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Chemical and isotopic characteristics of the Didwana-Rajod (H5) chondrite

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Abstract–The mineralogical and chemical characteristics of the Didwana-Rajod chondrite are described. The mean mineral composition is found to be olivine ($Fo_{83.2}$) and pyroxene ($En_{83.5}Wo_{0.7}Fs_{15.8}$), and feldspar is mainly oligoclase. Oxygen isotopic analysis shows $\delta^{18}O = +3.8‰$ and $\delta^{17}O = +2.59‰$. The nitrogen content of Didwana-Rajod is ~2 ppm with $\delta^{15}N \approx 3.4‰$. Based on microscopic, chemical, isotopic and electron probe microanalysis, the meteorite is classified as an H5 chondrite. Cosmogenic tracks, radionuclides and the isotopic composition of rare gases were also measured in this meteorite. The track density in olivines varies in a narrow range with an average value of $(6.5 \pm 0.5) \times 10^5/cm^2$ for four spot samples taken at the four corners of the stone. The cosmic-ray exposure age based on neon and argon is 9.8 Ma. $^{22}Na/^{26}Al \approx 0.94$ is lower than the solar-cycle average value of ~1.5 and is consistent with irradiation of the meteoroid to lower galactic cosmic-ray fluxes as expected at the solar maximum. The track density, rare gas isotopic ratios, ^{60}Co activity and other radionuclide data are consistent with a preatmospheric radius of ~15 cm, corresponding to a mass of ~50 kg. The cosmogenic properties are consistent with a simple exposure history in interplanetary space.

INTRODUCTION

The meteorite fell at Sonalias (P.O. Rajod), near Didwana in western Rajasthan, India on 1991 August 12. Preliminary mineralogical and petrological studies carried out by Paliwal *et al.* (1997) indicated the presence of enstatite, Fe metal, troilite and abundant chondrules. Based on these observations, the meteorite (called the Didwana-Rajod meteorite) was classified as an enstatite chondrite by Paliwal *et al.* (1997). Now we have carried out detailed petrographic, electron microprobe, chemical and isotopic analyses. These results indicate that the meteorite is an H-group ordinary chondrite of petrologic type 5 and its classification as an enstatite chondrite was erroneous. The classification as an H chondrite is supported by Mössbauer spectroscopy (Paliwal *et al.*, 2000). The results necessitating reclassification of this meteorite are described here. In addition, we have measured cosmogenic radionuclides (^{22}Na and ^{26}Al), tracks and the isotopic composition of oxygen, nitrogen and rare gases (He, Ne, Ar, Kr and Xe). These results are discussed in relation to isotope production by galactic cosmic rays and the exposure history of the meteoroid in interplanetary space.

FALL AND MINERALOGY

A fully crusted single fragment (Fig. 1) fell at ~10 P.M. Indian standard time on 1991 August 12 in an open field in the village of Sonalias (27°17' N; 74°25' E), near Didwana in the Nagaur District of Rajasthan. It was picked up by Sohan Ram, an undergraduate student residing in the village and was subsequently brought to the Jai Narain Vyas University, Jodhpur, where preliminary microscopic studies were carried out (Paliwal *et al.*, 1997).

The stone is pyramidal in shape and has a well-developed crust (~1 mm thick) all around with typical thumb marks. Polished sections as well as broken surface of the meteorite show abundant chondrules, metallic iron and troilite (Fig. 2). The chondrules occur in size range of 0.1 to 1 mm with a few up to 5 mm and are embedded in a medium- to coarse-grained fragmental matrix (Fig. 2a,c). They occur in a variety of textures, such as barred, radial, excentric, glassy or rimmed and some of them have degraded boundaries (Fig. 2b,d). Glassy chondrules show metal segregation (Paliwal *et al.*, 1997) indicating recrystallisation found in higher petrologic grades.

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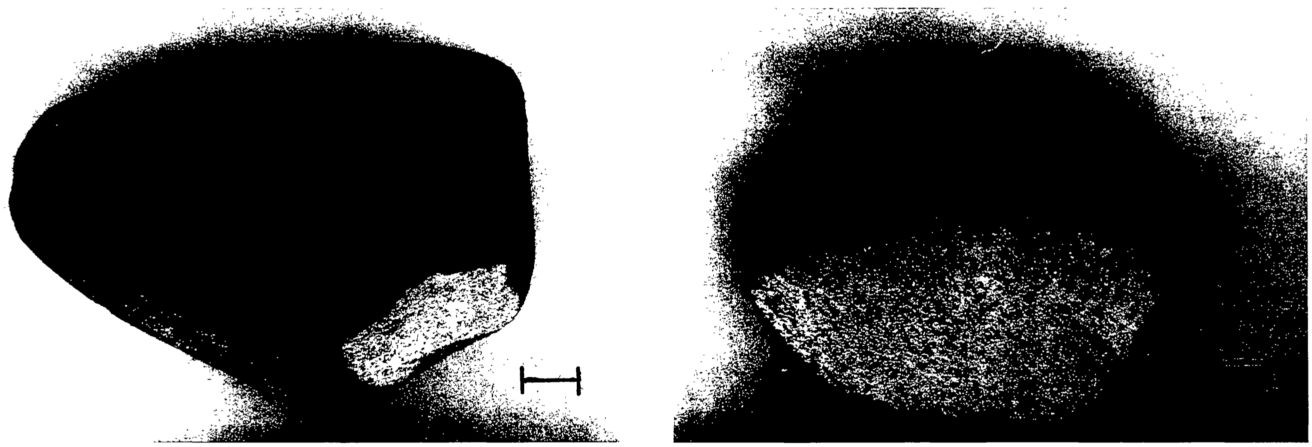

FIG. 1. Photographs of the Didwana-Rajod meteorite with a well-developed fusion crust. The meteorite was fully crusted when recovered. The fragmented faces show abundant metal iron. The bar is 1 cm.

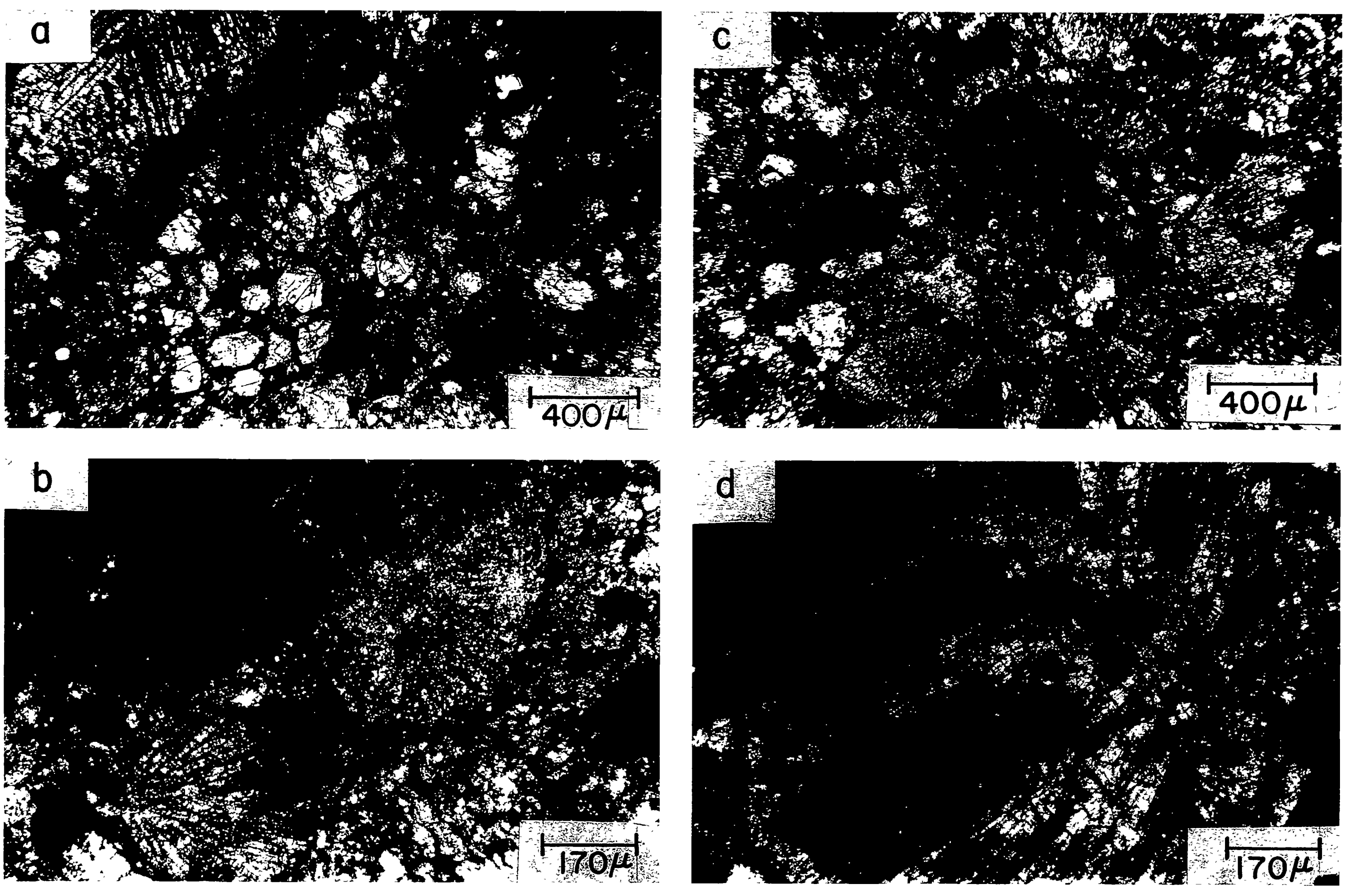

FIG. 2. Typical thin section photomicrographs of the Didwana-Rajod meteorite showing (a) olivines and pyroxenes as major minerals. The opaques are mostly chromite and troilite. A dendritic pattern in pyroxene chondrule is visible at the upper left. (b) Chondrules with well-rounded but diffused boundaries. (c) A fragmented chondrule at lower left. (d) Interior of a typical pyroxene chondrule.

These observations suggest that the Didwana-Rajod belongs to petrologic type 5 (Van Schmus and Wood, 1967). The mean composition of common pyroxenes is $En_{83.5}Wo_{0.7}Fs_{15.8}$. Olivine composition ranges around $Fo_{83.2}$ and plagioclase is mainly oligoclase. One chromite grain shows 6% Al_2O_3, 1.6% TiO_2, and 2.8% MgO. Metal kamacite and taenite show 6.1% and 44.8% Ni, respectively. No evidence for minerals that are characteristic of enstatite chondrites (*e.g.*, oldhamite) was found. Based on these observations and the chemical and isotopic analyses discussed later, the meteorite appears to belong to the H group and is not an enstatite chondrite, as inferred earlier (Paliwal *et al.*, 1997, 1998).

CHEMICAL AND ISOTOPIC ANALYSIS

Chemical analysis was carried out on powders prepared from about 1 and 3.7 g of interior chips free from fusion crust in an agate mortar. The elemental concentrations were determined using atomic emission (ICPAES), atomic absorption (AAS) and neutron activation (INAA) techniques at Physical Research Laboratory, Ahmedabad. Two aliquots of sample powders (203.4 and 124.8 mg) from the two chips were dissolved using HF-HCl digestion technique for ICPAES/ AAS analysis. For Si determination a separate aliquot (~100 mg) was dissolved using alkali fusion. Dhajala (H3.8) meteorite and diabase W2 were used as standards for ICPAES and AAS measurements. In this way, Si, Al, Mg, Ca, Fe, Ni, Ti, Mn, Co, K, Sr and V were measured. Six aliquots of sample powders (43.3 to 69.5 mg) were used for INAA in two separate irradiations. The irradiated samples were counted on a high purity Ge detector (148 cm^3) located in 10 cm thick lead shield following standard procedures (*e.g.*, Laul, 1979). Columbia river basalt BCR and Allende (CV) meteorite were used as INAA standards. Dhajala, Parsa (EH4) and eucrite Piplia Kalan were also included in the INAA analysis for comparison. Fe, Ni, Co, Cr, Ir, Os, Au, Na, Sc, Ca, Sm and Eu were measured using INAA procedures. Elemental concentrations given in Table 1 are weighted average for each element calculated from the replicate analyses. The average concentration of various siderophile elements (Fe, Ni, Co, Os, Ir and Au) for Didwana match reasonably well with the mean H chondrite composition (Kallemeyn *et al.*, 1989). Further, the Mg/Si (0.84) and Al/Si (0.07) ratios lie in the field of H chondrites and not EH chondrites which have lower values (0.63 and 0.05, respectively; Dodd, 1981). The chemical composition differs significantly from the previous analysis given by Paliwal *et al.* (1997).

TABLE 1. Chemical composition of the Didwana-Rajod chondrite.

Element	Concentration
Si (%)	16.9
Mg (%)	14.2
Al (%)	1.16
Ca (%)	1.33
Fe (%)	26.7
Ni (%)	1.54
Co (ppm)	757
Na (ppm)	6469
K (ppm)	842
Sr (ppm)	9.4
Sc (ppm)	7.6
Ti (ppm)	653
V (ppm)	49
Cr (ppm)	3729
Mn (ppm)	2446
Sm (ppm)	0.20
Eu (ppm)	0.08
Os (ppb)	1009
Ir (ppb)	777
Au (ppb)	225

Errors for major elements are ≤2% except for Ca (~5%). For trace elements, errors are ≤10%.

Isotopic Analysis of Oxygen

Isotopic analysis of oxygen was made at the Open University, U.K. following the procedure described in Miller *et al.* (1999) and the values are found to be $\delta^{18}O$ = +3.8‰ and $\delta^{17}O$ = +2.59‰, $\Delta^{17}O$ = 0.62‰. The data fall close to the field of H chondrites (Clayton *et al.*, 1991) and although $\Delta^{17}O$ is slightly lower than the average value (0.73), oxygen isotopes confirm that Didwana-Rajod is an H-group chondrite. On the basis of oxygen isotopic analysis, we can conclude that it does not belong to the E-chondrite group which have very different values of $\Delta^{17}O$ (*e.g.*, –0.04‰ and +0.05‰ for EH and EL chondrites, respectively; Clayton and Mayeda, 1984).

Noble Gas Studies

For noble gas and nitrogen studies, a 223.41 mg chip, without fusion crust (having track density of 6.5×10^5 cm^{-2}) was packed in a clean aluminum foil and loaded into the gas extraction system. The detailed procedure for extraction, purification and analysis of various gases has been described in Murty *et al.* (1998) and Bhandari *et al.* (1998). Briefly, after a combustion step at 400 °C in 2 torr oxygen, gases were extracted by stepwise pyrolysis at 1000, 1200 and 1600 °C. At each step, all the noble gases (He, Ne, Ar, Kr, Xe) and N were analysed. The data reported here have been corrected for blanks and instrumental mass discrimination. In addition, interference corrections have also been made at ^{20}Ne (from $^{40}Ar^{++}$), ^{22}Ne (from CO_2^{++}), ^{80}Kr (from $^{40}Ar_2^+$) and $\delta^{15}N$ (from CO) as described in Murty *et al.* (1998). Due to a large benzene interference at mass 78, the data for ^{78}Kr are not reliable and are not reported. The data for light noble gases and nitrogen are given in Table 2. The Kr and Xe results are given in Tables 3 and 4, respectively.

The light noble gases He and Ne are dominated by cosmogenic and radiogenic (^4He) components. On the other

TABLE 2. Light noble gases and nitrogen content of the Didwana-Rajod chondrite.

Temp. (°C)	^{4}He (10^{-8} cc STP/g)	^{22}Ne (10^{-8} cc STP/g)	^{36}Ar (10^{-8} cc STP/g)	$^{3}He/^{4}He$ (× 10^{4})	$^{20}Ne/^{22}Ne$	$^{21}Ne/^{22}Ne$	$^{38}Ar/^{36}Ar$	$^{40}Ar/^{36}Ar$	N (ppm)	$\delta^{15}N$ (‰)
400	135.2	0.042	0.165	73.95	1.598	0.8720	0.2099	2821	0.532	9.29
				±6.26	±0.024	±0.0074	±0.0004	±27		±0.67
1000	1405	1.65	0.294	60.48	1.042	0.8580	0.5662	17726	1.132	8.77
				±5.15	±0.004	±0.0060	±0.0027	±175		±0.56
1200	212.4	0.718	0.285	22.32	1.286	0.8685	0.4221	1682	0.009	11.6
				±1.89	±0.012	±0.0071	±0.0021	±16		±2.3
1600	30.4	1.15	2.211	117.7	0.7740	0.9099	0.2733	248.5	0.369	−21.8
				±10.0	±0.0066	±0.0064	±0.0003	±2.5		±0.5
Total	1783	3.56	2.95	57.93	1.011	0.8771	0.3133	2270	2.04	3.38
				±4.90	±0.007	±0.0064	±0.0006	±22		±0.59

Errors in concentrations are ±10%. Errors in isotopic ratios represent 95% confidence limit.

TABLE 3. Isotopic composition of krypton in the Didwana-Rajod chondrite.

Temp. (°C)	^{84}Kr (10^{-12} cc STP/g)	^{80}Kr (^{84}Kr = 100)	^{82}Kr (^{84}Kr = 100)	^{83}Kr (^{84}Kr = 100)	^{86}Kr (^{84}Kr = 100)
400	25.9	4.136	20.28	20.08	30.74
		±0.414	±0.30	±0.30	±0.46
1000	29.0	4.976	21.47	22.14	31.99
		±0.369	±0.11	±0.09	±0.01
1200	19.1	5.609	21.91	22.48	30.62
		±0.287	±0.37	±0.34	±0.57
1600	183.3	4.192	20.30	20.65	31.14
		±0.062	±0.17	±0.11	±0.14
Total*	231.4	4.407	20.58	20.99	31.20
		±0.119	±0.18	±0.12	±0.17

*The 400 °C fraction is not included in the total.

hand, Ar, Kr and Xe are mostly dominated by a trapped component. Using the trapped and cosmogenic end-member compositions suggested by Eugster (1988), we have derived the cosmogenic, trapped and radiogenic contributions for He, Ne and Ar which are given in Table 5.

Krypton and Xenon

The 400 °C fraction of both Kr and Xe show a contribution from air, probably an adsorbed surficial component. In the 400 °C fraction, Kr and Xe have not been separated and they have been analysed together by taking only 4 cycles of the data, as opposed to 10 cycles taken for our regular analysis. Therefore, the precision of the data for the 400 °C fraction is not good, particularly for the low abundant isotopes. Overall, both Kr and Xe are dominated by trapped components, with cosmogenic contributions amounting to <1% (at major isotopes). Radiogenic ^{129}Xe from the decay of extinct ^{129}I and small fission components in ^{134}Xe and ^{136}Xe can be clearly identified. We calculate the radiogenic $^{129}Xe_r = 83 \times 10^{-12}$ cc STP/g and $^{136}Xe_f = (2.0 \pm 0.7) \times 10^{-12}$ cc STP/g using OC-Xe for trapped composition. For a U content of 12 ppb, about 4×10^{-14} cc STP/g of $^{136}Xe_f$ can be produced during 4.5 Ga. Hence almost all the fission Xe has to originate in the fission of ^{244}Pu. Similar

TABLE 4. Isotopic composition of xenon in the Didwana-Rajod chondrite.

Temp. (°C)	^{132}Xe (10^{-12} cc STP/g)	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{134}Xe	^{136}Xe
		(^{132}Xe = 100)							
400	28.2	0.339 ±0.017	0.465 ±0.023	7.16 ±0.11	106.4 ±1.6	16.14 ±0.24	81.65 ±1.23	39.96 ±0.60	32.15 ±0.48
1000	43.4	0.499 ±0.020	0.552 ±0.015	8.38 ±0.07	142.9 ±0.7	16.58 ±0.10	81.89 ±0.25	39.56 ±0.17	33.04 ±0.15
1200	35.2	0.554 ±0.039	0.586 ±0.042	8.07 ±0.17	147.6 ±0.5	16.69 ±0.32	81.05 ±0.13	39.05 ±0.35	32.67 ±0.15
1600	291.1	0.535 ±0.051	0.466 ±0.013	8.23 ±0.04	120.7 ±0.5	16.38 ±0.04	81.97 ±0.11	38.40 ±0.18	32.69 ±0.15
Total*	369.7	0.533 ±0.046	0.487 ±0.015	8.23 ±0.06	125.9 ±0.5	16.43 ±0.07	81.87 ±0.13	38.60 ±0.19	32.73 ±0.15

*The 400 °C fraction is not included in the total.

TABLE 5. Cosmogenic and radiogenic amounts (10^{-8} cc STP/g) and ages.

Cosmogenic			Radiogenic		CREA* (Ma)			Radiogenic age (Ga)	
^{3}He	^{21}Ne	^{38}Ar	^{4}He	^{40}Ar	T_3	T_{21}	T_{38}	U,Th-^{4}He	K-Ar
10.1	3.11	0.423	1731	6704	6.4	10.2	9.3	4.2	4.53

*Cosmic-ray exposure age (uncertainties are ±15%).

conclusion can be drawn based on the amount of $^{134}Xe_f$ as well. This amount of ^{244}Pu fission ^{136}Xe for Didwana-Rajod is within the range of values reported for H5 chondrites (Eugster *et al.*, 1993) that have Pu-Xe ages similar to Angra dos Reis (Lugmair and Marti, 1977). The elemental ratios of the trapped component ($^{84}Kr/^{132}Xe$) = 0.65 and ($^{36}Ar/^{132}Xe$) = 67.2 fall within the typical range observed for chondrites (Swindle, 1988).

Nitrogen

The total N content in Didwana-Rajod is 2.04 ppm with $\delta^{15}N$ = 3.38 ± 0.59‰. The peak release of N occurred at 1000 °C, while the peak release of Ar, Kr and Xe is observed at 1600 °C. The first three temperature fractions wherein 82% of N is released have about uniform $\delta^{15}N$ of ~9‰, whereas the melting step wherein most of the trapped noble gases (Ar, Kr, Xe) are released has a $\delta^{15}N$ of –21.8‰. Since cosmogenic ^{38}Ar release, which roughly parallels release of cosmogenic ^{15}N, occurs at >400 °C with peak release at 1600 °C (Fig. 3), the nitrogen isotopic pattern can be understood as follows: There are at least two trapped N components, a heavy component released at low temperature and an admixture of a lighter component and cosmogenic nitrogen released at high temperatures. The large amount of N released at the 400 °C combustion step is unlikely to be a contaminant since its $\delta^{15}N$ is 9‰. It is most likely a labile indigenous N component, probably of organic origin, as commonly found in ordinary chondrites (Hashizume and Sugiura, 1995). The 1600 °C fraction, where a major proportion of cosmogenic nitrogen is expected to be released, having $\delta^{15}N$ of –21.8‰, indicates that the trapped N should have $\delta^{15}N$ < –21.8‰. This component is also accompanied by primordial noble gases. Assuming that there are only two trapped N components, an admixture of this lighter N component with cosmogenic N can explain the observed $\delta^{15}N$ in 1000 and 1200 °C fractions. It is fortuitous that $\delta^{15}N$ of the first three temperature fractions is similar. Though we can not determine the $\delta^{15}N$ of different trapped components, an average value of all the trapped N can be obtained by correcting the total $\delta^{15}N$ for cosmogenic contribution based on the $^{21}Ne_c$ of the sample. For H chondrites of the size of Didwana-Rajod (~15 cm) we take the production ratio of $(^{15}N/^{21}Ne)_c$ = 4.5 ± 0.5 (Mathew and Murty, 1993) to

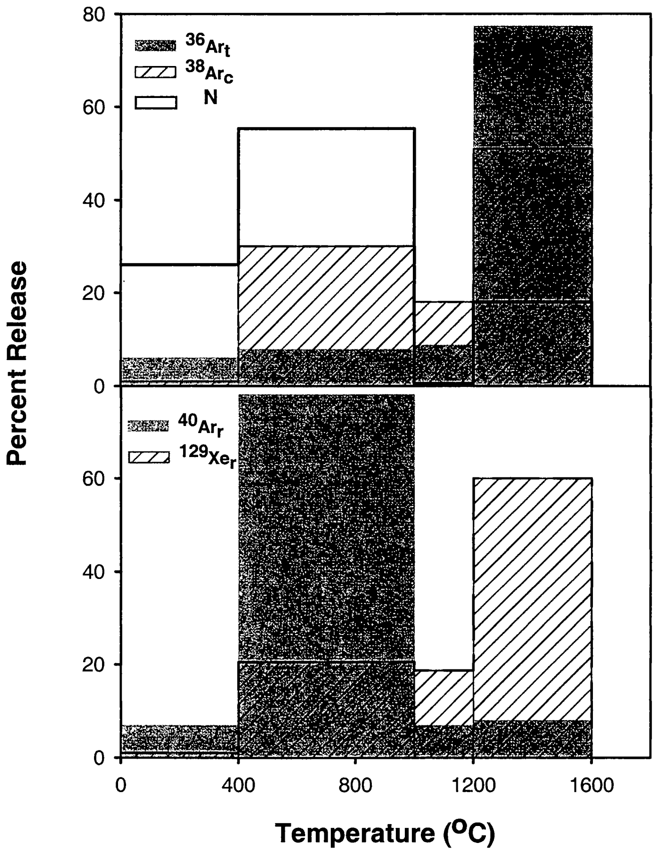

FIG. 3. Release pattern of trapped ($^{36}Ar_t$, N), cosmogenic ($^{38}Ar_c$) and radiogenic ($^{40}Ar_r$, $^{129}Xe_r$) components of nitrogen and noble gases. Two types of N components, a major release at 1000 °C, not accompanied by noble gases, and a minor release accompanied by most trapped noble gases at melting step are evident. While the carrier of $^{40}Ar_r$ is labile, that of $^{129}Xe_r$ is a refractory mineral. The peak release of $^{38}Ar_c$ occurs at 1600 °C, although a considerable fraction is co-released with $^{40}Ar_r$.

estimate the $^{15}N_c$. On correcting the measured $\delta^{15}N$ for cosmogenic component, we obtain a value of –8.3 ± 1.3‰ which represents the average value for the various trapped N components in this meteorite. The release patterns of cosmogenic, radiogenic and trapped Ar components are shown in Fig. 3. Trapped N and radiogenic ^{129}Xe are also shown in this figure. The trapped Ar was mostly released at the melting step (1600 °C) while radiogenic ^{40}Ar had peak release at 1000 °C. The bimodal release of cosmogenic ^{38}Ar at 1000 and 1600 °C indicates that the major mineral phase containing K (^{40}Ar released at 1000 °C) contributed ~30% to cosmogenic ^{38}Ar. Therefore it appears that the trapped Ar (as well as Kr and Xe) and N are not sited in the same phase. On the other hand, the radiogenic ^{129}Xe is as tightly bound as the trapped gases, indicating that ^{129}I is mostly sited in refractory silicates. The results suggest that there are at least two trapped N components, one of which is unaccompanied by trapped noble gases and is released at low temperature (400 °C) and the other, together with the trapped noble gases, at high temperature (1600 °C). In view of the fact that the N released at the two temperatures have different $\delta^{15}N$ signatures, it is unlikely that the same N component is trapped in different phases. The lighter $\delta^{15}N$ released at 1600 °C appears to have the Q-type component in its isotopic signature and is associated with the trapped noble gases (Murty, 1996).

COSMOGENIC EFFECTS

Track densities were measured in olivines separated from spot samples taken from under the crust from the four corners of the meteorite. Olivines were etched in boiling WN solution (40% EDTA + 1% oxalic acid and orthophosphoric acid, made to pH 8 by adding NaOH) for 6 h, following the procedure of Bhandari *et al.* (1980). The results (Table 6a) indicate that the track density varies within a narrow range. The ablation is roughly similar on all faces, estimated to be 6.5 ± 2.5 cm. This yields the preatmospheric radius of the meteoroid to be ~15 cm (equivalent to ~50 kg), assuming spherical geometry. The mass ablation is calculated to be ~98%.

Gamma emitting radionuclides (^{22}Na, ^{26}Al and ^{60}Co) were measured by counting ~700 g of the main fragment on a low-level gamma-ray spectrometer consisting of a hyperpure Ge detector located in a 20 cm thick lead shield. The results are given in Table 6b. ^{40}K (K = 842 ppm, Table 1) was used as an internal standard for calculating the activity of various radionuclides following the procedure of Bhandari *et al.* (1989). ^{60}Co is mostly produced by neutron capture on cobalt and only a small contribution comes from the spallation of nickel. The low activity of ^{60}Co (1.8 ± 0.45 dpm/kg) indicates low thermal neutron flux implying that the meteoroid was a small body

TABLE 6a. Track density in olivines from Didwana-Rajod surface samples.

Sample code	Track density/cm^2 (# of tracks)	Shielding depth (cm)
D1	7.5 × 10^5 (38)	7 ± 2.5
D2	6.6 × 10^5 (68)	6.5 ± 1.5
DA	6.8 × 10^5 (38)	6.6 ± 2
DB	5.0 × 10^5 (28)	6.5 ± 1.5

TABLE 6b. Gamma radioactivity in the Didwana-Rajod chondrite.

Isotope	Gamma energy (keV)	Cpm*	dpm/kg†
^{22}Na	1274.8	0.076 ± 0.003	49.2 ± 2.6
^{26}Al	1809.0	0.42 ± 0.004	52 ± 0.5
^{60}Co	1332.5	0.008 ± 0.002	1.8 ± 0.45

*At the time of counting (1999 January 8 to February 5).
†At the time of fall (1999 August 12).

when it was exposed to cosmic rays in interplanetary space (Spergel *et al.*, 1986). This is consistent with the track data discussed above. Comparison of the observed ^{26}Al activity (52 ± 0.5 dpm/kg) with its production profiles in meteoroids of various sizes (Bhandari *et al.,* 1993; Leya *et al.*, 2000) puts some constraints on the preatmospheric size and the average shielding depth of the recovered fragment. It implies a shielding depth of 5 to 15 cm in a spherical body of 18 to 100 cm radius. However, in view of the low activity of ^{60}Co, the lowest size is favoured and we may infer that the meteoroid radius was ~18 cm. This is slightly higher than the size determined from tracks. Considering the errors in measurement of ^{26}Al (statistical error ~1% and systematic errors ~5%, due to error in determination of ^{40}K, *etc.*) and that the shape of the meteoroid may not be spherical, there may not be much discrepancy in the size estimates based on tracks and ^{26}Al. We therefore adopt a value of 15 ± 3 cm for the preatmospheric size of the meteoroid. The meteorite fell at the time of sun-spot maximum of the solar cycle 22 when the modulation of the galactic cosmic rays due to heliospheric magnetic field was about the highest. ^{22}Na/^{26}Al ≈ 0.94 , within the errors of measurement, is close to the expected value of 1.05 (Bhandari *et al.*, 1994; Bonino and Castagnoli, 1997). The nearly consistent values of track density, ^{60}Co, ^{22}Na, ^{22}Na/^{26}Al and ^{22}Ne/^{21}Ne (discussed below) and their agreement with the expected values indicate that the meteoroid had a simple, one-stage, exposure history in interplanetary space.

Cosmic-Ray Exposure Ages

The production rates of ^{3}He and ^{21}Ne were calculated for the chemical composition of Didwana-Rajod following the procedure of Eugster (1988) for the purpose of determining the cosmic-ray exposure ages. However, in case of ^{38}Ar, the production rate of Eugster (1988) has been found to be an overestimate by up to 15% and therefore we have adopted the revised formula of Marti and Graf (1992). The calculated exposure ages are given in Table 5. The ^{3}He exposure age is lower by ~30% compared to those based on ^{21}Ne and ^{38}Ar, indicating partial loss of ^{3}He. The lower value of $(^{3}\mathrm{He}/^{21}\mathrm{Ne})_c$ = 3.24, as against the expected value of 5 for $(^{22}\mathrm{Ne}/^{21}\mathrm{Ne})_c$ = 1.115 also indicates some loss of ^{3}He. Partial loss of cosmogenic ^{3}He is generally observed in meteorites (Schultz and Kruse, 1989), more so in metal-rich meteorites, suggesting that the loss is most probably due to ^{3}H diffusion from the metal. We take the average of T_{21} and T_{38} (9.8 Ma) as the exposure age of Didwana-Rajod. This exposure age does not coincide with any of the two age clusters observed at 7 and 33 Ma for H chondrites (Marti and Graf, 1992).

Radiogenic Ages

Using the average concentrations of U = 12 ppb and Th = 42 ppb for H chondrites (Wasson and Kallemeyn, 1988) and the measured radiogenic ^{4}He concentration, we derive a U-Th-^{4}He age of 4.2 Ga. A K-Ar age of 4.53 Ga is calculated using the measured K = 842 ppm (Table 1). Both the U-Th-^{4}He and K-Ar ages agree within the uncertainties, suggesting that there is no appreciable loss of radiogenic ^{4}He from Didwana-Rajod, although some cosmogenic ^{3}He was lost during the terminal phase of its space exposure.

CONCLUSIONS

Didwana-Rajod was suspected to be an E chondrite by Paliwal *et al.* (1997). Its chemical, petrological and oxygen isotopic composition have now shown that it belongs to the H5 class of ordinary chondrites. The nitrogen and noble gas data further corroborate that Didwana-Rajod belongs to the H5 class, because E chondrites generally have ~50 ppm N (sometimes as high as several hundred ppm) with δ^{15}N ≈ –35‰ (Grady *et al.*, 1986) while Didwana-Rajod has only 2 ppm N with δ^{15}N ≈ 3.4‰, values typical of ordinary chondrites. Noble gases in E chondrites have a distinctively large ^{36}Ar/^{132}Xe > 100, due to the presence of the ^{36}Ar-rich subsolar component, a high value of ^{129}Xe/^{132}Xe >2 and a high concentration of $^{129}\mathrm{Xe}_r$ (Crabb and Anders, 1981). For Didwana-Rajod, these measurements lie outside the range observed in E chondrites, but are close to the typical ordinary chondrites of petrologic class 4/5 (Marti, 1967; Schultz *et al.*, 1990).

In summary, the chemical, petrographic and isotopic (O, N, noble gases) data indicate that Didwana-Rajod is a typical H5 chondrite. Cosmogenic radioisotopes (^{26}Al, ^{60}Co) and tracks indicate a meteoroid radius of ~15 cm with a simple one-stage exposure history to cosmic rays.

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