Heat transfer within the Earth

Three main mechanisms of heat transfer operate within the Earth; these are **conduction, convection and advection**.

Conduction- the most familiar mechanism, since it is the process of heat transfer experienced when the handle of a pan becomes hot.

Convection -involves the movement of hot material from regions that are hotter to those that are cooler and the return of cool material to warmer regions.

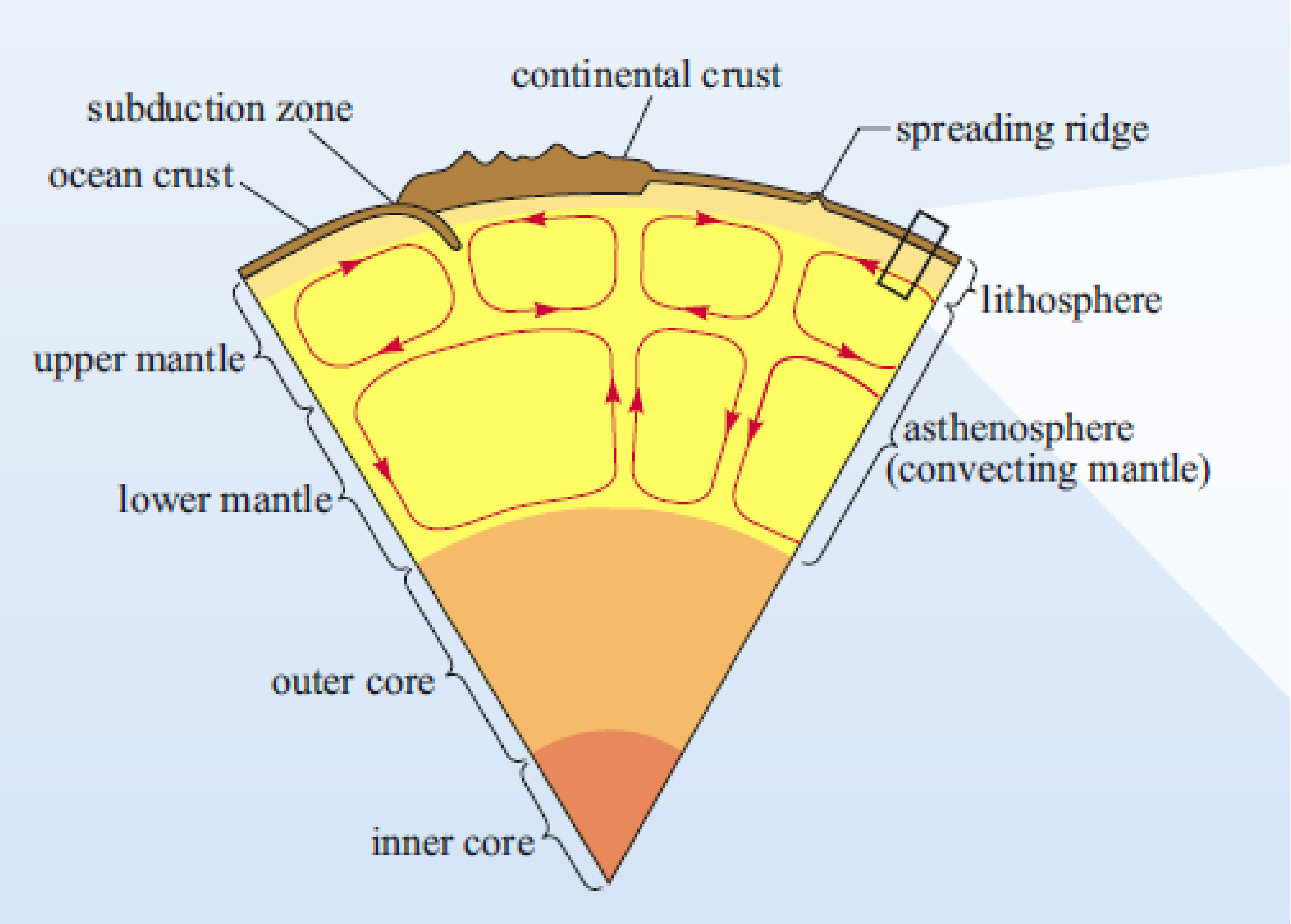
Advection -The final process of transferring heat is when molten material (magma) moves up through fractures in the lithosphere and remains there. This is termed advection and operates when magma spreads out at the surface as a lava flow or, if it is injected, cools and crystallises within the lithosphere itself.

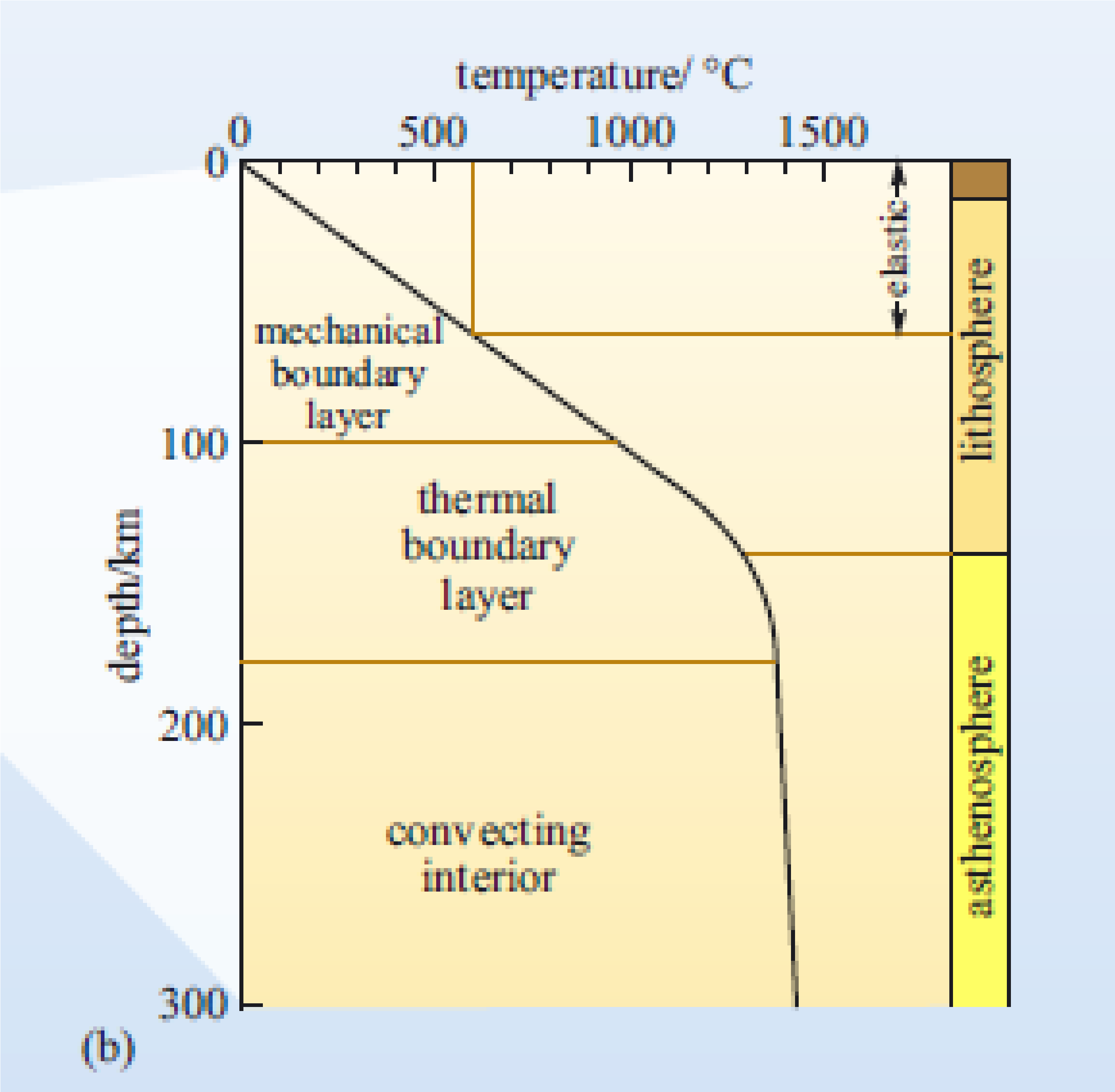
The effect is the same in both cases, since heat is transferred by the molten rock from deeper levels where melting is taking place to shallower levels where it solidifies, losing its heat by conduction into the overlying crust.

Under the conditions prevailing deep within the Earth
the solid rocks of the mantle can flow when subject to surface loads, leading to isostatic readjustment of surface elevations.

The mantle can also flow when subject to temperature differences in a process known as solid-state convection and, whilst rates may be no more than a few centimetres per year, it is the most efficient form of heat transfer within all but the outermost part of the mantle.

Near the Earth's surface the rocks are too cold and rigid to permit convection, so conduction is the most significant process.


continental crust
subduction zone
spreading ridge
ocean crust
lithosphere
upper mantle
asthenosphere
(convecting mantle)
lower mantle
outer core
inner core


temperature/ °C
0
500
1000
1500
0
100
200
300
depth/km
elastic
lithosphere
asthenosphere
mechanical
boundary
layer
thermal
boundary
layer
convecting
interior
(b)

The age of the Earth and its layers

Earth has been given as being around 4.6 Ga.
But where is the evidence for this?

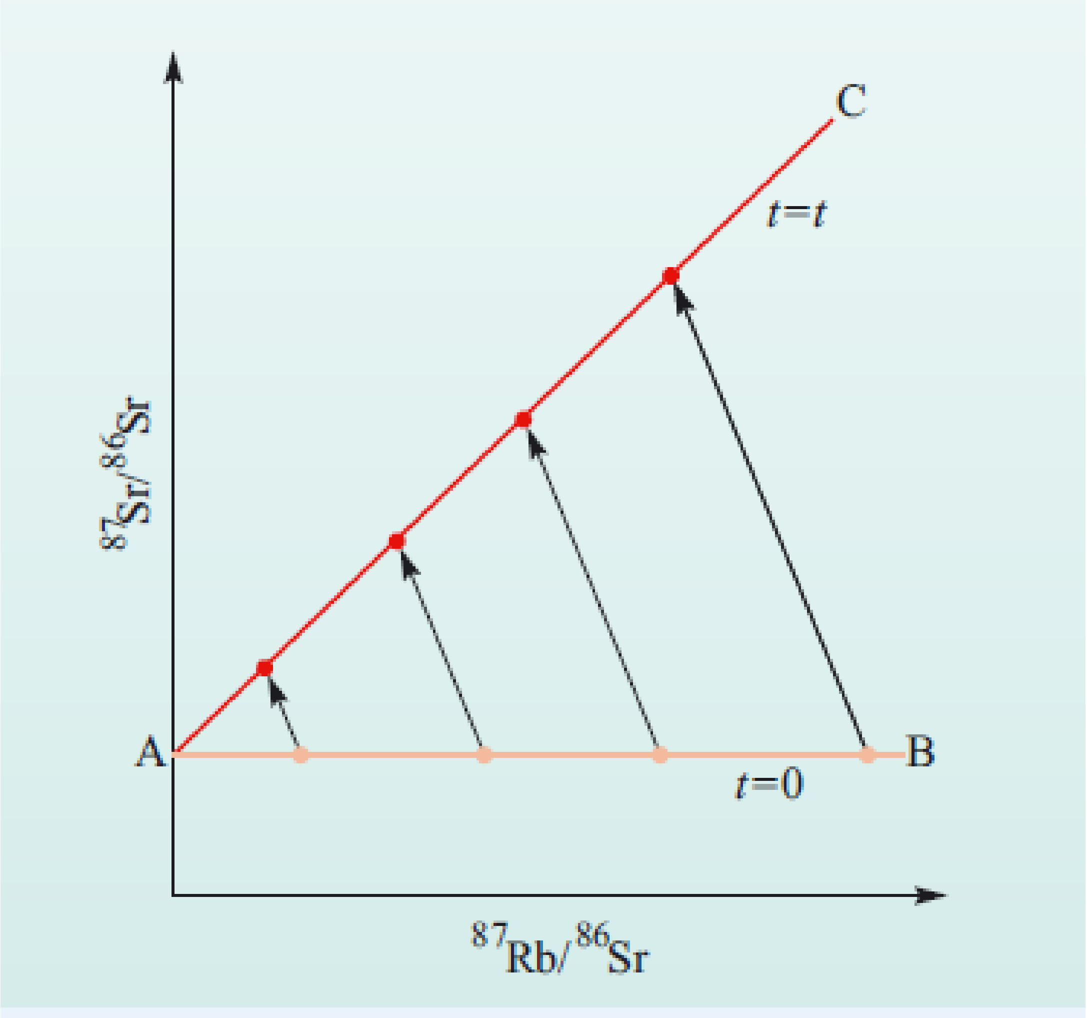
To find out just how old the Earth is we once again have to return to meteorites and radioactivity, for, in addition to being sources of heat in planetary systems, radioactivity also allows absolute ages to be determined from measurements of long-lived radioactive isotopes and their daughters.

Example- U-Th-Pb, K-Ar, Rb-Sr, Sm-Nd

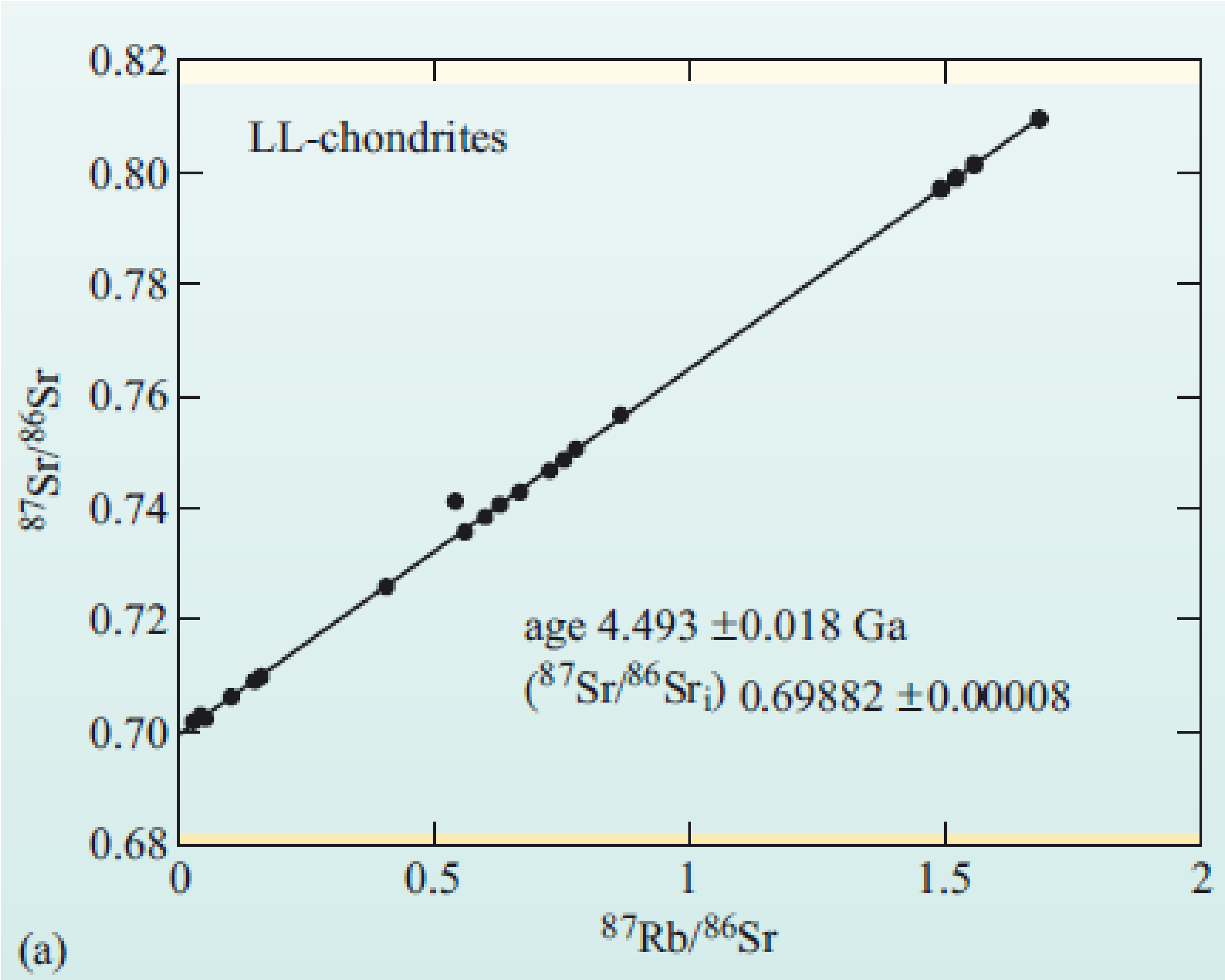
Radioactivity applied to dating

$$^{87}Sr = {}^{87}Sr_i + {}^{87}Rb(e^{\lambda t} - 1)$$

$$\underset{y}{\left(\frac{^{87}Sr}{^{86}Sr}\right)_P} = \underset{c}{\left(\frac{^{87}Sr}{^{86}Sr}\right)_i} + \underset{m}{\left(e^{\lambda t} - 1\right)}\underset{x}{\left(\frac{^{87}Rb}{^{86}Sr}\right)}$$



C
t=t
A
B
t=0
87Sr/86Sr
87Rb/86Sr

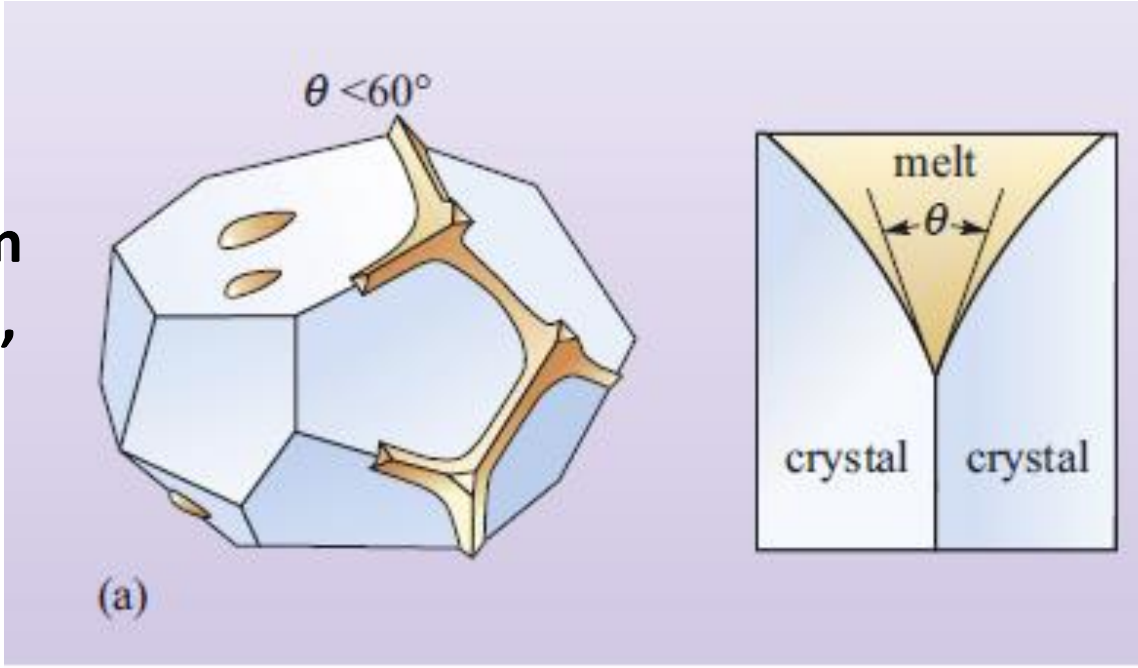


LL-chondrites
age 4.493 ±0.018 Ga
(87Sr/86Sri) 0.69882 ±0.00008
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
87Sr/86Sr
0
0.5
1
1.5
2
87Rb/86Sr
(a)

Core formation and magma oceans

One potential mechanism for Fe–Ni metal separation or **segregation** is that the metal melts and forms an interconnected network.

Dihedral angle, θ
The dihedral angle
is that formed by the liquid in contact with two solid grains, which in the case of the mantle will be silicate or oxide grains.



If θ is <60°, the melt will fill channels between the solid grains and form an interconnecting network, even in small melt fractions.
If θ is >60°, the melt is confined to pockets at grain corners and cannot easily move, unless the melt fraction is greater than 10%.

If melt is able to connect, its rate of migration is quite rapid, and can be calculated using Darcy's law:

$v = (k/\eta)\ \Delta\rho\ g$,
$\Delta\rho$ is the density difference between silicate melt and solid
v is the velocity of the melt relative to the solid matrix,
k is the permeability, η is the viscosity of the melt measured in Pa s,
Permeability can be defined as:
$K=a^2\Phi/24\pi$
where a is the mean grain radius and Φ is the melt fraction.

Question

Taking a grain radius, a, of 10^–3 m (1 mm), Φ of 0.1 (10% volume melt), Δρ of 3500 kg m^–3, g of 9.8 m s^–2 (the acceleration due to gravity on Earth) and a viscosity, , η of 0.005 Pa s, calculate the migration velocity of Fe–Ni metal (give your answer in kilometres per year). (Note: 1 Pa s = 1 kg m–1 s–1)

If θ is >60° then melts will be isolated at grain corners, creating an impermeable silicate framework through which metallic melts cannot segregate.
For this reason core formation is thought by many to occur only after the silicate framework has broken down after extensive silicate melting (>40%).

At these high degrees of melting the grain boundary framework will no longer be interlocked, but rather crystals will be floating in a silicate liquid – a crystal mush.

In such a mush, dense molten metal droplets would sink, but to achieve such high degrees of melting requires enormous amounts of heat.

It is important to note that there is no independent evidence that a magma ocean ever existed on Earth.

Any early formed crust has long since been destroyed by impacts, erosion and plate recycling.

The evidence also suggests that the Earth had a huge proto-atmosphere, formed by degassing of the Earth’s interior.

This would have provided a thermal blanket that retained the heat generated during accretion and sustained the magma ocean.