COSMIC-RAY EXPOSURE CHRONOLOGIES OF DEPLETED OLIVINE-PHYRIC SHERGOTTITES.
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Introduction: Martian meteorite Northwest Africa (NWA) 4925 is a depleted olivine-phyric shergottite [1, 2]. One corner of the originally larger stone was cut out and classified separately as NWA 4527 (mass of 10 g) earlier, and the remainder (282 g) was classified as NWA 4925 later (Fig. 1). The exterior of NWA 4925 is partially covered by a weathered fusion crust.

Figure 1. Whole NWA 4925 stone (282 g). The missing corner portion was cut out and classified as NWA 4527. Photo courtesy of S. Ralew.

The interior of NWA 4925 is relatively fresh, but there is a prominent weathering rind that implies a long terrestrial residence age (Fig. 2).

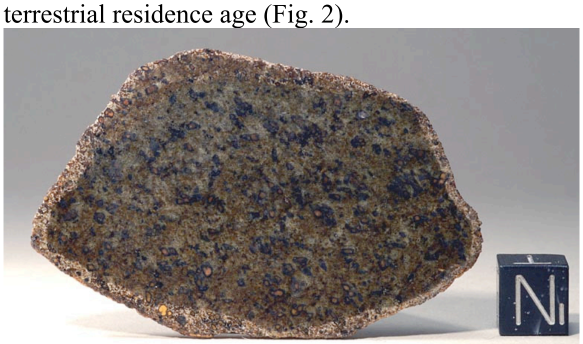

Figure 2. Cut surface of NWA 4925 clearly showing the weathering rind. Photo courtesy of S. Ralew.

Cosmogenic stable- and radionuclides can be used to determine the exposure histories, terrestrial ages, and ejection conditions from the Mars. From these we can ascertain whether these shergottites were ejected from Mars by the same event. We report here results of the four cosmogenic radionuclides: ^{10}Be (half-life = 1.36 Myr), ^{26}Al (0.705 Myr), ^{36}Cl (0.30 Myr), and ^{14}C (5,730 yr) in depleted olivine-phyric shergottites, NWA 4925 as well as NWA 2046, 2626, and 5789 and noble gases in NWA 4925.

Experimental Procedures and Results:
^{10}Be, ^{26}Al, and ^{36}Cl measurements. We received a powdered sample of NWA 4925. To eliminate terrestrial weathering products, the sample was leached twice with a 1.5 N HNO_3 solution in an ultrasonic bath for 10 minutes each. The weight loss was 27%, indicating severe terrestrial contamination. 57.38 mg of cleaned sample was dissolved in an HF-HNO_3 mixture along with Be and Cl carriers. The ^{10}Be, ^{26}Al, and ^{36}Cl AMS measurements were performed at PRIME Lab, Purdue University. Cosmogenic ^{10}Be, ^{26}Al, and ^{36}Cl concentrations (±1σ) in NWA 4925 and chemical compositions (Al, Ca, Mn, and Fe) in aliquot of samples are shown in Table 1.

^{14}C measurement. Samples were pretreated with 100% H_3PO_4 to remove weathering products. The residue was melting in a flow of oxygen to recover $^{14}CO_2$ in presence of a carrier. The AMS measurements were performed at the University of Arizona NSF-AMS facility. ^{14}C concentration in NWA 4925 is shown in Table 1.

Noble gas measurements. A chip of 10.7 mg was pre-heated in vacuum at ~150°C over night. Noble gases were released in a single step at 1800°C, followed by mass spectrometric analyses of all noble gases using modified-VG5400 mass spectrometer. Concentrations and isotopic compositions of He, Ne, and Ar as well as ^{84}Kr and ^{132}Xe are shown in Table 2.

Discussion: Cosmogenic radionuclide concentrations as well as chemical compositions in other 7 depleted olivine-phyric shergottites are also shown in Table 1. Preliminary results of NAW 1195, 2046, and 2626 [3], Dag 476-735 and SaU 005 [4] and Y 980459 [5] were reported earlier; results from NWA 5789 are new.

NWA 4925 and 5789. The noble gas exposure age of NWA 4925 is 0.6 Myr, similar to that of EET 79001. This exposure age is the shortest exposure age among Martian meteorites. Low concentrations of cosmogenic radionuclides can be explained by either short exposure age or heavy shielding within a large preatmospheric size object. However, ^{80,82}Kr/^{84}Kr and ^{128,131}Xe/^{132}Xe isotopic ratios do not indicate any neutron capture effects on Br, I or ^{130}Ba so exposure in a large object does not account for the paucity of radionuclides. Based on 4 radionuclides and noble gas concentrations, NWA 4925 had 0.60-0.73 Myr exposure in space followed by 420-490 kyr residence on Earth. Among non-Antarctic Martian meteorites this is the longest terrestrial age. The ejection age (summation of exposure age and terrestrial age) from Mars is 1.1±0.1 Myr. NWA 5789 contains high ^{26}Al, indicating solar cosmic ray production. The ablation depth is less than a cm and preatmospheric radius was <5 cm that was similar to Y 980459.

Ejection ages of depleted olivine-phyric shergottites. Table 3 summarizes our determinations of the terrestrial ages and exposure ages of 8 olivine-phyric shergottites. Based on the terrestrial ages and the recovery locations we identify at least 7 individual falls. Even though the terrestrial ages span a wide range, the ejection ages of all 8 depleted olivine-phyric shergottites form a tight cluster at 1.1±0.1 Myr. All 8 olivine-phyric shergottites must have been ejected from Mars by a single impact but reached Earth at different times individually as small objects. This circumstance accounts for the similar chemical compositions and petrology of those shergottites. Five of the NWA olivine-phyric shergottites presumably fell in similar locations at different times. In particular, the RBT 04261 and the RBT 04262 enriched shergottites were ejected by the same impact, fell in about the same location (within 1 km), but arrived 0.7 Myr apart [6]. Although this scenario seems unlikely, it indicates that each Martian impact consisting of many small bodies. Enough Martian and lunar meteorites have been recovered and characterized to allow meaningful comparisons. At present, 56 individual Martian meteorites have been recovered on Earth representing 8 (or 7) Martian impact events spanning 20 Myr. Each Martian impact event delivers on average 7 Martian meteorites, seemingly a high rate. On the other hand, ~70 individual lunar meteorites have been recovered. We have identified more than 12 lunar individual impacts spanning <0.5 Myr. Although capture rate of lunar meteorites by Earth is higher than that of Martian [7], why so many impact rate on Moon compared to Mars?

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Table 1. Chemical compositions and cosmogenic radionuclides in 8 depleted olivine-phyric shergottites.

Name	Al (%)	Ca (%)	Mn (ppm)	Fe (%)	^{10}Be (dpm/kg)	^{26}Al (dpm/kg)	^{36}Cl (dpm/kg)	^{36}Cl (dpm/kg*)	^{41}Ca (dpm/kg)	^{14}C (dpm/kg)
NWA 4925	2.56	4.51	3570	14.2	4.47±0.14	16.6±1.1	2.99±0.12	5.94±0.24	n.d.	< 1
NWA 1195	1.99	5.45	3800	15.8	7.58±0.28	31.9±0.6	6.20±0.18	10.4±0.3	2.0±0.9	0.8±0.6
NWA 2046	2.74	4.49	3570	14.0	8.30±0.11	37.9±1.7	8.11±0.37	16.3±0.7	n.d.	0.5±0.2
NWA 2626	2.47	4.77	3730	14.5	7.95±0.19	31.5±1.3	7.15±0.22	13.6±0.4	n.d.	n.d.
NWA 5789	2.45	4.01	3480	12.7	7.15±0.20	70.0±2.6	9.09±0.14	20.3±0.3	n.d.	n.d.
DaG 476-735	2.16	4.74	3490	13.5	7.9 - 9.6	36 - 47	7.2 -10.3	13.8 - 22.0	1.5 - 3.4	< 0.3
SaU 005	2.44	3.65	3640	15.4	8.53±0.19	39.5±1.0	8.86±0.23	19.9±0.5	6.0±1.3	13.5±0.4
Y 980459	2.18	4.96	3600	13.9	7.16±0.10	56 - 65	8.14±0.22	15.2±0.2	3.9±0.5	n.d.

*dpm/kg (8Ca+Fe)

Table 2. Noble gases in NWA 4925.

^{4}He	^{3}He/^{4}He	^{20}Ne	^{20}Ne/^{22}Ne	^{21}Ne/^{22}Ne	^{36}Ar	^{38}Ar/^{36}Ar	^{40}Ar/^{36}Ar	^{84}Kr	^{132}Xe
43±7	0.213	3.23±0.33	1.347	0.752	4.32±0.44	0.2637	350.8	0.117	0.0088

Gas concentrations in 10^{-9} cm^{3} STP/g, Uncertainties: 10% for concentrations, 16% for ^{3}He/^{4}He, 1% for other isotope ratios.

Table 3. Summary of terrestrial, exposure, and ejection ages of 8 depleted olivine-phyric shergottites.

Name	Recovered Mass (kg)	Preatmospheric radius (cm)	Terrestrial age (kyr)	Exposure age (Myr)	Ejection age (Myr)
NWA 4925	0.292	<20	420-490	0.60-0.73	1.1±0.1
NWA 1195	0.315		240±60	1.0±0.2	1.2±0.2
NWA 2046	0.063		90±50	1.1±0.2	1.2±0.2
NWA 2626	0.031		160±60	1.1±0.2	1.3±0.2
NWA 5789	0.049	<5	<40	1.0±0.2	1.0±0.2
DaG 476-1051	10.45	15-20	60±20	0.95±0.10	1.0±0.1
SaU 005-150	11.21	20-30	11±1	1.0±0.1	1.0±0.1
Y 980459/497	0.091	<5	60	1.0±0.2	1.1±0.2