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Textural characteristics of olivine crystals in the Oshima-Ōshima picrite basalt and their genetical implications

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Abstract : Picrite basaltic magma from Oshima-Ōshima volcano, Hokkaido, Japan, is a mixture of modified alkali basaltic melt and modified xenocrystal olivine formed during interaction between a primitive alkali basalt and mantle harzburgite. Olivine "phenocrysts" (= large crystals without regard to origin) in the picrite basalt have various textural characteristics. Xenocrystal origin is indicated by some of them, i.e., kink bands, phlogopite-rich veinlets, fluid inclusion trails, dusty inclusions, and chromian spinel lamellae. Presence of phlogopite-rich veinlets and fluid inclusion trails sometimes with magnesioferrite in olivine xenocrysts may further indicate a metasomatism in the harzburgite as a precursor of the alkali basaltic melt.

Introduction

Origin of picrite basaltic magma, especially of its olivine "phenocrysts", has been a subject of debate (e.g., Boudier, 1991). Wilkinson and Hensel (1988) interpreted that large crystals of olivine in some picrites from Mauna Loa, Hawaii, are of magmatic, that is, they are "true" phenocrysts mechanically concentrated. Eggins (1993) also concluded that olivine "phenocrysts" are of magmatic origin but are mostly derived from cumulates of earlier magma(s). Francis (1985) favors a similar origin for Mg-rich olivine in the Baffin Bay picrite. Albarède and Tamagnan (1988) clearly mentioned that olivine "phenocrysts" in some Réunion picrites are of xenocrystal origin, possibly from genetically unrelated olivine cumulates. Boudier (1991) demonstrated that some olivine "phenocrysts" , especially those deformed, could be morphologically modified xenocrysts derived from mantle peridotites. Ninomiya and Arai (1993) insisted the importance of melt-mantle interaction for the origin of the Oshima-Ōshima picritic basalt. They concluded that some olivine "phenocrysts" are chemically and morphologically modified xenocrysts derived from mantle harzburgite.

In this article we would like to describe various texture of olivine "phenocrysts" in the Oshima-Ōshima picrite basalts in order to give some constraints on their origin(s).

Oshima-Ōshima volcano

Oshima-Ōshima volcano is the most continent-ward one in the arc-trench systems of the Japan island arcs. It is located at the Sea of Japan, ca. 50 km off Oshima Peninsula, Hokkaido, northern Japan. The primary magma of the Oshima-Ōshima volcano is the most enriched in alkalis and other incompatible elements of all arc primary magmas on the present Japan arcs (e.g., Tatsumi et al., 1983: Sakuyama and Nesbitt, 1986).

Geology and petrology of the Oshima-Ōshima volcano were studied by Katsui et al. (1979) and Yamamoto (1984). The whole volcanic activity can be classified into three stages, Higashi-yama, Nishi-yama and Central cone, in an ascending order (Yamamoto, 1984) . Picritic basalt erupted at the latest stage of the Nishi-yama activity.

The lavas and pyroclastics of the Central cone consist of olivine-augite basalt, whereas those of Higashi-yama and Nishi-yama are composed of alkali basalt and calc-alkali andesite which are intimately associated with each other, even within a single cycle of eruption as in the recorded eruption in 1741-1742.

The volcanic rocks in Oshima-Ōshima sometimes contain ultramafic and mafic xenoliths. Most of them show a typical cumulate texture (Yamamoto, 1984). Ultramafic and mafic rocks often make composite xenoliths. Ninomiya and Arai (1992) found harzburgite fragments in gabbroic xenoliths in the Nishi-yama middle lava, calc-alkali andesite.

Oshima-Ōshima picrite

Petrography

Texture is porphyritic to seriate (e.g., Plate V-a). "Phenocrysts" consist of olivine, clinopyroxene and plagioclase. "Phenocrysts", especially of olivine, are not guaranteed to be genuine ones that are of magmatic origin as discussed below. Olivine crystals occupy approximately 20 volume %. Textural characteristics of olivine crystals will be described below in detail. Chromian spinel usually occurs as tiny inclusions within olivine, especially in the marginal part, and rarely as phenocryst. Clinopyroxene phenocryst is usually sector-zoned. The picritic basalt has intergranular texture: the groundmass is composed of olivine, clinopyroxene, plagioclase and magnetite.

Mineral chemistry

Chemical compositions of olivine (Fo component) and chromian spinel (Cr#= Cr/(Cr + Al) atomic ratio) are widely variable (Fig. 1). It is especially noteworthy that Fo of olivine demonstrates a very weak positive correlation with Cr# of spinel (Fig. 1), which may indicate a multi-origin of olivine crystals. Chromian spinel is generally Ti-rich, being concordant with conclusion of Arai (1992a). Clinopyroxene is mostly chromian diopside (Ninomiya, 1992). Phenocryst plagioclase is Ca-rich, around An80 in composition.

Textures of olivine "phenocrysts"

Textural characteristics of olivine "phenocrysts" in the Oshima-Ōshima picrite basalt are shown in Plates I to XIII. They may place some constraints on their origin(s). Euhedral chromian spinel is common in all types of olivine (e.g., Plate III-c), especially in the

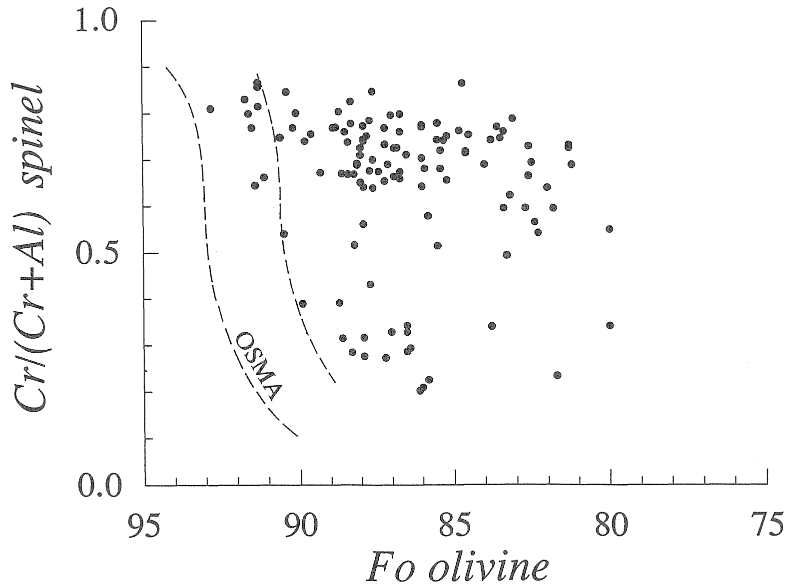

Fig. 1. Relationships between Cr/(Cr + Al) atomic ratio of spinel and Fo content of coexisting olivine in the Oshima-Ōshima picrite. OSMA, olivine-spinel mantle array, which shows the compositional field of mantle peridotites (Arai, 1987). Note the wide scattering of the points.

marginal part (e.g., Plate I-d). It is, however, very small in amount and is often absent in individual grains in thin section.

Olivine with dusty inclusions

Olivine sometimes has dusty inclusions, which are a few microns in diameter (Plate I and II). They are concentrated roughly in the central part. The shape of the dusty part is usually similar to the host olivine crystal (Plate I-a,b) but is sometimes more complex (Plate I-c,d). They are much more sparsely distributed in some cases (Plate II-a). Dusty inclusions usually do not make trails but are evenly distributed.

Constituents of the dusty inclusions have not yet been identified. Relatively large inclusions are, however, observed to consist of cavity and Cr-bearing spinel (Plate II-b,c). The filling of the cavity has not been known.

Inclusion trails in olivine

Inclusion trails are frequently found, cutting through olivine crystals (e.g., Plates I-c, VI-d). Individual inclusions have not yet been identified but may be largely composed of fluid. The possible fluid inclusions are sometimes thickened and have magnesioferrite (Plate III-a,b). As mentioned later fluid inclusion trails are sometimes parallel with phlogopite-rich veinlets in olivine (Plates IV-c; V-b).

Olivine without dusty inclusions or fluid inclusion trails

Olivine rarely contains neither dusty inclusions nor fluid inclusion trails (Plate III-c,d). It is noteworthy that the olivine crystals which are free of dusty inclusions and fluid inclusion trails are nearly euhedral with or without euhedral chromian spinel inclusions (Plate III-c, d).

Deformed olivine

Olivine is frequently deformed (Plates IV-a,b; VI-a,b; XII; XIII-a,b). Deformed olivine is either strongly anhedral (e.g., Plate IV-a,b) or nearly euhedral (e.g., Plate XII-d). Some crystals are so strongly deformed to be elongated and almost poly-grained (Plate IV-a,b). Euhedral crystal form is sometimes developed on individual sub-grains in anhedral and strongly kinked olivine crystal as discussed by Boudier (1991) (Plate XII-c).

Sub-grain boundaries are sometimes decorated with some inclusion trails (Plate XII-a, b). Some sub-grains are preferentially full of dusty inclusions (Plate XII-a,b).

Olivine with phlogopite-rich veinlets

Olivine is sometimes cut by phlogopite-rich veinlets (Plates IV-c,d; V-a,b; XIII-a,b). They are usually straight, almost parallel with cleavage (e.g., Plate IV-c,d), but are sometimes sinuous (e.g., Plate V-a) in thin section. Fluid inclusion trails are common around the vein, almost parallel with and frequently merging in the vein (Plate V-b). Olivine with phlogopite-rich vein is either nearly euhedral or anhedral. The vein in kinked olivine always cuts the kink bands (Plate IV-d).

The boundary between olivine and phlogopite-rich vein is not smooth but rather ragged, possibly indicating corrosion of olivine (Plate V-b). The vein is composed of phlogopite, orthopyroxene and small amount of apatite (Plate V-b). A phlogopite-orthopyroxene veinlet is observed to be changed to an orthopyroxene veinlet (Plate XIII-a,b, c).

Olivine with spinel lamellae

Olivine with lamellae of chromian spinel are rarely found in the Oshima-Ōshima picrite basalt; we have found only three grains (Plates V-c,d; VI). One olivine grain with chromian spinel lamellae is euhedral (Plate V-c,d), another is kinked (Plate VI-a,b) and has fluid inclusion trails (Plate VI-c,d). Chromian spinel lamellae are not evenly distributed but relatively concentrated in certain part(s) of olivine crystal (Plates V-d; VI-c). As reported by Arai (1978) the orientation of lamellar spinel may be controlled by crystallographic plane(s) of olivine (Plate VI-b).

Dunitic patches

Olivine is sometimes aggregated to form dunitic patches, usually less than 5 mm across (Plate VII-a). Olivine, less than 1 mm across, is nearly euhedral to anhedral and usually has dusty inclusions in the center (Plate VII-a). It is noteworthy that olivine in dunitic patches is not kinked.

Corroded olivine

Olivine is commonly suffered from apparent corrosion to various extent (Plate VII-b). Strongly embayed part of olivine is sometimes filled with phlogopite and orthopyroxene (Plate VII-b).

Orthopyroxene associated with olivine

In the Oshima-Ōshima picrite basalt orthopyroxene is found only associated olivine. Orthopyroxene is frequently grown in small vugs adjacent to olivine, usually overgrown on olivine (Plate VII-c,d). Orthopyroxene is usually prismatic (Plate VII-d) and is pleochroic, indicating a relatively Fe-rich character. Orthopyroxene is also commonly found in phlogopite-rich veinlet cutting olivine as mentioned above.

Polymineralic inclusions in olivine

Olivine frequently contain spinel-fassaite-glass inclusions, which are larger than other types of inclusions (Plates VIII-a; IX-a). Olivine is subhedral and free from duty inclusions and kink bands. They are circular to elliptic and 0.2 to 0.3 mm across (long). Minerals in the inclusions are frequently euhedral (Plates VIII-d; IX-c,d). Fassaite is sometimes stout, prismatic (Plate VIII-c,d) and is sometimes fine, saw-toothed on olivine wall (Plate IX-b,c). Spinel is mostly green Al-rich one but sometimes has a Cr-rich core with a sharp boundary (Plate VIII-d). Glass is silica-rich, containing about 60 wt % of SiO_2.

Phlogopite-rich inclusions are also found (Plate X-a,b). The constituent minerals are the same as those in the phlogopite-rich veinlets described above, i.e., phlogopite and orthopyroxene. Orthopyroxene is long prismatic and is pleochroic. Olivine is subhedral and free from kind bands (Plate X-a).

Al-rich green spinel is also found as a discrete inclusion in olivine (Plate XIII-d). Note that Al-rich green spinel never coexists with Cr-rich spinel as a discrete inclusion in the same olivine crystal.

Spinel-rich aggregates associated with olivine

Cr-bearing spinel is sometimes concentrated within (or near) olivine grains (Plates X-c,d; XI). Olivine associated with spinel concentration is relatively coarse, about 4 mm across, and subhedral. Dusty inclusions are sometimes found but almost free from kink bands (Plate X-c). Spinel is almost opaque and euhedral, and is associated with phlogopite (Plates X-c; XI). It is noteworthy that the spinel-rich aggregate is not completely enclosed by olivine but is more or less open to the groundmass (Plates X-c,d; XI).

Discussion

Textural characteristics of olivine crystals in the Oshima-Ōshima picrite basalt may indicate that some of them are of xenocrystal origin. Euhedral form of some crystals does not necessarily mean a magmatic origin, that is, a true phenocryst, although many authors have considered so. As discussed by Boudier (1991) euhedral olivine can be formed during partial fusion or interaction with melt. In the Oshima-Ōshima picrite basalt, partial dissolution of olivine, especially of kinked olivine, makes euhedral forms of olivine (Plates, XII-c; XIII-c).

Kink bands can not be formed in phenocrysts, and their frequent presence is strong evidence for their xenocrystal origin. Their source could be any kinds of peridotites, cumulates or mantle peridotites.

Fluid inclusion trails often cut through olivine grains and may be healed fractures once filled with fluids (or melts). They have not been formed after the rock was consolidated because they are not continuous through the groundmass. The olivine crystals with inclusion trails are, therefore, not phenocrysts. Phlogopite-rich veinlets also cut through only olivine crystals and, therefore, they have not been formed after the rock was formed, either. The olivine crystals cut by the veinlets are not phenocrysts, either.

Dusty inclusions and *lamellae of chromian spinel* are exsolution products from olivine, although mineralogical analyses have not been done in detail. Their presence may be consistent with a xenocrystal origin for some olivine crystals. Lamellar spinel in olivine is relatively common in peridotites (e.g., Arai, 1978). Dusty olivine is also relatively common in peridotites swept by hydrothermal fluids such as the Iwanai-dake peridotites (H. Hirai, personal communication, 1986). It is possible that those exsolution products may have partly disappeared (re-solved into olivine) due to heating during and after interaction with melt. It is also possible that the only dusty part of olivine is xenocrystal and the enclosing clear part is magmatic.

Spinel-rich aggregates associated with olivine may be interaction products between melt and chromian spinel in the peridotite invaded by the melt. In lherzolite xenoliths chromian spinel is sometimes reacted with alkali basalt to be an aggregate of fine euhedral spinel, which is very similar in appearance to the spinel-rich aggregate in the Oshima-Ōshima picrite basalt.

Chromian spinel inclusions are characteristically more abundant in the marginal part than in central part of olivine. It is possible that the olivine core almost free of chromian spinel inclusions is xenocrystal origin from peridotites and the olivine rim with chromian spinel is magmatic.

As discussed above some crystals of olivine are of xenocrystal origin. Their source could be peridotite(s) of any kind, cumulate or mantle peridotite. We think mantle harzburgite is most probable for the source of those olivine crystals. Ninomiya and Arai (1992) found a harzburgite fragment in a gabbroic xenolith from Nishi-yama middle lava, and concluded that relatively refractory harzburgite (olivine of Fo_{91}, spinel with Cr#=0.5) is present in the upper mantle beneath Oshima-Ōshima volcano. Orthopyroxene in harzburgite could be easily extinguished by the interaction of magma, especially of alkaline magma such as the primary magma of Oshima-Ōshima (Tatsumi et al., 1983; Sakuyama and Nesbitt, 1986). Large amounts of olivine xenocrysts (or picritic mixture), therefore, could be formed by the interaction of harzburgite and alkali basaltic melt at the uppermost mantle conditions (e.g., Arai, 1992b). Some textural characteristics of olivine in the mantle harzburgite have been inherited to the olivine crystals ("phenocrysts") in the Oshima-Ōshima picrite basalt.

Phlogopite-rich veinlets and fluid inclusion trails may indicate that the harzburgite interacted with alkali basalt melt had been metasomatized. Magnesioferrite frequently found in fluid inclusions is also found in peridotites metasomatized by aqueous fluids (Nagata, 1982). The metasomatizing agent may be alkali-rich aqueous fluid(s) released from the primitive alkali basalt melt as a precursor. A possible model for the origin of the Oshima-Ōshima picritic magma is shown in Fig. 2.

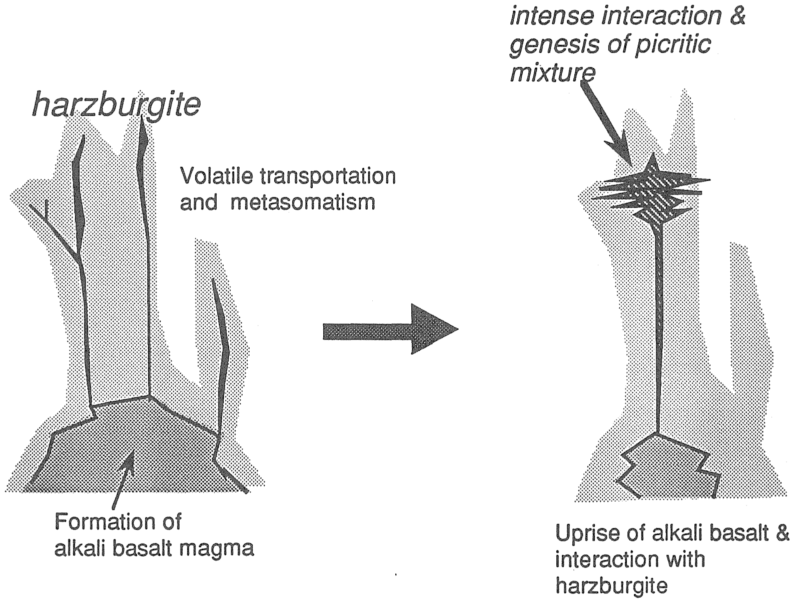

Fig. 2. Cartoon showing a genetical scenario of the picritic melt of Ohsima-Ōshima.

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Captions for Plates

Plates Photomicrographs of olivine "phenocrysts" with various textural characteristics in the Oshima -Ōshima picrite basalt, Hokkaido, Japan. Plane-polarized light if not otherwise mentioned. Scale bar is 0.5 mm if not otherwise mentioned.

Plate I Dusty inclusions in olivine.
(a) Olivine with dusty inclusions in the central part. Olivine, subhedral, slightly corroded and free of kink bands, also has a phlogopite-rich veinlet and fluid inclusion trails in addition to the dusty inclusions.
(b) Olivine with dusty inclusions in the central part. Olivine, subhedral and free of kink bands. The dusty part of olivine seems to be partly similar to the euhedral shape. Note that crisscrossing inclusion trails can be observed in the dusty part.
(c) Olivine with dusty inclusions. The dusty parts are relatively irregular in shape. A trail of fluid inclusions is present.
(d) Nearly euhedral olivine with dusty inclusions. The dusty part is rather irregular in shape but is partly parallel with the margin of the olivine crystal.

Plate II
(a) Olivine with sparse dusty inclusions, which are linearly arranged in the central part.
(b) A close-up of olivine with dusty inclusions. Fine grain of chromian spinel is precipitated within individual inclusions. Scale bar is 0.05 mm.
(c) Same as (b) above, by reflected light. Bright spots (arrow) denote chromian spinel in relatively large inclusions. Scale bar is 0.05 mm.

Plate III
(a) Magnesioferrite-bearing fluid inclusions in trails. Scale bar is 0.05 mm. Dusty inclusions are also present (lower right).
(b) Reflected light. Bright spots show magnesioferrite.
(c) Nearly euhedral olivine with euhedral chromian spinel inclusions (dark spots). Olivine is free from kink bands and dusty inclusions.
(d) Nearly euhedral olivine almost free of kink bands and any inclusions.

Plate IV
(a) Strongly deformed anhedral olivine free of dusty inclusions and fluid inclusion trails.
(b) Crossed-polarized light. Note the strong deformation.
(c) Olivine cut by a phlogopite-rich veinlet. Olivine is nearly euhedral, although partly corroded, and has kink bands and dusty inclusions. A rectangle shows the scope of (b) of Plate V below.
(d) Crossed-polarized light. Note the vein cuts kink bands at a high angle.

Plate V
(a) Olivine cut by a sinuous phlogopite-rich veinlet. Olivine is nearly euhedral and free of kink bands. Dusty inclusions are concentrated in the central part, which is cut by the veinlet.
(b) A close-up of a phlogopite-rich vein of (c) of Plate IV. The vein is composed of phlogopite (phl), orthopyroxene (opx) and apatite (ap). The olivine wall is rather ragged, possibly indicating corrosion. Note fluid inclusion trails almost parallel with the veinlet. Dusty inclusions are present in the lower right. Scale bar is 0.05 mm.
(c) Euhedral olivine with chromian spinel lamellae. Olivine is free from kink bands, dusty inclusions and fluid inclusion trails. Note fine chromian spinel inclusion trail parallel to the olivine rim. See below for the details. A rectangle shows the scope of (d).
(d) A close-up of (c). Note thin lamellae of chromian spinel. A trail of chromian spinel inclusions (dark dots) parallel to the olivine rim can be seen. Scale bar is 0.05 mm.

Plate VI Lamellae of chromian spinel
(a) Olivine full of chromian spinel lamellae. Fluid inclusion trails are also present. A rectangle for the scope of (d).
(b) Crossed-polarized light. Note the kink bands almost parallel with the lamellar spinel.
(c) Olivine with chromian spinel lamellae in the central part. Olivine is free from kink bands and dusty

inclusions.
(d) A close-up of (a). Note a trail of fluid inclusions oblique to the lamellar spinel. Scale bar is 0.05 mm.

Plate VII
(a) Dunitic patch. Olivine has dusty inclusions in the central part and is not kinked.
(b) Subhedral olivine strongly corroded. Phlogopite and orthopyroxene are found only in the embayed part of olivine.
(c) Olivine overgrown by orthopyroxene (opx) into a vug. Olivine has dusty inclusions.
(d) Orthopyroxene (opx) associated with olivine. Note that orthopryoxene is only present in vugs adjacent to olivine. Dark color of orthopyroxene indicates a relatively Fe-rich character.

Plate VIII Spinel-fassaite-glass inclusions in olivine
(a) Spinel-fassite-glass inclusions in nearly euhedral olivine free of kink bands and dusty inclusions. A rectangle for the scope of (c) and (d).
(b) Reflected light. Two bright spots indicate chromian spinel (see (c) and (d) below).
(c) A close-up of the inclusion of (a). Scale bar is 0.05 mm.
(d) Reflected light. Fassaite (cpx) is stout euhedral. Green spinel (G-sp) is also euhedral and sometimes has a chromian spinel core (Cr-sp) with a sharp boundary. Interstitial glass (gl) is present.

Plate IX Spinel-fassaite-glass inclusion in olivine
(a) Olivine with a polymineralic inclusion (within a rectangle). Olivine is free from kink bands and dusty inclusions.
(b) A close-up of the inclusion of (a), which consists of fassaite (cpx) green spinel (G-sp) and interstitial glass (gl). Scale bar is 0.05 mm.
(c) Reflected light. Note the small euhedral fassaite crystals on olivine wall. Green spinel does not appear on the surface.

Plate X
(a) Nearly euhedral olivine with two phlogopite-orthopyroxene inclusions. Olivine is free from kink bands. A rectangle for the scope of (b).
(b) A close-up of the inclusion. Prisms with high relief and well-cleaved laths denote orthopyroxene and phlogopite, respectively. Scale bar is 0.05 mm.
(c) Spinel concentration associated with olivine (within the frame). Olivine has dusty inclusions and free from kink bands.
(d) A close-up of (c). Chromian spinel (dark spots) is associated with phlogopite.

Plate XI
(a) Spinel concentration associated with olivine, which is anhedral and free from kink bands. A rectangle for the scope of (b).
(b) A close-up of (a). Chromian spinel (dark spots) is associated with phlogopite.
(c) Reflected light. Note that the spinel concentration is not totally enclosed by olivine but open to the groundmass.

Plate XII
(a) Olivine from a dunitic patch. Olivine is strongly deformed and some sub-grains are preferentially enriched with dusty inclusions. See (b).
(b) Crossed-polarized light. Note the sub-grain boundaries are decorated by inclusion trails.
(c) Strongly deformed anhedral olivine. Sub-grain boundaries are selectively corroded and the euhedral shape of olivine is partly developed on individual sub-grains. Crossed-polarized light.
(d) Subhedral kinked olivine with chromian spinel inclusions. Crossed-polarized light.

Plate XIII
(a) Anhedral strongly kinked olivine with a phlogopite-rich veinlet. Fluid inclusions are abundant.
(b) Crossed-polarized light. The phlogopite-rich veinlet cuts the kink bands at a high angle (almost perpendicularly).
(c) The same olivine grain as (a) but cut at more marginal part. Note that an orthopyroxene-rich vein

(arrow) is continuous to the phlogopite-rich veinlet of (a).
(d) Subhedral olivine with green spinel inclusions (arrow). Kink bands and dusty inclusions are absent. Note that chromian spinel never coexists with green spinel as inclusions within the same olivine grain.
Captions for Figures

Plate I

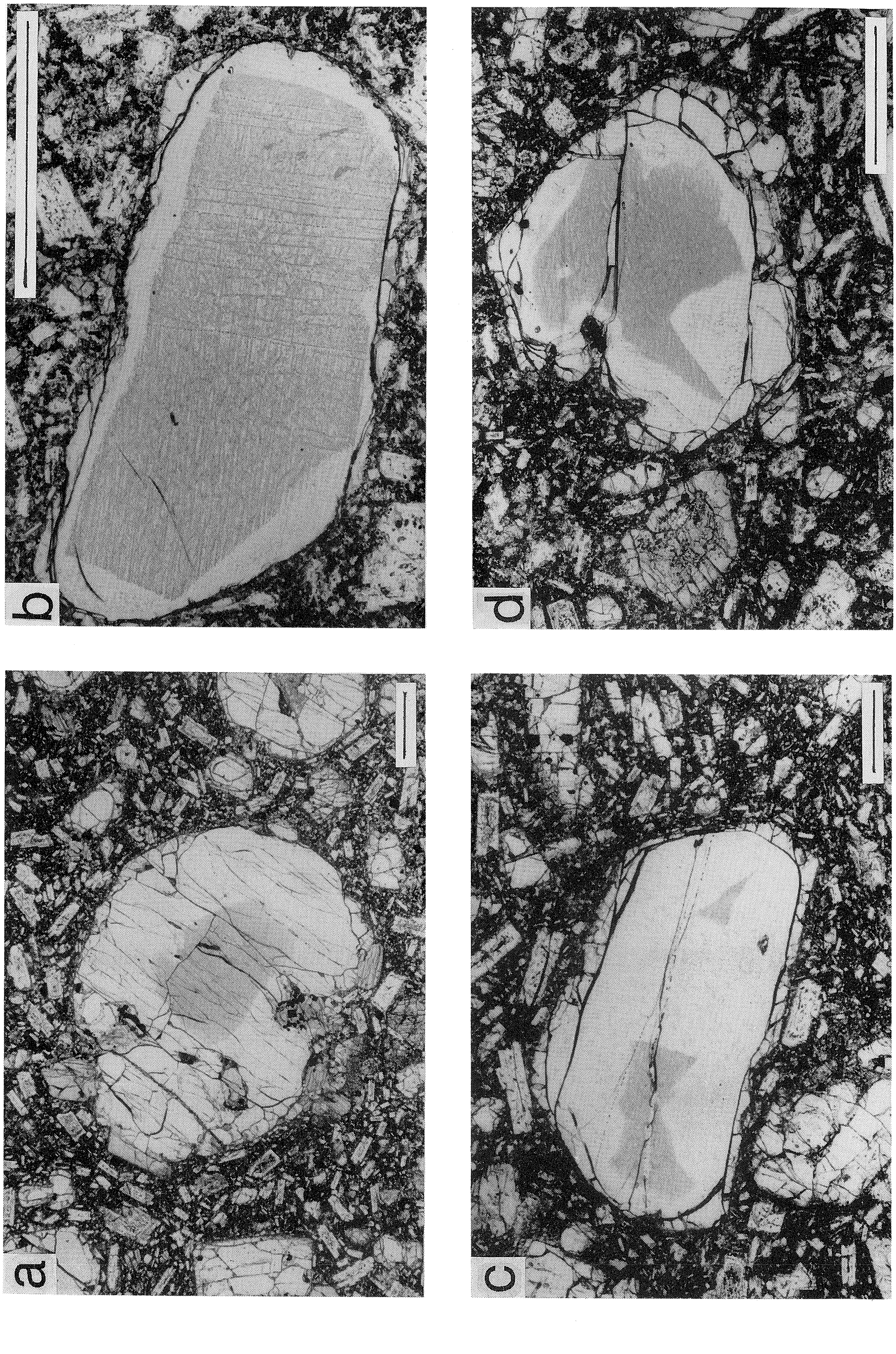


Plate II

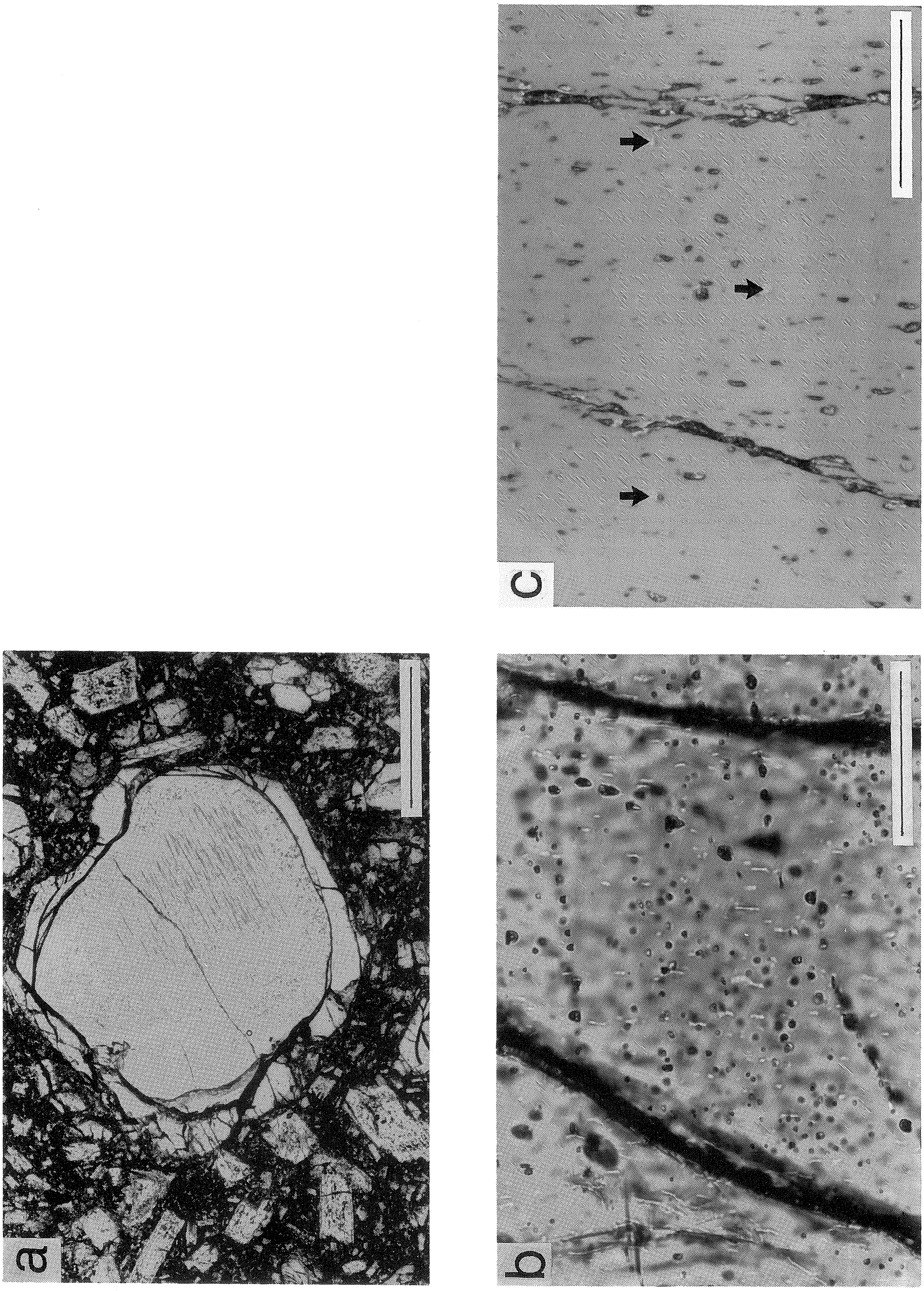


Plate III

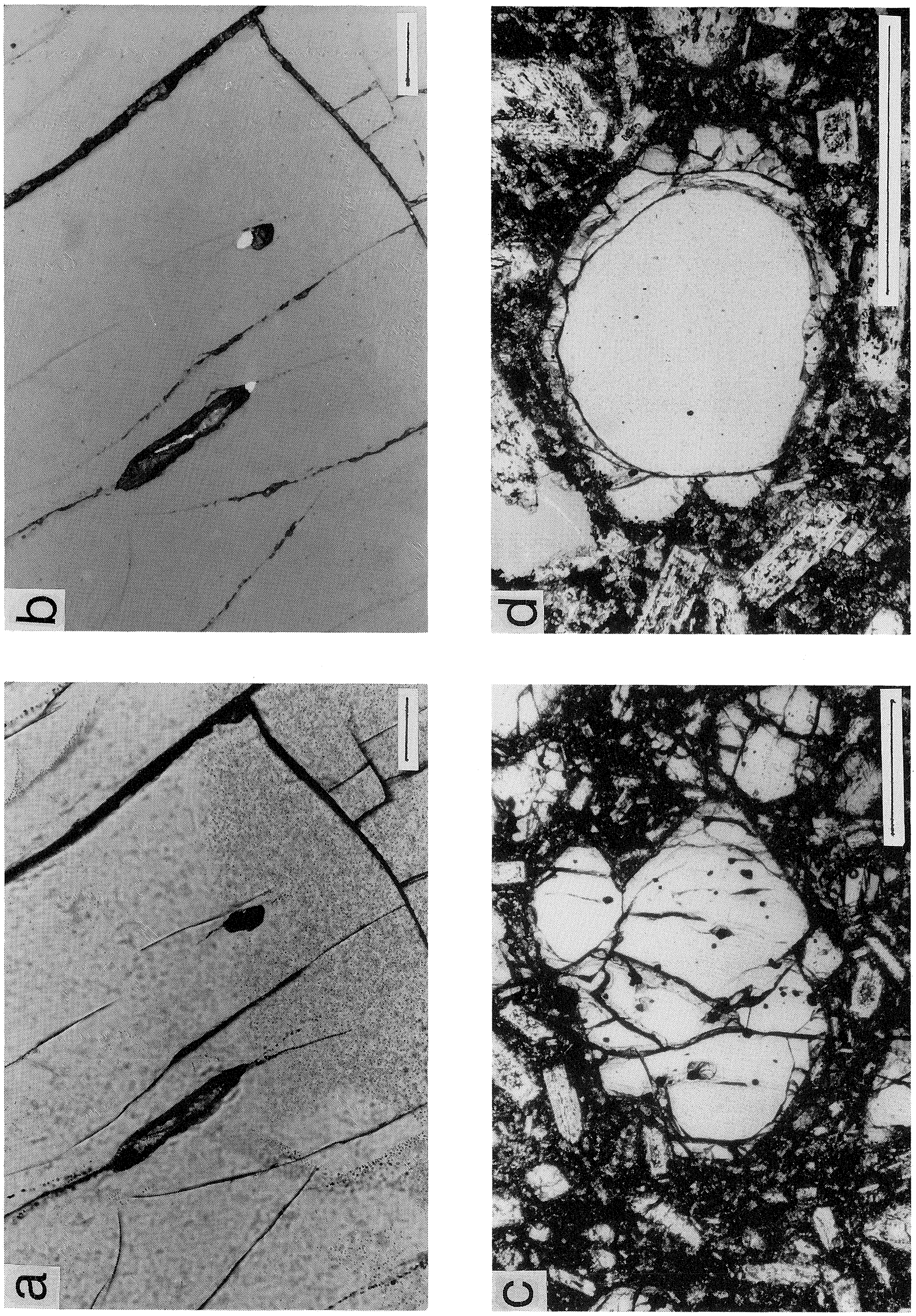
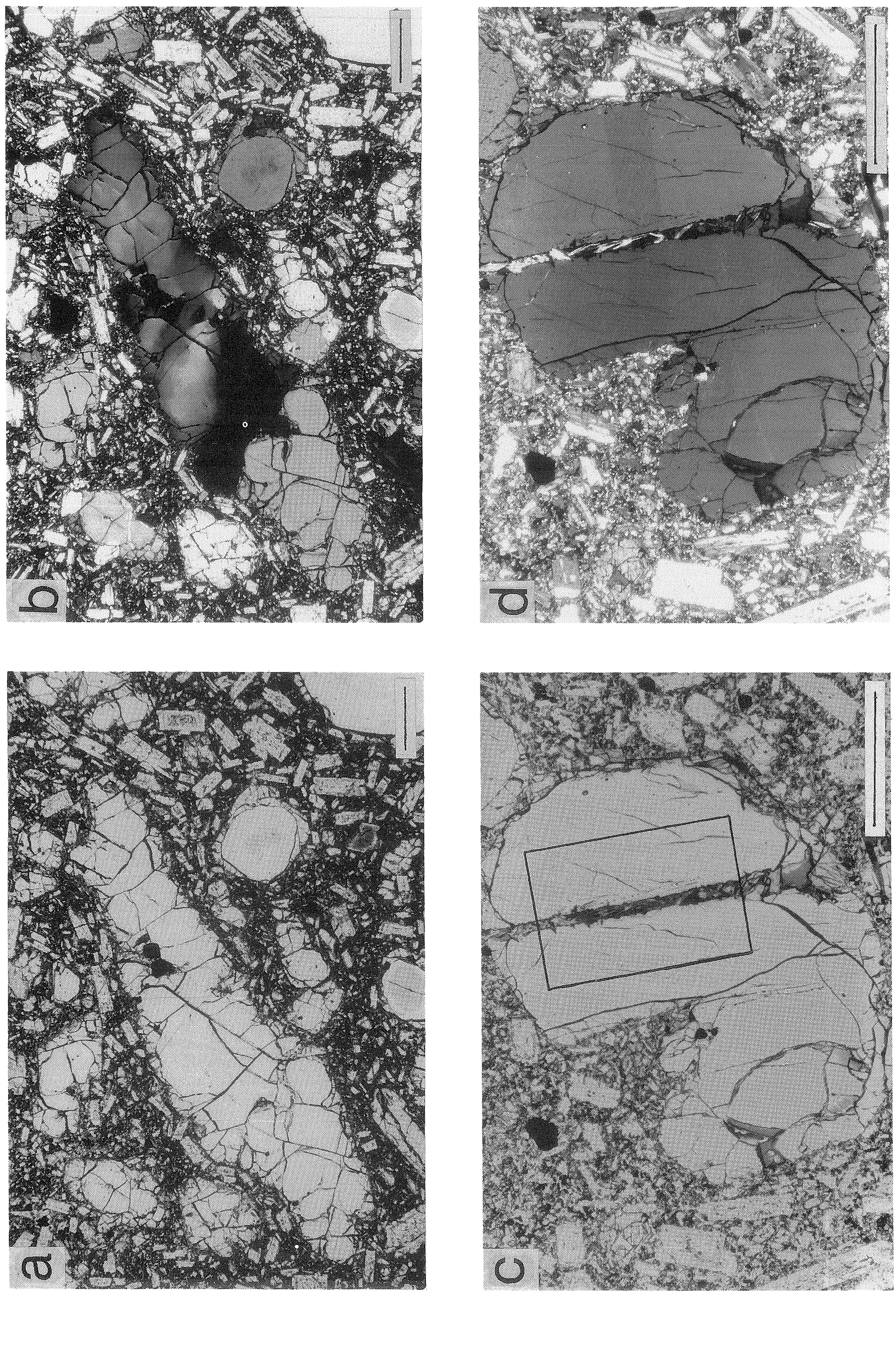


Plate IV



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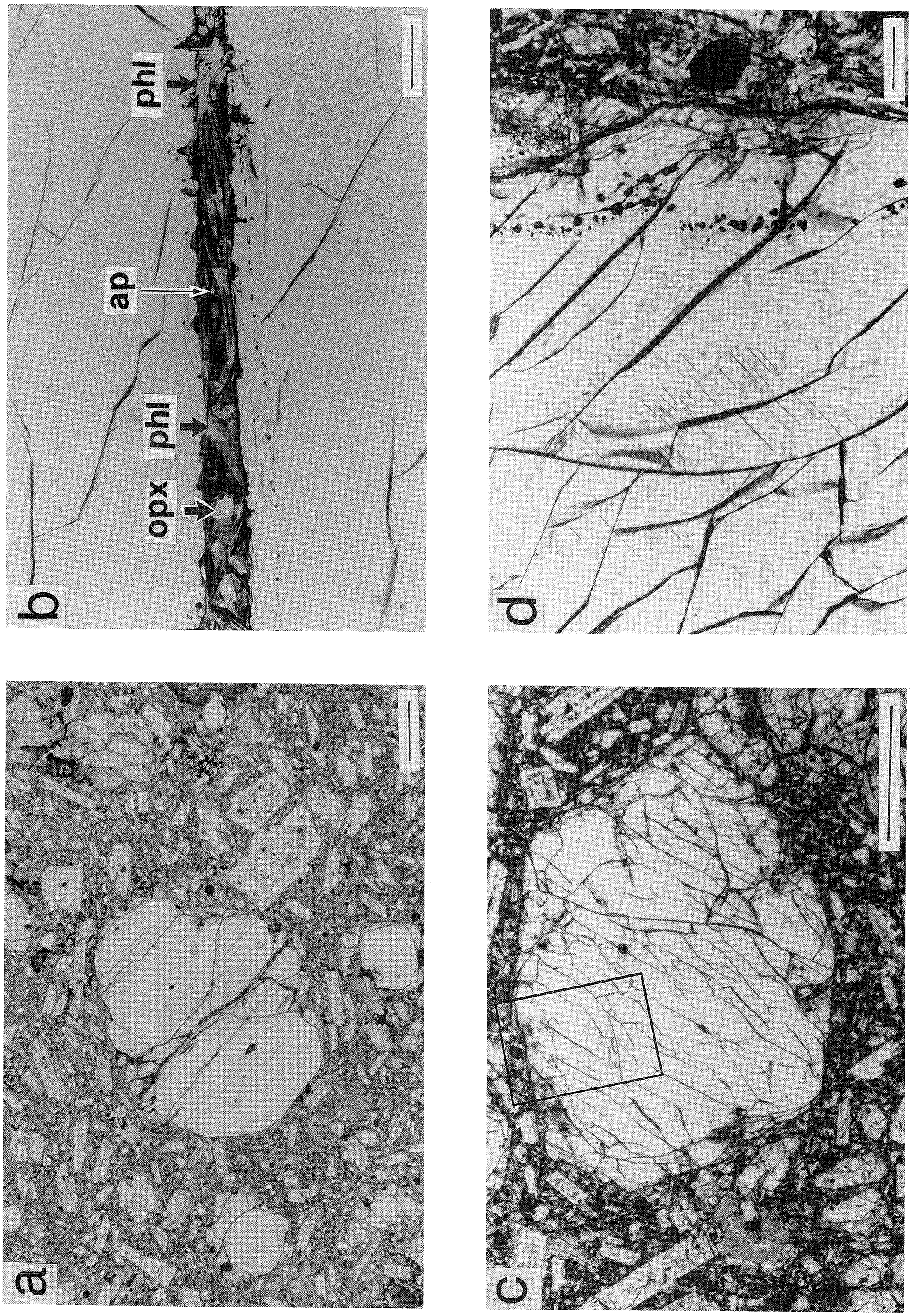

Plate VI

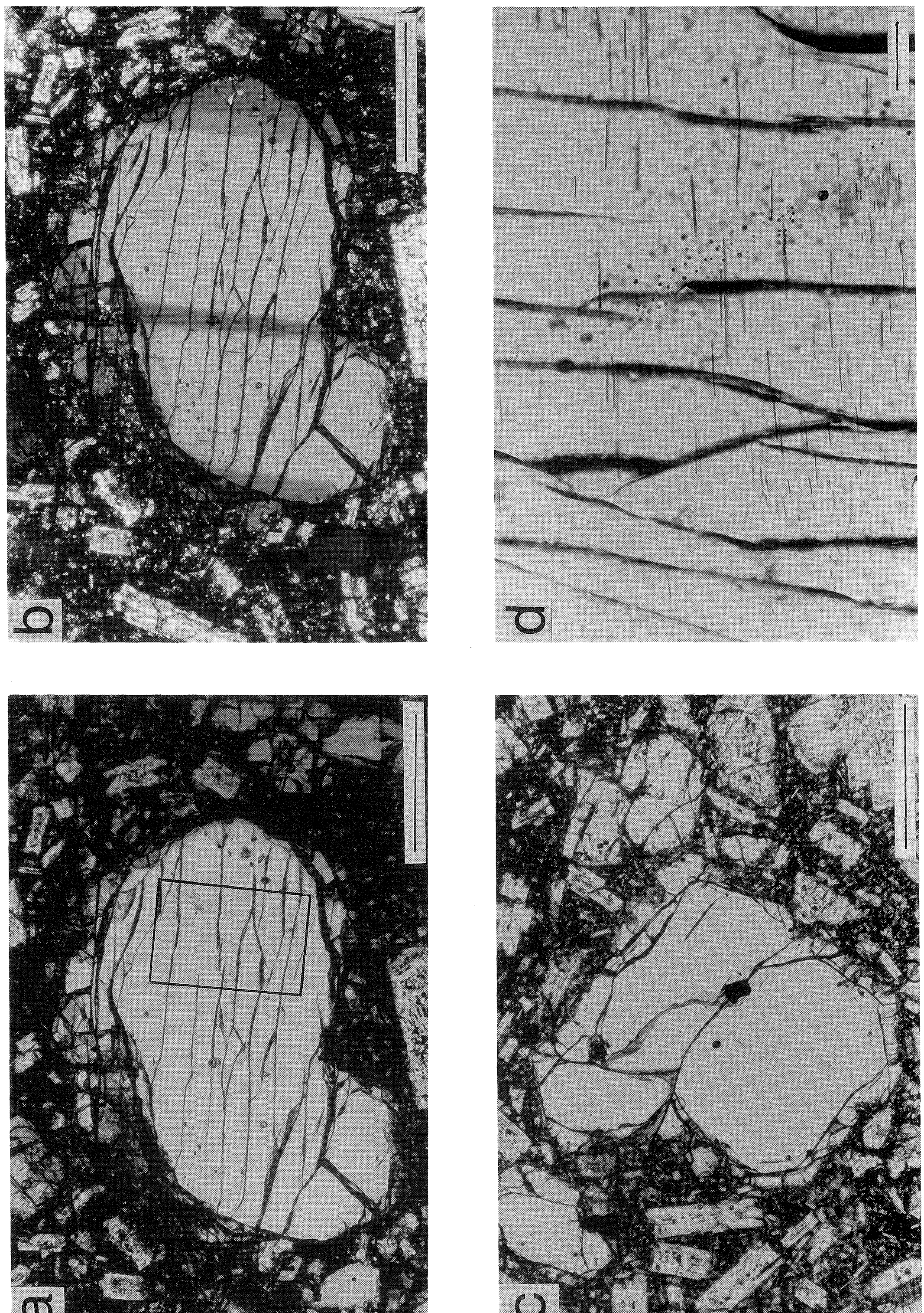

Plate VII

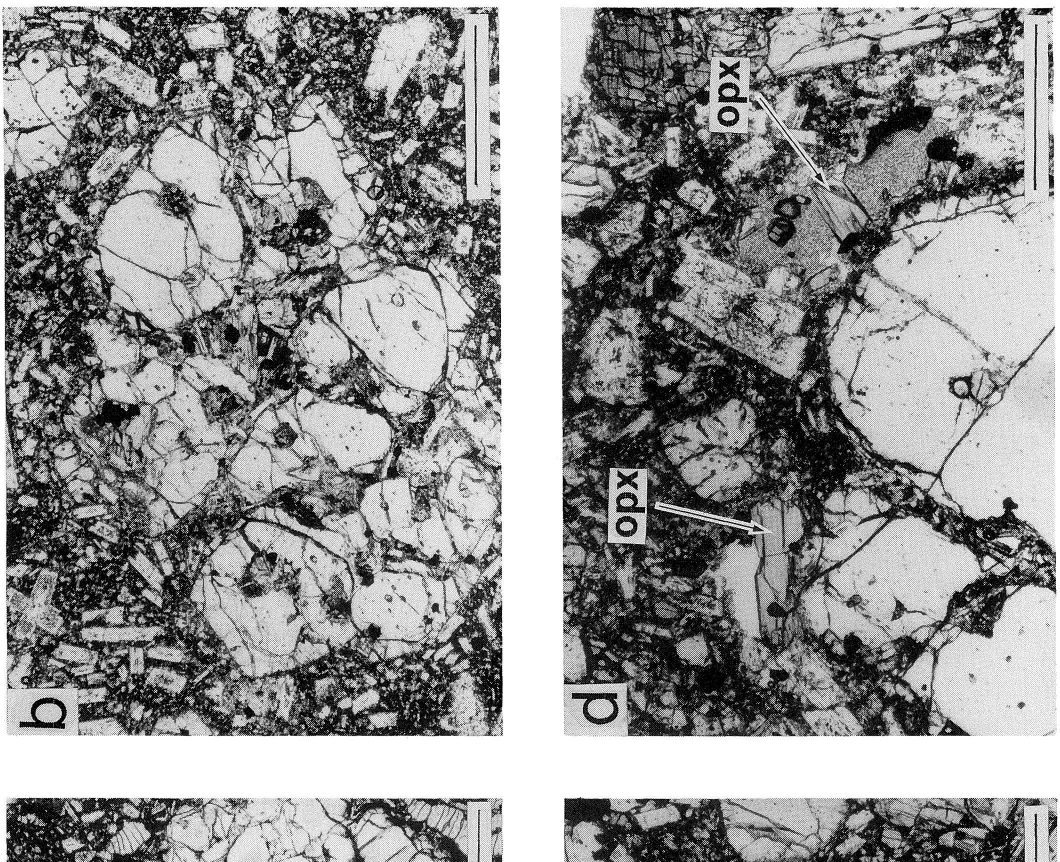

Plate VIII

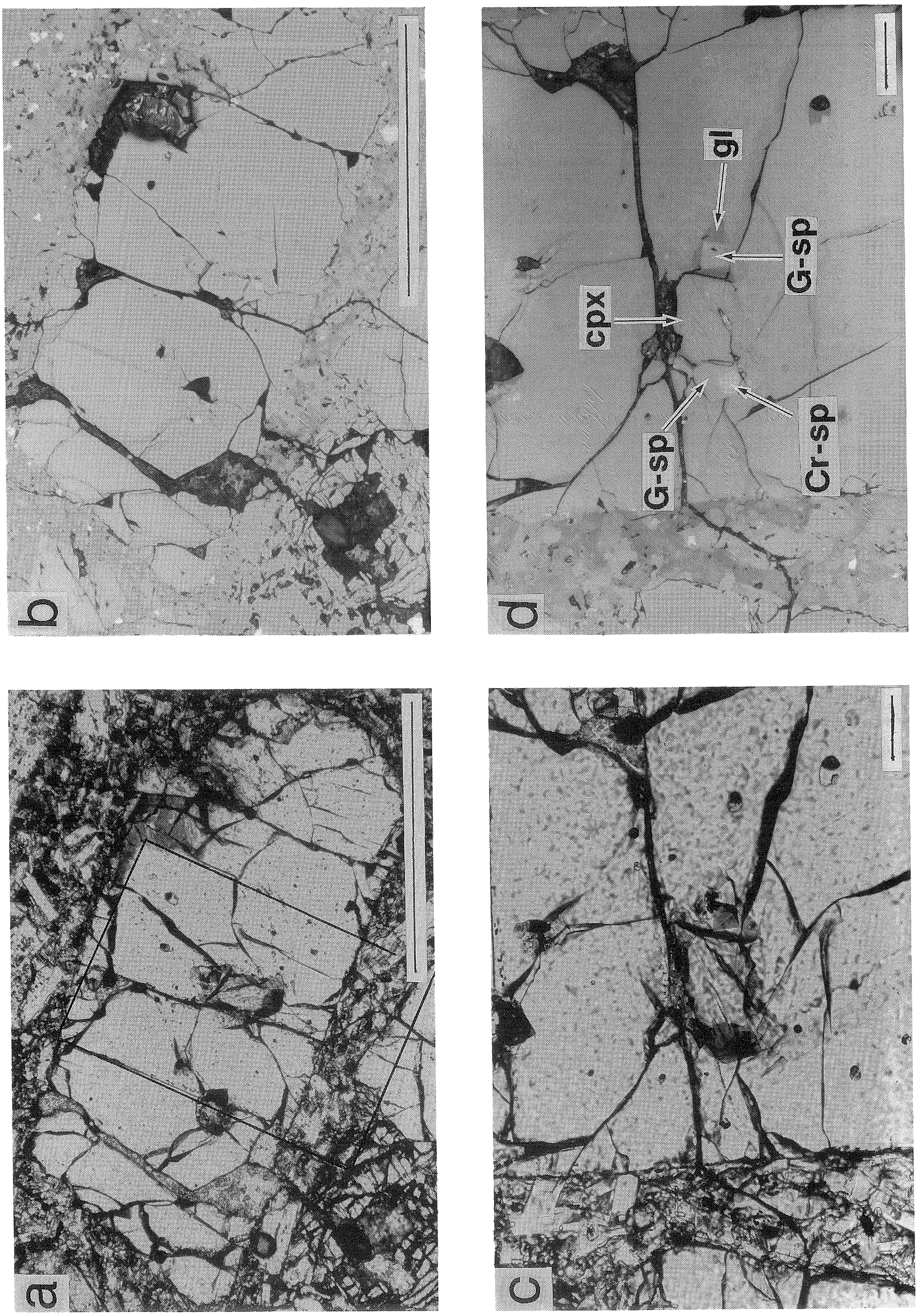

Plate IX

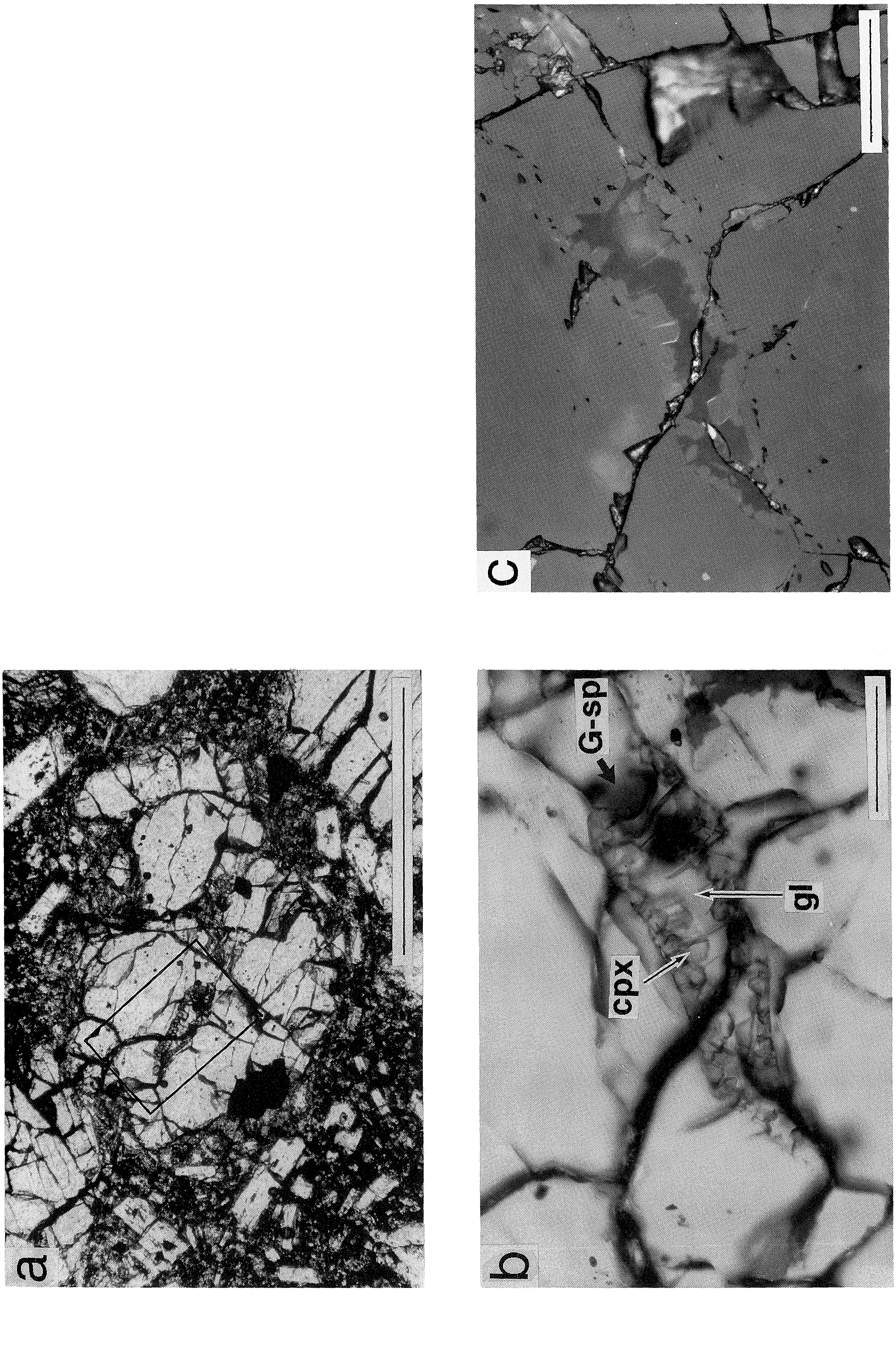

Plate X

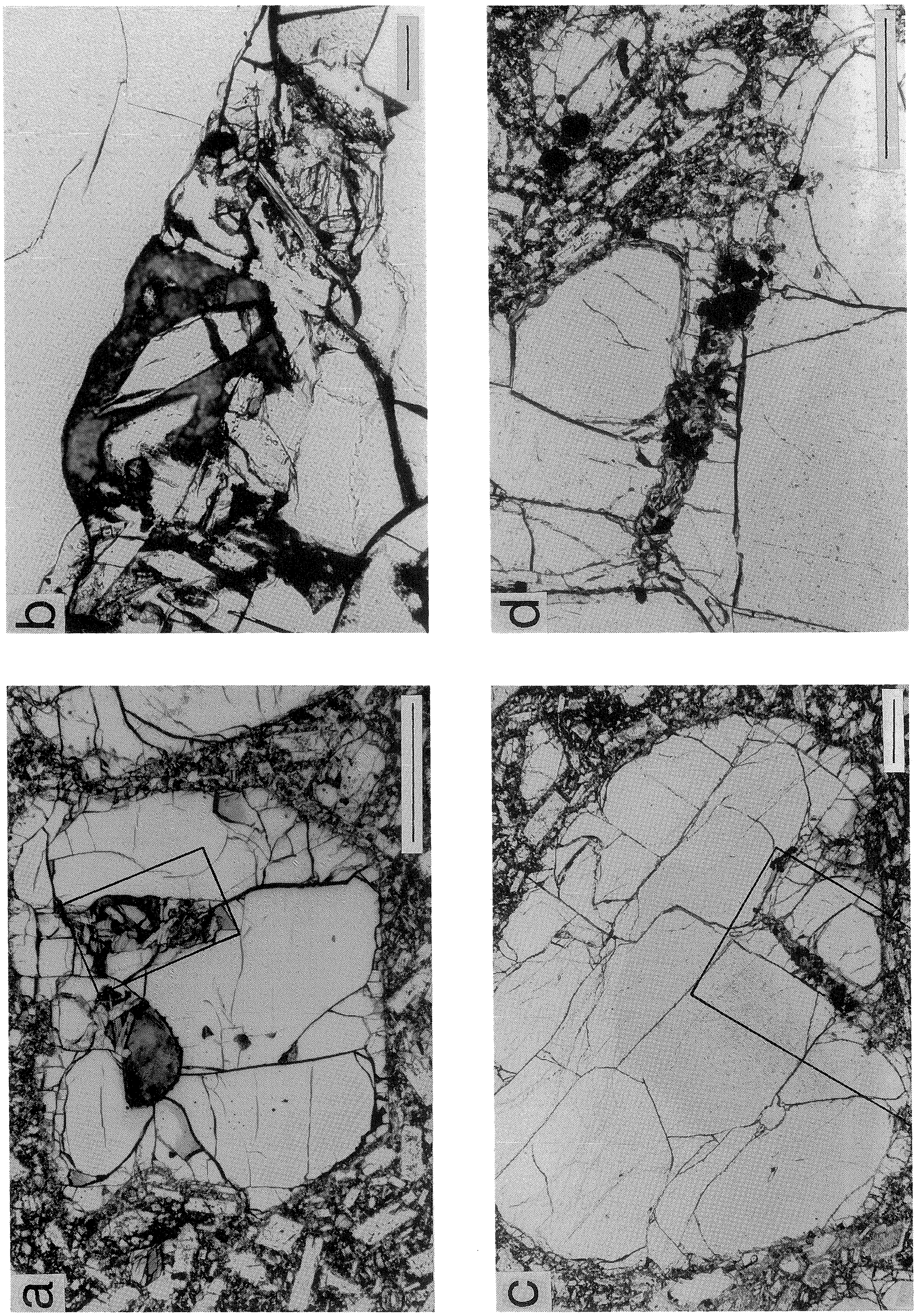

Plate XI

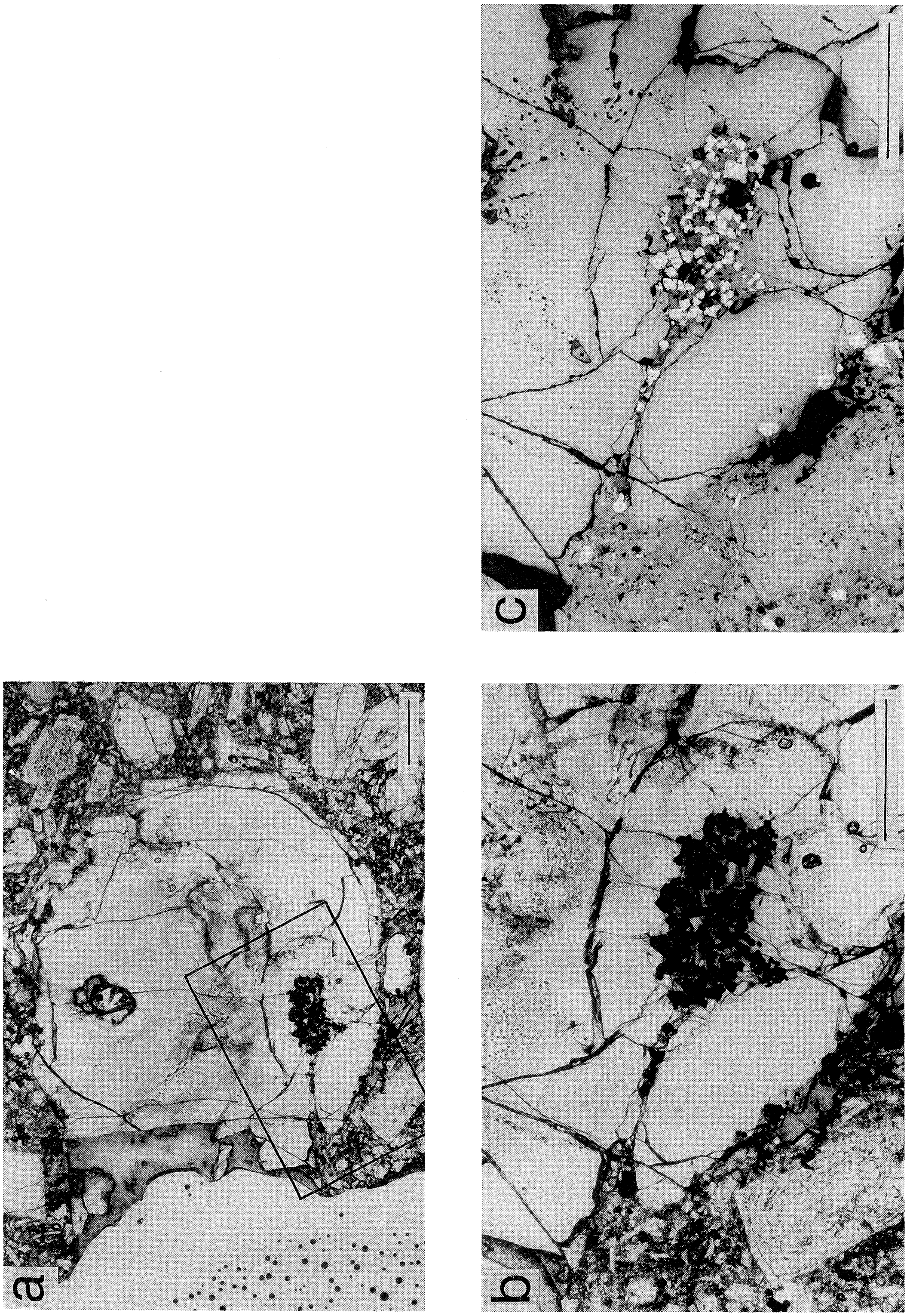

Plate XII

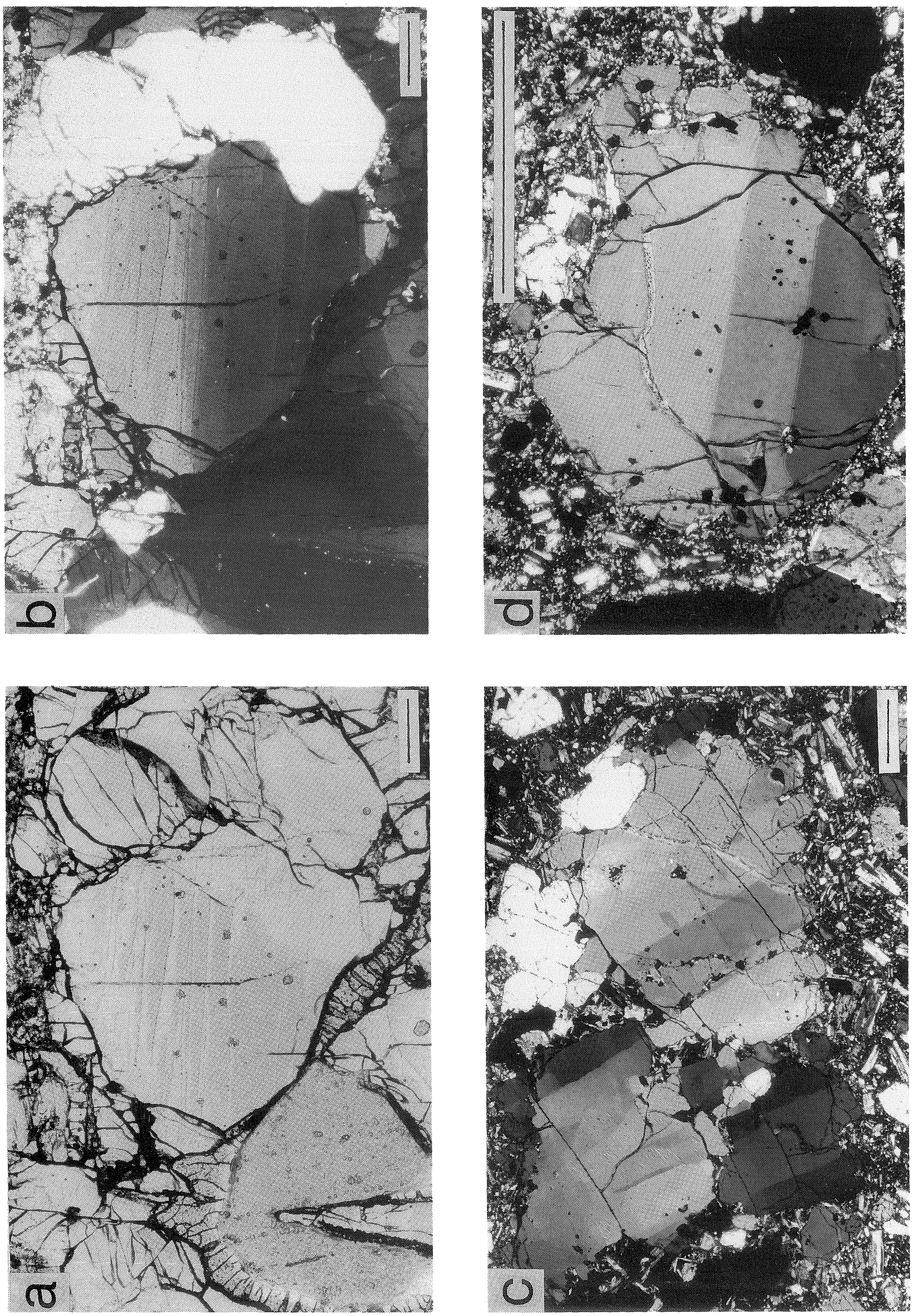

Plate XIII