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# Tracing Paleo-Redox Conditions During Serpentinization in Neo-Tethyan Ophiolites: Evidence from the Himalayan Orogen

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Serpentinization involves a series of hydration reactions in which the primary minerals, such as olivine and pyroxenes, transform into serpentine minerals, releasing hydrogen ($H_2$) and methane ($CH_4$). Remnants of the oceanic lithosphere, commonly preserved as ophiolites, serve as important archives for the study of serpentinites. In the Himalayan region, fragments of the Neotethyan oceanic lithosphere are exposed along the Indus Suture Zone (ISZ) and Indo-Myanmar Ranges. Petrographic studies of the serpentinites reveal that the degree of alteration depends primarily on the temperature-pressure condition of serpentinization, water-rock ratio, chemistry of serpentinizing fluid, and primary mineralogy of the protolith. These parameters are strongly influenced by the tectonic setting of the formation of the ophiolite and the nature and stage of the subduction and obduction processes involved. Lizardites and antigorites occur as dominant serpentine phases in Himalayan Neotethyan ophiolites, whereas chrysotile occurs in minor amounts in a few samples. Olivines are altered to form lizardites, exhibiting characteristic mesh and hourglass textures. Antigorites occur either as massive aggregates showing interpenetrating planar textures or as veins crosscutting earlier-formed lizardite. Chrysotiles are present as minor veins cutting primary lizardites and antigorites or as filling along the cleavage plane of relict pyroxene, which display folding and kinking, indicating deformation during serpentinization. Pyroxenes sometimes display bastite texture, where the lizardite pseudomorphs the primary pyroxene. Mineral chemistry and whole-rock major and trace element data from the Himalayan Neotethyan serpentinites record the signature of both mid-ocean ridge (MOR) and supra-subduction zone (SSZ) settings. Serpentinites are formed at spreading centers by alteration of the sea floor and are later obducted onto the accretionary prism during subduction. In subduction zones serpentinites are formed by the interaction of overriding oceanic lithosphere with downgoing slab-derived fluids and are later emplaced onto continental margins during ocean closure. Ultramafic rocks also contain various secondary base metal sulfides and metal alloys, which indicate the paleoredox condition of serpentinization. The presence of sulfide mineral assemblages such as awaruite and pyrrhotite is indicative of a reducing condition during serpentinization, whereas the presence of heazlewoodite and millerite indicates higher water-rock ratios and more oxidizing conditions during serpentinization.