Nature of the Mineralization and Alteration Mapped at the Clementine Porphyry Copper Prospect in the Northern Pioneer Mountains of Southwest Montana.

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A regional genetic model for the origin of linear belts of porphyry Cu-Mo deposits, including the giant deposits at Butte, Montana, Bingham Canyon, Utah, and a spectrum of smaller geochemically varied intrusion-related (Au, Ag, Cu, W, and Mo) deposits, occurring south west of Butte within the Pioneer Mountains, led to the discovery of a new zone of alteration and mineralization at the Clementine prospect. South west of Butte, a linear belt of historic mining districts with a regular spacing of about 7 km extends through the Pioneer Mountains from Beal Mountain on the north and Bannack on the south end. These ore deposits including the Quartz Hill, Cannivan Gulch, Hecla, Argenta, and Bannack Districts, many of which are localized within dome structures, occur along a single north-south trending regional anticlinal hinge of the frontal (easternmost) anticline of the Cordilleran fold and thrust belt of Sevier (Late Cretaceous) age. Regional interpretation, combined with new geological mapping, integrates structural, magmatic, and hydrothermal processes into a set of numerical process-based models consistent with an idealized east-west cross section published by Kalakay and others (2001). Taken altogether, this addresses problems associated with syn-compressional pluton emplacement centered on the need to make room for magma in environments where crustal shortening, not extension, occurs on a regional scale. Finite element modeling (Nemcok and Henk, 2006) of an analogous fold-and-thrust belt explored for oil in the Western Carpathians Mountains of Romania showed the existence of an overall mean stress decrease inside the thrust sheet anticlines. Our interpretation asserts that in south west Montana similar thrust sheet anticlines were also the loci of magma ascent, mineralization, and alteration processes in syn-compressional environments at the top of frontal thrust ramps where "releasing steps" at ramp tops served as initial points of emplacement, subsequent pluton growth, and exceptional levels of chemical differentiation within underlying laccoliths. Besides facilitating magma ascent, these localized lower pressure zones may also provide a mechanism for raising the probability of inducing magmatic water saturation, driving magmatic-hydrothermal mineralization, and thus explaining the ubiquitous mineralization and alteration of many of the plutons in the Butte-Pioneer Mineral Belt as defined by Brimhall and Marsh in 2014.

Besides the commonality of magmatic water saturation in the ore-forming plutons, we also propose here a mechanism that explains the regular spacing of mining districts; a theme that has been fundamental in focusing our field work leading to geological discoveries at Clementine. From aerially extensive buoyant ribbon-like layers presumably existing at depth along thrust fault flats, our calculations show diapiric ascent occurring at a regular spacing determined by Rayleigh-Taylor gravitational fluid (magmatic) instabilities. Ascent of magma up along thrust ramps into the anticlinal hinge zone supplies an additional component of hydrostatic head that pushes the melt up-dip, which feeds the diapir more easily, allowing it to rise more quickly from the source and hence, escaping solidification. In the absence of diapiric ascent, magmas would otherwise tend to rapidly cool and crystallize essentially in place, lacking enough thermal inertia to remain liquid in the form of a dike or sill.

Using our regional exploration model with both its regional structural and magma self-organizational aspects, we recognized a gap between the Beal Mountain and Quartz Hill Districts. Consequently, we focused our field work on the former Divide District, which had no prior history of metal production but occurs at a suggestive spacing with an associated anticlinal fold. While mapping in densely forested areas using digital mapping methods (Brimhall and Vanegas, 2001; Brimhall et al, 2002; Brimhall et al, 2006) within a nappe window into the Lewis Over-Thrust, Clementine Exploration LLC discovered a mineralized syn-tectonic frontal thrust fault-bend anticline surrounded by an orbicular alteration pattern similar to alteration in the contact aureole at Carr Fork, Bingham, Utah, described by Atkinson and Einaudi (1978) with the exception that instead of actinolite lining the orbicules, Clementine has chlorite and muscovite, at least on the surface (Figure 1). At Clementine, this orbicular chlorite-muscovite wall rock alteration with minor disseminated chalcopyrite, pyrrhotite and ilmenite on the eastern edge of the zone, occurs within the Cretaceous Kootenai and Blackleaf formations and is the outermost manifestation of discernable hydrothermal activity and chemical metasomatism related to mineralization processes farther inside the Clementine anticline. On the west side of the anticline, the orbicular zone extends northeastwards more than 3 km and on the east side, 2 km away, it extends at least 2.3 km northeastwards, but the exposure there is considerably worse and removed by a granitic pluton intruding the sedimentary section along the entire east side of the anticline. On the east side of the anticline, the orbicular zone has linings of biotite and muscovite rather than chlorite and muscovite, which we interpret as either a metamorphic overprint by the adjacent granite pluton to the east or additional heat supplied by that pluton which raised the local temperature (Figures 2A and 2B). On the western edge of this orbicular zone, minor chalcopyrite, pyrrhotite, and ilmenite occur as a mirror image of the same zonation across the Clementine anticline on the western flank of the fold axis. The importance of the size of the orbicular alteration zone in the context of exploration is important in at least two ways: (1) the extensive aerial alteration footprint indicates that the magmatic-hydrothermal system inside the anticline may be large, possibly very large, and (2) a potential exists for copper skarn mineralization as at Carr Fork.

While we believe that Butte, Bingham Canyon-Carr Fork and Clementine all formed as part of the Sevier thrust and fold structure, important differences exist locally in relation to district scale structure and differential interaction with reactive wall rocks. We see a spectrum of petrologic effects with Butte at one end with the homogeneous Butte Granite wall rock and Clementine on the other, dominated by differential reaction with Paleozoic through Cretaceous sediments formed on a Passive Tectonic margin. At Butte, the early high temperature pre-Mainstage wall rock alteration is biotitization of igneous hornblende and replacement of sphene by rutile and anhydrite (Roberts, 1973). Once the east-west striking porphyry dikes intruded the Butte granite, a dense fracture network developed and free convective flow circulated within the fractured volume of rock affected by biotitization of hornblende. In contrast, fluid flow at Clementine was confined by both the syn-tectonic frontal thrust fault-bend anticline in the foot wall of the Grasshopper thrust plate and the overlying hanging wall Missoula Group Belt series sediments.

We think that this confined flow led to superheating of the aqueous fluids. The hydrothermal system and underlying magmatic heat source was capped by impermeable rock such that the solutions could not establish a large regional network and undergo pervasive systematic cooling as happened at Butte. We view the axially-symmetric orbicular alteration zones, beyond the next inner zone of vein/fracture fillings, as representing an advancing reaction front for supersaturated solutions expressed as orbicular growths just outside of an advancing skarn zone, where the main reactive carbonate members were encountered. The orb zone represents the outer reaches of the Reaction Front of the ‘Supersaturated’ solution, and now represents the arrested development of the outward migration of the front, or, alternatively, it represents the point where the outward migrating fluid lost its ‘supersaturation’ or highly reactive condition. At Carr Fork (Atkinson and Einaudi, 1978), an Early Stage of contact metasomatism produced: diopside in quartzite and in interbedded, thin silty limestone beds;

wollastonite, with minor idocrase (vesuvianite) and garnet, in thick cherry limestone; and a trace amount of sulfides. Actinolite alteration of diopside in quartzite and garnetization of wollastonite-bearing marble represent the beginning of Main Stage mineralization and are time equivalent with biotite-orthoclase alteration of igneous rocks. At Clementine, while we have not yet recognized wollastonite, we have mapped extensive strike lengths of disseminated Fe- sulfides associated with the orbicular zone near the adjacent outer skarn front, making the mappable genetic parallels with Carr Fork fairly close.

At Clementine, the orbicular alteration zone surrounds a hornfels zone with a large elliptical breccia complex more than 2 km long, north to south and 0.5 km wide east to west, cross cutting the axial plane of the regional anticline where Madison limestone is exposed. Positioned exactly at the apex of the doubly-plunging anticline is a set of mineralized vein gossans extending over a strike length of 0.6 km cutting the breccia and also consisting of breccia fragments with a mineralized matrix. The iron content of the vein gossans varies between 2 and 35 weight percent. We interpret the gossans as oxidized equivalents of primary vein sulfide assemblages. Multi-element assays show a regional zoning pattern in the vein system discovered. Nearest the Madison limestone on the north end, the existing metal suite consists of tungsten, antimony, gallium, germanium, and rhenium, whereas away from the Madison and towards an exposed pluton on the south end, the metal suite is distinctly different and consists of: copper, silver, gold, molybdenum, zinc, lead, and tellurium. Arsenic occurs throughout the vein system implying that copper sulfides at depth may be analogous to Butte where tennantite occurs in the Intermediate Mainstage Zone and enargite in the Central Zone where a higher sulfidation stage existed with advanced argillic alteration. The porphyry copper geochemical signature clearly indicates that the Clementine prospect is NOT a Stibnite Idaho Yellow Pine type gold deposit nor a Beal Mountain sediment-hosted gold system. Instead, we interpret the zoned vein gossan geochemistry as most likely representing the upper reaches of a porphyry copper deposit influenced chemically on its margins by reactive carbonate wall rocks, much like a Cordilleran polymetallic deposit of the South American Andes.

Finally, discovery this summer of maroon, “live” limonite in the copper, silver, gold, molybdenum, zinc, lead, and tellurium vein zone helps considerably in target definition and effective use of field time. Using an Olympus “Delta” hand-held XRF unit we could acquire semi-quantitative chemical data far in advance of assays, thus adapting our mapping strategy in real-time. The mineralization we seek, then, is a deep, large underground copper metalloid mining target without the environmental burden of handling and emplacement of voluminous waste rock necessary in open pit mining dictated by high stripping ratios. Conversely, an underground mine specifically developed to minimize the environmental foot print could meet the challenge of a modern 21st Century underground mine in Montana, deserving of a social license for mining with production of copper and critical metalloid semi-conductor bi-products that could help support a sustainable energy future.

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Figure 1. Orbicular wall rock alteration consisting of chlorite and muscovite-lined orbs up to about 1- inch diameter also containing sparse disseminations of chalcopyrite, pyrrhotite, and ilmenite. Sample from the west side of the Clementine anticline along the Indian Creek Road.

Figure 2A. Orbicular wall rock alteration consisting of muscovite and biotite-lined orbs up to about 0.5 -inch diameter. Brown circles are oxidation effects where ferrous iron contained in pyrrhotite, ilmenite, and chalcopyrite escaped from the primary mineral hosts, diffused a short distance where it was fixed by oxidation in a ferric mineral state. Sample from the east side of the Clementine anticline north of US Forest Service Road 8486 near where a large granitic body intrudes the entire east flank of the Clementine anticline and may be responsible for either a higher ambient temperature of orbicular wall rock alteration or alternatively, later thermal metamorphism of a chlorite-muscovite assemblage in orbicules to a muscovite-biotite assemblage.

Figure 2B. Vein-type wall rock alteration nearby the sample shown in Figure 2A. Veinlets of biotite and muscovite appear to stream away from clotty mineral centers.