18.6% Al_2O_3, 3.0% CaO, 2.3% Na_2O, 3.9% MgO, 2.5% FeO). In places the pigeonite forms dendrites into the glass.

Additional Petrographic Observations: In places, the enclosed augite occurs as polycrystalline aggregates, with no interstitial phases along grain boundaries. In addition to augite, the oikocrysts include rare, small (up to ~180 μm), highly rounded grains of olivine (mg ~75), with reduced rims containing minor graphite. Aggregates of larger (up to ~1 mm), subhedral olivine grains occur between oikocrysts, with only minor graphite on grain boundaries. The oikocrysts also include patches of graphite ± chromite. Chromites have reduction rims containing Fe-Cr carbides (Cr-bearing cohenite was confirmed by TEM) and eskolaite-corundum [5,6], and has been corroded by a liquid, now represented by feldspathic glass containing blebs of SiO_2. Graphite, chromite, and glass occur more abundantly between the oikocrysts. Deformation lamellae, subparallel to the exsolution lamellae, occur in some oikocrysts.

Interpretation: Transmission electron microscope observations of the enclosed augite grains support the interpretation that they are remnants of larger, single crystals that were resorbed by reaction of primocrysts with pore liquid [1], rather than products of granule exsolution [7]. The olivine chadocrysts provide evidence that olivine also reacted with this liquid and was largely resorbed [e.g., 4]. The low abundance of graphite along primary grain boundaries indicates that it was mainly associated with the liquid. This suggests that the primocryst assemblage was a cumulate. The pore liquid was probably opx-saturated [1]. Though it was not in equilibrium with the primacryst assemblage, it was probably related to it [e.g., 4]. Transmission electron microscope observations of the pigeonite and glass support the interpretation [1] that the pigeonite formed from the augite remnants by late, solid-state reduction in the presence of a residual liquid. Larger amounts of this liquid were trapped between oikocrysts. Twinning in the augite and deformation of the opx probably result from late shock [8].

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ORIGIN OF THORIUM/URANIUM VARIATIONS IN CARBONACEOUS CHONDRITES.

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Thorium-, U-, and Pb-isotopic analyses of a wide variety of planetary materials show that Th/U ratio (by weight) varies from 3.5 to 4.2. It is generally believed that chondritic meteorites contain refractory lithophile elements in a relative proportions close to solar, i.e., CI chondrites [1]. Surprisingly, a number of analyses of different types of carbonaceous chondrites show a large (at least a factor of 3) scatter in Th/U measurements [2]. The widest spread in Th/U is observed in the most primitive materials, CI-type chondrites. Cosmochronological models rely on the precise knowledge of the average solar system Th/U, therefore it is important to achieve a better understanding of the actinide chemistry in chondrites, e.g., what causes the variations in Th/U ratio.

Variations in Th/U in equilibrated ordinary chondrites are dictated by the differences in relative proportions of two major actinide carriers: apatite and merrillite [3]. Even though phosphates are rarely observed in CI chondrites [4], the submicrometer-sized grains could have been overlooked. If CI phosphates concentrate actinides, sampling of such phases could produce the observed scatter in Th/U.

We performed Th, U, and P analyses in Orgueil (CI) and Murchison (CM2) in order to determine what fraction of actinides were associated with P-rich phases. Results for Orgueil are presented in Table 1.

Chen et al. [5] performed stepwise leaching experiments for Orgueil. We analyzed P concentrations using the Finnigan Element magnetic sector ICPMS in the exact same leaches and found that almost all Th is associated with the P-rich phase, whereas only half of U is in the same leach. The rest of U is in phases, leachable with weak acids, presumably carbonates and sulfates.

TABLE 1. Results from Orgueil (Th and U analyses from [5]).

Leach No.	^{238}U (%)	Th/U	P (%)
1. HAC	21	0.15	1.41
2. 0.1M HCl	14	1.14	1.08
3. 6M HCl	55	5.76	87.17
4. 7M HNO_3	7	5.33	9.57
5. Residue	3	3.87	0.76

Regardless of the origin of CI phosphates, they appear to maintain their traditional role as major actinide host phases. The concentration of U in nonphosphate phases probably represents the importance of the higher U valence states in the more oxidizing CI environment. Uranium in fluid phases would be highly mobile, accounting for the Th/U variations. Initial results for leaching of CM chondrites indicate that significant fractions of actinides are easily leachable, along with the bulk of the P.

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SAMPLING MECHANISMS FOR AN ASTEROID SAMPLE RETURN MISSION AND THE *HERA* SURFACE SAMPLER.

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A mission to return samples from a near-earth asteroid (NEA) is the logical next step in the scientific investigation of asteroids, comets, and meteorites. It is advocated in numerous advisory reports and in NASA's Space Science Strategic Plan and Roadmap. The successful test of solar electric propulsion by the *Deep Space 1* mission, the successful maneuvers of *NEAR Shoemaker* in the vicinity of Eros, and the extraordinary increase in the rate of discovery of NEAs, mean that a mission is now technically feasible. One of the new technologies required will be a sample collection device, and here we review past methods and describe a new method recently developed for a multiple NEA sample return mission called *Hera*.

To date, the Moon is the only extraterrestrial body that has been sampled by missions. The Apollo landers were manned so most samples were collected by hand, although rake, drill core, and drive tube samples were also obtained. The Luna missions used a small drill head attached to the end of a boom arm to collect samples from up to 2 m in depth. The canceled Mars sample return missions would have used minicorers and grab sampling. The *MUSES-C* mission involves a lander that fires a projectile and collects the ejecta. *Genesis* uses passive collectors for solar particles and *Stardust* uses aerogel to slow and capture interplanetary and comet dust.

Methods potentially available for sample collections from comets and asteroids are percussion methods, trowel/claws, microrovers, trawlers, drillers/corers, penetrators, and scoops. Most of these methods require landing and anchoring and involve considerable risk to the spacecraft. They also present major challenges in communication. The *Hera* surface sampler (HSS) avoids most of these difficulties by not landing. Instead, it dips momentarily to the surface, collects about 300 g of material, then returns to altitude before moving to another site.

The HSS consists of two or three pairs of cutting heads located on a flexible boom that can be deployed >1.5 m below the spacecraft. The cutting heads counter rotate at high speeds (>3000 rpm) and upon contact with the surface, small fragments are thrown up into a temporary storage chamber behind the cutting heads. Up to 200 mL of sample may be captured with a 1–2-s encounter with the surface.

The cutting head assembly is about 75 mm across and the temporary storage chamber is about 125 mm high. The HSS drive assembly consists of a