Governador Valadares – 158 grams

Nakhlite

find

Figure 1. *Photograph of Governador Valadares (158 grams) from Dr. Fernanda Ferrucci via Dr. Giuseppe Cavarretta. Photo taken by L. Spinozzi.*

Introduction

A well-preserved individual stone of 158 grams was found in 1958 near Governador Valadares, in Minas Gerais, Brazil. The single specimen appears shiny and well preserved, although extremely brittle (figure 1); these characteristics led Burragato *et al*. (1975) to conclude that it must have been collected a short time after the fall. The sample is almost completely covered by a black, glassy, fusion crust (Gomez and Keil 1980). It was classified as a Nakhlite by Burragato *et al*. (1975).

Governador Valadares has been dated as 1.37 b.y. old with exposure to cosmic rays for 10 m.y.

Petrography

Governador Valadares is a clinopyroxenite petrologically very similar to Nakhla (Burragato *et al*. 1975; Berkley *et al*. 1980; Mikouchi and Miyamoto 1997). The thin section (figure 2) shows a porphyritic texture with large augite phenocrysts embeded in a fine-grained mesostasis made up of glass and semi-radiating skeletal crystals of Fe-rich pigeonite, plagioclase, K-feldspar, silica, apatite, magnetite and sulfides. The elongate pyroxene phenocrysts are weakly aligned (Berkley *et al*. 1980). Rare Fe-rich olivine is also present.

The olivine in Governador Valadares contains magmatic inclusions which have been used by Harvey and McSween (1992d) to estimate the composition of the parental melt. The best overview of Nakhlites is that of Treiman (2005).

Mineral Chemistry

***Olivine*:** Olivine grains (Fo_{33}) up to 2 mm in size are found in Governador Valadares (Berkley *et al*. 1980). A second generation of smaller, more Fe-rich (Fo_{23}), olivine grains are found with plagioclase in the mesostasis (Berkley *et al*. 1980). The olivine in nakhlites has higher Fe/Mg than that of coexisting

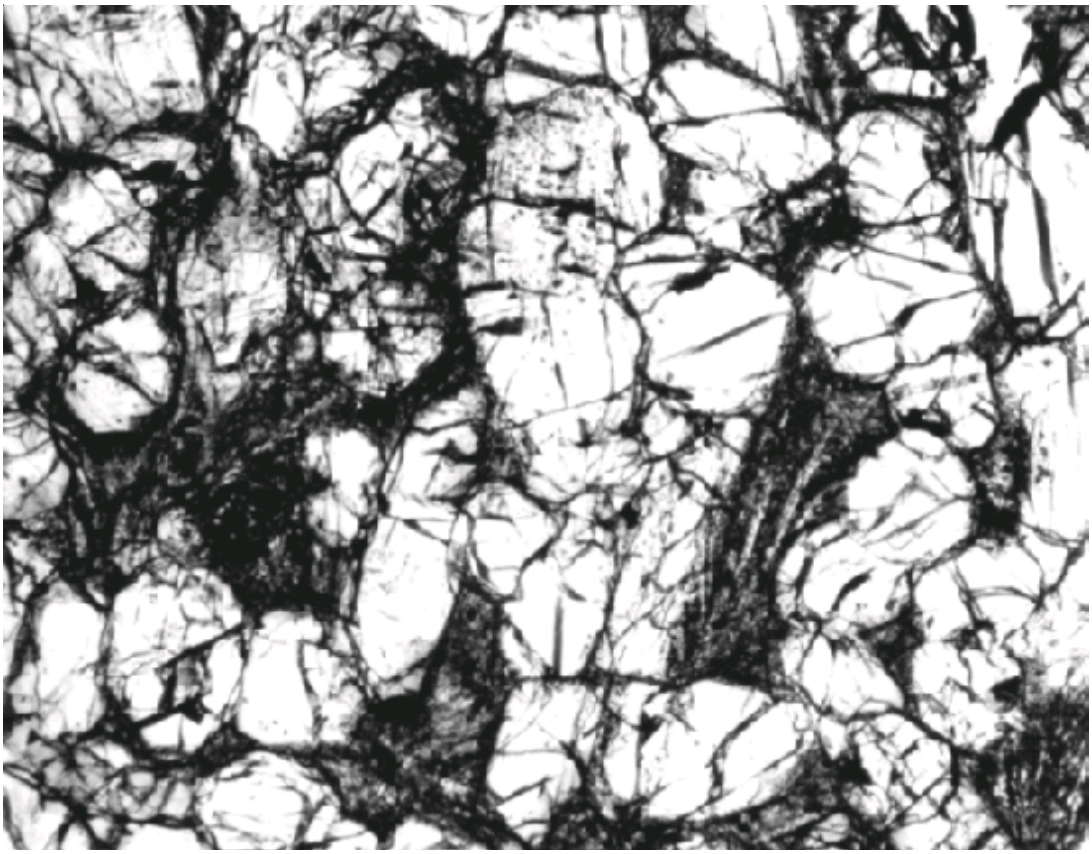

Figure 2. *Photomicrograph of thin section of Governador Valadares. Section number 479 from University of New Mexico. Field of view is 2.2mm.*

pyroxene. The olivine in Governador Valadares is zoned in composition with steep Fe/Mg profiles in the core regions and progressively flatter toward the crystal boundaries (Harvey and McSween 1991; Lentz *et al.* 1999). Mikouchi and Miyamoto (1997) and Greshake *et al*. (2000) reported fine lamelea of symplectite (augite and magnetite) in olivine (*similar to Nakhla*).

***Clinopyroxene*:** Augite is the major mineral in Governador Valadares. Clinopyroxene grains are elongate with an aspect ratio of 3:1. Berkley *et al.* (1980), Harvey and McSween (1991), Mikouchi and Miyamoto (1997) and Lentz *et al*. (1999) have studied the zoning in clinopyroxene in Governador Valadares. They find that the cores are homogeneous with zoning towards Fe-enrichment at the rims, with relatively steep transition zones in between (figure 3). The average composition of the augite is $Wo_{39}En_{39}Fs_{22}$ (Berkley *et al*. 1980).

***Plagioclase*:** Gomez and Keil (1980) report the composition of plagioclase in Governador Valadares as $An_{49}Ab_{48}Or_{3}$.

***Iddingsite*:** A reddish mixture of smectite clay and hydrous iron oxides, occurs on the rims or penetrates most olivine grains in Governador Valadares, as it does in the other nakhlites (Gooding *et al.* 1991a; Treiman *et al.* 1993). Bridges and Grady (2000) give an analysis of "goethite".

***Amphibole*:** Harvey and McSween (1992d) reported a Ti-rich amphibole in a magmatic inclusion in olivine in Governador Valadares.

Mineralogical Mode *(from Lentz et al. (1999)*

Olivine	9.7 %	7.2	13.4
Pyroxene	81.2	83.1	73.5
Mesostasis	9.1	9.6	13.1

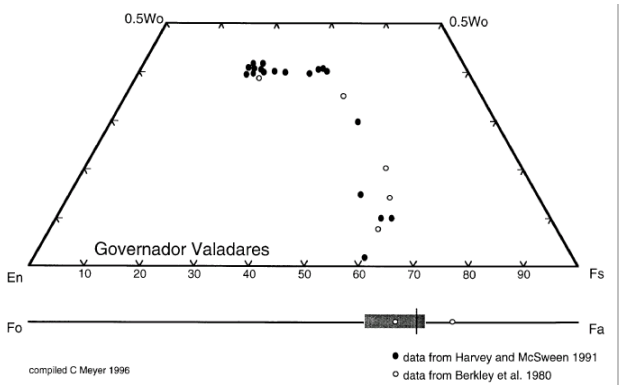

Figure 3. *Pyroxene and olivine composition diagram for Governador Valadares. Data compiled from Berkley et al. (1980) and Harvey and McSween (1991).*

***Magnetite*:** Harvey and McSween (1992d) found Ti-rich magnetite in melt inclusions in olivine in Governador Valadares. Berkley *et al*. (1980) reported ilmenite lamellae in the magnetite.

Symplectite: Mikouchi and Miyamoto (1997) have reported thin lamellar symplectic inclusions composed of augite and magnetite in host olivine. Greshake *et al.* report that the magnetite contains Cr (2%) and V.

***Spinel*:** Harvey and McSween (1992d) reported Fe, Al spinel in melt inclusions in olivine in Governador Valadares.

SiO_2: Pure SiO_2 is reported in minor amounts in Governador Valadares and Nakhla, but not in Lafayette (Berkley *et al.* 1980).

***Sulfides*:** Berkley *et al.* (1979, 1980) reported minor pyrite, troilite and chalcopyrite in the mesostasis. Chevrier et al. (2011) carefully studied the sulfides in GV and the other nakhlites.

***Glass*:** Interstitial glass has been found to be silica-rich (Berkley *et al.* 1980).

Salts: Siderite grains are located in intercumulus parts of the Governador Valadares (Bridges and Grady 1999). Gypsum is found in the interstitial areas, sometimes adjacent to siderite, but veins of gypsum up to 450 microns long are also reported present in cracks within augite and olivine. Bridges and Grady (2000) report trace element analyses of siderite and gypsum in Governador Valadares.

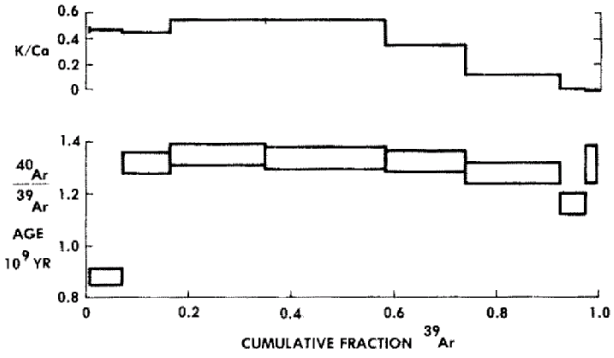

Figure 4. *Argon plateau diagram for Governador Valadares meteorite from Bogard and Husain (1977).*

Whole-rock Composition

Burragato *et al.* (1975) determined the bulk chemical composition (table 1) and noted that it was similar to that of Nakhla. Mittlefehldt and Lindstrom (1996) reported that the REE pattern was similar to that of Nakhla and Lafayette, but that the FeO content was ~10% less. Wang *et al.* (1998) completed the trace element analyses of Mittlefehldt!

Radiogenic Isotopes

Bogard and Husain (1977) determined a $^{39}Ar/^{40}Ar$ age of 1.32 ± 0.04 b.y. (figure 4) - essentially identical to that of Nakhla and Lafayette (Podesek 1973). Wooden *et al.* (1979) reported a Rb-Sr age of 1.33 ± 0.01 b.y. and Shih *et al*. (1996) determined a Sm-Nd age of 1.36 ± 0.03 b.y. Shih *et al.* (1999) determined the Rb-Sr age as 1.20 ± 0.05 b.y. (figure 5) and Sm-Nd as 1.37 ± 0.02 b.y. (figure 6). The low initial Nd value indicates formation from a light-REE-depleted source (Shih *et al.* 1996; Harper *et al.* 1995).

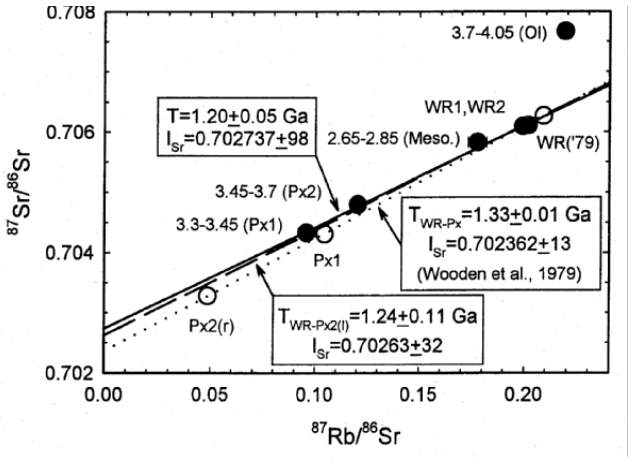

Figure 5. *Rb-Sr internal mineral isochron for Governador Valadares (from Shih et al. 1999).*

Table 1. Composition of Governador Valadares.

reference	Burragato 75	Mittlefehldt 96		Wang 98		Shih 99		Shih 99		*Lodders 98*
weight		*26.59 mg*				*27.35 mg*		*24.1 mg*		*averages*
SiO2	49.52									*49.5*
TiO2	0.35									*0.35*
Al2O3	1.74									*1.74*
FeO	19.7	19.5	(c)							*19.7*
MnO	0.67									*0.67*
CaO	15.85	15	(c)							*12.9*
MgO	10.92									*10.9*
Na2O	0.82	0.53	(c)							*0.82*
K2O	0.43	0.18	(c)							
P2O5										
sum										
Li ppm										
Sc		57.4	(c)							
V										
Cr	1437	1950	(c)							*5200*
Co		47.7	(c)	32.3	(a)					
Ni		80	(c)							*80*
Cu										
Zn		80	(c)	53.1	(a)					
Ga				2.99	(a)					
Ge										
As										
Se				0.0822	(a)					
Br		2.5	(c)							
Rb				3.56	(a)	3.68	(b)	4.06	(b)	
Sr		80	(c)			53.39	(b)	58.27	(b)	
Y										
Zr										
Nb										
Mo										
Pd ppb										
Ag ppb				34.2	(a)					
Cd ppb				50.8	(a)					
In ppb				18	(a)					
Sb ppb				6.3	(a)					
Te ppb				6.4	(a)					
I ppm										
Cs ppm		0.44	(c)	0.394	(a)					
Ba		40	(c)							
La		2.27	(c)							
Ce		6	(c)							
Pr										
Nd						3.247	(b)	3.532	(b)	
Sm		0.84	(c)			0.738	(b)	0.791	(b)	
Eu		0.25	(c)							
Gd										
Tb		0.12	(c)							
Dy										
Ho										
Er										
Tm										
Yb		0.41	(c)							
Lu		0.06	(c)							
Hf		0.37	(c)							
Ta		0.09	(c)							
W ppb										
Re ppb										
Os ppb										
Ir ppb										
Au ppb				1.13	(a)					
Tl ppb				3.56	(a)					
Bi ppb				3.03	(a)					
Th ppm		0.15	(c)							
U ppm				0.0666	(a)					

technique: (a) RNAA, (b) IDMS, (c) INAA

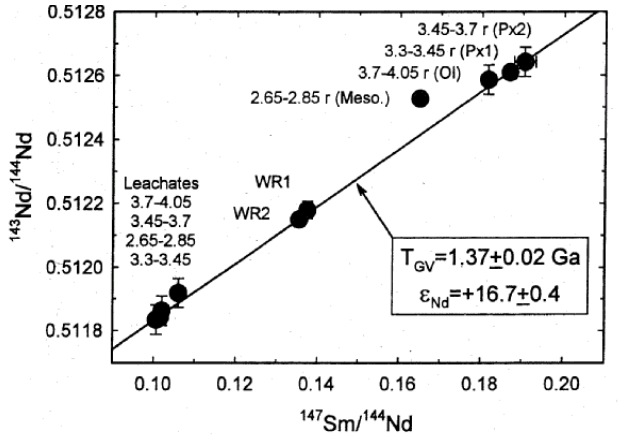

Figure 6. *Sm-Nd internal mineral isochron for Governador Valadares (from Shih et al. 1999).*

A high ^{14}C activity constrains the fall time of Governador Valadares (Jull *et al.* 1999) to be *"less than a few hundred years"*.

Cosmogenic Isotopes and Exposure Ages

Bogard and Husain (1977) originally determined a cosmic-ray exposure age of 8 ± 1 m.y. Swindle *et al.* (1989) determined ^{21}Ne and ^{38}Ar ages of 9.5 m.y. and 9.2 m.y. Nyquist *et al.* (2001) calculate an average for the exposure age as 10 ± 2 m.y. *(similar to that of the other Nakhlites and Chassigny, see figure I-13)*. Recently, Korochantseva et al. (2011) completed an exhausting study of cosmic-ray exposure ages in the Nakhlites and Chassigny, verifying that they all were blasted off Mars together at the same time.

Other Isotopes

The carbon and nitrogen content and isotopic composition has been reported by Wright *et al.* (1992). Leshin *et al*. (1996) reported isotopic compositions of hydrogen from water and carbon and oxygen released from CO_2.

Pal *et al.* (1986) and Jull *et al.* (1999) reported the ^{10}Be and ^{36}Cl activity.

Harper *et al*. (1995) and Shih *et al*. (1999) reported excess ^{142}Nd in Governador Valadares - -suggesting that isotopic heterogeneity has been present in the Martian mantle throughout Martian history.

Processing

The Governador Valadares specimen was 'found' by a mineral hunter in 1958 (Gomez and Keil 1980). The main mass (96 grams) was owned by Dr. Fernanda Ferrucci (Graham *et al.* 1985; Cavarretta, *personal communication*), but has been sold to a private meteorite collector. Thin sections can be borrowed from the University of New Mexico and/or British Museum.

Figure 7 shows what is known about the distribution of pieces of Governador Valadares.

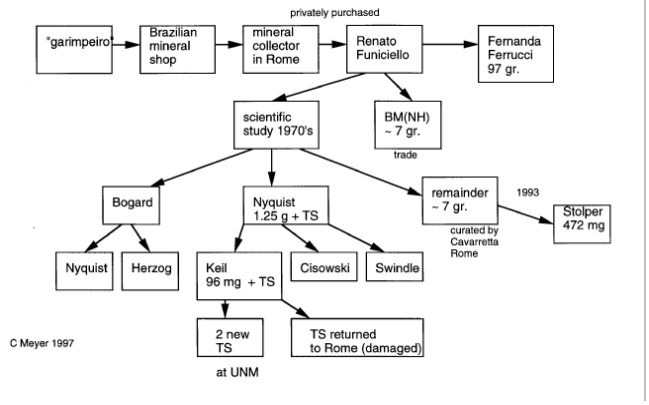

Figure 7. *Distribution of Governador Valadares.*

References for Governador Valadares