What do we know about asteroid interiors?

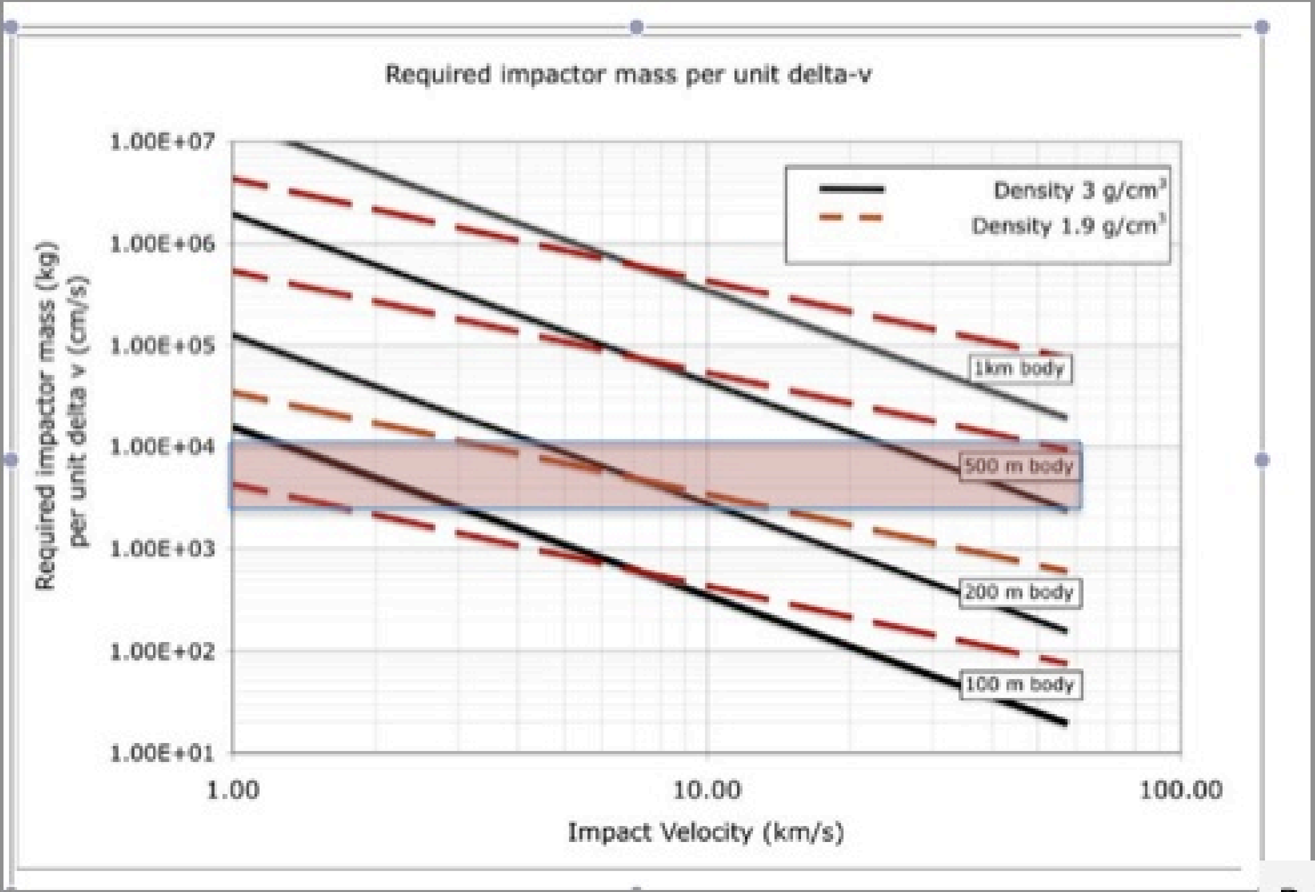
What matters for mitigation?

I consider only the most likely primary method: A kinetic Impact

And focus on the smaller objects : a few hundred meters..

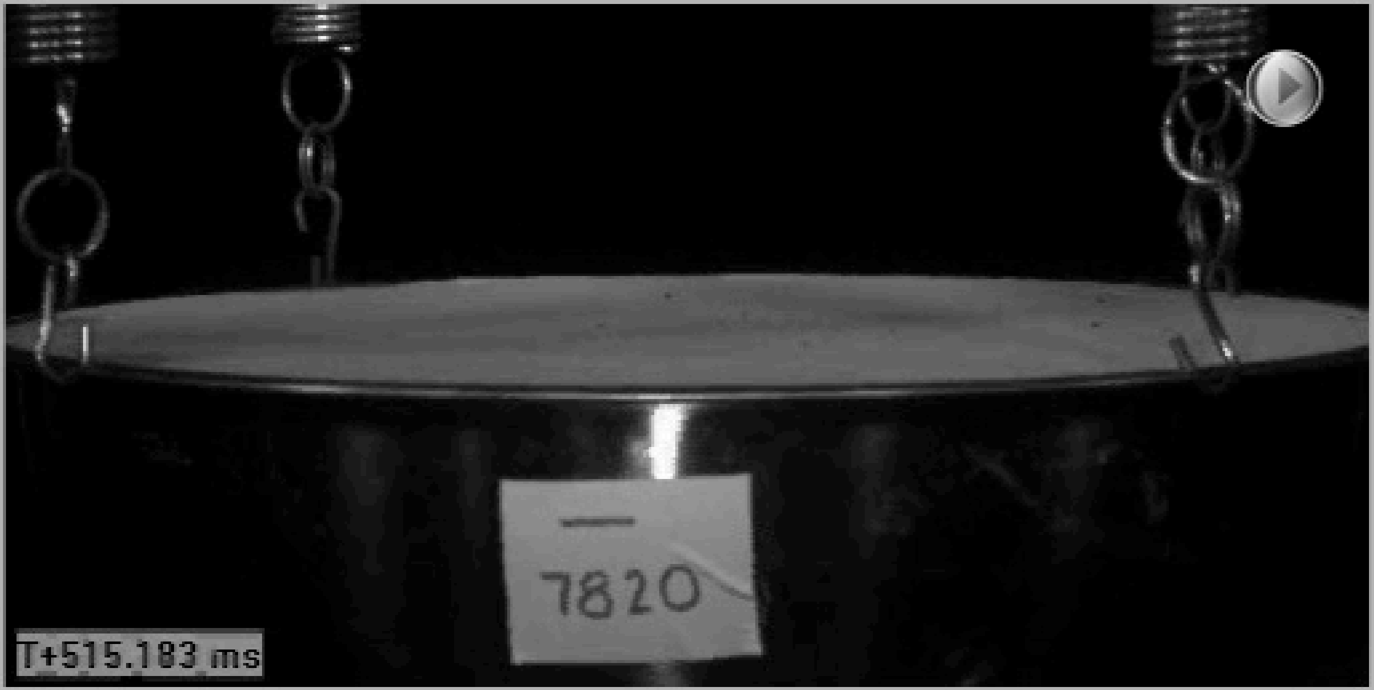
Keith Holsapple,
University of Washington

An impactor of up to 10 tons may impart sufficient velocity to deflect a 100-500 m object..



Ref: NRC Report, 2010

The ejecta from an impact may greatly enhance the direct effect of moving the asteroid (β factor)



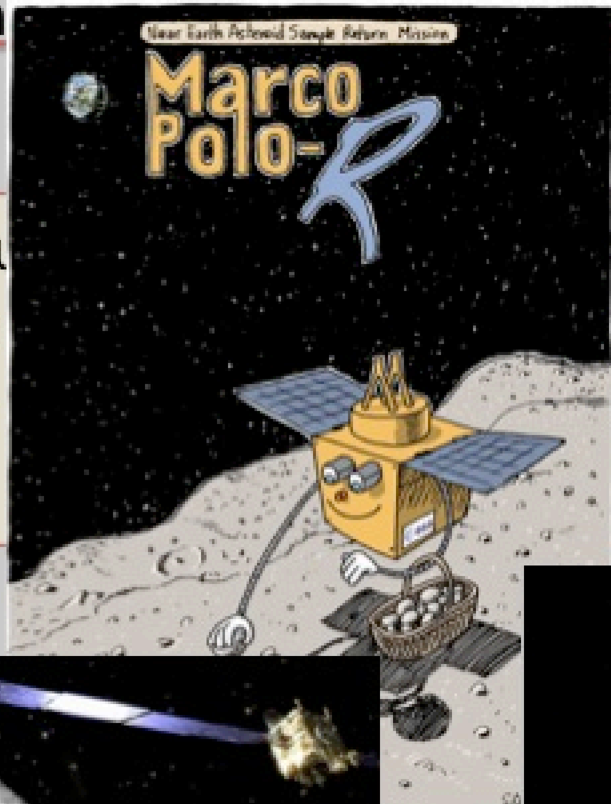
Next?

- Continue to study
- Plan Missions

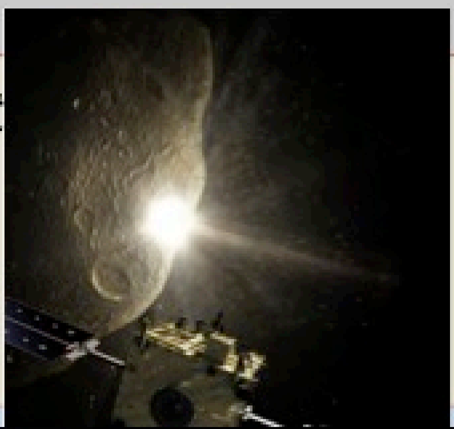
Thank You

Acknowledgement: This research was sponsored by the NASA NEOO program by grants NNX10AG51G and NNX12AG18G.

So, with all the uncertainty, and indirect inferen… …ily do??



- Mu… …cally interact…
  - … …ires
  - … …nd strength to



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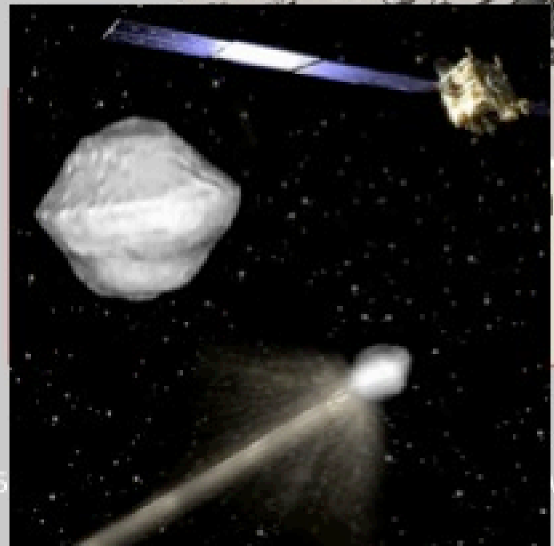
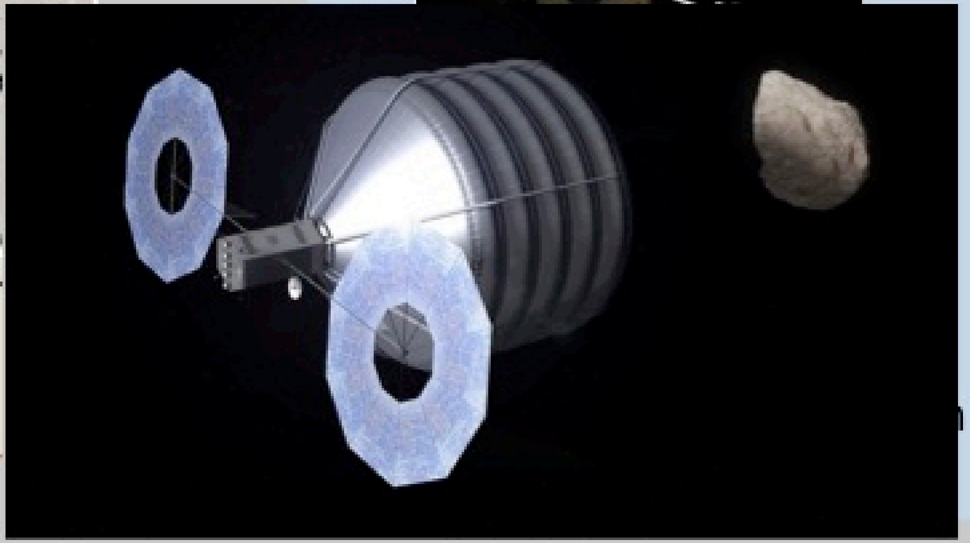




Conclusion

What matters for the impact deflection of a 100-500 m asteroid?

- The three most important features are the porosity, the porosity, and the porosity.

Low porosity: Spall strength (rocks) or shear strength(soils) are important.

Highly porous: Little else matters, β is essentially unity

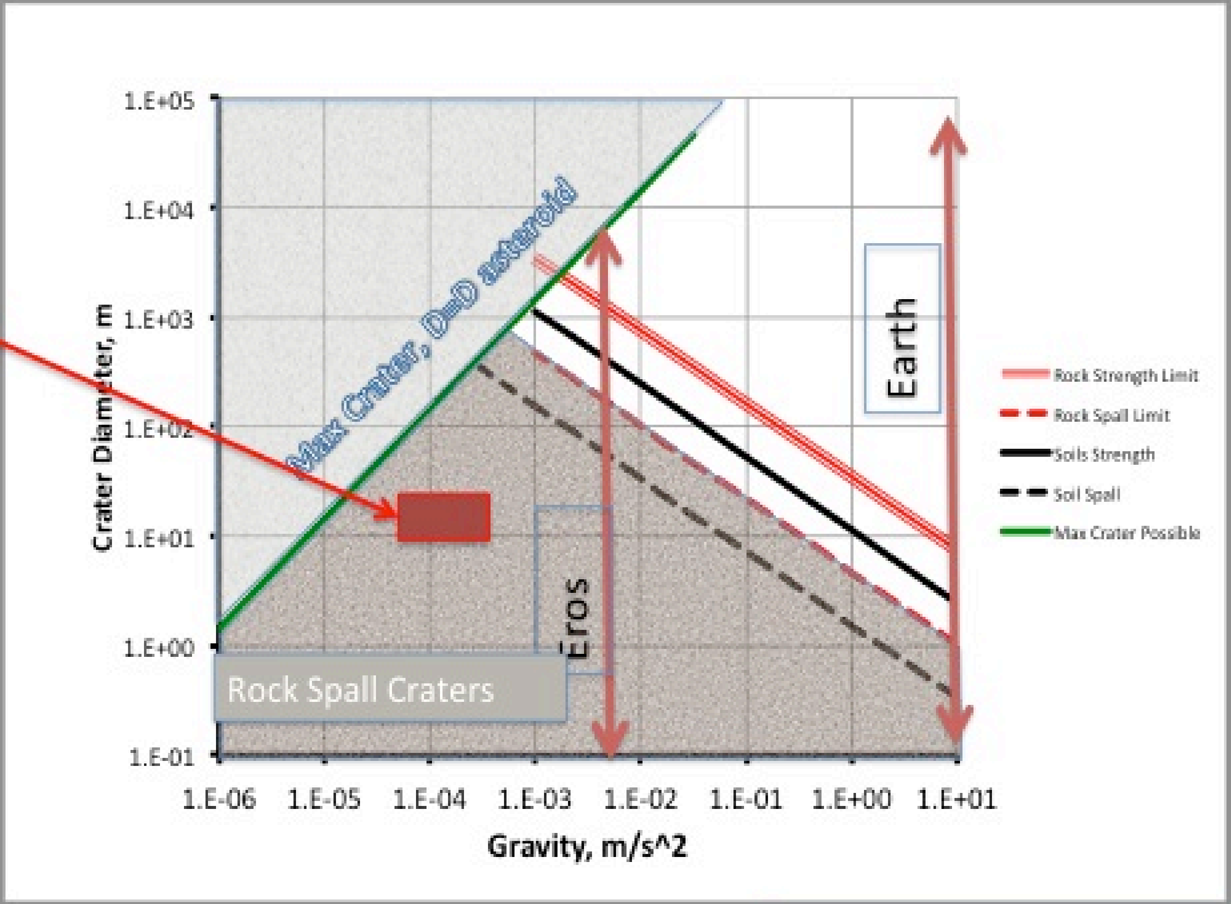
So our present conclusions about impact deflections are:

- Hard rock asteroid:
  - Crater will be a *spall crater*
  - It is determined by the *tensile strength*..
  - Large β *(5-20??)*
- Rubble Pile, density 1.5-2 g/cm^3
  - Crater will be "simple crater", determined by shear strength via *angle of friction*
  - Smallish β~1.5-2
- Highly porous material, 0.5-1.5 g/cm^3
  - Crater determined by *crush strength*
  - β~1
  - But it does not matter a lot anyway...

Tensile strength, Craters on small bodies.

BUT: On small bodies, all impact craters will be spall craters!!

You are here



The impacts we consider into a hard rock object will most certainly form a spall crater

Ref: Holsapple LPSC 2013

Tensile strength, Craters.

A spall crater in a lab rock target

STRENGTH

Tensile strength, Craters.

A spall crater in a lab rock target

Tensile strength, Craters.

On Earth, small craters in brittle materials are spall craters

In the lab that has been treated primarily as an annoyance: we cannot make 'real' craters

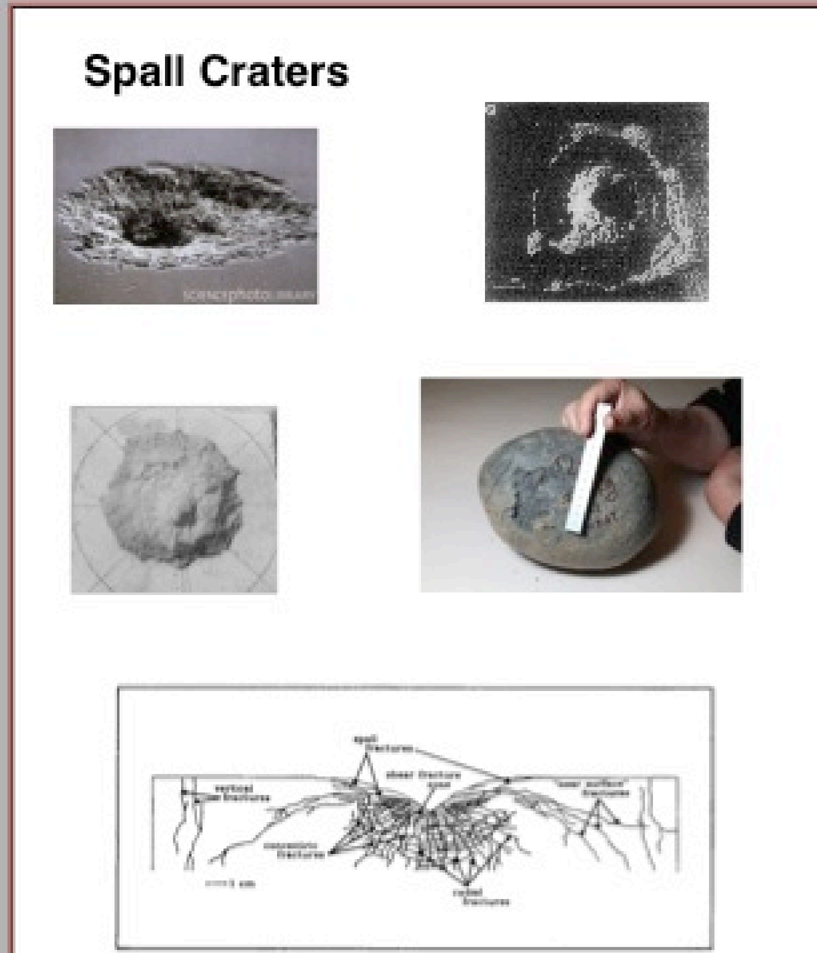


FIG. 5. Cross section of the target from shot 840904 illustrating the classification of internal fractures. Note that all fractures have been drawn with the same line thickness despite actual variations in the target. The shaded area immediately below the crater indicates a highly fractured region.

STRENGTH

Shear strength, Fireball Breakup.

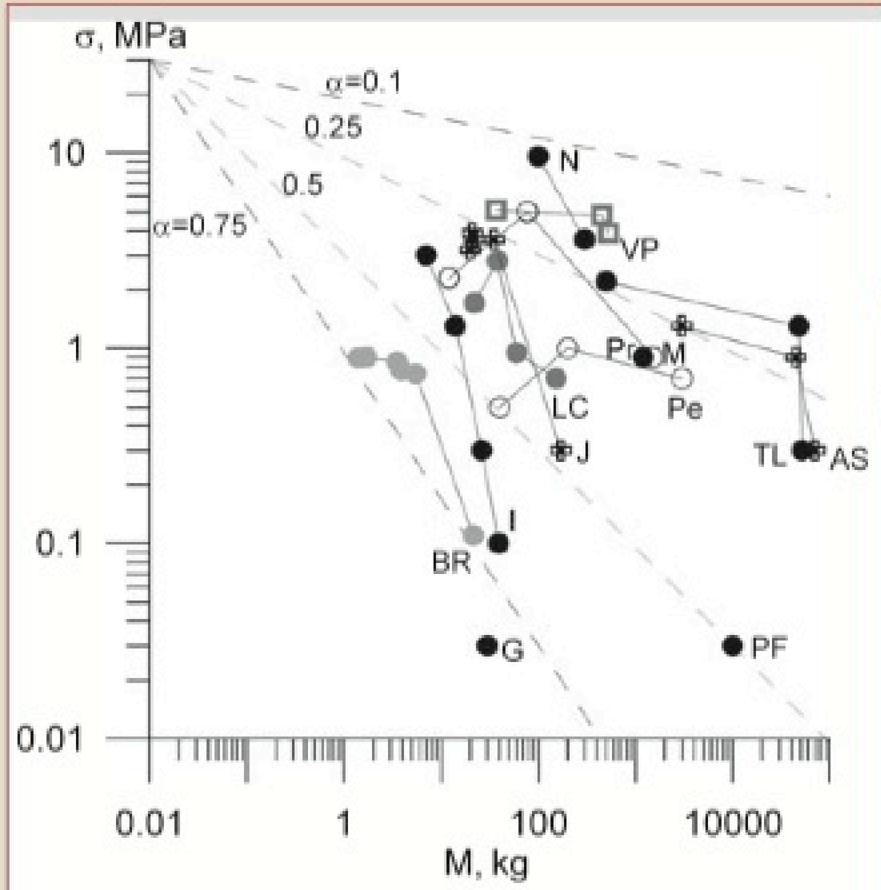
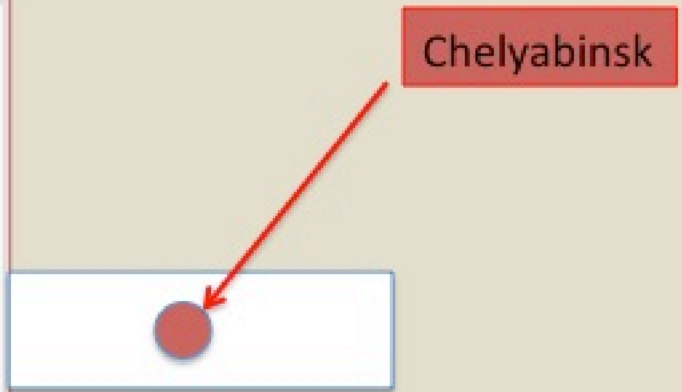


Fig. 4. Estimated apparent bulk strength (=ram pressure in Table 4) at first, second, and third breakups as a function of mass for our 13 cases (Pr—Příbram; LC—Lost City;



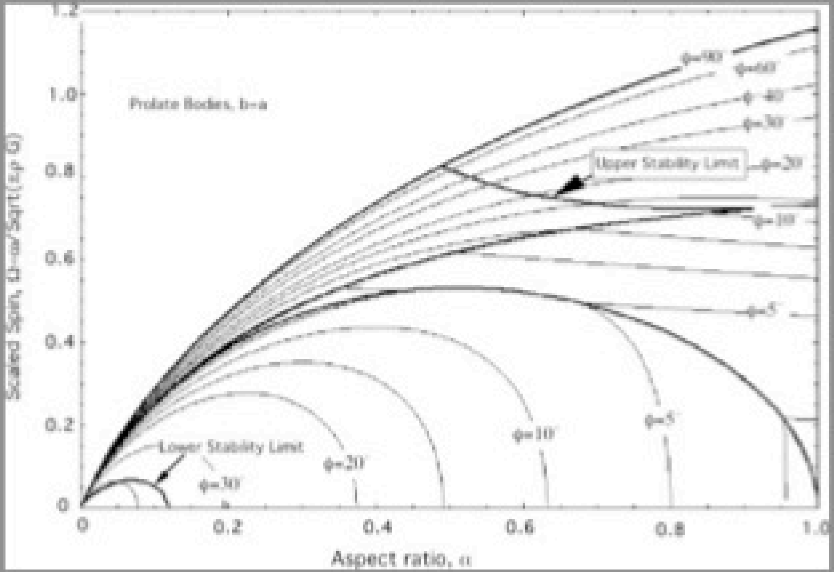
Fireballs break up at atmospheric pressure of a few to a few tens of Mpa.

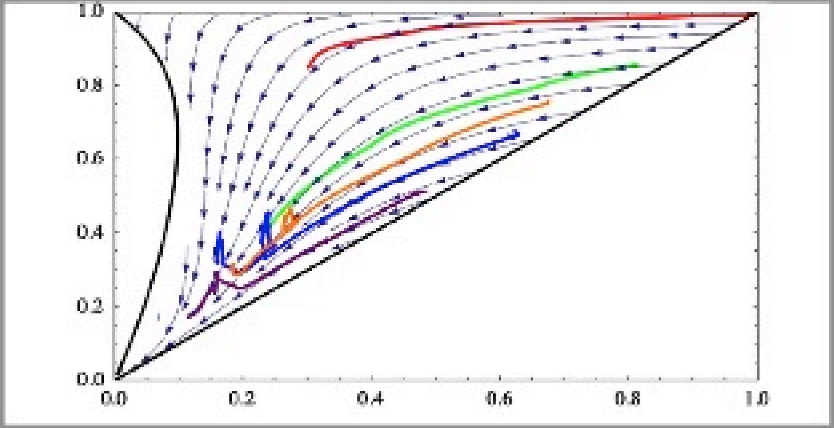
Ref: Popova, Hartmann, et al., 2011, M&PS

STRENGTH

Shear strength, Spin Limits

For rubble piles, max spin depends on angle of friction: (Holsapple, 2001, 2004)

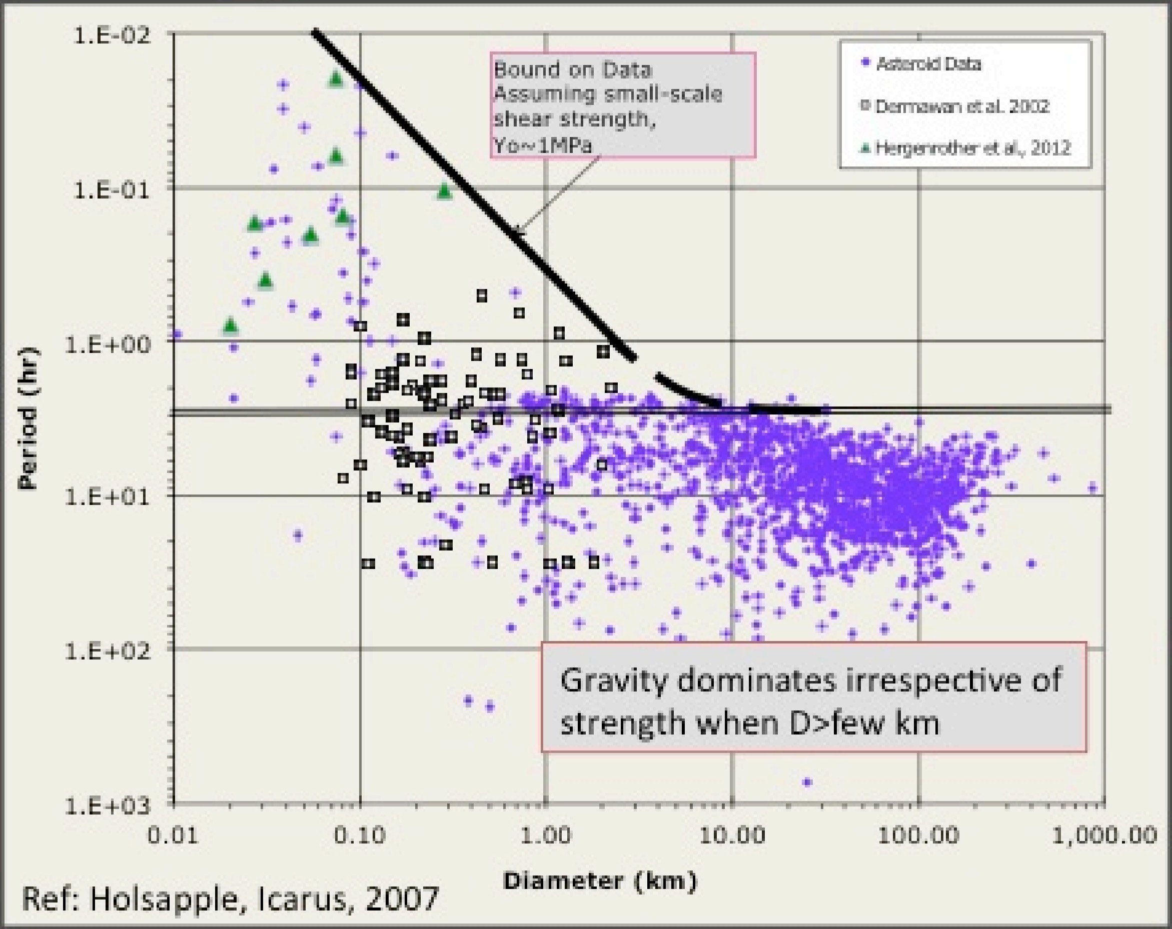




And determines the paths followed for shape changes due to Yorp spin-up (Holsapple, 2010, Sanchez and Scheeres, 2012)

STRENGTH

Shear strength, Spin Limits.



Ref: Holsapple, Icarus, 2007

This is the only direct data on the global strength of actual asteroids. The theory is consistent with the data if the small-scale strength is ~few Mpa.

The origin of that strength is under debate: rocks with cracks (Holsapple), or rubble piles with van der Walls (Scheeres, Sanchez)?

Shear strength, Planetary cratering.

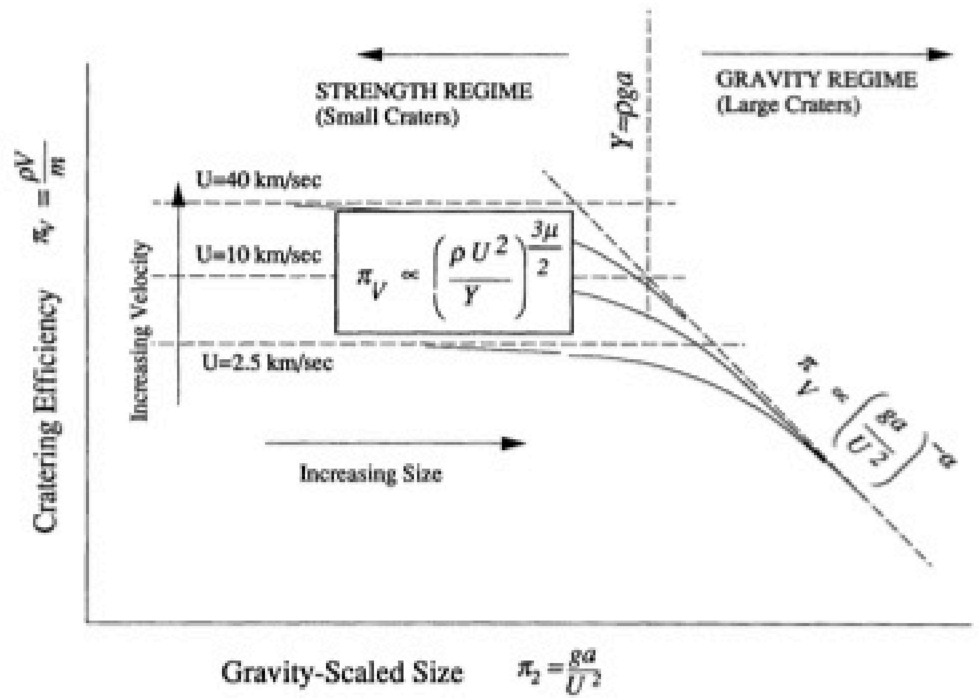
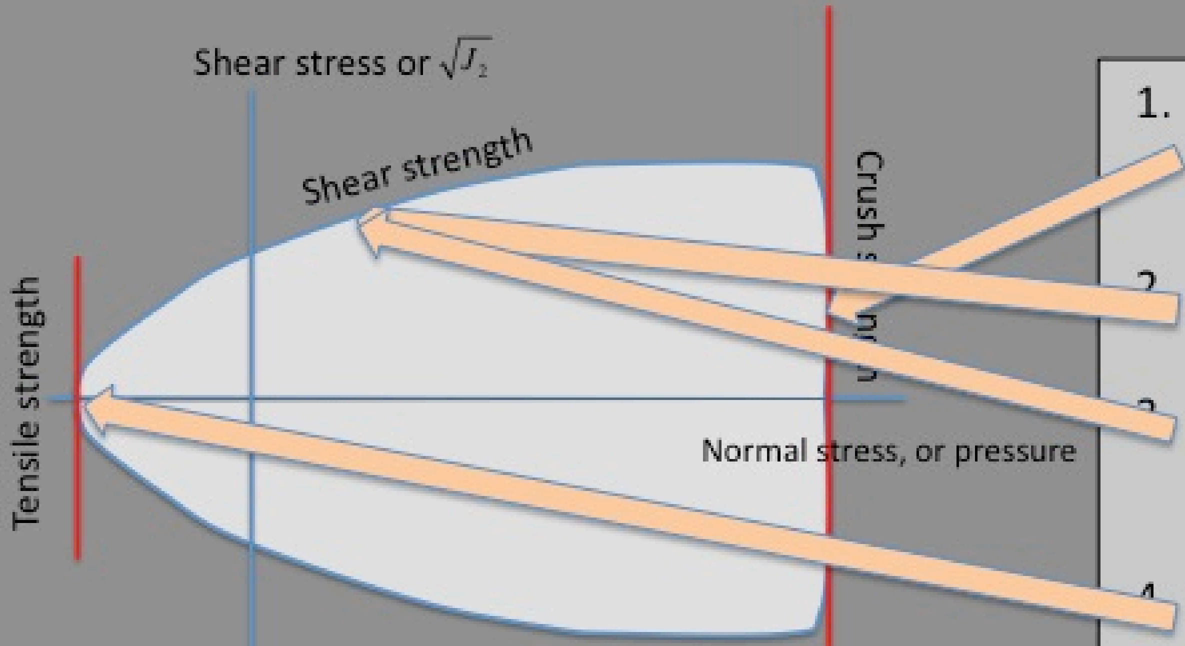


Figure 3 The regimes of cratering for a material with strength. In the strength regime the cratering efficiency depends on the impact velocity, but is independent of gravity-scaled size. For increasing size at a fixed velocity, there is a transition to the gravity regime in which the cratering efficiency has a power law decrease with increasing size. Most experiments in geological materials are by necessity in the strength regime.

Transition from strength->gravity craters indicates value of shear strength.

Holsapple, 1993

What is the strength of GEOL0GICAL MATERIALS?

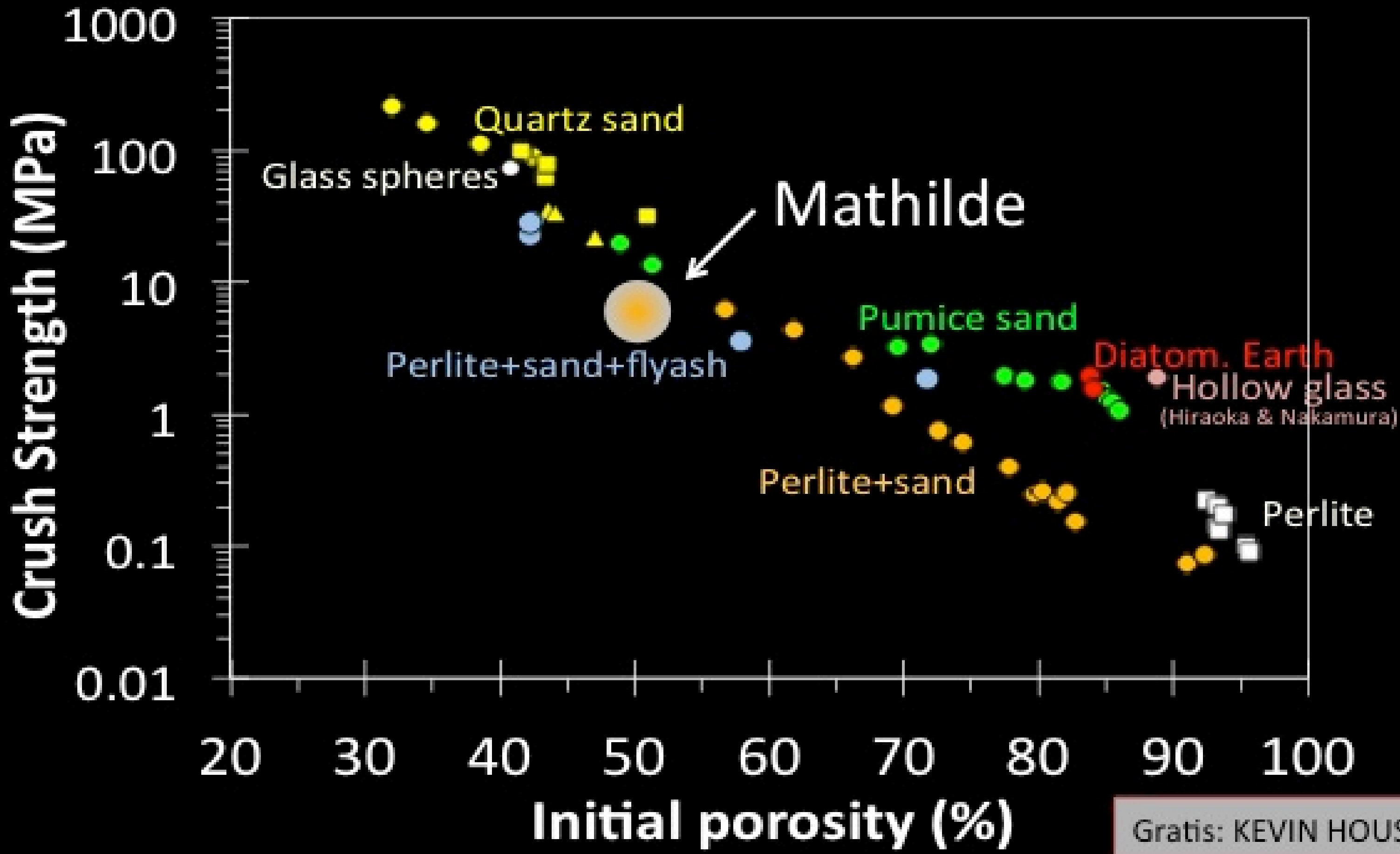


Mohr-Coulomb or Drucker-Prager envelopes

1. Highly porous materials: <u>crush strength</u>
2. Sand craters: <u>shear strength</u>
3. Large rock and ice craters: <u>shear strength</u>
4. Small rock and ice craters: <u>tensile strength</u>

Porosity

Mathilde's crush strength is consistent with other geological materials.



Gratis: KEVIN HOUSEN

Example: Mathilde

- Centrifuge experiments: ejecta blankets are suppressed when

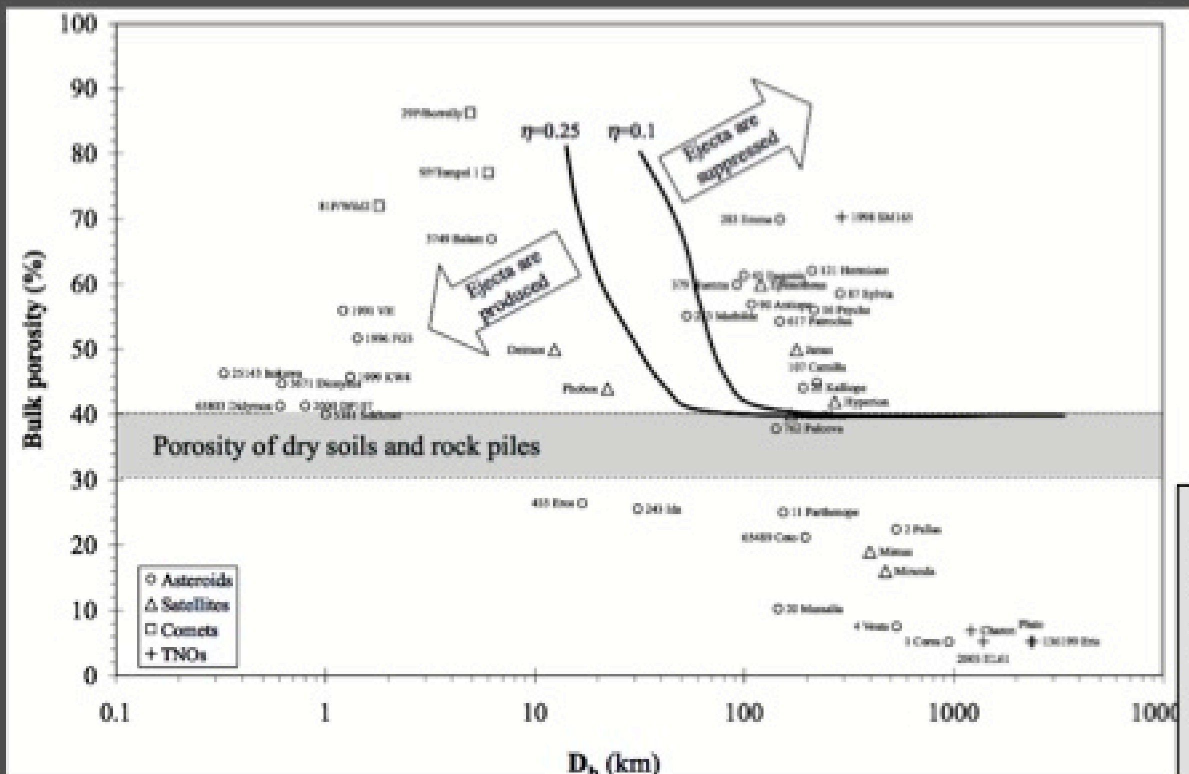
  $\rho g h = 0.01\ Y_c$

  ρ=density (1300)
  g=gravity (10^{-3} G)
  h=crater depth
  Y_c=crush strength

- On Mathilde, the transition crater depth is less than 5 km.

- Thus, Mathilde's crushing strength must be < 6 MPa.

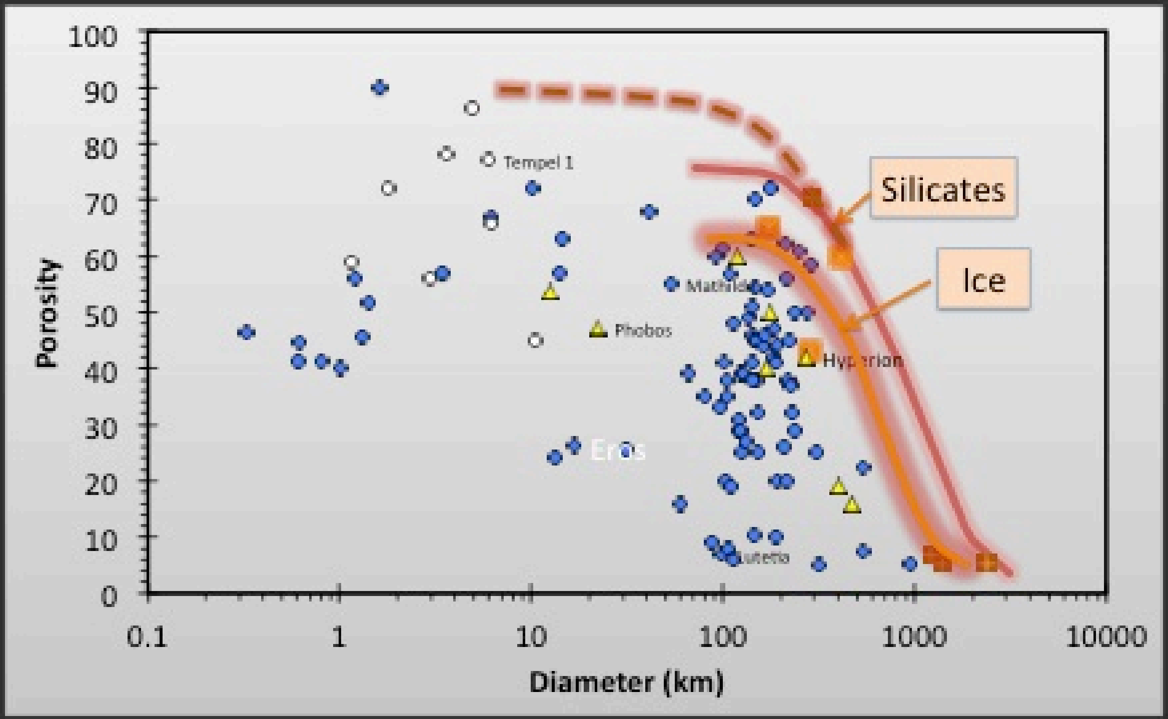
And the Crush strength determines crater morphologies



Crater transition size from external ejecta to retained ejecta indicates crush strength

Ref: Housen and Holsapple, Icarus, 2012

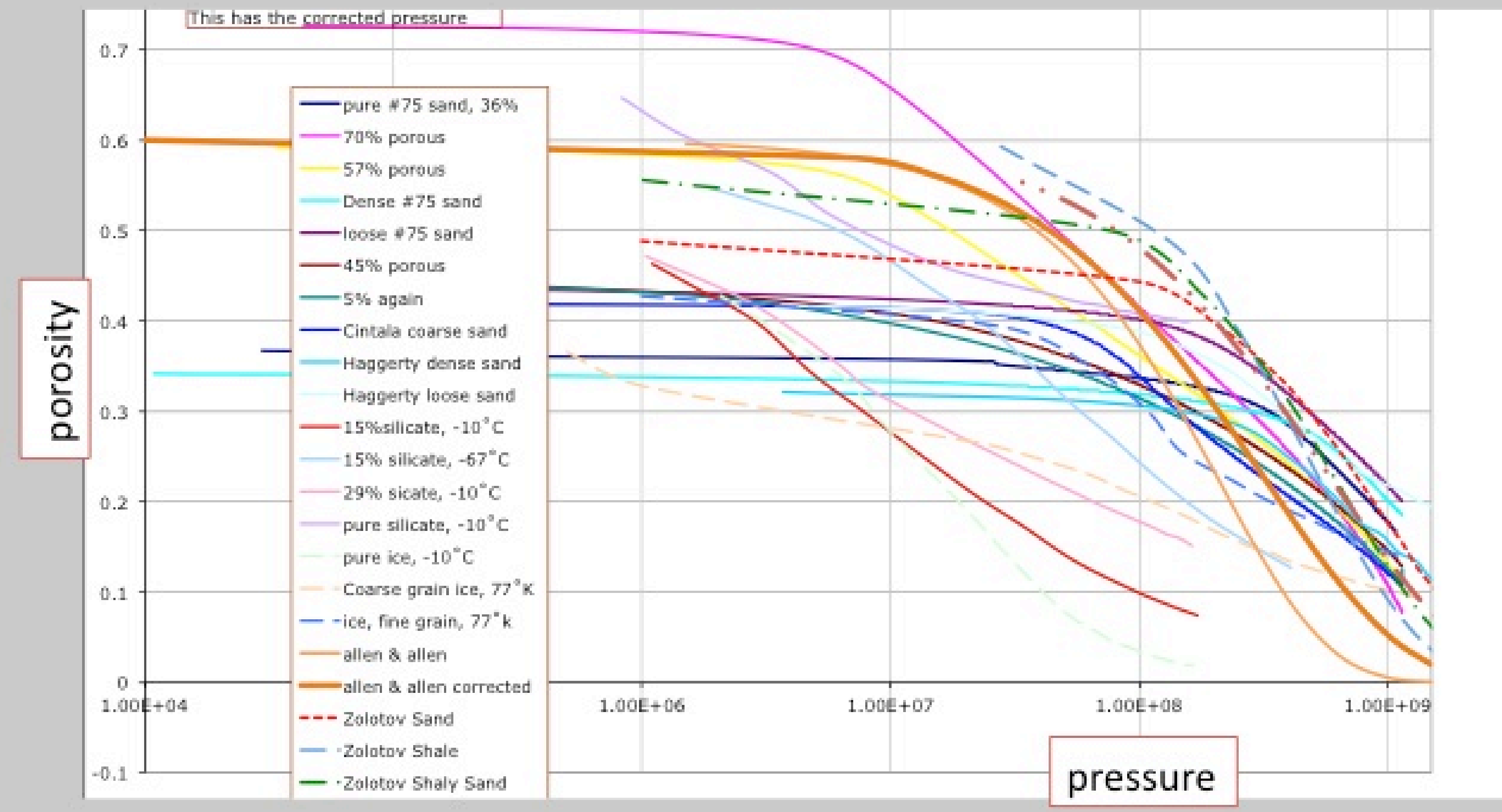
The Crush strength determines porosity limits



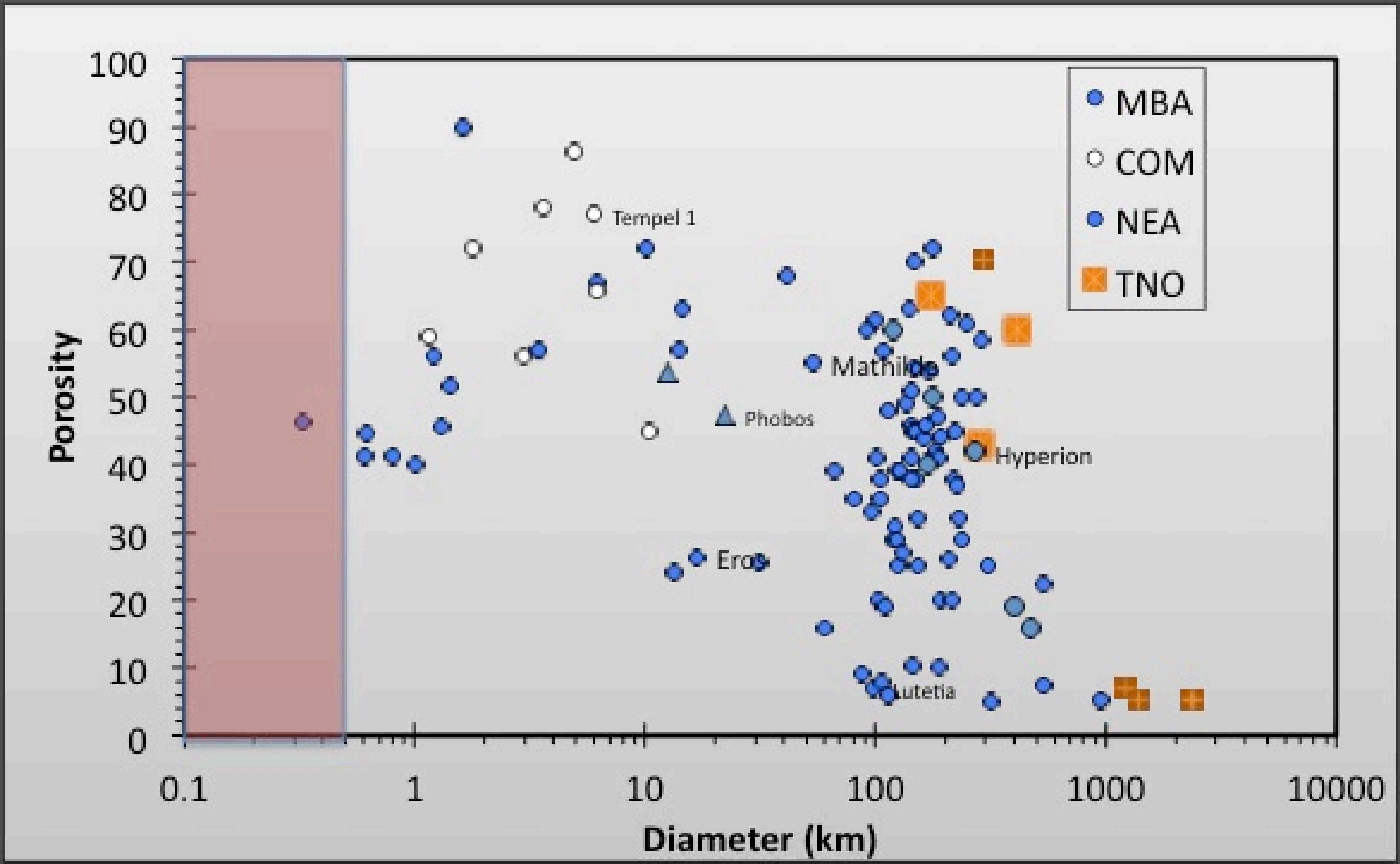
The distribution of the porosity of small bodies is as predicted from lab experiments

Porosity

Lab measurements of porosity and crushing



We know something of the *global* porosity of the small bodies

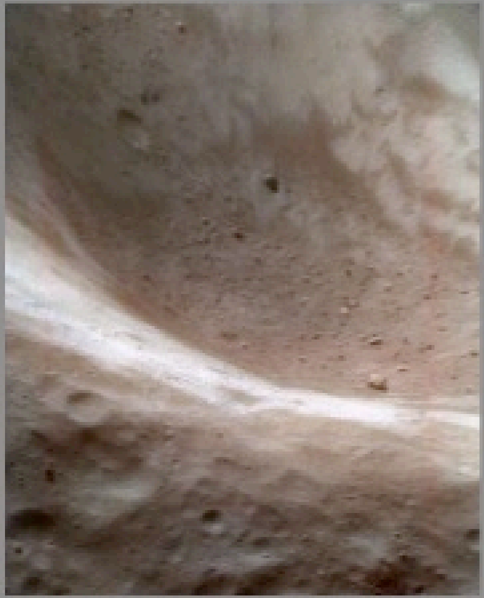


From Carry, B., 2012, by way of Housen, K.

And especially,
what is the structure the top 10m?

Regolith or not?
Eros: 10's of meters, from impact ejecta

Regolith or not?
Itokawa: Reaccumulated rubble?



What porosity can we exp

So the important questions about an asteroid are:

1. What is the porosity of the top 10 meters?

2. What is its "strength"?
   1. Spall strength
   2. Shear strength
   3. Crush strength

And what do we know about those?

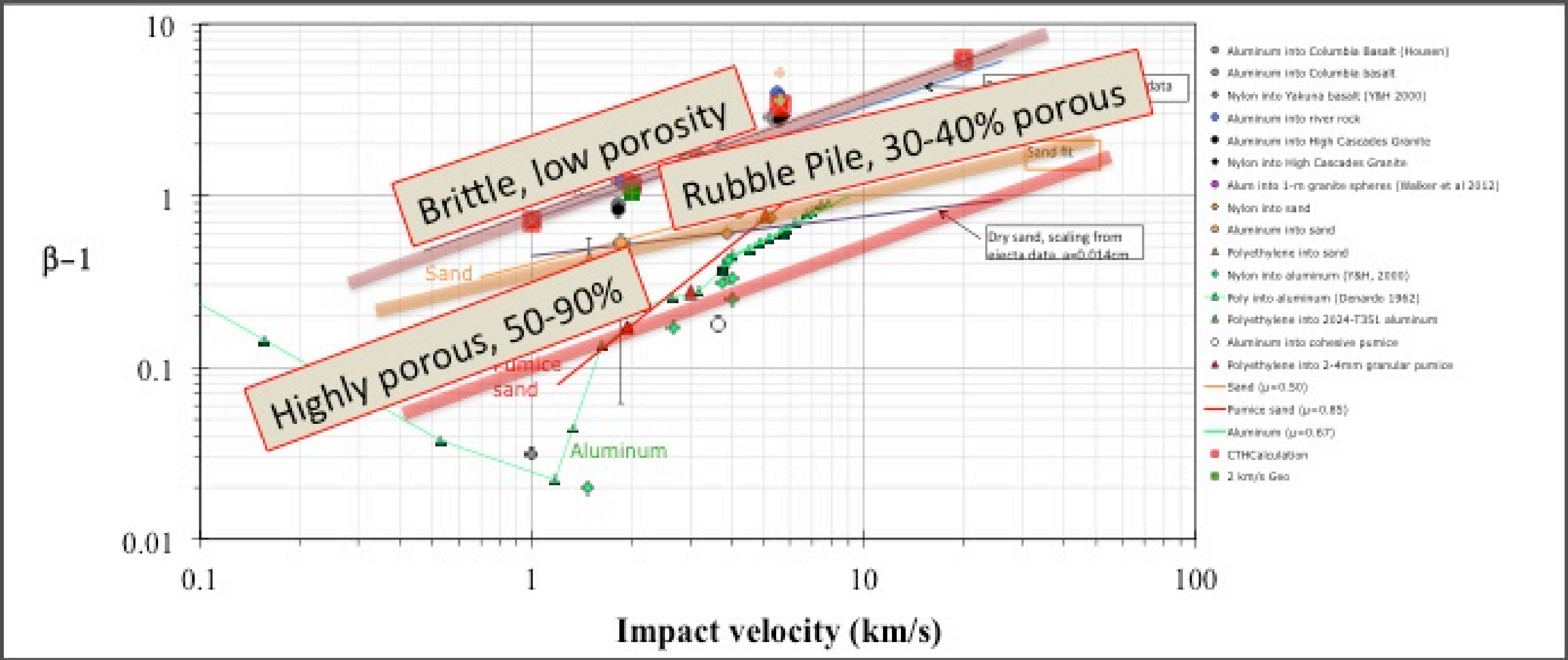
The rest of this talk will focus on that question..

From these experimental and numerical results, we can make tentative predictions…

i.e.....

- Low porosity rock or ice asteroid:
  - Crater will be a *spall crater*
  - It is determined by the *tensile strength*..
  - Large β *(5-20??)*
- Rubble Pile, porosity 30-40%
  - Crater will be "simple crater", determined by shear strength via *angle of friction*
  - Smallish β~1.5-2
- Highly porous material, porosity 40-90%
  - Crater determined by *crush strength*
  - β~1 in any case

So what is β??



Ref: Holsapple and Housen, Icarus, 2012;
& Presentation by Kevin Housen tomorrow

Our experiments have showed three types of results..

Let me explain that…

Assumptions:
- ~1 meter impactor
- 5->20 km/s impact velocity
- Makes a crater in the top 10+ m structure

Then, *how much change in velocity can we achieve with a given impactor?*

The velocity increment is determined by the impactor momentum *times the momentum multiplication factor* β

So, what matters for the deflection of a 100-500m object?

velocity

spin

mass

albedo

strength

taxonomy

Characterization!

orbit

companions

shape

porosity

regolith

families

density

It is the strength and porosity of the top 10 m that matters…