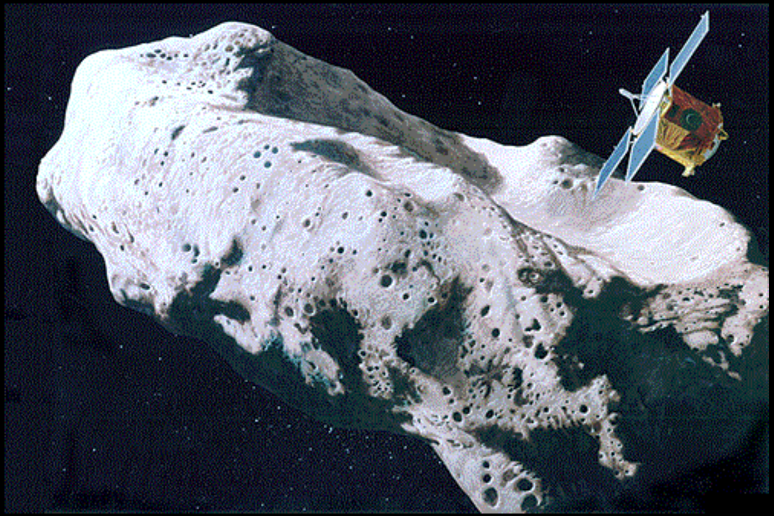


Les météorites

Des roches extraterrestres qui racontent la Terre et les Planètes

GRENOBLE 1
UNIVERSITE JOSEPH FOURIER
SCIENCES. TECHNOLOGIE. SANTÉ

CNRS

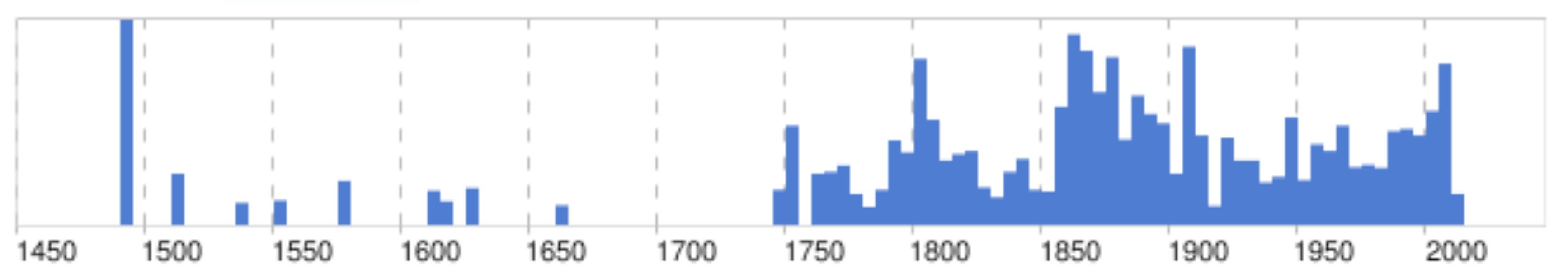
Laboratoire de Planétologie Grenoble

cnes
CENTRE NATIONAL D'ETUDES SPATIALES

Observatoire OSUG des Sciences de l'Univers de Grenoble

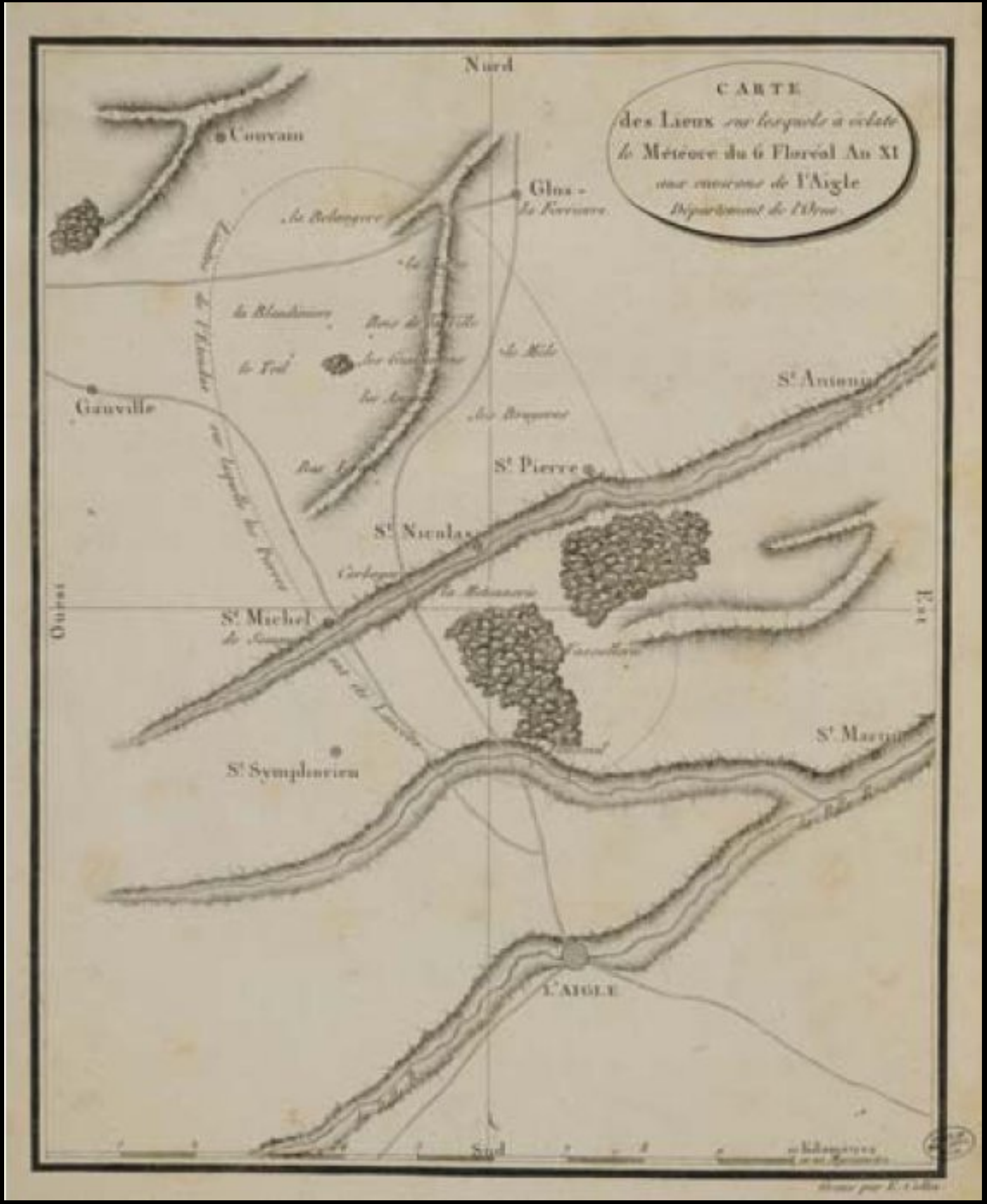
Que sont les météorites ?

- Des roches extra-terrestres
- Issues d'astéroïdes, de la Lune ou de Mars

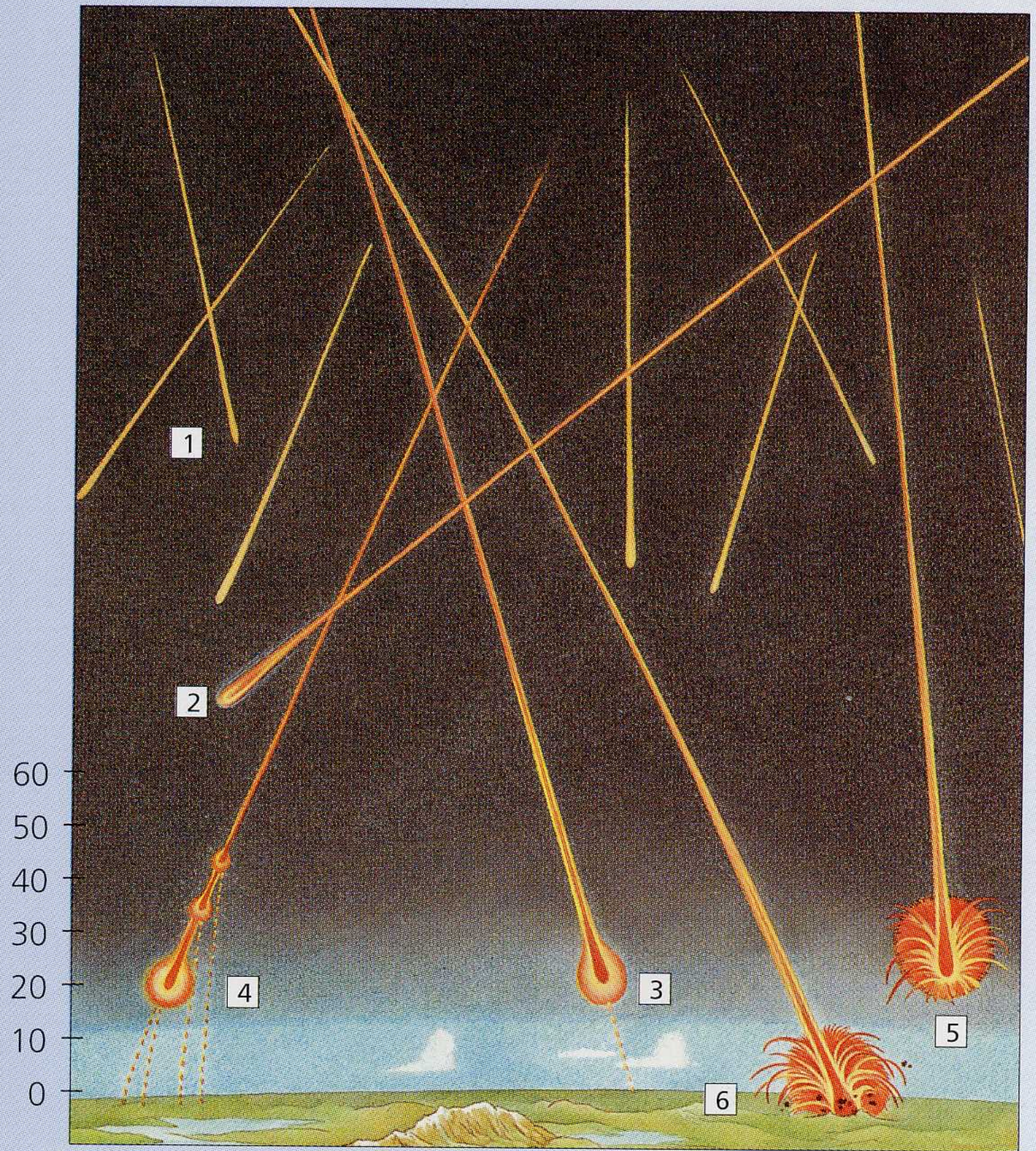


Chute d’Ensisheim (1492)

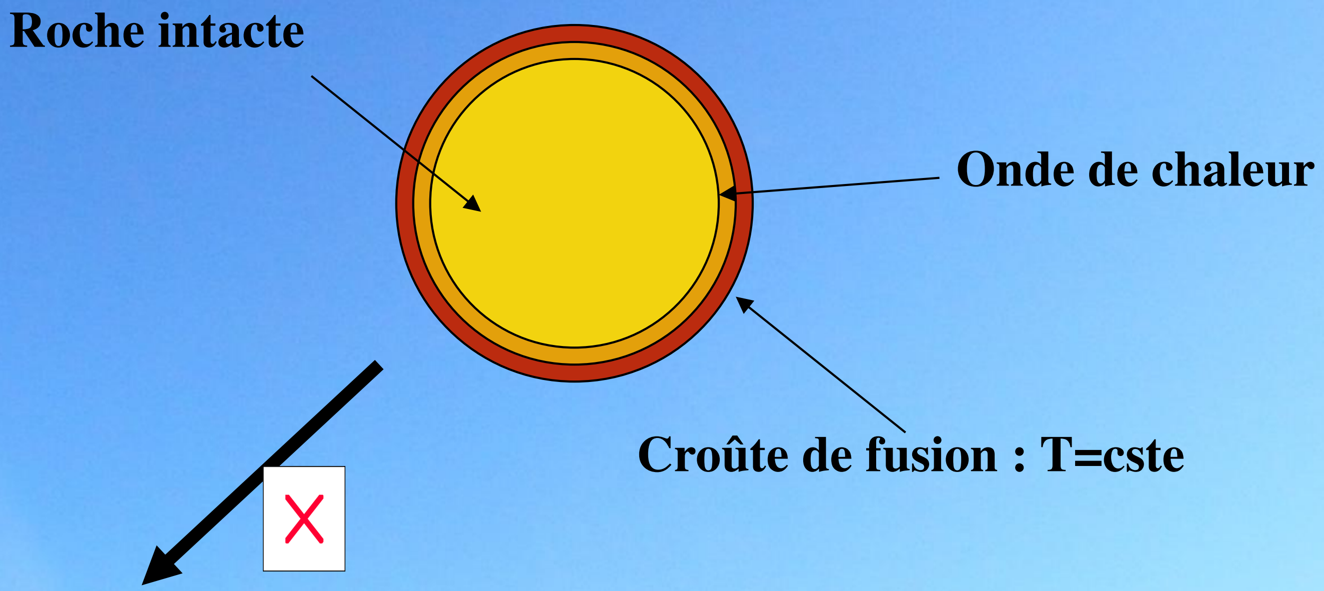
Chute de L'Aigle (1803)



Jean-Baptiste Biot



Représentation schématique du passage dans l'atmosphère de différentes météorites.
Par ordre de masses croissantes :
1 : étoiles filantes,
2 : boule de feu ; l'objet est entièrement détruit par ablation dans l'atmosphère,
3 : l'objet est détruit en grande partie dans l'atmosphère et une météorite atteint le sol,
4 : fragmentation d'une météorite dont les morceaux se répartissent sur une ellipse de chute,
5 : météorite de pierre d'une dizaine de mètres de diamètre explosant dans l'atmosphère,
6 : très grosse météorite formant un cratère d'impact en arrivant au sol.

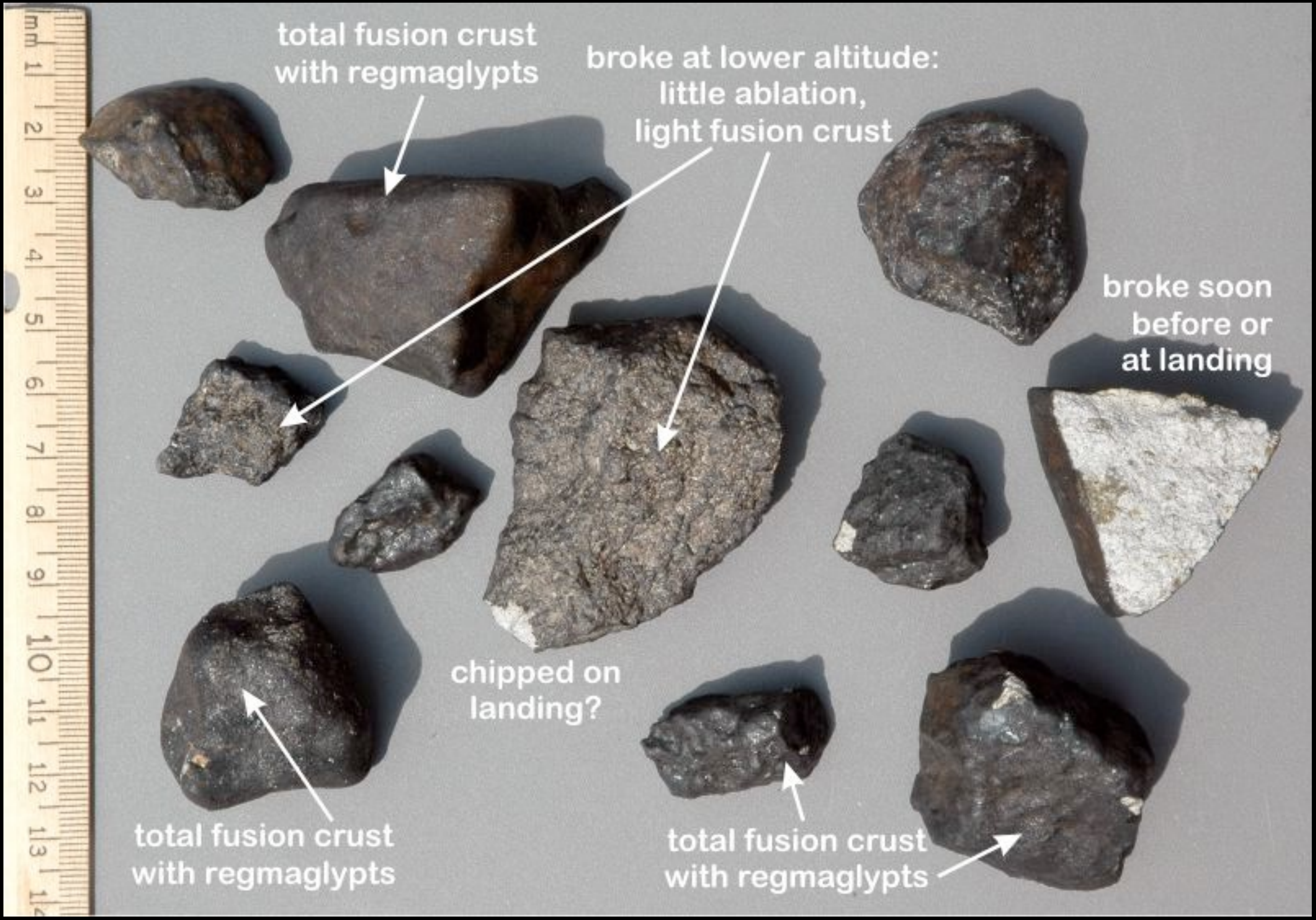


Roche intacte

Onde de chaleur

Croûte de fusion : T=cste

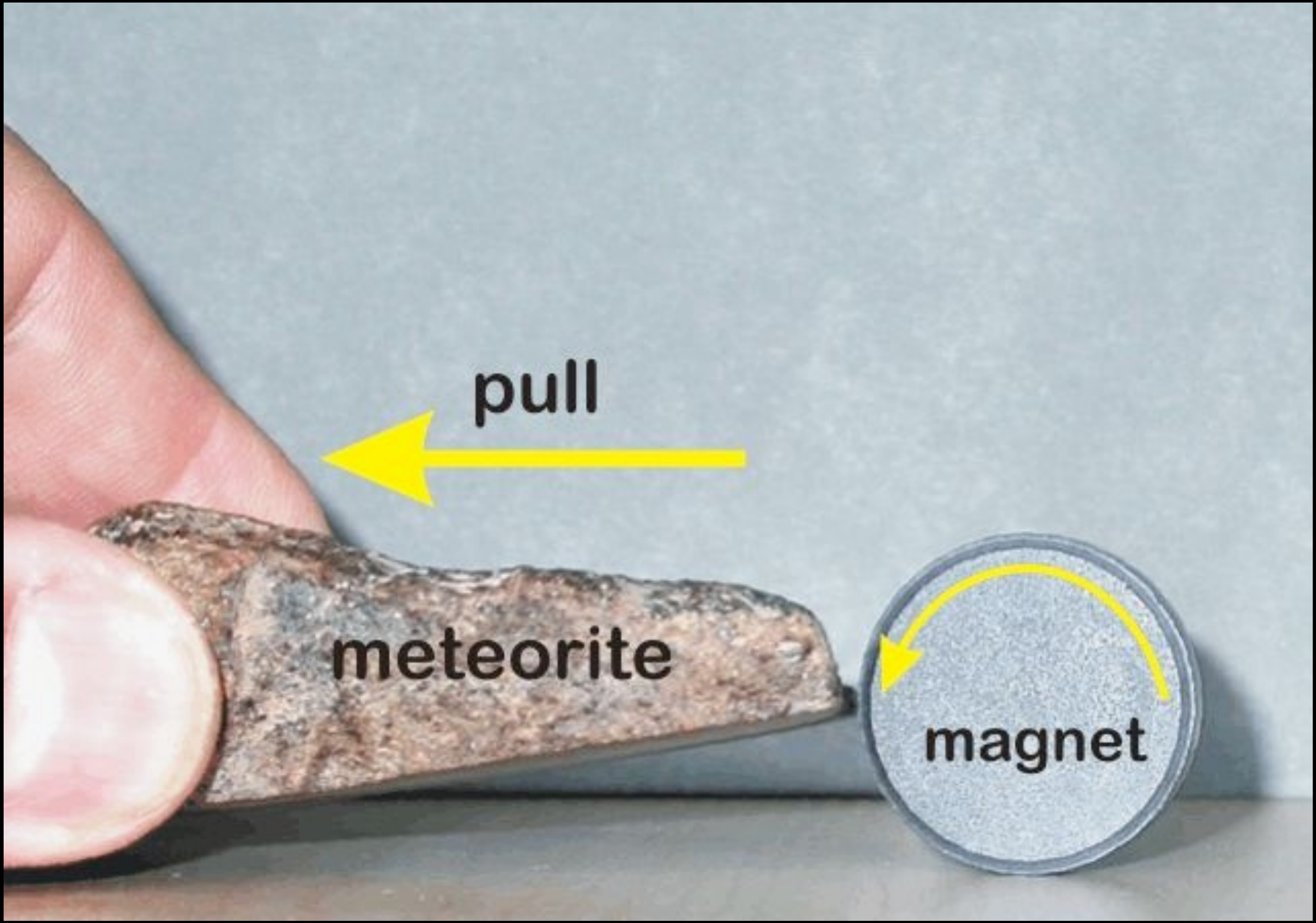
Croûte de fusion



Contours anguleux mais émoussés

Regmaglypts

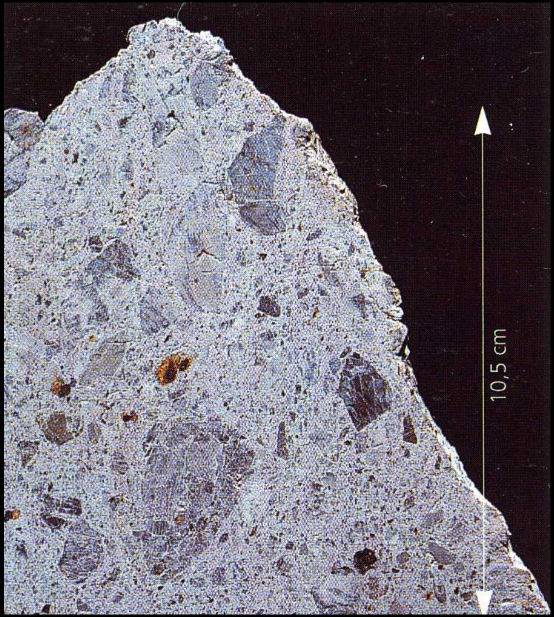
Métal et aimantation

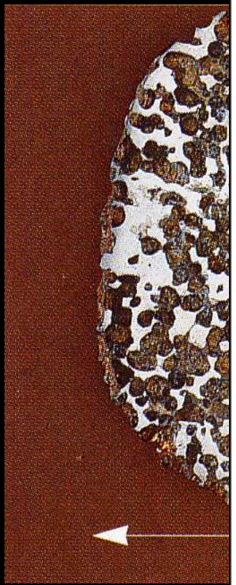


Faux positifs !


5
A.
4

Quatre familles principales





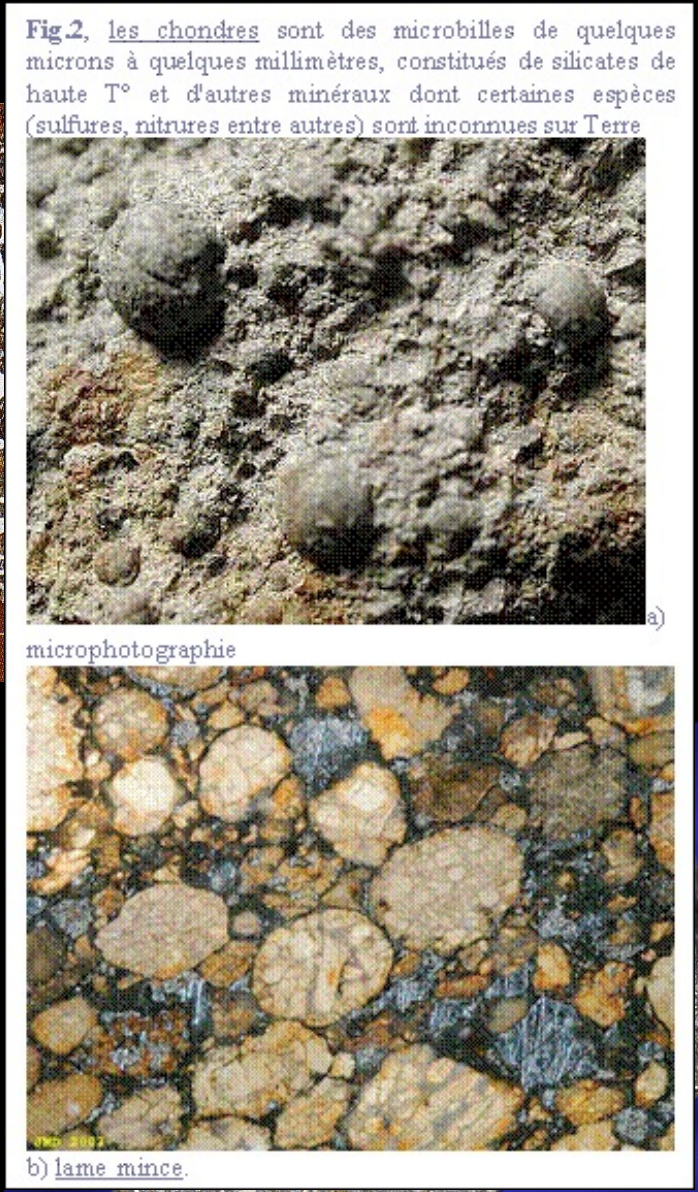
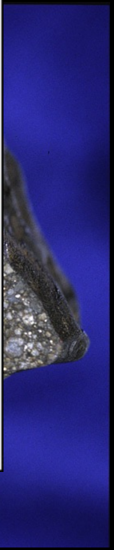
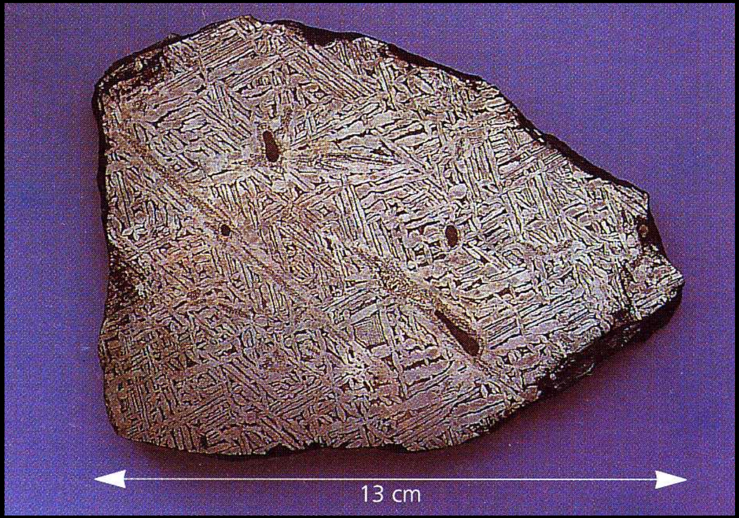


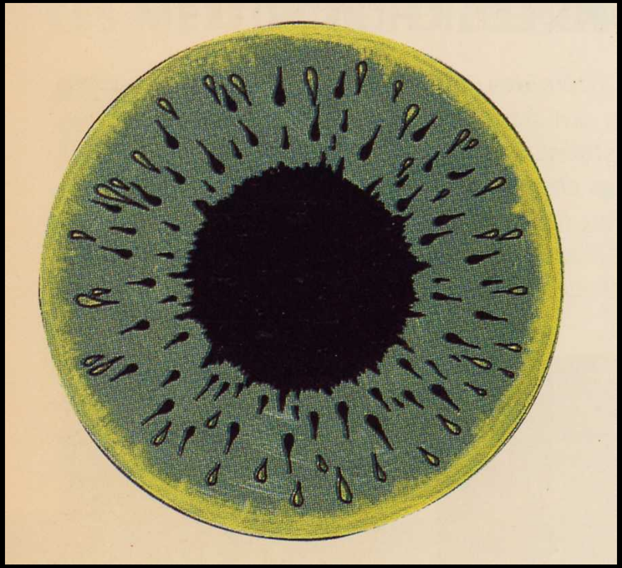
Fig.2, les chondres sont des microbilles de quelques microns à quelques millimètres, constitués de silicates de haute T° et d'autres minéraux dont certaines espèces (sulfures, nitrures entre autres) sont inconnues sur Terre

a) microphotographie

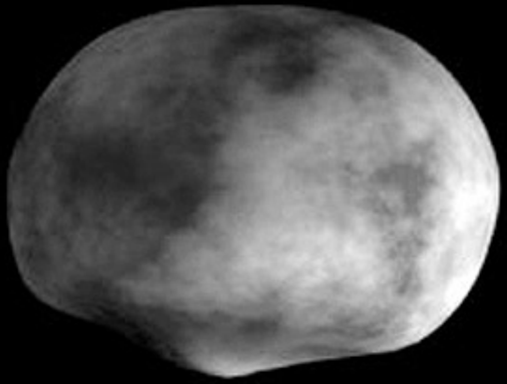
b) lame mince.

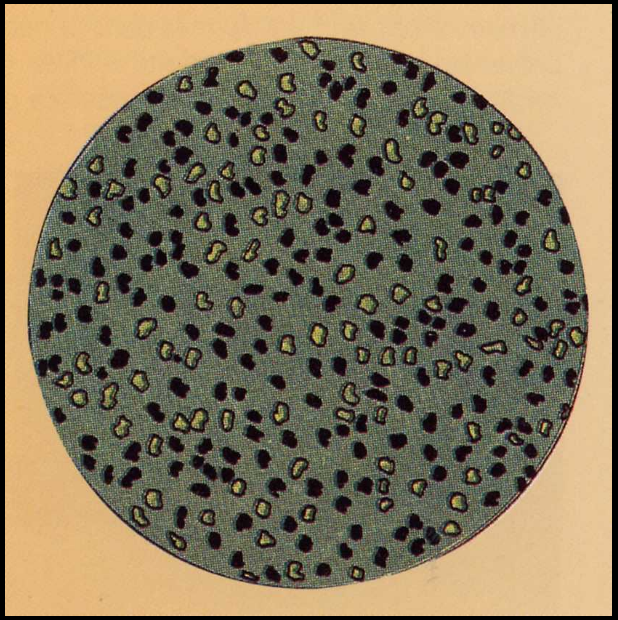




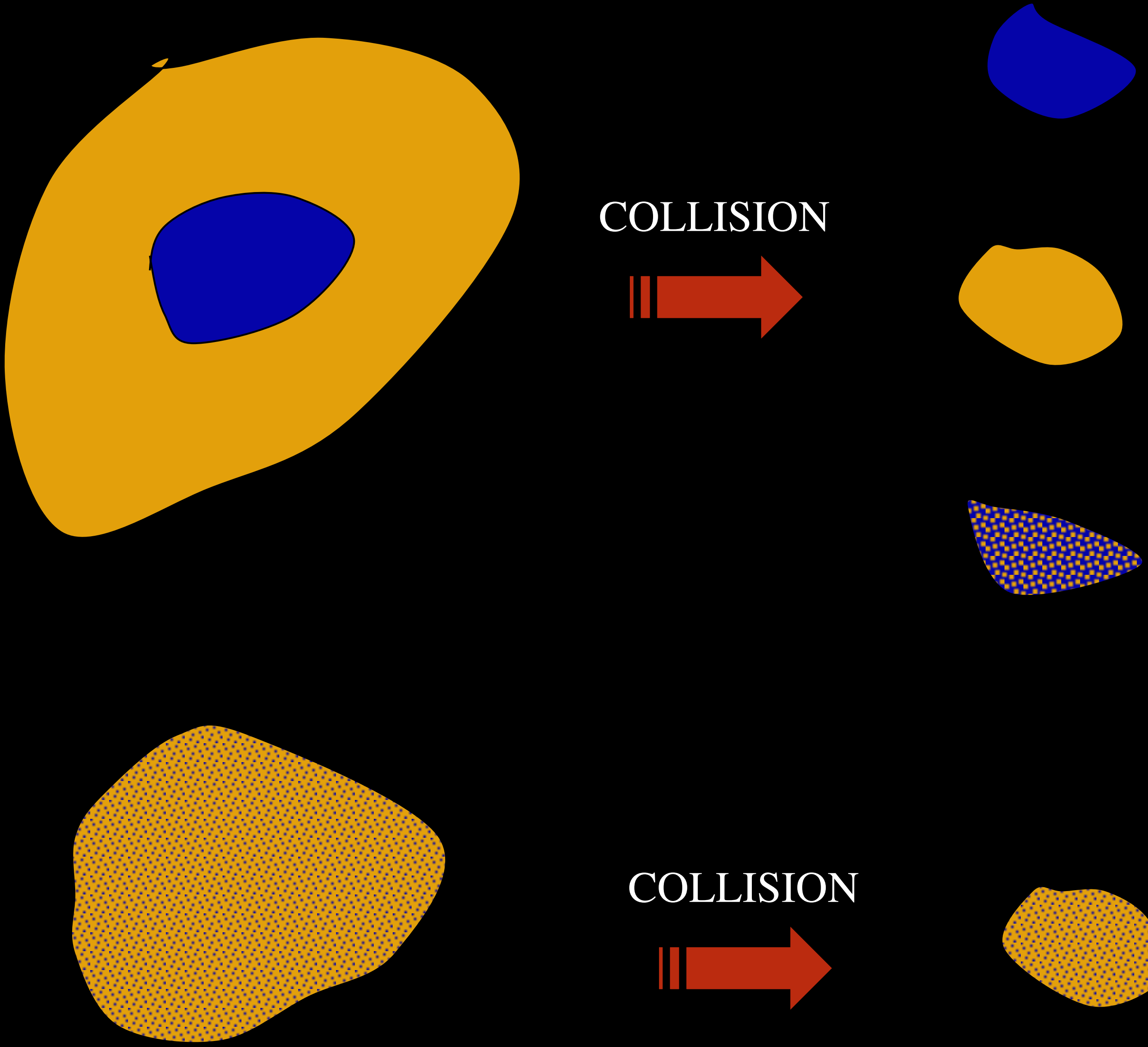


Corps Différencié
NOYAU : métalliques
MANTEAU : achondrite
INTERFACE N-M : Pallasites





Corps non différencié
Chondrites



COLLISION

Métallique

Achondrite

Litho-sidérite
(pallasite)

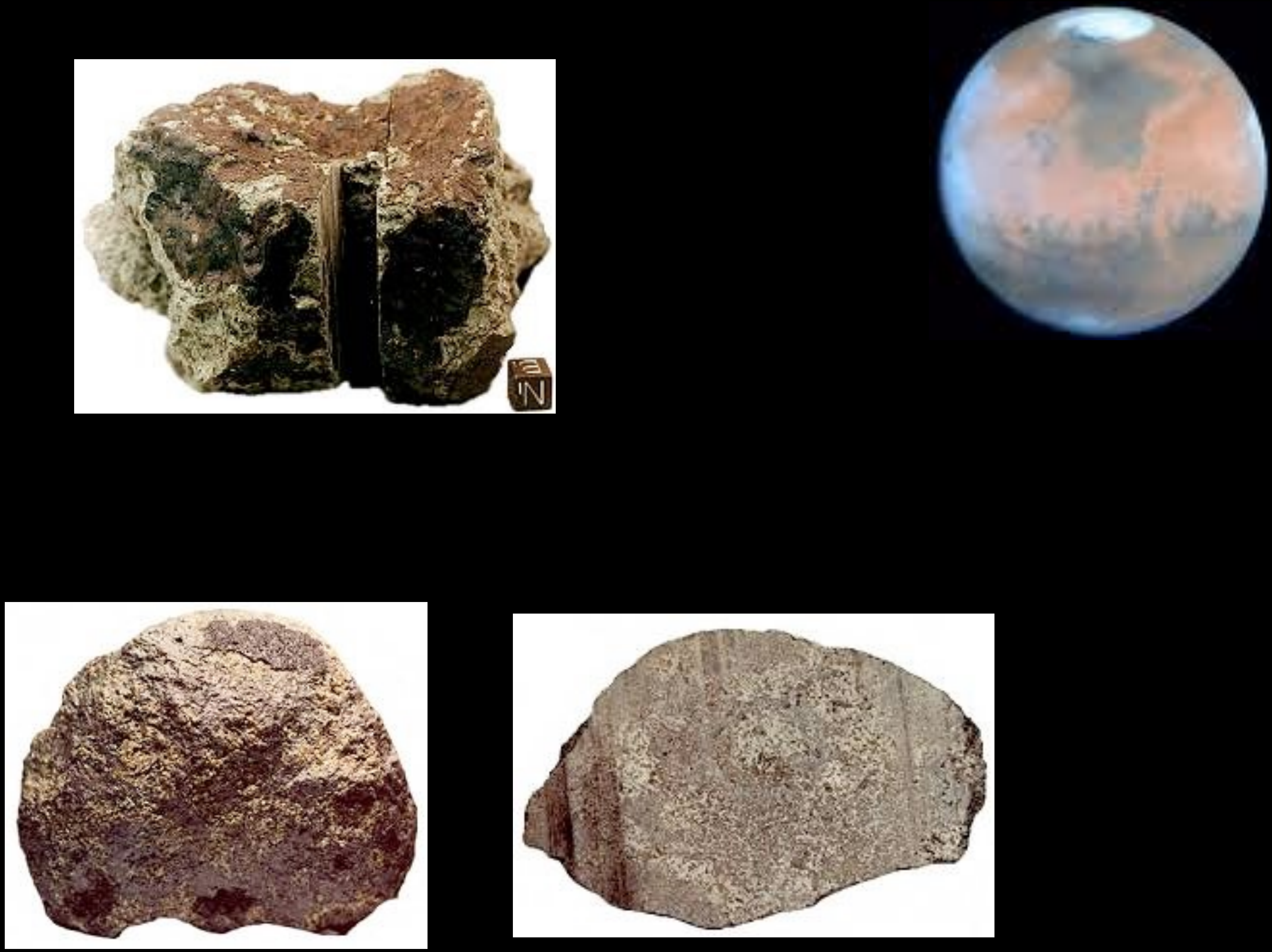
COLLISION

Chondrite


inch
1
2
3
4
5
6


1 cm


1 cm

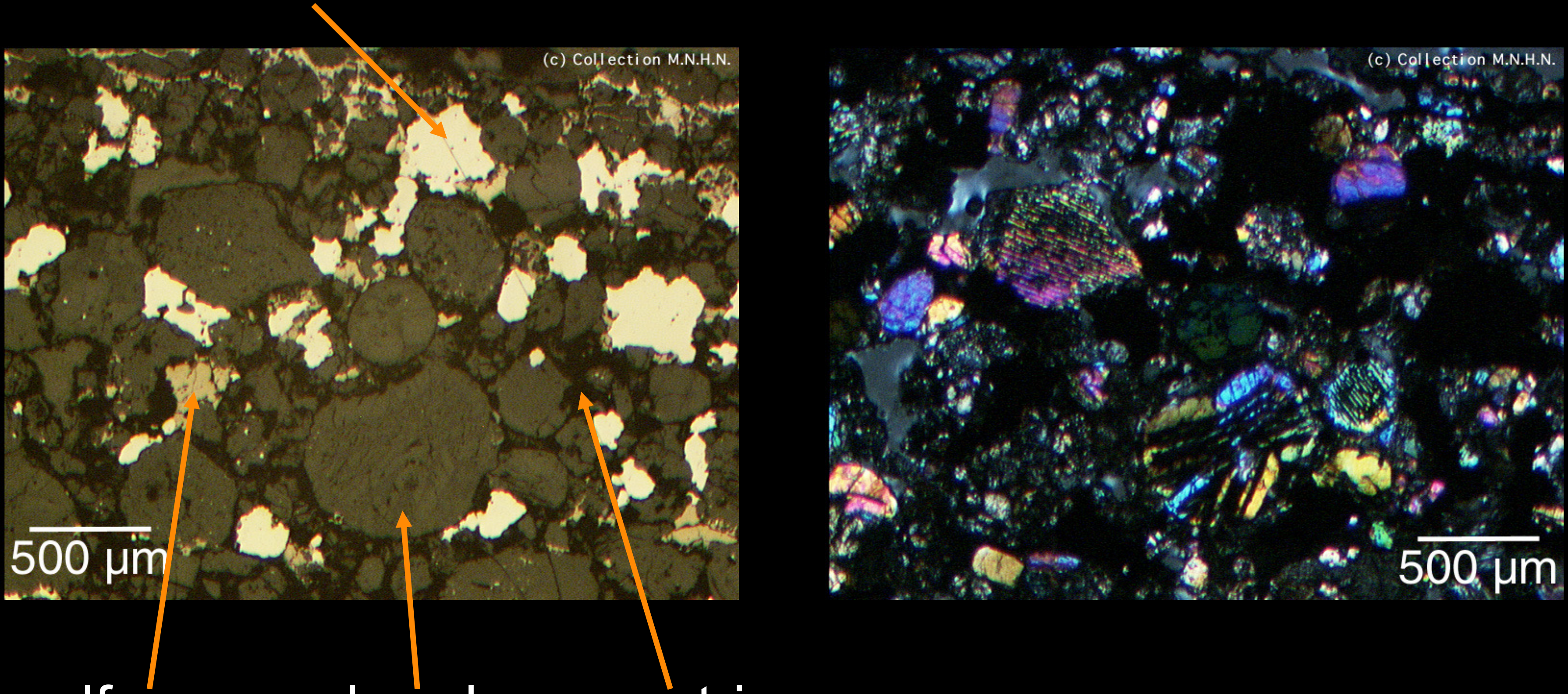



E
1


(a)

Que contiennent-elles ?

Les chondrites : roches primitives



métal

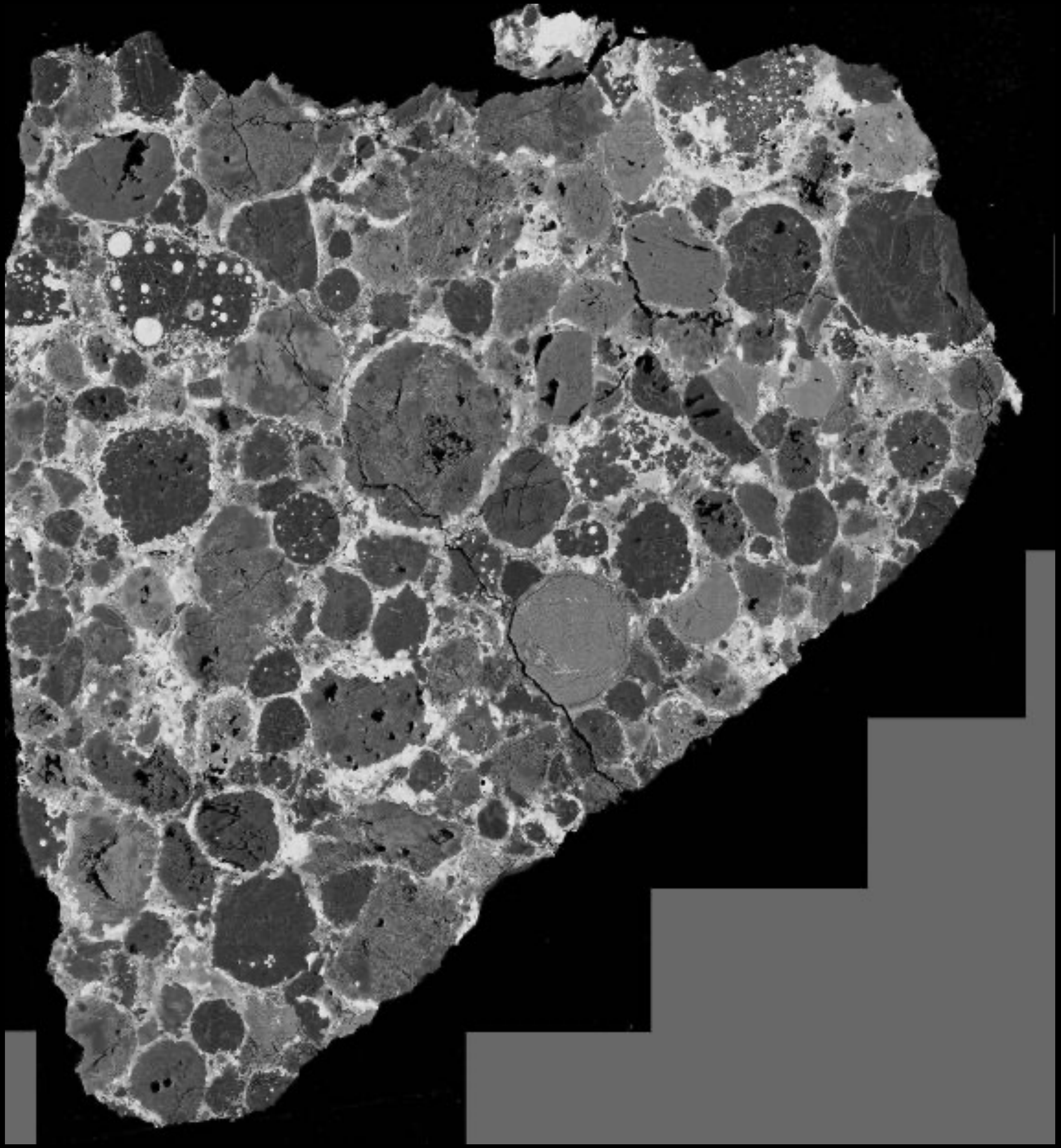
sulfure

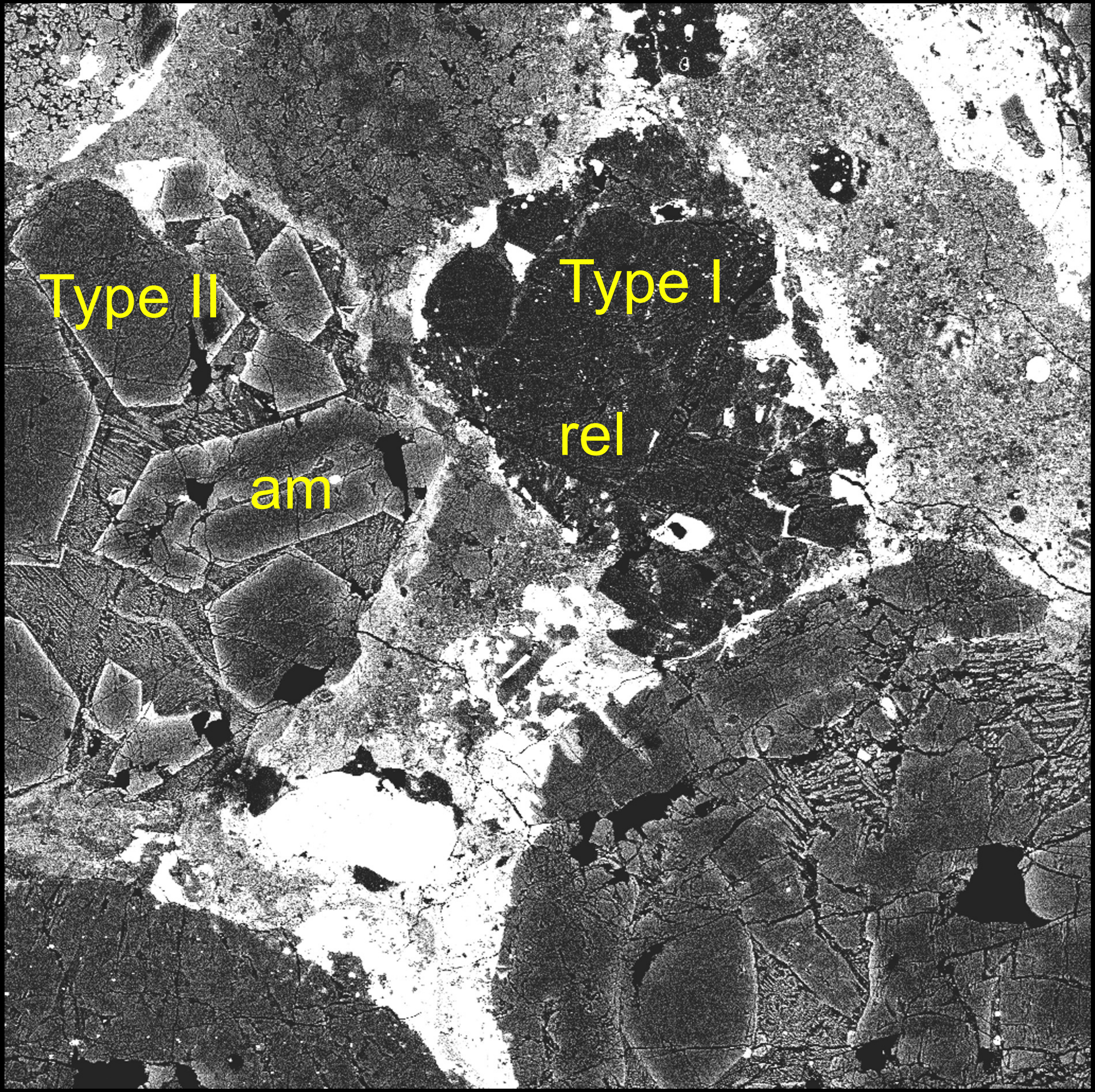
chondre

matrice

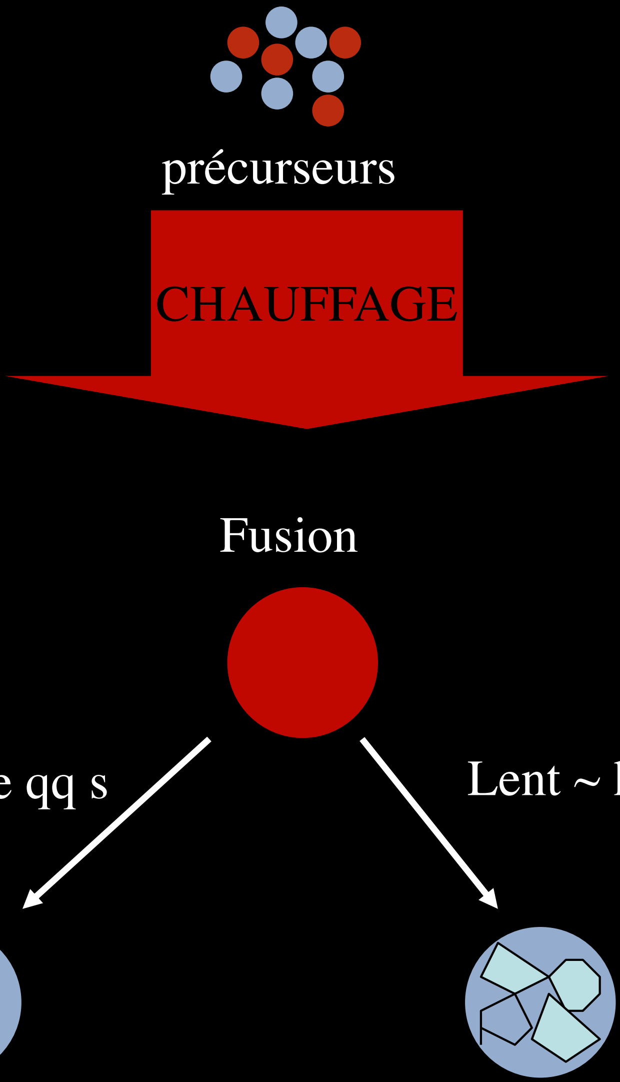
(c) Collection M.N.H.N.

(c) Collection M.N.H.N.




Type II
Type I
rel
am

Les chondres : phases formées en apesanteur dans la nébuleuse



précurseurs

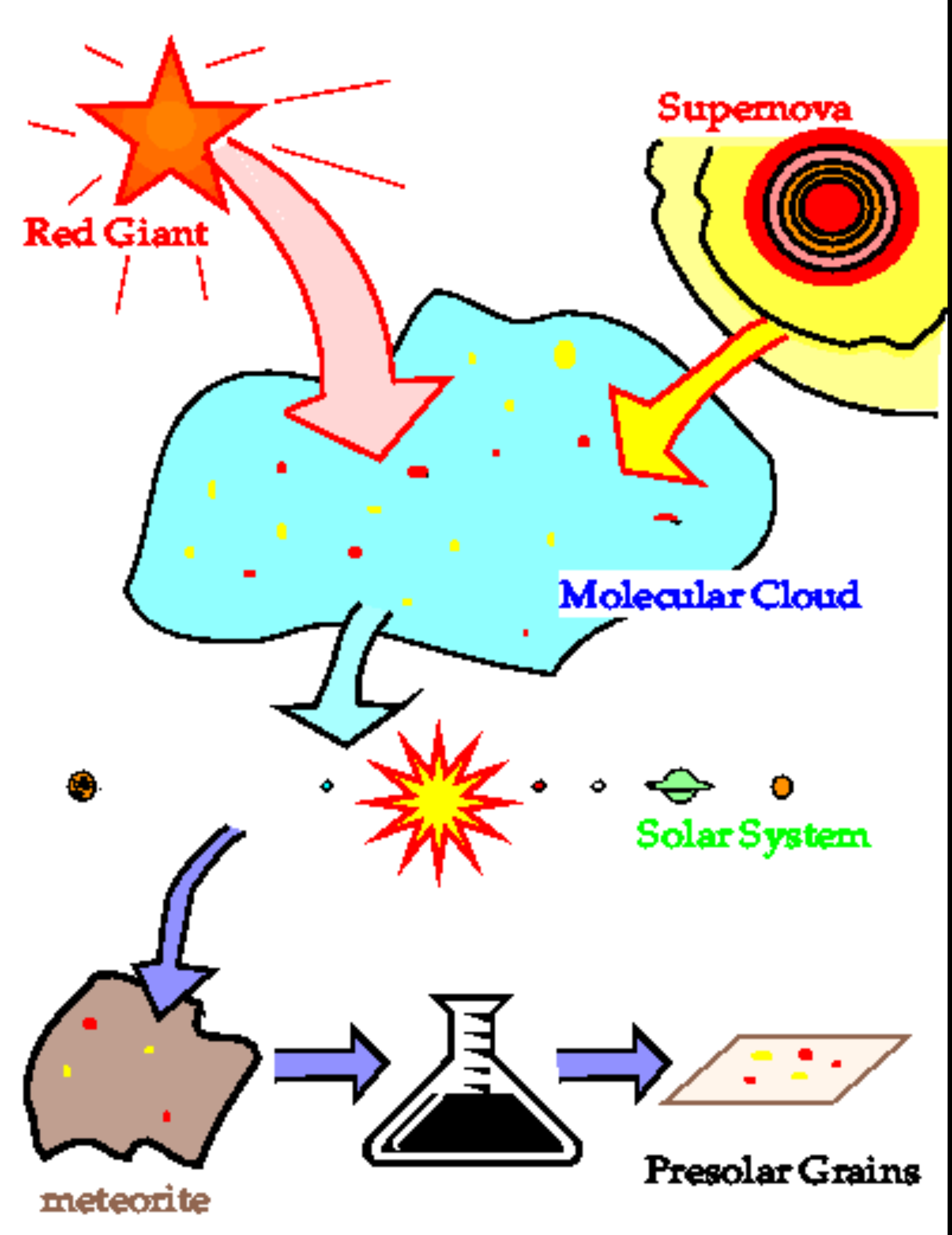
CHAUFFAGE

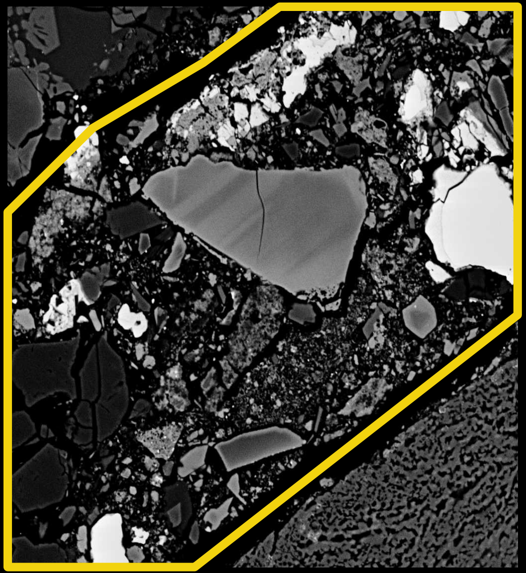
Fusion

Trempe qq s

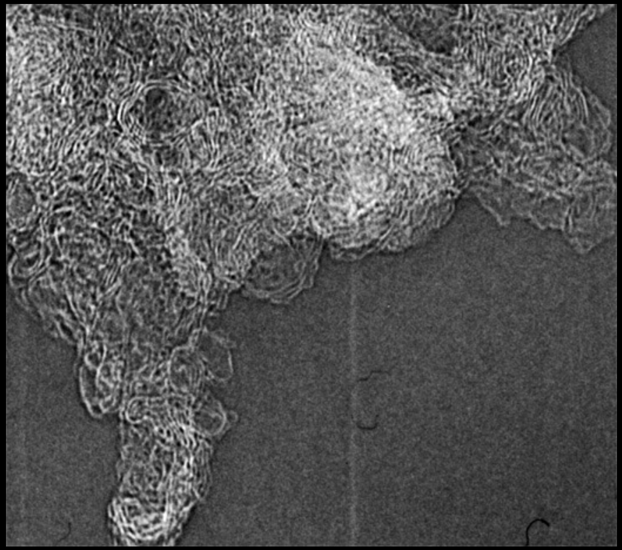
Lent ~ heure

Des phases présolaires dans la matrice des chondrites

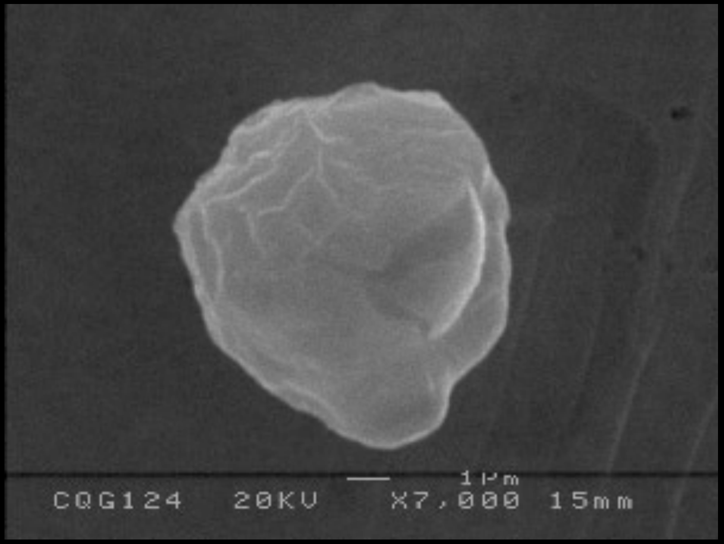




Matière organique

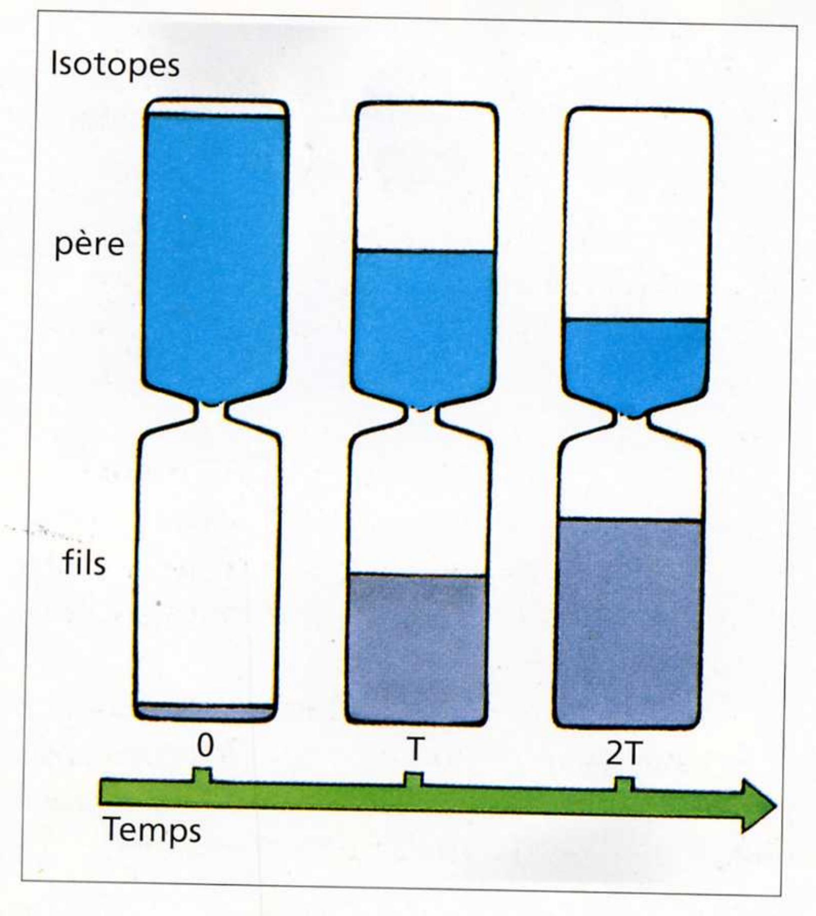


Grains présolaires

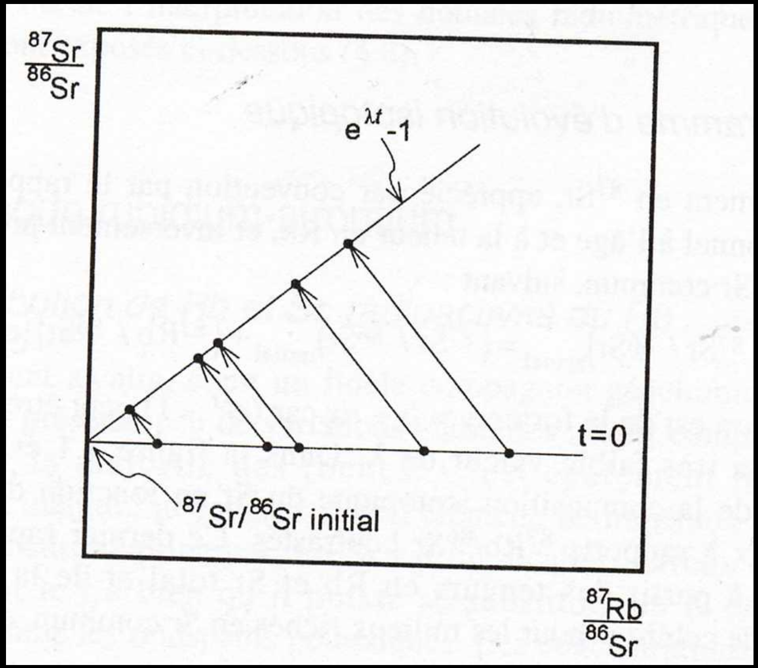


Quel âge ont-elles ?

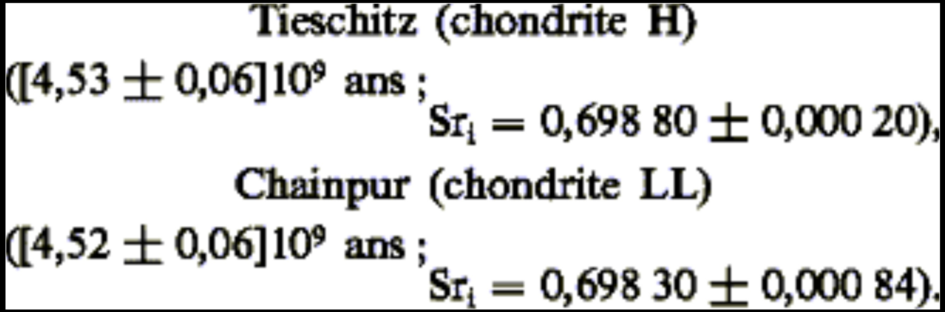
CHRONOMETRES RADIOACTIFS



Droite de fractionnement



Objets non-différenciés



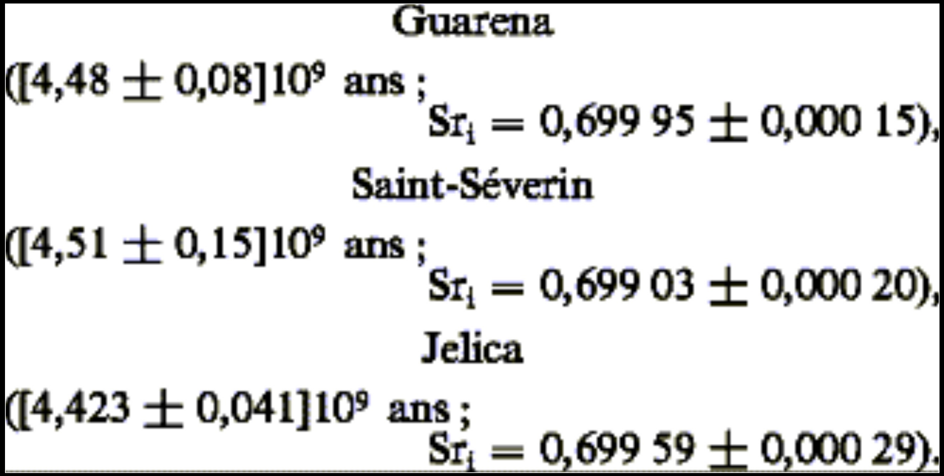
Tieschitz (chondrite H)

([4,53 ± 0,06]10^9 ans ; $Sr_i = 0{,}698\,80 \pm 0{,}000\,20$),

Chainpur (chondrite LL)

([4,52 ± 0,06]10^9 ans ; $Sr_i = 0{,}698\,30 \pm 0{,}000\,84$).

Objets différenciés



Guarena

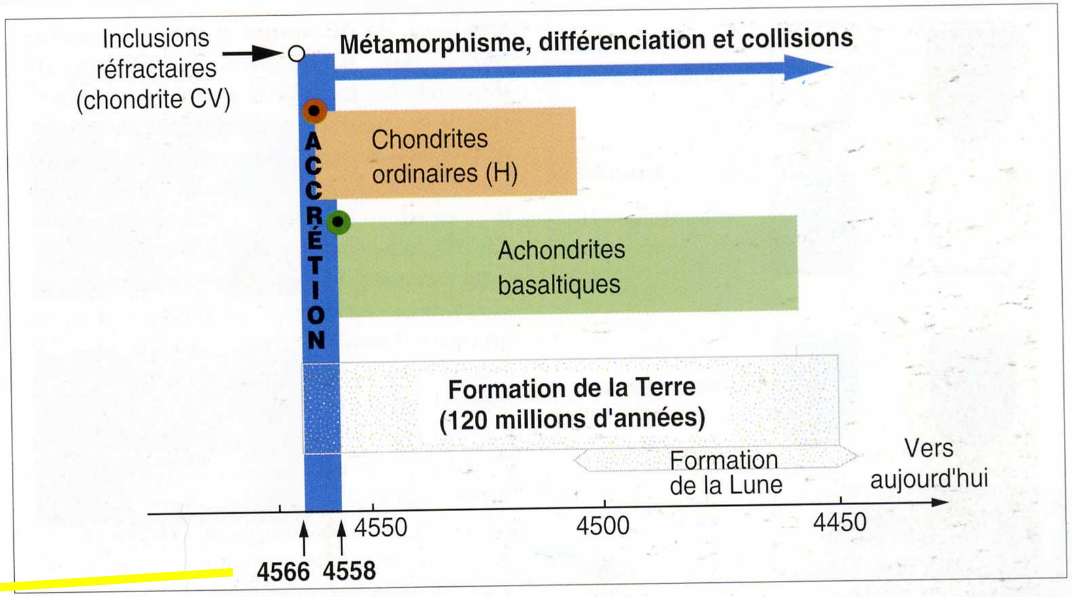
([4,48 ± 0,08]10^9 ans ; $Sr_i = 0{,}699\,95 \pm 0{,}000\,15$),

Saint-Séverin

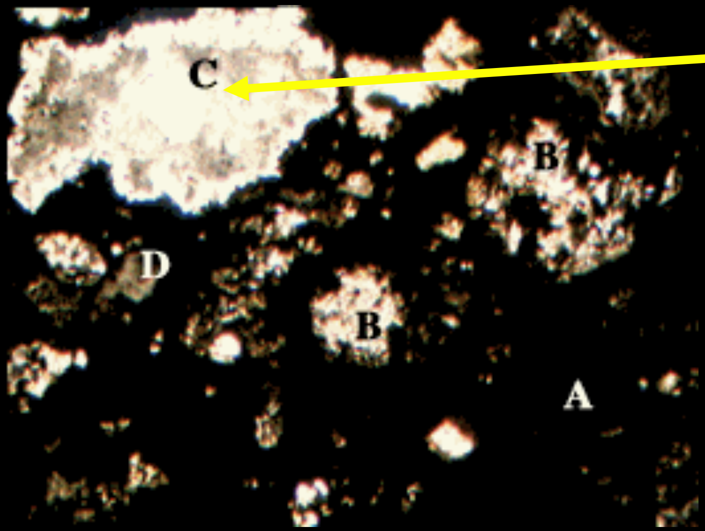
([4,51 ± 0,15]10^9 ans ; $Sr_i = 0{,}699\,03 \pm 0{,}000\,20$),

Jelica

([4,423 ± 0,041]10^9 ans ; $Sr_i = 0{,}699\,59 \pm 0{,}000\,29$).

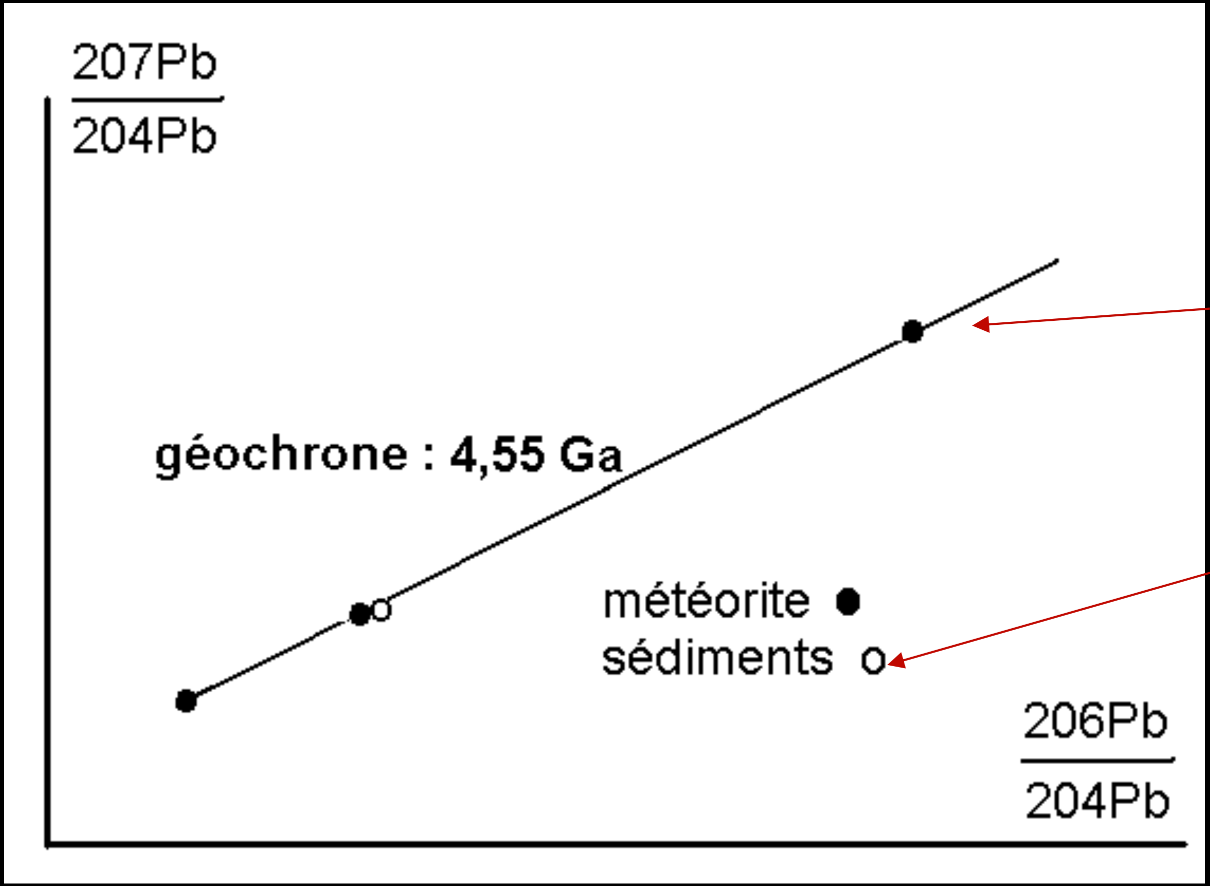


Les inclusions réfractaires, premiers objets solaires, se sont formés il y a 4,566 milliards d'années. La formation des chondrites qui les englobe et des achondrites a duré 8 millions d'années. Le réchauffement dû aux collisions ou au métamorphisme dans les corps parents a pu modifier les structures minérales pendant encore 100 millions d'années. La Lune aurait pu être formée suite à la collision d'un gros planétoïde avec la Terre, il y a environ 4,5 milliards d'années. Les plus vieilles roches lunaires sont datées de 4,4 milliards d'années.



L’âge de la Terre

6000 ans	80000 ans	10 Ma	Plusieurs Ga	4.55 Ga
	Buffon	Lork Kelvin	Rutherford	C. Patterson

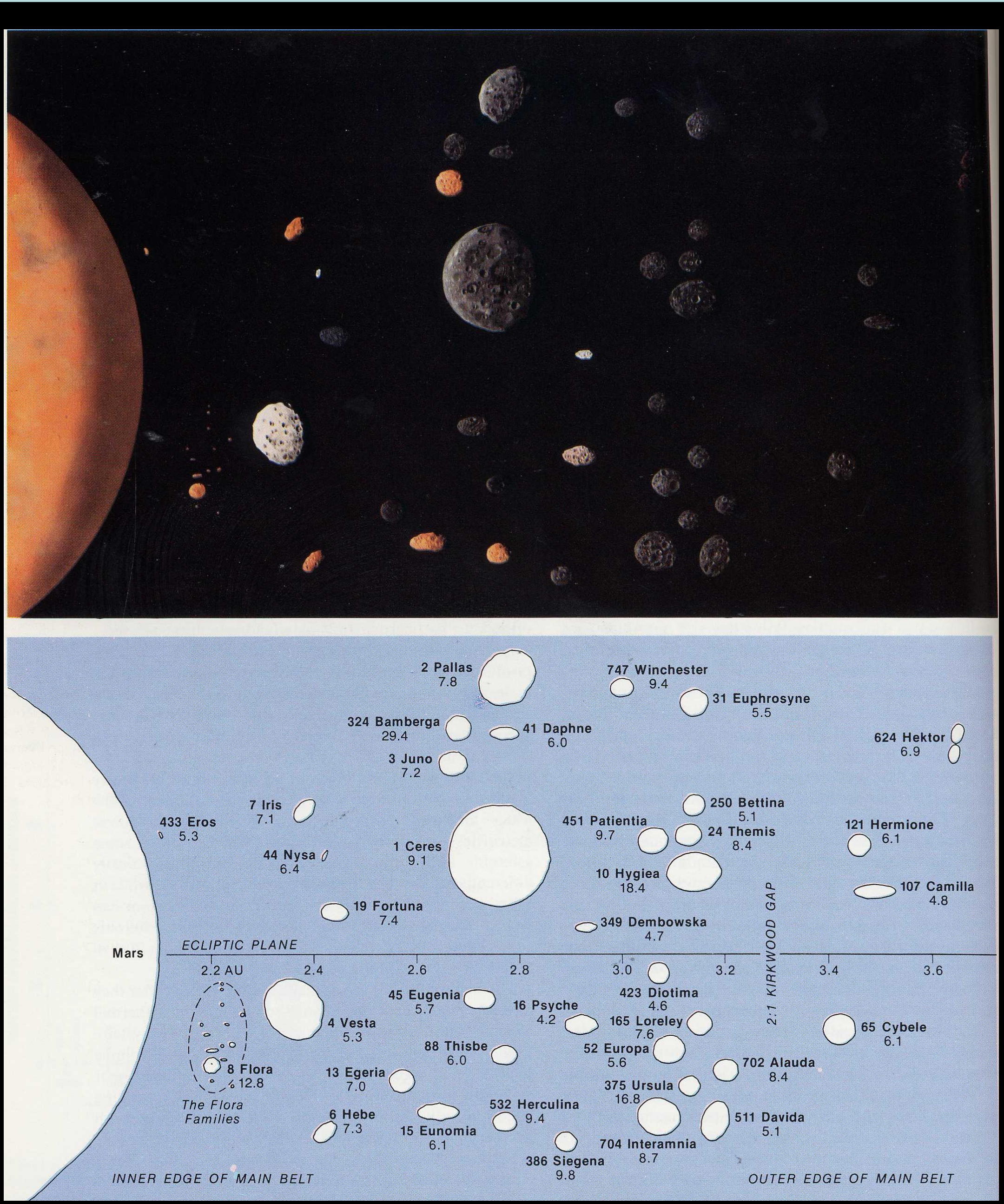


« âge modèle de la Terre »

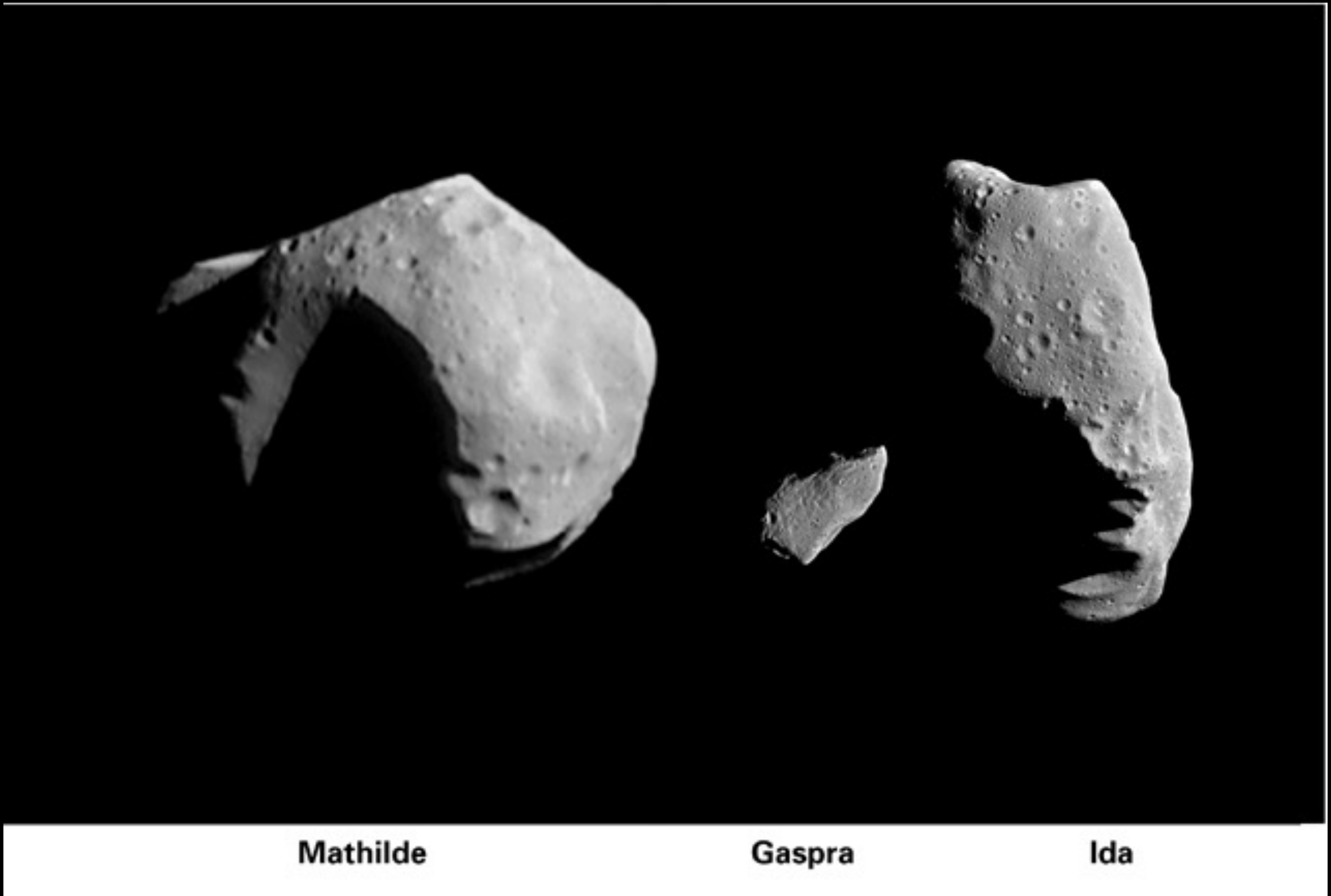
Laves Hawaienne : manteau inférieur, échantillon moyenné de la composition de la Terre

Terre, Lune et Météorites sont cogéniques

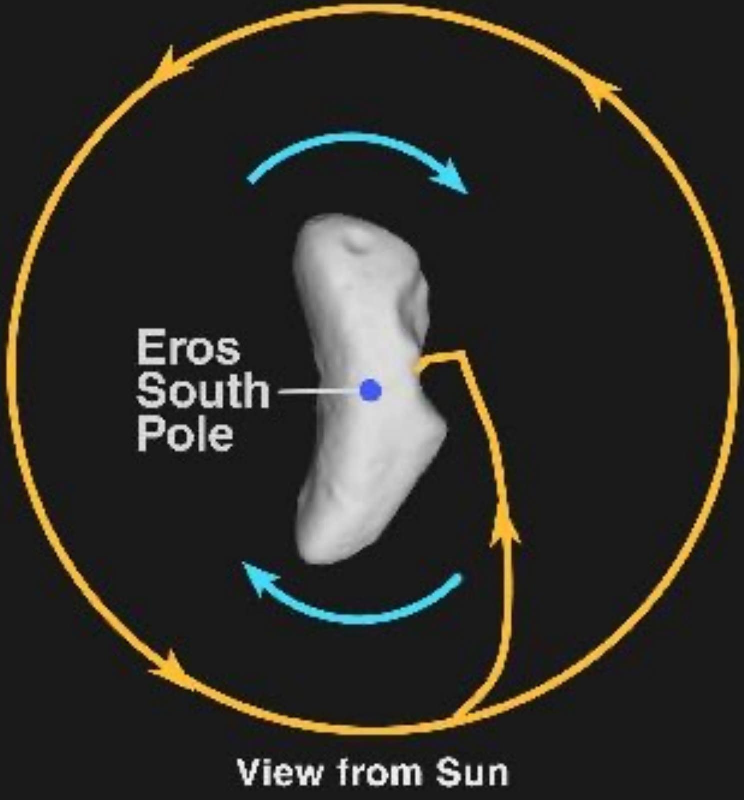
Les astéroïdes, parents



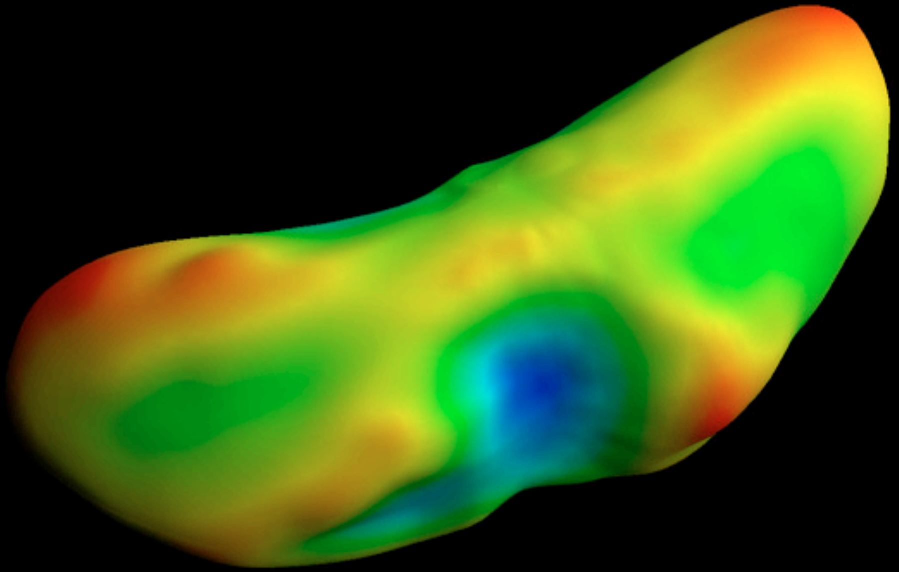
Exploration spatiale

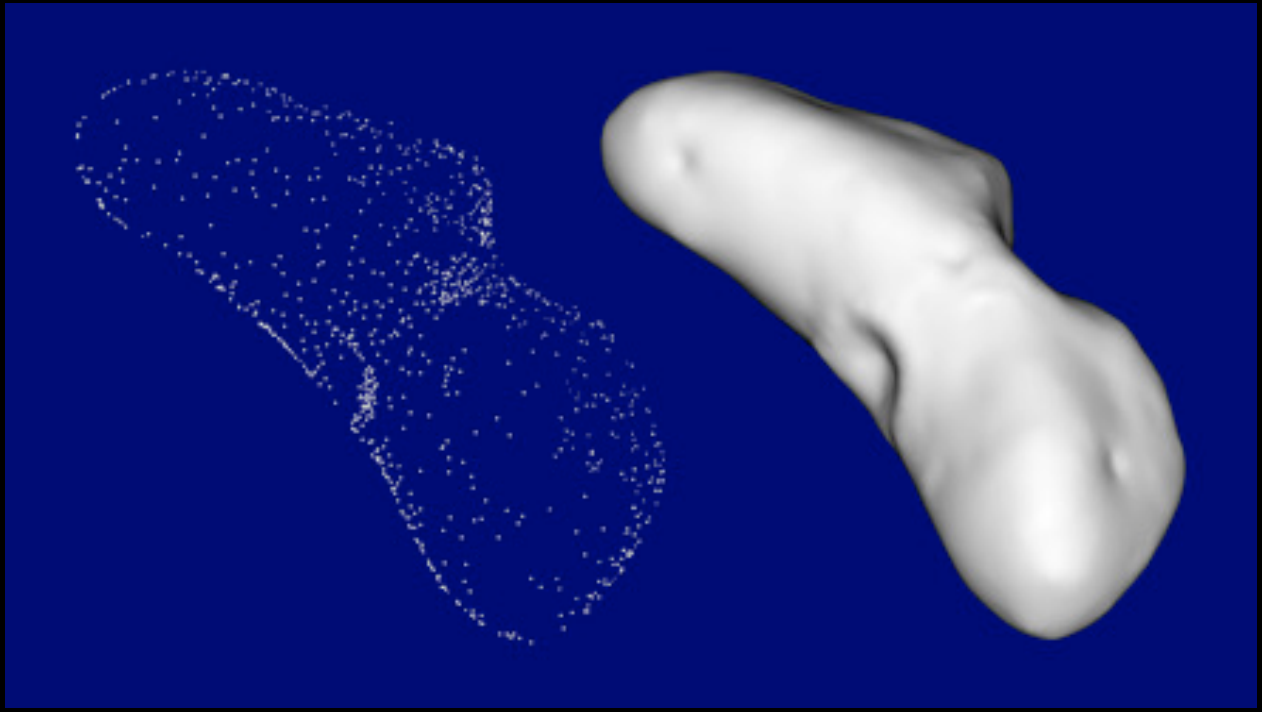


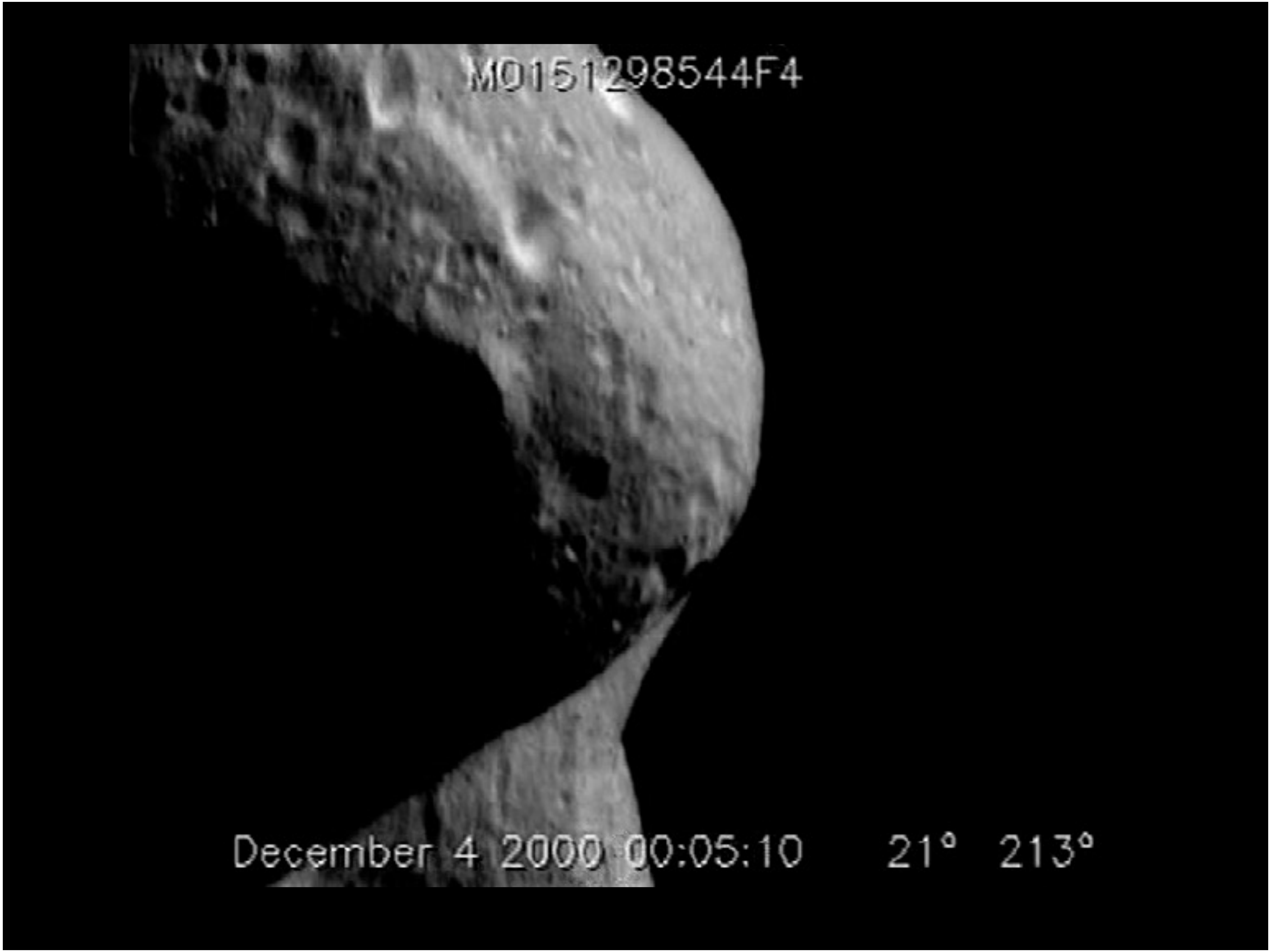
NEAR Shoemaker Final Descent from 35-km Orbit



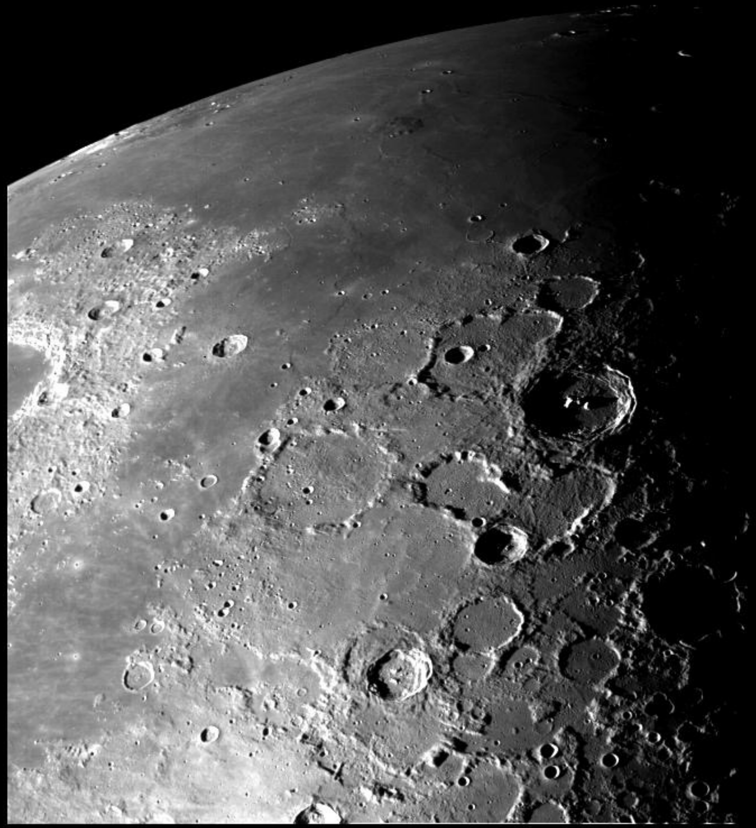
Farquhar
01-0074-1






M0151298544F4
December 4 2000 00:05:10
21°
213°

Planétologie comparée : la Lune



Pas d’atmosphère
Pas de champ magnétique

ERROSION SPATIALE

ALTERATION DE LA ROCHE DE SURFACE

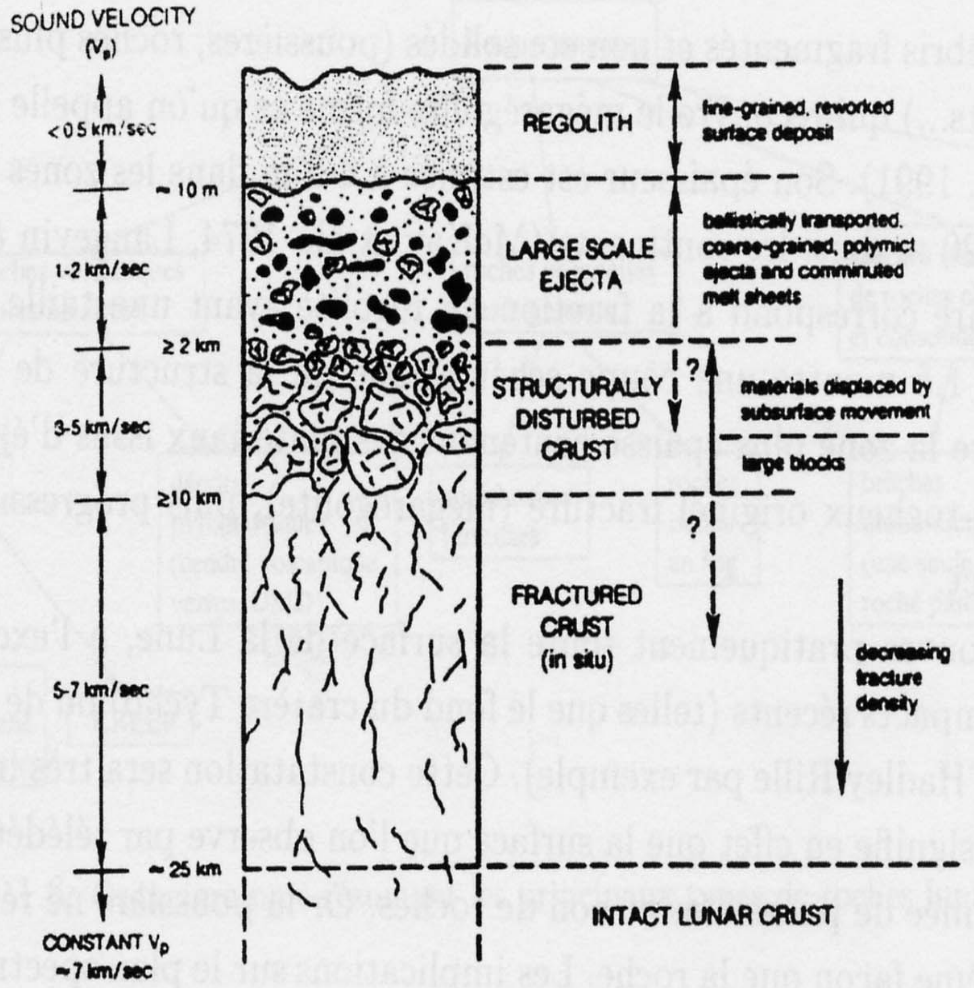
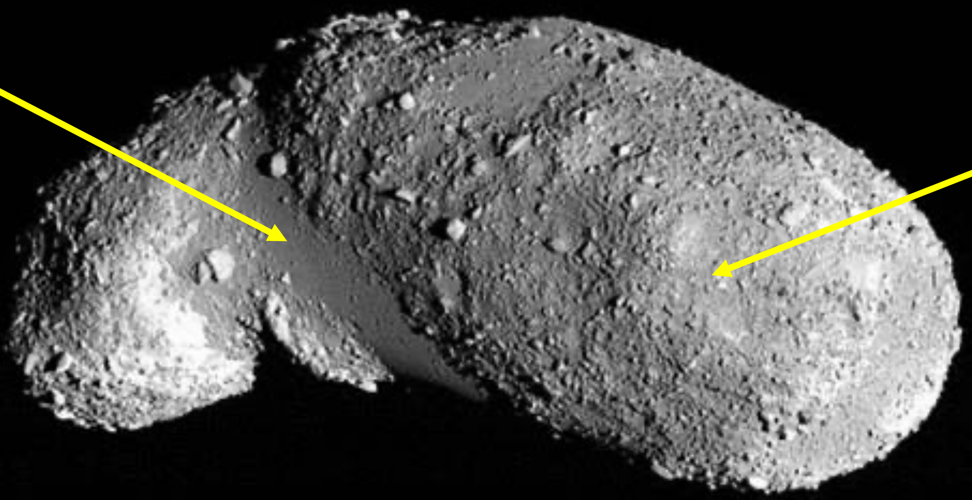
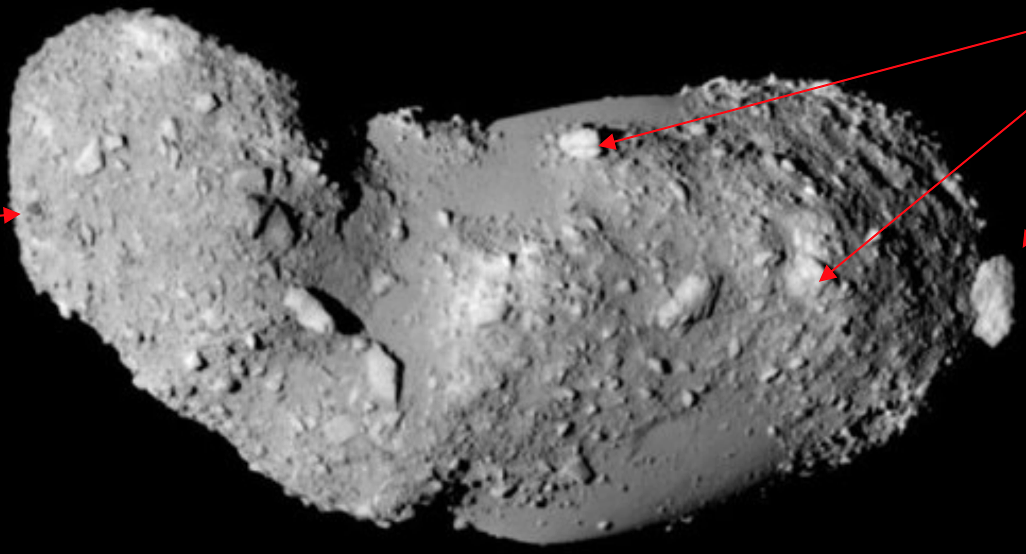
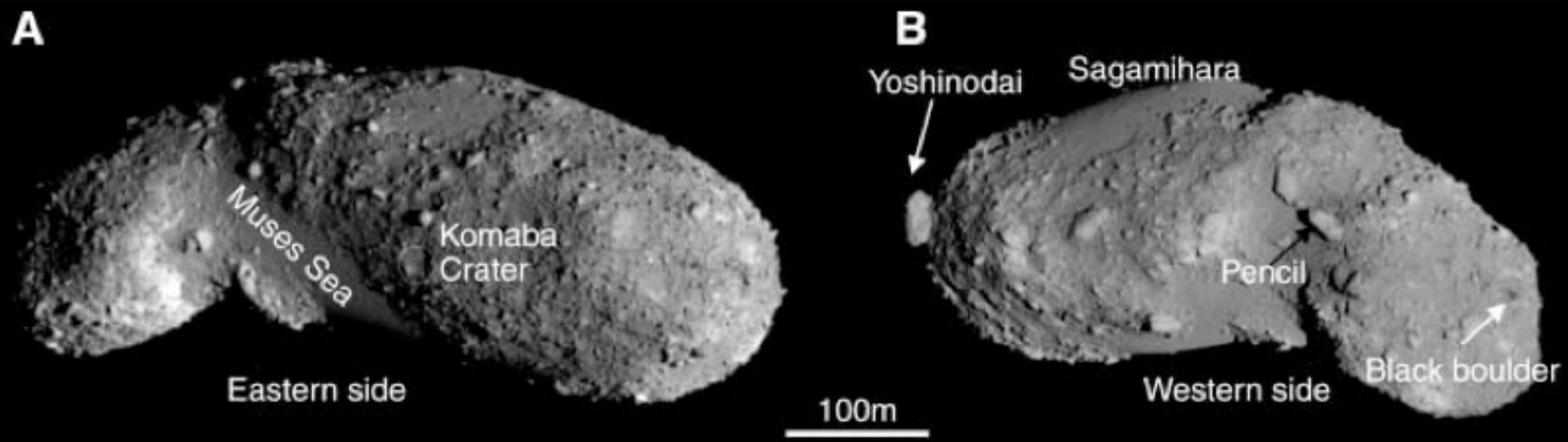


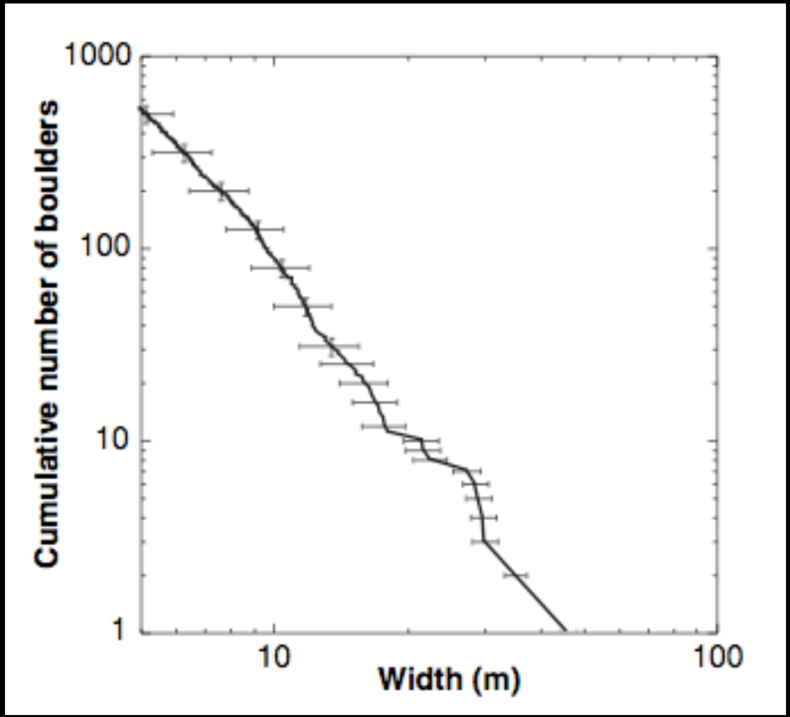
FIG. 1.5: Coupe schématique de la croûte lunaire montrant le régolite, le mégarégolite et le socle rocheux. D'après Horz et al. (1991).

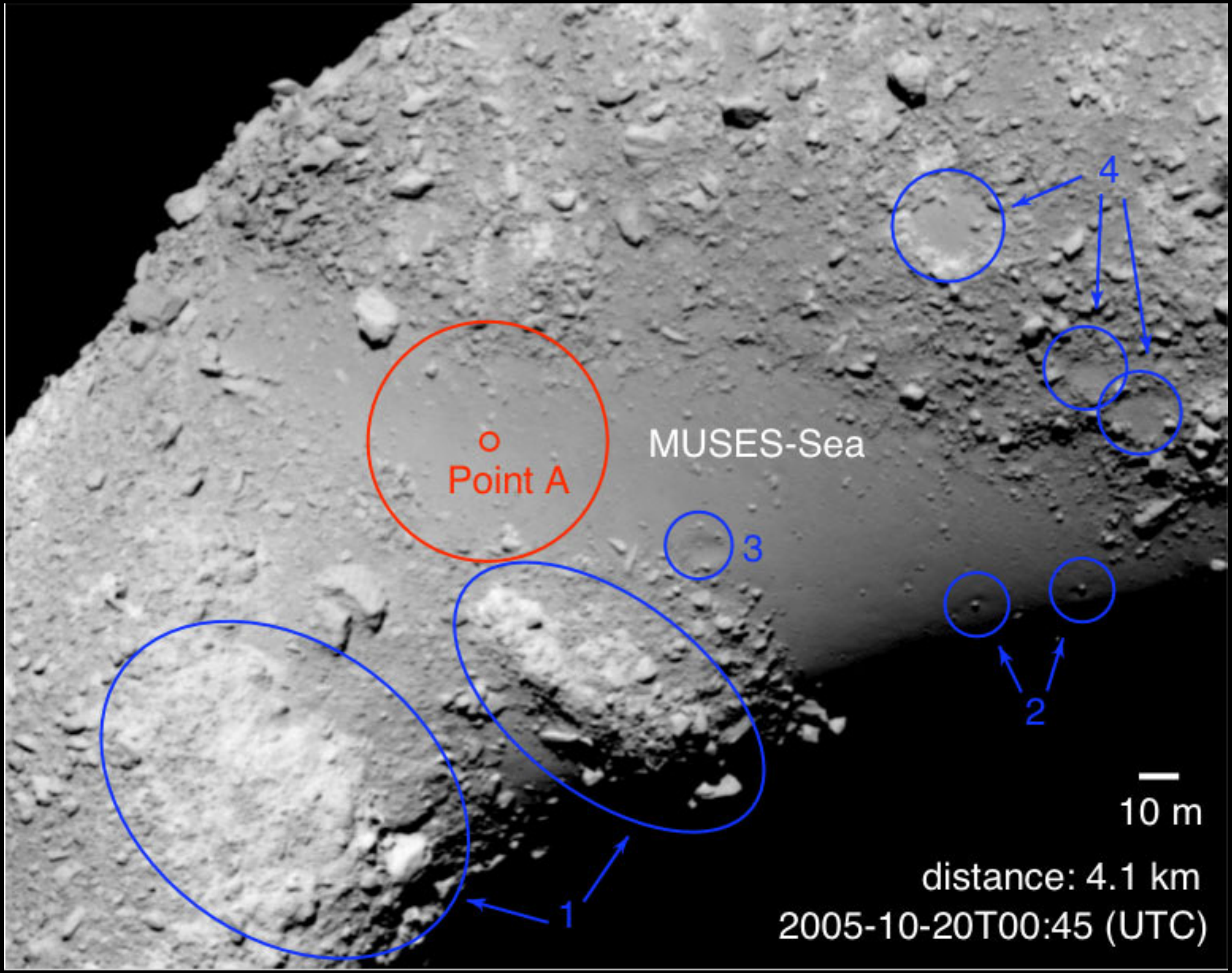
Itokawa





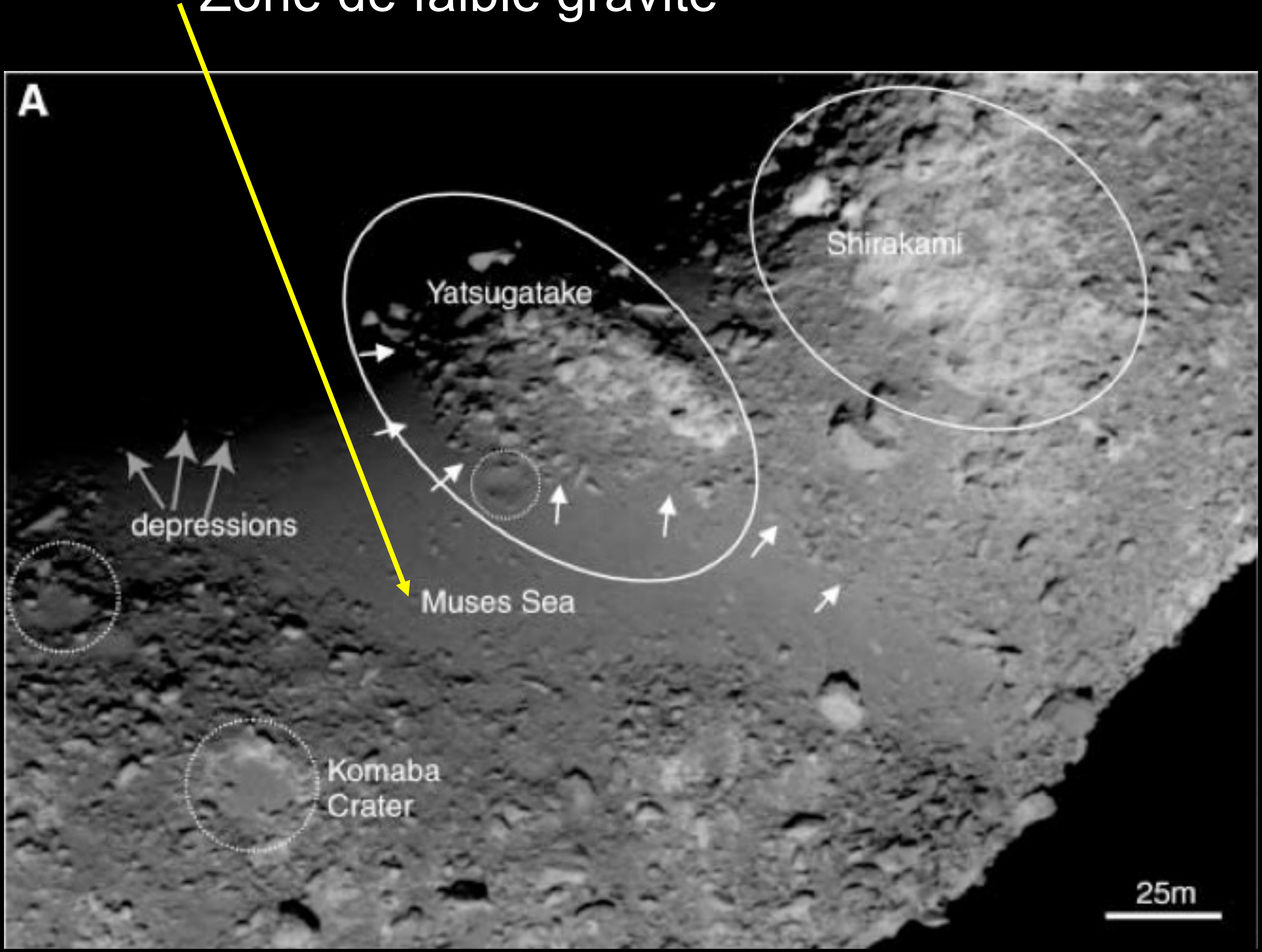

A
Muses Sea
Komaba
Crater
Eastern side
100m
B
Yoshinodai
Sagamihara
Pencil
Western side
Black boulder


1000
100
10
1
Cumulative number of boulders
10
100
Width (m)


4
Point A
MUSES-Sea
3
2
1
10 m
distance: 4.1 km
2005-10-20T00:45 (UTC)


Univ Tokyo/JAXA

Zone de faible gravité



Mécanismes de transport et de déposition

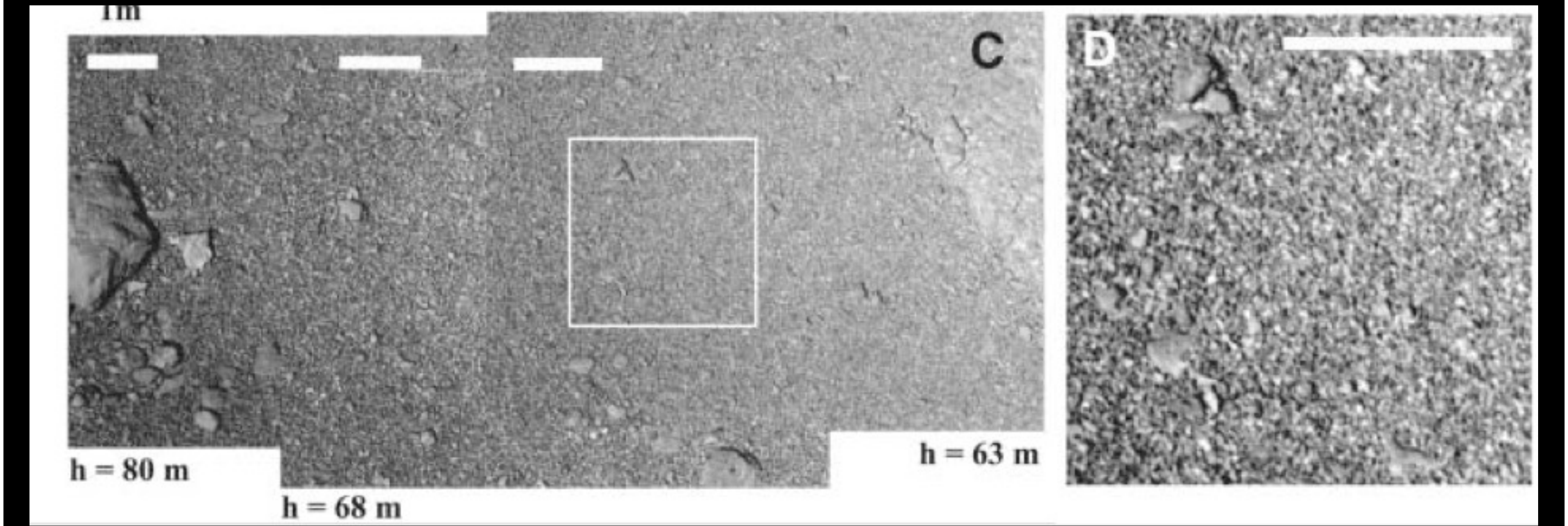

1m
C
D
h = 80 m
h = 68 m
h = 63 m

Fig. 2. (**A**) Elemental ratios of Itokawa (shaded area) plotted as Mg/Si versus Al/Si, together with typical compositions of stony and stony iron meteorites. (**B**) Enlargement of shaded area in (A). The dashed and dotted lines in (A) denote the best-fit values and their 2σ uncertainties, respectively.

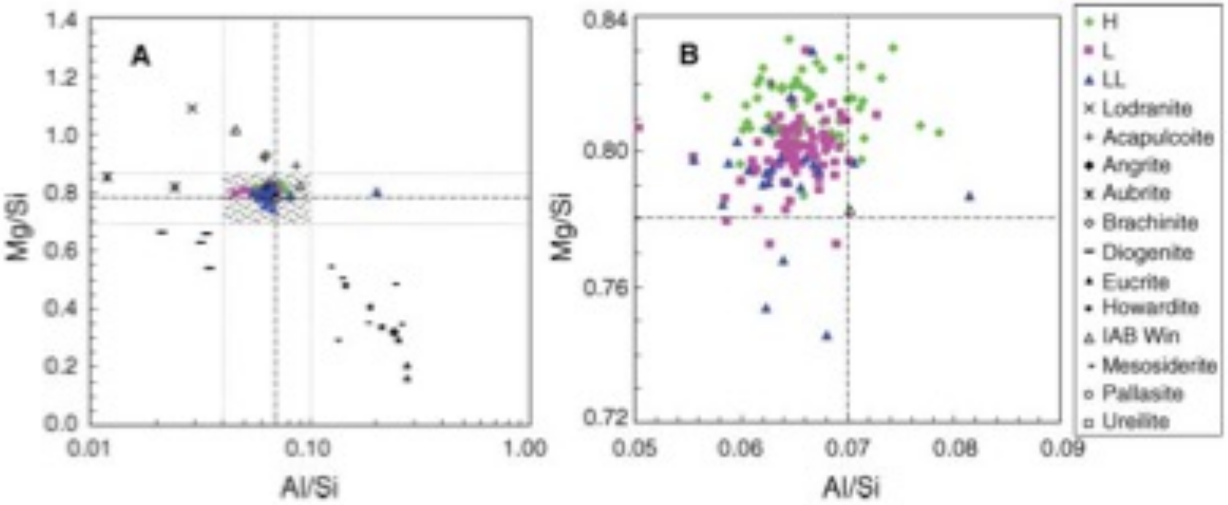
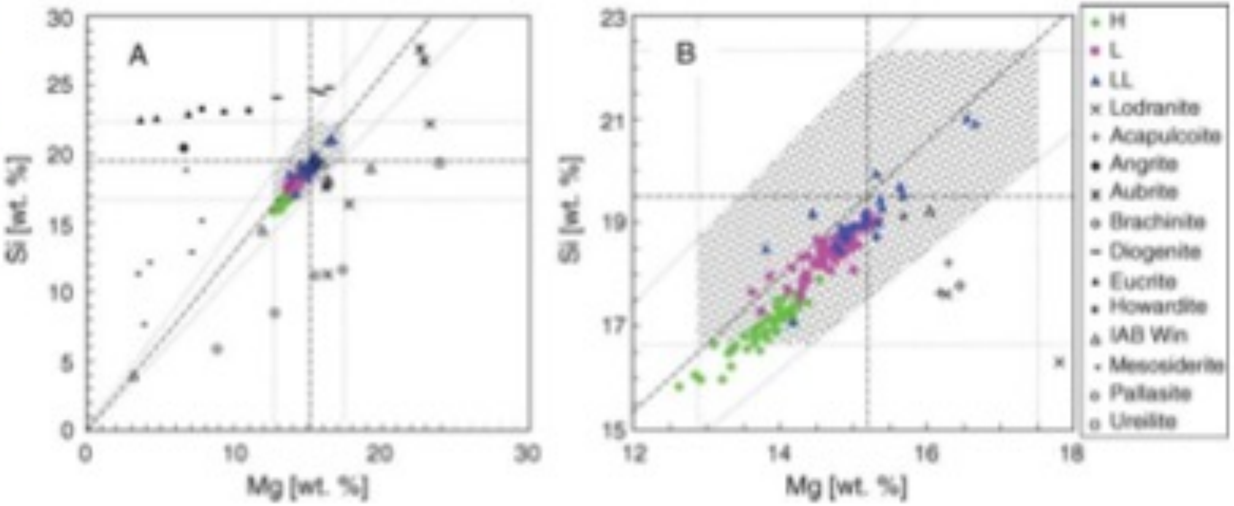


Fig. 3. (**A**) Elemental composition of Itokawa (Si/Mg) plotted as in Fig. 2. (**B**) Enlargement of the shaded area in (A). Ordinary chondrites, acapulcoites, and IAB winonaites appear closest in composition, and Itokawa appears to be more like an LL- or L-chondrite in composition than an H-chondrite.



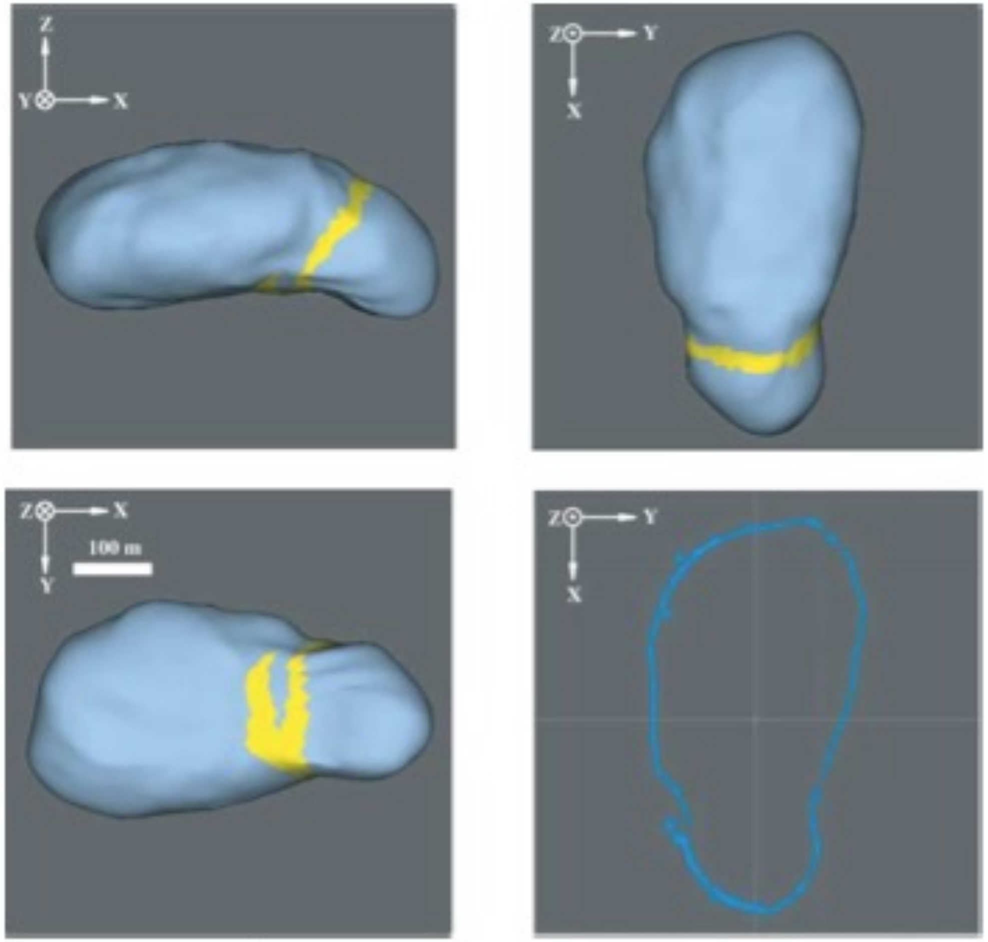


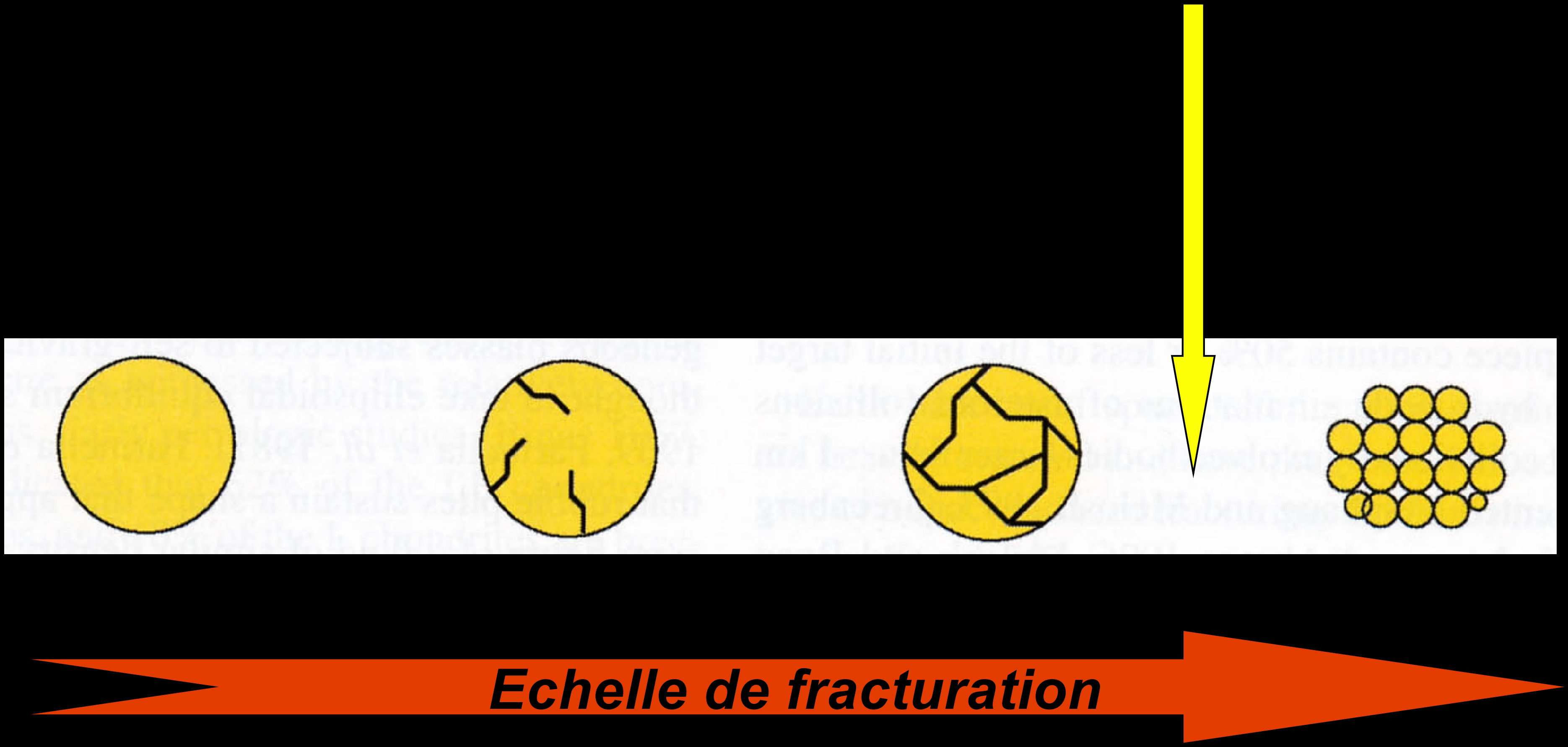
Fig. 1. Three views of Itokawa's shape model and a detailed cross section along the equator. The *z* direction is north of Itokawa, and the *x* direction is the prime meridian. The most substantial structure is two pieces (head and body) separated by a circular concave structure (neck). To help guide the eye, a headward slope of the neck is colored in yellow; this region is defined by surface texture of deposits and mass movements derived from the head. A quasi-eyeballed feature of southern polar region shows a local hill (named Yatsugatake in Fig. 3) surrounded by the deposits, but the hill might be an emplacement.

Porosité ~ 40 %

Un objet plein de vides !!!

D_{Eros}=2.67 g.cm^{-3}
D_{CO}=3.4 g.cm^{-3}

Porosité ~ 30 % !

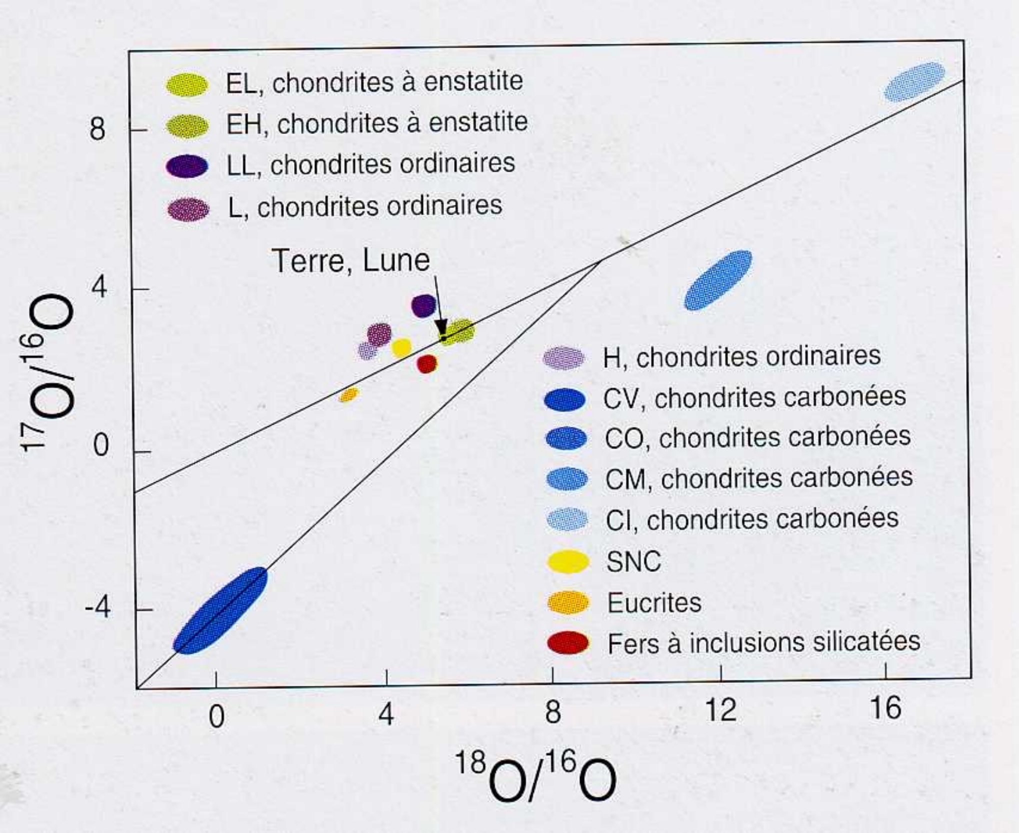


Echelle de fracturation

Origine des astéroïdes ?

FORMATION PAR ACCRETION

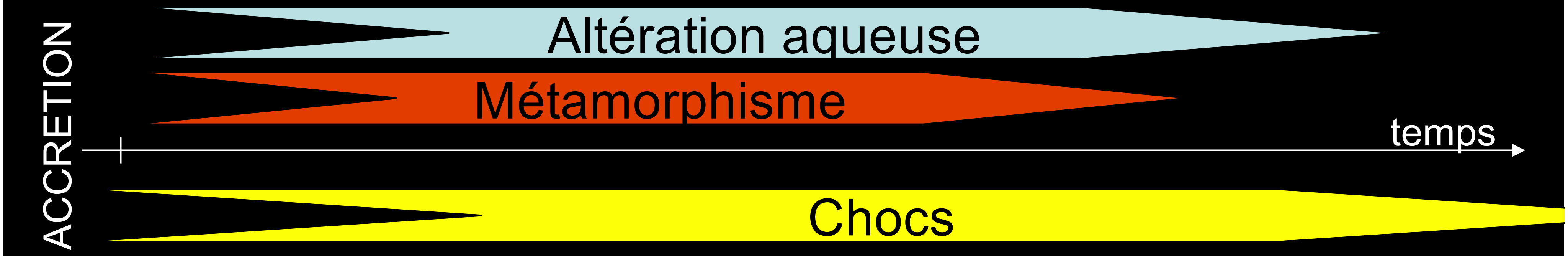
NE SONT PAS LES VESTIGES D'UNE ANCIENNE PLANETE



Isotopes de l'oxygène

Empreintes digitales

Histoire géologique ?



ACCRETION

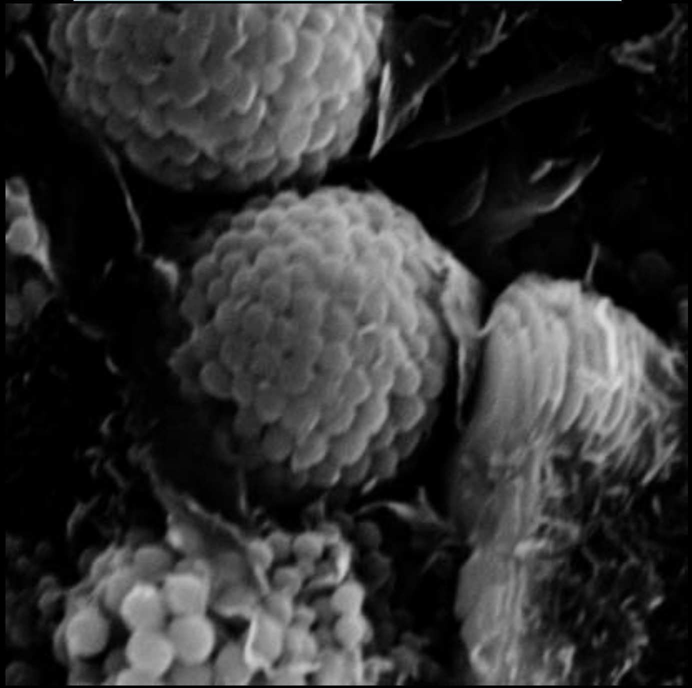
Altération aqueuse

Métamorphisme

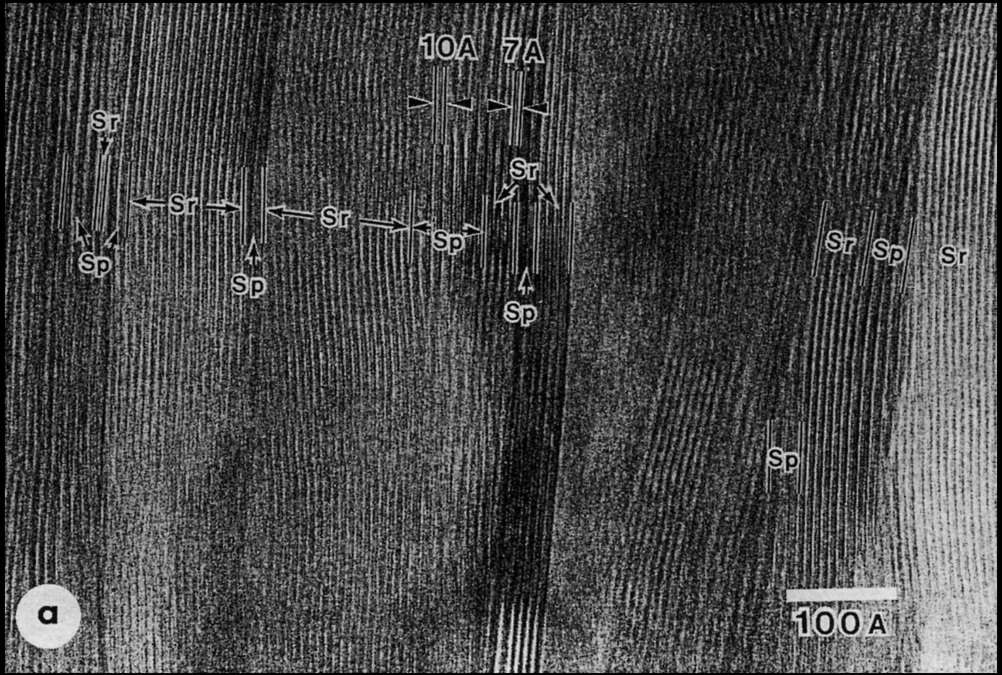
temps

Chocs

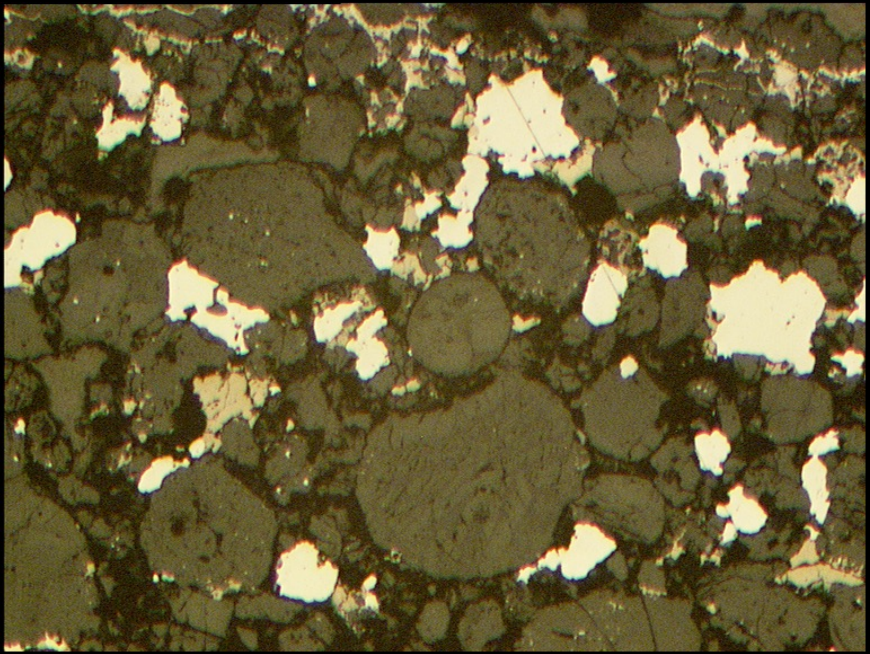
Magnétite framboïdale

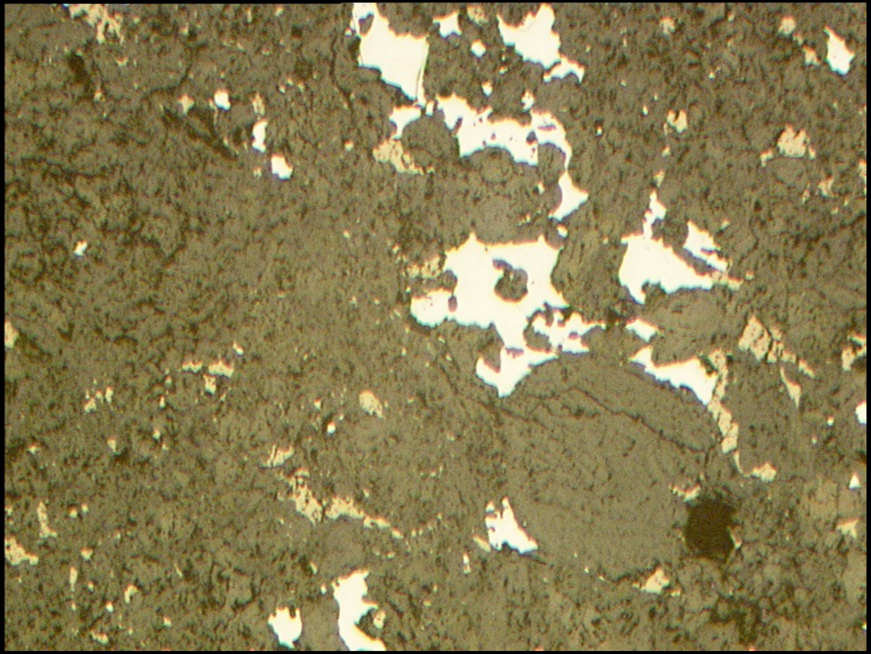


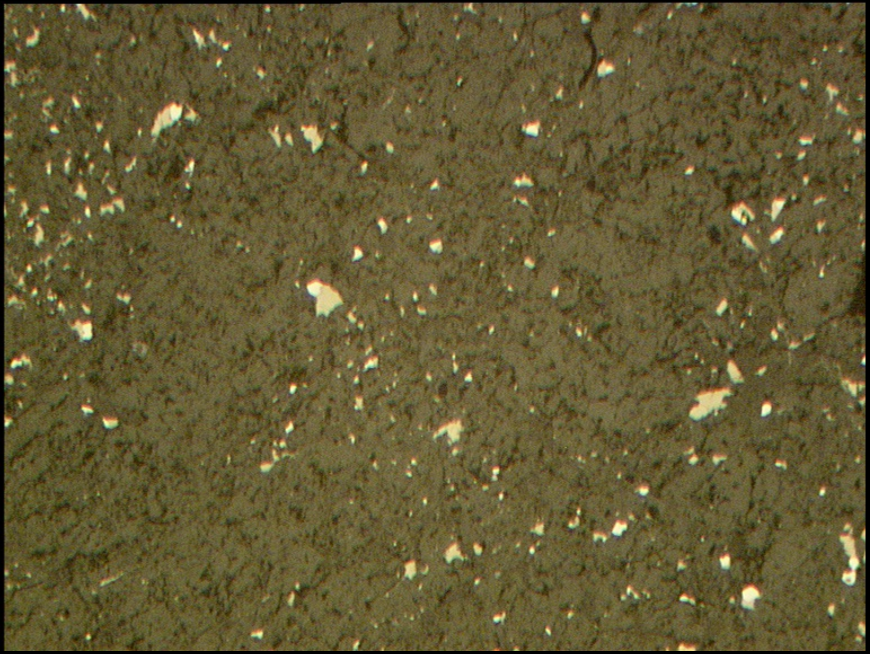
Argiles



Effet du métamorphisme







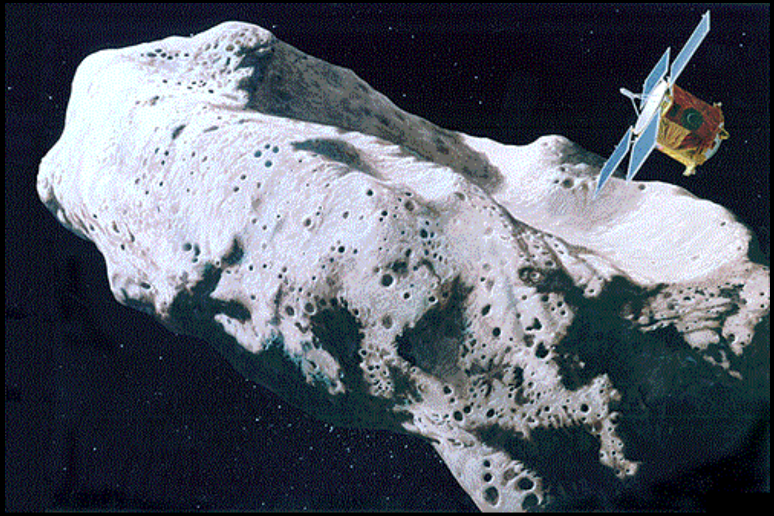
RÉSULTAT D'INVENTAIRE

CE QUE NOUS APPRENNENT LES MÉTÉORITES SUR LES ASTÉROÏDES

- 4.5 milliards d'années
- Histoire géologique brève
- Les chocs transforment la surface
- Ne sont pas les fragments d'une ancienne planète
- Composition et processus dans la nébuleuse

Mais aussi…

- Des laves martiennes…
- Des morceaux de Lune
- L'âge de la Terre et du Système Solaire



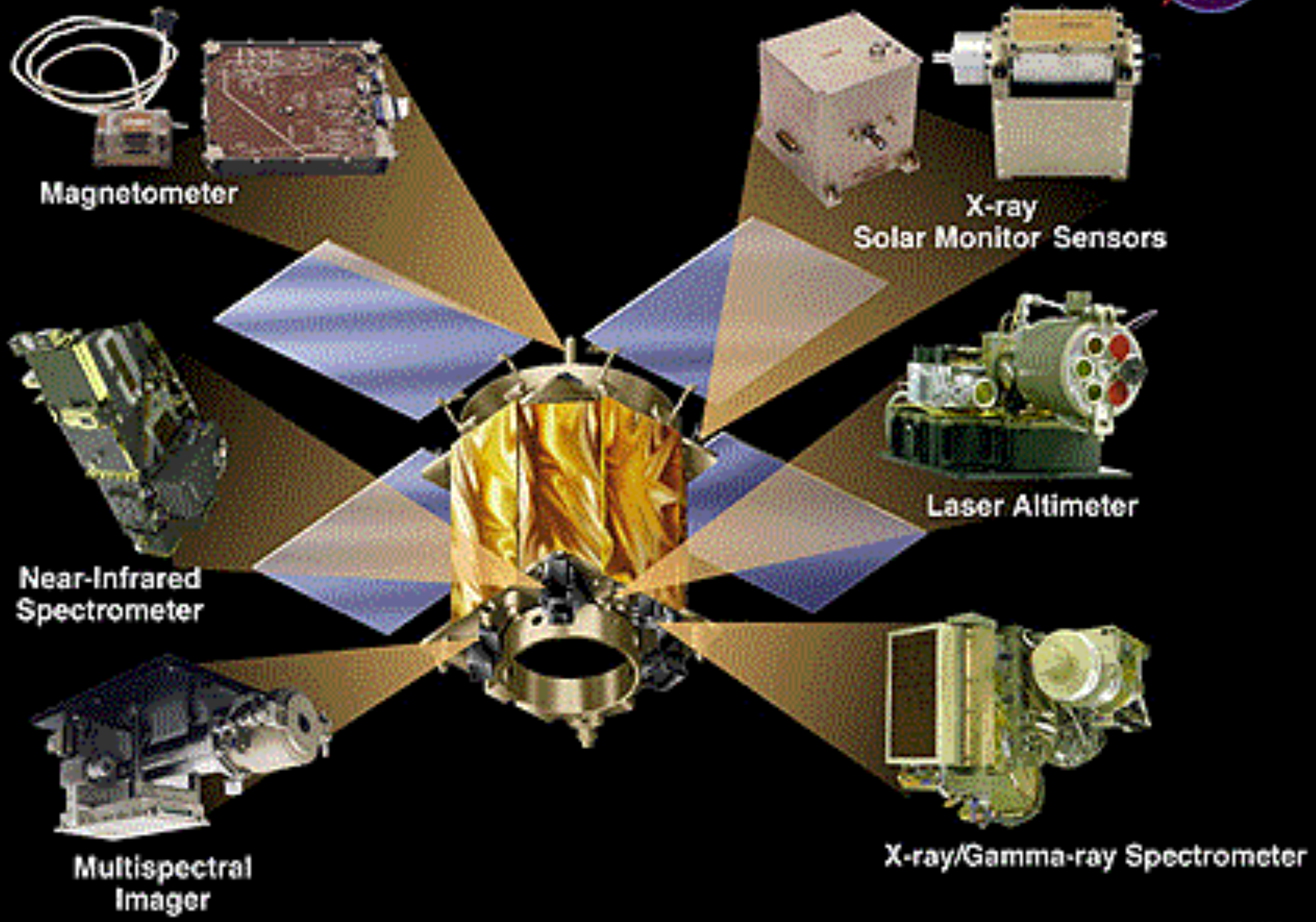
Filiation ?…


ALLENDE
Chihuahua, Mexico
Fell 1969, February 8, 0105 hrs
Stone. Carbonaceous chondrite (CV3)
Total known weight ~ 2000 kg
10
11
12
13
14
15
16
17

Partie III

Retour sur 433 Eros avec NEAR

NEAR SCIENCE PAYLOAD



Magnetometer

X-ray
Solar Monitor Sensors

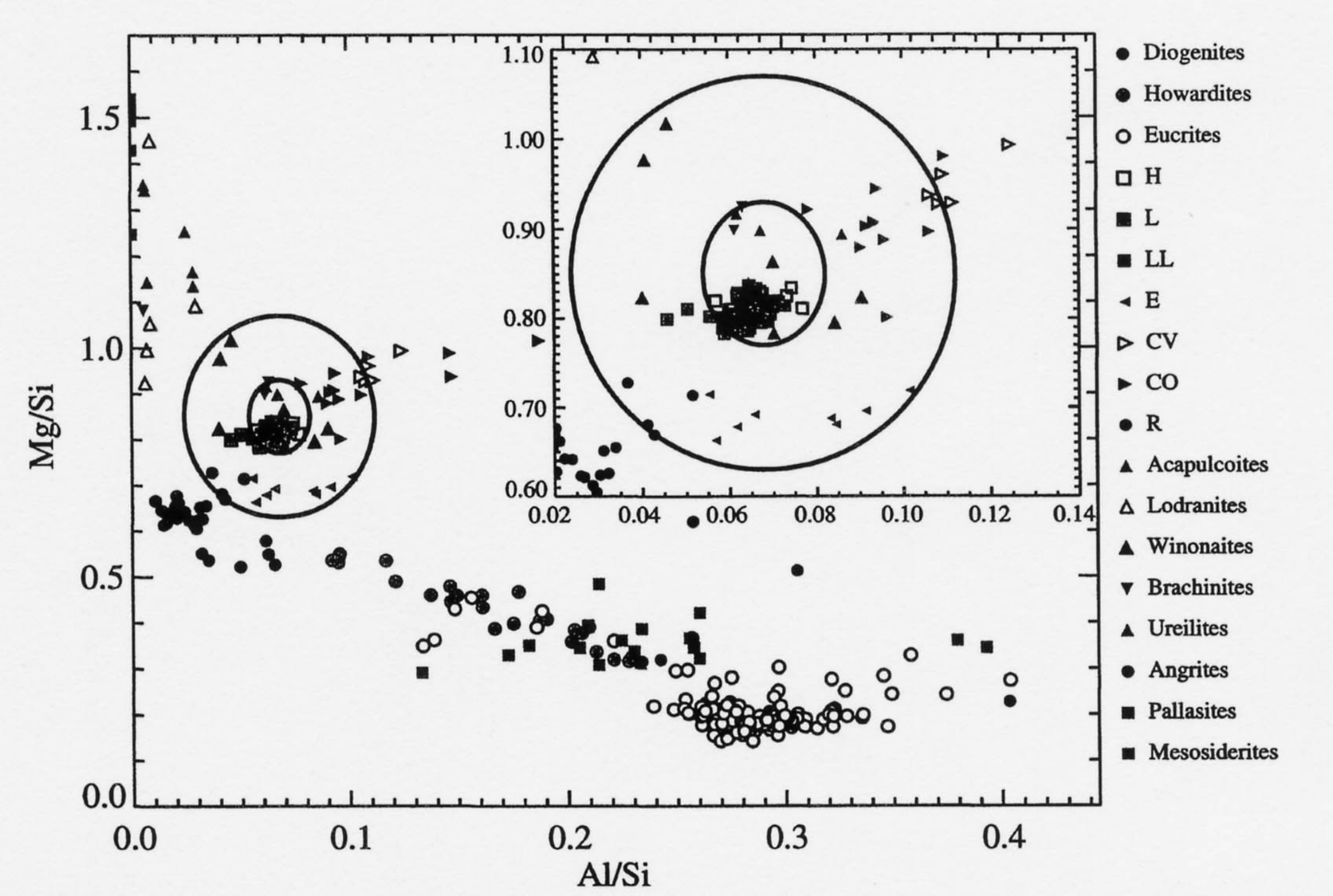
Near-Infrared
Spectrometer

Laser Altimeter

Multispectral
Imager

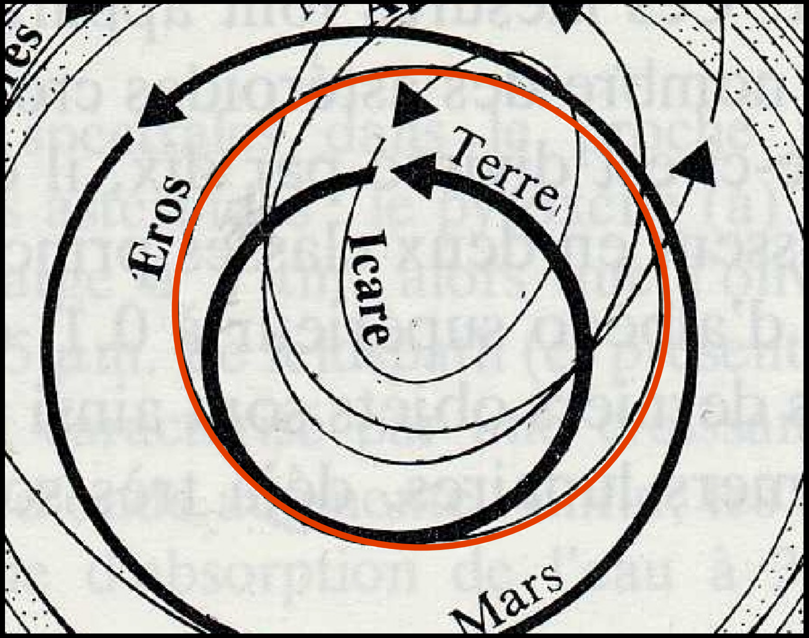
X-ray/Gamma-ray Spectrometer

XRGS: composition surface = chondrites ordinaires

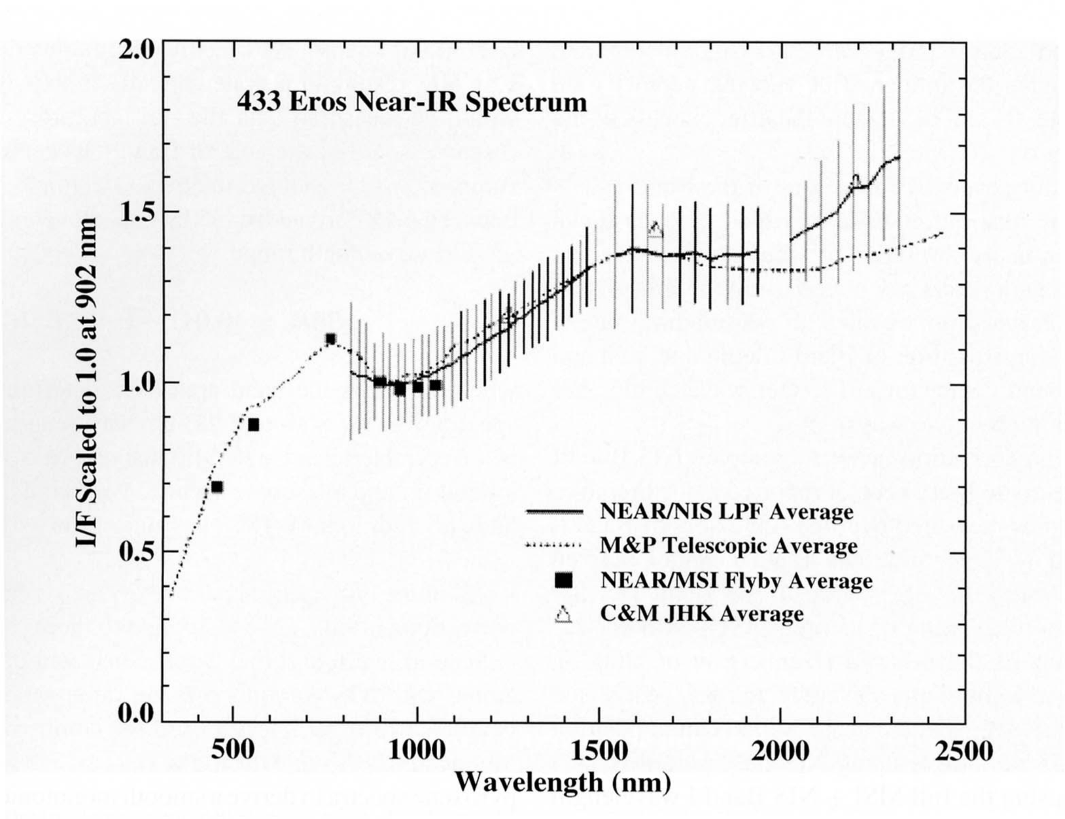


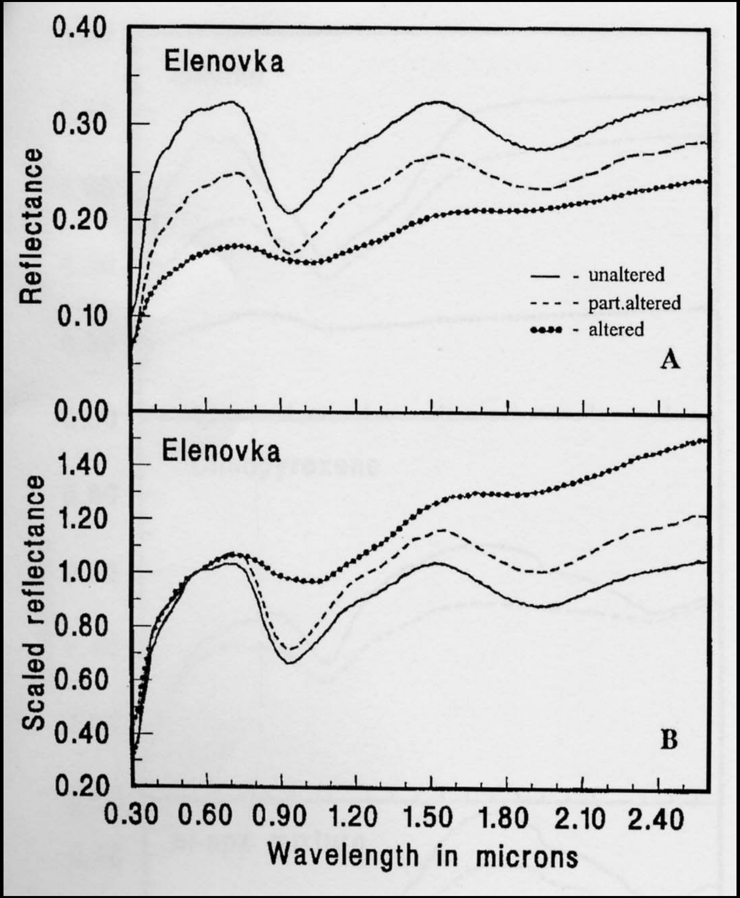
chondrites ordinaires = 80 % des chutes

Eros = géocroiseur qui tangente l'orbite terrestre… !



Cohérence avec les mesures infrarouges





Partie IV

Perspectives présentes et futures

HAYABUSA - Mission japonaise en cours

Astéroïde Itokawa

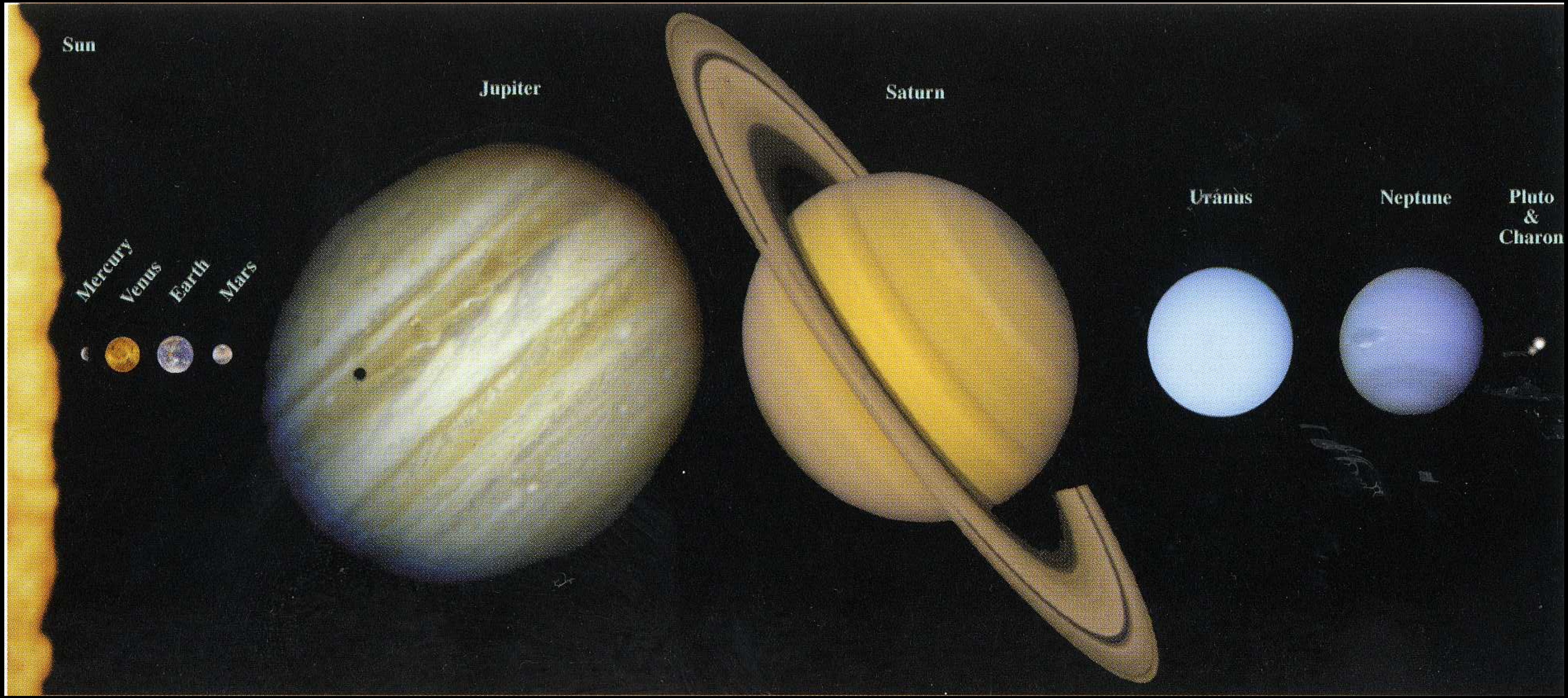
Tomographie Radar (LPG-JPL)

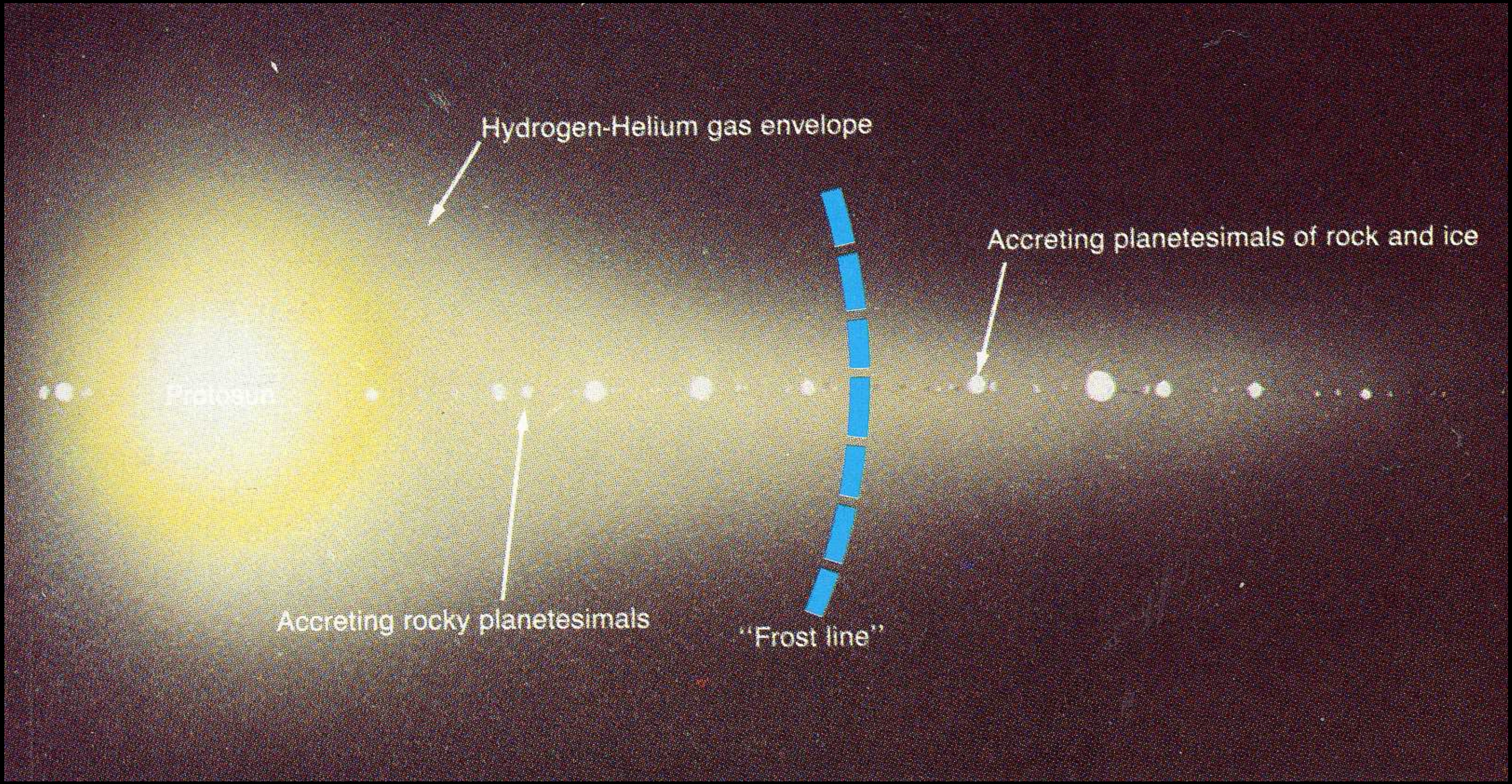
Technologie dérivée de l’instrument CONSERT (ROSETTA)

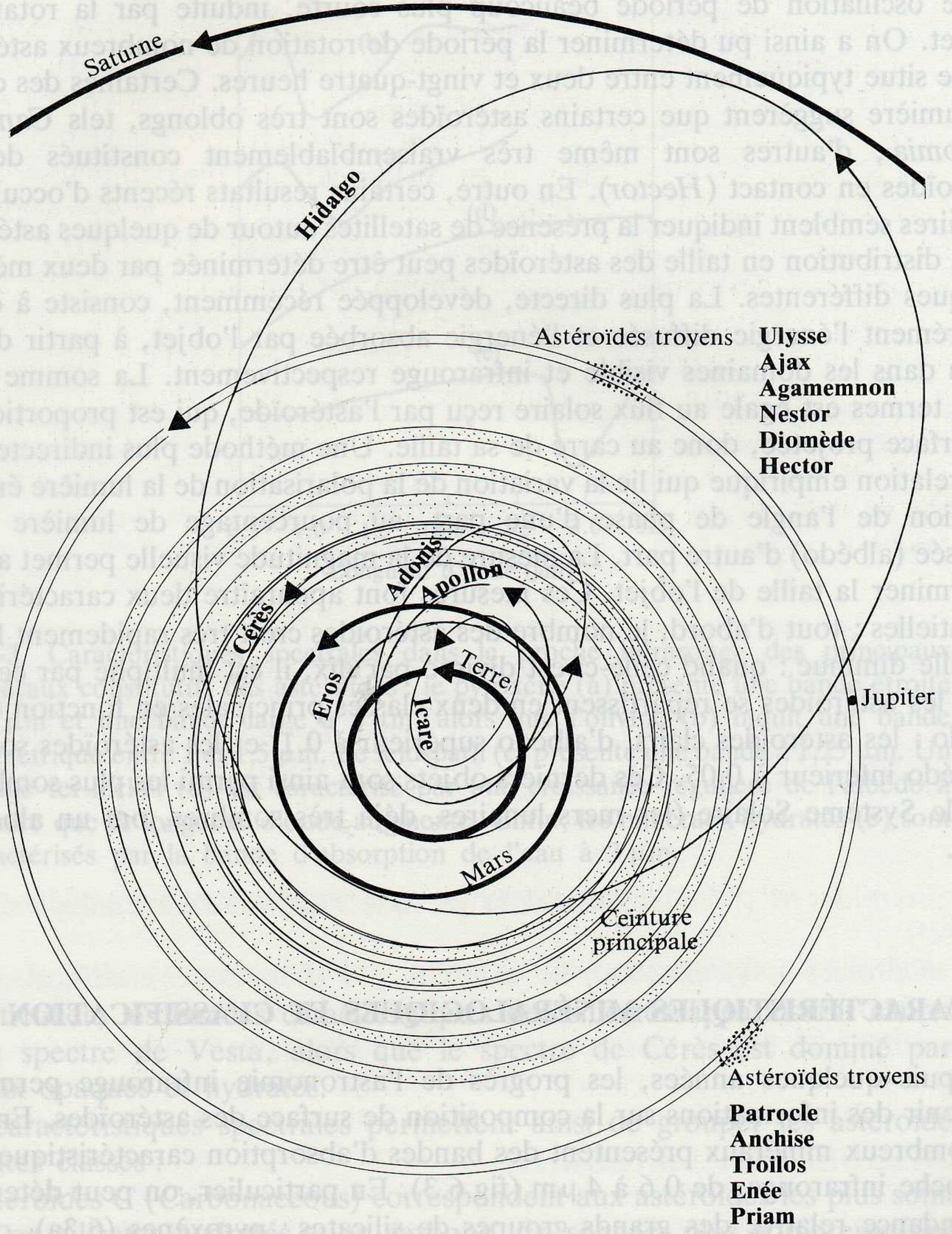
Maîtrise d’œuvre W. Kofman - LPG-UJF

Partie I

Les Astéroïdes, petites planètes inabouties


Sun
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
&
Charon


Hydrogen-Helium gas envelope
Accreting planetesimals of rock and ice
Protosun
Accreting rocky planetesimals
"Frost line"


Saturne
Hidalgo
Astéroïdes troyens
Ulysse
Ajax
Agamemnon
Nestor
Diomède
Hector
Adonis
Apollon
Cérès
Eros
Terre
Icare
Jupiter
Mars
Ceinture principale
Astéroïdes troyens
Patrocle
Anchise
Troilos
Enée
Priam

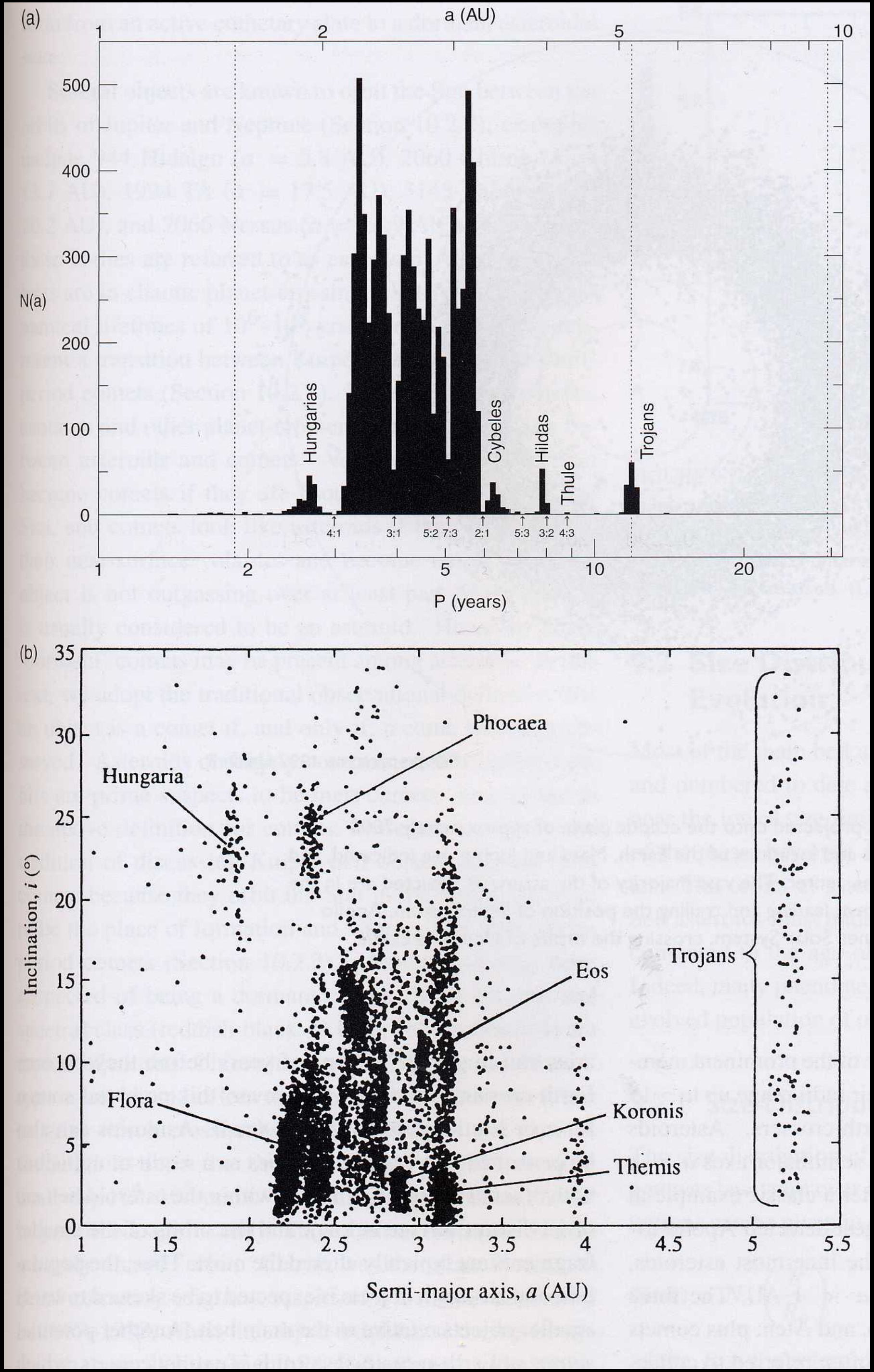

(a)
a (AU)
1
2
5
10
N(a)
500
400
300
200
100
0
Hungarias
Cybeles
Hildas
Thule
Trojans
4:1
3:1
5:2
7:3
2:1
5:3
3:2
4:3
1
2
5
10
20
P (years)
(b)
Inclination, i (°)
35
30
25
20
15
10
5
0
Phocaea
Hungaria
Eos
Trojans
Flora
Koronis
Themis
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
Semi-major axis, a (AU)

TABLE 9.1 Twenty Largest Asteroids ($a < 6$ AU).

#	Name	Diam. (km)	Tax. Class	a (AU)	e	i (deg)	Ω (deg)	ω (deg)	M (deg)	Period (yr)	Rotation (hr)
1	Ceres	933	G?	2.769	0.0780	10.61	80.0	71.2	287.3	4.607	9.075
2	Pallas	525		2.770	0.2347	34.81	172.6	309.8	273.8	4.611	7.811
4	Vesta	510	V	2.361	0.0906	7.14	103.4	150.1	43.3	3.629	5.342
10	Hygiea	429	C	3.138	0.1201	3.84	283.0	316.1	33.0	5.656	27.659
511	Davida	337	C	3.174	0.1784	15.94	107.3	339.0	244.5	5.656	5.130
704	Interamnia	333	F	3.064	0.1475	17.30	280.4	92.2	276.8	5.364	8.727
52	Europa	312	C	3.101	0.1002	7.44	128.6	337.0	92.6	5.460	5.631
15	Eunomia	272	S	2.644	0.1849	11.76	292.9	97.5	327.9	4.299	6.083
87	Sylvia	271	PC	3.490	0.0820	10.87	73.1	273.3	248.8	6.519	5.183
3	Juno	267	S	2.668	0.0258	13.00	169.9	246.7	115.4	4.359	7.210
16	Psyche	264	M	2.923	0.1335	3.09	149.9	227.5	318.7	4.999	4.196
31	Euphrosyne	248	C	3.146	0.2290	26.34	30.7	63.1	341.0	5.581	5.531
65	Cybele	240	C	3.437	0.1044	3.55	155.4	109.8	20.1	6.372	4.041
107	Camilla	237	C	3.484	0.0842	9.93	173.5	296.0	139.7	6.503	4.840
624	Hektor	233	D	5.181	0.0246	18.23	342.1	178.0	2.9	11.794	6.921
88	Thisbe	232	C	2.767	0.1638	5.22	276.3	35.3	259.0	4.603	6.042
451	Patientia	230	C	3.062	0.0709	15.24	89.0	343.2	269.4	5.358	9.727
324	Bamberga	228	C	2.681	0.3409	11.14	327.8	43.4	189.6	4.390	29.43
48	Doris	225	C	3.110	0.0693	6.54	183.4	262.8	278.8	5.485	11.89
532	Herculina	225	S	2.771	0.1764	16.36	107.4	75.1	199.4	4.613	9.405

All data are from Yoder (1995).

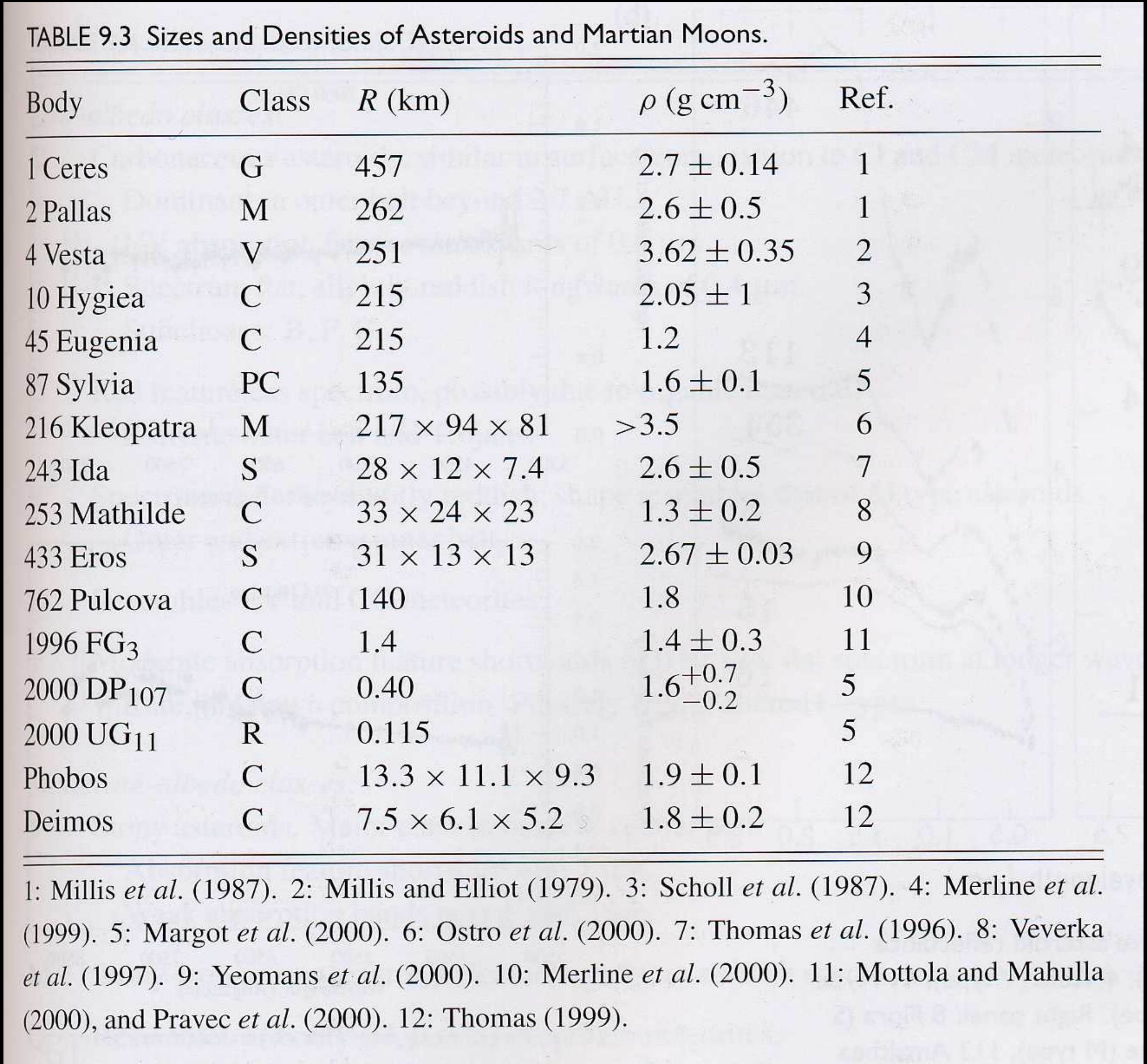
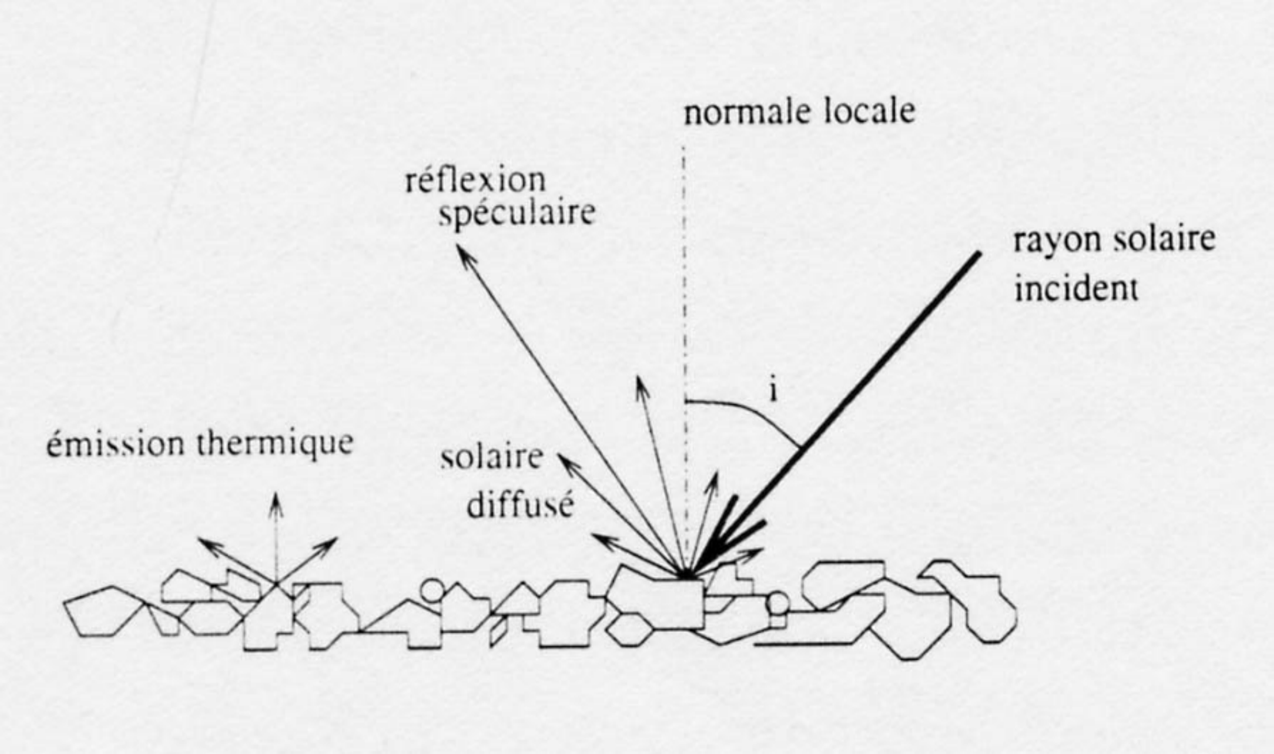


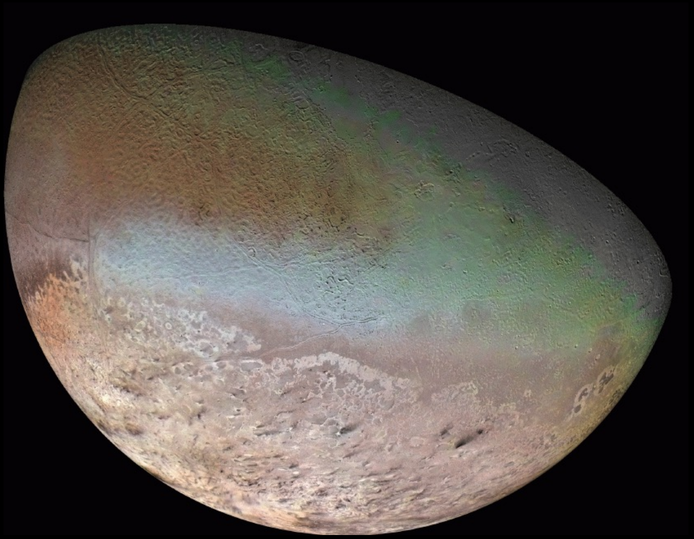
TABLE 9.3 Sizes and Densities of Asteroids and Martian Moons.

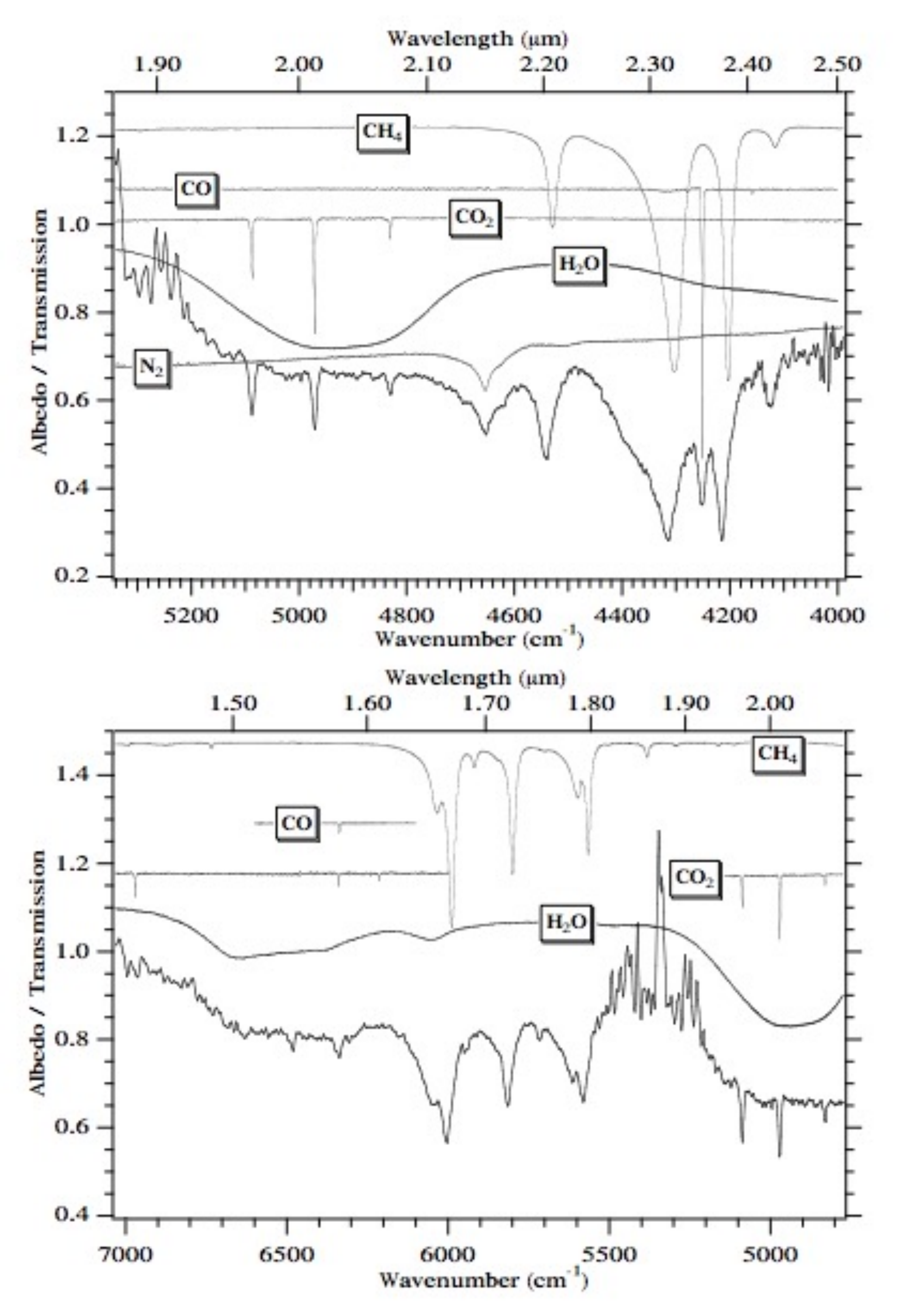
Body	Class	R (km)	ρ (g cm^{-3})	Ref.
1 Ceres	G	457	2.7 ± 0.14	1
2 Pallas	M	262	2.6 ± 0.5	1
4 Vesta	V	251	3.62 ± 0.35	2
10 Hygiea	C	215	2.05 ± 1	3
45 Eugenia	C	215	1.2	4
87 Sylvia	PC	135	1.6 ± 0.1	5
216 Kleopatra	M	$217 \times 94 \times 81$	>3.5	6
243 Ida	S	$28 \times 12 \times 7.4$	2.6 ± 0.5	7
253 Mathilde	C	$33 \times 24 \times 23$	1.3 ± 0.2	8
433 Eros	S	$31 \times 13 \times 13$	2.67 ± 0.03	9
762 Pulcova	C	140	1.8	10
1996 FG_3	C	1.4	1.4 ± 0.3	11
2000 DP_{107}	C	0.40	$1.6^{+0.7}_{-0.2}$	5
2000 UG_{11}	R	0.115		5
Phobos	C	$13.3 \times 11.1 \times 9.3$	1.9 ± 0.1	12
Deimos	C	$7.5 \times 6.1 \times 5.2$	1.8 ± 0.2	12

1: Millis *et al.* (1987). 2: Millis and Elliot (1979). 3: Scholl *et al.* (1987). 4: Merline *et al.* (1999). 5: Margot *et al.* (2000). 6: Ostro *et al.* (2000). 7: Thomas *et al.* (1996). 8: Veverka *et al.* (1997). 9: Yeomans *et al.* (2000). 10: Merline *et al.* (2000). 11: Mottola and Mahulla (2000), and Pravec *et al.* (2000). 12: Thomas (1999).

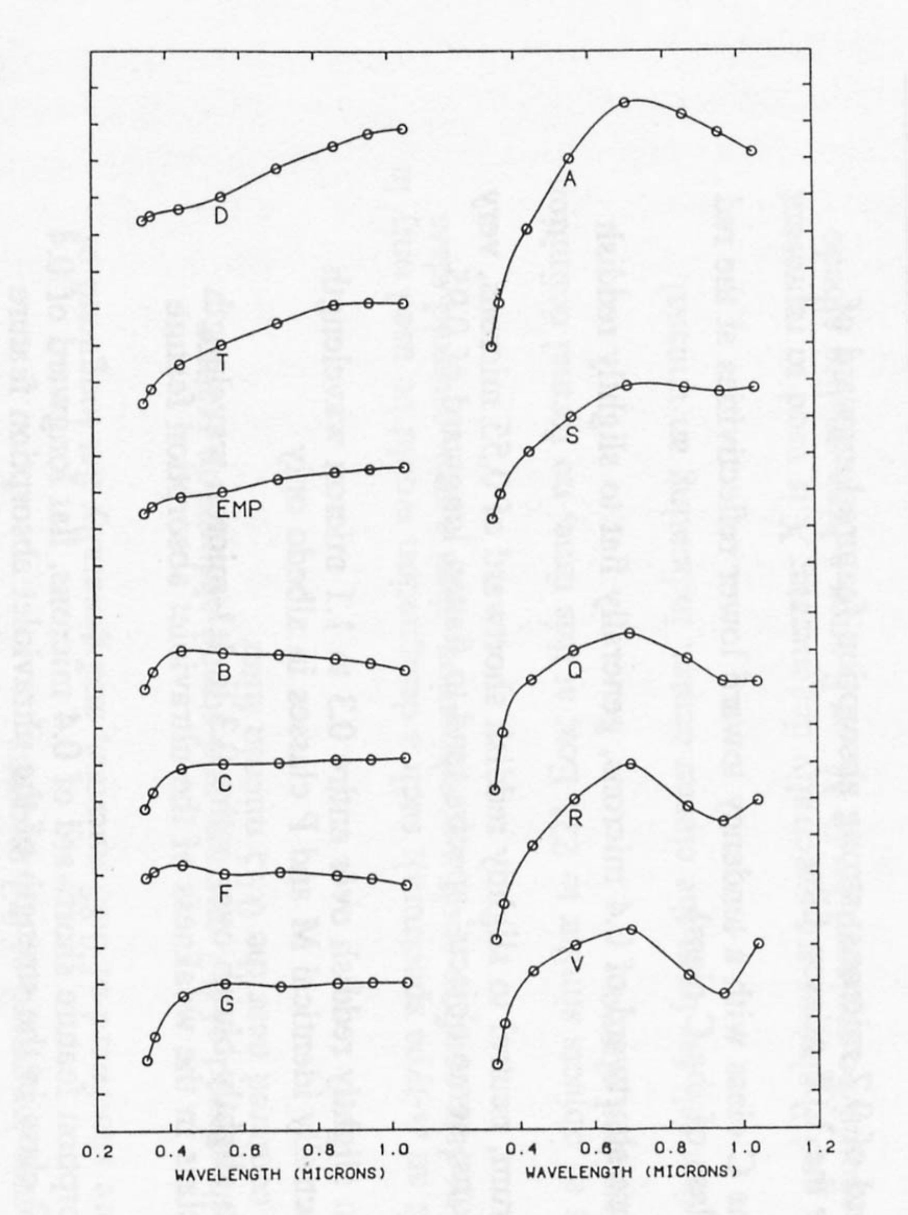
Télédétection visible et infrarouge





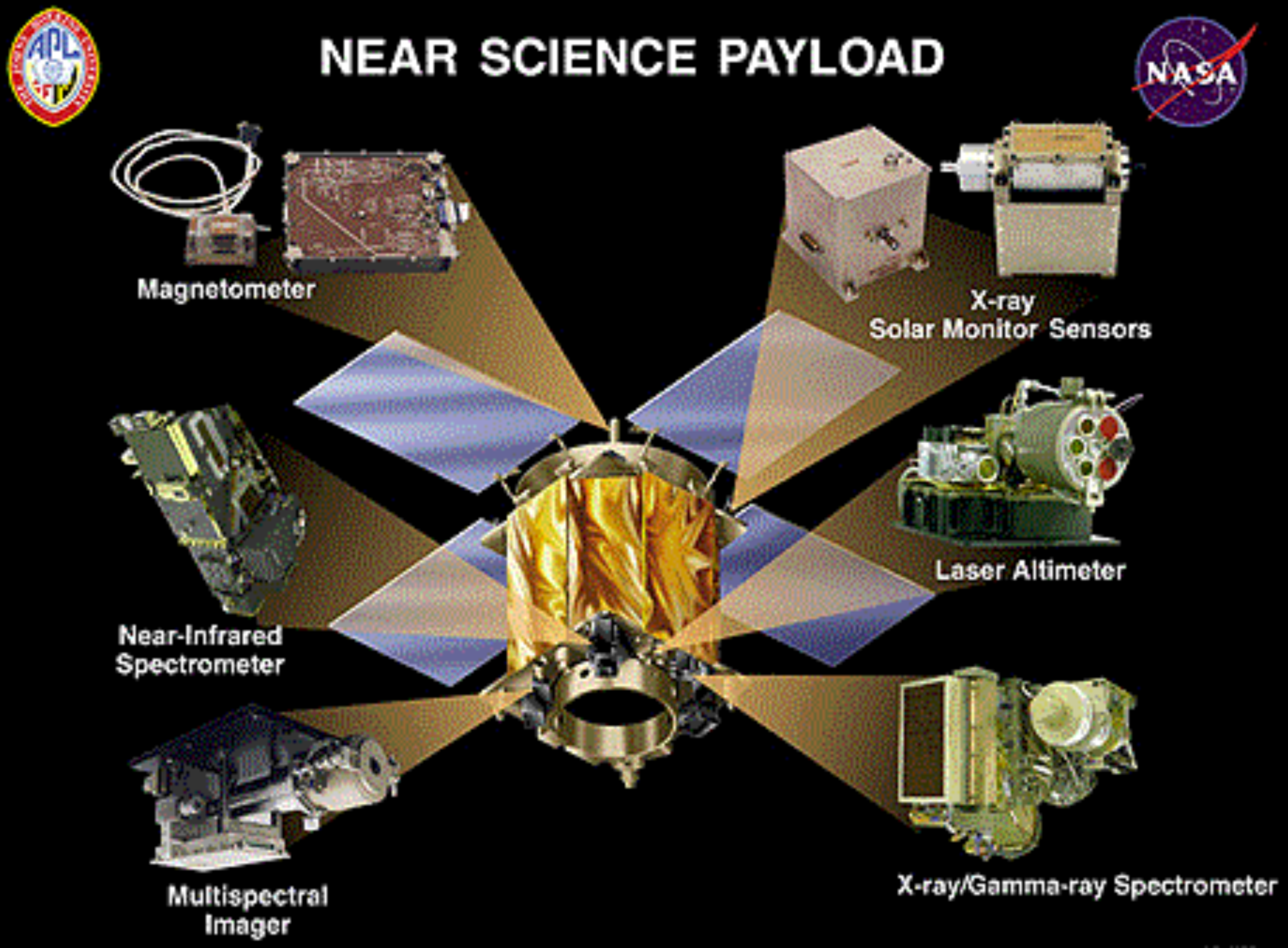

Wavelength (µm)
1.90
2.00
2.10
2.20
2.30
2.40
2.50
Albedo / Transmission
1.2
1.0
0.8
0.6
0.4
0.2
CH_4
CO
CO_2
H_2O
N_2
5200
5000
4800
4600
4400
4200
4000
Wavenumber (cm^{-1})
Wavelength (µm)
1.50
1.60
1.70
1.80
1.90
2.00
Albedo / Transmission
1.4
1.2
1.0
0.8
0.6
0.4
CH_4
CO
CO_2
H_2O
7000
6500
6000
5500
5000
Wavenumber (cm^{-1})

Classification spectrale



Classification spectrale
Rare identification minéralogique

La mission NEAR



[redacted]

Range to Surface 5.462 km

PERTE DE L’INFORMATION DE COMPOSITION INTERNE

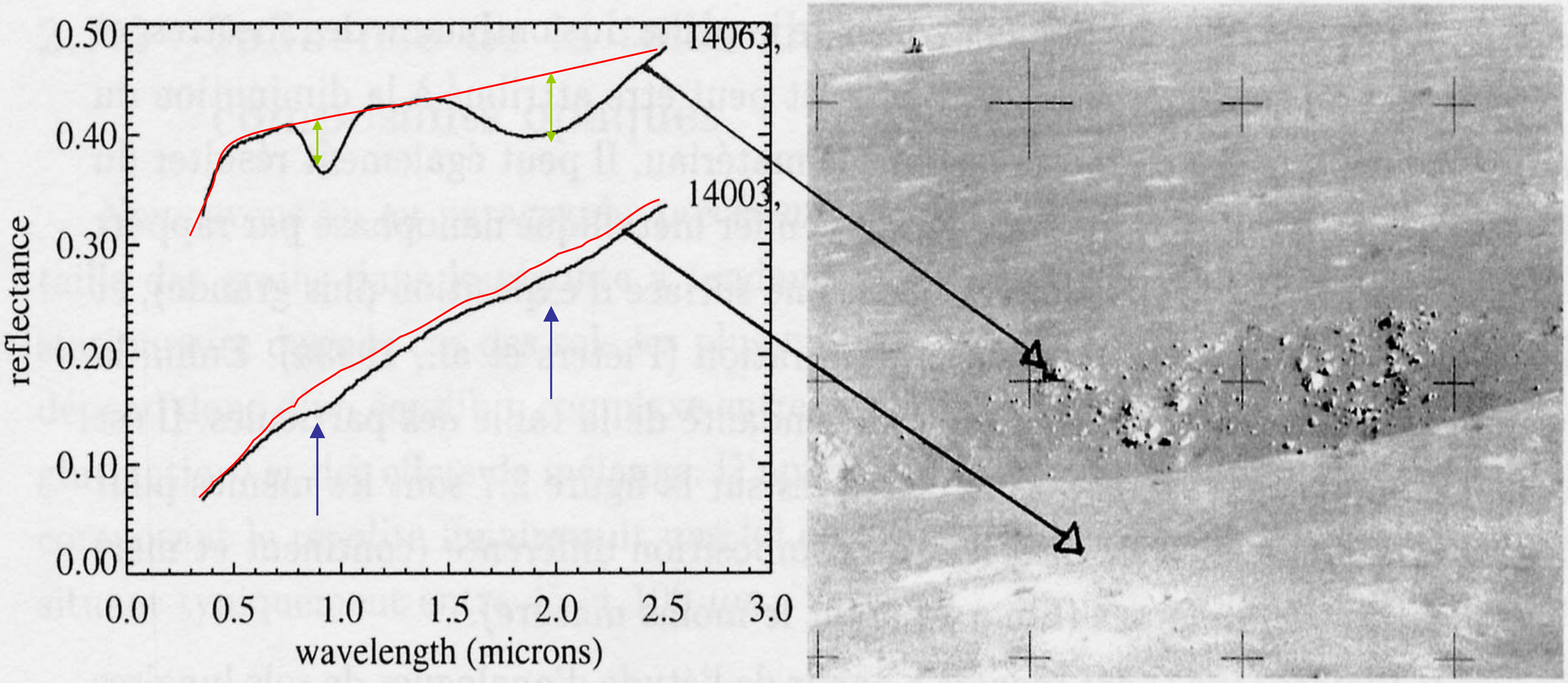
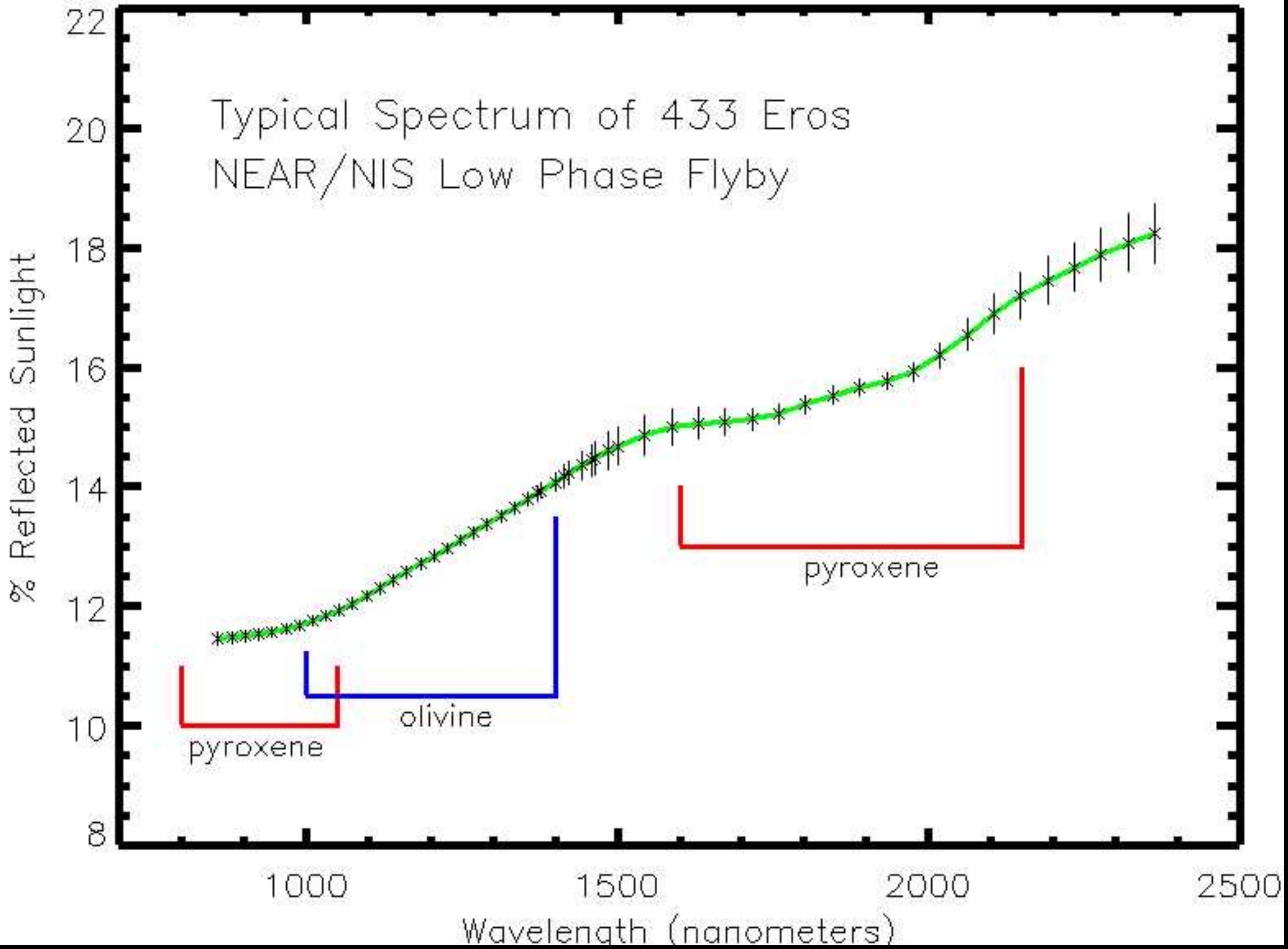


FIG. 2.8: A gauche : spectres d’échantillons de sol (14003) et de roche (14063) prélevés sur le site Apollo 14. Les sols ont des bandes d’absorption peu profondes par rapport aux roches (constituées de minéraux peu altérés) dont ils sont issus. Sur une échelle de quelques centaines de mètres un spectre moyen de cratère frais sera un mélange de spectres de type roches et de spectres de sol (à droite).


Typical Spectrum of 433 Eros
NEAR/NIS Low Phase Flyby
% Reflected Sunlight
8
10
12
14
16
18
20
22
1000
1500
2000
2500
Wavelength (nanometers)
pyroxene
olivine
pyroxene

BILAN DE L’OBSERVATION SOL ET SPATIALE

- Caractéristiques orbitales
- Taille et forme d’un astéroïde

Densité

- Classification des astéroïdes
- Propriétés optiques de surface

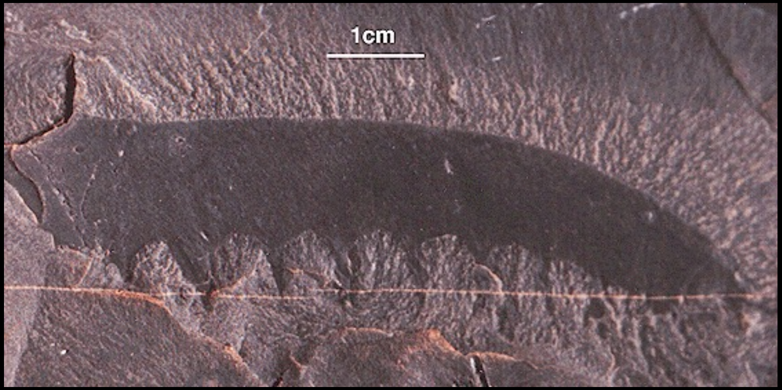
Information compositionnelle marginale

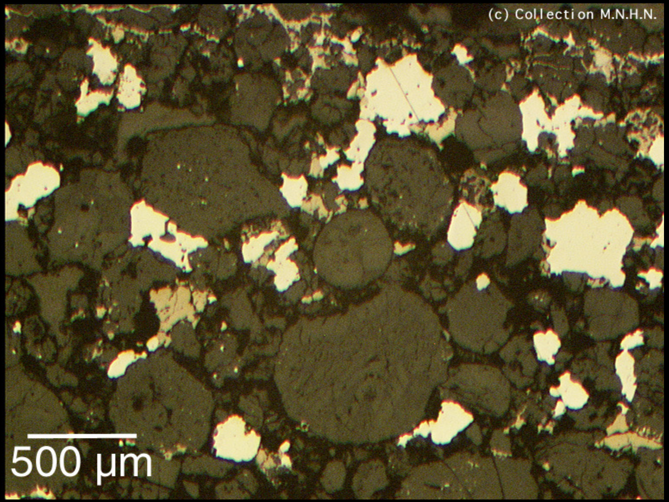
Partie II

Les météorites : une lecture de la nature des astéroïdes

Astéroïdes primitifs = Objets fossiles

Archives du système solaire




(c) Collection M.N.H.N.