NEW SAPCE RESOURCES OF RARE-EARTH ELEMENTS IN THE MOON, MARS AND ASTEROIDS.

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Introduction: Among three kinds of global resources for energy and materials of carbon-bearing, hydrogen-bearing materials and rare-earth elements (REE), the 17 rare-earth elements (REE) are considered to be new space resources from the Apollo lunar data and meteoritic chemical data by author [1]. The main purpose of the present paper is to elucidate new space resources of the rare-earth elements on the Moon and other extraterrestrial places for advanced materials.

Global resources: The following three kinds of resources for energy and materials are largely classified as shown in Table 1 by author [1].

1) *Carbon-bearing resources of the interior of the Earth:* Carbon-bearing resources of energy (such as oils and coals etc.) are produced only in the water planet Earth with cyclic three states of air, sea-water and solid (VLS) rocks [1].

2) *Hydrogen-bearing resources from the Sun:* Nuclear-fusion productions of the solar hydrogen and helium are applied for a solar battery on the terrestrial surfaces and advanced instruments on space explorations [1].

3) *Heavy elements of the REE*: Heavy elements of the 17 REE are i) mainly obtained at the interior melting of the terrestrial underground rocks, and ii) firstly found relatively in the impact-melting rocks as solid space bodies of the Moon, Mars, Asteroids and the Earth in this study [1].

Table 1. Major space resources of energy and materials

1) *Coal and oils etc. (carbon-bearing resources):*
Active Earth planet (in cyclic three VLS states)
2) *Solar energy (hydrogen-bearing resource):*
Nuclear-fusion production (for a solar battery)
3) *Heavy elements of the REEs:*
Solid space bodies (the Moon and Earth etc.)

Terrestrial resources of the REE: The rare-earth elements (REE) are classified as elemental resources of Earth planet as follows as shown in Fig. 1[2]:

1) Elemental abundances for the rare-earth elements (REE) of seventeen elements with the Lanthanide, Y and Sc are classified mainly as advanced industrial elements.

2) Those of the industrial elements REE are located at intermediate quantity between rock-forming elements and precious rare-metals [2], where the REE play strangely significant chemical roles for industrial applications [1, 2].

3) Elemental abundances of the REE are relatively richer in terrestrial crust than carbonaceous meteorites [3], though active Earth planet produces much concentration of the REE by the irregularly complicated concentration processes for long terrestrial history.

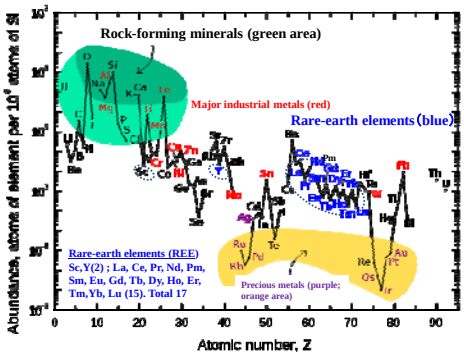

Fig.1. Elemental abundances for the rare-earth elements (REE, in blue colors) between rock-forming elements (in green color area), industrial elements (in red colors) and precious rare-metals (in purple & orange color area). Seventeen REE elements consist of 15 (Lanthanide) and Y and Sc, separately in industrial elements [1, 2].

Apollo lunar resources of the REE: The rare-earth elements (REE) on the Apollo lunar samples are summarized as follows (as shown in Fig.2) [1, 4]:

1) Lunar highland rocks of anorthosite, troctolite and norite show relatively the least contents of the rare-earth elements (REE), where some positive REE pattern of Sm-Eu-Gd elements are the similar with carbonaceous chondritic meteorites (Fig.2) [1, 3].

2) Lunar Mare basalts and regolith soils of the Apollo samples show relatively richer contents of the REE than the terrestrial crustal rocks (Fig.2) [1, 4].

3) Apollo samples of lunar breccias contain relatively the richest contents of the REE which can be considered mainly by impact mixing processes (Fig.2).

Formation of Space REE resources: Comparative formation processes of the rare-earth elements (REE) as new space resources are summarized as follows [1]:

1) The rare-earth elements (REE) of the Asteroids show relatively the least contents of the REE which is considered to be mainly primitive impact mixing process without further interior mixing (Fig. 2).

2) The rare-earth elements (REE) of the terrestrial crust rocks reveal relatively richer contents of the REE, which is formed by complicated mixing of active Earth planet with the interior rocks and meteoritic supply to wide ocean water area of the Earth (Fig. 2).
3) The lunar Mare basalts show irregularly richer contents of the REE, which is similar with terrestrial crusts with various mafic contents (Fig.2).
4) The Apollo lunar impact breccias show relatively the richest contents of the REE, which is considered to be new significant space resources on the huge impact processes as shown in Fig. 2 [5-8].
5) The present results of the REE contents are strongly consistent with significant carbon and calcium contents of the Apollo lunar impact breccias, together with some terrestrial REE mining deposits [1, 4, 6-8].
6) New space resources of the REE are considered to be the best candidates of new space resources outside the Earth (*i.e.* the Moon, Mars and Asteroids), which can be used to the present advanced instruments [1].

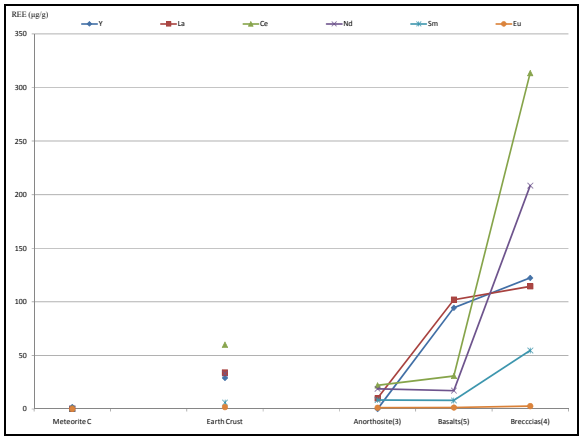

Fig. 2. Comparative contents of the rare-earth elements (REE) at meteorite, terrestrial crust, and Apollo lunar rocks data of lunar highland anorthosite, Mare basalts and impact melt rocks [4]. Lunar impact breccias are considered to be the best candidate for new space resources.

Summary: The present results are summarized as follows (in Table 1 and Figs.1 and 2):
1) Among global resources of carbon-bearing, hydrogen-bearing materials and rare-earth elements (REE), the REE should be considered to be unknown formation processes, though that significant application with limited terrestrial resources can be inevitable mining resources for the present advanced instruments for space explorations and our life activity including astronauts.
2) The Apollo lunar highland rocks of anorthosite, troctolite and norite show relatively the least contents of the rare-earth elements (REE), where some positive REE patterns of Sm-Eu-Gd elements are similar with those of carbonaceous meteorites with carbon element.
3) Apollo Mare basalts and regolith soils show relatively richer REE contents than the terrestrial crustal rocks of cyclic water Earth planet.
4) Apollo lunar breccias show relatively the richest REE contents mainly produced by impact mixing processes.
5) The rare-earth elements (REE) of the carbonaceous asteroids show relatively the least contents of the REE, which is considered to be mainly primitive impact mixing process without further interior mixing.
6) The lunar impact breccias show relatively the richest contents of the REE, which is considered to be signifi-cant space resources on the huge impact processes.
7) The present REE results are strongly consistent with contents of carbon and calcium elements of the lunar impact breccias, which indicate new space resources on the Moon, Mars and Asteroids, together with limited terrestrial REE mining deposits.

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