7-2011

Penrose Conference Report: Neotectonics of arc-continent collision

Paul Mann

Carlos Vargas

Caroline Whitehill

Penrose Conference Report

Neotectonics of arc-continent collision

Manizales, Colombia • 17–21 January 2011

CONVENERS

Paul Mann, *Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, Austin, Texas 78758-4445 USA; paulm@ig.utexas.edu*

Carlos Vargas, *Depto. de Geociencias, Universidad Nacional de Colombia, Bogotá, Colombia; cvargas@unal.edu.co*

Caroline Whitehill, *Dept. of Geological Sciences, Central Washington University, Ellensburg, Washington 98926, USA*

INTRODUCTION

Collisions of arcs with continents are some of the most significant tectonic processes on Earth, leading to crustal accretion, continental growth, formation of sedimentary basins, large areas of regional uplift and deformation, complex interactions between continuous and torn subducted slabs and the surrounding mantle, and large regions of large earthquakes and seismic, volcanic, and landslide hazards that can threaten the lives of millions.

The objective of this conference was to bring together an international group of scientists to discuss the neotectonics and seismic hazards of shallow slab subduction in areas of arc-continent collisions. Important questions included the following:

1. How do the plate tectonic settings and crustal structures of ongoing arc-continent collisions in different parts of the world (e.g., Taiwan, Papua New Guinea, Japan, Kamchatka, Italy, Alaska) control the pattern of surface deformation and the geometry of shallowly subducted slabs? Are plate-driving forces the main control on the regional deformation patterns or do mantle forces acting on subducted or broken off slabs also play a role?
2. How do arc collision and shallow subduction generate anomalously broad crustal zones of deformation as seen in areas like the Andes, Taiwan, the Banda arc, and the Himalayas? Are these broad zones of crustal deformation "thin-skinned" and deforming on shallow detachments with large amounts of shortening or "thick-skinned" and rooted on older fault surfaces and reactivated rifts?
3. The process of vertically detaching slabs or "slab breakoff" and torn slabs shown by areas of strong slab dip change is common to many areas of arc-continent collision and shallow subduction, yet the tectonic mechanisms and timing of this process are not well understood. How have recent advances in seismology, tomography, and geodynamic modeling improved our imaging and understanding of slab subduction and breakoff, and how do these observed breakoffs affect the pattern of observed earthquakes and slab-related volcanism?
4. Is coupling of the subducted slab and arc in arc-collision zones any greater than that observed along non-collisional subduction boundaries and therefore linked to higher levels of larger and more destructive earthquakes? How can this improved level of academic understanding of arc collision and shallow subduction at all levels in the crust and upper mantle help improve maps of seismic hazard and be communicated to the public living in broad plate boundary zones?
5. How can this tectonic and geologic data be used to better inform policy makers and planners about the potential seismic, volcanic, and landslide hazards of those inhabitants living in arc-continental collisional zones?

VENUE

The Cordillera Central of Colombia, 130 km to the west of Bogotá, was chosen as the meeting venue because it is the setting for many of the tectonic, volcanic, and sedimentary processes related to arc-continent collision discussed at the meeting. From the late Cretaceous to Miocene, accretion of arcs and oceanic plateaus has shaped the active margin. Since the middle Miocene (ca. 12 Ma), the Panama arc has been colliding with the continental margin of the northwestern South American plate and has superimposed earlier tectonic events. This cumulative tectonic history has produced many features illustrative of the conference themes: (1) formation of the widest area of the Andean mountain chain (500 km) over its entire >8000-km length from Colombia to Tierra del Fuego; (2) shallow subduction of the Caribbean slab beneath the northern Andes with active slab tears defining distinct slabs seen with tomographic studies and "breakoff" occurring along the downdip edge of the slab; (3) large, historic earthquakes produced by strong coupling at the shallow subduction interface; and (4) thick Miocene to present sedimentary basins that provide a record of structural events.

Manizales was also an ideal location for the meeting because of its location near the major transverse Caldas slab tear separating a steeper dipping Nazca slab in southern Colombia from a more shallowly dipping slab beneath northern Colombia.

The alpine setting, interesting geology, active tectonics, and many interesting interactions all made for a stimulating meeting. We greatly appreciate the financial support of Ecopetrol-ICP for making this meeting possible.

Presentations and Field Trips

The five-day Penrose meeting, the first meeting of its type to be held in Colombia, was divided into five parts. Paul Mann

opened the meeting with an overview of the deformational and rotational effects produced by colliding arcs and buoyant ridges as compiled in a summary of geologic and GPS effects by Wallace et al. (G3, v. 10, May 2009).

The morning talk session focused on the crustal response to arc-continent and buoyant ridge collision that included descriptions of different active collisional zones found along the length of the Andes, using geologic and thermochronologic studies of basement rocks and overlying basins (Victor Ramos, Richard Spikings, German Bayona, Joel Saylor, Mauricio Parra); the Banda arc, using a combination of GPS and geologic studies (Ron Harris); and Taiwan, using a combination of earthquake studies and deep geophysical profiling (Wu-Cheng Chi).

In the case of the Banda arc and Taiwan, there is no question about the driver of collision, because the colliding block is well defined. However, the subsurface geometry of the subducted slabs within the collisional zone is less clear due to the limits of imaging to depths of 50–100 km using reflection and refraction methods. One issue is the fate of the forearc basin during the collisional process. In the Andes, the relative importance of colliding ridges is less obvious, and there was much discussion about the relative effects of the various ridges on the Andes themselves.

The afternoon talk session focused on lithospheric responses to arc-continent collision and included talks on the possible causes of flat-slab subduction, including its impact on plate coupling and great earthquakes along the length of the Andes (Marc-Andre Gutscher); deep crustal imaging of the Taiwan arc-continent collision, including recent tomographic data (Kirk McIntosh); the application of deep seismic imaging to the Himalayas from a passive geophysical experiment (Anne Sheehan); tomographic methods from the BOLIVAR study applied to the southern Caribbean and northern Andes (Gary Pavlis, Alan Levander, Carlos Vargas); and stratigraphic effects in the northern Andes of collision (Hermann Duque-Caro). The afternoon session was followed by presentation of 15 posters on the crustal and lithospheric responses mainly in the northern Andes.

Tuesday was an all-day field trip to Nevado del Ruiz volcano, led by Carlos Borrero, that combined outcrop stops of volcanic rocks up the flank of the 5300-m-high snow and glacially capped volcano. A highlight was Borrero's investigation of post-glacial stratigraphy of interbedded paleosols and tephra deposits that document ~11 minor eruptive events in the past 11,000 years. The group visited the headwaters of a massive lahar (mud and debris flows) that buried the downstream town of Armero and caused an estimated 23,000 deaths on 13 Nov. 1985. Discussions included how to better protect the surrounding towns from future eruption-related floods and the volcano's tectonic setting near the northern projection of the Caldas slab tear, which is proposed to separate the steeper dipping Nazca plate to the south from the more shallowly dipping Panama arc indentor to the north.

Talks on Wednesday addressed the measurement and modeling of fault motions, paleoseismology, and determination of seismic risk in areas of arc-continent collision and shallow subduction. Serge Lallemand began the session with a discussion of active tectonics and seismic risk in Taiwan using a combination of reflection and refraction data with earthquake data. These data suggest that the slab is being torn in the collisional area beneath Taiwan. Ross Stein provided an overview of the utility of Coulomb stress models for understanding the large 2010 Haiti and Chile events. Hector Mora summarized his work with James Kellogg on the 20-year-long CASA GPS study of the northern Andes and more recent permanent GPS receiver installation toward a denser GPS array. Tom Rockwell discussed the deformation of Panama as a consequence of its collision with northern South America using both paleoseismologic and GPS data. Hans Diederix summarized the state of paleoseismologic work on Holocene fault scarps in Colombia. Franck Audemard summarized GPS and paleoseismologic data for the northward motion of the Maracaibo block that includes faults in both Venezuela and Colombia. This refined work indicates ca. 5 Ma inception of right lateral slip on the Bocono system responsible for ~30 km of cumulative displacement. Carlos Costa introduced a perspective from the southern Andes in Argentina and Chile on the distribution and style of late Quaternary faults and folds in that area. Sergio Lopez and Cristina Dimate summarized earthquake and GPS data for Colombia showing evidence for strain partitioning, and Omar Cardona described the CAPRA (Central American Probabilistic Risk Assessment) plan for probabilistic risk assessment in Colombia and other parts of the world. Afternoon talks included a session on volcanism in the arc-continent collisional zone of Panama (Camillo Montes, David Farris) and Colombia (Maria Luisa Monsalve, Carlos Borrero). Seven afternoon posters addressed issues of active deformation and volcanism in Colombia.

The field trip on Thursday, led by Alvaro Nivia, Carlos Vargas, and Andreas Kammer, provided a regional structural transect from Manizales in the Cordillera Central to the Cordillera Oriental of western Colombia, which is adjacent to the modern Colombian trench. The main features examined included highly deformed rocks along the broad zone of the Romeral fault zone—the suture between oceanic rocks and continental rocks of South America. We discussed the active versus ancient origin of prominent topographic basins in western Colombia, such as the Cauca, given their setting in the zone of convergence of the impinging Panama arc. Our final stop was near the town of Salento to observe tectonic geomorphology suggestive of Holocene faulting. The group agreed that much work remains to be done on mapping of Holocene faults and tectonic geomorphology in Colombia.

Discussion Theme 1: Global plate tectonic setting and crustal structures; group leaders: Marc-Andre Gutscher and Ron Harris. This group compiled a list of all arc-continent collisions and attempted to show which processes are shared and which processes appear unique.

Discussion Theme 2: Deformation zones associated with arc collision and shallow slab subduction; group leaders: Paul Mann and Victor Ramos. This group compiled a list of arc-continent collisions around the world and used information from the Thursday field trip to construct a regional cross section from the colliding Panama arc to the meeting venue

in Manizales, Colombia. A broad consensus emerged on the nature of the belts within the collisional zone and their tectonic origins.

Discussion Theme 3: Imaging and modeling slab tears in arc-collisional areas; group leaders: Carlos Vargas and Anne Sheehan. This group attempted to better define the terms *slab breakoff* and *slab tear* and to identify specific examples of each feature. Geophysical field experiments for determining breakoffs and tears were also summarized.

Discussion Theme 4: Geohazards assessment in regions of arc-continent collision; group leaders: Ross Stein and Omar Cardona. This group outlined three main strategies for improving the next generation of seismic hazard maps in Colombia: (1) use GPS and paleoseismology to better define fault slip rates; (2) focus on faults that are closer to large urban areas like Bogota; and (3) improve understanding of seismic sources using magnitudes, b-values, and recurrence intervals. The CAPRA and GEM (Global Earthquake Model) programs are the first step in developing standards for fault compilations and training and to gain visibility on an international scale.

Participants: Tricia Alvarez, Mónica Arcilla, Franck Audemard, German Bayona, Gabriel Bernal, Rocio Bernal-Olaya, Carlos Borrero, Andrex Calle, Henry Campos, Alexandar Caneva, Omar Cardona, Fabio Cediel, John Ceron, Wu Cheng Chi, German Chicangana, Martin Cortes, Carlos Costa, Ruth Costley, Hans Diederix, Yildrim Dilek, Christina Dimate, Herman Duque-Caro, Juan Sebastian Echeverri, David Farris, Christian Gonzalez, Marc-Andre Gutscher, Ron Harris, Andreas Kammer, Suzanne Kay, Serge Lallemend, Alan Levander, Sergio Lopez, Paul Mann, Carlos Marcillo Jaramillo, Mabel Marulanda, Kirk McIntosh, Carlos Molindres, Gasper Monsalve, Hugo Monsalve, Maria Luisa Monsalve, Camillo Montes, Hector Mora-Paez, Freddy Nino, Alvaro Nivia, German Ojeda, Mauricio Parra, Gary Pavlis, Maria Prieto, Victor Ramos, Andres Reyes Harker, Tom Rockwell, Geovanni Romero, Mario Salgada, Joel Saylor, Anne Sheehan, Richard Spikings, Ross Stein, Javier Tamara, Mike Taylor, Roelant Van der Lelij, Carlos Vargas, Gabriel Veloza, and Caroline Whitehill.