NWA 998

Clinopyroxenite

456 grams

***Figure 1**: Photograph of 165 g end piece of NWA 998 by Adam and Greg Hupé (with permission)*

Introduction

Irving *et al.* (2002) report that a piece of a nakhlite was acquired in Morocco in September 2001. Figure 1 shows what appears to be a broken "slab", with a fusion crust around the outside.

Petrography

The texture of NWA 998 is that of a hypabyssal, adcumulate igneous rock. According to Irving *et al.* (2002), the crystallization sequence was olivine, orthopyroxene, titanomagnetite, augite, apatite and plagioclase. Treiman (2005) compares NWA998 with the other nakhlites. Treiman finds that the mesostasis has completely crystallized.

Mineral Chemistry

Olivine: Irving et al. (2002) reported olivine is Fo_{36}. Mikouchi et al. (2006) report Fo_{40}.

Pyroxenes: Irving et al. and Treiman (2006) found the dominant mineral is clinopyroxene $Wo_{39}En_{78}$, with minor orthopyroxene Wo_4En_{51}. Mikouchi et al. (2006) found that the pyroxene in NWA998 was the least Fe-rich of the nakhlites (figure 3) (slowest cooling?). Pyroxene contains tiny melt inclusions. Wadhwa et al. (2004) have reported the REE contents of augite cores and melt inclusions.

Plagioclase: Interstitial plagioclase exhibits normal birefringence and is An_{39}. Mikouchi et al. (2006) report that some grains are up to 500 microns.

Opaques: Symplectitic intergrowths of titanomagnetite and lo-Ca pyroxene are present at grain boundaries between large, discrete olivine and titanomagnetite grains. Cr-titanomagnetite inclusions occur within olivine.

Secondary minerals: Ankeritic carbonate, K-feldspar, (?) serpentine, calcite and a Ca-sulfate are present on

Mineralogical Mode for NWA998

	Treiman 05
Olivine	10
Augite	68
Orthopyroxene	2
Other	19

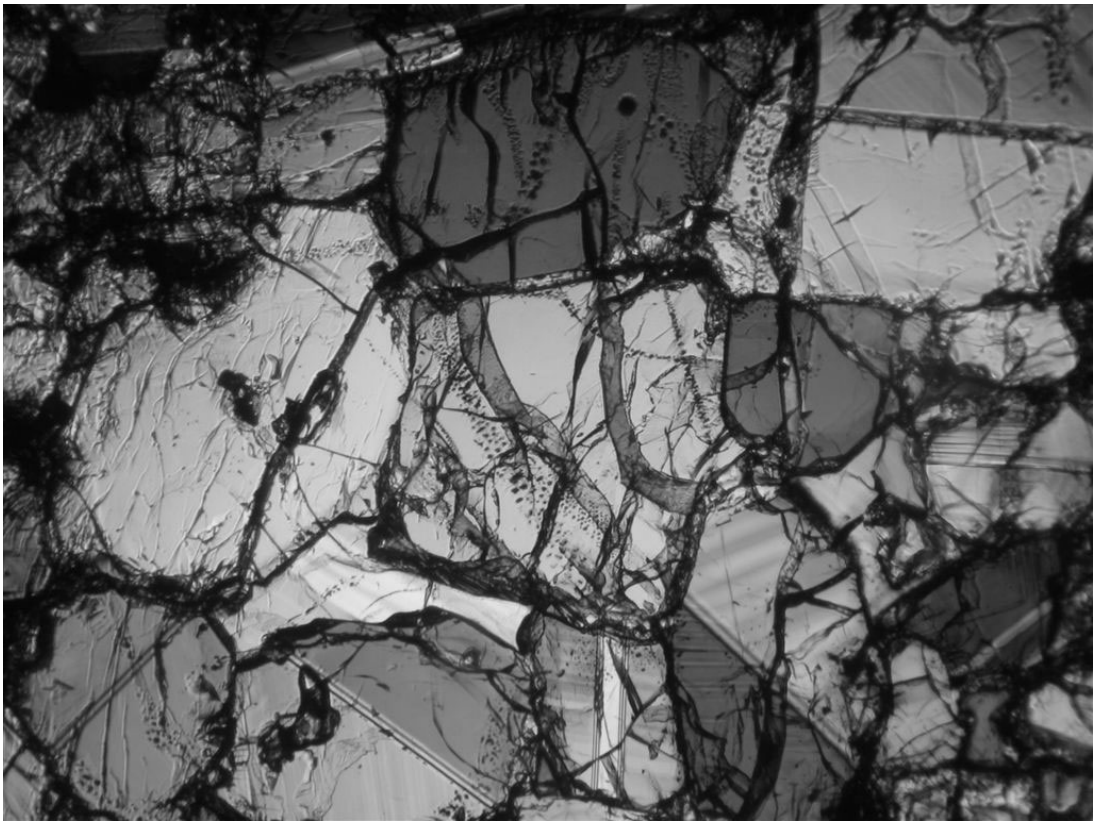

Figure 2: Thin section photomicrograph of NWA 998, field of view 1.54 mm wide. Crossed polarizers. Taken by John Kashuba (with permission).

grain boundaries. Irving *et al.* (2002) suggest that these *secondary minerals* may have a pre-terrestrial origin!

Phosphate: Wadhwa et al. (2004) have reported the REE abundance of apatite in NWA998.

Whole-rock Composition

Dreibus et al. (2006) report 88 ppm F, 127 ppm Cl, 0.18 ppm Br, 0.281 ppm I, 280 ppm S and 1324 ppm carbon.

Radiogenic Isotopes

A Sm-Nd isochron has been determined by Carlson and Irving (2004), yielding a crystallization age of 1.29 ± 0.05 b.y. (figure 4). U-Pb, Rb-Sr and Lu-Hf isotope systems were disturbed or contaminated. Garrison and Bogard (2005) reported the crystallization age as 1.332 ± 0.008 b.y. (figure 5).

Cosmogenic Isotopes

The ^{38}Ar cosmic ray exposure age of NWA998 (9.3 m.y.) was determined by Garrison and Bogard (2005). The ^{14}C terrestrial age of NWA998 is 6 ± 1 k.y. (Nishiizumi et al. 2004). Nishiizumi et al. also report ^{10}Be and ^{41}Ca.

Other Isotopes

Oxygen isotopes of acid-washed augite as determined by D. Rumble (reported by Irving), were ä^{18}O = +3.9 ± 0.2, ä^{17}O = +2.2 ± 0.01 and Ä^{17}O = + 0.24 ± 0.01 ‰.

Boctor et al. (2005) used secondary ion mass spectroscopy to determine the volatile (H_2O, CO_2, F, S and Cl) content of minerals in NWA998 and the isotopic ratio of hydrogen/deuterium.

Mathew and Marti (2005) reported isotopic data for gas (N_2, Ar and Xe) released during heating experiments (figure 6). It is consistent with gas released in similar experiments on Chassigny and the other nakhlites. The He and Ne isotopic data by Garrison and Bogard (2005) need to be considered in this light (*there appears to be a mystery component*).

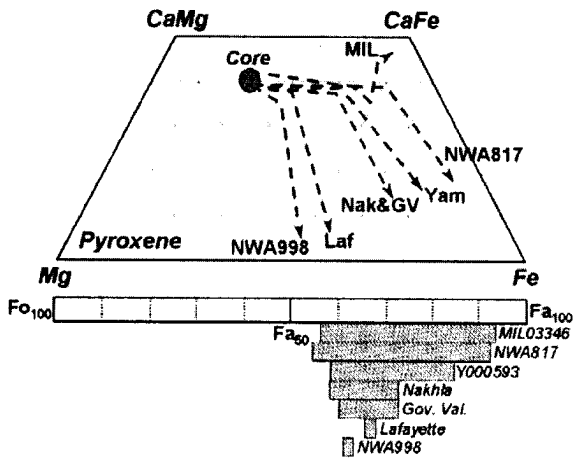

Figure 3: Composition of pyroxene and olivine in NWA998 compared with other nakhlites (Mikouchi et al. 2006).

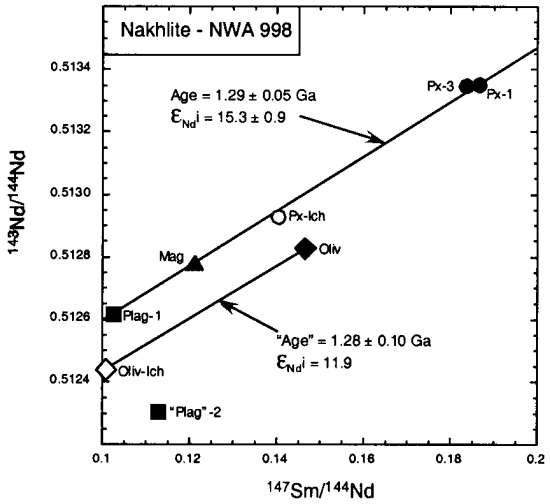

Figure 4: Sm-Nd isochron for NWA998 by Carlson and Irving (2004)

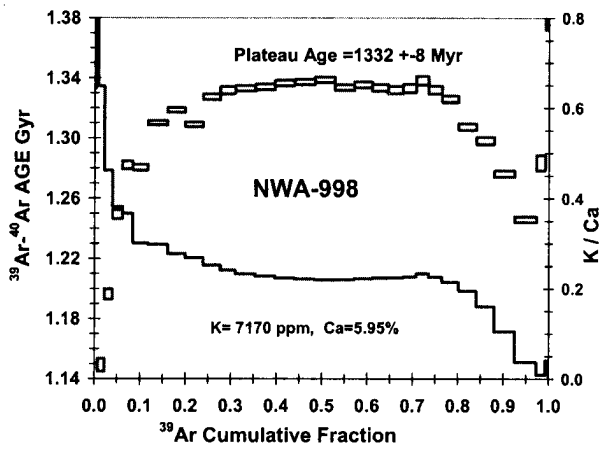

Figure 5: Garrison and Bogard (2005) reported the Argon release pattern.

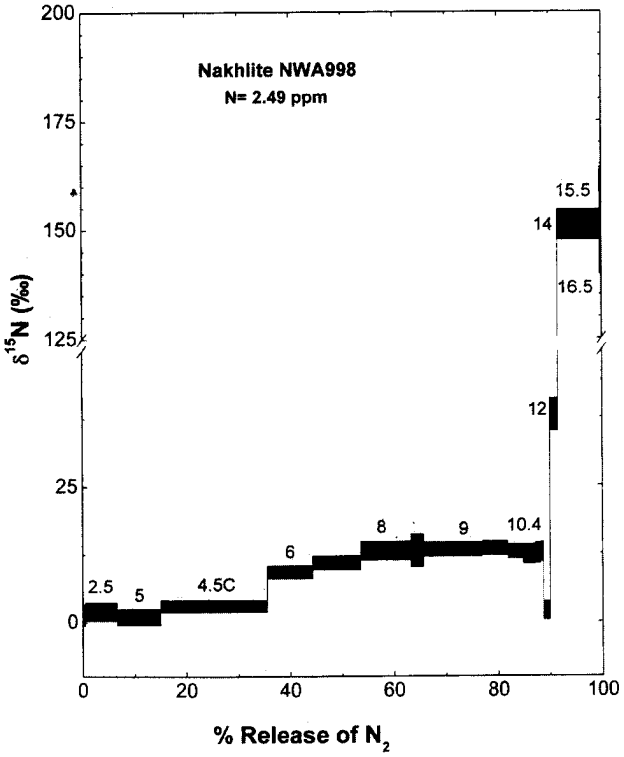

Figure 6: Nitrogen isotopes as function of release temperature showing that NWA998 has a high temperature component of strange gas (from Mathew and Marti 2005).