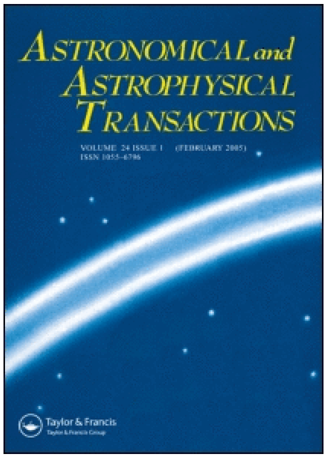

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

A review of: "Resources of near-earth space"

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Online Publication Date: 01 April 1995
To cite this Article: Shevchenko, V. V. (1995) 'A review of: "Resources of near-earth space"', Astronomical & Astrophysical Transactions, 7:1, 75 - 78
To link to this article: DOI: 10.1080/10556799508203257
URL: http://dx.doi.org/10.1080/10556799508203257

Astronomical and Astrophysical Transactions, 1995,
Vol. 7, pp. 75–78
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BOOK REVIEW

RESOURCES OF NEAR-EARTH SPACE

edited by J. S. Lewis, M. S. Matthews, M. L. Guerrieri
The University of Arizona Press/Tucson & London, 1993, 977 pp.

The book is a new volume in the acclaimed Space Science Series which has been published by the University of Arizona Press. The editors of the volume, encompassing the work of 86 collaborating authors, are John S. Lewis, Professor of Planetary Science in the Lunar and Planetary Laboratory, University of Arizona, and Mildred S. Matthews and Mary L. Guerrieri, staff editors for the Space Science Series, also at the Lunar and Planetary Laboratory.

Part I – "Introduction" discusses common problems of using resources from near-Earth space. Every highly industrialized country knows that technical innovation and improved productivity are the keys to economic health. Space stands out as one of very few areas of human endeavor that not only satisfy the explorative urge and provide us the facts and insights we need to exercise our stewardship of the Earth, but also keep the cutting edge of scientific and technological innovation razor sharp. Space is already worth roughly $100 billion per year to the global economy. The book discusses many non-terrestrial resources of energy and materials that could eventually make space ventures begin to pay for themselves. We need energy without radioactive waste; without carbon dioxide emissions; without strip mining, smog, soot, and massive oil spills. We need to find a source of cheap, clean energy. Perhaps the most promising prospects for achieving this goal are the construction, using nonterrestrial materials, of solar power satellites in high orbits around the Earth or on the lunar surface, beaming power down to receiving antennas on the ground, and clean fusion of nonterrestrial ^{3}He with terrestrial deuterium.

Part II – "The Moon" examines the possibility of utilizing lunar materials to produce propellants, structural materials, refractories, and life support fluids on the lunar surface and in near-Earth space, to reduce the costs of space exploration. It also examines the Moon as a possible source of materials and energy for our own planet that would not be environmentally destructive to the Earth. To estimate the value of the Moon's resources, it is needed to have a geochemical assessment of possible lunar ore formation. The dry state of the Moon's interior and surface complicates our perception of the lunar ore potential. Most ores on the Earth depended on internal or external water for their formation. The Moon apparently has no appreciable internal or surface water, so we may not expect to find most types of terrestrial ores on the Moon. Nevertheless, there is abundant evidence that substantial geochemical separations occurred during the formation of the Moon's crust. Moreover, the Moon is laterally heterogeneous, and recent Galileo data indicate that this heterogeneity extends to the farside. It is considered the present evidence for the types of geochemical separations that occurred on the Moon during its development to speculate whether those processes might have been capable of producing concentrated mineral deposits that might someday serve as ores.

The production of oxygen on the Moon utilizing indigenous resources and materials is of paramount importance for a successful permanent habitation on the lunar surface. At least 20 different processes have been put forth to accomplish this. The two lunar liquid oxygen generation schemes which have received the most study to date are those involving: reduction of ilmenite ($FeTiO_3$) with H_2, but also CO and CH_4; and molten silicate (magma) electrolysis, both direct and fluoride-fluxed. Four different schemes of lunar oxygen production are considered in detail.

Human expansion into deep space will depend on an ability to use local materials. High transportation coats assure this. Because it is likely that at least early cislunar space transportation will be based on cryogenic chemical (lunar O_2/lunar H_2) propulsion, and because most of the mass of such a system is a propellant, and 6/7 of that is oxygen, it seems that oxygen would be a good candidate for early indigenous space material utilization. The results of a special study clearly show that the benefits obtained from the use in-situ-derived propellant for lunar and Mars operations are considerable if Earth-to-orbit launch costs stay as high as they are now. If a factor of 10 reduction in these launch costs is forthcoming, then the benefits of using lunar propellants become minimal. The analytical data are used to discuss the available data on the abundances of the noble gases, hydrogen, carbon, nitrogen, sulfur, fluorine and chlorine in lunar soils.

The development of structural materials from locally derived space materials and the study of their mechanical properties for construction and other uses are important toward the establishment of outputs and habitats on the Moon and planets. Now various methods have been proposed such as sintering and casting for the manufacture of construction materials from lunar simulants. It is found that the thermal liquefaction leads to materials with significantly enhanced flexural and ductility properties compared to the sintered materials that are found to be brittle. It is believed that the materials from lunar simulants may be produced on the Moon by using solar energy without the use of water, and can lead to applications not only for construction, but also for machines and other structures for use in the colonization of space.

Lunar exploration may also reveal new and unexpected deposits, including water at the poles, water trapped from impacts of carbonaceous asteroids and comets, or local geochemical concentration of sulfur, potassium, chromium, and other potentially useful resources. Geochemical mapping from orbiter and lander missions will help us to select the optimum outpost site, and will provide the scientific framework for future detailed science investigations. Lunar base science program will include not only lunar investigations, but also astronomy, radio astronomy, space physics, and life sciences. The equatorial limb sites appear the best selection for science and have a broad range of materials within about 100 km. Polar sites are the best for operations, and could afford substantial savings in base establishment costs, but are much less favorable for astronomy and lunar surface science.

Part III – "Near-Earth Objects" includes analyzing the possibilities of utilizing resources of near-Earth asteroids, martian moons, and short-period comets. At least one fifth of the near-Earth asteroids are volatile-rich, with abundances of hydrogen, carbon, nitrogen, etc. over 100 times as high as in the most volatile-rich lunar materials. Almost all the others are metal-rich, again with over 100 times the free metal content of the lunar material. Also, about one fifth are energetically more accessible than the surface of the Moon: about 250 of the near-Earth asteroids larger than 1 km in diameter are easier to reach than the lunar surface. The main drawback is that the trip times to visit these nearby asteroids and return are about 1 to 3 yr, similar to Mars missions, compared to a one-week round trip to the Moon. Schemes are already known by which a spacecraft dispatched on round-trip missions to the best of these asteroids could return over 100 times its own mass of the asteroidal resources to the near-Earth space.

Possibly some fraction of the near-Earth asteroids are actually extinct or dormant cometary nuclei. These objects have already been perturbed into orbits with relatively low Earth encounter velocities, and so the difficulty of matching orbits with them is significantly reduced. The spacecraft flybys of the comet Halley in 1986 showed that comets are far richer in volatiles than any other class of the Solar System bodies. Water is the most abundant volatile, comprising roughly 80% of the gas flowing out from the nucleus. CO is next with a content of 15% relative to water, though with at least half of that coming from an extended source in the cometary coma, most likely hydrocarbon dust grains.

Part IV – "Mars and Beyond" gives a systematic description of the physical and chemical properties of the martian surface from the perspective of providing resources to support human activities on Mars. In the early phase of human activities on Mars, the ability to transport materials from where they occur to where they will be used will be extremely limited. Thus, it will be necessary to use the materials at or near the location of the human base. Martian soil of the type found at the Viking landing sites contains significant amounts of extractable water and metals including iron, magnesium, aluminium and titanium. The soil also contains significant concentrations of sulfate and chloride salts, the resources for sulfur and chlorine compounds. Water will be an important resource for future missions to explore Mars. The success of future long-term human exploration or habitation on Mars will undoubtedly depend on the successful location and utilization of indigenous sources of water. The atmosphere was found to be mainly CO_2 with small amounts of N_2 and Ar, and even lower quantities of CO, O_2 and H_2O vapor. Propellants such as hydrogen, methane, methanol, oxygen, and hydrogen peroxide can all be made in relatively direct chemical processes from these compounds, alleviating the supply line from the Earth for return propellant and rover propulsion.

The parts of the Solar System that are most accessible from the Earth are rich in materials of great potential value to humanity. Immediate uses of these resources to manufacture propellants, structural metals, refractories, life-support fluids and glass can support future large-scale space activities. In the long- term, non-terrestrial sources of rare materials and energy may be of great importance here on the Earth.

The book is intended to be an introduction to the use of nonterrestrial materials for scientists, engineers, and industrial and government project managers who seek to make space more accessible.

V. V. SHEVCHENKO