ITEM 7. Geological Setting and Mineralisation

7.1 Global distribution of nodules and the CCZ

Polymetallic nodules with various grades of base metals are found in submarine settings worldwide (ISA, 2000b). The geology of formation likely varies as the settings vary widely, e.g., from about 4,000 to 6,000 m depth in the mid Pacific versus about 200 m depth in the Gulf of Bothnia (Bostrom, Wiborg and Ingri, 1982), and these variances are reflected in part in nodule chemistry (e.g., Fe:Mn ratio). Importantly, the consistently highest base-metal grades, and often highest abundances, of nodules are found in the CCZ (Table 7.1).

Table 7.1 Summary of Global Nodule Grades (McKelvey et al., 1983)

Element	All Pacific Ocean	Pacific Ocean outside CCZ	CCZ	Atlantic Ocean	Indian Ocean
Mn wt%	20.1	18.8	26.3	13.3	15.3
Fe wt%	11.4	12.8	6.6	17.0	14.2
Ni wt%	0.76	0.63	1.20	0.32	0.43
Cu wt%	0.54	0.41	0.98	0.13	0.25
Co wt%	0.27	0.29	0.20	0.27	0.21

The quality of the CCZ deposit is related to the supply of anomalously high levels of base metals to the nodules (Figure 7.1, Figure 7.2). Four factors interplay to form the CCZ deposit:

- Modest to high **primary productivity** near the sea-surface (ocean fertility) – this supplies higher than seawater concentrations of important metals via exported “marine snow” (e.g. dying plankton and fish and their waste products) that are not consumed at the surface so fall to the seabed (Figure 7.2), with the base metals of interest complexed in organics and calcite ($CaCO_3$). A high zone of surface primary productivity lies south of the CCZ (Figure 7.2), where warmer weather, circum-pacific surface currents and upwelling at the equator, result in high phytoplankton concentrations and an associated food chain (Wyrtki, 1981; Yool et al, 2007).
- The **location of the lysocline** just above the seabed – this means that the falling biological material in carbonate form breaks down due to CO_2 attack just as it reaches the seabed releasing the metals into the slowly growing nodules. Most plankton for example have light, delicate and readily soluble skeletons. If the seabed is much shallower the material would not dissolve and would be incorporated in limestone; and if the seabed is much deeper the material would dissolve before reaching the bottom and disperse the metals into the sea water.

  The key reaction involved can be summarized as: $CaCO_3(s) + H_2O + CO_2 \rightarrow Ca^{2+}(aq) + 2HCO_3(aq)$.

  The lysocline is the depth in the ocean below which the rate of dissolution of calcite increases dramatically due to higher concentrations of contained CO_2 and the effect of higher partial pressures (Sepmstrata, 2013). Deeper and older seawater also has higher concentrations of CO_2, while upwelling zones at the equator have significantly less. The CCD (Calcite Compensation Depth) forms where the rate of supply of calcite starts to lag behind the rate of dissolution and is often defined where sediments with 10% or less calcareous material are found. It is typically a few hundred metres below the lysocline (e.g. Figure 7.2) but this distance depends in part on the amount of calcite input in ‘marine snow’ (i.e. primary productivity).

  The location of the lysocline and CCD in the region of the CCZ is not well understood or published, so notional Pacific figures (Butler, 1991) were used in Figure 7.2.
- The **extensive area of optimally deep-seabed** and the gentle slope between the Clarion and Clipperton fracture zones. Figure 7.2 shows how the seabed between the fracture zones is both at the right depth (+/- a few hundred m) and relatively flat (meaning a large area can grow nodules in just the right conditions).
- A **scarcity of competitor minerals** in the sediment due to the distance from continental landmasses and absence of significant volcanic activity. The clastic component of the benthic sediments is mostly windblown dust from central Asia (Glasby, 2006), i.e. mostly illite, feldspar and quartz. Weathering volcanic minerals such as chlorite and smectite are relatively rare in the sediments – these minerals can also accumulate base metals.