Nodules and Crust Economics: Relationship Between Cobalt and Nickel Price

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ABSTRACT
This paper compares the economic feasibility of two deep seabed mining deposits, manganese nodules and cobalt crust using a new quantitative indicator, the cobalt/nickel price ratio, that verifies the equality between the net present value (NPV) of the two resources. NPV is based on two different models, a multi-period and a single-period time cash-flow. In both cases results are similar and show that the current price of nickel could produce equality between NPV of manganese nodules and cobalt crust only if the cobalt price were several hundreds dollars per kg. Results are based on cost of mining estimated by Yamazaki for Japanese licensed deposits, and can be used as a guide in the absence of more recent commercially-derived cost models.

KEY WORDS: seabed mining; manganese nodules; cobalt crust; mining economics; sensitivity analysis; cobalt/nickel price ratio; discounted cash-flow.

INTRODUCTION
Many studies on the economics of deep seabed polymetallic manganese nodules (manganese nodules) have been produced since the end of the 1960s, along with a more recent interest in the potential of cobalt-rich ferromanganese crust (cobalt crust) mining, sustained by the high price of cobalt caused by the political crisis of the major African producers at the end of the 1970s. Currently, commercial interests focus on seafloor massive sulphides located in back-arc basins and arc-volcano systems on convergent plate boundaries (Hoagland et al., 2010). The private company Nautilus Mineral Inc. is already committed in the commercial exploration of polymetallic sulphides in Papua New Guinea, where the world's first seafloor copper-gold project, Solwara 1, is expected to be operational in 2012. Nonetheless a certain interest in nodules mining is professed by the same private company, whose aim is to start a commercial operation before the end of this decade (Cobalt News, 2008). Following this recent interest in manganese nodules, the object of this paper is to re-open the debate on the economics of mining nodules and crust in the context of mutual exclusivity of these ventures (a condition that makes one venture exclude the other in the first commercial phase). Two reasons mainly justify mutual exclusivity between the two mining ventures: firstly, the limited size of the cobalt market (60,000 tons per year of world refinery production in 2009 - Cobalt News, 2010); and secondly, the high capital investments which prevent competition by private companies, but which facilitate the creation of consortia reducing the number of mining operations. These reasons effectively control the mineral contribution from the seabed preventing the drop in mineral prices and dramatic consequences for the main terrestrial producers (largely developing countries for cobalt and copper) (Sorensen and Mead, 1968; Tilton, 1983).

At present there are no commercial mining operations, and metallurgical systems are still only prototypes. Therefore a comprehensive economic analysis of deep seabed mining is not straightforward (Clark and Clark, 1986). However, some meticulous economic analysis regarding manganese nodules has been proposed in the past by Andrews et al. (1983); Charles et al. (1990); Soreide et al. (2001), but this list is not exhaustive. Recent studies on cobalt crust economics, based on the first economic analysis in the EEZ of Hawaii (Hawaii DPED, 1987), have been carried out by Yamazaki et al. (2002) and Yamazaki (2006, and 2008). Results from the latter author emphasize higher prices of cobalt to sustain future cobalt crust mining, at a level of at least 50 $/kg (Yamazaki et al., 2002). In fact at lower prices cobalt crust recovery is not favorable because the internal rate of return (IRR) of the investment is significantly below 10% (Agarwal and Goodrich, 2003), while a 30 % IRR is advocated by private companies to start ocean mining (Agarwal and Goodrich, 2003). However, a more reasonable 15-20 % IRR, as for land-mining, can be achieved, as confirmed by Johnson and Otto (1986), and Soreide et al. (2001), because the riskiest part of the mining operations (the seafloor mining) accounts for not more than 35 % of the whole cost, and on land risks can be reduced by plant able to process both laterites and ocean ores (Johnson and Otto, 1986).

In this paper we use the costs of mining and processing proposed by Yamazaki (2006, and 2008). These are the most recent published estimations of such costs, although they could most likely be superceded by relevant information from the commercial sector. We show that even a cobalt price higher than 50 $/kg is not sufficient to make crust mining more profitable than manganese nodules. Instead of