

IV. Governador Valadares

clinopyroxenite, 158 grams

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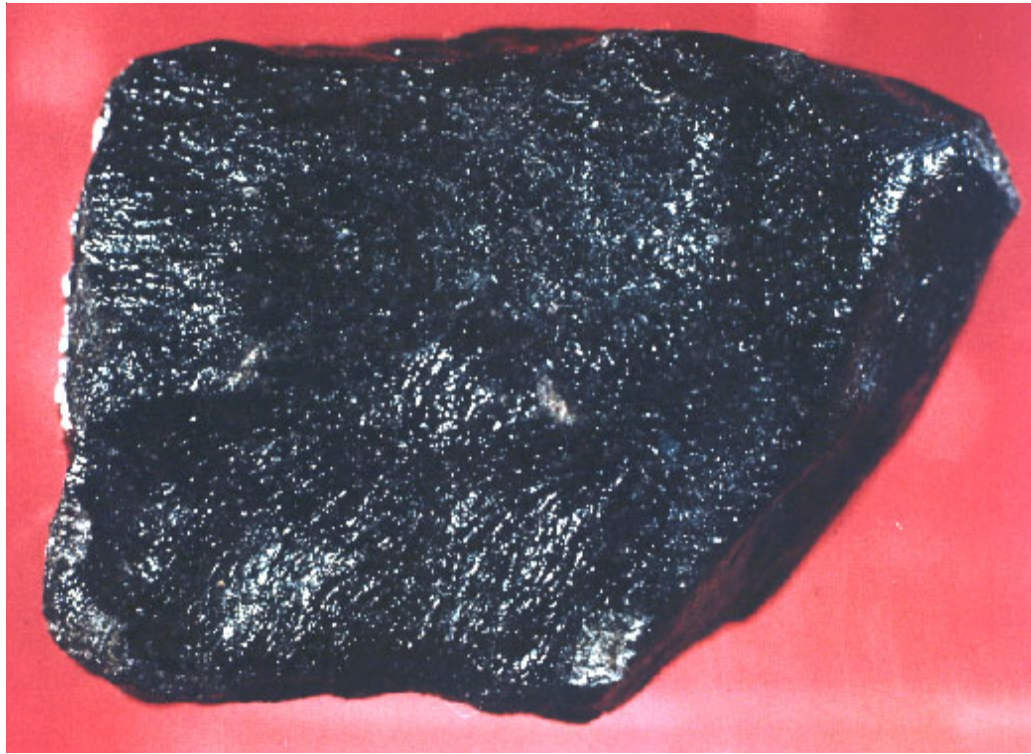


Figure IV-1. Photograph of Governador Valadares (158 grams) from Dr. Fernanda Ferrucci via Dr. Giuseppe Cavarretta. Photo taken by L. Spinozzi.

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 IV-1); these characteristics led Burrigato *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 Burrigato *et al.* (1975).

Petrography

Governador Valadares is a clinopyroxenite petrologically very similar to Nakhla (Burrigato *et al.* 1975; Berkley *et al.* 1980; Mikouchi and Miyamoto 1997). The thin section (figure IV-2) shows a porphyritic texture with large augite phenocrysts embedded 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.

Mineral Chemistry

Olivine: Olivine grains (Fo₃₃) up to 2 mm in size are found in Governador Valadares (Berkley *et al.* 1980). A second generation of smaller, more Fe-rich (Fo₂₃), 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 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.*

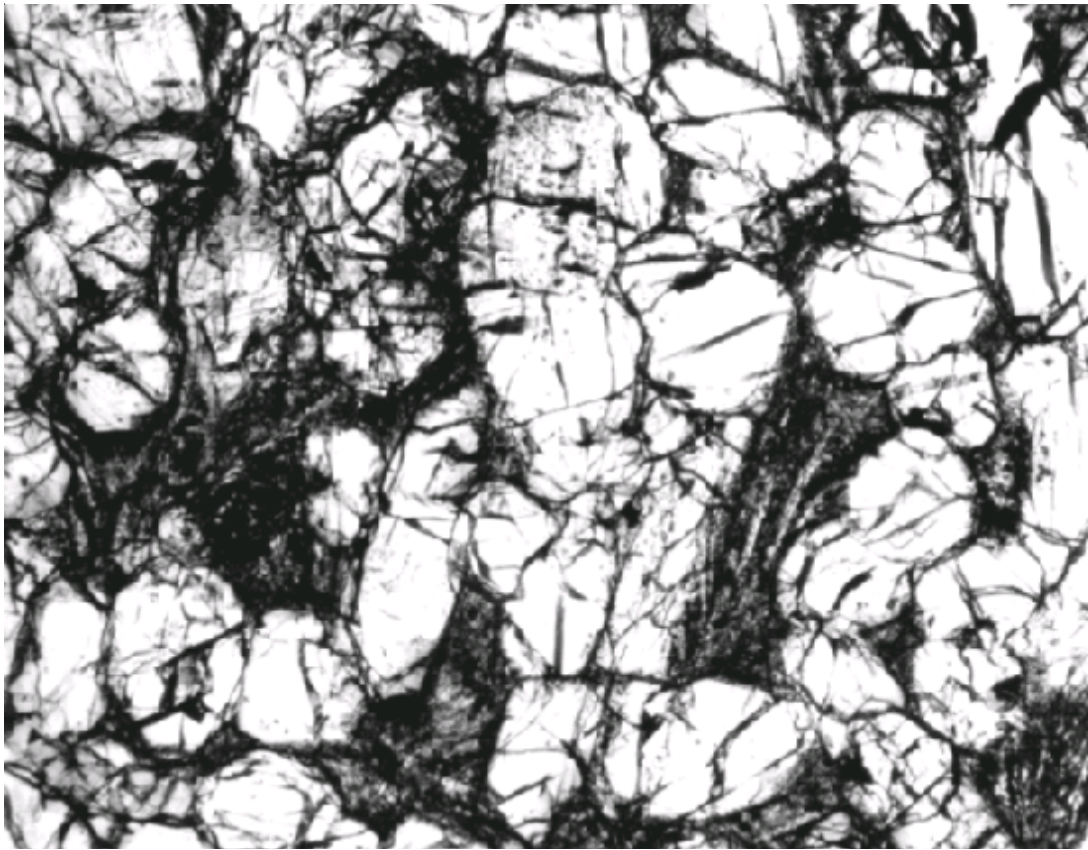


Figure IV-2. Photomicrograph of thin section of Governor Valadares. Section number 479 from University of New Mexico. Field of view is 2.2mm.

1999). Mikouchi and Miyamoto (1997) and Greshake *et al.* (2000) reported fine lamella of symplectite (augite and magnetite) in olivine (*similar to Nakhla*).

Clinopyroxene: Augite is the major mineral in Governor 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 Governor Valadares. They find that the cores are homogeneous with zoning towards Fe-enrichment at the rims, with relatively steep transition zones in between (figure IV-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 Governor 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 Governor 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 Governor Valadares.

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

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

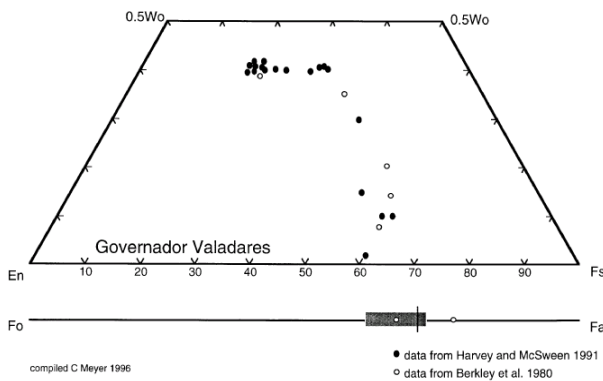


Figure IV-3. Pyroxene and olivine composition diagram for Governorador Valadares. Data compiled from Berkley *et al.* (1980) and Harvey and McSween (1991).

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 Governorador Valadares.

SiO₂: Pure SiO₂ is reported in minor amounts in Governorador 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.

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

Salts: Siderite grains are located in intercumulus parts of the Governorador 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 Governorador Valadares.

Whole-rock Composition

Burrigato *et al.* (1975) determined the bulk chemical composition (table IV-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

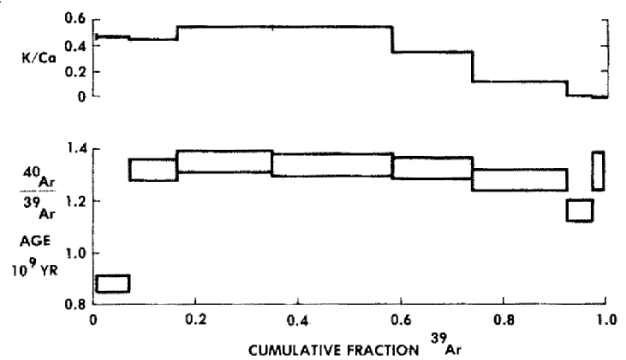


Figure IV-4. Argon plateau diagram for Governorador Valadares meteorite from Bogard and Husain (1977). This is figure 1 in their paper in *Geophys. Res. Lett.* 4, 69.

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 ³⁹Ar/⁴⁰Ar age of 1.32 ± 0.04 Ga (figure IV-4) - essentially identical to that of Nakhla and Lafayette (Podsek 1973). Wooden *et al.* (1979) reported a Rb-Sr age of 1.33 ± 0.01 Ga and Shih *et al.* (1996) determined a Sm-Nd age of 1.36 ± 0.03 Ga. Shih *et al.* (1999) determined the Rb-Sr age as 1.20 ± 0.05 Ga (figure IV-5) and Sm-

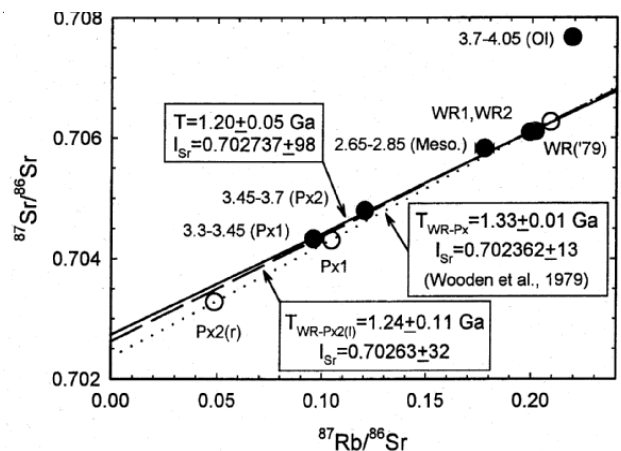


Figure IV-5. Rb-Sr internal mineral isochron for Governorador Valadares (from Shih *et al.* 1999, *M&PS* 34, 650).

Table IV-1. Composition of Governador Valadares.

reference <i>weight</i>	Burragato 75	Mittlefehldt 96 <i>26.59 mg</i>	Wang 98	Shih 99 <i>27.35 mg</i>	Shih 99 <i>24.1 mg</i>	<i>Lodders 98 averages</i>
SiO ₂	49.52					49.5
TiO ₂	0.35					0.35
Al ₂ O ₃	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
Na ₂ O	0.82	0.53	(c)			0.82
K ₂ O	0.43	0.18	(c)			
P ₂ O ₅ 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

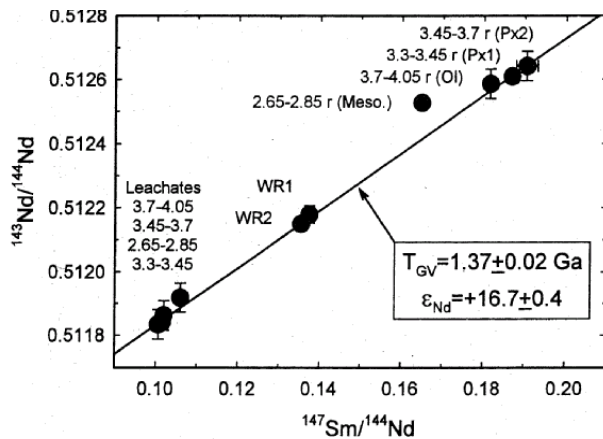


Figure IV-6. Sm-Nd internal mineral isochron for Governador Valadares (from Shih *et al.* 1999, *M&PS* 34, 650).

Nd as 1.37 ± 0.02 Ga (figure IV-6). The low initial Nd value indicates formation from a light-REE-depleted source (Shih *et al.* 1996; Harper *et al.* 1995).

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 Ma. Swindle *et al.* (1989) determined ^{21}Ne and ^{38}Ar ages of 9.5 Ma and 9.2 Ma. Nyquist *et al.* (2001) calculate an average for the exposure age as 10 ± 2 Ma (similar to that of the other *Nakhlites* and *Chassigny*, see figure I-13).

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

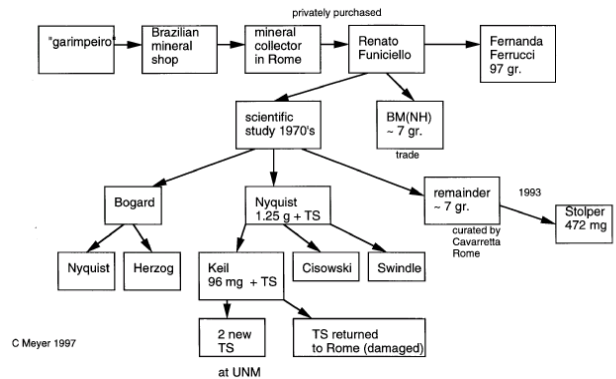


Figure IV-7. Distribution of Governador Valadares.