Mining Asteroid Resources – P.V. Sukumaran, Geological Survey of India (Retd.), Mangaluru.

The finiteness of earth's mineral resources vis-à-vis growing consumption is a matter of great concern. What will the human race do when these resources get depleted? There is no need to worry at all because virtually unlimited resources are waiting to be tapped in near space itself.

Mining the skies is no longer a subject of science fiction stories and movies. Two private companies, *Planetary Resources* and *Deep Space Industries*, are already floated in the United States with the ultimate aim of mining asteroids. NASA is also vigorously pursuing plans to mine asteroids. The idea of asteroid mining was popularised by John Lewis in his book "*Mining the Sky: Untold Riches from the Asteroids, Comets, and Planets*".

The drivers for space mining are the affordability to acquisitioning resources from space and the mindboggling market value of asteroids. For instance, the metal asteroid *Amun* (2 km wide) holds incredible wealth in terms of Fe, Ni, Co, and precious metals like Au, Ag and PGMs with gross values of ~\$22 trillion!

Asteroids are flotsams of planetary accretion. They are relatively small, rocky bodies orbiting the Sun, between the orbits of Mars and Jupiter in a region called the *Asteroid Belt*. There are millions of bodies in the asteroid belt ranging from the largest asteroid Ceres (Dia: 950km) down to dust particles. Besides the main belt asteroids, others known as *Trojan Asteroids* share the orbit of Jupiter and still others called *Near Earth Asteroids (NEAs)* have orbits close to and sometimes intersecting with earth's orbit.

The asteroids represent primordial bodies that failed to fuse to form planetesimals that accreted into planets. Subsequent collisions comminuted these bodies, losing most of the materials in the early stages of planet formation. However, the larger asteroids are differentiated into a metallic core, a rock-metal mantle and a stony crust. Gravitational perturbations sometimes kick some of these out of the main belt and bring them closer to the sun forming the class of NEAs. Some NEAs could sneak into the earth's orbit posing collisional hazards on earth with the potential to cause considerable destruction. Those with orbits within 0.5 AU would be wholly inside the earth's orbit and are called *Potentially Hazardous Asteroids (PHAs)*. The useful products that can be recovered from asteroids include volatiles, metals including precious metals and semiconductor elements.

Asteroids fall into three categories: C-type (Carbonaceous); M-type (Metallic) and S-type (Stony). Though most of the meteorites originate in the asteroid belt there is no one to one correlation between them. However, M-type asteroids are comparable with IRON meteorites, S-type with STONY IRONS and STONY meteorites and C-type with carbonaceous chondrites.

The C-type asteroids are rich in volatiles, mainly water, and would serve as future fuel stations for solar system voyages. S-type asteroids or ordinary chondrite asteroids are subdivided into three groups, designated as H (High in total iron and metals), LL (Low in total iron and Low in metals) and L (intermediate between H and LL types) chondrites.

Precious metals are uniformly distributed in asteroids as their

parent bodies were not differentiated. All the three groups of asteroids contain precious metals, but the M-type is exceptionally enriched averaging about 100 ppm. However, being metallic and ductile M-asteroids are difficult to mine in a microgravity environment. Among the chondrite asteroids the LL type holds bright prospects for mining. They do not contain much metal, but their metal fractions are extremely enriched in PGMs with values of 50-60 ppm. The C-type asteroids also have considerable precious metals: the residues left after their volatiles are extracted contain about 30% native metal with the metal fraction having 50-220 ppm of PGMs.

The first step in asteroid mining is the identification of promising and prospective bodies followed by exploration of prospective ones with explorer satellites. *Planetary Resources* is contemplating launching of a series of satellites called Arkyd for detection, exploration and eventual mining of asteroids. *Deep Space Industries* is planning to launch CubeSat from carrier spacecrafts for prospecting and exploration. Once a prospective asteroid is identified suitable mining methods will have to be designed depending upon its characteristics.

The asteroidal volatiles such as water can be processed on-site to draw the propellant fuel H₂ and life-sustaining O₂; this circumvents the need to haul fuel from earth during space voyages, drastically reducing the cost of launch. The PMs processed on asteroids can be returned to earth

There are two scenarios in asteroid mining: either travel to the asteroid for mining or move the asteroid to a stable orbit near the earth for subsequent mining. NEAs pass by earth rapidly and usually do not return for a decades making mining impracticable. The alternative is to bring and park them at stable locations near earth such as the moon's orbit, the earth-moon Lagrange points or high earth orbits (>35,786 km altitude). Retrieving asteroids from their orbits and stabilising them in low earth orbits (<2000 km altitude) is a risky proposition. Failure may lead to catastrophic impacts on earth. Therefore a small size asteroid (< 30 m diameters) of the C-type would be the initial target for return mission so that even if the mission fails the asteroid will burn in the earth's atmosphere. The initial choice is to capture and transport a carbonaceous asteroid of ~30 m diameter and berth it in lunar orbit; failure in stabilising it would lead to impact on the moon, not earth.

Though technically feasible, substantial legal issues will have to be addressed before any kind of space mining could commence. The international laws are not very clear about utilization of outer space or ownership rights of space resources. The existing "UN Outer Space Treaty, 1967" will have to be expanded/modified or completely rewritten for the benefit of all because the space resources, like the deep marine resources, should be the common heritage of mankind. Obviously there is imminent need for global cooperation to enact globally acceptable regulations for space mining. Asteroid mining would obviously be a very complex venture with both technical and political challenges.

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