ABSTRACT
ABSTRACT

The northern part of the Indian shield hosts various Proterozoic rock sequences. The NE-SW trending Aravalli-Delhi belt occupies the northwestern margin of the Indian shield, which preserves one of the best developed Proterozoic supracrustal sequences of the Indian subcontinent. Although considerable amount of data is available on various aspects of geology in this area, very little attention has been given to its numerous mafic and ultramafic rocks, which are of both extrusive and intrusive nature. Such investigations may provide useful clues to understand the Proterozoic magma genesis and therefore, the evolutionary history of Aravalli region in particular and Proterozoic terrains in general. The Aravalli mountain range is constituted of various domains, viz, the Banded Gneissic Complex (BGC) which served as the basement for the younger supracrustal units of Bhilwara belt, Udaipur-Jharol belt, Delhi belt and the Vindhyan basin. These lithostratigraphic units ranges in age from early Archaean (3300 Ma) to late Proterozoic (550 Ma).

The Udaipur-Jharol belt occupies the central part of Aravalli mountain range and represents the Aravalli Supergroup rocks, which consists of two contrasting subfacies. The Udaipur belt represents the shallow water facies sequence and Jharol belt is considered to be the deep water facies, of the Aravalli Supergroup.

The Jharol belt, hosts deep water metasediments including mica schists, phyllite and thin bands of quartzite, also contains numerous mafic ultramafic rocks. The volcanic rocks are distributed at two different stratigraphic levels. The Bagdunda volcanics occur at the base, having unconformable relationship with the Archaean basement (BGC) and Gopir volcanics and dykes, occurring at higher stratigraphic levels is associated with ultramafic magmatic rocks. The ultramafic
rocks are confined to two major lineaments. One at the eastern margin of Jharol belt referred to as Rakhabdev lineament which is devoid of any mafic rocks (as per the data available) and the other is referred to as Kaliguman lineament (which runs along the central part of Jharol basin between Gogunda in the north and Damana in the south) located at the west central side of Jharol belt roughly marking the boundary between Jharol and Delhi belts. The latter lineament comprises both mafic and ultramafic rocks (subject of the present current study).

Their mode of occurrence, despite deformation and metamorphism (up to the grade of green schist facies), indicates their eruption and emplacement contemporaneously with sedimentation in Jharol basin. The eruptive nature of these volcanics is indicated by the intercalation of Bagdunda volcanics with fine grained quartzite bands, the presence of deformed amygdules and intercalation between the Jharol ultramafic rocks and fine grained quartzite bands.

The mafic-ultramafic rocks of Jharol belt have suffered multi-phase deformation and regional metamorphism up to the grade of green schist facies therefore, the primary mineralogy and textures have generally been obliterated. However, the petrographic and mineralogical features of these rocks can be used to classify them into different varieties. The ultramafic rocks do not have any spinifex texture or any other similar texture. These rocks are of three main varieties: (1) consisting predominantly of serpentine (antigorite), which may represent the alteration products of olivine and pyroxene, (2) essentially constituting of chlorite in random orientation, which was probably formed in response to metamorphic and alteration processes and (3) consisting mainly of actinolite-tremolite with variable proportions of talc, asbestos and carbonates. The Gopir mafic volcanics and dykes on the other hand, contains more than 50% hornblende ± quartz ± plagioclase and are fine to medium grained varieties. However, the dykes are massive and coarse grained rocks. Bagdunda volcanics display uniform mineralogical assemblages and textural relations. They consist of amphiboles with variable quantities of plagioclase and quartzite. Opaques are mainly magnetite and ilmenite. In less altered samples relics of clinopyroxene and plagioclase feldspar sometimes are seen.
Least altered samples have been selected for analyses in this study. Forty seven mafic samples representing both Gopir and Bagdunda volcanics and dykes were analysed for major, trace and rare earth elements. However, due to the altered nature of the ultramafic rocks, only thirteen samples were analysed for major element and few selected trace elements (Ni, Cr, V and Co).

Compositional changes due to secondary processes are expected particularly in ancient volcanic rocks. Jharol volcanics and dykes have been regionally metamorphosed and they have been subjected to intensive deformation. Therefore, in order to determine the nature and extent of mobility of various elements and to assess the effect of secondary processes on these rocks before using them for any petrogenetic consideration, have been verified by using various diagrams and chemical criteria. On the bases of their REE patterns and a combination of their ratios (CaO/TiO₂, Al₂O₃/TiO₂, CaO/Al₂O₃, MgO/TiO₂, FeO'/MgO, Zr/Y, Y/Nb), various major oxides (TiO₂, SiO₂, P₂O₅, Al₂O₃, MgO) and Trace elements (Zr, Nb, Y, Cr, Ni and the REEs) we infer that these mafic rocks have not suffered any serious elemental mobility. However, our interpretation are based preferentially on minor and trace elements including REE which are considered less mobile.

Chondrite normalized REE patterns of Gopir volcanics range from LREE depleted [avg. (Ce/Sm)_N = 0.55) and (Ce/Yb)_N = 0.75] through to nearly flat patterns [avg. (Ce/Sm)_N=1.12 and (Ce/Yb)_N=1.23]. The dykes on the other hand are LREE enriched [avg. (Ce/Sm)_N=2.07 and (Ce/Yb)_N=5.05]. The REE patterns of Bagdunda volcanics are remarkably similar to each other, displaying LREE depleted patterns resembling N-type MORB, with more depleted nature than those of Gopir samples. However, the REE concentrations in both the volcanic suites, do not show any relationship with their Mg-numbers. This may suggest their derivation by complex petrogenetic processes or their generation from a heterogenous mantle source by different extents of melting with each magma phase undergoing fractionation independently. The overall smooth REE patterns of these rocks probably suggest that most of their REEs are not affected by post crystallization mobilization processes.
In order to classify the magma type(s) of Gopir and Bagdunda volcanics and dykes, they are plotted in various diagram which are based on immobile or less mobile elements during the secondary processes. In AFM diagram, these volcanics follow the iron enriched trend suggesting their tholeiitic nature, although the classification remains doubtful due to the mobility of alkalis. Their tholeiitic nature is also confirmed from their FeO'/MgO versus FeO' and TiO₂ diagrams. Their Mg-Fe enriched nature is illustrated from Jensen’s plot, where both the suites are classified as high Mg rocks, ranging from high Mg-tholeiite to basaltic komatiite. This observation is also supported by their Zr+Y-Cr-TiO₂ x 100 (YTC) ternary variation diagram which is analogous to AFM diagram, but better constrained. Other diagrams based on minor and trace elements (Nb/Y versus Zr/P₂O₅, P₂O₅ versus Zr and Zr/TiO₂ versus Nb/Y) confirm the tholeiitic basalt affinity of Gopir and Bagdunda samples.

Major and trace elements relationships of these volcanics and dykes illustrate the role of partial melting and fractional crystallization in their evolution. The relationships of CaO/Al₂O₃ versus TiO₂, FeO'/MgO versus CaO/Al₂O₃, CaO/TiO₂ and Al₂O₃/TiO₂ versus TiO₂, Zr versus TiO₂ and Ni versus Cr suggest possible fractionation of olivine and clinopyroxene. Moreover, plots of Si/Zr versus (Fe+Mg+Mn)/Zr (in cation %) also indicate fractionation of olivine and clinopyroxene. Al₂O₃, TiO₂ and CaO relationships suggest that both the suites may be related to similar source and were generated by various degrees of partial melting and fractionation of olivine and clinopyroxene in various proportions, at various stages of melting. The lack of negative Eu (except for the dyke samples) and Sr anomalies in most of the REE and PM-normalized multi-element patterns of these volcanics, also suggest that plagioclase fractionation was insignificant.

In Al₂O₃ versus FeO'/(FeO'+MgO) diagram, these magmatic rocks show their tholeiitic to komatiitic affinity, indicating their transitional nature and reflecting their aluminum undepleted nature. Trends of Gopir and Bagdunda volcanics and dykes suggest their generation by various degrees of partial melting and fractionation of olivine and clinopyroxene in various proportions.
The Mg-numbers and MgO contents of Gopir volcanics and dykes (50.28 to 63.73; 8.2% to 13.4% and 56.15 to 68.16; 10.5 to 14.4 respectively) and Bagdunda volcanics (48.81 to 66.90; 7.7% to 12.7%) suggest that they have undergone magmatic differentiation. The more primitive nature of Gopir volcanics and dykes compared to Bagdunda volcanics is also suggested by the abundances of compatible trace elements (e.g., Ni, Cr etc.).

The moderately enriched nature (except for LREEs) of these volcanics is reflected by their incompatible element concentrations and ratio patterns. However, Gopir volcanics are relatively more enriched than Bagdunda volcanics. The chemical features of these volcanics overwhelmingly indicate that the compositional characteristics of these rocks have been inherited from their mantle source, rather than ascribing these features as a result of crustal contamination.

The insignificant effect of crustal contamination on Gopir and Bagdunda volcanics can be demonstrated from the presence of positive Nb anomalies for all the samples (except for GRV30). This is further evident from their high FeO' and TiO₂ content. Moreover, the relationships of Zr-Y, Zr-Nb and Zr-TiO₂ clearly depict their enriched source characteristics. The Ce versus Nd diagram strongly puts limitations on the possibility of their contaminated nature and suggest that these volcanics represent variable degrees of melting ranging from less than 10% to higher degrees ca. 25%.

The uncontaminated nature of Gopir and Bagdunda volcanics and dykes is also illustrated in their various primordial mantle normalized multi-element patterns, their plots in Y/Nb versus Zr/Y and their double normalized ratio plots (Ratio(rock)/Ratio(PM)) of trace elements which are usually known to be less effected by fractional crystallization and high degrees of partial melting (expected for tholeiitic basalts). Therefore, the observed characteristics of these volcanics are considered to be related to their mantle source.

The discrimination diagrams, based on major elements (Al₂O₃, MgO, CaO and FeO'), minor (TiO₂ and P₂O₅) and trace elements (Zr, Y and Cr) show oceanic affinity
of these volcanics. In fact N-MORB normalized multi-element patterns for averages Gopir and Bagdunda volcanics appear to reflect trace element characters transitional between N-MORB and OIB. The dykes on the other hand show continental tholeiites signatures.

Petrogenetic modelling based on the compositionally corrected [Mg] and [Fe] abundances for Gopir and Bagdunda volcanics and dykes indicates: (a) their derivation from non-pyrolitic source as both the volcanic suites and dykes plot outside the calculated fields, (b) their derivation from sources which were variably enriched in [Fe/Mg] ratio with large variation in their [Fe] contents, (c) olivine was a major phase to fractionate followed by lesser amount of clinopyroxene in case of Gopir volcanics, whereas in Bagdunda volcanics a combination of olivine and clinopyroxene fractionation is suggested, (d) Gopir dykes have restricted [Fe] for similar [Mg] with respect to the Gopir volcanics. Overall Gopir volcanics are more enriched in terms of [Mg] and [Fe] than Bagdunda volcanics, indicating the higher degrees of partial melting of more fertile source for the Gopir volcanics. This diagram again indicates that plagioclase was not a major fractionating phase.

Various tectonic models have been put forward to propose a tectonic model for the evolution of Jharol belt, but none of these models, involving Wilson cycle to resurgent rifting, have considered geochemical evidences. A synthesis of the chemical characteristics of Gopir and Bagdunda volcanics and dykes supported by field evidences indicate their similarity with those of rift environments. Overall features of these volcanics can be explained by a situation where plume related lithospheric extension produced intra-cratic (BGC) and marginal basin rifts, probably during the late Archaean-early Proterozoic period. Progressive rifting in this area caused episodic magmatism in the intra cratic basins represented by Bhilwara, Udaipur belts and in Jharol basin, which developed at the margin of the BGC craton.

In Jharol belt, during initial opening of the basin, attenuation of crust (which was naturally thin from the beginning) and rise of asthenospheric mantle generated
basic melts which reached the surface and got intercalated with contemporary sediments, which is now represented by Bagdunda volcanics. With progressive rifting, further attenuation of crust resulted in the second phase of melting both in the asthenospheric source below the Jharol basin and sub-continental lithosphere below the BGC, generating the Gopir volcanics and dykes respectively. At this stage of rifting an oceanic crust very similar to those in marginal sea developed in the Jharol basin. The magmas with their uncontaminated nature indicated that these melts did not interact with crust which was highly attenuated.

Detailed synthesis of the available data indicated that the basal Aravalli volcanics (Udaipur belt), the basal Jharol volcanics (Bagdunda volcanics) and the younger volcanics and dykes (Gopir volcanics), probably came from different sources. This is evident from the LREE and LILE enriched nature of the basal Aravalli volcanics and Bhilwara volcanics with distinct negative HFSE anomalies, which indicate their sub-continental lithospheric source characteristics. On the other hand, the Gopir and Bagdunda volcanics (Jharol volcanics) are LREE depleted with positive Nb anomalies and with high Nb/Ce ratios, probably indicate their generation from asthenospheric source with variable influence from mantle plume (OIB source). The mafic and ultramafic rocks being less abundant than the associated sediments, opens the possibility that the mafic-ultramafic rocks of Kaliguman lineament may actually represent a suture zone within the Jharol marginal sea/ocean basin.