Colourful Perth Pennies – A Tentative Answer Part One

In the last article published, the role of varying alloy levels as one determinate factor in the colour of Australia pre-decimal bronze was forwarded. The second factor – and one which I have not heard a great deal of in Australian numismatics - is of alloy mixing errors. However, it was only in updating Top End Coin's numismatic library with an old edition of a JNAA article by Paul Holland that the penny dropped (pun intended) on colourful Perth bronze.

The key word was *pressure*. It then took me several weeks to make the links between pressure applied to the mintage of Perth mint bronze, the role of chemical pollution in oxidation and the varying nature of that oxidation according to alloy. I believe these three factors provide a tentative answer to the question that has bedevilled so many in the collecting community.

Alloy Mixing Error

No doubt many collectors have seen an alloy mixing error but may not have understood what they were looking at. Information on alloy errors was recently acquired by the author from an American numismatic error site (1), which is recommended reading. A simple and easy example of an alloy mixing error is this 1948 Melbourne penny on the right (figure 1). A blob of tin (Sn) or zinc (Zn) has been streaked across the coin by the rolling press. Both alloys oxidize more slowly than copper (Cu) and thus retains a light coloured patina after 70 years. The author labels this error as a type of "intrinsic metallic inclusion" (1). On the left, the 1951PL reverse is an unusual alloy mix. The two bank rolls I pulled apart looking for a suitable example display an olive green patina, with flecks of alloy still visible in some coins. The 1964P obverse shows a similar mixing error, with flecks of alloy in an oxide of copper. The reverse however is mostly bright salmon pink, indicative of alloy.

Annealing Error

An easy to understand visual representation of this error (figure 3) is this 1975D five cent piece (PCGS Cert. #40430976). The alloy of 75% Cu and 25% nickel (Ni) have separated, with copper atoms rising to the surface. Mike Diamond – senior editor/author of *error-ref.com* wrote to the US Mint (2) and received a reply worth sharing in full. It was in relation to some highly oxidised and damaged Jefferson nickels (see online article for images). The US Mint wrote:

The samples shown in the photos were the result of a loss of protective atmosphere or being stuck in the annealing furnace for a prolonged period of time, or both.

This would result in migration of the copper and nickel to the surface of the blank. *Since there is three times as much copper then nickel in the outer layer of these coins, the diffusion of copper to the surface will be significantly greater than the diffusion of the nickel, resulting in the reddish appearance noted.*

Depending on the time the blank sits in the annealer, and whether it is exposed to oxidizing conditions, various reactions can occur. This will result in the type of phenomenon shown in the photos, where a distinct layer of material forms on the blank surface (primarily copper, with a high degree of oxidation), which is quite brittle, and will break off in pieces. This will expose the original blank surface, which would also be oxidized, but closer in color to the original alloy. We have seen these types of blanks but only infrequently.

An annealing oven heats the blanks to soften the metal and break down large metal crystals into a finer and more malleable structure. From the US Mint correspondence above, different outcomes can occur as a function of time and levels of oxygen in the annealing oven. Temperature is also another factor. The digital upload of Levy’s lecture papers referred to in the previous article (3) provide some useful reading on the deleterious effects of excessive oxygen and other impurities in copper.

I’m unsure if this 1955M (figure 4) is an alloy mixing error, annealing error or both. An examination of the reverse suggests unusual alloy oxidation as opposed to cleaning (96.88/2.65/.48 Cu/Zn/Sn). The obverse’s excess of Cu raises the possibility that there was metal migration. Does exposure to air or contact with other coins in the annealing oven influence particle migration? More research is required.

The Mechanics of Oxidation

The internet is a wealth of information on the subject of metallurgy. The online store for Cambridge University Texts provides an overview for a metal textbook (4), which notes that “many of the factors described for the oxidation of pure metals also apply to the oxidation of alloys. However, alloy oxidation is generally ***much more complex***…” (author emphasis). While much of the available literature concerns itself with high-temperature oxidation, “at normal temperatures, the oxides of the metals (except gold) are more stable than the metals. Metals being in the metastable state are bound to form oxides.” (5) Furthermore:

In most other metals, the first oxygen molecules coming in contact with the clean surface of metal, dissociate into oxygen atoms and then, these oxygen atoms bond chemically with the atoms of the metal surface.

This monolayer of oxygen atoms which forms rapidly over the whole surface of the clean metal is said to be chemisorbed. This process, involving dissociation and ionisation of oxygen molecules is known as chemisorption. Additional oxygen may be physically adsorbed on such a layer.

In the chemisorbed layer, oxide is nucleated at favourable sites on the surface such as ends of dislocations, steps in surface, impurity atoms, etc. This nucleation occurs slowly at low temperatures, but soon the whole surface is covered with a thin film of oxide, which continues to thicken…. (5)

We can say that copper oxidises as a film and then thickens as a scale (Verdigris). However, varying states of alloy oxidise with greater complexity. What I’ve attempted to illustrate in these initial articles on Australian bronze (see CAB March, p.28) is the huge variety of alloy that permeates Australian pre-decimal bronze. Let’s move on to the science of colour.

Figure 5 is the same coin. In normal light the coin has a darker appearance than what is displayed on the left. The colour is passing from red brown to brown. We know that tin (Sn) and zinc (Zn) are less reactive than Cu. The nature of oxidation leads me to believe that I am looking at black flecks of Cupric Oxide or some other impurity. That these flecks are running along the grain with lamination errors (behind the kangaroo's leg and below the H in ELIZABETH) suggests the possibility of an alloy mixing error. You can see differing levels of alloy oxidation. A small spot of film has now thickened into scale (Verdigris) in front of QEII's forehead. Figure 6 was shot with axial lighting to mimic the flash of colour one sees when tilting a coin under strong light. Those colours lead us to 'thin film interference', to follow as part two of this article.

References:

1. Planchet Errors: Improper Alloy Mix: https://www.error-ref.com/improper-alloy-mix/

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3. Levy, Donald. Modern Copper Smelting: https://www.gutenberg.org/files/59328/59328-h/59328-h.htm

4. Introduction to the High-Temperature Oxidation of Metals: https://www.cambridge.org/core/books/abs/introduction-to-the-high-temperature-oxidation-of-metals/oxidation-of-alloys/EDFFD03A2DA9B56710DDC996C9E6ED04

5. Oxidation in Metals: Mechanism & Kinetics | Corrosion | Metallurgy: https://www.engineeringenotes.com/metallurgy/oxidation/oxidation-in-metals-mechanism-kinetics-corrosion-metallurgy/43616