Manganese Nodules Mining Approaches

Table 1. Characteristics of E1 (BGR) and of the exemplary mine site of the Blue Mining project (Rahn 2016).

Item	Values		Unit
	German exploration area E1	Exemplary mine site within E1	
Area	58,000	255	km^2
Depth	1,460–4,680 (4,240)	3,987–4,022	m
Nodule abundance[a]	0–23.6 (13.7)	10.3–21.3 (16.5)	kg/m^2, dry
Copper, nickel and cobalt grades[a]	1.22–3.45 (2.75)	2.58–3.13 (2.84)	%
Manganese grade[a]	20.5–40.3 (31.3)	— (29.3)	%
Total tonnage of nodules	560	4	Mt, dry
Copper, nickel, and cobalt tonnage	14	0.11	Mt
Manganese tonnage	159	1.17	Mt

[a]Arithmetic mean (average value) in brackets.

Formula 1: Quantity of SMnN in the mine site or license area.

$$RSC = NA_{TOT} \times A_{TOT} \times 10^3$$

where RSC = resource (t, dry weight), NA_{TOT} = average nodule abundance in the total area (kg/m^2, dry weight), A_{TOT} = total area (km^2), and 10^3 = conversion from kg to t and from km^2 to m^2.

The "reserve" (*RSV*) is defined as the quantity of SMnN contained in the mineable proportion of a particular area (A_{TOT}). In general, a reserve represents the probable or proven mineable share of a mineral resource "[…] taking into account all relevant metallurgical, economic, marketing, legal, environmental, social and governmental factors." (Rendu and Miskelly 2013) Beside general criteria, area-specific criteria apply, distinguishing between mineable and nonmineable seafloor (Formula 5). The quantity of SMnN in the potentially mineable area is again estimated on the basis of the average nodule abundance and size of the area (Formula 2).

Formula 2: Quantity of SMnN in the mineable area.

$$RSV = NA_M \times A_M \times 10^3$$

where RSV = reserve (t, dry weight), NA_M = average nodule abundance in the mineable area (kg/m^2, dry weight), A_M = mineable area (km^2).

The “in-field reserve” (RSV_F) is defined as the quantity of SMnN contained in the mining fields (A_F). Mining fields are those fields of the mineable area that are actually mined.

Expecting a field to be bulk-mined, it is assumed that the average nodule abundance in the field is equal to the abundance in the covered area.

The quantity of SMnN in the fields is estimated on the basis of average nodule abundance and the total size of the fields (Formula 3).

Formula 3: Quantity of SMnN in the mining fields.

$$RSV_F = NA_F \times A_F \times 10^3$$

where RSV_F = in-field reserve (t, dry weight), NA_F = average nodule abundance in mining fields (kg/m^2, dry weight), A_F = area of mining fields (km^2).

The "gross mineable proportion" (α) is defined as the percentage of the seafloor (A_{TOT}) which meets all criteria of being mineable (Formula 4).

Formula 4: Gross mineable proportion.

$$\alpha = \frac{A_M}{A_{TOT}} \times 100\%$$

where α = gross mineable proportion (%).

The “mineable area” (A_M) corresponds to the former definition but is expressed in square kilometers. A raster unit (cell or pixel) may not be mineable due to its economic value, environmental protection, or inaccessibility (water depth, slope, or obstacles in that area like cliffs, pot holes, and scarps).

Formula 5: Mineable area.

$$A_M = A_{TOT} - \bigcup_{i=1}^{n} A_{Crit\ i}$$

where n = number of exclusion criteria, $A_{Crit\ i}$ = area excluded from mining by criterion i (km^2).

The "net mineable proportion" (β) is defined as the percentage of seafloor (A_{TOT}) where mining would actually be performed (A_F; Formula 6). In image or spatial analysis, the net mineable proportion is estimated by dividing the number of raster units (cells or image pixels) planned to be mined by the total number in the area.

Formula 6: Net mineable proportion.

$$\beta = \frac{A_F}{A_{TOT}} \times 100\%$$

where β = net mineable proportion (%).

The "production rate" (P) is defined as the dry mass of SMnN recovered per unit of time. It is expressed in kilograms of dry solids per operational second. The production rate is controlled by the mining rate, nodule abundance, and collecting efficiency in the area covered (Formula 7). Dilution of ore with sediments and transport losses are neglected. The production rate is constrained by the mining capacity (MR_{Max}) and the production capacity (P_{Max}).

Formula 7: Production rate.

$$P = NA \times MR \times \eta_C$$

where P =production rate (*kg/s, dry weight*), NA = nodule abundance (kg/m^2, *dry weight*), MR = mining rate (m^2/s), see Formula 9, and η_C = collecting efficiency (%).

The “production rate” (P) is defined as the dry mass of SMnN recovered per unit of time. It is expressed in kilograms of dry solids per operational second. The production rate is controlled by the mining rate, nodule abundance, and collecting efficiency in the area covered (Formula 7). Dilution of ore with sediments and transport losses are neglected. The production rate is constrained by the mining capacity (MR_{Max}) and the production capacity (P_{Max}).

Formula 7: Production rate.

$$P = NA \times MR \times \eta_C$$

where P =production rate (*kg/s, dry weight*), NA = nodule abundance (kg/m^2, *dry weight*), MR = mining rate (m^2/s), see Formula 9, and η_C = collecting efficiency (%).