Noble gas composition in Ogi and Siena meteorites

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Abstract. The elemental and isotopic composition of noble gases in two chondritic meteorites which belong to documented "falls" is reported. Ogi, which belongs to the group of H-chondrites, fell in Saga, Kyushu (Japan) at 11 AM on 8 June 1741 and Siena which belongs to the group of LL-chondrites, fell in Tuscany (Italy) at 7 PM on 16 June 1794. The recovered mass of Ogi and Siena were 14.2 and 4 kg respectively. Their exposure ages are 13 ± 2 m.y. and 13 ± 3 m.y. respectively.

Keywords. Meteorite; noble gas; nuclear track; cosmic rays; exposure age.

1. Introduction

The measurement of noble gas composition is important part of meteorite research and provides information on the history of meteorites, the evolution of solar system objects and on the processes induced by solar and galactic cosmic rays. Cosmic ray exposure ages are derived using the abundance of spallogenic noble gas isotope and the theoretically derived production rates. Cosmic ray exposure ages in stony meteorites are generally studied by measurements of two or more stable cosmogenic nuclides like ^3He , ^{21}Ne and ^{38}Ar . These nuclides are good cosmogenic monitors as they have low abundances in primordial noble gases and also they are not produced by the decay of longlived radionuclides. Precise exposure ages are based on ^{21}Ne , because Ne is more retentive compared to He and primordial contributions in Ne are small. Besides it is easier to separate them than in He and Ar.

Charged-particle tracks offer another tool to decipher the cosmic ray exposure history of the meteorites. We have used them to supplement the noble gas studies.

2. Experimental

The noble gases were analysed in Reynolds-type ultra high vacuum all-glass mass spectrometer which was indigenously fabricated. A meteorite sample piece was wrapped in a pure Al foil and stored in vacuum before being dropped into a molycrucible to be heated by a rf induction heater at 1600°C for 1 hr. The released gases were purified using standard procedures (Rao *et al* 1979; Bhai *et al* 1978; Gopalan *et al* 1977). The analyser section is normally operated at 2×10^{-9} torr and the extraction system at 3×10^{-8} torr. All the isotopic ratios are corrected for mass discrimination and these corrections range from 0.6 to 1.47 per mass for the noble gases discussed here. The typical sensitivities of the spectrometer for different noble gases are $^{22}\text{Ne} =$

1×10^{-10} CCSTP/mV and $^{132}\text{Xe} = 8 \times 10^{-14}$ CCSTP / mV. A source magnet was used for all gases.

3. Results and discussion

The elemental and isotopic composition of He, Ne and Ar are given in table 1.

Noble gases originating from different sources such as solar wind, planetary gases, spallation and earth's atmosphere, have different characteristic isotopic compositions (table 2). From our results of noble gases in Ogi and Siena, it appears that all He, Ne and Ar compositions are cosmogenic in nature. The very high 40/36 ratios 7322 and 2026 in Ogi and Siena respectively suggest that most of ^{40}Ar is radiogenic. In the absence of K measurements, if we take K abundance in Ogi and Siena to be 800 ppm (as is generally observed in stony meteorites), the ^{40}K - ^{40}Ar age of Ogi and Siena turns out to be 4.5 b.y. and 3.9 b.y. respectively using the following equation which are consistent with their meteorite types H and LL respectively.

Table 1. Elemental and isotopic composition of noble gases.

	Sample (mg)	
	Ogi (123)	Siena (169)
1) Helium		
3/4	0.0276 ± 0.0006	0.0202 ± 0.0002
(4)*	8.96 ± 0.36	10.087 ± 0.057
2) Neon		
20/22	1.02 ± 0.01	1.62 ± 0.01
21/22	0.864 ± 0.007	0.819 ± 0.007
(22)*	5.314 ± 0.054	4.96 ± 0.05
3) Argon		
38/36	1.146 ± 0.001	0.474 ± 0.001
40/36	7322 ± 022	2026 ± 12
(36)*	0.823 ± 0.098	2.029 ± 0.082

* He contents are given in units of 10^{-6} cc STP/g while Ne and Ar are given as 10^{-8} cc STP/g.

Table 2. Noble gas isotopic ratios in different reservoirs*.

Reservoir	Helium	Neon		Argon	
	3/4	20/22	21/22	38/36	40/36
Solar wind	3.9×10^{-4}	13.5	0.034	0.186	~ 1
Solar flare**	0.01 – 1	11.8	0.040	0.186	~ 1
Planetary	1.4×10^{-4}	8.2	0.025	0.192	~ 1
Spallation gas	~ 1	0.9	0.85	1.52	~ 1
Air (terrestrial)	0.0139	9.8	0.029	0.188	296

* Reynolds *et al* (1978) and references therein.

**Venkatesan *et al* 1981.

Table 3. Cosmic ray exposure ages of these meteorites.

	Meteorite	
	Ogi	Siena
Exposure age (m.y)		
^3He	11.0 ± 2.2	9.6 ± 1.9
^{21}Ne	13.8 ± 1.4	16.2 ± 1.6
^{38}Ar	15.4 ± 1.6	13.8 ± 1.4
^{40}K - ^{40}Ar age (b.y)	4.5	3.9
NeR ($^{22}\text{Ne}/^{21}\text{Ne}$)	1.158 ± 0.01	1.221 ± 0.01

$$^{40}\text{K} - ^{40}\text{Ar} \text{ age} = t = 1.8854 \times 10^9 \times \ln \left[1 + 1.3315 \times \frac{^{40}\text{Ar}}{^{40}\text{K}} \right] \text{ years}$$

where ^{40}K in ppm units and ^{40}Ar in $\times 10^{-8} \text{ cc STP/g}$ units.

The spallation of ^3He , ^{21}Ne and ^{38}Ar concentrations were calculated according to the procedures described by Gopalan *et al* (1977) and the cosmic ray exposure ages for these two chondrites were calculated after applying proper corrections and the results are given in table 3.

Recently Bhandari and Potdar (1982) calculated cosmogenic ^{21}Ne and ^{22}Ne production rates in chondrites considering the dependence on shielding depth, size of meteorite and chemical composition. Their ^{21}Ne production rates for meteoroid sizes of 25 cm preatmospheric radius are in good agreement with those given by Eberhardt *et al* (1966). They compare at the same time the production rates given by Cressy and Bogard (1976) which do not agree and are quite different. As in most cases of chondrites, data on preatmospheric sizes are not available and most chondrites have preatmospheric sizes about 10 to 25 cm, we therefore adopt ^{21}Ne production rate given by Eberhardt *et al* (1966) as they fully agree with those given by Bhandari and Potdar (1982).

The ^3He , ^{21}Ne and ^{38}Ar ages are in good agreement within errors. The lower ^3He exposure ages can be ascribed to diffusion loss of helium.

In the aliquot samples of these two meteorites, large olivine crystals were carefully selected and the cosmic ray produced particle track densities were measured using standard procedures. The observed track densities are: Ogi— $78 \times 10^5 \text{ tracks/cm}^2$ and Siena— $34 \times 10^5 \text{ tracks/cm}^2$ (Bhandari *et al* 1980). The resulting TPM ($\text{tracks/cm}^2/\text{m.y.}$) values are for Ogi— 5.6×10^5 and Siena 2.1×10^5 . Using these results, the pre-atmospheric radii of these two meteorites are determined and turn out to be about 13 cm and 12 cm respectively. Moreover these data points in TPM-NeR diagram plot between the limits set (Bhandari and Potdar 1982) and justify the above pre-atmospheric size estimation.

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