

# Genetic aspects of basalts from the Carlsberg Ridge

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**The origin of the basaltic rocks with heterogeneous composition from the Carlsberg Ridge (CR) is of interest for more than one reason. In comparison to other Mid-Oceanic Ridge (MOR) systems sufficient data on petrochemical and petrographical aspects of the CR rocks are sparse. The bulk chemical, mineral chemical and ore mineralization aspects of the dredged basalts from a segment of the CR (at 3°37'N, 64°57'E) are synthesized to indicate the influence of fractional crystallization coupled with magma mixing on their genesis.**

THE Carlsberg Ridge (CR), north of the Central Indian Ridge (CIR), with a spreading rate of 1.2 to 1.3 mm/yr (half-rate)<sup>1</sup>, has been investigated since the classical work of Vine and Matthew<sup>2</sup> on the origin of seafloor magnetic anomalies. The CR was so named by Farquharson<sup>3</sup> whose cruise was sponsored by the famous Carlsberg beer company. During the Swedish expedition, petrological studies on CR rocks were carried out<sup>4</sup> and three decades later, other workers<sup>5-7</sup> reported the presence of ultrabasics, gabbros, dolerites, spilites and metamorphosed effusives besides basalts along different segments of the CR.

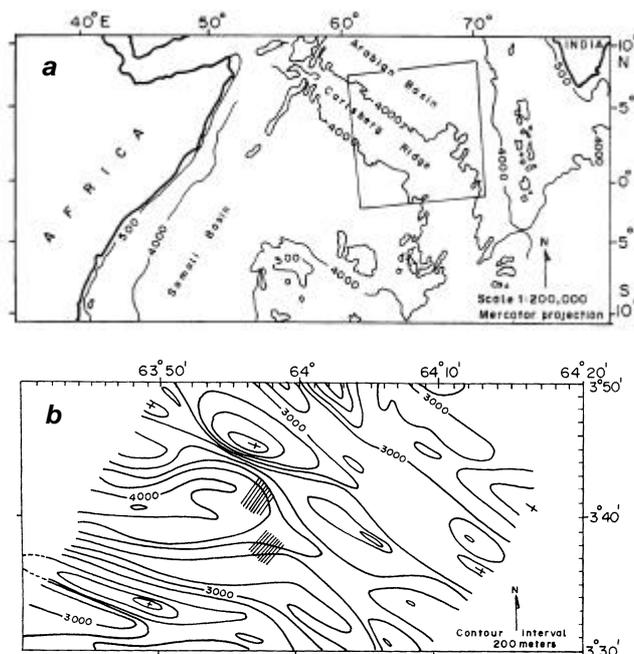
Isotopes and rare earth element contents of rocks from different segments of the CIR and CR indicated the likelihood of homogeneous magmas and magma mixing processes below these ridge systems as responsible factors for their compositional trend<sup>8-10</sup>. The ultramafic rocks occur in regions with large offsets and vertical displacements while basalts are common in areas of low offsets and in rift valleys<sup>11</sup>. No single magmatic process can solely account for this diversity, which may be the consequence of mixing of cogenetic basaltic magmas coupled with subsequent fractional crystallization<sup>12,13</sup> or alternatively be due to the result of low but variable amounts of melting of a heterogeneous mantle source<sup>14</sup>.

The studied basalts were dredged from a segment of the CR at 3°37'N and 64°07'E (avg. water depth 3750 m) (Figure 1), have a thin veneer of glass (1–3 mm) with phenocrysts mostly of plagioclase and rarely of olivine. Forty representative samples were selected and three textural zones of the basalt fragments examined, viz. vitrophyric glassy outermost, variolitic intermediate and

holocrystalline interior with intergranular and subophitic textures. Plagioclase is dominant, followed by olivine and a few pyroxenes<sup>15,16</sup>. Olivine, although less dominant, usually occurs as anhedral to euhedral, skeletal and lantern-shaped forms in the groundmass and as micro-phenocrysts while zoned olivine is rare. The ore minerals are mainly pyrite, chalcopyrite and magnetite<sup>17</sup>. The petrographic aspects resemble the moderately phyric plagioclase basalts (MPPB) from the Mid-Atlantic Ridge (MAR).

## Analytical methods

Selected samples for petrography were also used for petrochemical studies. Major and minor elements were determined using Atomic Absorption Spectrophotometer (Perkin-Elmer, PE 5000) and the precision was better than 5%. Si, Al, Ti and P contents were measured by spectrophotometer and FeO content by potassium dichromate titration. For normative calculations a CIPW computer program was utilized<sup>18</sup>. Microprobe analyses were



**Figure 1.** *a*, Map showing the study area on the Carlsberg Ridge. *b*, A detailed bathymetry map of the area indicating the dredge locations (hatched).

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carried out with a Camebax Micro-571 microanalyser operated at 15 kV and 10 to 20 mA sample current. Silicate and oxide standards were used and ZAF correction was used for the raw data.

### Whole rock chemistry

CR basalts at 3°37'N are relatively enriched in alkalis compared to basalts from the CIR and other parts of the CR (Table 1). The relation between SiO<sub>2</sub> and total alkalis among most of these basalts indicates them to group above the tholeiitic fractionation path<sup>16,19</sup>. The MgO contents of these basalts are nearly similar while TiO<sub>2</sub> is lower than those of the earlier reported values of CIR and CR basalts<sup>5,8</sup>. The samples show a systematic change from Ne-normative to Q-normative through Ol normative in the Ne-Di-Ol-Hy-Q projection<sup>20</sup>. The basalts grouping near the Ne-normative field are similar to T-(transitional) type MOR basalts (MORB) from the Atlantic and the Pacific<sup>21</sup>. In the AFM diagram (Figure 2), the samples grouping near the FeO-MgO side of the triangle probably correspond to the fractional crystallization of an olivine-rich parental melt<sup>22</sup>.

The P<sub>2</sub>O<sub>5</sub> and TiO<sub>2</sub> contents show variable degrees of positive correlation with MgO. Positive correlation between Ni and (Ni + Cr) with MgO indicates the role of olivine during the process of fractional crystallization. On a plot of TiO<sub>2</sub> vs MgO (Figure 3) most of the studied rocks lie in the CIR domain<sup>23</sup>. The enrichment pattern of trace elements (Cr, Co, Ni, Cu) in these basalts is similar to that from the Rodriguez triple junction<sup>8,10</sup>. The hyperbolic relation of the ratio-ratio plot of trace elements (Figure 4) and a positive correlation in their companion plots could indicate influence of magma mixing during their evolution<sup>16</sup>.

**Table 1.** Average composition of basalts of this study and previous analyses from CR and CIR

Wt%	A	B	C
SiO <sub>2</sub>	50.8	49.14	48.17
TiO <sub>2</sub>	1.29	1.65	1.63
Al <sub>2</sub> O <sub>3</sub>	15.30	16.22	16.22
Fe <sub>2</sub> O <sub>3</sub>	3.26	2.70	3.55
FeO	6.95	7.57	7.46
CaO	8.80	10.83	11.74
MgO	6.12	7.62	6.39
Na <sub>2</sub> O	4.04	3.02	2.93
K <sub>2</sub> O	0.94	0.18	0.31
P <sub>2</sub> O <sub>5</sub>	0.17	0.08	0.19
MnO	0.12	0.20	0.16
Cr	283	205	—
Co	120	69.25	—
Ni	178	128	—
Cu	112	93	—

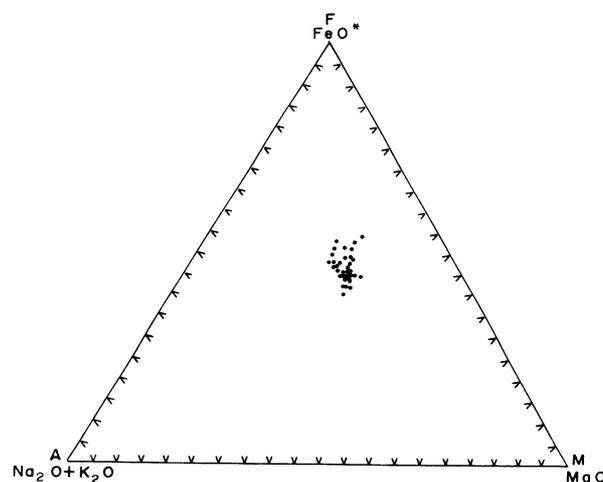
A, Average of presently studied 40 basalts from the CR.

B, Average of six basalts from 5.5°N CR<sup>5</sup>.

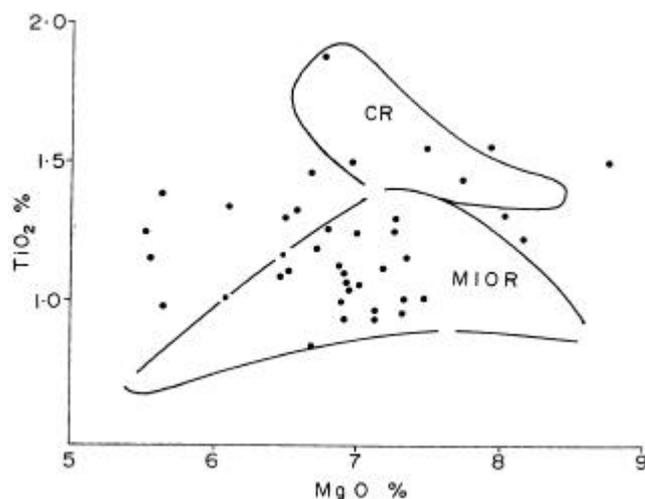
C, Average of six basalts from the CIR<sup>8</sup>.

### Ore minerals

Ore minerals form an important assemblage in basalts, besides plagioclase, olivine and pyroxenes. Polished thin sections of the CR basalts show frequent presence of pyrite, chalcopyrite and magnetite while hematite is less frequent. Pyrite occurs in anhedral to subhedral shapes in the glassy groundmass, as grains and specks within the plagioclase phenocrysts following the twin lamellae and also surrounding the vesicles in association with fine cryptocrystalline silica. Yellow to brass-yellow grains of chalcopyrite occurs in the matrix as disseminated euhedral crystals of varying size and show distinct mutual boundary with pyrite. Magnetite occurs as isolated grains in subhedral to skeletal forms and is associated with pyrite and chalcopyrite within the groundmass.



**Figure 2.** (Na<sub>2</sub>O + K<sub>2</sub>O)-FeO\*-MgO (AFM) plot for the CR samples. The samples plot near FeO\*-MgO end corresponding to the effects of fractional crystallization<sup>22</sup>.



**Figure 3.** Variation diagram of TiO<sub>2</sub> vs MgO, depicting that the majority of the present samples fall in the Mid-Indian Ocean Ridge domain.

Generally, subhedral to euhedral pyrite crystals have been interpreted to be early formed and grown unobstructed in silicate melts. But certain minerals (e.g. pyrite, arsenopyrite) tend through their force of crystallization to form well-developed crystals regardless of their position in the paragenetic sequence<sup>24</sup>. Unobstructed growth, especially in rapidly cooled basalts, sometimes result in the formation of skeletal magnetite crystals that may be wholly or partially contained within subsequent crystallizing silicates. Iron (plus nickel, copper)–sulphur (–oxygen) melts, from which Fe–Ni–Cu assemblage forms, generally crystallize later than the enclosing silicates<sup>24</sup>. The magnetite often present in such an assemblage crystallizes 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  $\mu\text{m}$ ) rounded droplets trapped in rapidly cooled basalts and basaltic glasses, as observed in the MAR basalts<sup>25</sup>. In the CR, magnetite may have been emplaced from a rapidly cooled melt according to the former mechanism<sup>17</sup>.

Fe–Cu–Ni assemblages normally form by the separation of an immiscible sulphide–oxide (S–O) melt from a sulphide saturated silicate melt shortly before, during or

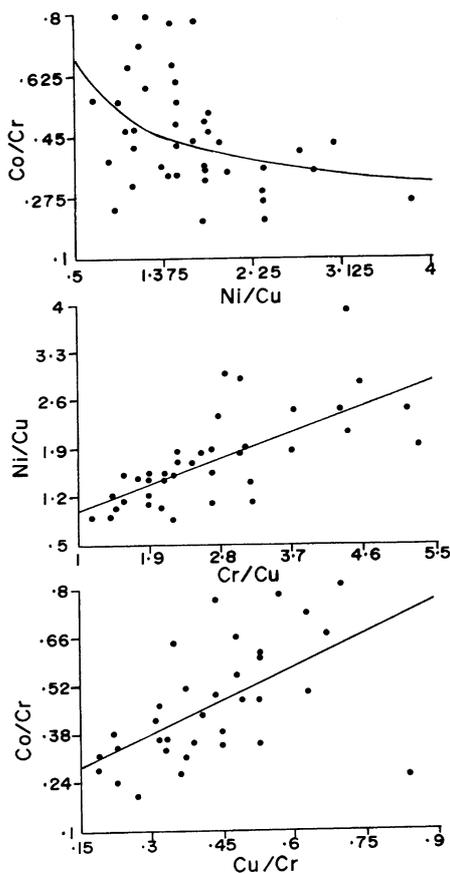
shortly after emplacement of the pillow lava at temperature of 900°C or above<sup>24</sup>. The S–O melt may settle through the partly crystalline silicate magma or if segregated early, may intrude separately to form massive to disseminated or even brecciated ores. When emplaced, it involves sub-aerial or submarine basaltic extrusions and the separated sulphides occur as mm- or smaller-sized droplets of various shapes dispersed within or interstitial to the silicates<sup>26</sup>. In the CR basalts this is corroborated by our observation of disseminated pyrite crystals in a cryptocrystalline silicate ground mass. Furthermore, such immiscible liquid is evident in these basalts by the presence of fluid and melt inclusions within the plagioclase phenocrysts<sup>16</sup>, analogous to the Shikoku and Daito Basin basalts in the Philippines Sea<sup>27</sup>. Minute pyrite grains occurring as droplets within the plagioclase phenocrysts, also support the S–O liquid immiscibility process for the emplaced melts.

On the basis of morphology and association of the S–O minerals in the CR basalts, we infer that these have formed by a liquid immiscibility process during the emplacement of the basalts from a shallow seated magma chamber. Paragenetically, pyrites are earlier formed followed by skeletal magnetite, indicating their origin from a rapidly cooled melt. Previous studies suggested the presence of hydrothermal activity in different segments of the CR and CIR (from 6°N to 24°S)<sup>28</sup>. In contrast, magmatic origin for sulphide–oxide mineralization has been suggested at 5°23'N of the CR<sup>29</sup> and the present study also support this conclusion.

### Mineral chemistry

Plagioclase feldspars, olivine, pyroxenes and amphiboles, among others, tend to exhibit different morphological and compositional variations in the form of zoned and twinned crystals. Plagioclase crystals generally show zonings, e.g. normal, reverse, patchy, oscillatory and sector-type, with one or all of these occurring even within a single slide. Plagioclases are neutrally buoyant in basaltic magmas and do not re-equilibrate rapidly and this makes them an excellent proxy of the pre-eruptive history of magma batches since they record variation in the compositions, temperature and storage depth of the host magma including the changes in the volatile content and the hydraulic pressures of the magma chamber<sup>30</sup>.

Totally 283 plagioclase grains of different morphotypes (41 phenocrysts, 21 laths, 7 zoned and 14 twinned) were analysed from the CR basalts<sup>31</sup>. Plagioclase occurs as euhedral to subhedral crystals of varying dimension forming phenocrysts, microphenocrysts and laths. The phenocrysts and microphenocrysts are calcic ( $\text{An}_{82-87}$ , avg. 85 mole%) and are characterized by low  $\text{K}_2\text{O}$  (0.02 to 0.29%; avg. 0.06%); while the laths show  $\text{An}_{67-79}$  mole% (avg. 74 mole%) and  $\text{K}_2\text{O}$  (range 0.03–0.18; avg. 0.10%)



**Figure 4.** The ratio–ratio plot of Co/Cr vs Ni/Cu showing hyperbolic trend and the companion plots of Co/Cr vs Cu/Cr, Ni/Cu vs Cr/Cu showing positive correlations, attest to magma mixing process<sup>23</sup>.

(Table 2). Some of the plagioclase phenocrysts show both normal and reverse zones.

Locally devitrified melt inclusions are prominent in the groundmass and in the relatively Na<sub>2</sub>O-rich plagioclase phenocrysts and this possibly indicate exchange between the host feldspar and the melt inclusions. Melt composition within some plagioclase and the basaltic ground mass has a range of orthoclase (Or) component from 0.48 to 9.63 mole% and 1.08 to 5.82 mole% respectively, and probably account for the enhanced K<sub>2</sub>O content in these basalts<sup>17</sup>. Factors that conceivably control the abundance and chemistry of plagioclase are the mantle compositions, temperature, pressure, crystal growth rate, interface kinetics, partial melting and volatile content<sup>32</sup>.

The MPPB characteristic of the CR basalts can be due to the separation of the plagioclase from a basaltic magma at a slower rate than the co-precipitating olivine and/or pyroxenes, due to the high-pressure effect<sup>33</sup> or density differences between plagioclase and the basaltic magma<sup>34</sup>. Plagioclase phenocrysts with An-rich zone and corroded rims indicate their non-equilibrium state with the cooling lava that could lead to the variations in the An content of the plagioclase of different morphologies<sup>16</sup>. Such An-rich plagioclases could crystallize from more 'primitive' calcic melts prior to their incorporation in the phyric basaltic magma<sup>12</sup>.

Laboratory experiments on aphyric basalts have revealed plagioclase to occur on the liquidus over a considerable temperature interval<sup>13</sup> as typified by the CR basalts that precipitated plagioclase to reach the cotectic. Such a liquid composition might occur through mixing and/or resorption of cumulate plagioclase in a normal cotectic

liquid<sup>35</sup>. The presence of various morpho-types of plagioclase in CR basalts suggests different crystal growth rates due to differential cooling, or increasing degrees of supercooling of the liquid in which they grew<sup>36</sup>.

One of the causes for different degrees of zoning in minerals occurring in oceanic basalts is probably related to kinetics of magma cooling, because the amount of zoning will be roughly inversely proportional to the rate of ascent of the magma<sup>37</sup>. Magmas that are brought to the surface quickly and without cooling should show no zoned mineral, while those that ascend slowly are more likely to cool extensively and have zoned phenocrysts. Further, the size of the magma chambers could also have an effect in those lavas that originated from a large, thermally heterogeneous and actively mixed magma chamber and phenocrysts originating from those lavas are likely to show signs of zoning. Similar to MAR basalts<sup>30,38</sup>, diversity in zoning patterns and compositions in CR basalts could be interpreted as evidence for magma mixing.

The upwelled mantle material ('primitive' magma) may be repeatedly injected into the magma chamber containing more evolved, consanguineous fractionated basalts of earlier episode of injection and mixing<sup>12</sup>. The injected magma may be a primary melt with olivine on the liquidus or it may have fractionated somewhat during ascent and be saturated with both olivine and plagioclase. Each episode of injection and mixing is followed by a quiescent period while the mixed magma fractionates further and evolves more. Similar to the plagioclase in MAR basalts (An<sub>70-90</sub>)<sup>33</sup>, the observed accumulation of calcic plagioclase (An<sub>67-87</sub>) together with the slow-spreading rate of the CR, supports the contention that the widespread accumulation of calcic plagioclase may be due to polybaric fractionation.

The twinned plagioclases in the CR basalts are distinctly enriched in Na<sub>2</sub>O (up to 2.84%) for one part of the twin *vis-à-vis* the other, within a single crystal. Twinning forms late in the history of the crystal and updates zoning and could obliterate the zones. This fact is reflected by the compositional differences observed in contiguous twin lamellae, which partly substitutes for the compositional differences occurring in the zoned plagioclases. Further, Na-rich plagioclase may crystallize from a mixed magma that had a low CaO/Na<sub>2</sub>O value<sup>34</sup>. Such sodic-rimmed plagioclases may also represent low-pressure growth of plagioclase during or immediately prior to the magma eruption<sup>39</sup>. The studied CR basalts have all such evidences indicating their low-pressure crystallization from a mixed magma.

The forsterite (Fo) content in the olivine ranges from 83 to 91 mole% (avg. 88 mole%) while NiO content is up to 0.36% (ref. 19). The minor compositional variations indicate crystallization of olivine over a narrow temperature range, with little or no change in the ferromagnesian content of the magma. Had the magma cooled before eruption, zoned olivine phenocrysts are expected to form, but

**Table 2.** Six representative microprobe analyses and norms of plagioclase from the CR basalts

	Phenocrysts					
	1	2	3	4	5	6
SiO <sub>2</sub>	46.56	48.13	47.38	46.44	48.96	51.21
Al <sub>2</sub> O <sub>3</sub>	30.96	30.59	31.29	31.56	30.09	29.63
CaO	19.20	18.05	19.73	21.04	18.48	17.63
Na <sub>2</sub> O	1.87	1.97	1.78	1.78	2.13	2.02
K <sub>2</sub> O	0.02	0.06	0.05	0.03	0.06	0.04
Or	0.11	0.33	0.26	0.15	0.32	0.22
An	84.95	83.26	85.76	86.62	82.50	82.67
Ab	14.95	16.41	13.98	13.24	17.18	17.11
	Laths					
	1	2	3	4	5	6
SiO <sub>2</sub>	50.16	52.94	51.78	51.77	50.61	53.10
Al <sub>2</sub> O <sub>3</sub>	28.16	27.45	27.98	28.67	27.64	27.34
CaO	16.37	17.11	15.65	13.41	17.15	15.27
Na <sub>2</sub> O	3.03	2.64	3.65	2.68	2.60	3.87
K <sub>2</sub> O	0.18	0.10	0.11	0.07	0.03	0.05
Or	0.97	0.54	0.59	0.39	0.16	0.27
An	74.21	77.78	69.95	76.92	78.37	68.41
Ab	24.81	21.68	29.47	22.69	21.46	31.32

the rarity of zoned olivine in the CR basalts suggests insignificant cooling between the time of olivine crystallization and quenching of the magma<sup>40</sup>. In rare instances, olivine xenocrysts occur with high Fo content (~91 mole%) at higher Mg# (~73%) of the bulk rock. Nickel prefers to enter at early-stage in the mafic minerals and decreases when olivines crystallize. The Fo vs NiO content of the olivines (Figure 5) in CR basalts shows the trend of magma fractionation and the similarity with the Pacific N-MORB<sup>39</sup>.

### Magma genesis at Carlsberg Ridge

Fractional crystallization of a primary magma cannot solely account for the compositional diversity in lavas reported from seamounts, MOR and transform faults from different parts of the world oceans<sup>41</sup>, but may also result from differential melting of a heterogeneous mantle<sup>12,13</sup>. As the CR rocks are inhomogeneous, the factors that could conceivably bring about the observed compositional differences include magmatic processes like fractional crystallization and/or magma mixing involving primary olivine and plagioclase. Source inhomogeneity has been noticed at accreting plate boundaries of MAR<sup>42</sup>, at parts of the Central Eastern Pacific<sup>43</sup>, and at the CR<sup>9</sup> and CIR<sup>14</sup>.

The corroded margins of the plagioclase phenocrysts and their progressive enrichment in An content than that of the microphenocrysts towards the inner zones of the CR basalts, reflect their non-equilibrium nature with the melt and formation of the phenocrysts at higher levels during ascent of the magma. The phenocrysts with An-rich cores (range An<sub>82-87</sub>) indicate their non-equilibrium state with melts appropriate to the whole rock composition. The variable An content of the plagioclase of different morphologies from different zones of these basalts supports this contention<sup>15</sup>.

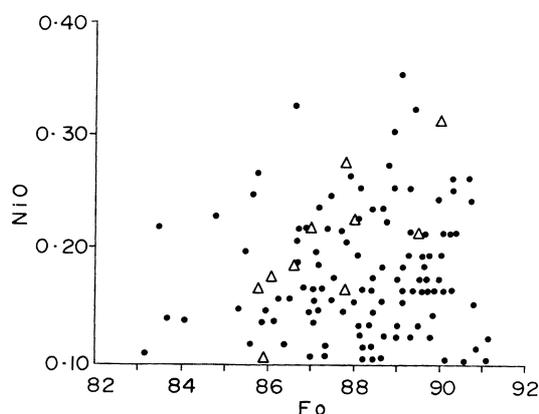
The CaO/Al<sub>2</sub>O<sub>3</sub> ratio is useful to determine the qualitative fractionation relationship between and within basaltic suites, to elucidate the magma mixing process, the depth and extent of partial melting. The low CaO/Al<sub>2</sub>O<sub>3</sub> ratio (range 0.52–0.68, avg. 0.59) in the CR basalts, could result from mixing of a primitive high CaO/Al<sub>2</sub>O<sub>3</sub> magma (containing high calcic plagioclase and Fo-rich olivine), with an evolved magma having a low CaO/Al<sub>2</sub>O<sub>3</sub> ratio, rather than by fractional crystallization alone<sup>40</sup>. This could also explain the absence of clinopyroxene, which was no longer stable after mixing, while plagioclase and olivine of appropriate composition continued to crystallize.

Based on Na<sub>2</sub>O/(Na<sub>2</sub>O + CaO) vs MgO and CaO/Al<sub>2</sub>O<sub>3</sub> vs MgO (Figure 6), the trends of olivine and plagioclase fractionation in relation to the degree of partial melting were studied. These plots indicate greater influence of fractional crystallization over partial melting in concurrence with the olivine and plagioclase fractionation<sup>44</sup>.

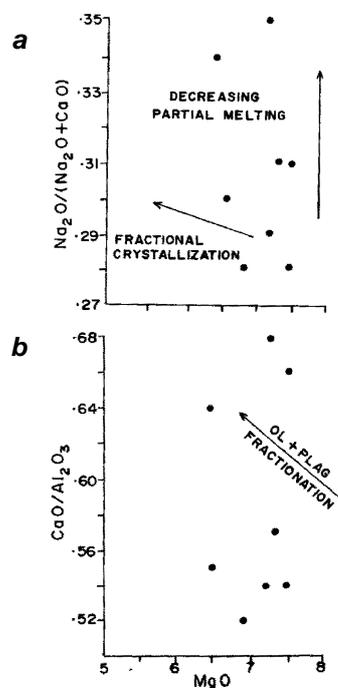
A positive correlation of axial spreading ridge depth with Na<sub>2</sub>O and TiO<sub>2</sub> and a negative correlation with CaO/

Al<sub>2</sub>O<sub>3</sub> in erupted MORB could be attributed to the extent of initial partial melting that occurs at greater depths beneath the slow-spreading ridges<sup>45</sup>. Thus, the CR basalts with low CaO/Al<sub>2</sub>O<sub>3</sub>, CaO/TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>/TiO<sub>2</sub> and high Na<sub>2</sub>O/(Na<sub>2</sub>O + CaO) ratios could represent products of lesser amounts of partial melting at shallow depths. Apart from the mineral phases, crystallization of magma at different depths could increase or decrease the CaO/Al<sub>2</sub>O<sub>3</sub> ratio at high or low pressure, respectively, leading to the formation of clinopyroxene at high pressure (5–10 kbar) and plagioclase and olivine at low pressure (1–5 kbar).

The dominant presence of plagioclase and less frequency of olivine, together with the rarity of clinopyroxene and



**Figure 5.** Fo vs NiO plot of olivine phenocrysts (solid dots) observed in the CR basalts. Triangles represent basalts from the EPR<sup>39</sup>.



**Figure 6.** *a*, Na<sub>2</sub>O/(Na<sub>2</sub>O + CaO) vs MgO and *b*) CaO/Al<sub>2</sub>O<sub>3</sub> vs MgO plots of representative samples in CR basalts suggesting the role of fractional crystallization over partial melting. OL, Olivine; PLAG, Plagioclase.

low CaO/Al<sub>2</sub>O<sub>3</sub> ratio in the present instance, probably indicate a rapid ascent of the magma from a region of high pressure to one of very low pressure. Similar to other global ridge systems<sup>38</sup>, magma mixing may have occurred episodically in small shallow magma chambers at CR, immediately beneath the spreading ridge axis during the origin of these basalts. As in the FAMOUS region<sup>46</sup> and Iceland<sup>47</sup>, the following signatures of magma mixing exist in the CR basalts:

- Presence of plagioclase phenocrysts with An-rich core and corroded margins. The anomalously high An content of a few plagioclase megacrysts may be related to the increasing Na<sub>2</sub>O contents produced by magma mixing<sup>34</sup>, e.g. the compositions of megacrysts in the FAMOUS area range from An<sub>89-92</sub>, whereas the phenocrysts range from An<sub>86-89</sub> (ref. 46). High calcic megacrysts (up to An<sub>91.5</sub>) in the MAR basalts suggest that such megacrysts could represent the Na-poor (1.5% Na<sub>2</sub>O) parental magmas for some, if not many<sup>48</sup>.
- Coexistence of calcic plagioclase and olivine with minor compositional variations of the latter (range Fo<sub>83-91</sub>) may be due to the short time interval of olivine crystallization or due to magma mixing<sup>12</sup>. Further, the rare presence of the high forsteritic olivine phenocrysts also suggest a lower melt Mg# than the whole rock Mg# due to the effect of magma mixing<sup>12</sup>.
- Presence of twinned sodic plagioclase and/or reverse zoned plagioclase in CR basalts similar to the Site 648 basalts of the MAR<sup>49</sup>.
- Low CaO/Al<sub>2</sub>O<sub>3</sub> ratio in the bulk composition of these rocks and typical absence of clinopyroxene.
- Hyperbolic relation of the ratio–ratio plots of trace elements and the variable range of TiO<sub>2</sub> at a given FeO\*/MgO in the bulk rocks.

Variations in the texture and mineral chemistry of the CR basalts may have been influenced by the tectonic setting. It is noteworthy that the present study area lies within a down-faulted segment bounded by two transform faults<sup>50</sup>. It was suggested that shallowing and narrowing of the CR axis in the middle perhaps facilitated the excess outpouring of magma at the wider opening of the valley, thus giving rise to a large amplitude magnetic anomaly<sup>1</sup>. In the NW part of the study area, the free-air gravity is low and appears to be offset left-laterally by a transform fault<sup>1</sup>. The nature of this transform fault and the magnitude of ridge offsets might have resulted in congenial conditions for the eruption of basaltic flows. It is opined that at cooler, thermal environments, e.g. large offsets transform faults on slow-spreading ridges, there is a decrease in the extent of melting and with alkalic volcanism being an extreme manifestation of the transform fault effect (TFE)<sup>51</sup>. The TFE together with the concept of a spreading cell<sup>41</sup> could explain the differential extent of partial melting coupled with shallow depth of magma generation

beneath the CR, that brought about the resultant changes in the texture and mineral composition.

Under the auspices of the future Indian Ridge research Program (InRidge), exhaustive study of the CR and CIR would be carried out to obtain additional details including mapping and extensive petrochemical investigation to better understand the nature of the magma genesis of these most unexplored ridge systems.

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