MIDDLE CRUSTAL PROCESSES OF OBLIQUE COLLISION IN THE CENTRAL SOUTHERN ALPS, NEW ZEALAND: WHAT RECORD IS PROVIDED BY DUCTILE FABRICS IN THE ALPINE SCHIST?

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Middle crustal rocks in the hangingwall of the oblique-slip Alpine fault near Franz Josef Glacier have been uplifted and exhumed during the past ~2-3 Ma providing a rare sample of the ductile underbelly of modern obliquely convergent orogen (e.g., Holm et al, 1989). The Southern Alps exposes a crustal section through the western edge of the Pacific Plate, a SE-tilted slab of rocks that have been up-ramped along the Alpine fault (e.g., Norris et al., 1990). The basal ~1 km of this slab was mylonitized in the late Cenozoic in proximity to the Alpine Fault at depth. The Alpine Schist includes amphibolite-facies rocks at its structural base near the Alpine Fault, and chlorite-zone rocks ~15 km to the east of that structure near the Main Divide of the Southern Alps. Seafloor data indicate that ~6.4 Ma this part of the Australia-Pacific plate boundary changed from a dextral-slip transform margin to an obliquely convergent one with an interplate convergence angle of ~20° (Sutherland, 1995). Since then, ~90 km of continental crust of the Pacific Plate has been removed by convergence-related uplift and erosion across the Southern Alps, and ~230 km of dextral-slip motion has accrued between the two plates (Walcott, 1998). The Alpine fault has a late Quaternary strike-slip rate of 25-30 mm/yr, about 55-80% of the total plate motion (Cooper and Norris, 1994; Sutherland, 1994). In this talk we will use the Alpine Schist as a "natural laboratory" to examine how ductile deformation is imprinted on rocks in a well-understood, modern oblique collision zone, and to predict how such processes may be preserved in the fabric record of ancient orogens.

(1) What is the evidence that ductile fabrics in the Alpine Schist have recently been exhumed from the middle crust of an oblique continental collision zone?

In the Southern Alps, inherited Mesozoic fabrics bearing no relationship to the present Southern Alps orogen are widely preserved, even in the mylonites. The overprint of late Cenozoic deformation constructively reinforced pre-existing fabrics making the two difficult to distinguish. Near vertical and striking obliquely to Alpine Fault, the pre-existing "Alpine foliation" was predisposed in attitude to accommodate a transpressive overprint in the modern oblique collision zone. The older foliation lay in the extensional sector of the late Cenozoic incremental strain, and was "reused" rather than being crenulated or transected by a new foliation. Upright Mesozoic folds and crenulations which had resided at depth in the middle crust for tens of millions of years were tightened during the late Cenozoic under only slightly different metamorphic conditions. The resultant composite fabric is diachronous. This diachroneity is also expressed in the growth history of syntectonic garnet porphyroblasts, the cores of which nucleated in the Late Cretaceous, but the rims of which resumed syntectonic growth during crustal thickening much later in the Cenozoic. In the central Southern Alps, thermochronometers, including hornblende $^{40}Ar/^{39}Ar$ are widely reset at deep structural levels recording their rapid cooling from depth during uplift and unroofing since the Pliocene, but retain older ages along strike and at higher levels above the partial retention zones for these minerals. This results in a complex spatial distribution of ages across the collision zone.

Evidence for late Cenozoic transpressive ductile flow in the Alpine Schist includes deformation of young veins and analysis of a fossil brittle-ductile transition zone (BDTZ) within the exhumed section. Brittle-ductile shears within the ~1 km thick BDTZ are the youngest ductile fabric element identifiable in the nonmylonitic Alpine Schist. These strike parallel to the Alpine Fault and vertically crosscut the older "Alpine foliation" with a dextral-oblique sense of slip. Below the BDTZ, changes in quartz microstructure reflect the superposition of a late increment of ductile strain across those deeper parts of the Pacific Plate. As predicted by modelling of transpressive flow (e.g., Tikoff and Fossen, 1999) strain shape was distinctly oblate and the finite stretching lineation is down-dip. Above the BDTZ, polygonal quartz grain-shape fabrics are relict from the period of schist burial predating the present collisional phase.

(2) What do these ductile fabrics and surface geodetic observations tell us about crustal-scale mechanisms of oblique collision and uplift in New Zealand?

GPS-derived velocities of the Pacific Plate relative to the Australian plate across the central South Island suggest a pattern of oblique convergence parallel to the plate motion vector (Beavan et al., 1999). Every mm of convergence is matched by ~3 mm of dextral motion. This deformation is approximately uniformly distributed over a ~150 km wide zone. Any material moving west towards the Alpine Fault must first decelerate through an eastern zone of oblique shortening. Extending geodetic and plate motion rates back in time, rocks presently exposed at the surface along the Alpine Fault would have originated in the middle crust ~50 km to the east. During the next ~2 m.y, they would have moved westward through the outboard part of the orogen, shortening and thickening by ~6%. Seismic data image a gentle westward thickening in the present-day crust (Davey et al., 1998). Ductile fabrics support the idea that the rocks have undergone a phase of transpressive flow associated with vertical thickening (Holcombe and Little, 2000). This deformation was accompanied by reinforcement of the steep "Alpine foliation" and development of a down-dip stretching lineation. After ~2 m.y., the rocks would have been transported onto the SE-dipping Alpine Fault ramp. Field observations indicate that the ramping process involved passage of the rocks through a sequentially activated, escalator-like array of nearly vertical, oblique-slip shear zones that are upthrown to the west. Passage through this fixed shear zone tilted the delaminated Pacific Plate crust to the SE. This process would structurally thin the section by ~25%. Such "back-shearing" is obvious in the BDTZ, where brittle-ductile shears form a systematic, closely spaced array; the same sense of shear pervades downward into the section of ductilely deformed rocks beneath the BDTZ. A final phase of deformation was chiefly confined to the Alpine mylonite zone, but extended up to ~5 km away from it, as expressed by a drag-like oversteepening and shallowing of foliation towards the Alpine Fault.

(3) What are the implications of these observations for recognition of ancient oblique collisions zones?

Other than the Alpine fault, its mylonite zone, and the late shears in the BDTZ, evidence for Cenozoic oblique collision is sparse in the Alpine Schist. In the non-mylonitic part of the section, post-biotite measures of incremental strain suggest only ~30-40% of foliation-orthogonal shortening during the late Cenozoic, a magnitude that accords with our strain modelling which incorporates available data on geodetic strain rates and ramp kinematics. This strain takes the form of a modest constructive overprint which might be overlooked in an ancient orogen. Because of its small magnitude, older ductile fabrics are widely preserved, providing the unwary with opportunities for misinterpretation. The "soft footprint" of collision-related Cenozoic finite strain reflects the following important point: oblique collision in the New Zealand orogen is dominated by translation, erosion, and interplate slip on the Alpine Fault. To the east of that structure, rocks migrate rapidly through the deforming zone, preventing the accumulation of large finite strains.

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