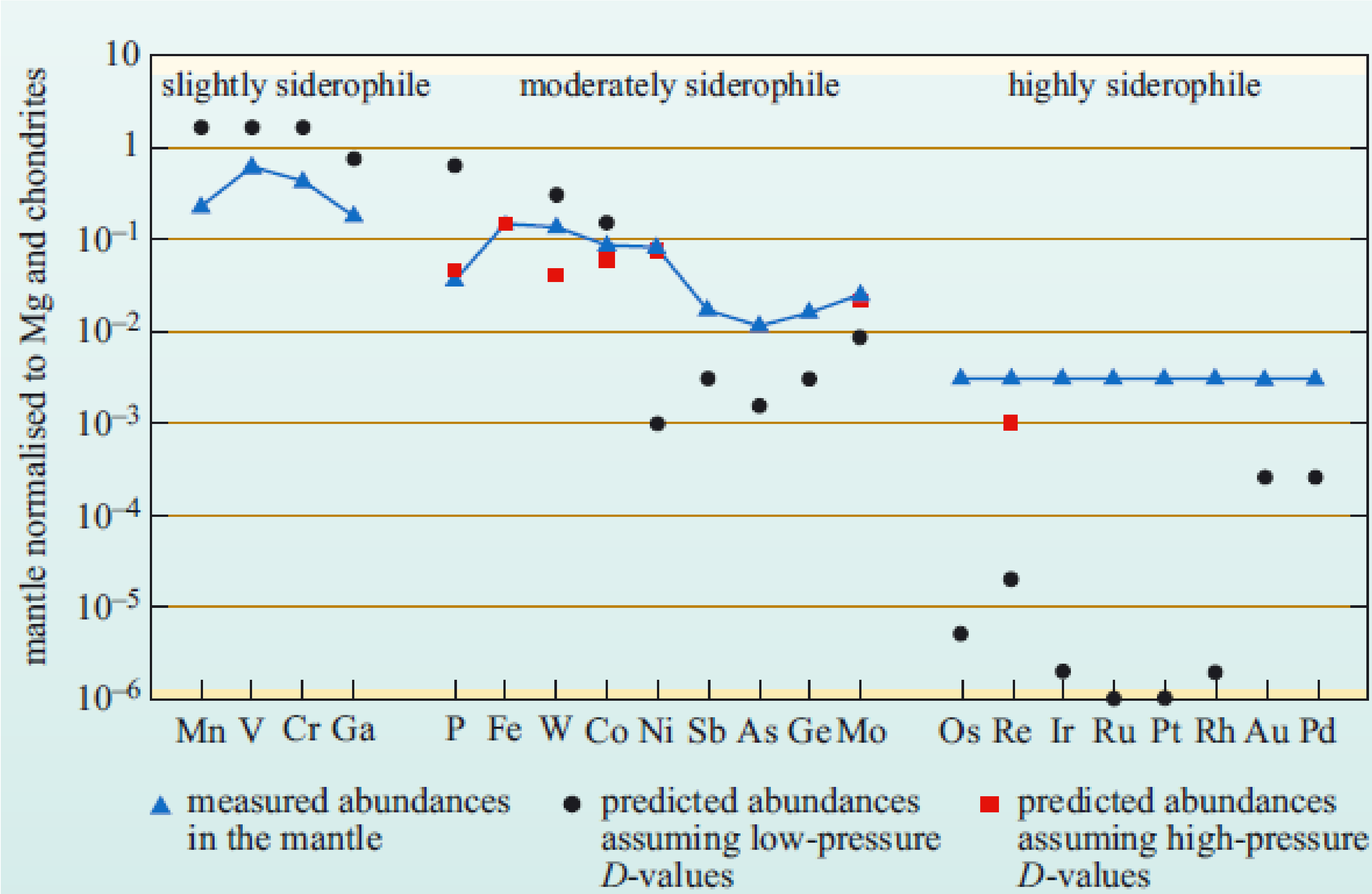
Core–mantle equilibration

one consequence of core–mantle separation is that the metal-loving siderophile elements would be strongly partitioned into the metallic core.

However, trace amounts of siderophile-elements are retained in the mantle and if metal segregation were an equilibrium process then these elements would provide important clues for deducing the conditions of core formation.

An assumption of many early core formation models was that metal segregation was contemporaneous with accretion, and that metal and silicate equilibrated at near-surface, low-temperature (T) and low-pressure (P) conditions.

Low T–P metal silicate distribution coefficients for highly siderophile elements have been determined experimentally and found to lie between 10^–7 and 10^–15. These values lead to the expected abundances in the mantle as shown in Figure



abundances of the highly siderophile elements observed in the silicate mantle compare with what would be expected from the experimentally determined low-pressure partition coefficients?

As you have seen, metal segregation in a magma ocean would probably occur over a range of temperatures and pressures, and so equilibrium metal segregation at high temperature and high pressure in a deep magma ocean becomes a realistic possibility

However, given their dramatically different partitioning behaviour at low temperature and pressure it is unlikely that there exists any set of conditions at which all siderophile partition coefficients converged to a single value, which is required by the uniform depletion of the most highly siderophile elements.

The failure of low-temperature, low-pressure metal/silicate equilibration models to explain the siderophile excess inspired a number of alternative models,

But the most popular is-

• the heterogeneous accretion or ‘**late veneer**’ model in which core

formation effectively strips out all the siderophile elements from the mantle, which are subsequently raised to the observed values by another process.

What process could have raised siderophile element abundances in the silicate mantle following core formation?

Continued accretion of meteoritic materials from new impacts of meteorites with chondritic proportions of the siderophile elements.

Of these elements, Ni and Co provide some key constraints because their abundances in the mantle are accurately and precisely known, and their partitioning behaviour has been studied over a wide range of conditions.

Figure shows that within uncertainty, Ni and Co are present in proportions that are close to chondritic, i.e. both at ~0.1 chondrite.

The chondritic ratio of Ni to Co in the mantle requires the ratio of the two partition coefficients D_{Ni}/D_{Co} to be about 1.1. Experiments show that an increase in pressure and/or temperature causes both Ni and Co to become less siderophile, but at different rates.

a D_{Ni}/D_{Co} ratio of 1.1 occurs at a pressure of about 28 Gpa equivalent to a depth of 900–1000 km, implying high temperature and pressure metal–silicate equilibration and core segregation.

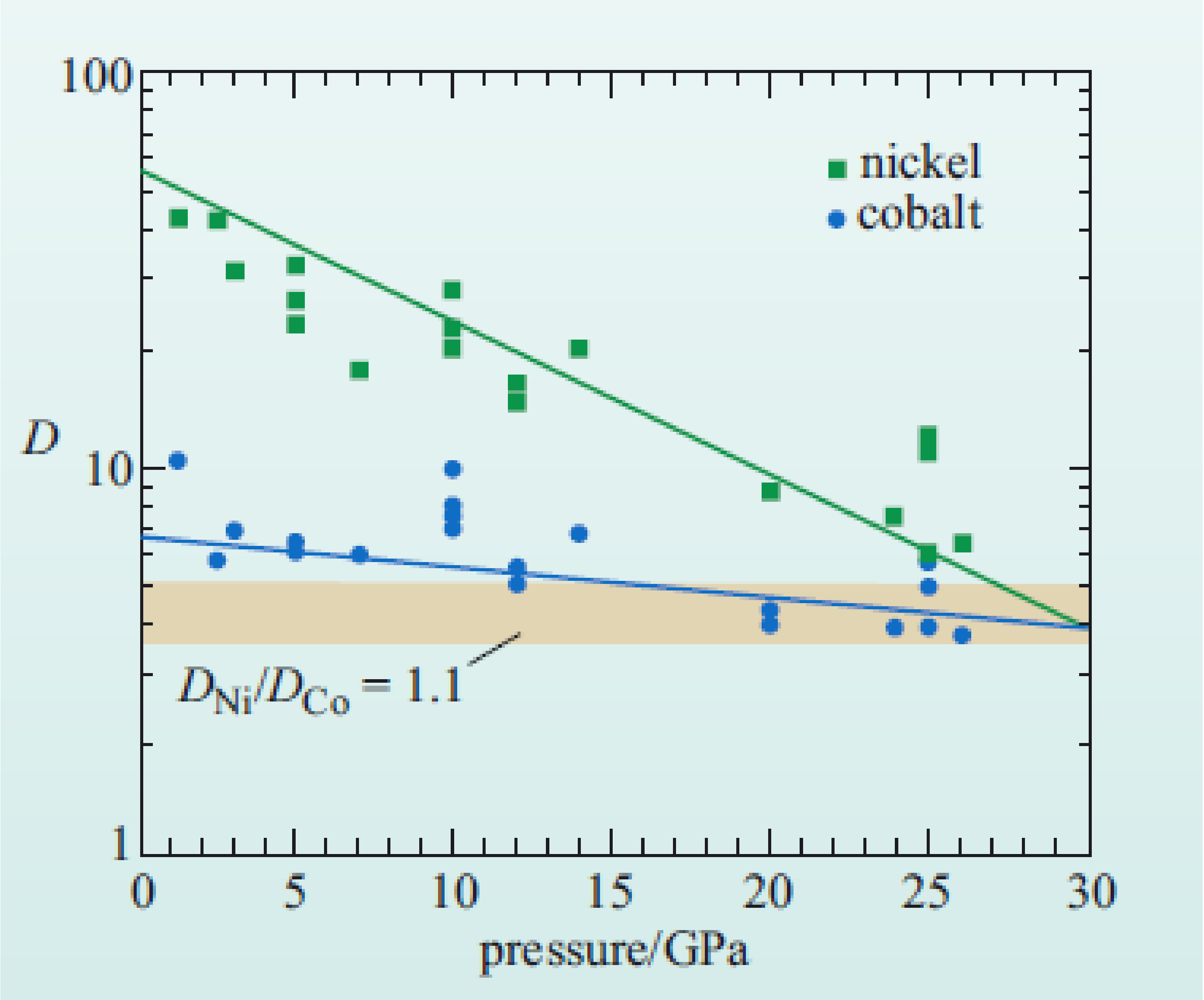
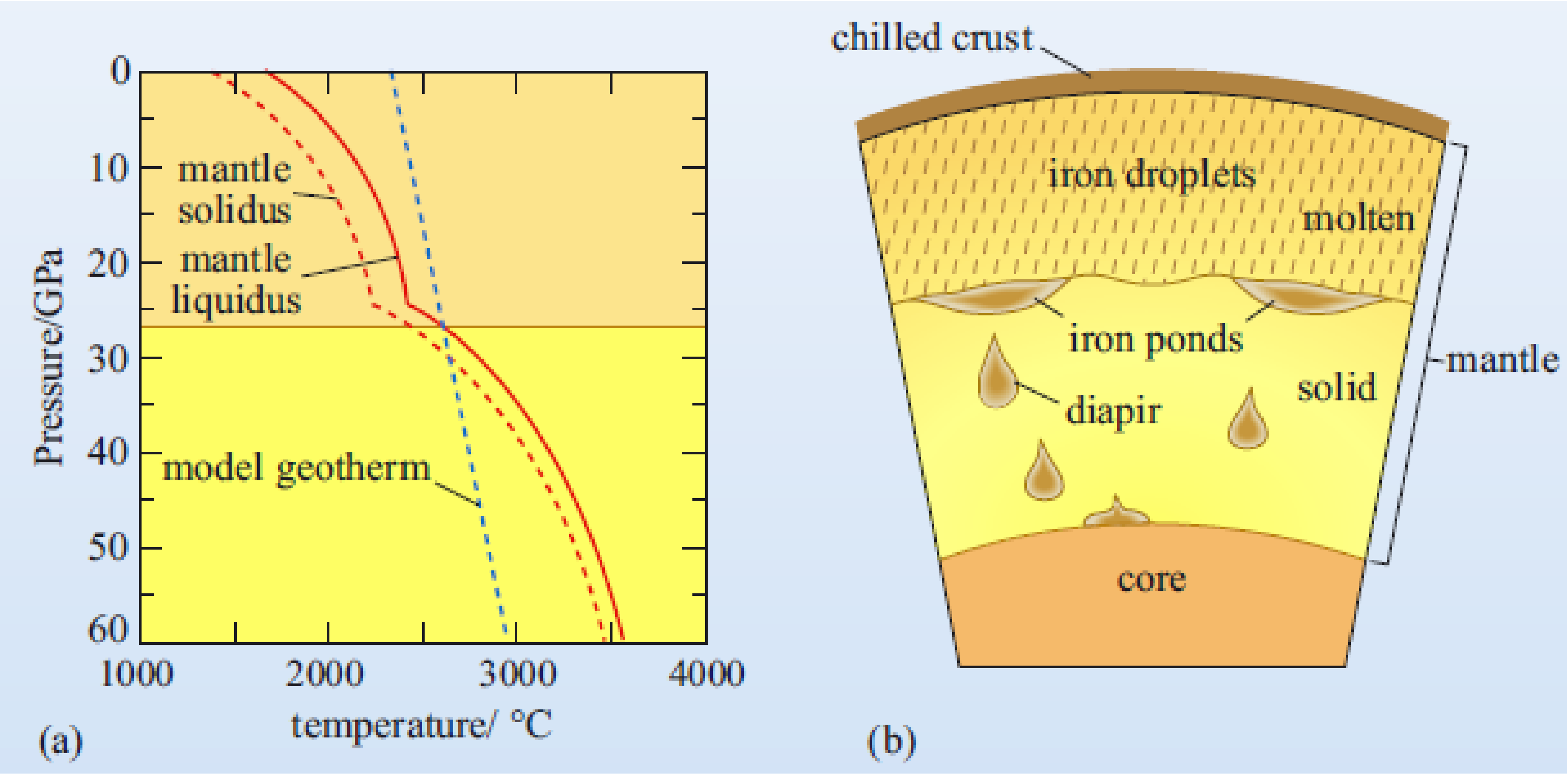


Figure 2.7 Metal/silicate partition coefficients (*D*) as a function of pressure for nickel (Ni) and cobalt (Co). See text for explanation. (Walter et al., 2000)


0
10
20
30
40
50
60
Pressure/GPa
mantle
solidus
mantle
liquidus
model geotherm
1000
2000
3000
4000
temperature/ °C
(a)
chilled crust
iron droplets
molten
iron ponds
diapir
solid
mantle
core
(b)

In the upper part of the mantle, equilibrium metal segregation from the upper mantle would occur by the ‘rain-out’ of small, liquid metal globules over a wide range of temperature and pressure conditions, and the metal would accumulate at the magma ocean floor. At the boundary between the lower and upper region, the metal would equilibrate a final time, giving the upper mantle its present siderophile element signature. Finally, gravitational instability would cause the formation of large metal diapirs that sink through the lower region, with or without reequilibration.

Tungsten isotope ratios and their notation

The beta decay of 182Hf to 182W (t = 9 Ma) has proven to be of enormous value in determining the relative timing of events during planetary accretion and core formation.

Because 182Hf is now extinct, evidence for its original presence is recorded in the isotope ratios of its daughter element, tungsten (W).

Tungsten consists of five stable isotopes but only one of these, 182W, has been partly produced by the radioactive decay of 182Hf. Therefore, to use this geochronometer, geochemists need to measure the abundance ratio of 182W to another of the isotopes of W, conventionally 184W.

tungsten isotopes, differences in isotope ratios are measured in the number of parts in 10^4 (10 000) and are designated by the Greek letter ε (epsilon), defined according to the following equation:

$$\varepsilon^{182}W = \left[\frac{\left(\frac{^{182}W}{^{184}W} \right)_{sample}}{\left(\frac{^{182}W}{^{184}W} \right)_{BSE}} - 1 \right] \times 10^4$$

Consider the following example. A chondritic meteorite has a measured 182W/184W ratio of 0.864640. In the same experiment, a standard representative of the bulk silicate Earth has a measured 182W/184W ratio of 0.864810.

What is the ε 182W value of the meteorite?

What is the $\varepsilon^{182}W$ value of the meteorite?

$$\varepsilon^{182}W = \left[\left(\frac{0.864640}{0.864810}\right) - 1\right] \times 10^4$$

$$= (0.999803 - 1) \times 10^4$$

$$= -0.000196 \times 10^4$$

$$= -1.96 = -2.0 \text{ (to 2 sig. figs)}$$

This result shows that the chondrite measured has a slightly lower amount of radiogenic 182W than the bulk silicate Earth by 0.02%, or 2 parts in 10 000. Quite clearly, saying it has a ε 182W value of −2 is much easier than dealing with a six figure decimal, while the sign conveys that it is less radiogenic than BSE.

A sample with a positive value has more radiogenic W than the BSE.

Calculate the ε 182W value for the following data from another laboratory in which the same meteorite has a measured 182W/184W ratio of 0.864523 and a standard representative of the BSE has a measured 182W/184W ratio of 0.864696.