

Un modèle thermique pour le corps parent des chondrites de type H:

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Introduction

H-chondrites

Metal-rich ordinary chondrites:

Bulk chemistry and oxygen isotopes consistent with a single parent body.

Introduction

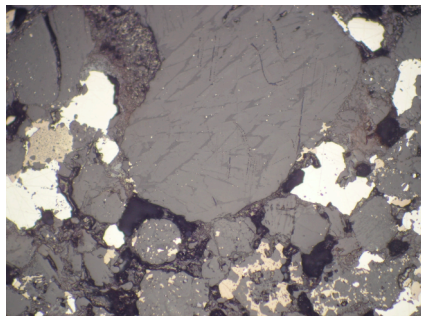
H-chondrites

Metal-rich ordinary chondrites:

Bulk chemistry and oxygen isotopes consistent with a single parent body.

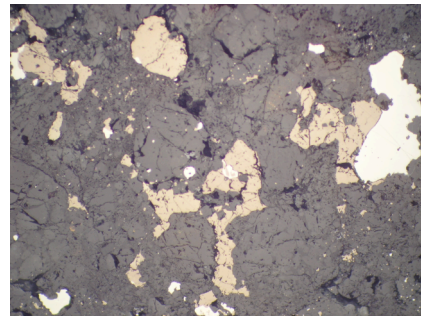
Petrographic classification

Homogenization
of olivine



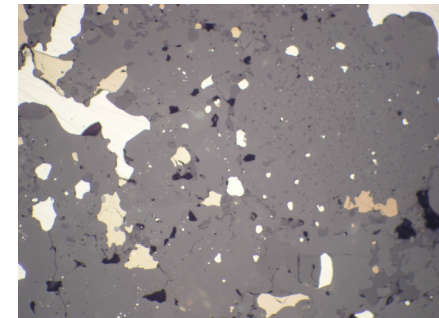
H4

Appearance
of plagioclase

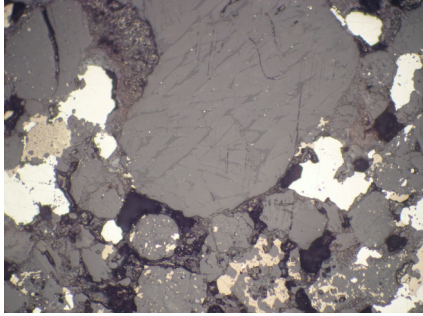


H5

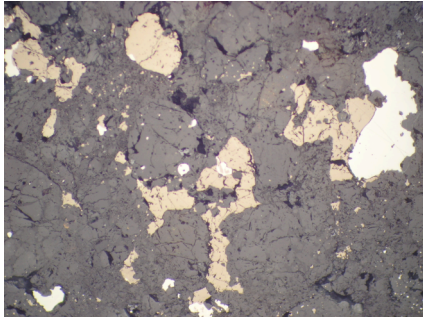
Disappearance
of chondrules



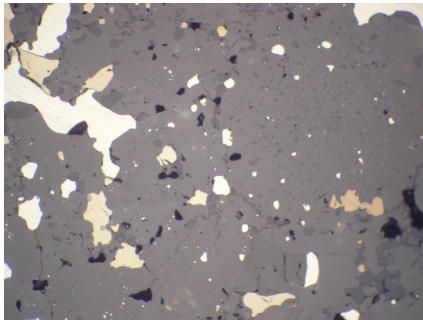
H6



H4
~973K



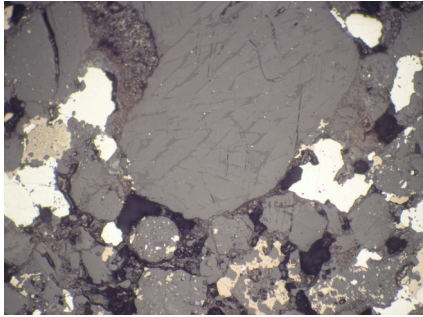
H5
~1023K



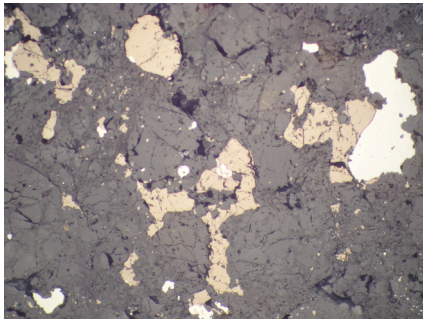
H6
~1223K

Temperature

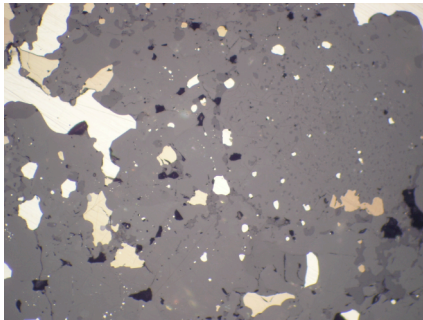




H4
~973K

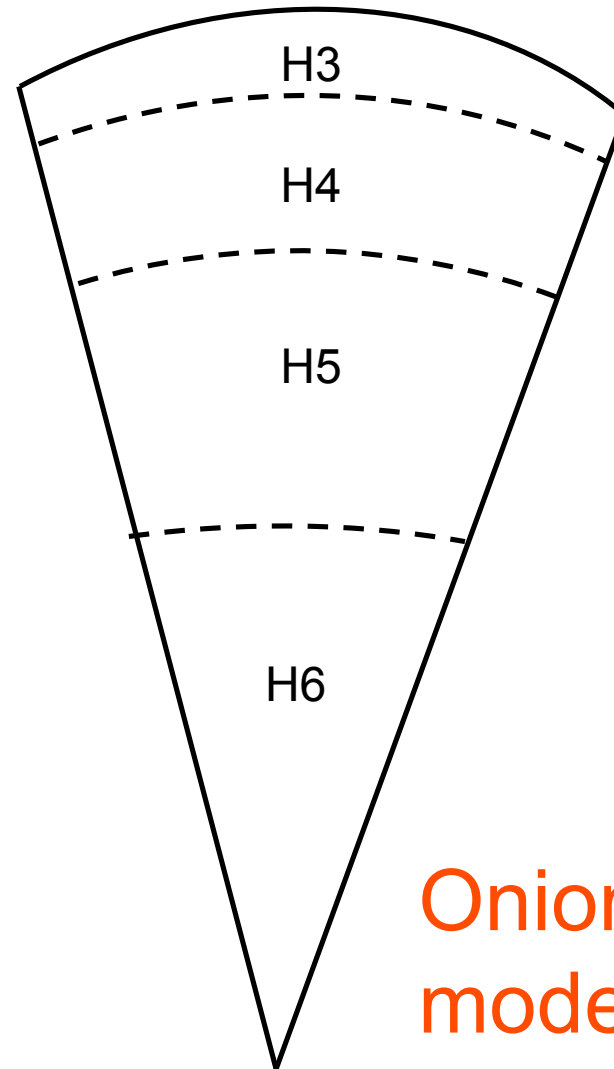


H5
~1023K

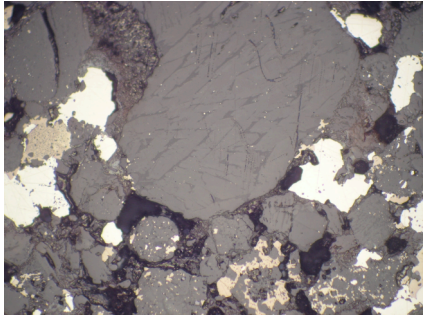


H6
~1223K

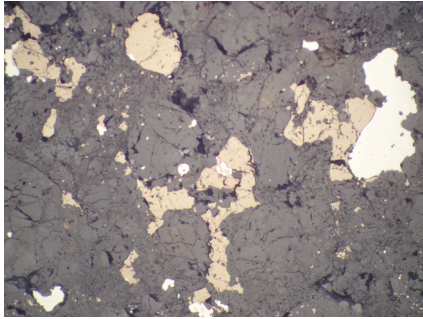
Temperature



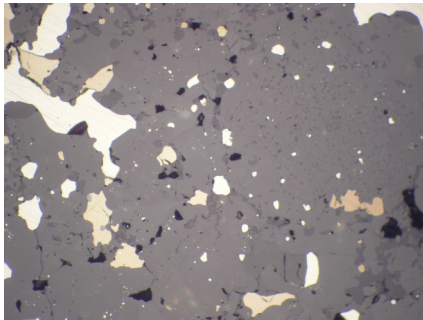
Onion shell
model



H4
~973K

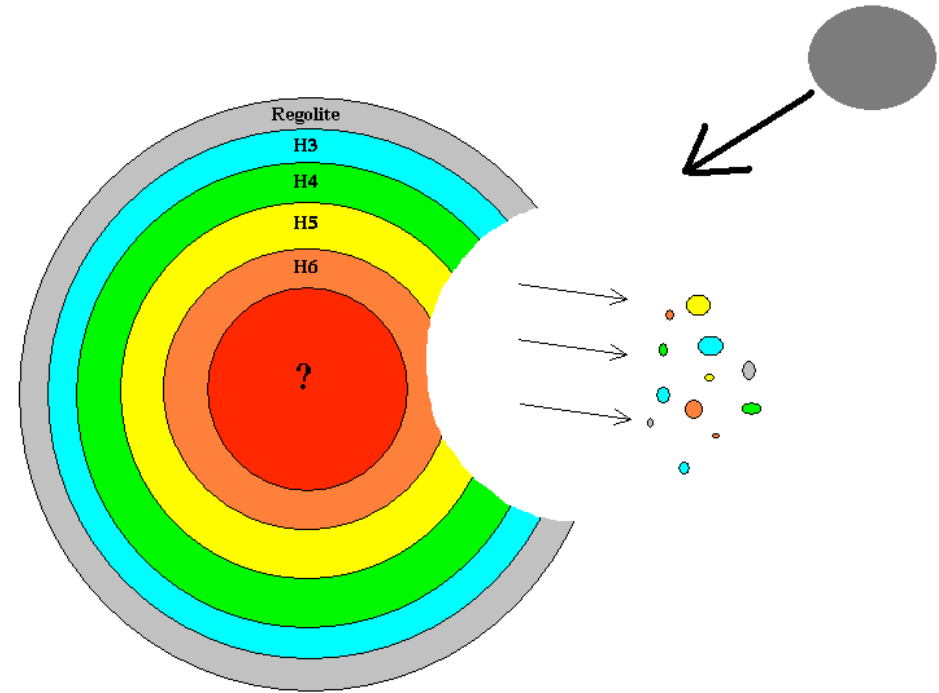


H5
~1023K



H6
~1223K

Temperature



Modèle d'évolution thermique

$$\rho C_p \frac{\partial T}{\partial t} = \frac{1}{r^2} \frac{\partial}{\partial r} \left(K r^2 \frac{\partial T}{\partial r} \right) + A_0 e^{-\lambda t}$$

T	température
t	temps
r	rayon
ρ	densité
C_p	capacité calorifique
K	conductivité thermique
A_0	taux de chauffage à t_0 dû à la désintégration de ^{26}Al
λ	taux de décroissance de $^{26}\text{Al} = 1.39 \times 10^{-6} \text{ a}^{-1}$

Une modélisation thermique

L'équation de diffusion de la chaleur

$$T = T_0 + \frac{\kappa A_0}{K\lambda} e^{-\lambda t} \left(\frac{(R \sin r (\lambda/\kappa)^{1/2})}{(r \sin R (\lambda/\kappa)^{1/2})} - 1 \right) + \frac{2R^3 A_0}{r\pi^3 K} \sum_{n=1}^{\infty} \frac{(-1)^n}{n(n^2 - \lambda R^2 / \kappa \pi^2)} \sin \frac{n\pi r}{R} e^{-\kappa n^2 \pi^2 t / R^2}$$

Si on connaît:

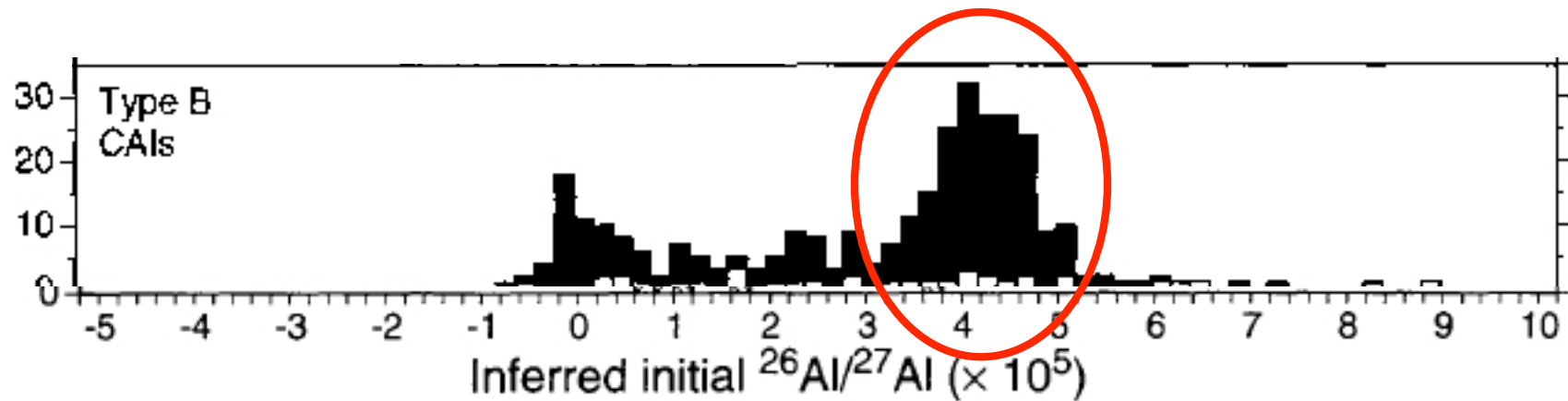
Le rayon du corps

La concentration en radioéléments

Les propriétés thermiques

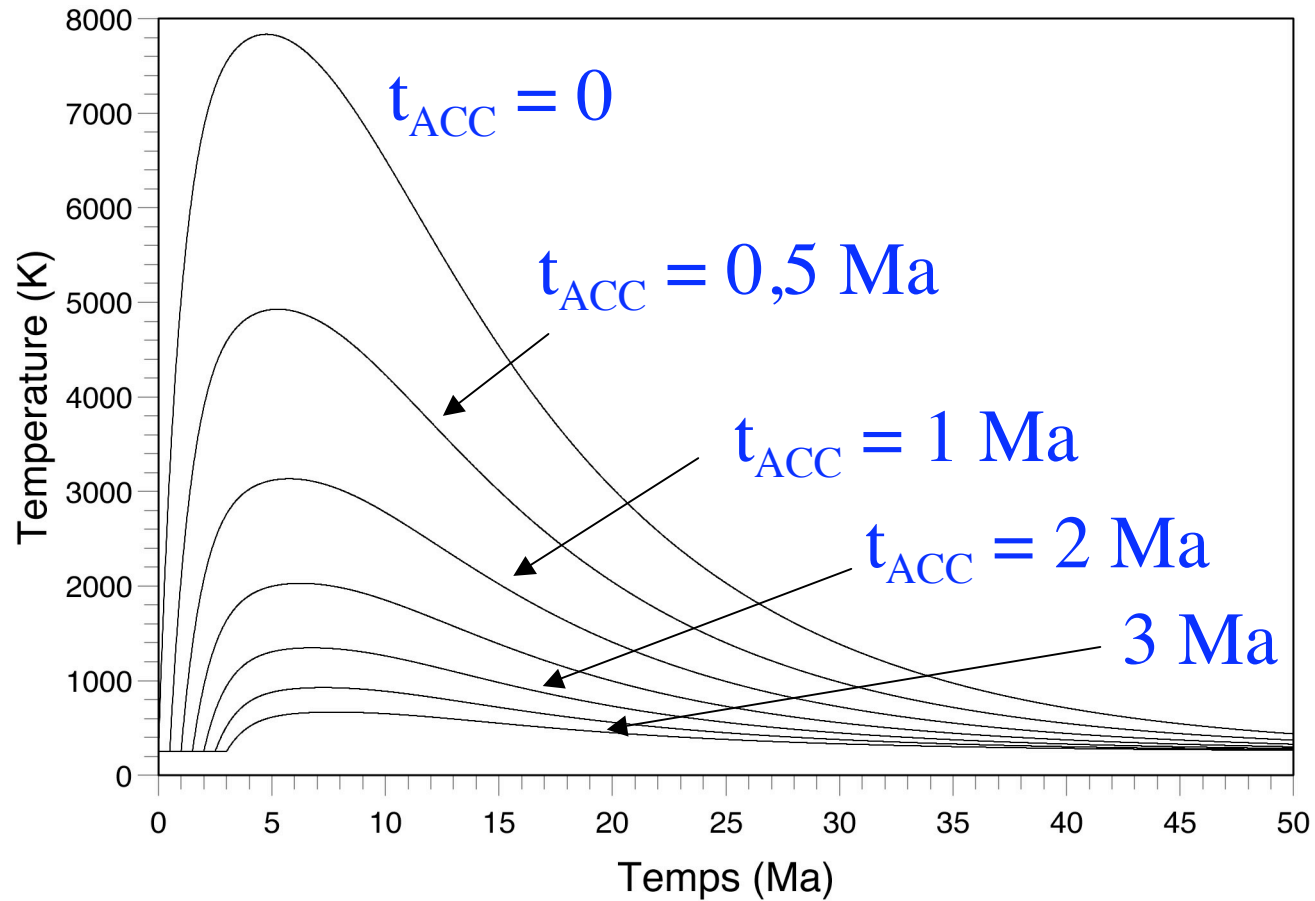
$$T = f(r, t)$$

La source de chaleur? Al^{26}



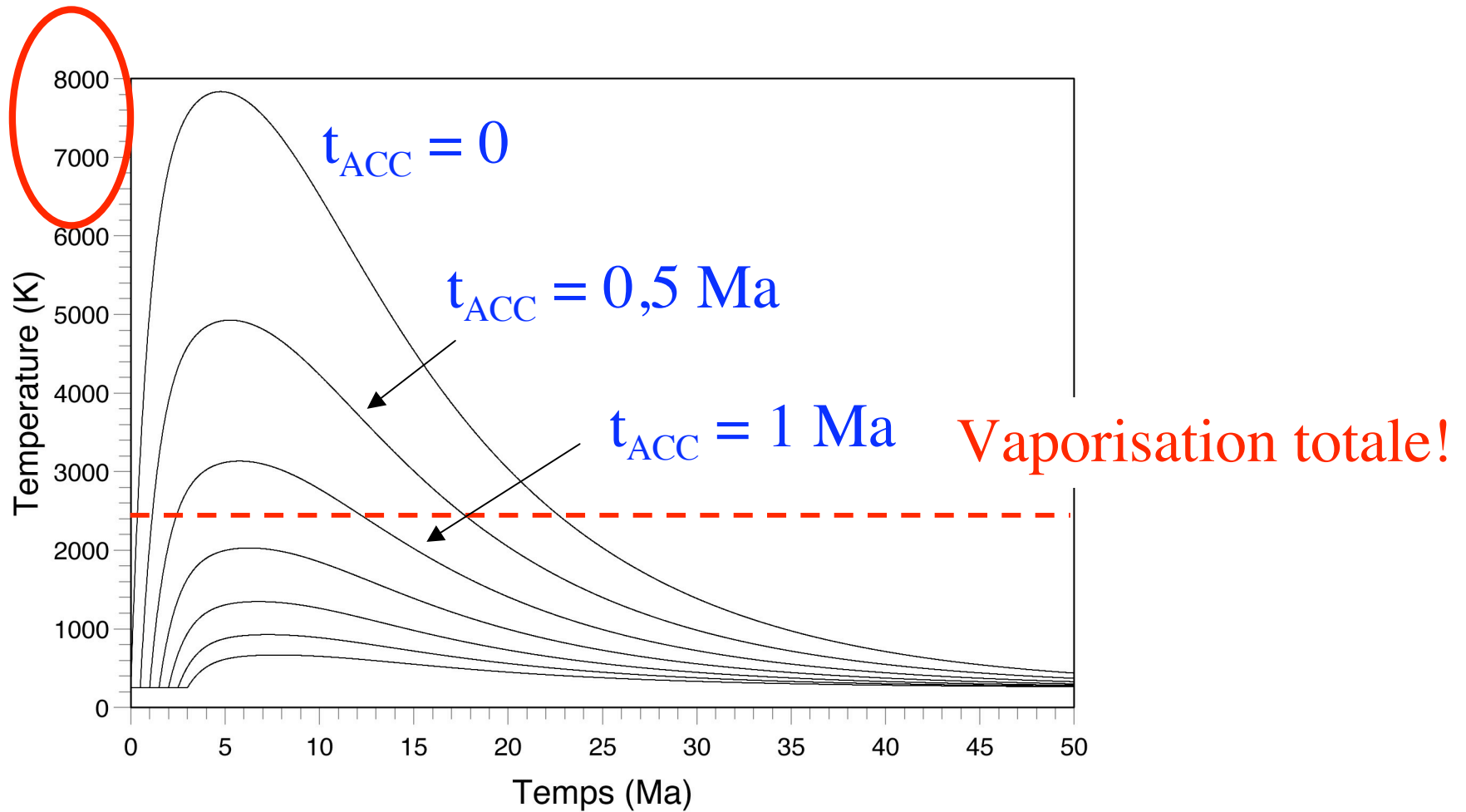
Peut-on fondre un corps planétaire?

Par exemple, au centre d'un corps de 50 km de rayon

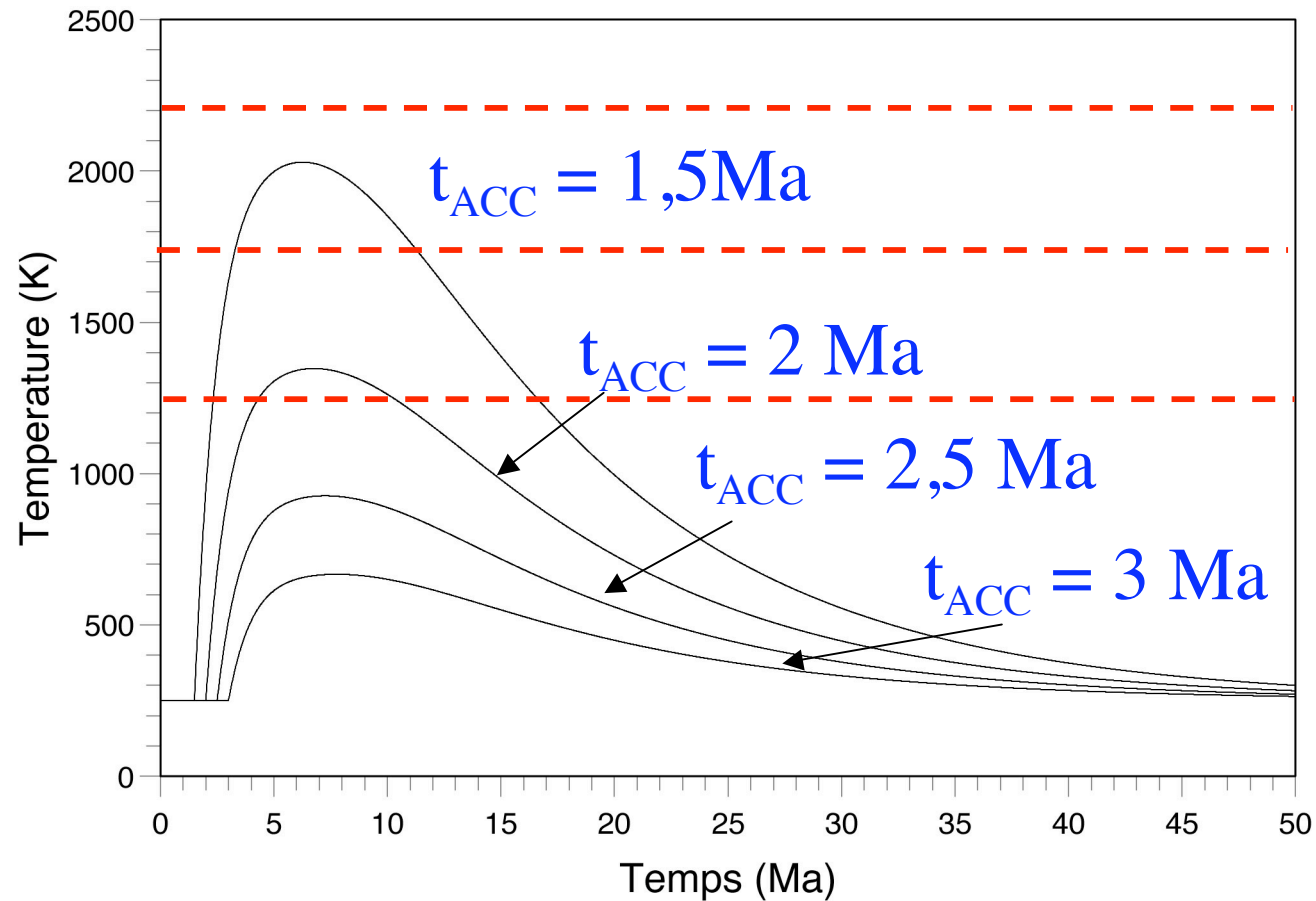


Si l'accrétion est retardée, moins d' Al^{26} , et ça chauffe moins

Par exemple, au centre d'un corps de 50 km de rayon

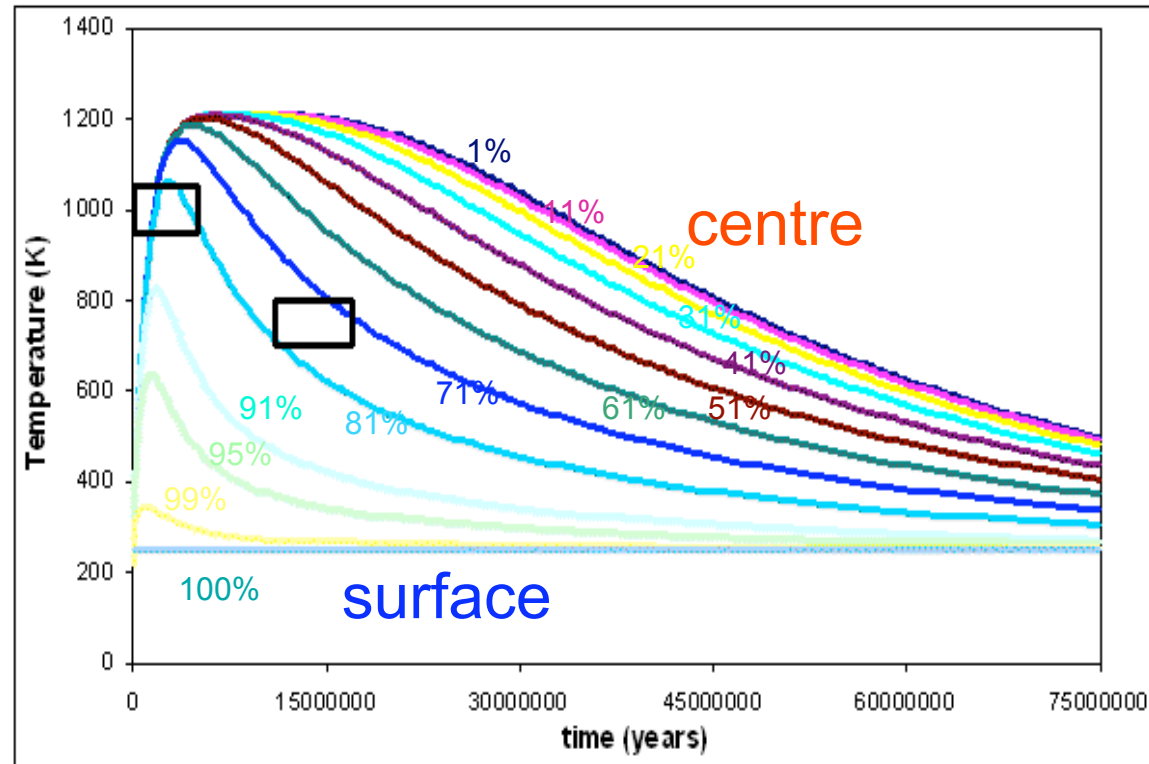


Si l'accrétion est retardée, moins d' Al^{26} , et ça chauffe moins



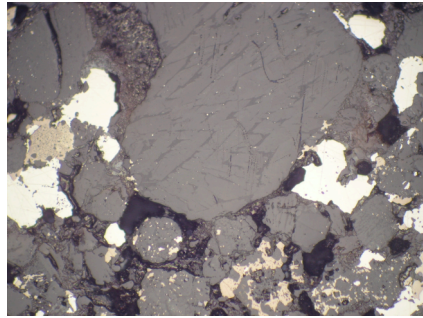
Avec l' Al^{26} une grande diversité d'histoires thermiques sont possibles

Aussi à l'intérieur d'un seul corps.....

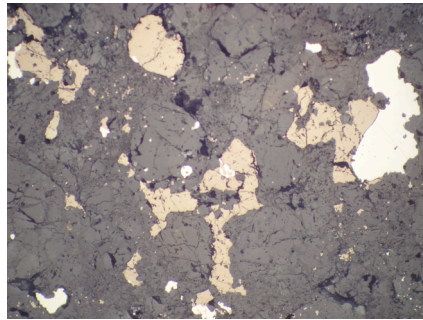


Température au sein d'un corps de 180km de diamètre, et accretion 2,4 Ma après formation des CAI.

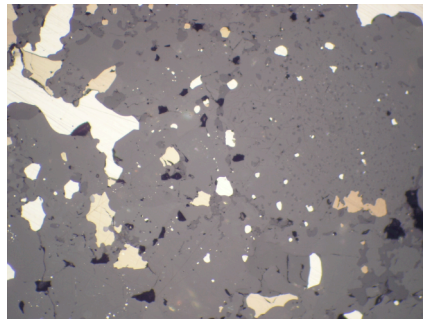
Et les types H?



H4
~973K



H5
~1023K



H6
~1223K

Temperature

Besoin de datations

La datation...

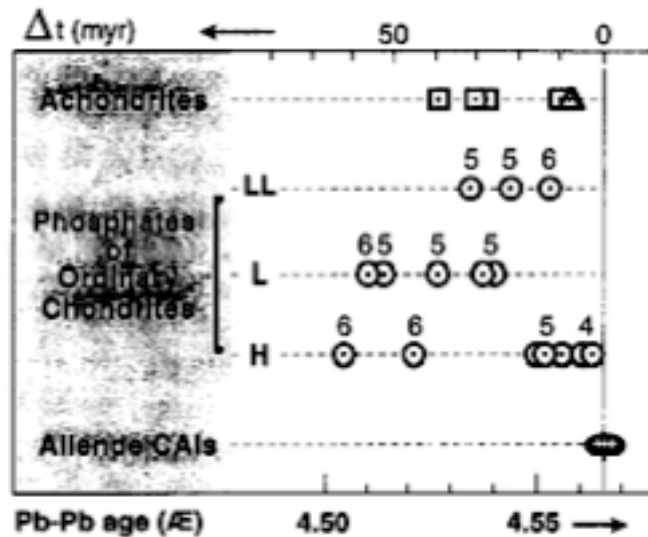


FIG. 6. Pb-Pb chronology in meteoritic material, characterized by high $^{238}\text{U}/^{204}\text{Pb}$ values. Pb-Pb ages are indicated as absolute ages (lower abscissa) or as time differences (upper abscissa) relative to 4.566 Ga, which corresponds to the Pb-Pb age defined by the most radiogenic Allende refractory inclusions. Two different types of achondrites are represented: angrites (open triangles) and eucrites (symbolised by open squares). Phosphates from ordinary chondrites are shown as open circles. The number above the symbol indicates the metamorphic grade of the host meteorites. The oldest samples of achondrites and chondrites indicates that the early formation of planetary bodies relative to Allende, the time interval of 6 Ma indicated by the spread of ages, is interpreted as the early period of accretion and shock events.

Mais, qu'est ce qu'on date?.....

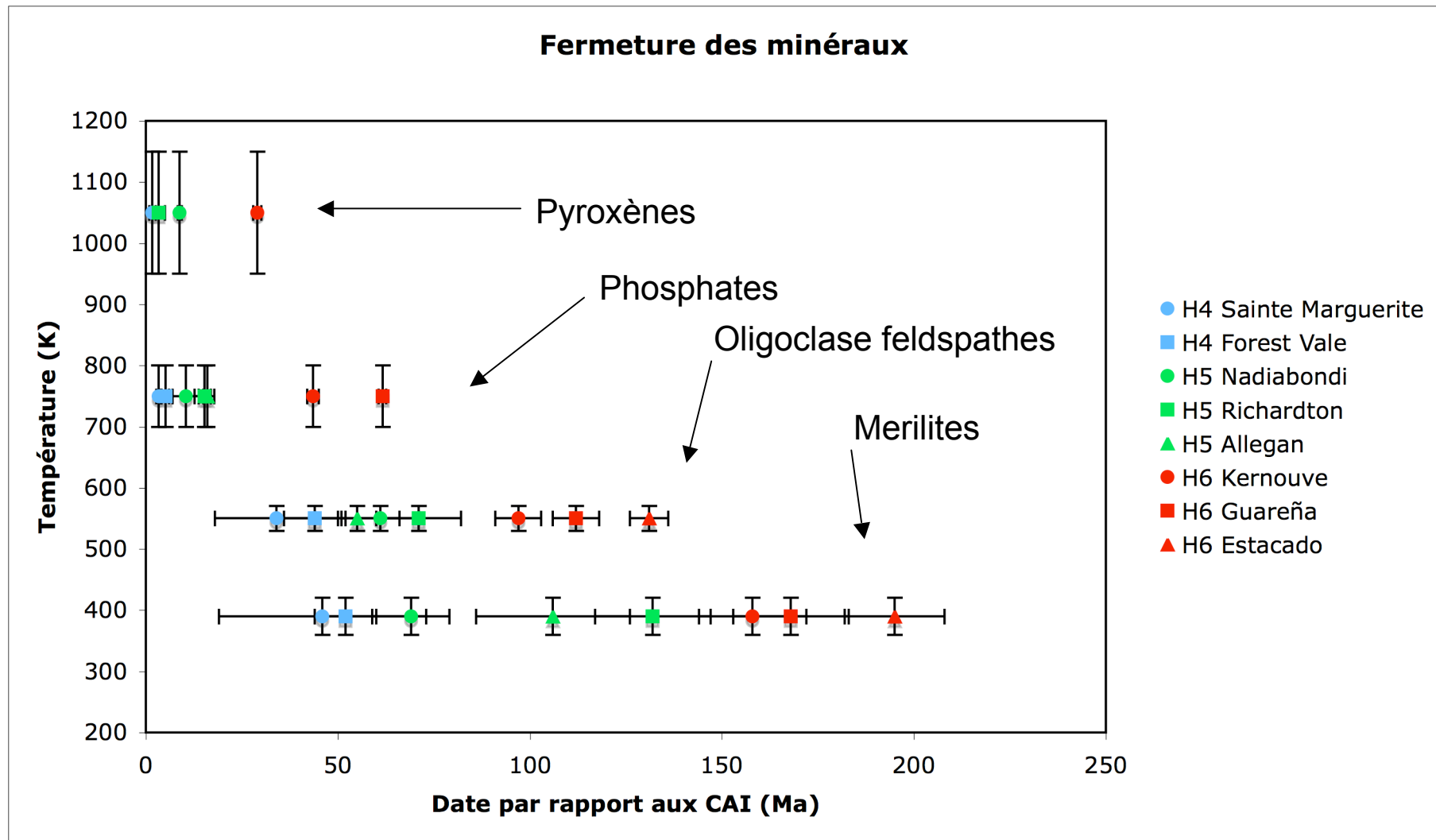
Pb dans les Px's

Pb dans les phosphates

Pu dans les phosphates etc.

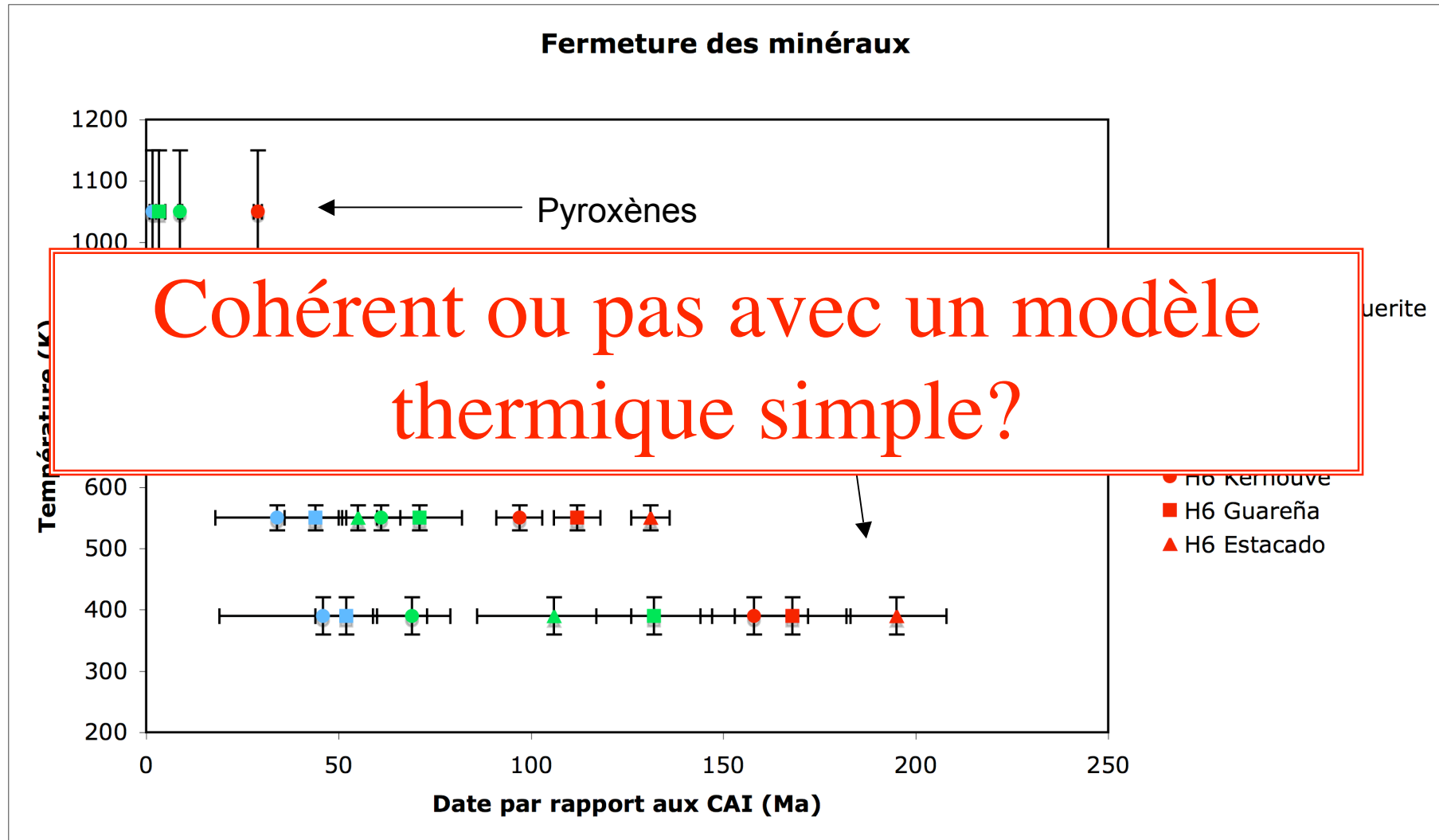
La température de fermeture contrôlée par la diffusion.

Construction d'une grille température-temps....



28 ages pour 8 échantillons

Construction d'une grille température-temps....



28 ages pour 8 échantillons

Solution analytique (Carslaw et Jäger, 1959)

$$T = T_0 + \frac{A_0}{\rho C_p} \left[\left(\frac{\sin(\pi r' \sqrt{\lambda \tau})}{r' \sin(\pi \sqrt{\lambda \tau})} - 1 \right) \frac{e^{-\lambda t}}{\lambda} + \frac{2\tau}{\pi r'} \sum_{n=1}^{\infty} \frac{(-1)^n \sin(n\pi r')}{n(n^2 - \lambda \tau)} e^{-n^2 t / \tau} \right]$$

$$\tau = \frac{\rho C_p R^2}{\pi^2 K} \quad r' = r/R$$

Contraintes

Age du système solaire: 4568,5 Ma

$Al^{26}/Al^{27} = 5 \times 10^{-5}$ à age zéro

Pas de fusion partielle des H6 ($T < 1273K$)

Accrétion instantanée

Contraintes

Age du système solaire: 4568,5 Ma

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Pas de fusion partielle des H6 ($T < 1273K$)

Accrétion instantanée

Paramètres libres

Taille du corps

Date d'accrétion

Contraintes

Age du système solaire: 4568,5 Ma

$Al^{26}/Al^{27} = 5 \times 10^{-5}$ à age zéro

Pas de fusion partielle des H6 ($T < 1273K$)

Accrétion instantanée

Calcul de la température en fonction de la position (300) et du temps (30,000)

Pour des corps de taille variables, accrétés à des moments différents

Contraintes

Age du système solaire: 4568,5 Ma

$Al^{26}/Al^{27} = 5 \times 10^{-5}$ à age zéro

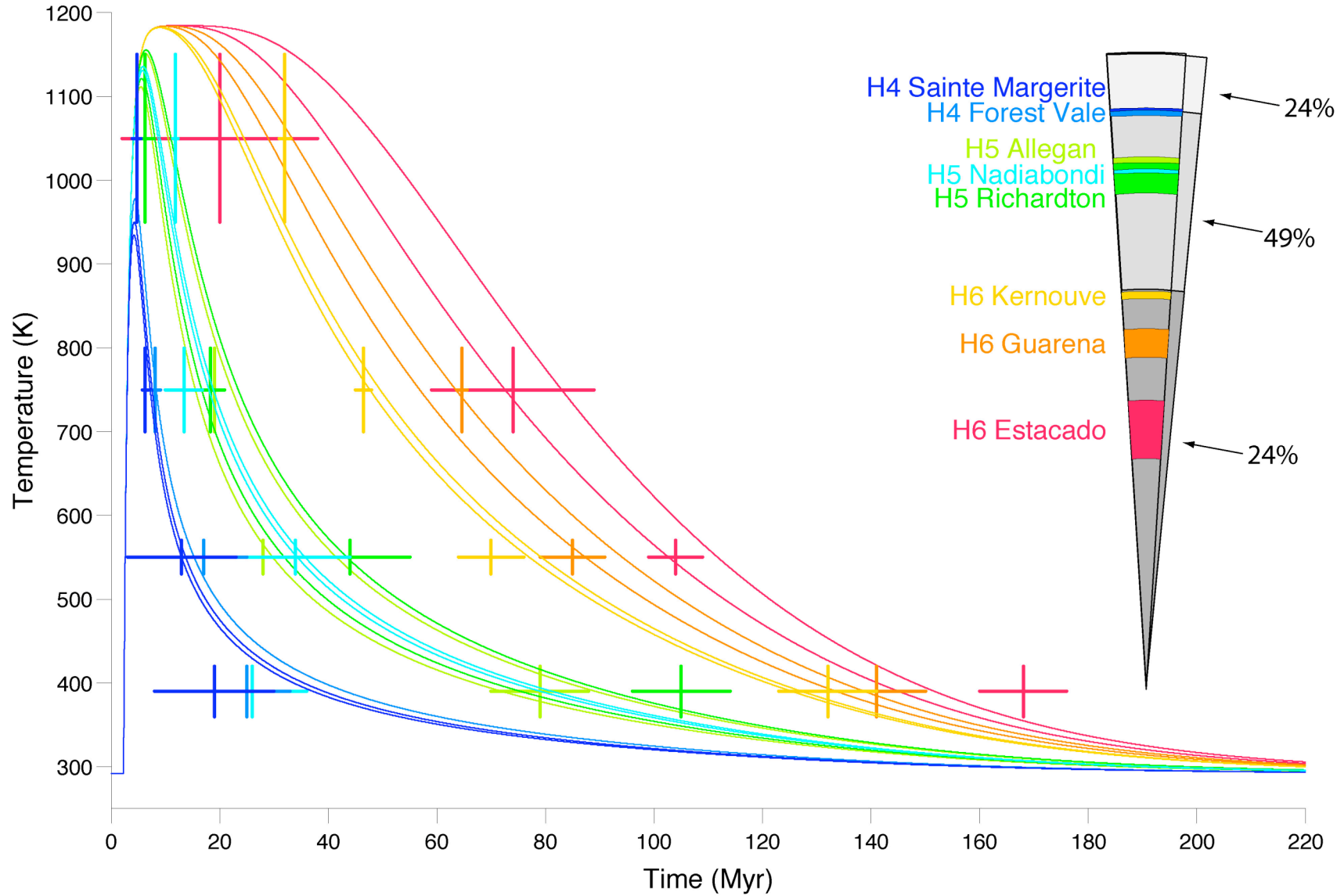
Pas de fusion partielle des H6 ($T < 1273K$)

Accrétion instantanée

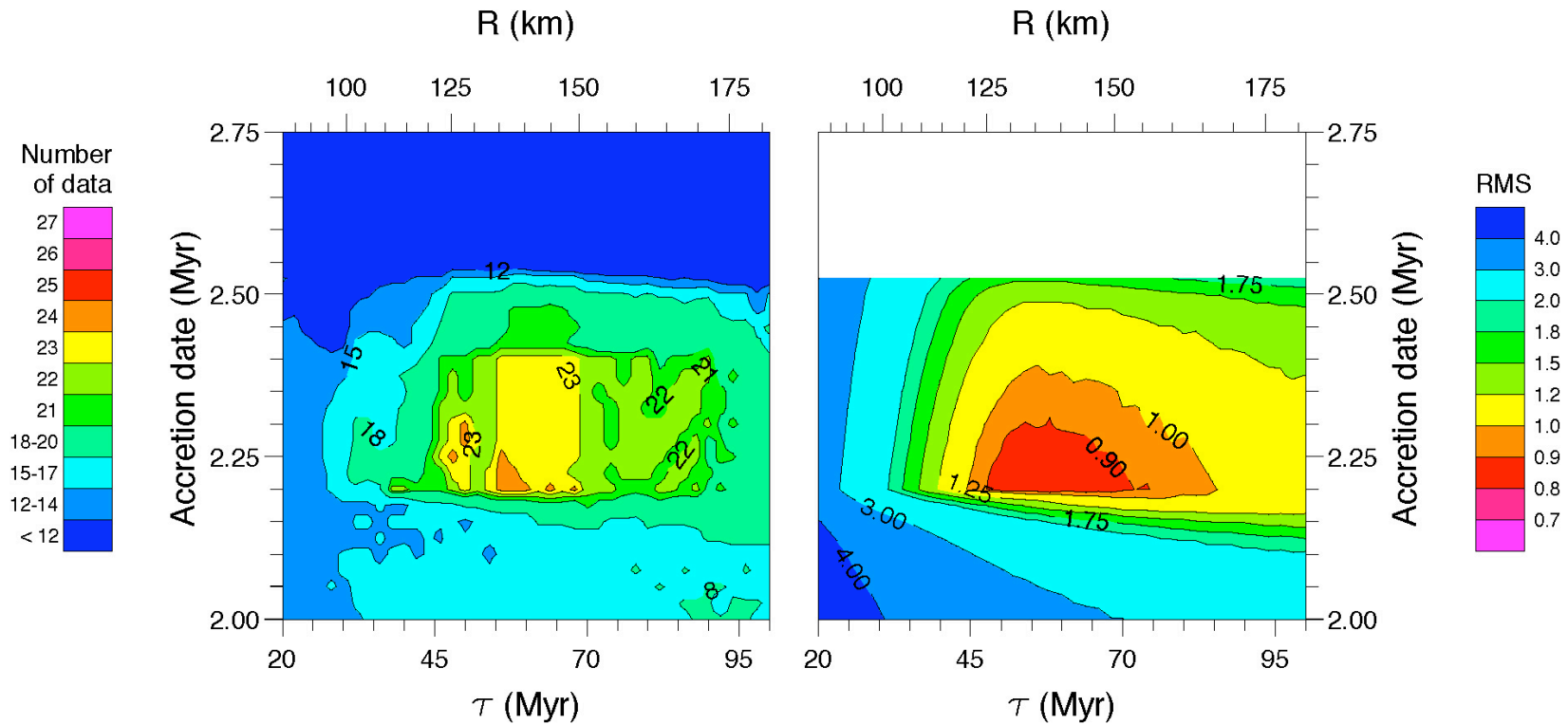
Pour chaque corps parent synthétique,
comparaison entre la solution numérique et
les données obtenues sur les objets naturels

$R_{\text{body}}=124. \text{ Km}$, $\tau= 47. \text{ Myr}$, $t_{\text{acc}}= 2.25 \text{ Myr}$

$k(T)= 4 \times (T_{\text{E}}/T)^{0.5} \text{ W/mK}$ with $T_{\text{E}}= 292\text{K}$



Age of the solar system: 4568.5 Myr
Temperature of the solar nebula: 292 K
Constant conductivity
 $K=2 \text{ W/mK}$



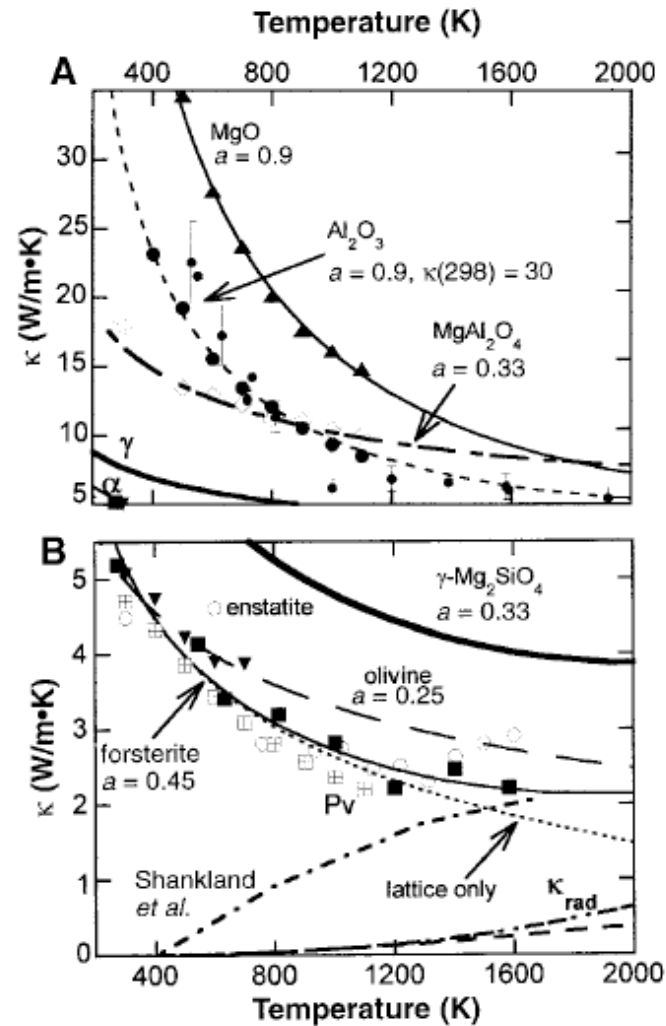
Nombre de données
Validées (max. 24)

RMS

Solutions acceptables

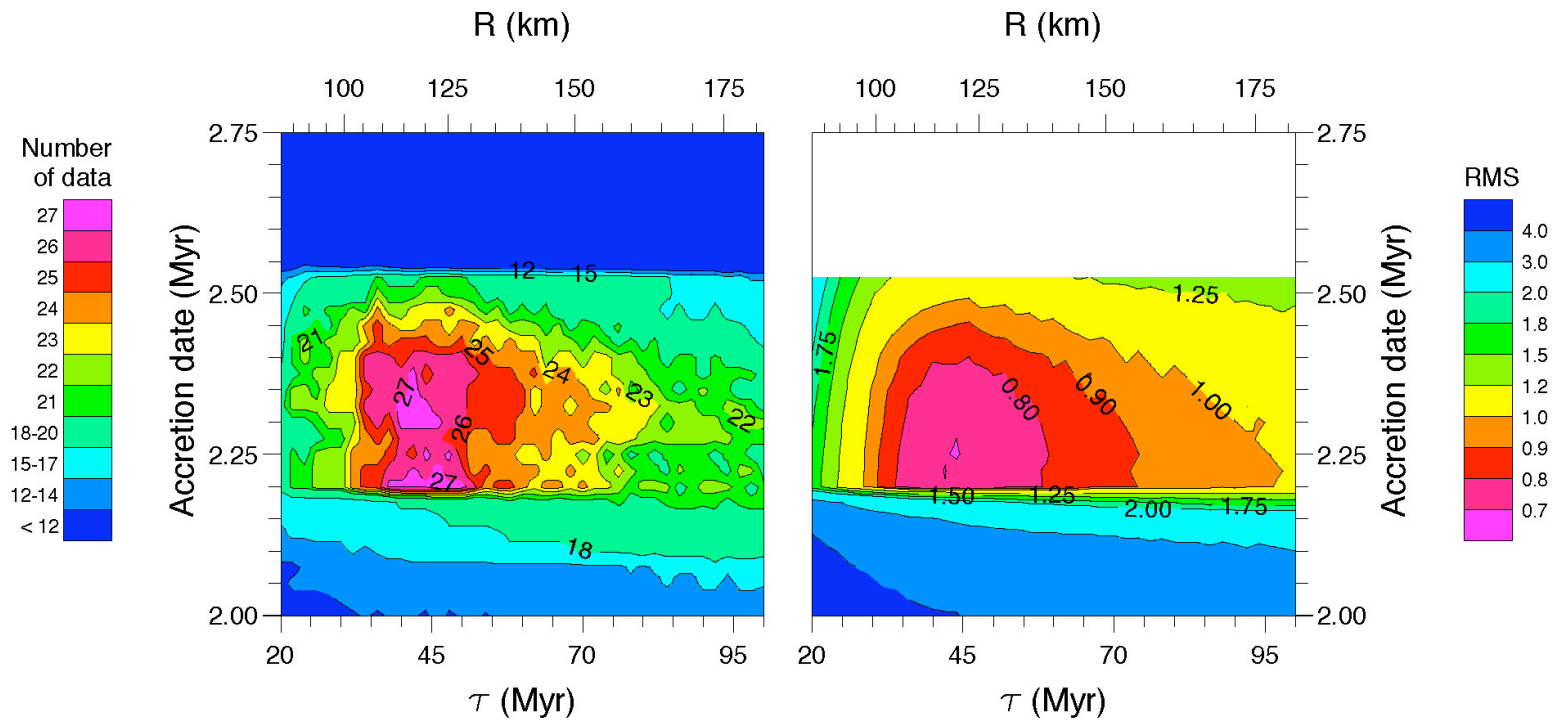
Mais encore meilleures avec une conductivité variable

Fig. 1. Thermal conductivity versus temperature. (A) Mostly oxides; (B) mantle silicates (note the difference in y-axis scales). Data from conventional measurements (3): \blacktriangle , MgO; \bullet , Al_2O_3 ; \diamond , spinel; \blacktriangledown , olivine. Data from laser heating (18): small dots with error bars, Al_2O_3 ; \blacksquare , Fo; \circ , enstatite having $\sim 0.19 \text{ Fe}/(\text{Mg} + \text{Fe})$. Shaded circle at left in (A), room-temperature κ for corundum (51); \boxplus , Pv κ calculated using D from 100 to 400 K from (61), $C_p(T)$ from (63), and $V(T)$ from (62). Dot-dash line, previous radiative contribution for olivine (23). Dot-dot-dash-dash line, radiative contribution calculated for Fo from overtone lifetimes. Medium-dashed line, radiative contribution calculated for olivine from overtone and Fe^{2+} lifetimes. Dotted line, Fo fit to lattice contribution only. Long-dashed line, olivine fit to radiative contribution (including Fe effects). All other lines are lattice contribution plus radiative contribution from overtones fit to the various minerals by varying a values, as labeled. For corundum, $\kappa(298)$ was fitted to 30 $\text{W}/(\text{m}\cdot\text{K})$ to match the high- T measurements, instead of using data from (51). Heavy solid line, γ phase; $\kappa(298)$ was calculated from IR reflectivity (54), and a was assumed to equal that of the silicates and spinel.



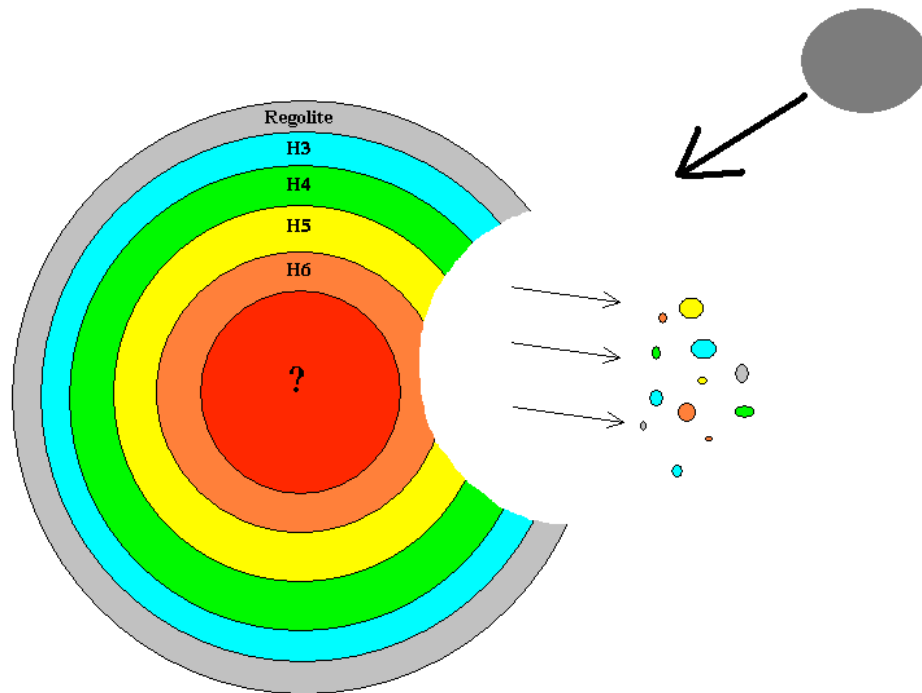
Hofmeister, science, 1999

Age of the solar system: 4568.5 Myr
Temperature of the solar nebula: 292 K
Temperature dependent conductivity
 $k(T) = 4 \times (T_E/T)$ W/mK with $T_E = 292K$



27 données validées

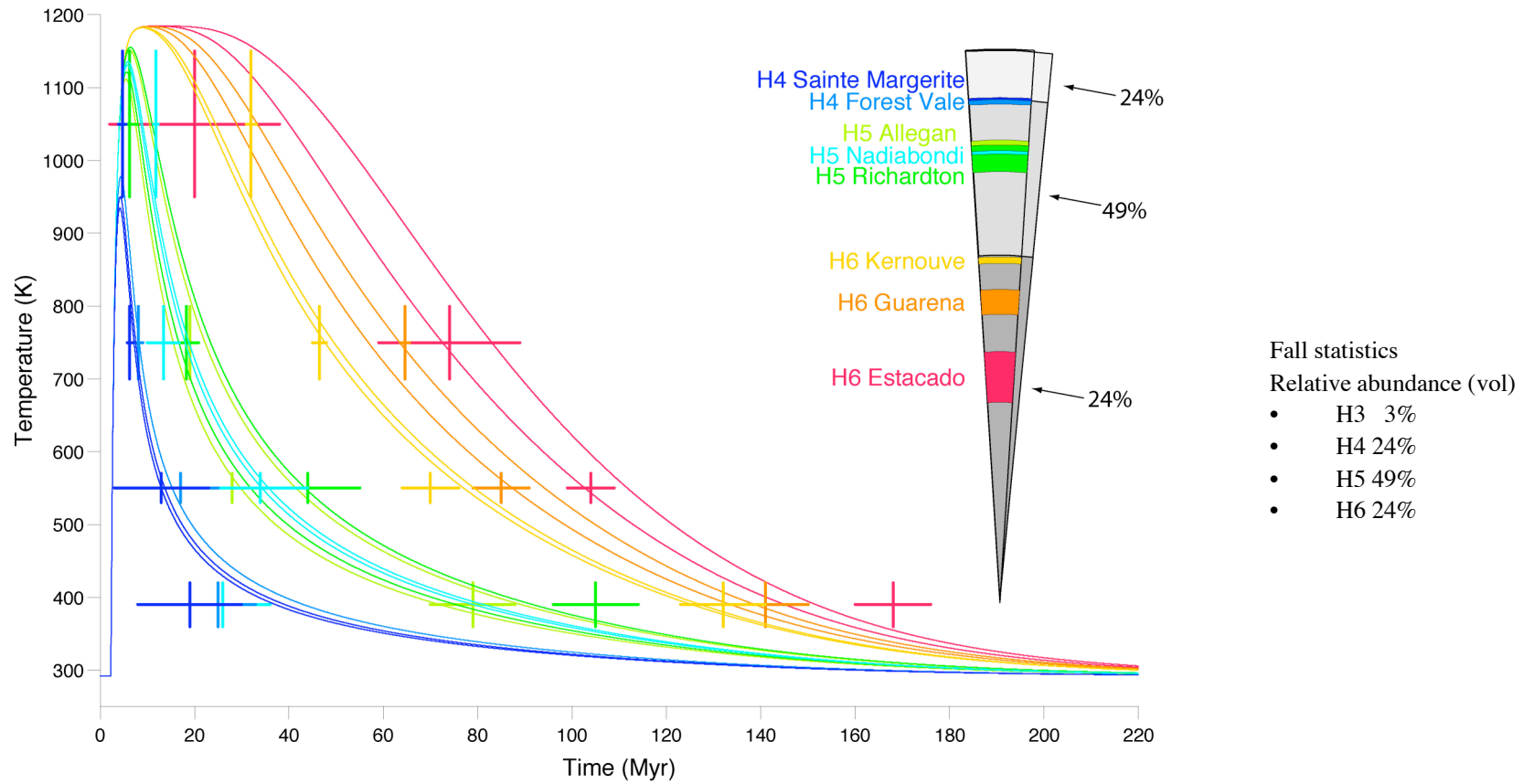
Les proportions relatives des types pétrologiques et le corps parent dans la ceinture d'astéroïdes?



Sur-représentation des
types pétrologiques
faibles

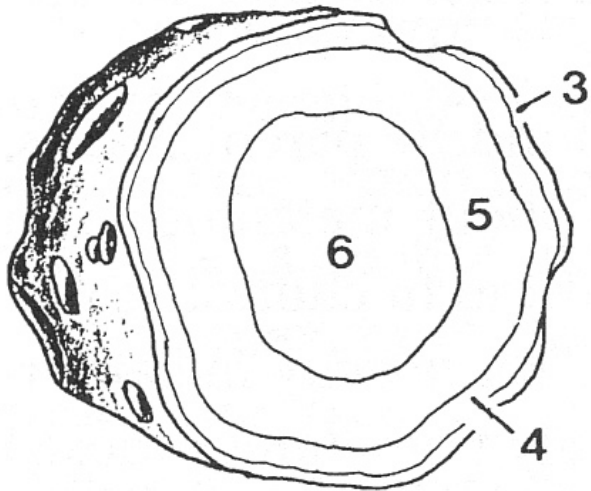
$R_{\text{body}}=124. \text{ Km}$, $\tau= 47. \text{ Myr}$, $t_{\text{acc}}= 2.25 \text{ Myr}$

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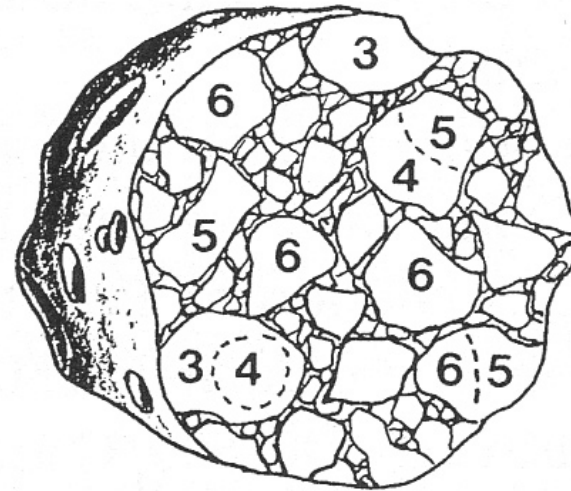


Mais ça marche très bien!

Asteroid Structures



Onion Shell



Rubble Pile

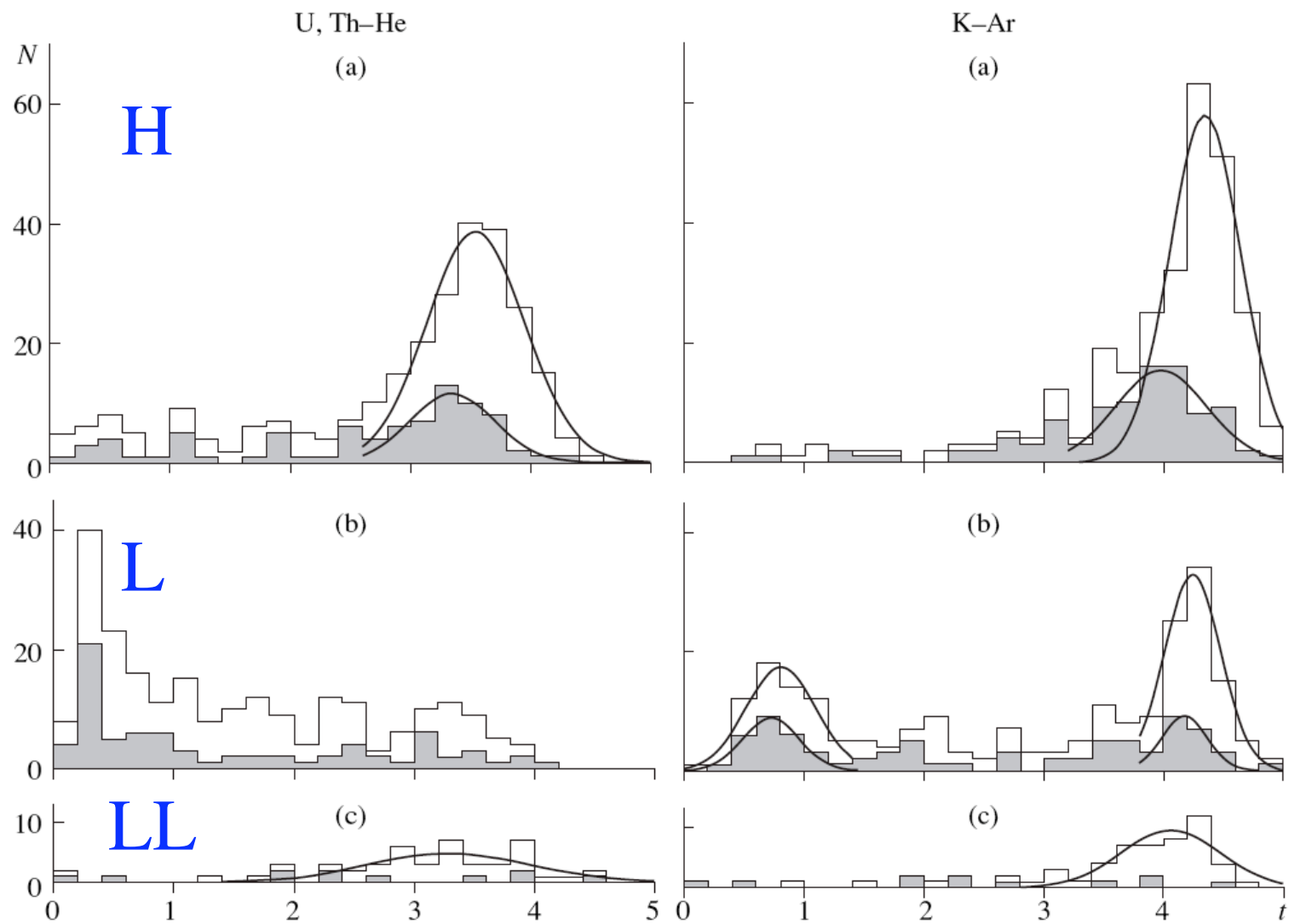
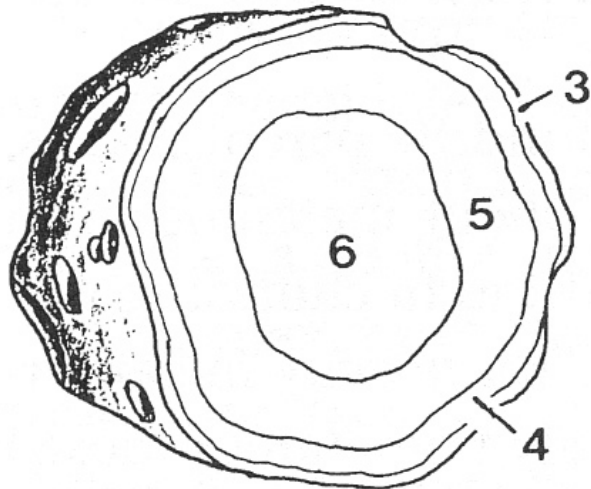
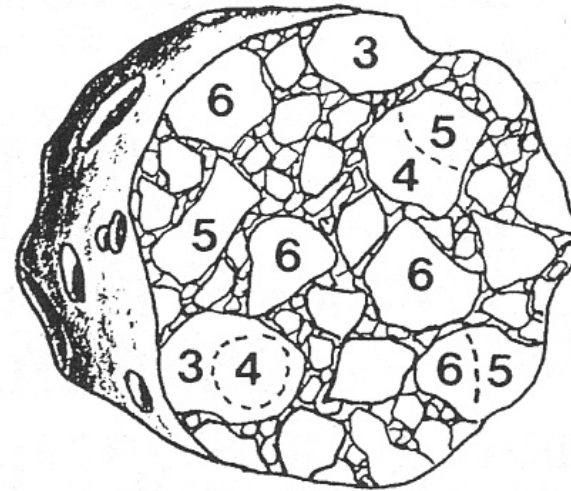


Fig. 2. The distributions of the U, Th-He and K-Ar ages of H (a), L (b), and LL chondrites (c). The shadowed areas of the histograms correspond to meteorite finds (without those found in Antarctica and in deserts).

Asteroid Structures



Onion Shell



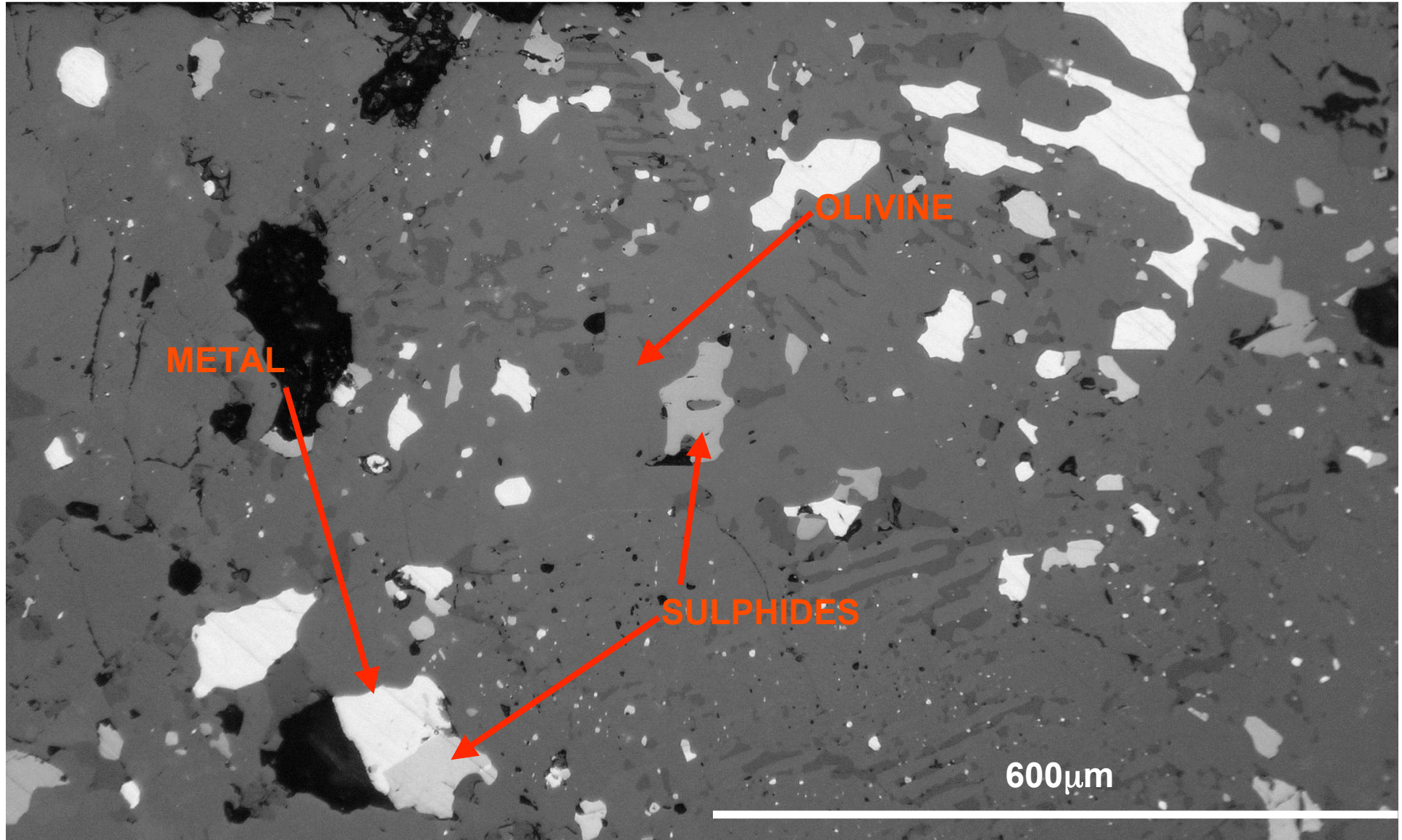
Rubble Pile

Pas la peine d'aller chercher le corps parent initial!....

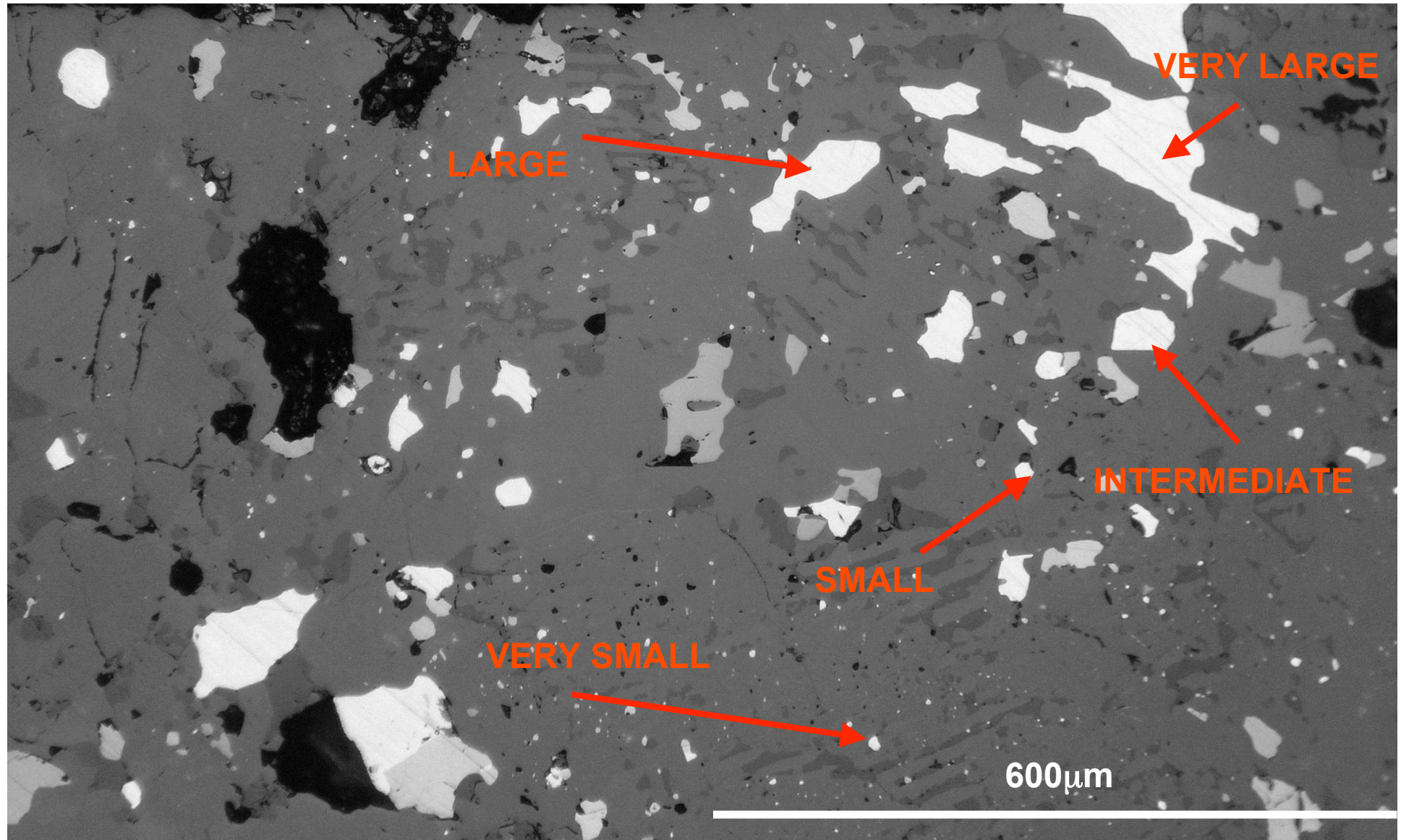
Que faire avec un modèle thermique fiable?

Possibilité de mieux comprendre les
changements pétrographiques et texturaux

Phases and their proportions

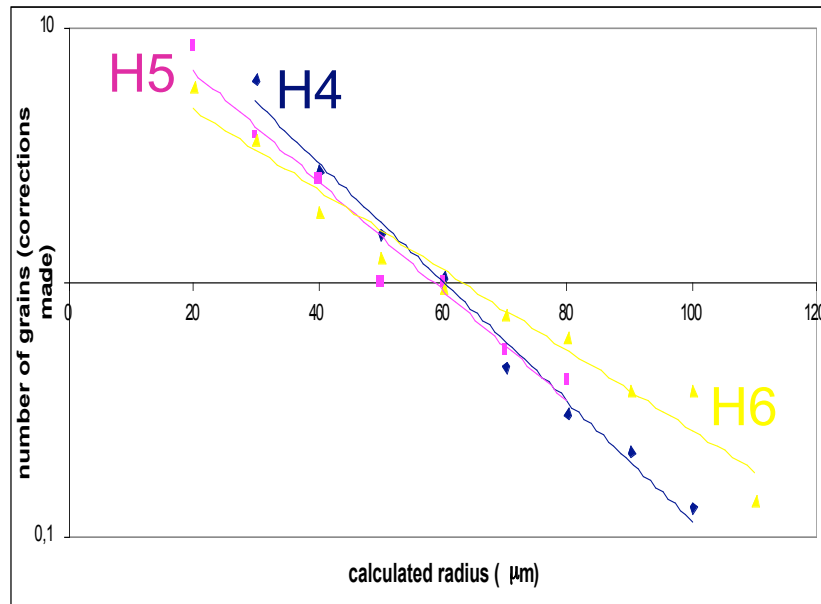


Grain sizes and their distribution

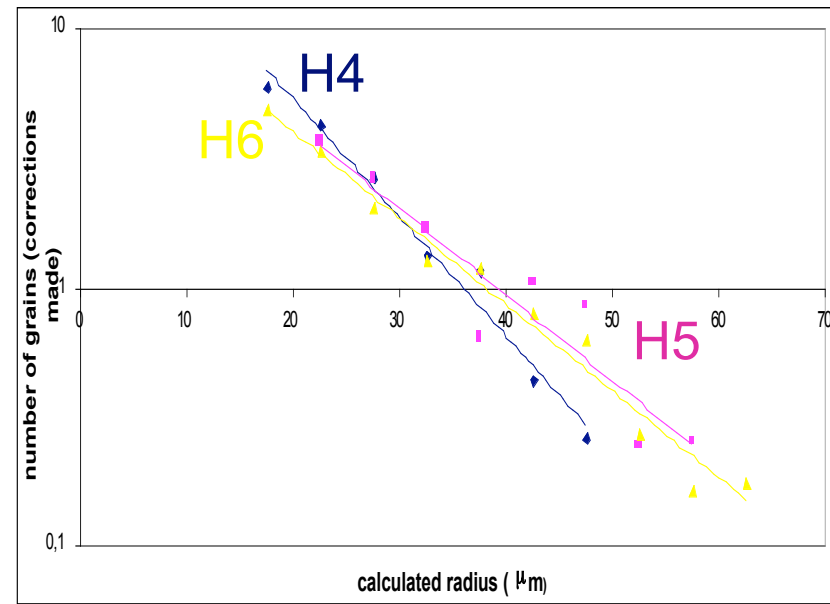


Grain sizes and their distribution

METAL



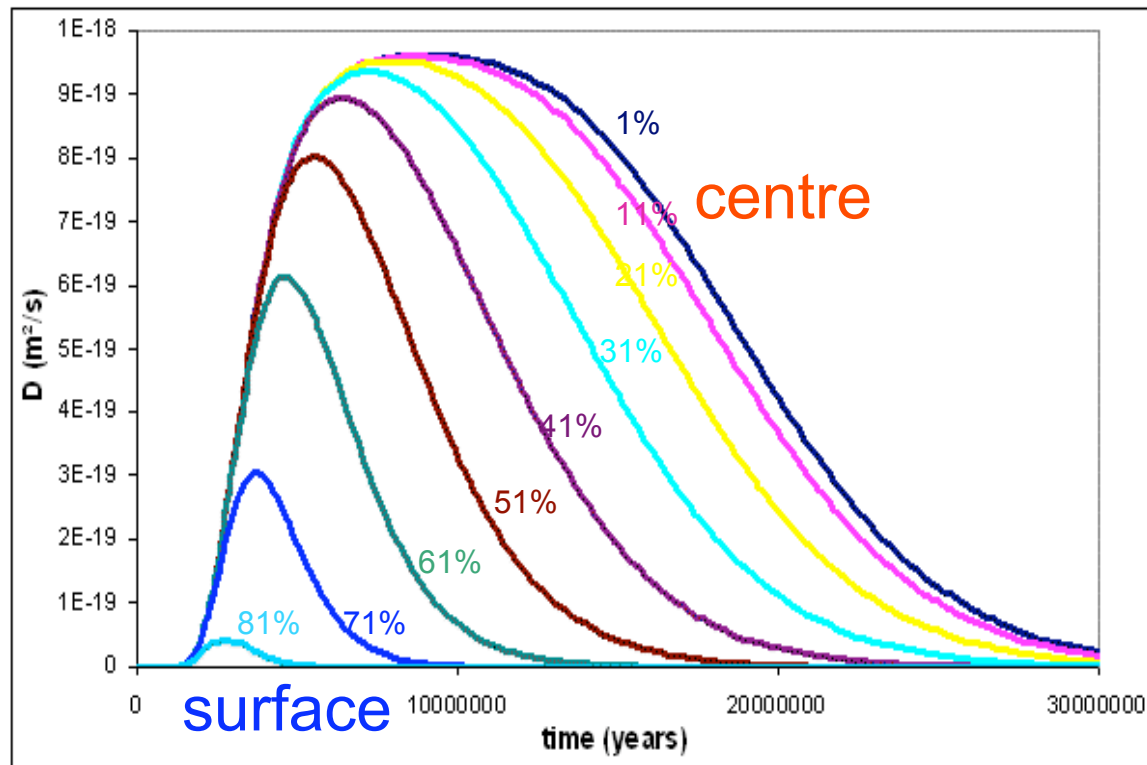
TROILITE



- Number of grains per unit volume is a log-linear function of grain size (effective radius)
- Rotation of the CSD's (textural ripening) with increasing T

Diffusion of Fe

Given the experimentally determined variation of diffusion coefficient as a function of T (Chakraborty, 1997), the variation of D as a funcⁿ of time may be calculated.

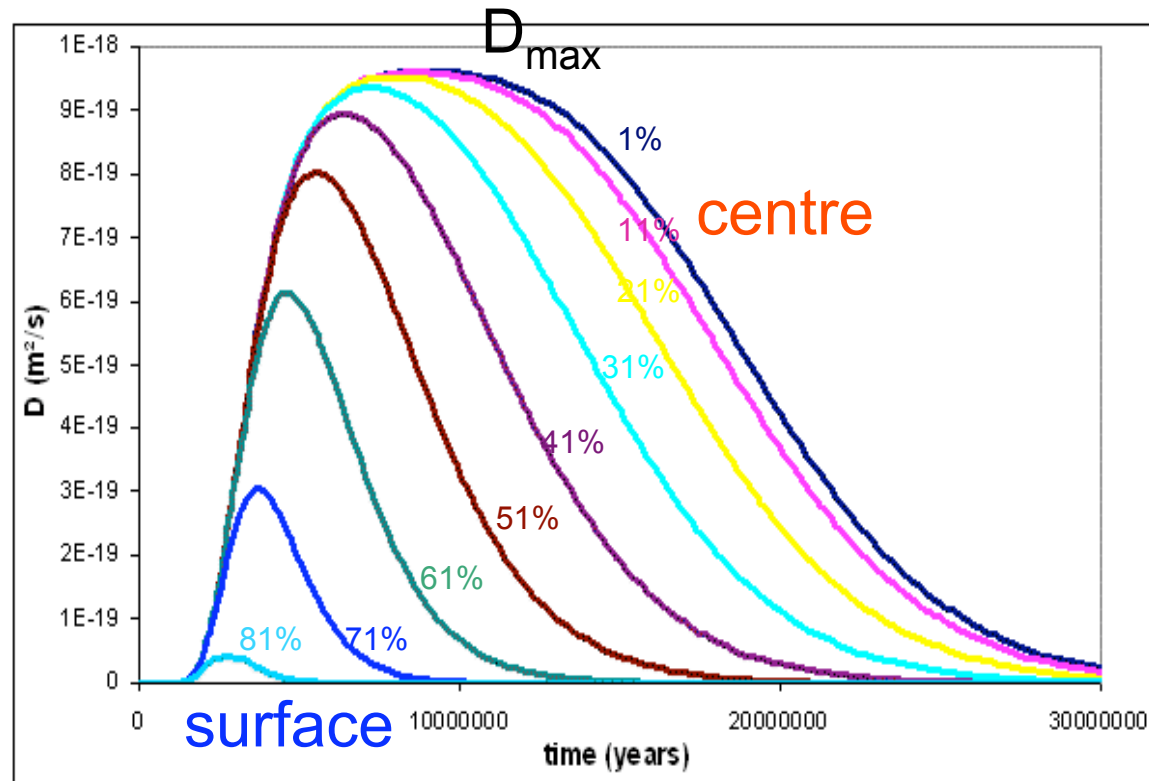


Diffusion of Fe

How far will Fe diffuse along these paths?

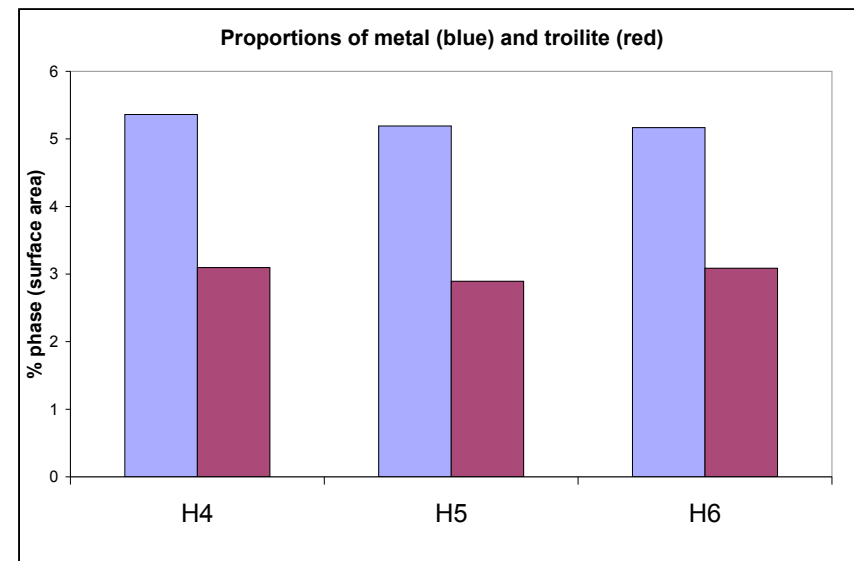
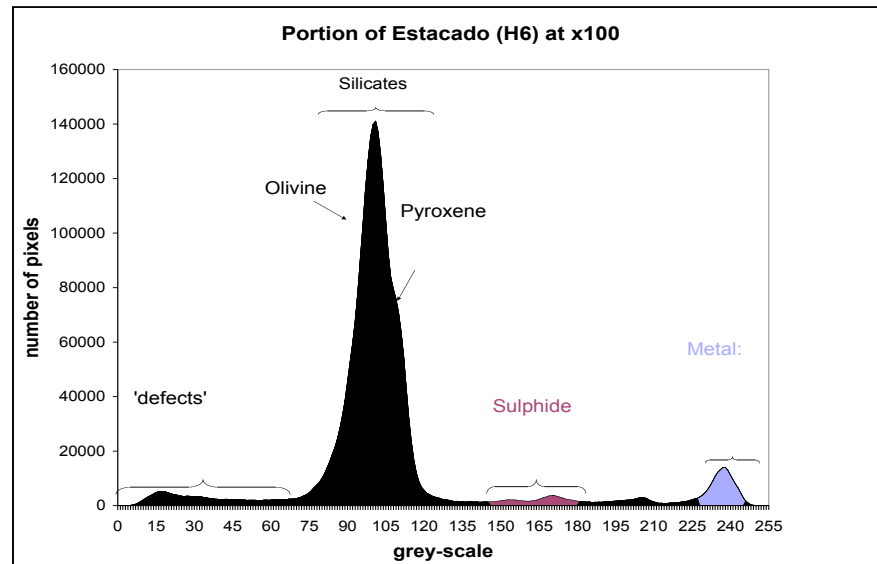
$$d = \sqrt{D_{\max} \cdot t}$$

Two endmember cases considered: $t = \text{time above } 0.5 \text{ and } 0.9$



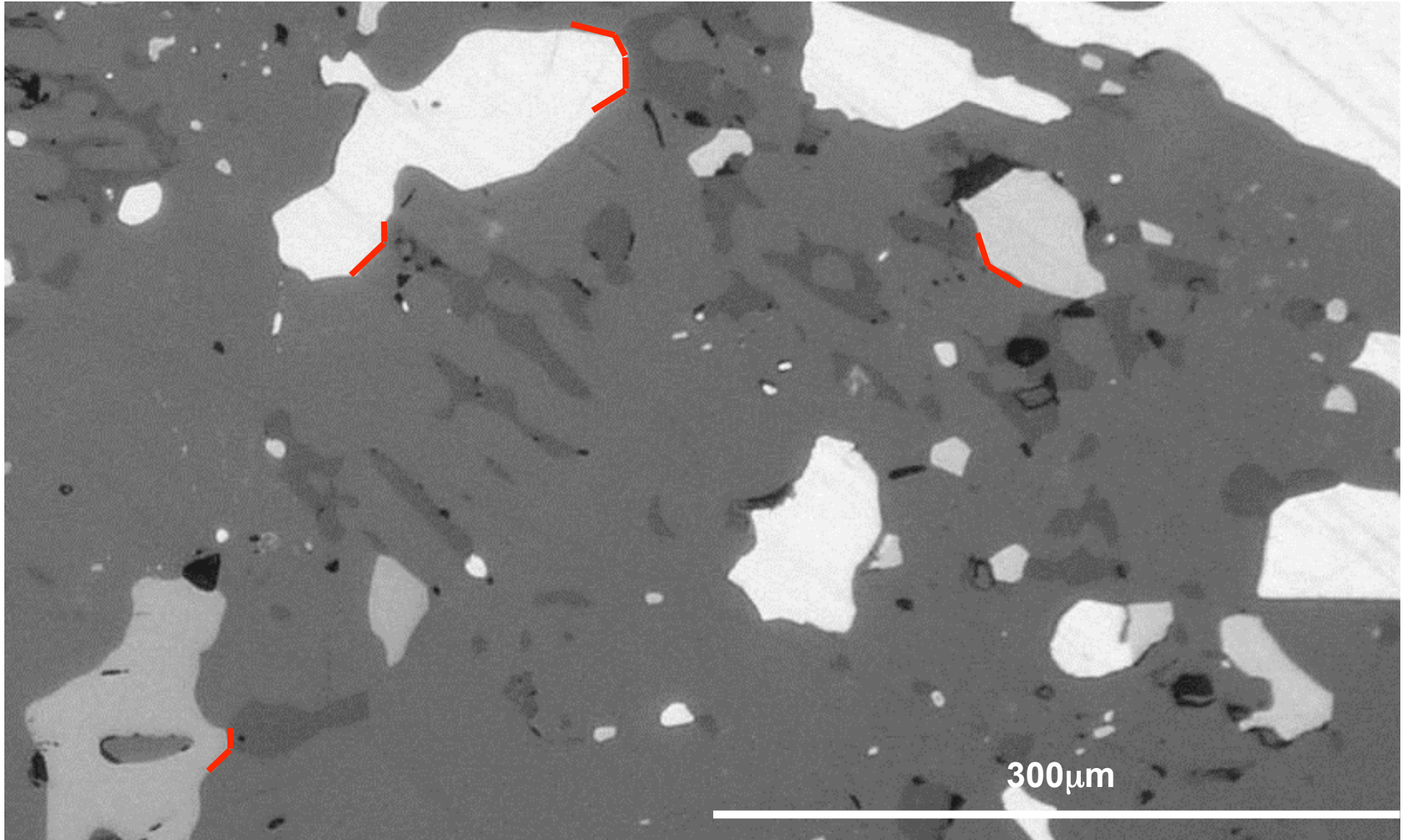
Phases and their proportions

Grey-scale image analysis of photos



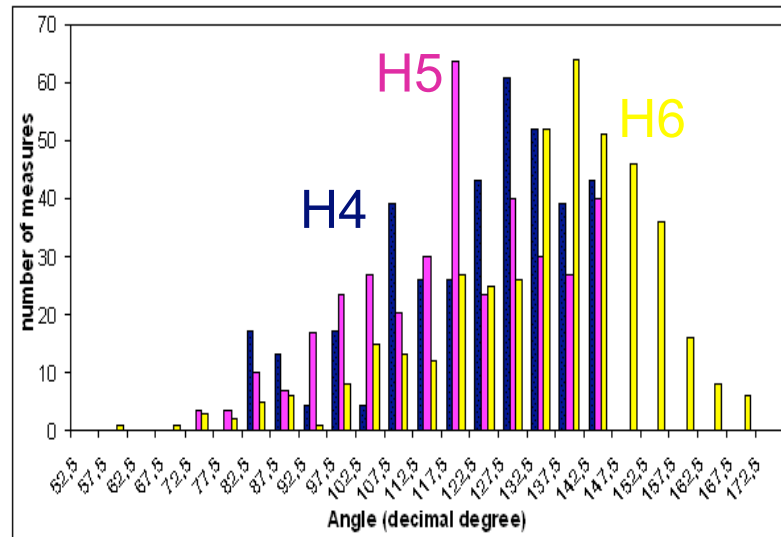
Proportions of metal and sulphide independent of degree of metamorphism

Dihedral angles

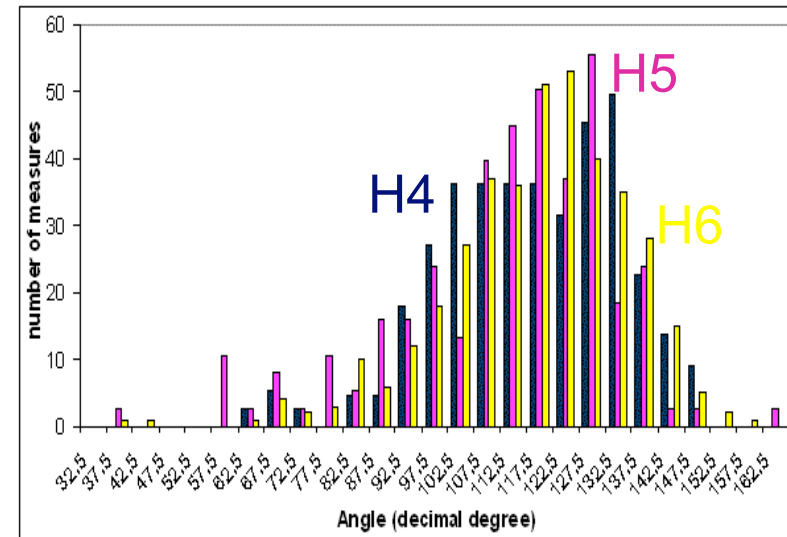


Dihedral angles

METAL

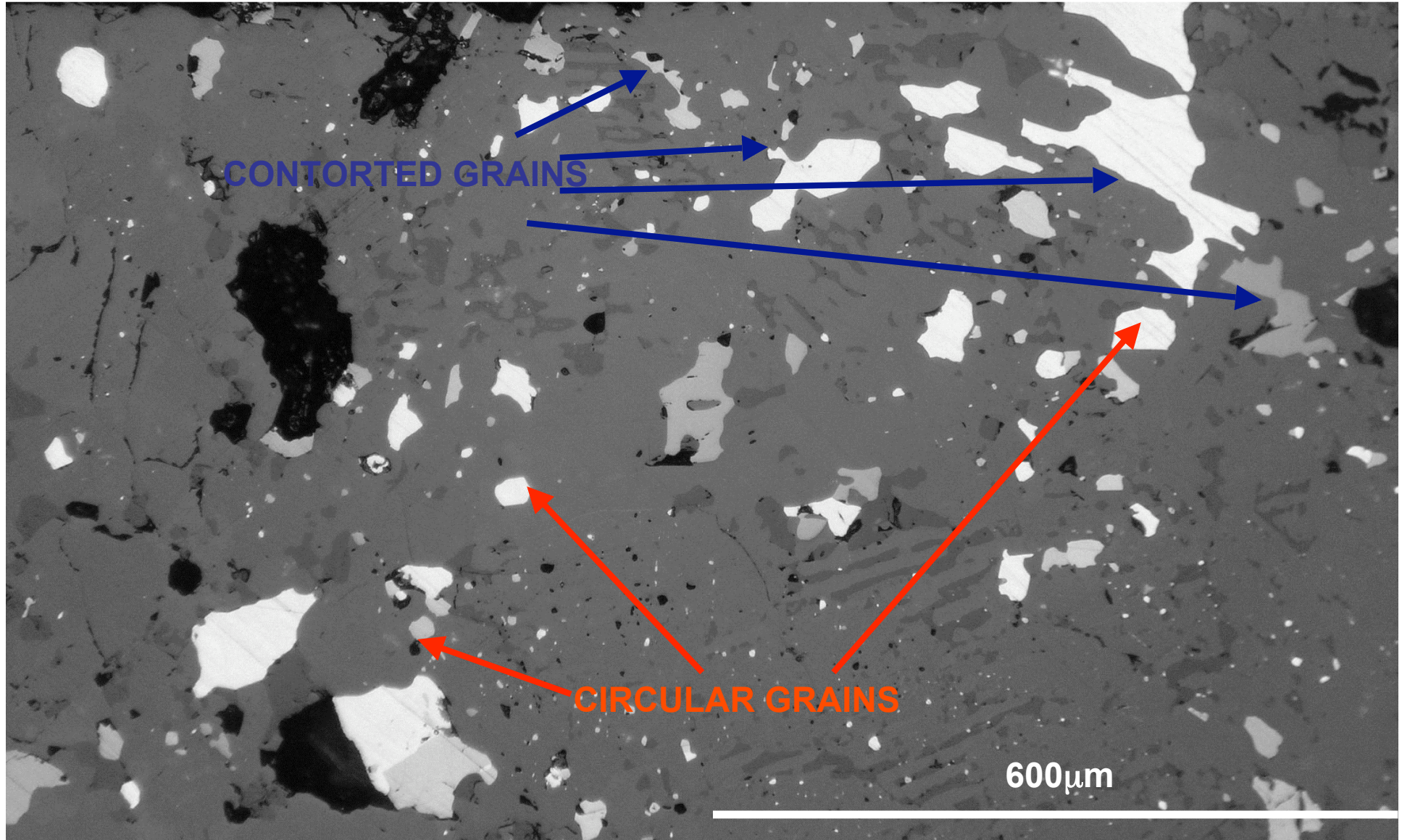


TROILITE



- Little influence of surrounding silicates (Ol±Pyx)
- Clear increase in θ with T, reaching modes at $\sim 135^\circ$
- Significant change between H5 and H6 for metal, but between H4 and H5 for sulphide

Grain shapes



Grain shapes

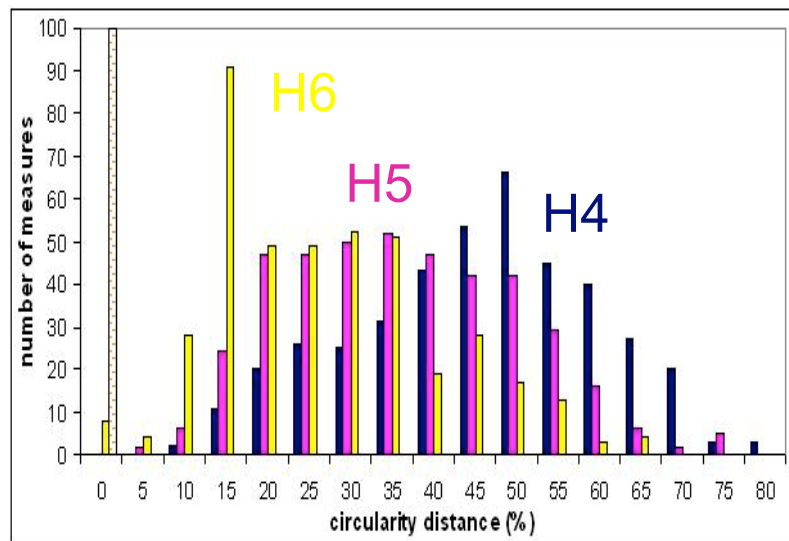
Degree of non-circularity

Defined as: $(P_m - 2\pi R_{\text{eff}}) / P_m \times 100$

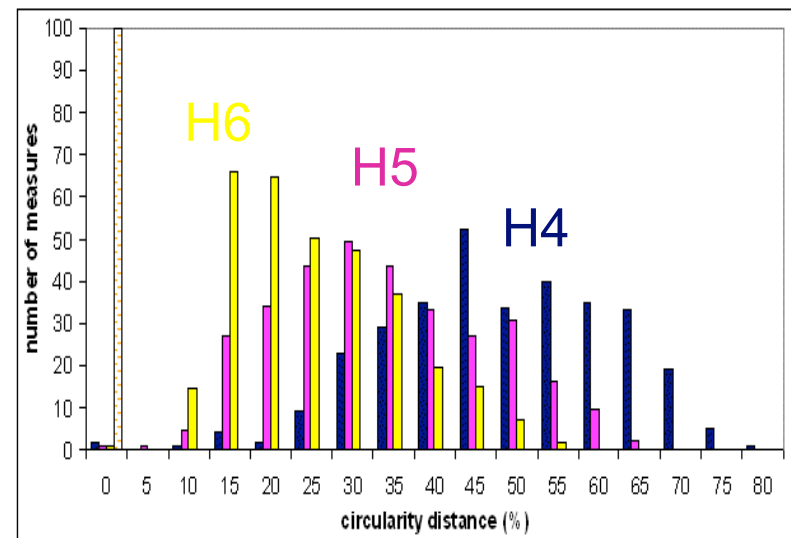
P_m = measured grain perimeter

R_{eff} = effective grain radius calculated from area

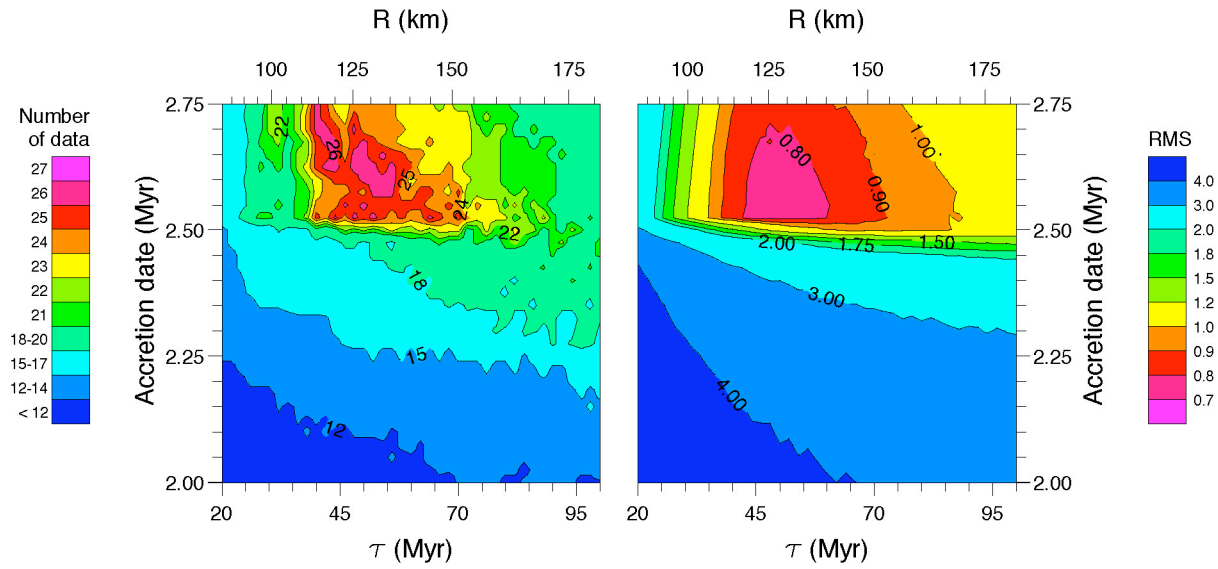
METAL



TROILITE



Age of the solar system: 4568.5 Myr
Temperature of the solar nebula: 600 K
Temperature dependent conductivity
 $k(T) = 4 \times (T_e/T)^{0.5}$ W/mK with $T_e = 292$ K



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