Plate Tectonic and Stress-Field Modeling of the North Arm of Sulawesi (Naos), Indonesia, to Better Understand Distribution of Mineral Deposit Styles

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The North Arm of Sulawesi Island (NAoS) in Indonesia has traditionally been a major focus of exploration and gold mining since colonial times, and has an estimated production of >90 t. There are currently four gold mines in operation and it is postulated that there is still >30 Moz Au in geological resource potential residing in >200 mineral occurrences within the NAoS of mixed economic viability. Despite intensive modern exploration and mining work in the past two decades, there is little up-to-date compilation or synthesis of the understanding of the complexity and tectonic control of the mineral districts of the NAoS. This paper seeks to provide some clarity to that understanding.

We have compiled an extensive and systematic GIS database from exploration records and open source data to analyze the plate tectonic and large-scale geological features in relation to the geology and mineral occurrences of the NAoS. Plate tectonic boundaries and regional structures have been digitized from research publications, geology maps, and seismic sections. Digitized lineaments have been kinematically annotated in our proprietary stress-field modelling and iterative models have been created. An extensive database of earthquake hypocenters has been compiled from various sources and visualized in 3-D with Leapfrog mining software. Subducting slabs have been modelled down to 700 km below surface while stress-field models have been compared with the 3-D model of slabs in order to create a viable plate tectonic proposal.

Subduction under the NAoS is very complex and comprises three oceanic plates; here named the Molluca, Celebes, and Sangihe plates. The Molluca and Celebes plates are dipping opposite to each other while the Sangihe plate is dipping at right angles to the other two, reaching 640 km in depth. There is great variation of depth and angle of subduction both across north-south and east-west sections. These variations in the subducting plates are marked by major “breaks” of morphology and earthquake intensity. The location of these breaks usually corresponds to major, first-order arc-transform structures in the upper plate. These arc transfer structures subdivide the NAoS into five main tectonic blocks from west to east. Each block seems to have its own geological and geochemical characteristics and significantly predefines the type of mineral occurrences.

Our stress-field modeling suggests, in accordance with recent hypotheses, that despite the well depicted regional collisional-subduction setting of most of the Sulawesi Island, the land of North Sulawesi as well as the Tomini Bay and Gorontalo Bay sea basins is currently subsiding in a dominantly extensional stress regime. The most significant uplifts that occurred in a number of metamorphic core complexes are also associated with extensional detachment tectonics. Based on our review it is postulated that slab detachment and/or rollback of the Sulawesi trench is responsible for regional extension.

Furthermore, the most significant younger (5-1 Ma) Au-Cu mineralized districts in the NAoS appear to be spatially related to major extensional geologic features such as E-W-trending intra-mountain basins or crustal scale ring structures and their intersection with transtensional arc normal faults those may extend to the lower plate and act as tear faults on the subduction plates, opening a window to the mantle.