[1]McDonnell Center for the Space Sciences and the Physics Department, Washington University, St. Louis MO 63130, USA, [2]Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria.

An unusual inclusion of a triangular cross section (5 × 2.5 mm in size) from the Maralinga CK chondrite has a zonal structure, consisting of core, mantle, and crust. The core (2.5 × 1 mm) consists mainly of plagioclase-olivine intergrowth (troctolite) with ophitic texture, but also contains minor clinopyroxene and Cl-apatite, as well as some calcite, which partially fills pore space. The mantle varies in thickness (0.1–1.5 mm) and consists of a dense intergrowth of green spinel and plagioclase with abundant dispersed magnetite grains of widely varying sizes (1–100 µm) and shapes. The spinel-plagioclase intergrowth has, in places, symplectitic texture and variable plag/sp ratios and grain sizes. The mantle is frequently cut by plagioclase-rich veins connecting the core with the crust. Minor phases in the mantle are ilmenite (exsolution lamellae in magnetite) and calcite (in rare pore space). The thin (~10-µm) discontinuous crust consists mainly of plagioclase with some olivine and magnetite and is commonly intimately intergrown with the chondrite matrix. An indentation contains an olivine-plagioclase intergrowth with subophitic texture in places. A supercrust of calcite almost continuously covers the inclusion.

Phase compositions, as determined by EMP, are olivine: Fa = 33.1, NiO = 0.62 wt%; plagioclase: An 55–74 with high-An compositions in the mantle; clinopyroxene: Fs 10, Wo 46.7; spinel: Fe/Fe + Mg = 0.55, NiO = 1.53 wt%; and magnetite: TiO_2 = 0.50 wt%, NiO = 0.57 wt%. Abundances of up to 37 trace elements were determined by secondary ion mass spectrometry [1]. Most phases are rich in trace elements and have group II REE patterns [2] with depletions of the refractory HREEs, a strong positive Tm anomaly, and, commonly, a negative Eu anomaly. The exceptions are olivine, which has LREE depletions relative to the HREEs, and calcite, which does not show any significant REE fractionation at the 1× CI abundance level. Thus, trace-element abundances in most phases are determined by volatility [3] and not by interphase distribution coefficients, and only olivine appears to have lost the LREEs. This suggests formation of the Maralinga inclusion by condensation from a gas depleted in the superrefractory REEs. Similar patterns have been reported from spinel-hibonite inclusions in Murchison [4], spinel-rich inclusions in Mighei [5], grossite-hibonite inclusions in Acfer 182 [6], and spinel inclusions in micrometeorites [7]. The essentially unfractionated REE abundances in calcite must represent an independent reservoir. A search for ^{26}Al in plagioclase was mostly negative, with only one measurement giving a small ^{26}Mg excess. The Ti isotope ratios in ilmenite are normal, as expected.

The formation history of the inclusion appears to be the following: plagioclase and olivine condensed simultaneously from a gas depleted in superrefractory elements, forming the igneous-looking troctolite core. Plagioclase continued to condense and was joined by spinel and magnetite (or a phase that was subsequently replaced by magnetite). Finally, plagioclase was again joined by olivine, forming the crust. Subsequently, metasomatic exchange reactions under oxidizing conditions in a volatile-rich gas added Fe^{2+} and Na (among others) to the phases and led to the formation of phosphate (from phosphide?) and magnetite (from a reduced precursor?). Continuing oxidizing conditions caused mobilization of Ca from inside (and probably also outside) the inclusion that precipitated calcite into available pore spaces and at the inclusion's surface.

References: [1] Zinner E. and Crozaz G. (1986) *Int. J. Mass Spectr. Ion Processes, 69,* 17–38. [2] Mason B. and Martin P. M. (1974) *Nature, 249,* 333–334. [3] Boynton W. V. (1975) *GCA, 39,* 569–584. [4] Ireland T. R. et al. (1988) *GCA, 52,* 2841–2854. [5] MacPherson G. J. and Davis A. M. (1994) *GCA, 58,* 5599–5625. [6] Weber D. et al. (1995) *GCA, 59,* 803–823. [7] Kurat G. et al. (1994) *LPS XXV,* 763–764.

NITROGEN ISOTOPIC DISEQUILIBRIUM IN THE CAPE YORK IIIA IRON.

J. Zipfel[1], Y. Kim[1,2], and K. Marti[1], [1]University of California, La Jolla CA 92093-0317, USA, [2]Present address KRISS, Yusong, Daejon 305-600, Korea.

Cape York is a medium octahedrite of the class IIIA, which is presumed to have been formed by fractional crystallization of an asteroidal metal core [1]. Within the Cape York kamacite-taenite matrix, abundant troilite nodules are found. From their elongated form it has been suggested that immiscible S-rich liquids were trapped under the influence of a gravity field. Some of these nodules contain chromite grains, preferentially at the bottom of the troilite/metal boundary [2,3]. Minor phases within the troilite are sulfides, phosphates, SiO_2, and Cu. Carlsbergite (CrN) is exclusively found within the metal matrix.

The N isotopic composition in metal of Cape York was analyzed by several workers and found to be enriched in ^{14}N (δ^{15}N −32.3‰ to −94.8‰) with concentrations varying from 7 to 37 ppm. The large range of N concentrations may reflect artifacts due to experimental difficulties [4], but also might be attributed to varying amounts of CrN within the metal separates. The N in troilite (δ^{15}N −3.8 ± 1.2‰) was found to be heavier than that observed in metal [4]. In one temperature step (1100°C) during stepwise release, N with a δ^{15}N of −32‰ was measured, indicating inclusions of an isotopically distinct phase in troilite.

In order to trace the nature of the inclusion we determined the N isotopic composition first in a small pilot sample and then in a larger (23.93-mg) chromite separate. The latter was stepwise heated at temperatures between 400° and 1000°C, and the release of sample N started at 700°C (δ^{15}N −9.6 ± 2.4‰). The lightest N component was measured in the 1000°C step with δ^{15}N −56.4 ± 13.0‰, and the average N composition is obtained as δ^{15}N −25.8‰. This result supports earlier evidence that N is isotopically not equilibrated between chromite, surrounding troilite, and metal matrix. Possible processes that could lead to a disequilibrium as observed in Cape York include (1) survival of primary isotopic heterogeneities and (2) N loss during secondary processes, e.g., metamorphic heating and shock deformation.

In scenario 1, graphite grains within metal of the Acapulco meteorite were identified as carriers of isotopically distinct N and C components and were interpreted as surviving (possibly presolar) grains unaffected by the igneous alteration of the bulk meteorite [5]. Obviously such grains exchanged N isotopically with metal and chromite, but not with sulfides and silicates, as these do not carry the light N of metal and chromite [6]. The mechanism of this exchange is, however, unclear. No graphite has been observed so far in Cape York. Yet, isotopic heterogeneities in the precursor material of Cape York cannot be excluded. During melting of the parent asteroid one would expect homogenization of the N isotopes. Since chromite and metal crystallize at high temperatures, a probable exchange of N between the S-rich melt and a distinct N reservoir at lower temperature might explain the disequilibrium.

In scenario 2, troilite nodules in Cape York indicate a small degree of shock deformation [2,3,5]. One might argue that some N was lost and the residue fractionated during this event. However, ^{107}Ag/^{109}Ag ratios from metal and troilite correlate with Pd/Ag ratios, which is not the case in severely shocked magmatic irons [7]. In addition, similar isotopic N fractionations are found in the "magmatic" Acapulco meteorite, which shows no indication of shock deformation. Therefore, secondary loss of N preferentially from troilite can be excluded.

References: [1] Haak H. and Scott E. (1993) *GCA, 57,* 3457–3472. [2] Buchwald V. (1975) *Handbook of Iron Meteorites, Vols. 1–3,* Univ. of California and Arizona State Univ., Berkeley. [3] Kracher A. et al. (1977) *Geochem. J., 11,* 207–217. [4] Murty S. and Marti K. (1994) *GCA, 58,* 1841–1848. [5] El Goresy A. et al. (1995) *Nature, 373,* 496–499. [6] Kim Y. et al. (1992) *LPS XXIII,* 691–692. [7] Teshima J. et al. (1986) *GCA, 50,* 2073–2087.

CYCLICAL REGOLITH PROCESSES ON HYDROUS ASTEROIDS.

M. E. Zolensky, Earth Sciences and Solar System Exploration Division, NASA Johnson Space Center, Houston TX 77058, USA.

Carbonaceous chondrites experienced and recorded a very wide range of chemical and physical processing in both nebular and asteroidal settings. Among the features arising from asteroidal processes are (1) most of these meteorites are breccias; (2) some CV3s and CMs contain flattened chondrules and exhibit foliation; (3) veins are found in some CIs, CMs, and CV3 dark inclusions; (4) CR2s, all CIs, and some CR2s and CMs display weak alignment of matrix phyllosilicates; and (5) shearing (mylonitization) around lithic fragments. While these features have generally been assumed to have involved impact deformation in asteroidal regoliths, a process sometimes referred to as regolith or impact gardening, we suggest here that all of these particular features would have arisen naturally from cycles of wet-dry and freeze-thaw environmental conditions in asteroid regoliths.

All the extensively (Y 82042, ALH 83100, Cold Bokkeveld, Y 891198, EET 90047) and completely (ALH 88045, EET 83334, Kaidun CM1 lithology) altered CMs contain rounded to elliptical aggregates of phyllosilicates, carbonates, spinels (chromite and magnetite), Fe-Ni sulfides, and embayed olivines and pyroxenes, which we interpret as relict chondrules [1]; these sometimes define a definite foliation direction generally ascribed to impact shock [2,3]. We examined all available relict olivines from CMs showing the most pronounced chondrule flattening and foliation, and found only a few planar fractures in a single olivine grain in one sample (EET 90047), and no sign of shock effects in the others. We therefore suggest that static burial pressure was the agent responsible for chondrule flattening in this case, and believe that the processes involved in burial compaction deserve more attention than they have hitherto received in the asteroid literature.

It is probable that even in the wettest regions of an asteroid, dry periods were experienced during the periodic breaching of an icy surficial rind [4], which could have occurred during impacts or "volcanic" venting of gas and heat from the interior (this assumes internal heating). Thus, there should have been multiple wet-dry cycles involved in the genesis of these materials. It is well known to soil scientists that conditions of radically alternating humidity can have important morphologic and petrologic consequences. Grains and lithic clasts can become rotated, crushed, and drawn out into linear features (shearing). Porosity (including contraction and shearing cracks) and other bulk physical properties will vary in dramatic manner. These effects would be most pronounced for the CI and CR chondrites, as well as the Kaidun CM1 lithology, where the swelling clay saponite is found in abundance. Easily altered materials will be dissolved, while more resistant materials will be pulverized and mixed into matrix [5].

Another important process to be considered is periodic growth and melting of ice crystals in the regolith [6]. The positive molal volume change during crystallization of water will induce oriented microfabrics to develop in the regolith, normal to the direction of ice crystal growth. Thus, platy grains (such as phyllosilicates) will develop a pronounced compaction and preferred alignment. Since the orientation of the growing ice mass will vary for each succeeding generation of growth, the eventual result will be to impart a particular, invasive, regolith fabric consisting of anastomosing strings of phyllosilicates with roughly aligned basal directions for each string. Such textures are common in the wettest chondrites: CIs and CMs. Growth and collapse of these asteroidal icicles will also impart cyclical changes in bulk regolith porosity, induce rotation and movement of crystals and lithic fragments through frost heaving, and consequent shearing. This process could also account, to some degree, for the flattened chondrules.

We therefore suggest that cyclical, indigenous environmental processes, rather than impact gardening, could be responsible for many (most?) of the late-stage petrologic characteristics of wet carbonaceous chondrites. Bulk petrographic features of chondrites should be investigated more systematically in order to test this suggestion.

Acknowledgments: We thank R. Drees, B. Hallet, and L. Browning for constructive conversations.

References: [1] Zolensky M. E. and Browning L. (1994) *Meteoritics, 29*, 556. [2] Sneyd D. S. et al. (1988) *Meteoritics, 23*, 139–149. [3] Scott E. R. D. et al. (1992) *GCA, 56*, 4281–4293. [4] DuFresne E. R. and Anders E. (1962) *GCA, 26*, 1085–1114. [5] Nahon D. B. (1991) *Introduction to the Petrology of Soils and Chemical Weathering*, pp. 122–133. [6] Van Vliet-Lanoe B. (1987) *Le Role de la Glace de Segregation*, unpublished thesis, Univ. Paris I-Sorbonne, 854 pp.