20TH CARIBBEAN GEOLOGICAL CONFERENCE 2015
Port-of-Spain . Trinidad & Tobago, W.I.

Conference Field Trip Field Guide

Trinidad's Northern Range: "reversal of fortune": Bedrock Structure and Metamorphic Geology, and Tectonic Geomorphology

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Logistics:

When: Full day trip, May 21, 2015
Departure Point: Hyatt Regency Hotel Lobby (CGC conference venue)
Departure Time: 7AM
Return Time: 7PM
Logistics: Transport and box lunch included

Description:

On this trip participants will see and learn about the bedrock geology and geomorphology of Trinidad's spectacular Northern Range, known locally for it's fabulous mountain hikes, pristine forests, cascading waterfalls, and unique wildlife. The Northern Range, together with Venezuela's Cordillera de la Costa, forms the deeply exhumed metamorphic hinterland of the syn-collisional (mid-late Miocene) Caribbean orogen. Now finding itself attached to and traveling with the Caribbean plate, and in a transform plate margin setting, the range is now in a new, post-collisional phase of development.

The trip covers: 1) structural and metamorphic geology, and geochronology and thermochronology, which indicate significant bedrock variations along strike, and 2) tectonic geomorphology, which gives the ages, character, and origin of the young deposits in and along the range, and indicates how modern erosion, uplift, and subsidence rates vary along strike.

The Northern Range has experienced a great "reversal of fortune". Deeply exhumed midcrustal rocks in the west are now being sunken into the Gulf of Paria pull-apart basin. Pleistocene marine terraces are being lifted out of the sea in the east. On this full-day trip, we will lay out and explore the geological and geomorphic basis for this tale of "reversal" as we traverse the range from west to east.

TIME	WHAT	PLANS
7:00 AM	Depart from the Hyatt Regency Hotel	Please meet in the hotel lobby or parking lot prior to 7AM for a prompt departure; POS Savannah water wells en route.
7:30-8:00	**Stop 1: Lady Young Road overlook**	Overview of macro-geomorphology, basin-wide erosion dynamics, timing and rates, and recent neotectonics of western NR. Bedrock deep ductile structures and metamorphic features.
8:00-8:30	**Stop 2: Hilton car park**	Bedrock geology (deep, ductile D_1 deformation) of "Chancellor schists". POS Savannah and Curepe water wells en route.
8:30 – 10:30	Drive along the NR mountain front eastward	Note geomorphic changes en route: the appearance of alluvial fans, elevation increase of river mouths, & mountain front straightening. **Restrooms available** along roadside in transit.
10:30 – 11:30 PM	**Stop 3: Valencia Fans**	Geomorphology of the NR mountain front, the Arima fault, the Northern Basin bedrock "bulge" = Mahica high, and timing of fan deposition. NR guppies-geomorphology connection
12:00 – 1:00	Drive east along the NR front and north along the Atlantic coast	Bedrock geology and geomorphology and refreshment stops TBD.
1:00 – 3:00	**Stop 4: Tompire Bay & Lunch**	**Box lunch** (provided) at Tompire Bay. Geomorphology & stratigraphy of marine terraces, timing and magnitudes of tectonically driven surface uplift, and basin wide erosion. Bedrock geology of semi-brittle upright D_1 and D_2 structures in upper crustal eastern NR "lid".
3:00 – 3:30	Drive north to the easternmost point of mainland Trinidad	Enjoy sea breeze and beautiful views of rugged emergent eastern Atlantic coastline.
3:30 – 5:00	**Stop 5: Galera Point**	Coastal geomorphology, marine terraces, uplift, NR tilting, and neotectonics. Bedrock geology- Toco cataclacite = brittle deformation "carpet" *beneath* mechanically strong, stretched, overturned (?) Galera Grit.
5:00 – 7:00 PM	Drive back to the Hyatt Regency Hotel, POS	

Introduction

What's the origin of Trinidad's highest and most spectacular, northern mountain range? How and when did these metamorphic rocks form? How and when did they get to Earth's surface? What controls the current landforms in the range? Participants on this trip will examine the rocks, structures, and metamorphic features at several key bedrock outcrops and relate them to the structural architecture of the range, as well as visit important stops illustrating the range's landforms and flanking Quaternary deposits. The bedrock geology, Quaternary geology, and landforms all vary significantly from east to west. We will discuss the observations and models that give possible origins for these west-to-east differences in bedrock geology, Trinidad's landscape, geomorphology, and Quaternary geology.

Our bedrock geology stops are designed to illustrate the contrast between rocks and structures in the western Northern Range, which are mid-crustal, greenschist-grade schists with sub-horizontal ductile fabrics, and the upright semi-brittle structures in lower-grade (subgreenschist grade) slates in the northeastern Northern Range. We will examine outcrop-scale structures, metamorphic features, and relict sedimentary features; discuss interpretations of range-wide structural architecture; present clips from the Latinum geologic map of the Northern Range; introduce and discuss geochronological and microstructural data (including recently published apatite fission-track and unpublished $^{40}Ar/^{39}Ar$ data); and discuss the timing of metamorphism and exhumation.

As we travel across the range, we will also examine landforms and the Quaternary deposits that flank the Northern Range (alluvial fans, marine terraces, etc.). Recognizing and quantifying spatial and temporal patterns in these features will play a critical role in understanding the recent evolution of the Northern Range; until recently, they have been largely understudied. The distribution and age of these landforms and young deposits relate to both neotectonic and climatic driving forces. Our focus has been to try to understand relationships between these features and the neotectonic driving forces. We will present and discuss new ^{14}C and OSL (optically stimulated luminescence) ages from the flanking Quaternary sediments, ^{10}Be cosmogenic exposure ages, and results from recent mapping, sedimentology, and GIS analysis of these deposits and landforms.

Tectonics: old and new

Trinidad is geologically complex. It has a highly diverse surface geology, and a long, rich tectonic history, set in an active plate margin in which the driving plate kinematics has changed through time. Until fairly recently it was commonplace for tectonic interpretations to mix up fossil tectonic processes (and products) with modern, active ones. Both have contributed to shaping Trinidad's geology and landscapes. A clearer, simpler picture emerges once they are separated. On our day together, we will examine both products of fossil tectonics (recorded in the bedrock geology) and active tectonics (recorded in the landscape and flanking Quaternary sediments). The trip leaders have worked and are working on both aspects of

Trinidad's tectonics, with a strong and recent emphasis on quantifying and understanding the modern, active (i.e., neotectonic) products and processes.

GPS shows that today Trinidad sits in an active wrenching plate boundary along which the Caribbean plate slides ~eastward (precisely toward an azimuth of 085°±3°) past the South American plate at a rate of ~2 cm/year (Fig. 1) (Weber et al. 2001a). The main transform (strike-slip) faults in this active system right-step across two major pull-apart basins, the Gulf of Cariaco and the Gulf of Paria pull-aparts (Fig. 1). In addition, the active transform in Trinidad, the Central Range Fault, is slightly oblique to plate motion (Weber et al. 2001a); it is also aseismic and appears to be creeping and possibly partly elastically locked.

The record of past plate motions and their effects in Trinidad has been ascertained less directly than the current ones. Obviously, we cannot observe the ancient plate motions today, so we must infer them from their fossil rock and structural products. Figure 2 shows some of the major inferred fossil tectonic products. Some of these features are not dead, and can clearly be linked to modern, active tectonic processes—this complicates the simple view that there are two families of features completely separated in time. For example, the oceanic Tobago terrane, obducted over or wedged into South America earlier in the Cenozoic, is sliding back to the north along a reactivated low-angle thrust fault. Reactivation of the Tobago terrane-South America thrust created the largest earthquake recorded in the region (M = 6.7, April 22, 1997) (Weber et al., *Tectonics*, in press). More directly, the Northern Range is probably a topographically high range today because it is buoyed up by isostasy acting on a thick, hinterland crustal root that was produced earlier in the Cenozoic, prior to the current dextral wrenching phase of tectonics, despite active sinking into the Gulf of Paria, although new models and ideas are emerging and will be presented and discussed.

The metamorphic rocks in the Northern Range, together with those in the Paria and Araya peninsulas of neighboring Venezuela, make up the internal or hinterland part (Fig. 2) of the Caribbean-South American orogen, which comprises a long, narrow belt of high coastal mountains. Avé Lallemant (1997) synthesized the geologic history of this belt. Greenschist- and subgreenschist-grade lateral equivalents of the Mesozoic South America passive margin deposits in the foreland are present in the Paria Peninsula in eastern Venezuela and in the Northern Range of Trinidad (Frey et al., 1988, Algar and Pindell, 1993, Weber et al., 2001b) (Fig. 2). The main objective of our bedrock geology stops is to observe the systematic changes in rock types, deformation temperatures, and structural fabrics from east-to west across the Northern Range and to interpret what they may mean.

Pindell et al. (1998) present geologically derived reconstructions of fossil Caribbean-South American plate motions. Accordingly, the wrenching observed today began about 10 m.y. ago. Prior to ~10Ma, the geology shows that the boundary was in oblique convergence (Fig. 3). Your trip leaders will argue that active wrenching and pull-apart tectonics control northern Trinidad's landscapes and, in part, the distribution and nature of the Quaternary sediment flanking the Northern Range, and that the earlier pre-10 Ma oblique convergent phase of tectonics controls the structures, fabrics, and structural architecture (i.e., the bedrock geology) of the Northern Range.

The major theme of the field trip is that there has been a "reversal of fortune" in the Northern Range. The western side, which was quickly exhuming deep mid-crustal schists and shedding off sediment to the north coast marine area in the Pliocene, is today sinking. The eastern side, where mostly slates and other low-grade metasedimentary rocks are predominantly exposed, is today being tilted upward, and its young, fossil beaches (marine terraces) are being lifted out of the sea.

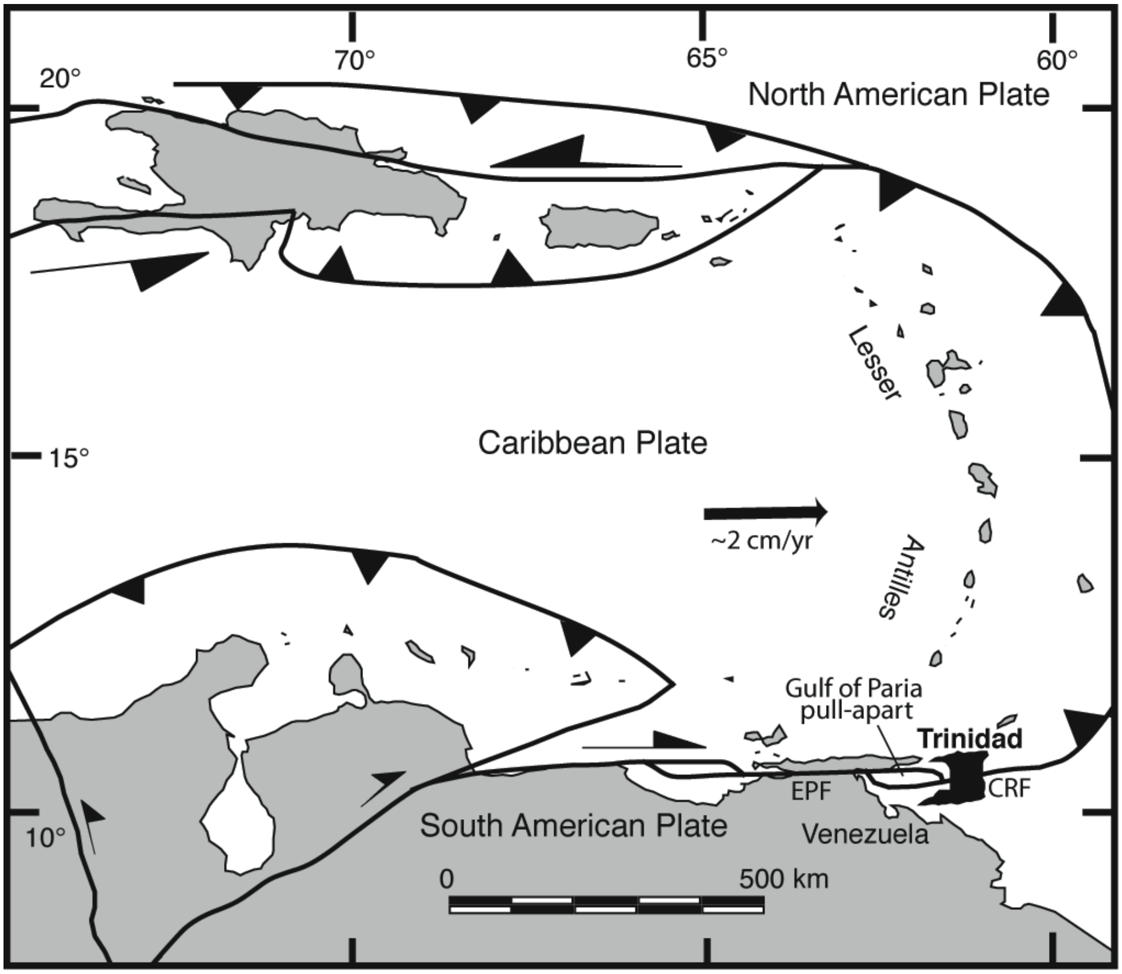


Figure 1. Map showing Trinidad's active tectonic setting. According to GPS, the Caribbean plate moves ~2 cm/yr eastward relative to a stationary South American plate (Weber et al. 2001a). Note major transform (strike-slip) faults: EPF-El Pilar fault, CRF-Central Range Fault, and pull-apart basins at right-steps in the active transform system.

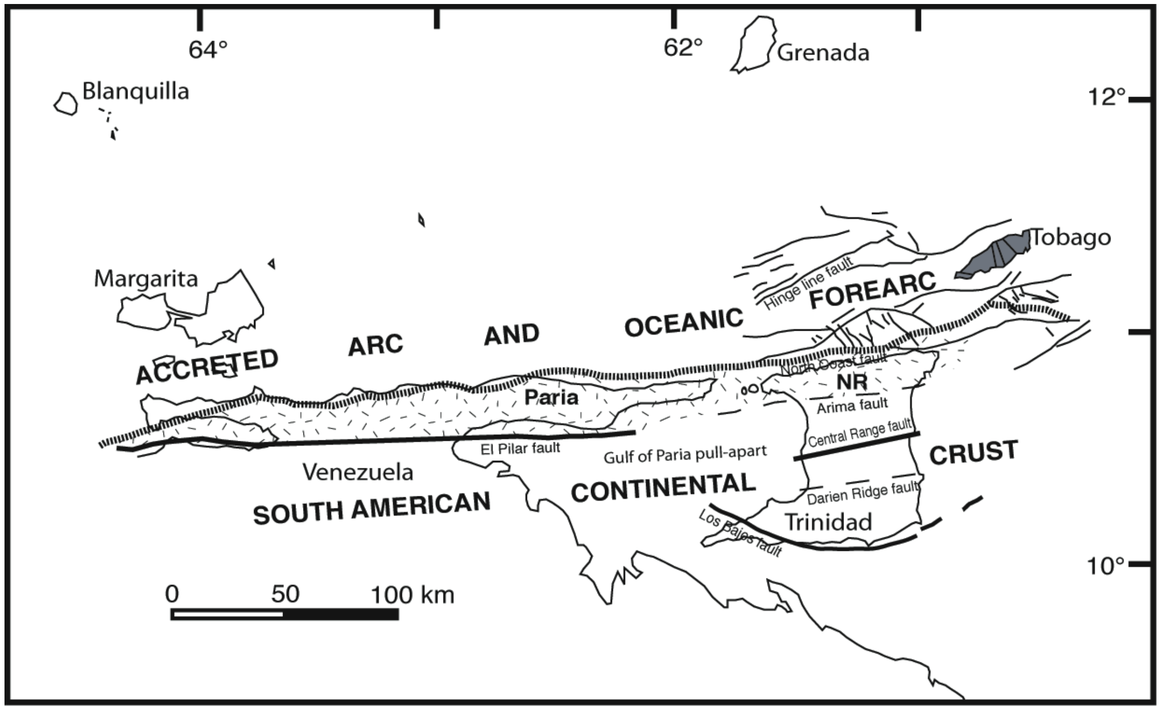


Figure 2. Map showing some of Trinidad's pre-10 Ma paleotectonic products: arc and oceanic forearc (Tobago terrane) that were accreted to continental South America during oblique convergence, and the hinterland (stippled; NR-Northern Range) and foreland portions of the South American crust that were horizontally shortened and vertically thickened. Vertical thickening was likely focused in the hinterland belt where there are topographic mountains today despite active sinking into pull-apart basins. Superposed on the fossil tectonic products are the active, wrench-related, El Pilar, Central Range, and Los Bajos Faults, and Gulf of Paria pull-apart basin.

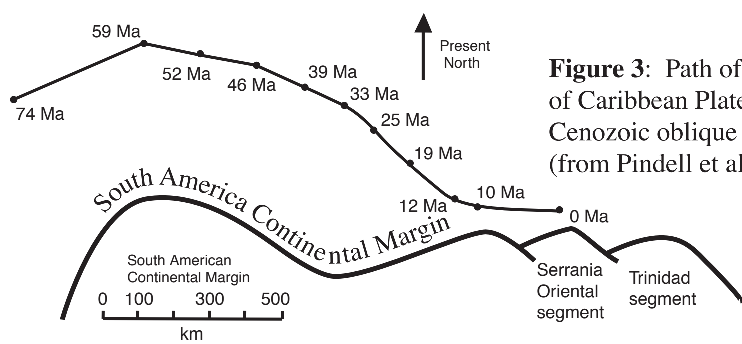
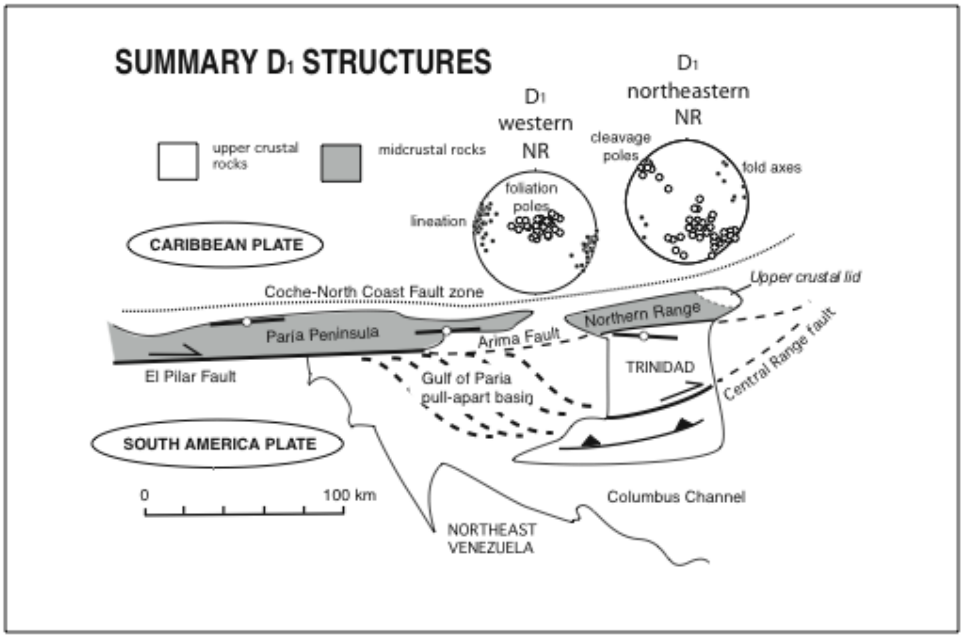


Figure 3: Path of Blanquilla representing the motion of Caribbean Plate relative to South America showing Cenozoic oblique convergence
(from Pindell et al. 1998)



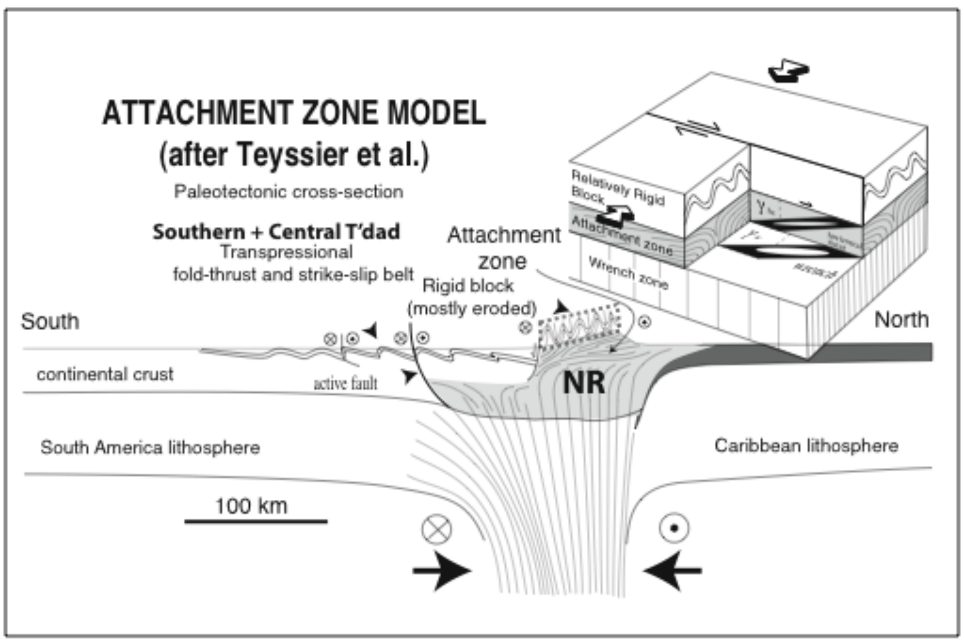


Figure 4. From Teyssier et al. (2002) indicating one possible origin for the Northern Range bedrock geometries, structures, west-to-east variations, and overall architecture.

Denison et al. (2008) Northern Range ATF Results

- **AFT Ages between ~4 Ma and ~18 Ma**
- **Dates rocks upward passage through ~110°C**
- **Spatial pattern: Older – east / Younger - west**

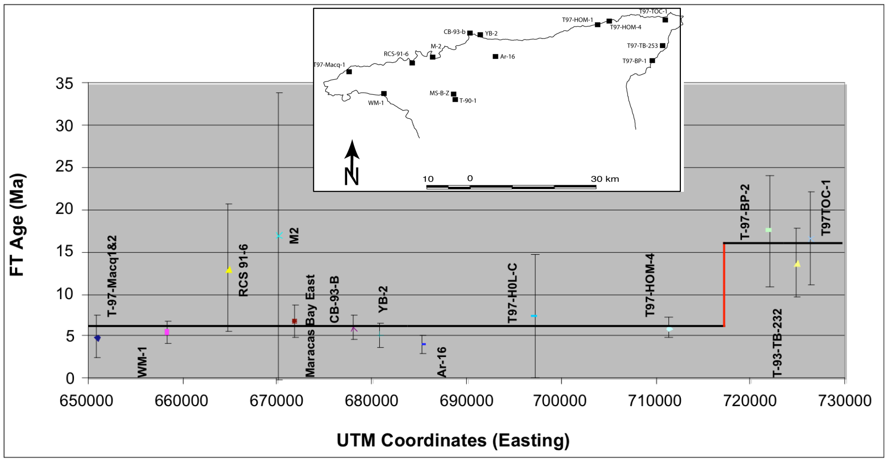


Figure 5. Summary figure showing Denison et al.'s (2009) Northern Range apatite fission-track results.

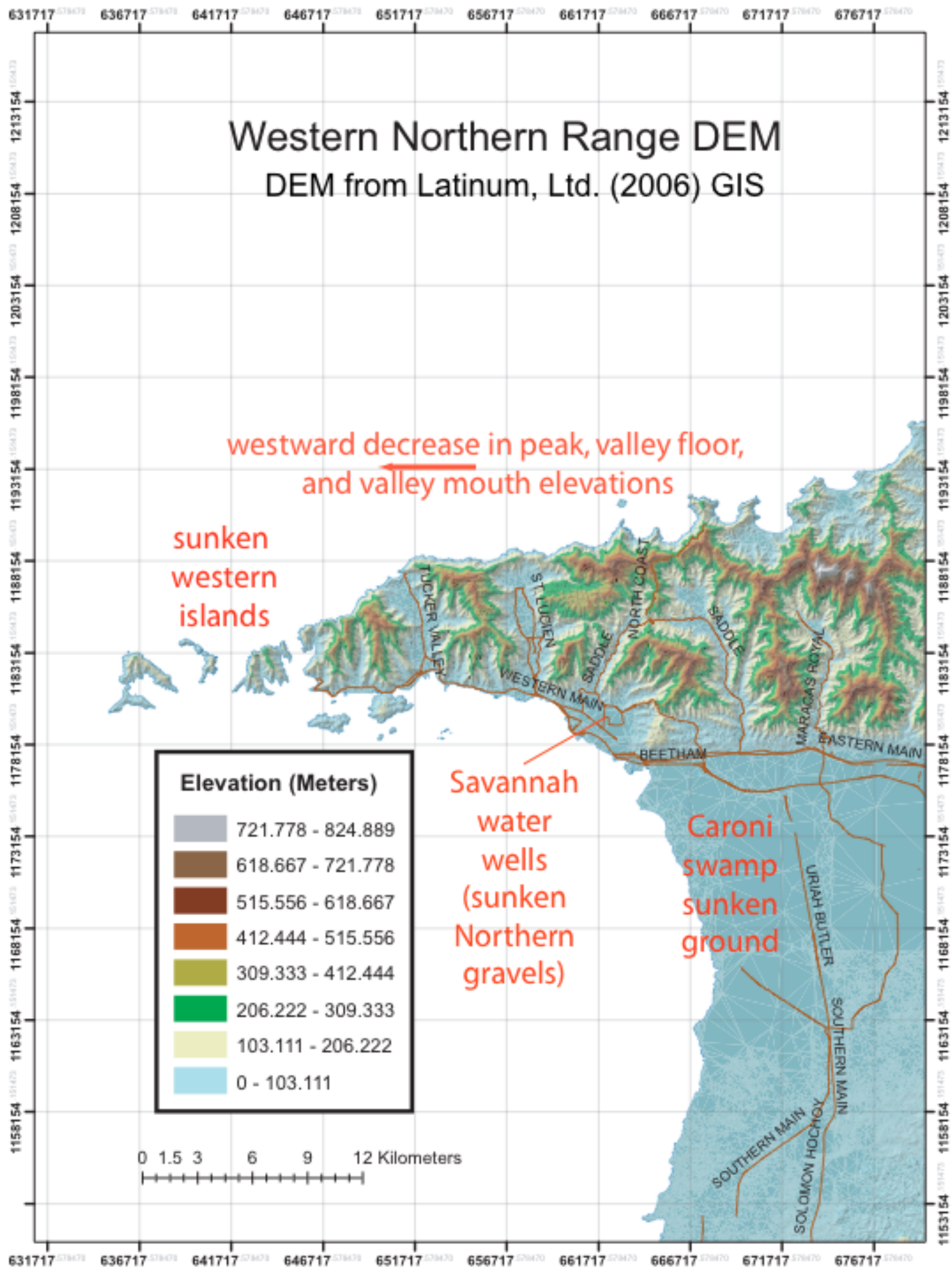


Figure 6. Some of the landforms in the sunken western Northern Range.

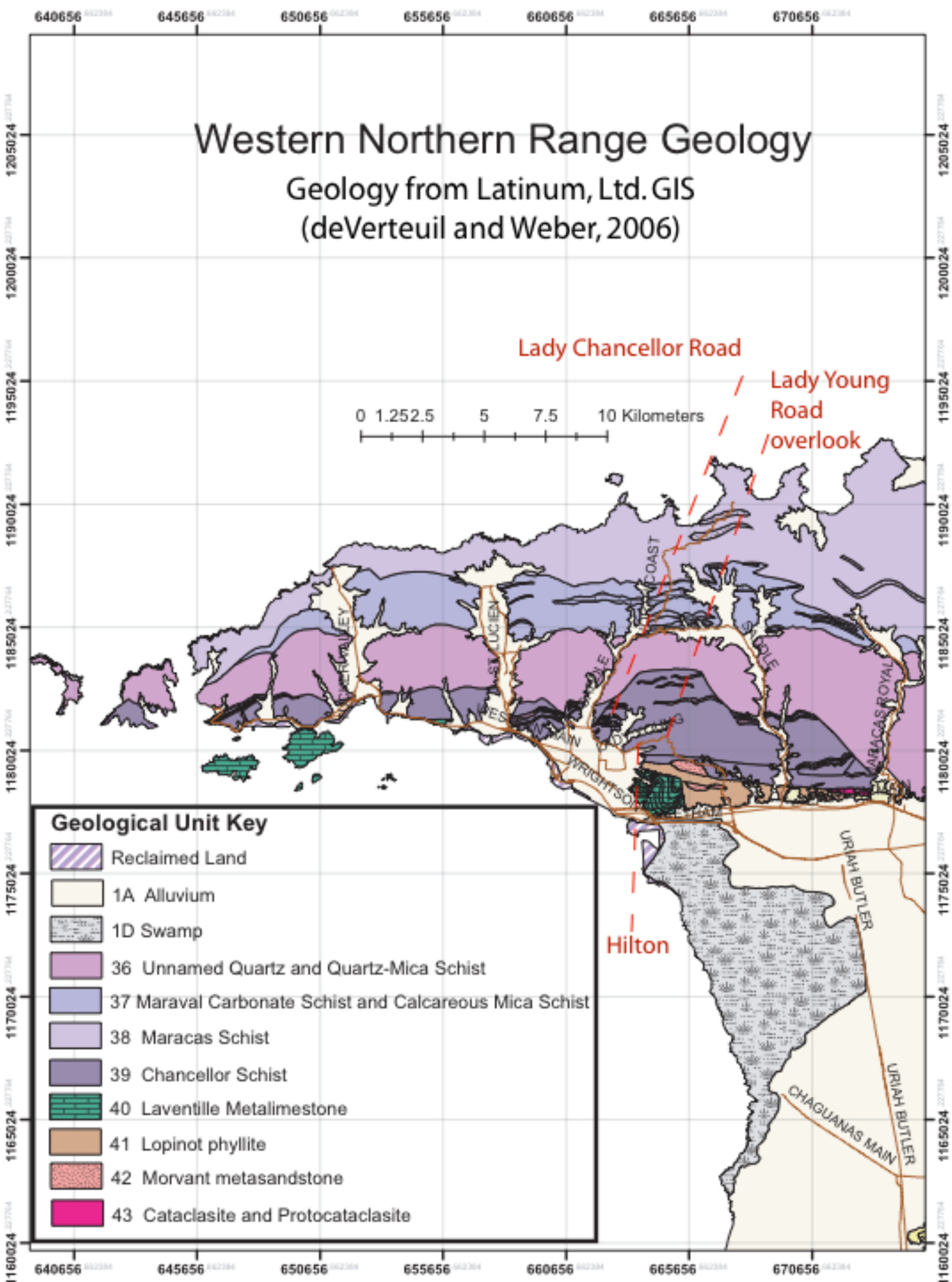


Figure 7. Geologic map of STOPs 1 & 2.

STOPS

STOP 1 & 2: Lady Young Scenic Overlook, Hitlon Parking Lot, Lady Young Road

Rocks: Chancellor quartz-, quartz-mica, carbonate-, and carbonate-mica schist; metasedimentary; metamorphosed in the mid-crust at lower greenschist grade (see geologic map).

D_1 structures: During the first and most ductile phase of deformation, D_1, S_0 (sedimentary bedding) was transposed into the S_1 tectonic foliation (old layers are highly modified, strained, and replaced by new tectono-metamorphic layers during transposition). S_0 is tightly to isoclinally folded at microscopic and mesoscopic scales. F_1 "accordian-style" mesofolds have highly attenuated limbs, and occur as isolated mesofold noses. S_1 is penetrative, schistose, and approximately axial-planar to F_1 mesofolds. Well-defined E-W L_1 stretching lineations are present in metaquartzites. S_1 dips consistently and gently (< 20-30°) southward, and forms a homocline in which resistant metasandstone layers protrude as hogbacks (see map on pg. 8). Correlative F_1 macrofolds have not been rigorously identified and mapped. Potter's (1973), Algar's (1993), and and Algar and Pindell's (1993) large-scale structural model for the Northern Range, that of an northward overturned D_1 macroscopic anticline, is based on correlating a now-nonexistent protolith stratigraphy across the transposed rocks in the western Northern Range, and is thus inappropriate.

D_2 structures: Late folds that deform S_1 are common, and may represent one or more deformation phases, which Weber et al. (2001b) collectively refer to as D_2. In the main body of the range and along the north coast, F_2 folds are commonly asymmetric, generally indicating top-south D_2 shearing.

D_3 structures: Along the southern boundary of the range (i.e., along the range front), early structures have been strongly overprinted by pervasive D_3 brittle faulting. Late shear bands with consistent ~80-85° southward dips and top-south normal offsets are common along the range front and present along the upper Landy Chancellor Road. The cataclastic zones in which D_3 faults occur are km-scale in thickness, and are very distinctive, found only along the range front, and roughly coincide with Kugler's (1961) Arima fault trace (see WNR geologic map). The range-front shear bands and systematic faults accommodated subhorizontal north-south principal extension late in the paleotectonic history of the range, but are probably not active today (rationale given below).

Deformation temperatures: D_1 deformation temperatures of 300-400°C are interpreted from the reset zircon fission tracks and completely recrystallized calcite (Type V) and quartz (Regime 3) microstructures that these rocks contain (Weber et al. 2001b).

Geochronology: $^{40}Ar/^{39}Ar$ plateau ages of ~25 Ma on mica separates from carbonate-mica schists and fine mica separates from quartz-mica schists give the age of metamorphism (Foland et al. 1992; Foland and Speed, 1992; Weber, Dunlap, and Teyssier, unpublished data). Zircon fission track ages were reset at ~12 Ma during cooling and exhumation (Algar, 1993; Algar et al. 1998; Weber et al., 2001b). The age of the hinterland metamorphic fabrics, as well as that of the exhumation of these rocks, is related to pre-10 Ma transpression (e.g., Teyssier et al. 2002). However, the high coastal topography, and young fission-track ages in Paria (apatite fission-track ages: ≥ 5.2±1.6 Ma; zircon fission-track ages: ≥ 4.7±1.8 Ma; Cruz et al.

200x; Denison et al. 2008) suggest that uplift and erosional exhumation, driven by isostasy acting on a deep crustal root that developed during pre-10 Ma transpression, continued until more recently.

Geomorphology: Looking to the west one can clearly see landforms related to the sinking portion of the western Northern Range. The western islands represent former, now sunken, Northern Range mountaintops. The "bocas" between the islands represent highly drown and flooded former fluvial valleys.

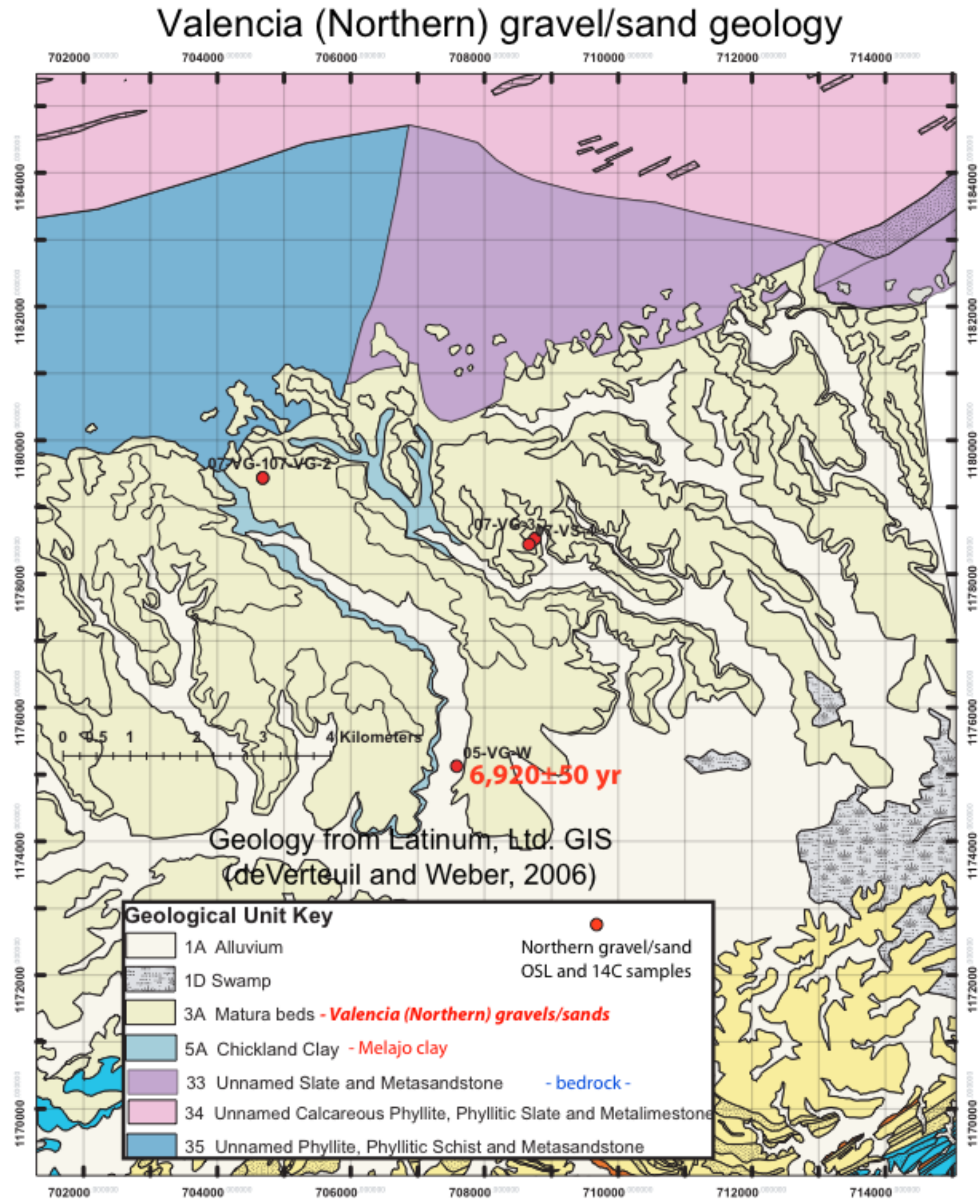


Figure 8. Geological map of STOP 3.

STOP 3: Valencia Range-Front Fans

Bedrock: is largely covered here by the younger sand and gravel deposits.

Geomorphology: The Valencia gravel deposits represent a large coalesced alluvial fan complex, or a bajada. The vein-quartz-pebble gravels and clean quartz sands clearly indicate a Northern Range provenance. These deposits are intensely dissected by the modern streams and their tributaries that flow from N-to-S out of the Northern Range. These streams are the "Home of the Guppy", one of the most intensively studied animal species on the planet. The Valenicia deposits are mapped as the Pleistocene Cedros Formation on Kugler (1961), but their ages are not well studied nor well understood. We will present and discuss new OSL ages that we are in the process of obtaining and working up to better constrain their ages.

STOP 4: Eastern Northern Range, Tompire Bay, Green Acres Estate; Lunch Stop

Introduction: Weber and Ferrill (2002) studied in detail the structures exposed in 340 m of nearly continuous, superbly well-exposed, coastal outcrops of slate and metasandstone along Tompire Bay in the eastern Northern Range of Trinidad. They describe the characteristics, sequence, and geometry of the structures, present several representative sketch cross-sections of parts of the outcrops, and interpret deformation conditions and tectonics. They interpret that the rocks at Tompire Bay experienced two major phases of deformation and fabric development, D_1 and D_2. A full copy of Weber and Ferrill (2002) is attached here FYI.

Rocks: unnamed slate, graphitic slate, metasandstone, metaconglomerate (see attached geologic map).

D_1 structures: Bedding (S_0) is well preserved in low strain zones ("strain shadows"), which are generally developed in thick metasandstone layers. Weber and Ferrill (2002) interpret that the upright NE-SW striking S_1 spaced to slaty cleavage, upright F_1 buckle folds, and D_1 faults formed in the upper crust, probably during E-W dextral transpression.

D_2 structures: D_2 produced ramp-flat fault systems, fault-bounded forced F_2 folds, and spaced S_2 cleavage, and probably occurred when these rocks were at shallower depths than during D_1. Weber and Ferrill (2002) interpret that the NW-SE striking vertical π-girdle of S_2 poles resulted from movement on D_2 faults and that the D_2 structures may be due to later regional extension. The D_2 structures at Tompire Bay might be related to the multi-directional extensional structures observed in the Galera Grit and underlying Toco Cataclastite that we will study at STOP 4.

Deformation temperatures: Non-reset zircon fission tracks, type III calcite twins, and regime 1-2 quartz microstructures, indicate upper-crustal D_1 deformation temperatures of only 200-300°C (Weber et al. 2001b).

Geochronology: Apatite grains from the Galera Grit at Galera Point yielded reset fission track age of 15-20 Ma, but zircon fission-tracks are not reset in the northeastern Northern Range and give detrital ages (Weber et al 2001b; Denison et al. 2008).

Geomorphology: The Green Acres copra Estate sits on a broad, flat gravel-capped surface, which we interpret as an uplifted marine terrace. We will present measured sections of these deposits and present and discuss OSL ages and uplift rates that we are currently in the process of obtaining and interpreting.

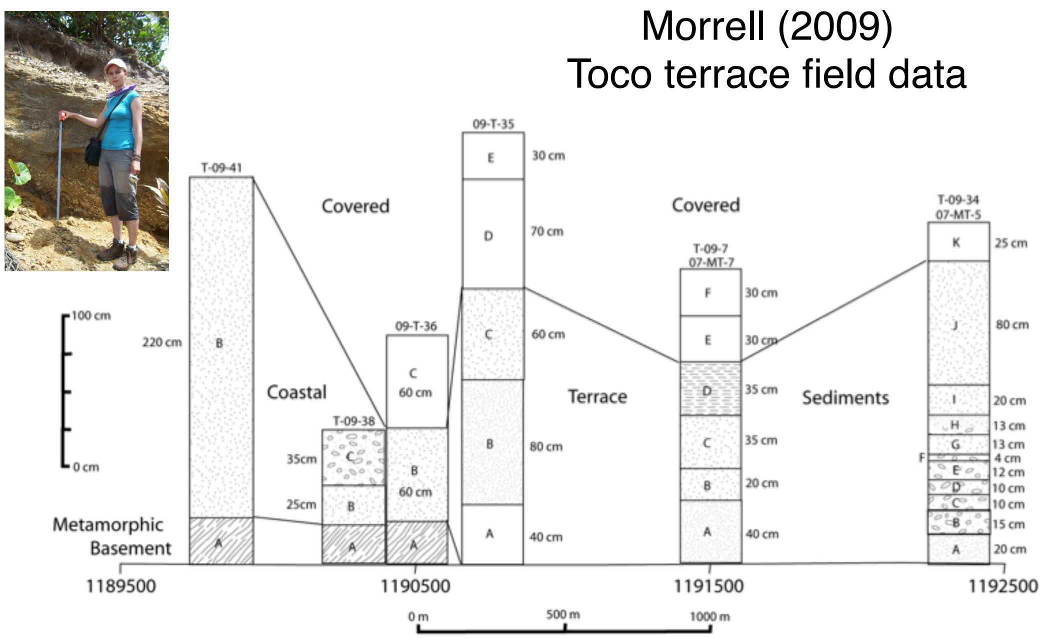


Figure 5. Quaternary coastal terrace stratigraphic sections measured near Toco. Horizontal scale based on UTM Northing component (WGS 84) of measured section locations. Each column is subdivided into units that are described in detail in Appendix A. Three main units (cover, coastal terrace sediments, and metamorphic bedrock) are shown here. Thicknesses in cm in or on sides of stratigraphic sections represent sub-unit thicknesses.

Figure 9. Measured sections of uplifted coastal terrace sediments, NE NR.

STOP 5: **Galera Point.** Mechanically strong and mult-directionally extended Galera Grit. Underlying brittlely deformed “carpet” of Toco Cataclasite. Uplifted Marine Terrace

Bedrock Geology: The Galera Grit represents a low-grade, mechanically strong unit with a lithology and structural style that are both unique to the NE Northern Range. Most of the dm-m scale thick grit beds that define this unit are relatively flat-lying and have been either systematically flipped completely upside down (stratigraphically inverted) or are possible systematically inversely graded. At Galera Point, the Galera Grit dips gently E, clearly overlies and is structurally connected with the underlying Toco Cataclasite. The Galera Grit is cut by normal faults with a variety of orientations, indicating that it has been flattened vertically and stretched horizontally and multidirectionally. The late normal faults that cut the Galera Grit might coincide with the D_2 structures at Tompire Bay. Algar (1993) imagined NE-SW striking subvertical fabrics in the Toco mélange (= all Galera lithologies) that wrapped SW around a Sans Souci allocthon. The basic Galera-Toco structural geometries that we observe (see figures below) demand a brittlely deformed Toco cataclastite “carpet” beneath a strong, extended, probably overturned, Galera cap.

Geomorphology: Again, one can observe a broad, flat uplifted marine terrace here.

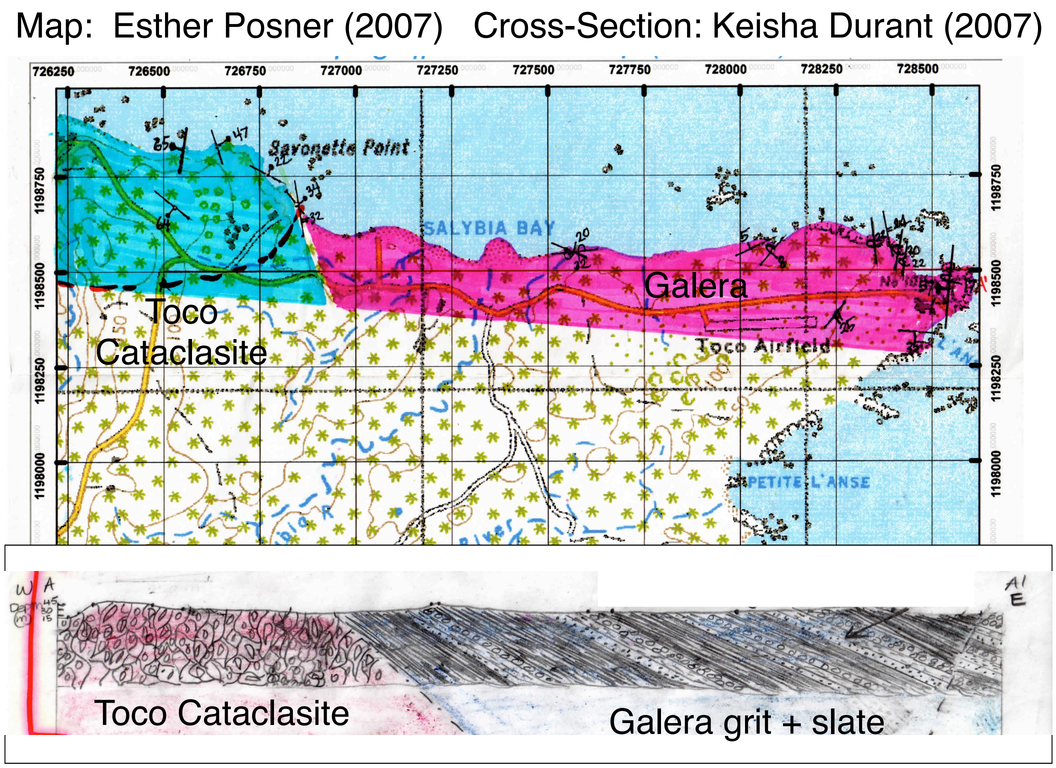


Figure 10. Unpublished geological map and cross-section showing basic structural geometries between Galera Grit and underlying Toco Cataclasite "carpet".

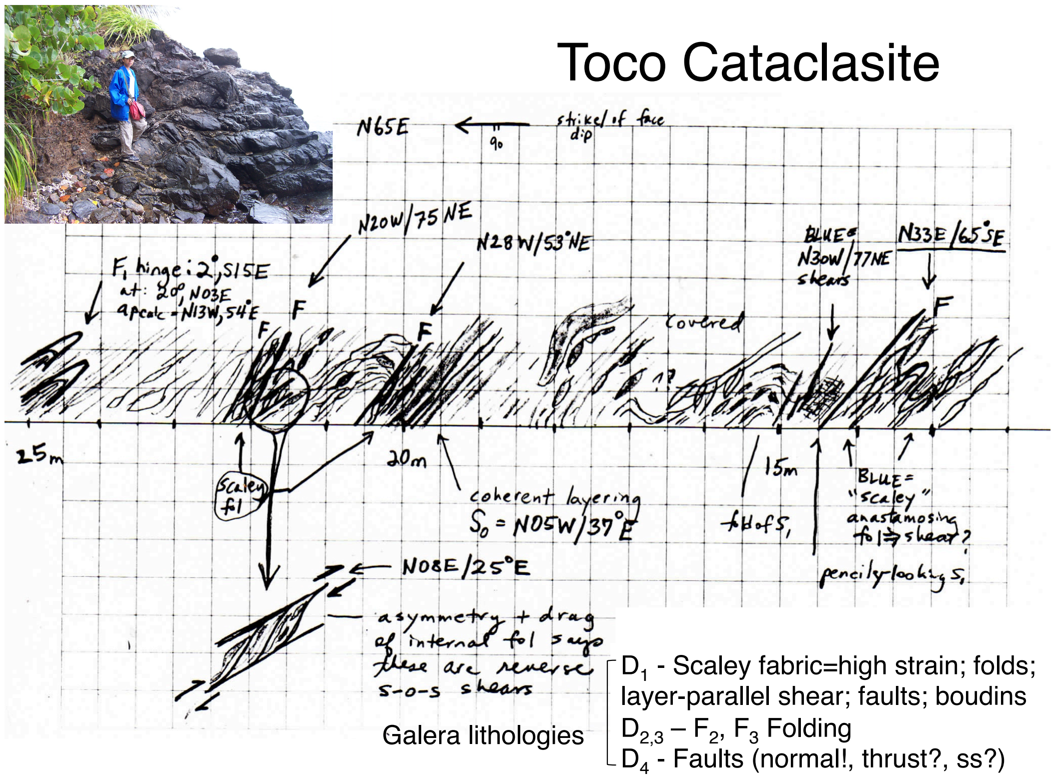


Figure 11. Unpublished field sketch and interpreted sequence of structural events in Toco Cataclasite. Note that all brittle deformation occurs in typical Galera lithologies – dark slates, grits, and metasandstones.

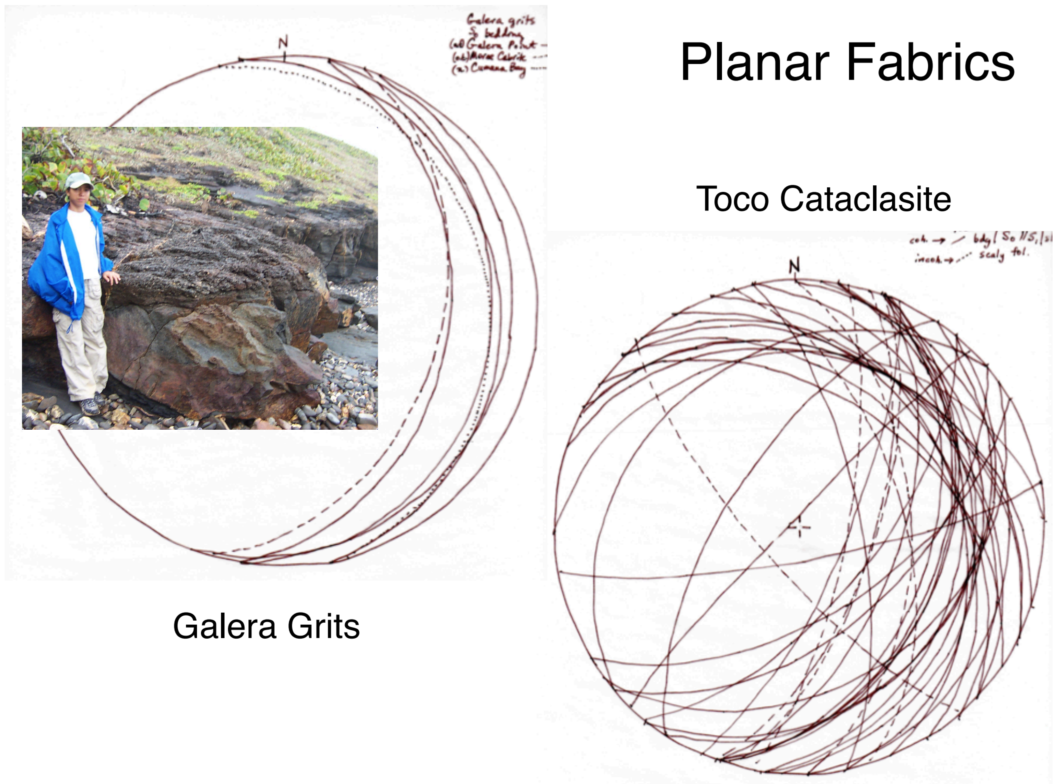


Figure 12. Unpublished field data plotted on lower-hemisphere, equal-area stereonets that show a relatively clear relationship between the orientation of measured planar surfaces in the structurally overlying Galera Grits (gently E-dipping beds) and those in coherent (solid lines) and incoherent (dashed lines = scaly) parts of the underlying Toco Cataclasite "carpet".

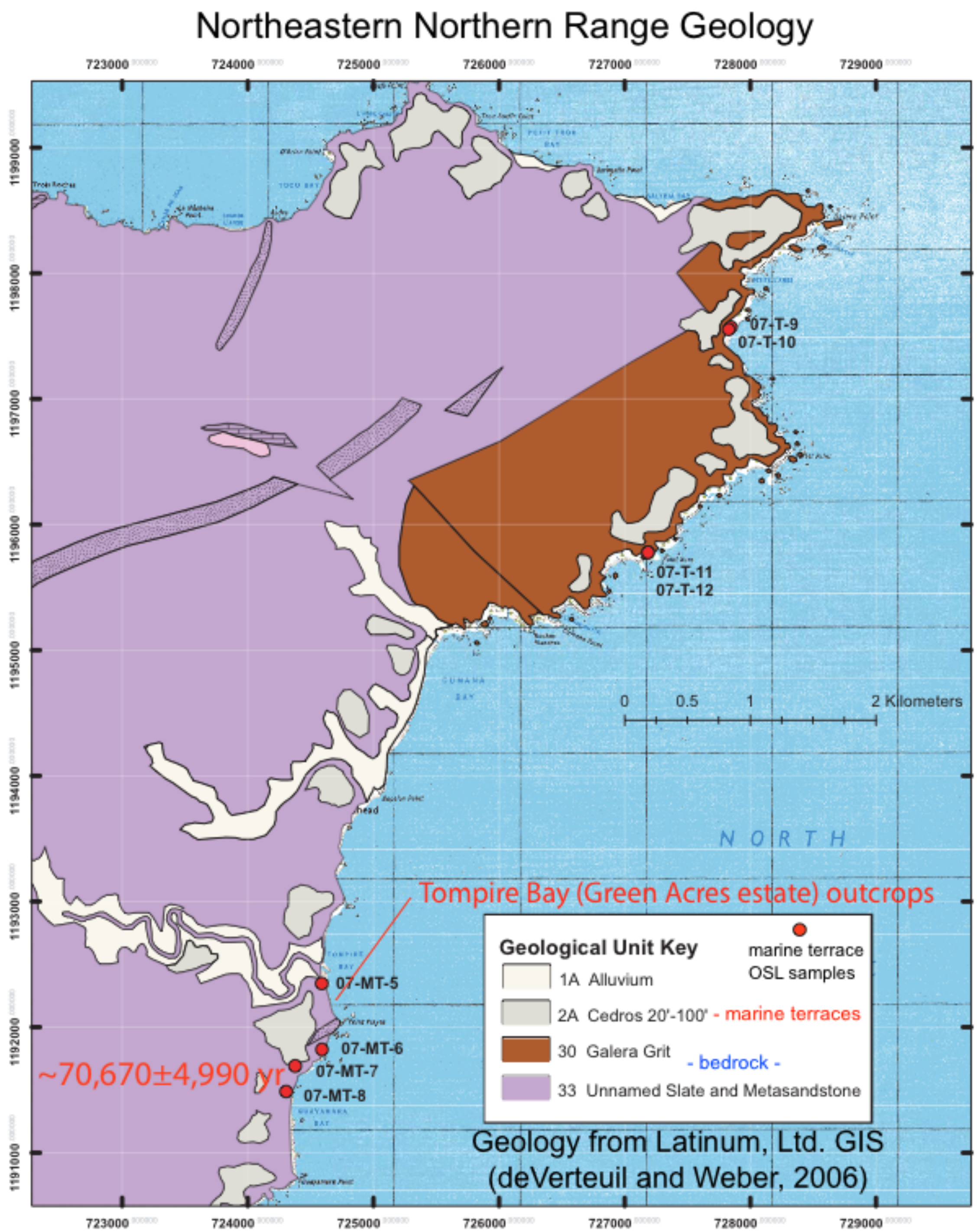


Figure 13. Bedrock and Quaternary Geology of NE NR STOPS 3 and 4.

Geomorphology

As determined quantitatively by Ritter and Weber (2005, 2007), Northern Range drainage basin morphology, alluvial deposits within the range and alluvial fans adjacent the mountain-front, and megageomorphology of the coastline and range vary west to east, and record differential uplift and subsidence of northern Trinidad during Quaternary. The primary objective of our geomorphic research is to date the surface deposits flanking the range, and to quantify modern erosion (using basin-wide ^{10}Be) and uplift rates (using OSL on uplifted marine terraces) across the range.

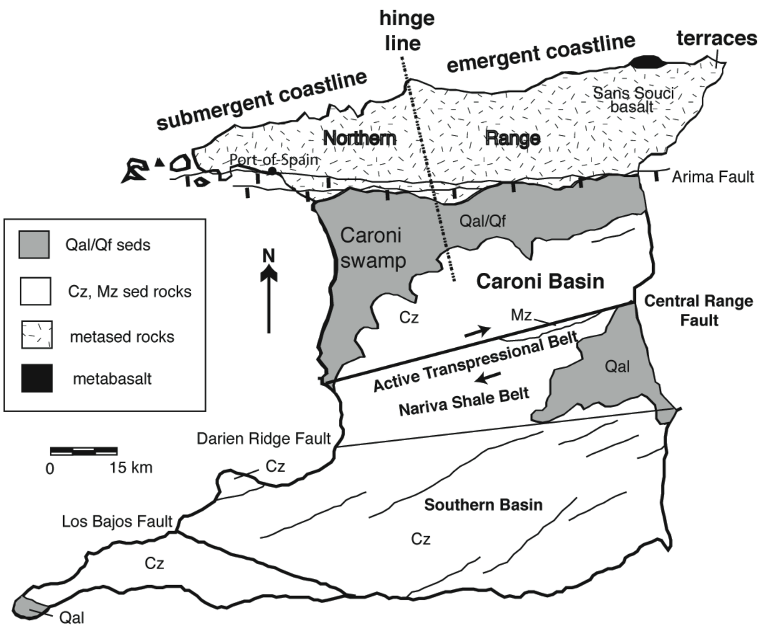


Figure 14. Generalized geologic and megageomorphic map of Trinidad (Weber et al, 2005). The hinge line separates areas of subsidence in west from those of uplift in east and is inferred from coastline and drainage basin morphology.

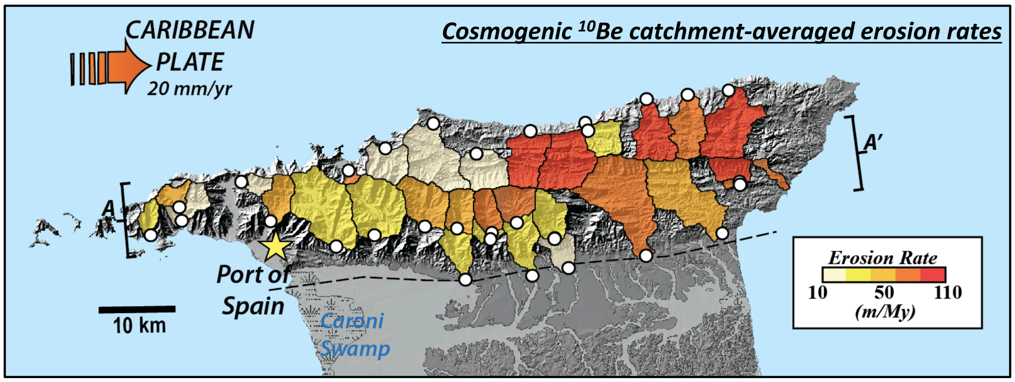


Figure 15: Map (30m DEM) of terrestrial cosmogenic (TCN) ^{10}Be catchment-averaged erosion rates for 33 catchments from the Northern Range. White dots are locations of stream sediment samples collected for TCN analysis. Data are from Arkle et al., in prep.

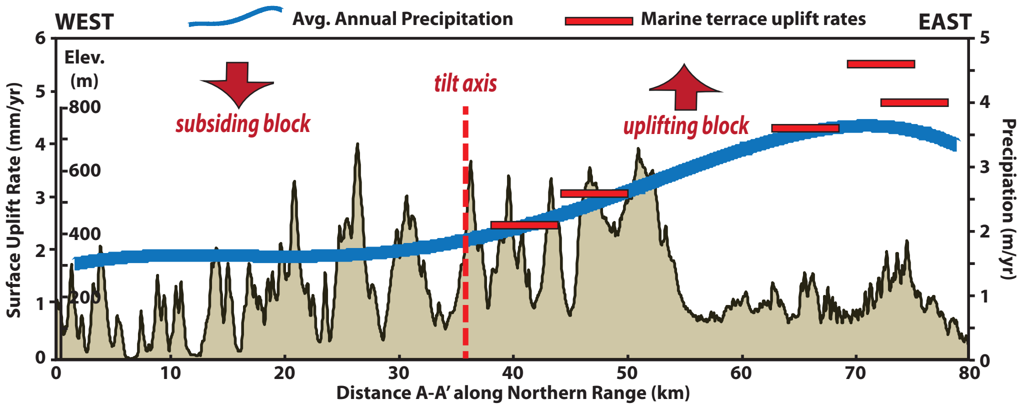
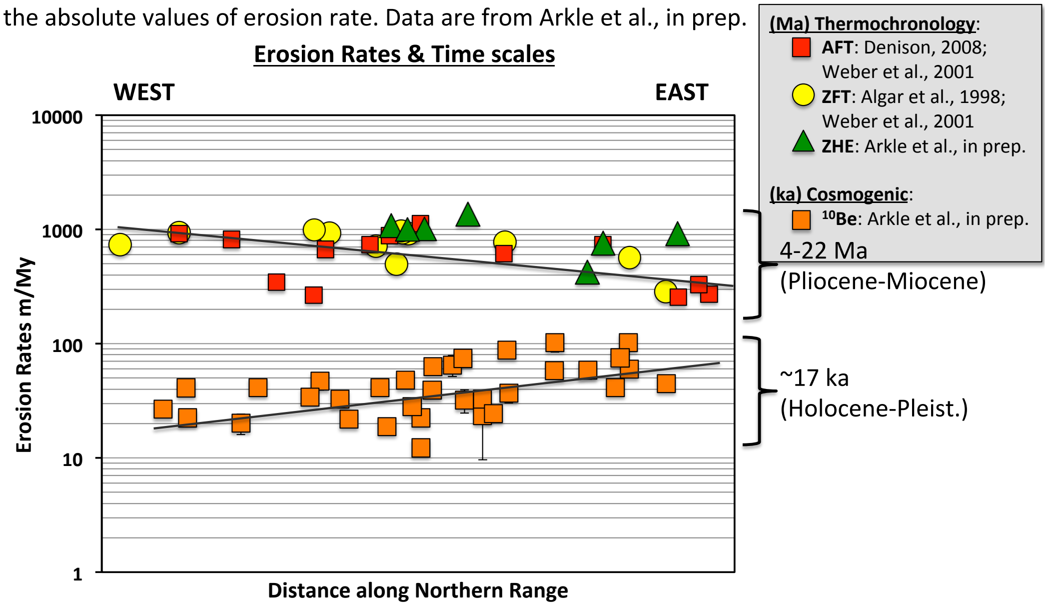


Figure 16: Figure and data are from Arkle et al., in prep. Profile from west to east along the Northern Range. The elevation profile is an average of elevations across a 10 km wide swath derived from a 30 m DEM. The precipitation profile is an area-weighted average of mean annual precipitation for each drainage basin in the Northern Range and the best fit 3rd order polynomial to these data (thick blue line). Precipitation is measured over 12 average annual from TRMM satellite data. The red boxes are surface uplift rates calculated from OSL ages collected on marine terraces. Note the elevation of the outlets of the drainage basins increase to the east and the difference of average elevations and slope angels from west to east. The axis of tilit (thick red dashed line) indicates the approximate location of a major change from Northern Range uplift in the east and subsidence to the west after Ritter and Weber (2005, 2007).

Figure 17: Erosion rates derived over multiple time scales plotted from west-east along across the Northern Range. The cosmogenically derived 10Be data (orange boxes) and exhumation rates from thermochronology data from published studies (red boxes, yellow circles, and green triangles) integrate over time periods from ~17 ka and 4-22 Ma, respectively. Note a major transition in the locus of erosion over these time periods and the order of magnitude difference in the absolute values of erosion rate. Data are from Arkle et al., in prep.



Discussion

After a full day in the field, maybe you now have some of your own observations and ideas to share with the group. Do you agree with our theme that "a reversal of fortune" has occurred in the Northern Range? If not, why not? If so, how and when do you think that the Northern Range's reversal of fortune occurred? Please reflect, speculate, hypothesize, and share. Thanks for spending the day with us. Look for our work in the geological literature. We'll look for yours!

References

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