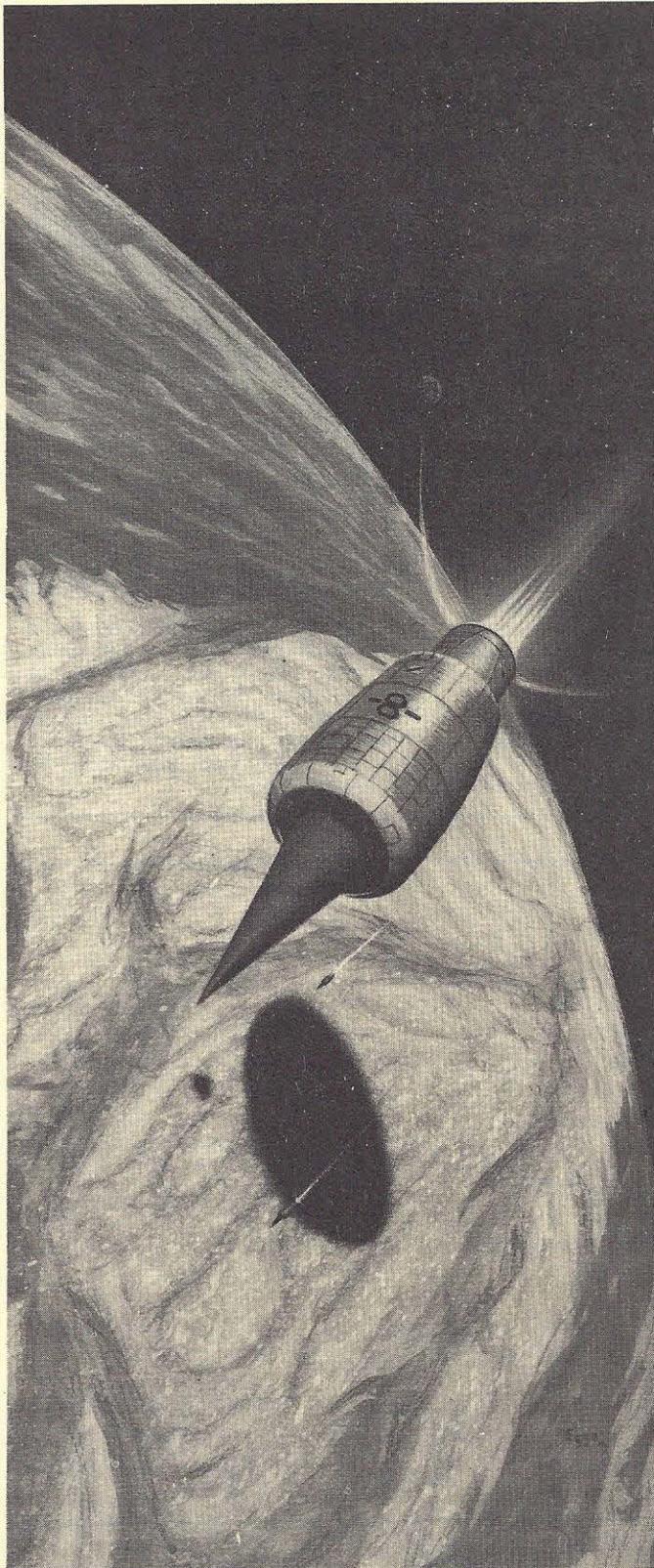


# FOUNDATION REPORT:

ADVANCES IN COMMERCIAL AND GENERAL SPACE DEVELOPMENTS



## EXTRATERRESTRIAL RESOURCES IN THE SOLAR SYSTEM

Materials Shortages? Never Again

by Professor Calvin Alexander

Until recent times, humans have had access to only a very limited and biased sample of the material of the solar system—namely that particular mixture of elements available at or near the surface of the earth. Geochemists have long known that many of the elements that are rare (and therefore costly) in human commerce are not particularly rare in the solar system. Such elements are rare in the earth's crust simply because their chemistry is such that they did not wind up near the surface during the formation of the planet. To illustrate the point, consider platinum. It is seven times as abundant as gold in the solar system, and only three times less abundant than lead—but its chemistry is such that it is enriched only in the earth's core and not in the crust.

One of the great opportunities of the commercial utilization of space arises because in space we will have free access to the several different mixtures of material which comprises the solar system. No longer will we need to seek an element like platinum in a medium like crustal rocks where it has always been depleted, but rather we can mine it from iron asteroids where it is fundamentally enriched.

The fundamental or bulk composition of the solar system is the same as that of the sun, and is known as the "cosmic", or more correctly, "solar" abundance. The abundances of the elements in the sun are well known, based on spectroscopic studies, chemical analyses of certain types of "primitive" meteorites,

*continued on page 2*

Scoopships mine the atmosphere of Jupiter for Hydrogen and Helium. The original solar nebula condensed leaving most of the low temperature volatile gases in the outer planets: Jupiter, Saturn, Uranus and Neptune. This illustration shows robot ships about to dip into the Jovian atmosphere following their long fall from a very elliptical orbit. The ships follow an orbit which takes them from the fringes of the atmosphere to more than two million miles out into space where manned tanker ships collect the liquified gases obtained from the atmospheric transit. The ships have pointed inlets like hypersonic jet engines and use a portion of the collected gases as reaction mass to maintain orbital velocity while experiencing drag forces during the point of closest approach to the giant planet. With onboard nuclear heat exchanger engines, they can be considered to be similar to nuclear powered jet turbine engines. Billions of cubic meters of atmosphere would be scooped during each flight, producing thousands of tons of hydrogen and helium each mission. The shadows of the Jovian satellite Amalthea (large shadow) and Europa can be seen on the clouds below the ships, and Io is visible in the distance. Original artwork by Foundation Staff Artist D. Egge.

continued from page 1

and so on. A graph on page 2 shows the calculated solar abundance by atomic weight, and based on silicon abundance equal to one. The sun (and therefore everything else in the system) is 93.4% hydrogen (atom percent), 6.5% helium, and .13% everything else.

Ironically, although hydrogen is the most abundant element in the solar system, it may well prove to be the element most difficult to obtain during the initial phase of space development. This is because of all of the fractionation processes described elsewhere in this article concentrate various combinations of the elements which are more massive than helium and thus very efficiently discard hydrogen and helium. More or less pristine samples of the solar abundance are available in at least two environments, however.

The surfaces of objects in the solar system which are not shielded by atmospheres and/or magnetic fields are constantly being battered by the solar wind. Particles in the solar wind are traveling with several thousand electron volts of energy, and when they impact a solid object they penetrate about a thousand angstroms (10 millionths of an inch) into its surface. This means that the outermost layer of particles on the surface of the moon (and presumably other similar bodies) contain hydrogen, helium and other elements in solar proportions. This hydrogen may be the most readily available source of the element above low earth orbit until "ice mountains" can be brought into cislunar space from Jupiter or beyond.

The atmospheres of the giant planets are also relatively unfractionated samples of the solar elemental ratios. These atmos-

## New Gold, New Conquistadores, No Natives

About 0.0002% of the mass of the earth is orbiting the sun in the form of meteoric material. That may not seem astounding at first glance except for the fact that almost all of that matter is in bodies a few hundred meters in diameter or smaller, and the total mass is  $10^{16}$  tons. To get at this material, there is no requirement for underground or pit mining, no waste disposal problems, no need to pay outrageous prices for energy in the form of process heat. The access to valuable resources is fundamentally simple—once the problem of access to space is solved economically.

The table at right shows the relative concentrations of valuable elements and compounds in three classes of asteroids. Generally, terrestrial miners are happy to find concentrations of one to ten percent of the material they are seeking distributed in useless rock. In the asteroid belt, and among the Apollo/Amor asteroids which cross the orbit of the earth, we can find concentrations of useful elements as high as ninety percent—as in the case of iron in iron-nickel asteroids.

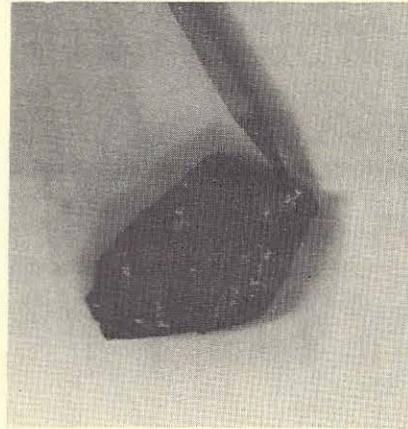
The carbonaceous chondrite meteorites have been found to contain white inclusions, known to be 4.5 billion years old, which are the condensed elements with high melting points. The photo shows a piece of Allende, a carbonaceous chondrite which fell near the town of the same name in Mexico in 1969. These nodules (at pencil point) have very high concentrations of osmium, zirconium, tungsten and rhenium.

Economic value of a 100 meter dia-

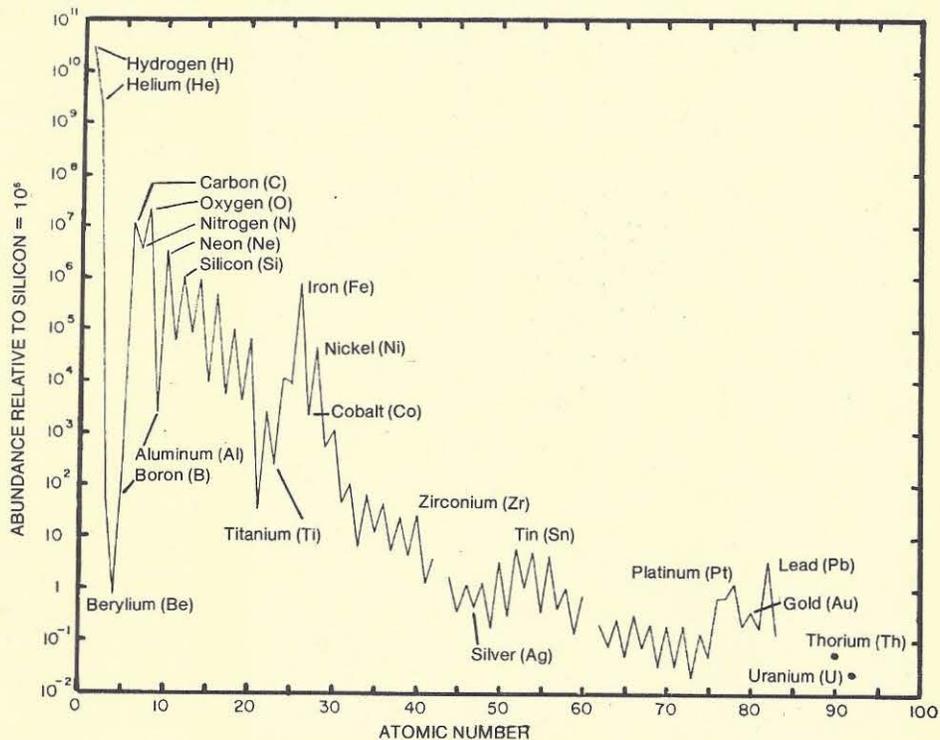
### Representative Compositions of Different Types of Meteorite Materials

(in weight percent unless otherwise noted)

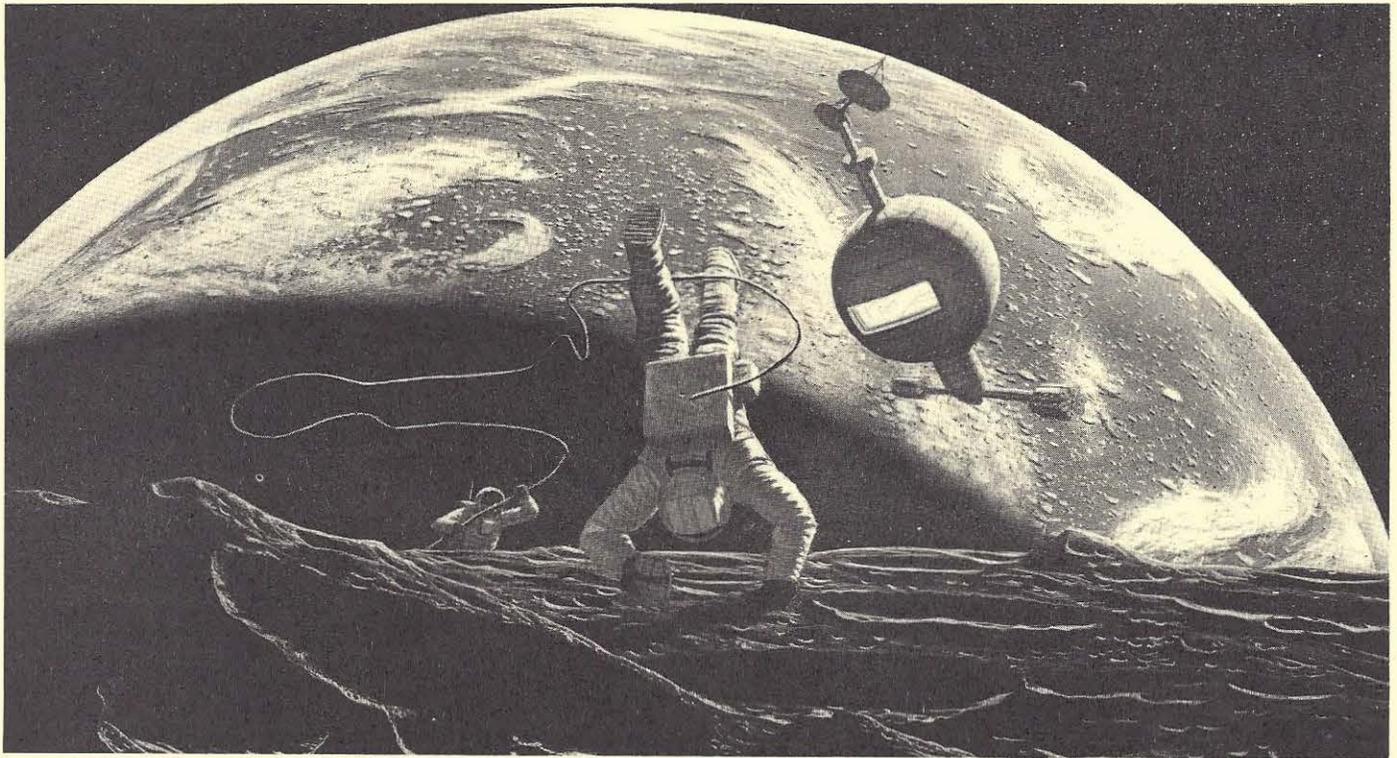
Material	Ordinary Chondrites		Irons
	Chondrites	Carbonaceous Chondrites	
Fe	6.27	0.00	90.78
Ni	1.34	0.00	8.59
Co	0.046	0.00	0.63
FeS	5.89	3.66 (S)	Variable
SiO <sub>2</sub>	39.93	27.81	—
TiO <sub>2</sub>	0.14	0.08	—
Al <sub>2</sub> O <sub>3</sub>	1.86	2.15	—
MnO	0.33	0.21	—
FeO	15.44	27.34	—
MgO	24.71	19.46	—
H <sub>2</sub> O	0.27	12.86	—
C	0.03	2.48	Variable (C)
trace elements			
Mo	1.6 ppm		~ 13 ppm
Au	0.18 ppm	0.17 ppm	1.15 ppm
Ag	0.102 ppm	0.250 ppm	0.020 ppm
Pt	~ 0		20 ppm



meter rock of nickel-iron composition is \$1.5 billion plus, based on 3.8 million tons iron, 360,000 tons nickel and 84 tons platinum. The value of the platinum alone is \$32,250,000. In a single carbonaceous chondrite of the same size, the value of the gold would be \$15,250,000—GCH.



The abundances of the elements in the primitive solar nebula. The vertical scale is logarithmic: each division indicates an abundance ten times higher than the one immediately below it. The number on the scale indicates the numbers of atoms in the solar system with silicon set at one million. It can be easily seen that hydrogen and helium are by far the most abundant elements in the solar system (and the universe as well), but significant amounts of other commercially useful materials exist, including iron and silicon. Uranium and thorium are given as their calculated availability 4.6 billion years ago: since they are radioactive, they will have decayed significantly since then. This graph after one in *Abundances of the Elements in The Solar System*, Cameron, A.G., *Space Science Review*, 15 (1970) p. 126-146.



pheres may eventually be mined for hydrogen and other light elements.

All of the other solid objects in the solar system appear to be fractionated samples of the solar abundance. These elements concentrated due to similarities in the condensation temperatures (the point at which they change from gaseous to solid phase). The conceptual picture which emerges from studies which include analysis of the returned Apollo lunar samples suggests that the first stages of the life of the solar system saw a primitive solar nebula form. This nebula was heated hot enough (greater than 2000°Kelvin, 3140° Fahrenheit) to completely vaporize all of the elements. The nebula subsequently cooled and the elements began to condense out. The sequence of condensation of the elements and compounds can be calculated from known thermodynamic data.

The first things that condense from a cooling gas cloud of solar composition are the refractory elements such as osmium, tungsten, zirconium (as  $ZrO_2$ ) and rhenium. Since these elements are in very small quantities, they do not produce much solid material. The first reasonably abundant element which condenses is aluminum (as corundum,  $Al_2O_3$ ) at about 1670°K. Next comes hafnium oxide, yttrium oxide, scandium oxide, molyb-

denum, perovskite ( $CaTiO_3$ ), the rare earth oxides, iridium, ruthenium, gehlenite ( $Ca_2Al_2SiO_7$ ), spinel ( $M_3Al_2O_4$ ), tantalum oxide and thorium oxide. By now the temperature of the cooling nebula is about 1400°K. The reason that I have gone to the trouble to list all of these elements and compounds is because we have recently found in certain very old meteorites centimeter-sized white inclusions which appear to be a sample of these high temperature condensates from the solar nebula. Since only 5.7% of the condensable elements will have come out of the gas phase by 1400°K, the elements listed above are observed to be enriched by 17 times (100 divided by 5.7) in these white, high temperature inclusions. Such material can presumably be found and mined in the asteroids. The mining process would be a simple matter of crushing asteroidal rock and separating by differences in mass. Many of these elements are extraordinarily valuable to a technological society, and thus are expensive due to their relative scarcity on earth.

The temperature to which the material in the solar nebula cooled decreased with time and with distance away from the sun. Therefore there probably exists a continuum of materials with varying condensation temperatures within the solar system.

Three major classes of materials

Mining an asteroid in earth orbit. About 6000 miles above the Pacific Ocean with the west coast of the United States in the background, a 3000 ton self powered factory ship closes in on its target. Two project geologists are removing core samples of the carbonaceous chondrite asteroid, which is about 30 meters in diameter and weighs about 30,000 metric tons. It contains about 200 million dollars worth of useful materials, which may be sold on earth or employed in space construction and manufacturing. The factory ship is one hundred meters in diameter with solar furnaces at one end and rotating booms with living and working quarters at the other. Probably three hundred workers would be stationed at the site. Following capture of the asteroid, the ship will return to low orbit to avoid prolonged exposure to high radiation levels in the Van Allen belt. *Original artwork by Foundation Staff Artist D. Egge.*

are known to exist in the system which represent fairly well defined temperature points which are cooler than the temperature of condensation of the white inclusions mentioned above. Ordinary chondrites (which include the vast majority of meteorites which have fallen to earth) represent samples of solar nebula material which condensed at 650°K to 1000°K. By this temperature metallic nickel-iron had condensed, part of which reacted with gaseous hydrogen sulfide to form FeS. Also, the major silicate minerals like enstatite ( $MgSiO_3$ ) had come out of the gas phase and part of this material had reacted with sodium vapor to form feldspar and related minerals. Ordinary chondrites are there-

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# LEASING INCOME AT AN INTERNATIONAL SPACE FREEPORT

by Dr. Alvin Rabushka

Recent analysis has projected the lease revenues which could be generated by Earthport, an international space launch center operating as a free trade zone. Regulation, taxation, and red tape are assumed to be minimal to attract investment, and to secure broad international support for the spaceport and its activities.

An administering authority would be empowered to write appropriate regulations for Earthport. It would monitor sanitation and health standards, restrict the import of weapons and other non-peaceful commodities, and provide police services inside the port. Revenues to finance Earthport administration would be derived from leases of port land to space and other commercial users.

## Revenue Projections

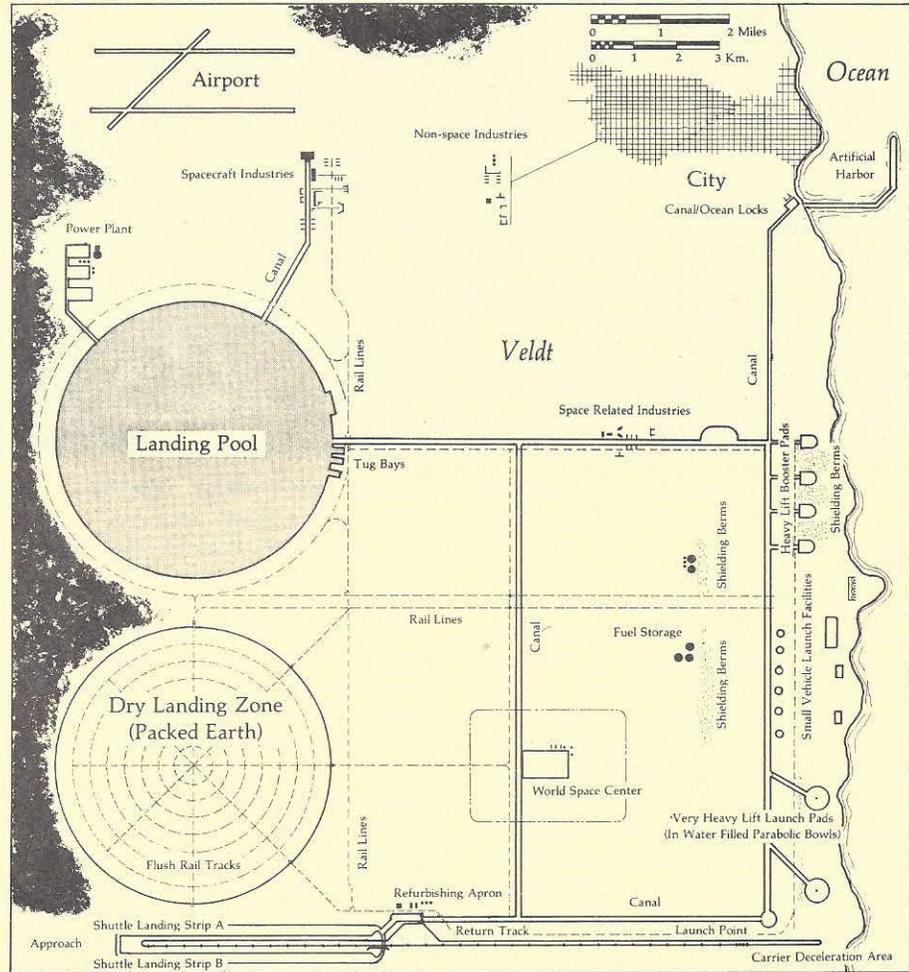
Estimates of Earthport revenues are based upon the acquisition of a 200 square mile territory to be leased, in the first instance, for a period of 99 years in an equatorial region suitable for space launch activities. A 200 square mile area represents a territory about 14 miles wide by 14 miles long. The freeport must contain suitable space for a major air strip and preferably a harbor site.

All revenues to be generated from the operation of Earthport would come solely from land rentals. Calculations are based on charges which the Republic of China (Taiwan) levies for its land rentals in its three major "Export Processing Zones" located in Kaohsiung, Nantze and Taichung. Charges are fixed at US\$0.12 per square meter per month, or US\$1.44 per square meter on an annual basis. One acre of rentable land thus yields US\$5,827.68 in annual rentals. Further calculations show that one square mile of fully rented land generates \$3,729,715.20.

Of the 200 square mile space freeport zone, it is estimated that about one-half, or 100 square miles, may be required for roads, residential facilities, an airstrip, a common landing area for launch activities, and other administrative facilities. The remaining half,

approximately 100 square miles, can be rented to commercial users. Land rentals, when the entire 100 square mile commercial zone is

- No exchange controls; free banking activities in all currencies.
- No personal income or corporation taxes (conventional depreciation write-downs are irrelevant).
- All profits may be 100 percent repatriated.
- All infrastructure charges,



fully let, would total \$373 million per year. These projections are based upon the very low ground rentals charged in Taiwan's "export processing zones," and are thus realistic estimates of fees that prospective manufacturers are willing to pay for rental space on which to build factory or commercial facilities.

Earthport should be even more attractive to potential entrepreneurs than the "free trade zones" which are presently found in a number of world locations. This is because Earthport would impose fewer charges than any other present freeport or free trade zone. The Space Freeport would enjoy the following set of benefits:

- No customs duty, no commodity tax, nor sales tax.

utilities, and import costs at world market prices.

- Land leases freely transferable at market prices.

Restrictions in the operation of Earthport would be minimal. The initial minimum size of a ground lease area would be one-quarter of an acre; the maximum 10 square miles. There would be no restrictions on transfer of lease sites, except that no one firm could occupy more than five percent of the leased area within the commercial zones.

Earthport expects that its commercial zones can be fully let within 10 years. (In Taiwan, the smaller zones were fully let in a few years.) Its initial focus will be on launch activities and about eight square miles will be set aside for that pur-

pose. Earthport will also encourage space related industries and supporting suppliers. However, the international space freeport will be open to all peaceful enterprises in its remaining territories.

Land rentals will be implemented in a series of graduated steps over a period of 10 years. Thus, full rentals should be in effect 10 years after the opening of Earthport. Rentals are to be maintained in constant price terms to protect against inflation, and will be determined on the basis of the relative purchasing power of a "basket" of world currencies.

### Use of Revenues

Earthport should be attractive to a number of potential host countries. Approximately one-third of all Earthport rental revenues will be turned over to the host country for granting a 99 year, 200 square mile lease to Earthport. Approximately one-third of Earthport rentals will be used for Earthport Authority operating expenses, but any surplus accrued beyond a one-year contingency fund will be rebated to holders of Earthport leases. The final third, about \$125 million per year, will be used for humanitarian, international space efforts of benefit to developing countries and Earthport launch organizations.

*Dr. Rabushka is a Senior Fellow of the Hoover Institution on War, Revolution and Peace in Stanford, California. This article copyright by Dr. Rabushka, 1977.*

(Facing page) A conceptual layout of the two hundred square mile Earthport free trade zone. The zone will have facilities for launch of various types of chemical vehicles including heavy lift boosters for large scale space construction, and winged horizontal takeoff single-stage reusable spacecraft (at bottom of drawing). Recovery areas included a four mile diameter water filled pool for heavy lift vehicles and a four mile diameter gravel packed area for smaller vertical landing types. Canals would connect launch pads, recovery sites and manufacturing areas. The World Space Center would be the recipient of most of the \$125 million dollars in lease revenues which would be used for international space projects. *Drawing and design by Tom Brosz for Earthport Project, copyright the Foundation 1977.*

(Right) Artist's conception of the Earthport from an aerial perspective. Visible are the landing areas and horizontal launch track, as well as a heavy lift booster pad (center, far right) and other launch pads and tracking facilities. A small reusable rocket has just been launched moments before. The industrial park and community housing area is shown to the top of the picture near the artificial harbor. *Artwork by James McMenamin of Spaceport Enterprises, Inc. for Earthport (Earthport copyright 1977).*

## OTRAG'S, BONN REACTION TO CRUISE MISSILE TEST CHARGES: "PURE NONSENSE"

Both the West German government and Orbital Transport und Raketen A.G. have labeled as "pure nonsense" charges by Penthouse magazine that the company is secretly developing cruise missiles and intermediate range ballistic missiles at the OTRAG test range in Shaba North, Zaire.

In an article scheduled for publication in the March issue of Penthouse magazine, former New York Times diplomatic correspondent Tad Szulc claimed that OTRAG was a front operation for the Bonn government, and that the United States, through the Central Intelligence Agency, has provided cruise missile hardware for the alleged tests. Szulc claims the article was based "on private discussions with highly reliable sources who have access to most of the relevant knowledge, in Washington as well as Western Europe." At one point, the article cited "Carter administration officials".

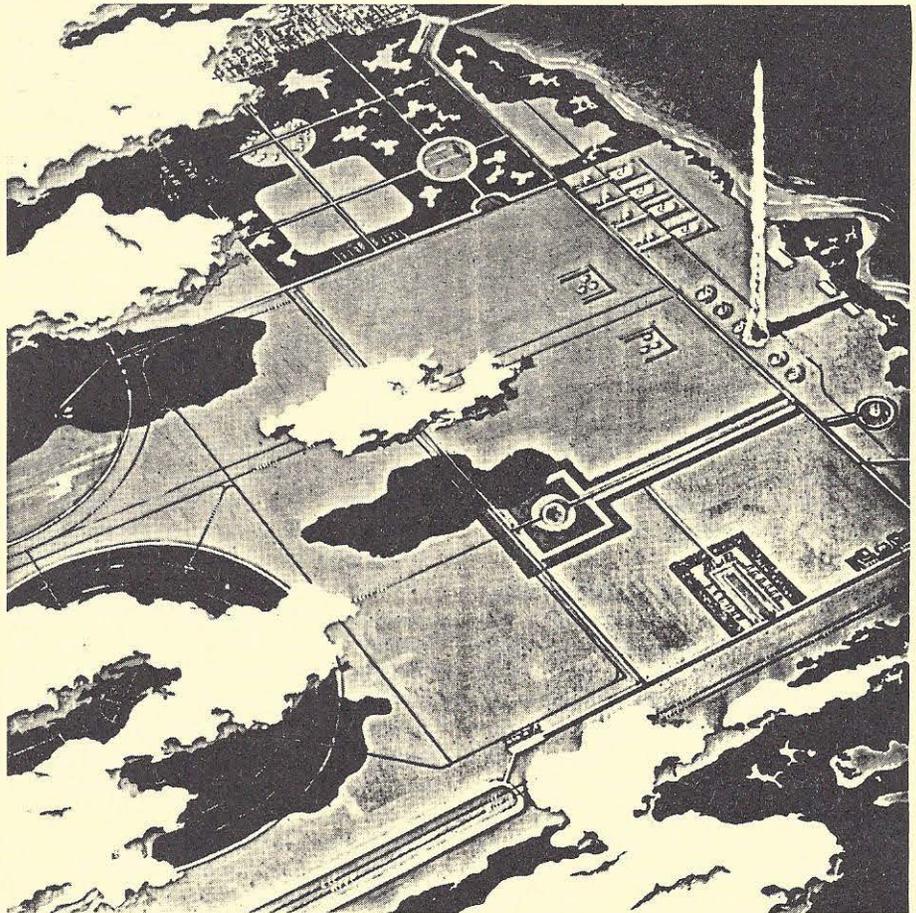
Szulc's article claimed that the OTRAG operation in Zaire violates

the 1954 Treaty of Brussels, which forbids the production of long-range missiles and cruise weapons on German territory.

But a spokesman for the German Foreign Ministry, Juergen Sudhoff, called the report that the rockets which OTRAG is developing are paid for by the Bonn government "pure nonsense". "OTRAG is a private investment company and the government is not involved," Sudhoff said. He commented further that the only government funds received by OTRAG were \$3.1 million granted to the firm by the Research Ministry several years ago for a 1971-1974 analysis of the launch vehicle. OTRAG spokesmen in Germany and the United States denied the article's claims as well.

Lutz Kayser, President of OTRAG, noted that Soviet leader Leonid I. Brezhnev has accused Germany, OTRAG and the West of establishing "military strongholds" in Africa "such as the missile testing center in Zaire" to "strengthen

*continued on page 6*



fore silicate rock containing chunks of nickel-iron (low grade stainless steel) and iron sulfide (FeS or trolite). The ordinary chondrites do not contain significant water or hydrated minerals.

The second major class of condensed matter is represented by the carbonaceous chondrites. Although carbonaceous chondrites are a fairly unusual type of meteorite, ground-based astronomy indicates that this type of material may be much more common in the asteroid belt than it is in museum collections. Carbonaceous chondrites contain all of the material in ordinary chondrites, and condensed about 360°K. However, at that temperature, silicate minerals reacted with water vapor to form hydrated materials—i.e., the carbonaceous chondrites are wet. The purest, Type I carbonaceous chondrites, are about 20% water by weight. Also, as the name indicates, this type of chondrite contains carbon—up to 3%, usually in the form of complex hydrocarbons. Most of the free iron has been oxidized to form magnetite (Fe<sub>3</sub>O<sub>4</sub>) by 360°K.

The third major class of material consists of solids present in a nebula which had cooled to about 100°K. By that temperature, most of the light molecular weight elements would have condensed as ices: oxygen as water ice, nitrogen as an ammonia-water ice clathrate (NH<sub>3</sub>·H<sub>2</sub>O) and carbon as methane ice and methane-water clathrate (CH<sub>4</sub>·7H<sub>2</sub>O). Only hydrogen, helium, neon and argon remain uncondensed at 100°K. This last class of material will not survive as a solid body inside the orbit of Mars, and consequently we have no samples for our collections. We are, however, certain it exists in the outer solar system and samples of it occasionally venture into the inner solar system in the form of comets.

We also know that *differentiated* samples of the ordinary and carbonaceous chondrite asteroids exist. Very early in the history of the solar system some of the condensed material accreted to form asteroid sized objects. These objects, heated up, melted and differentiated. The heavier free nickel-iron and FeS phases sank to the middle of the bodies and formed Fe-Ni, and FeS cores, while the

the last bastions of racism and colonialism." The accusation was made during a speech welcoming the Angolan head of state Agostinho Neto to Moscow. Neto won

lighter silicates floated on top to form differentiated mantles. The bodies subsequently cooled and were broken up in mutual collisions and small pieces of these mantles and cores fall to earth as achondrites and iron meteorites. The latter are particularly significant since they indicate the presence of large mountains of nickel-iron—*already in the correct oxidation state*. The iron and steel industry in space will consist of grabbing a convenient chunk of nickel-iron, melting it, perhaps adding alloying elements (and subtracting valuable siderophile [iron loving] elements—platinum, gold, etc.) and then forming the appropriate girders, plates or whatever—no blast furnaces, coal strip-mines, taconite wastes, etc.

In summary there should be at least seven fundamentally different mixtures of material available in space: 1) the solar elemental mixture which is dominated by hydrogen and helium, the surfaces of lunar soilgrains, the atmospheres of Jupiter and Saturn; 2) high temperature condensates (the white inclusions in meteorites, the Mercurian crust, etc.); 3) intermediate temperature condensates (ordinary chondrite meteorites); 4) carbonaceous chondrite material; 5) low temperature ices (the moons of Saturn and the outer planets, comets, etc.); 6) differentiated silicates (the achondrites); and 7) differentiated nickel-iron (the iron meteorites).

One final comment: the initial phases of materials development in space will involve enormous "swings" in the availability of different materials. As a mountain sized chunk of each different material is brought to the processing centers, the material balance will swing radically. Water, for instance, will be very rare until the first carbonaceous chondrite composition chunk of ice mountain is brought in—at which point it will suddenly become very abundant.

*Professor Calvin Alexander is an Assistant Professor of Geochemistry at the University of Minnesota.*

his position with the help of Cuban troops and Soviet hardware and money, and sponsored the recent attack on Shaba province this spring. Kayser scoffs at Breshnev's remarks.

"He ought to be better informed about the project. We frequently see Soviet MiG-23 reconnaissance jets over our testing grounds."

Articles about OTRAG and the cruise missile charges can be found in the Los Angeles Times (Wed., Dec. 14, 1977, and Thurs., Dec. 15, 1977) as well as the Santa Barbara News Press (Dec. 14, 1977).

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