The Nature and Significance of Colloform Textures in the Pernatty Lagoon Copper Deposits, South Australia

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The most significant of the Pernatty Lagoon copper deposits occur along a major disconformity within Adelaidean rocks of the Stuart Shelf, a subdivision of the Adelaidean Supergroup. Adelaide Supergroup rocks form a middle to late Proterozoic apron around the older and deformed Gawler Craton. The sediments were derived from the crystalline basement of the Gawler Craton to the west, but the Mt Painter and Willyama Inliers to the north-east were sources that made contributions to later rock units. Graben structures provided deep basins which accumulated thick blankets of sediment throughout Adelaidean time. On the Stuart Shelf the sediment wedges were thin following the deposition of the relatively thick Willouran Pandurra Formation. Post Pandurra Formation units lap onto the Pernatty ‘Culmination’, a major paleo-structural high on the Stuart Shelf. The Cattle Grid orebody was the most significant of the deposits. The sulfides occurred along a disconformity between the Pandurra Formation, a quartzite, and the Whyalla Sandstone. There is evidence in other areas that breccias and disconformities – open spaces in the rocks, localize the mineralisation. A full description of the geology and the ore deposits can be found in Creelman (1984) and Tonkin and Creelman (1990).

Metal sulfides that deposit in the body of the rock can be early in the rock history, before diagenesis, or later than diagenesis. Whether consolidated or unconsolidated, deposition in a rock body requires open spaces, or if open spaces are not available, then the depositing minerals must create space for themselves. The accommodation can be accomplished in three ways:

1. The mineral grows in open fissures or cavities in the rock. The process is called ‘secretionary growth’ (Ramberg, 1952);
2. The mineral grows in a space by pushing aside other minerals as it crystalizes. The process is called ‘concretionary’ growth (Ramberg, 1952);
3. The mineral grows by replacing an older mineral or cluster of minerals occupying space in the rock mass. This is chemical replacement sensu stricto.

Although it is possible to isolate one of the three processes as dominant in any depositional situation, clearly all three can operate simultaneously and some situations are the product of the combination in whole or in part. There are many good examples of minerals that fill spaces in the Pernatty Lagoon copper deposits. The interstitial sulfide minerals in the arenites, vughs coated by sulfide crystals, and the colloform textures in the Pernatty Lagoon ores are all notable examples. Other examples are the carrollite-arseniferous pyrite spheroids, marcasite rosettes, and frambooidal pyrite. It is the colloform textures that are of special interest in the Pernatty Deposits.

Colloform texture is defined as rounded reeniform masses of mineral which result from colloidal precipitation. Ramdohr (1969) writes that according to the laws of physical chemistry all colloidal precipitates are metastable with a tendency to crystalize. This manifests in the loss of water as
crystallization proceeds, perhaps with later increase in grain size and an exsolution-like precipitate of other minerals. Ramdohr notes that sphalerite and milnikovite-pyrite are the most common sulfides exhibiting colloform textures, although rotund and spherical forms of minerals, banding accompanied by syneresis cracking and pellet or oolitic structures are relatively common in oxides of iron, manganese and aluminium. Ramdohr’s ideas are based on work by Rodger (1917) and Grigoriev (1928) who included all reniform shapes made up of fine crusts, spheroids, vesicular, bubble-like masses, concentrically banded radial spheroidal masses, and devitrified masses of various forms dominated by concentric or reniform structures. Grigoriev extended the definition to Liesegang rings and shells that included solid material more appropriately classified as concretionary growth.

The above ideas have left an indelible mark on the definition of what is colloform as it was a self-evident truth that colloform textures indicated the involvement of a colloid or gel stage during deposition. Roedder (1968) systematically examined the many textural criteria used to argue for gels and found them to be either ambiguous or invalid. Roedder considered that the dominant parameter controlling colloform texture formation is a high degree of super-saturation that results in many points of nucleation and rapid crystallization. The result is many small crystals coated on a flat surface, rather than a few large crystals that grow in the depositing fluid. Super-saturation is easy to achieve in solutions of substances that have low solubilities.

The balance between conditions that produce fine banding and those that grow large crystals is delicate. Roedder postulated that a flowing fluid becoming more saturated as it moved through a conduit could grow crystals, but stagnant solutions at very high levels of super-saturation produce colloform layers. It is noteworthy that large chalcocite crystals are directly associated with colloform textures in the Cattle Grid ores, which implies that conditions of colloform deposition have given way to those that produce crystals. The change from colloform deposition to crystal growth deposition is, using Roedder’s criteria, indicative of changing hydrological conditions from stagnation to flow.

A change from one mineral phase to another in the fine bands is indicative of changing geochemical conditions. The majority of the bands seen in the Pernatty Lagoon ores are sulfur-rich bornite and chalcopyrite that represent low redox conditions relative to chalcocite (Garrels and Christ, 1965; Creelman, 1984). Redox levels are possibly the most variable parameter in the Pernatty groundwaters and are directly related to the activities of HS and S²⁻ in the solutions. At ambient temperatures the only demonstrated mechanism that produced sulfides is biogenic reduction of sulfate. Lambert et al. (1971) found sulfate-reducing bacteria in all groundwaters around Pernatty Lagoon, including the hypersaline playa lake waters themselves. An explanation of the banding must therefore involve variations in biogenic activity. Biogenic sulfate reduction is controlled by the supply of nutrient to the bacteria and, if the system is closed with respect to sulfur, it is possible that depletion of sulfur or oxygen will result in progressively lower levels of sulfide production, which can be readdressed by recharge. It is then possible to have a series of bacterial blooms and decays which result in either excess sulfide or depleted sulfide supply.

The recharge is the temporal control. Roedder favoured the change in hydro-geochemical conditions as due to the annual fluxing of groundwater recharge, which
would bring new nutrient and perhaps redistribute depleted elements and radicals. He consciously used the term “varve” to describe the bands. Annual recharges are not necessarily the only mechanism. Longer term aquifer recharges, e.g., one in ten, twenty or even one hundred years are all possible redistribution-resupply events. What is necessary is the temporary removal of stagnation conditions in the groundwaters, i.e., to periodically open the system.

The significance of colloform textures at Pernatty Lagoon is that they represent remobilization and redeposition of copper-bearing sulfides under special geochemical conditions. Normally, redeposition of copper-bearing sulfides results in covellite, but in the case of the colloform textures redox levels have been low enough to redeposit iron as well as copper. Such conditions can only be the result of active bacterial reduction in aqueous media. It is postulated that changing redox conditions, reflected by bands of different sulfide phases, represent blooms and decays of biogenic activity. Above all, colloform banding is the product of supersaturation in the aqueous media under hydrological conditions that are at, or approach, stagnation and the texture is evidence for ‘supergene’ enrichment under active reducing conditions. The fine banding is particularly fragile as copper and copper iron sulfides re-equilibrate, recrystallize and are easily replaced with only minor changes in physical and chemical conditions. The texture is consequently rare and only seen in ore deposits where the processes are close to or contemporary.

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