Both orogenic gold deposits and gold deposits with atypical metal associations contain a few giant and numerous world-class examples, whereas the intrusion-related group contains very few world-class examples, and no giants, unless Muruntau is included in this group. Preliminary analysis suggests that the parameters of individual world-class to giant gold deposits of any type show considerable variation, and that it is impossible to define critical factors that control their size and grade at the deposit scale. However, there appears more promise at the terrane to province scale where there are greater indications of common factors such as anomalous subduction-related tectonic settings, reactivated crustal-scale deformation zones that focus porphyry-lamprophyre dike swarms in linear volcanosedimentary belts, complex regional-scale geometry of mixed lithostratigraphic packages, and evidence for multiple mineralization or remobilization events.

There are a number of outstanding problems for all types of gold deposits in metamorphic belts. These include the following: (1) definitive classifications, (2) unequivocal recognition of fluid and metal sources, (3) understanding of fluid migration and focusing at all scales, (4) resolution of the precise role of granitoid magmatism, (5) precise gold-depositional mechanisms, particularly those producing high gold grades, and (6) understanding of the release of CO<sub>2</sub>-rich fluids from subducting slabs and subcreted oceanic crust and granitoid magmas at different crustal levels. Research needs to be better coordinated and more integrated, such that detailed fluid-inclusion, trace-element, and isotopic studies of both gold deposits and potential source rocks, using cutting-edge technology, are embedded in a firm geological framework at terrane to deposit scales. Ultimately, four-dimensional models need to be developed, involving high-quality, three-dimensional geological data combined with integrated chemical and fluid-flow modeling, to understand the total history of the hydrothermal systems involved. Such research, particularly that which can predict superior targets visible in data sets available to exploration companies before discovery, has obvious spin-offs for global- to deposit-scale targeting of deposits with superior size and grade in the covered terranes that will be the exploration focus of the twenty-first century.