Our recent field work and microstructural observations in aureoles around the Tuolumne Intrusive Suite (TIS), Sierra Nevada, reveal a striking spatial coincidence of abruptly increasing finite regional strain and a transition in dominant deformation mechanisms. Strain analyses at the northern tip and eastern margin of the TIS show a dramatic increase of north-northeast to south-southwest directed regional strain from ca. 43% to ca. 80% shortening towards the eastern pluton margin. The abrupt change in finite strain corresponds with a transition from dislocation creep to superplasticity aided by melt and high diffusion rates. Additionally, we observed increasingly more microfracturing and prograde metamorphic phase transitions towards the margin. Our results document the critical importance of magma emplacement on the rheology of pluton aureoles and of the lower crust. Furthermore, this study implies that temperature-induced rheological changes, which normally are observed along vertical crustal cross sections, may be condensed into much shorter length scales in contact aureoles.

174-12 **4:40 PM** Lackey, Jade Star

PRIMARY AND SECONDARY TITANITE $\delta^{18}O$ VALUES AS RECORDS OF MAGMATIC AND ALTERATION PROCESSES IN THE SIERRA NEVADA BATHOLITH

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Titanite is a widespread accessory mineral in granitic (diorite to granite) rocks of the Sierra Nevada Batholith (SNB), California. Primary and secondary titanite (Tt_1 & Tt_2) commonly coexist in the same rock and can be differentiated based on color, trace element concentration, and crystal size and morphology, as has been done in geochronology studies of Tt (e.g., Frost et al., 2001, *Chem.Geo*). In the SNB, Tt_1 is of magmatic origin and Tt_2 formed during subsolidus alteration of biotite, Fe-Ti oxides, or hornblende. Values of $\delta^{18}O(Tt_1$ & $Tt_2)$ across the central SNB reveal the magmatic and alteration histories of the batholith.

The range of $\delta^{18}O(Tt_1)$ values (3.5–7.6‰, n=111) generally track and reflect regional variations in magma source across the central SNB; values of $\delta^{18}O(Tt_2)$ (1.2–7.6‰, n=87) reflect both magma source and superimposed alteration. Comparison of $\delta^{18}O(Tt)$ to $\delta^{18}O$ of zircon (Zc), as δ(Zc–Tt), provides a measure of isotopic resetting in Tt because $\delta^{18}O(Zc)$ gives a reliable record of magmatic $\delta^{18}O$ (Lackey et al., 2003, *GSA abst*). Average $\delta(Zc–Tt_1)$ values (1.6±0.3‰; 1s.d.) are generally larger than expected for magmatic temperatures (<0.9‰ @ >800°C, King et al., 2001, *GCA*) and reflect resetting of $\delta^{18}O(Tt_1)$ during cooling of the SNB. Regionally, variations in $\delta(Zc–Tt_2)$ (avg.=2.4±0.6‰; 1s.d.) correlate to pluton depth (Al-in-hornblende barometry, Ague & Brimhall, *GSAB*, 1988). For example, $\delta(Zc–Tt_2)$ values are uniform in plutons of the Fine Gold Series, the deepest (3–4 kbar; 10–13 km) exposed in the central SNB, but are highly variable in shallow (1–2 kbar; 3–7 km) plutons like the Mt. Givens pluton & Tuolumne Intrusive Series. During growth of T_2, shallow plutons were subject to meteoric water exchange while deeper plutons were internally buffered.

Trace element concentrations, including REE, are higher and more variable in SNB Tt_1 than Tt_2, which occurs due to sequestration these elements in Tt_1 and other magmatic phases (e.g., Frost, *ibid*). Correlation of increasing $\delta(Zc–Tt_2)$ values to decreasing Ce and Fe concentrations in Tt_2 is consistent with lowering of $\delta^{18}O(Tt_2)$ values by progressively more oxidized meteoric fluids. These results show that analysis of $\delta^{18}O(Tt)$ is can be used to recognize Tt_1 from Tt_2 and provides a powerful complement to geochronology studies.

SESSION NO. 175, 1:30 PM

Tuesday, November 9, 2004

T85. Whence the Mountains? New Developments in the Tectonic Evolution of Orogenic Belts: Celebrating the Dynamic Career of Raymond A. Price at the 50-Year Mark III (*GSA Structural Geology and Tectonics Division, Geological Association of Canada*)

Colorado Convention Center, 708/710/712

175-1 **1:45 PM** Rowley, David B.

INDIA-ASIA COLLIISION AND HIMALAYA-TIBET OROGENESIS SENSU STRICTO

ROWLEY, David B.[1], CURRIE, Brian S.[2], KIDD, W.S.F.[3], and ZHU, Bin[3], (1) Dept of the Geophysical Sciences, The Univ of Chicago, 5734 S. Ellis Ave, Chicago, IL 60637, rowley@geosci.uchicago.edu, (2) Department of Geology, Miami Univ, 114 Shideler Hall, Oxford, OH 45056, (3) Earth & Atmospheric Sciences, Univ at Albany, Albany, NY 12222

We integrate new data from the Himalaya and Tibet system that shed light on the relation between plate kinematics and the evolution of the Tibetan Plateau. Collision in the region north of Mount Everest is now dated biostratigraphically on the south flank of the Zhepure Shan as during plankton zone P8 in the late Ypresian. P8 is the shortest planktonic zone in the early Eocene and essentially constrains the age of initiation of collision at 50.6±0.2 Ma. This dates the time at which Asian margin derived sediments were first deposited above unequivocally Indian passive margin sediments. This is synchronous within P8 with the onset of collision in the Zanskar region to the west constraining initiation of collision along greater than 50% of the length of the suture. Onset of collision at 50.6 Ma thus predates the 50% reduction in India-Eurasia convergence by more than 4 m.y. at Chron 21, implying greater than 400 km of continent-continent convergence before buoyancy related effects slowed convergence. Collision-related crustal thickening can be discerned using paleoaltimetry estimates from various basins from the Himalaya across Tibet. Estimates of paleoaltitude from the Lunpola basin in central Tibet, currently some 300 km N of the India-Asia suture indicate that this region had already achieved its current elevation of 4.7 km by the Late Eocene (~35±2 Ma). Approximately 950 km of continent-continent convergence had already taken place by that time suggesting that at least about 2/3 of the convergence was accommodated N of the suture. Coeval paleoaltimetry estimates from the Fenghuoshan, in northern Tibet, some 750 km N of the suture indicate that crustal thickening had not affected this region until after Eocene, and probably not until later in the Oligocene. Paleoaltimetry data from southern Tibet and Himalaya are restricted to younger than 20 Ma, but demonstrate that these regions have maintained their current high elevations (>4.6 km) for 15 or more million years. Together these data indicate crustal but not correlative mantle thickening have dominated the collision process, and that there are no data supporting lithospheric mantle delamination in this system.

175-2 **2:00 PM** Burchfiel, B. Clark

COMPLICATIONS FOR LARGE MAGNITUDE EARLY CENOZOIC EXTRUSION OF INDOCHINA

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Perhaps the most accepted model for the early Cenozoic tectonics around the Eastern Himalayan syntaxis was first proposed by Tapponnier and others (l982), since modified but with the initial emphasis largely unchanged. In this model Indochina moved to the SE ~700 km as an essentially rigid crustal fragment with ~14° of clockwise rotation, bounded on the north by the left-lateral Ailao Shan shear zone and on the west by the right-lateral Gaolingong shear zone, to make way for the northern penetration of India into Eurasia. Our paleomagnetic studies of the Lanping-Simao tectonic unit in the northern part of Indochina crust indicates complex rotations of from 30-90° clockwise during early Cenozoic time that results from rotation of smaller fragments. Structrual patterns south of the Lanping-Simao also suggest breaking of crust into smaller clockwise rotated fragments to be test by further paleomagnetic studies. Our work has shown this southern part of Indochina is cut by the poorly known NW-trending Chong Shan shear zone which shows both left- and right-lateral Cenozoic shear indicating that relative movements of crustal fragments within Indochina was complex. Paleomagnetic data from the LP-S belt do suggest at least 500 km of SE movement relative to South China. Compilation of a detailed tectonic map for the entire SE Tibetan region and adjacent foreland has raised doubt on the northwestward continuation of some of the shear zones responsible for large magnitude extrusion. Across the supposed northern boundary Ailao Shan shear zone Upper Triassic and Paleogene rocks are very similar. Other tectonic units with the Three Rivers area are not obviously offset across projected boundary faults and the location of large magnitude offsets within SE Tibet are difficult to locate at present. This region has been complicated by offsets that may be Mesozoic in age and significant Cenozoic crustal shortening. Detailed studies are on going to resolve these problems.

175-3 **2:15 PM** St-Onge, Marc R.

THE TRANS-HUDSON OROGEN OF NORTH AMERICA AND THE HIMALAYAN OROGEN OF ASIA, PART 1: STRUCTURAL AND THERMAL EVOLUTION OF THE LOWER PLATE

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Collision of the Superior plate with the composite Churchill plate ca. 1.8 billion years ago led to formation of the Trans-Hudson Orogen of North America, possibly the largest and most recognizable continental collision recorded in the first 2,200 million years of Earth history. Similarly, collision of the Indian plate with Asia ca. 50 million years ago resulted in the formation of the Himalaya, the Karakoram-Hindu Kush mountain ranges and the Tibetan Plateau, arguably the largest continental collision in the last 450 Ma of Earth history. Both orogens share key tectonic, structural and petrological collisional traits, which suggest that the India-Asia collision zone is an instructive present-day analogue for collisional orogens in the Paleoproterozoic.

The structural and thermal evolution of the lower plate Superior margin during continental collision involves (1) early, thin-skinned thrusting and consequent regional metamorphism (400-575°C; 6.3-9.1 kbar; 1820-1814 Ma), (2) out-of-sequence thrusting and regional Ky grade metamorphism (585-720°C; 7.7-9.8 kbar; 1814-1795 Ma), and (3) amphibolite facies re-equilibration (675-775°C; 7.0-8.9 kbar; 1795-1758 Ma), partial melting and leucogranite formation. The crustal evolution of the Indian plate along the Himalaya involves (1) early, deep subduction of thinned continental crust to UHP eclogite depths (~680°C; 28 kbar; 49-46 Ma), (2) regional Ky grade metamorphism (550-680°C; 10-12 kbar; 35-32 Ma), and (3) widespread, regional Sil ± Crd grade metamorphism (650-770°C; 3.7-4.5 kbar; 30-16.5 Ma) associated with partial melting and leucogranite formation.

In the Himalaya, the shallow depths of high-temperature metamorphism and melting are consistent with mid-Miocene ductile flow of an Indian plate mid-crustal channel, southward from beneath southern Tibet to the Greater Himalaya. This zone is bounded by crustal scale shear zones, the Main Central Thrust, with its inverted and compressed metamorphic isograds along the base, and the South Tibetan Detachment system of low-angle, normal sense shear zone along the top. In contrast, the thermal evolution of the lower plate in Trans-Hudson Orogen appears to be primarily a consequence of the thermal relaxation of crustal isotherms in tectonically thickened crust without recourse to a mid-crustal channel.

175-4 **2:30 PM** Searle, Mike

THE TRANS-HUDSON OROGEN OF NORTH AMERICA AND THE HIMALAYA-KARAKORAM-TIBETAN OROGEN OF ASIA, PART 2: STRUCTURAL AND THERMAL EVOLUTION OF THE UPPER PLATE

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The collisional upper plate to the 1.8 Ga Trans-Hudson Orogen (THO) in NE Canada comprises a collage of Archean crustal blocks and Paleoproterozoic terranes that were assembled, deformed, and metamorphosed prior to terminal collision with the Superior plate. Early tectonothermal events include (1) accretion of Meta Incognita microcontinent to the Rae craton and consequent tectonic thickening of continental margin strata between 1880-1865 Ma, (2) pre- and post-accretion emplacement of Andean-type plutonic suites including the 1865-1848 Ma Cumberland batholith, (3) Grt-Crd-Sil metamorphism at mid-crustal depths (790-830°C; 6.9-8.5 kbar; 1849-1836 Ma), partial melting, and Crd-And metamorphism at higher crustal levels (550-600°C; 3.0-4.0 kbar; 1856-1835 Ma), (4) accretion of the intra-oceanic Narsajuaq arc to the upper plate between 1845-1836 Ma, and (5) emplacement of Andean-type plutons and granulite facies metamorphism along the leading edge of the upper plate between 1836-1820 Ma. Terminal collision is manifest by crustal-scale (re)-imbrication and Bt-Sil-Grt metamorphism (670-760°C; 5.0-7.8 kbar; 1820-1790 Ma).

In the Himalaya, the upper plate includes the vast Tibetan Plateau north of the Indus-Yarlung Tsangpo suture zone, and its extensions to the west, and the Karakoram and Hindu Raj - Hindu Kush Ranges. The geology of the plateau comprises mainly sedimentary and volcanic rocks, rarely deep crustal metamorphic rocks, whereas the Karakoram Range exposes extensive lower crustal rocks and pre- and post-collisional granites. Pre-collisional, 150-95 Ma Andean-type granite-diorites are related to subduction of the Tethyan ocean crust beneath the southern margin of Asia. Post-collisional granites include the Baltoro Bt-monzogranite and Grt-Bt-Ms leucogranites formed 25-18 Ma by melting of lower crust gneisses. St, Ky, and Sil metamorphism is sporadic and semi-continuous from 70-0 Ma along the southern margin of the Karakoram, following collision of the Kohistan arc during the Late Cretaceous, and India in the earliest Eocene.

Late thick-skinned folding and cross-folding in THO is constrained at 1758-1742 Ma. Himalayan manifestations might be the >1cm/year erosion rates in the Nanga Parbat syntaxis of Pakistan, and the Miocene-Pliocene Sil grade gneiss domes in the southern Karakoram.

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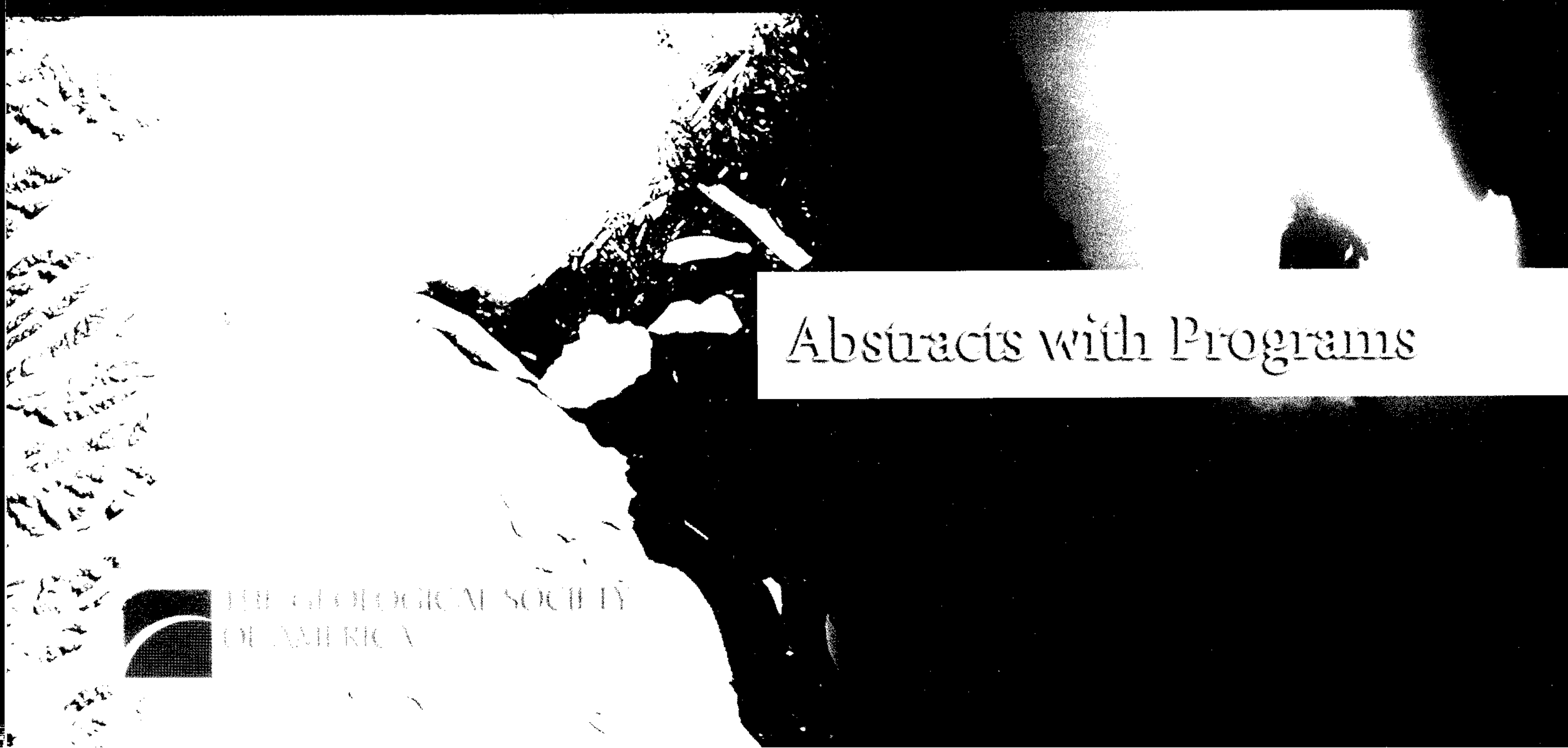

Abstracts with Programs

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