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Inverted Clinobronzite in Eastern Connecticut Diabase

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Abstract

The morphology of bronzite phenocrysts ($Ca_5Mg_{75}Fe_{20}$) in the chilled margins of a diabase dike in eastern Connecticut indicates that this mineral crystallized with a monoclinic form and later inverted to orthorhombic pyroxene. Oscillatory zoning, sector zoning, and very faint basal exsolution lamellae in the bronzite of the coarser-grained parts of this dike also reveal the previous $2/m$ symmetry of this pyroxene. The (100) lamellae, so typical of bronzites, are preferentially developed in the (100) and ($\bar{1}$00) sectors of the Connecticut bronzite. Their development may be related to the monoclinic → orthorhombic inversion. Crystallization of clinobronzite in this diabase suggests that bronzite in many other igneous bodies may have crystallized with monoclinic form.

Introduction

A narrow discontinuous quartz-diabase dike extends through eastern Connecticut in a northeasterly direction from New Haven to the Massachusetts border. Along most of its length it is less than 200 feet wide and is commonly segmented into a series of smaller *en enchelon* dikes. Bronzite, ranging in composition from $Ca_5Mg_{78}Fe_{17}$ to $Ca_5Mg_{72}Fe_{23}$, occurs as euhedral, millimeter-sized phenocrysts in the chilled margins and as larger but more irregular crystals in the interior of the dike. Augite and plagioclase phenocrysts and glomeroporphyritic aggregates are also present in the chilled margins. Pigeonite is absent from the chilled margins but is intimately associated with the bronzite and augite in the coarser-grained diabase. An excellent exposure of this dike occurs in the deep road-cut at the Ponset exit from Route 9, 6.5 miles south of Middletown, Connecticut. The internal optical features and the morphology of the bronzite from this locality indicate that this mineral crystallized with monoclinic symmetry and subsequently inverted to an orthorhombic form.

Morphology

The morphology of the euhedral bronzite phenocrysts provides the most direct evidence of their previous monoclinic history. Their habit is prismatic with the forms {100} and {010} equally prominent and the prism {110} developed to a lesser extent (Figs. 1 and 2). These indices are assigned on the assumption that the axial ratios of monoclinic bronzite are similar to clinopyroxenes in general. The crystals are doubly terminated by a form consisting of a set of four faces which U-stage measurements indicate are inclined to (010) and (100) at 148° and 99° respectively. Within the accuracy of the measurements these faces could be indexed as belonging to either of the prisms {011} or {$\bar{1}$11} since the external morphology by itself favors neither alternative. However, in (010) sections through these crystals, diffuse birefringent lamellae (<7 μm thick) lie perpendicular to (010) and parallel to the trace of the terminal faces (Fig. 3). If these features are considered to be approximately parallel to (001) in the original monoclinic bronzite, an assumption which would not be unreasonable if they are exsolution lamellae, the correct indexing of the termination form would be {011} and the monoclinic β angle would have been approximately 107°. It is interesting to note that the morphology and interfacial angles of these bronzite phenocrysts are similar to the monoclinic crystals of synthetic iron-free pigeonite recently described by Yang and Foster (1972). The correspondence is best seen if Yang and Foster's crystals are reindexed using a doubled c-dimension. Thus, instead of a:b:c being 0.905:1.0:0.313, it would be 0.905:1.0:0.626, which is closer to the accepted morphological axial ratios of clinopyroxenes.

Internal Features

Faint oscillatory zoning and sectoral features can be recognized in bronzite crystals from both the margin and interior of the dike. The symmetry of the three-dimensional distribution of the zoning and sector boundaries (Figs. 2 and 3) is $2/m$ and identical to the symmetry of the external morphology of the phenocrysts. Consequently, throughout their growth the bronzite crystals in this dike must have been monoclinic.

The optics of the bronzite crystals are complicated by the presence, notably in (100) and ($\bar{1}$00) sectors, of thin (<20 μm) twin-like lamellae parallel to (100) which are only visible (Fig. 3) under crossed nicols in sections close to (010) near extinction. There is no apparent difference in the refractive indices or birefringence of adjacent lamellae, nor was the electron probe able to detect any compositional differences. On the basis of their optic orientation the lamellae can be divided into two distinct sets. Both share α which coincides with crystallographic b, but their γ directions are symmetrically inclined on either side of [001] at between 5° and 7°. Although lamellae are absent in certain sectors, their optic orientation throughout the crystal coincides with one or the other set. Indeed, in some crystals even the supposedly symmetrically equivalent sectors have different extinction positions corresponding to the two possible optic orientations.

Scholtz (1936) described identical (100) lamellae in the orthopyroxenes of the Insizwa complex of South Africa which he considered to be the result of twinning. Hess (1960), who disagreed with Scholtz's explanation, preferred to interpret similar optical lamellae in Stillwater orthopyroxenes as the result of strain in the vicinity of clinopyroxene exsolution lamellae. However, neither explanation is tenable for the Ponset bronzites. Single-crystal X-ray photographs and electron transmission and diffraction studies reveal no strain or twinning of the orthopyroxene lattice. Nor is there any evidence of exsolution of a calcium-rich clinopyroxene in the electron transmission pictures or in precession photographs taken with exposures of several days. However, in precession photographs exposed for a week, several very faint, diffuse reflections were detected which violate the b glide of the orthopyroxenes. These may result from a small amount of exsolved augite, but we were unable to collect sufficient data to make a positive identification. In view of the very prominent nature of the (100) lamellae, it appears unlikely that these faint reflections are a direct manifestation of the structure that causes the lamellae, although they may be related. These reflections more likely come from the very faint lamellae seen in some crystals parallel to (001) of the original monoclinic bronzite.

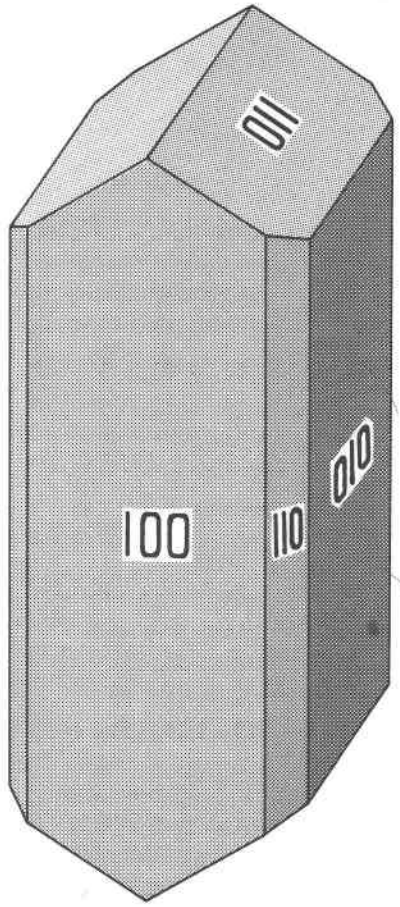

FIG. 1. Clinographic projection showing typical morphology of clinobronzite crystals.

The origin of the lamellae remains in doubt, but there are several features exhibited by the Ponset bronzites which do give hints as to their mode of formation and which may be of use to others working in this field. Firstly, the distribution of lamellae within crystals outlines sectors which coincide with those revealed by oscillatory zoning (Fig. 3). Secondly, in those crystals where the lamellar structure is clearly developed, almost identical sequences of thick and thin lamellae can be seen in opposite (100) and ($\bar{1}$00) sectors (Fig. 3). In addition, prominent lamellae can be correlated from one of these sectors to the other by use of the oscillatory zoning. These features suggest that the oscillatory compositional zoning plays a role in determining the location and thickness of the lamellae. However, since some lamellae do cross sector boundaries and consequently cross the compositional layering marked by the oscillatory zoning, they cannot be entirely compositionally dependent. In

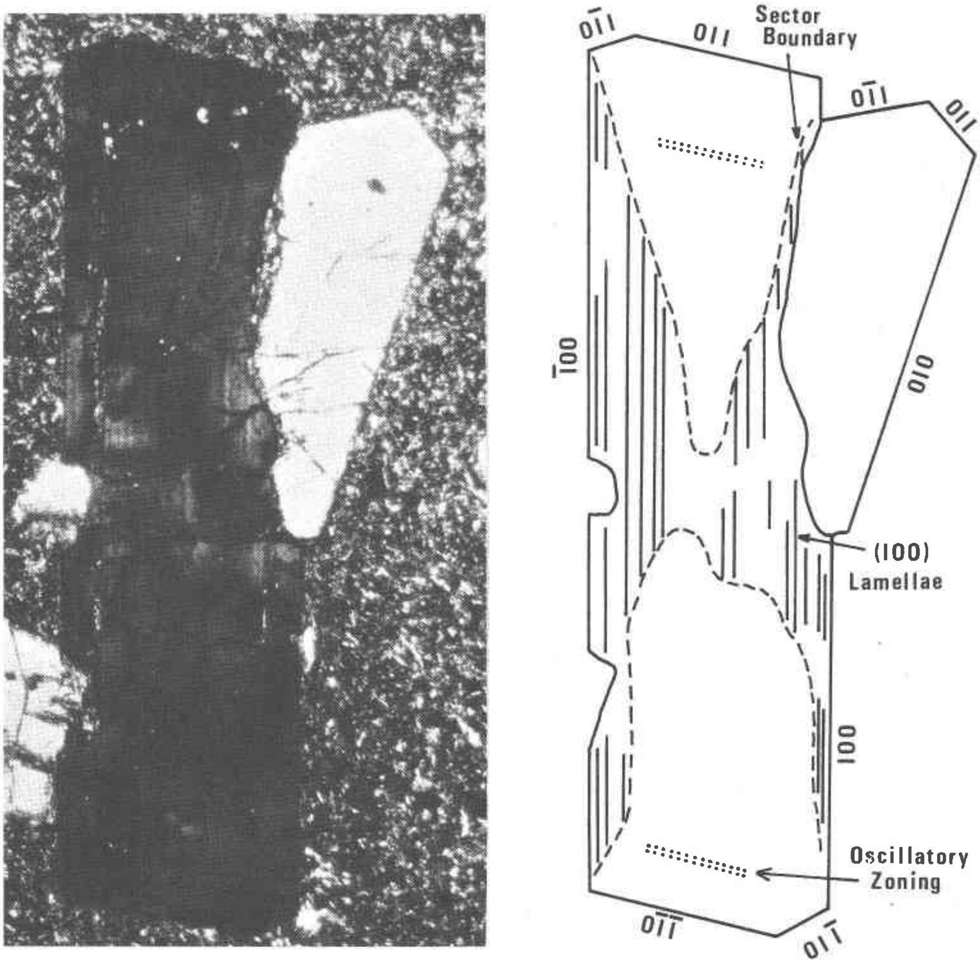

FIG. 2. Approximate (010) section of inverted clinobronzite under crossed nicols, showing undulose extinction, oscillatory zoning, and (100) lamellae in (100) and $(\bar{1}00)$ sectors. The crystal is bounded by (100), $(\bar{1}00)$, (011), $(01\bar{1})$, $(0\bar{1}1)$, and $(0\bar{1}\bar{1})$, as shown in the accompanying outline drawing. The small crystal on the side of the larger one shows an approximate (100) section of inverted clinobronzite with (011) and $(0\bar{1}1)$ terminal faces. Width of large crystal is 0.5 mm.

addition, there is no change in the 5° to 7° extinction angle of the lamellae in passing from the core to the margins of zoned crystals (constant Ca, but varying Fe and Mg). It appears likely, therefore, that the changes in composition may serve only as some type of triggering mechanism that initiates the formation of the lamellae.

Discussion

The diabase in which the clinobronzite crystallized was a typical tholeiitic magma and, therefore, we can expect bronzite in other similar magmas to have also crystallized with monoclinic symmetry with later inversion to orthorhombic. It is tempting to speculate that the lamellar structure so typical of bronzites results from this inversion. Smyth (1969) found a 30° change in the orientation of the *c* axis on heating orthorhombic pyroxene to the monoclinic form, but the Connecticut bronzite retained its *c* and *b* axes during inversion. Since sections of these crystals cut normal to (010) invariably show sharp parallel extinction and all of the optical anomalies in sections parallel to (010) can be attributed to rotations of the indicatrix about the *b* axis, it appears that the initial monoclinic symmetry played a role in controlling the development of the lamellae. However, a few miles north of Ponset, Connecticut, the diabase dike is much narrower and bronzites there, which have presumably undergone the same inversion, contain no lamellae. We conclude therefore, that slow cooling is necessary for the development of the la-

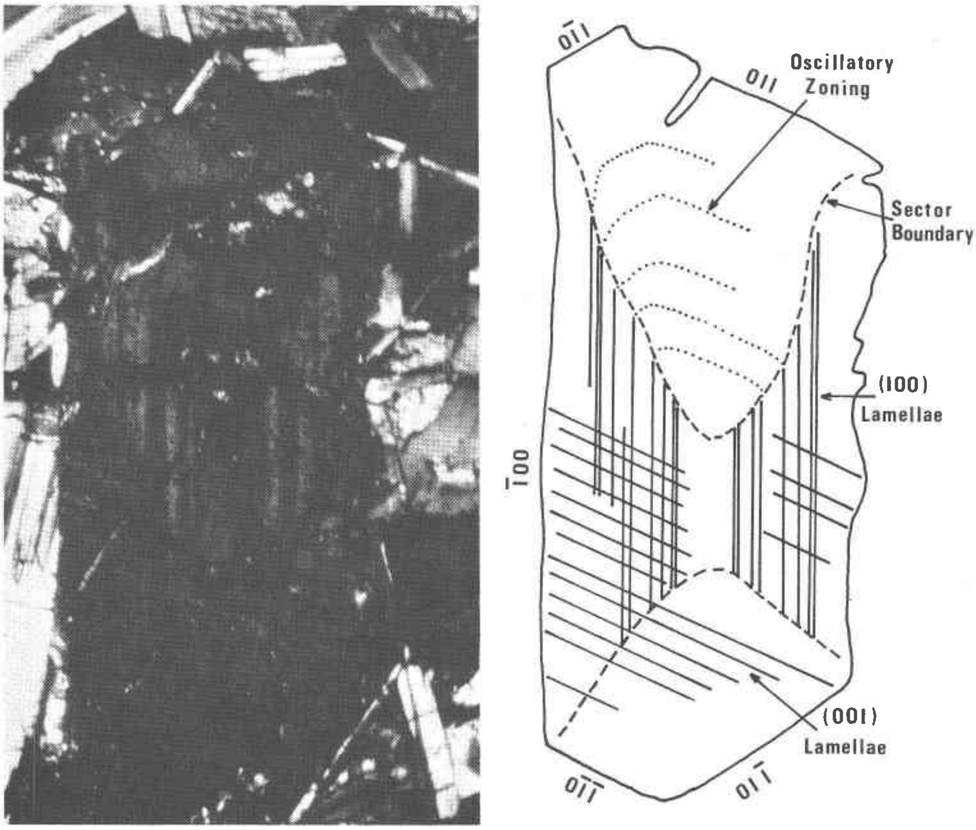

FIG. 3. Approximate (010) section of inverted clinobronzite under crossed nicols. Prominent (100) lamellae in the (100) sector can be correlated with prominent ones in the ($\bar{1}00$) sector by use of the oscillatory zoning (see accompanying sketch of crystal). Faint lamellae approximately parallel to (001) of the original clinobronzite are seen to pass through the (100) lamellae and the oscillatory zoning. Width of crystal is 0.6 mm.

mellar structure and that it is not simply a product of the inversion from monoclinic to orthorhombic bronzite.

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