The Earth’s core

It is clear that the Earth’s core is primarily made of iron.

Samples of the core are not available at the Earth’s surface,
so any scientific investigation of the composition of the core
has to be done either remotely or by using laboratory analogues
and simulations.
Meteorites, Earth Reference model

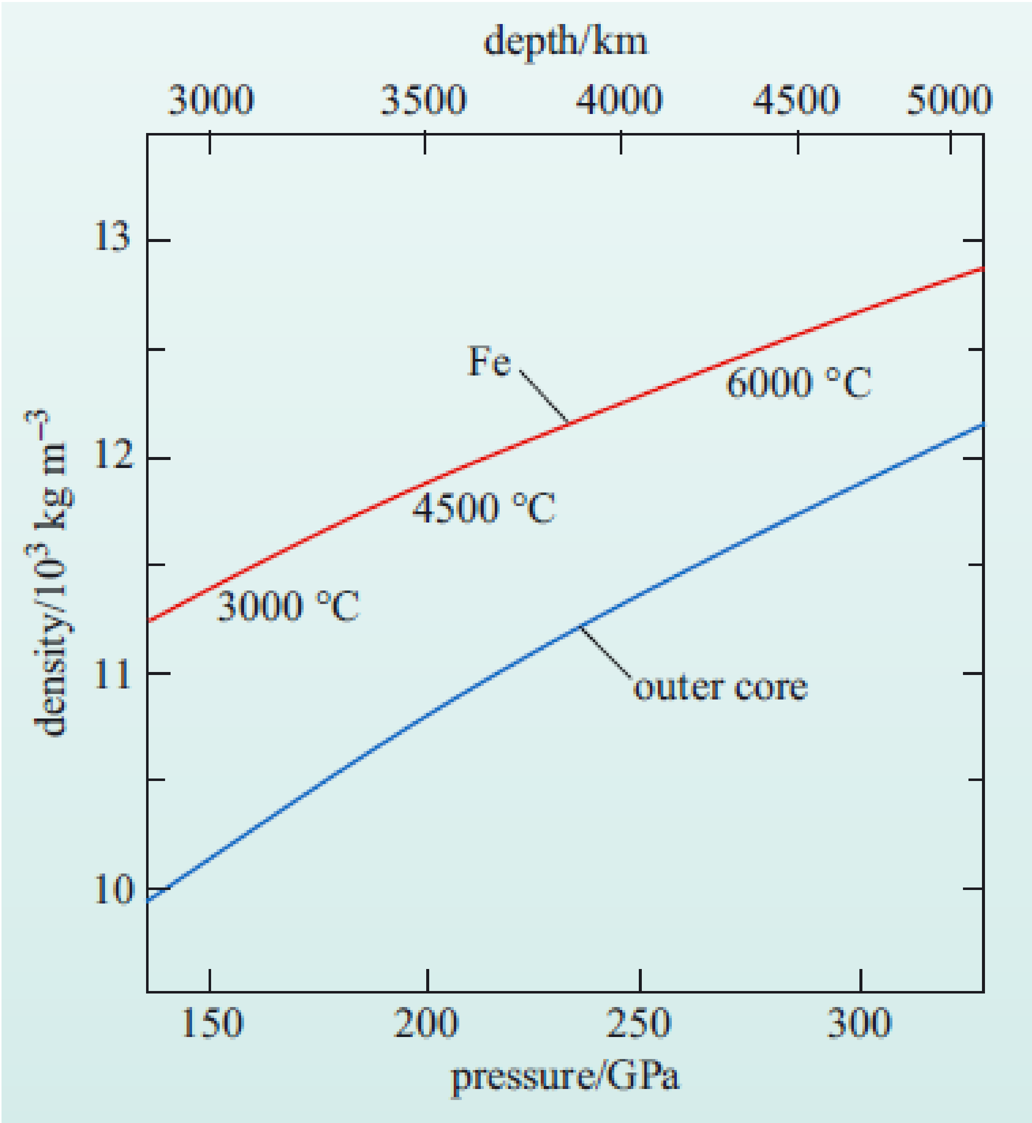


Figure 1.25 Variation of density with pressure in the outer core and the density of iron as determined experimentally for conditions in the core. Temperatures are indicated along the curve for pure iron.

The mismatch between the curves for the core and pure iron requires the core to include other elements that reduce its overall density.

The core must contain significant amounts of siderophile elements, but can these elements account for the lower density of the core?

In short, the answer is no.

Most of the siderophile elements have atomic masses, and hence densities, either similar to or even greater than that of iron –

if anything, siderophile elements make the problem of the core's low density even worse!

The unavoidable conclusion is that the core includes a significant fraction of an element (or elements) with an atomic number and density less than liquid Fe–Ni alloy.

Recalling the comparison between chondrites and the mantle, which of the abundant elements is depleted in the mantle?

Silicon.

Si, is depleted by 10% in the mantle, may be due to volatility.
Possibly Si could have partitioned into the core.
Some Si has been measured in the iron and stony iron meteorites,
But concentration are far too low, few ppm as compared to 10-15% required to reduce the density of the core.
However, it has been shown that Si is siderophile at high pressure.

Other elements suggested O and S in the forms of FeO and FeS.

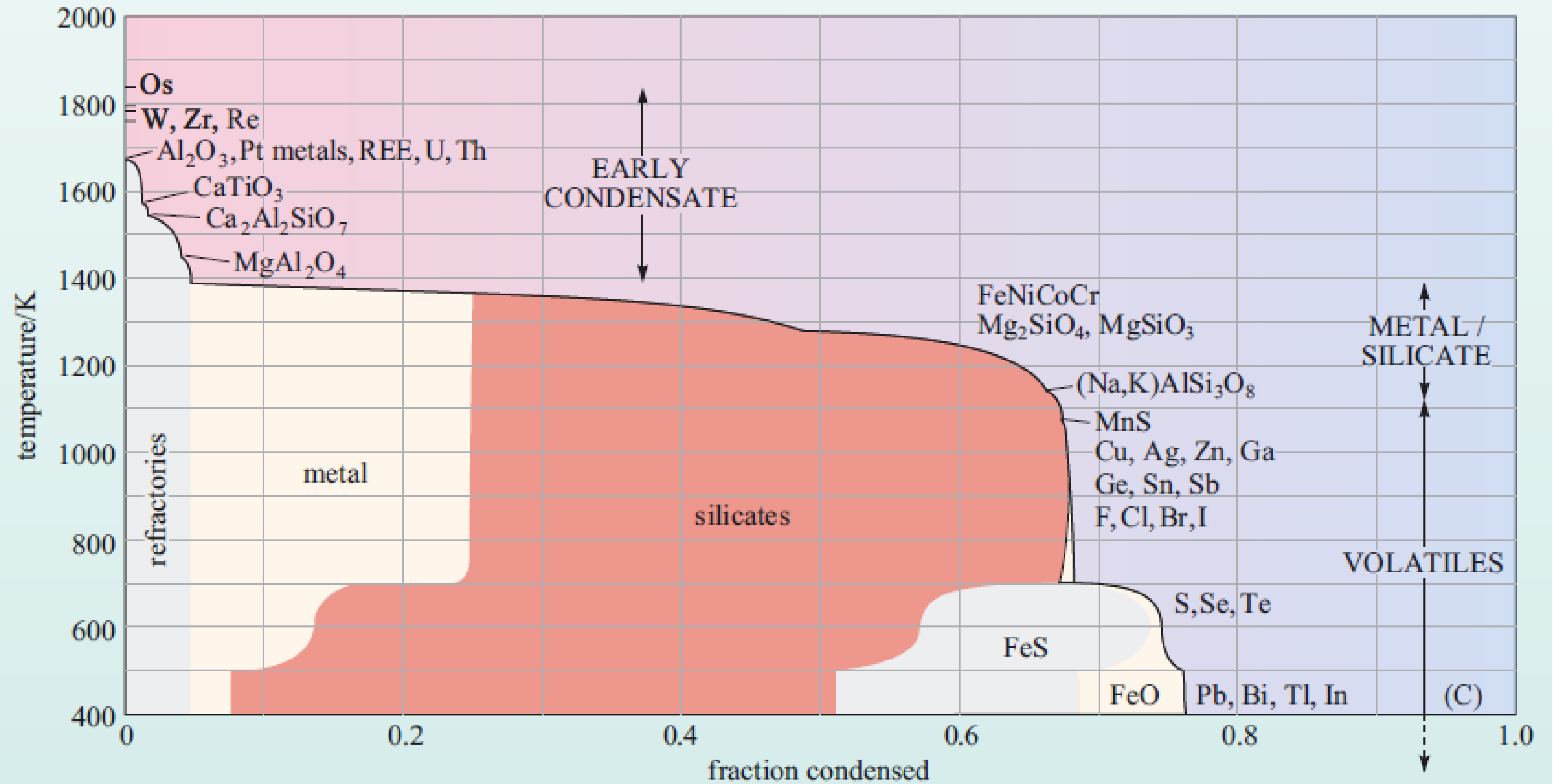


Figure 1.16 The condensation sequence of the solar nebula at a pressure of about 10 N m^{-2}. The *x*-axis represents the fraction of the nebula that has condensed at the temperature given on the *y*-axis. The curve is annotated to show which elements and compounds condense at which temperatures. At this low pressure, all materials condense from gases to solids directly without an intervening liquid phase. (K = kelvin = T °C + 273) (Morgan and Anders, 1980)

S is a volatile element and so may have lost from the Earth before the core formed.

Whereas O is highly electronegative and suggesting a lithophile behaviour.

Experimental studies have shown that, at the conditions appropriate, oxygen can dissolve in molten Fe as FeO.

The mantle contains abundant oxygen bound in silicates that dissociate into dense oxide phases in the deep mantle, and a variety of reactions between these oxides and oxygen-free molten iron have been suggested, all of which lead to the production of FeO (wüstite).

Thus, mechanisms for transferring oxygen from the mantle to the core can be demonstrated on the basis of high-pressure experiments, and oxygen remains the main candidate for the light element in the Earth’s core.

The Earth's core and the magnetic field

Continuing on the theme of what makes the Earth unique in the Solar System, it is an important aspect of maintaining and preserving a benign environment on the Earth's surface by protecting the surface from cosmic rays and high-energy particles.

Curie point?

Given that the Earth's core is considerably hotter than this **(<4000 °C)** the field must be generated by some other mechanism.

geological record reveals rapid flips in the Earth's magnetic polarity many times, suggest that the magnetic field must originate in a region of the Earth that can move and respond rapidly – in other words it must originate in a very fluid part of the Earth, the outer core.

However, the mechanism whereby the field is generated is still not fully understood. It is thought to be related to an interaction between the Earth's rotation and convection within the outer core that, in turn, is driven by a combination of solidification of the inner core and secular cooling.

Earth’s magnetic field has been in existence for at least ~3.8 Ga. If compositional convection is the principal means of generating the Earth’s magnetic field, then the inner core must be at least as old as the magnetic field.

Compositional convection caused by crystallisation of the inner core also involves cooling of the core. However, the estimated cooling rate of the core is too great for the core to maintain heat for 3.8 Ga, and suggests that the inner core cannot be older than about 1 Ga.

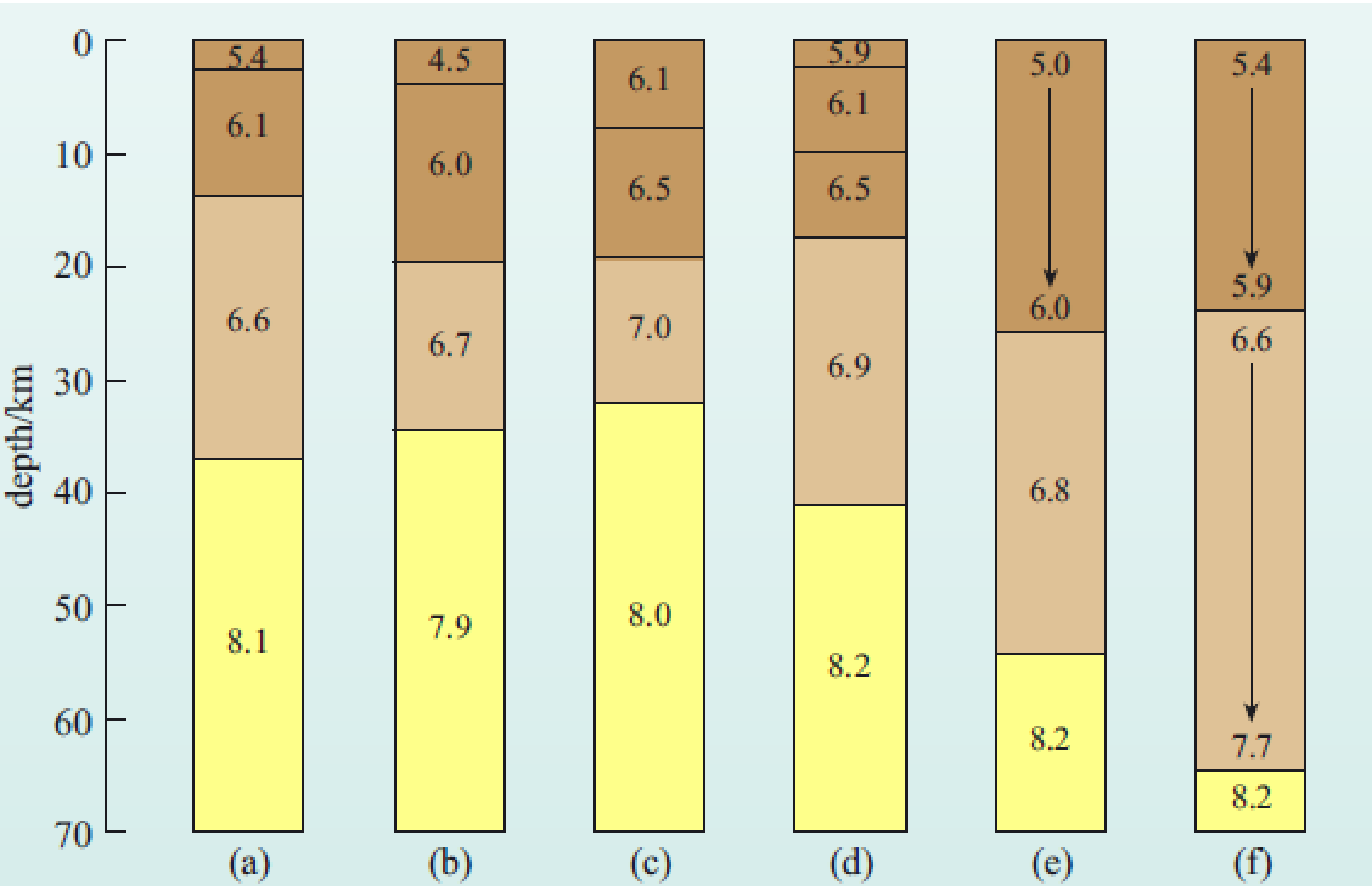
In order to account for the age of the magnetic field and this cooling rate, it has been suggested that there may be significant radioactive heating of the core.

Alternatively it has been suggested that cooling rates and compositional convection may have been slower earlier in Earth's history

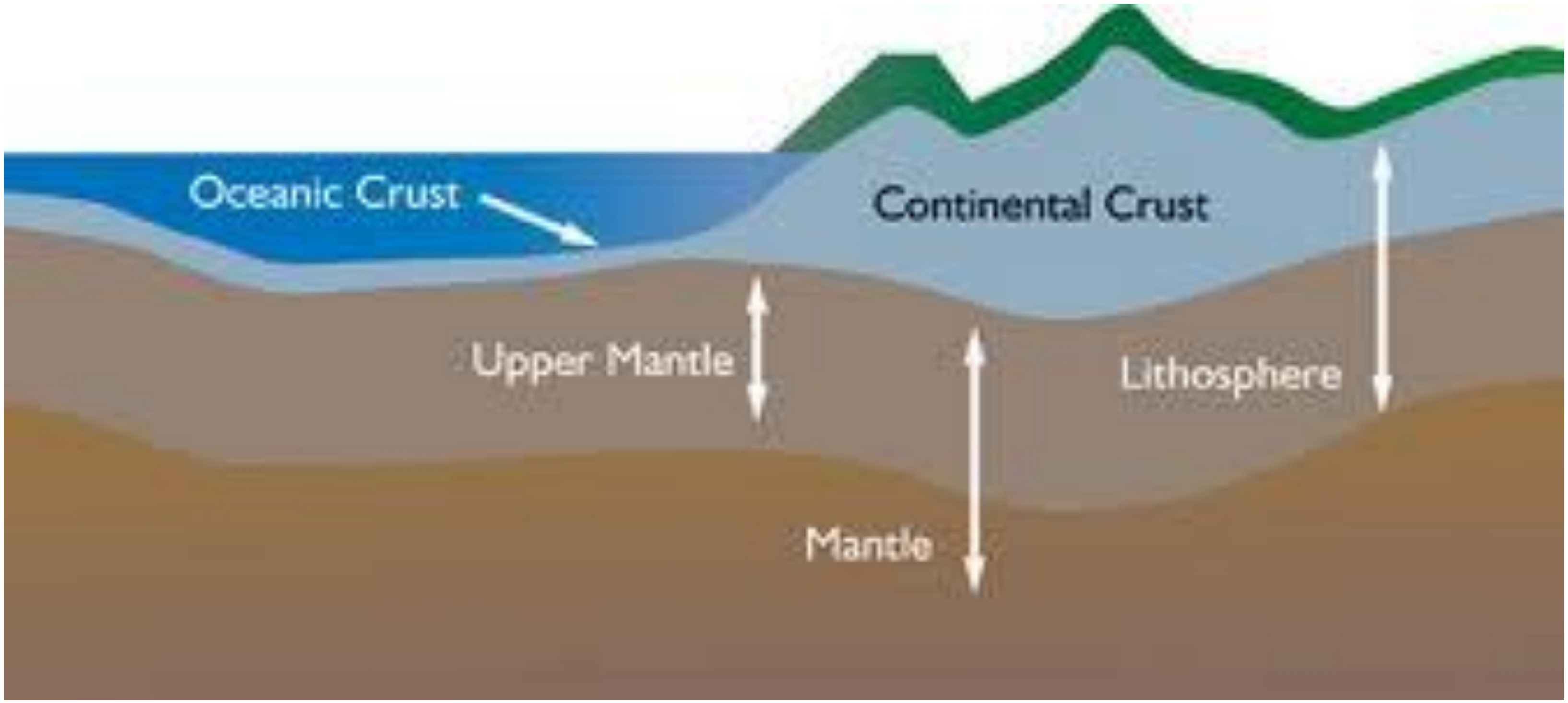
The Earth’s crust: continents and oceans

within many crustal sections a marked increase in seismic velocities occurs at ~15 km depth. Known as **the Conrad discontinuity**, it separates the upper crust from the lower crust and, while not apparent in all sections, it is best developed in regions of older rocks of Archaean or Proterozoic age

The oceanic crust contrasts with the continental crust in almost all physical and compositional characteristics. Whereas the continental crust is of variable thickness, the oceanic crust is much thinner and of a more uniform thickness.



depth/km
0
10
20
30
40
50
60
70
5.4
6.1
6.6
8.1
(a)
4.5
6.0
6.7
7.9
(b)
6.1
6.5
7.0
8.0
(c)
5.9
6.1
6.5
6.9
8.2
(d)
5.0
6.0
6.8
8.2
(e)
5.4
5.9
6.6
7.7
8.2
(f)



Oceanic Crust
Continental Crust
Upper Mantle
Lithosphere
Mantle

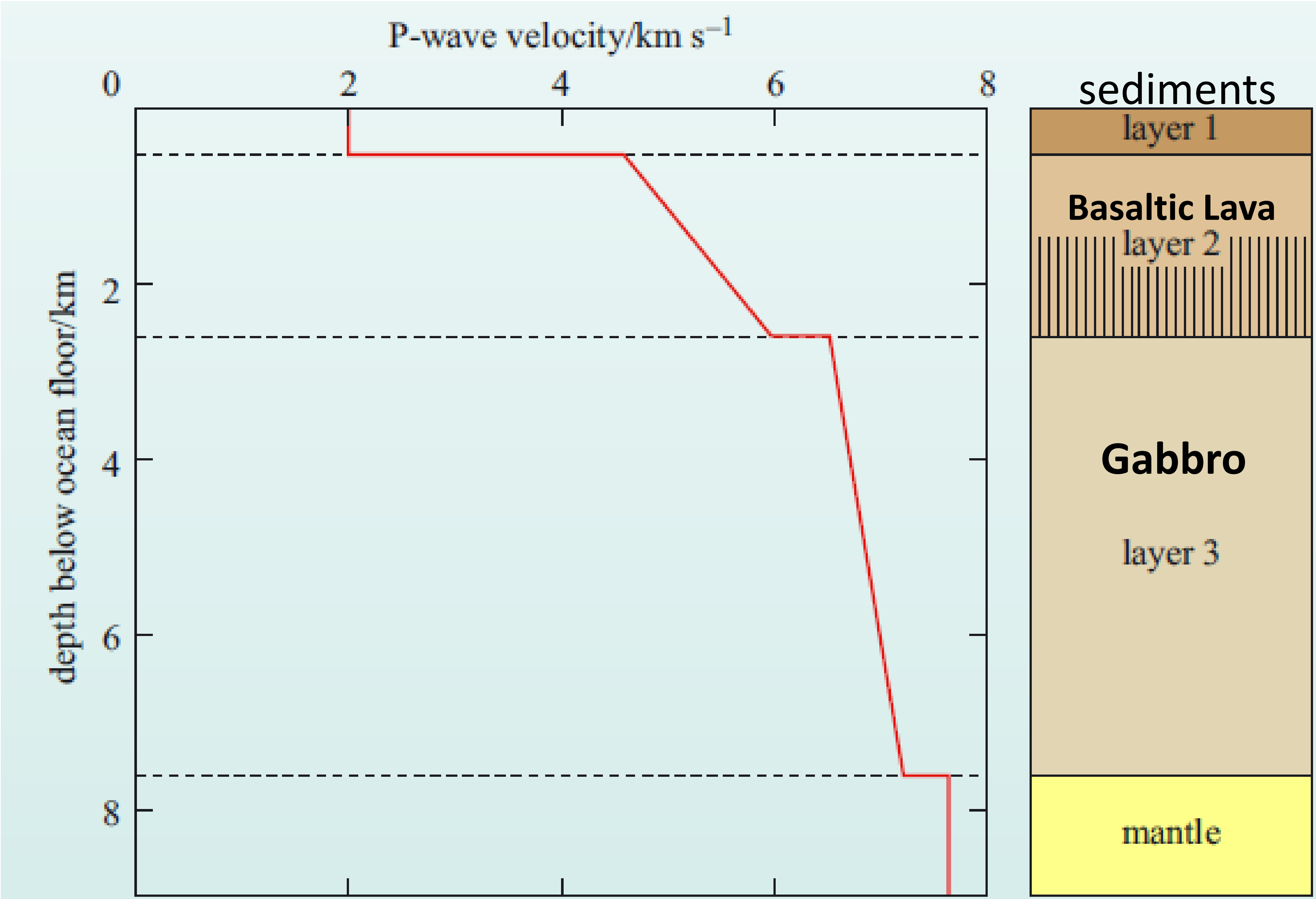
The general consensus is that the upper crust has a composition approximating **granodiorite**, which is a type of granite containing plagioclase and alkali feldspar in roughly equal proportions, 20% quartz and small amounts of biotite and hornblende.

The lower crust, by contrast, is thought to be made up of **granulites** with a slightly more mafic composition, i.e. more Fe and Mg and less Si than in granodiorite.
Granulites are metamorphic rocks that have been subjected to high pressures and temperatures such that they have lost most of their volatile components (largely water) and their mineralogy is dominated by plagioclase feldspar, pyroxenes and garnets, which give the lower crust its higher density.

Overall, the bulk composition of the continental crust is thought to be close to that of the intermediate rock type, **andesite**, or to its plutonic equivalent, **diorite**.

The most important difference between continental and oceanic crust is its thickness. Beneath the oceans, the Moho is located on average at <10 km depth, compared with an average of 35 km beneath the continents. Secondly, the oceanic crust has a pronounced layered structure.

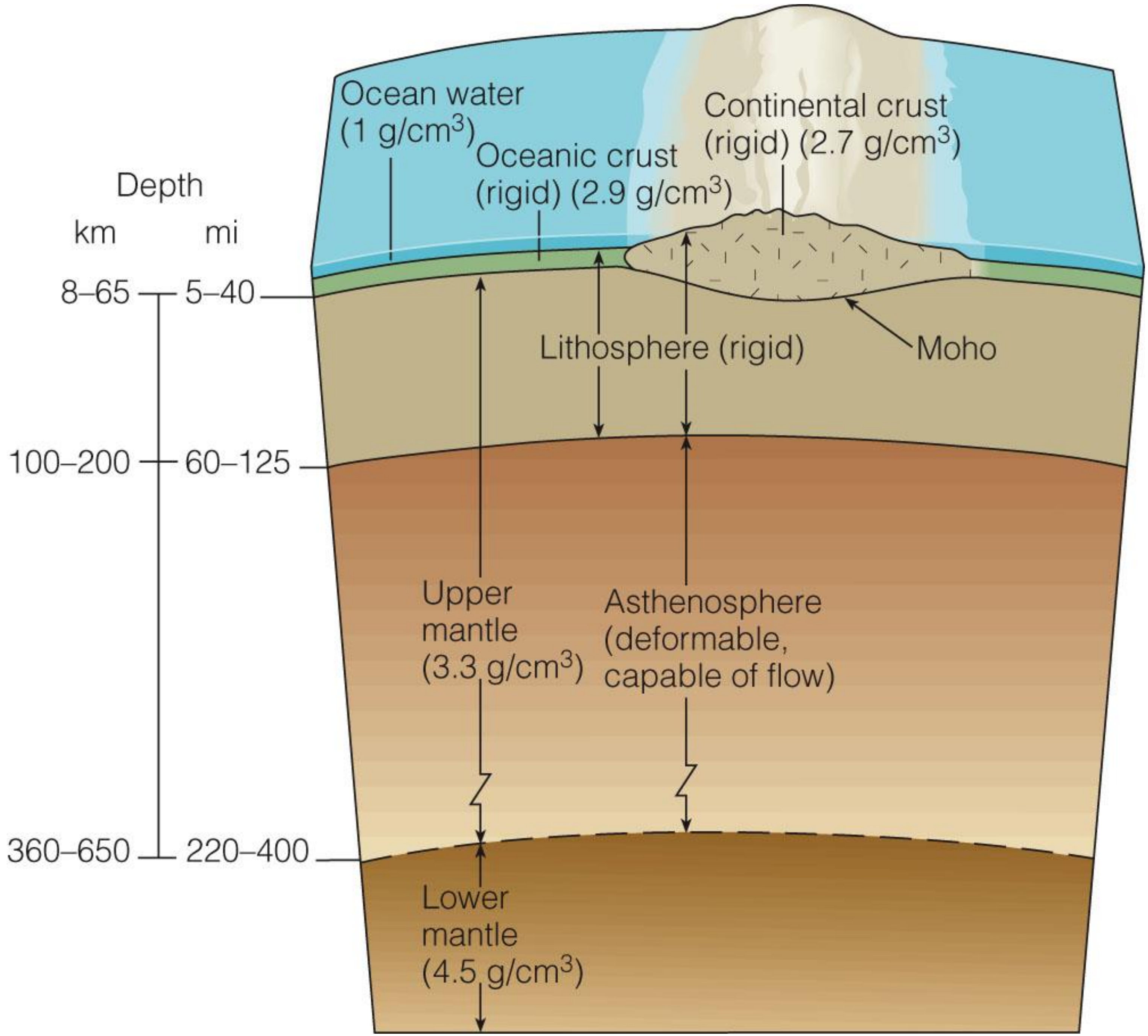
Overall, oceanic crust is basaltic compared to the andesitic composition of the continental crust. Importantly, the continental crust contains much less Fe, Mg and Ca and more Na, K and Si than the oceanic crust.


P-wave velocity/km s^{-1}
0
2
4
6
8
depth below ocean floor/km
2
4
6
8
sediments
layer 1
Basaltic Lava
layer 2
Gabbro
layer 3
mantle

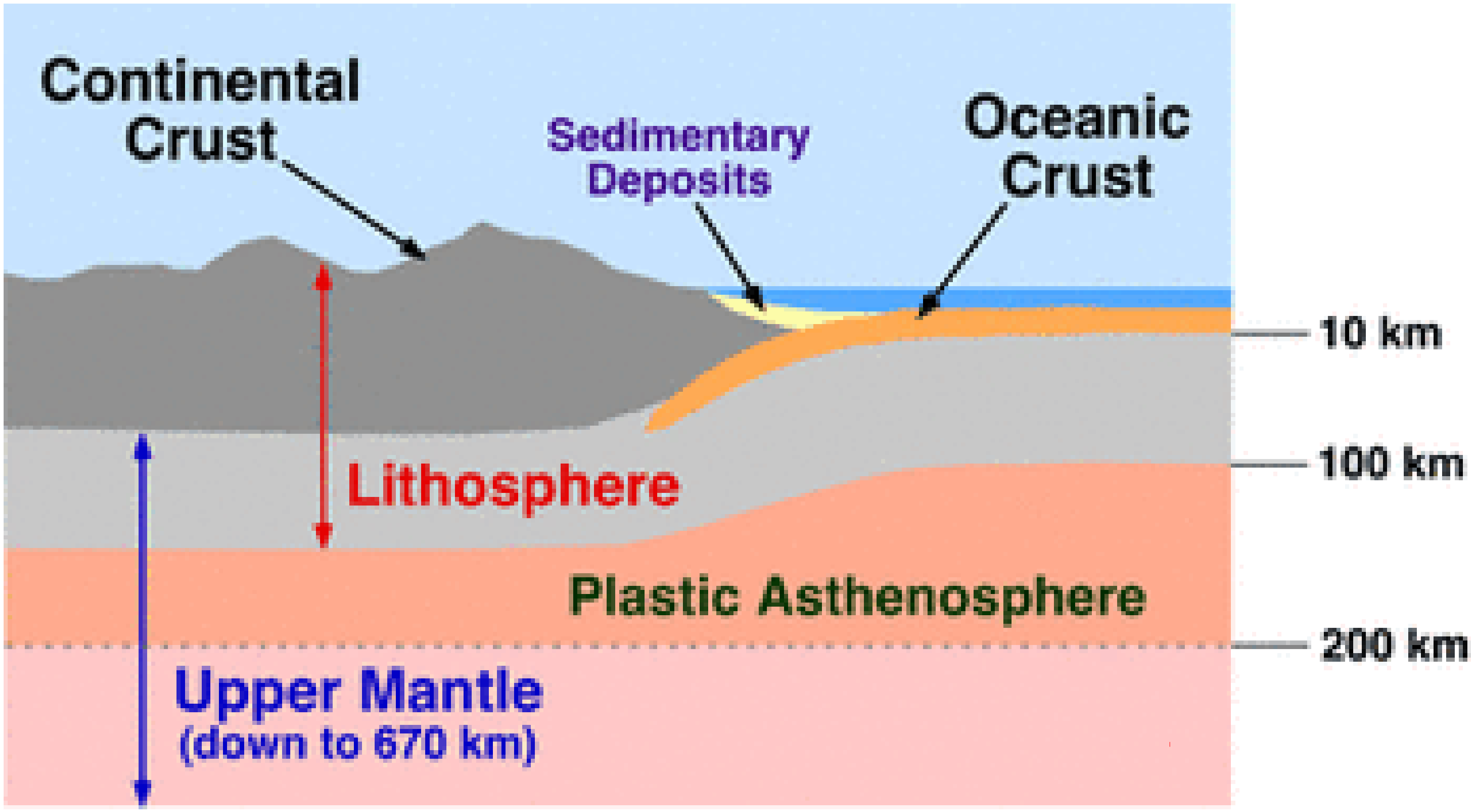
Earth is composed of solid rocks that behave in a rigid way,

At depth, rocks begin to behave more as fluids than as rigid solids, and when loaded with ice sheets, volcanoes or mountains they begin to flow. This leads to a new mechanical, as opposed to compositional, division of the outer layers of the Earth.

The rigid, cold surface layer is known as the **lithosphere** and it includes the crust and the uppermost mantle. Below this is the more mobile mantle known as the **asthenosphere** (from the Greek asthenos, meaning weak), which can deform like a viscous fluid when under stress.



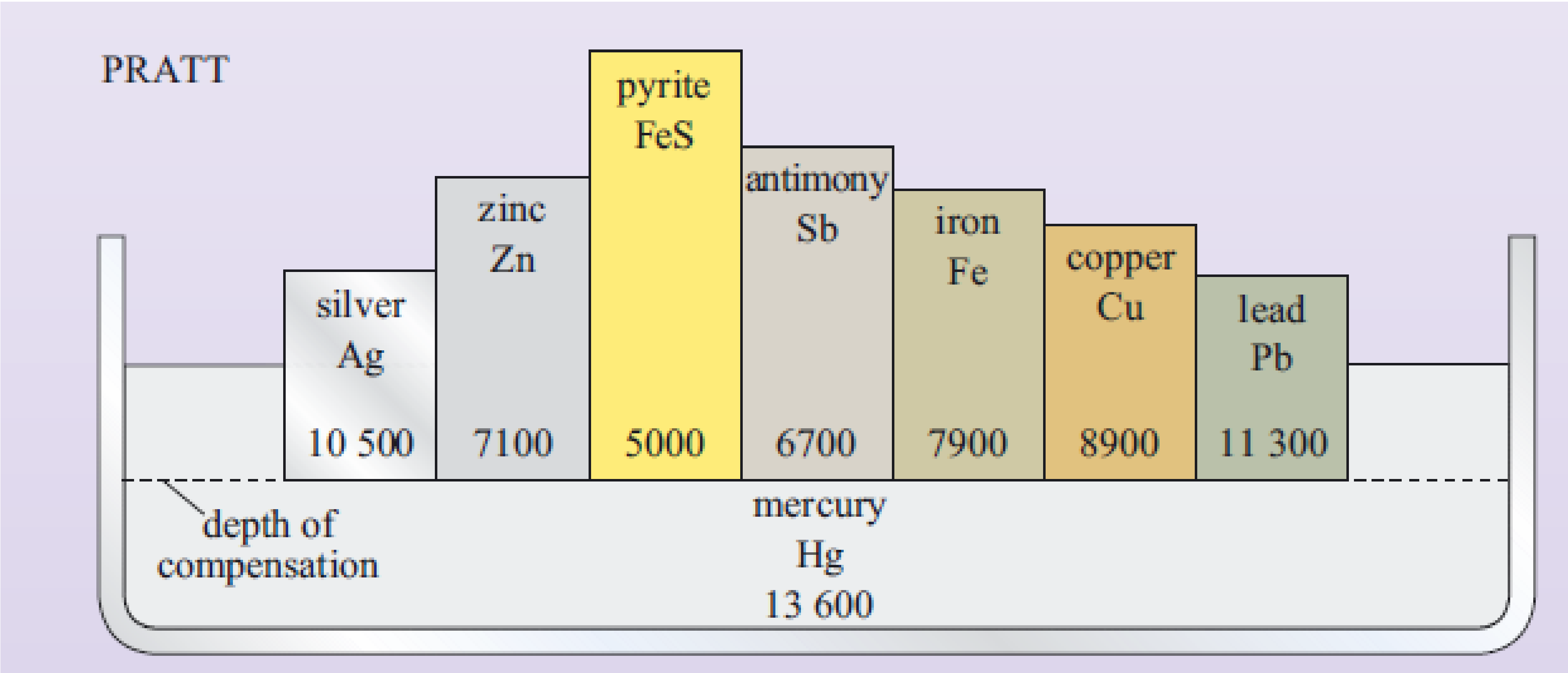
Ocean water
(1 g/cm3)
Continental crust
(rigid) (2.7 g/cm3)
Oceanic crust
(rigid) (2.9 g/cm3)
Depth
km
mi
8–65
5–40
Lithosphere (rigid)
Moho
100–200
60–125
Upper
mantle
(3.3 g/cm3)
Asthenosphere
(deformable,
capable of flow)
360–650
220–400
Lower
mantle
(4.5 g/cm3)



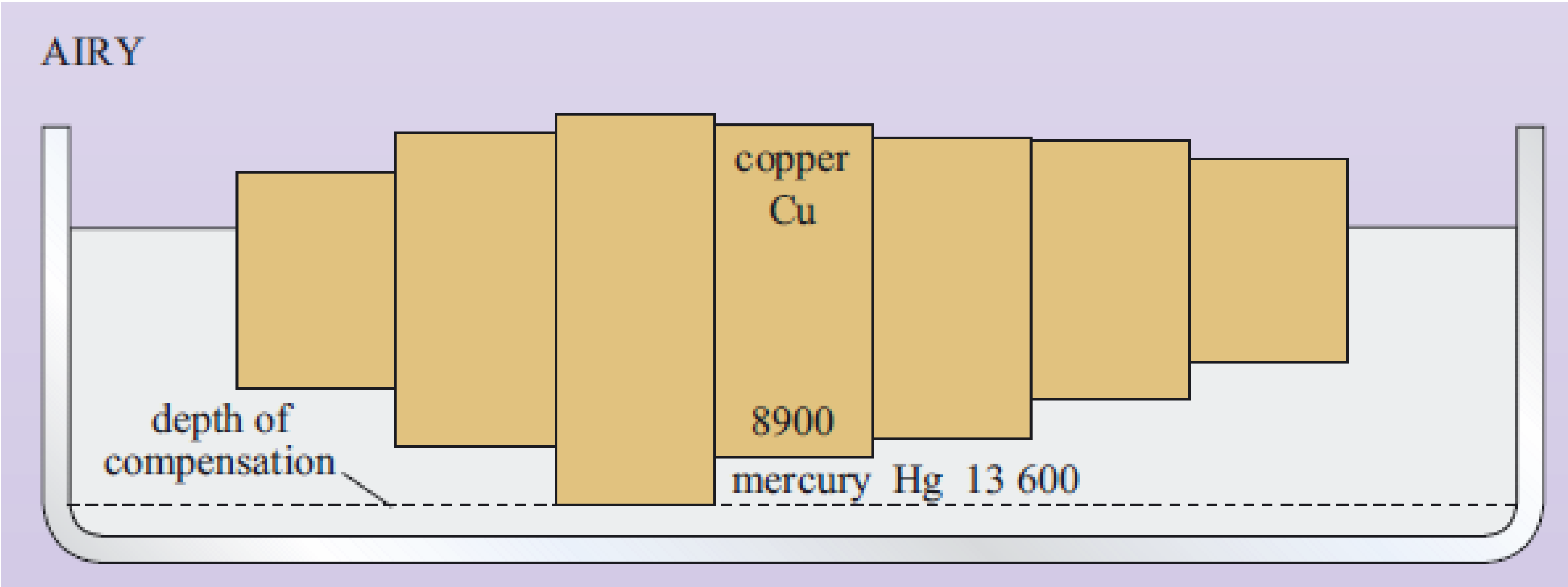
Continental Crust
Sedimentary Deposits
Oceanic Crust
10 km
100 km
Lithosphere
Plastic Asthenosphere
200 km
Upper Mantle
(down to 670 km)

When a load is applied to the Earth's surface, the lithosphere subsides into the underlying asthenosphere; by contrast, when the load is removed the lithosphere rises again.

In essence this is simply Archimedes principle applied on a grand scale, but when considering the Earth it is known as isostasy and it controls the surface topography of the Earth.



The principles of isostasy: (a) a series of metal blocks with different densities (numbers indicate densities in kg m–3) floating in a container of mercury; (b) copper blocks of varying lengths floating in mercury. Note the differences in the depth of compensation.


AIRY
copper
Cu
8900
depth of
compensation
mercury Hg 13 600