APPENDIX

Methodology

Twenty five apatite fission-track data were obtained from various sources and include analyses acquired with the External Detector Method (EDM, e.g., Donelick et al., 2005) in fourteen samples and by Laser-Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)) in eleven samples (Hasebe et al., 2004; Donelick et al., 2005). Analytical methods followed standard procedures which are described in detail Parra et al. (2009)

Thermochronometric data were complemented with provenance data derived from 3996 new detrital zircon U-Pb ages retrieved from 42 Late-Cretaceous to Miocene surface samples from the central and southern portions of the Middle Magdalena Valley basin. They were combined with 3339 published ages from 35 surface and subsurface samples from the northern sector (Nie et al., 2010, 2012; Caballero et al., this volume).

We present 202 new individual zircon (U-Th)/He ages obtained in 52 Jurassic to Miocene surface and subsurface samples in the western sector of the Eastern Cordillera and the Middle Magdalena Valley basin. Analyses were conducted at the Thermochronology Laboratory at Kansas University, following standard methods described in Restrepo-Moreno (2009).

Vitrinite reflectance (Ro) data were acquired from the seven stratigraphic units complemented with six more from organic matter-rich mudstones sampled in the nearest possible outcrops to those with thermochronology samples. Analytical methods followed standard procedures described in Cook (2006) and ICP.

Thermal histories that account for the observed thermochronometric and paleothermometric data were generated using the software HeFTy (Ketcham, 2005). In addition to AFT, He, and Ro data, constraints in the t-T space were chosen so that t-T paths honor geological observations such as the unconformities and periods of burial deduced from the overlying stratigraphy of each particular area.

Laser Ablation–Inductively Coupled Plasma–Mass Spectrometry (LA-ICP-MS) U-Pb analyses in detrital zircon from 33 samples were carried out in different sessions at the Arizona Laser Chron Center ALC (Montgomery et al., 2001) of the University of Arizona and the Isotopic Radiogenic Lab at Washington State University (IRL). Separated single zircon crystals were mounted in epoxy (~500-1000 zircon crystals/sample), accompanied by standards (e.g., SL2 and R33 for ALC and Peixe and FC1 for IRL). Mount surfaces were grinded and polished in order to expose zircon crystals. Cathodoluminiscence (CL) images were made in order to map details in zircon crystals structures.

At ALC, zircon material is ablated from the sample surface using a DUV193 Excimer laser system operating at a wavelength of 193 nm, with typical 35 -25 micron spot size. Laser was operated at output energy (~40 mJ) with a repetition rate of 8 pulses per second. A pit created by the laser is ~15 microns in depth for a typical 20 second analysis. The ablated material is carried in Helium gas into the plasma source of a VG Isoprobe multicollector inductively coupled plasma mass spectrometer, allowing simultaneous analysis of U, Th, and Pb isotopes (Gehrels et al., 2008).

Zircon U-Pb LA-ICP-MS conducted at the IRL at Washington State University used a New Wave Nd: YAG UV 213-nm laser coupled to a Thermo Finnigan Element 2 single collector, double-focusing, magnetic sector ICP-MS (Chang et al., 2006). Laser spot size was 30 nm and the repetition rate was 10Hz. The sample aerosol was delivered to the plasma by He and Ar carrier gases.

Each analysis comprises a 30 seconds blank analysis followed by 250 or 300 sweeps through masses 204, 206, 207, 208, 232, 235, and 238. U-Pb data from both laboratories were reduced with in-house software and plotted in normalized, age probability plots using a spreadsheet macro available at ALC's website.

U-Pb Interpretation: The rationale for the interpretation of provenance is that potential sources for the Cenozoic Middle Magdalena Valley basin comprise two main source areas with distinct U-Pb signatures. A western source area includes magmatic-arc related plutons that make part of the Central Cordillera, with U-Pb ages younger than 180 Ma. In contrast, an eastern source area is devoid of such ages, and includes a suite of Proterozoic and Palaeozoic populations originally derived from the Guyana Shield or the Craton and the Eastern Cordillera basement. These detrital populations could have been supplied to the Middle Magdalena Valley basin either directly from these sources or recycled from Palaeozoic and Cretaceous strata (Horton et al., 2010; Caballero et al., this volume; Nie et al., 2011; Saylor et al., 2011; Silva et al., 2011).

Inverse Modeling

Eastern flank Central Cordillera

The Triassic granodioritic gneiss of the Cajamarca Complex (1018-25), was modeled with a population of 101 tracks and a Dpar between 1.14 and 1.65 µm and the volcaniclastic Jurassic Segovia Granodiorite (1018-28), with a population of 102 tracks, and a Dpar between 0 and 2.32 µm (Figure A1).

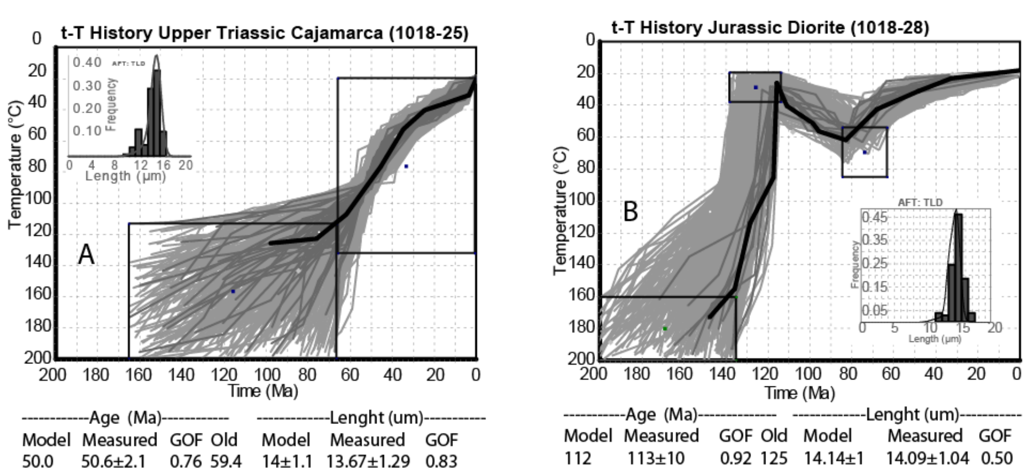
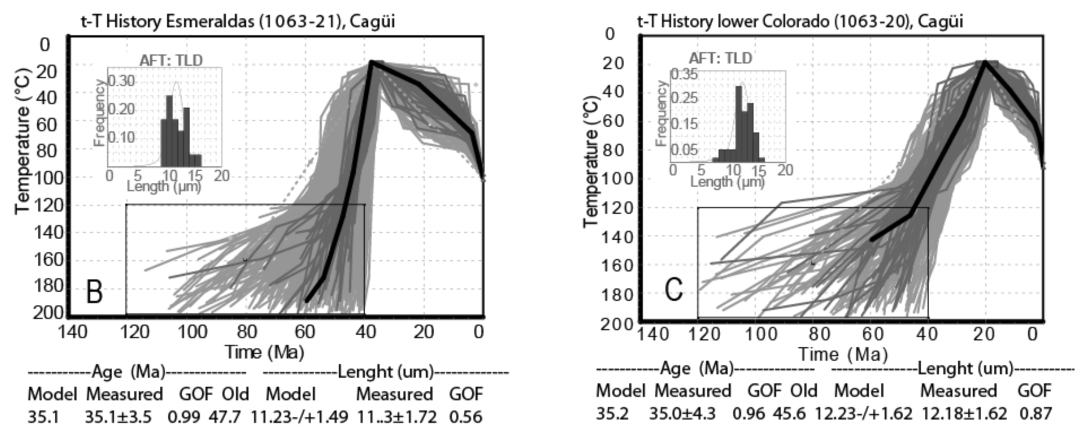


Figure A1: Inverse models of samples from the Central Cordillera obtained using the HeFTy software (Ketcham, 2005). A. Time-temperature history of the reset Upper Triassic granodioritic gneiss of the Cajamarca Group. B. Time-temperature history of unreset Jurassic Granodiorite underlying the Jurassic Morrocoyal Formation.

Both models show high Palaeocene to Early Eocene cooling rate and slow cooling rate since Middle Eocene. The dark-grey areas enclose time-temperature paths with a good-fit to the measured apatite-fission track data. Light grey area encloses paths with only acceptable fit. Black boxes correspond to constraints in the t-T space derived from stratigraphic relationship in the well.

Middle Magdalena Valley

The Lower Cretaceous Rosablanca Formation (1063-25) below the unconformity in the Cagüi well, was modeled with a population of 35 tracks and chlorine content between 0.02 and 0.25 wt%., vitrinite reflectance of 1.23±0.07%, and constraints derived from the stratigraphy above and below the unconformity (Figure A2).



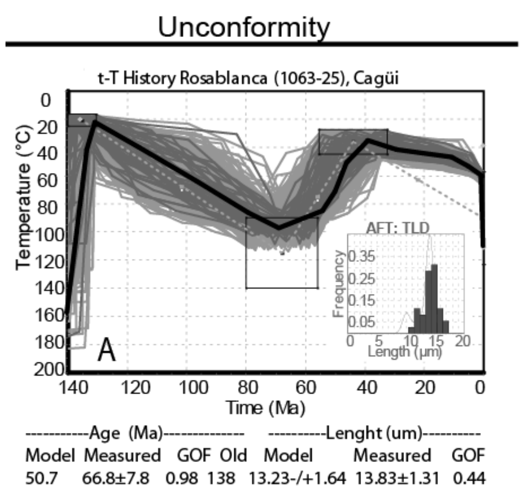


Figure A2: Time-temperature histories of the samples above and below the Eocene unconformity from a well in the Cagüi area, A. Below the unconformity, the Rosablanca Formation shows Late Cretaceous onset of cooling related to inversion and thrusting. B. the Esmeraldas Formation shows rapid cooling between Paleocene to Early-Middle Eocene (~60 and 40 Ma), followed by burial and heating

Above the Unconformity, the Upper Eocene Esmeraldas Formation (1063-21) was modeled with a population of 24 tracks and chlorine content between 0.01 and 1.12 wt., a Ro value of 0.53%, and constraints derived from the stratigraphy (Figure A2). And the overlying Lower Miocene Colorado Formation (1063-20) was modeled with a population 62 tracks, chlorine content between 0.02 and 1.06 wt%., and constraints derived from the stratigraphy (Figure A2). It was interpreted a Central Cordillera source of sediment for the Upper Eocene Esmeraldas Formation, and an Eastern Cordillera source for the Lower Miocene Colorado Formation based on the style of cooling of the time-temperature history.

The Jurassic Girón Formation (1082-12) below the unconformity in the Sonero well was modeled with a population of 18 tracks, chlorine content between 0.01 and 0.82 wt% and constraints derived from the stratigraphy above and below the unconformity (Figure A3).

The Upper Miocene Real Formation (1082-01) above the unconformity in the Sonero well, was modeled with a population of 32 tracks and chlorine content between 0.0 and 0.94 wt%. (Figure A3).

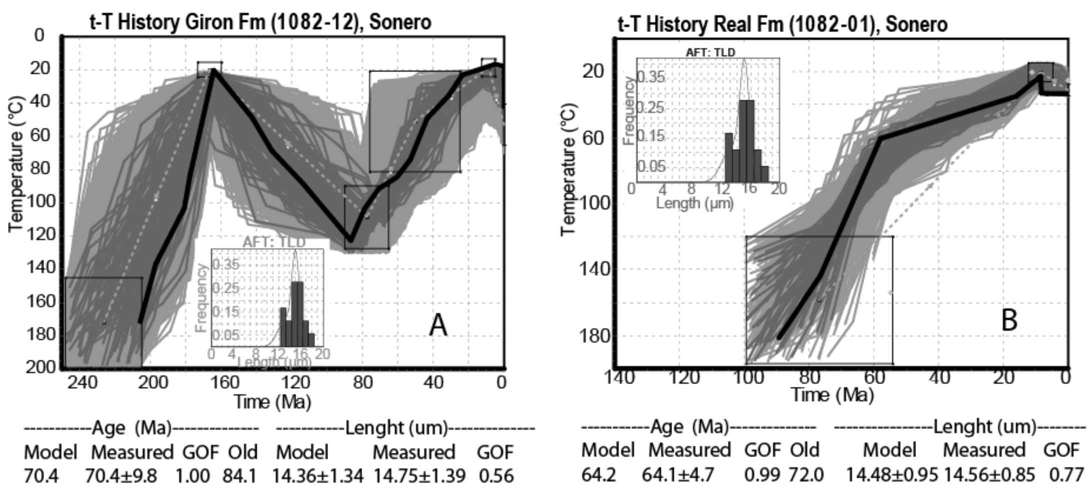
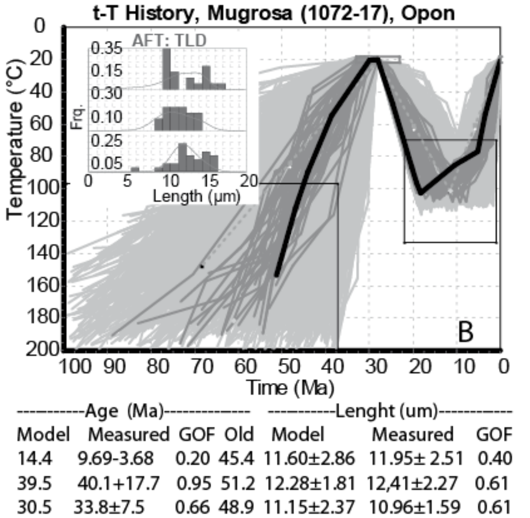
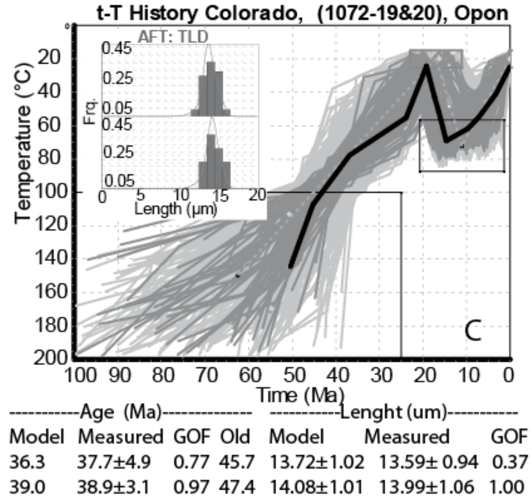


Figure A3: Inverse models of subsurface samples in the Sonero-1 well, northwestern Middle Magdalena Valley basin. A. Below the unconformity, thermal history of the Jurassic Giron Formation showing late Cretaceous (sometime between 75 and 86 Ma), onset of cooling related to inversion and thrusting. B. Thermal history of the Upper Miocene Real Formation showing high Palaeocene cooling rate followed by lower Eocene and Oligocene cooling rate, a pattern reminiscent of the exhumation of the Central Cordillera.

Western flank Eastern Cordillera

In the Opon syncline, the Upper Eocene Esmeraldas (1072-18) was modeled with a population of 21 tracks and Dpar value between 1.19 and 1.98 µm. The Ro value of the La Paz Formation below is 0.66%. The overlying Oligocene Mugrosa (1072-17) was modeled with 69 tracks in 3 populations with Dpar of 1.24-2.0 µm, 2.05-2.70 µm and 2.76-4.24 µm, and The Lower Miocene Colorado (1072-19, 20) was modeled with 96 tracks in 2 populations with Dpar of 1.14-1.73 µm, and 1.83-2.35 µm (Figure A4).





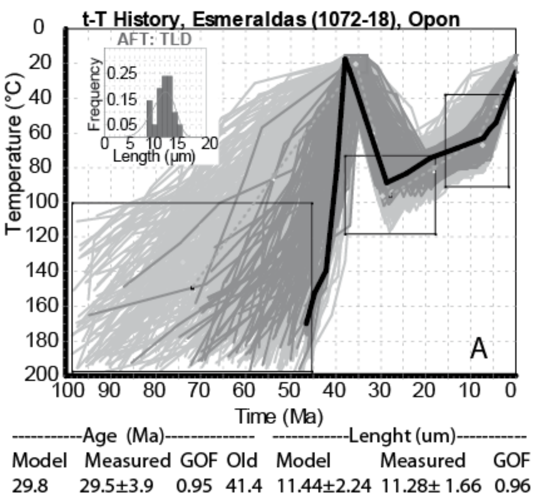


Figure A4. Images of inverse models in Cenozoic units from the Opon syncline. A. The Esmeraldas Formation reveals high cooling rate during Palaeocene and Early Eocene, which is consistent with a source area located in the Central Cordillera. B, C. The Oligocene Mugrosa and the Lower-Middle Miocene Colorado shows low cooling rate during Eocene and Oligocene which suggest that their source area may have been

In the Rio Ermitaño syncline, the Middle Eocene La Paz Formation (1072-91) was modeled with two populations of 76 and 24 tracks with Dpar of 1.46-1.84 µm and 1.88-2.66 µm respectively. The overlying Upper Eocene Esmeraldas Formation (1072-92) was modeled with a population of 28 tracks with Dpar value between 1.13 and 1.66 µm. The Oligocene Mugrosa Formation (1072-94) was modeled with one population of 101 tracks with Dpar values of 1.92-3.03 µm. And the Lower Miocene Colorado Formation (1072-93) was modeled with two populations of 75 and 102 tracks with a Dpar between 1.58-1.85 µm (Figure A5).

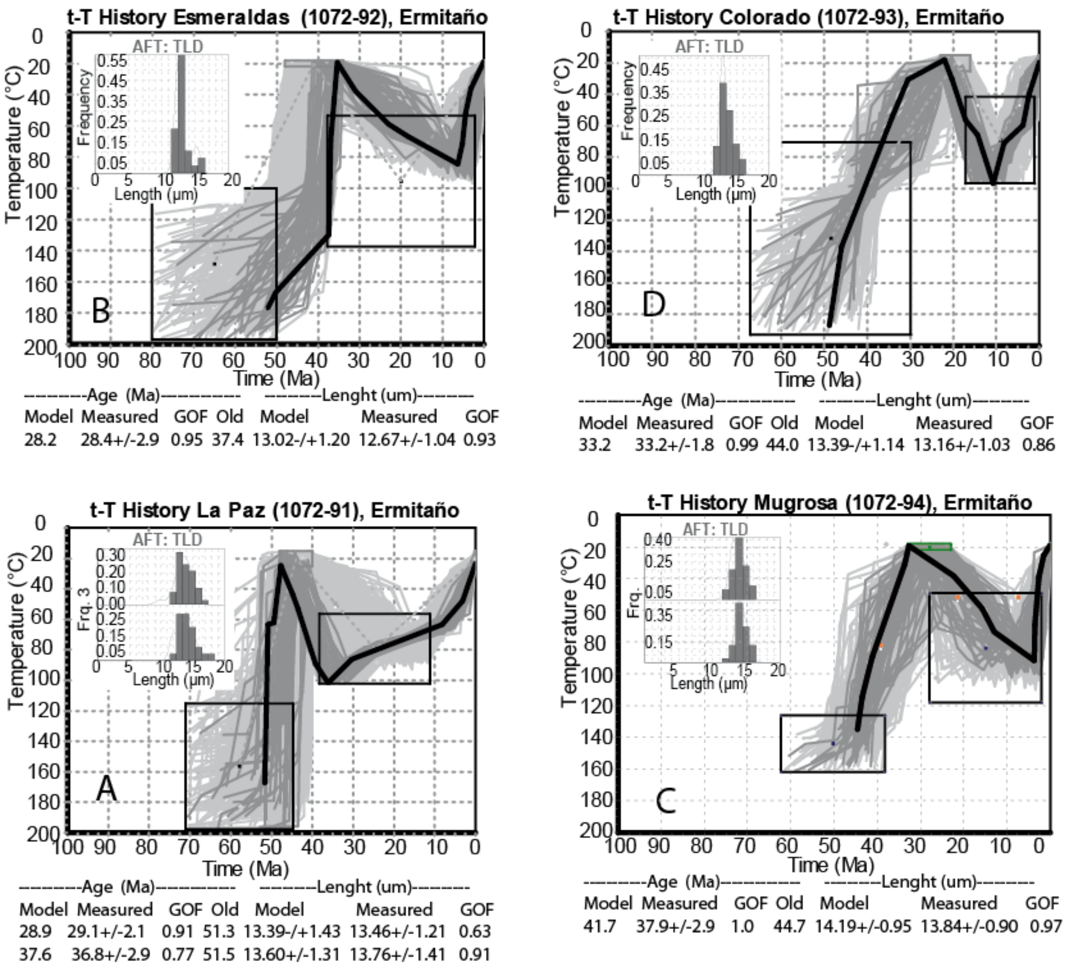
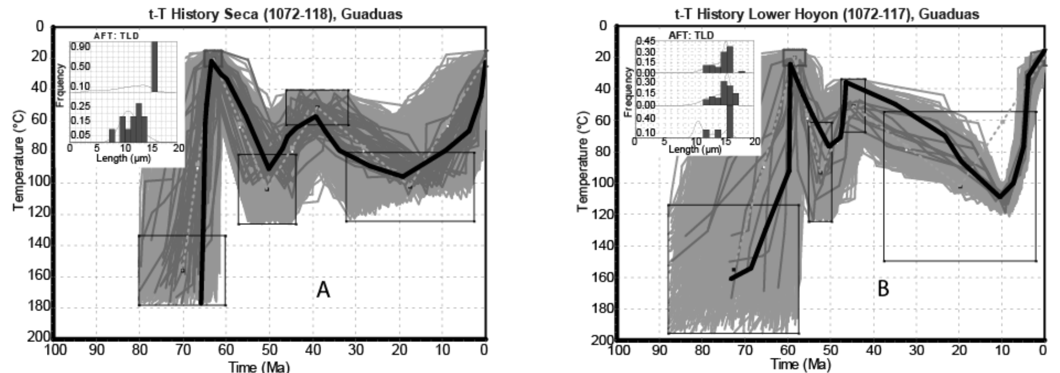


Figure A5. The AFT inverse models of samples from the Cenozoic units in the Ermitaño syncline. A, The La Paz Formation shows high cooling rate during the Paleocene and Early Eocene. B. The Esmeraldas Formation shows high cooling rate during Middle Eocene. Based on these t-T histories we attribute their source of sediment from the Central Cordillera. C, D. The modeling shows slow cooling rate during the Eocene and Oligocene in the Mugrosa and Colorado formations, indicating possible source of sediment from the Eastern Cordillera.

In the Guaduas syncline, the Maastrichtian-Lower Paleocene Seca (1072-118) was modeled with two populations of 1 and 11tracks, Dpar values between 1-46-1.47 and 1.57 and 3.07 µm respectively and vitrinite reflectance of 0.6%. The Overlying Middle-Upper Paleocene Hoyón (1072-117) was modeled with three populations of 37, 52, and 6 tracks, each one with Dpar values of 0.95-1.71, 1.72-2.0 and 2.14-2.3 µm respectively. We imposed constrains on both samples in accordance to the geology of this region like the presence of the unconformity (Figure A6).



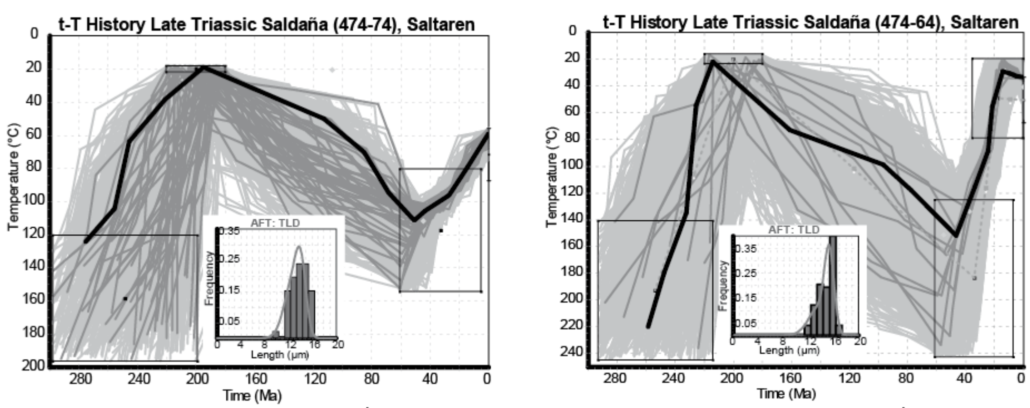
Age (Ma)				Lenght (um)		
Model	Measured	GOF	Old	Model	Measured	GOF
16.6	16.4+/-5.8	0.97	49.2	11.16+/-2.66	15.73+/- 0,0	0.29
39.3	61.6+/-17.2	0.19	65.6	10.53+/-2.43	11.37+/-1.84	0.51

Age (Ma)				Lenght (um)		
Model	Measured	GOF	Old	Model	Measured	GOF
7.83	8.05+/ 0.78	0.78	10.4	14.30+/- 1.53	14.34+/-1.42	1.00
8.70	7.60+/ -0.91	0.23	14.1	14.25+/-1.72	14.53+/-1.37	0.94
19.5	30.2+/-8.7	0.22	63.8	12.37+/-2.26	14.66+/-1.74	0.23

Figure A6. AFT inverse models of samples from Cenozoic units in the Ermitaño syncline. Inverse modeling of these two samples shows t-T trajectories suggesting that cooling and exhumation due to slip along the Cambao thrust that led to folding of the western limb of the Guaduas anticline may have commenced between ~20 and 10 Ma

Upper Magdalena Valley

In the Saltaren area, northern Upper Magdalena Valley, two samples of the Jurassic volcaniclastic Saldaña Formation at depths of 6600 – 6900 ft and 3600 – 3900 ft were modeled. The first sample has a population of 98 tracks and Dpar values between 1.94 and 2.64 µm. The second sample was modeled with a population of 125 tracks and a Dpar between 1.57 and 2.94 µm (Figure A7).



Age (Ma)				Lenght (um)		
Model	Measured	GOF	Old	Model	Measured	GOF
32.3	32.0±3.3	0.94	53.5	13.20±1.41	13.44±1.38	0.68

Age (Ma)				Lenght (um)		
Model	Measured	GOF	Old	Model	Measured	GOF
34.4	34.5±6.6	0.99	42.7	14.55±1.48	14.43±1.27	0.49

Figure A7. Thermal inverse models of subsurface samples in well-3 of the Saltarén area, Upper Magdalena Valley. Thermal histories of two samples from the Late Triassic Saldaña Formation indicate onset of uplift of the Natagaima and El Patá arch in Middle-Late Eocene time.

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