

Interstratified low-Ti and high-Ti volcanics in arc-related Khairagarh Group of Central India

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We report here the petrotextonic implications of interstratified low-Ti and high-Ti volcanics in the Khairagarh metabasalts of Sitagota Syncline, Central India. The low-Ti volcanics have higher CaO/TiO_2 , $\text{Al}_2\text{O}_3/\text{TiO}_2$ ratios and LILE (?), LREE, Zr, Hf, and Cr concentration and distinct negative Eu anomalies, and lower FeO^T/MgO , P, V, Sc, HREE than high-Ti volcanics. Although low-Ti and high-Ti volcanics are both arc-related tholeiites, they are not related to each other by crystal fractionation and/or crustal contamination processes. They represent different degrees of partial melting of heterogeneous mantle source under different subduction fluxes, $P_{\text{H}_2\text{O}}$ and f_{O_2} conditions.

INTERSTRATIFIED low-Ti and high-Ti volcanics are a characteristic feature of arc-related volcanics globally¹⁻⁴. They have also been reported from many ophiolites⁵. Recently, several geochemical studies have suggested that the younger Khairagarh volcanics of the Dongargarh Supergroup have an arc-related tholeiitic affinity⁶⁻⁸. We report here for the first time, the occurrence of two chemically coherent geochemical groups of interstratified volcanics from the Early Proterozoic (~ 2.1 Ga) (ref. 23) Sitagota and Mangikhuta Metabasalts of Central India: one higher in TiO_2 (> 0.7 Wt.%) and the other, subtly but distinctly lower in TiO_2

(< 0.7 Wt.%). We suggest the occurrence of similar low-Ti and high-Ti volcanics from other parts of the Khairagarh volcanics, albeit with different minor elemental geochemical characters^{7,9,10} (Figure 1). These observations have important petrotextonic implications for the role of 'subduction-related processes' in the evolution of the Central Indian craton in particular, and the nature of Early Proterozoic global tectonics, in general.

The low-Ti and high-Ti volcanics reported in this communication are fine- to medium-grained metabasalts. Overall, they have retained their relict textures that includes subvariolic, subophitic to ophitic and porphyritic types. However, except for relict clinopyroxenes, all other magmatic phases have been replaced by secondary mineral assemblages during alteration(s) and prehnite-pumpellyite grades of metamorphism. Petrography reveals that olivine (?) was followed by clinopyroxene and plagioclase as fractionating phases. The magmatic clinopyroxenes are augites, in both low-Ti and high-Ti volcanics and paradoxically have overall similar chemistry, including their overall Ti contents but with different Ti/Al ratios.

Representative analyses of primitive low-Ti and high-Ti volcanics are given in Table 1. Samples were analysed at NGRI, Hyderabad by XRF and ICP-MS. Analytical techniques, accuracy and precision of the analyses are given elsewhere^{11,12}. The low-Ti and high-Ti volcanics are rather primitive by island-arc standards, in terms of high MgO, Cr and low Al_2O_3 contents. The basaltic ($\text{SiO}_2 < 52$ wt.%) to basaltic andesites ($\text{SiO}_2: 52$ to 55 wt.%) of the low-Ti volcanics have high MgO (~12 to 7 wt.%) and Cr (~ 850 to 250 ppm), whereas high-Ti basalts (excluding an anomalous basaltic andesite) have MgO between 8.4 wt.% and 7.2 wt.% and Cr between ~350 ppm and 85 ppm. The high-Ti volcanics have higher concentrations of FeO^T (~ 17 wt.% to 15 wt.%) compared to the low-Ti volcanics (~ 14 wt.% to 12 wt.%). The high-Ti volcanics are more evolved in terms of their FeO^T/MgO ratios, whereas in terms of SiO_2 , the low-Ti volcanics are more evolved. In the $(\text{Zr} + \text{Y})$ vs $(\text{TiO}_2 \times 100)$ vs Cr plot¹³, the low-Ti suites are classified as magnesian tholeiites, whereas the high-Ti suites are normal tholeiites. In the CaO/TiO_2 and $\text{Al}_2\text{O}_3/\text{TiO}_2$ versus TiO_2 plots (Figure 2), the low-Ti suites of all the Khairagarh volcanics have higher CaO/TiO_2 and $\text{Al}_2\text{O}_3/\text{TiO}_2$ ratios and spread around the primitive (i.e. modal pyrolite) compositions, whereas the high-Ti suites have lower CaO/TiO_2 and $\text{Al}_2\text{O}_3/\text{TiO}_2$ ratios, and plot away from the primitive composition. Assuming a simple pyrolite source, this diagram indicates that the low-Ti and high-Ti volcanics represent higher and lower degrees of partial melting, respectively⁵.

The low-Ti volcanics show LREE enriched patterns ($\text{Ce}/\text{Sm}_N: 2.43$ and 2.85), whereas the high-Ti volcanics show moderately enriched LREE patterns ($\text{Ce}/\text{Sm}_N: 1.55$

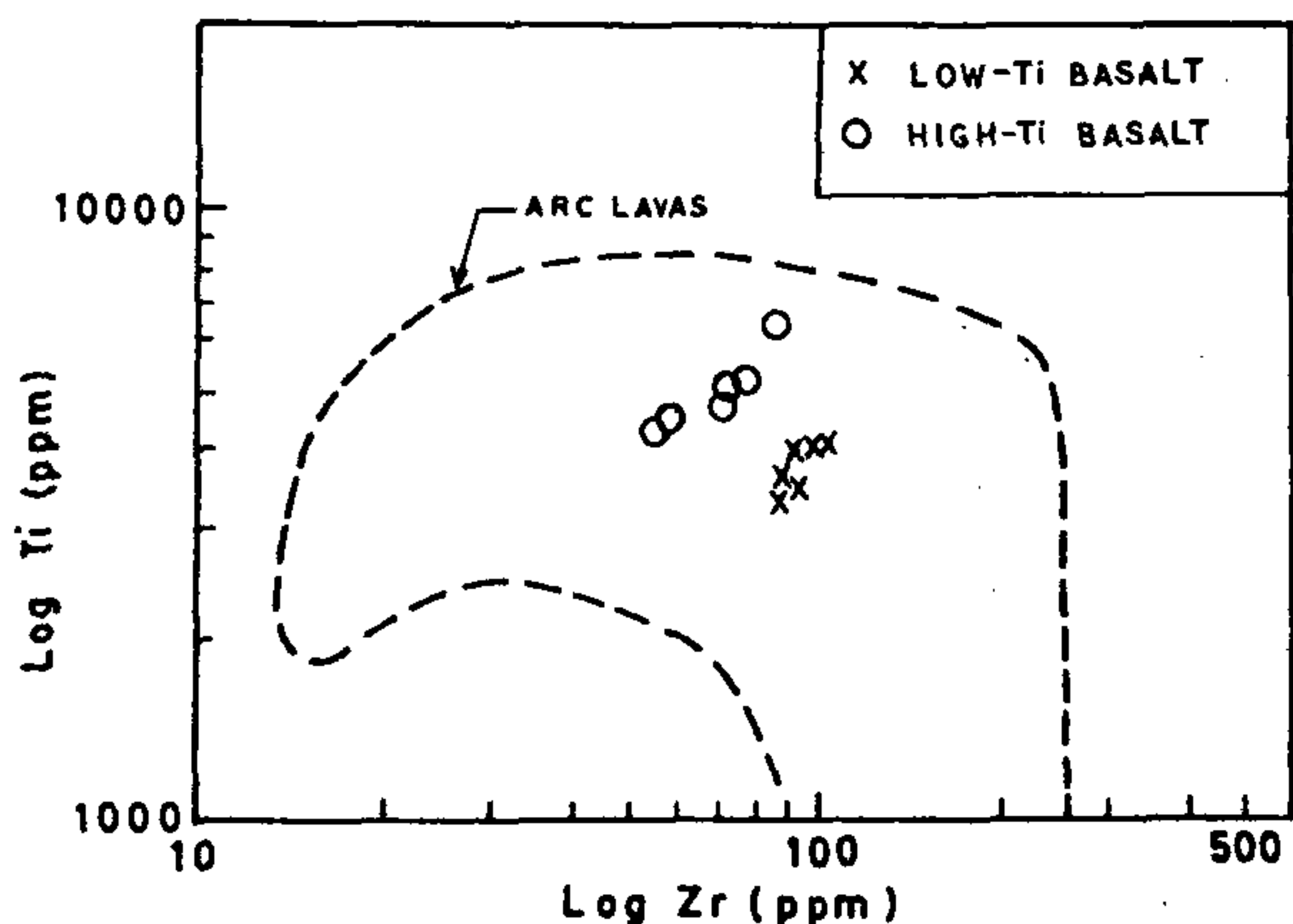


Figure 1. TiO_2 vs Zr plot showing two distinct trends in Khairagarh Volcanics, Sitagota Syncline. Also shown is the volcanic-arc lava field of Pearce (1982).

Table 1. Representative analyses of low-Ti and high-Ti Sitagota Metabasalts, Central India

Elements	Sample no. 34	Sample no. 13
	(wt. %)	
SiO ₂	50.75	49.50
TiO ₂	0.53	0.93
Al ₂ O ₃	13.50	14.65
FeO(T)	14.17	15.17
MnO	0.19	0.23
MgO	11.97	8.36
CaO	7.08	8.50
Na ₂ O	1.01	2.57
K ₂ O	0.69	0.52
P ₂ O ₅	0.10	0.10
LOI	1.52	7.10
Total	100.85	100.75
	(in ppm)	
Sr	130	232
Rb	35	17
Ba	352	225
Th	6.9	1.4
U	2.7	0.4
Nb	1.7	—
Zr	94	57
HF	2.5	1.8
Y	21	26
Sc	26	41
Cr	841	345
Ce	32	16
Pr	4	2.2
Nd	15	9
Sm	3	2.6
Eu	0.8	0.9
Gd	3	3
Dy	2.9	3.6
Er	2.0	2.3
Yb	1.6	2.4
Lu	0.2	0.4

to 1.85). The HREE patterns of the low-Ti volcanics are almost flat (Gd/Yb_N : 1.29 to 1.67), whereas the high-Ti volcanics have flat to moderately fractionated HREE patterns (Gd/Yb_N : 1 to 2.01). The contrasting REE patterns together with subtle major and minor element differences rule out the possibility of relating the high-Ti and low-Ti volcanics by any conceivable fractionation processes¹⁴. The primitive nature of these samples rule out the possibility of crustal contamination to relate them¹⁴⁻¹⁶.

Another distinct feature is the presence of pronounced negative Eu anomalies in the low-Ti volcanics, indicating plagioclase fractionation. In island-arc related suites, early plagioclase removal takes place under low P_{H_2O} conditions^{17,18}. This is also corroborated by the behaviour of V, which increases with fractionation in the low-Ti volcanics, whereas lack of plagioclase removal in the high-Ti volcanics (i.e. no Eu anomaly) indicates relatively high P_{H_2O} condition, however, not high

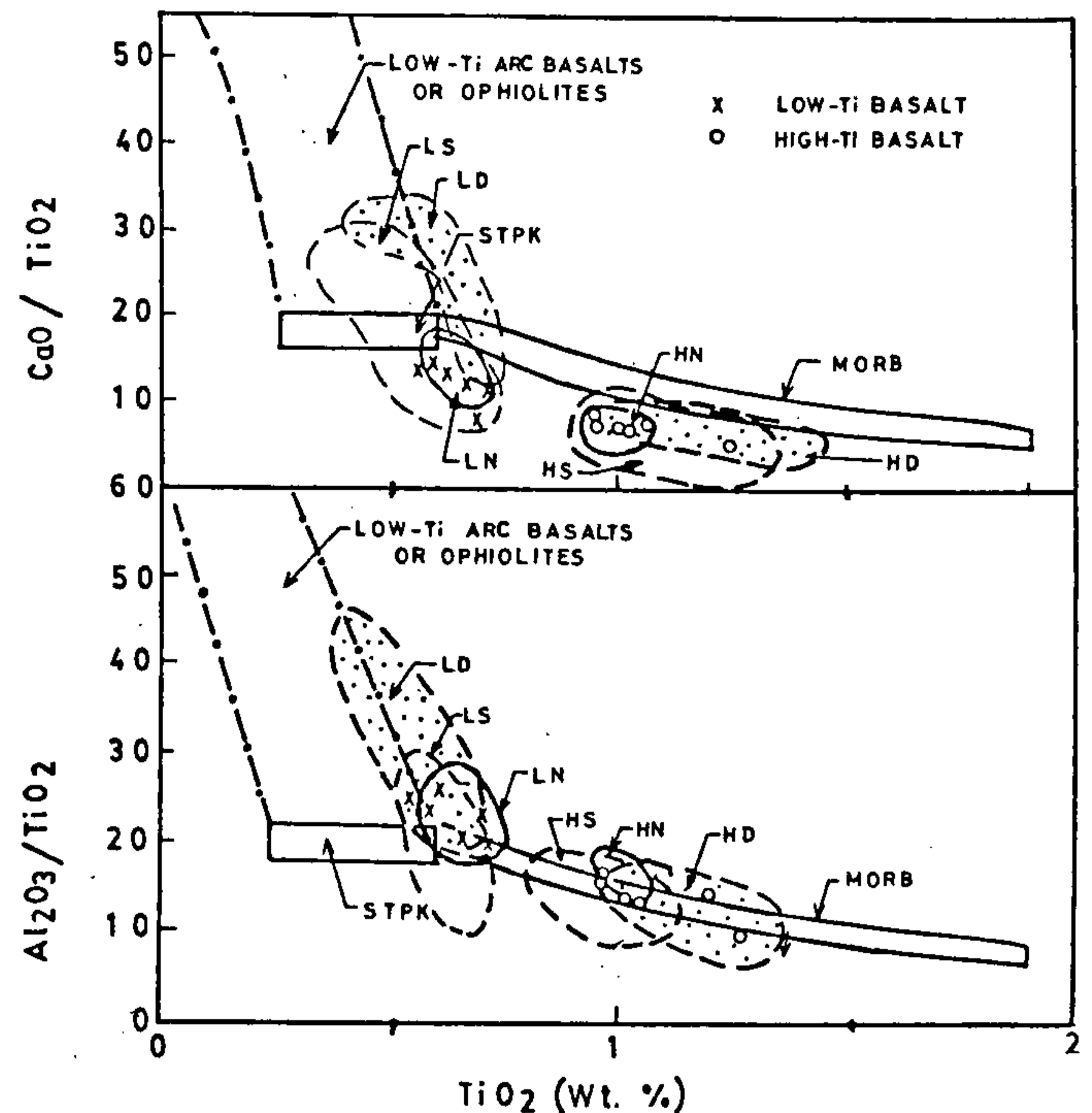


Figure 2. TiO₂ vs CaO/TiO₂ and Al₂O₃/TiO₂ plots (after Sun and Nesbitt⁶) for high-Ti and low-Ti volcanics of Khairagarh Group. Fields of Mid-oceanic Ridge Basalt (MORB), Spinifex-textured periodotitic komatiites (STPK) and low-Ti arc basalts or ophiolites⁶. Fields of low-Ti volcanics (Ls, LD and LN respectively) and high-Ti volcanics (HS, HD and HN respectively) are for Khairagarh volcanics^{7,9,10}.

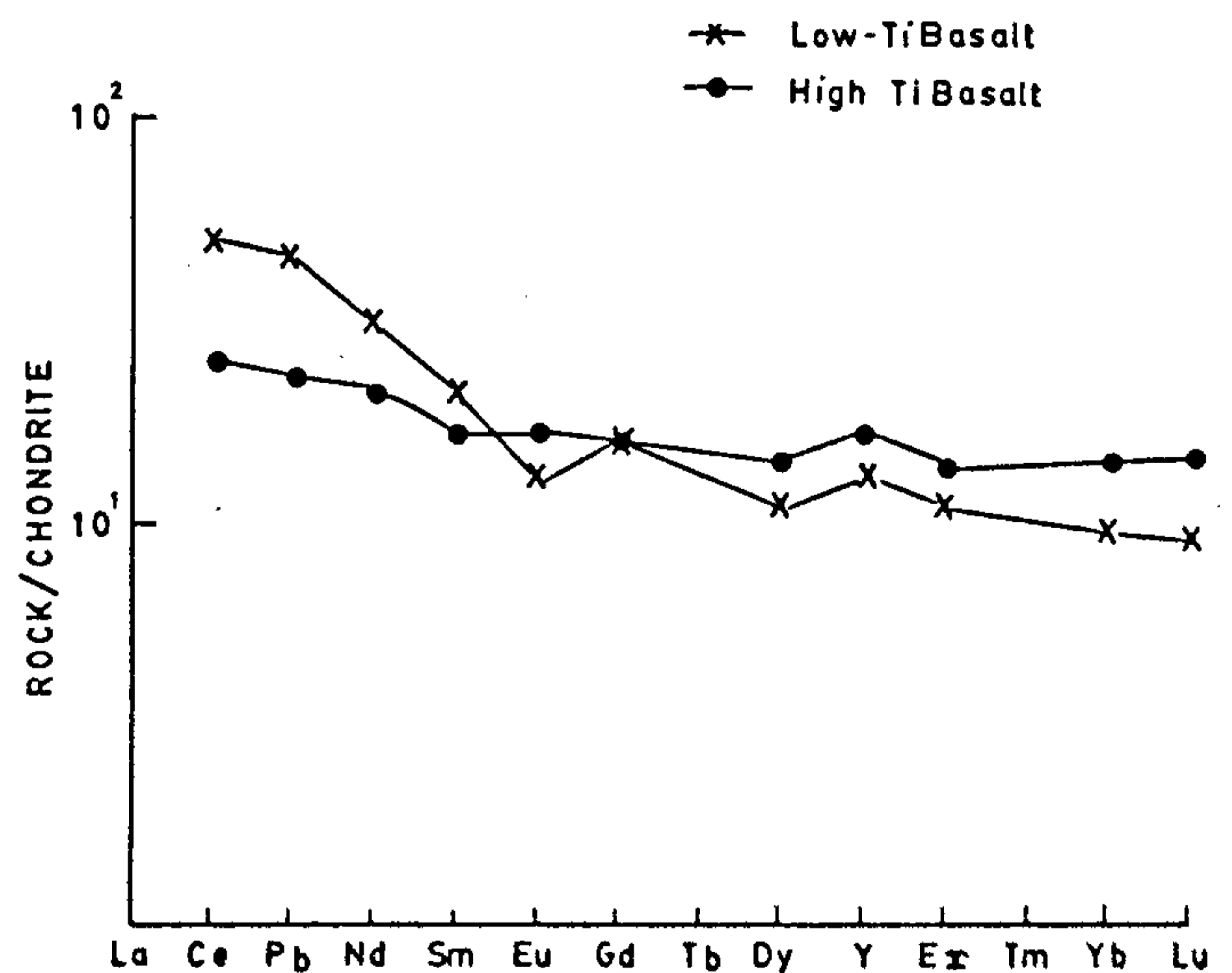


Fig. 3

Figure 3. Chondrite normalized REE patterns of representative samples of low-Ti and high-Ti volcanics, Khairagarh Group.

enough to produce calc-alkaline volcanics^{17,18}. High P_{H_2O} conditions in the generation of high-Ti suite is corroborated by the falling concentrations of V with fractionation. V versus Yb plot¹⁹ also indicates relatively

higher f_{O_2} conditions in the high-Ti suite, compared to the low-Ti volcanics; between QFM and higher than QFM + 1.

The mantle source of the low-Ti volcanics was LREE enriched (i.e. E-MORB and/or higher subduction flux²⁰) compared to the high-Ti volcanics. Higher proportions of garnet in the mantle residue of the low-Ti volcanics retained Ti, HREE and Sc compared to the high-Ti volcanics. Therefore, the subtle major and minor element differences between the arc-related high-Ti and low-Ti volcanics (Figures 1–3) are neither related to elemental mobility, nor can they be explained by clinopyroxene and plagioclase fractionation²¹, but are due to different degrees of partial melting of a heterogeneous mantle source (with respect to garnet) under different P_{H_2O} , f_{O_2} and subduction fluxing conditions.

The enriched MORB source of the low-Ti volcanics implies early stages of back-arc spreading, as in the Izu-Marianas arc or interarc rifting²⁰ and provides a simple explanation for the paradoxical presence of interlayered sedimentary formations of the Khairagarh Group⁷. Similarly, the presence of only tholeiitic lavas in the Khairagarh volcanics indicates the subduction of a relatively young and thin (< 20 km) oceanic plate with relatively high (> 7 cm/yr) convergence rates²².

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Unusual aspects of pressure-induced phase transitions in $CuGeO_3$

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High pressure Raman and optical studies on the spin-Peierls compound $CuGeO_3$ have revealed three novel pressure-induced phase transitions in the 7–8 GPa range. One of these occurring only under hydrostatic conditions, is believed to be a ferroelastic-ferroelectric phase. The other two high pressure phases are brilliant blue and green, respectively. Of these, the blue-phase is quenchable, while the green-phase reverts to the blue. From crystal chemistry, Raman spectral features and metastability considerations, it is suggested that the blue and the green phases have the pyroxene type chain structure similar to enstatite polymorphs, and non-hydrostatic pressure is essential for the formation of pyroxene type chain structures.

COPPER metagermanate ($CuGeO_3$) is a very interesting material, for it is the first inorganic system that exhibits the so-called spin-Peierls transition¹, when cooled below 14 K at ambient pressure. It is a very soft layer-type light blue material (like mica), crystallizing in the orthorhombic space² group $Pbmm$ (C_{2h}^5). The backbone of the structure consists of chains (parallel to the c -axis of the crystal) of corner shared GeO_4 tetrahedra linked by edge-sharing CuO_6 octahedral chain co-parallel to the GeO_4 chain², as shown in Figure 1 on the left. The structure is related to the pyroxene family minerals, viz. enstatite, but differs from it in having a unique arrangement of GeO_4 tetrahedra called 'einer' chain, stabilized