The Leoville CV3 chondrite revisited: Prime material for the study of refractory trace elements. A. Patzer[1], D. C. Hezel[2], V. Bendel[3] and A. Pack[3], [1]Earth and Planetary Sciences, University of Tennessee, Knoxville, TN, 37996, [2]Department of Mineralogy, Natural History Museum, Cromwell Road, SW7 5BD, London, UK, [3]Geowissenschaftliches Zentrum, Universität Göttingen, Goldschmidtstr. 1, D-37077 Göttingen, Germany.

Introduction: Leoville, a reduced CV3 meteorite find from Kansas (USA), is one of the most primitive carbonaceous chondrites (petrologic type 3.1-3.4 [1]). Its low degree of parent body alteration makes it a prime candidate for studies exploring processes that predated planet formation. At the onset of Solar System evolution, high-temperature condensation played a significant role. Trace elements were systematically fractionated between the gas phase and different refractory condensates [e.g., 2]. Typical refractory mineral assemblages found in CV chondrites include Ca-Al-rich inclusions (CAIs) and amoeboid olivine aggregates (AOAs). Their bulk inventory of refractory elements as well as that of bulk chondrules have not been studied in much detail yet. In continuation of previous work [3, 4], it is the goal of this survey to a) thoroughly describe the petrographic features of Leoville's parent rock, b) examine the trace element content of individual components, c) quantify their contribution to the bulk rock, and d) reconstruct the evolutionary history of those constituents.

Our study, applying electron microprobe (EMP) and laser ablation ICP-MS techniques, was carried out on a thick section (2.02 cm^2 area) of Leoville. We determined the type and abundance of all constituents >300 µm and selected 32 representative objects. These were examined for their mineralogical composition and bulk content of refractory lithophile elements.

EMP work was done in Göttingen, Germany (JEOL JXA 8900R), and Knoxville, TN (Cameca SX 100). The examination of refractory lithophile elements was conducted at the Australian National University in Canberra, Australia, using their Hewlett Packard Agilent 7500 series quadrupole instrument coupled to a Resonetics 193 nm wavelength excimer laser system and a customized sampling unit [e.g., 5].

Results: *Petrography.* A number of new findings can be reported. While previously being recognized as an accretionary breccia [6], our aliquot was made up of reduced CV3 parent rock only. It consists of approx. 65 vol% ferromagnesian chondrules, 25 vol% matrix, 3 vol% CAIs, and 3 vol% Al-rich chondrules (ARCs). Additional phases are a very fine-crystalline mafic component of sub-lathy shape, amoeboid olivine aggregates (AOAs), type II chondrules, and metal nuggets. In disagreement with other reports [e.g., 7, 8], the examined sample contains a significant amount of troilite but only rare metal. Troilite is concentrated in fine-grained chondrules and rim layers.

The vast majority of chondrules belong to type I (Fe-poor). Textural types are limited to PPs, POs, and POPs with variable amounts of groundmass. Petrographically, two categories can be distinguished: fine-grained sulfide-rich convoluted species (this type of material is also present as rim layers) and medium- to coarse-grained chondrules containing more or less troilite. The latter category often displays igneous rims. Generally, the fine-grained sulfide-rich material is slightly more oxidized and composed of low- and high Ca-pyroxenes and lesser forsteritic olivine.

Refractory inclusions (4 CAIs, 1 AOA) are mostly small fine-grained unzoned species. Typical refractory phases include spinel, melilite, anorthite, Al-diopside, and fassaite. The largest (>3 mm) member is coarse-grained and classifies as a typical type B CAI. All refractory inclusions are rimless.

Among the previously unrecognized ingredients, we count three ARCs, an accessory very fine-crystalline constituent exhibiting a sub-lathy shape, two ferromagnesian chondrules containing spinel, a single type II chondrule, and a single metal nugget. Regarding the ARCs, only the "plagioclase-phyric" variety [9] was detected. All of them were rimmed, although to differing extent.

Trace elements. The refractory trace element data are still being processed and evaluated. On the expected, yet preliminary level, each type of constituent displays a distinct elemental pattern. While CAIs, ARCs, and AOAs show fractionated volatility-controlled REE signatures, those of the ferromagnesian chondrules are typically flat [see also 10]. Finalized results including the individual contribution to the bulk rock's budget of each compositional fraction will be presented at the conference.

Discussion: The presence of troilite-rich (fine-grained), troilite-bearing (medium-grained), and opaque-poor or -free (coarse-grained) chondrules may reflect a thermal maturation process as described by [11]. Igneous rims on many chondrules can be attributed to the pre-accretionary acquisition of dust mantles in a dust-filled environment [e.g., 12]. Subsequently, reheating and, in some cases, partial melting of the rim layers occurred.

The ARCs display textures somewhat different from the ferromagnesian species. The two larger objects are composed of lathy plagioclase, blocky olivine or low-Ca pyroxene, and interstitial high-Ca pyroxene. The third ARC shows a dendrite texture of plagioclase and pyroxene with lesser blocky olivine. The differences probably resulted from variable cooling histories [see also 9]. Furthermore, rim features suggest the partial loss of rim material or less efficient rim acquisition for the two smaller members of this group.

The observed high abundance of troilite in absence of any significant metal is the most striking discrepancy from previous studies of Leoville. Assuming sample heterogeneity for lack of other evidence at this point, the troilite-rich unit(s) of the Leoville parent rock could have been thoroughly sulfurized prior to accretion. [13] found that some dust-rich environments where rimmed chondrules formed must have also shown S fugacities high enough to effectively convert kamacite into troilite. Subsequently, troilite-rich chondrules and matrix must have co-accreted with metal-bearing chondrules and matrix as well as xenolithic clasts to form small but distinct rock units within the Leoville parent body. If this scenario is dynamically consistent with the evolution of the protoplanetary disk, remains to be explored.

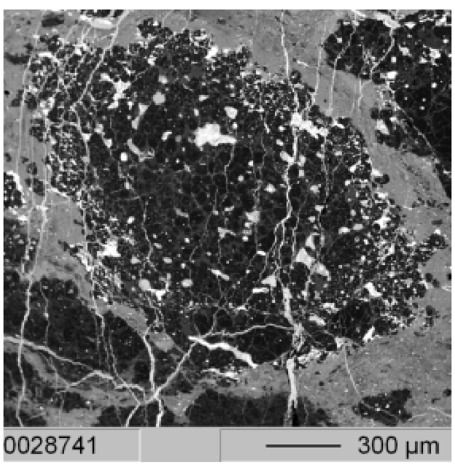

Fig. 1. Back-scattered electron image of a typical medium-grained sulfide-rich ferromagnesian type I chondrule with igneous rim in Leoville. Contours are highly irregular and convoluted.

More often than not, chondrules and CAIs in Leoville display irregular shapes and ragged looking surfaces (Fig. 1). Exceptions include very few (coarse-grained) ferromagnesian chondrules, two of the ARCs, the metal nugget, and the single type II chondrule. A common denominator of these exceptions is their lack of igneous rims. But CAIs and the sub-lathy component are devoid of rims as well. And yet, they show more or less convoluted outlines. For the fine-grained sulfide-rich chondrules and the rimmed constituents, surface roughening may have been produced by the irregular adhesion of silicate-sulfide dust and incomplete melting thereof. This would also explain the smoothness of most rimless constituents. Alternatively, or in addition, some form of grain size-/hardness-controlled erosion may have taken place prior to accretion, e.g., wind-induced abrasion in a turbulent, dust-filled regime. This type of process could have affected the sub-lathy component and CAIs.

[14] recently presented a study on non-spherical lobate chondrules in CO3 chondrites proposing that rough chondrule contours could be generated by fracture surfaces. For Leoville, fracture surfaces may play a role. The full scope of circumstances leading to the manifestation of irregular, i.e. convoluted, amoeboid profiles, however, is still uncertain.

Summary: Leoville's main ingredients are ferromagnesian type I chondrules and matrix. Minor constituents are (in order of 2D abundance) CAIs, ARCs, and a very fine-crystalline mafic component of sub-lathy shape. Accessory objects identified include AOAs, type II chondrules, and metal nuggets.

The majority of events molding and affecting individual constituents appear to have taken place prior to the final accretion of Leoville's parent body. Most notably, many objects acquired sulfide-rich dust mantles that were subsequently reheated and, in several instances, partially melted. The lack of metal may indicate thorough sulfurization of kamacite prior to accretion and possibly even before chondrule rim formation. In addition, a substantial number of constituents were exposed to a process (or series of processes) leaving their contours looking ragged, convoluted, and/or amoeboid. Some raggedness may be caused by fracture surfaces and/or was inherent to the dust accretion event. Another conceivable mechanism is erosive abrasion in a turbulent dust-filled regime.

Predating the processes listed above, fractional gas-solid condensation took place and co-affected the inventory of refractory elements in meteoritic constituents. We will present the patterns of relevant components and calculate their relative contributions to the CV3 chondrites' budget.

References: [1] Bonal L. et al. (2006) *GCA, 70*, 1849-1863. [2] Lodders K. (2003) *Astrophys. J., 591*, 1220-1247. [3] Pack A. et al. (2007), GCA, 71, 4592-4608. [4] Patzer A. et al. (2010) *Meteoritics & Planet. Sci., 45*, 1136-1151. [5] Eggins S. et al. (2003) *QSR, 22*, 1373-1382. [6] Kracher A. et al. (1985) *JGR, 90*, D123-135. [7] Cain et al. (1986) *EPSL, 77*, 165-175. [8] Zanda B. et al. (1990) *Meteoritics, 25*, A422. [9] MacPherson G.J. and Huss G.E. (2005) *GCA, 69*, 3099-3127. [10] Bendel V. et al. (2011), this volume. [11] Zanda B. et al. (2002) *LPS XXXIII*, Abstract #1852. [12] Rubin A.E. (2010) *GCA, 74*, 4807-4828. [13] Lauretta D.S. et al. (2002) *Meteoritics & Planet. Sci., 37*, A84. [14] Rubin A.E. and Wasson J.T. (2005) *GCA, 69*, 211-220.