ABSTRACT

Fragments of eclogite-facies oceanic crust preserved along the suture zones record the thermal history of burial and exhumation cycles in fossil subduction zones. Reports of oceanic high-pressure (HP) to ultra-high pressure (UHP) /low-temperature metamorphic rocks, including eclogites, are rather rare in the Himalayan segment of the Alpine-Himalayan mountain chain. Although eclogites were previously reported from the Nagaland Ophiolite Complex, NE India, considered to be the south-eastern extension of the Yarlung-Tsangpo Suture Zone, their metamorphic evolutionary history, relationships with other high-pressure metamorphic rocks in the terrane and the timing of eclogite facies metamorphism are not well understood at present. In this study, an attempt has been made to establish the source reservoir and tectonic setting of HP/LT metamorphic sequence and the timing and thermal history of HP to UHP metamorphosed oceanic eclogites from two new locations in the Nagaland Ophiolite Complex (NOC), NE India. An integrated approach of geochemical, petrographic, mineral chemical, metamorphic evolutionary history, results of conventional geothermobarometry, phase equilibria modelling, and sensitive high-resolution ion microprobe (SHRIMP) U-Pb dating techniques has been applied to achieve the objectives.

Previous studies reveal the NOC to be the largest exposed remnant of an array of HP/LT metamorphic rocks within the eastern Neo-Tethys. Newly discovered eclogites in both the locations near Thewati and Mokie villages, occur as ~5 to ~50 m long and ~2-5 m wide tectonic lenses within a lawsonite blueschist facies metamorphosed package of oceanic basalt-limestone-radiolarian chert (peak P-T at ~11.5 kbar, ~340^{o}C).

Major, trace, and rare earth element chemical study of metabasic rocks ranging in grade from greenschist (GS) through pumpellyite-diopside (PD), lawsonite blueschist (LBS) to epidote eclogite (EC) facies and mineral trace element study of selected rocks from the same sequence reveal a common feature of these rocks in recording (a) a subalkaline basalt lineage, (b) generally flat to light rare earth element (LREE)-depleted patterns in chondrite normalised REE plots, with a few rocks additionally showing mildly enriched LREE patterns, (c) relative enrichments in large ion lithophile (LIL) elements such as Ba, Rb, and Sr and (d) a compositional spread between N- and E-

MORB compositions in Th/Yb vs. Nb/Yb, TiO2/Yb vs. Nb/Yb, and V vs Ti plots. These geochemical attributes are consistent with the derivation of the dominant population of the Nagaland HP metamorphites from a variably depleted MORB-type, depleted mantle reservoir and due to shallow melting in the stability field of spinel peridotite. The metamorphites with mildly enriched LREE patterns indicate possible mixing between N-MORB with either E-MORB or OIB reservoirs. The enrichments in LILEs are linked with a combination of processes from pre-metamorphic, seafloor to sub-seafloor hydrothermal alterations to interaction with sediment-derived fluids.

The Thewati eclogites reveal a single-cycle, clockwise (CW) metamorphic P-T path of evolution that consists of a segment of epidote blueschist facies prograde burial at ~18.8 kbar, 555°C, peak epidote eclogite facies metamorphism at ~25–28 kbar, ~650°C and a two-stage exhumation. The initial exhumation through successive amphibole-eclogite and epidote blueschist facies P-T regimes (from 25.5 kbar, 650 ^{o}C to 10 kbar, 510 ^{o}C,) took place along a steep dP/dT gradient. The latter phase of exhumation of the eclogites to transitional lawsonite blueschist and greenschist facies metamorphic conditions at ~6 kbar, 300°C took place along a gentler *dP*/*dT* gradient.

The Mokie eclogite, in contrast, is polyphase metamorphosed and records three cycles of metamorphism, $M_1 \rightarrow M_2 \rightarrow M_3$ in sequence. The M_1 cycle along a CW P-T trajectory records an epidote blueschist facies prograde burial at ~13.6 kbar, ~495°C, peak UHP epidote eclogite facies metamorphism at ~30.3 kbar, ~690°C, and two successive phases of exhumation in eclogite (~19.8 kbar, 570 ^{o}C,) and epidote blueschist (~19.2 kbar, 465 ^{o}C,) facies metamorphic conditions. The M_2 cycle, also along a CW P-T loop, reveals a two-stage prograde heating segment (ΔT>100 ^{o}C), involving an early stage of burial (~22 kbar, 520 ^{o}C), being followed by combined decompression and heating to the peak stage at ~15 kbar, 590 ^{o}C. The retrograde segment of the M_2 cycle shows a combined decompression and cooling (ΔT ~300 ^{o}C) to ~4.9 kbar, 300 ^{o}C. The final M_3 cycle has a cryptic record of two-stage prograde burial and heating at metamorphic conditions transitional between prehnite-pumpellyite and lawsonite blueschist facies and then to epidote blueschist facies, culminating in peak P-T at 7.7kbar, 320 ^{o}C.

SHRIMP U–Pb zircon dating of two samples of Mokie and Thewati eclogites yields age groupings at ~205 Ma, ~185–189 Ma, and ~172 Ma (minor). These are

sequentially linked with the minimum age of formation of the oceanic protolith, the timing of (U)HP eclogite facies metamorphism, and the onset of retrograde cooling and exhumation.

In summary, the Nagaland eclogites together reveal the following: (a) a Jurassic-aged ultra-cool (apparent thermal gradient at the metamorphic peak between ~7^{o}C/km and ~8^{o}C/km) intra-oceanic subduction system within the Neo-Tethys, (b) subduction burial to ~100 km of depth, putting them in the select category of rare global UHP oceanic eclogite facies metamorphism during the cold mature stage of subduction, (c) a change in its exhumation style from an initial buoyancy-driven material transport in a rheologically weak and fluidized subduction channel, often interspersed with possible slab roll back events, leading to pulses of prograde heating of partially exhumed UHP rocks to terminal thrust stacking and tectonic mixing of the eclogites from different crustal levels with the cooler, prograde blueschists at shallower crustal levels (P~5-6 kbar). The Nagaland eclogite samples present the oldest Neo-Tethyan remnant (cf. Late Triassic age) and evidence of the earliest subduction (cf. Early Jurassic) within the Yarlung-Tsangpo Suture Zone. The cryptic record of this pre-Cretaceous subduction system within the Neo-Tethys that incorporated an Early-Middle Jurassic Andean-type convergent margin can be traced westwards from the Indo-Myanmar Ranges along the southern Eurasian margin to Pakistan.

Keywords: Neo-Tethyan, UHP metamorphism, Eclogite, U-Pb SHRIMP geochronology.