Classification and U-Pb isotopic study of Northwest Africa 6514. L. Kööp[1,2] and D. W. Davis[1], [1]Department of Geology, University of Toronto, [2]Department of the Geophysical Sciences, The University of Chicago (Koeoep@uchicago.edu)

Introduction: The formerly unclassified chondrite Northwest Africa 6514 was chosen for a combined petrographic and Pb and U isotopic study. Information obtained by optical and electron microscopy as well as electron microprobe spot analyses was used for the classification of the meteorite. The U-Pb study aimed at investigating the distribution of Pb components and U in the chondrite by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). A high-precision Pb-Pb age determination of a single chondrule by thermal ionization mass spectrometry (TIMS) is in progress.

Petrography: The meteorite is characterized by a high abundance of chondrules (~70 vol%), which are set in a dark matrix (fine-grained to clastic). In addition, circular to amoeboid metal-sulfide nodules and xenolithic clasts are present. The overall metal abundance is low (~2 vol%).

The chondrules have an average diameter of 0.8 mm (1 mm for fluid droplet chondrules) and most have a glassy, undevitrified mesostasis. Olivine (Ol) and pyroxene (Px) phenocrysts are highly unequilibrated (e.g., the percent mean deviation is >50% at a mean fayalite (Fa) content of 12.1 mol%), and ferroan Ol grains have Cr_2O_3 contents of 0.37 ± 0.22 wt% (or 0.34 ± 0.12 wt% if outliers >1 wt% are excluded; errors are 1σ).

About 40% of metal in NWA 6514 has been replaced by alteration products, with matrix and nodule metal being more affected than chondrule metal. Also, all chondrules show red-brown staining, but the centers of larger chondrules are less stained than their edges.

NWA 6514 contains a carbon-bearing, presumably igneous xenolithic clast (diameter ~1 cm) with a homogeneous albitic groundmass. In addition to xenomorphic carbon-rich grains, which are usually associated with sulfide grains, the clast contains unequilibrated silicates (Ol: ~0–23 mol% Fa, low-Ca Px: ~1–33 mol% Fs, high-Ca Px: ~38 mol% wollastonite). The silicate grains range from xeno- to hypidiomorphic. Ol grains show inverse zoning (Fe-rich cores, Fe-poor mantles) and one grain is poikilitically enclosed by Px.

Classification: Metal and chondrule abundances as well as chondrule sizes in NWA 6514 are consistent with the L and LL ordinary chondrite groups [1]. Due to the low degree of equilibration, the iron group of NWA 6514 cannot be inferred from FeO contents in Ol and Px or from Co contents in matrix kamacite (e.g. [2]). The unequilibrated silicates are among the many features that imply a petrologic type classification of 3, and the mean Cr_2O_3 content of FeO-rich Ol suggests that NWA 6514 is a 3.1 subtype [3]. However, if outliers are excluded as suggested in [3], the standard deviation is lower than that of other 3.1 subtypes [3].

The meteorite can be assigned a shock stage S2 because about half of the Ol grains show undulatory extinction, but no mosaicism was observed [4]. From the degree of replacement of metal grains, a weathering classification of W2 can be inferred [5].

Overall, NWA 6514 appears to be a very primitive ordinary chondrite and preservation of the original Pb isotopic signatures in primary chondrule phases would be expected.

LA-ICPMS isotopic study:

Methods. A large (diameter >1.2 cm) type II POP chondrule was chosen for high-precision Pb-Pb dating and most LA-ICPMS measurements. The edges of the chondrule are more stained than central regions and the devitrified mesostasis contains unusually large high-Ca Px grains (>10 µm) and an Fe-Ti oxide phase.

All in-situ measurements were performed with a Thermo Elemental (VG) PlasmaQuad PQ ExCell ICP-MS coupled to a Nu-Wave UP-213 Laser Ablation Microscope. The laser beam diameter varied between ~30 and ~200 µm. The standard NIST 610 was used for correction and was measured before and after each set of sample analyses. Because of its higher Pb and U abundances, measurements of the standard were performed with a small beam diameter (~30-50 µm) and after these measurements, at least 10 minutes were allowed for washout. To remove terrestrial contamination, the analysis spots on sample and standard were pre-ablated with a rastering procedure.

The data were processed by removing the background signals and excluding extreme outliers. Isotopic ratios were calculated with two methods. For method 1, the ratios were calculated from the sum of the total signals (analogous to r_1 in [6]). For method 2, ratios were calculated from the individual signals, which were then averaged (analogous to r_2 in [6]).

Results and discussion. Isotopic ratios calculated with method 2 are generally higher than those calculated with method 1. As the ratio of the total counts is inherently more accurate [6] and matches expectations better, only results established with method 1 will be discussed below. Chondrule analyses with count rates above 300 counts per second (cps) are generally consistent with expectations (i.e., mixtures between radiogenic Pb, corresponding to an age of ~4565 Myr [7], and common Pb, presumably primordial [8] and modern terrestrial [9]), while analyses with count rates below ~300 cps show a high degree of scatter and are mostly inconsistent with expectations. We therefore conclude that count rates of 300 cps are a lower limit for meaningful measurements and only results from higher count rates will be discussed below.

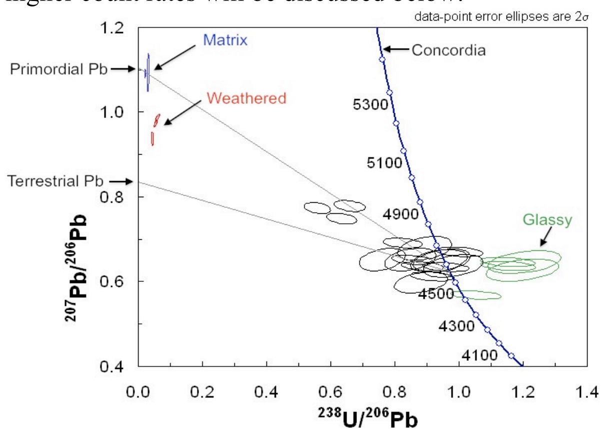

Figure 1: Tera-Wasserburg diagram showing analyses of the mesostasis (black ellipses) and weathered regions in the big chondrule (red ellipses), the matrix (blue ellipses) and a glassy chondrule (green ellipses), all are processed with method 1. Gray lines illustrate mixing between radiogenic Pb corresponding to an age of 4565 Myr and the common Pb endmembers, i.e. primordial and modern terrestrial Pb [8.9].

The mesostasis (feldspathic mesostasis ± high-Ca Px ± Fe-Ti oxide) has the highest ^{238}U abundances in the large chondrule (150±40 ppb (error is 1σ), consistent with fission track measurements of chondrule mesostases in [10]). Most analyses from optically pristine mesostasis regions in the large chondrule plot on or close to concordia in the Tera-Wasserburg diagram (Fig. 1), which suggests that the mesostasis has undergone little or no loss of radiogenic Pb, and that the common Pb contribution is insignificant. However, a Pb-Pb age calculated from the average of the most concordant mesostasis data (4608±34 Myr, error is 2σ) is too imprecise for a relevant chondrule formation age. Analyses of three less pristine mesostasis regions (reversely discordant black ellipses in figure 1) seem to represent mixtures with common Pb.

The weathered chondrule regions have low ^{238}U-^{206}Pb and high ^{207}Pb-^{206}Pb ratios, which suggests that common Pb is the dominant Pb component, with a signature corresponding to a mixture between primordial and terrestrial Pb (Fig. 1). The absolute abundances of ^{206}Pb in these regions match those in the mesostasis. Pb and U signals of Ol and low-Ca Px analyses were below the 300 cps limit, but in the case of Ol, this may partly reflect less efficient ablation by the laser.

Four of five analyses of a glassy chondrule plot to the right of concordia in the Tera-Wasserburg diagram (green ellipses in figure 1). These have approximately the same ^{207}Pb-^{206}Pb ratios as other concordant data but higher ^{238}U-^{206}Pb ratios. Possible explanations include recent loss of a small amount of radiogenic Pb (T=0 is at infinity on the horizontal axis) or a general bias in the sample standard calibration.

Analyses of the matrix yield ^{206}Pb abundances that are significantly higher than those in the chondrule mesostasis (500±90 ppb of ^{206}Pb in the matrix compared to 150±40 ppb in the mesostasis, errors are 1σ), and ^{207}Pb-^{206}Pb ratios of ~1.1 (fig. 1).

Conclusion. Although U-Pb isotopic analyses by LA-ICPMS cannot rival the precision of dissolution and leachate analyses of meteoritic components by TIMS or multicollector (MC) ICPMS (e.g. [11] and [12]), it is a useful reconnaissance tool for identifying closed system phases with relatively high U and low common Pb concentrations. Our measurements indicate that the mesostasis is the major carrier of U, which is consistent with [10] and the fact that U is an incompatible element that should be concentrated in the last phase to solidify. The only parts of the meteorite that contain significant amounts of common Pb are those affected by weathering and the matrix. The Pb isotopic signatures of weathered chondrule regions suggest that both terrestrial and primordial Pb are present, the latter may have been remobilized from the matrix.

For high-precision Pb-Pb dating of meteorite finds by TIMS or MC-ICPMS, these results suggest that the overall radiogenicity of the sample, and especially that of early leachates, can be significantly improved if clean, radiogenic material (i.e., mesostasis from chondrule centers) can be sampled selectively, which is supported by our preliminary TIMS results.

References:

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