Along-strike strain variation and timing of deformation in the lower Himalayan metamorphic core, west-central Nepal

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Orogens are typically simplified as two-dimensional systems, downplaying potentially significant along-strike strain variation. In the Himalaya, along-strike variations in seismicity (Arora et al., 2012), topographic profile (Duncan et al., 2003), precipitation (Bookhagen and Burbank, 2006), collision rates (Larson et al., 1999), and crustal architecture (Goscombe et al., 2006; Yin, 2006) have been documented. Along-strike comparisons of the deformation history of the metamorphic core are lacking, despite the extensive debate surrounding the mechanism of its emplacement (Beaumont et al., 2001; Bollinger et al., 2006; Beaumont and Jamieson, 2010; Larson et al., 2010). Contrasting tectonic interpretations may reflect locally or regionally distinct pressure-temperature-time-deformation paths due to along-strike strain variation in the metamorphic core.

Our study examines how strain and the timing of deformation vary along-strike in the lower metamorphic core in west-central Nepal. The study area was selected due to documented along-strike variation in the thickness and regional strike of the metamorphic core, a wealth of existing structural and metamorphic data available for comparison along strike (Larson et al., 2010; Vannay and Hodges, 1996; Catlos et al., 2001; Martin et al., 2005; Carosi et al., 2007; Larson and Godin, 2009; Corrie and Kohn, 2011), and the possible presence of cross-strike basement structures (Godin and Harris, 2014) that could influence strain partitioning (Fig. 1). The lower metamorphic core is defined here as the 'Lower Greater Himalayan sequence', which includes lithotectonic units previously referred to as upper 'Lesser Himalaya' (Martin et al., 2005; Carosi et al., 2007), the base of which is the top-to-the-south reverse-sense Main Central thrust (MCT) (Sarle et al., 2008). This study investigates how the style and age of deformation vary along-strike of the lower metamorphic core, and attempts to reconcile disparate tectonic models and place constraints on three-dimensional orogenic models.

Along-strike analysis of the lower metamorphic core is based on fieldwork in the lower Dolpo and Annapurna foothills, west-central Nepal (Fig. 1). The base of the metamorphic core is a ~1-5 km thick top-to-the-south reverse-sense high strain zone; the lower boundary is mapped as the MCT. The immediate footwall rocks of the MCT are characterized by multiple cleavages, relic detrital grains, and an absence of shear-sense indicators. Hanging-wall rocks contain dynamically recrystallized minerals and predominantly top-to-the-south shear-sense indicators. Lower metamorphic core rocks typically exhibit a penetrative schistosity and down-dip mineral elongation lineation. From northwest to southeast in lower Dolpo, the schistosity shifts from moderately E-dipping to steeply NE-dipping; this shift corresponds to a more westerly-strike. In the Annapurna foothills, the schistosity gradually shifts from gently NNE-dipping in the west to moderately NE-dipping in the east with a WNW to NW strike. A slight increase in metamorphic grade and mylonitization in the MCT hanging-wall rocks corresponds with a decrease in the structural thickness of the high strain zone.

Quartz-rich tectonites from near the base of the lower metamorphic core are characterized by well-developed plane strain top-to-the-south quartz crystallographic preferred orientation fabrics, consistent with deformation temperatures of ~400-450ºC. The quartz petrofabrics are similar along strike, though samples from the central Annapurna foothills yield slightly more constrictional strain and higher apparent deformation temperatures. The minimum age of these quartz petrofabrics, as constrained by muscovite $^{40}Ar/^{39}Ar$ ages, ranges in the Annapurna foothills from ~6.8 in the west to ~4.1 Ma in the east. At a higher

Cite as: Gibson, R., et al., 2014, Along-strike strain variation and timing of deformation in the lower Himalayan metamorphic core, west-central Nepal, in Montomoli C., et al., eds., proceedings for the 29th Himalaya-Karakoram-Tibet Workshop, Lucca, Italy.

structural level, near the kyanite isograd, the muscovite $^{40}Ar/^{39}Ar$ age in the central Annapurna foothills is ~19.4 Ma, which decreases to the west (~13.0 Ma) and east (~5.3 Ma). The $^{232}Th/^{238}Pb$ ages and corresponding yttrium zonation of *in situ* monazite from samples along the kyanite isograd illustrate protracted prograde metamorphism in the Eocene-Oligocene followed by a Miocene retrograde metamorphic phase, with ages of each phase varying along-strike. The age of early prograde metamorphism is constrained with Th/Pb age peaks from zones of pre-garnet monazite crystallization; these ages range from ~39 Ma in lower Dolpo to ~31 and ~27 Ma in the western and eastern Annapurna foothills, respectively. The minimum age of peak metamorphism ranges, from western lower Dolpo to the eastern Annapurna foothills, from ~25 Ma to ~18 Ma. Retrograde metamorphic Th/Pb age peaks from post-garnet monazite zones yield ~19 to ~23 Ma from west to east in lower Dolpo, and ~21 to ~16 Ma from west to east in the Annapurna foothills.

Results indicate there is along-strike variability in the deformation and metamorphic history of the lower Himalayan metamorphic core. Variations in the style and timing of strain, thickness of the high strain zone, and timing of metamorphism have occurred. A thicker high strain zone correlates to more distributed strain, and relatively old monazite Th/Pb and muscovite $^{40}Ar/^{39}Ar$ ages. Variation in the metamorphic core proximal to the across-strike basement structure[17] include structural thinning, a shift in the regional strike, and a decrease in muscovite $^{40}Ar/^{39}Ar$ and monazite Th/Pb ages. These results illustrate the importance of incorporating along-strike variation into the interpretation of the Himalayan orogen and the potential influence of across-strike basement structures on strain partitioning.

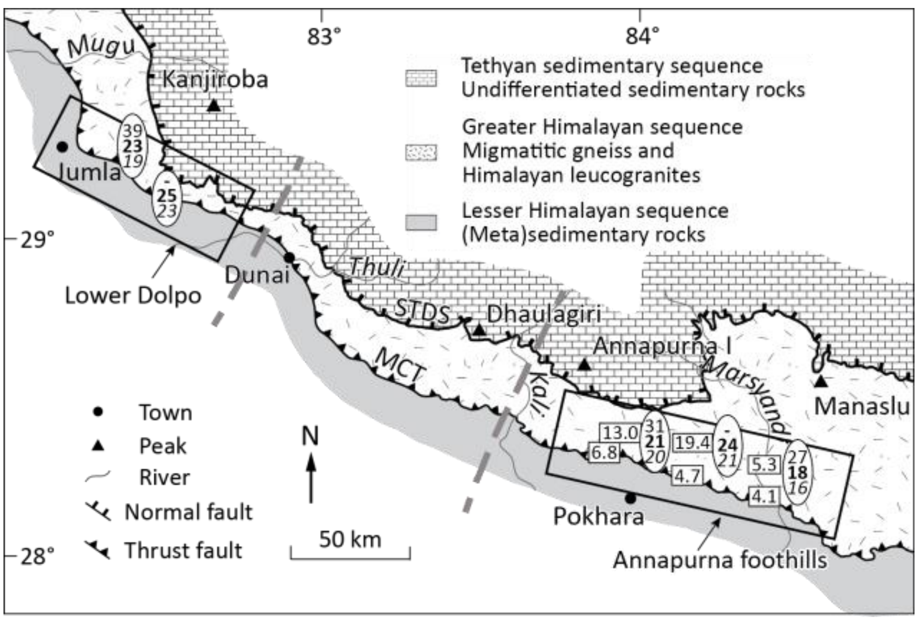

Figure 1. Simplified geologic map of west-central Nepal with field areas highlighted by black rectangles. STDS=South Tibetan Detachment System. Approximate muscovite $^{40}Ar/^{39}Ar$ (rectangle) and monazite $^{232}Th/^{238}Pb$ (ellipse) ages are listed at approximate sample location.

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