

A Note on Sulphide-Oxide Mineralisation in Carlsberg Ridge Basalts

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Abstract : Pillow basalts from the Carlsberg Ridge at 3°35'N contain disseminated chalcopyrite, pyrite, and magnetite. The euhedral shape of the pyrite grains indicate them to be early formed and grown unobstructed while magnetite occurs as skeletal crystals. These opaque minerals indicate their origin from a rapidly cooled silicate melt and probably resulted by a process of liquid immiscibility during lava emplacement.

Keywords : Carlsberg Ridge, Basalts, Petrology, Indian Ocean

INTRODUCTION

Opaque minerals constitute an important assemblage in basaltic rocks, besides plagioclase, olivine and pyroxenes. Although recent studies confirmed the presence of hydrothermal activity in different segments of the Carlsberg Ridge (CR) and Central Indian Ridge (CIR) (from 6° N to 24°S) (Rona *et al.*, 1981; Herzig and Plugger, 1988; Plugger *et al.*, 1990), earlier observations confirm the presence of magmatic sulphide-oxide mineralisation at 5°23'N of the CR (Baturin and Rozanova, 1975).

Earlier, from the mineralogical, textural and petrochemical characters of these basalts it was concluded that fractional crystallisation is one of the major processes for their evolution (Banerjee and Iyer, 1989, 1991). Presently we have investigated the influence of magmatic over hydrothermal processes in the formation of the observed ore minerals in the CR rocks, and also the importance of liquid immiscibility process in their evolution.

METHODS

The samples for the present study are pillow fragments of typical mid-oceanic ridge basalts (MORB), dredged from a segment of the CR, at 3° 35' N and 64° 07' E (average water depth 3750 m). For ore microscopy

forty polished thin sections were investigated with oil immersion objectives (magnifications x 320 to x 1250).

Spot chemical examinations of these sections were conducted with a CAMEBAX-MICRO scanning electron microscope (SEM) using back-scattered electrons (BSE).

RESULTS AND DISCUSSION

Petrography of these basalts revealed the presence of plagioclase and olivine to vary in abundance from the outermost glassy to the fresh interior zones, forming a textural gradation from vitreous to intergranular through variolitic, spherulitic and subophitic (Banerjee and Iyer, 1989). A magmatic process involving fractional crystallisation of plagioclase and olivine and/or magma mixing leading to a heterogeneous mantle source for the origin of these basalts was suggested (Banerjee and Iyer, 1991). These observations are similar to that made for the basalts from 21.5° S and 23°S of the CIR wherein a mixed heterogeneous magma is regarded as a source (Herzig and Plugger, 1988).

Polished thin sections of the CR basalts show pyrite, chalcopyrite and magnetite as major opaque minerals while hematite is found in lesser amount. Pyrite occurs as disseminated crystals with anhedral to subhedral shapes in the glassy groundmass (Figs.

1a,b). Fine anhedral to drop-like specks of pyrite also occur as inclusions within the plagioclase phenocrysts following the twin lamellae (Fig. 1c). Their presence as fine grains (50 μm) was observed within and surrounding the vesicles in association with fine cryptocrystalline silica (Fig. 1d). Chalcopyrite occurs as yellow to brass-yellow grains showing distinct mutual grain boundary with pyrite (Figs. 2 a,b). Disseminated euhedral chalcopyrite crystals of varying sizes were also commonly found to occur in the matrix (Fig. 2c). Magnetite occurs as isolated grains in association with pyrite and chalcopyrite within the groundmass, in subhedral to skeletal forms (Fig. 2d). The BSE images at different spots of these sections reveal the presence of Fe, Cu and S in the dispersed ore minerals.

The shape of individual crystals and the nature of the contacts between adjacent grains have been used as criteria for determining paragenesis of ore minerals in any particular rock assemblage. In the CR basalts, the pyrite grains show euhedral nature, although less commonly anhedral, subhedral and small bubble-like forms occur. In general, subhedral to euhedral crystals have been interpreted as early formed and grown unobstructed in silicate melts. But certain minerals (e.g., pyrite, arsenopyrite) tend through their force of crystallisation to form well-developed crystals regardless of their position in the paragenetic sequence. The position of pyrite in the paragenetic sequence of these rocks would have depended on the local bulk sulphur of the magma (Craig and Vaughan, 1981). However, in the present case its tendency to form euhedral crystals masks its position in the paragenetic sequence.

Magnetite crystals have been observed as subhedral and skeletal forms (Fig. 2d) in many instances within these basalts. Unobstructed growth, especially in rapidly cooled

basalts, sometimes results in the formation of skeletal crystals that may be wholly or partially contained within subsequent crystallising silicates. According to Craig and Vaughan (1981) iron (plus nickel, copper) -sulphur (-oxygen) melts, from which Fe-Ni-Cu assemblages form, generally crystallise later than the enclosing silicates. The magnetite often present in such an assemblage crystallises earlier while the iron sulphides are wholly or partially molten and thus the magnetite tends to be euhedral or skeletal. Primary iron-sulphur (-oxygen) melts can also result in the formation of small (100 μm) rounded droplets trapped in rapidly cooled basalts and basaltic glasses as observed in basalts of Mid-Atlantic Ridge (Czamanske and Moore, 1977). Since the presently studied basalts indicate them to be emplaced from a rapidly cooled melt (Banerjee and Iyer, 1991), the formation of skeletal magnetite crystals could have taken place according to the former mechanism.

Fe-Cu-Ni sulphide assemblages are commonly associated with ultramafic and mafic igneous rocks of extrusive or intrusive types in massive to disseminated forms. Such assemblages are generally considered to have formed as a result of the separation of an immiscible sulphide-oxide (S-O) melt from a sulphide saturated silicate melt shortly before, during or shortly after emplacement of the pillow lava at temperature of 900° C or above (Craig and Vaughan, 1981). The S-O melt may settle through the partly crystalline silicate magma or if segregated early, may intrude separately resulting in the formation of massive to disseminated or even brecciated ores. When emplacement involves subaerial or submarine basaltic extrusions, the separated sulphides can form as millimeter or smaller-sized droplets of various shapes dispersed within or interstitial to the silicates

Figure.1. Photomicrographs of sulphides in plane polarised light. Magnification $\times 1250$ except for D which is $\times 500$.

- p=pyrite.
 A. Anhedral to subhedral pyrite in a glassy groundmass of the basalt.
 B. Isolated pyrite grain in a glassy matrix.
 C. Fine, anhedral to drop-like pyrite. Specks of pyrite occur as inclusions within plagioclase phenocryst following the twin lamellae
 D. Cryptocrystalline silica and pyrite surrounding a vesicle.

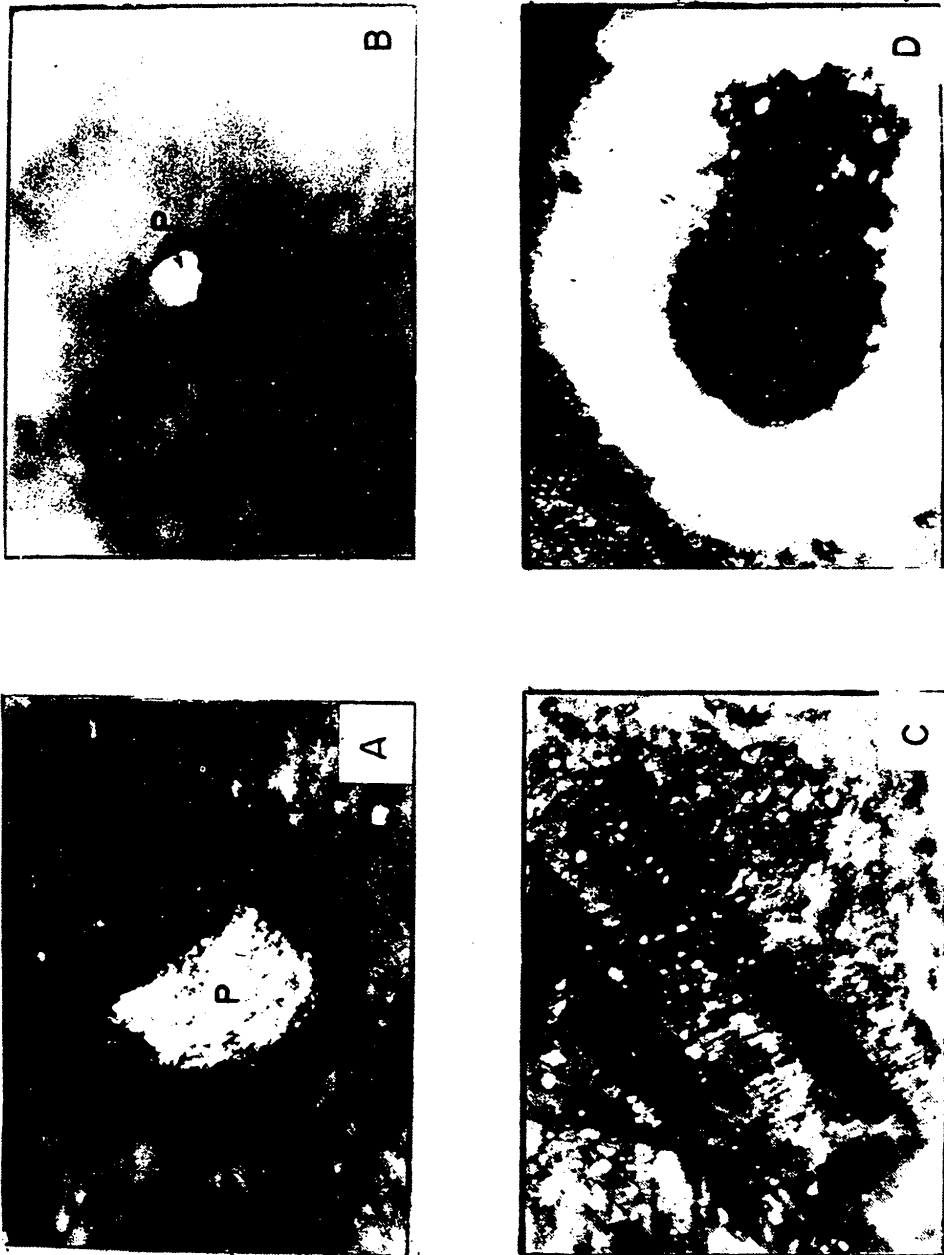


Figure 1.

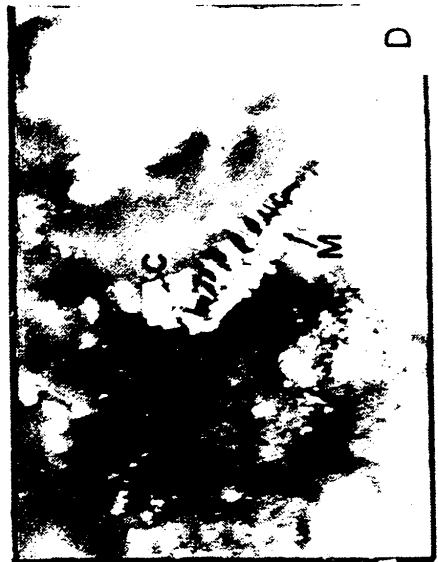


Figure 2.

Figure.2. Photomicrographs of sulphide grains. Magnifications $\times 1250$. p=pyrite, c=chalcopyrite, m=magnetite.
 A. An association of pyrite and chalcopyrite with distinct grain boundaries.
 B. An association of anhedral pyrite with chalcopyrite.
 C. Disseminated, euhedral chalcopyrite in hypocrySTALLINE groundmass.
 D. Skeletal magnetite in association with euhedral chalcopyrite in a glassy groundmass.

(Lorand, 1990). This is corroborated by our observation of disseminated pyrite crystals in a cryptocrystalline silicate matrix (Fig. 1d).

In cases where massive ores grade upwards into disseminated ores in which isolated grains of sulphide minerals are suspended in a silicate matrix, it is usually suggested that the sulphides (chalcopyrite, pyrite) and magnetite had their origin as immiscible S-O melts, which after separation from the parent silicate magma, coalesced at the base of the intrusion through gravitational settling. Subsequent discovery of similar sulphide grains in crusts of basaltic lava lakes on Hawaii and mid-ocean ridges and laboratory studies on the solubility of sulphur in ultramafic melts confirm the possibility of this general mode of origin (Francis, 1990). In the CR basalts, in addition to the disseminated nature of sulphide minerals the evidence for such immiscible liquid is further indicated by the presence of fluid and melt inclusions observed within the plagioclase phenocrysts (Banerjee and Iyer, 1989). Minute pyrite grains occurring as droplets within the plagioclase phenocrysts, also support the S-O liquid immiscibility process for the emplaced melt in the present case (Fig. 1c). Similar observations were made for basalts of the Shikoku and Daito Basins in the Phillipine sea and a process of liquid

immiscibility was envisaged (Nistrenko, 1980).

Based on the morphology and association of the S-O minerals in the CR basalts, we conclude that these are the likely products of a liquid immiscibility process which probably occurred during the emplacement of the pillow basalts from a shallow seated magma chamber. The observed disseminated nature of the S-O mineralisation of magmatic origin are comparable with those studied from $5^{\circ} 23' N$ of the CR (Baturin and Rozanova, 1975). From the paragenetic sequence of the S-O minerals it is inferred that the pyrite crystals are early formed, and the skeletal nature of the magnetite crystals indicate their origin from a rapidly cooled melt. In the absence of any supportive evidence for a hydrothermal origin for these ore assemblage we conclude that they could be the product of a magmatic process in this part of the Carlsberg Ridge.

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