EXPLORING EXOGENIC SOURCES FOR THE OLIVINE ON ASTEROID VESTA. L. Le Corre, V. Reddy, J. Sanchez, T. Dunn, E. A. Cloutis, M. R. Izawa, P. Mann, A. Nathues, Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719, USA, lecorre@psi.edu, Colby College, Department of Geology, 5808 Mayflower Hill, Waterville, ME 04901, Department of Geography, University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba, Canada, Max-Planck-Institute for Solar System Research, Göttingen, Germany.

Introduction: Ground-based and Hubble Space Telescope observations of asteroid Vesta showed evidence for the possible presence of olivine. However, subsequent analysis of data from NASA’s Dawn mission proved that this “olivine-bearing unit”, identified as Oppia crater and its ejecta blanket, was composed of HED impact melt rather than olivine [1]. The lack of widespread olivine in the 19 km deep Rheasilvia basin on the South Pole suggests that the crust-mantle boundary was not breached during the formation of the basin, and that Vesta’s crust is thicker than originally anticipated [2].

Recently, local-scale olivine units have been reported in the walls and ejecta of two craters (Fig. 1), Arruntia (42 km in diameter) and Bellicia (11 km in diameter), located in the Northern Hemisphere of Vesta, 350-430 km from the Rheasilvia basin [3]. These units were interpreted as exposed plutons by [2] rather than of mantle origin excavated during the formation of the Rheasilvia basin. We explored alternative sources for these olivine-rich units by reanalyzing the data published by [3].

Morphology of the Olivine-Rich Deposits: Distribution of the olivine around the Arruntia and Bellicia craters has been described by [3] and [4]. The exposures range in size from a hundred meters to few kilometers. The olivine is found on crater walls (in high reflectance outcrops), secondary craters nearby, and in the ejecta blanket of Arruntia and Bellicia (radial distribution around the crater rim). As proposed by [5], the observed distribution suggests that these deposits could have originated from an ancient impact further North, such as the Alban crater (91 km in diameter).

Proposed Options for the Origin of the Olivine: Several hypotheses have been proposed in order to account for the non-detection of olivine in the Rheasilvia basin and for the detection of olivine in unexpected locations in the Northern hemisphere.

Endogenic olivine from plutons. Olivine formed in magmatic intrusions in the vestan upper crust in the form of plutons (or dikes) and was subsequently exposed by impact craters (as proposed by [2] and [3]).

Endogenic olivine from mantle. Crystallization of the magma due to complete melting of parent body leading to the formation of an olivine mantle. Subsequent, catastrophic impact exposes the olivine-rich mantle and eject material in the northern hemisphere of Vesta (as proposed in [3]).

Exogenous origin from A-type asteroids. Olivine could have been brought by olivine-rich A-type impactors, but as mentioned in [3] and [4] these asteroids are rare in the main asteroid belt, so this hypothesis was not favored in most recent work.

Comparison with Olivine-OPX Mixtures: Our mineralogical analysis gives olivine abundance between 70-80 vol.%, consistent with those obtained previously (for example [4] found >60% of olivine). However, no single laboratory spectrum of olivine-OPX mixture can accurately reproduce both the Band I shape and Band I center of the VIR data (Fig. 2), as well as the Band II center due to different pyroxene composition.

Alternatives Sources for the Olivine: Olivine-rich asteroids and meteorites. Several meteorites contain olivine that is not produce in the mantle (Table 1). [6] observed some olivine-rich asteroids matching the composition of R-chondrites. In addition, S-types asteroids with ordinary chondrite (OC)-like compositions contain a significant fraction of olivine. Other meteorites rich in olivine are CV chondrites,
pallasites, and primitive achondrites such as brachin-
ites, ureilites, acapulcoites, lodranites (Table 1).

*Exogenous material in HEDs.* Meteoritic evidence
suggests contamination of HEDs by several exogenic
impactors present in the form of clasts or diffuse in
the impact melt breccia. HEDs show widespread contam-
nation of Vesta by CM chondrite material mixed with
HED impact melt [8], but most OC xenoliths are
less than 1 vol.% in HEDs [9]. OC is the second most
abundant exogenic material in HEDs after carbona-
ceous chondrite material. Other exogenic materials
observed by [9] include ureilite, acapulcoite/lodranite.

<table>
<thead>
<tr>
<th>Meteorite class</th>
<th>Olivine abundance</th>
<th>Evidence in HEDs</th>
</tr>
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<tbody>
<tr>
<td><strong>Primitive meteorites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV chondrites</td>
<td>75-85%</td>
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</tr>
<tr>
<td>R chondrites</td>
<td>70-90%</td>
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<tr>
<td><strong>Differentiated meteorites</strong></td>
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<td></td>
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<td>Angrites</td>
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<td>Brachinites</td>
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<tr>
<td>Acapulcoites/Lodranites</td>
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</tr>
<tr>
<td>Pallasites</td>
<td>25-75%</td>
<td>Maybe</td>
</tr>
<tr>
<td>Ureilites</td>
<td>Variable</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Ordinary chondrites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H: 29-40%</td>
<td>L: 38-45%</td>
<td></td>
</tr>
<tr>
<td>LL: 47-57%</td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1: Olivine abundance for different types of olivine-
bearing meteorites and summary of their presence in HEDs. Table adapted from [10].

**Testing the Exogenic Olivine Hypothesis:**

*Curve-matching of spectral data.* We compared the
VIR spectrum from [3] to spectra of various olivine-
rich meteorites (Table 1) (Fig. 3 shows some H chon-
drites), and mixtures of selected meteorites with eu-
crite Northwest Africa 7465 (NWA 7465) in an
attempt to find a better fit (Fig. 4).

Figure 3: Continuum-removed spectra of selected H chon-
drites from the RELAB database, compared to the olivine-
rich unit observed by VIR [3].

**Band parameters comparison.** The olivine-rich unit
plots in the S(IV) region and slightly below the oli-
vine-orthopyroxene mixing line (Fig. 5). Asteroids
falling in the S(IV) region could be analogous to or-
nary chondrite meteorites. The VIR data point falls
in the L chondrite group within the S(IV) region and
close to ureilite meteorites (near the S(III) zone). This
suggests the olivine on Vesta could be from the con-
tamination of the regolith by ordinary chondrites (pos-
sibly L), ureilites or mixtures of HED with some oli-
vine-dominated meteorites such as R-chondrites.

**Summary:** Based on exogenic materials in HEDs,
the most likely contaminants are OC and possibly
primitive achondrites. Curve matching suggests the
presence of pure OC or mixtures of R-
chondrite/brachinite/OC with eucrite-rich howardite.
Therefore, the vestan olivine-rich unit could be ex-
plained by the delivery of exogenic material rich in
olivine, this favors a recent model of Vesta with a deep
crust/mantle boundary from [2].

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