A SCANNING ELECTRON MICROSCOPE STUDY OF OLIVINE CRYSTAL SURFACES

Edward J. Olsen
Field Museum of Natural History
Chicago, Illinois 60605

Lawrence Grossman
The University of Chicago
Chicago, Illinois 60637

SEM photographs were taken of euhedral olivine grains from the Murchison C2 chondrite and several terrestrial and lunar occurrences. In general, the crystal faces of the meteorite grains are rough and uneven, with irregular growth patterns. They are very similar to crystal faces on terrestrial olivine grains that formed by sublimation from a vapor phase. They are very different from the relatively smooth and featureless surfaces of magmatic olivine crystals that precipitated from igneous melts. Qualitatively, the surface morphology of the crystal supports the contention that many euhedral crystals of olivine in C2 meteorites condensed from a gas phase.

INTRODUCTION

Fuchs *et al.* (1973) noted the presence of euhedral olivine crystals and fragments of crystals contained in the matrix and within white aggregates in the Murchison C2 chondrite. They suggested these crystals formed in free space by direct condensation from a cooling solar nebular gas. The faces of such crystals appear dull and "frosted" when viewed at low magnification under a binocular microscope. Grossman and Olsen (1974) indicated that petrographic and chemical evidence supports the condensation origin of these and similar crystals in other C2 chondrites. This paper presents the results of a scanning electron microscope (SEM) study of the crystal surface morphologies of Murchison olivine crystals. In addition, olivines of known genesis from a number of terrestrial and lunar localities were studied in order to investigate any differences that can be related to modes of origin.

ANALYTICAL

During the course of the study two field-emission SEM instruments were used, a Hitachi model HFS-2 and a Coates-Welter model 50. Specimens were mounted on clean aluminum or bronze discs using silver paint, and were then vacuum-coated with a thin film of gold metal. Magnifications of 100X to 35,000X were studied; however, in general, 100X and 1000X to 5000X were found to provide adequate information.

RESULTS

Figures 1 and 2 show a crystal (Fa_{18}) that was dredged from the east flank of the Mid-Atlantic Ridge. It originally crystallized from basaltic lava and was found in foraminiferal sand which had been cleaned with dilute HCl (Switzer *et al.*, 1972). In general, all the faces are smooth and featureless, with some pitting that probably is due to the acid cleaning or to etching by sea water. Unetched faces may have been much smoother, since etching might be expected to accentuate surface irregularities rather than erase them.

Figures 3 and 4 show a crystal ($\approx Fa_{14}$) obtained from Hawaiian beach sand, formed by the erosion of olivine basalt fragments. The crystal shows clear signs of abrasion, with some pitting on the faces. Nevertheless, several faces were not seriously affected. At a magnification of 3,200X (Fig. 4), a pattern of tiny surface irregularities is barely visible. Some of the raised specks also seen on the surface of this face appear to be adhering volcanic glass.

Figures 5 and 6 show a crystal ($\approx Fa_{35}$) from lunar vesicular basalt 71055,45. All the faces are exceptionally smooth and featureless, showing only the edge of a growth layer and some particles of volcanic glass adhering to the surface.

Figure 7 shows two thin tabular crystals ($> Fa_{85}$) that were found growing in cristobalite-lined lithophysae in black obsidian from Coso Hot Springs, Inyo County, California (Rogers, 1922; Murdoch and Webb, 1940). The crystals formed from a vapor phase (Wright, 1915; Rogers, 1922) which consisted of occluded volcanic gases inside the lithophysae after the quenching of the lava. Two crystal faces are seen prominently here, the large (100) and the narrow (120) (Murdoch and Webb, 1940). The (100) face is smooth at higher magnification, showing only some specks of adhering cristobalite, while (120), shown in Fig. 8, is very rough, displaying a series of irregular parallel ridges.

Figure 9 shows the (010) face of a fayalite crystal ($> Fa_{90}$) that occurs on a substrate of euhedral sodalite and K-feldspar crystals that line miarolitic cavities in the Vesuvius lava flow of 1631, at Cupa de Sabataniello, Italy. Identification of this crystal face and those following is based on published illustrations of crystal morphologies. The occurrence is very similar to the California fayalitic olivine. The olivine crystals formed in the cavities in the lava by direct sublimation from a vapor phase (Lobley, 1889). The (010) face is highly decorated with a series of linear growth features.

Figures 10 and 11 are views of a euhedral olivine crystal ($< Fa_{10}$) removed from the Murchison C2 chondrite. A system of irregular, parallel ridges is seen in Fig. 11, a magnified view of a face whose index could not be determined. Figure 12 shows similar ridges on the (120) face of another olivine crystal from Murchison.

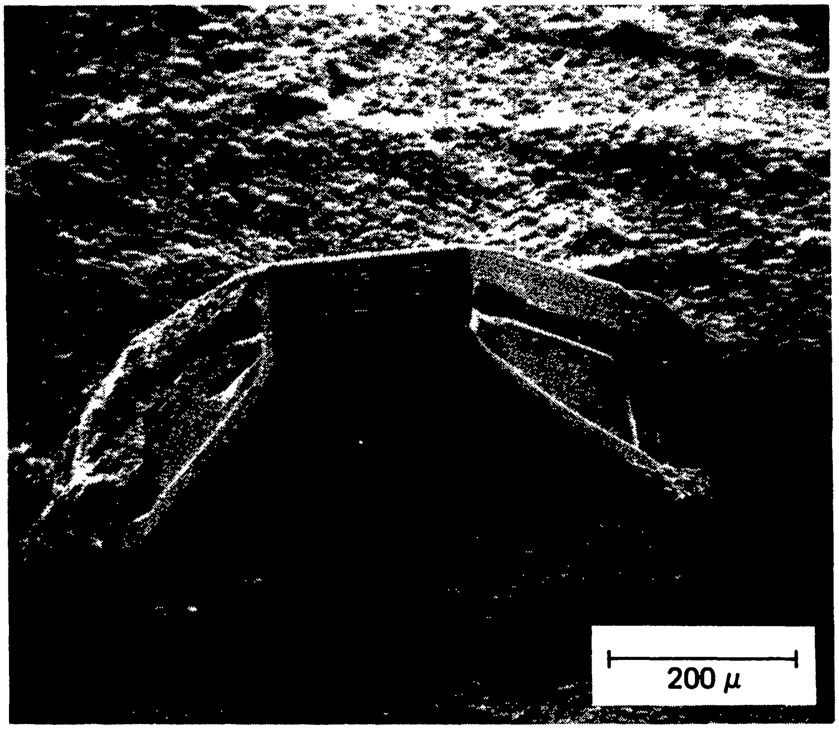

Fig. 1 Single crystal of olivine (Fa_{18}) from basalt, dredged from Mid-Atlantic Ridge.

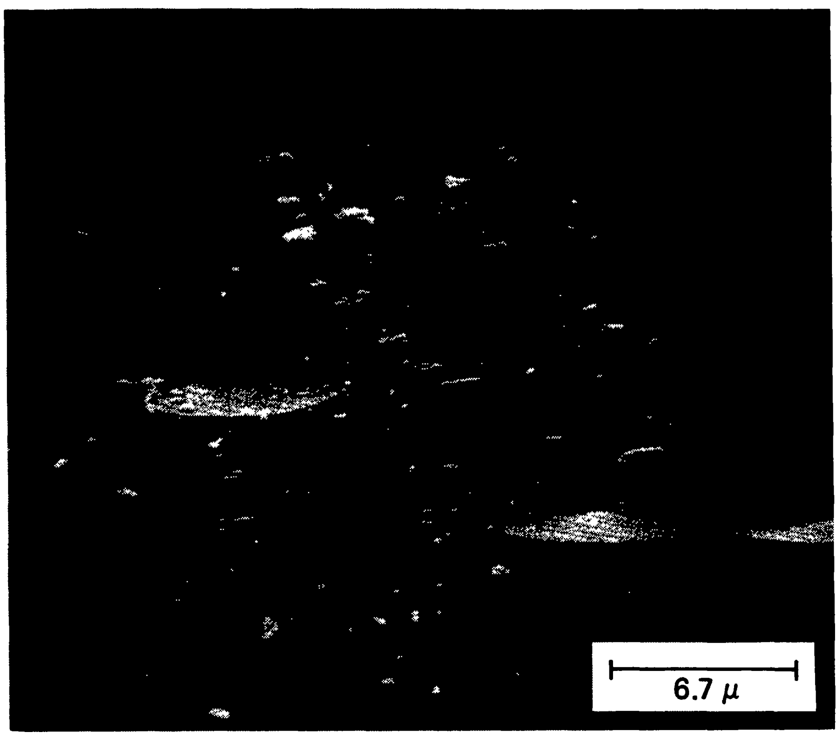

Fig. 2 (010) face of olivine in Fig. 1.

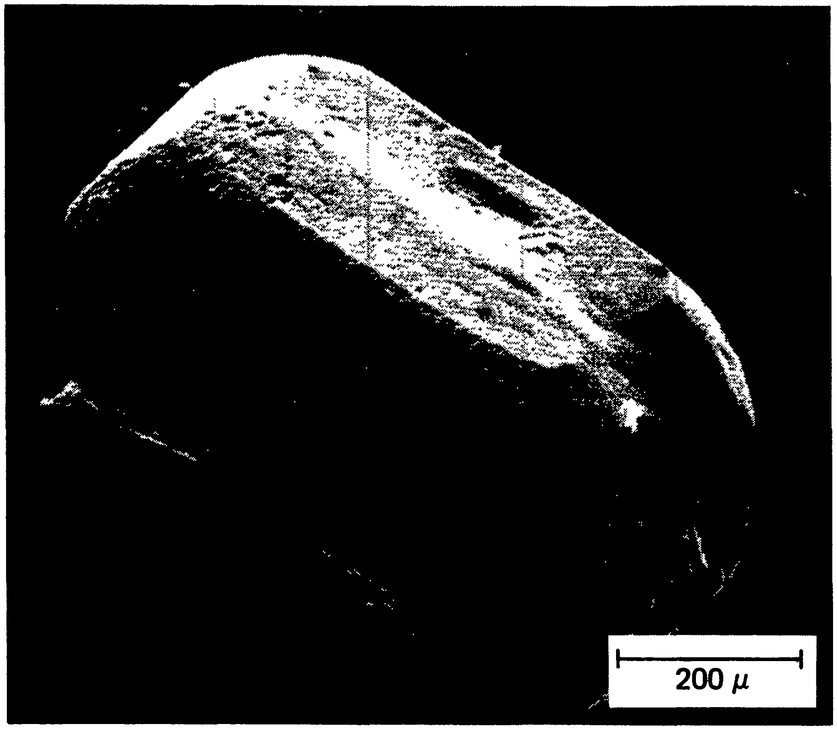

Fig. 3 Single crystal of olivine (≈ Fa_{14}) from Hawaiian basalt.

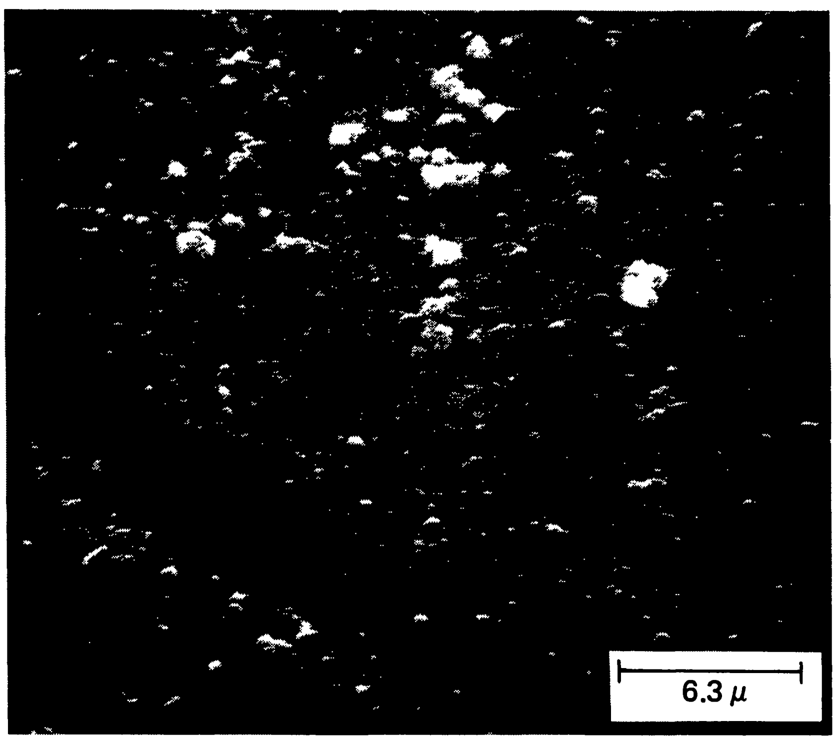

Fig. 4 (120) face of olivine in Fig. 3.

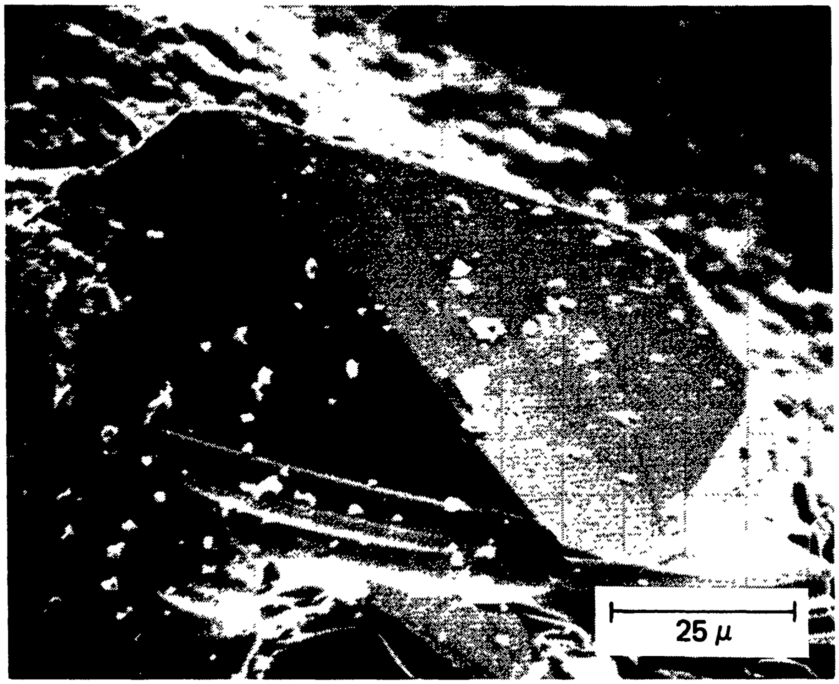

Fig. 5 Single olivine crystal ($\approx Fa_{35}$) from lunar basalt 71055,45.

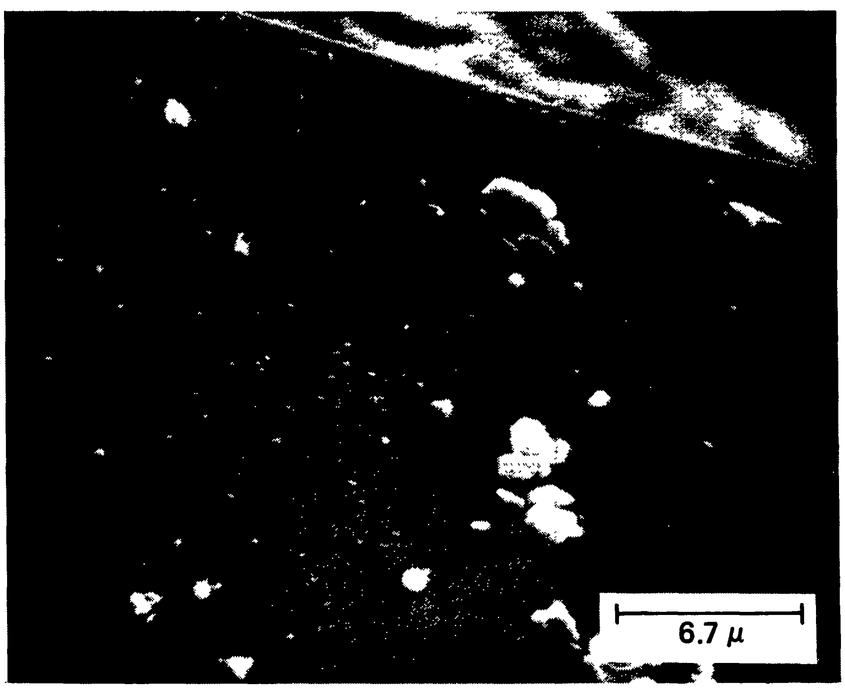

Fig. 6 Close-up view of (101) and (120) faces of olivine in Fig. 5.

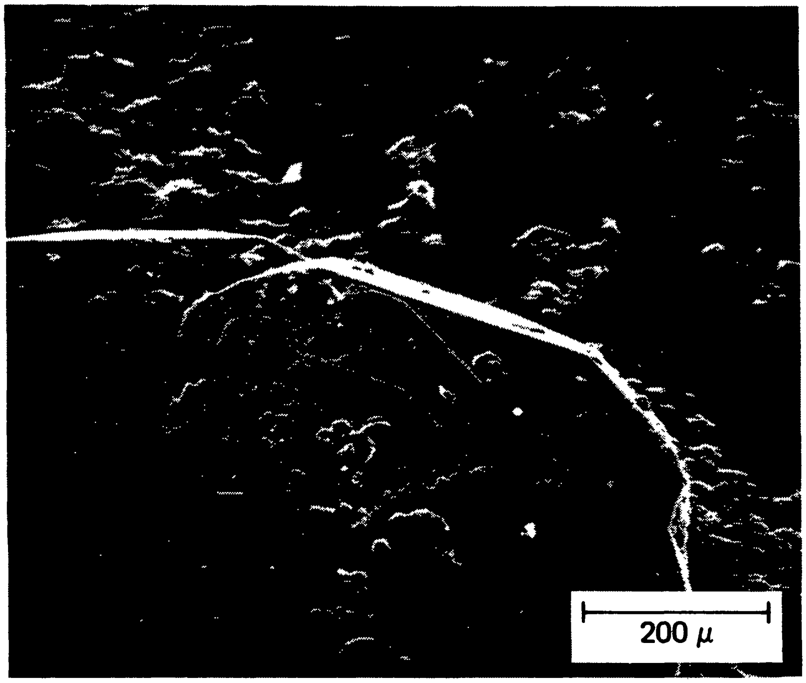

Fig. 7 Two intergrown plate-like crystals of olivine (> Fa_{85}) from lithophysae in obsidian from Inyo County, California.

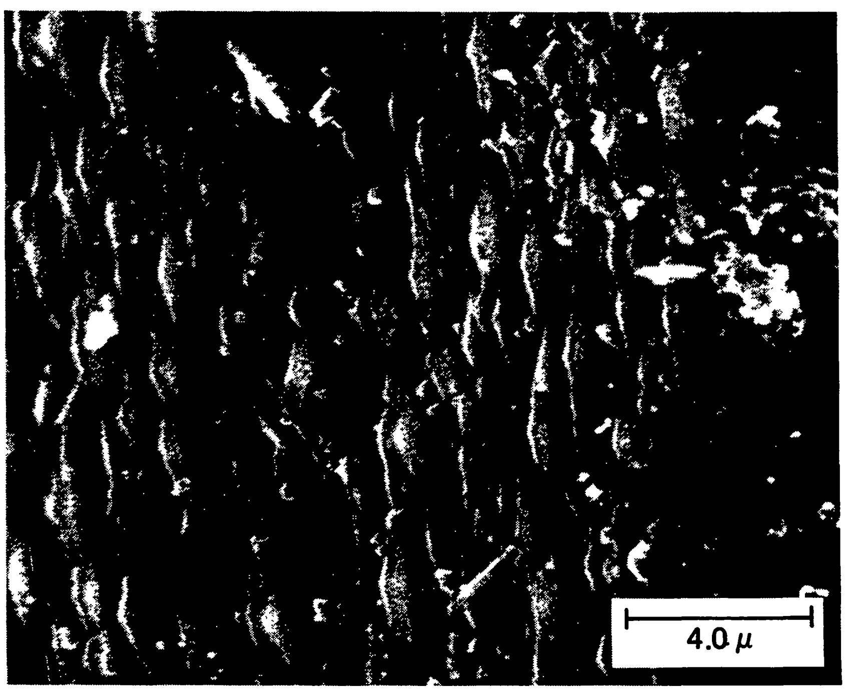

Fig. 8 View of (120) face of one of the olivine crystals in Fig. 7.

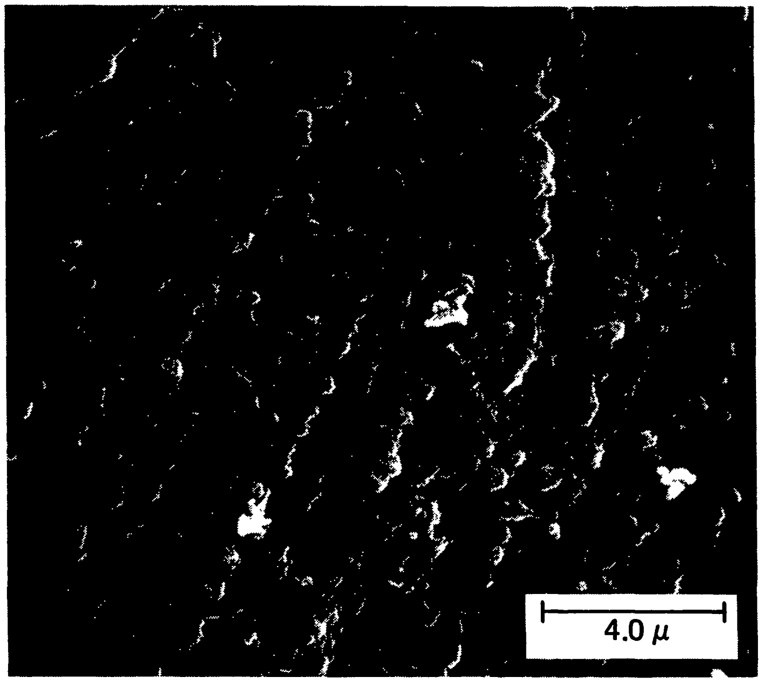

Fig. 9 Close-up view of (010) face of olivine (> Fa_{90}) crystal from cavity in Vesuvian volcanic rock.

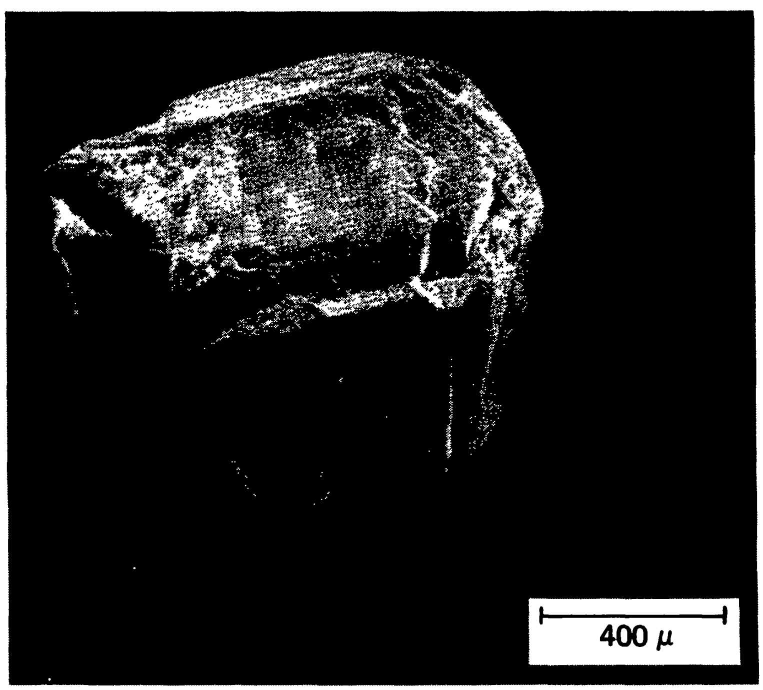

Fig. 10 Olivine (< Fa_{10}) single crystal face from the Murchison C2 chondrite.

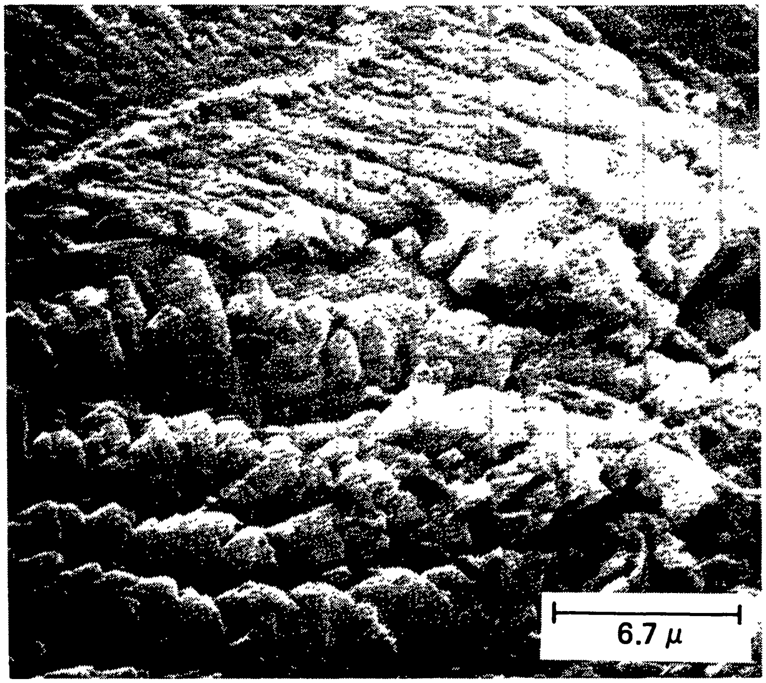

Fig. 11 Close-up view of crystal face (index not determinable) of olivine in Figure 10.

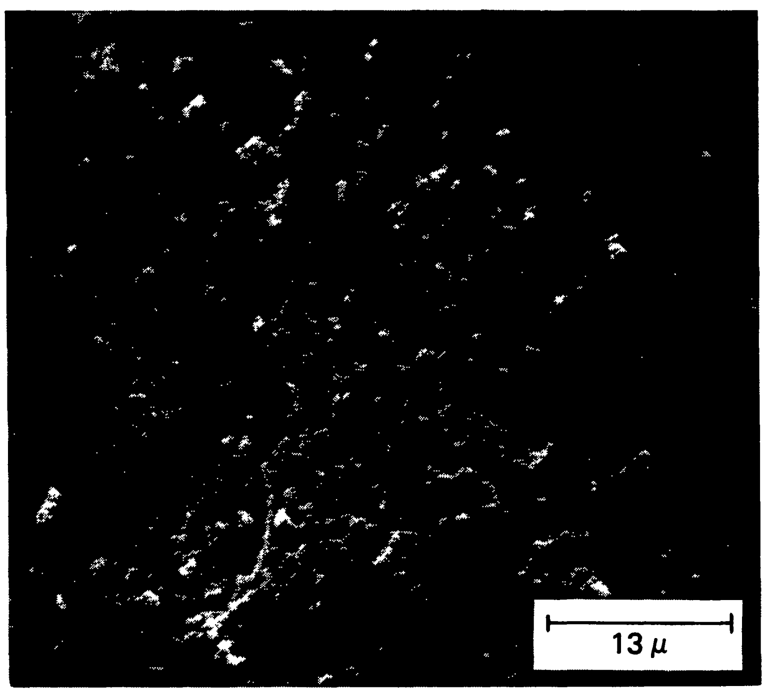

Fig. 12 (120) face of a Murchison olivine crystal.

A third Murchison olivine crystal is seen in Figs. 13 and 14. The high magnification view of its (001) face shows considerable irregularity and surface bumpiness.

Figure 15 shows another euhedral olivine from Murchison. Its (120) face, shown in Fig. 16, is very rough and irregular.

DISCUSSION

It is apparent that the single crystals from the Murchison meteorite exhibit roughened to highly decorated crystal faces comparable to the surfaces of terrestrial olivines which sublimed from a vapor phase inside of volcanic cavities. There seems to be some crystallographic control over the process which causes the roughness. The face (100), when present, is relatively smooth while other faces show surface patterns of varying morphology. In sharp contrast, olivine crystals of magmatic origin have strikingly smooth and featureless crystal faces, independent of the index of the face.

There are numerous physical and chemical variables which may affect the development of the surface of a crystal face during its condensation from a vapor. Among these are the density of the gas, the gas composition, the cooling rate and the composition of the crystalline phase. Many of these parameters had different values for different crystals shown here. The gas phase in the volcanic cavities was certainly much denser and much more water-rich than that of the solar nebula from which the Murchison olivines are postulated to have condensed (Fuchs *et al.*, 1973; Grossman and Olsen, 1974). Thus, on crystal surface morphological grounds alone, no quantitative, rigorous case can be made for the origin of euhedral olivine crystals in C2 chondrites. Nevertheless, it *is* noteworthy that the Murchison olivines compare favorably with olivine crystals that formed from a gaseous phase and decidedly contrast with those that formed by crystallization from a silicate melt. This fact, added to the several lines of evidence noted at the beginning of this paper, supports the contention that these euhedral olivines in C2 chondrites condensed from the vapor of the solar nebula.

It should be pointed out that the Murchison crystals could not have been formed in cavities in volcanic rocks on some parent body in a manner similar to the terrestrial cavity olivines studied here. The olivine crystals from the terrestrial volcanic cavities are always attached to a wall and cannot be obtained with full symmetrical morphologies; only the projecting ends are morphologically complete. The Murchison crystals, on the other hand, are completely euhedral and symmetrical, with no sign of the past existence of any attachment. They occur embedded in the black layer-lattice silicate matrix of the meteorite and can be completely removed, leaving behind a negative mold.

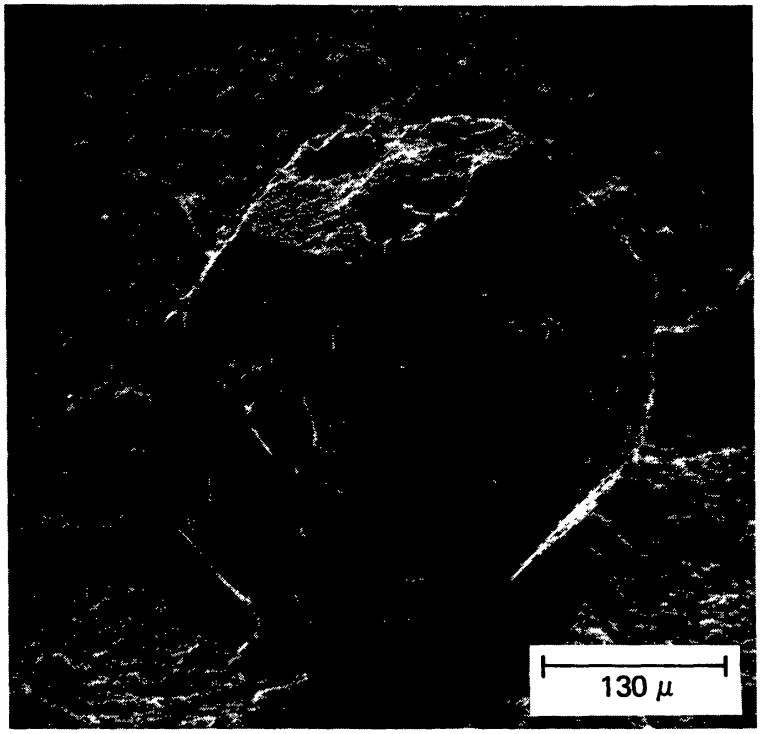

Fig. 13 **Olivine crystal (< Fa_{10}) from the Murchison C2 chondrite.**

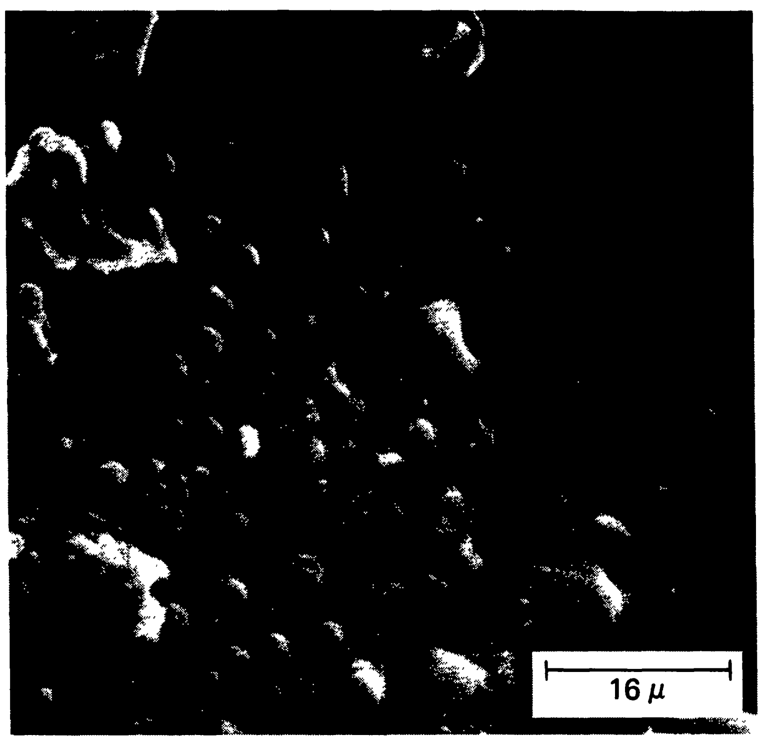

Fig. 14 **(001) face of olivine in Fig. 13.**

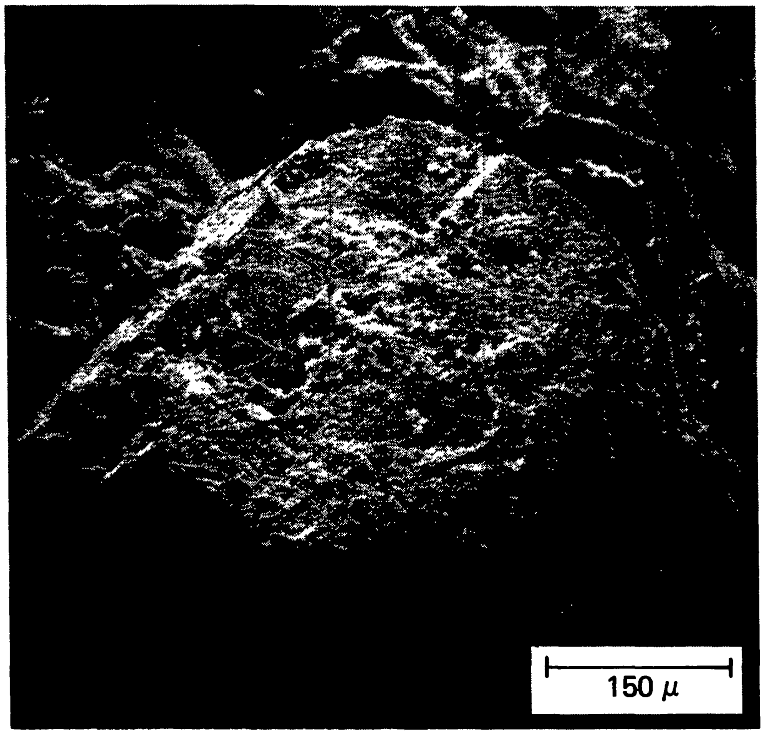

Fig. 15 Olivine crystal (< Fa_{10}) from Murchison C2 chondrite.

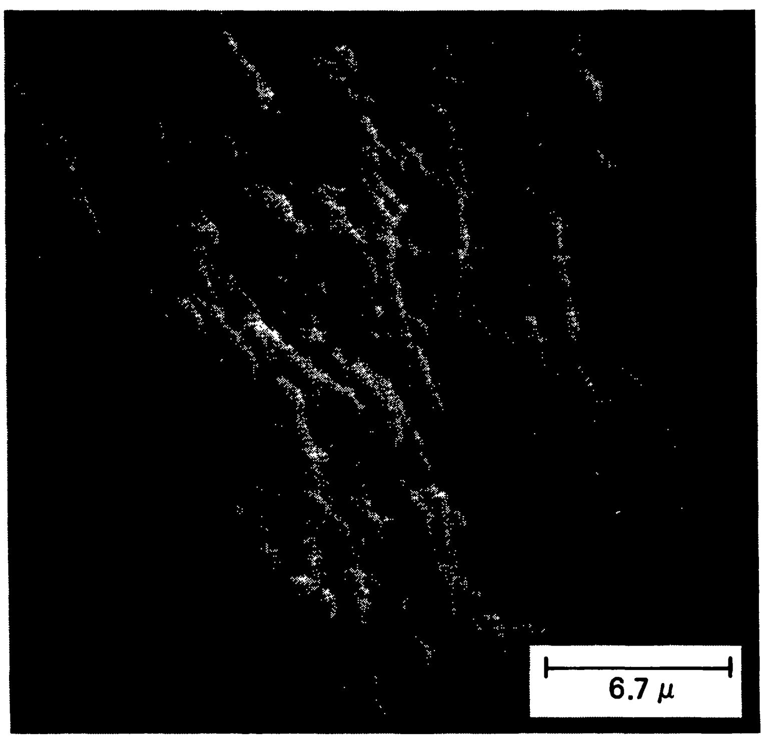

Fig. 16 (120) face of olivine in Fig. 15.

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