

Cosmic Ray Effects in the Fresh Fall Portales Valley

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Abstract

The Portales Valley meteorite fell as a large shower on 13 June 1998. About 50 specimens have been recovered. These various fragments located at different depth within the meteoroid provide an opportunity to study cosmogenic effects also as a function of shielding. Portales Valley was classified as a H6 ordinary chondrite. It consists of large silicate-rich regions crosscut by unusual thick veins of metallic Fe-Ni. We measured the gamma-activity and the nuclear tracks in a fragment weighing about 600 g. Twelve cosmogenic radioisotopes were revealed with high accuracy of counting. Measurements in other fragments are in progress. Cosmogenic ²²Na ($T_{1/2} = 2.6$ y) shows an exposure to GCR during the last years of low solar activity, similar to those measured in our Laboratory in other chondrites which fell in similar phase of the solar activity.

1 Introduction :

The Portales Valley meteorite shower fell on 13 June 1998 near the town of Portales, New Mexico. About 50 fragments, ranging between 12 g to 34 kg, covered a strewn field of about 10 km x 2 km, centered at 34° 10.2' N and 103° 17.5' W (Mc Hone et al., 1999). As it was a large shower, various fragments located at different depth within the meteoroid provide an opportunity to study cosmogenic effects also as a function of depth. Such information is useful for understanding the complex phenomena involved and for validation of the theoretical models developed to calculate the production rates of the cosmogenic nuclides in function of depth and for different meteoroid sizes (e.g. Bhandari, 1981, Reedy, 1995, Graf et al., 1990 ; Michel et al., 1991, 1995 ; Bhandari et al., 1993). Measured depth profiles are available only for few meteorites. Furthermore a fresh fall, like Portales Valley, allows to extend this analysis to several nuclides.

Portales Valley, which has been classified as a H6 ordinary chondrite (Grossman, 1999), consists of large silicate-rich regions crosscut by unusual thick veins of metallic Fe-Ni (Ruzicka et al., 1999 ; Rubin et al., 1999 ; Pinault et al., 1999 ; Kring et al., 1999). While some fragments appear to be entirely composed of chondritic material, others contain these thick metal veins of different sizes and concentrations. Due to the availability of several fragments with different metal veins content, this meteorite gives an unusual opportunity for a detailed evaluation of the production rate of the cosmogenic radioisotopes, in particular of those produced from the interaction of galactic cosmic ray (GCR) with the main target elements Fe and Ni, and of the shielding effects for the same radioisotopes.

2 Measurements :

We measured the gamma-activity of the cosmogenic radionuclides in a first fragment of Portales Valley weighing about 600 g. This measurement was performed in the underground Laboratory of Monte dei Cappuccini in Torino, at a depth of 70 m of equivalent water, by a Ge-NaI(Tl) gamma spectrometer with high efficiency and low background (Bonino et al., 1992). The principal Ge detector operates in normal, in anticoincidence as well as in coincidence with the NaI detector. We measured this fragment for about 9.5 million of seconds in order to obtain a suitable counting statistics of the low activity of the cosmogenic

^{44}Ti which is useful to infer on the century scale variations of the GCR flux and of the heliospheric behavior in the past (Bonino et al., 1995, 1999).

In table 1 are reported the twelve cosmogenic radionuclides measured in the fragment, together with their half-lives, the gamma peak energies and the main target elements for production of the cosmogenic nuclides by interaction of GCR with the meteoritic material. In the last column are reported the measured counting with the standard deviations. We can observe that for some radionuclides, such as ^{54}Mn , ^{22}Na and ^{26}Al , these standard deviations are very low ($< 1\%$) due to the long lasting time of measurement and to the high efficiency of the gamma-spectrometer.

Tab. 1 - Cosmogenic Radionuclides in the Portales Valley meteorite

Isotope	E_g (keV)	$T_{1/2}$	Main target elements	c.p.m. ⁽¹⁾
^{48}V	983.50	15.97 d	Ti, Fe	0.0125 ± 0.0013
	1312.10			0.0114 ± 0.0010
^{51}Cr	320.07	27.70 d	Fe, Ni, Co	0.0399 ± 0.0032
^7Be	477.59	53.29 d	O, Si, Al	0.0499 ± 0.0032
^{58}Co	810.77	70.86 d	Fe, Ni	0.1571 ± 0.0026
^{56}Co	846.70	77.27 d	Fe, Ni	0.0693 ± 0.0020
^{46}Sc	889.26	83.79 d	Ti, Fe	0.0976 ± 0.0022
^{57}Co	122.06	271.74 d	Fe, Ni	0.4055 ± 0.0056
^{54}Mn	834.83	312.3 d	Fe, Mn	2.2345 ± 0.0063
^{22}Na	1274.51	2.6088 y	Mg, Al, Si	0.7125 ± 0.0038
^{60}Co	1173.23	5.2714 y	Co, Ni	0.0925 ± 0.0025
	1332.51			0.0899 ± 0.0020
$^{44}\text{Ti} (^{44}\text{Sc})$	1157	$59.2 \text{ y}^{(2)}$	Fe, Ni	0.00396 ± 0.0003
^{26}Al	1808.65	$7.4 \cdot 10^5 \text{ y}$	Al, Si	0.4003 ± 0.0026

⁽¹⁾ At the time of measurement. ⁽²⁾ T. Ahmad, G. Bonino, G. Cini Castagnoli, S.M. Fischer, W. Kutschera and M. Paul (1998) Phys. Rev. Lett., 80, 2550-2553.

To determine the specific activity (dpm/kg) of the different cosmogenic radioisotopes we use the inherent ^{40}K concentration in the meteorites as an internal standard for determining the effective efficiency of counting for each meteorite fragment (Bhandari et al., 1989). In the case of Portales Valley for the fragments containing the above quoted metal veins, which are present with different sizes and concentrations we need a precise evaluation of the bulk chemical composition of each fragment in order to evaluate the bulk K concentration and the bulk abundances of the main target elements (table 1) for production of the cosmogenic radionuclides. For this purpose, the K, Fe, Mg, Al, Ti, Mn, Cr, Co and Ni concentrations, in 7 different samples taken in 4 different spots in the chondritic portion of the fragment, were measured at the Joint Research Centre of E.U., Ispra, Italy. All the measurements were verified by NIST standards. They show a good uniformity in the chemical composition of the chondritic matrix.

The chemical composition of the metal veins, which consist mainly of kamacite, is known from the measurements performed in different veins by different authors (Kring et al., 1999 ; Pinault et al., 1999 ; Ruzicka et al., 1999 ; Rubin and Ulf-Möller, 1999). On the basis of the chemical composition of both chondritic and metal vein portions, we can deduce the bulk chemical composition by the additional measurement of the average density of each fragment. The density of the considered fragment is 4.00 g/cm^3 . It was measured at the Southwest Meteorite Laboratory adopting the method of Consolmagno and

Britt (1998). This bulk density is higher than the average value of $3.35 \pm 0.05 \text{ g/cm}^3$ found by the same authors from the measurement of 7 H ordinary chondrites. This higher value is due to the presence of the metal Fe-Ni veins.

From the data a) of the gamma-activity, b) of the chemical composition, in both chondritic and metal vein portions, and c) of the bulk density we can deduce the specific activity of the cosmogenic radionuclides in dpm/kg meteorite, dpm/kg chondritic material, or normalized to the main target element abundance (e.g. dpm/kg Fe or Fe+Ni).

3 Cosmic Ray Exposure :

The different cosmogenic radionuclides in meteorites reveal the exposure history to GCR during a time interval before the fall of about two of the different half-lives. For the evaluation of the production rate of the nuclides, which is proportional to the GCR flux, it is necessary to correct the measured activity in a fragment for the shielding effects of the meteoroid in the interplanetary space and for the target element abundance. The meteoroid size and the shielding of each fragment of a chondrite can be calculated from the measurement of the nuclear track density produced by heavy nuclei of cosmic radiation in pyroxene and olivine crystals and from the time of exposure deduced from the stable isotope concentrations. The track density in two locations on the fragment of Portales Valley, was measured at PRL and was found to be similar, having a value of about $1.6 \times 10^6 \text{ cm}^{-2}$ in olivine grains. The exposure age, when available, will allow to estimate the shielding correction.

We consider, for the present, the $^{22}\text{Na}/^{26}\text{Al}$ activity ratio, because these radionuclides are produced in similar nuclear reactions of GCR with the meteoritic material and in similar target elements. Therefore, this ratio is about independent from chemical composition and shielding effects, but contains informations on the GCR flux and consequently on the effects of the solar activity over a time scale covering the last few years being the half-life of ^{22}Na of 2.6 years. Figure 1 show the $^{22}\text{Na}/^{26}\text{Al}$ ratio for the fragment of Portales Valley together with the measurement of the chondrite fresh falls Torino, Mbale and Fermo measured in our Laboratory, compared with the GCR flux J_G . This flux was deduced from the Climax neutron monitor data following the procedure described in Bhandari et al. (1989).

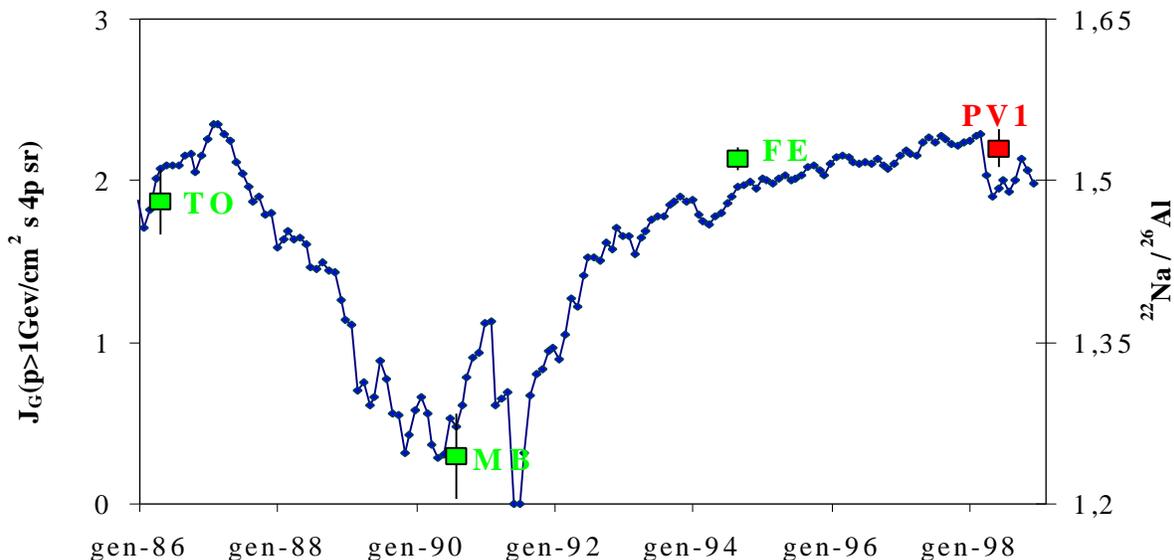


Fig. 1: $^{22}\text{Na}/^{26}\text{Al}$ measured in Torino (TO), Mbale (MB), Fermo (FE) and Portales Valley (PV1), compared with the GCR flux J_G . The data are shifted of two years, due to the lag with respect to J_G . The value of Portales Valley, which contain the effects of the solar activity minimum at the transition from solar cycle # 22 to 23, is very similar to those of Fermo and Torino which fell in 1996 and 1988

respectively, near minima (GCR maximum) of solar activity, while Mbale which fell in 1992 has imprinted the solar maximum (GCR minimum) of solar cycle # 22. These results show that Portales Valley, Fermo and Torino were exposed to similar GCR fluxes, at least in their last years of exposure. Preliminary results obtained from the measurements in progress in two other fragments of Portales Valley confirm this result.

Acknowledgment.

We are grateful to Prof. C. Castagnoli for useful discussions and generous support and to Mr. A. Romero for invaluable technical assistance. This work was supported by MURST, Co-finanziamento 1997.

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