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IMPLICATIONS OF ISOTOPIC SIGNATURES OF NOBLE GASES FOR THE ORIGIN AND EVOLUTION OF TERRESTRIAL ATMOSPHERES.

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The author (1, 2, 3) has proposed successive accretion models for the origin of terrestrial planets based (a) on the sequence of zones of condensation of solar nebula (b) on the condensation sequence of minerals, iron and nickel in different P-T regimes of the solar nebula and (c) on the sequence in the nucleation of iron cores of the terrestrial planets. Any model proposed for the origin of the terrestrial planets should also be capable of explaining the origin and evolution of the terrestrial atmospheres. The origin and evolution of the atmospheres are intimately related to the sizes and masses, thermal histories and tectonics of the terrestrial planets and the interactions of the degassed volatiles with the lithospheres of the planets. According to the successive accretion model the quantities of volatile rich bodies (similar to carbonaceous chondrites (6) low temperature assemblages-LTA) captured by the terrestrial planets were controlled by the masses and sizes of the terrestrial planets. For example, larger planets (Earth and Venus) must have captured almost all of the available volatile rich materials while smaller planets (Mars and Mercury) had captured only negligible quantities of volatile rich bodies during the final stages of their formation.

A comparison of the abundances of ^{40}Ar and ^{4}He (radiogenic) in various planetary atmospheres provides clues on the tectonics and outgassing histories of the planets and the comparison of primordial noble gases (^{20}Ne, ^{36}Ar, ^{84}Kr, ^{132}Xe) in the planetary atmospheres provides clues on the quantities of volatile rich materials captured by each of the planets. Finally, the absolute amount of degassed CO_2 of a planet provides clues regarding the quantity of noble gases (primordial) that accreted to planets in the form of carbonaceous chondrites, the host for the primordial noble gases (6). A comparison of the noble gases (primordial) contents of Mars, Earth and Venus clearly shows that their absolute abundances of gases (^{36}Ar, ^{20}Ne, etc.) are intimately related to the amounts of degassed CO_2 into the planets' atmospheres.

^{36}Ar was found to be about 75 times more abundant (Table I) in the Venus atmosphere than in the Earth's atmosphere and Mars is depleted in ^{36}Ar content by a comparable factor relative to the Earth (Table I). Surprisingly the pressures of degassed CO_2 are 90, 80 and 0.1 bars in the atmospheres of Venus, Earth (if all the CO_2 locked up in the sediments is put in the atmosphere) and Mars respectively. The greater the amount of degassed CO_2 the greater will be the amount of ^{36}Ar in the atmosphere of the planet. This model also can explain the 200 times more ^{4}He in the atmosphere of Venus than that in the Earth's atmosphere. This may also probably indicate that no significant quantities of ^{4}He escaped from the Venus atmosphere.

The successive accretion model for the formation of the planets can explain the nearly constant $^{20}Ne/^{36}Ar$ ratio (4) (Mars, Earth and Venus) and also accounts for the $^{36}Ar/^{132}Xe$ variation (see Table I) taking into account the Xe locked up (5) in the Earth's sedimentary rocks and Mars' regolith. This ratio $^{36}Ar/^{132}Xe$ is an indicator of interactions between Xe and water formed terrestrial rocks of a planet.

The ^{40}Ar content of Venus is only four times less than that of the Earth, indicating that degassing history of Venus (in spite of single plate, water poor mantle and slightly smaller size) is somewhat similar to that of the Earth. Similarly, the atmosphere of Mars compared to the Earth and Venus is deficient in ^{40}Ar due to small mass and paucity of K-rich material.

This paper maintains that the quantities of primordial noble gases that were captured into the outer layers of the terrestrial planets were controlled by the sizes and masses of the planets and the successive accretion model proposed by the author can explain the key trends (several orders of magnitude increase in ^{20}Ne and ^{36}Ar from Mars to Earth to Venus and a constant $^{20}Ne/^{36}Ar$) in the primordial noble gas contents of the planetary atmospheres.

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TABLE-I*

Absolute Abundance of ^{36}Ar (g/g) and Nuclide Ratios of Noble Gases in Planetary Atmospheres and Extraterrestrial Samples (4)

Object	^{36}Ar	$^{36}Ar/C$	$^{20}Ne/^{36}Ar$	$^{36}Ar/^{84}Kr$	$^{36}Ar/^{132}Xe$
Venus	2.5×10^{-9} (±0.3)	9.4×10^{-5} (±1)	0.15^{b} (±0.04)	50-1200	>3000
Earth	3.5×10^{-11} (±0.003)	1.3×10^{-6} (±0.6)	0.57 (±0.003)	48 (±0.5)	1300^{c} (±15)
Mars	2.1×10^{-13} (±0.6)	4.1×10^{-7} (1— 20)	0.43 (0.15-1.0)	31 (10-90)	230 (100-900)
CCI	1.6×10^{-9}	5.0×10^{-8}	0.27	109	114
CCII	6.9×10^{-10}	2.8×10^{-8}	0.30	74	89
CCIII V	7.7×10^{-10}	1.4×10^{-7}	0.19	99	126
CCIII C	1.6×10^{-9}	2.9×10^{-7}	0.03	154	242
CC4	1.8×10^{-10}	1.3×10^{-7}	0		126
Ureilites	7.4×10^{-9}	2.5×10^{-7}	0.01	94	143
Aubrite	2×10^{-11} 2×10^{-9}		16	2300	17,000
E chondrite	1.5×10^{-11} 1.2×10^{-8}	4.2×10^{-9} 3.3×10^{-6}	0.003-0.2	64-450	70-2700
Lunar soil	5×10^{-7} 1.3×10^{-6}	10^{-2}	8 ± 3	1050 $\pm$ 500	10,500 $\pm$ 5000
"Brownlee" dust	8×10^{-6} (±0.5)		9 ± 3	125	500 ± 200
Sun	3×10^{-5}	4.8×10^{-2}	35	2500	25,000

* Table-II from reference (4) is partly reproduced.