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ASTEROID SELECTION

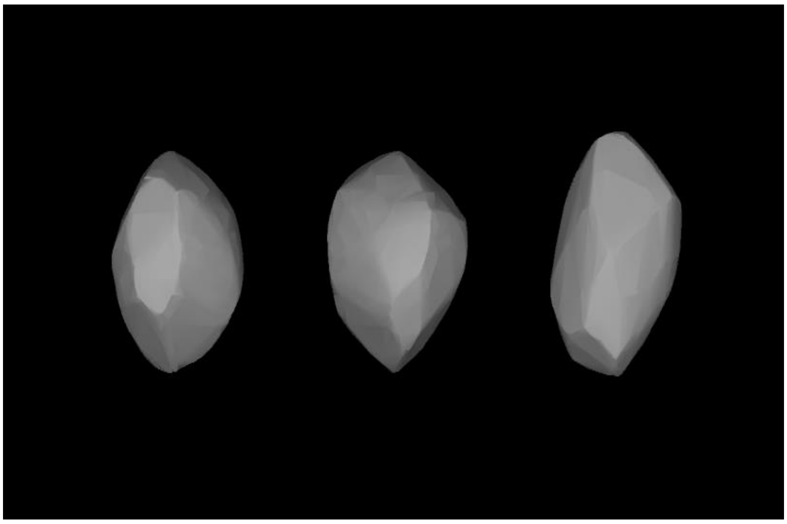
In order to extend our research for practical purposes, it is extremely important to be clear for what we are looking for. Resources are of varied importance, but we have to focus on the ones that are high on the pecking order, and satisfy the need of the hour. Hence, it is important to know **WHAT DO WE NEED** from an asteroid and **WHICH** asteroid can provide us with all the necessities.

Types of Asteroids

Profoundly, asteroids can be classified on the basis of their composition in the following types:

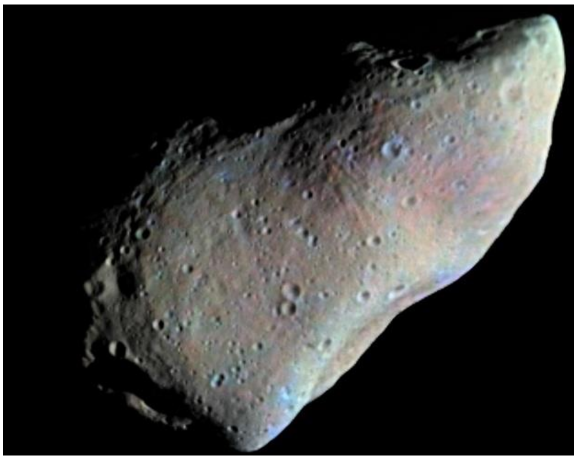
- ✓ The C-type (chondrite) asteroids are most common, probably consist of clay and silicate rocks, and are dark in appearance. They are among the most ancient objects in the solar system.
  Few examples of C type asteroids are **CERES** (unambiguous dwarf planet) **, 10 Hygiea , 24 Themis, 52 Europa.**

ERES

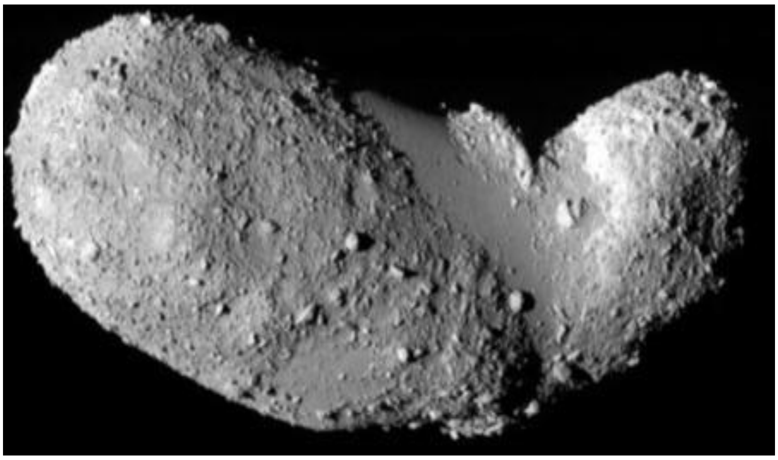


10 Hygiea

- ✓ The S-types ("stony") are made up of silicate materials and nickel-iron. They are dominant in the inner part of the asteroid belt. They moderate to weak absorption features around 1μm and 2μm. The 1μm absorption is indicative of the presence of silicates (stony minerals.)
  Few examples of S-type asteroids are **951 Graspa, 25143 Itokawa.**

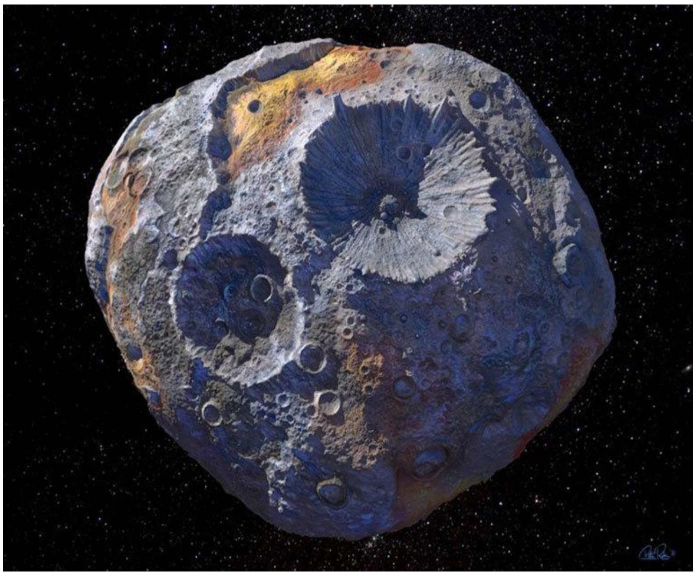


51 Graspa

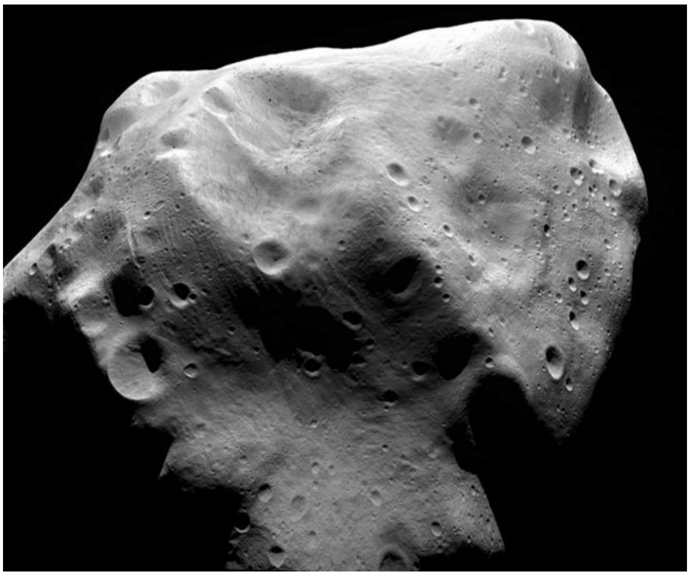


25143 Itokawa

- ✓ The M-types are metallic (nickel-iron). The asteroids' compositional differences are related to how far from the sun they formed. Some experienced high temperatures after they formed and partly melted, with iron sinking to the centre and forcing basaltic (volcanic) lava to the surface.
  Few examples of M-type asteroids are 16 **Psyche, 21 Lutetia.**



6 Psyche



21 Lutetia

<u>Purpose and Selection:</u>

Our research targets M- Type asteroids, particularly.

As we live in a physically growing world, it is important to consider alternatives for life sustenance, and therefore the prime purpose of our research is to devise an approach to mine asteroids near the Martian belt, so as to derive essential resources to successfully facilitate the colonization of Mars, as envisioned by pioneers such as Elon Musk.

Now the reason for targeting M-type asteroids is that , they are a untouched and untapped source of precious metals such as GOLD , PLATINUM, SILVER, (which can help us build our own fully functional economy) , and constructive metals such as IRON, NICKEL, MAGNESIUM (Magnetite ores), (which can help us process the manufacturing of buildings for inhabitation).

MINING CONSDIERATIONS

Ways of Mining

There are three options for performing mining operations in space can be categorised as:

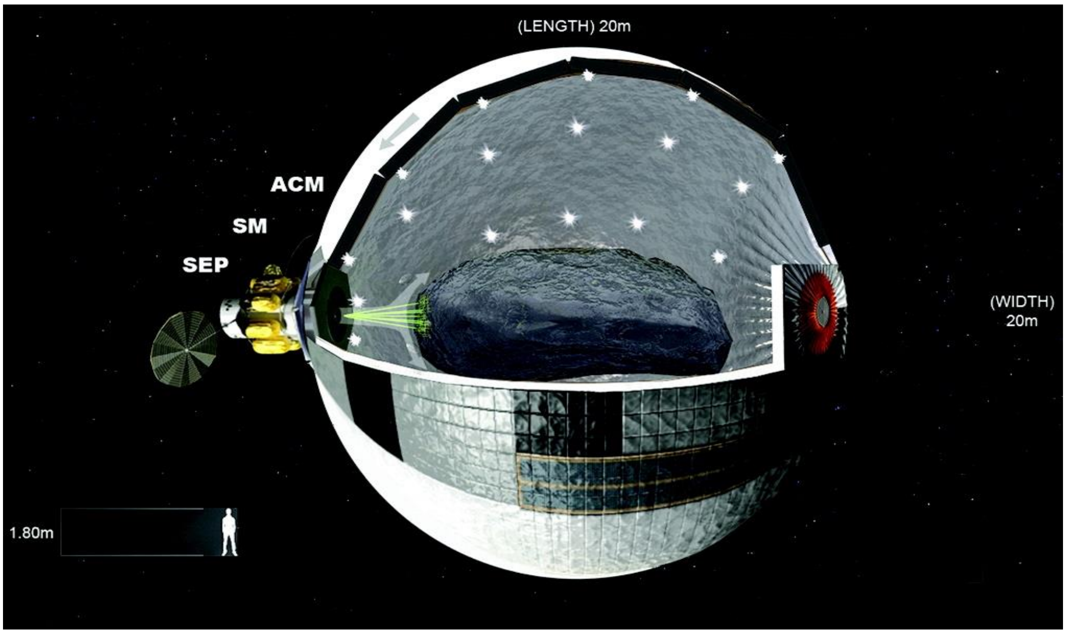
1. Bring raw asteroid to Earth for the process of refining.
2. Capture the asteroid and process on-site to bring back only processed materials, and perhaps produce propellant for the return trip.
3. Transport the asteroid to a safe orbit around the Moon, Earth or to the ISS. This can hypothetically allow for most materials to be used and not wasted.

Our Agenda

Our agenda here mainly focuses on carrying out the mining processes in the space itself instead of bringing it back to earth, to reduce expenses of individually, bringing every asteroid to earth, from the Martian belt of asteroids. We plan to setup a fully functional artificial working environment on Mars itself (equipped with all the necessities to support man power, like artificial gravity, oxygen, etc.)

How we plan to do it, is elucidated in the following points.

- ✓ First of all, the enclosure that we have built for the targeted asteroid will engulf the M- type asteroid, as a whole.
- ✓ Now, within the enclosure, a process of laser cutting will be employed, to cut down the asteroid to extractable size.
- ✓ Now from our enclosure system, the asteroid will be deployed onto on the Martian surface via small pods that will be launched from the surface of the enclosure system, carrying parts of asteroids that are to be extracted.
- ✓ Once the pods reach our extraction facility, setup at Mars, the pods will be configured for a relaunch back to the enclosure.
- ✓ The asteroids will be taken out, and their composition will be studied.
- ✓ According to their metal composition, suitable extraction techniques will be employed.
- ✓ Once the metals are extracted, they are used for structural processing, in our mission to colonize Mars.
- ✓ We wish to setup such enclosure systems close to every asteroid belt in our reachable space, so as to maximise our resource gains. Every once in a while, (say in a few years), a team of engineers and scientists, from the International Space Station will travel to the Enclosure systems and check for any possible technical faults.
- ✓ Moreover, though our main goal is to use the resources derived from the asteroids, to propagate our inhabitation mission only, but every once in a while, deposited chunk of resources (including extracted metals in excess , eolith , impurities obtained as a result of extraction, which can be of use) will be sent back to earth.



CAPTURING THE ASTEROID

As per the selected type of asteroid, a M-type asteroid will be approached by a spherical enclosure called the Capsule. Just before placing itself in position alongside the asteroid the Capsule would split into two semi-spheres. Then it will place itself alongside the asteroid in such a way that the asteroid and the two semi-spheres align in the same plane (as shown in Fig. 1.) This is called the Transition Phase. The two semi-spheres also include instruments such as Synthetic Aperture Radar (SAR), Terrain Mapping Camera (TMC) for mapping the surface and Collimated Large Array Soft X-ray Spectrometer (CLASS) for mapping the abundance of minerals on the surface. Mapping the surface and finding the composition of the surface are also a part of the Transition Phase before moving to the next phase.

After the transition phase is complete, the two semi-spheres will start moving towards each other steadily. This would continue till the two semi-spheres lock themselves, encapsulating the asteroid in the Capsule (as shown in Fig. 2.) This stage is called the Encapsulation Phase. This process would be guided by the LASER Distance Sensors for (LDS) measuring distance between the surface of the spheres and the asteroid surface.

The major problem encountered with asteroids while changing their orbits is that, to introduce any change in the orbit some force needs to be applied into the system which disturbs the closed system. In space the asteroids are not under influence of gravitational force of another massive object such as some planet or moon. This means that there is no gravitational pull from another body is binding the asteroids together, the asteroids are chunks of rocks bound together by the phenomena of microgravity. If any additional force is introduced into the system rapidly without any measures to counter its effects and put everything back into place, the asteroid would break into several pieces defeating the purpose.

To counter the problem discussed above, the Suspension Phase is designed. When the Encapsulation Phase is complete, the Suspension Stage would start. In which, multiple silicon padded arms with hydraulic suspension extending from the inner surface of the Capsule would touch the surface of the asteroid. These arms would also be housing the same LASER Distance Sensors (LDS) used in the Encapsulation Stage assisting them to determine how long to extrude till they touch the asteroid surface. After the arms touch down on the surface a computer would keep the measurement of the pressure levels in the arms and maintain them according to the direction of the force applied while performing the orbit changing maneuvers. This way the asteroid is suspended in the middle of the Capsule and the force introduced into the system is countered by the hydraulics pushing the separated pieces back in place, while changing the course of the asteroid and bringing it to the orbit of Mars. The Suspension phase is represented in the Fig. 3.

After the asteroid is encapsulated, it is now ready for the changes in its orbit which would be made by the rocket thrusters present on the exterior surface of the Capsule. The thrusters would fire multiple small bursts after a considerate gap of time giving the asteroid time to adapt to the force introduced into the system and being brought back to its shape by the hydraulic suspension arms. This procedure making small changes would continue till the asteroid is set on a course to Mars where its further extraction would take place.

EXTRACTION/MINING OF MATERIALS

Mining Phase

Mining Phase is breaking down the asteroid into smaller blocks for further refining process. The inner surface of the Capsule would also house 8 high powers LASERS mounted on 90º rotatable platforms, one in each quarter-sphere. These LASERS would help in cutting the asteroid into several smaller pieces. This process if slicing and trimming the asteroid would be accompanied by the array of Collimated Large Array Soft X-ray Spectrometers (CLASS) helping in cutting the asteroid according to concentration of materials in each of the smaller cut pieces. This technique converts the homogeneously mixed rocks into heterogeneous ores helping in choosing the techniques for refinement.

Basis of Process Selection

Choosing to perform the mining procedure in the Capsule itself eliminates the need for deploying another facility for the same process. Another problem it solves is that if another facility is to be made for the mining then it would restrict its operations only to a certain size of asteroids that can be exploited. For future operations also choosing to mine within the capsule also leads to a further approach where more Capsules of different size could be created to capture different sized asteroids but still using only one facility to refine materials brought from different Capsules. This approach also proves to be more economical since making multiple capsules of different size is more feasible than making several facilities for refining different sized asteroids.

Why use LASERS for Mining

Using LASERS for cutting big to small helps in precise shaping of the pieces, thus eliminating creation of any smaller particles as debris. And because of being assisted by the CLASS instruments it also helps in easier classification of the smaller chunks and reduction of the amount of unusable material being left out. Using LASERS also eliminates the possibility of disintegration of the asteroid while mining which means that the shape of the asteroid will be relatively intact later helping in transferring the materials.

Extraction Procedure

Once the Mining Phase is over, the retentions arms inside the Capsule holding the asteroid in place will then retract while the broken asteroid still suspends in its place. The Capsule would then open into two semi-spheres releasing the materials inside and slowly move away getting ready for another mission.

Now the suspended material would be approached by small pods. Each pod collecting ores of different metals. The pods would be equipped with a collection bay, a pair of two arms for grapping materials, and sensors helping in determine which piece of rock is what kind of an ore. Once they collect the materials from the orbit, they would descend to the surface of Mars where the ores would be dumped into other machines for the refinement process and return back to the orbit.

Until now every phase from Capturing the Asteroid to bringing the materials to Martian surface was automated and only monitored by humans but the refinement process would see more involvement of the humans.

REFINING

Considering that the refinement process is happening on Mars, all the processes devised and discussed further adhere to the to this facts that there should be no or minimum amount of biproducts generated, there is very little gravitational force on Mars, and all the materials and apparatus required to refine the ore would be sent from earth.

IRON:

- Iron is extracted from its ore, haematite, by reduction with carbon.
- This takes place in a blast furnace (named after blasts of air [20% oxygen], heated to 1000 °C, which are blasted into the bottom of the furnace):
- A mixture of crushed iron ore, coke (an almost pure form of carbon) and limestone is fed into the top of the blast furnace.
- The coke is oxidised to carbon dioxide:
  $C + O_2 \rightarrow CO_2$
  The reaction is exothermic.

- The carbon dioxide reacts with coke to form carbon monoxide.
  $CO_2 + C \rightarrow 2CO$
  The reaction is endothermic.

- Iron (III) oxide in the ore is reduced to iron by the carbon monoxide.
  $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
  The reaction is exothermic.

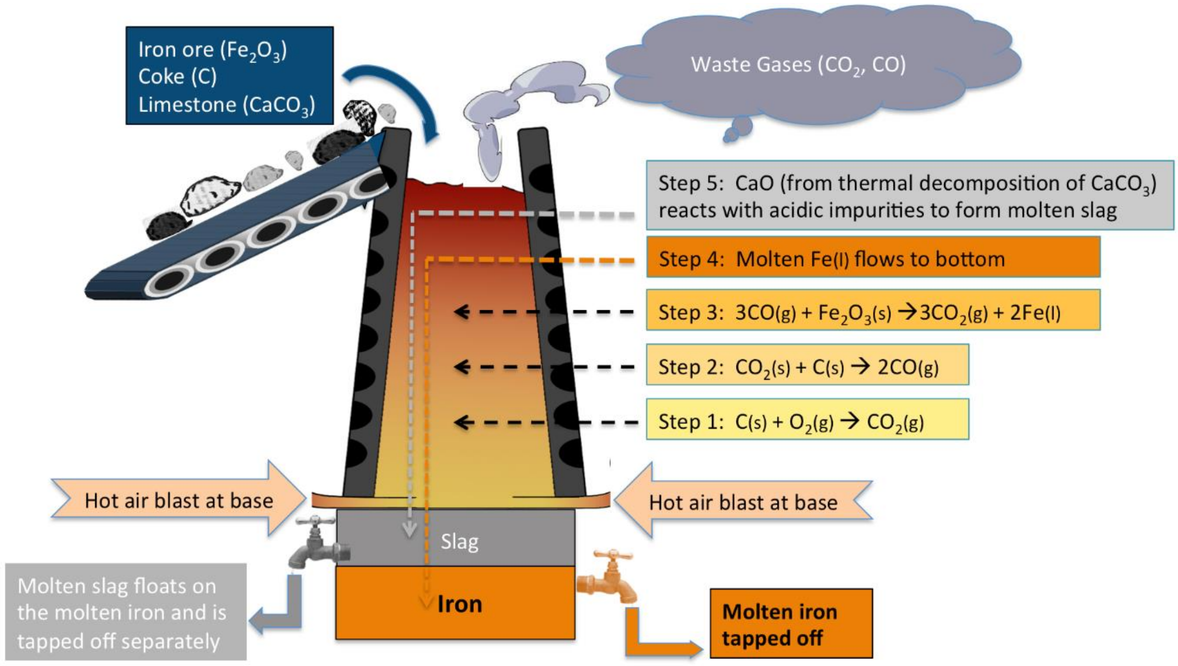
- The iron falls to the bottom of the blast furnace where it melts

- Limestone, or calcium carbonate ($CaCO_3$), is used to removed impurities
- $CaCO_3$ decomposes in the blast furnace to calcium oxide:
  $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

- The CaO then reacts with SiO_2 and Al_2O_3 impurities:
  $CaO(s) + SiO_2 \rightarrow CaSiO_3(s)$
  $CaO(s) + Al_2O_3 \rightarrow CaAl_2O_4(s)$

- The $CaSiO_3$ and $CaAl_2O_4$ is less dense than the iron so it forms a *slag* which floats on top of the iron
- The slag can then be removed.

We wish to develop the blast furnace facility on mars itself. The iron will be converted to its molten form via heat obtained by focussing the rays of sun using lenses. We can use the maximum potential of paraxial heat rays of the sun, by deploying suitable convex lenses to concentrate these rays directly at the chunk of metals to convert them into their molten form.



<u>NICKEL:</u>

Mond process

- The purest metal is obtained from nickel oxide by the Mond process, which achieves a purity of greater than 99.99%.
- In this process, nickel is reacted with carbon monoxide in the presence of a sulphur catalyst at around 40–80 °C to form nickel carbonyl.
- Iron gives iron pentacarbonyl, too, but this reaction is slow.
- If necessary, the nickel may be separated by distillation.
- Dicobalt octacarbonyl is also formed in nickel distillation as a by-product, but it decomposes to tetracobalt dodecacarbonyl at the reaction temperature to give a non-volatile solid.
- Nickel is obtained from nickel carbonyl by one of two processes.
- It may be passed through a large chamber at high temperatures in which tens of thousands of nickel spheres, called pellets, are constantly stirred.
- The carbonyl decomposes and deposits pure nickel onto the nickel spheres.
- In the alternate process, nickel carbonyl is decomposed in a smaller chamber at 230 °C to create a fine nickel powder.
- The by-product carbon monoxide is recirculated and reused. The highly pure nickel product is known as "carbonyl nickel”.

(1) Mond Process

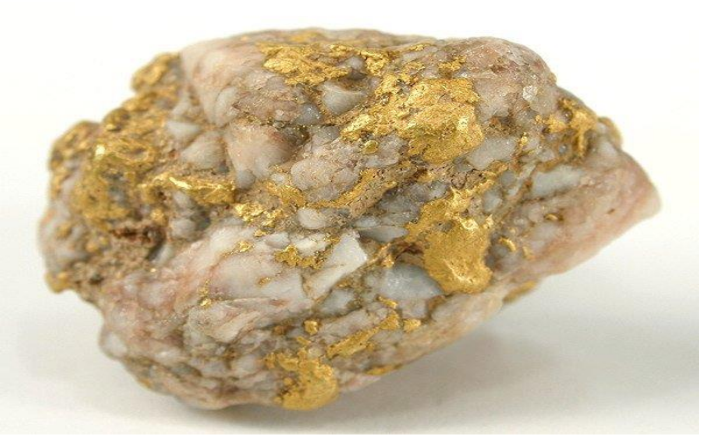
$$Ni + 4CO \xrightarrow{330-350K} Ni(CO)_4 \text{ (nickel tetra carbonyl)}$$

Impure nickel

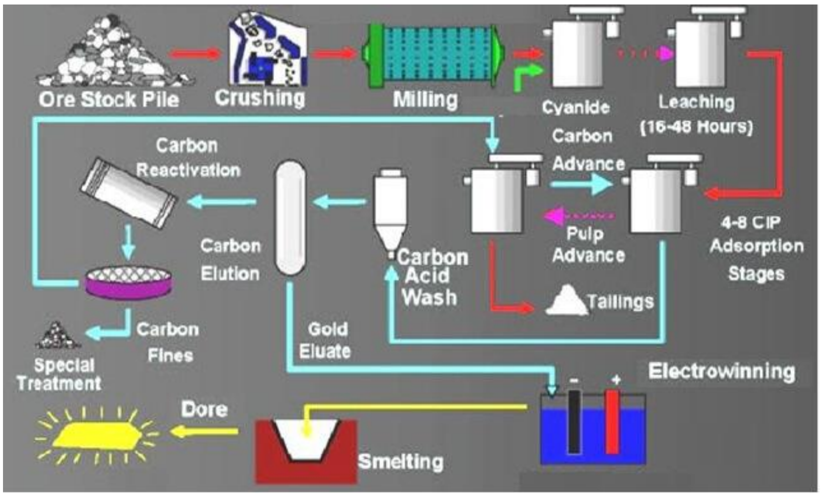
$$Ni(CO)_4 \xrightarrow{450-470K} Ni \text{ (pure nickel)} + 4CO$$

GOLD & PLATUNUM:

- ✓ Gravity concentration is the most important way of extracting the native metal using pans or washing tables.
- ✓ **Amalgamation with mercury** was used to enhance recovery, often by adding it directly to the riffle tables, and mercury is still widely used in small diggings across the world.
- ✓ However, **froth flotation** processes may also be used to concentrate the gold.
- ✓ In other cases, particularly when the gold is present in the ore as fine particles or is not sufficiently liberated from the host rock, the concentrates are treated with cyanide salts, a process known as **cyanidation leaching**, followed by recovery from the leach solution.
- ✓ Recovery from solution typically involves adsorption on activated carbon then stripping (eluting) the gold from the carbon and passing the pregnant solution through **electrowinning** and then onto the smelting process.
- ✓ Froth flotation is usually applied when the gold present in an ore is closely associated with sulphide minerals such as pyrite, chalcopyrite or arsenopyrite, and when such sulphides are present in large quantities in the ore.
- ✓ In this case, concentration of the sulphides results in concentration of gold values.
- ✓ Generally, recovery of the gold from the sulphide concentrates requires further processing, usually by roasting or wet pressure oxidation.
- ✓ These pyrometallurgical or hydrometallurgical treatments are themselves usually followed by cyanidation and carbon adsorption techniques for final recovery of the gold.



Impure Gold **Pure Gold**



Schematic Diagram

MAGNESIUM:

Magnesium is similar to aluminium in appearance but weighs 1/3rd less.

It is the lightest structural metal known. At temperatures above 645 degrees Celsius, it is strongly reactive with oxygen.

There are two ways to extract magnesium from its ore – by thermal reduction of magnesium oxide after calcination as it is a carbonate ore, or by electrolysis of magnesium chloride.

We opt for the thermal reduction since the purity of magnesium obtained is about 99.99%

In thermal production, dolomite is calcined to magnesium oxide (MgO) and lime (CaO), and these are then reduced by silicon (Si), yielding magnesium gas and a slag of dicalcium silicate. The basic reaction is endothermic

$2CaO + 2MgO + Si \text{ ----------> } 2Mg + Ca_2SiO_4$

Due to heat requirements in the presence of air, industrial extraction processes take place in vacuum.

After extraction, crude magnesium metal is transported to cast shops for removal of impurities, addition of alloying elements, and transformation into ingots, billets, and slabs. During melting and handling, molten magnesium metal and alloys are protected from burning by a layer of flux or a gas such as sulphur hexafluoride or sulphur dioxide.

APPLICAIONS OF MATERIALS PROCURED

As discussed in the introduction of the research, we are targeting the M-type asteroids (Metallic Asteroids) which have great concentrations of metals in them. The introduction also discusses the reasons for choosing this particular breed of asteroids, but seeing as a conclusion of this research paper we found out that we need concentrate the output of the complete mining and extraction operation according to the materials required by humans to fulfil their Mars Colonisation aspirations. So, the metals finally mined and extracted out of these M-type asteroids will be IRON, NICKEL, MAGNESIUM, GOLD, PLATINUM. These applications and use of these metals would be enormous for making Mars a habitable place, and these materials can also be used in replicating and manufacturing more number of Capsules enhancing the speed and the efficiency of the whole mining operation itself.