

4<sup>th</sup> September 2018

**Processing Technologies, Metal Recoveries and Economic Feasibility of Deep Sea Mining Workshop  
Warsaw**

**Dear Attendees**

**TOML Comments on Processing and Economics**

Tonga Offshore Mining Limited (TOML) apologises that it cannot be with you at this important workshop. In this situation we can however offer the following comments:

1. Processing of nodules seems to be possible by several means. (e.g. as indicated in Item 13 of the 2012 Golders NI43-101 technical report for our parent Nautilus Minerals and as reproduced below);
2. The markets for the two primary metals (Mn and Ni) and secondary metals (Co and Cu) seem robust and growing. Indeed deep sea sources of metals will be timely for the end-users of the metals without serious threat to land based producers. (e.g. as indicated in Item 19 of the 2016 AMC NI43-101 technical report for our parent Nautilus Minerals and as reproduced below).
3. The greatest uncertainty regarding revenue and saleable product applies to the manganese. Thus we would suggest a lower (1/2?) level of royalty on the manganese compared to Ni, Cu and Co, at least at the outset.

**Yours sincerely**



**John Parianos**

Tonga Offshore Mining Limited

## ITEM 13 Mineral Processing and Metallurgical Testing

TOML has not done any mineral processing or metallurgical test-work on the seafloor nodules from the TOML Exploration Area. Such test work will be incorporated into a prefeasibility study planned for 2013-2014.

However, considerable historical work has been done, predominately at a laboratory scale, with some test work at a pilot plant scale (Sen, 2010), which indicates that processing of the nodules is technically feasible. To maximise recoveries of valuable metals the high valence Mn lattice in nodules has to be broken down either through pyrometallurgical or hydrometallurgical/biohydrometallurgical reduction.

Haynes et al (1985), in a NOAA funded US Bureau of Mines managed study, examined in detail the chemistry, morphology, and mineralogy of the nodules as well as five discrete processing routes. The processing routes are either solely hydrometallurgical or combinations of pyrometallurgical and hydrometallurgical processes, and were investigated at the bench top scale with nodule feed with a specific focus on tailing and slag composition (Haynes et al, 1985). The potential process routes (Figure 0-1) include:

- Gas reduction and ammoniacal leach process (Caron process)
- Cuprion ammoniacal leach process (as developed by Kennecott in their nodule studies in 1970s and 80s)
- High temperature and high pressure sulfuric acid leach process (HPAL)
- Reduction and hydrochloric acid leach process
- Smelting and sulfuric acid leach process

These processes use either an acid or ammoniacal leach followed by solvent extraction and electro-winning for the selective recovery of copper, nickel and cobalt metals. The first three processes are three-metal recovery systems with manganese reporting to a waste stream, with the last two also recovering manganese. The cuprion process operates at atmospheric pressure and temperature and flotation of the tailings can produce commercial grade manganese concentrates (NIOT, 2008).

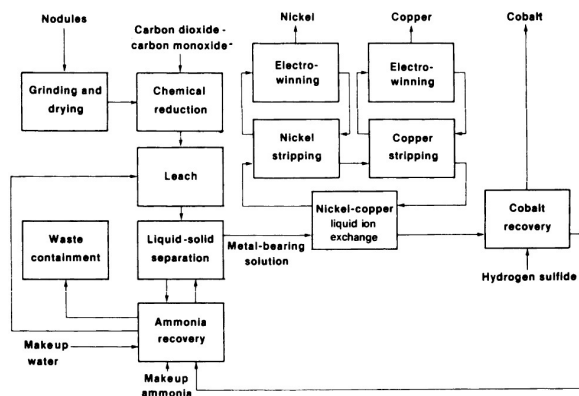
Additional process routes, including biohydrometallurgy and alternative reducing agents, have been studied, e.g. Wang et al (2005, Figure 0-1) and general reviews by Mukherjee et al. (2008) and Sen (2010).

Haynes et al (1985) and Wang et al. (2005) both conclude that the studied flow sheets for nodules are technically feasible. At the laboratory (bench top) scale Ni, Cu and Co recoveries vary but for the processes not using ammonia leach generally exceeded 90%. For the ammonia leach type processes recoveries vary with Haynes et al (1985) achieving greater than 90% for Ni and less for Co and Cu and Wang et al.(2005) achieving 95% for Cu, 65% for Co and 84% for Ni.

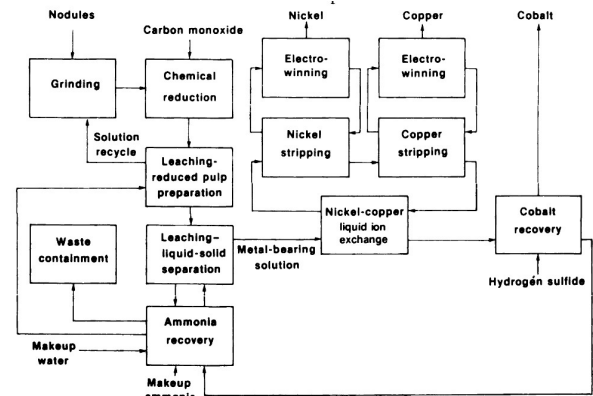
Neither Haynes et al (1985) nor Wang et al. (2005) reported Mn or REE recovery, although the smelting process produced Mn rich tailings and a ferro-manganese product, and the hydrochloric

acid leach process could also produce manganese. Sen (2010) reports process options with manganese recoveries of 85%. In NIOT (2008) COMRA reports that pilot tests on 'smelting – oxidative leaching-SX' returned metal recoveries of Ni, Cu and Fe of greater than 90%, Co of 89%, and Mn of 82%, while IOM, who studied both hydro and pyrometallurgical process routes, report extraction efficiencies via sulphur-dioxide leaching of greater than 98% for Ni and Mn and greater than 90% for Co.

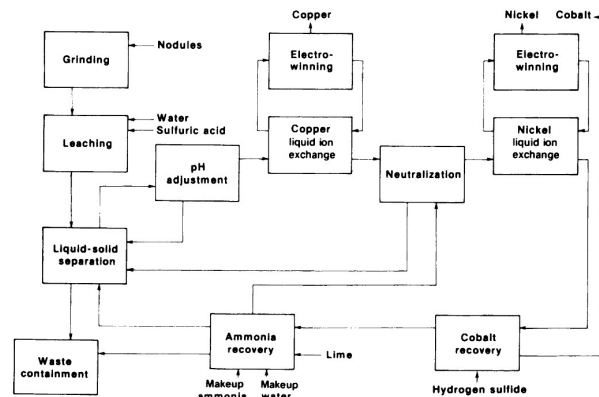
Spickermann (2012) does not look at how REE could be extracted, but notes that any hydrometallurgical process that extracts all of the Mn, Ni, Co and Cu (without REE losses or reagent additions) would effectively create a tail with over 3 times the original REE grade. This could be very competitive compared to other REE sources, with substantially lower environmental risks due to the negligible uranium and low thorium contents of nodules.



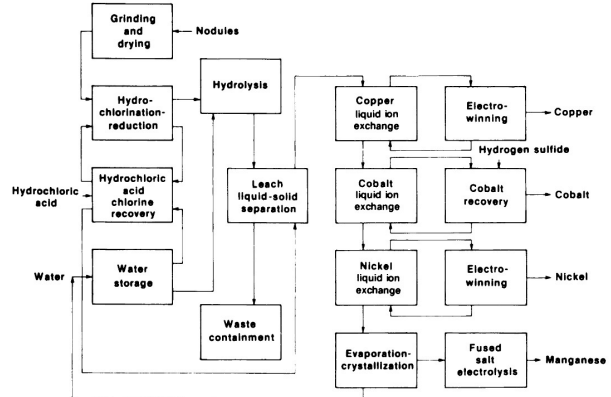
1. Gas reduction and ammoniacal leach



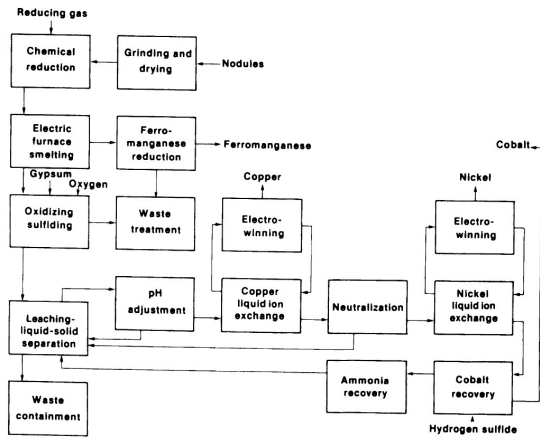
2. Cuprion ammoniacal leach



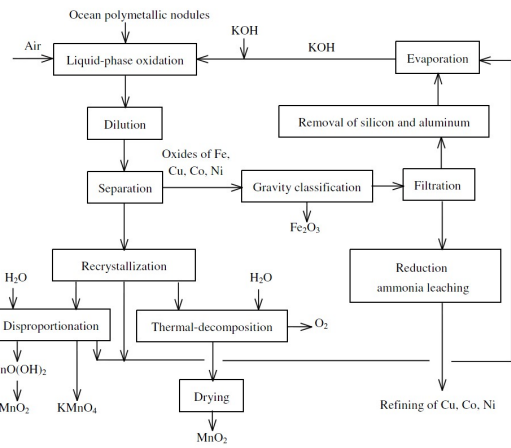
3. High temperature/pressure sulfuric acid leach



4. Reduction and hydrochloric acid leach



5. Smelting and sulfuric acid leach



6. Potassium hydroxide oxidation ammonia leach

1-5 studied by Haynes et al. (1985) and 6 by Wang et al. (2005)

Figure 0-1: Potential Process Flow-sheets for Seafloor Nodules.

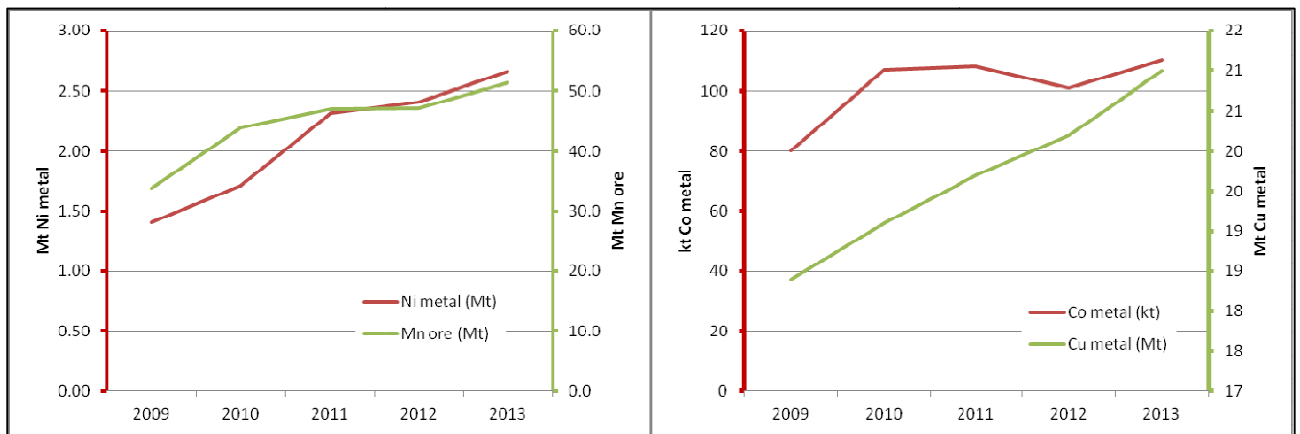
## ITEM 19 Market Studies and Contracts

There are no Mineral Reserve estimates for the TOML Exploration Area of the CCZ and the potential viability of the Mineral Resources has not yet been supported by a preliminary economic assessment, a pre-feasibility study or a feasibility study.

In terms of metal markets it is worth noting however that:

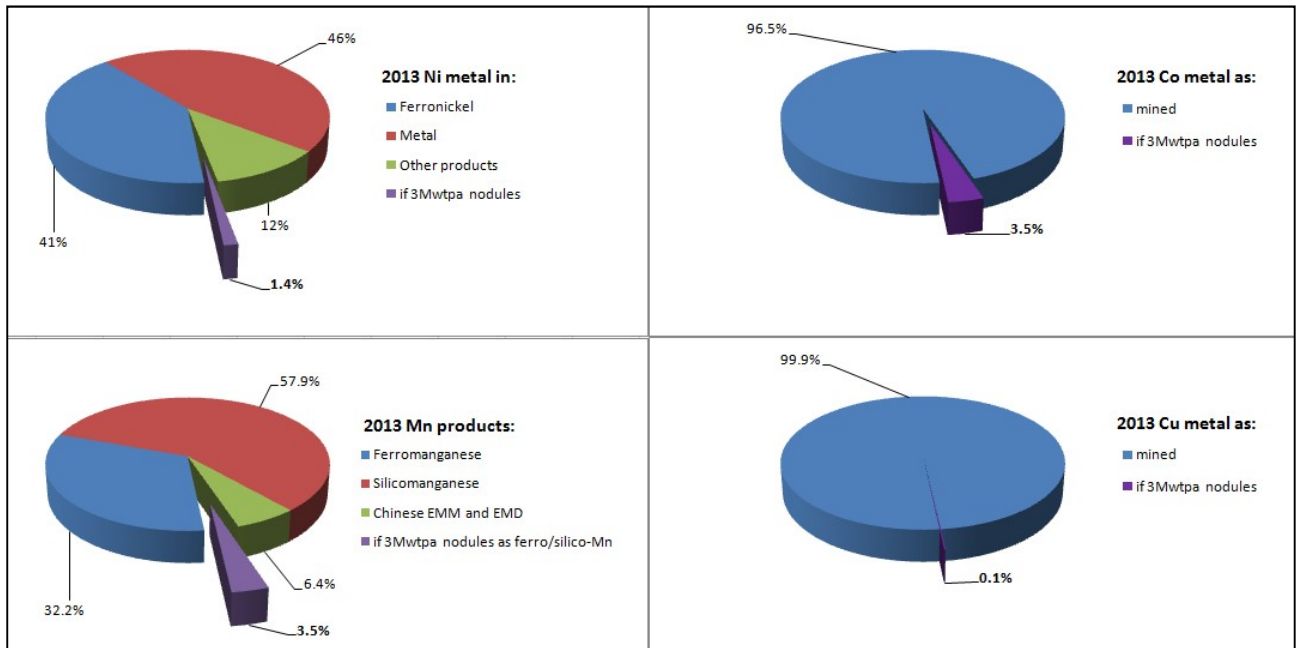
- Markets for the metals estimated in the Mineral Resource have grown over the last few years for which statistics are publically available (2009 to 2013; USGS, 2016)
- Marketable product ultimately is linked to metallurgical process circuit and then to the size of established intermediate and final product markets;
- Production of nodules at a nominal rate of three million wet tonnes per annum would not seriously disturb the land based supply industries.

Figure 0.1 Manganese, nickel cobalt and copper production



Source: USGS (2016)

Figure 0.2 Manganese, nickel cobalt and copper markets relative to conceptual contribution from nodule mining



Source: USGS (2016) and International Manganese Institute