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From September to November 2002, a marine geophysics experiment was carried out, using 2 ships and onshore personell, recording deep MCS (Multichannel Seismics), wide angle, gravity, magnetic and bathymetric data. The main objective of this experiment is to better understand the continental breakup processes and the rifting of the Baja California Peninsula from Mexico mainland. An array of airguns with a total air volume of 8000 cu.in. was the seismic source and a 6000 km-long, 480-channel streamer was used to record the deep MCS data. This equipment was towed by the R/V Maurice Ewing. A series of stacked and migrated sections have been obtained, showing a number of noticeable structures. To the W of the line corresponding to the Pacific margin, the fossil trench is covered by recent sediments, that are part of the Magdalena Fan. Towards the E, near the slope break, the Tosco-Abreojos fault zone is clearly imaged, showing some extensional component. Further to the E, an old syncline is covered in erosive unconformity by recent sediments. In the eastern part of the section, a half-graben structure can be observed. Under this structure, a reflective zone can be interpreted as the mylonitic zone corresponding to a detachment. Some basement scarpments seem to be parallel faults to the semigraben master fault. Other normal faults in the sediments of the basin are synthetic and antithetic with it. The master fault probably is the continuation to the S of the Santa Margarita-San Lazaro fault, reported previously as a detachment in Santa Margarita and Magdalena islands. The seismic line in the Gulf of California margin begins at a conspicuous slope at the mouth of the La Paz Bay, and corresponds to the same strike-slip fault observed in Partida and Espiritu Santo islands. The rest of the line is characterized by numerous strike-slip and normal faults, producing strong bathymetric variations.

T32D-08 1525h

Late Miocene (Proto-Gulf) Extension and Magmatism on the Sonoran Margin

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Constraints on the magnitude and character of late Miocene (Proto-Gulf) deformation on the Sonoran margin of the Gulf of California extensional province are key to understanding how and when Baja California was captured by the Pacific plate and how strain was partitioned during the early stages of this transtensional rift system. Our new geologic mapping in southwestern Sonora and $^{40}Ar/^{39}Ar$ dating of pre-, syn-, and post-tectonic volcanic units indicate that late Miocene deformation and volcanic activity were largely restricted to a NW-trending, 100-120 km wide belt adjacent to the coast. Inboard of this belt, NW-SE extension is mainly older (>15 Ma) and occurred in an intra-arc or back-arc setting. Proto-Gulf deformation within the coastal belt was profoundly transtensional, with NW-striking, dextral strike slip faults operating in concert with N-S and NNE-striking normal and oblique slip faults to produce an inferred NW or NNW tectonic transport direction. The total amount of late Miocene NW directed dextral shear within the coastal belt is still poorly constrained, but may exceed 100 km. The locus of deformation and volcanic activity migrated westward or northwestward within the Sonoran coastal belt. in the eastern portion (Sierra Libre and Sierra El Bacatete) major volcanic activity commenced at ~13.0 Ma and peaked at 12.0 Ma, and major faulting and tilting is bracketed between 12.0 and 10.6 Ma. Further west in the Sierra El Aguaje/San Carlos region, major volcanic activity commenced at 11.5 Ma and peaked at 10.5 Ma, and most faulting and tilting is bracketed between 10.7 and 9.3 Ma. On the coastal mountains northwest of San Carlos, rift related faulting and tilting continued after 8.5 Ma. Voluminous late Miocene (13-8 Ma) volcanic rocks within the Sonoran coastal belt were erupted from numerous centers (e.g. Sierra Libre, Guaymas, Sierra El Aguaje). These thick volcanic sections are compositionally diverse (basalt to rhyolite, with abundant dacite and andesite), and are intimately associated in space and time with tectonic activity. Overall, the Sonoran coastal belt provides a spectacular example of distributed transtension and associated magmatism that ultimately led to rupturing of the continental lithosphere.

T32E MCC: 3007 Wednesday 1600h

Late Cenozoic Tectonics, Climate, and Topography in the Central and Southern Andes II *(joint with G, H)*

Presiding: **E R Sobel,** Institut für Geowissenschaften**; R Amundson,** Division of Ecosystem Sciences

T32E-01 1600h INVITED

Drainage Divide Migration, Orographic Precipitation, and Uplift in the Southern Andes

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Statigraphic and geomorphic evidence within the Patagonian Andes suggests that rapid uplift starting in lower to middle Miocene caused drastic changes of drainage and sediment transport patterns. In particular, capture of formerly E-draining channels by headward erosion of W-draining fluvial systems indicates that an eastward migration of the drainage divide took place in this area. We hypothesize that this migration was caused by the development of an asymmetry in the distribution of precipitation and erosion that progressively concentrated on the windward (western) side of the uplifting mountain belt. We coupled the bedrock fluvial power-law incision model to climatic models that consider the impact of relief on precipitation with constant base-levels on either side of the uplift zone. Forward models indicate that when rock uplift rates are low, relief remains relatively subtle within the orogen, the topography is approximately symmetric, and precipitation is uniformly distributed over the mountain belt. However, high rock uplift rates concentrate precipitation along the windward slopes of the orogen at the expense of the leeward slopes. The increase in erosional power on the windward slopes causes the drainage divide to migrate towards the leeward portions of the orogen. For high uplift rates, enough topography is constructed to completely starve moisture from the leeward portion of the orogen. This eliminates erosional power within the fluvial systems in these areas, preventing the development of steady-state topography. To apply this model to the southern Andes, we used topographic and precipitation data from this region to constrain the parameters in the precipitation and fluvial bedrock incision model. We found that an order-of-magnitude increase in rock uplift rates or decrease in the erosional efficiency during the lower to middle Miocene can explain the approximate magnitude of drainage divide migration observed. Therefore, we speculate that an increase in uplift rates within the southern Andes has concentrated precipitation along the western flanks of the mountain belt, reduced precipitation along the eastern flanks, and forced the drainage divide to the east.

T32E-02 1615h

Tectonic feedbacks in the Southern Andes arising from variations in the equilibrium line altitude

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There is considerable interest on the role of climate in controlling topography and local relief in tectonically active landscapes. Much of this discussion has focused on the role of fluvial erosion, but more recently the debate has turned to include glacial erosion as well, which is probably important in limiting the maximum elevation in convergent mountain belts such as the Andes, in which the summit regions are covered by significant amounts of alpine glaciers. We present a theoretical model that shows that the Andes presents a clear test case of quantifiable feedbacks between climate and tectonics. A convergent wedge model of Andean orogen development suggests that the lowering of the Equilibrium Line Altitude (ELA) since the Late Miocene may have lead to a lowering of the relief in the Southern Andes of around 1 km. Analytic calculations suggest that a lowering in relief of the ELA is capable of reducing the mass of the orogen by in excess of 30%. These estimates are supported by a numerical model of fluvial-glacial erosion at convergent orogens, with which we predict that the rate of tectonic rock uplift in the Southern Andes may have increased by more than 20% since the inception of the glacial cycles of the Quaternary, in response to increased erosion.

T32E-03 1630h

Applying low temperature thermochronology to resolve the climatic, erosional and tectonic controls on the geomorphic development of the southern Andes

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The southern Andes are an ideal orogen in which to study the interplay between tectonics, variable climate, and glacial erosional processes on the geomorphic development of mountains. They represent a mid- to high-latitude high relief mountain chain developed largely since late Cenozoic times in a relatively simple non-collisional convergent margin tectonic setting perpendicular to the prevailing mid-latitude westerly weather systems. An orographically induced rainshadow is well developed with the leeward (east) side receiving less than 10 % the precipitation of the windward (west) side. Preliminary new apatite (U-Th)/He (AHe) low temperature thermochronologic data have been obtained from samples previously analysed using the fission track (AFT) method to investigate in more detail variations in late Cenozoic cooling and hence erosional denudation both along strike and across the southern Andes. The cooling histories indicated by the AHe ages agree well with earlier AFT results, and indicate increased amounts of late Cenozoic erosional denudation on the windward side, with the youngest ages and amounts of exhumation apparently increasing toward the present day topographic divide. The AHe ages, when combined with AFT thermal modelling, also provide a well constrained age of ca. 8 Ma for the onset of accelerated denudation close to the present day topographic divide at ca. 47-48°S. With the acquisition of a more detailed low temperature thermochronologic AHe data we aim to test geodynamic models that predict the effects of variable climate (orographic precipitation), glacial and fluvial erosion, and tectonic uplift in a steady state orogenic wedge similar to the situation in the southern Andes. Such models imply similar topographic expression, but different spatial erosion responses to tectonic uplift in an orogenic wedge dependent on whether fluvial or glacial processes were the dominant erosion mechanism. Such differences should be better resolvable with the higher precision and lower temperatures (and hence nearer surface denudation record) provided by AHe data.

T32E-04 1645h

Ephemeral Sedimentary Basins and Limits of Lateral Plateau Growth at the Eastern Puna Margin, NW Argentina

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Similar to the northeastern margin of the Tibetan Plateau the eastern margin of the Puna Plateau of the southern Central Andes is characterized by laterally growing ranges and intervening intramontane basins in a tectonically active and arid environment. However, in contrast to Tibet, lateral plateau growth along the SE Puna by incorporation of filled sedimentary basins appears to be inhibited. In fact, reverse-fault bounded

and sediment filled arid basins straddling this plateau are ephemeral. The relations between deformation, uplift, basin formation, and climate are illustrated well in the Quebrada del Toro at about 24° S in the Cordillera Oriental. The basin records the transition from a foreland to a broken foreland setting with range uplift beginning after about 8 Ma. Deformed sediments are overlain by about 1000-m-thick, poorly lithified conglomerates; in the lower 200 m of the section they laterally grade into plant-bearing lake deposits indicating a humid environment similar to the eastern windward slopes of the present basin border. Conglomerate deposition began after 8 Ma following deformation but before deposition of a 4.17 Ma tuff in the lower part of the sequence and continued until 0.98 Ma, when renewed thrusting along the basin margins and within the basin deformed these strata. These deposits were incised to elevations comparable to the present base level, suggesting integration of the Toro basin into the foreland drainage system. However, this event was superseded by a second, important influx of conglomerates, which filled the pre-existing erosional paleotopography to levels that are up to 700 m above the present trunk stream. Subsequently, these conglomerates and all older units were extensively stripped and incised again to the present local base-level. Incision was episodic as documented by five inset strath terraces that follow the course of the trunk stream. Mapping of the Quaternary deposits and DEM analysis indicate that a minimum of 61.5 km^3 of material was removed from the basin during the Pleistocene. The average elevation change within the Quebrada del Toro is 158 m, which corresponds to 0.158 mm/yr of exhumation within the ultimate 1 Ma. This exhumation rate appears to be far lower than regional minimum rock uplift rates. Therefore, the basin surface was, and continues to be uplifted, which may be coupled with continuing uplift of the adjacent Puna Plateau. Unlike the margin of the northeastern Tibetan Plateau, where continued thrusting creates intramontane basins that are being filled with sediments that are ultimately incorporated into the plateau realm, the Toro basin is clearly transitory. Identical histories exist in other basins along the Puna edge. In contrast to basins with similar geometries in the arid Puna the basins straddling the eastern plateau margin cannot be sustained as depocenters and closed basins due to a very effective erosional regime of a wetter climate acting on the basin margins. This leads to large rainfall gradients in this area with easterly moisture sources, headward erosion, drainage capture, and ultimately basin exhumation.

T32E-05 1700h

Shallow Seismic Reflection Imaging of the Salar de Uyuni, Bolivia: Quaternary Neotectonics and Stratigraphy

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Results from a shallow seismic reflection experiment in 2000 on the Salar de Uyuni at the southern end of the Bolivian Altiplano will be presented. This salar is the largest salt flat in the world (130 km x 80 km) and is a remnant of the Quaternary paleolake Minchin/Tauca. Paleoshorelines of this lake mapped by GPS show marked deformation (Bills et al., GRL, 1994). The salar also shows evidence for both Quaternary volcanic activity and active faulting from Andean tectonics. The paleolake stratigraphy of the salar, therefore, may record neotectonic deformation from three different processes: (1) isostatic rebound from the evaporation of the deep lakes that have occupied this region periodically during Quaternary climate fluctuations, (2) active faulting along local/regional fault systems, and (3) regional uplift and/or tilting of the Andes. The seismic experiment was designed, in part, to determine the extent to which the Quaternary lake stratigraphy documents neotectonic deformation and, if possible, to separate the effects of the different processes. The seismic profiles were collected using IRIS PASSCAL instruments and a hammer source. The stratigraphy is imaged to a depth of at least 200 m at surprisingly high frequencies and can be tied to the 220 m deep paleoclimate corehole drilled by Baker et al. (Nature, 2001). One 130-km transect was collected across the entire E-W width of the salar. A second 50-km N-S transect crosses at the corehole. These profiles are limited by very low spatial sampling but clearly show that the shallow Quaternary lake deposits now dip to the east and north and are offset by sets of faults, particularly on the eastern side of the salar. The tilting of the stratigraphy conforms with the thickening of the young surficial salt layer to the east, although the shallowmost seismic data quality doesn't allow one to determine the youngest age of layers offset by the imaged faults. Current efforts are to separate out the isostatic rebound signature from the deformation from faulting.

T32E-06 1715h

Late Cenozoic tectonics of the Coastal Cordillera of N Chile and implications for paleoclimate and interplate processes

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The Coastal Cordillera of northern Chile is located in the hyperarid Atacama Desert and is situated over the interplate seismic zone of the Nazca-South America convergent plate boundary. The Coastal Cordillera is bounded to the west by a 1000 m high escarpment that plunges directly to the sea north of Iquique but to the south has a 1-5 km wide Pleistocene abrasion platform at its base. We use a 20 m InSAR digital elevation model (DEM) combined with fieldwork to investigate the relations between the late Cenozoic tectonics and drainage development in the Cordillera between the Río Loa (21.6S) and the Quebrada de Camarones (19S). Late Cenozoic structures in this region consist of EW striking reverse faults and NS striking normal faults. The primary development of the reverse faults occurred in the Miocene and early Pliocene, though warped Pleistocene marine terraces indicate some later reactivation. These structures produce about 1% shortening parallel to, and appear to be related to the seaward concave curvature of, the plate boundary. Late Miocene to Recent normal faults throughout the Coastal Cordillera parallel the plate boundary and dip both towards and away from the trench. At several places in the study area, paleodrainages were incised across the uplifting EW reverse fault blocks prior to being dammed, producing internally drained evaporite basins in the footwalls of the structures. These relations indicate that there was considerably more water in the Coastal Cordillera in the latest Miocene and early Pliocene than is available at present, in agreement with the prior suggestion that the onset of hyperaridity in the region post-dates 5 Ma. The Río Loa, the only river to reach the sea along more than 500 km of coastline, truncates on of these paleodrainages indicating that the Loa was incised at its current location after the middle Miocene. The incision of the Río Loa could be due either to uplift of the Coastal Cordillera, or due to lateral (W to E) migration of its baselevel were it debouches into the ocean as the Coastal Escarpment retreats from W to E. These two processes of incision are probably controlled by underplating and subduction erosion, respectively.

T32E-07 1730h

Late Cenozoic Evolution of the Mejillones Peninsula, Northern Chile

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The Mejillones Peninsula, located on the Pacific margin of Northern Chile, contains outer shelf, shelf and coastal terrace deposits that record the paleoceanographic, tectonic, and topographic evolution of the region. Preliminary micropaleontologic, geochemical, sedimentological and geochronological analyses of sedimentary sequences within the Tiburon Basin and uplifted coastal terraces of the Mejillones Peninsula together document Plio-Pleistocene sea-level cyclicity, as well as coeval changes in marine productivity, regional uplift, and displacement on local faults. The sedimentary succession within the Tiburon Basin can be subdivided into a lower set of diatomaceous sedimentary cycles containing thin phosphatic horizons, marine vertebrates and abundant planktonic and benthic foraminifera. Preliminary analyses of these sediments indicate an initial deep-water (∼500 meter) basin with high primary productivity related to upwelling of cold intermediate water interrupted by periods of little to no sediment input. This style of deposition was interrupted by an uplift event, probably involving vertical motion on the Mejillones Fault immediately to the west of the Tiburon Basin, which dominated the character of the upper set of sedimentary cycles and comprise coarse clastic sediments including vertebrate fossils, blocks up to boulder size, interpreted as detritus from the nearby fault scarp, and well-rounded pebbles derived from the interior of the Mejillones Peninsula. This switch from diatomaceous to clastic sedimentary cycles indicates abrupt (1) shallowing of the basin to shelfal (50-100 meters) to nearshore depths, (2) generation of significant local relief on the fault scarp, and (3) large-scale uplift and erosion of the Mejillones Peninsula. An Ar/Ar age of 2.8 ± .04 Ma from an ash horizon near the top of the succession indicates a Pliocene age for the Tiburon succession, which is consistent with the foraminiferal biostratigraphy of the diatomaceous sequences. At least 10-12 coastal terraces occur within the Mejillones Peninsula, the highest of which can be traced to the margin of the Tiburon Basin and document contemporaneous subaerial exposure, uplift, and continuing sea-level cyclicity through the Quaternary.

T32E-08 1745h

Did Andean Uplift Control Climate Change in the Central Andes

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Sedimentological data indicate that a semi-arid/arid climate has prevailed across the Central Andes from over 25 Ma to 4 Ma. Between 4 and 3 Ma a marked switch to hyperaridity occurred along the western margin of South America between 10 and 27 degrees South. Palaeoaltitude data, although poorly constrained, suggest that a substantial proto-Central Andean mountain range was in place between 15 and 9 Ma. Evidence for this is provided by the presence of thick successions of evaporates developed within endorheic basins in the Altiplano/Puna area. These data support the idea that the Andean rain shadow existed by 15 Ma or earlier, and that rather than changing the pre-existing climatic regime it reinforced the already arid climate. The change to hyperaridity in western South America is attributed to a combination of global climate cooling and enhanced upwelling of the Humboldt current generated by closure of the Central American Seaway between 3.5 and 3 Ma, and did not result from the rain shadow generated by Andean orogenesis. Evidence for a global causal mechanism is seen in the Namib Desert. The switch to hyperaridity in the Namib also occurred around 3 Ma but was independent of orographic effects generated by a large mountain range.

T32F MCC: 3005 Wednesday 1600h

Orogenesis, Metamorphism, and Exhumation II *(joint with H, V)*

Presiding: **R N Pysklywec,** University of Toronto**; J Rahl,** Yale University

T32F-01 1600h

Bransfield Basin and Cordilleran Orogenesis

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