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SOME IMPORTANT IMAGING GOALS FOR ASTEROID MISSIONS

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This paper discusses five important objectives for any imaging experiment on a future asteroid mission, based on our current prejudices of what asteroids are like. These prejudices are based on extrapolations from other bodies whose surfaces have been studied at close range by spacecraft (most notably the Moon, and the two satellites of Mars) and on numerous indirect inferences. Imaging provides the most direct means of verifying whether actual asteroids conform to our current view of what they ought to be like.

INTRODUCTION

This paper outlines five major imaging objectives of any serious asteroid mission. They are:

1. Determination of volume, mass and mean density
2. Search for surface inhomogeneities
3. Characterization of asteroid regoliths
4. Comparative study of cratering mechanics
5. Characterization of non-crater surface morphology on objects of different compositional types.

Of these major objectives, the first two are of fundamental and crucial importance to our understanding of the nature of evolution of asteroids. The first is properly an imaging objective, since to determine an accurate mean density one needs not only the mass, but an accurate volume.

DETERMINATION OF MASS, VOLUME AND MEAN DENSITY

Probably the most important task of any asteroid mission is to determine the object's mass and volume. If both determinations are made accurately, to within ±10%, a useful mean density $\bar{\rho}$ can be obtained. The obvious importance of $\bar{\rho}$ is that it tells us about the interior composition of the asteroid and appears to be the most direct means of remotely determining anything about asteroid interiors.

The Viking experience with Phobos and Deimos (Tolson *et al.*, 1978) as well as studies made by the Comet Halley Science Working Group (Belton, 1977) prove that it is feasible to obtain accurate masses and accurate volumes, even for very small bodies (radius $\gtrsim 1$ km). In the asteroid context it will be essential to image the asteroid at high resolution long enough on either side of encounter to be able to determine its shape and dimensions accurately. (As typical asteroid rotation periods are 6-8 hours, the above requirement should be easy to meet.) High resolution images will also be useful during a flyby for determining the distance of closest approach which is needed in order to determine the mass. Of course, the distance of closest approach can be determined even more accurately given an on-board radar.

Given an accurate value of $\bar{\rho}$, one has obtained some information on the possible bulk composition of the asteroid. As shown in Table 1, knowledge of $\bar{\rho}$ to ±20% or better is very useful for distinguishing differences in bulk compositions. Some of the important questions that can be answered once $\bar{\rho}$ is known are:

1. *How representative are asteroid surfaces of the interiors?* Surface compositions can be inferred from remote sensing; mean compositions from $\bar{\rho}$. What classes of asteroids have surfaces representative of the interiors? What classes of asteroids have differentiated interiors? For a given class this might be a function of asteroid size (radius). What is the critical radius?

2. *Are there large metallic cores among the asteroids?* Chapman (1974) suggested that certain large asteroids were stripped-down metallic cores of larger parent-bodies. Such bodies should have high mean densities. Knowing with certainty that 100-200 km metallic cores did form in the asteroid belt would be important information.

3. *Are there small, low density objects in the asteroid belt?* If some small asteroids ($1 \leq r \leq 10$ km) are present which are not fragments of much larger bodies, then it is conceivable that some may have very low densities ($\bar{\rho} \ll 2$ g/cm^3). For example, finding a $\bar{\rho} \sim 1$ g/cm^3 object would not only indicate that this is probably a primitive object but would provide information about the accretion mechanism of small bodies.

It should be noted that sophisticated measurements could yield data on the mass distribution within the object. It would be of interest, especially for small irregular asteroids, to see whether the mass distribution is homogeneous (*i.e.*, do the centers of figure and of mass coincide?). Large density inhomogeneities in the case of a small, irregular asteroid would indicate that it is a fragment of a larger, differentiated object, or that it is an accretional composite.

Table 1. Densities of Meteorites (after Wasson, 1974)

Meteorite Type	Density (g/cm^3)
Carbonaceous Chondrites	
CI	2.2 - 2.3
CM	2.6 - 2.9
CV, CO	3.3 - 3.6
Ordinary Chondrites	3.4 - 3.6
Enstatite Chondrites	3.5 - 3.8
Achondrites	3.1 - 3.4
Stony-Irons	$\sim$5
Irons	$\sim$7.9

SEARCH FOR SURFACE INHOMOGENEITIES

High resolution imaging is needed to look for evidence of variation in:

1. morphology
2. texture
3. composition
4. age

over the surface of an asteroid at various scales. Surface morphology can be characterized in terms of the types of surface features visible; differences in surface texture can be determined by photometry; differences in surface composition can be searched for by means of color measurements; differences in age can be found from crater counts.

Such variations could arise from internal activity. It is clearly very important to look for evidence of internal activity on the surfaces of 100-200 km asteroids and to study the style of this activity and determine the time of its occurrence. There is strong evidence that "lava flows" have occurred on the surface of Vesta (Drake and Consolmagno, 1977), but are the surfaces of smaller asteroids totally devoid of any traces of internal activity?

Surface variations could also arise from large cratering events and from spallation (*i.e.*, knocking away a significant fraction of an asteroid during a catastrophic impact). Current prejudice holds that in the case of large asteroids such severe impacts were common only during the first 1 billion years or so of the solar system's history. Thus, we shouldn't expect to see any evidence of "recent" large-scale impacts on the surfaces of asteroids, but this is still worth checking into.

Variations in surface composition could also be evidence for fragmentation from a large parent body. For example it would be of great interest to definitely establish that some 50 km asteroid was once a fragment of a much larger parent body.

CHARACTERIZATION OF ASTEROID REGOLITHS

Our present understanding of how regoliths are generated and maintained on small bodies is very poor. There is good evidence that asteroids as small as 1 km in radius have some sort of regoliths, while the two satellites of Mars are known to have well-developed regoliths even though the objects are only some 10-20 km across (*e.g.*, Veverka, 1978). The ability of a body to retain a regolith should be primarily a function of surface gravity and hence of the body's size. However, laboratory experiments suggest that the nature of the surface may also play an important role in the evolution of regoliths (*e.g.*, Chapman, 1978). Thus, an important advance in our understanding of regoliths would occur if we could compare the surface characteristics of:

1. Two asteroids of similar composition but of vastly different size. For example, two S objects, one with a radius of 5 km, the other with a radius of 50 km;

2. At least two asteroids of comparable size (actually similar g) but of widely different composition. For example, a C object and an M object; or a C object and an S object.

The only small objects for which we have direct information about the surfaces are the two satellites of Mars. However, it has been argued that the surfaces of these two bodies may not be representative of those asteroids of similar size since Phobos and Deimos are in the potential well of Mars. Soter (1972) has argued that this circumstance helps the two martian satellites recapture a significant fraction of the ejecta thrown off their surfaces by impacts. The investigation of a single 20 km C asteroid would resolve this issue once and for all. A second-order investigation which would help our understanding of how regoliths are retained on small bodies would consist of comparing the surface properties of two asteroids of similar size and composition, one of which is nearly spherical and has a long rotation period, while the other is irregular and has a short rotation period.

A first order characterization of regolith properties can be obtained by means of photometry and high resolution images. Photometry will give information on the texture of the surface and on the lateral homogeneity of the regolith. High resolution images should reveal the presence or absence of ejecta blocks, filling-in of impact craters, and possible near-surface layering exposed in crater walls. From the morphology of small craters one should be able to determine the regolith thickness as was done in the lunar context by Quaide and Overbeck (1968).

COMPARATIVE STUDY OF CRATERING MECHANICS

The mechanics of high velocity impact cratering are not perfectly understood. It appears that gravity effects have a dominant influence on crater morphology (given a certain impact energy) but mechanical characteristics of the target material are also important. Hartmann (1972) has proposed a gravity dependent crater morphology sequence in which crater morphology scales essentially as g^{-1}. Thus, for example, Hartmann proposes that central peaks will occur in craters 10 times smaller on a body whose $g = 100$ cm/sec^2 than on the surface of one whose $g = 10$ cm/sec^2. Other gravity effects have been discussed by Gault *et al.* (1975) in the case of Mercury and the Moon: for example, semicontinuous ejecta blankets should occur closer to the crater rim if g is high. Comparative studies of the crater morphology on different asteroids provide a unique means of testing such gravity scaling ideas, as well as the possible importance of the mechanical properties of the target material.

Ideally, one would like to compare the morphology of craters (depth/diameter ratio, diameter at which central peaks occur, extent of ejecta blankets, height of crater ramparts, the occurrence and extent of ray systems) on:

a. asteroids of similar surface g, but very different surface composition (*e.g.*, a C object and an M object);

b. asteroids of similar composition (*e.g.*, two S objects) but with very different g's (*e.g.*, 20 cm/sec^2, and 2 cm/sec^2).

Such experiments, especially when compared with previous results on the larger planets and on Phobos and Deimos would provide a crucial test of our understanding of impact cratering.

CHARACTERIZATION OF NON-CRATER SURFACE FEATURES ON OBJECTS OF DIFFERENT COMPOSITIONS

Interesting non-crater surface features almost certainly occur on the surfaces of some asteroids, and contain important information about the evolutionary history of these objects. Three possible examples are:

1. *Lava flows on objects with achondritic surfaces.* The style, extent and age of such flows are of great interest, as is any evidence of the possible flooding of large craters.

2. *Groove patterns associated with large craters on small C objects.* It has been suggested that patterns of grooves similar to those found on Phobos may be common on the surfaces of many small, mechanically weak asteroids (Veverka *et al.*, 1977). Any evidence of internal modification of such grooves would be of great interest.

3. *Unusual surface features on M objects?* In view of the malleability and high tensile strength of nickel-iron, one might expect some unusual morphology on the surfaces of M objects, if they are truly metallic.

CONCLUSIONS

The above list of imaging objectives is seriously limited by our lack of knowledge of what asteroid surfaces are like. It is true that one can extrapolate to some extent from past experience with the Moon and especially with Phobos and Deimos, and one can even bolster these guesses by intelligent theoretical reasoning. Nevertheless, it is this author's opinion that no one is clever enough to imagine what the surface of any particular asteroid is really like. The only way we will ever find out is if we send our instruments there and look.

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DISCUSSION

MATSON: Is measurement of density the only way to get internal structure?

VEVERKA: Density is the only practical way I see in the next 20 years. It is much more difficult to do a seismic experiment. You have to land a seismic net. I don't believe we can do that now.

FANALE: You made a very optimistic statement that we would find out something about zonal structure from tracking.

VEVERKA: It is a difficult thing to do and depends, in part. on being lucky.

MORRISON: Could you put the mass determination in a little better perspective for me? For objects the size of Ceres and Vesta, it is quite easy to determine mass by going into orbit. But for a kilometer-size comet nucleus, it is hard. Where does the crossover take place and how do you go about making accurate measurements for small bodies?

VEVERKA: My impression is that for all rendezvous missions mass determination is a relatively trivial matter. Nor am I suggesting that in the case of Ceres it will be difficult to determine the volume. Most of what I have been saying about the need to measure volume accurately really applies to the smaller main belt asteroids where it is difficult to determine the volume because of their irregular shapes.

ANDERS: Could you distinguish complex accretionary structures from those produced by later, very large-scale brecciation events caused by inter asteroid collisions?

CHAPMAN: There is a big difference in the velocity regime at which the impact has taken place. During accretion the velocity must have been much smaller.

SHOEMAKER: In the context of this meeting, I don't know anything that we could learn about accretionary structures with the optical resolutions that have been discussed here. I am convinced that if you could really investigate a small body with the same techniques used in manned lunar missions, it would be extraordinarily interesting. Many questions could be addressed. You could take a proper sample and images with a wide range of scales which would enable us to address the question of accretionary structures. Right now I can't give you any of the definitive criteria, but I have a hunch that interesting structures at the scales of tens of centimeters, meters, and tens of meters are there to be found.