EXTRATERRESTRIAL MINERALS AND FUTURE FRONTIERS IN MINERAL EXPLORATION

MINERALES EXTRATERRESTRES Y FUTURAS FRONTERAS EN LA EXPLORACION MINERAL

WILMER GIRALDO

Estudiante de Ingeniería Geológica, Universidad Nacional de Colombia Sede Medellín, wegirald@gmail.com

JORGE IVÁN TOBÓN

PhD, Departamento de Materiales y Minerales, Universidad Nacional de Colombia Sede Medellín, jitobon@unal.edu.co

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ABSTRACT: Due to the high rates of consumption of minerals and the high human population growth, mineral resources on planet Earth are in the process of exhaustion, this shortage creates the need to find new alternatives to supply the growing needs. An additional alternative to the traditional search for new deposits on Earth, is the search for deposits beyond our planet, these new resources can be found in the vicinity of our planet. The mining of bodies of our solar system like the Moon, Mars and the asteroid belt can provide abundant energy resources such as helium 3 and minerals such as potassium, rare earth elements, iron and platinum group minerals. Now some companies are planning this exploration and for geologists and mining professionals in general, it has considerable potential for scientific research, technological innovation and professional development in new fields.

KEYWORDS: Space Mining, Mineral Exploration, Moon, Mars, Asteroids, Helium 3.

RESUMEN: Debido a las altas tasas de consumo de minerales y el alto crecimiento de la población humana, los recursos minerales en el planeta Tierra se encuentran en proceso de agotamiento, esta escasez crea la necesidad de encontrar nuevas alternativas para suplir las crecientes necesidades. Una alternativa adicional a la tradicional búsqueda de nuevos yacimientos en la tierra, es la búsqueda de yacimientos más allá de nuestro planeta, estos nuevos recursos se pueden buscar en la vecindad de nuestro planeta. La extracción en cuerpos de nuestro sistema solar como la Luna, Marte y el cinturón de asteroides puede proporcionar abundantes recursos energéticos como el helio 3 y minerales como el potasio, elementos de tierras raras, hierro y minerales del grupo del platino. Ahora, algunas compañías están planeando esta exploración y para los geólogos y profesionales de la minería en general, esto abre grandes posibilidades para la investigación científica, innovación tecnológica y desarrollo profesional en nuevos campos.

PALABRAS CLAVE: Minería Espacial, Exploración Mineral, Luna, Marte, Asteroides, Helio 3.

1. INTRODUCTION

According to UN (United Nations) estimates, in 2012 the world population is over 7000 million and will continue to increase. It is evident the large quantities of minerals are necessary to supply the global needs, taking into account that the largest mineral deposits and easiest to extract are almost completely depleted at present, additionally, the perception about the Natural Capital has changed as the developing world has risen and the effects of population explosion was made visible, promoting resource extraction without affecting the environment **[1]**.

Currently, it is necessary to find new alternatives to supply the growing world need, presently mineral exploration focuses on the search for deeper, lower grades and more remote deposits, but it is necessary to consider new frontiers, not only to look for minerals beneath our feet, over our heads can be a promising place. Due to the depletion of the mineral resources on Earth, in the future, the exploration for minerals and resources are going to be in space.

2. LOOKING IN OUR NEIGHBORHOOD

When the decision to look for new minerals deposits is taken, the first step consist in researching alternatives, to look around us for the nearest possibilities in our solar system. These alternatives are relatively well known and offer resources that are scarce or nonexistent in our planet.

The celestial bodies closest to the Earth are the Moon, Mars, Venus, the asteroids, and comets. Due to the high temperatures and pressures prevailing in the surface of Venus, the opportunities to develop mining projects there are very limited, therefore, we focus on analyzing the possibilities in the other bodies, which offer better conditions, additionally there are major technical challenges to develop mining in low gravity environments but some companies are working on the development of these new mining methods

2.1. The Moon

The Moon provides the greatest potential for mining in our solar system; due to its proximity to our planet and the fact that we have traveled there successfully in the past.

The high mineral potential of the Moon is mainly based on two conditions, first, the Moon consist in differentiated material from the Earth, i.e. rich in materials not very common in the Earth, another very important feature is the absence of magnetic field and weak atmosphere, this makes the lunar surface susceptible to receive large amounts of cosmogenic isotopes that cannot reach the Earth's surface due to the protection provided by the magnetic field and atmosphere, these elements are trapped in the lunar soil and can be exploited economically.

One possibility of returning to the Moon could rely on extracting and using helium-3 that is trapped on the Moon within glass particles, along mineral crystal grain boundaries, and within Moon dust. According to estimates by Slyuta et al.**[2]**. On the lunar surface there is an average of helium-3 between 1.4 and 15 ppb (parts per billion), it is estimated that in some places the average can reach 50 ppb (Figure 1).

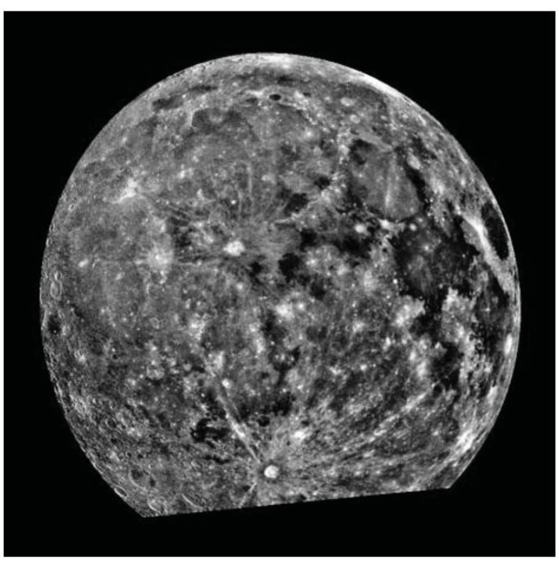

Figure 1. Galileo false-color composite image of the Moon. The exaggerated color helps determine surface composition (blue is titanium-rich soil). **[3]**.

According to Schmitt **[4],** just in the resources of the titanium-rich basaltic soils of the Mare Tranquillitatis there are at least 10,000 tons of helium-3, additionally, the Lunar Prospector orbiting during 1997-1999 identified that helium-3 may be concentrated at the lunar poles. Just 25 tons of helium-3 can supply the annual energy demand of the United States **[5]**, this implies that for each ton of helium-3 could produce energy with a value of 3 billons of USD.

The fusion of Helium-3 (Figure 2) is important because they are a safer and cleaner nuclear reactions **[6]** because it uses no radioactive fuels and produces no radioactive isotopes, furthermore it releases large amounts of energy, with 1 kg of helium-3 and 0.67 kg of Deuterium (isotope of hydrogen, hydrogen-2) 19 megawatt year would be produced.

Other major minerals on the Moon are the rare earth elements (REE), these elements have become very important for the development of current technologies (from wind turbines and glass for solar panels to use in hybrid cars, and even guided missiles and other defense-oriented creations) and their existence on the planet Earth is limited, additionally, producing countries are limiting their availability and banning exports in order to supply the domestic demands, the scarcity of these valuable minerals grows, therefore it is important to ensure the availability of this limited resource.

The REE on the Moon are associated with other elements of great economic importance. KREEP is an acronym based on element symbols for the geochemical component in lunar rocks rich in potassium (K), rare-earth elements (REE), phosphorus (P), thorium, and other so called "incompatible" elements **[7]**. All these elements are more easily found on the Moon than on Earth because of the high degree of differentiation of the Moon rocks.

2.2. Mars

Martian rocks, present evidence of interaction with water, and also show evidence of a complex geological history. Mars shows large amounts of meteorite impacts and had high volcanic activity as evidenced by Mount Olympus, an extinct volcano and the highest mountain in the solar system.

Different Martian exploration projects have found evidence of dikes and extinct volcanoes **[8],** suggesting large heat fluxes under the Martian surface, this heat and the igneous activity can cause the development of major mineral deposits.

In meteorites from Mars valuable elements like magnesium, aluminium, titanium, iron, chromium and trace elements like lithium, cobalt, nickel, copper, zinc, niobium, molybdenum, lanthanum, europium, tungsten, and gold are relatively common. It is quite possible that in some places these materials may be concentrated enough to be mined **[9]**.

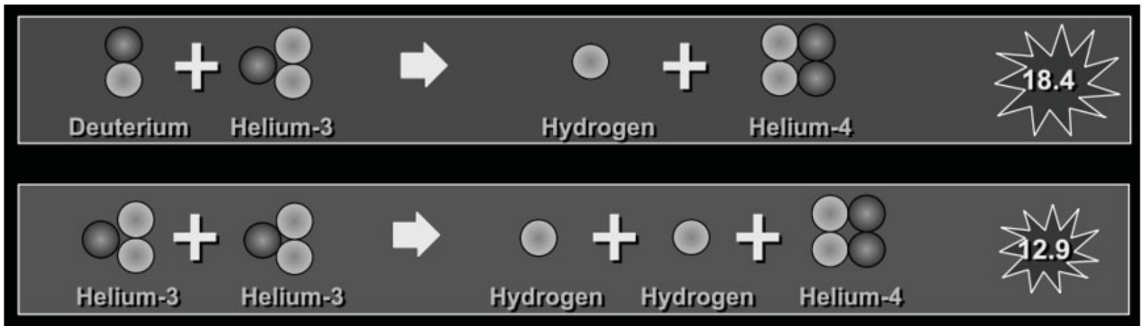

Figure 2. Fusion reaction of the Helium-3 and their energy outputs in million electron volts, modified from **[6]**

The principal limitation of the Mars exploration is the distance from Earth, for that reason, much of the mineral exploration of Mars is made through multi-spectral remote sensing which observes the Martian surface from orbit. One of the latest and most important space probes are the Mars Reconnaissance Orbiter and its sensor HiRISE (High-Resolution Imaging Science Experiment). This sensor shows the presence of large eolian deposits of black sand that could contain chromite, magnetite, and ilmenite.

Currently we have very few samples of the Mars surface that have been studied, just meteorites and a few soil and rock samples of the Mars Landers Viking I, Viking II, Pathfinder, Opportunity Rover, and Spirit Rover that identified aluminium, iron, magnesium, and titanium in the Martian soil.

The next challenge in Mars exploration is on the first trip of humanity to its surface, probably one of the first humans to set foot on its surface will be a geologist that allows us to learn more about this planet and the resources it could offer to the habitants of planet Earth and to the possibility of a future permanent community on Mars.

2.3. Comets and asteroids

Around our planet there are a large number of asteroids, some of their orbits coincide with the Earth's orbit while the vast majority of these are orbiting after the Mars orbit (Figure 3), in the denominated asteroid belt. The main advantage of mining these celestial bodies is that they can have orbits close to Earth and come to us for their exploitation.

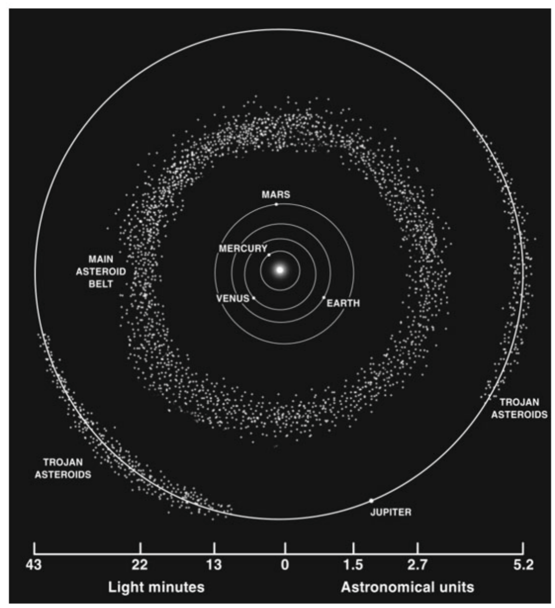

Figure 3. Large number of asteroids in the inner solar system and Jupiter, image from the NASA Lunar and Planetary Institute.

They are the objects that could be most easily exploited for their raw materials. Lewis **[10]** estimated that the mineral wealth resident in the asteroid belt between the orbits of Mars and Jupiter would be equivalent to about

100 billion dollars for every person on Earth, they are rich resources for water and carbon-based molecules, iron, and nickel; The surface water ice could provide copious quantities of liquid hydrogen and oxygen, the two primary ingredients in rocket fuel.

Asteroids are also very rich in platinum group elements (ruthenium, rhodium, palladium, osmium, iridium and platinum), these metals have high prices (rhodium (1325 USD/oz), palladium (589 USD/oz), platinum (1424 USD/oz), **[11]**) that enhance the possibility of economically profitable extraction in the near future.

The first asteroid mining companies are already established and beginning research to develop their projects, the most important of these is PLANETARY RESOURCES, a company who "is establishing a new paradigm for resource discovery and utilization that will bring the solar system into humanity's sphere of influence" **[12]**, as in traditional mineral exploration, the first step in space exploration is the identification of promising prospects, looking for asteroids with close orbits and the appropriate size and composition, after that, the exploration of these prospects with explorer satellites, and if they are viable for exploitation then the most appropriate mining method, according to the characteristics of the asteroid, would be designed.

This company estimated more than 9000 near-Earth objects, of these 1,500 are of easy access, 900 are located at a shorter distance to the surface of the Moon, a 1,000 more are discovered every year. composed mainly of iron and nickel. The initial goal will be volatiles such as water, oxygen and hydrogen, for use in fuel or stored to supply manned space missions, they could sell them to NASA. In 2013, the first stages of exploration consisting of sending probes in low orbits, began to study the asteroids.

With the development of new technologies in commercial satellites and the latest research and projects related to asteroids conducted by NASA, they are developing the technologies needed to exploit these asteroids at low costs. PLANETARY RESOURCES currently work on satellites like Interceptors (a low cost asteroid mission that enables accelerated exploration) and RENDEZVOUS PROSPECTOR (to characterize an asteroid's value and prepare it for mining operations) **[12]** which in the coming years will be the first to take steps in space mining.

3. THE MINING PROFESSIONALS

The current generation of professionals in the areas of geology and mining were not trained to think of space as a possible source of mineral resources, it is the same for the vast majority of students that are now at school, this may be a mistake if we consider the current conditions. It is necessary that some of these professionals study these new opportunities presented, now it is necessary to work on the adaptation of knowledge and technologies to contribute to the development of extraterrestrial exploitation, we need to develop curiosity for the things that we can find, and open this new possibility in the minds of future professionals. Surely in the not too distant future, humans will begin to develop as an extra planetary species and it is outside the planet where we need to find the resources to take this step.

4. CONCLUSIONS

Celestial bodies closest to the planet Earth have plenty of opportunities for mineral exploration, utilization of new materials and alternative clean energy, they also possess a reserve of materials that are depleted, near depletion or very scarce in planet Earth. The exploration and exploitation of these resources today present great technical difficulties but due to current technological advances and the high prices of minerals and energy, this exploitation is getting closer to being economically and technically feasible.

The role to be played by professionals in the mining area of the current generation and students who are in today's classrooms is critical to the development of these resources, as scientists we must be alert to new possibilities, it is necessary to end paradigms that limit us to think only of Earth's resources and to open our minds to new possibilities and alternatives.

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