

SERPENTINITE FROM NIDAR OPHIOLITE COMPLEX OF LADAKH, INDIA : IMPLICATIONS FOR AQUEOUS ALTERATION TO EARLY MARS. D. Ray¹, A.D. Shukla¹, S. Bhattacharya², R. Singh³, and T. Nirmal Kumar¹, ¹Physical Research Laboratory, Ahmedabad, India 380009 (dwijesh@prl.res.in), ²Space Applications Centre, Ahmedabad 380015, India, ³Semi-Conductor Laboratory, Punjab 160071, India.

Introduction: On Earth, serpentinisation vis-à-vis alteration and or water/rock interaction of mantle peridotites has been common and particularly observed in ultramafic rocks on the seafloor, subduction zone and on continents as ophiolites.

Serpentinites on Mars were discovered from Noachian terrain and suggested for early “wet” Mars [1,2]. One of the major limitations to understand Martian serpentinisation is lack of in-situ data (except in a few Nakhlite meteorite) and also the orbital remote sensing data lacks the crucial ground truth information. Therefore, better understanding the serpentinisation and interpretation of remote sensing data sets are likely to be achieved via careful mineralogical examination and subsequent verification of spectroscopic data sets from terrestrial analog sites.

Olivine-rich protoliths are prerequisite for serpentinisation. Continental serpentinisation always plays a natural laboratory to study present day serpentinisation and also important for other terrestrial planets and Moon have mafic and ultramafic crust and thus can provide new insights on “habitable environments in the Universe”. The Nidar ophiolite complex in Indus Suture Zone of higher Himalaya is ideal for comparative planetology as the entire mantle sequence has been well exposed with variegated lower crustal and mantle units. More importantly, Nidar is located in extreme cold environment, insolation condition of Ladakh.

The present communication is aimed for discussing mineralogy and geochemistry of serpentinite to assess condition of serpentinisation. Additionally, this study will also help to assess the Mars’ ancient aqueous alteration and therefore will be helpful to develop strategy for future planetary exploration.

Geological setting: The Nidar Ophiolite complex in SE Ladakh is one of the well exposed Ophiolite suites in the Indus Suture Zone that separates the Indian plate in the south from Asia to the north (Fig. 1,[3]). Apart from Nidar, the other ophiolite complex is Spontang ophiolite complex. From top to bottom, the ophiolite sequences follow typical ocean lithosphere units- the uppermost radiolarian chert and basalt, middle section mainly consists of gabbro. The formation age of the SE Ladakh ophiolite including the Nidar ophiolite is poorly constrained. The best available date so far is based on radiolarian chert and yields an age range from Cretaceous to Eocene. However, ocean floor metamorphism provides an age of ~130 Ma.

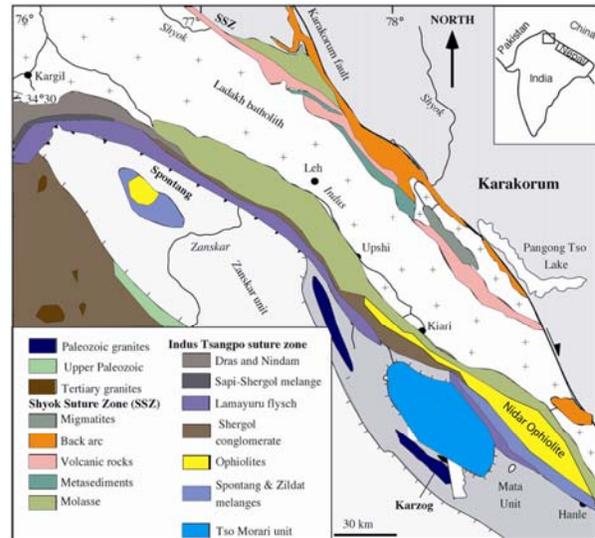


Fig. 1. Geological map of Ladakh (modified after [3]). Based on modes of occurrences, the peridotites of the basal Nidar Ophiolite can be classified into three types: (1) peridotites cut by the discordant dunite; (2) the discordant dunite; and (3) the peridotites entrapped within the channelized dunites [4].

Mineralogy and Geochemistry: Dunites are mostly prone to alteration and characteristically develop typical mesh texture (Fig. 2), however, relict grains of olivines are also preserved despite serpentinisation. Magnetite and chromite are also found. Serpentinites along the fractures of megacrystic olivines are also common. In contrast, pyroxenes look relatively fresh. Parallel veins of serpentinite are also noticed and appear to postdate the mesh network (Fig. 3).

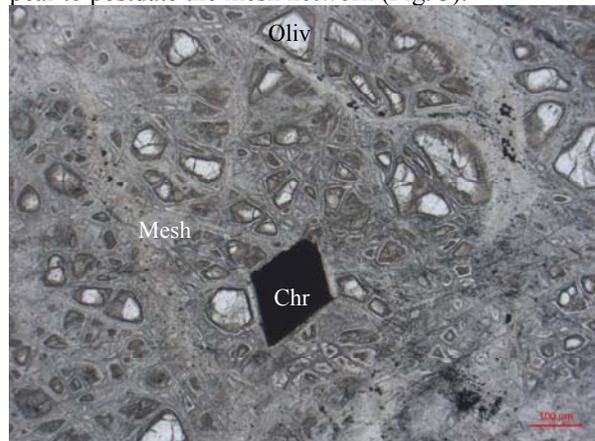


Fig. 2. Serpentine mesh textures with relict olivine at mesh centre. Euhedral chromite grain also seen (under

PPL). XRD analyses of serpentine shows typical peaks for serpentine pseudomorphs lizardite (7.33\AA , 2.50\AA) and antigorite (7.25\AA , 2.53\AA).

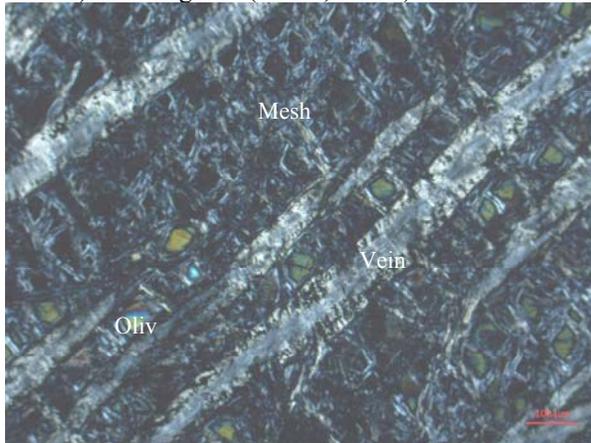


Fig. 3. Parallel veins of serpentine. Relict grains of olivine also seen with mesh texture (under XPL).

Stable isotope Geochemistry: Serpentinised peridotites exhibit a depleted range of whole rock $\delta^{18}\text{O}$ values, from 2.7 to 4.1‰ as compared to pristine mantle peridotite ($5.5 \pm 0.2\text{‰}$). At temperature of 250-350°C, water/rock ratios of 0.1-1 produces serpentinite having $\delta^{18}\text{O}$ of ~2-5‰. The presence of relict olivine probably suggests low water/rock ratio. Carbon stable isotope measurements from Nidar carbonates show negative and restricted $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values (mean -11.11 and -15.48‰ VPDB).

Spectroscopic data: Samples with high MgO content (>32%), dominantly serpentinites, exhibits similar spectral features. The band centres (calculated after continuum removal) for spectral feature near 2300 nm is observed to be very near to each other (2325-2328 nm) and lacks any discernible dependence on the composition of metal cations. This implies the same process and same species are involved. This band is caused due to metal-OH stretching and the 2320 nm position is assigned to $\text{Mg}_3\text{-OH}$ for a serpentine [5]. To further confirm the Mg-rich type, a doublet unique to serpentine is observed at 2110 nm and 2130 nm along with a weak overtone of $\text{Mg}_3\text{-OH}$ at 2430 nm (Fig. 4).

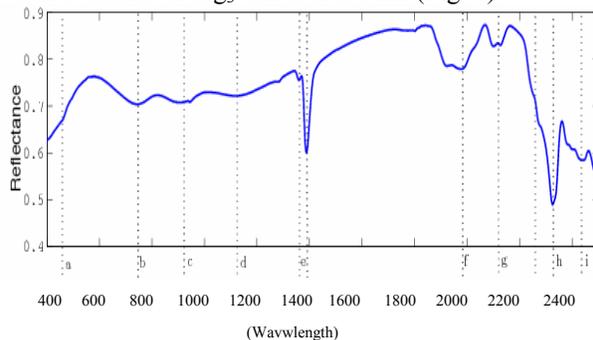


Fig. 4 Visible-near infrared spectra (using FieldSpec) of Nidar serpentinite. a. spin forbidden tetrahedrally coordinated Fe^{3+} , b. $\text{Fe}^{2+}/\text{Fe}^{3+}$ intervalence charge transfer, c,d. electronic transition of octahedrally coordinated Fe^{2+} , e. $-\text{OH}$ (hydroxyl ion), f. H_2O (water).

Discussion: Degree of serpentinisation has almost attained 100% for olivine-rich protolith while pyroxene-rich samples suffered relatively less effect of serpentinisation. The Nidar serpentinites dominantly show mesh texture with often parallel veining suggests serpentinisation is not strictly in static condition. Low bulk silica (SiO_2 ~36 to 45 wt%) and higher MgO (32 to 40 wt%) content indicates predominance of olivine-rich precursor (probably dunite). Further, Nidar serpentinites fall under depleted mantle field in SiO_2 versus MgO space. The depleted nature is further confirmed by the oxygen isotope data. The upper temperature limit of mineral alteration is controlled by the stability of olivine and pyroxene. In the presence of a fluid and an elevated SiO_2 activities, pyroxene decomposes faster as compared to olivine at temperature >350 to 400°C. In contrast, serpentinisation of olivine is faster as compared to pyroxene decomposition at temperature <250°C [6,7]. The pyroxene of Nidar peridotite appears to remain intact while olivine is strongly serpentinised suggest serpentinisation temperature of <250°C.

There is no evidence found formation of carbonate veins are attributed to seawater derived fluids. Rather meteoric water (or hydrothermal fluid) interacted with peridotite appear more reasonable for negative $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values.

The presence of serpentinites and carbonates at Nidar ophiolite complex resembles Mg-carbonate and Mg-serpentinite discovered at Nilli Fossae, Mars [1]. Olivine-rich ultramafic crust and low water/rock ratios of Nidar serpentinite suggests similar process might have prevailed and invoked serpentinisation on Mars. This could be a potential site for exploring abiogenic methane and to understand Martian habitability.

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References: [1] Ehlmann B. et al. (2010) *GRL*, 37, L06201. [2] Carter J. et al. (2013) *JGR*, 118, 831-858. [3] Mahéo G. et al. (2004) *Chem. Geol.*, 203, 273-303. [4] Das S. et al. (2015) *Geol. Soc. Spec. Pub.* 412, <http://doi.org/10.1144/SP412.12>. [5] Clark R.N. (1990) *J Geophys Res.*, 95, 12653-12680. [6] Bach W. et al. (2004) *Geochim. Geophys. Geosyst.*, 5(9): 22. [7] Frost B.R. and Beard J.S. (2007) *J Petrol.*, 48(7), 1351-1368.