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# Contrasting origin of Ladakh block ophiolites along Indus Suture Zone, Ladakh Himalaya, Jammu and Kashmir

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## ABSTRACT

*In Ladakh Himalaya, ophiolitic slices represent the remnants of the Neo-Tethys ocean existed between Indian and Eurasian continental plates during the Mesozoic-Cenozoic Eras. In Ladakh area, these ophiolitic slices are now present as tectonic slices emplaced along the Indus Suture Zone (ISZ) during the late Cretaceous period. The ophiolite peridotites are moderately to highly serpentinized with serpentine pseudomorphs of olivine and pyroxene. Rare earth element (REE) and multi-element patterns of the Ladakh ophiolitic peridotites suggest contrasting origins. The moderately to highly depleted nature of Nidar peridotites reflect supra-subduction zone origin while as, Shergol serpentinized peridotites are moderately depleted similar to abyssal peridotites suggesting mid-ocean ridge tectonic setting. On the basis of Cr-spinel geochemistry, Shergol peridotites are characterized by high-Al low-Cr spinels whereas, Nidar peridotites are characterized by high-Cr low-Al spinels.*

***Keywords: Ladakh Himalaya, Indus Suture Zone, mid ocean ridge, Shergol ophiolite, Rare Earth Elements***

## I.INTRODUCTION

Ophiolites are key features for unraveling the geological history not only the oceanic lithosphere (as it provides the only direct way to study the oceanic lithosphere) but most importantly of the orogenic belts like Himalaya. The Alpine-Himalayan orogenic belt is a result of collision between two continental land masses, Gondwana on south and Eurasia on north during Late Mesozoic-Early Cenozoic, preceded by the consumption of the Tethys Ocean that separated these two continental plates [1,2]. In northern India this collision manifests itself in the form of Indus Suture Zone (ISZ) representing a collage of different units that record the closure of the Neo-Tethys Ocean [3,4,5]. During this collision some remnants of the Neo-Tethys escaped subduction and were obducted that are now present as ophiolitic slices along the ISZ. In Ladakh Himalaya, the ISZ exhibits two groups of ophiolites and their associated ophiolitic mélanges [6]. The Dras and the Shergol dismembered ophiolitic slices form the first group, also known as northern ophiolite group while the second group consists of Spontang and Nidar ophiolite complexes, also known as Southern ophiolite group.

The various questions regarding the origin of Ladakh ophiolites whether they are produced at mid-ocean ridges (MOR) or in supra-subduction zone (SSZ) settings are still debated. The aim of this contribution is to compare

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Ladakh block ophiolites particularly Shergol and Nidar ophiolitic slices on the basis of whole-rock and mineral geochemistry data in order to put constraints on geodynamic processes active in the Neo-Tethys Ocean.

## II. STUDY AREA

The Ladakh block (Fig. 1) occupies the central position in the Himalayan mountain belt and is delimited by the ISZ on south and Shyok Suture Zone (SSZ) or Northern Suture Zone on north [7]. This block comprises from south to north the Lamayuru flysch, Jurassic-Cretaceous Dras island arc volcanics, Indus molasse and Ladakh batholith [8]. The ophiolitic slices along the ISZ from NW to SE are; Dras-Shergol ophiolitic slices [9,10], Spontang ophiolite complex [11,12] and Nidar ophiolite complex [13,14,15]. The Shergol ophiolitic slice near Shergol village (30 km south of Kargil district), is associated with the Shergol sedimentary Formation dominantly includes serpentinized peridotites with minor diabase's and gabbros [5,10,16] Towards south-east Ladakh, the Nidar ophiolitic complex crops out along the ISZ and comprises three lithological units; a crustal section of basic to intermediate lavas, a thick massive gabbro in the middle and spinel-peridotite at the bottom [13,17].

Earlier Lydekker [18] recognized and described mafic and ultramafic rocks from ISZ. De Terra [19] applied the Steinmann's [20] ophiolite concept to these mafic and ultramafic rocks and was followed by many other later workers [e.g., 3,5,6,8,15,16,21-26].

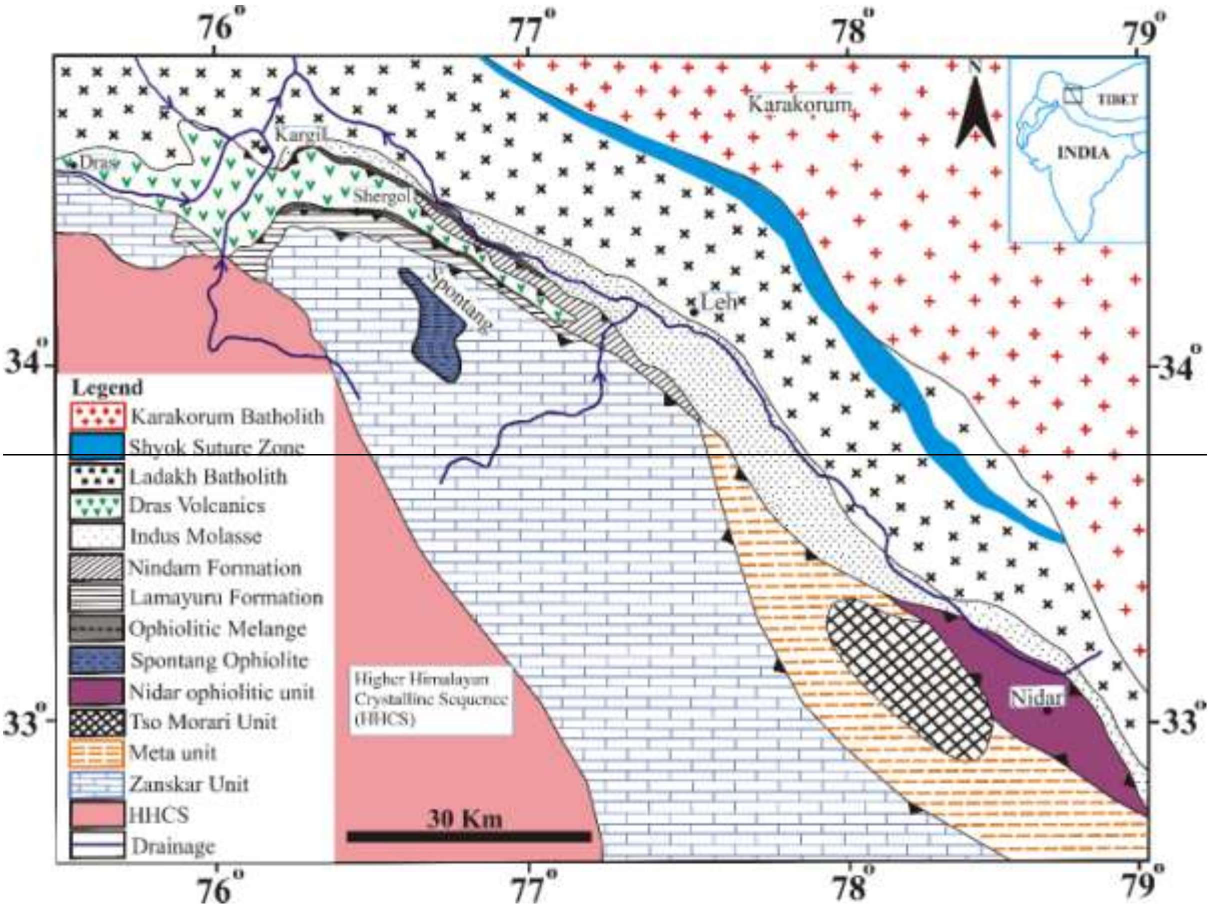


*Figure 1. Geological map of the NW-Himalaya modified after Frank et al. [3] and Maheo et al. [15] showing the occurrence of the Ladakh ophiolitic units along Indus Suture Zone.*

## III.ANALYTICAL DATA-SETS USED

For the present comparative study, we have used geochemical data (i.e., whole-rock and spinel mineral chemistry) on Shergol serpentinized peridotites from our published papers [27,28] whereas, for South Ladakh ophiolite peridotites i.e., Nidar and Spontang ophiolitic slices, we have used data from Maheo et al. [15].

## IV. DISCUSSION

In terms of major element geochemistry, the Shergol peridotites have similar geochemical characteristics to that of Nidar and Spontang peridotites, both represent residual mantle peridotites [15,27]. However, their trace element and Cr-spinel chemistry is quite distinct and reflect complex origin. The Shergol spinels are characterized by high-Al low-Cr compositions whereas, Nidar spinels have high-Cr and low-Al composition. Nidar Spinels have high $Cr^{3+}$# [cationic ratio of $Cr^{3+}/(Cr^{3+} + Al^{3+} + Fe^{3+})$] ranges from 0.5 – 0.6 [15], higher than that of Shergol peridotites where it ranges from 0.34 – 0.40 [28] typical of the oceanic abyssal peridotites [29]. The $Cr^{3+}$# of Nidar peridotite spinels is similar to that observed for peridotites associated with supra-subduction zone setting [30].

The Chondrite-normalized rare earth element (REE) and primitive mantle-normalized multi-element patterns of the Shergol peridotites in comparison to Spontang and Nidar harzburgites are shown in figure 2. The Shergol peridotites show a characteristic U-shaped chondrite normalized REE-patterns with higher concentration than Nidar and Spontang harzburgites (Fig. 2a). Similarly, their multi-element patterns are quite distinct thereby reflect more depleted nature of Nidar and Spontang harzburgites than Shergol peridotites (Fig. 2b). In Nidar and Spontang harzburgites, the multi-element patterns are comparable to sub-arc mantle settings [31] as compared to Shergol peridotites which show affinity to mid-ocean ridge peridotites [32]. However, the strong enrichment of LILE (Rb, Ba, U, Pb, Sr) in highly depleted Nidar and Spontang harzburgites reflect extensive metasomatism in their mantle source as commonly observed in sub-arc mantle settings such as the Mariana fore-arc [30].

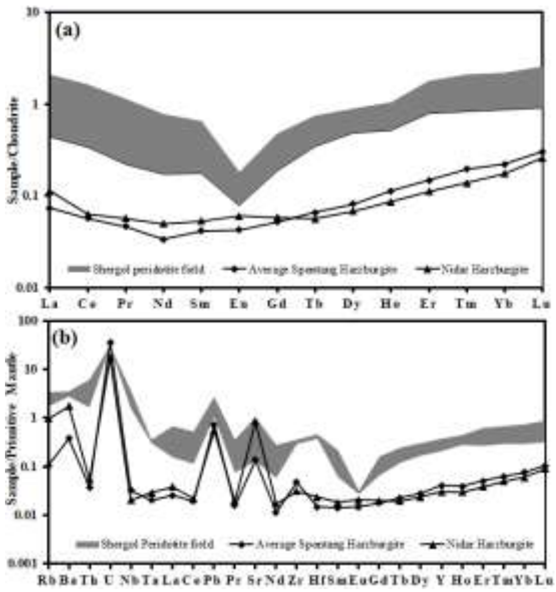

*Figure 2. (a) Chondrite-normalized REE patterns and (b) primitive mantle normalized multi-element patterns of the Shergol serpentinized peridotites in comparison to Spontang and Nidar harzburgites. Chondrite and primitive mantle normalization values are from Sun and McDonough, [33]. Shergol peridotite field is from Bhat et al. [27] while Spontang and Nidar harzburgite data is from Maheo et al. [15].*

In mantle peridotites, Cr-spinel composition can be used to infer the geodynamic setting of host peridotites [29,34,35]. In a plot of $Cr^{3+}$# [100 x $Cr^{3+}/(Cr^{3+} + Al^{3+} + Fe^{3+})$] against $Mg^{2+}$# [100 x $Mg^{2+}/(Mg^{2+} + Fe^{2+})$] (Fig. 3), the Shergol peridotites plots distinctly in abyssal peridotite field in comparison to Nidar peridotites which show a mixed field of abyssal and SSZ peridotites. According to Zhou et al. [36], high-Al low-Cr spinels are a result of lower degrees of partial melting at MOR tectonic setting whereas, low-Al high-Cr Cr-spinels are a result of moderate to higher degrees of partial melting of a depleted mantle at SSZ tectonic affinity. The $Cr^{3+}$# of Shergol peridotites (0.34 - 0.40) is lower than that of Nidar harzburgites (0.5 - 0.6) which are thought to be evolved in subduction zone setting [15] however, is lower than that of Tso Morari (Ladakh, Himalaya) serpentinites [37]. Thus it is concluded on the basis of spinel chemistry that the Shergol peridotites were originated in a MOR tectonic setting [28] whereas, Nidar peridotites have affinity to SSZ setting [15].

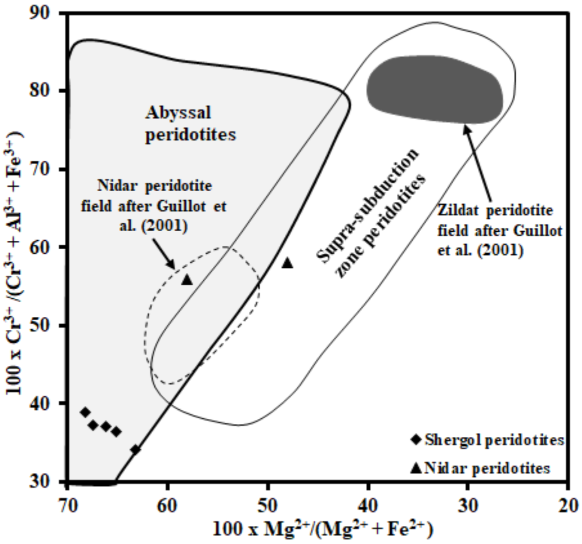


*Figure 3. Plot of $Mg^{2+}$# against $Cr^{3+}$# showing Cr-spinel core compositions of Shergol peridotites after Bhat et al. [28] in comparison to Nidar peridotites after Maheo et al. [15]. Cr-spinel compositional fields of Zildat and Nidar peridotites are from Guillot et al. [37], abyssal peridotite field from Dick and Bullen, [29] and supra-subduction zone peridotite field from Ishii et al. [38].*

As the ophiolites are thought to represent on-land analogues of the oceanic crust and depleted upper mantle [39] formed not only at MOR but in other tectonic settings associated to subduction zones such as, back arcs and fore arcs [40,41]. The absence of the sheeted dike complex in Nidar ophiolite reflects its origin in a tectonic setting other than MOR environment possibly an intra-oceanic arc setting. Although sheeted dike complex is not a key feature of ophiolites to suggest MOR tectonic setting, but still MOR environment is the only setting were sheeted dike complex is generated [42]. The geochemistry of the Tethyan ophiolites of the Mediterranean region such as, Mirditi, Vourinos, Pindos, Troodos, Kizildag and Oman ophiolites suggest their origin in a SSZ settings

[43,44]. Earlier Radhakrishna et al. [24], studied the geochemistry of Dras ophiolite and suggested MOR tectonic setting. Therefore, it is concluded that the ISZ preserves the ophiolites of mixed origin with Shergol-Dras peridotites originated at MOR while as, Nidar and Spontang peridotites originated at SSZ tectonic setting in the context of Mesozoic Neo-Tethys Ocean.

## V. CONCLUSION

The Ladakh block ophiolites represent the remnants of the Neo-Tethys Ocean and originated in various geotectonic settings. The paucity of the sheeted-dike complex in the stratigraphic section of Nidar ophiolite reveals its generation other than mid ocean ridge. Based on present comparative study using trace element and spinel mineral chemistry data, it is concluded that the ISZ preserves the ophiolites of complex origin with Shergol-Dras peridotites of mid ocean ridge tectonic affinity while as, Nidar-Spontang peridotites of supra-subduction zone tectonic setting in the context of Mesozoic Neo-Tethys Ocean. This comparative study of the Ladakh block ophiolites puts light on the complex geodynamic processes operative in the Neo-Tethys Ocean.

## VI.ACKNOWLEDGEMENT

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