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The *d/h* Ratio and the Heating of the Early-Earth

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Abstract

Recent data from the Rosetta probe of the comet 67P/Chuyumov-Gerasimenko is examined assuming that the d/h ratio may have declined since the Earth first formed.

Keywords: early-earth and cometary water, deuterium-hydrogen ratio, earth's heat

1. Introduction

The recent remarkable visit of the European Space Agency's mission to the comet 67P/Chuyumov-Gerasimenko (hereafter 67P/C-G) by the Rosetta spacecraft see Altwegg et al. (2014) returned new important data regarding the origin of the water on Earth. The experimental data showed very clearly that the water found in the comet had a quite different ratio of d (deuterium) to h (hydrogen), considerably larger (by about 3.6 times) than the water found here on Earth. This result would appear to contradict the argument that comets delivered water during Earth's early era of formation. There have been a number of measurements and arguments put forth by planetary scientists about this issue (see the discussion and references in Altwegg et al. (2014). The d/h data from the Rosetta mission, therefore, seems to have conclusively answered the question "did the Earth get its water from comets such as 67P/C-G?" in the negative. That this conclusion may not be correct is the subject of this paper. Specifically, the d/h ratio may not have remained constant on Earth over its history due to a more rapid consumption of deuterium than of hydrogen (Note: p and h will be used interchangeably).

2. Tresino Thermal Energy Generation

Our recent paper Mayer and Reitz (2014) hereafter M&Rb, presented a new picture of the Earth's heating in our era. The present paper, however, examines the implications of the same Earth heating to the issue of the d/h ratio and heating in the early-Earth. In M&Rb, we showed that heating in the Earth was a consequence of the conversion of protons and deuterons into Compton-scale composite particles called "tresinos" (see Mayer & Reitz, 2012) ("Tresinos" are composed of common particles, being formed from two electrons and one proton or deuteron. Details can be found in the aformentioned reference). Furthermore, due to the difference between consumption of hs and ds we had anticipated (in M&Rb) a difference between the cometary water d/h ratio and that on Earth today.

Moreover, in M&Rb, it was shown that the Standard Earth Energy Paradigm (SEEP) was inconsistent with many geophysical observations; the most important was that the α-decay of U and Th was the heat source in the Earth. Rather, it was shown that the formation of proton and deuteron tresinos produced the Earth's heating as well as the populations of ^{4}He and ^{3}He observed in geophysical experiments. The SEEP assumption that α-decay was responsible for the heat from the Earth was incorrect. The energy from the p-tresino formation and the d-tresino reaction chain produced the Earth's heat in quantitative agreement with the present total Earth thermal power of about 44 TW (terawatts).

3. Thermal Energy and the *d/h* Ratio

In this Section, the connection between the power generation and the amount of deuterium in the water is examined. The power produced in the tresino formation reaction chains can be written,

$$P(t) = \epsilon_p N'_p(t) + \epsilon_d N'_d(t)$$

where $\epsilon_p = 3.7 \times 10^3$ eV is the p-tresino formation energy per particle, $N'_p(t)$ is the number of protons per unit time that undergo the formation reaction, $\epsilon_d = 22 \times 10^6$ eV is the total energy release from one completed d-tresino reaction chain that takes place over a very long time due to the 13 year half-life of tritium decay. So, whereas the energy release in both tresino formations is immediate, the energy release in the complete d-tresino chain takes place over hundreds of years.

In the above equation, the power can be simplified by relating $N'_d(t)$, the rate of d-reaction chain formation to the p-tresino formation rate as

$$N'_d(t) = (\, r\, 1.5 \times\ 10^{-4}\,) N'_p(t)/3$$

that depends upon the amount of deuterium in the water (see Section 3 of M&Rb). The 1.5×10^{-4} term is the present d/p ratio. The factor of three is required as there are three deuterons consumed in the completed d-tresino reaction chain (see Figure 5 of M&Rb). With the parameter $r = 1$ represents the present value on the Earth but taking r greater than one allows for higher d/h waters. So, the tresino power generation equation (over many tritium decay times) is

$$P(t) = [\, \epsilon_p + \epsilon_d\, (r/3)\, 1.5 \times 10^{-4}\,] N'_p(t). \tag{1}$$

Before proceeding, let's first consider the Earth values at present. With $r = 1$ we have $P(t) = P_0 = 44$ TW. One then finds that $N'_p(t) \approx 5.7\times10^{28}$ protons/sec. This rate is equivalent to hydrogen consumed in about 1.7 m^3 of water per second going into tresino formation reactions to generate the present level of thermal power production. In addition, note that the $N'_p(t)$, representing the p-tresino formation rate, would be expected to have been approximately constant in the early Earth whereas the amount of deuterium in the water may have changed sustantially because three deuterons are consumed in one completed d-tresino chain (see Figure 5 of M&Rb) over a long period compared to p-tresino consumption. It is worth noting that the fraction of the present heating rate due to the d-tresino chain is about 23% of the total power produced.

Equation (1) is linear in the parameter r and is plotted in Figure 1 where the power has been normalized to its present level P_0. As expected, the power level declines as the amount of deuterium in the water is reduced. The red-triangle in Figure 1 locates the Rosetta probe data value of 67P/C-G (Altwegg et al., 2014). Notice that this suggests that the early Earth, with a much higher d/h ratio, could have been substantially "warmer" than it is at present.

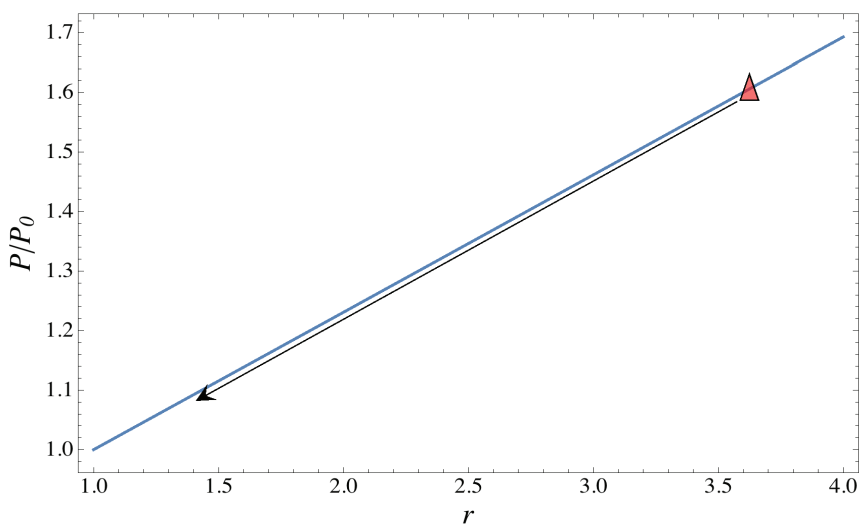

Figure 1. Normalized power as a function of r at larger d/h ratios. The arrow indicates the power reduction expected as deuterium is consumed

This simple power calculation indicates that the early Earth could have contained water with a larger d/h ratio, such as observed in the 67P/C-G comet, with the subsequent consumption of the deuterium over the long history of the Earth.

There is, of course, the issue of the mixing of the sea water as the deuterium is preferentially depleted. First notice that the deuterium consumption takes place on the few hundred year time-scale. Mixing of the ocean over the scale of the Earth is complex but it has been suggested that the mixing time-scale is of the order of 1600 years (Ocean, 2015, see Mixing time) not too different from the deuterium depletion time-scale. Since our concern here is for time-scales of billions of years it would appear that there is sufficient time for the mixing of the deuterium-depleted water in the oceans.

It is interesting to estimate the amount of water consumed by the tresino power producing process over the history of the Earth. It is easily calculated assuming that the *p*-tresino rate remained about the same over the 4.5 billion year history. Recall, from above, that this rate was $N'_p(t)$, the equivalent of about 1.7 m^3 of water per second. If this amount of water had been removed uniformly in a thin shell around the Earth, the depth being removed would have been about 480 meters. Actually the heating process does not remove oxygen only the protons and deuterons in this depth of water. Therefore a substantial amount of oxygen could have been liberated early in the Earth's history by the same process that created the heat.

4. Conclusions

The model calculation, presented herein, provides a method by which comets, such as 67P/C-G, could have delivered water to the infant Earth without a conflict with the d/h of water of todays Earth. The model calculation also has assumed that all of the water with the larger d/h value, as found in 67P/C-G, was delivered at the time of the formation of the Earth. There are, of course, scenarios whereby the same deuterium consumption and heating process (even non-linearly) could have led to our presently observed d/h value.

Dedication

It is with deep sadness that the author dedicates this paper to his mentor, collaborator, and friend, Dr. John R. Reitz, who passed away recently.

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