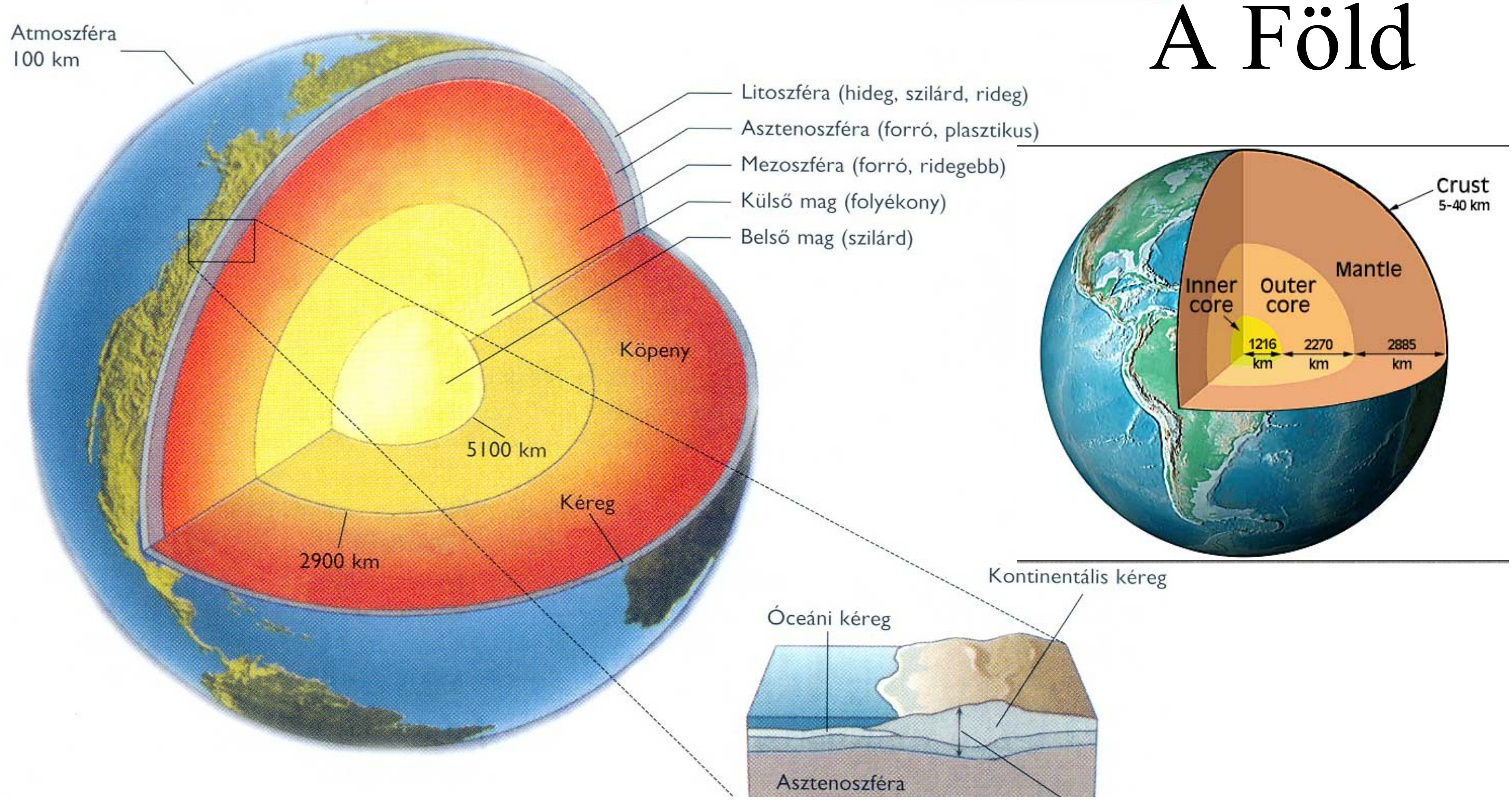
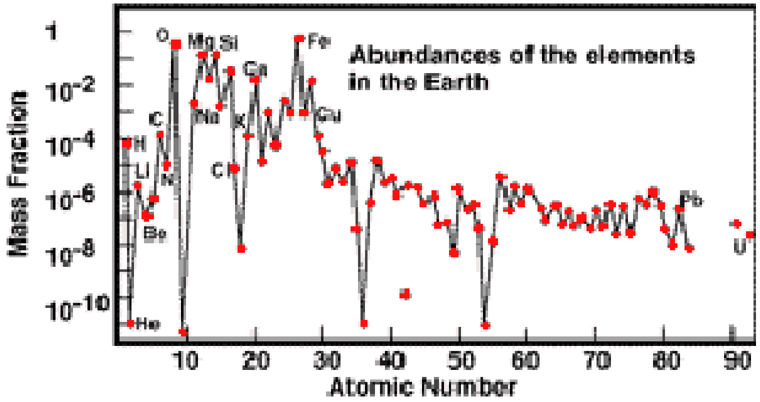
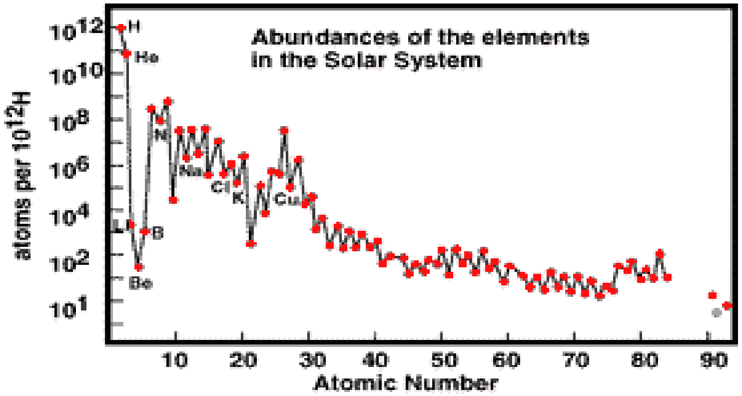
A Föld geokémiája

A Föld



A Föld belső övei. A külső merev litoszférát a szilárd, de képlékeny („gyenge”) asztenoszféra követi, majd a mezoszféra ismét ridegebb. Az alatta lévő külső mag folyékony, majd a belső mag – bár kémiai összetétele hasonló a külső magéhoz - az óriási nyomás miatt szilárd. A litoszférán belüli kéreg kontinentális és óceáni kéregre tagolható.

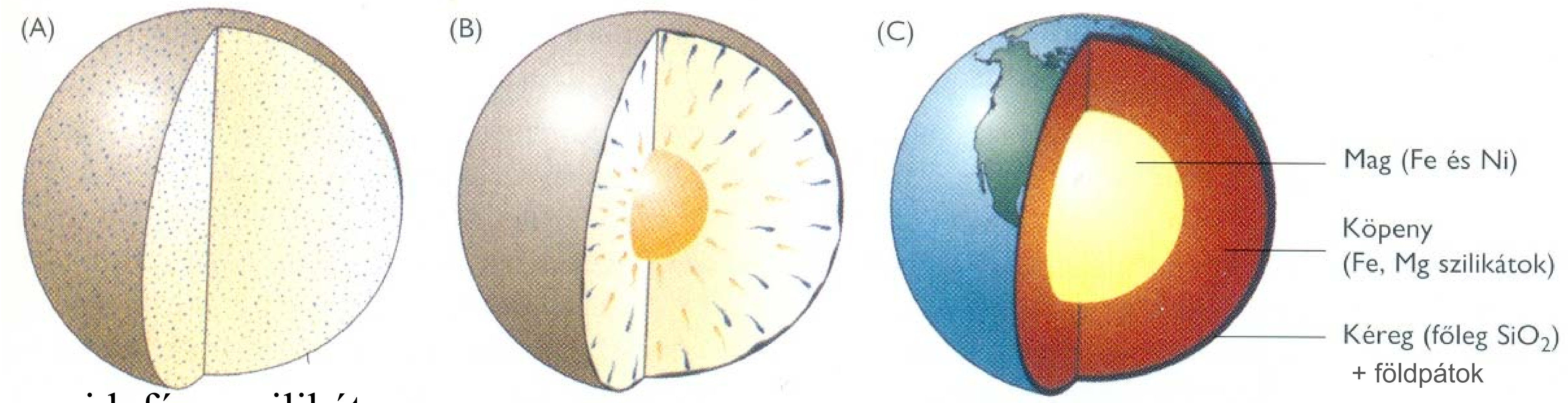




O - 62.5% (atomic %)
Si - 21.2%
Al - 6.5%
Fe - 1.9%
Ca - 1.9%
Na - 2.6%
K -1.42%
Mg - 1.84%

Note that the ordinate for the Earth Abundance diagram is given in terms of mass fraction (all elements together would make up 1, or 100%; note that Oxygen and Iron are the two most abundant in/on/above the Earth. The Solar Abundance ordinate compares all elements to Hydrogen (as scaled to an arbitrary H = 10^{12} atoms).

A Föld kémiai összetétele



oxid, fém, szilikát

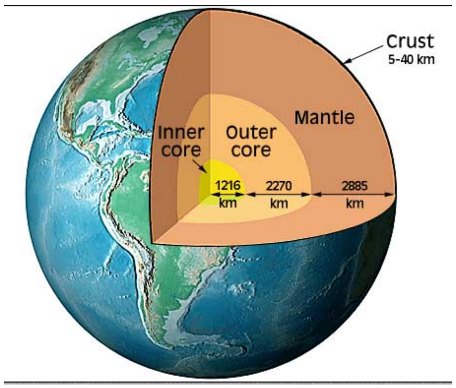
Szilárd, homogén
4 560 millió év

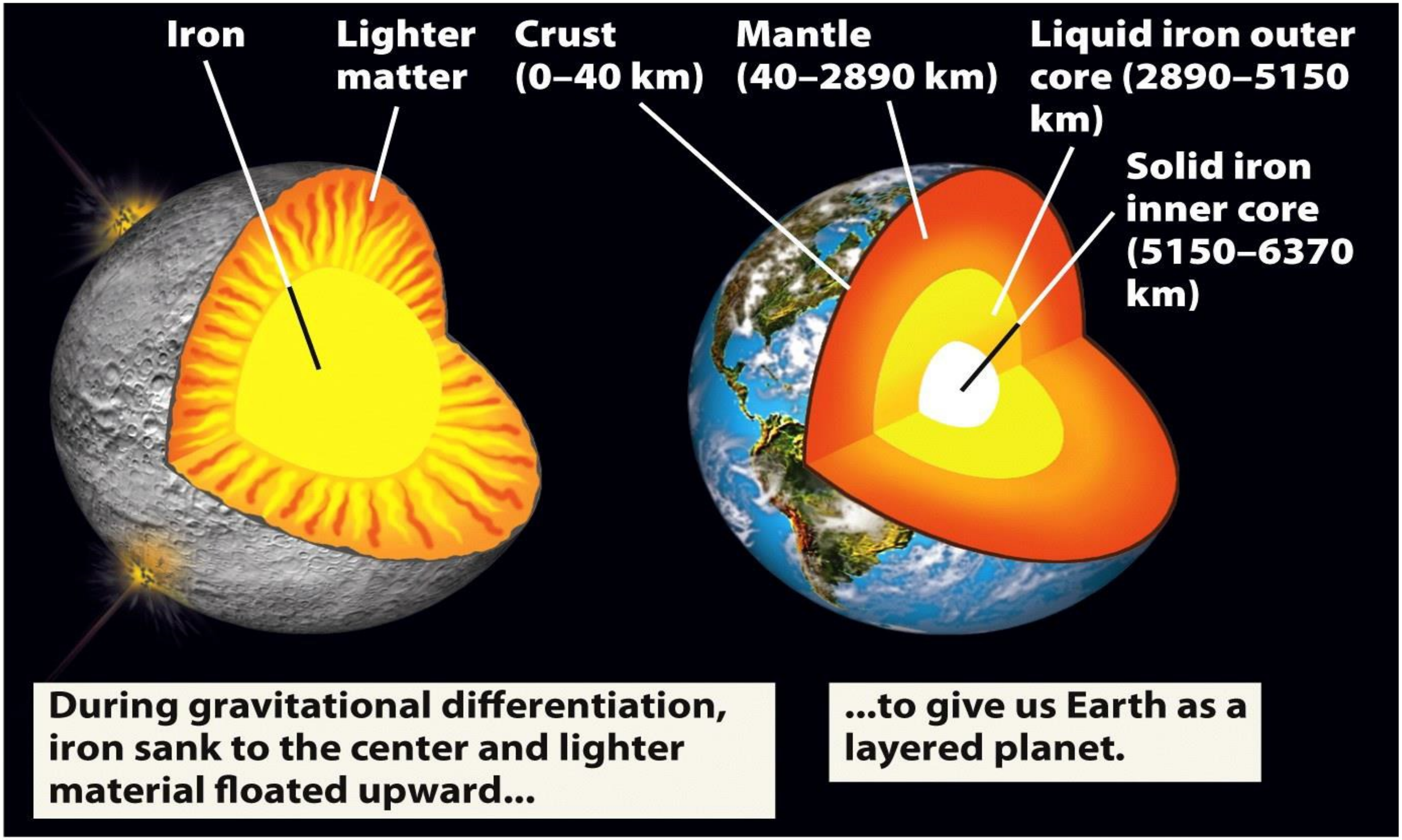
→

Olvadás, majd
mag/köpeny
differenciáció
(magmaóceán)
4 530 millió év

→

További differenciáció (a kéreg képződése ma is tart), hosszú folyamat, az elkülönülés során a nehéz elemek a magban, a könnyebbek a külső övben koncentrálódtak





During gravitational differentiation, iron sank to the center and lighter material floated upward...

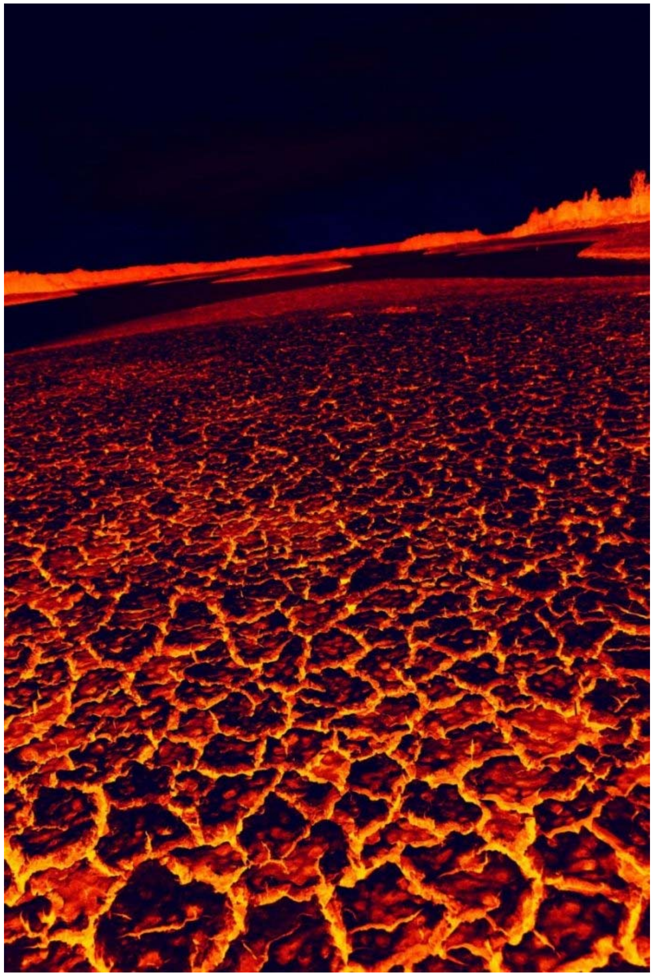
...to give us Earth as a layered planet.

Figure 9.5
Understanding Earth, Sixth Edition

Formation of Earth

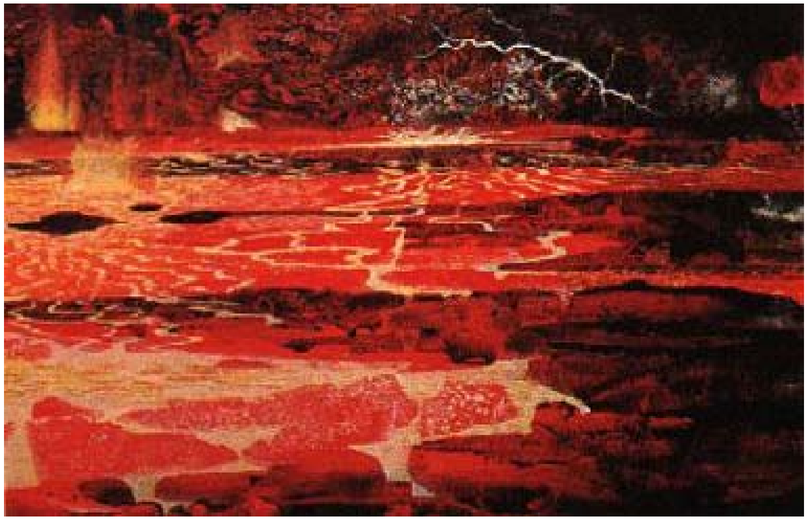
- *Planets formed by accretion of smaller objects = impact*
- *Very tiny objects hold together by atomic forces*
- *Objects kilometers across hold together by gravity*
- *How do objects the size of a refrigerator hold together?*
- *As planets get bigger, gravity gets stronger, impacts get more violent*
- **Big impacts throw out ejecta, trap heat**
- **Magma ocean**
- **Formation of core early in earth history as iron sinks**

Magma óceán




teljes olvadás → magma ócean, vagy
parciális olvadás → szilárd komponens az ‘alsóköpeny”-ben
(a vasmeteoritok alapján inkább az előzőnek van nagyobb valószínűsége)

Magma Ocean

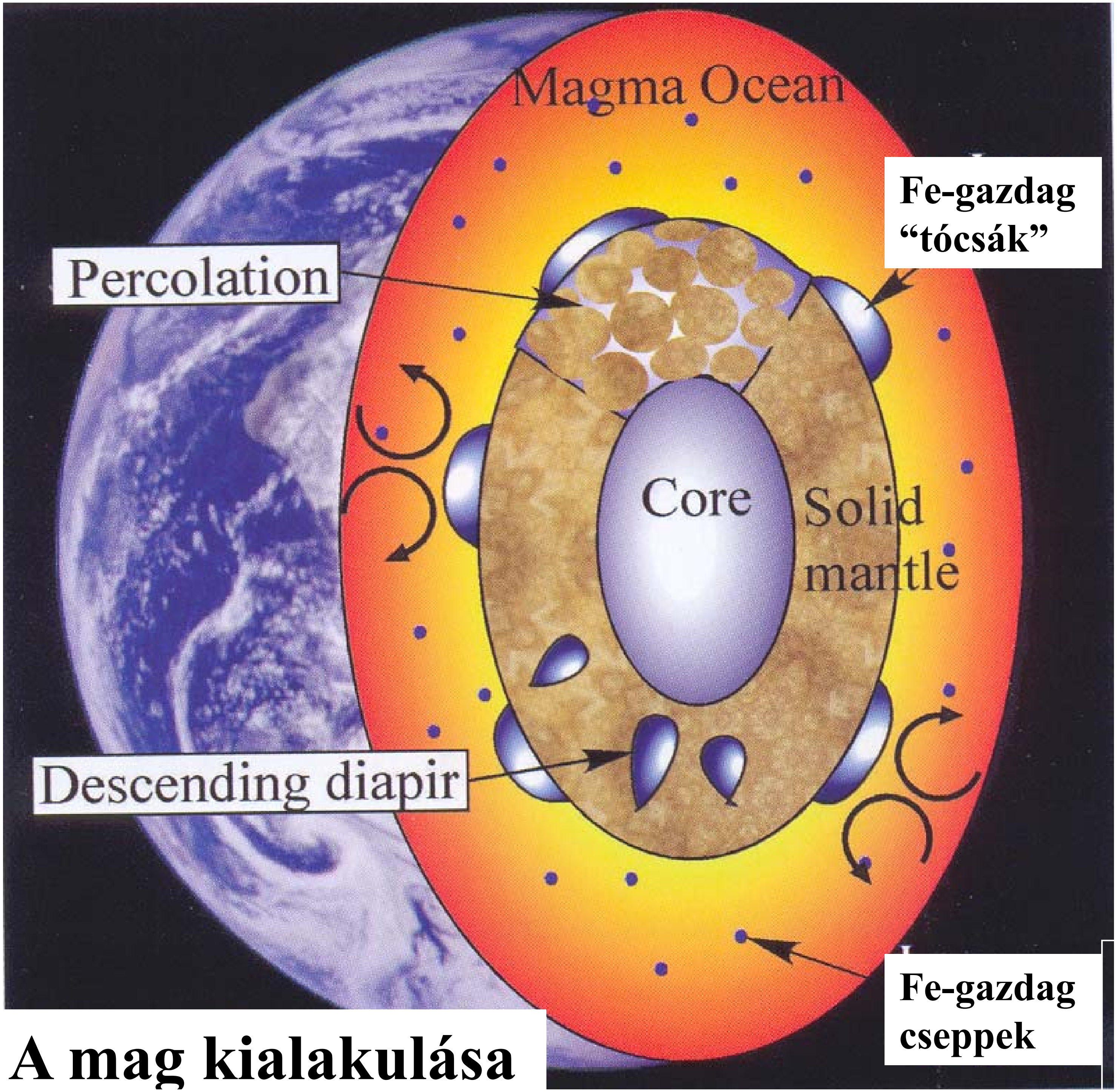


Various planetologists argue about the "completeness" of this melting - some restricting it to just the outer layers, forming the so-called "magma ocean", others accepting partial melting. The indication that the core is almost all metallic iron + nickel, a deduction based in part on the nickel-iron meteorites that presumably were involved in another, now disrupted planet, would be most easily explained by complete melting. This illustration is a conception of the early Earth surface as a partial magma ocean with "islands" of cooler solid bodies.

It is reasonable to assume, in this model, that the magma oceans cooled sufficiently to form a thin solid crust of compositions similar to today's basic igneous rocks (principally basalts at and near the surface and gabbros and ultrabasics [e.g., pyroxenites] at greater depths). Parts of such a crust floundered, much like the crusts on the lake in Halemaumau Crater at the summit of today's Hawaii's Kilauea Iki volcano.

Hawaii's Kilauea volcano

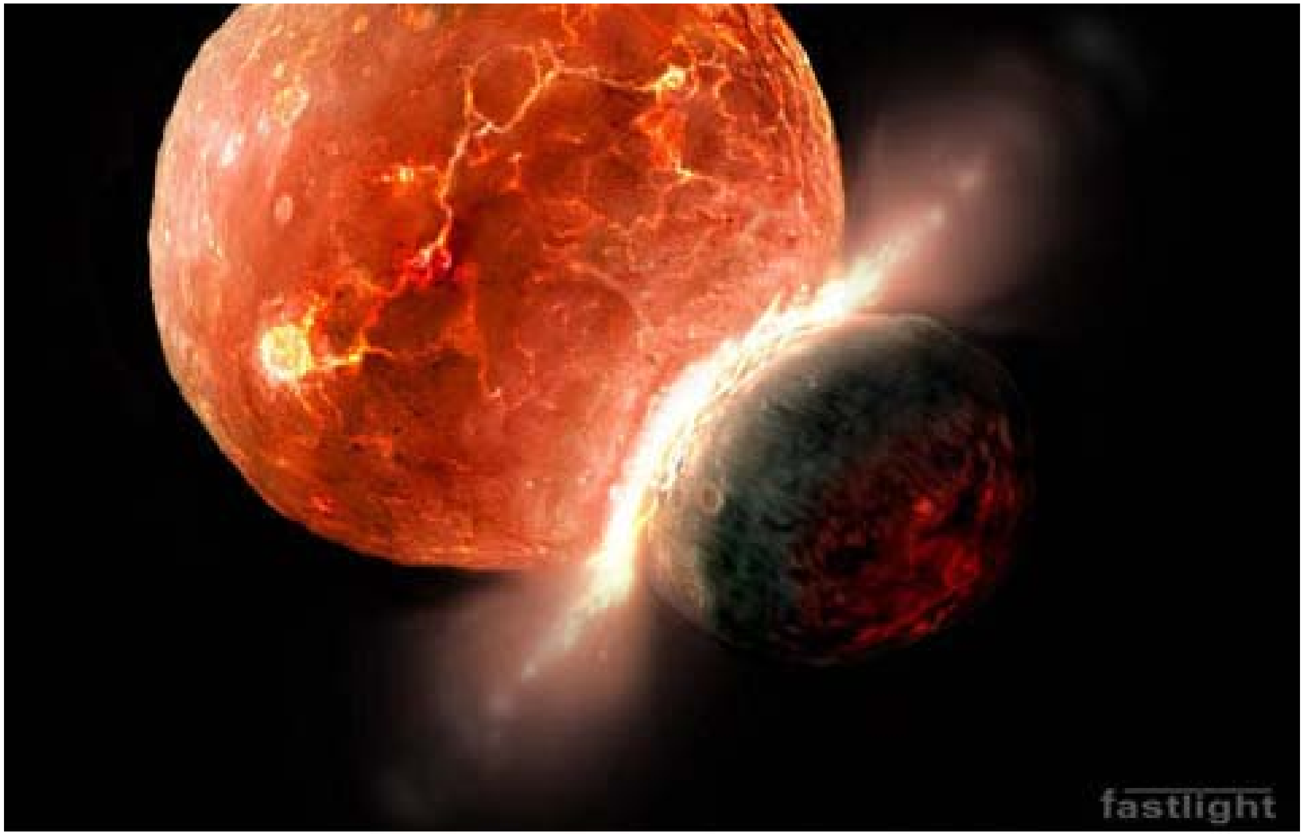
A mag kialakulása



Mélyen áramló magma óceánban a folyékony Fe-gazdag fém cseppek elkülönülnek a folyékony Si-gazdag olvadéktól és Fe-gazdag “tócsákban” akkumulálódnak a szilárd alsó köpenyen.

A felhalmozódott folyékony Fe lesüllyed a proto-magba vagy nagy diapirként (kis kémiai kölcsön-hatással) vagy szemcseközi perkolációval a polikristályos alsó köpeny szilikáton át.

Elsődleges, gravitációs differenciáció

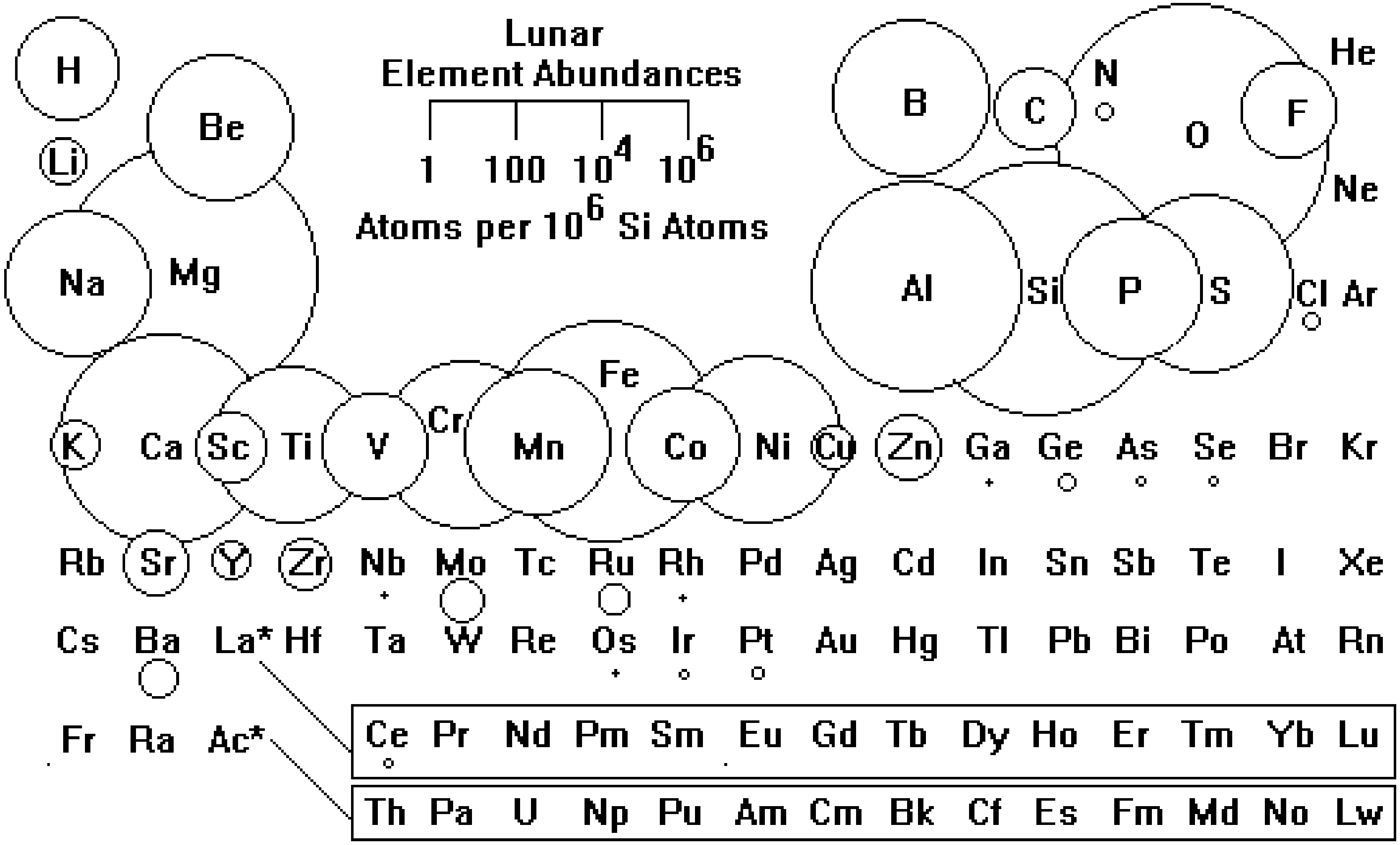


During the final stage of assembly of the inner planets, large planetary embryos accreted to each other, as depicted in this painting by James Garry. All were of substantial size (Moon to Mars size), so the accretionary impacts must have caused a lot of heating. The Moon formed from one such event in which the impactor was offset just the right amount to hurl melted and vaporized rock into orbit.

Mars méretű meteorit becsapódás -

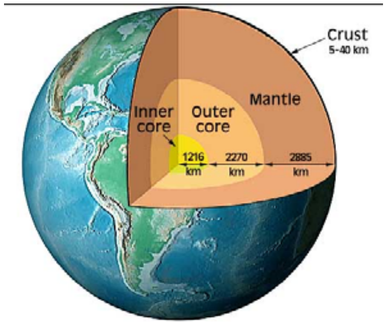
A Hold keletkezése

A Hold



The Moon looks quite **different from chondritic material** and the continental crust. **H** is enormously depleted, reflecting the almost total absence of water on the Moon. Among the **metals (Pb, Ga, Ge)**, the right side of the Periodic Table (+Cd, In, Hg, Tl, Pb, Bi, Sb, Te) is strongly depleted. These elements tend to be more volatile, and the Moon is **strongly depleted in volatile materials**. Generally, the lower the boiling point of an element, the lower its abundance on the Moon.

Goldschmidt-féle geokémiai csoportosítás



Sziderofil elemek:

affinitás folyékony fém fázishoz; vaskedvelő, terméselemekben, ötvözetekben → magban

Kalkofil elemek:

affinitás folyékony szulfid fázishoz; kén- (+Se- és As-) kedvelő, szulfidokban → köpenyben (szilikát-szulfid elkülönülés)

Litofil elemek:

affinitás szilikát fázishoz; kőzetkedvelő, szilikátokban és oxidokban → kéregben, köpenyben

Atmofil elemek:

erősen illók → hidro- és atmoszférában

Biofil elmek: *élőlényekben (H, O, N, C, P)*

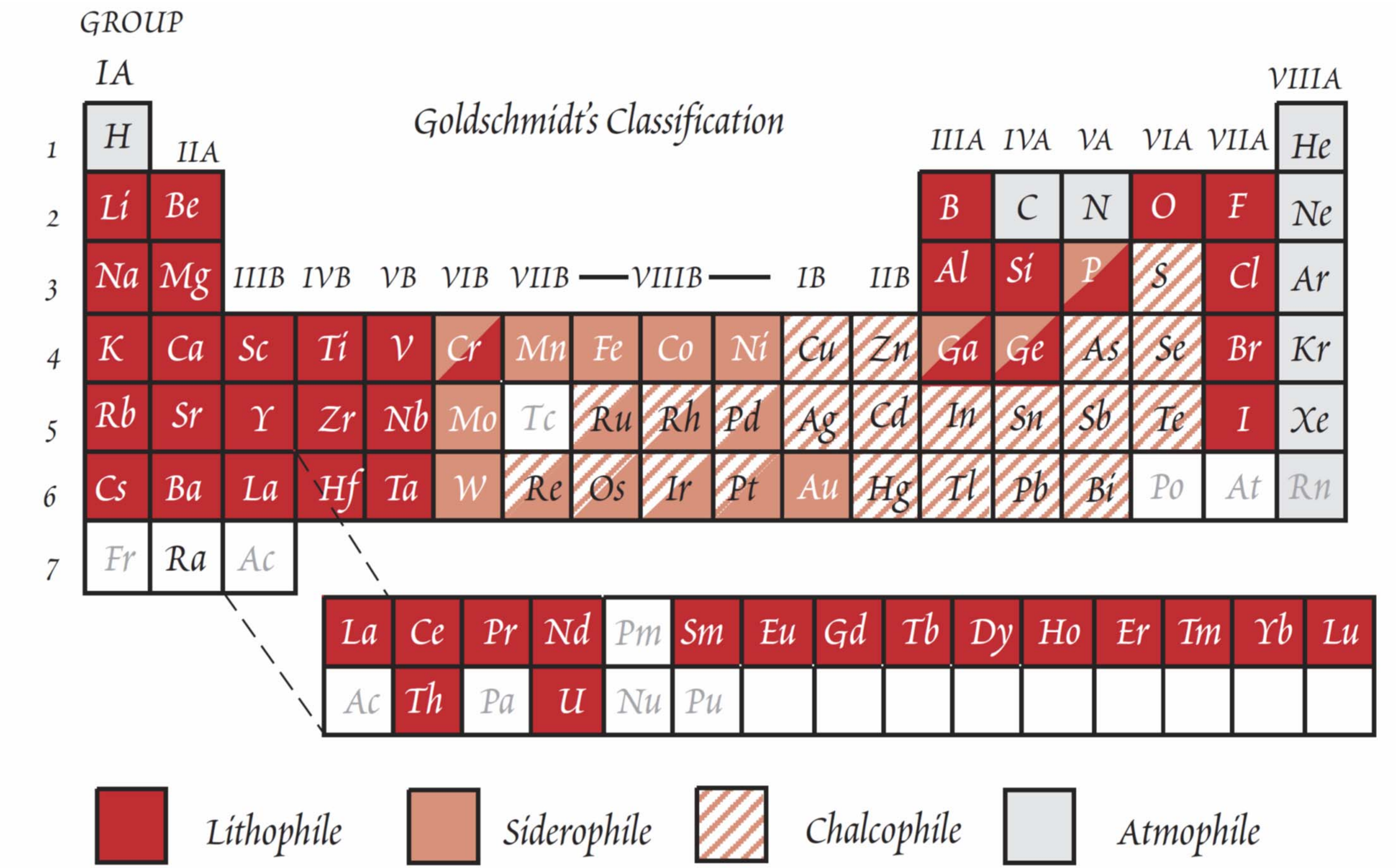
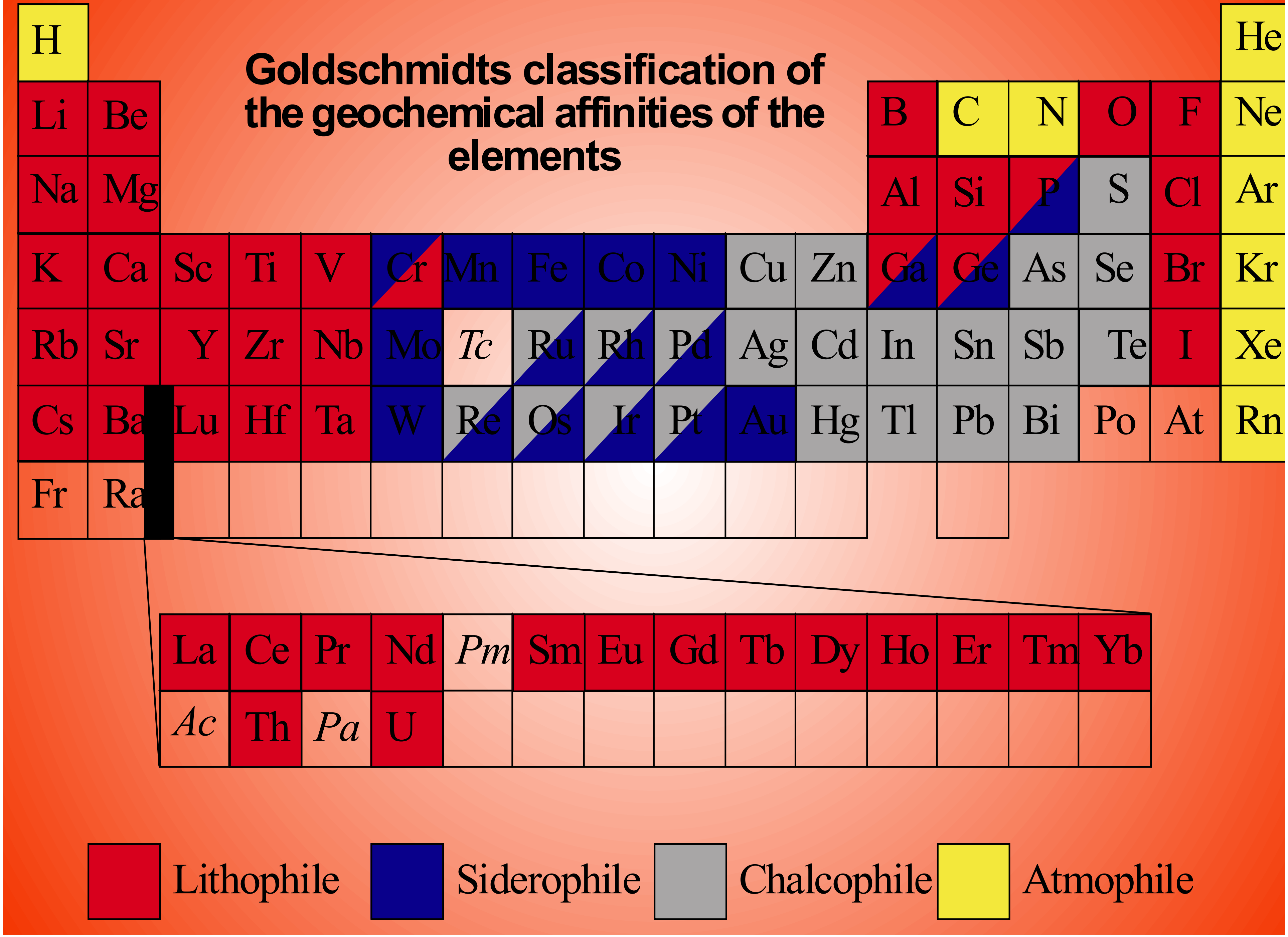


Figure 7.2. Goldschmidt's classification of the elements.

White, 2007

Goldschmidts classification of the geochemical affinities of the elements

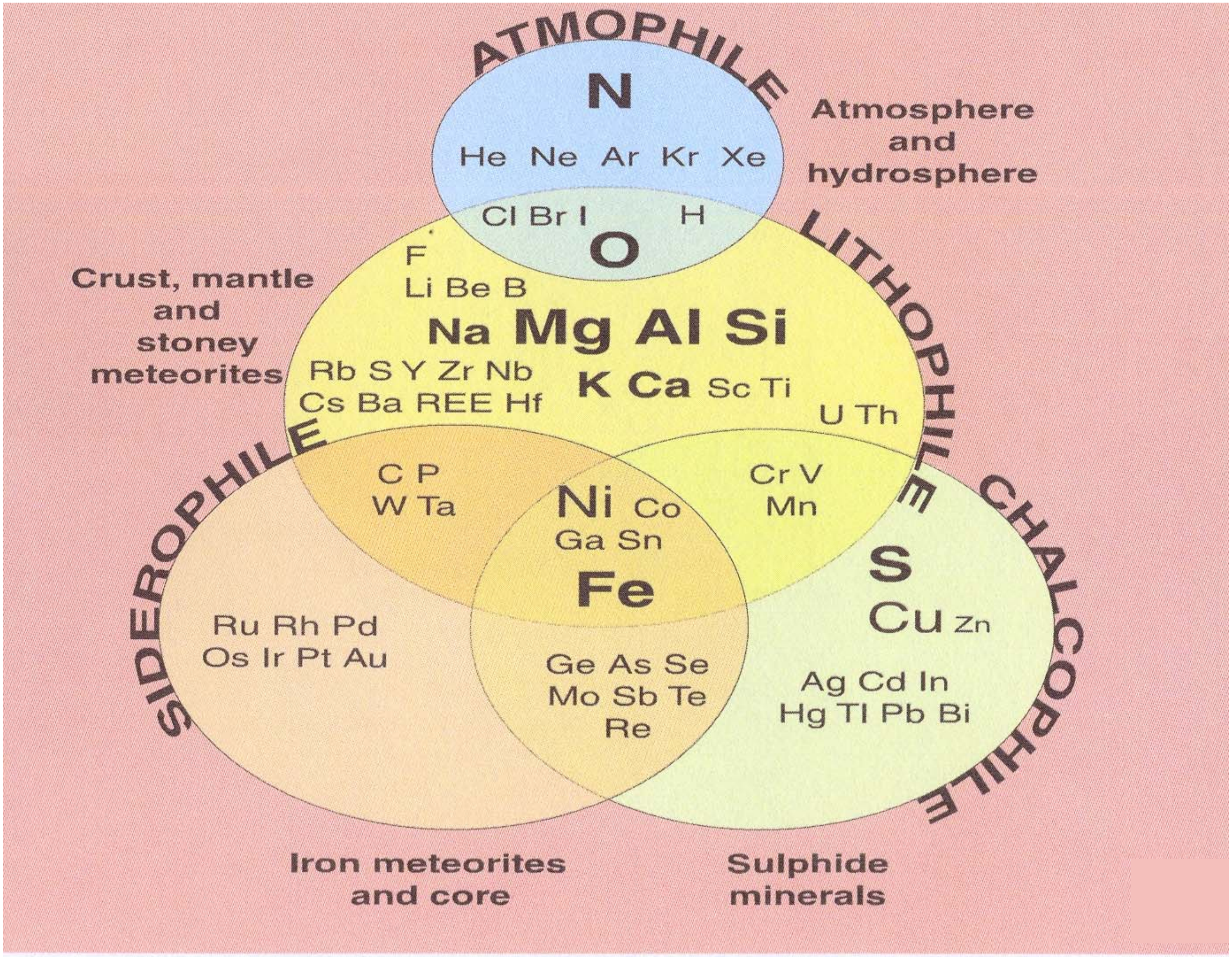


🟥 Lithophile

🟦 Siderophile

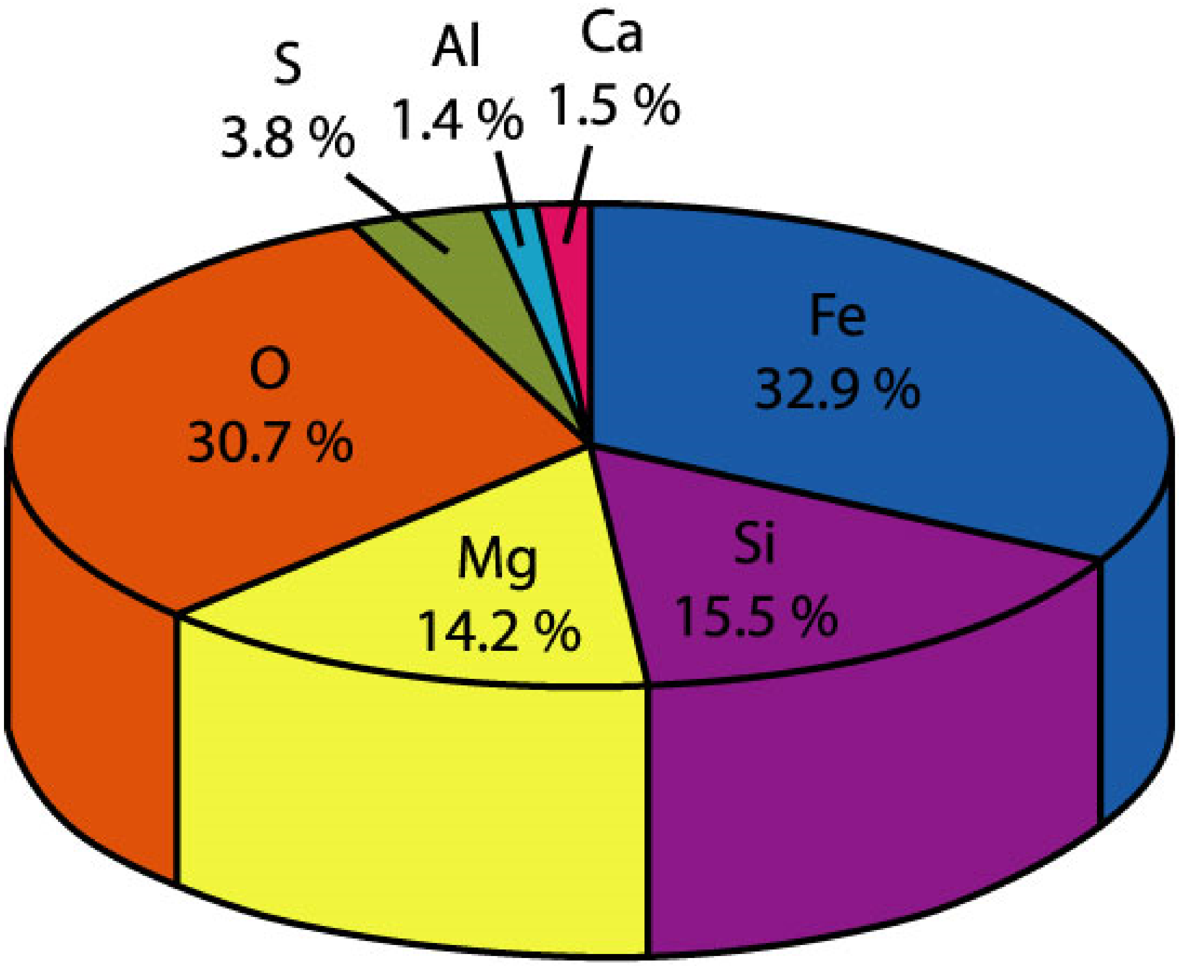
⬜ Chalcophile

🟨 Atmophile



A schematic diagram of the affinities of the elements. Note that size of print approximates to concentration.

A hét leggyakoribb elem a Földben

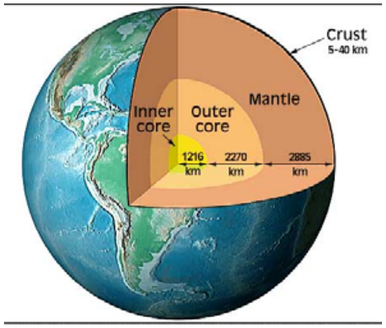


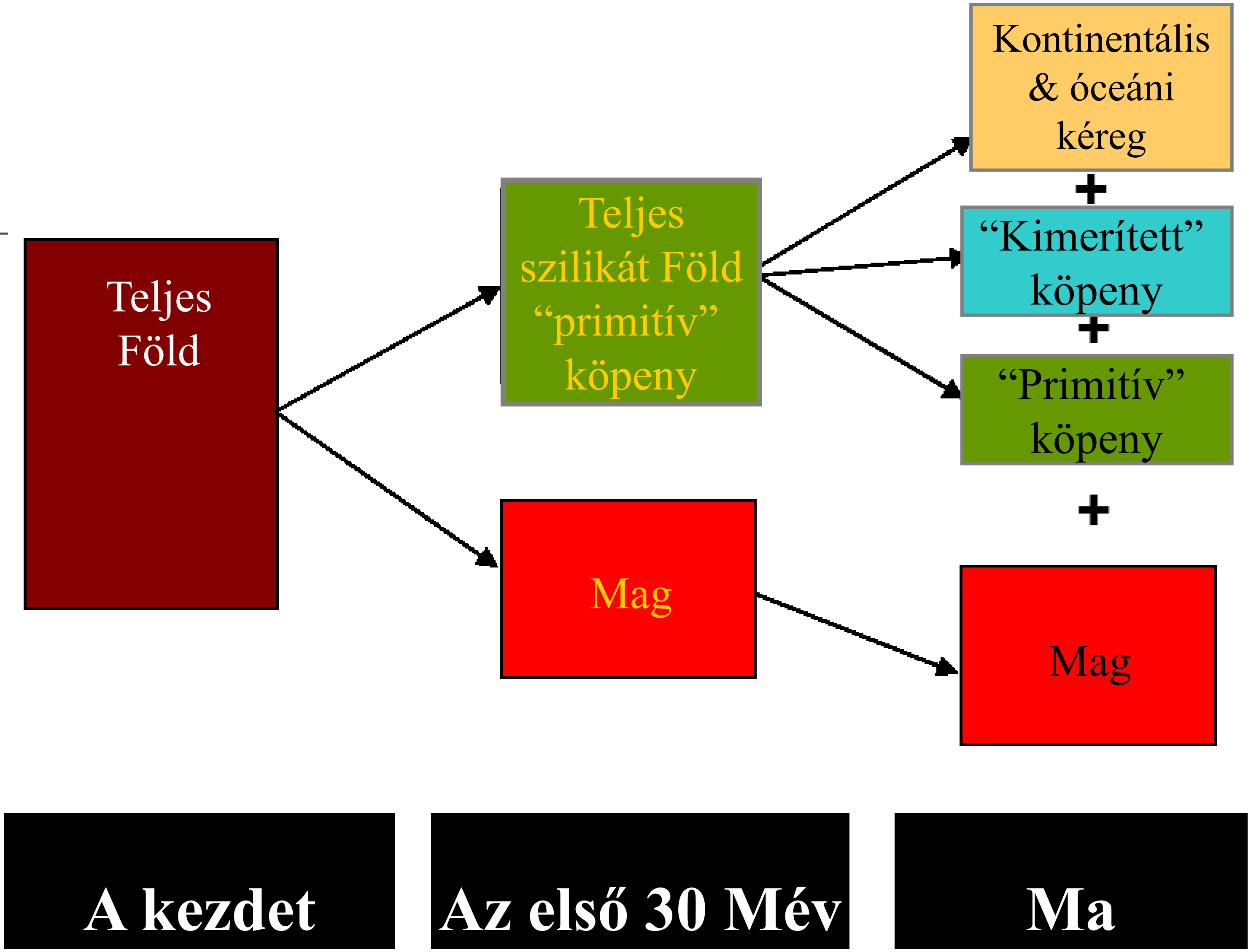
Mg, Si, Fe és O
> 90%-ban a
Föld tömegéhez

Refrakter?
Volatil?
Mag/köpeny?

Relative atomic abundances of the seven most common elements that comprise 97% of the Earth's mass. An Introduction to Igneous and Metamorphic Petrology, by John Winter , Prentice Hall.

A Föld teljes összetétele





Teljes Föld

Teljes szilikát Föld “primitív” köpeny

Mag

Kontinentális & óceáni kéreg

+

“Kimerített” köpeny

+

“Primitív” köpeny

+

Mag

A kezdet

Az első 30 Mév

Ma

Figure 2.4. Schematic diagram illustration the simple concept of determining the bulk composition of the Earth by adding up all the reservoirs that have formed.

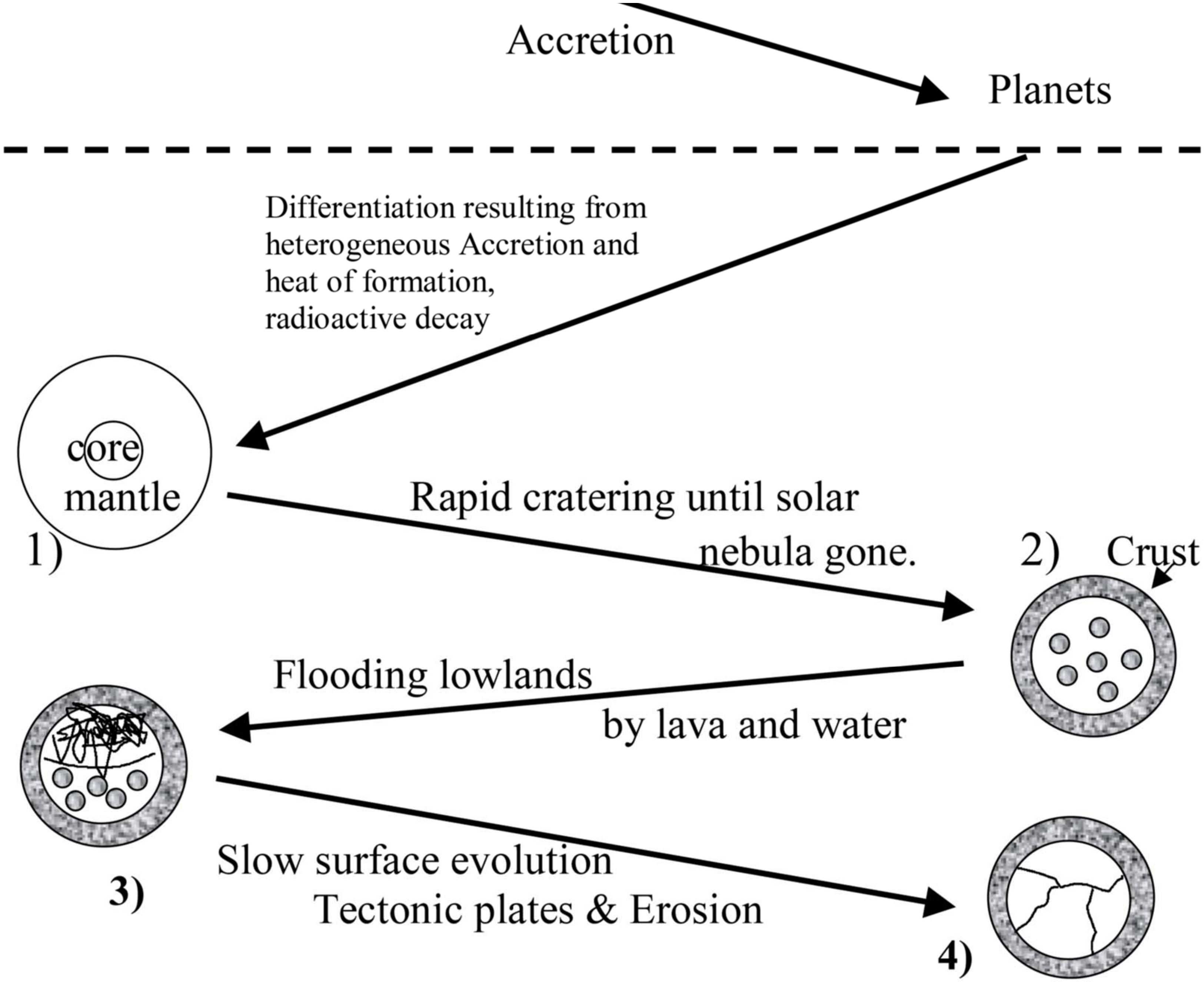
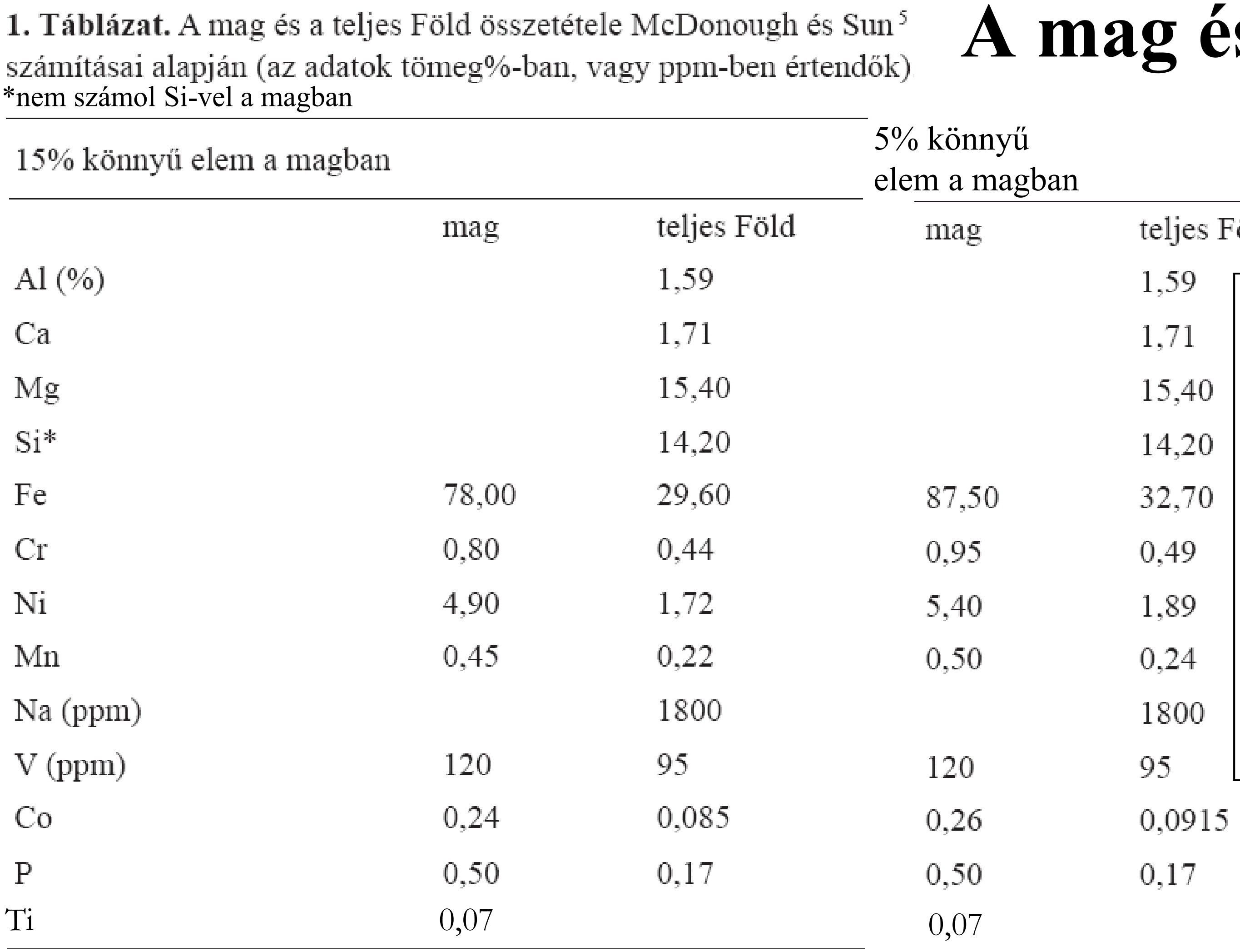

Accretion
Planets
Differentiation resulting from heterogeneous Accretion and heat of formation, radioactive decay
core
mantle
1)
Rapid cratering until solar nebula gone.
2)
Crust
Flooding lowlands by lava and water
3)
Slow surface evolution Tectonic plates & Erosion
4)

Plate Tectonics

- Very early earth may have had thin, unstable crust
- Large areas of continental crust by 2.5 billion years
- Plate tectonics since at least two billion years
- Wilson Cycle and Supercontinents
  - Supercontinents
  - Dispersal
  - Reassembly
  - Rodinia 800 million years
  - Pangaea 250 million years

A mag és a teljes Föld



1. Táblázat. A mag és a teljes Föld összetétele McDonough és Sun[5] számításai alapján (az adatok tömeg%-ban, vagy ppm-ben értendők)
*nem számol Si-vel a magban

	15% könnyű elem a magban		5% könnyű elem a magban	
	mag	teljes Föld	mag	teljes Föld
Al (%)		1,59		1,59
Ca		1,71		1,71
Mg		15,40		15,40
Si*		14,20		14,20
Fe	78,00	29,60	87,50	32,70
Cr	0,80	0,44	0,95	0,49
Ni	4,90	1,72	5,40	1,89
Mn	0,45	0,22	0,50	0,24
Na (ppm)		1800		1800
V (ppm)	120	95	120	95
Co	0,24	0,085	0,26	0,0915
P	0,50	0,17	0,50	0,17
Ti	0,07		0,07	

Kondritos Föld Modell (CEM)

SiO_2	**29,77**	**29,83**
TiO_2	**0,13**	**0,14**
Al_2O_3	**2,18**	**2,98**
Cr_2O_3	**0,26**	**0,25**
MgO	**25,15**	**24,56**
FeO	**5,25**	**5,31**
MnO	**0,09**	**0,08**
CaO	**2,05**	**2,39**
Na_2O	**0,26**	**0,23**
K_2O	**0,02**	**0,02**

Fe, Ni, Co, Ti, Cr and V have densities and seismic velocities matching those in the core.

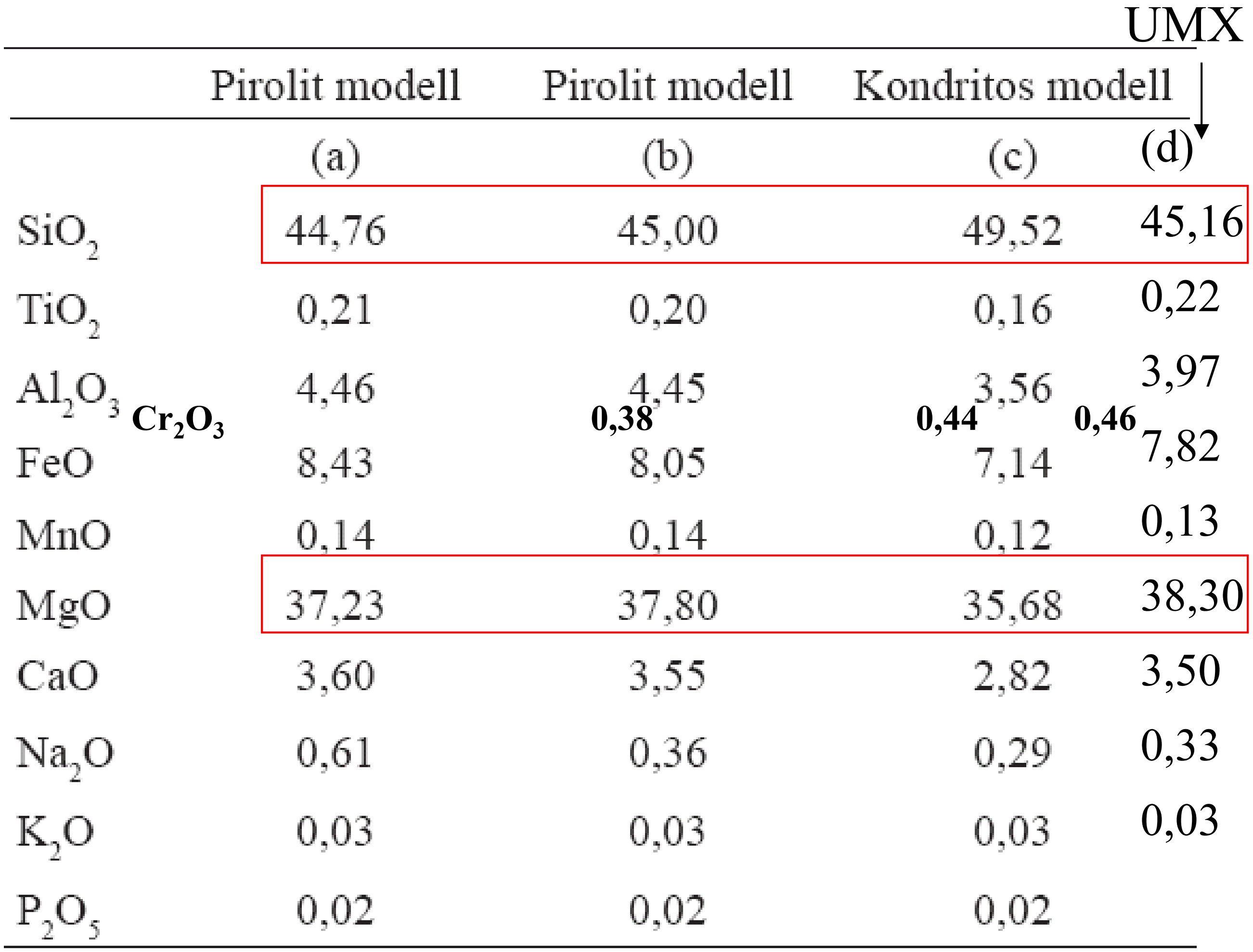
mag: a Föld 32,5 tömeg%, többi:? (crust: 0,4 m/m%)
Fe/Ni→ kondritban: 17, köpenyben: 31,9, akkor a magban: ~16 (+Fe-meteoritok!)
külső mag sűrűsége: <Fe+Ni ötvözet (könnyű elemek a magban: Si, C, K, S, H, O, N)
p = 130 – 330 GPa, T = 4600-5200 – 6600 K (ettől nagyobb pT?)

primitív köpeny (kéreg előtti) = teljes szilikát Föld (amiből atmo- és hidroszféra)

Embey-Isztin Dobosi, 2004

A köpeny

2. Táblázat. A primitív köpeny (szilikát Föld) összetétele különböző számítások alapján (az adatok tömeg%-ban értendők).



	Pirolit modell	Pirolit modell	Kondritos modell	UMX
	(a)	(b)	(c)	(d)
SiO_2	44,76	45,00	49,52	45,16
TiO_2	0,21	0,20	0,16	0,22
Al_2O_3	4,46	4,45	3,56	3,97
Cr_2O_3		0,38	0,44	0,46
FeO	8,43	8,05	7,14	7,82
MnO	0,14	0,14	0,12	0,13
MgO	37,23	37,80	35,68	38,30
CaO	3,60	3,55	2,82	3,50
Na_2O	0,61	0,36	0,29	0,33
K_2O	0,03	0,03	0,03	0,03
P_2O_5	0,02	0,02	0,02	

[a] Köpenyből származó minták alapján, Ringwood[7].

[b] Köpenyből származó minták alapján, McDonough és Sun[5].

[c] Szenes kondrit összetétel mínusz mag, Hart és Zindler[8].

[d] Köpeny xenolit. Jagoutz et al.

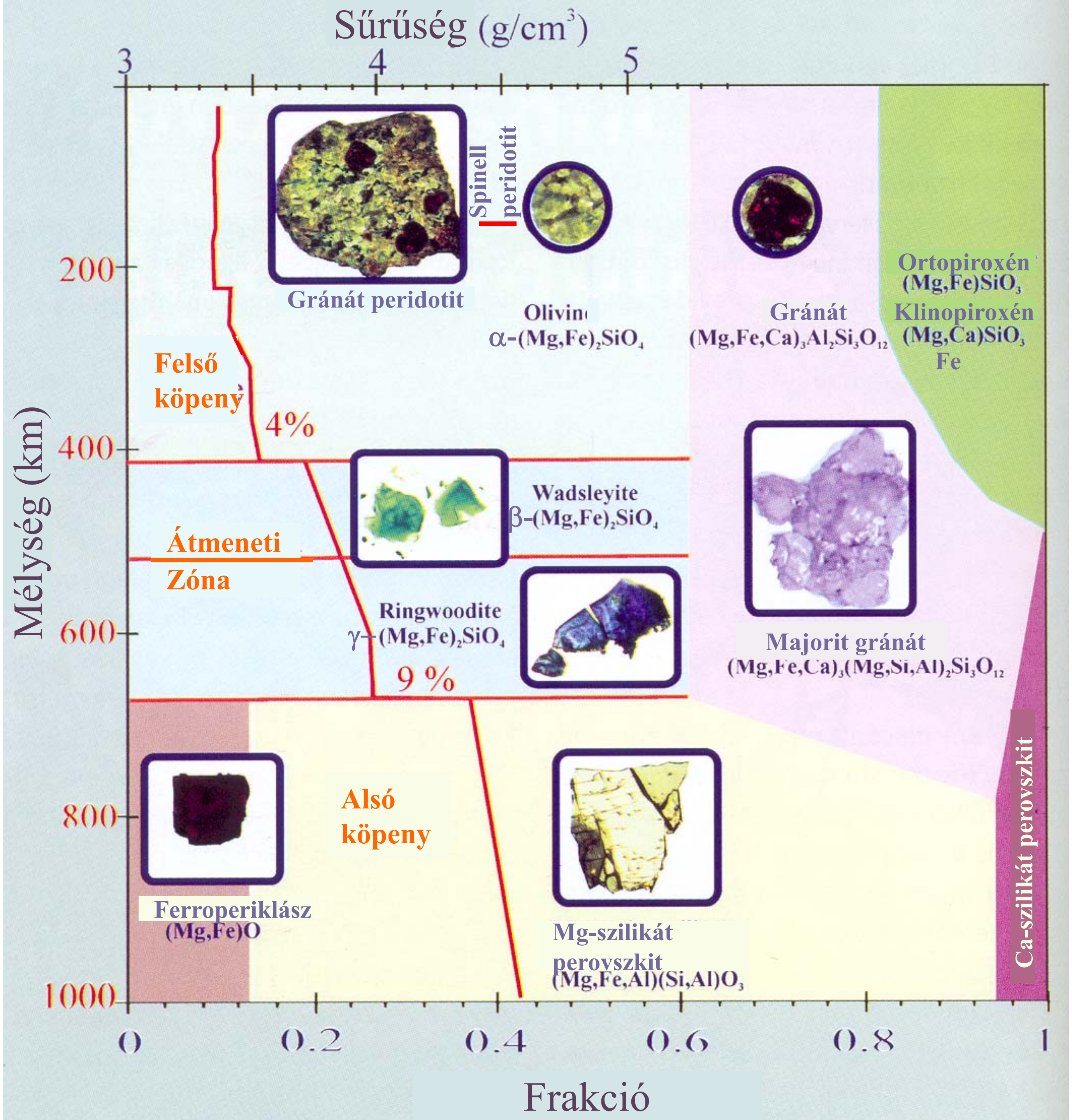
homogén?
szilárd?
konvekciós áramlás (ok?)

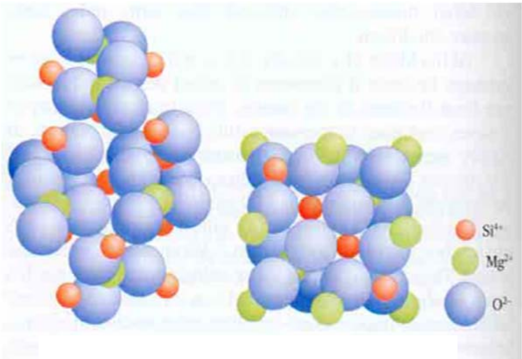
modell:
Geofizika (felső, átme..)
peridotit xenolit és köpeny masszivum, kondrit, pirolit

Mg/Si a Föld köpenyében nagyobb, mint a kondritban, a köpeny összetétele
1/ Mg/Si-re homogén → Si veszteség, ami a külső magban lehet (→kisebb sűrűség)
2/ nem homogén → a köpenyben több Si

Embey-Isztin Dobosi, 2004

A felső köpeny, az átmeneti zóna és az alsó köpeny ásványi összetétetele, továbbá a sűrűség változása a mélység függvényében

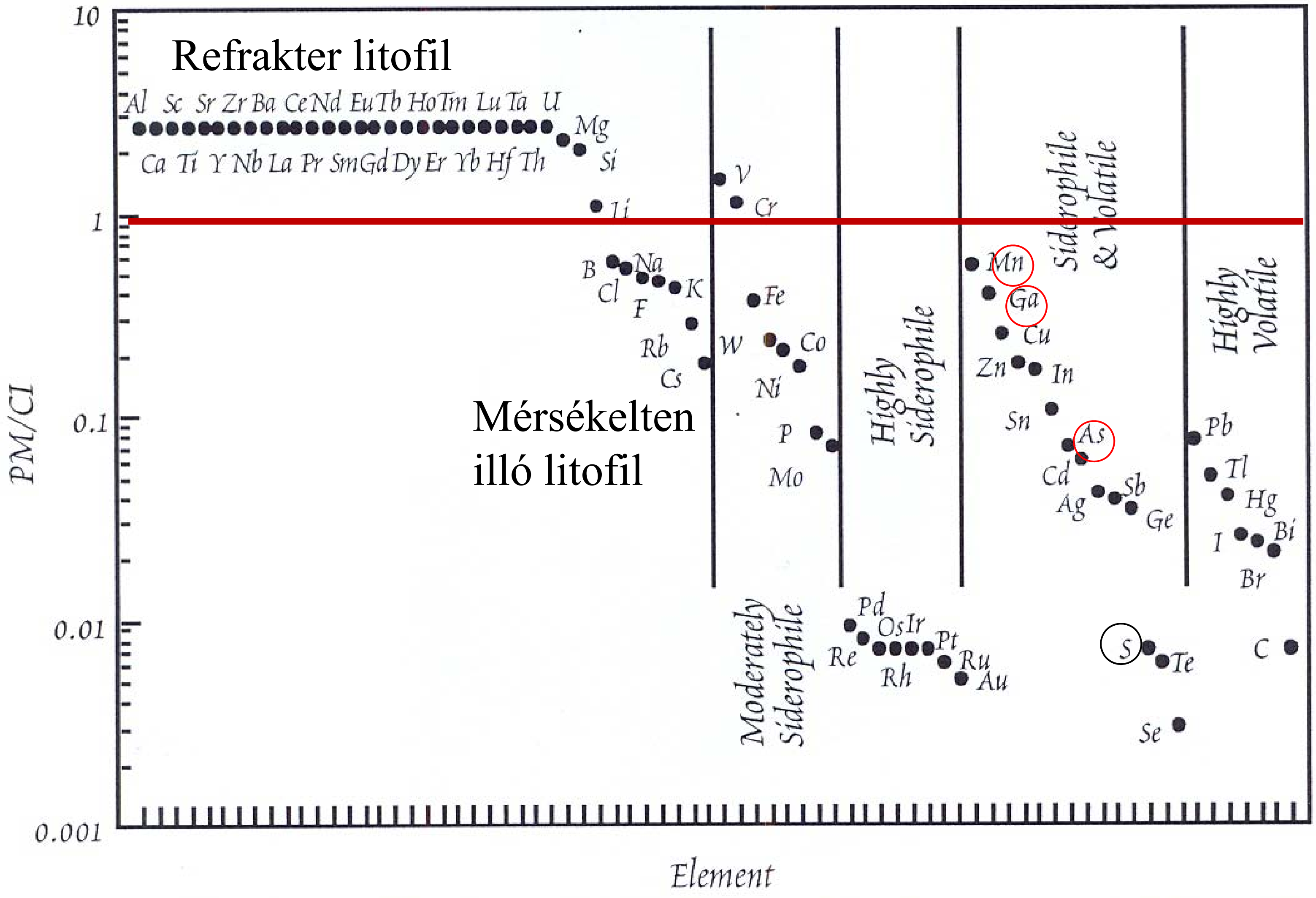




olivin spinell

Peridotitos köpeny

Refrakter és illó elemek viselkedése



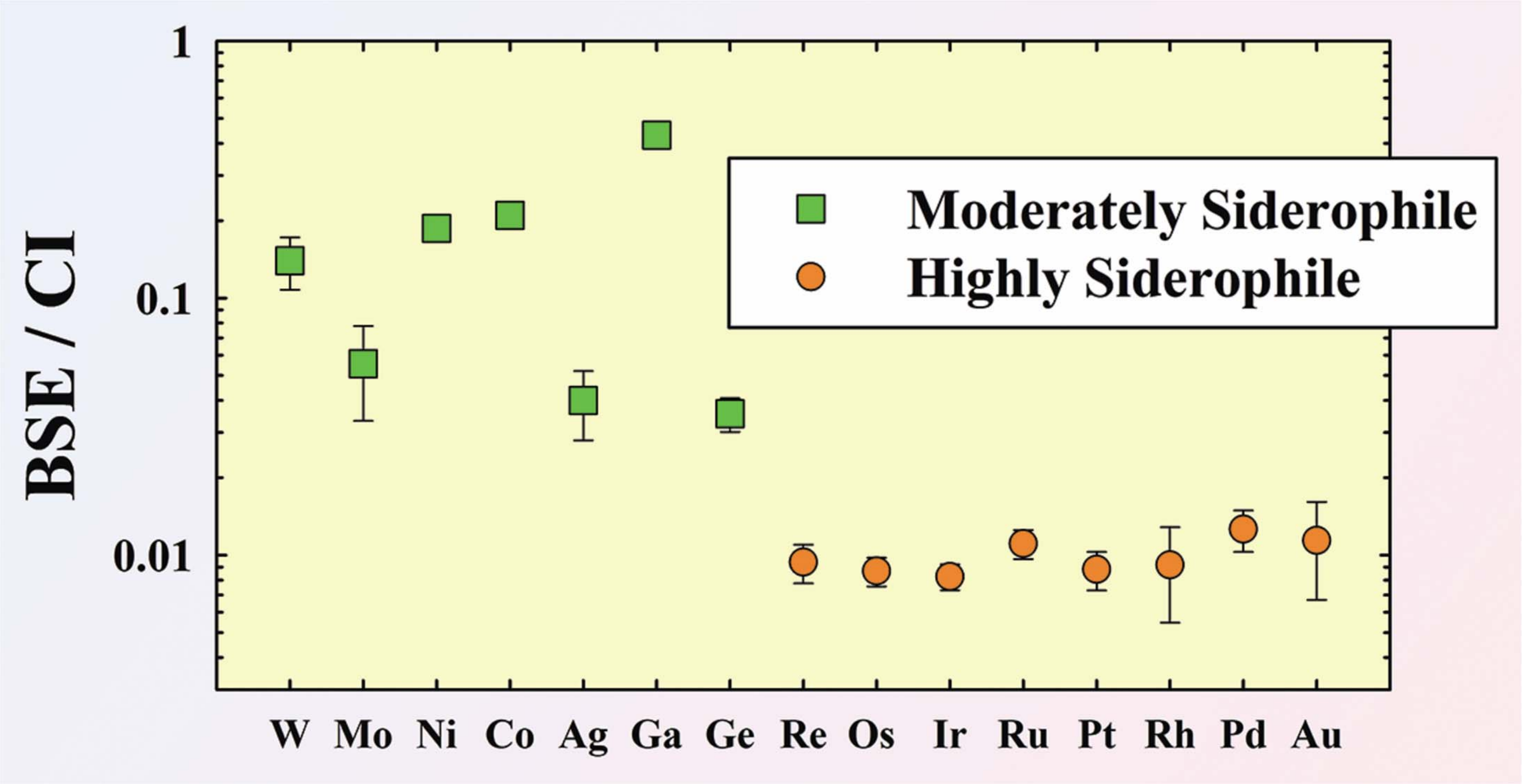
Refrakter litofil

Mérsékelten illó litofil

Figure 11.10. Abundances of the elements in the Primitive Mantle compared to CI chondrites.

Hold: szintén refrakter 2-3-szorosa, mérsékelten illó elszegényedett

Embey-Isztin Dobosi, 2004



Abundances of moderately and highly siderophile elements in the bulk silicate Earth (BSE) normalised to CI chondrite abundances. Concentrations and uncertainties are from Table 2.1. For each category of siderophile nature, the elements are arranged from left to right from most to least refractory, based on their 50 % condensation temperatures (Lodders, 2003) (Table 2.1).

Walker, 2016

A tellúr-vita

„A tellúrnak, az egyetlen erdélyi magyar elemnek a felfedezése, ma is vitatható története a magyarországi ásványtannak. A tellúrt **Müller Ferenc József** bányamérnök-mineralógus, mint az erdélyi bányászat vezetője fedezte fel 1783-ban, majd tőle függetlenül **Kitaibel Pál** 1789-ben. Ezek után Müller felfedezésének ismeretében **Martin Heinrich Klaproth** német vegyész írta le az elemet és nevezte el tellúrnak 1798-ban. A kibontakozott prioritási vitában végül is Kitaibel Pál hivatalos nyilatkozatban elismerte, hogy az elemet Müller F. J. fedezte fel. Így két magyar, ill. magyarországi tudós felfedezését egy harmadik, külföldi tudós határozottabb fellépésével tette magáévá. Nem egyedülálló esete a magyar tudománytörténetnek” – olvasható a Budapesti Műszaki Egyetem honlapján.

Primitív köpeny (szilikát Föld)

Refrakter litofil elemek 2,8-szoros dúsulása a C1-hoz csak látszólagos
→ nincs a magban, a köpenybeli összetételük a teljes Földet képviselik

Mérsékelten és erősen illó litofil elemek kimerülése
1) Föld gázfrakcionált kondritos anyagból keletkezett olyan hőmérsékleten, ami túl nagy volt a volatil elemek teljes kondenzálódásához (>1000 K),
2) Napszél tevékenység, ami a belső bolygók térségéből kisöpörte a könnyű és illékony elemeket,

Mérsékelten sziderofil elemek kimerülése → Földnek van vasmagja,

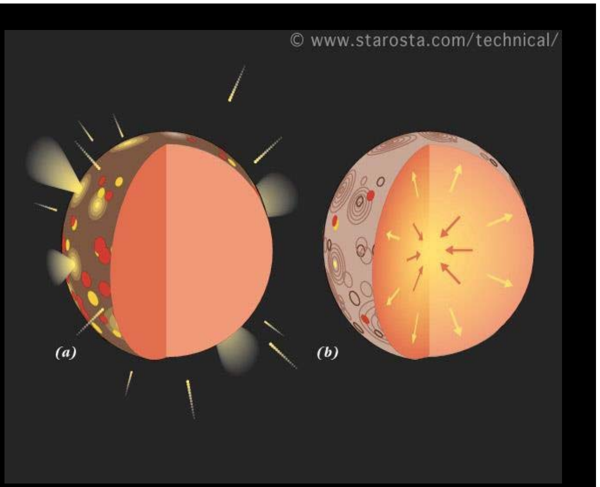
Erősen sziderofil elemek mennyisége jelentősebb a primitív köpenyben, mint várt a fém/Si megoszlásból; jelenléte → kései hozzáadódás, azaz késői akkréciós folyamat eredménye (a mag kialakulása után)

S és Se elkülönülése

A Föld Fe-többlete

A Földnek kb. 20 % Fe-feleslege van a C1-hez képest.
A növekedése nagy, Hold és Mars méretű bolygóembriókkal való ütközésekkel magyarázható. A nagy becsapódások a földi anyag egy részének eltávozását okozták, ami inkább érintette a szilikátos (köpeny) részt, mint a vasmagot (feltéve, hogy a Földnek már volt vasmagja, amikor a becsapódások megtörténtek).
/Hasonló ütközéses-eróziós modell magyarázhatja a Merkúr kiemelkedően nagy fém részarányát, l. később./

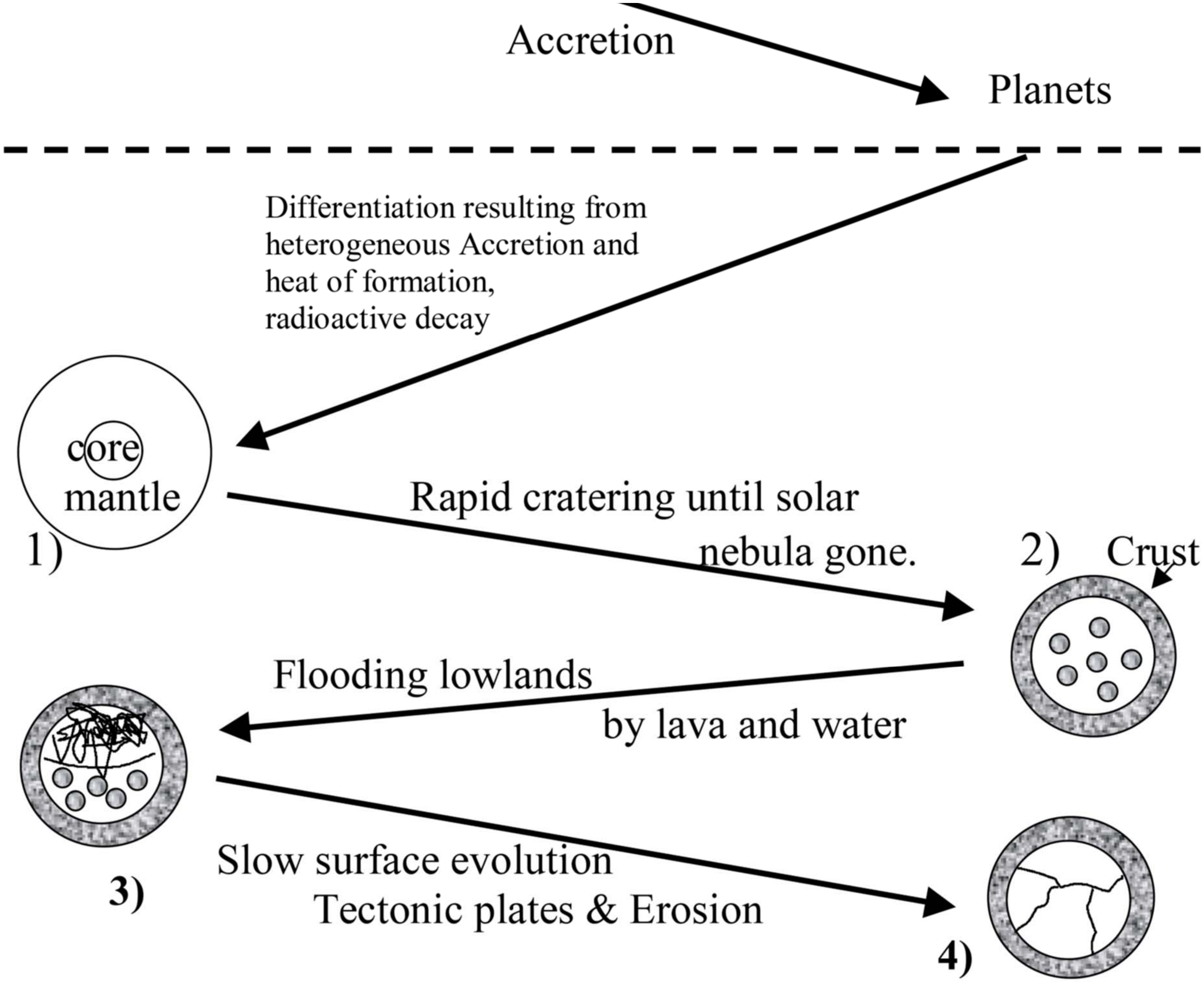
Hydrogen loss



- Accretion of the early earth due to impact of numerous planetesimals
- Thereby native iron was added to the >1000 ^{o}C hot surface.
- On the surface iron reacts with H_2O: $Fe^0 + H_2O = FeO + H_2$

- Even today on Earth (final size) H and He can escape,
- Only the two lightest elements can reach the escape velocity
- of ~ 40,300 km/h (11 km/s)
- The early earth had no magnetic field so solar wind reached
- earth surface enhancing the loss of the atmosphere

gas	**mass**
H_2	2
He	4
CH_4	16
CO_2	44
N_2	28
O_2	32
Ar	40


Accretion
Planets
Differentiation resulting from
heterogeneous Accretion and
heat of formation,
radioactive decay
core
mantle
1)
Rapid cratering until solar
nebula gone.
2)
Crust
Flooding lowlands
by lava and water
3)
Slow surface evolution
Tectonic plates & Erosion
4)

Kompatibilis – inkompatibilis elemek

- Azokat az elemeket, amelyek (inkább) a köpenyásványok rácspontjaiban foglalnak helyet és olvadás során a **szilárd fázisban** tartózkodnak (maradnak)
  - **kompatibilis** elemeknek nevezzük
  - pl: Ni, Co, Cr, Os, Mg, Sc

- Azokat az elemeket, amelyeknek töltése és mérete a köpenyásványok rácspozicióitól különböznek és az **olvadék fázisba** particionálódnak olvadás során
  - **inkompatibilis** elemeknek nevezzük,
  - pl: K, Rb, Sr, Ba, REY, Nb, Ta, Zr, Hf, U, Th, Pb

- Megoszlási koefficiens:

$$D = C_S / C_L$$

ahol C_S valamely elem koncentrációja a szilárd fázisban és C_L valamely elem koncentrációja a olvadék (folyadék) fázisban

– inkompatibilis elemek:	D « 1
– kompatibilis elemek:	D » 1

/általában nyomelemre/

Kompatibilitás függ

az ásványtól és olvadéktól (amiben jelen van)

Mely elemek kompatibilisek? Főelemek, nyomelemek?

Table 9-1. Partition Coefficients (C_S/C_L) for Some Commonly Used Trace Elements in Basaltic and Andesitic Rocks

		Olivine	Opx	Cpx	Garnet	Plag	Amph	Magnetite
Rb		0.010	0.022	0.031	0.042	0.071	0.29	
Sr		0.014	0.040	0.060	0.012	1.830	0.46	
Ba		0.010	0.013	0.026	0.023	0.23	0.42	
Ni		*14*	5	*7*	0.955	*0.01*	6.8	29
Cr		0.70	10	34	1.345	*0.01*	2.00	7.4
La	Rare Earth Elements	0.007	*0.03*	0.056	0.001	0.148	0.544	2
Ce		0.006	0.02	0.092	0.007	0.082	0.843	2
Nd		0.006	0.03	0.230	0.026	0.055	1.340	2
Sm		0.007	0.05	0.445	0.102	0.039	1.804	1
Eu		0.007	0.05	0.474	0.243	0.1/1.5*	1.557	1
Dy		0.013	0.15	0.582	1.940	0.023	2.024	1
Er		0.026	0.23	0.583	4.700	0.020	1.740	1.5
Yb		0.049	0.34	0.542	6.167	0.023	1.642	1.4
Lu		0.045	0.42	0.506	6.950	0.019	1.563	

Data from Rollinson (1993).

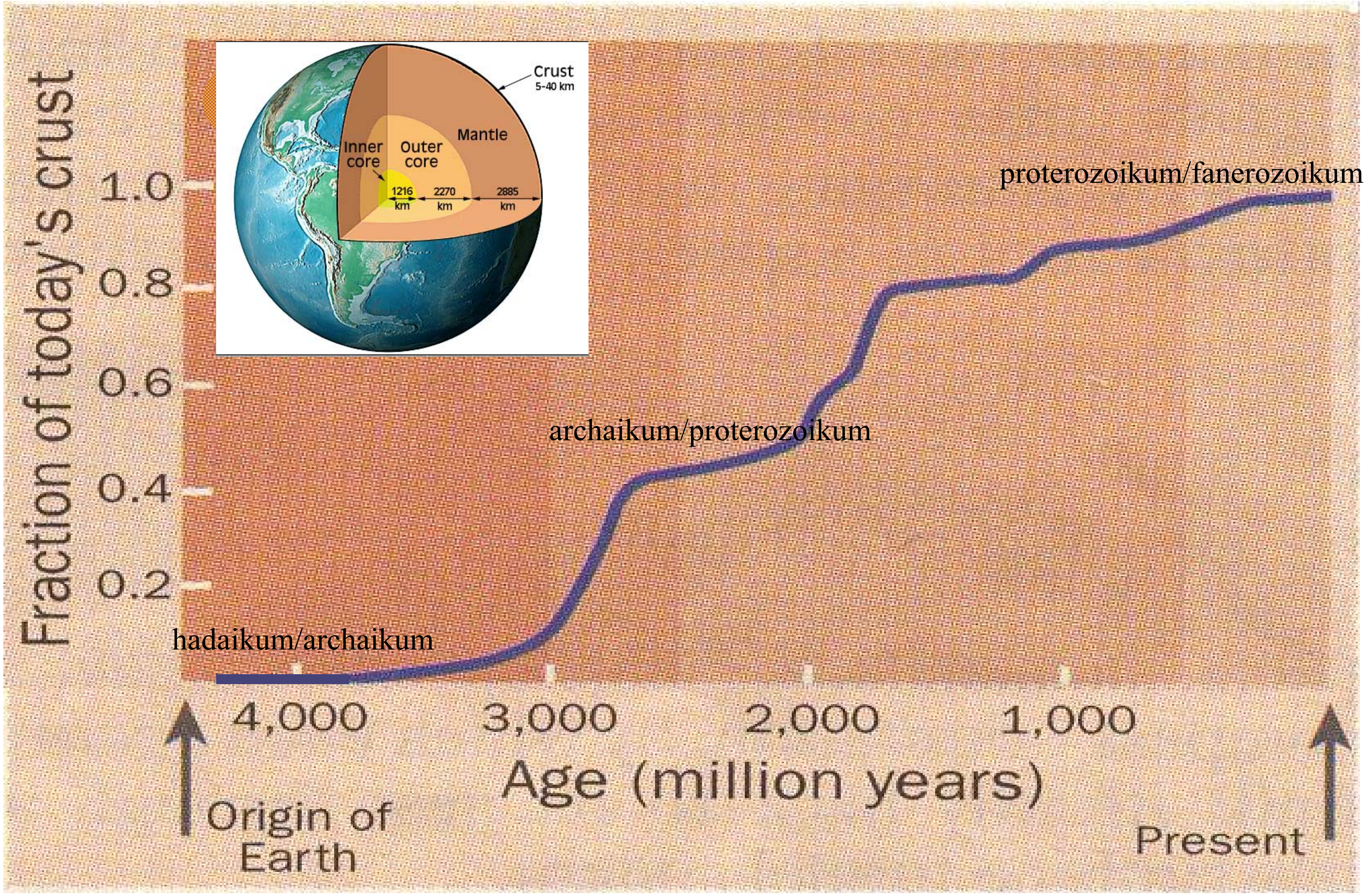
* Eu^{3+}/Eu^{2+} *Italics* are estimated

Elemviselkedés

Nyom-elemek	Petrogenetikai indikátorok
Ni, Co, Cr	Erősen kompatibilis elemek. Ni és Co olivinben, Cr spinellben és klinopiroxénben koncentrálódik → nagy koncentráció → köpenyforrás.
V, Ti	Mindkettő erős frakcionációt mutat Fe-Ti oxidba (ilmenit, Ti-magnetit). Ha eltérően viselkednek, akkor a Ti akcesszórikus ásványaiba frakcionálódik (titanit és rutil).
Zr, Hf	Erősen inkompatibilis elemek, amelyek kőzetalkotó szilikátokban nem helyettesítenek (bár Ti-t helyettesíthetnek titanitban vagy rutilban).
Ba, Rb	Erősen inkompatibilis elemek, amelyek K-t helyettesítenek K-földpátban, csillámban és amfibolban. Rb helyettesítése amfibolban kevésbé kifejezett, mint K-földpátban és csillámban → a K/Ba aránnyal e fázisok elkülöníthetők.
Sr	Ca-t helyettesíti plagioklászban (de nem piroxénben) és – kevésbé kiterjedten – K-t K-földpátban. Kis nyomáson, ahol plagioklász képződik, kompatibilis elemként viselkedik. Nagy nyomáson, ahol a plagioklász nem stabil, inkompatibilis elemként viselkedik.
REE	Álatalában inkompatibilis, a nehéz RFF gránátban dúsúlnak sokkal inkább, mint a könnyű RFF, ugyanígy ortopiroxénben és amfibolban, csak kismértékben. Plagioklász és titanit több könnyű RFF-t fogad be. Eu^{2+} erősen a plagioklászba particionálódik.
Y	Általában inkompatibilis a nehéz RFF-hez hasonlóan → gránátban, ortopiroxénben és amfibolban koncentrálódik. Titanitban és apatitban azonban szintén dúsul, ezért ezeknek a fázisoknak a jelenléte jelentős hatással lehet a mennyiségére.

Nb-Ta vízben oldhatatlanok, olvadékban (szilikátos, karbonatitos) azonban mobilisak, köpenyben inkompatibilisak (TNT)

Kontinentális kéreg ←→ óceáni kéreg



proterozoikum/fanerozoikum

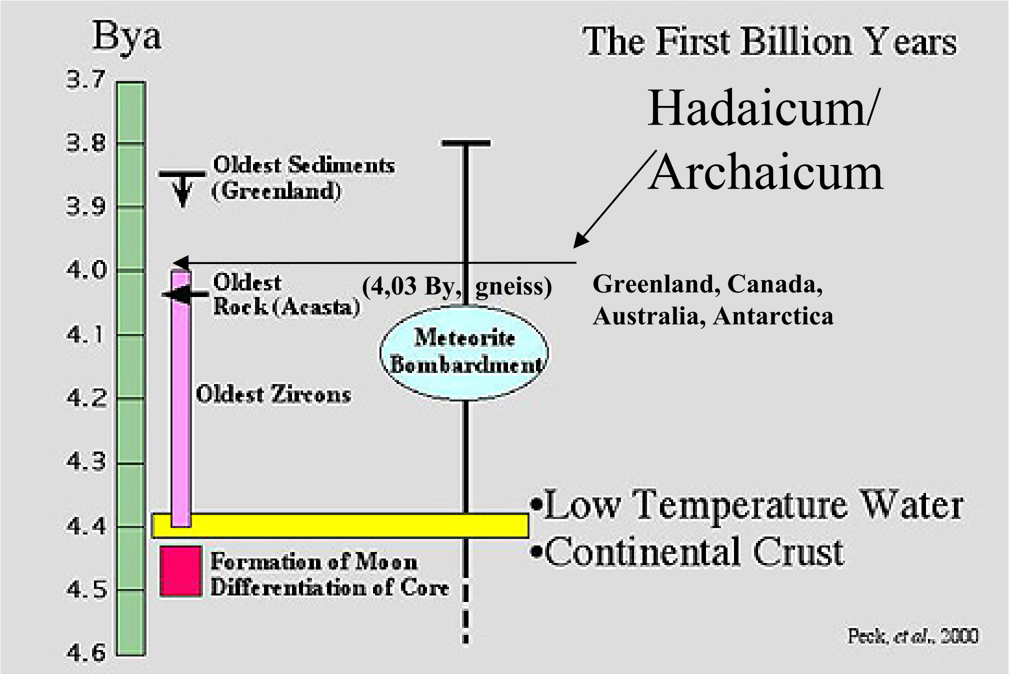
archaikum/proterozoikum

hadaikum/archaikum

This figure combines two views of the Hadean landscape: the first is one of those wonderful artist's impressions of fiery volcanoes, frequent meteorite impacts and a looming close-by Moon. The second shows a more clement, cool, early Earth on which a shallow ocean laps over a rugged shoreline of volcanic and impact craters.

Arndt, 2013, GeochemPers 2/1

Kéreg keletkezése



Hadaicum/ Archaicum

(4,03 By, gneiss)

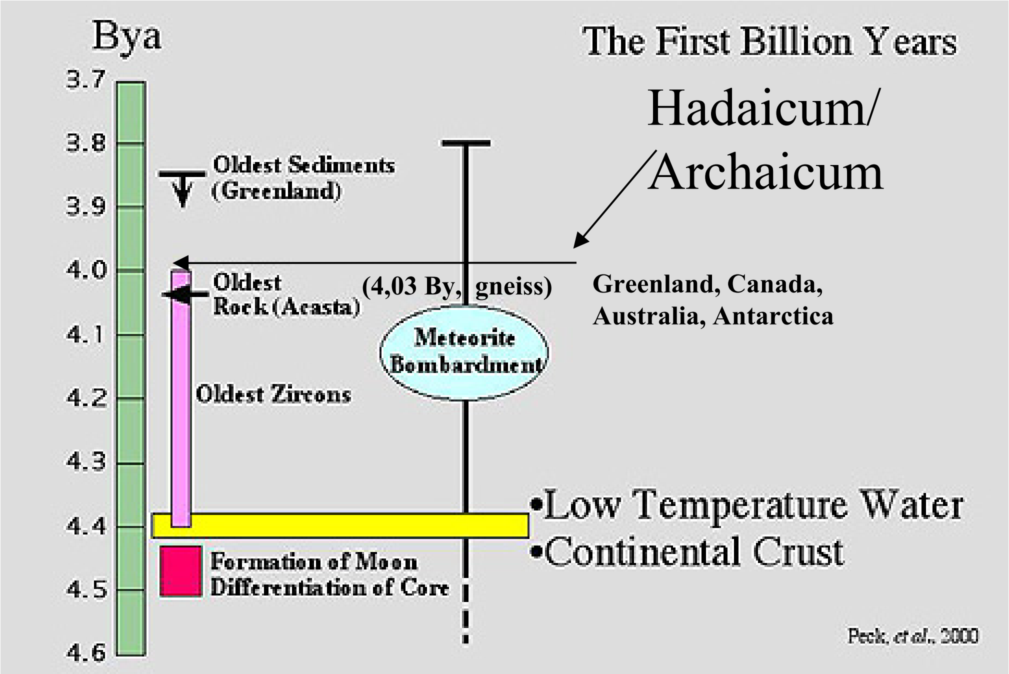
Greenland, Canada, Australia, Antarctica

Legidősebb extraterresztrikus kőzetek:
holdkőzetek: 4,6 milliárd év
meteoritok: 4,5- 4,7 milliárd év

Acasta Gneiss Complex

Fragment exhibited
at the Natural History Museum in Vienna

Kéreg keletkezése



Legidősebb extraterresztrikus kőzetek:
holdkőzetek: 4,6 milliárd év
meteoritok: 4,5- 4,7 milliárd év

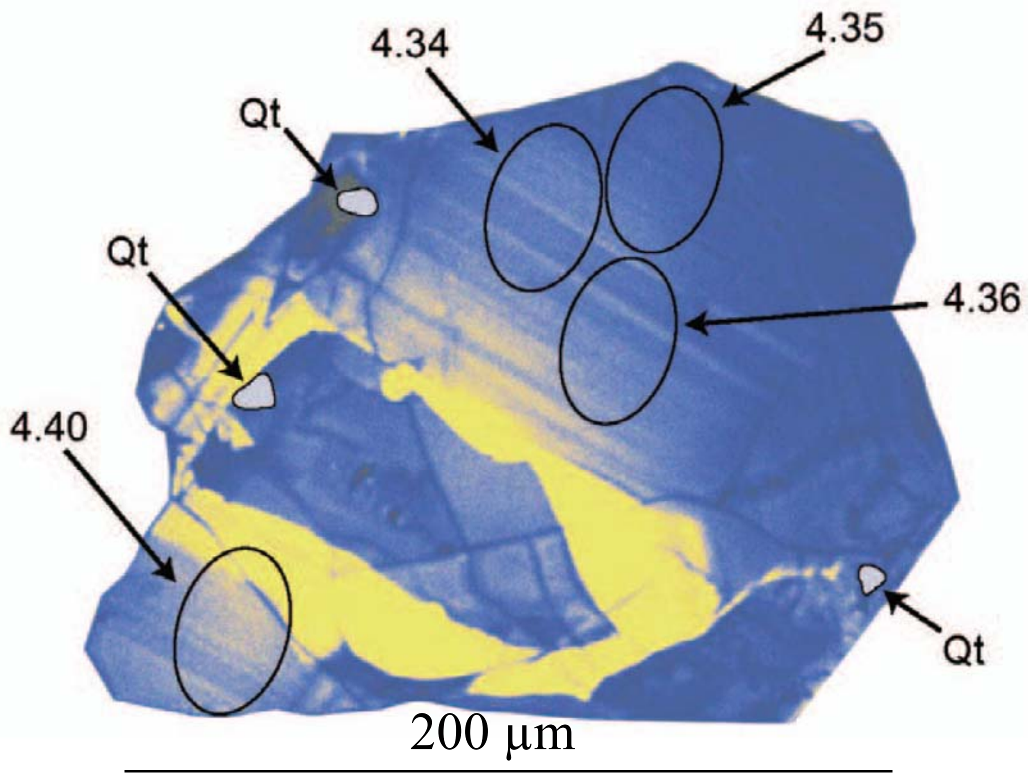
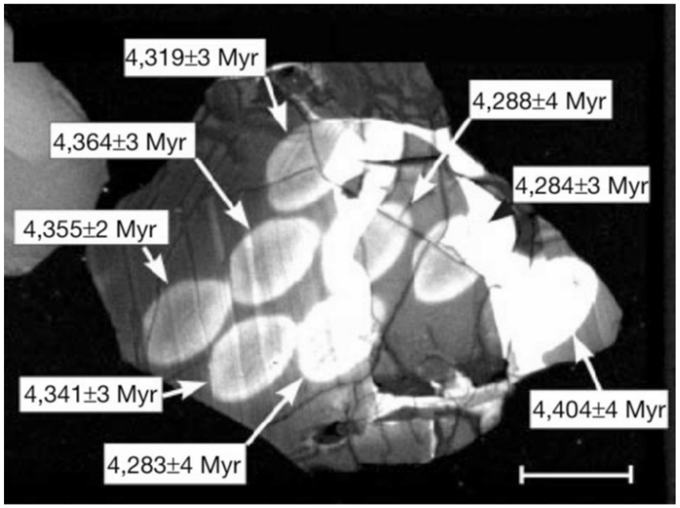


FIGURE 4 False colour cathodoluminescence image of the 200 μm diameter, approximately 4.4 Ga Jack Hills zircon. This zircon is the oldest-known part of Earth. Ion microprobe analytical sites are indicated by black ellipses with ages in billions of years. Qt denotes quartz inclusions in the zircon crystal. IMAGE SUPPLIED BY JOHN VALLEY



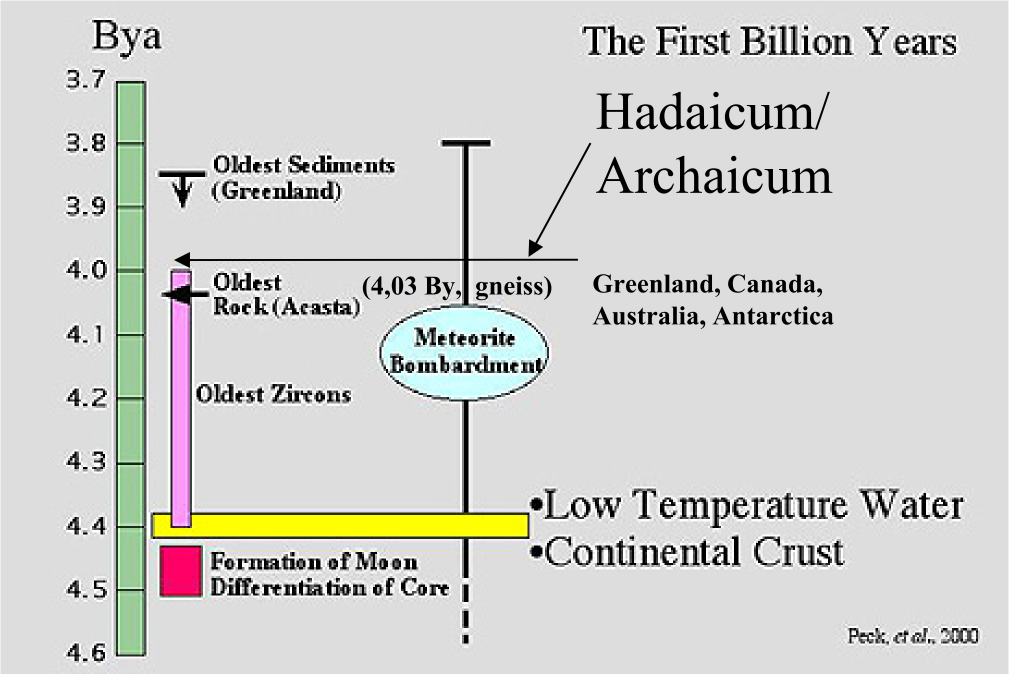
Photomicrograph of the oldest zircon known. Light area are regions of ion probe analysis. Ages determined on these areas are shown.

Wilde et al. (2001)

Deep in the Australian Outback under the sparse vegetation of the **Jack Hills**, scientists have uncovered secrets about conditions on the Earth over 4 billion years ago. Crystals within the rocks hint that the surface of the early Earth was cool and wet—not the roiling inferno that some theories and asteroid crater observations suggest. (Photograph copyright Bruce Watson)

The bits and pieces of rocks that make up the Jack Hills rock formation are **ancient - over 3 billion years old. Individual crystals of zircon within the rocks are 4.4 billion years old**, only 150 million years or so younger than the age of the Earth itself. These crystals are the oldest fragments of the Earth yet found. (Photograph copyright Bruce Watson)

Kéreg keletkezése



<u>ultramafikus</u> magma óceán

↓

vékony bazaltos kéreg (Mars),
gravitációs differenciáció? (Hold)

↓

parciális olvadás (meterorit, termális konvekció)

↓

savanyú-neutrális kéreg (inkompatibilis elemek; tonalit)

↓

parciális olvadás (meteorit, termális konvekció)

↓

savanyú kéreg (erősen inkompatibils elemek: K, Zr, U, Pb; gránit)

↓

vastagodás, stb.

↓

kontinensek magja (kraton)

Alternatív és/vagy másik folyamat:

H_2O kondenzáció a másodlagos légkörből →ősóceán →oldódás, szedimentáció →metamorfózis (cirkon?)

Kéreg

If there was a magma ocean, the crust would have started to form from outlier "rafts" that eventually were enclosed by the first thin solid crust that survived remelting. From knowledge of other terrestrial planets, that crust was almost **certainly basalt-rich** (a more general term is simatic, which refers to igneous rocks low in Si and high in Fe, Mg, and Ca) in composition (the idea of a thin floated feldspar anorthositic analog to the Moon has been discounted by some planetologists [but remains an alternative]).

As the mafic crust thickened, parts of it also were **remelted** repeatedly **by large impacts**, and probably also by internal **thermal convection currents from the mantle**. **<u>Elemek kompatibilitása és inkompatibiltása működik!! Földi geokémiai tulajdonság</u>.**

From knowledge of differentiation mechanisms occurring in the younger Earth, it seems plausible that here and there sialic (high in Si, Al, and Na) crust formed regionally. This newly fromed crust could have compositions described as **tonalites** and then **granites (K!)** were produced by remelting of tonalite crust which are a common host of the accessory mineral **zircon**.

Another way to form sialic rocks is by **metamorphism** of sediments that have been enriched in Si, Al, Na.

Regardless of mechanism, the end result was to develop clots of silica-enriched crust that rose above the general crustal elevations - these would form nuclei (analogous to the term craton in the Earth's present geology) that grew mainly by **accretion** to their boundaries (perhaps by obduction or terrane addition, especially if plate tectonics mechanisms developed early in Earth history.

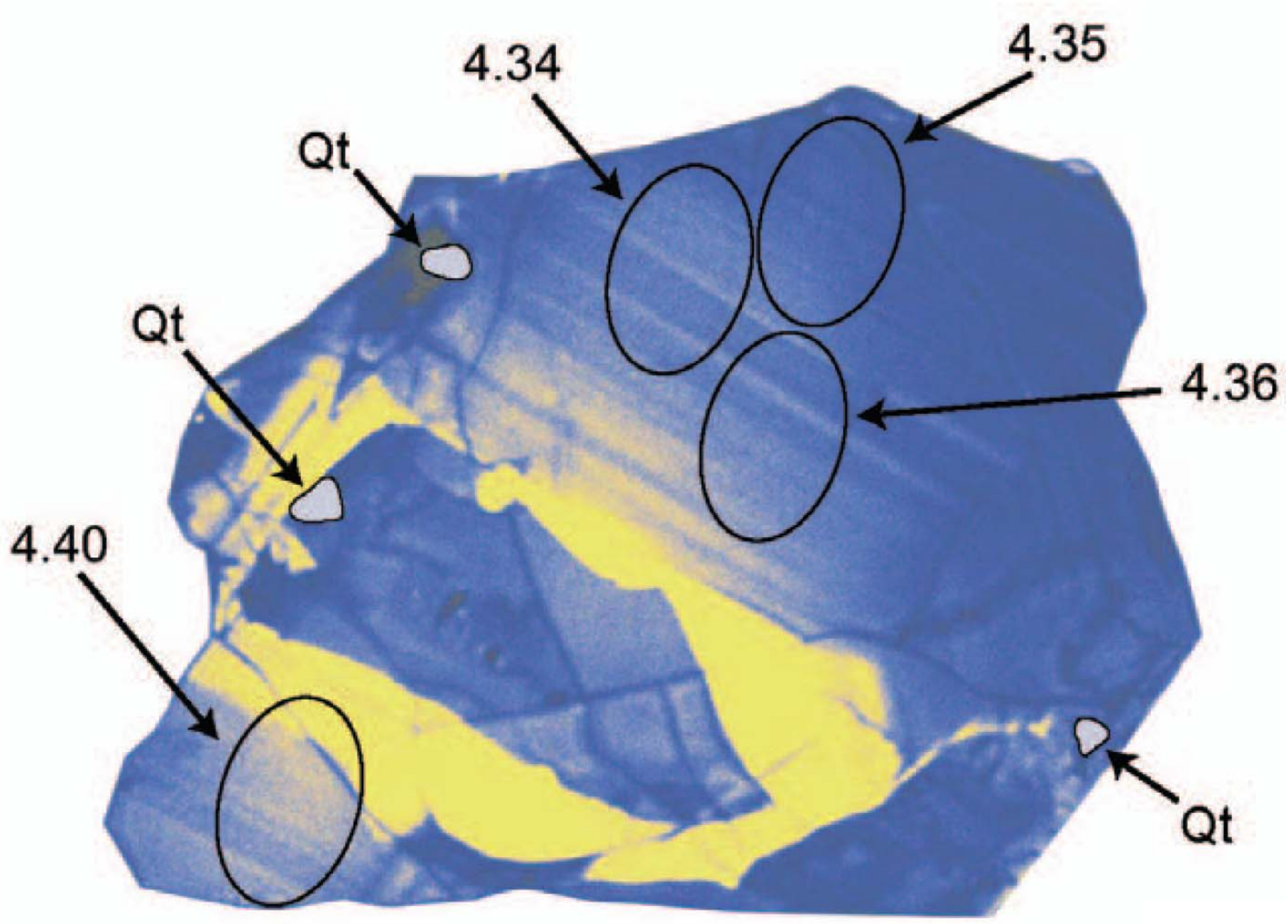
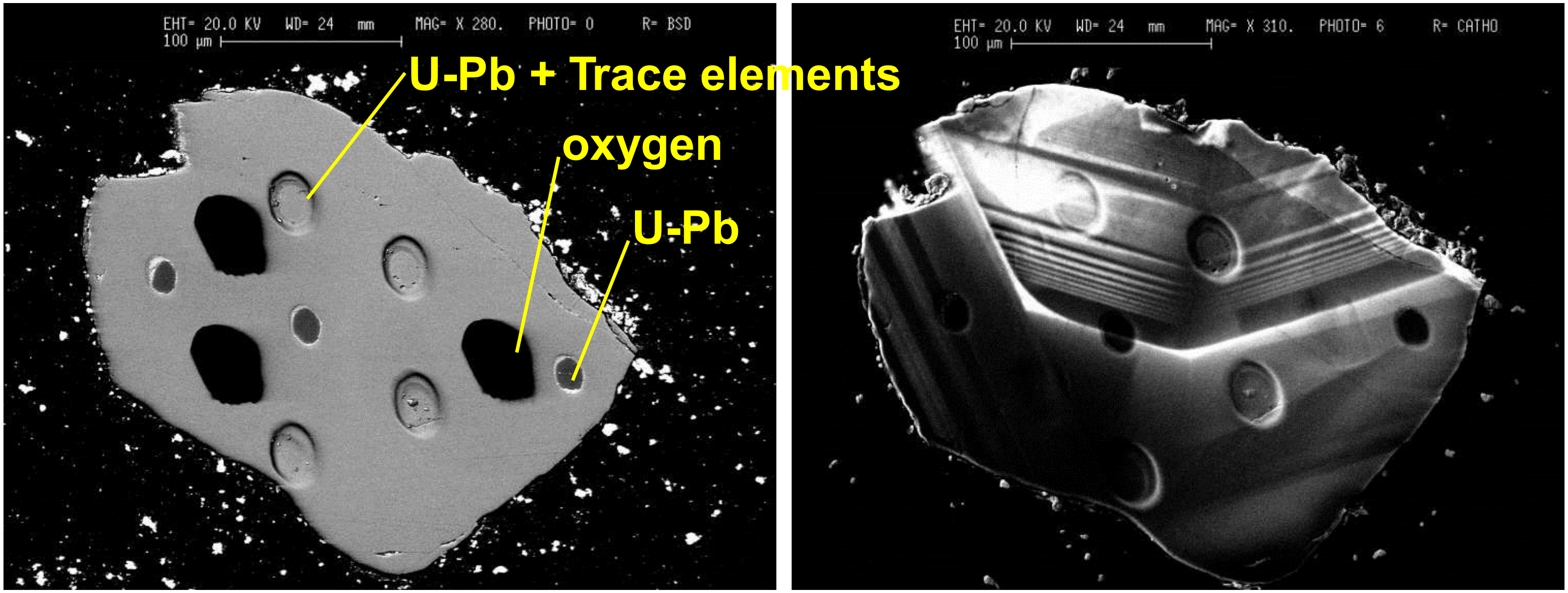


Figure 4 False colour cathodoluminescence image of the 200 µm diameter, approximately 4.4 Ga Jack Hills zircon. This zircon is the oldest-known part of Earth. Ion microprobe analytical sites are indicated by black ellipses with ages in billions of years. Qt denotes quartz inclusions in the zircon crystal. Image supplied by John Valley

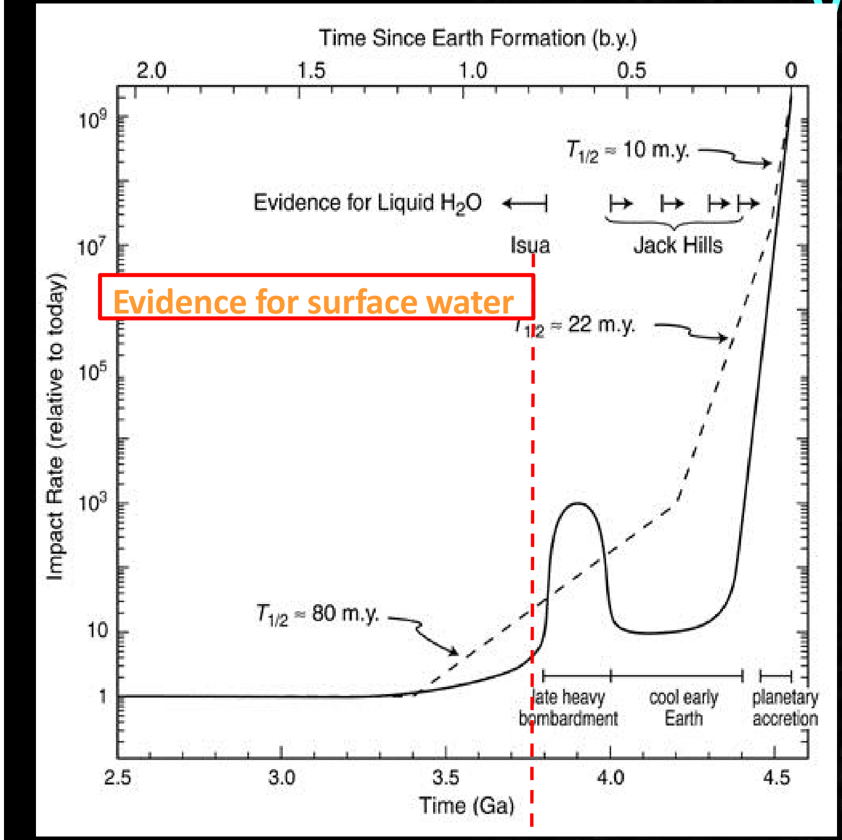
must h
have la

Analyses of oxygen isotopes in Zircons possible indicate presence of water at > 4 Ga

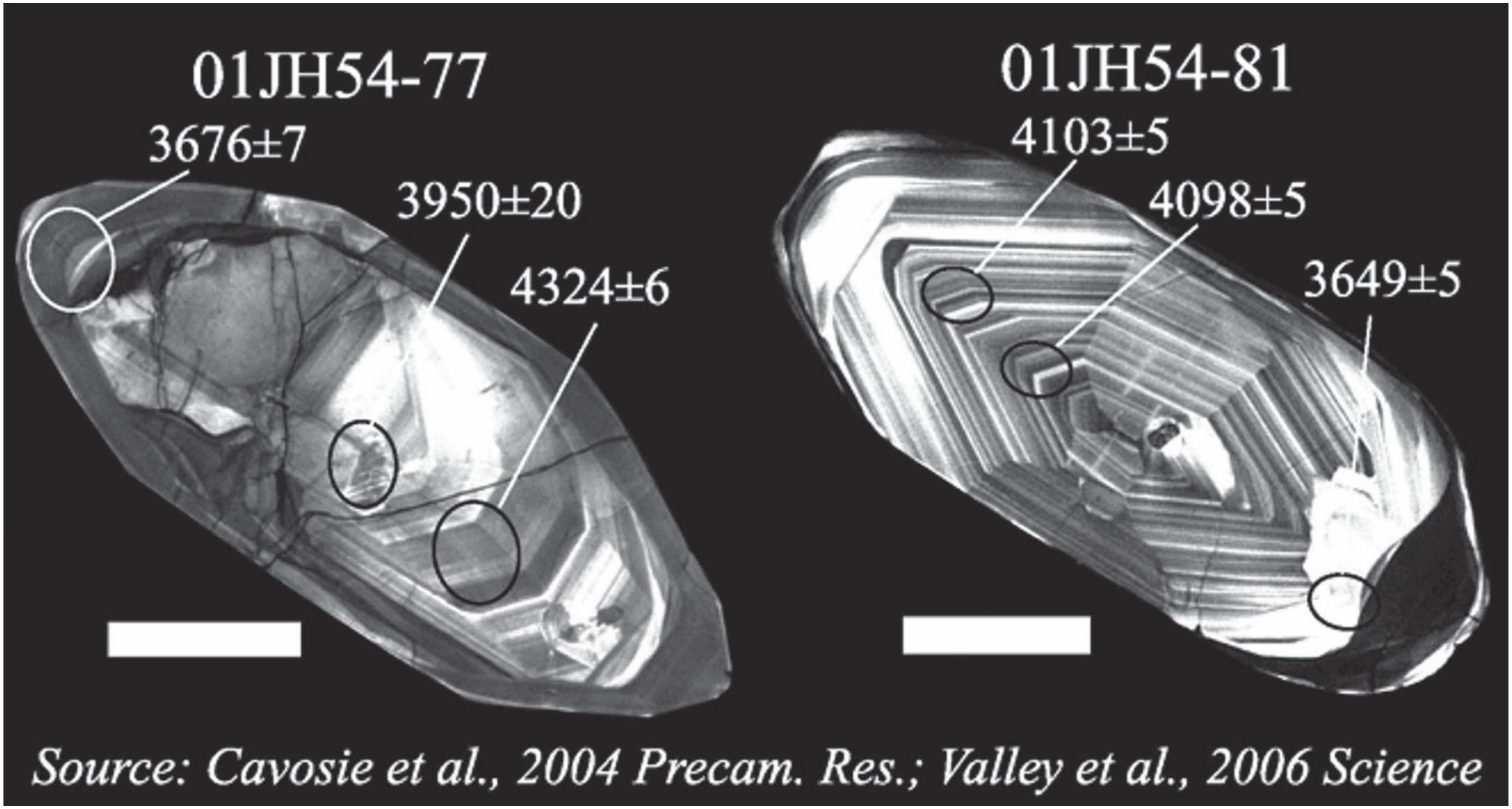


http://ocw.mit.edu/help/faq-fair-use/

Why does the Earth have so much water ?



Likely added by a later event…

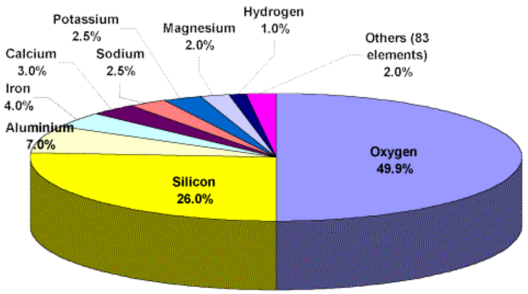


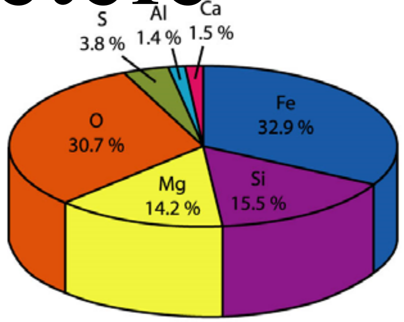
Source: Cavosie et al., 2004 Precam. Res.; Valley et al., 2006 Science

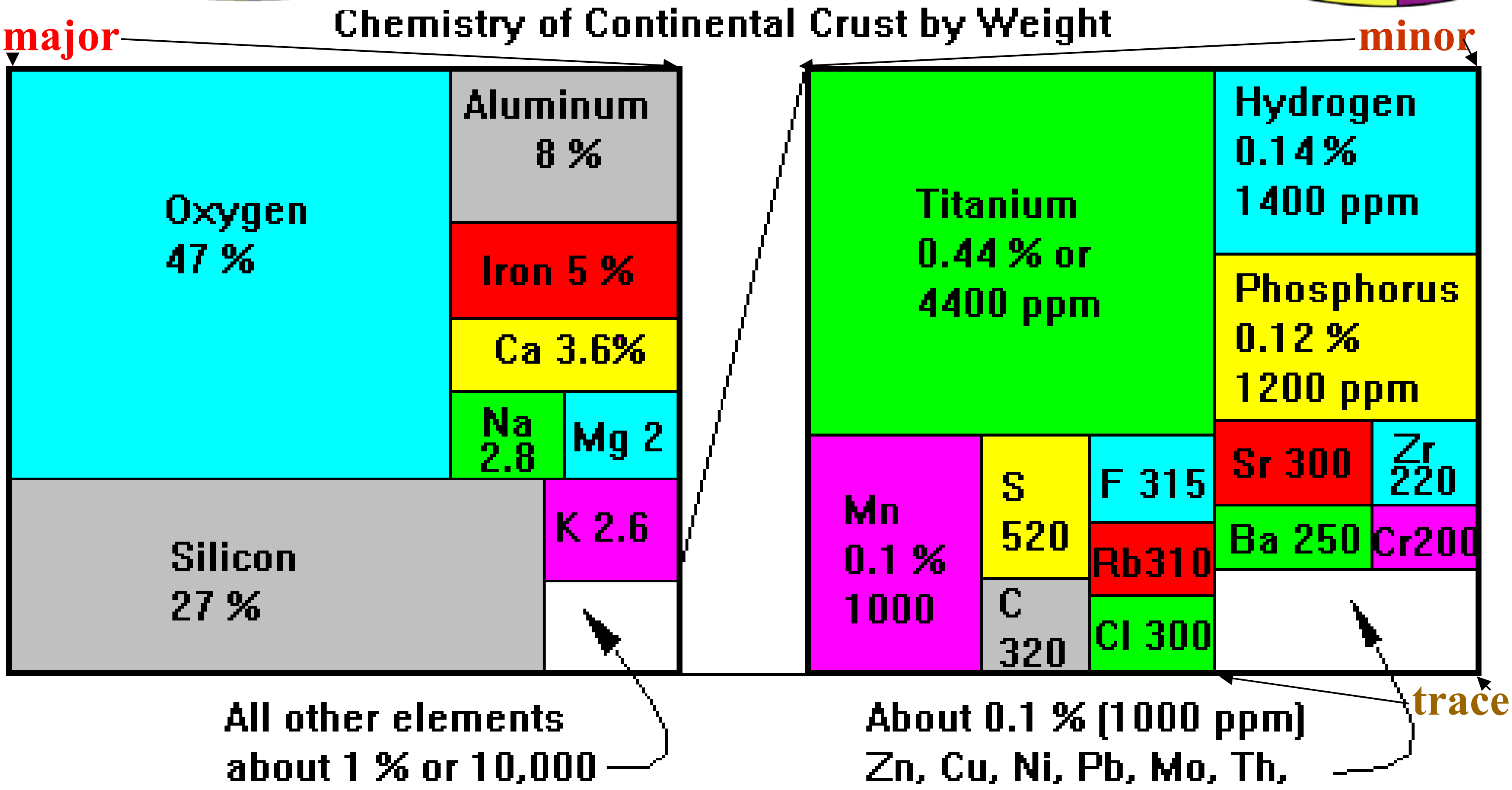
Cathode luminescence images of two Jack Hills zircons illustrating magmatic zoning and differing ages of parts of each grain. The portion with an age greater than 4.3 Ga is seen in the grain to the left (from Cavosie *et al.*, 2004, with permission from Elsevier).

Arndt, 2013, GeochemPers 2/1

A kontinentális kéreg összetétele

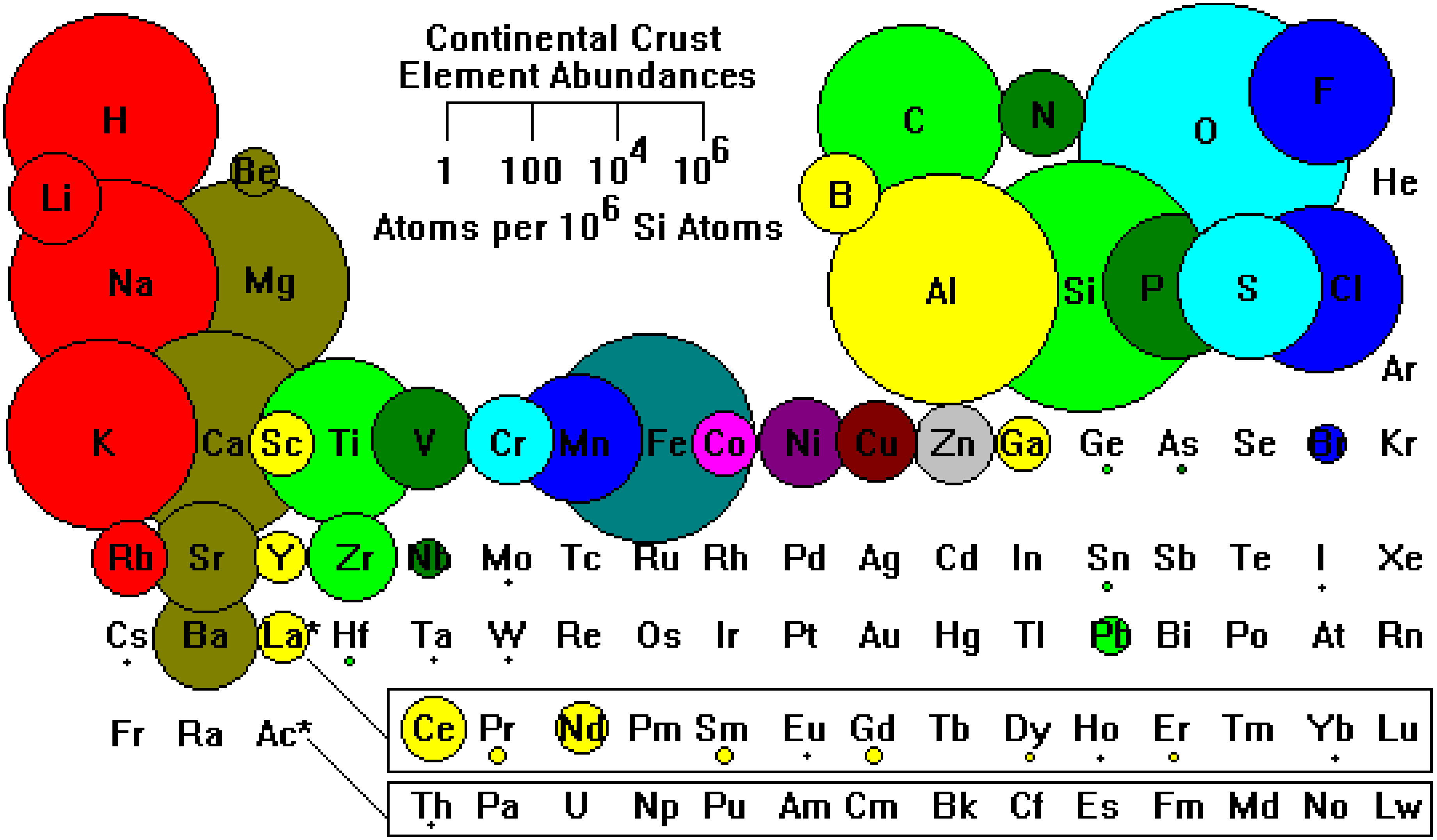


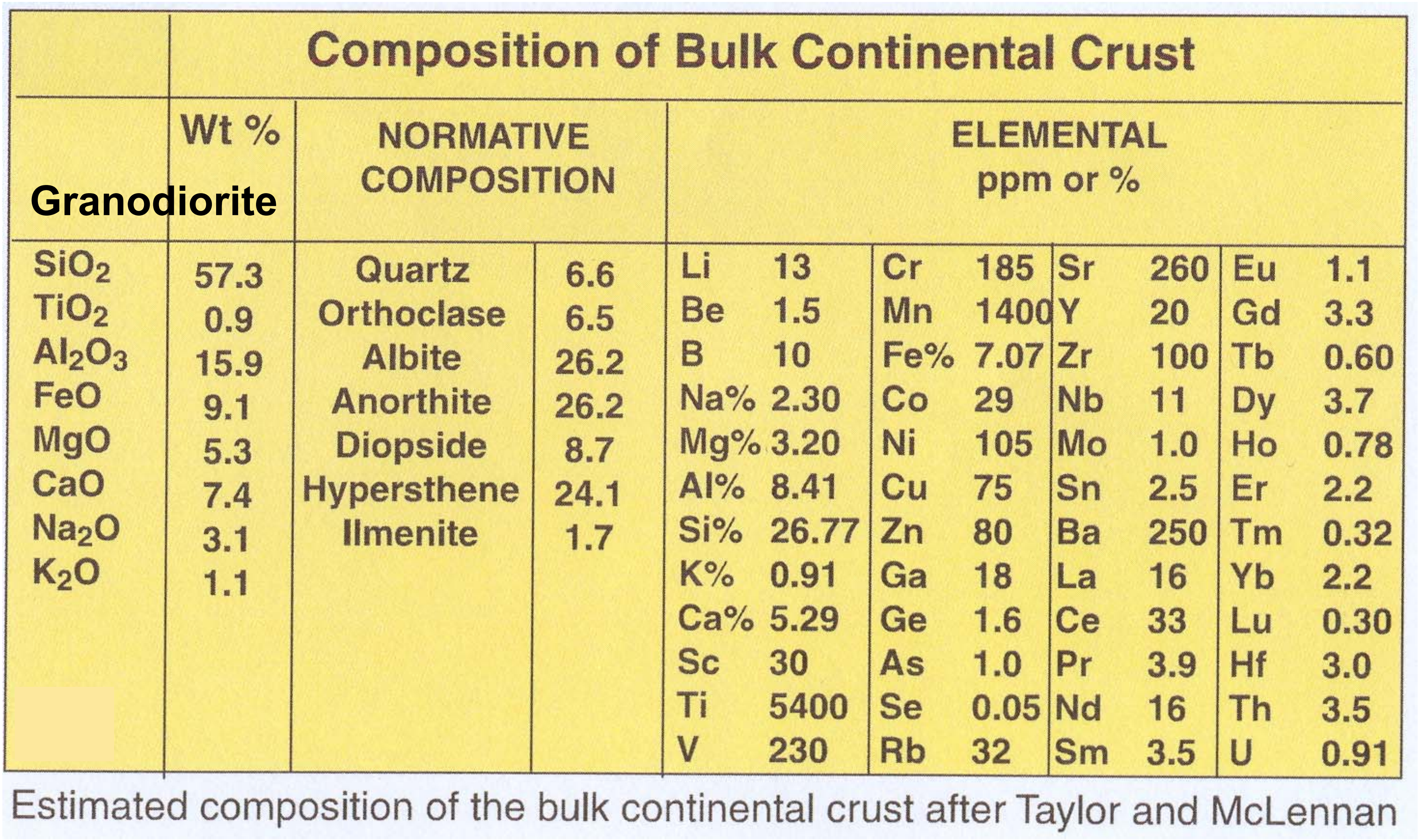




Fő-, mikro- és nyomelemek

A kontinentális kéreg összetétele





Composition of Bulk Continental Crust

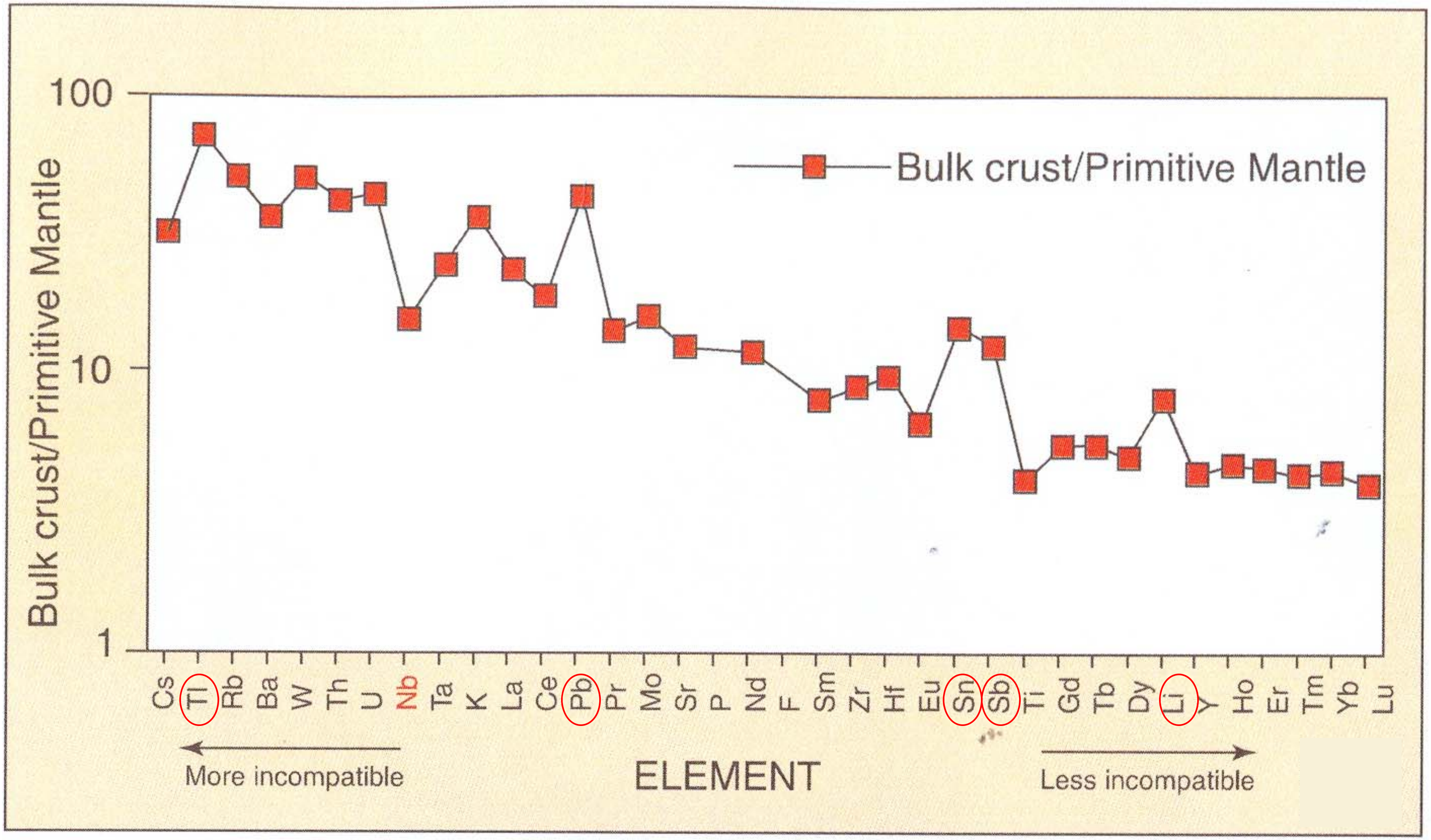
Granodiorite

	Wt %	NORMATIVE COMPOSITION		ELEMENTAL ppm or %							
SiO_2	57.3	Quartz	6.6	Li	13	Cr	185	Sr	260	Eu	1.1
TiO_2	0.9	Orthoclase	6.5	Be	1.5	Mn	1400	Y	20	Gd	3.3
Al_2O_3	15.9	Albite	26.2	B	10	Fe%	7.07	Zr	100	Tb	0.60
FeO	9.1	Anorthite	26.2	Na%	2.30	Co	29	Nb	11	Dy	3.7
MgO	5.3	Diopside	8.7	Mg%	3.20	Ni	105	Mo	1.0	Ho	0.78
CaO	7.4	Hypersthene	24.1	Al%	8.41	Cu	75	Sn	2.5	Er	2.2
Na_2O	3.1	Ilmenite	1.7	Si%	26.77	Zn	80	Ba	250	Tm	0.32
K_2O	1.1			K%	0.91	Ga	18	La	16	Yb	2.2
				Ca%	5.29	Ge	1.6	Ce	33	Lu	0.30
				Sc	30	As	1.0	Pr	3.9	Hf	3.0
				Ti	5400	Se	0.05	Nd	16	Th	3.5
				V	230	Rb	32	Sm	3.5	U	0.91

Estimated composition of the bulk continental crust after Taylor and McLennan

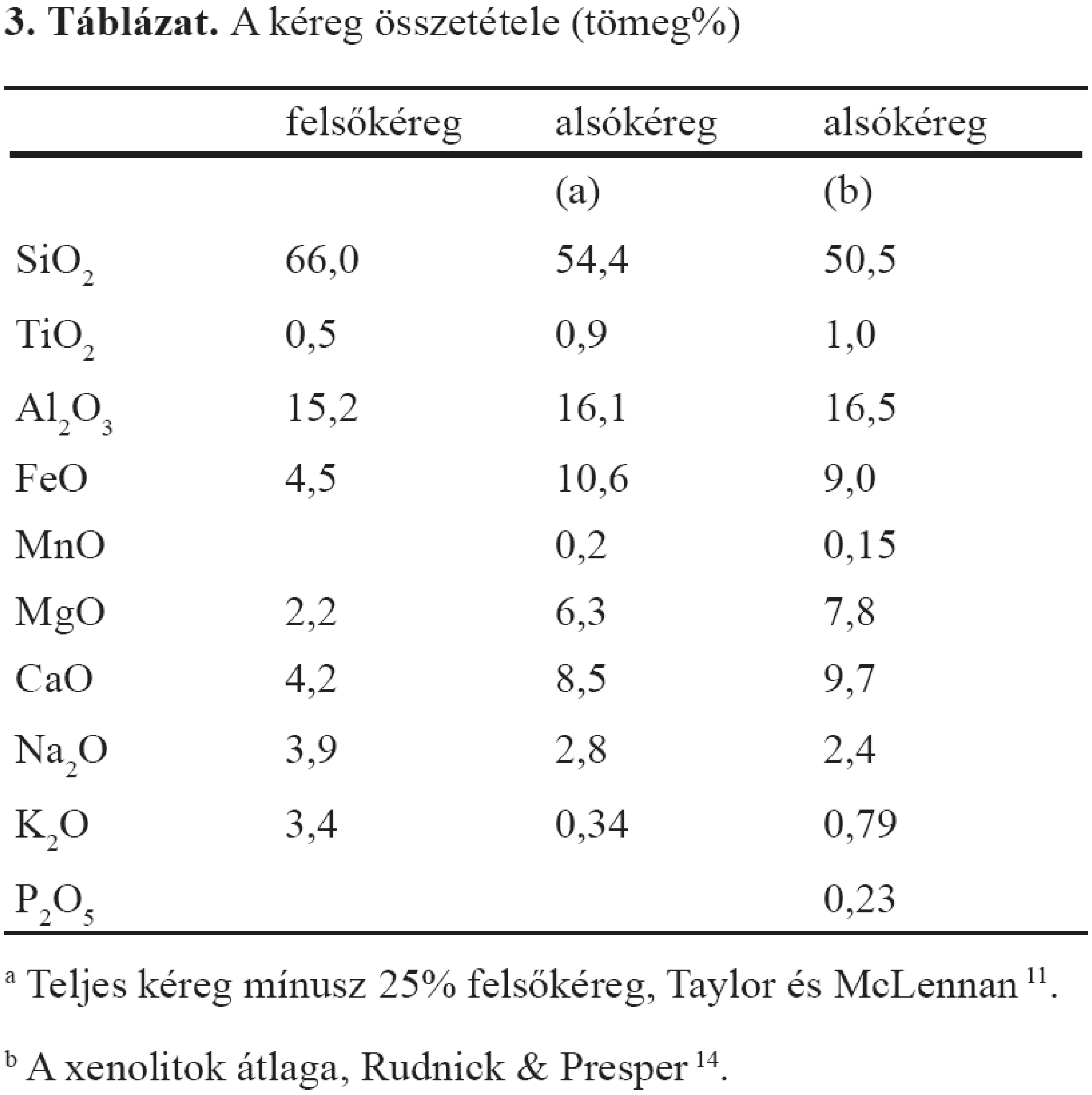
normative → ← modes

Modális összetétel? Illók?



Plot showing that all trace elements in continental crust are enriched at least 5 times above the primitive mantle. Note the Nb anomaly, probably due to subduction processes.

A kéreg



3. Táblázat. A kéreg összetétele (tömeg%)

	felsőkéreg	alsókéreg	alsókéreg
		(a)	(b)
SiO_2	66,0	54,4	50,5
TiO_2	0,5	0,9	1,0
Al_2O_3	15,2	16,1	16,5
FeO	4,5	10,6	9,0
MnO		0,2	0,15
MgO	2,2	6,3	7,8
CaO	4,2	8,5	9,7
Na_2O	3,9	2,8	2,4
K_2O	3,4	0,34	0,79
P_2O_5			0,23

[a] Teljes kéreg mínusz 25% felsőkéreg, Taylor és McLennan [11].

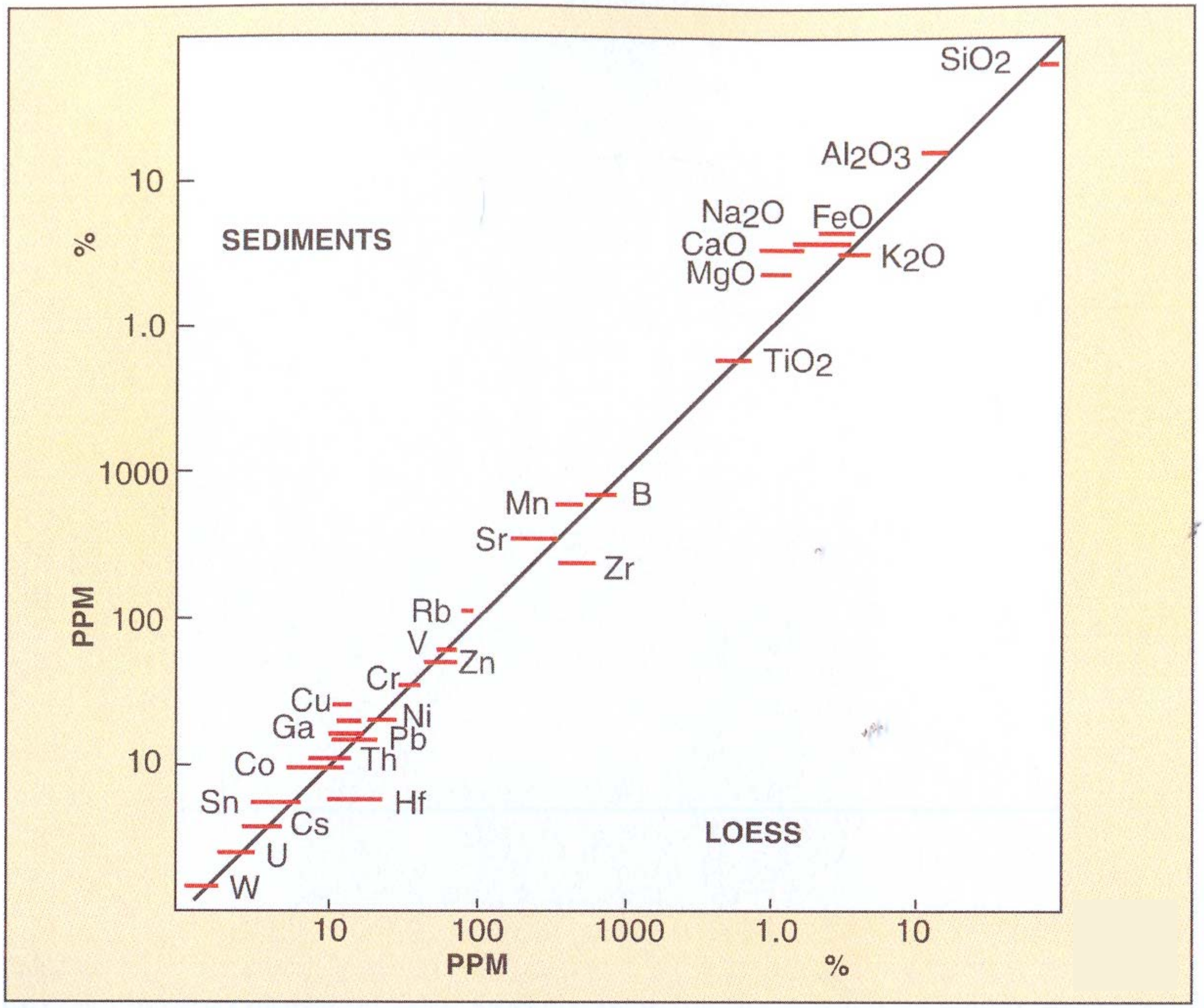
[b] A xenolitok átlaga, Rudnick & Presper [14].

F.kéreg: lösz, terrigén üledék, pala

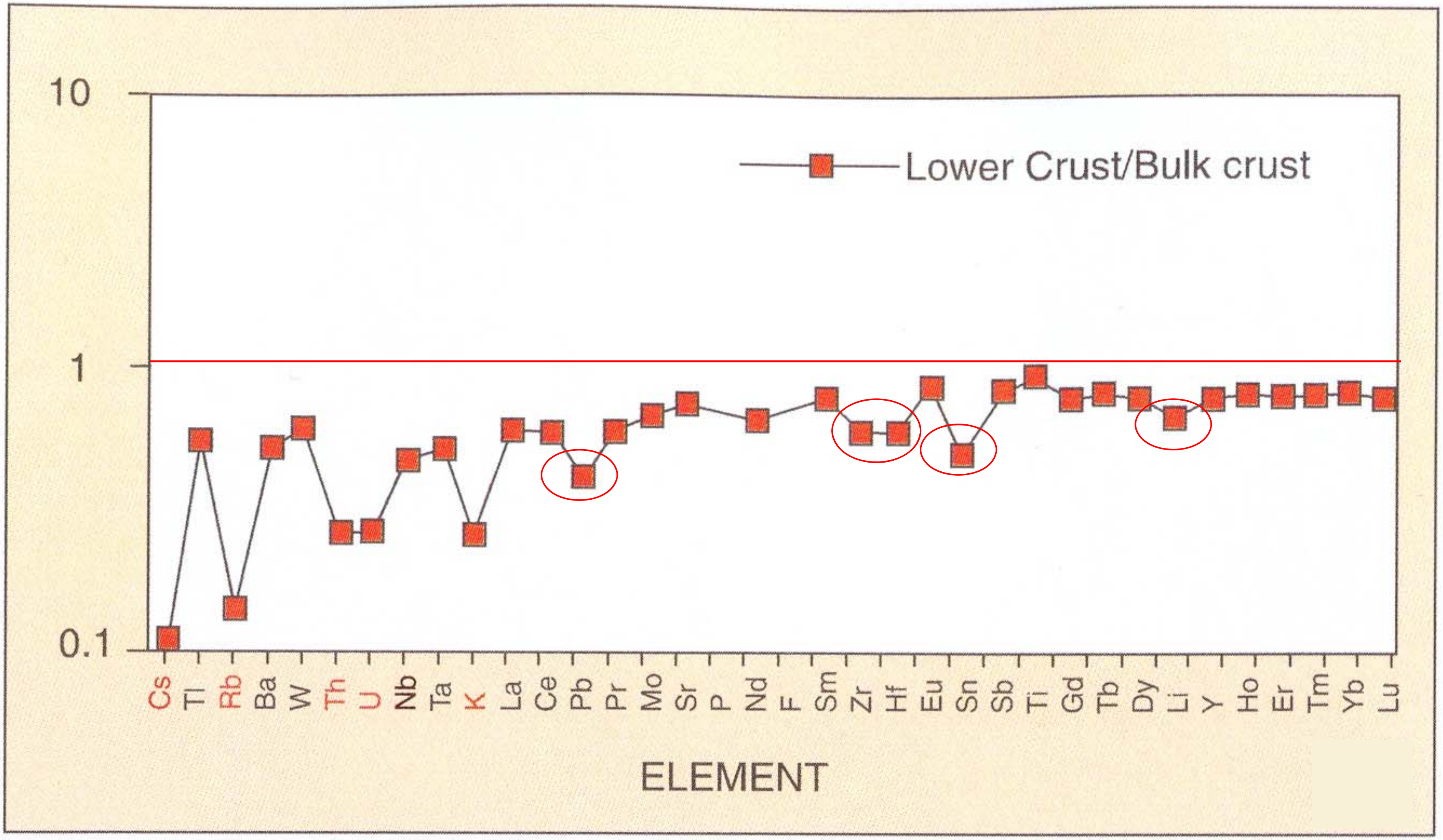
A.kéreg: granulit xenolit

F.kéreg: részben differenciáció a.kéregből?

Embey-Isztin Dobosi, 2004

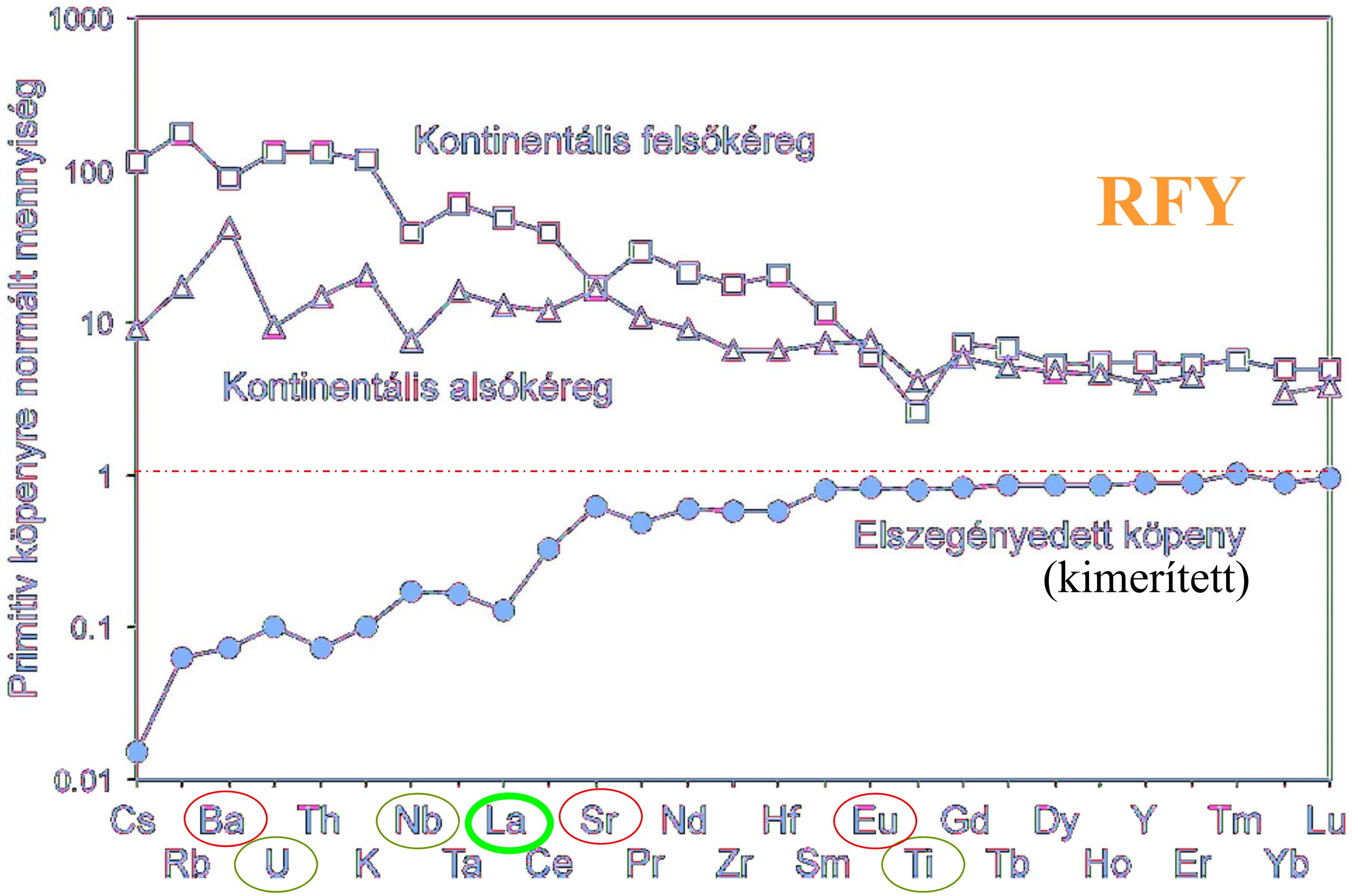


Ranges of elements and oxides found in loess and in upper crustal sediments.



Elements in decreasing order of incompatibility, of the lower crustal composition/bulk crust, shows depletions in Cs, Rb, K, Th and U.

(A különbség 25% felsőkéreg “kivonást” jelez! Imkompatibilitas - kompatibilis)



Az elszegényedett köpeny és a kontinentális kéreg primitív köpenyre normált inkompatibilis nyomelem összetétel diagramja. Az adatok Rudnick és Fountain [10], valamint Taylor és McLennan [11] cikkéből származnak.

Embey-Isztin Dobosi, 2004

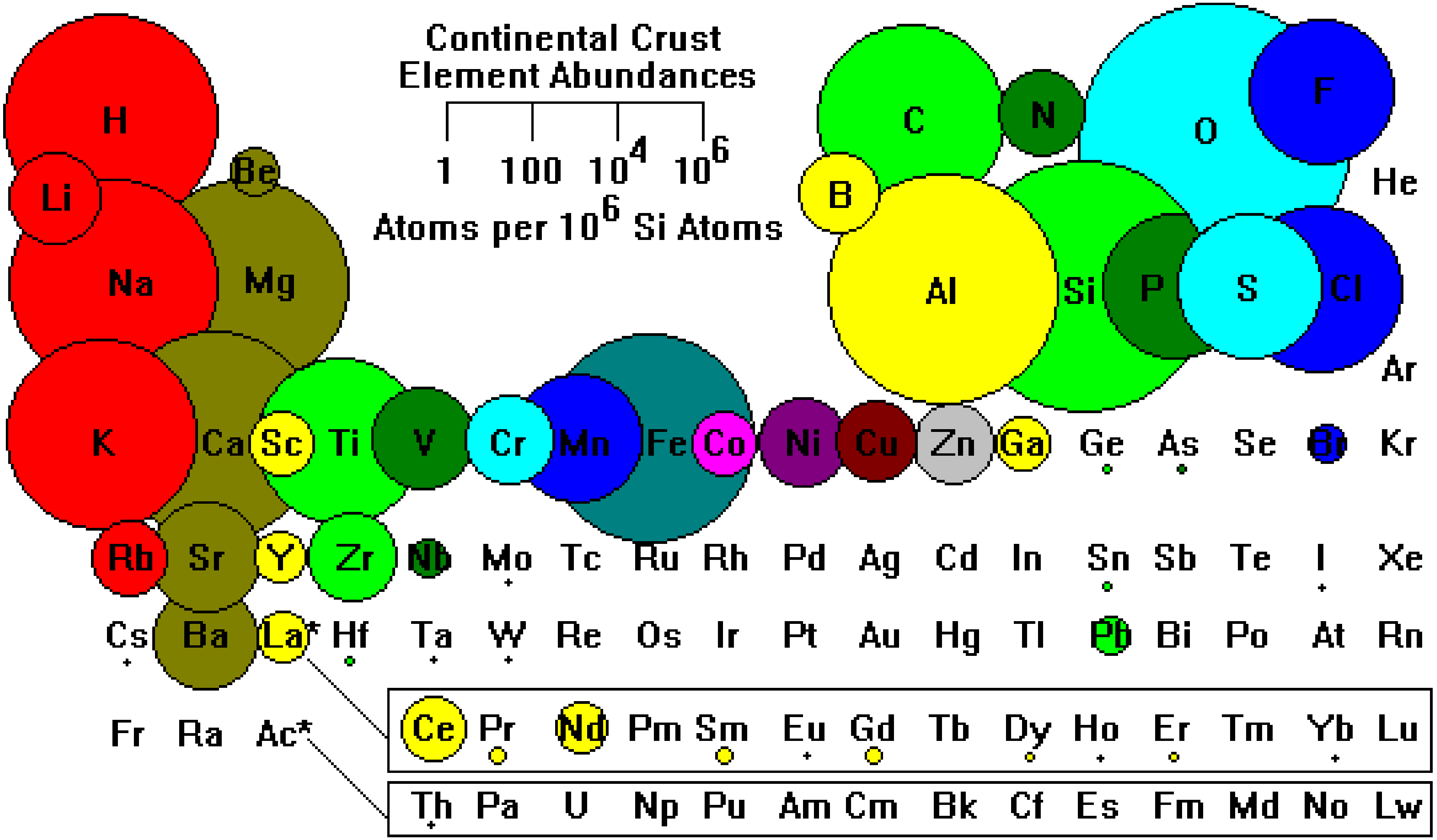
Mantle vs. Continental Crust (in m/m%)

	mantle	crust
SiO_2	45	60
MgO	37	4
FeO	8	4
Al_2O_3	3	15
CaO	3	6
Na_2O	0.5	3
Cr_2O_3	0.4	0.01
MnO	0.2	0.1
TiO_2	0.1	1

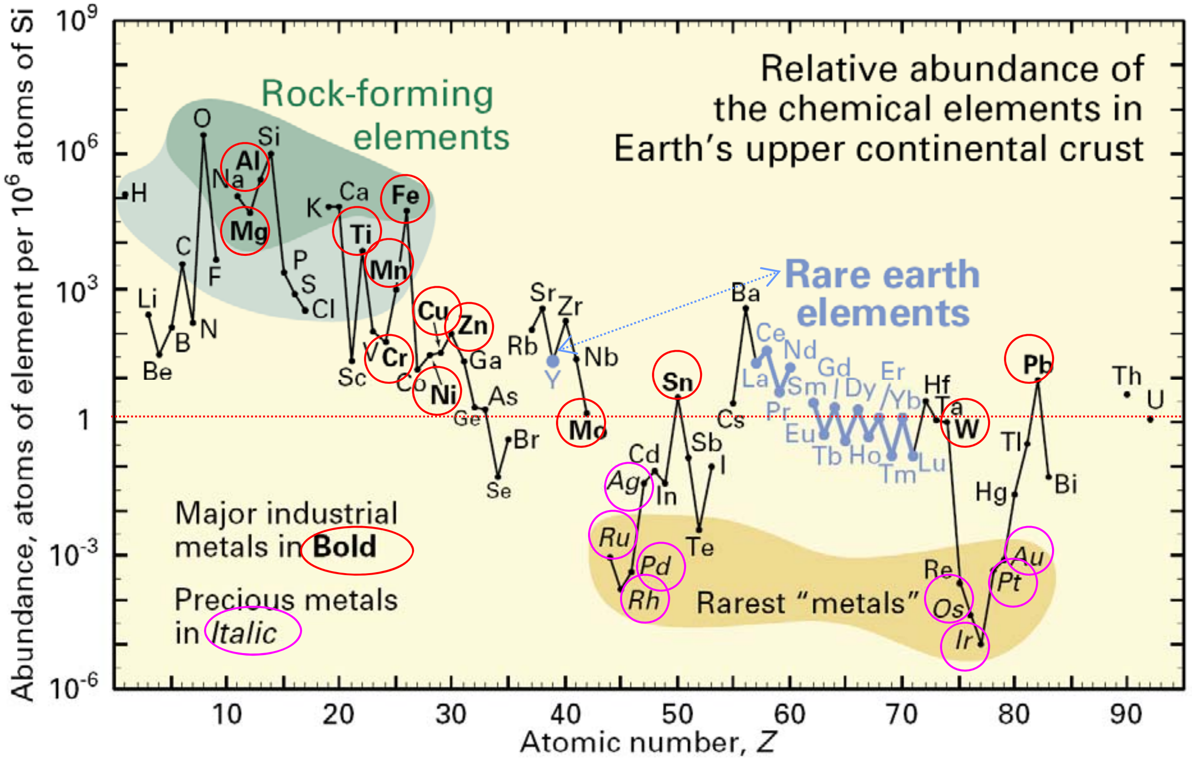
Secondary differentiation

illómentes

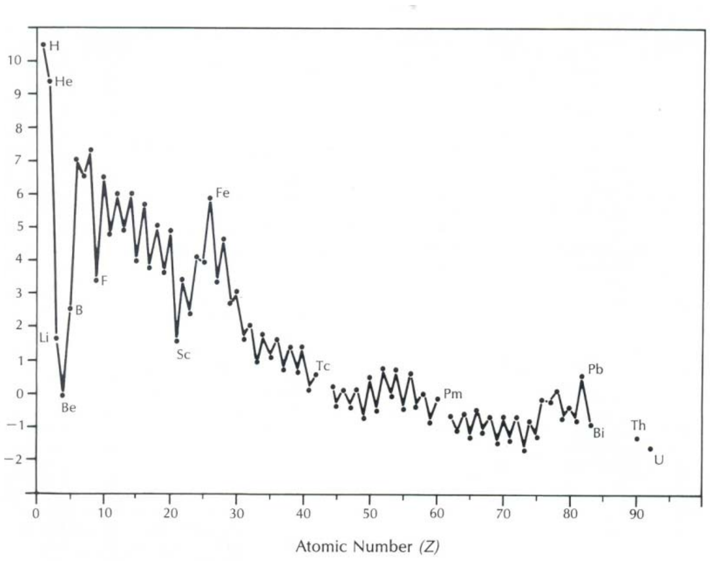
A kontinentális kéreg összetétele



Az elemek gyakorisága a felső kontinentális kéregben



Ferszman



Abundance (atom fraction) of the chemical elements in Earth's upper continental crust as a function of atomic number. Many of the elements are classified into (partially overlapping) categories: (1) rock-forming elements (major elements in green field and minor elements in light green field); (2) rare earth elements (lanthanides, La–Lu, and Y; labeled in blue); (3) major industrial metals (global production >~3x10^7 kg/year; labeled in bold); (4) *precious metals (italic)*; and (5) the 9 rarest "metals"— the 6 platinum group elements + Au, Re, and Te (a metalloid).

Hő és forrása a Földben

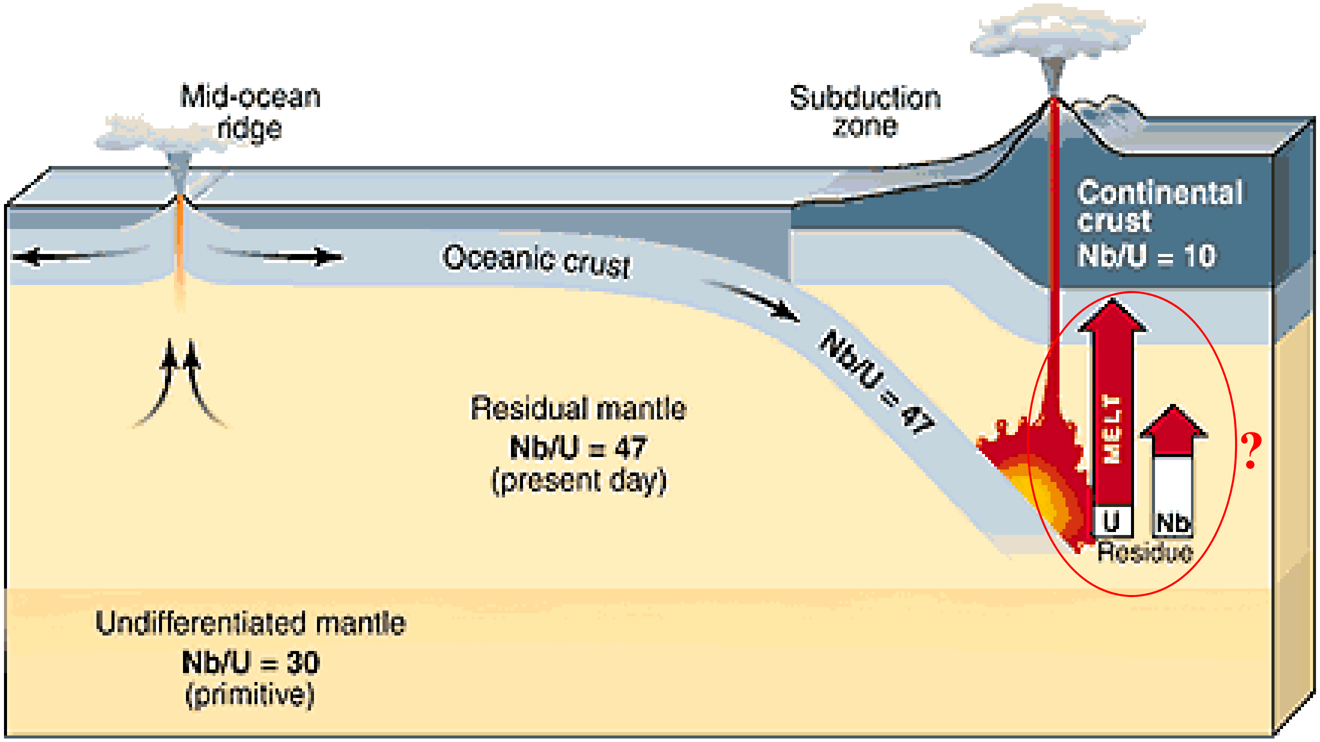
Radioaktív elem koncentráció és hőtermelés a Földben

	U (ppm)	Th (ppm)	K (%)	Totál hőprodukció $\mu W/m^3$
Kontinentális kéreg	**1,6**	**5,8**	**1,7-3,0**	**1,0-1,1**
Óceáni kéreg	**0,9**	**2,7**	**0,4**	**0,5**
Köpeny (szilikátos)	**0,015**	**0,08**	**0,1**	**0,02**

A felszínen mért hőáram ($\mu W/m^2$) 60%-a köpenyből jön.

Brown & Mussett, 1981

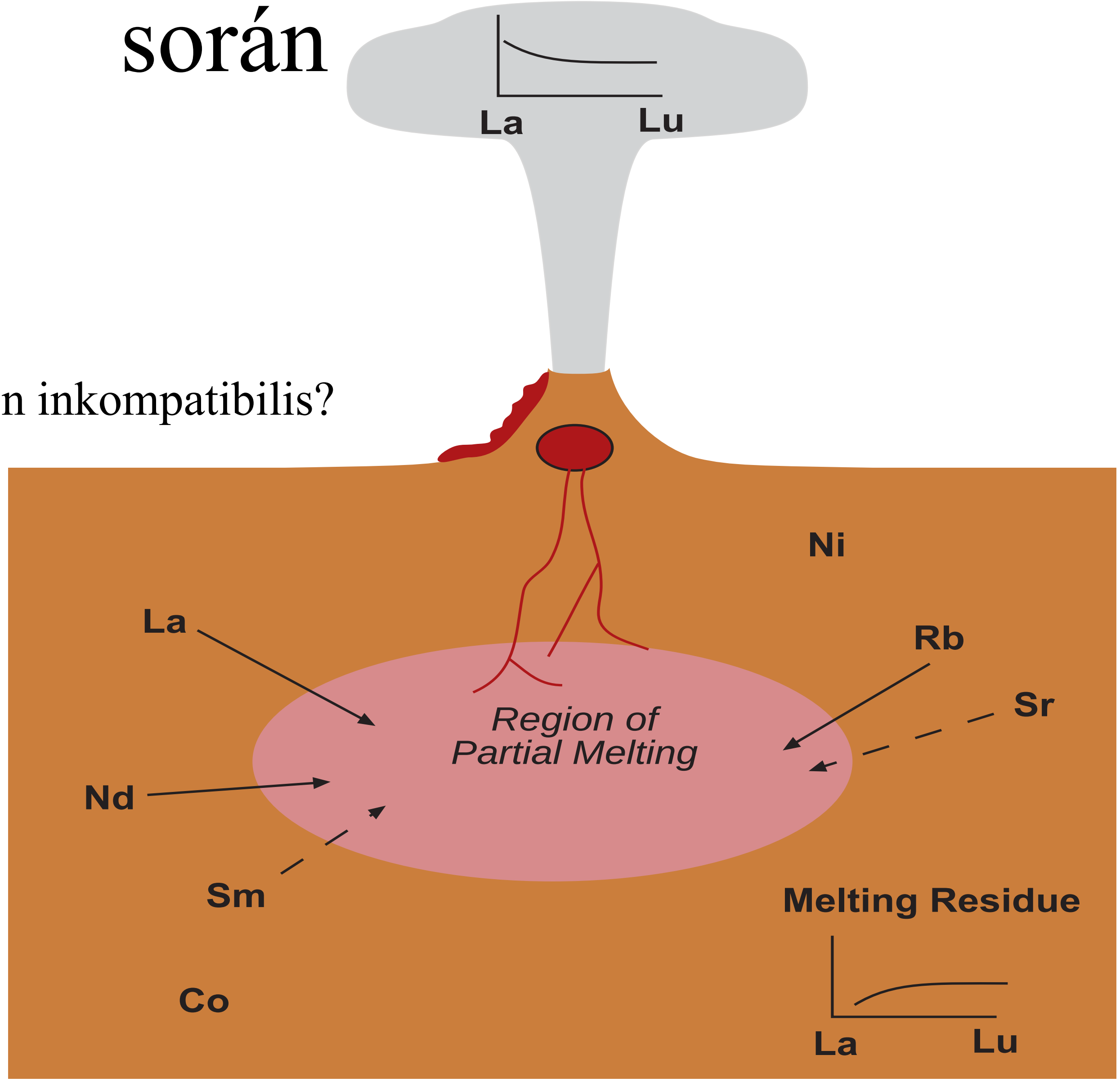
Kéreg fejlődése



Nb és U: melyik erősebben inkompatibilis?

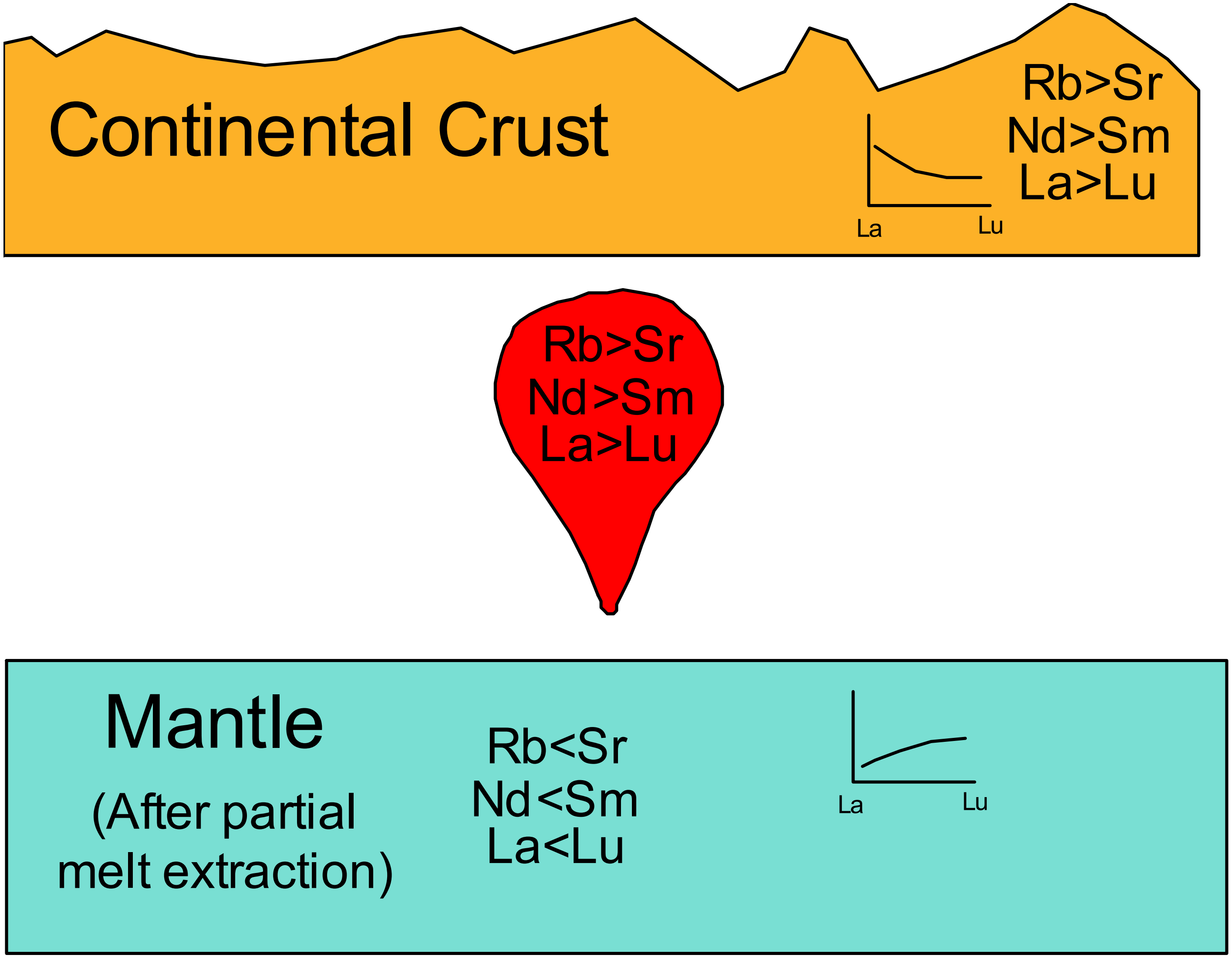
Nyomelem frakcionáció parciális olvadás során

La és Lu: melyik erősebben inkompatibilis?
Nd és Sm?
Rb és Sr?
Ni?



From: http://www.geo.cornell.edu/geology/classes/geo302

A Föld differenciációja



Continental Crust

Rb>Sr
Nd>Sm
La>Lu

Rb>Sr
Nd>Sm
La>Lu

Mantle

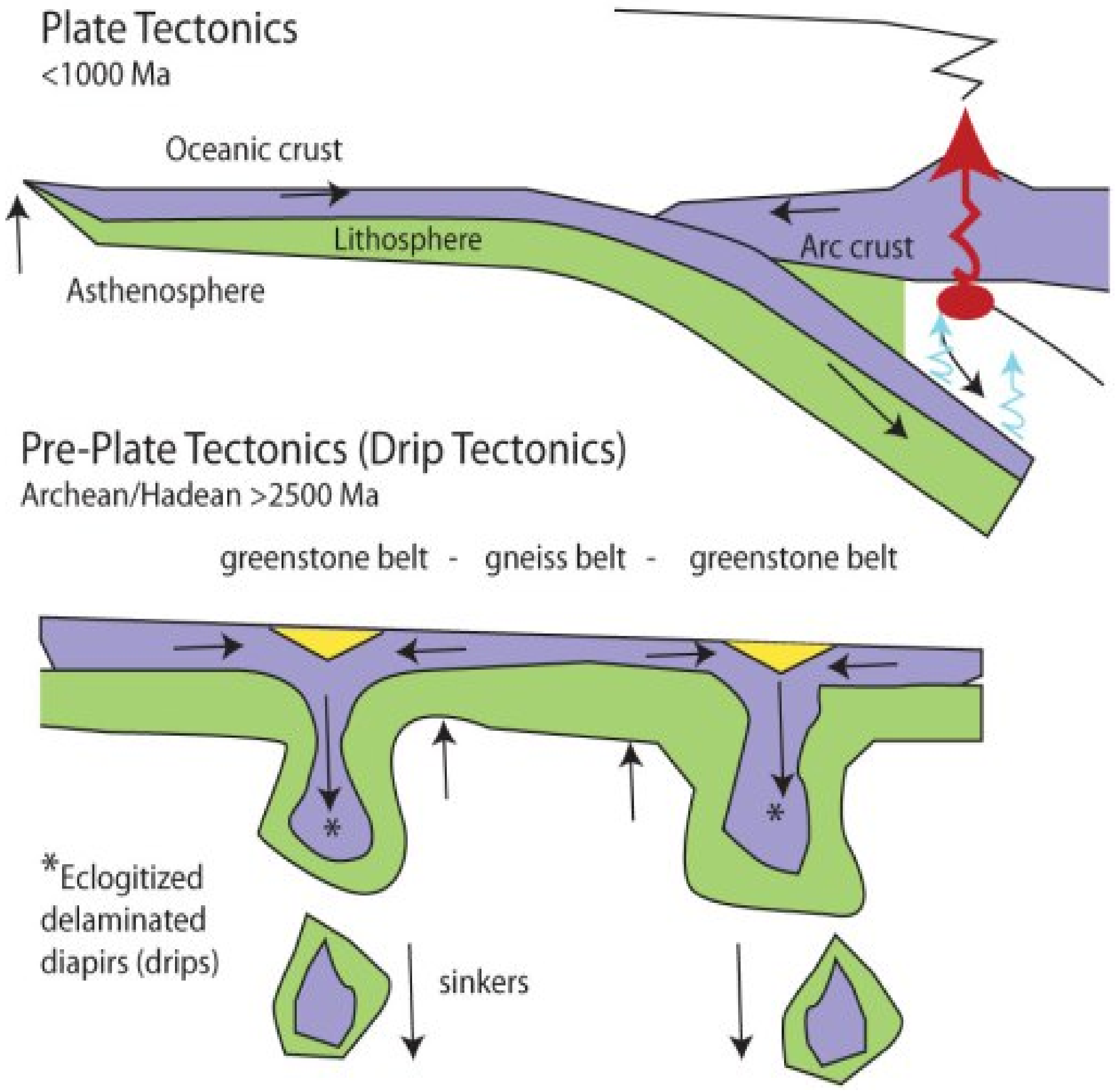
(After partial melt extraction)

Rb<Sr
Nd<Sm
La<Lu

From: http://www.geo.cornell.edu/geology/classes/geo302

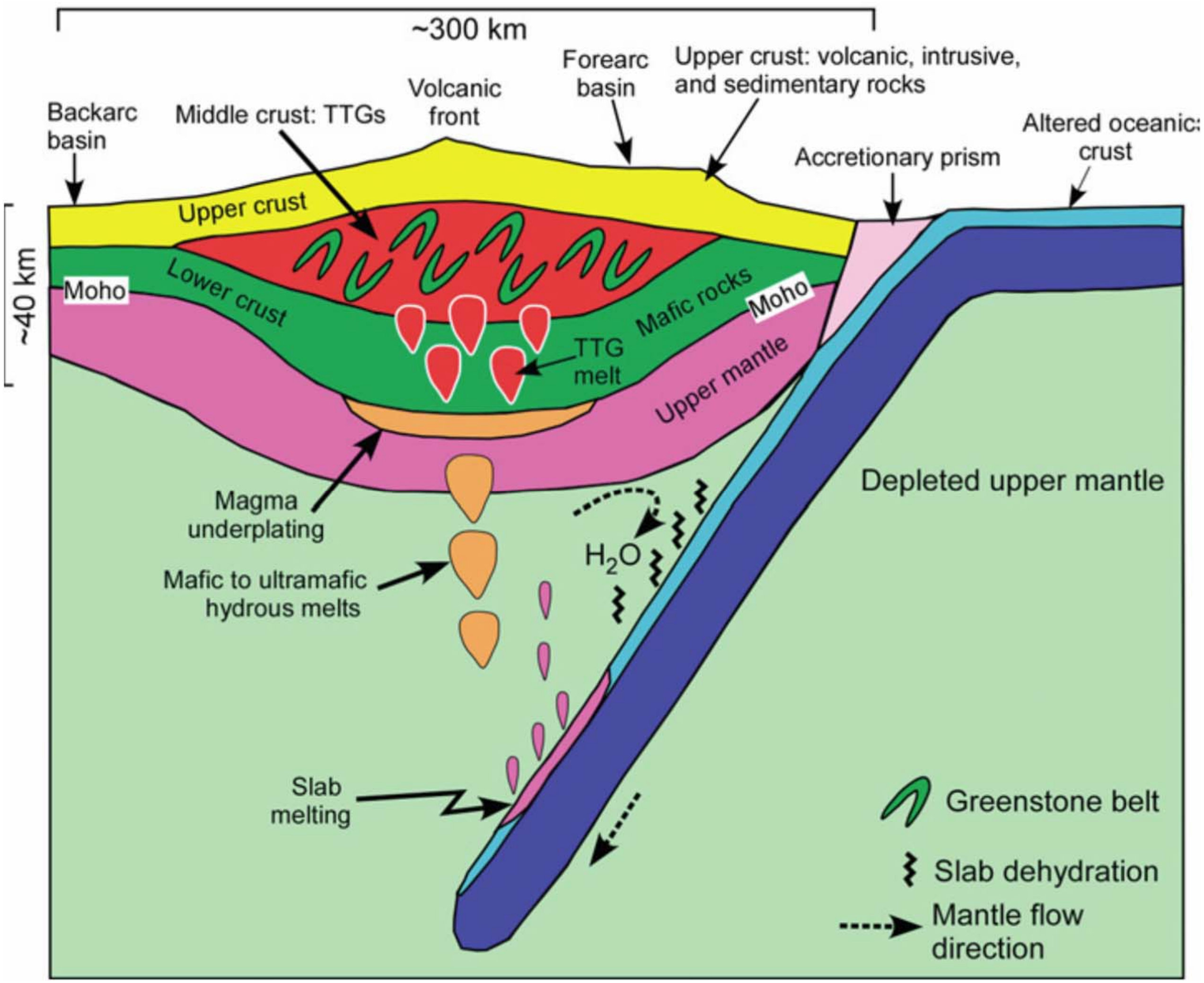
A Föld differenciációja

- Az olvadék, ami kivonódott a köpenyből a kéregbe emelkedik és magával viszi az inkompatilis elemgazdagságát, így
  - a kontinentális kéreg folyamatosan gazdagodik inkompatibilis elemekben, miközben
  - a felsőköpeny inkompatibilis elemekben pedig elszegényedik



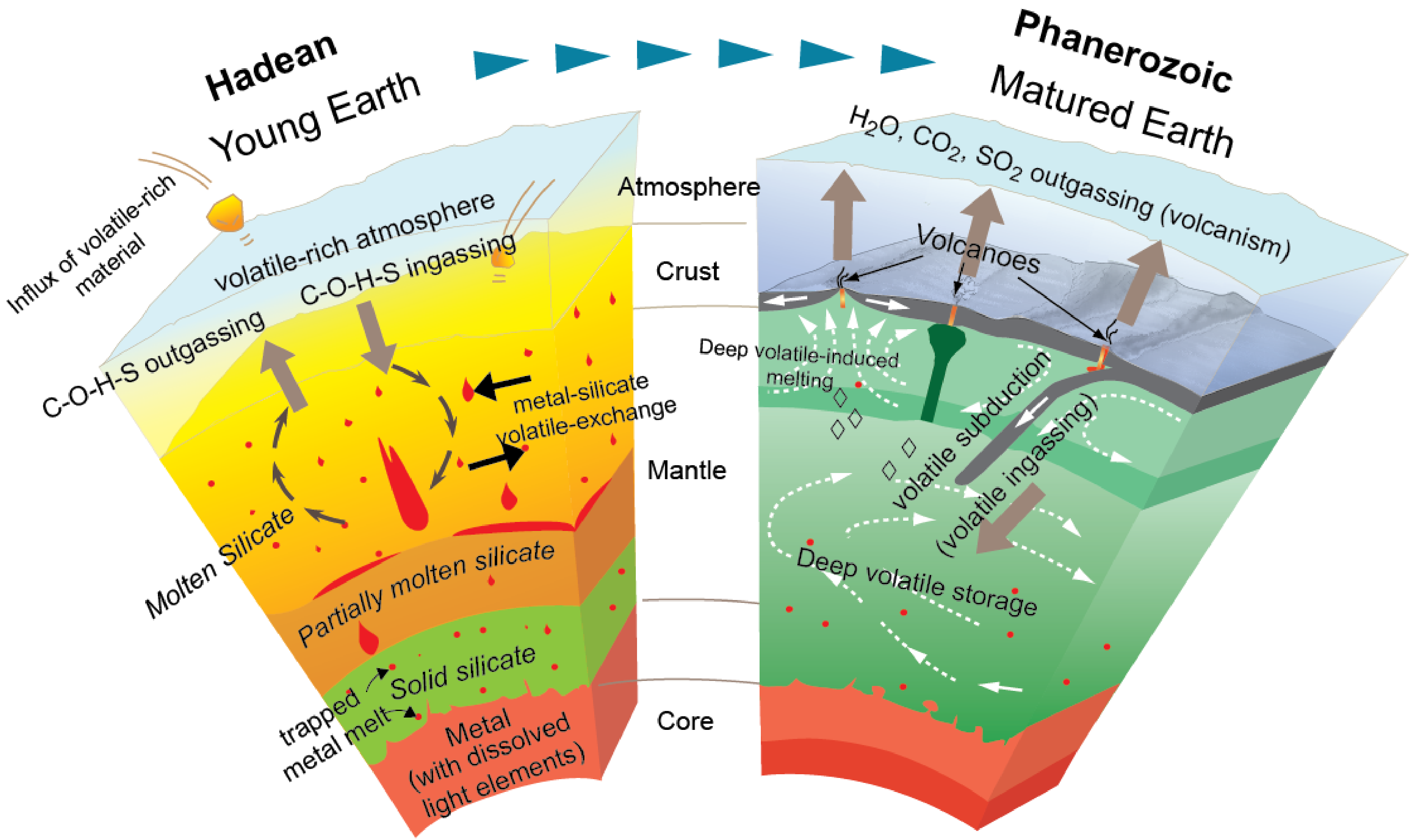
When did plate tectonics begin on Earth?

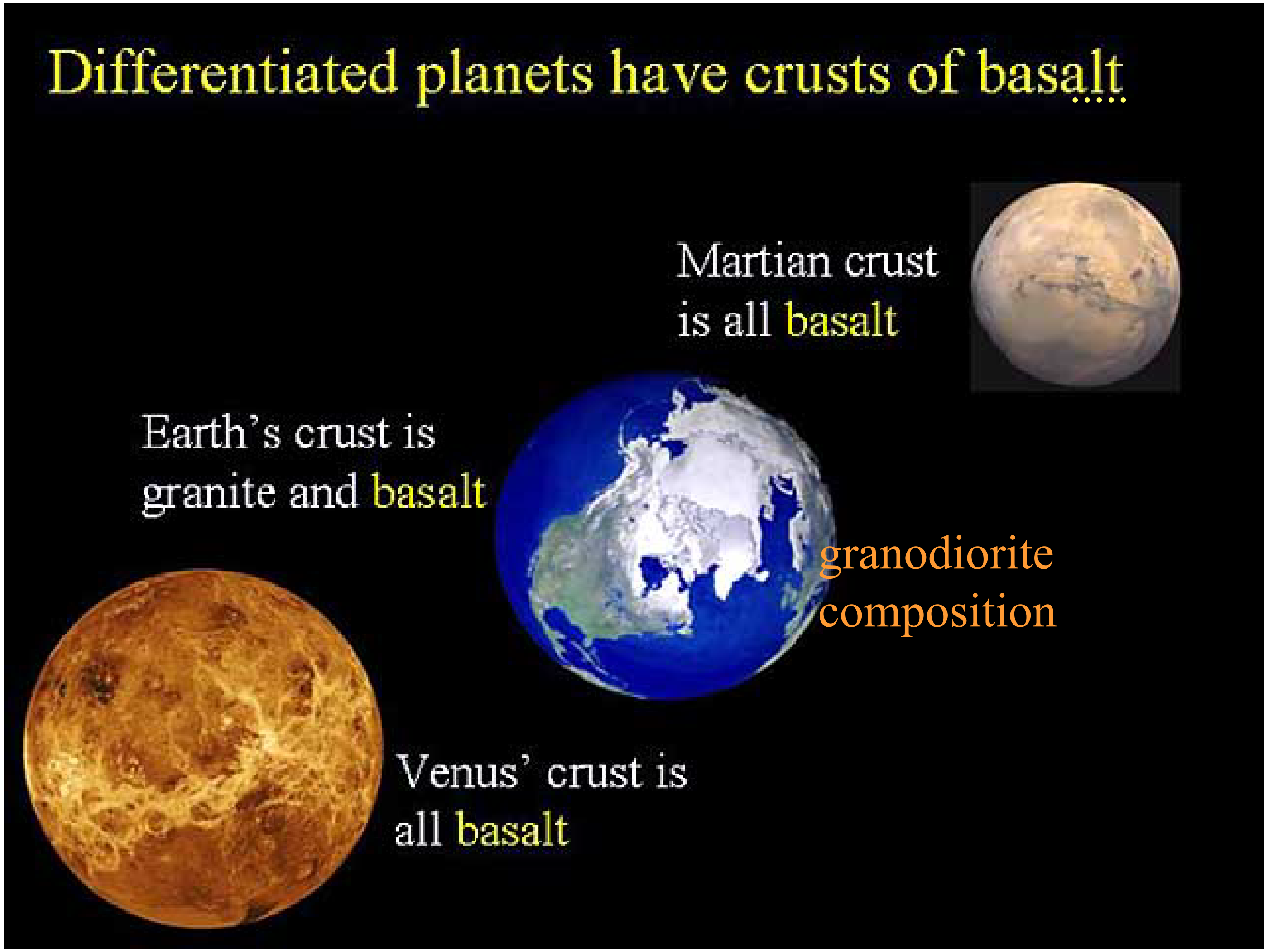
A comparison of plate and drip tectonics (from Stern, 2013). Upper panel shows a simplified version of modern plate tectonics, driven by the edgewise sinking of strong, dense lithosphere in subduction zones. Lower panel shows a cartoon of how Earth's tectonic regime might have been before plate tectonics began. In a hotter Earth, thin, weak lithosphere sank vertically, similar to modern scenarios of delamination or "drip tectonics".



A simplified geodynamic model for the generation of Archean continental crust (tonalite-trondhjemite-granodiorite, TTG) through partial melting of mafic lower crust at the base of an oceanic arc (modified after Davidson and Arculus, 2006).

Polat, 2012, Geology


Hadean
Young Earth
Phanerozoic
Matured Earth
Influx of volatile-rich material
volatile-rich atmosphere
C-O-H-S ingassing
C-O-H-S outgassing
metal-silicate volatile-exchange
Molten Silicate
Partially molten silicate
Solid silicate
trapped metal melt
Metal (with dissolved light elements)
Atmosphere
Crust
Mantle
Core
H_2O, CO_2, SO_2 outgassing (volcanism)
Volcanoes
Deep volatile-induced melting
volatile subduction
(volatile ingassing)
Deep volatile storage



Differentiated planets have crusts of basalt

Martian crust
is all basalt

Earth's crust is
granite and basalt

granodiorite
composition

Venus' crust is
all basalt

Geologically, melting is a very strange process. Ice is solid water: when it melts, we get liquid water, but rocks don't behave this way. Venus and Mars are differentiated planets with crusts made from volcanic basalt lavas, similar to the composition of the ocean floors on Earth. Where does basalt come from? Basalt is made of two minerals called feldspar and pyroxene, and it's the product of the partial melting of a third mineral called olivine. Partial melting means you don't melt all of the olivine, just part of it. In other words, if you partially melt one thing, the melt you get is another composition entirely. However, the geology of magmas or melts is just as weird when it comes time for them to cool down and crystallize, If a magma cools slowly, instead of forming one kind of rock it forms a whole family of different rocks at different temperatures. What all this means is that if you start with one mineral and you melt it progressively, then let the melt cool progressively, you end up with a variety of rocks that range from basalt to granite! This is how chondrites differentiate into the host of different rocks that the rocky planets are made of.

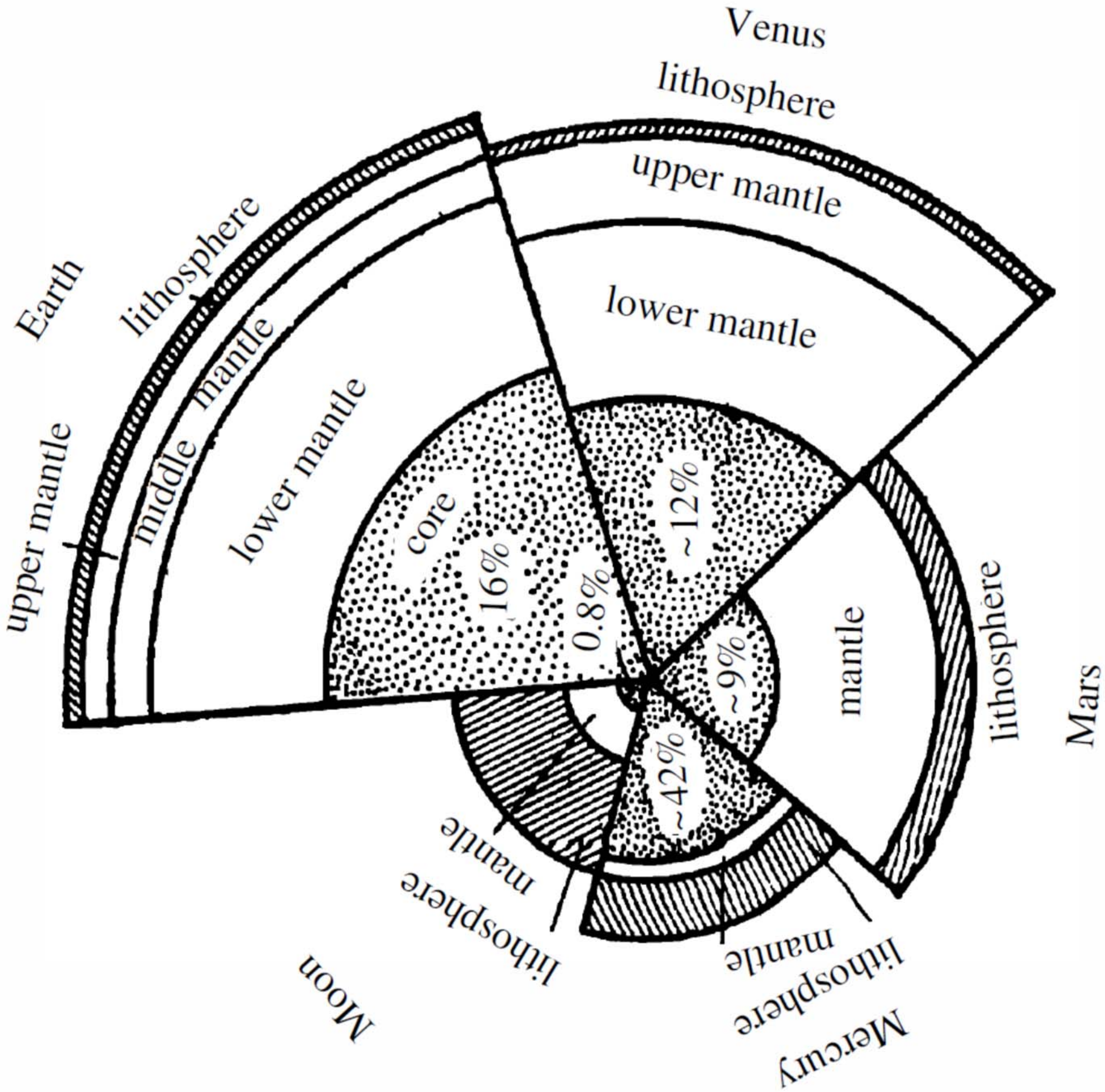


Fig. 15. Comparison of models of the inner structure of terrestrial planets; the relative sizes of their cores are indicated in relative % (after Marov, 1981 with corrections).

Sharkov Bogatikov
Petrology, 2009

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(1) All terrestrial planets evolved according to similar scenarios. The examples of the Earth and Moon illustrate that the development of their primordial cores started during the solidification of the global magmatic oceans, a process that proceeded from bottom to top due to the difference in the adiabatic gradient and the gradient in the melting point. As a result, the uppermost zones of the planets became enriched in the lowest melting components, which enriched the melts during their crystallization differentiation. This process gave rise to the primordial sialic crust of the Earth and the basite crust of the Moon (which was controlled by the depths of the magmatic oceans). Relicts of these primordial crusts are preserved at continents and largely predetermined their inner structure and composition. The development of the primordial crusts was responsible for the depletion of the mantles in low-melting components. The crusts at continents (*terrae*) of Venus and Mars also consist of lighter material and seem to have been formed in a similar manner.

(2) A principally important distinctive structural feature of the planetary bodies discussed here is that their crusts are of two distinct types: ancient “continental”, which is preserved at topographically elevated areas, and young basite (basaltic) crust, which composes extensive lowlands at larger planets and round “seas” (*maria*) at the Moon (the situation with Mercury is uncertain). Results obtained by studying magmatism at the Earth and Moon indicate that the first evolution ary stages of these planets produced high-Mg melts, which were derived from the depleted mantle and formed mantle thermal superplumes of the first generation.

(3) Intermediate evolutionary stages of the Earth and Moon (as well as other terrestrial planets) were marked by an irreversible drastic change in the course of evolution, which is thought to have been related to the development of liquid cores of these planets. This is consistent with the fact that the magnetic field strength reached its maximum at 2.3–2.2 and 3.9 Ga at the Earth and Moon, respectively. This initiated the ascent of mantle superpluems of the second generation (thermochemical), whose material was enriched in Fe, Ti, Nb, Ta, incompatible elements, and fluid components. The head parts of these superplumes laterally spread at shallower depth levels and induced significant transformations in the upper shells of the planets and the gradual replacement of their primordial crusts by secondary basaltic crusts.

(4) A change in the character of tectono-magmatic activity on the Earth in the Middle Paleoproterozoic was associated with a change in the environment at the planet’s surface, for example, the appearance of an oxygenated atmosphere, hydrocarbons, phosphorites, changes in the chemistry of seawater and the isotopic composition of carbonate sediments, and the onset of the evolution of aerobic organisms. Analogous processes on Mars and Venus were also accompanied by significant environmental transformations.

(5) It follows from the aforesaid that tectono-magmatic processes started then to involve principally new type of material, which had been “conserved” at deep levels before. This was possible only if the planetary bodies initially had a heterogeneous inner structure (an iron core and silicate mantle made up of chondritic material), and their heating proceeded from their peripheries to central parts by means of the passage of a thermal wave and was associated with the cooling of their outer shells.

(6) The examples of the Earth and Moon are used to demonstrate that the passage of this wave through the silicate mantle of a planet should have induce the development of plumes of the first generation. When the wave reached the core, whose composition close to the Fe + FeS eutectic, the core was melted and brought about the development of superplumes of the second generation.

(7) The wave is thought to be generated as the rotation of the newly formed planets was accelerated in response to a decrease in their radii due to the compaction of their material. Upon the completion of this process, the rotation of the planets stabilized, and these planets entered their second evolutionary stages. Now the Earth’s core is partly solidified, while the cores of the Moon, Mars, Venus, and possibly also Mercury are already completely solid, as follows from the low intensity of their geomagnetic fields (or their virtual absence) and the absence of modern tectono-magmatic activity.

(8) Available information on terrestrial planets suggests that they are spontaneously evolving systems, whose evolution was associated with an irreversible change in their tectono-magmatic processes. Now all of these planets, except the Earth, which is the largest of them, have completed their evolution and are “dead bodies”.