Rig for Mining Asteroids

An exploration into the challenges, and a first attempt at designing a viable construction

NEAmines Group, May 2007

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Summary

This is the synthesis of an intensive debate and design effort among members of the NEAmines group (http://www.asteroidmines.net) for coming up with a first viable design for a machine that can dig into asteroids of the type "chondrite floating blob of loose rubble". The design emerged through intensive interaction with changing graphic models. The main challenges for which options for solutions were sought are: Attaching the machine to the asteroid surface, borehead and fracturing into "grit" for further processing, transporting the grit".

Further challenges were identified and some of them integrated into an overall design of the machine: Dealing with volatiles, propulsion for local manoeuvering and transport to Low Earth Orbit, LEO, the issue of human presence nearby, structural stability of the asteroid after repeated boring, energy, temperature control, and interface with the processing/refining systems. Some strategic thoughts for sequencing operations on an asteroid also emerged.

Situation

The assumptions on which this exploration is based:

- Near Earth Asteroids, ie: in Solar orbit similar to Earth's.
- A chondrite asteroid, ie: rock that never went through melting and subsequent crystallization and metamorphosis, with lightly compacted "chondrules" of various chemical compositions (small globules coalesced out of dust-disk around the Sun), of which around 10% are metal chondrules distributed throughout the matrix. Based on frequency of meteorite finds, such chondrites are expected to be the most frequent Near Earth Asteroids.
- Very low gravity, resulting in very low escape velocity.
- Slow rotation of around 15 hrs, typical of blobs of rubble.
- A "floating blob of rubble", ie. a collection of rocks, gravel and sand very loosely held together by weak gravity, and with a porosity (empty space between rocks) of up to 40%. Irregular mass-concentrations expected within the blob of rubble. Based on rotational data and considerations about survival after impacts, loose rubble piles are expected to be the most frequent type of asteroid. An example is Itokawa.
- Unknown structural conditions beneath the surface, in particular the concentration, status and distribution of volatiles in the open cracks between the hard rubble. Of immediate interest is water ice.

This article is published both as a printable document as well as a webpage at:
http://www.asteroidmines.net/documents/MiningRig/RigForMining.html
(The webpage is preferred for viewing graphics and downloading large versions of them)

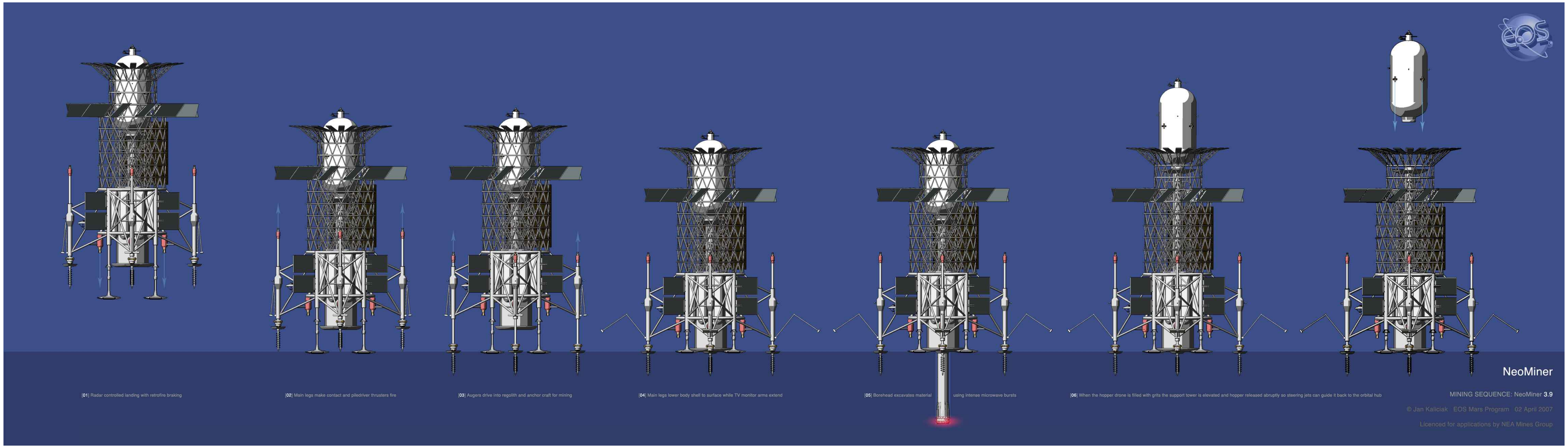

FIGURE 01 See a full-size version at – http://www.asteroidmines.net/documents/MiningRig/Fig1.JPG

1. The rig slowly descends to the surface until contact by its legs with the surface.
2. Rockets ignite to push the legs down onto the asteroid while screws wind themselves into the loose rubble until a secure hold is achieved.
3. The microwave borehead is lowered and bores its way into the asteroid. The asteroid material is thereby fractured to a substance similar to grit or sand, ie. single chondrules and smaller.
4. The almost weightless grit is lifted by archimedes screws up through the elevator tube into the rig.
5. A container "hopper" is filled at the upper end of the elevator tube.
6. The hopper undocks and travels on its own to where the grit is processed further, while another empty hopper docks to the upper end of the column.

Encountered challenges and ways to deal with them

Attaching

Since gravity cannot assist to keep the rig in place, it has to be attached to the asteroid in order for forces to be exerted onto the asteroid. This is made even more difficult due to the loose rubble structure of the asteroid.
The solution in this instance has been screws on the legs of the rig winding into the asteroid rubble, initially assisted by rockets acting as jack hammers pushing the screws down into the asteroid.

Transporting grit

The "grit" needs to be transported away from the borehead and into a container. This is an action that is mostly the simple movement of mass, and not much countering of gravitational weight.
The solution in this instance are a pair of helical screw elevators that pass the virtually weightless grits up the elevator tube to a further vestibule, where a final screw moves the material into the hopper.

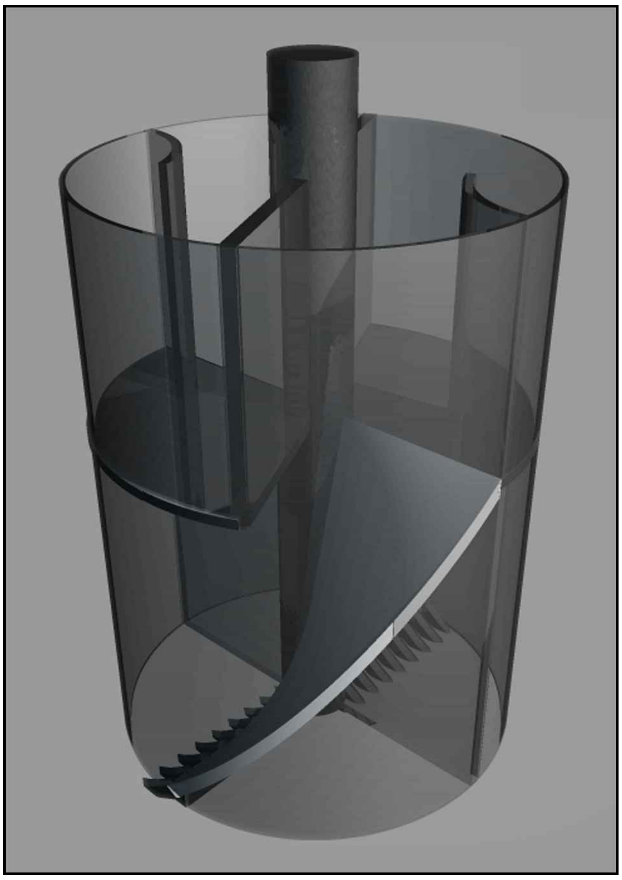

FIGURE 02 See short Film at – http://www.asteroidmines.net/documents/MiningRig/Film.swf

Process asteroid material to "grit"

A wide range of diverse sizes of rocks, gravel, sand and even dust is expected, interspersed with ices of volatiles and open cracks. This material needs to be dug into and fractured to be able to separate the various chondrules according to their chemical composition for further processing and refining. In particular magnetic sifting should allow to separate out the metals during later processing (not on the rig). This process of digging and fracturing must exert as little mechanical force as possible in order to avoid shifting of the rig in the weak gravitational field. The generation of heat needs to be controlled while digging and fracturing in order to avoid losing volatiles due to gassing out. And finally, as few moving parts as possible should be put to work on the asteroid material in order to reduce abrasion.
The solution in this instance is a borehead that contains a paired array of magnetrons that generate intense bursts of microwave energy. The magnetrons tune in various frequencies which resonate with the various chondrite materials

and thereby shatter the whole matrix of the rock. The borehead sweeps the magnetrons over the rockface of the bore, exerting minimal mechanical force. Walled behind the magnetorn array in the borhead tube are an alternating pair of toothed helical ramps that gouge up the granulated material into a pair of vestibules higher up in the elevator tube (See Figure 2). The result is crumbled "rock" with grains of various chemical compositions (including metal grains), called "grit". The borehead works in a casing that progressively follows it down into the asteroid.

Overall concept

A first overall concept is graphically shown in commented Figure 3 and as a 3D stereoscopic vision (with blue/red glasses) in Figure 4 for easier structural grasp. (For full-scale versions go to website at: http://www.asteroidmines.net/documents/MiningRig/RigForMining.html). The elevator column is supported by an exoskeleton that also has an internal tower which allows to telescope the borehead and column down into the asteroid. Antenna for capture of beamed microwave energy and radiation panels for cooling are also shown, as are PV panels.

Further encountered challenges

Dealing with volatiles

One major concern is what happens with volatiles when the borehead makes its short but heavy bursts of microwaves into the matrix. Will they gas out, and will that gas leak out through cracks surrounding the borehead or will it immediately flash-freeze back onto whatever cold surfaces are around, ie. filling any cracks or glazing the grit with ices? Freeze-glazing back onto the grit seems to be an attractive solution, as it would help against abrasion, but it might clog the helical screws.

So a careful monitoring of temperatures and pressures at the borehead and up the elevator and active cooling/heating to make the mass-flow easier may have to be developed.
Catching the volatiles is important as these too have high value at LEO, particularly water as fuel.

MET-propulsion and tugs.

The rig has to be moved around. And so will the hoppers of grit. And whatever can be sold in LEO has to be boosted there. The choice of drive falls for all these purposes on Microwave Electro Thermal, MET: Microwaves heat water to just beyond the break-up point and release it through nozzles where it shoots out at very high speeds and also releases energy through its reconstitution. Higher ISPs are achieved than drives working on cryogenic H_2/O_2, at medium thrust levels suited for orbital manoeuvering. The energy for the microwaves is solar, and water for the reaction mass is locally available.
So water needs to be processed right away in situ to levels of purity that allow use in the MET-drives for local manouevers and for transports to LEO. There may be ways to gas out water vapour in the column and condense it for storage in tanks. The drives need to be attachable to the equipment to be moved in a modular way, ie. in the form of detachable multipurpose "tugs".

Human presence

A mining operation will almost certainly need human presence nearby, at least periodically. This implies radiation shielded habitats with at least some artificial gravity. EVAs in space-suits are not considered due to radiation. So most work will be done by robots controlled from within the habitats ("Robonauts"). Any remaining outside work requiring human eye-balling will be done in small radiation hardened EVA-pods with manipulator arms (analogous to the small crewed deep-sea submarines).
Telepresence and robotics will therefore have to be developed. A major challenge is also how to bootstrap viable local habitats with as much local resources as possible.

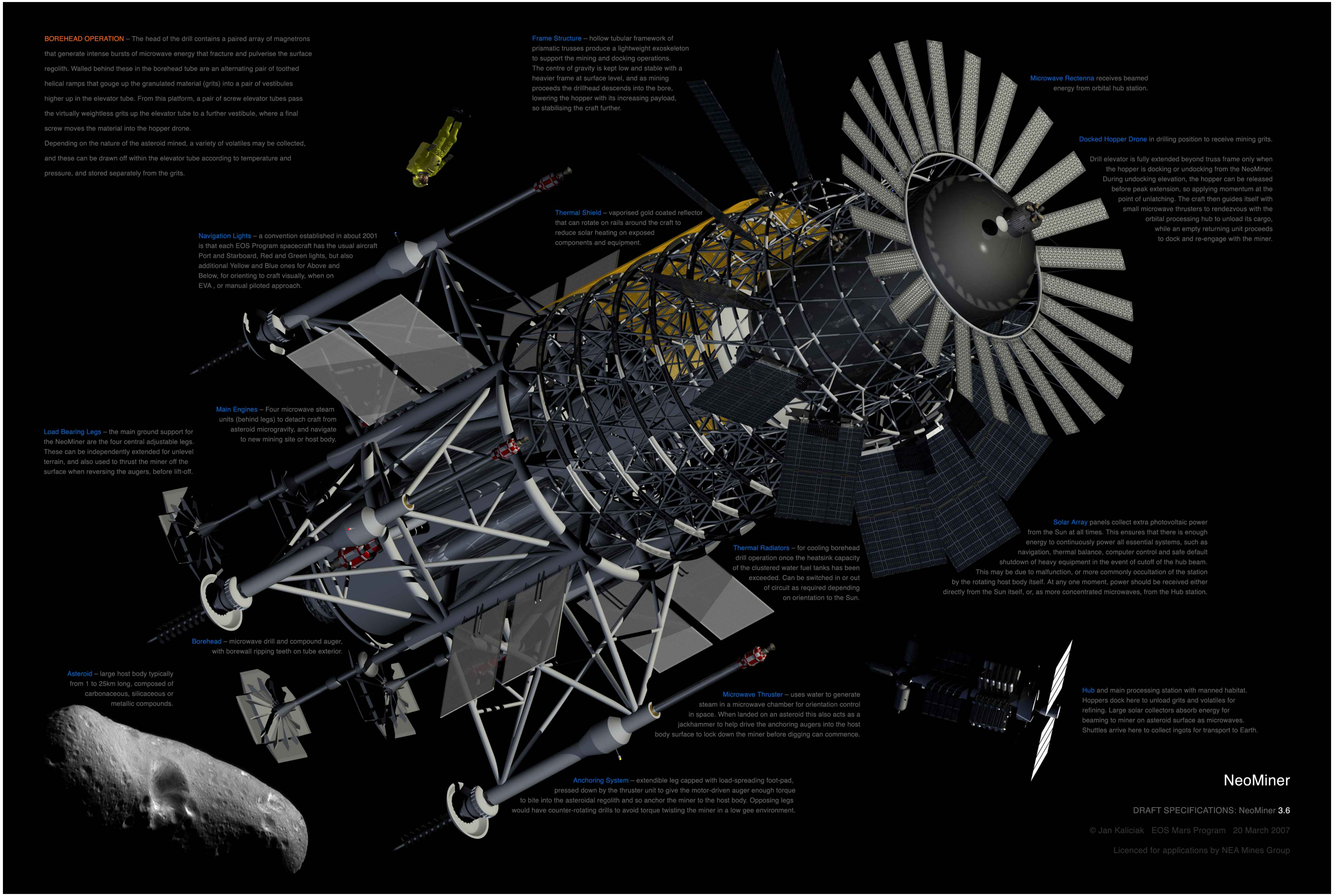

FIGURE 03 See a full-size version at – http://www.asteroidmines.net/documents/MiningRig/Fig3.JPG

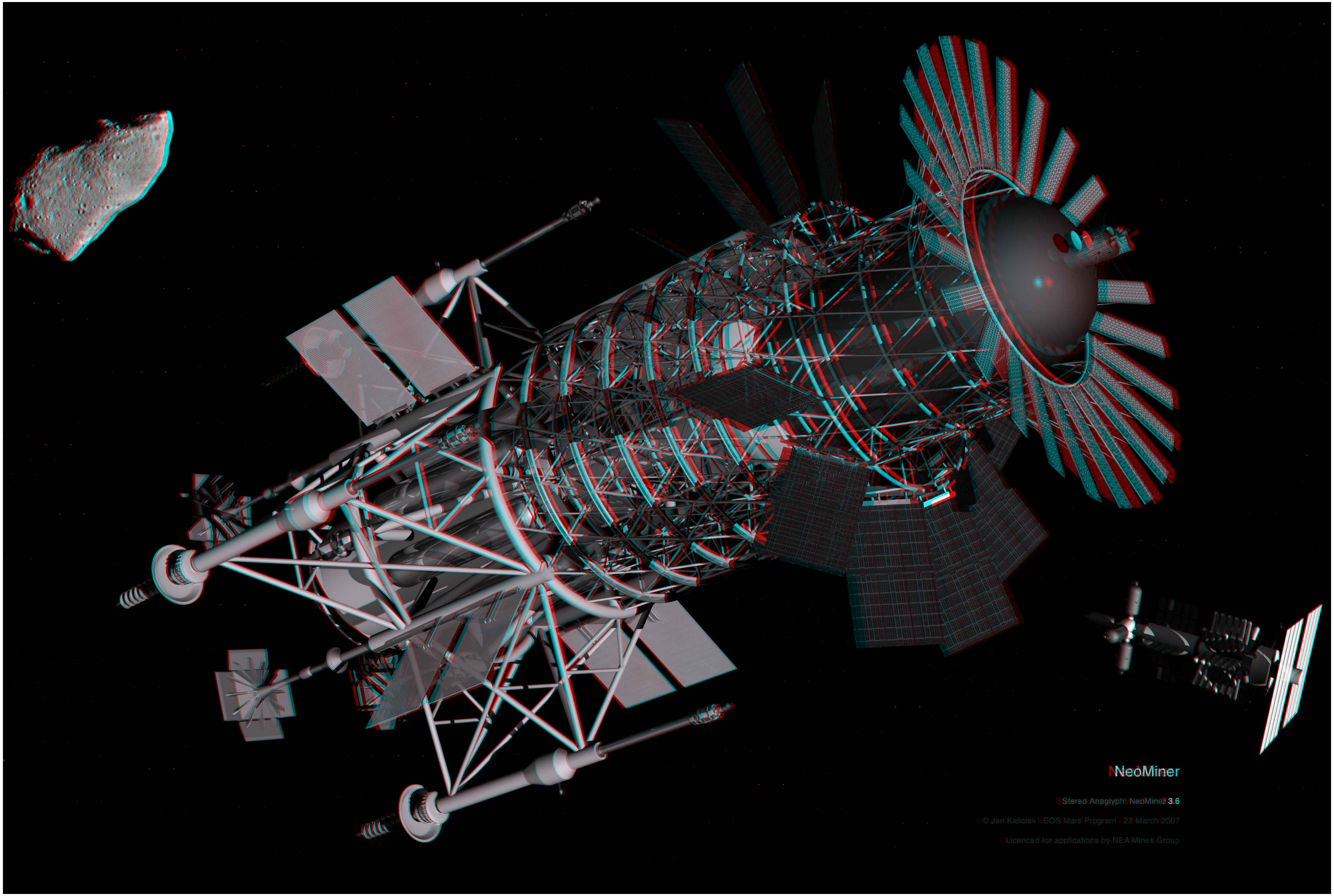

FIGURE 04 See a full-size version at – http://www.asteroidmines.net/documents/MiningRig/Fig4.JPG

Diameter of bores and structural effects on asteroid

In principle the design can work for all diameters of bores. However, the concern is what happens after a bore has reached its final depth. Retreat, shift the rig, and bore again! After a while this will result in instabilities of the asteroid, probably boreholes will slowly close up again with shifting rubble, resulting in seismic problems? How often can such a rig bore into an asteroid before it gets dangerous due to the shifting grounds? Or will it not be a problem to bore down into caved in old boreholes?

Energy

Energy for the rig is here thought to be coming from a station at a distance from the asteroid that captures solar power and transmits a tight microwave beam to the rig, which then captures it with its own antenna ("Rectenna"). However, a rig will rotate with the asteroid while the power station will stay in virtually the same spot, resulting in frequent occultations. Furthermore the power station will have to maintain station and pointing while being continuously drawn by the very light gravity of the asteroid.
One alternative would be to have power stations girdling the asteroid and connected up with a power line that connects with the rig, resulting in several power stations always being exposed to the sun.
Another alternative may be to place a power station at that pole of the asteroid which is always exposed to the sun and connect a power line from there to the rig.

Temperature control

Heating and cooling may be required at the various points along the elevator column. Heating is not the problem, but cooling requires cooling panels. With the rig rotating along with the asteroid's surface the Sun's orientation changes, and therefore the cooling panels may have to swivel or switch on and off depending on their orientation. The same applies for the PV panels.

Hopper-canister and further processing

The can at the top of the column, also called hopper in analogy to mining equipment on Earth, will be filled with what? This design simply fills the hopper with all that comes up the column, including any frozen volatiles etc. The reason is that this hopper will travel to the "hub".
"Hub" refers to the processing plant which takes in asteroid material and separates it out into the various components, mainly metals, water for fuel, other volatiles, rocky slag. For this design it was assumed the hub will be a freefloating facility at some distance from the asteroid. Refining is only to the point where: a) water is locally available for propulsion in METs, and: b) any other material that makes sense to send to LEO for further processing there. All the rest is slag. "Hub" is a placeholder concept to be further developed.

Major options and variants

The work on this design has triggered ideas for fundamentally different strategies and other applications:

Hollowing out the asteroid?

One idea is to think of asteroid mining as digging cavities into an asteroid. This would have the advantage of radiation shielding and less problems with material being bumped into escape velocity. This would be started with a shaft from a pole down the rotational axis, held open by a geodesical structure made of concrete-type or reinforced ceramic struts processed from asteroid slag. The "hub" would be sitting on the surface near the pole, along with the solar power station. Later the shaft can be internally enlarged into an internal globe exactly aligned with the rotational axis, held open by a geodesical structure. Inside this globe radiation would be down to normal levels and a spinning construction could achieve artificial gravity (a 100m diameter globe could accommodate a spinner that achieves 0.5g at 3 rpm).

Prospector-Probe?

An important machine for asteroid mining will be what has been dubbed the "Prospector" by the NEAmines group. This is a probe that digs into the asteroid and sends back samples. It is sent after a "Scout" probe has made a first assessment with a flyby and sent back data. The Prospector then sends samples to LEO for assessing the viability of investing in the mining of this asteroid.

The designed machine may be adapted to become such an automated "Prospector". The hopper-canister then becomes the sample return vehicle to LEO. Adaptation would mean:

- Miniaturization as far as possible
- Prolongation of the bore as far as possible
- A whole range of sensors and telerobotic functions that work even with a time-lag (similar to what is possible with the Mars Rovers today).

Comet-NEAs?

In case one aims for a NEA which appears to be a "burnt out" comet, water may become the main target substance for mining, as opposed to the chondrite asteroid where metals and ceramics for construction are just as important as water. It is expected that such Comet-NEAs are blanketed with a thick layer of dark black carbonaceous compounds that shield and isolate the internal ice from heating up and evaporating. What the adaptations would be for such a machine will depend on what the internal structure of such a comet will look like. One may want to be careful when puncturing the carbonaceous blanket with a bore.

The NEAmines group welcomes feedback on these preliminary designs.
We also welcome people who may want to join the effort.
Please surf to **http://www.asteroidmines.net** and contact the site-manager.
