IUGS-UNESCO IGCP PROJECTS

546 “Subduction Zones of the Caribbean” and

574 “Bending and Bent Orogens, and Continental Ribbons”

Field Trip

“From arc growth to orocline formation: The record from the Panama Canal and East Panama”

February 9-11, 2010, Panamá

Field Trip Leaders

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Smithsonian Tropical Research Institute

Workshop and Field Trip in Panamá

Presentation

During the last year, a wealth of new data has been collected in Panamá, including new radiometric ages, paleomagnetic investigations, geochemical analyses and field mapping. During this workshop and field trip, we will place all of this information in a regional context where the trailing edge of the Caribbean Plate enjoyed multiple episodes of arc magmatism, vertical-axis block rotation and deformation. The field trip will concentrate on East Panamá (San Blas range) and the Canal basin, with stops and transects to study the Cretaceous basement to the Miocene cover rocks. We hope this meeting will provide an opportunity to discuss the evolution of the Isthmus and its place in the subduction zones of the Caribbean and the development of oroclinal belts.

River exposures in east Panamá

See high resolution panoramas at: http://gigapan.org/profiles/24156/

General Information

Weather in Panamá during the month of February is hot and dry. Expect temperatures around 33°C (90°F), and no rain. Bring sunblock, hat and bug repellent. Most of the stops will be near highways and roads with little hiking needed, but at least one day may require either trekking along the river bed or —water level permitting— white-water rafting!. We will keep you posted, as river access depends on the water levels. Please let us know of any special access requirements or requests. An extra pair of sandals in your field bag are a good idea.

Fossil forest, Panamá Canal

The official hotel is the **El Panama Hotel** (Via España and Via Veneto), near a wide selection of international restaurants. We strongly encourage all participants to stay in this hotel to be able to stay within the schedule (*see attached registration form*).

Registration fee of $350 dollars includes brown-bag lunches and beverages in the field and transportation, as well as lunch, snacks and an ice-breaker during the workshop. A complete field guide with maps and stop descriptions will be printed for each participant.

Currency in Panamá is the US dollar. Please check visa requirements, we will provide invitation letters if needed. For most nationalities the purchase of a Tourist Card on arrival (U$ 5) valid for 90 days is all that was needed. This seems to have recently changed and now there is no need to purchase it. There is however, an ~ **U$ 30 airport fee** when you leave the country. Panamá is free of malaria. Yellow fever vaccination is not required to enter the country.

All **field trip departure times** will be from the El Panamá Hotel at **7:00 am**, returning to the Hotel at 4 or 5 pm. Check the guide for stops where you may get wet, we suggest you bring your sandals along to change into for the drive back to the hotel.

Materials:

1) Shaded-relief map of Panamá with structure and new radiometric ages; 2) Geologic map of the Canal area by Stewart et al., (1980) with cross-section along the highway and paleomag data; 3) Canal detailed mapping and stratigraphic/geochronologic data; 4) East Panamá geologic map and cross-section; 5) Geologic map of Panamá 1:500.000 (MICI); 6) Key to the fossils of the Gatún Formation.

Day 1, February 9:

Panamá Canal and roadcuts to Colón. We will spend the day taking advantage of man-made rock exposures along the Panamá Canal and new roadcut exposures crossing the isthmus. The huge investment that the country of Panamá is doing to update its infrastructure, is also allowing us to make direct observations otherwise hindered by dense vegetation cover and deep weathering profiles. Following these exposures we will try to patch up a full transect across the isthmus, looking at the extensional structures, late strike-slip and the Oligocene-Miocene magmatic-stratigraphic evolution of the Canal basin. We will visit a Paleogene-Neogene basin split in three different compartments (Cucaracha-Culebra, Quebrancha and Gatún) with shifting depocenters and constrasting stratigraphy. We are building on efforts by many generations of geologists, summarized in Stewart et al., (1980) professional paper, maps and references therein.

Culebra Cut viewed Gold Hill,

Stop 1: Standing at the former water divide (Gold Hill) we will get an overall idea of the outcrops we will visit this morning along the western side of the Panamá Canal. Starting from the north, the early Miocene Cucaracha Formation (fossil-rich paleosol and ash tuff) and the overlying Pedro Miguel Formation (basaltic/andesitic lavas and agglomerates) define the outline of an old caldera. To the south, a massive basalt intrudes the early Miocene sequence. The Cucaracha and Pedro Miguel Formations continue south of the late basalt intrusion. Left-lateral, NNE–SSW oriented strike-slip faults offset southwest-dipping beds within the Cucaracha Formation. A thick ash and lapilli tuff bed caps a coaly shale that preserves a fossil forest where tree trunks are still standing.

Stop 2: Bas Obispo –We will drive to the north end of the Culebra cut and make stops as we return south towards Gold Hill. At this stop we will observe the Bas Obispo Formation, the oldest rocks exposed along the Culebra cut (Oligocene?), and basement to the late Oligocene to early Miocene sequence. This is a massive agglomerate where bedding is faint but distinguishable and pervasively cross-cut by normal faults and strike-slip faults. A breccia is present at the contact with Las Cascadas, but its genesis is still unclear. We will look at the geochemical characteristics of these rocks and contrast them with younger volcanic products along the Canal.

Columnar basalts, Canal

See high resolution panoramas at: http://gigapan.org/profiles/24156/

Stop 3: Cascadas/Emperador Limestone contact– At this stop, we will take advantage of one the largest normal faults along the canal (with approximately 200 m of vertical throw) that brings together slivers of almost every lithostratigraphic unit of the Canal basin within a few meters of exposure. To the north, you will see the Las Cascadas Formation, a sequence of sub-aerial tuffs and volcanosedimentary layers that are yielding precious new fossil discoveries. A series of faults separate the tuffaceous sequence from marine limestone and shale of the Culebra Formation, the paleosols of the Cucaracha Formation and the lava and agglomerate of the Pedro Miguel Formation. This normal fault with a likely growth component, is cross-cut by a mafic dyke that is deformed by late strike-slip.

Bruce MacFadden's (2009) description of a Miocene horse found in the Cucaracha Formation

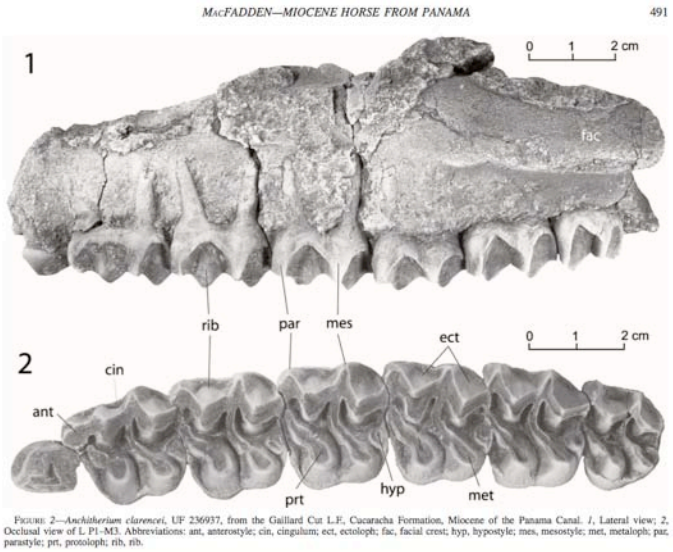
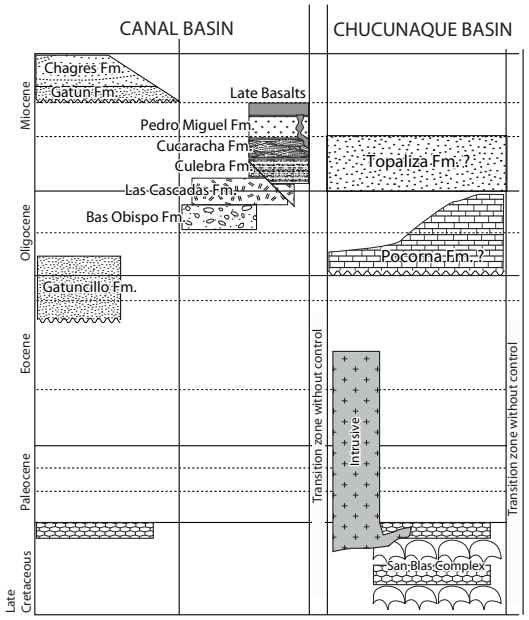


FIGURE 2—*Anchitherium clarencei*, UF 236937, from the Gaillard Cut L.F, Cucaracha Formation, Miocene of the Panama Canal. *1*, Lateral view; *2*, Occlusal view of L P1–M3. Abbreviations: ant, anterostyle; cin, cingulum; ect, ectoloph; fac, facial crest; hyp, hypostyle; mes, mesostyle; met, metaloph; par, parastyle; prt, protoloph; rib, rib.

Stop 4: At Hodges Hill we will look at the Cucaracha Formation, a continental unit that not only has yielded faunas that confirm a direct paleogeographic connection between North America and Panamá during the Miocene, but also contains evidence for the Miocene unroofing of the arc roots in the form of detrital zircon populations matching those of the basement massifs to the east. The overlying Pedro Miguel Formation preserves the structure of a caldera with tuffs and lavas at the base.

We will drive out of the Canal area to head north and have **Lunch** at the Soberanía National park.



Stratigraphic correlation table
Modified from Coates et al., 1992

See high resolution panoramas at: http://gigapan.org/profiles/24156/

Stop 5: Sabanitas quarry– This quarry exposes 40-50 m of the lower member of the Late Miocene Gatún Formation. This is an active quarry. Be aware of trucks!

Late Miocene 8 to 5 Ma Gatún Fm

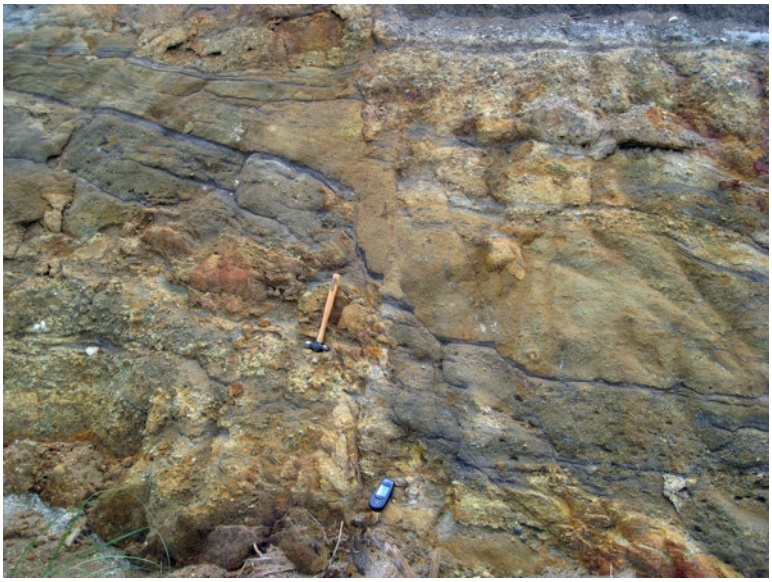
The Gatún Formation is estimated to reach a total thickness of at least 500 m and is divided into three informal members, largely on the basis of macrofaunal zonation (Woodring, 1957). The formation dips around 5° with steep normal fault sets. The lower member presumably overlies (unconformably) Cretaceous basement east of Cativa, and unconformably overlies the late Oligocene Caimito Formation near Lake Gatun and to the west of the quarry. The upper member is overlain by Pliocene strata of the Chagres Formation. The Gatún Formation is renowned for its high diversity, with over 400 species of molluscs recorded (Woodring, 1957, 1959, 1964, 1973, 1982), and many more remaining unnamed (Jackson et al., 2001). Molluscs can be easily collected in dump piles below the quarry walls and are dominated by the gastropods *Turritella*, *Strombina*, *Cancellaria*, and *Oliva*, and bivalves *Anadara*, *Clementia*, *Lirophora*, and *Caryocorbula*. A number of shellbeds are exposed in the quarry walls, and include storm even beds containing *Turritella*, and more developed transgressive shellbeds rich in oysters (*Ostreola*) and scallops (*Flabellipecten*). The ecology and preservation of these molluscs suggest an offshore environment, above storm wave-base, possibly between 20 and 80 m.

Stop 6: Paleomag site-Old Highway–This stop is a paleomagnetism site from within the Late Cretaceous to Paleogene volcanic basement that documents counterclockwise vertical-axis rotation and southern paleolatitudes. The outcrop is a deep marine volcanosedimentary sequence. This basement exposure is north of the northeast-striking Rio Gatun Fault. We will discuss some of the paleomagnetic data here and then will discuss the paleomagnetic data in more detail on the following days of the fieldtrip.

Stop 7: Gatuncillo quarry– (Mineral Básico) The Middle-Late Eocene Gatuncillo Formation unconformably overlies the highly weathered basement to the south of this locality. Basal Gatuncillo comprises subangular clasts of basement in a sandy conglomerate, grading upsection into a pebbly sandstone and more massive gritty sandstone. A poorly preserved macrofauna includes numerous brackish-water to shallow-marine mollucs, dominated by *Brachidontes* and *Nerita*. The basal siliciclastic sequence passes upsection into calcareous sandstone, and then into an algal-foraminiferal limestone that is quarried commercially to the south of the highway. Identifiable fossils in the limestone include large forams (*Lepidocyclina*), occasional molluscs (*Spondylus*) and echinoids. This facies sequence clearly indicates an Eocene transgression and

planation of low-lying exposed basement topography prior to deposition of Neogene units.

Stop 8: Faulted Gatuncillo Formation– Please do not access the highway benches. This is only a panoramic view of the fault style. This outcrop is likely the basal portion of the middle Eocene Gatuncillo Formation. It is the southwestern extension of the **Quebrancha** syncline. Mudstone, siltstone, sandstone and conglomerate layers that contain coal seams are dissected by normal faults with 1–3 meters of offset. The faults contain pyrite mineralization. The Gatuncillo Formation is a transgressive sequence resting on top of basaltic units considered as the basement of east Panamá, likely late Cretaceous in age.



Gatuncillo beds, one of the earliest records of shoaling in the isthmus

Maria Eugenia quarry, Oligocene (~25 Ma?) andesite

Stop 9: (optional) Maria Eugenia quarry–This quarry digs out a Tertiary andesite body. The andesite contains clinopyroxene and plagioclase laths. It has developed heavy weathering rinds. Fractures and veins within the andesite contain quartz and a deep green mineral. We suspect the green mineral is either chalcedony or jasper, though this has not been investigated.

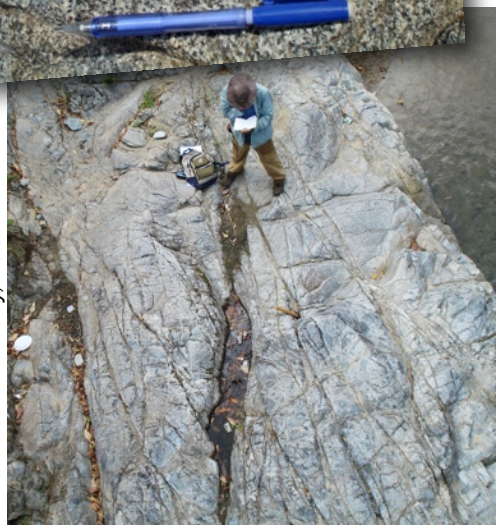
See high resolution panoramas at: http://gigapan.org/profiles/24156/

Day 2, February 10:

We will spend this day looking at the Paleogene intrusive bodies exposed along riverbeds in eastern Panamá. These bodies may be considered the roots of the arc. We will have the opportunity to see the pristine as well as deformed intrusives and the contact with the basaltic sequences and the Eocene-Oligocene sedimentary cover. Be prepared to get your feet wet!

Stop 1: Utivé river –Quartz diorite, gabbro, tonalite intruded by basalt and diabase dikes and containing magmatic enclaves of basalt and diabase. The exposures along the river display compositional changes, ranging from felsic to intermediate, with a wide range of pyroxene proportion. The intrusive rocks display local magmatic flow fabrics. In addition, there is abundant evidence for magma mingling between the mafic dikes and intermediate intrusive phases. These observations suggest the preservation of the high temperature magmatic history in the East Panama Intrusive complex. Within the outcrop, a crosscutting basaltic dike has phenocrysts of plagioclase and epidote ± pyroxene. Thin section studies show that the quartz diorite contains subhedral clinopyroxene that is commonly altered to green hornblende. Orthopyroxene occurs, but is rare. Plagioclase grains are twinned and zoned. Quartz grains are anhedral and have undulose extinction. Myrmekitic intergrowths of quartz and plagioclase occur in numerous samples. Plagioclase alters to epidote and sericite.

Mafic enclaves in quartzdiorite, Utivé river



Sheared tonalite body, Pacora river

Stop 2: Rio Indio –Pacora river. Tonalite with mafic magmatic enclaves. The enclaves show multiple orientations and textural relationships with the main intrusive body. The outcrop displays two generations of brittle shears that are epidote- and chlorite-filled. Within the fractures there is commonly fine-grained granitic material and possible evidence for K-Feldspar growth. We interpret the fractures to represent the late stages of emplacement of the intrusive body and the minerals found within these fractures to be related to fluid percolation possibly related to release of fluids during crystallization or

intrusion of another local magmatic pulse. Thin sections reveal subhedral hornblende that alters to chlorite, subhedral plagioclase, and anhedral quartz grains. Plagioclase is zoned and twinned. Quartz grains have undulose extinction.

We will walk upstream along the road to see a tonalite with mafic magmatic enclaves and a crosscutting basaltic dike. This outcrop highlights the texture of the tonalite body and the relationship with the basaltic dike.

Stop 3: Pacora river transect–This stop is an ~1 km transect from volcanic basement to sedimentary cover the along the Pacora river, a popular touristic destination for the locals. This transect will involve hiking downstream in the river. Be prepared to get your feet (and legs) wet!!. We will have **lunch** in one of the river outcrops.

We will start this transect at a volcanic basement containing layers of lapilli tuff, ash tuff, basalt, diabase and chert. This volcano-sedimentary sequence is one of the more deformed sequences in east Panamá. The basaltic rocks have fractures that display dextral strike-slip.

From this outcrop we will proceed downstream to look at shallow-dipping calcarous sequence that contains macro-foraminiferal calcarenites with glauconite, algae and lithic biomicrite. Thick calcareous beds display local cross-bedding and represent the first shallow marine sedimentation on the isthmus. Specimens of *Lepidocyclina* (*Nephrolepidina*) *vaughani* have been recovered from these rocks indicating a Middle Oligocene age (Jon Bryan, per. comm.).

Deformed basalt/tuff sequence on the Pacora river

Stop 4: (optional) Mañanitas-Panamerican Highway–This outcrop exposes layered fine-grained tuff. The tuff layers are offset by minor thrust and reverse faults. A sandstone dike intrudes the tuff sequence and kaolinite-rich blocks form sedimentary structures within the tuff sequence. These rocks are likely to be part of the Topaliza Formation.

Day 3, February 11:

Pillow basalts, Mamoní river

A transect along the scenic Mamoní river to look at fresh exposures of mostly undeformed ocean-floor sequences. We will attempt to follow the exposures in rafts, water-level permitting. Be prepared to get completely wet!.

Since the stops in this day are contingent upon water levels, they could be different whether we drive or raft down the river. In general, we are going to start near the axis of a large, north-verging anticline defined by massive basalt and diabase interfingering with well-bedded sequences of submarine lapilli tuff, agglomerate, chert and pillow basalt. We have been able to map this large anticlinorium for over 20 km along the axis, showing consistently steeper dips on the northern flank and shallower dips along the southern flank. The proportion of basalt/diabase decreases to the east where tuff and agglomerate are by far more common. If we drive, we will look at three outcrops along the Mamoní river and then drive out to the Panamerican highway to reach the Chararé river, where the tuff/agglomerate beds are spectacularly exposed.

Optional stop along the Chararé river

We will have the chance to visit at least three of the paleomagnetic sampling sites where clockwise vertical-axis rotations and southern paleolatitudes are documented.

The pillow basalts are microporphyritic with an aphanitic matrix. The microphenocrysts are clinopyroxene, olivine, plagioclase, and epidote. Olivine aggregates have iddingsite alteration along grain boundaries and fractures and plagioclase grains have corroded cores, embayments, and sieve texture. The matrix consists of plagioclase laths, fibrous epidote, and Fe-Ti oxides. Within the massive basalts and diabases, plagioclase grains display normal zoning and have inclusions of titanite and opaque minerals. Clinopyroxene phenocrysts are euhedral. Epidote is pervasive in these rocks. It is commonly acicular with radial extinction. Fe-Ti oxides and chlorite are present. The ash tuffs are commonly heavily altered with aphanitic crystals of plagioclase, quartz, and hornblende. The matrix shows alignment of grains around microphenocrysts. Within the lapilli tuffs, lithic fragments of basaltic material are present, as well as phenocrysts of plagioclase, hornblende, and quartz. The chert layers consist of very fine-grained quartz. Chert layers rarely contain micro-lithic fragments and microphenocrysts of plagioclase and epidote, suggesting a gradation into tuffaceous siltstone. The chert layers have significant epidote alteration.

See high resolution panoramas at: http://gigapan.org/profiles/24156/

Detailed itinerary and driving directions:

All distances and times measured from El Panamá Hotel starting at 7:00 am. Coordinates in UTM zone 17N.

Day 1:

Stop 1: From El Panamá Hotel take the route to Miraflores and Pedro Miguel Locks, following signs for Corredor Norte. Go through the town of Paraiso, continue on the road to Chilibre and turn left at the entrance Gold Hill. The entrance is across from the Summit Golf Course and Hotel and it is 20 km and 30 minutes from El Panama Hotel. After passing the guard station, turn right to proceed up the hill. Then turn left at the next intersection and continue up the hill. Parking is at the top of Gold Hill.

Stop 2: Bas Obispo. Time 9:00 am, km 35, coordinates (644872mE, 1004874mN). At the exit of the Canal area, turn right towards Paraiso. Take the exit (to the right, west) for Arraijan to cross the Centennial Bridge. Immediately after the Centennial Bridge take the exit (to the right, north) for Paraiso. Continue on this road towards the Canal entrance (5 km). After the canal entrance, turn left at the first intersection (north, towards the Centennial Bridge). At the base of the hill, turn right and then take your first left. Continue on this road parallel to the Canal passing the reference sign, sector light cunette Sur (10 km).

Stop 3: Cascadas/Emperador Limestone. Time 10:10, km 39, coordinates (646615mE, 1001953mN): From Stop 2, head South along Canal (on same route), then turn left at 4 km. Follow this road for 400 m.

Stop 4: Hodges Hill. Time 11:00 am, km 44, coordinates (648094mE, 1000379mN). Return to main road and turn left. Drive 2 km and turn left (the road to your right will be very wide). Follow this road for 500 m.

Lunch at Camino de Cruces Trailhead. Time 12:00. Return to exit of Canal area. Take the first exit to the right for Bethania. Cross over the Centennial Bridge and take the second exit to the right towards Chilibre, headed north. The lunch spot is at the trailhead for the Camino de Cruces trailhead on the left side of the road.

Stop 5: Sabanitas Quarry. Time 1:30 pm, coordinates (627737mE, 1034044mN). Continue on same road and join the new Colón Highway all the way to Sabanitas. On the right hand side of the road you will see a Rey Supermarket. 5.5 km after the Rey, turn left right before the Cochez store (yellow building on the corner). Turn left again at the roundabout to enter the quarry.

Stop 6: Paleomag Site. Time 2:45 pm, coordinates (639481mE, 10026665mN). Exit the quarry the same way you entered and turn right to join the road towards Panamá. 8.6 km later there will be a split to take the old road to Panamá. Continue on the old road to Panamá for 10.1 km more and park on the side of the road or a dirt road to the right.

Stop 7: Gatuncillo Quarry (Mineral Básico). Time 3:30 pm, coordinates (639521mE, 1026185mN). Continue on the old road to Panamá for 2 km more and turn right at the Mineral Básico road sign before blue pedestrian bridge.

Stop 8: Faulted Gatuncillo. Time 4:30 pm, coordinates (644701mE, 1021991mN). Exit the quarry the same way you entered and turn right to join the road towards Panamá. Continue on the same road for 4.6 km until you see a white pedestrian bridge after crossing Rio Duque bridge. Turn right on paved road driving 1.3 km until blue bus stop. Do not cross the bridge over the new Colón highway. Turn left right before the blue bus stop taking the dirt road for 1.2 km. Park the car on top of the hill.

Stop 9: (optional) Maria Eugenia Quarry. Coordinates (654174mE, 1009717mN). Exit the outcrop the same way you entered and turn right to join the road towards Panamá. Continue south (to the right) along the Old Highway towards Chilibre. Turn left at the mini market La Esmeralda. This turn is shortly after the right turn towards the Autopista.

Day 2:

Stop 1: Utivé River. Time 8:00 am, km 47, coordinates (683288 mE, 1013409 mN). Take the Panamerican Highway towards the airport. At 35 km (30 min) on the highway, at the junction turn left towards Utivé. 1 km from this junction turn to the left onto the old road to Chepo. 1 km farther, there is a construction site, take the turn to the right. On this road, you must first pass through the Praderas de La Paz Cemetery (40km) and then at the Y located in front of the police station (43km) take the road to the left that leads to the town of Utivé. At 45 km are the antennae of Cable and Wireless and Utivé is at 47 km. Within the town, at San Judas Tadeo chapel, cross to the right and advance 300m, then take the turn right before reaching the river and advance 200m.

Stop 2: Rio Indio. Time 9:45 am, km 65, coordinates (693397 mE, 1017177 mN). To reach stop 2 return to the police station (6 km, 15 min) and take the turn to the left, cross the Cabobré river and continue straight until you reach the town of La Mesa, located 30 minutes from the stop 1 (11 km). In La Mesa, turn to the right along the main road. After passing through the Loma Bonita bus stop and crossing 2 steel bridges, at 40 minutes and 17km from the stop 1, turn right at the junction, where there is a mini market. Continue along a dirt road 1km to reach the bridge that crosses the Rio Pacora at the Rio Indio community (18 km)

Stop 3: Rio Indio. Time 10:30 am, km 66, coordinates (693609 mE, 1017428 mN). Hike upstream 300m aprox.

Stop 4: Pacora River. Time 12:00 pm, km 72, coordinates (692009 mE, 1013542 mN). Take the main road back towards Carriazo, then keep along main road to La Mesa and cross the 2 steel bridges. At the Loma Bonita bus stop turn left in direction to Los Lajones farm (very small sign, 6 km, 7 min) and keep left. From this point it is necessary to walk about 10 min to reach the Pacora river.

Stop 5: Pacora River. Time 01:00 pm, km 73, coordinates (691666 mE, 1013918 mN). Hike downstream 600m aprox.

Stop 6: Mañanitas. Time 02:40 pm, km 92, coordinates (681736 mE, 1006548 mN). Back on the Pan American Highway, turn to the right in direction of Panama City. Stop 6 is 6 km from this point.

Day 3:

Stop 1: Mamoní River overlook. Time 8:40 am, km 70, coordinates (707657mE, 1020667mN). Take the Panamerican Highway towards the airport. Turn left in Las Margaritas, which is 64 km from Panama City. There is a gas station close to the intersection (if rafting, we will park the trucks here). Turn right at the first 3-way intersection. Go straight and turn left at the church near the town center. You will pass a police station. At the T in the road, the stadium, turn right. Go straight and turn left (the second left) at a small blue house (1.5 km from Las Margaritas). Go straight and stay to the right, leaving the paved road, at Jardin la escondida. Follow the dirt road and the overlook is 6.6 km from Las Margaritas.

Stop 2: Paleomag Site, dropoff point for rafting. Time 9:00 am, km 75, coordinates (706961mE, 1023480mN). Continue on dirt north towards stop 2 along the Mamoni River. Cross a bridge that is the dropoff point for white-water rafting (9.2 km from Las Margaritas).

Stop 3: Pillow basalts. Time 10:15 am, km 81, coordinates (709055mE, 1021998mN). Drive south on the dirt road, back towards Las Margaritas, and turn left (very sharp turn) just beyond stop 1 overlook. Continue on this road until a gated section of fence 1 km from the turn. Open the gate and go down the dirt two-track road 1 km. Stop 3 is in the Mamoni River beyond the farm at the end of the road. Return to Las Margaritas for lunch.

Stop 4: Chararé. Time 1:00 pm, km 112, coordinates (712187mE, 1021159mN). If high water levels: From Las Margaritas continue on the Panamerican highway driving east. Turn left at the El Tecal sign 5 km from Las Margaritas. Turn left at the T in the road. Turn right at the next intersection 5 km from the Panamerican highway. Continue on this dirt road and stay to the right at the Y in the road. Continue on this road until the Charare River. If the rivers are low: at the small blue house 1.5 km fom Las Margaritas (see stop 1) don't turn left. Go straight, this road will take you to the river crossing and continue east to reach the Chararé.

Field guide and geology by:

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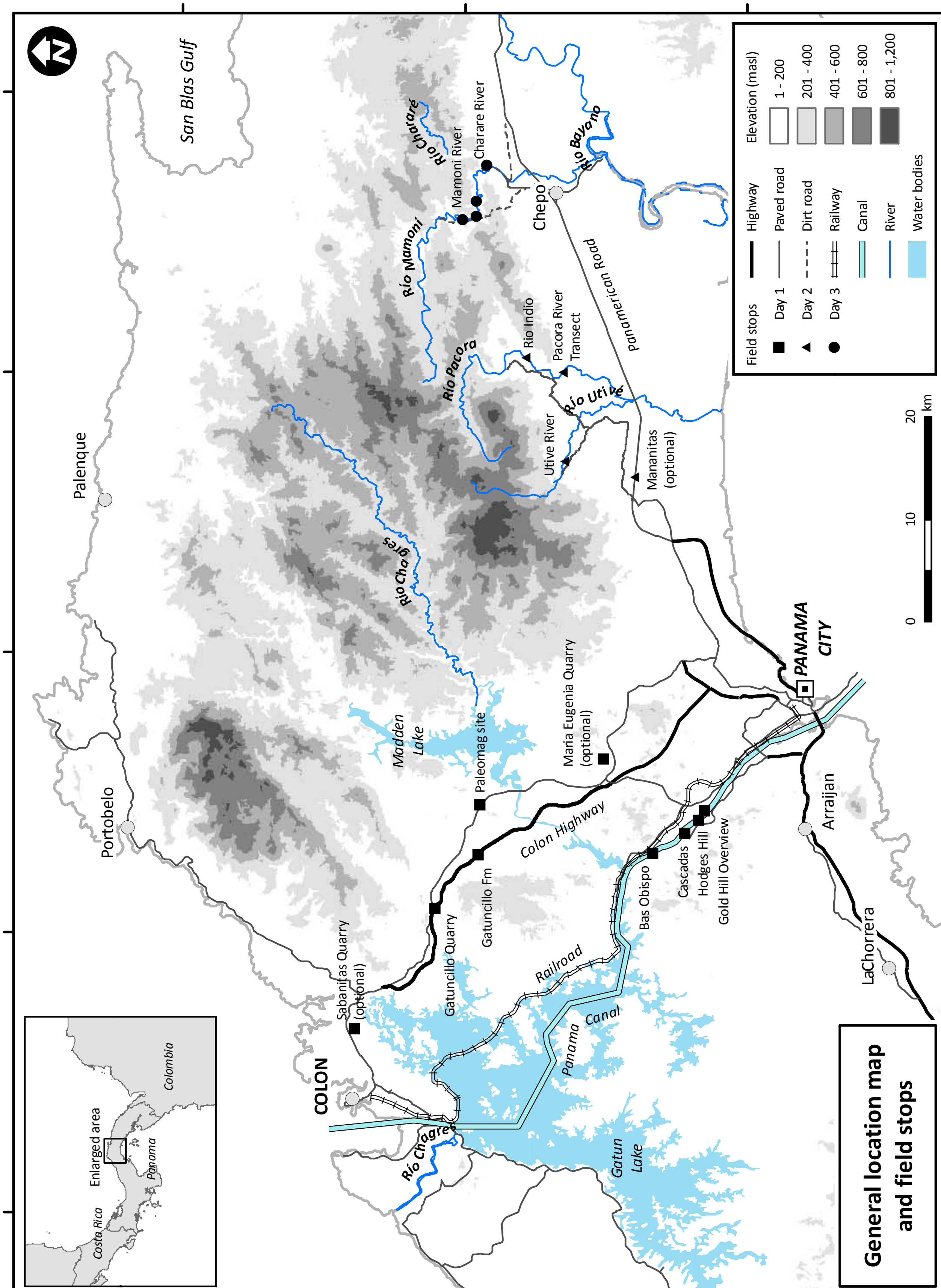
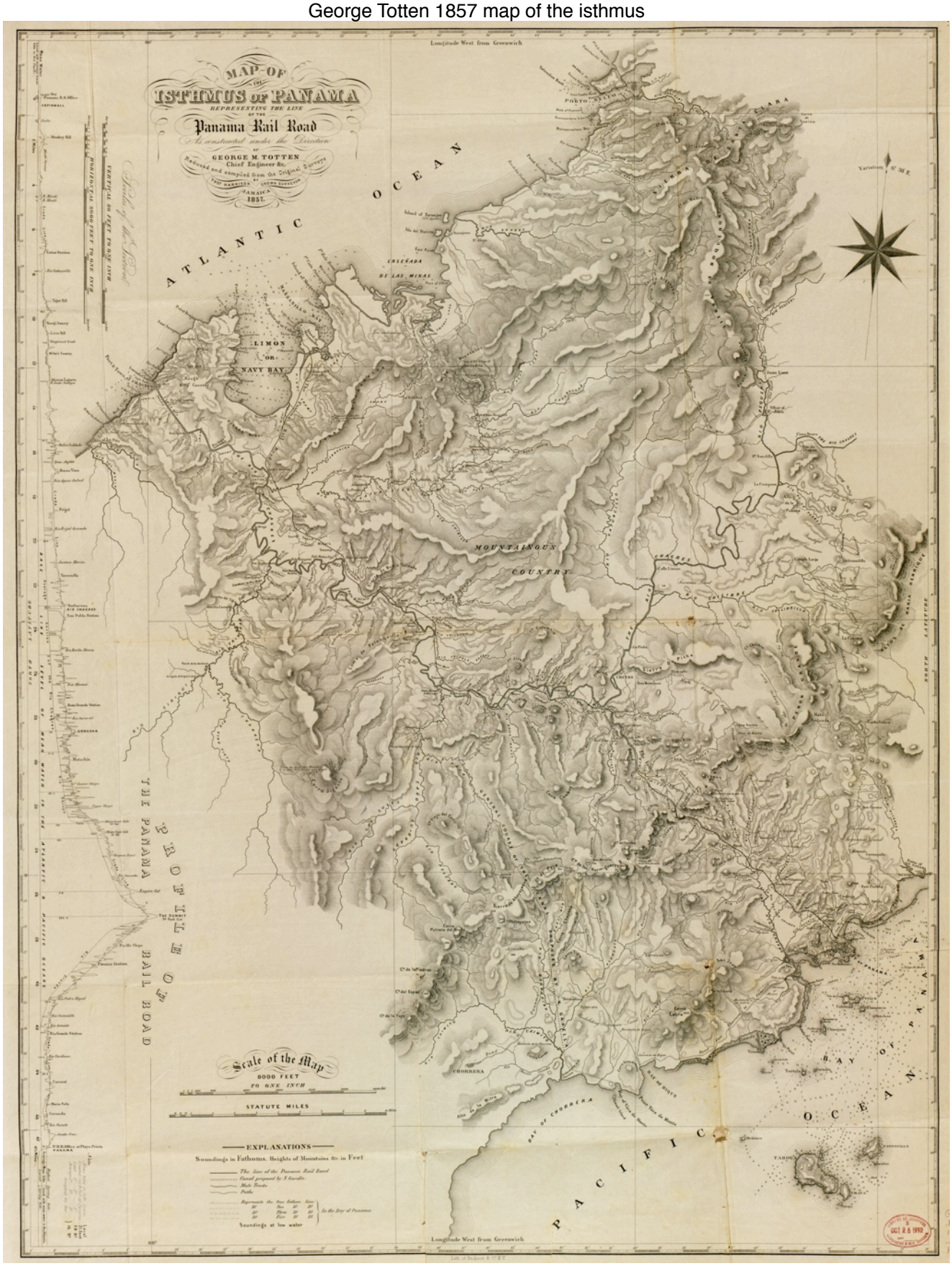


See high resolution panoramas at: http://gigapan.org/profiles/24156/

George Totten 1857 map of the isthmus



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