Asteroid mining outpost: Rate of extraction of materials from asteroids

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Abstract

All asteroid mining studies I could find focussed on the energy needed for transport of materials back to earth or total mineral content. As an approximation, here I apply the data about modern mining sites on the surface of the earth to deduce a plausible rate of extraction of various elements from an asteroid.

I find that in every hour of operation earthen mines on average extract material from the earth at a rate of $474.47cm^3/h/m^2 \pm 221.4cm^3/h/m^2$ (based on their land area). As such given the assumptions taken here, and knowing the elemental makeup of asteroids, the rate at which material will be extracted from the asteroid (in kg/h) can be easily calculated based on the surface area being mined out, which is presented here with an example in section 3.

Contents

1 Material density in asteroids

Below I present a table of the makeup of metal and stony meteorites from chview.nova.org, percentage by mass (I assume):

	Iron meteorite	Stony meteorite	Lunar crust	Earthen crust
Iron	91%	26%	13%	4.7%
Nickel	8.5%	1.4%	-	-
Cobalt	0.6%	-	-	-
Oxygen	-	36%	42%	49%
Silicon	-	18%	21%	26%
Magnesium	-	14%	6%	1.9%
Aluminum	-	1.5%	7%	7.5%
Calcium	-	1.3%	8%	3.4%
Sodium	-	-	-	2.6%
Potassium	-	-	-	2.4%

For densities of the asteroids, with wikipedia as a source, I take that S-type asteroids have a density (average) of $3000kg/m^3$ and M-type asteroids have densities from $3000kg/m^3$ (low end) to $8000kg/m^3$ (high end). Based on that I present below densities of the individual materials in S-type (stony) and M-type (metal) asteroids, assuming the same makeup as the stony & iron meteorites.

	Stony (average)	Metal (low end)	Metal (high end)
All	$3000kg/m^3$	$3000kg/m^3$	$8000kg/m^3$
Iron	$780kg/m^3$	$2730kg/m^3$	$7280kg/m^3$
Nickel	$42kg/m^3$	$255kg/m^3$	$680kg/m^3$
Cobalt	-	$18kg/m^3$	$48kg/m^3$
Oxygen	$1080kg/m^3$	-	-
Silicon	$540kg/m^3$	-	-
Magnesium	$420kg/m^3$	-	-
Aluminum	$42kg/m^3$	-	-
Calcium	$39kg/m^3$	-	-

This table simply tells you how many kilograms of a given material in raw, unrefined form you would get if you were to extract a cubic metre of the given type of asteroid. The assumption here is that asteroids are homogenous, which I can see would not necessarily the case, especially with ones that are big enough to have significant gravity, but I don't have a way to account for it.

2 Material extraction rate in earthen mines

I focus mostly on pit mines, and calculate the volume of the mine from it's dimensions, then divide the volume by the time for which the mine was operational to get material the extraction rate.

Pit volume is calculated as a cone. If 2 different dimensions in horizontal axis are given they are averaged to get the radius.

$$V_{cone} = \frac{1}{3} \times \pi \times r^2 \times h$$

where:

- r is radius of the cone
- h is height of the cone, in this case depth of the mine

Below I present a list of the mines I selected and their dimensions.

1. Chuquicamata
   4.3km long, 3km wide, 900m deep
   "Production started on May 18, 1915", ". . . until the end of 2007"

2. Mir mine
   1200m in diameter, 525m deep
   "Open-pit mining began in 1957 and was discontinued in 2001."

3. Bingham Canyon Mine
   "a pit over 0.75 miles (1,210 m) deep, 2.5 miles (4 km) wide, and covering 1,900 acres (3.0 sq mi; 770 ha; 7.7 km^2)" - if it covers $7.7km^2$ then it would have to have a radius of 1.56km, or 3.13km diameter rather than 4km, I guess it's either rounding or asymetry. I'll assume the stated area is correct so $\frac{1}{3} \times 7.7 \times 10^6 m^2 \times 1210m = 9756739584m^3$
   "The mine has been in production since 1906"
   The mine is still active, but the source cited for the dimensions of the pit is from 2016.

4. Super Pit gold mine
   "approximately 3.5 kilometres long, 1.5 kilometres wide and over 600 metres deep" in 2020 $\approx 981747704m^3$
   Opened in 1893

5. Hull-Rust-Mahoning Open Pit Iron Mine
   "The pit stretches more than three miles (5 km) long, two miles (3 km) wide, and 535 feet (163 m) deep." in 2012
   " It was established in 1895 and was one of the world's first mechanized open-pit mines."

A table with the years of activity of selected earthen mines and their volumes, from which I deduce the extraction rate of the rock by dividing the volume by the time it took to create that pit.

	Years operation	pit volume	extraction rate
Chuquicamata	1915-2007 (92y)	$3139040100m^3$	$3892m^3/h$
Mir mine	1957-2001 (44y)	$197920337m^3$	$513.14m^3/h$
Bingham Canyon Mine	1906-2016 (110y)	$9756739584m^3$	$10118m^3/h$
Super Pit gold mine	1983-2020 (127y)	$981747704m^3$	$881.85m^3/h$
Hull-Rust-Mahoning	1895-2012 (117y)	$682772803m^3$	$665.7m^3/h$

Below I also present a table with the land area which the mine takes up, and the resulting extraction rate per area.

	area	extraction rate per area
Chuquicamata	$10463467m^2$	$372cm^3/h/m^2$
Mir mine	$1130973m^2$	$453.7cm^3/h/m^2$
Bingham Canyon Mine	$7700000m^2$	$1314cm^3/h/m^2$
Super Pit gold mine	$4908739m^2$	$179.65cm^3/h/m^2$
Hull-Rust-Mahoning	$12566371m^2$	$53cm^3/h/m^2$

The extraction rate per area averages to $474.47cm^3/h/m^2 \pm 221.4cm^3/h/m^2$, meaning that on average each square metre of a mine adds $474.47cm^3/h/m^2$ to the extraction rate, and with 68.3% confidence any given site should have that value somewhere between $253.07cm^3/h/m^2$ and $695.87cm^3/h/m^2$. This is a sample, ie. a few data points from a larger set so for the margin of error:

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \overline{x})^2}$$

$$s_{\overline{x}} = \frac{s}{\sqrt{N}}$$

where:

- s is the deviation
- $s_{\overline{x}}$ is the margin of error (68.3% confidence)
- x_i is the value of the i'th sample (ie. $372cm^3/h/m^2$ for i=1)
- $\overline{x}$ is the average of all samples (here $474.47cm^3/h/m^2$)
- N is the sample size (here 5)

3 Expected asteroid mineral extraction rate

Taking the previously found average material extraction rate per area which came out to $474.47cm^3/h/m^2$ ($0.00047447m^3/h/m^2$), it can be applied to the previously presented types of asteroids to find at what rate the material is extracted if such a mine were to be present on an asteroid.

Below I present extraction rates per area of mining operation for various elements on the given types of asteroids.

	Stony (average)	Metal (low end)	Metal (high end)
All	$1.42341kg/h/m^2$	$1.42341kg/h/m^2$	$3.79576kg/h/m^2$
Iron	$0.3700866kg/h/m^2$	$1.2953031kg/h/m^2$	$3.4541416kg/h/m^2$
Nickel	$0.01992774kg/h/m^2$	$0.12098985kg/h/m^2$	$0.3226396kg/h/m^2$
Cobalt	-	$0.00854046kg/h/m^2$	$0.02277456kg/h/m^2$
Oxygen	$0.5124276kg/h/m^2$	-	-
Silicon	$0.2562138kg/h/m^2$	-	-
Magnesium	$0.1992774kg/h/m^2$	-	-
Aluminum	$0.01992774kg/h/m^2$	-	-
Calcium	$0.01850433kg/h/m^2$	-	-

The use of this data can be illustrated with a mine 1 square kilometre (1 000 000 m^2) in area on a low-end metal asteroid. Multiplying the mine area with "all" material would yield the total mass extracted per hour, which would be $1000000m^2 \times 1.42341kg/h/m^2 = 1423410kg/h$, so on average the mine is extracting 1 423 410 kg of materials, a bit over 1.4 thousand tonnes every hour, or a bit over 34 thousand tonnes in a 24-hour day.

Doing the same for Iron, Nickel and Cobalt alone gives the results:

- 1 295 303.1 kg (just under 1.3 thousand tonnes) of iron every hour.
- 120 989.85 kg (nearly 121 tonnes) of nickel every hour.
- 22 774.56 kg (a bit under 22 tonnes) of cobalt every hour.

It should ofcourse be noted that the material is being extracted in raw, combined form, which will need refining, but in that regard while I made no connection with the actual amount of equipment needed to do so, basing the data on real earthen mines means the resource extraction rate probably is tailored to the overall rate at which the finished refined product is made.

Relating the production rate to amount of equipment can be as simple as calculating the amount of area which some given amount of equipment, however measured, can adiquately operate - ultimately this would require it's own closer look to avoid oversimplification & arbitrary numbers.