Fracturing of the Panamanian Isthmus during initial collision with South America

David W. Farris
Department of Earth, Ocean and Atmospheric Science
e-mail: dwfarris@fsu.edu

Abstract

Tectonic collision between South America and Panama began at 23-25 Ma. This is significant because the collision ultimately led to development of the Panamanian Isthmus, which in-turn had wide ranging oceanic, climatic, biologic and tectonic implications. Within the Panama Canal Zone, volcanic activity transitioned from hydrous mantle-wedge derived arc magmatism to localized extensional arc magmatism at 24 Ma, and overall marks a permanent transition in arc evolution. We interpret this change to result from fracturing of the Panama block during initial collision with South America. Fracturing of the Panama block led to localized crustal extension, normal faulting, sedimentary basin formation and extensional magmatism in the Canal Basin and Bocas del Toro. Synchronous with this change, both Panama and inboard South America experienced a broad episode of exhumation indicated by (U-Th)/He and fission-track thermochronology coupled with changing geographic patterns of sedimentary deposition in the Colombian Eastern Cordillera and Llanos basin. Such observations allow for construction of a new tectonic model of the South America-Panama collision, northern Andes uplift and Panama orocline formation. Finally, synchronicity of Panama arc chemical changes and linked uplift indicates onset of collision and Isthmus formation began earlier than commonly assumed.

Introduction

Traditionally, the Isthmus of Panama is interpreted to have completely separated the Caribbean Sea and Pacific Ocean by 3-3.5 Ma (Keigwin, 1978; O'Dea et al., 2007), and is widely speculated to result from collision between South America and the Panama block (Trenkamp et al., 2002; Coates et al., 2004) (Fig. 1). However, this closure date is based primarily on the evolutionary divergence of marine organisms and therefore must be a minimum age. Other evidence on when Isthmus formation began comes from shallowing sequences in Panamanian and Colombian bathyal sedimentary basins at 14.8-12.8 Ma (Duque-Caro, 1990; Coates et al., 2004) and folded-and-thrusted Upper Miocene strata in eastern Panama (Mann and Kolarsky, 1995). These observations document that significant contraction in eastern Panama occurred since the Middle Miocene, but do not put a firm limit on when or how the collision between South America and the Panama block initiated. We suggest that the collision initiated at 23-25 Ma when South America first impinged upon Panamanian arc crust as observed by distinct changes in the Panamanian arc chemical evolution, broad exhumation of the northern Andes and Panama, and extensive foreland deposition in the distal Llanos basin of Colombia (Fig. 1).

Panama arc evolution within the Canal Zone

The Panama arc formed on the trailing edge of the Caribbean plate at approximately 75-65 Ma (Buchs et al., 2010). Wegner et al. (2011) divide arc activity into a depleted late Cretaceous-Eocene initial episode and an enriched Miocene arc. Modern magmatism in Panama exists only west of the Canal Zone and consists of a < 2-3 Ma adakitic suite attributed variously to slab-melting (Defant et al., 1992), a slab-window (Abratis and Worner, 2002; Wegner et al., 2011), or subduction erosion (Goss, 2006).

We report that volcanic and plutonic rocks with characteristics of the oldest group persist until 25 Ma within the central Panama Canal Zone. In terms of rock type, the older arc is heterogeneous and consists of plutonic and extrusive rocks that range from calc-alkaline to tholeiitic and basaltic to andesitic in composition. However, these rocks are dominantly hornblende bearing (Rooney et al., 2010), have a large Ta anomaly, exhibit relative enrichment in fluid mobile LILE's (e.g. Cs, Rb, Ba), and have moderate HREE concentrations (Fig. 2A). Such characteristics are indicative of hydrous mantle wedge derived subduction zone magmas (Pearce and Peate, 1995).

Within the Canal Zone, volcanic rocks younger than 24 Ma range from basalt to dacite in composition, but are significantly less hydrous and exclusively tholeiitic. Rock types within the younger group are bimodal with individual units either dominated by silicic tuffs and welded units (Las Cascadas Fm.) or basalt to basaltic-andesite lava flows and intrusive sills (Pedro Miguel Fm.). Hornblende and other hydrous minerals are absent. In comparison with earlier arc rocks (Bas Obispo Formation and older), they are have low LILE's, relatively high HREE's and Ti, and a significantly decreased Ta anomaly (Fig. 2A).

Discussion

Exhumation in Panama and the Northern Andes is synchronous with the onset of Canal Zone extensional magmatism shortly after 25 Ma. We suggest the simplest explanation is the onset of collision between South America and Panama arc crust. Collision with South America is the dominant explanation for the Panama orocline (Silver et al., 1990), and as suggested above, this structure can explain the localized zones of extension within the Panama arc. Other options to explain exhumation and changes in arc processes in Panama and northern South America include: A 25-30 Ma westward increase in absolute South American plate motion as proposed by Silver et al. (1998), the 23 Ma fissioning of the Farallon plate (Lonsdale, 2006), or our prefered option, combination of the above with the collision of Panama and South America. The motion of South America is almost certainly the driver of broad Andean tectonic trends and the 23 Ma exhumation event is observed throughout western South America (Allmendinger et al., 1997). However, the width of the Colombian orogenic belt inboard of Panama is approximately twice that farther south in Ecuador. This suggests a causitive relationship. Overall, our prefered interpretation is that South America surged westward at the end of the Oligocene and collided with Panama arc crust. Due to arc crust unsubducibility, the Panama block detached from the Caribbean plate and was thrust over it leading to the formation of the North Panama deformed belt. The North Panama deformed belt and Llanos Basin form opposite verging fold and thrust belts occuring ≈500 km on either side of the Panama-South America suture (the Atrato fault, Trenkamp, 2002) (Fig. 4). Bi-vergent orogenic float (Oldow et al., 1990) could produce the widespread exhumation observed at 23-25 Ma during the collision initiation. Finally, we suggest that the semi-rigid beam of Panama arc crust fractured and underwent rotation in response to collision with South America leading to the observed zones of extensional magmatism.

Conclusions

1) The collision between South America and Panama initiated at 23-25 Ma. This collision ultimately separated the Caribbean Sea and Pacific Oceans.

2) In response to the collision, the Panamanian Isthmus fractured.

3) In the Canal Zone evidence of this includes: a change to extensional arc magmatism, low-temperature thermochronology, basin formation and significant normal faulting.

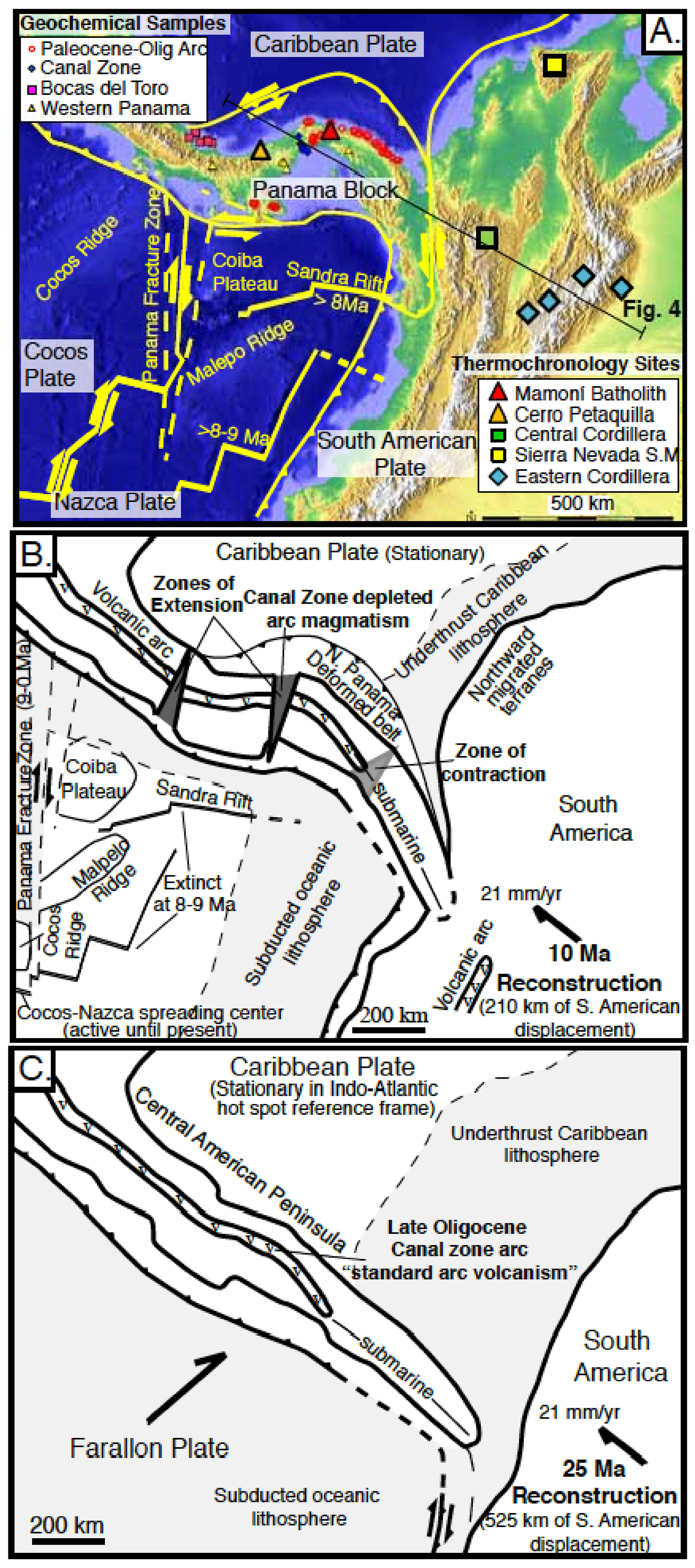

Figure 1: A) Modern tectonic map with the location of geochemical samples in Panama and low-temperature thermochronology profile sites in Panama and South America. B) 10 Ma tectonic reconstruction. This is an intermediate step in the collision between South America and Panama. The Panama block has fractured resulting to two zones of extension (the Canal Zone and Bocas del Toro) and one zone of contraction in eastern Panama. Also, the North Panama deformed belt has partially formed and a seaway >200 km wide separate Panama and South America. C) 25 Ma tectonic reconstruction. This immediately proceeds collision between Panama arc crust and South America.

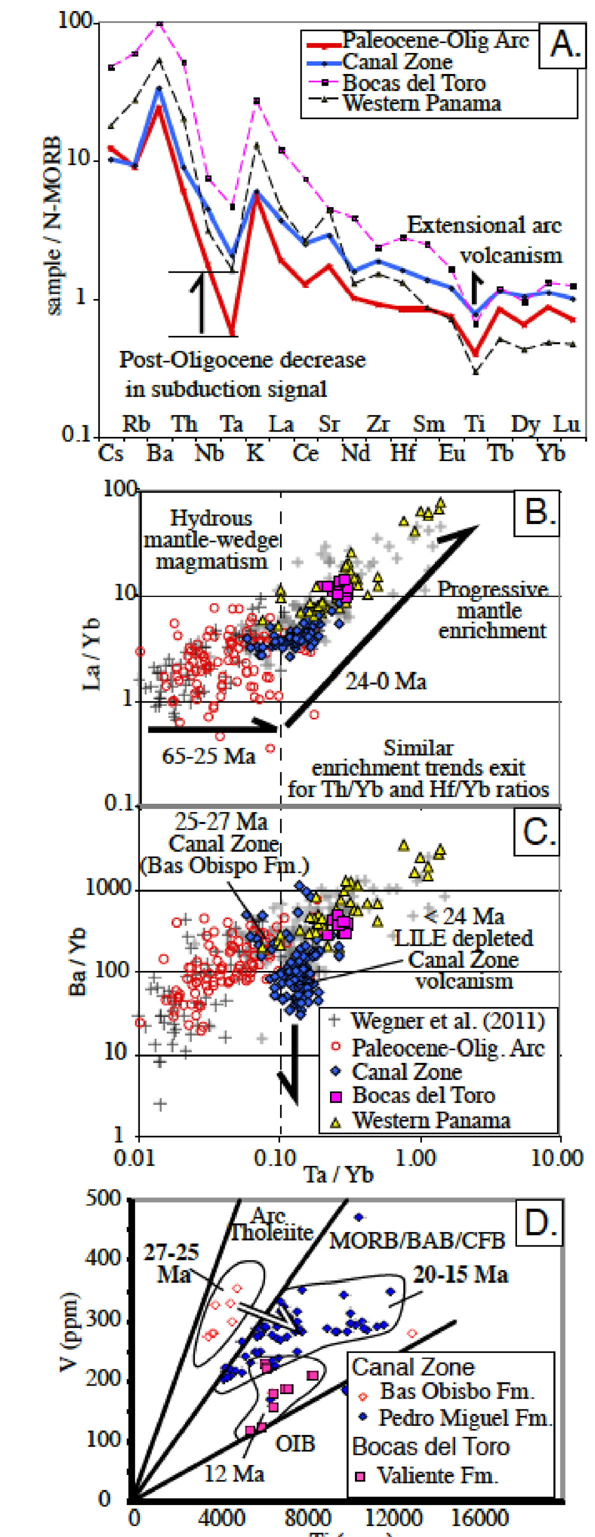

Figure 2: INAA trace element geochemistry from the Panama arc . A) Averaged trace element geochemistry from different temporal and spatial groups of Panama arc rocks. B) La/Yb vs Ta/Yb with individual samples plotted. The sharp inflection point at 23-25 Ma indicates a permanent change in arc chemistry. C) Ba/Yb vs Ta/Yb with individual samples. The Canal Zone volcanic rocks have sharply lower Ba/Yb ratios indicative of general LILE depletion. D) Shervais (1982) tectonic discrimination diagram. Canal Zone rocks transition from arc tholeiites to extensional products after 25 Ma. Rocks from Bocas del Toro also plot in the extensional field.

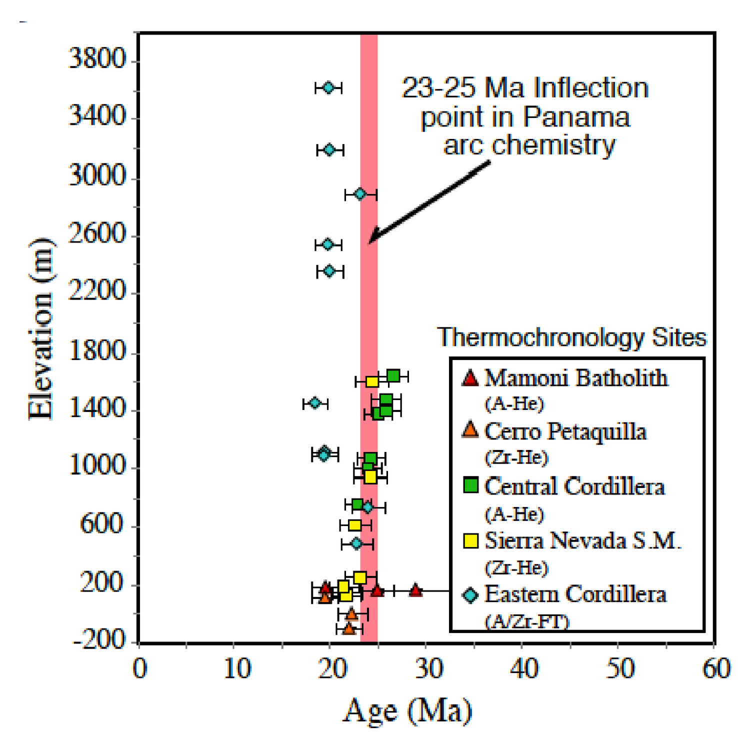

Figure 3: Low-temperature thermochronology from Panama and inboard South America. Ages shown are (U-Th)/He and fission track dates from apatite and zircon sampled on vertical profiles through igneous intrusive suites. Note how the cooling ages coincide with the inflection point in the Panama arc chemistry at 23-25 Ma.

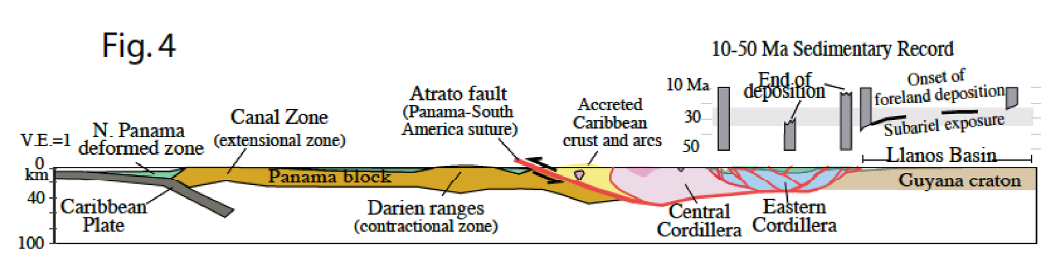

Figure 4: Modern cross-section through Panama and South America. Gray bars indicate sedimentary depositional history. Panama and the northern Andes form a bi-vergent orogen with the N. Panama deformed belt and Llanos basin forming opposing thrust belts. Exhumation and eastward Llanos basin propagation is synchronous with Panama arc geochemical change, and is interpreted to result from accretion of Panama arc crust to South America at 23-25 Ma.

Detailed Canal Zone Geologic and Geophysical Observations

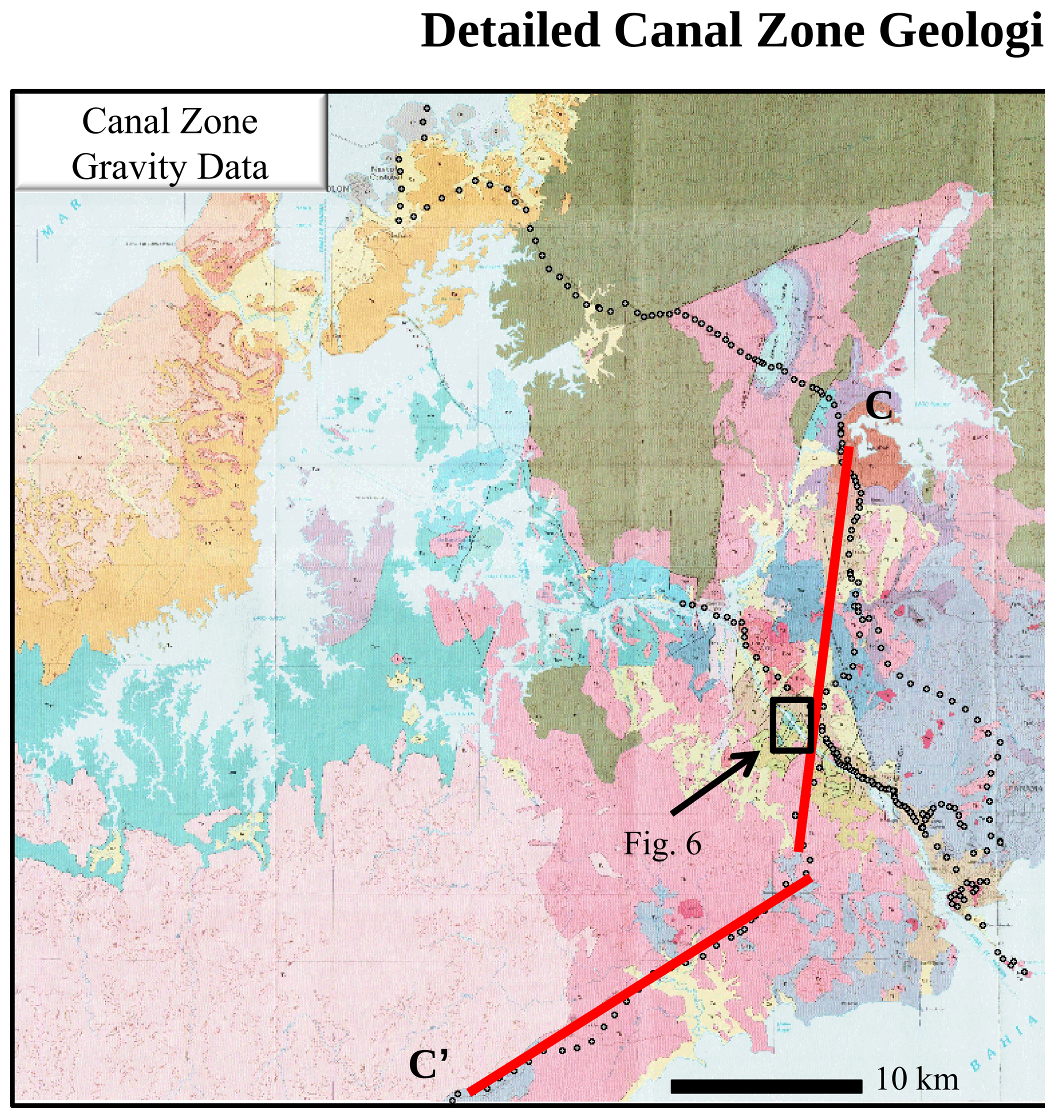

Figure 5: Geologic map of Central Panama and the Panama Canal. Circles indicate locations of gravity observations

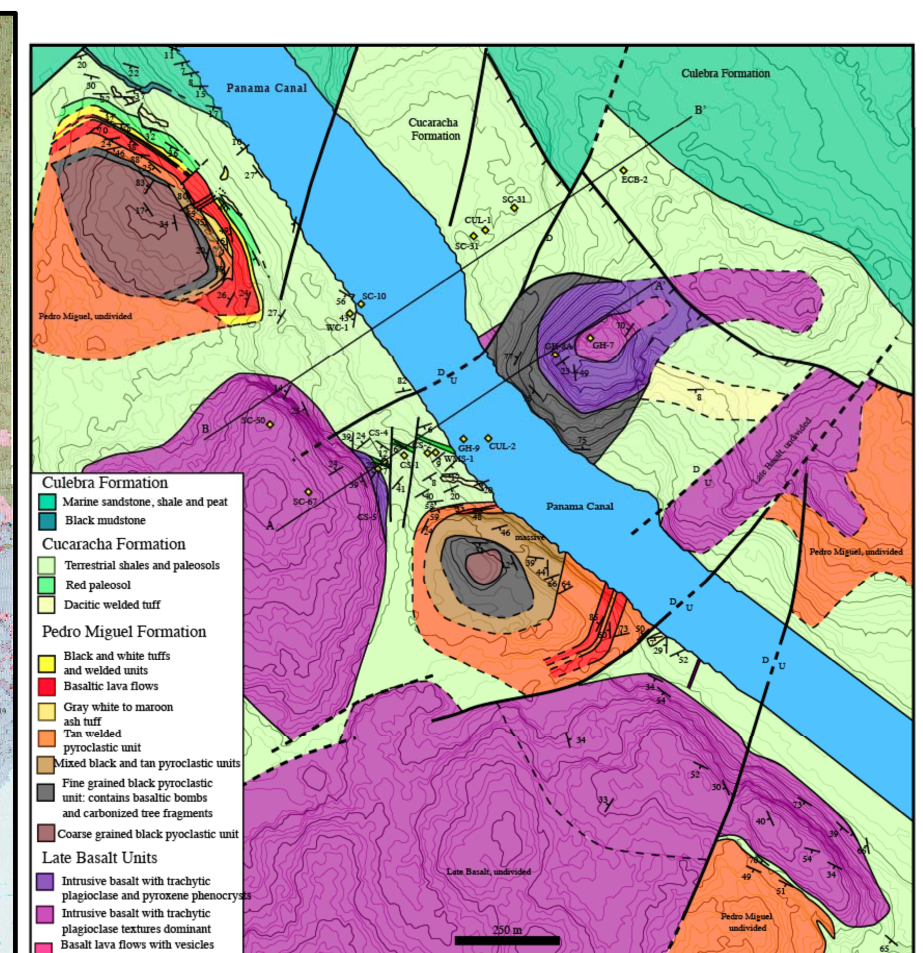

Figure 6: Detailed geologic map of the Culebra Cut along the Panama Canal. The map contains Miocene volcanic sills and pipes that intrude into and are inter-bedded within the Canal sedimentary basin.

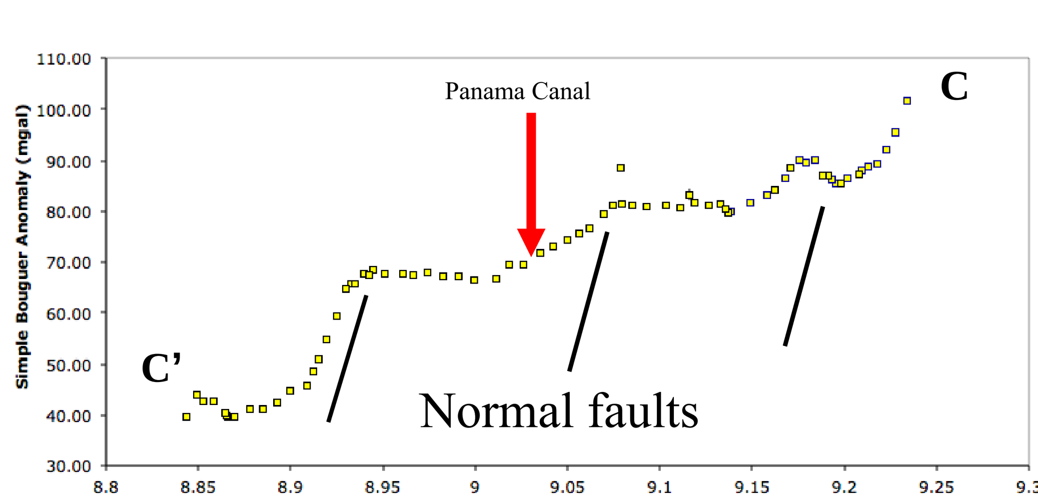

Figure 7: Bouguer anomaly gravity profile perpendicular to Canal Basin. The major steps in the profile correspond to large normal faults.

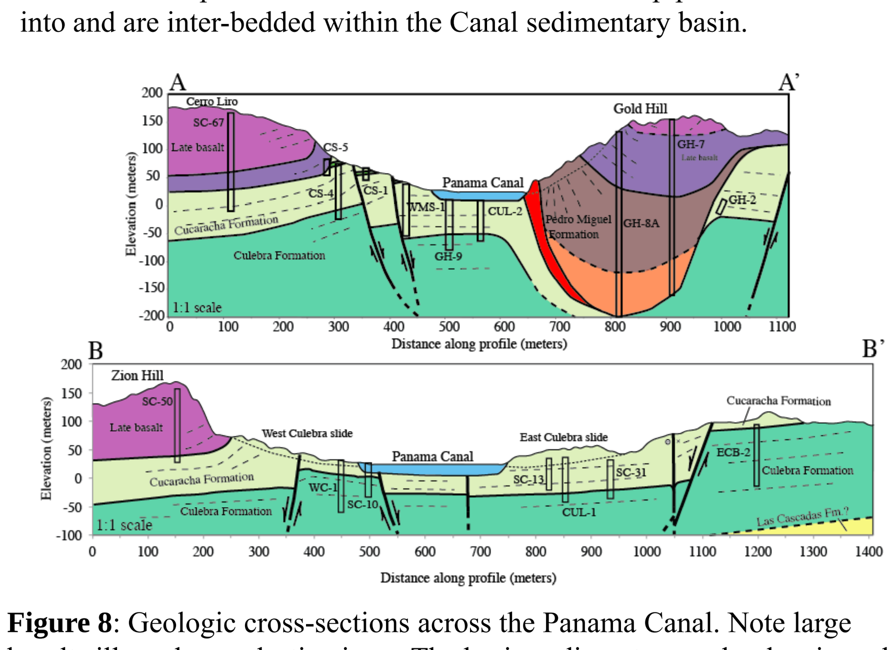

Figure 8: Geologic cross-sections across the Panama Canal. Note large basalt sills and pyroclastic pipes. The basin sedimentary and volcanic rocks are cut by normal faults. See Fig. 6 for map locations.