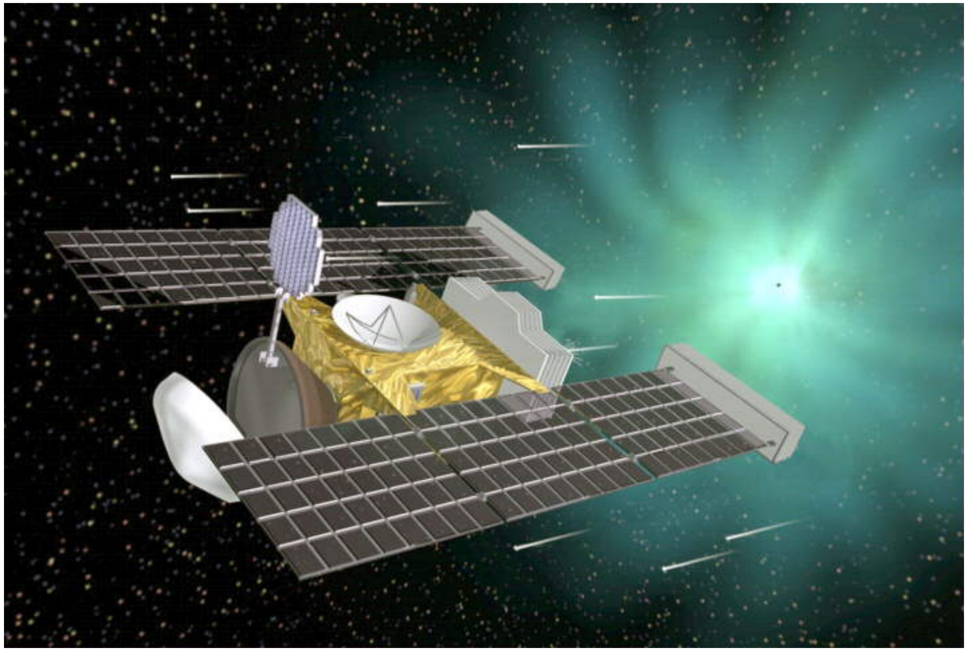
# *In situ* studies of comets (2)

Studies carried out in vicinity of comets with help of spacecraft play an extremely important role in cometary physics.

The main advance of such studies is that the number of assumptions on cometary particles is substantially reduced in comparison with ground based observations.

So far, only six comets have been visited by spacecrafts:

| | | |
|---|---|---|
| 21P/Giacobini-Zinner | 1985 | International Cometary Explorer (ICE); |
| 1P/Halley | 1986 | VeGa-1, 2; Giotto; ICE; Suisei; Sakigake; |
| 26P/Grigg-Skjellerup | 1992 | Giotto |
| 19P/Borrelly | 2001 | Deep Space 1 |
| 81P/Wild 2 | 2004 | Stardust |
| 9P/Tempel 1 | 2005 | Deep Impact |



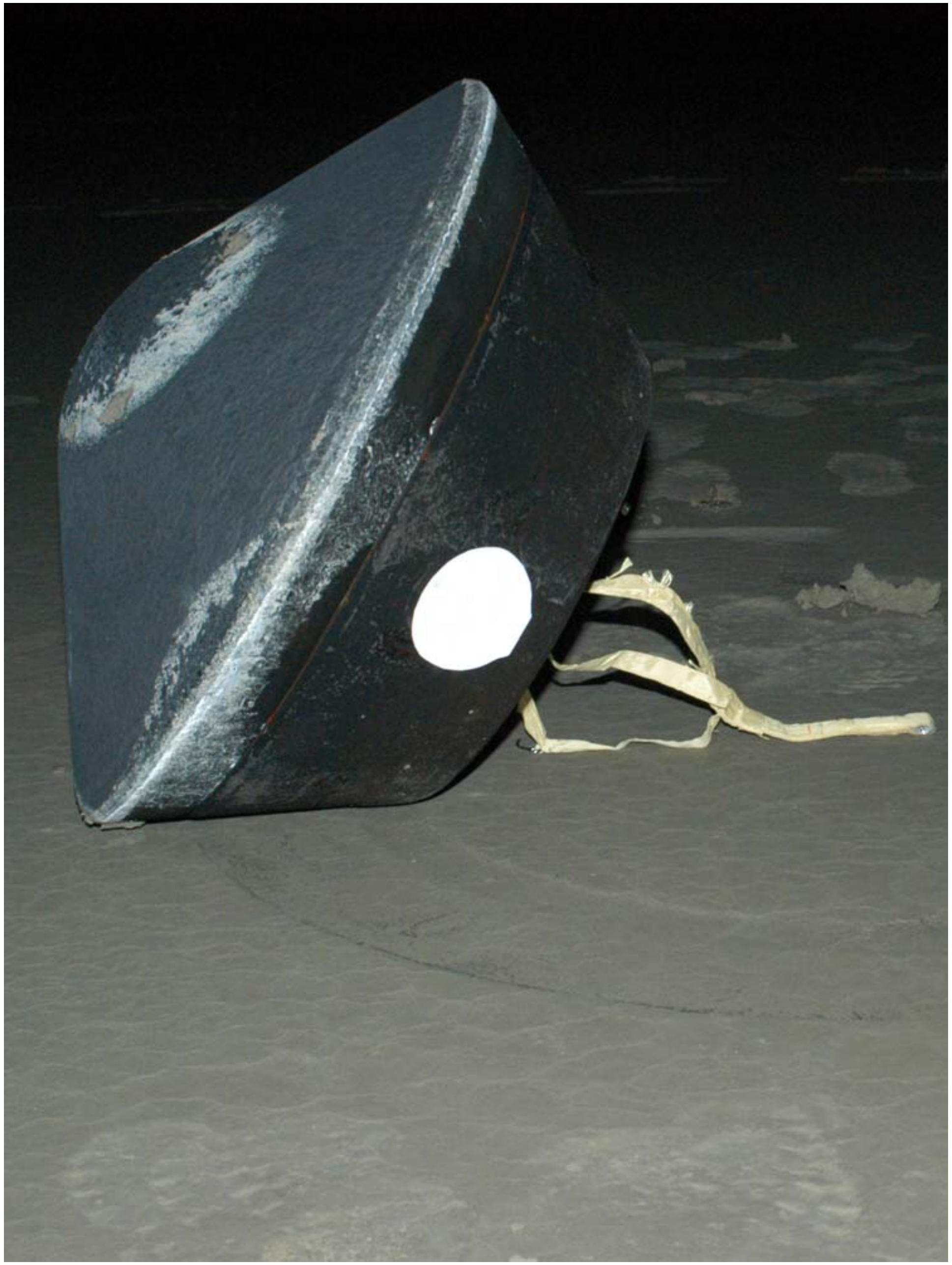
(6) Stardust

Spacecraft for sampling material from comet 81P/Wild 2.

Stardust flew near the nucleus (at distance of 234 km) with velocity of 6.1 km/s.

The closest approach was on January 2, 2004. The capsule with samples has been returned to Earth on January 15, 2006.

On the day of approach, heliocentric distance of the comet was 1.86 AU.

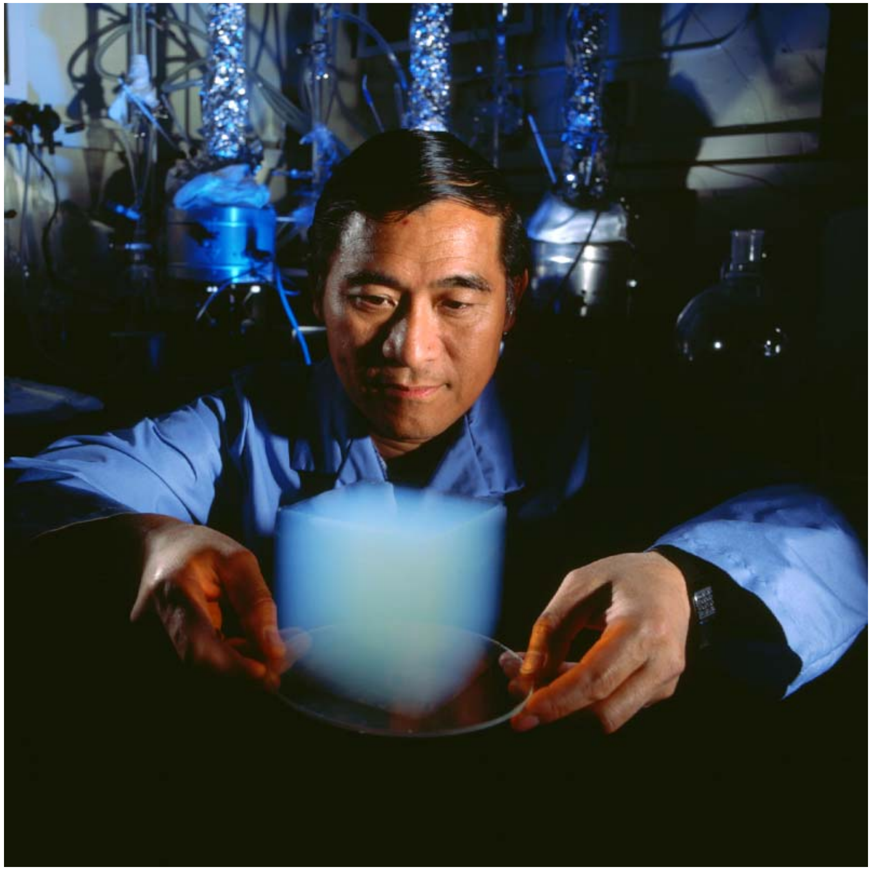


The spacecrafts were equipped with devices as follows:

(a) Aerogel sample collectors (packed into Sample Return Capsule)

(b) Comet and Interstellar Dust Analyzer (*in situ* study, the device is full analoug of those employed on VeGa-1, 2 and Giotto; 29 impacts)

(c) Stardust Imaging Camera (or Navigation camera – NavCam)

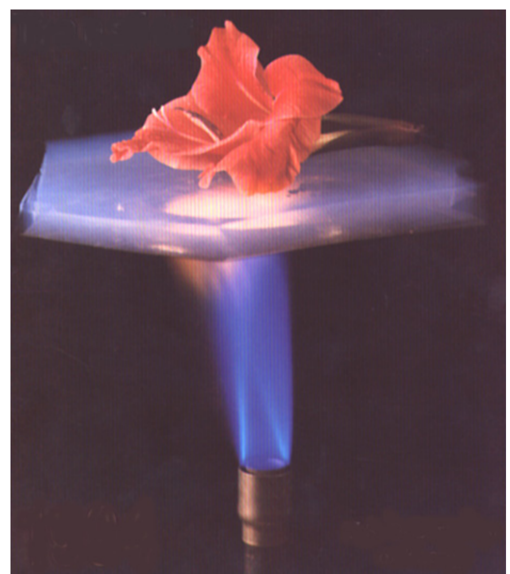


Aerogel sample collectors.

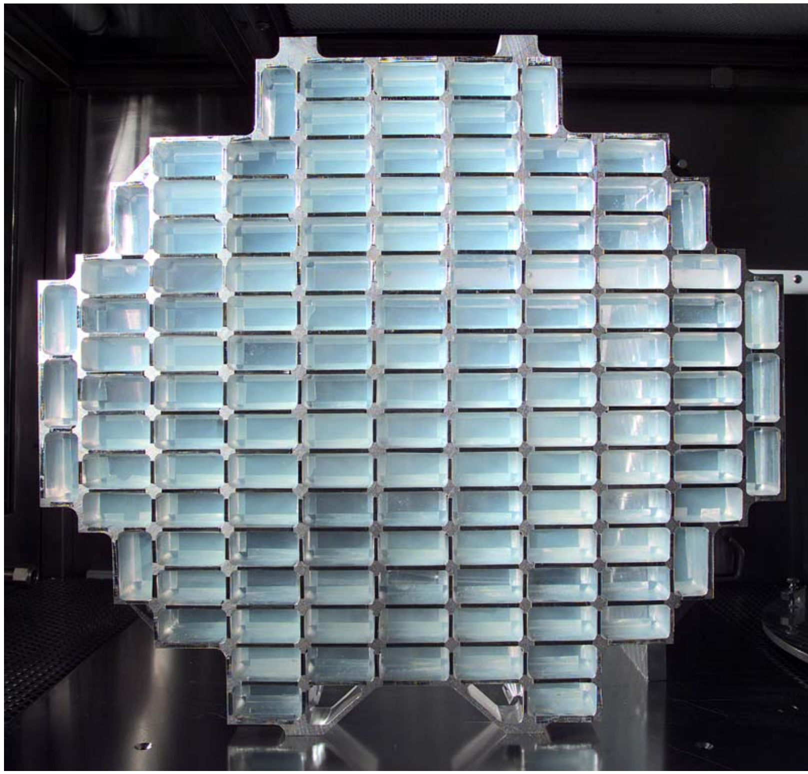
Aerogel is a porous glass composed of nanometer-sized silica particles with bulk density varying from less than 0.01 g/sm$^3$ (near the surface) to 0.05 g/sm$^3$ (at depth of more than 3 sm).

Other properties of aerogel:

- An extremely low thermal conductivity;
- Very strong material.



Dust collector was consisting of 130 aerogel blocks.



During flyby near the nucleus, the sample collectors have been exposed to the surrounding space for short time.

Stardust collected more than 10000 particles with sizes from 1 to 300 μm.

An extremely porous structure of aerogel may produce a false impression on its solidity.

Indeed, hitting of a dust particle into aerogel causes very rapid deceleration. For instance, silicate particle with size of 10 μm and relative velocity about 6 km/s passes only 1 mm (!) in aerogel!

Depending upon size of dust particles, full deceleration takes time from a microsecond to less than a nanosecond.
It leads to quite strong heating of surrounding aerogel >2000 K.

However, it is believed that such a strong heating does not alter significantly the internal structure of cometary dust particles. Particles are protected by their own thermal inertia; whereas, changes take place only in very shallow surface layer (~0.1 μm).

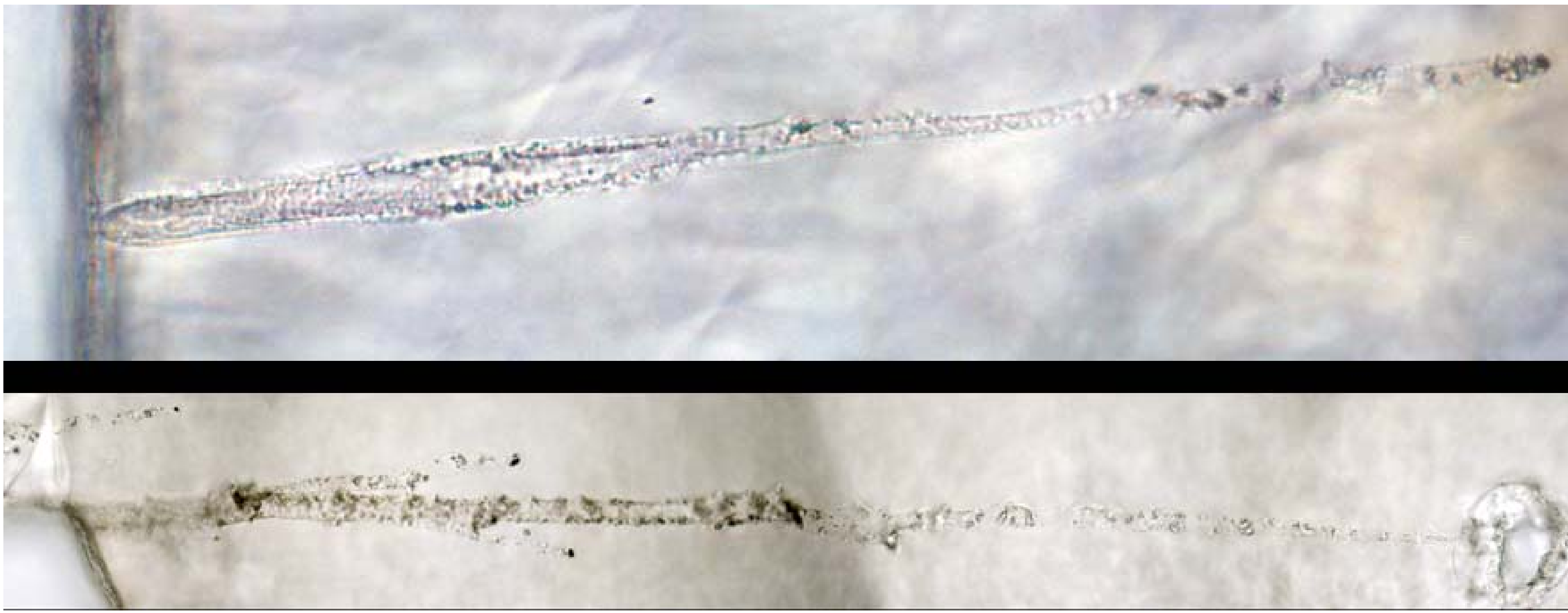
In general, components larger than micron-size were often well preserved; whereas, smaller or finer-grained components were strongly modified.

The penetration tracks in aerogel displayed a wide range of morphologies. One can distinguish three major groups:

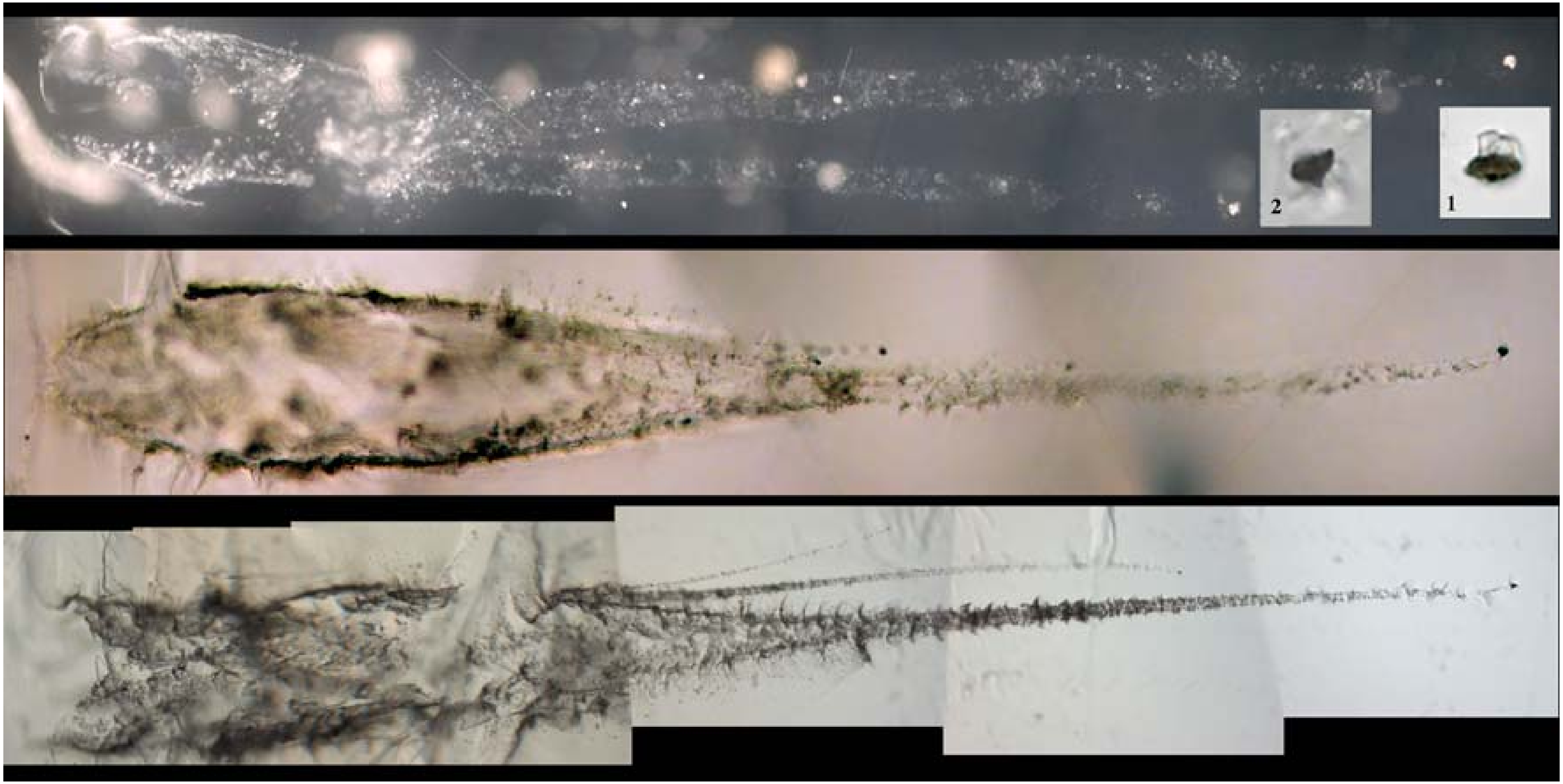
- type A tracks are carrot-like, with long, slender, continuously tapering walls;
- type B tracks have more bulbous cavities, from which either one or a small number of slender tracks emerge, and resemble turnips with single or multiple roots;
- type C tracks consist only of a bulbous, rather stubby cavity.

The deepest penetration of particle into aerogel was found to be 21.9 mm long; the widest track had a bulb diameter of 9.6 mm.

Examples for type A tracks – carrot-like, with long, slender, continuously tapering walls:

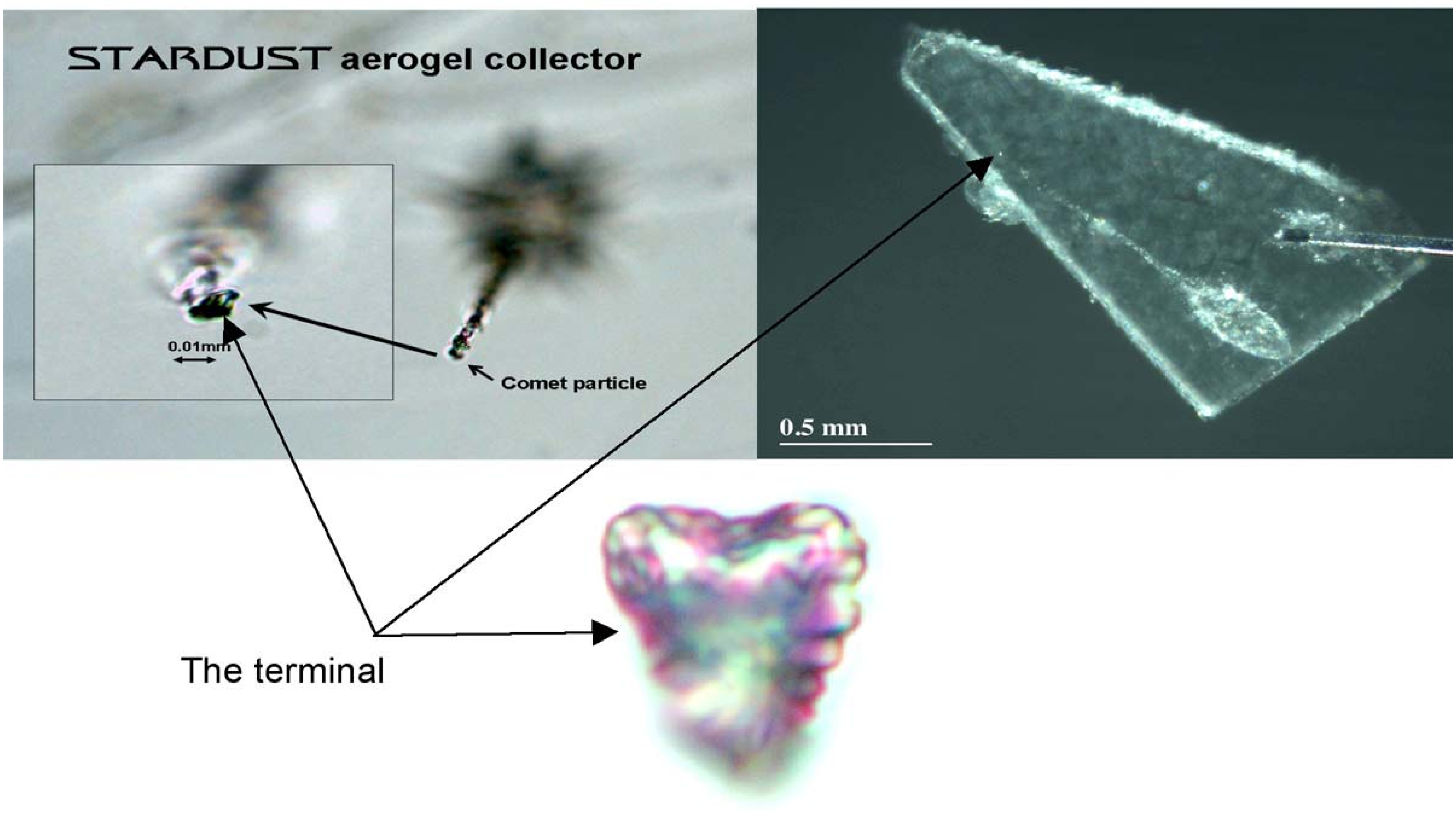


Examples for type B tracks – more bulbous cavities; one or a small number of slender tracks emerge, and resemble turnips with single or multiple roots:



Example for type C track – only of a bulbous, rather stubby cavity:

Shape of the captured dust particles (or fragments of particles) is quite smoothed. It is probably due to abrasion during passage through aerogel, although the particle contains only trace amounts, at most, of adhering aerogel.



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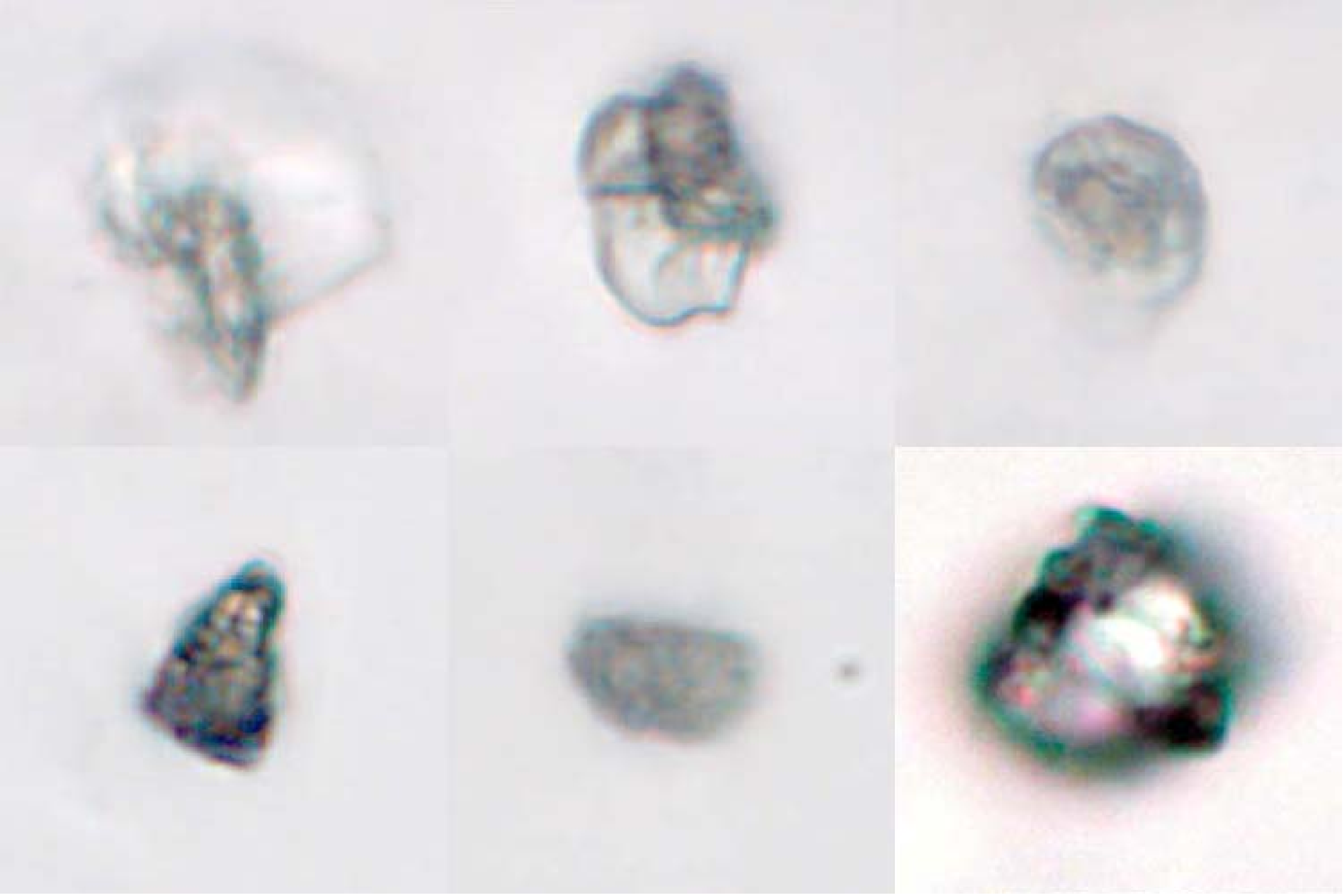


Composition of the captured dust particles (ROCKs):

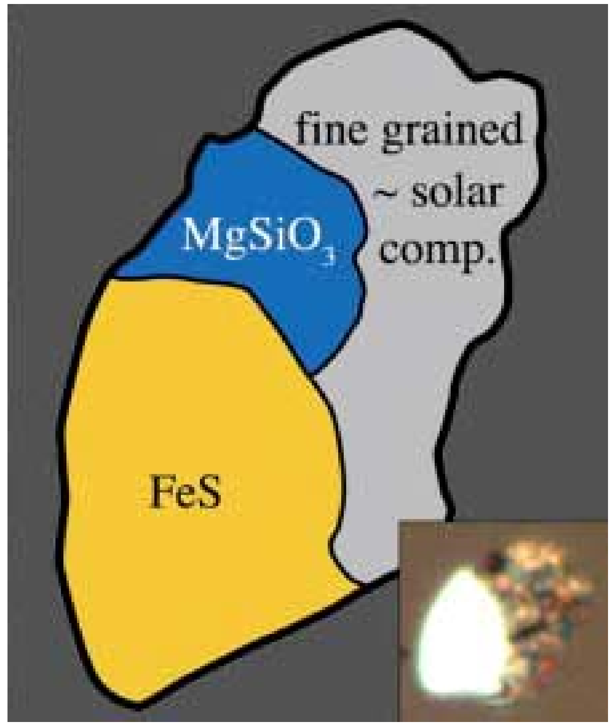
(1) No homogeneous particles;

(2) An abundant component is chondritic material, which is similar to material forming the matrix of primitive carbon-rich meteorites (Mg, Al, Si, S, Ca, Fe, and Ni; in solar ratios);

(3) A major portion of particles larger than a micron is composed of the silicate minerals olivine and pyroxene (i.e., crystalline solids). The standard explanation for this is that crystalline silicates in comets were produced by annealing, the devitrification of glass or amorphous silicates at elevated temperature (~ 800 K);

(4) There are also amorphous silicates in some of the samples.

Composition of the captured dust particles (ROCKs):




70-nm-thick microtome section of the 8-μm terminal particle. There are three major components: pyrrhotite (ferrous sulphide FeS in hexagonal crystalline form), a 3-μm enstatite grain ($MgSiO_3$), and fine-grained porous chondritic material.

Composition of the captured dust particles (Organics):

(1) The aerogel collector medium, which consists predominantly of amorphous $SiO_2$, contains from 0.25 to 3% C (by weight). However, this C is largely in the form of simple $Si\text{-}CH_3$ groups easily distinguishable from the cometary organics;

(2) The distribution of organics (overall abundance, functionality, and relative elemental abundances of C, N, and O) is heterogeneous both within particles and between particles;

(3) High O and N contents, lower contents of polycyclic aromatic hydrocarbons (PAHs), and elevated $-CH_2 / -CH_3$ ratios indicate that the Stardust organics are not similar to organic materials seen in the diffuse ISM and primitive meteorites. These facts are more consistent with what is expected from radiation processing of astrophysical ices.

About 15% of the total collection surface was the frame used to hold aerogel. The frame is made of aluminum foil.

An impact of cometary dust particle with velocity of 6.1 km/s produces a crater on the surface of aluminum foil.

By 2007, there were studied about 250 craters. The largest has diameter of 680 μm; whereas, about 200 craters are <5 μm.

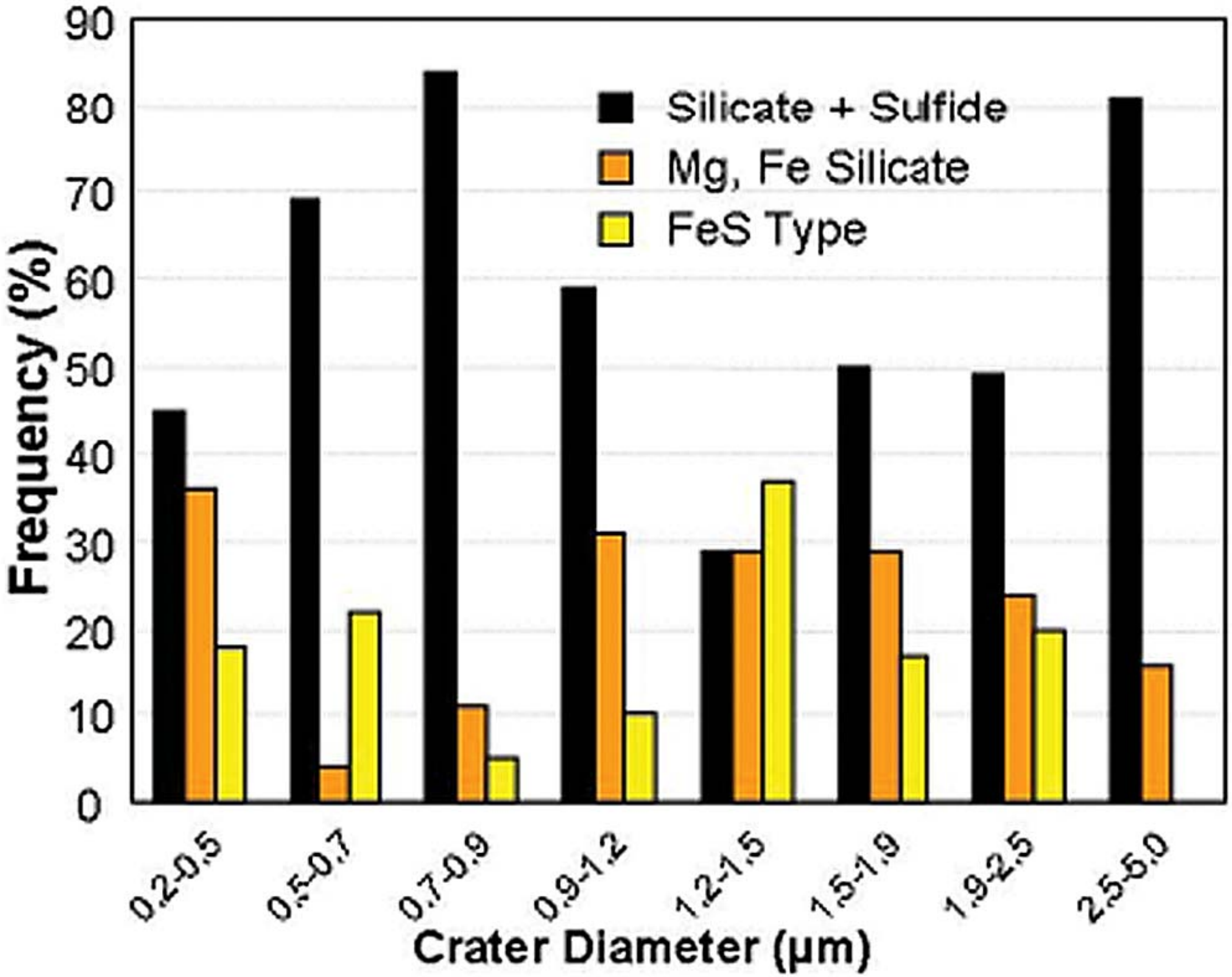
Spectral analysis of the residues in small craters (<5 μm) shows:

(a) 56% particles had composite structure made of olivine $(Mg,Fe)_2SiO_4$, pyroxene $(Mg,Fe)_2Si_2O_6$, FeS;

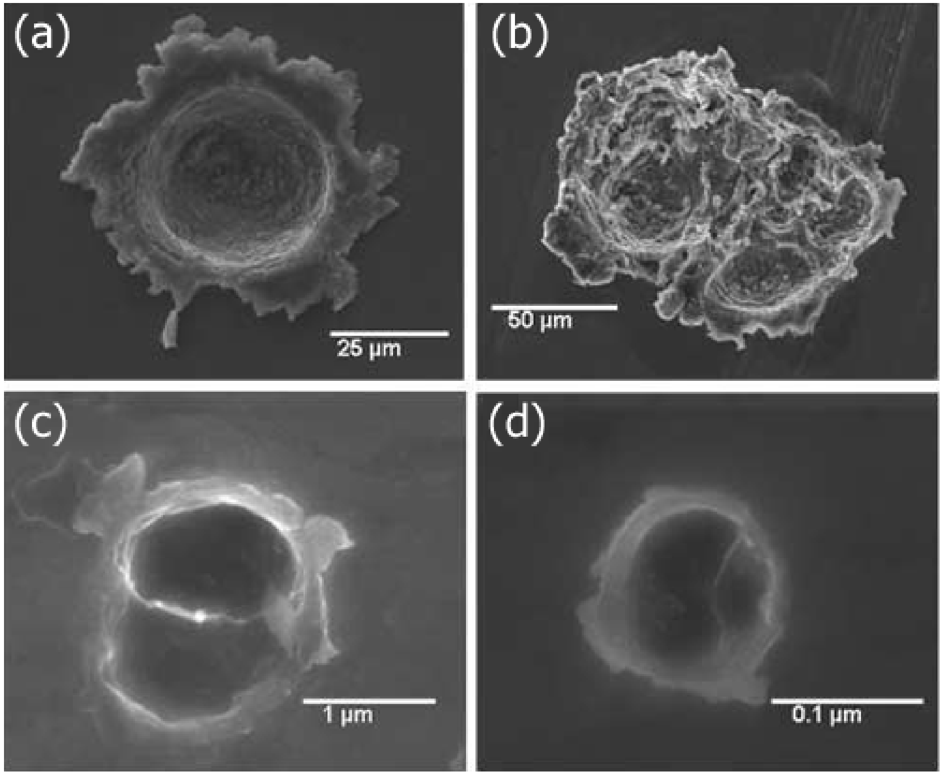
(b) 22% particles were pure Mg- and Fe-rich silicates;

(c) 14% particles were pure iron-sulfides FeS.

Particles composition versus size of crater.



Shapes of craters.




(a) Deep bowl-shaped crater produced by a dense impactor (identified as Mg-rich silicate). (b) Shallow crater produced by irregular impactor with heterogeneous mass distributions (aggregate with low bulk densities). Craters (c) and (d) are produced by aggregate impactors with discrete mass centers.

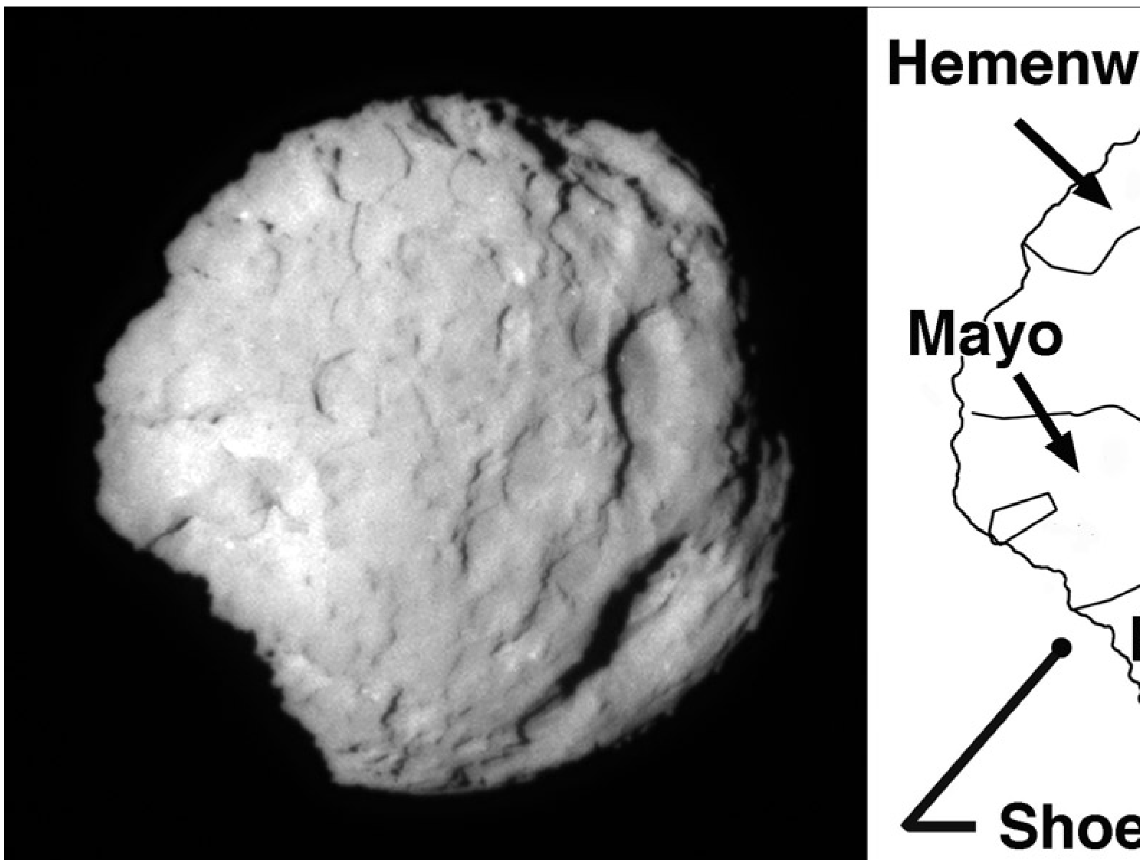
Shapes of craters.

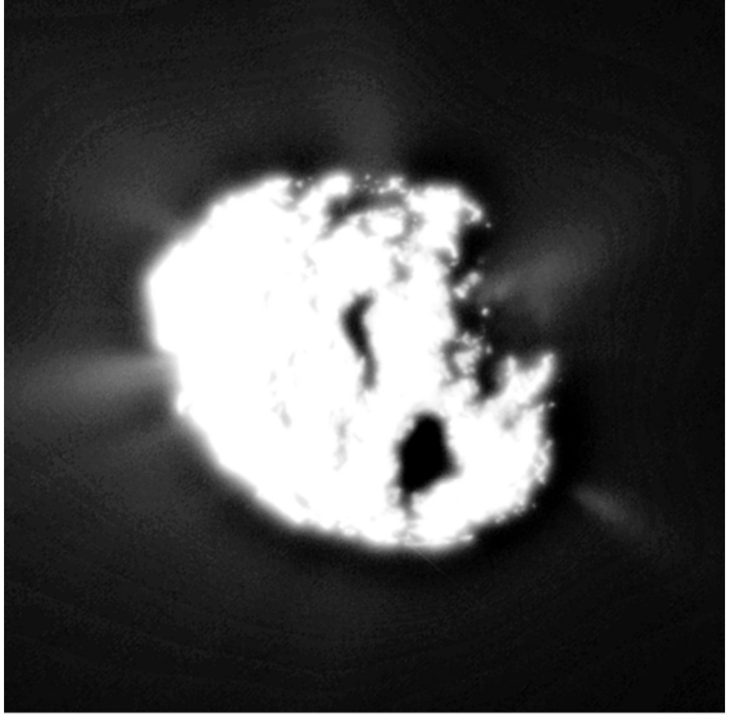
By comparison of craters in aluminum frame of the Stardust’s collector with laboratory simulation of impact features, one can conclude that:

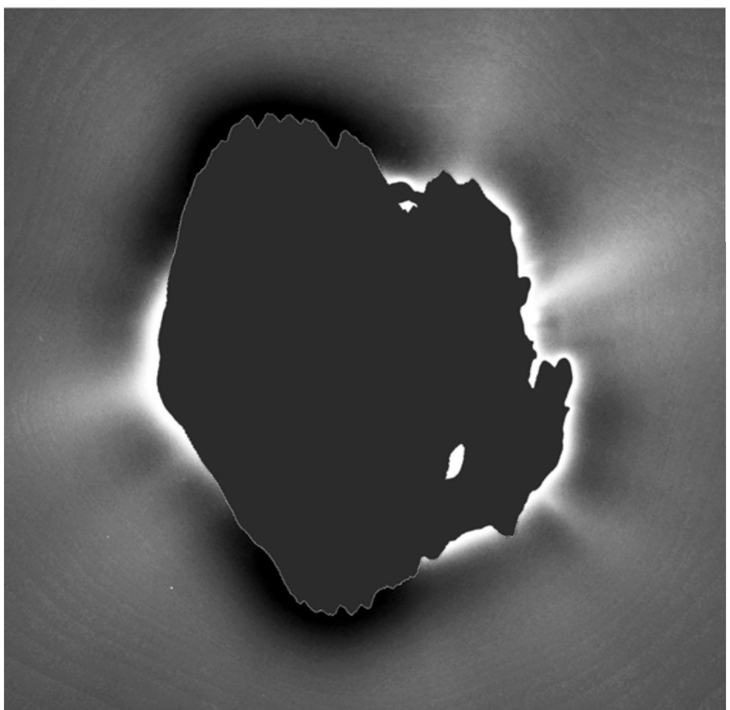
> Notable diversity among Stardust craters brought about by impactors that range from dense objects, such as nonporous silicates of ~3 $g/cm^3$, to highly porous aggregates with bulk densities as low as 0.3 $g/cm^3$.

Morphology of nucleus of comet 81P/Wild 2.

Size of the nucleus is ~5 km.      The surface is highly cratered.







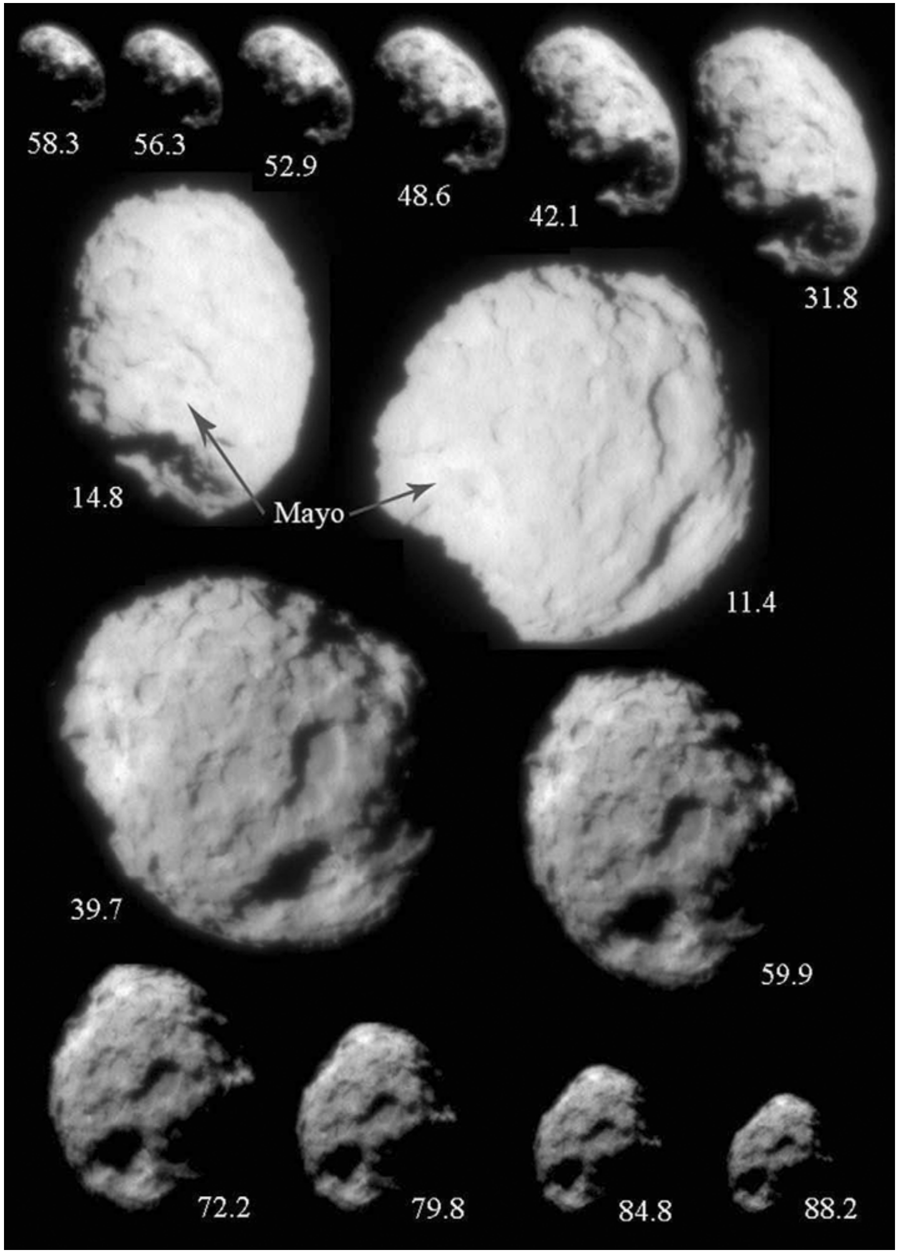
Jet activity of comet 81P/Wild 2.

Despite large heliocentric distance (1.86 AU), comet 81P/Wild 2 revealed significant activity: 20 jets!
It is substantially more than previously studied comets.

Two jets emanate from the nucleus dark side.

Sources of seven jets, including five in the Mayo depression, coincide with relatively bright surface spots.

# Photometry of the nucleus of 81P/Wild 2.




The nucleus was observed in wide range of phase angle – from 11 to 100 degrees.

Using these data, geometric albedo $A$ of the nucleus was estimated to be about 5.9%.

The surface of the nucleus is rather homogeneous. Geometric albedo varies within 15% through the surface. The latter finding is well-consistent with ground based observations.

Literature:


1. Science, **314**, 1707–1739 (2006).
2. Sekanina et al., Science, **304**, 1769–1774 (2004)
3. Li et al., Icarus, **204**, 209–226 (2009)