k38 Metallogenic provinces < regional zoning >

The beginning of wisdom is to call things by their right names.—Confucius.[1]

A principle of mineral exploration is to "look for lion in lion country." That is, prospect for what is sought where others already have stumbled onto showings (***Footnote k38.1***). Ore deposits occur in localities and narrow zones, and usually very little of the same is found between. A finding of exploration geology is that ore-deposit types can be classified by tectonic settings and geologic age. A. M. Bateman in *Economic mineral deposits*, 1950, defined a *metallogenic province* as a region of relatively abundant mineralization, one type of which predominates. For example, a well studied oceanic island arc is Japan, where in 1973 C. Nishiwaki described four metallogenic provinces:[2]

Related to the activities of the present arc-trench system are

Quaternary volcanogenic sulfur deposits with or without pyrite (***Footnote k38.2***),

Pliocene and Late Miocene gold-silver veins, and

Late and Middle Miocene shallow sea, caldera-pyroclastic, copper-zinc "Kuroko (black ore)"deposits,

and related to an older, parallel, arc-trench system are

Late Mesozoic folded and metamorphosed Late Paleozoic bedded cupriferous iron-sulfide deposits.

Also relatable to subduction are active volcanoes in the Andes mountains of South America. In 1973, Richard H. Sillitoe found that massive-sulfide ore types can be associated with the magma-origin depth down slope an oceanic-lithosphere slab subducting beneath a continental plate.[3] In Chile and Peru, metallogenic province are: volcanic iron ore deposits near the coast, copper ores mostly in a separate belt farther inland, and lead-zinc ores at higher elevations there.

Regional zoning of chemical variations in rocks, and ores, inland from continental margin related to subduction of oceanic plate below the continental plate have likewise been described since the 1970s for the Mesozoic mobile belt of western American Cordillera (***Figure k38.1***) and the Paleozoic mobile belt of the eastern American Appalachians. The zones away from the former trench margin are matched with (what can be calculated to have been) increasing pressure and decreasing volatile conditions on the upper part of the subducting oceanic-lithosphere slab. The relatively great variability of the composition of ancient crust through which the magmas rise, and partly assimilate, results in district zoning.

To remind of the importance of scale, John M. Guilbert and Charles F. Park recommend that the adjectives *regional*, *district*, and *orebody*, be employed consistently:[4]

Regional zoning (although still speculative as to its value and meaning) can be known by a statistical analysis of numerous samplings of areas not less than that of the Sierra Nevada batholith to as great as the Cordilleran orogenic belt.

District zoning (the bread and butter of mining consultant geologists) is what has been traditionally recognized as observable of mining districts as: Butte, Montana; Bingham, Utah; and, Cornwall, England.

Orebody zoning (currency for science-degree earning geology theses) as the name implies, is mine site variation and circumstances of mineralization, which, as these become known, aid in the planning of the ongoing operation.

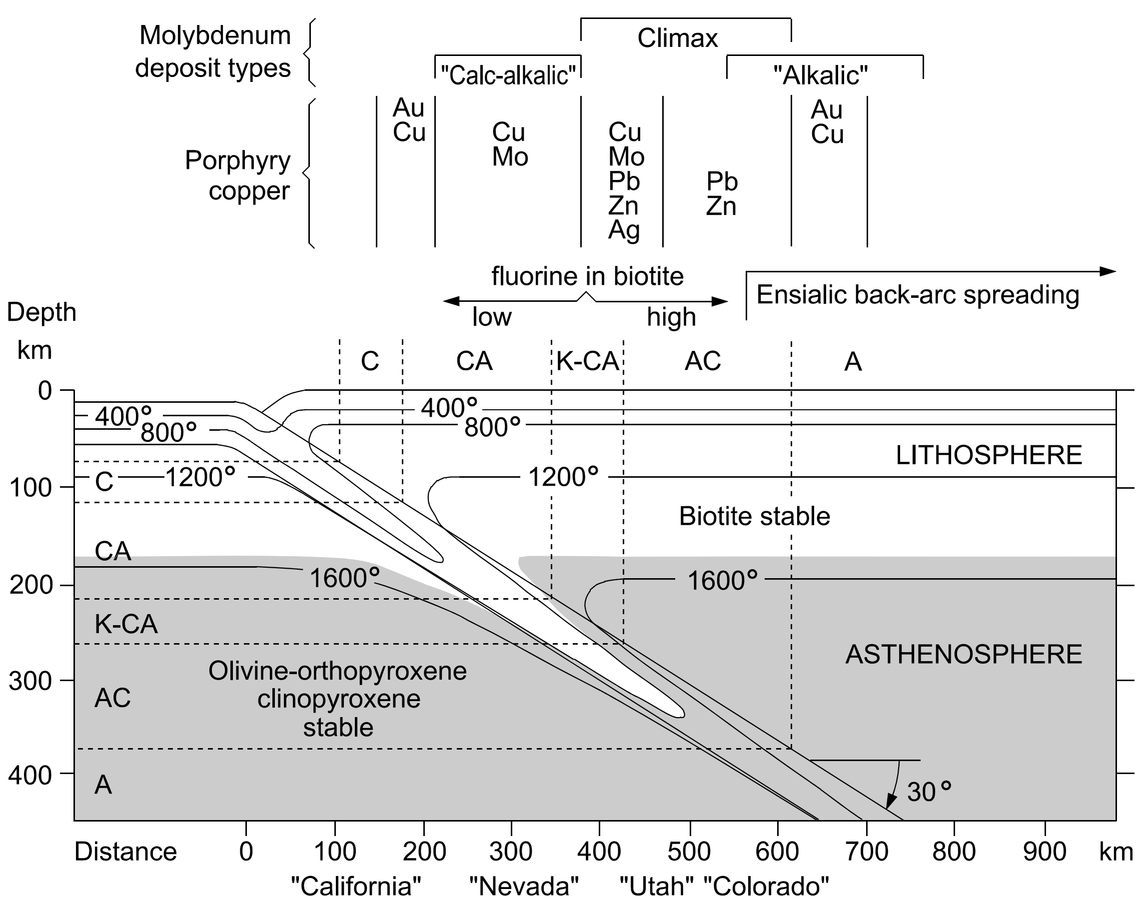
K/Ar radiometric dating of micas from the shield rocks of Canada allowed C. H. Stockwell in the 1960s to delineate Precambrian metamorphic provinces. Since, this work was completed, U/Pb radiometric dating of zircons beginning in the 1970s has been widely applied to determine the age of original crystallization of igneous rocks within these provinces. Short of the rock remelting, metamorphism even at high grades does not cause recrystallization of zircons present in an igneous rock and the time of original cooling from a magma can be determined to an accuracy of <5 My. The findings are that the Churchill province (*see* Topic *k32* and Figures *k32.1* and *k33.1*) is a composite of "Cordilleran wide" mobile belts. Two, named the Rae and Hearne, with the youngest Proterozoic ages, involve reworked Archean continental crust. The Rae has an orogenic contact with the Slave craton. Across from this, its boundary with the Hearne mobile belt is not yet well described. Between the Hearne and the Superior province, a third mobile belt, called the *Trans-Hudsonian* belt, is exclusively with metamorphic and intruded igneous rocks of Proterozoic age interiorly. The orogeny that last deformed it, called the *Hudsonian* orogeny, closed an ocean (recorded by graywackes and pillow lavas) against the margin of the Superior province, and isoclinally folded the boundary zone demarked now by Setting Lake, Northern Manitoba.[5]

Belts of ore deposits that once seemed to be at odds with the stability of shields, are now understood to be continent-continent sutures. W. Sullivan in 1979 discussed intracratonic basins and ore deposits in this light.[6]

In 1986, plate tectonic analysis of metallogenic belts, epochs, and individual deposit-type distributions was used by John M. Guilbert and Charles F. Park, Jr. as the organizing theme of *The Geology of Ore Deposits*.[4]

The challenge is to see if metallogenic regional zoning can be demonstrated for Proterozoic mobile belts. ❏

Figure k38.1 [7] **Metallogenic regions** (cross section across California, Nevada, Utah and Colorado) interpreted as being related to the subduction of an oceanic plate beneath the continental plate during the Mesozoic. Calcic (C) to alkalic (A) ore bearing magmas, some potassium (K) rich, were produced by melting at different depths of the upper edge (seafloor sediments and basalt crust) of the down going oceanic-lithosphere slab, and by assimilation of some continental rock in their ascent.



*Footnote **k**38.1*

Unhelpful were alchemists' belief that rays emanating from the heavenly bodies of the Ptolemaic system formed metals and ores of these: silver by Moon, mercury by Mercury, copper by Venus, gold by Sun, iron by Mars, tin by Jupiter, and lead by Saturn. So Johann Gottlieb Lehmann (1719-1761) could (misleadingly) write: "Thus we see that gold, which is the most perfect of all metals comes most abundantly in hot climates, silver, copper, and lead require less heat in their formation and come in cooler lands."[8]

*Footnote **k**38.2* Gold in a rush

Fritz Haber (laudable for the Haber–Bosch method for producing abundant cheap ammonia and so paving the way to feed billions) on the strength of Swedish chemist Svante Arrhenius's report that every ton of the ocean water contained 6 milligrams of gold sought a cost effective way of extracting it as quick fix to ease Germany's post-WW1 reparations burden. (Less laudably, Haber had orchestrated Germany's first poison gas attack on the battlefield, so depressing Clara née Immerwahr, his first wife, that she forthwith committed suicide with his military handgun).[9] However, his finding from extensive experiments and many trips on the oceans of the world during the 1920s is that seawater contains but 0.01 milligrams of gold per ton. In total a vast amount but not an ore.[10] What of hydrothermal solutions?

In a cooling magma when magnetite starts to crystallize, SO_4^{2-} is reduced to S^{2-}. These latter ions in exsolved water bond to and put into solution gold and copper (both highly chalcophile elements). The brine that exits the magma chamber is a buoyant fluid that makes its way upwards fairly easily through fractures in the country rock. In magmatic hydrothermal solutions, gold concentrations have a theoretical upper limit (as determined by inclusion fluid analyses and calculations) of 10,000 ppm. As the fluid ascends, pressure decrease results in boiling and loss from the aqueous solution of volatile components as H_2S and HS^- that keep gold in solution as a transportable gold bisulfide complex.

In active volcanoes associated in their origin with plate subduction and the melting of the water bearing top of a downgoing slab, gold fluxes measured are: 80 to 1200 kg/year for Mt. Etna, 37 kg/year for White Island, and 24 kg/year for dormant Ladolam volcano on Lihir Island, Papua New Guinea. Stuart F. Simmons and Kevin L. Brown calculate a mere 55,000 years would be needed for the 1600 metric tones of gold in the Ladolam ores assuming a constant aqueous gold concentration and fluid flow (50 kg/s), and 100% deposition.[11]

However, the higher gold fluxes (noted above) than are observed at Ladolam today have not resulted in a natural ore.

Ladolam ore, Christoph A. Heinrich notes, "is contained in minerals cementing a highly fragmented rock, which was produced by a dramatic event about half-a-million years ago, when the peak of a former volcano that had built high above the present area of the deposit collapsed and formed the present semicircle of mountains around the deposit. This sector-collapse would have led to sudden decompression of magmatic-hydrothermal fluids beneath the volcano, which originally could have been orders of magnitudes more gold- and sulfur-rich.

"Could a rush of rapidly expanding fluids have formed the deposit ... even on the time scale of a human life? And could the extraordinary geothermal waters sampled today be a mere trickle representing the 'spent' ore fluid, still circulating through the rocks half-a-million years after the rush of fluids that formed the deposit?"[12]