

THE ACCRETIONARY ORIGIN OF NOBLE GASES IN THE EARTH'S MANTLE. G. Holland and C.J. Ballentine. School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Oxford Road, Manchester. M13 9PL. U.K. Email: g.holland@manchester.ac.uk.

Introduction: An outstanding problem in the Earth and planetary sciences is the source and mechanism by which the Earth-like planets accreted their highly volatile elements. Unlike highly refractory elements, which preserve close to solar proportions in even quite evolved meteorites and the inner planets, moderately refractory and more volatile elements are depleted relative to the highly refractory elements. While the degree of depletion of moderately refractory and even volatile elements all appear to be related to degree of parent body processing [1], the origin of the planetary ice-forming elements and inert noble gases is more complex. This is because gravitational capture of the solar nebula as an early atmosphere and subsequent equilibration with a magma ocean has the potential to source these elements in considerable excess to that found trapped in accreting material [2–5].

Well gases – a unique noble gas resource: Early studies of terrestrial noble gases in erupted basalts found isotopic anomalies in $^3\text{He}/^4\text{He}$ ratio when compared to air, a ^3He excess implying a previously undegassed primordial component within the mantle [6]. It is still the case today that most studies of terrestrial volatiles focus on xenoliths and basalts. However, the eruptive origin of these samples may introduce elemental fractionation during magmatic degassing and the low abundances of noble gases retained in erupted samples often leads to substantial air contamination [7].

In contrast, noble gas data from magmatic CO_2 natural gases have proved to be an additional and invaluable resource in these investigations. Measurements from a single well head yielded $^3\text{He}/^4\text{He}$, $^{20}\text{Ne}/^{22}\text{Ne}$, $^{40}\text{Ar}/^{36}\text{Ar}$, and $^{124-136}\text{Xe}/^{130}\text{Xe}$ all in excess of air values and, combined with elevated MORB-like $^3\text{He}/^4\text{He}$ and $^{20}\text{Ne}/^{22}\text{Ne}$, provide clear evidence for a significant mantle component [8,9]. In contrast to these studies from a single gas well sample, [10, 11] showed how a suite of samples with varying mantle / crust+air components can be used to unambiguously resolve the mantle endmember noble gas composition both elementally and isotopically.

The primordial component in the Earth: Work on well gases and MORB samples has found that Ne (and He) in the mantle are dominated by implanted solar-derived gases [10-13]; Ar and Kr appear to be dominated by recycled atmosphere and as yet provide no resolvable information about accretionary gases; only Xe amongst the heavy noble gases in the terres-

trial mantle contains a resolvable mixture of solar and recycled atmosphere [11]. Therefore, in this work, we concentrate only on Ne and Xe.

Ne and Xe ratios: The variable proportions of mantle and air+crust components in individual well samples results in a mixing line between these two endmembers that intersects the Air-MORB mixing line. Following [10], we re-assessed the robustness of this intersection with a data set containing more mantle-rich well gases enabling a redefinition of the convecting mantle as $^{20}\text{Ne}/^{22}\text{Ne}=12.49\pm 0.04$ [11]. Using a mantle isotopic composition $^{20}\text{Ne}/^{22}\text{Ne}=12.49$, we derive a convecting mantle Ne concentration from MORB data [14] of 1.1×10^{-10} cc/g ^{20}Ne .

The primordial $^{129}\text{Xe}/^{132}\text{Xe}$ can be derived from the measured ^{129}Xe excess over air and the accompanying proportion of primordial Xe, calculated from $^{124-128}\text{Xe}$ excess over air: a measured $^{129}\text{Xe}/^{132}\text{Xe}=1.0625$ in a sample containing 10% primordial component yields $^{129}\text{Xe}/^{132}\text{Xe} (1.0625-0.984)\times 10+0.984=1.77$ for the primordial component. Also from $^{124-128}\text{Xe}$ excesses we can establish the elemental ratio of primitive Ne/Xe in the mantle (i.e. with recycled atmosphere-Xe removed) as $^{20}\text{Ne}/^{132}\text{Xe}\approx 1400$, yielding 7.8×10^{-14} cc/g ^{132}Xe in the convecting mantle.

Earth / meteorite comparison: To understand the accretionary history of the Earth and put these data in context, we need to compare terrestrial noble gas data with that of other volatile reservoirs in the solar system - meteorites. As a first order approach, using suitable bulk meteorite databases we have compiled Ne and Xe isotopic ratios and elemental abundances. This shows similar $^{20}\text{Ne}/^{22}\text{Ne}$ and $^{129}\text{Xe}/^{132}\text{Xe}$ ratios in relatively unprocessed meteorites (type 3 to 4) and the Earth (figs 1 & 2). We attribute the similarity in Ne isotopes between the Earth and chondrites to an implanted solar wind component which, although variably present in meteorites is the dominant source of terrestrial Ne due to the closer proximity of the Earth forming region to the Sun. ^{129}Xe is produced from ^{129}I . The correlation of $^{129}\text{Xe}/^{132}\text{Xe}$ with Xe concentration in carbonaceous chondrites is attributed to Xe loss while ^{129}I was live. Therefore we can investigate both the timing and extent of this loss process on bulk meteorites and compare the results with the isotopic and elemental Xe composition of the primordial terrestrial mantle defined above.

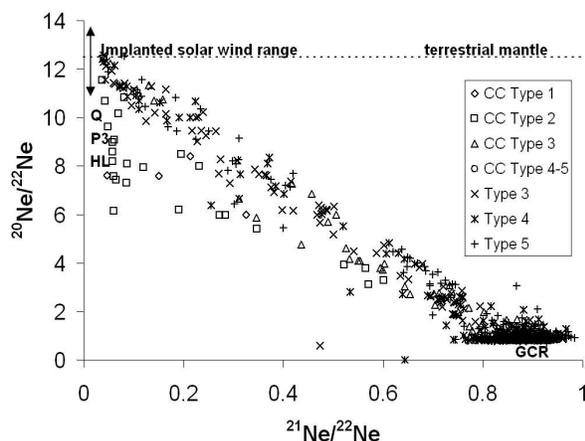


Fig 1: compilation of Ne isotope chondrite data showing mixing between implanted solar wind, planetary Ne and a galactic cosmic ray component.

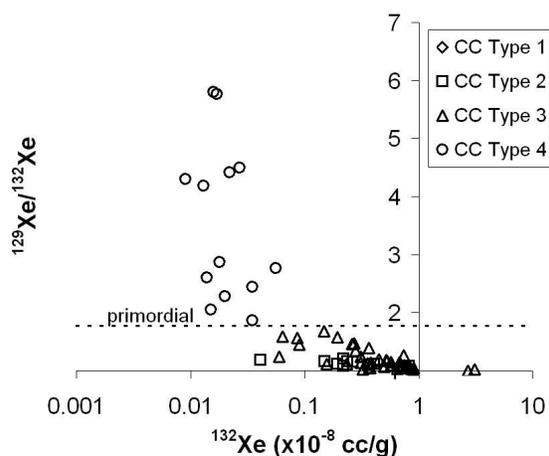


Fig 2: Xe data from carbonaceous chondrites. The correlation between the two quantities reflects processing which causes Xe loss that ultimately leads to elevated $^{129}\text{Xe}/^{132}\text{Xe}$. Horizontal dashed line is the terrestrial value.

Simple gas loss model: A simple degassing model [15,16] incorporates I and Xe into a bulk meteorite followed by a period of decay, interrupted at some later time by partial degassing of Xe. To generate the mantle $^{129}\text{Xe}/^{132}\text{Xe}$ ratio using this model requires that meteorites with initial Xe concentration of 1×10^{-8} cc/g ^{132}Xe (fig 2) have retained 7.0×10^{-12} and 6.4×10^{-11} cc/g ^{132}Xe for closure ages of 50Ma and 100Ma respectively. This is 90 to 820 times higher than calculated earlier for the mantle. However, the current paradigm states that primitive noble gas signatures e.g. ^3He and ^{129}Xe excesses are sourced not in the convecting mantle but from a comparatively undegassed primitive mantle [17-19]. From mass balance considerations of He isotope ratios in solar wind and the MORB source mantle, this primi-

tive reservoir is calculated to have ~100 times greater concentration than the convecting mantle. Assuming (1) that the convecting mantle is completely degassed initially and the comparatively undegassed reservoir supplies all the primitive noble gases and (2) that the ^3He and ^{129}Xe flux together, then this primitive mantle reservoir compares favourably with the concentration derived from the 100Ma closure age model (i.e. 100 times greater than observed versus 80 times greater than observed in the model). If we return to Ne, and require the same extent of gas loss as Xe during accretion, the initial Ne concentration is required to be $\sim 2 \times 10^{-5}$ cc/g ^{20}Ne . This is near the maximum observed in chondrites, implying that the Earth precursor material was irradiated to a greater extent than we observe in the majority of meteorites, as also required to generate a mantle without significant planetary (Q) Ne.

Summary: The mechanism of Ne delivery to planetary forming bodies in the inner solar system is observed in both relatively unprocessed meteorites and the Earth, and this process is solar wind implantation. Xe systematics, which are affected to a lesser extent by solar wind implantation, also show a relationship between these meteorites and the Earth. The majority of bulk meteorite Xe data and the primitive terrestrial Xe component can be described using a single starting composition. Further processing of the Earth causing more extensive degassing over longer periods provides Xe concentrations observed in the convecting mantle. This extended degassing suggests implanted Ne may have been acquired by Earth precursors in higher concentrations than observed in meteorites due to the smaller heliocentric distance of the former.

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