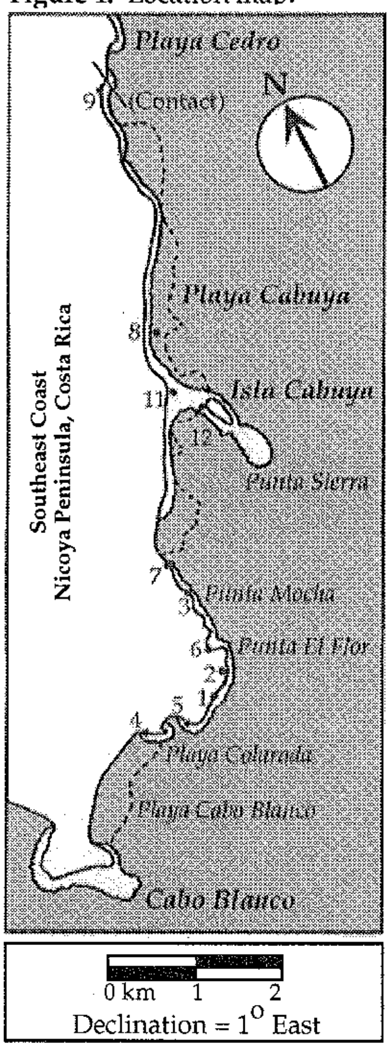
Faults and folds in the Cabo Blanco Formation, Peninsula de Nicoya, Costa Rica

Alexander Claypool
Department of Geology, Franklin and Marshall College,
501 Harrisburg Pike, Lancaster, PA 17603
Faculty Sponsor: Edward Beutner, Franklin and Marshall College

PURPOSE

The Cabo Blanco Formation is a sedimentary unit of interbedded deep water marine, hemipelagic mudstones and fine grained terrigenous turbidites deposited from Paleocene to lower Eocene times. Crustal uplift has exposed the Cabo Blanco on marine terraces along the southeastern shore of the Peninsula de Nicoya , Costa Rica (Figure 1). Faults and folds exposed on the terraces and in adjacent sea cliffs record the deformational history of this unit. The purpose of this project was to unravel the deformational history and to develop an explanation for deformation of the Cabo Blanco Formation. Understanding the strains involved in producing these faults and folds will provide insight as to the interactions between the Cocos and Caribbean plates that have affected the Cabo Blanco since Paleocene times.

Figure 1: Location map.



TECTONIC SETTING

The Middle American Trench (MAT) strikes about N50W and lies nearly 70 km southwest of the Peninsula de Nicoya. At the MAT the Cocos plate is subducting below the Caribbean plate at a rate of approximately ~9 cm/yr. Convergence between these plates along an azimuth of N29E (Lundberg, 1982) indicates subduction is slightly oblique. The time at which subduction initiated along the MAT remains uncertain, and is part of a larger dispute over the tectonic history of the entire Caribbean region. The presence of volcanic rocks and volcaniclastic sediments of late Cretaceous age landward of the trench suggests that subduction began between 60 to 70 Ma (Lundberg, 1982: McIntosh, 1993). However, it has also been postulated that present MAT subduction initiated as late as the Oligocene, forming the Talamanca volcanic belt (de Boer, 1979). Trench-related compression has caused the Caribbean crust to warp as a broad anticline, uplifting the forearc. Regional uplift began during the Paleogene and has remained active during Quaternary times (Lundberg, 1982; Gardner et al., 1992). The initial age of MAT subduction is important for distinguishing the origin of the sediments that comprised the Cabo Blanco turbidites. Assuming that subduction began prior to the deposition of the Cabo Blanco sediments, this unit can be restricted to the parautochtonous landward slope along the Caribbean margin. However, if subduction initiated following the deposition of sediments, the source and site of initial deposition is less constrained relative to the trench.

METHODS

Field observations included measuring and classifying faults, folds, and bedding at 11 separate localities. All measurements were made using a Brunton compass. Fault orientations, striations and sense-of-slip, cross-cutting relationships, and character of fill were determined. Axial surfaces were determined from combining hingeline and axial trace measurements on folds. Sense of rotation was also determined. Stereonet and Faultkin were used to plot fault and fold sets and to make location comparisons. Hand samples were collected and prepared for thin-section analysis. Samples were appropriately cut and observed for evidence of microstructural deformation and composition.


Figure 1: Image of a normal fault. Field book for scale.


Figure 2: Image of soft-sedimentary faults. Faults are the gray bands running horizontally across the image. Hammer for scale.

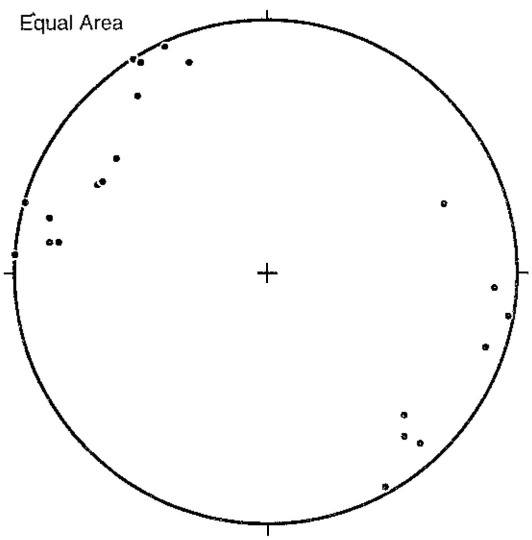


Figure 3: Stereonet plot of the poles to the fault planes at site 1, which is located at the southernmost tip of the field area. Note the clustering of points around the northwestern and southeastern regions.

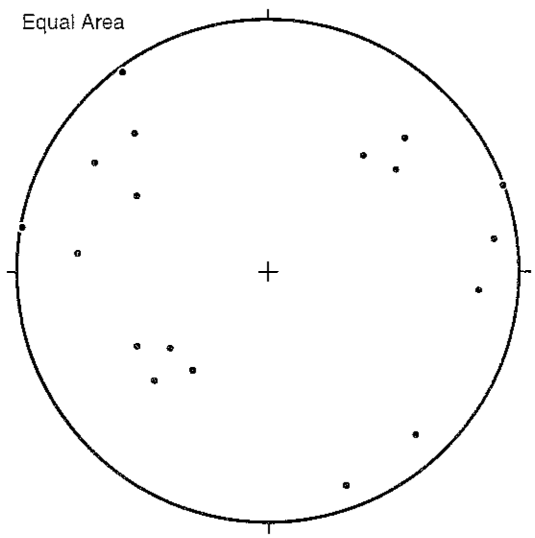


Figure 4: Stereonet plot of the poles to the fault planes at site 7, near the northern end of the field area, just south of the coherent/incoherent boundary. Note there are several clusters of points illustrating the more diverse range of fault orientations in the north.

OBSERVATIONS & DISCUSSION

The Cabo Blanco Formation consists of two distinct sections, varying somewhat in lithology and dramatically in structure. These two sections also differ slightly in age. Strata in the northeastern section are believed to be of Paleocene age while the southwestern strata are believed to be of younger late Paleocene and Eocene age (Chaves, 1983, unpublished). In thin section the compositions of the southwestern strata are foraminifera-rich calcareous mudstones. Many samples showed multiple episodes of veining. Twinning of sparry calcite indicated additional strain post-veining. Fault breccia samples included angular clasts and styolitic pressure solution seams. The northeastern strata are predominantly composed of fine-grained graywackes, mudstones, and shales. In thin section foraminafera were rarely seen in any of the northern rock. Grain sizes were slightly larger than those in the southern section, while calcite veining was less common. Both sections possess volcanic rock fragments and feldspar laths indicating a regional volcanic source. A significant hemipelagic component indicates that both sections of the Cabo Blanco were likely deep water slope deposits. The fine grain size of these sediments indicates a distal facies, so it has been postulated by Lundberg (1982) that a bathymetric high prevented much of the coarser detritus from reaching this area. Some graywackes are subtly laminated and weakly graded and are interpreted to be turbidites. The severely folded strata in the northeast and the intensely faulted strata in the southwest distinguish these sections structurally. The transition of these two sections in the Cabo Blanco is somewhere south of Cabuya Playa and north of Cabo Blanco where the shoreline presently has no exposed terrace outcrops. There does appear to be some exposure of a transition near the southwest segment of the isthmus connecting Isla Cabuya to the peninsula near station 12 in Figure 1. An abrupt change from the folding to faulting is separated by a 20 to 30 meter covered interval of incoherent rubble.

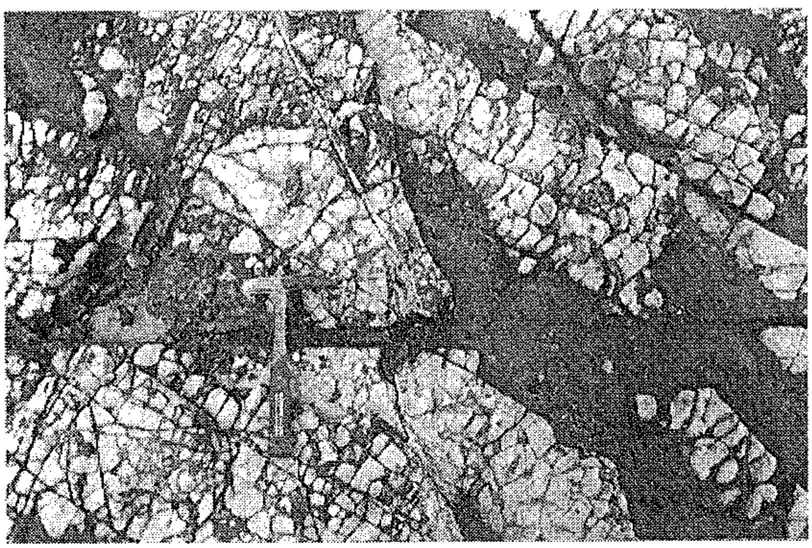


Figure 2: This photo, at station 2, shows a gouge-filled fault offsetting an older calcite vein-filled fault in a right-slip sense.

Structure in the Southwestern Section: Strata in the southwestern section are intensely faulted, with abundant calcite vein-filled and gouge-filled faults. When fault offsets were observed, in all cases the vein-filled faults were cross cut by younger gouge-filled faults (Figure 2). Most locations revealed several fault orientations, and observed cross-cutting relationships indicated several generations of faulting had occurred. South of Punta El Flor, at station 1, as many as five fault sets may be present. Cross-cutting relationships indicate two gouge-filled faults sets that post-date an array of calcite-filled faults. The calcite-filled faults strike approximately: north, dipping steeply to the east and west; N60E, dipping steeply to the SE; and N55W, dipping shallowly to the NE and SW, suggesting that there could have been as many as three generations. The absence of cross-cutting relationships makes it impossible to determine the precise number and sequence of fault sets. Some locations exhibit mainly faults with similar attitudes indicating a single generation of faulting. The most widespread fault set was a calcite-filled right-lateral strike-slip set striking approximately N40W and dipping to the NE. Another major set seen in many localities is a left-lateral strike-slip fault set striking approximately N45E and dipping steeply to the SE (Figure 3). Younger normal faults striking NW and filled with up to 1 meter of gouge were observed in the sea cliffs at stations 3 and 5.

Structure in the Northeastern Section: Well exposed terrace outcrops at Cabuya Playa exhibit intense folding and contain a set of layer-shortening wedge faults that strike approximately N80W and N70E and dip steeply to the south. Here, the buckle folds are disharmonic with an overall counterclockwise sense of rotation viewed looking NW (Figure 4). Axial surfaces strike approximately N75W, with hinge lines trending roughly trench parallel and plunging shallowly to the NW and SE (Figure 5). The mechanism of folding is uncertain. Some sedimentary slumping features were observed, but most structural features indicate tectonic deformation. Extensive bending of some axial surfaces indicates that more than one generation of folding deformed this location, but

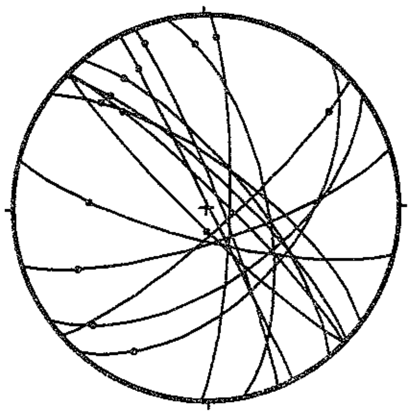


Figure 3. Stereonet plot of station 2. Two fault sets striking: N40W, dipping steeply to the NE; and N55E, dipping SE with subhorizontal slip.

shearing along fold hinges made it impossible to measure earlier folds. Using Stereonet, faults at Cabuya Playa were rotated back to paleohorizontal by removing the dip of adjacent folded bedding. This provided a stereonet with gently NE and SW dipping contemporaneous fault pair striking nearly N50W with near parallel striations, indicating these faults were likely produced prior to folding by a roughly MAT-perpendicular compression (Figure 6). South of Cabuya Playa, at station 11, axial surfaces change strike to nearly N40E with hingelines plunging shallowly to the SW. It is unclear whether these folds are related to the set at station 8 or whether they were rotated by secondary deformation associated with the contact.

South of Playa Cedro, the northern edge of the Cabo Blanco is in contact with mid Cretaceous basalt of the Nicoya Complex. This is a structural shear zone and does not indicate an angular unconformity as proposed by Lundberg (1982). An intense vertical anastomosing shear fabric striking approximately N45W was observed within the 12 to 15 meters of Cabo Blanco adjacent to the contact. Under thin section Cabo Blanco graywacke samples do not contain any basaltic grains from the Nicoya Complex, further indicating this contact is a structural shear zone.

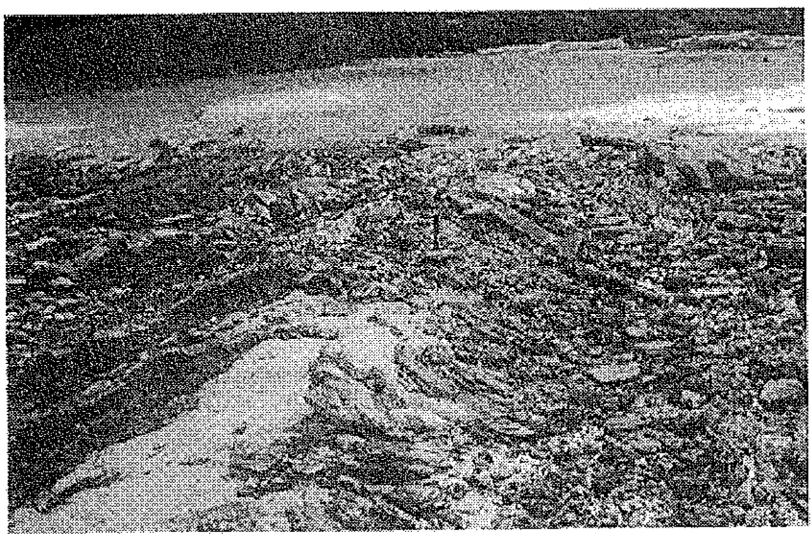


Figure 4: This photo, facing NW at station 8, shows an asymmetrical anticline exposed in the marine terraces at Cabuya Playa.

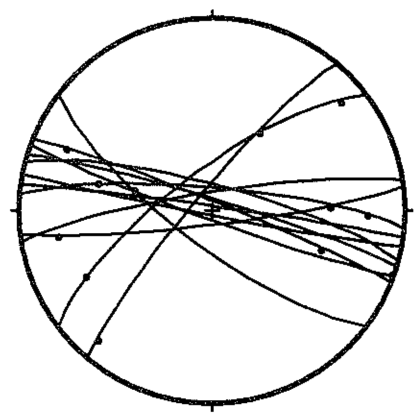


Figure 5. Stereonet plot of axial surfaces and hingelines at station 8, Cabuya Playa,

INTERPRETATIONS

The Cabo Blanco Formation as a whole can be differentiated by the structural and lithologic differences between the strata of the northeastern and southwestern sections. The folding and wedge faulting of the slightly older northeastern section did not affect the southwestern section. This means that either all of the deformation in the northeastern section occurred prior to the deposition of the southern section or that the strains recorded in the Cabo Blanco to the northeast did not affect strata to the southwest. This must mean that either strains were localized or these sections of strata were at a greater distance from each other than they are presently. It is equally apparent that faulting in the younger southern strata did not affect the strata of the northeastern section. For example, fault sets do not correlate across the transition between these sections. This supports the idea that the strains on the Cabo Blanco affected these sections locally and that they have since been brought closer together. As most of the transition which separates these sections remains unexposed, an explanation for why the sections differ must in large part be inferred.

One possibility is that the abrupt transition between these two sections near Isla Cabuya may represent a past subduction-related thrust that placed some of the older northeastern strata on top of the younger southwestern

Cabo Blanco. The orientation and vergence of folds at Cabuya Playa in the northern section supports this hypothesis. This places the shortening direction at approximately N15E, within 15 degrees of the present direction of subduction. The layer-shortening wedge faults, believed to have predated folding indicate shortening was earlier oriented close to N80E. This requires a 65 degree counterclockwise rotation of shortening between the times of formation of the faults and the folds. A counterclockwise change in the direction of shortening is supported by evidence indicating that the convergence of the Cocos Plate has rotated counterclockwise from a more easterly direction since deposition of the Cabo Blanco (Pindell and Barrett, 1990).

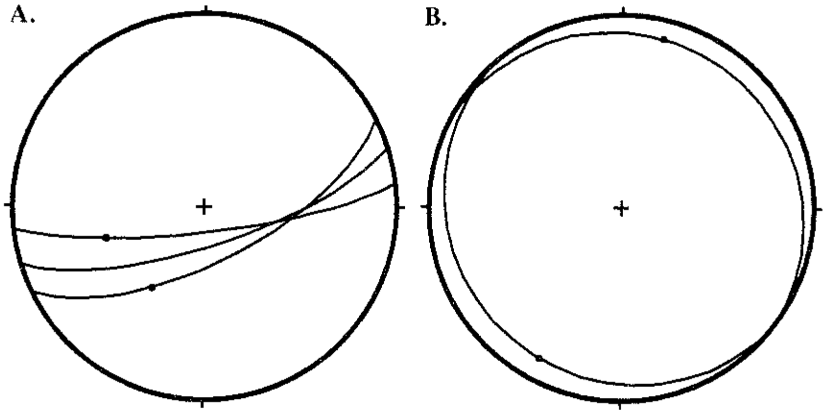


Figure 6. This set of Stereonet plots shows how the layer shortening wedge faults were rotated back to paleohorizontal. Stereonet A) shows a fault pair with rakes and local average bedding. Stereonet B) shows this fault pair after the dip was removed from bedding.

ACKNOWLEDGMENTS

I would like to recognize a few individuals whom helped make this project possible. I would like to thank Edward Beutner for his continued support and guidance throughout this year as my project sponsor. I would like to commend Tom Gardner for his organization and leadership as the director of the 1998-99 Costa Rica KECK project, his efforts made this project a joy to be a part of. I would also like to thank Alix Krull and Becky Stamski for their dedicated assistance in the field.

REFERENCES

Chaves, Ana, Leyla, Chincilla, 1983, *Geologia del Area de Montezuma y Alrededores, Peninsula de Nicoya, Provincia de Puntarenas, Costa Rica*: Universidad de Costa Rica, Unpublished work.

de Boer, J., 1979, *The Outer Arc of the Costa Rican Orogen (Oceanic Basement Complexes of the Nicoya and Santa Elena Peninsulas)*: Tectonophysics, v. 56, p. 221-259.

Gardner, Thomas, W., Verdonck, David, Pinter, Nicholas, M., Slingerland, Rudy, Furlong, Kevin, P., Bullard, Thomas, F., and Wells, Stephen, G., 1992, *Quaternary Uplift Astride the Aseismic Cocos Ridge, Pacific Coast, Costa Rica*: Geological Society of America Bulletin, v. 104, p. 219-232.

Lundberg, Neil, 1982, *Evolution of the Slope Landward of the Middle American Trench, Nicoya Peninsula, Costa Rica*, in Leggett, Jeremy, K., ed., Trench-Forearc Geology: Sedimentation and Tectonics on Modern and Ancient Active Plate Margins: London, England, Geological Society of London. p. 131-147.

McIntosh, Kirk, Silver, Eli, and Shipley, Thomas, 1993, *Evidence and Mechanisms For Forearc Extension at the Accretionary Costa Rica Convergent Margin*: Tectonics, v. 12, p. 1380-1392.

Pindell, James, L., and Barrett, Stephen, F., 1990, *Geological Evolution of the Caribbean Region; A Plate Tectonic Perspective*, in Dengo, Gabriel, and Case J. E., eds., The Geology of North America: The Caribbean Region: Boulder, Colorado, The Geological Society of America, v. H, p. 405-432.

A Study of Paleomagnetism of the Nicoya Terrane, Costa Rica

Anna Reeves
Department of Geosciences, Mississippi State University,
P.O. Drawer 5448, Mississippi State, MS 39762
Faculty sponsor: Bruce Panuska, Mississippi State University

Abstract

The Chorotega Terrane constitutes the backbone of the southern Middle America volcanic arc, formed on the western edge of the Caribbean plate. The adjacent Nicoya Terrane, lying trenchward of the Chorotega Terrane, was previously determined to be located at 7° S during the Cretaceous, with conflicting data constraining accretion timing. New paleomagnetic data from Paleocene rocks reveal that the Nicoya Terrane was at its present latitude relative to the autochthonous Chorotega Terrane. These data suggest that the Nicoya Terrane accreted to the Chorotega Terrane by Paleocene time.

Introduction

The Nicoya Terrane and the adjacent Chorotega Terrane are located between the converging Caribbean and Cocos Plates along the Middle America Trench (Gardner, this volume, Fig. 1). The accretion timing of the two terranes is at present poorly understood. DiMarco et al. (1995) suggest that Paleocene coarse channel-fill and overbank deposits, including boulders of andesites and limestones, indicate the initial amalgamation of the two terranes. Previous paleomagnetic studies indicate that the Nicoya Terrane was located about 7° S latitude, compared to the 10° N latitude of the Chorotega Terrane in Late Cretaceous time (DiMarco et al., 1995). The present latitude of the Nicoya Terrane is 10° N, indicating a 17° northward latitudinal displacement (~ 1900 km). These data largely support the reconnaissance paleomagnetic work of Gose (1983). However, Gose's (1983) Tertiary paleolatitudes give equivocal results for age of accretion, possibly due to uncertain age control and/or questionable assignment of outcrops to various terranes. The purpose of this study is to provide additional paleomagnetic evidence to help constrain the accretion timing of the Nicoya Terrane.

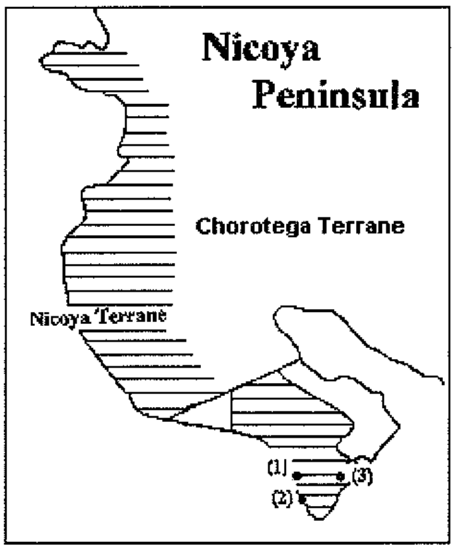


Figure 1. Diagram showing Nicoya Peninsula with Nicoya and Chorotega Terranes. Sample localities: (1) Punta Barrigona (2) Punta Cuevas (3) Playa Cabuya and adjacent Rio Lajas area. Diagram from DiMarco et al. (1995)(Figure 8).