Deciphering high-pressure metamorphism in collisional context using microprobe mapping methods: Application to the Stak eclogitic massif (northwest Himalaya)

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ABSTRACT

The Stak massif, northern Pakistan, is a newly recognized occurrence of eclogite formed by the subduction of the northern margin of the Indian continent in the northwest Himalaya. Although this unit was extensively retrogressed during the Himalayan collision, records of the high-pressure (HP) event as well as a continuous pressure-temperature (*P-T*) path were assessed from a single thin section using a new multiequilibrium method. This method uses microprobe X-ray compositional maps of garnet and omphacitic pyroxene followed by calculations of ~200,000 *P-T* estimates using appropriate thermobarometers. The Stak eclogite underwent prograde metamorphism, increasing from 650 °C and 2.4 GPa to the peak conditions of 750 °C and 2.5 GPa, then retrogressed to 700–650 °C and 1.6–0.9 GPa under amphibolite-facies conditions. The estimated peak metamorphic conditions and *P-T* path are similar to those of the Kaghan and Tso Morari high- to ultrahigh-pressure (HP-UHP) massifs. We propose that these three massifs define a large HP to UHP province in the northwest Himalaya, comparable to the Dabie-Sulu province in China and the Western Gneiss Region in Norway.

INTRODUCTION

The recent discovery of microdiamond and coesite inclusions in rocks previously considered as collision-type granulites (Kotkova et al., 2011) suggests that evidence for subduction-related metamorphism is commonly obliterated during late collisional events. Le Fort et al. (1997) considered that the Stak massif in northern Pakistan (Fig. 1) is a retrogressed eclogitic massif, but the pervasive retrogression made it difficult to evaluate the peak metamorphic conditions, which were only constrained to be >1.3 GPa and >610 °C. We report a new approach involving X-ray mapping of a single thin section, 520 µm × 670 µm in size, which yielded information to determine a detailed pressure-temperature (*P-T*) path. This path is similar to those of eclogitic units of Kaghan and Tso Morari (~150 km and ~500 km from the Stak massif, respectively), which suggests the presence of a large high-pressure (HP) to ultrahigh-pressure (UHP) province in the northwest Himalaya.

GEOLOGICAL SETTING AND SAMPLE DESCRIPTION

The Stak area is located in the Indus valley northwest of Skardu, Pakistan (Fig. 1). High-pressure rocks are exposed on the northern edge of the Indian continental plate within the Main Mantle Thrust, between the Ladakh arc to the south and the Nanga Parbat–Haramosh gneisses (Higher Himalayan crystallines) to the north (Fig. 1B). These units (weakly metamorphosed garnet-free amphibolites of the Ladakh arc, strongly metamorphosed metasedimentary rocks of the Nanga Parbat, and felsic gneisses of the Nanga Parbat core) are imbricated in tight, multiphase folds up to a kilometer in scale with superimposed NNE-SSW and east-west trends. Mafic dikes that originally intruded the sedimentary rocks form metric to decametric eclogitic boudins within the felsic gneisses in an area ~2 km wide by ~10 km long, with poorly delineated boundaries (Guillot et al., 2008); this area is defined as the Stak massif. Our investigation focused on these eclogitized mafic boudins, which contain layers of small rounded garnet and omphacitic pyroxene. The cores are rimmed by hydration products of amphibole and biotite formed during the Himalayan collision. Sensitive high-resolution ion microprobe (SHRIMP) dating on zircon yielded scattered Himalayan ages between 70 and 50 Ma (Riel et al., 2008).

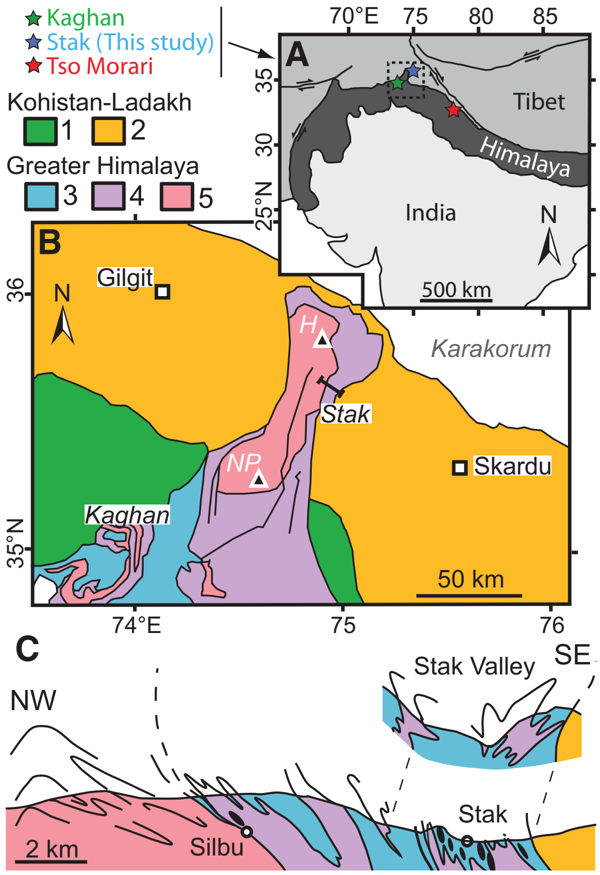

Figure 1. A: Map of northern India and Himalaya area with locations of known eclogitic massifs (Tso Morari, Kaghan, and Stak). B: Northwest Himalayan massif, modified from Pêcher et al. (2008). NP—Nanga Parbat; H—Haramosh. C: Cross section through the Stak massif. Geological units: 1—amphibolites (Kohistan) and Chilas complex (Ladakh); 2—undifferentiated Kohistan and Ladakh units (volcano and metasediments, batholiths, and Eocene volcanics); 3—Neotethyan sedimentary group; 4—Higher Himalayan crystallines and Paleozoic intrusives; 5—basement gneiss.

Samples show evidence for three deformation events, with each represented by a specific paragenesis. An early paragenesis (P1) consists of garnet with phengite inclusions and relict omphacitic pyroxene in small areas (<1 mm^2) in the matrix. Omphacite is partially replaced by symplectic intergrowths of secondary pyroxene, plagioclase, and amphibole (Fig. 2). The foliation associated with P1 is defined by the preferred orientation of omphacite and garnet. A later paragenesis (P2) is composed of millimetric amphibole and biotite in discontinuous layers along the main

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