From Rivers to Deep-Sea Fans:

Coastal Filtering and Selective Routing of Provenance Signals along an Active Continental Margin (Colombian Caribbean)

Estefany Villanueva-García*, Yamirka Rojas-Agramonte, Daniel Rincón-Martínez, Delia Rösel, Óscar Álvarez-Silva, Andrés Mora, Christian Winter

*Institut für Geowissenschaften, Universität Heidelberg · estefany.villanueva@geow.uni-heidelberg.de

Detrital Zircon U–Pb · n ≈ 2,879 ages

XRD Bulk + Clay Mineralogy

~300 km · Colombian Caribbean

DZstats · DZmds · DZmix

PROVENANCE SIGNALS EVOLVE THROUGH:

Partitioning → Coastal Filtering → Selective Canyon Routing → Distal Mixing

Supplementary Material · EGU26-1674

Session GD4/SSP/TS · Subduction and Plate Boundary Geodynamics in the Americas · Poster Hall X2, Mon 04 May 2026

The Problem: What Does the Coastal Domain Do to Provenance Signals?

Motivation & research gap

CONTEXT

Sediment-routing systems transfer material — and the geochemical record of source rocks — from mountains to deep-sea basins. The coastal domain sits between rivers and submarine canyons. Whether it preserves, modifies, or generates provenance signals has been poorly constrained, because few studies sample coasts, rivers, canyons, and fans simultaneously.

FLUVIAL-DOMINATED COAST

Passive?

High discharge overwhelms local inputs → coastal signal mirrors river

THE SWITCH

Supply vs. Erosion

Coastal role depends on balance between fluvial supply and direct shoreline erosion

EROSION-DOMINATED COAST

Active?

Crystalline outcrops erode directly → new provenance signatures generated

Core Question: Under what conditions does the coastal domain act as a passive conduit vs. an active provenance source — and do coastal-generated signals reach the deep sea?

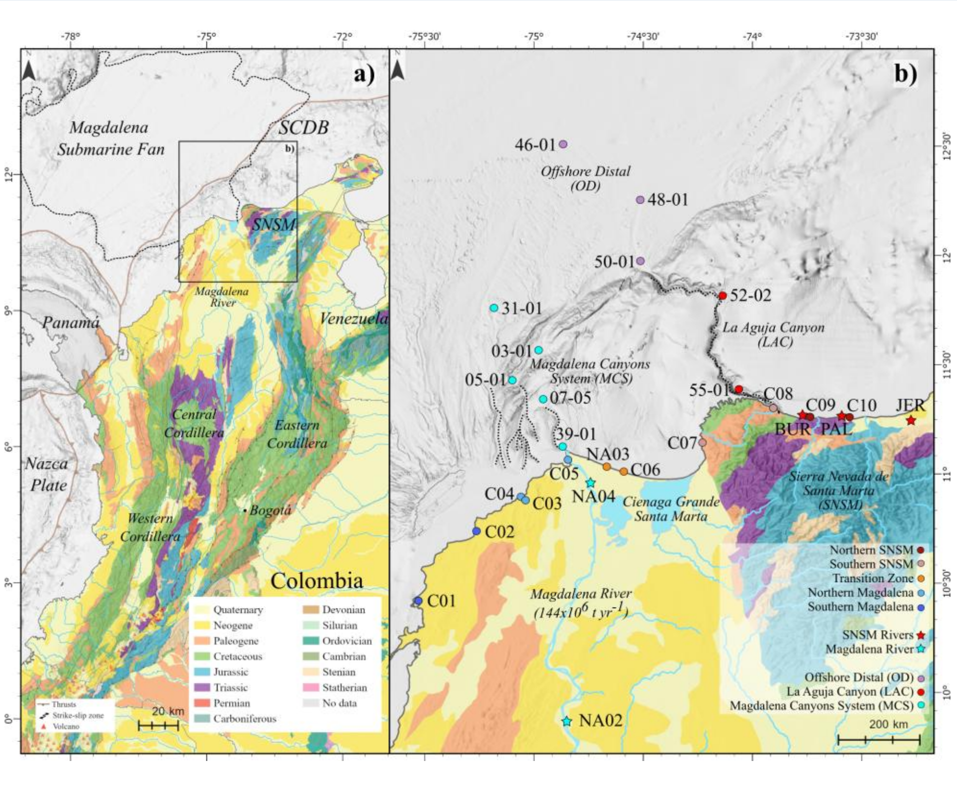
Our Approach: New coastal U–Pb detrital zircon (n=10, ~1,150 ages) + XRD mineralogy integrated with published fluvial and offshore records (~1,729 ages) across two contrasting routing systems within ~300 km under similar oceanographic forcing.

KEY TAKEAWAY The coastal domain is routinely omitted from source-to-sink provenance models — yet it may fundamentally alter the signal before it reaches the deep sea.

Natural Laboratory: Two Contrasting Routing Systems

Northern Colombian Caribbean margin · ~300 km transect · 10 new coastal stations (C01–C10)

STUDY AREA



MAGDALENA RIVER

$\sim 144 \times 10^{6}$ t yr^{-1}

Large Andean-integrated drainage. Dominates Caribbean sediment budget (~97%). Directly connected to MCS submarine canyon network.

SIERRA NEVADA DE SANTA MARTA

$\sim 0.01 \times 10^{6}$ t yr^{-1}

Small, steep catchments. Crystalline rocks exposed at shoreline. Feeds La Aguja Canyon (LAC) through structural control.

SHARED OCEANOGRAPHIC FORCING

Caribbean Current + Trade Winds

Panama–Colombia Gyre drives redistribution. Allows isolation of routing controls from oceanographic variables.

10	2,879	2
New coastal stations (C01–C10)	Total concordant zircon ages	Proxies: U-Pb XRD

KEY TAKEAWAY Same oceanographic forcing for both systems — differences in provenance signals reflect routing configuration, not oceanographic variability.

Analytical Framework: Multi-Proxy Integration Across the Full Source-to-Sink Transect

Three independent proxies — coastal, fluvial, and offshore datasets combined

METHODS

Detrital Zircon U–Pb Geochronology

n = 10 coastal stations · ~1,150 new ages
LA-ICP-MS at Univ. Gothenburg + Washington State Univ. 100–120 grains/sample. Detrital zircon ages span from <1 Ma to ~2700 Ma. Integrated with 1,729 published ages (Pepper et al. 2016; Caracciolo et al. 2025).

XRD Mineralogy (Bulk + Clay <2 µm)

10 coastal + offshore samples
X-ray diffraction at ICPET–Ecopetrol (Colombia). Bulk: quartz, feldspars, amphiboles, heavy minerals. Clay fraction (<2µm): illite, kaolinite, chlorite, smectite — independent proxy from U-Pb.

Statistical Analysis: DZstats · DZmds · DZmix

Quantitative inter-sample comparisons
DZstats (Saylor & Sundell 2016): cross-correlation, Kuiper V. DZmds: MDS ordination, stress=0.102. DZmix (Sundell & Saylor 2017): Monte Carlo unmixing — all coastal + fluvial samples as independent end-members.

Grain Size

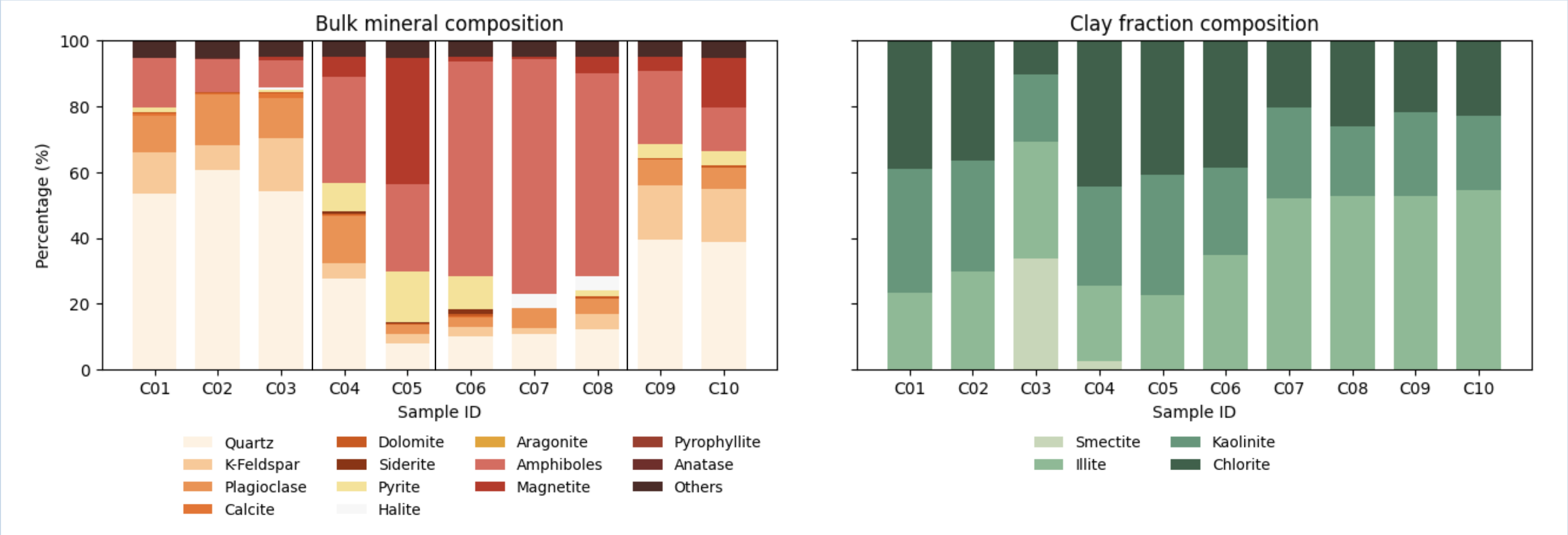
Laser diffraction · Kiel University
d_{50} = 180–550 µm across transect. All samples: 0–5 cm unconsolidated beach sand. Compositional domains persist at constant texture — ruling out hydrodynamic sorting as a driver of provenance variability."

KEY TAKEAWAY Three independent proxies on the same samples — spatial coherence across proxies provides strong internal validation of domain interpretations.

05 Coastal Partitioning: XRD Mineralogy Defines Compositional Domains

RESULTS

Bulk + clay fraction composition · C01–C10 SW → NE transect



SW SECTOR C01–C03

Quartz 53–60%

Polymodal Andean-integrated signal preserved. Clay: kaolinite + chlorite — moderate chemical weathering from large integrated basin. Passive transfer zone.

DELTA FRONT C04–C05

Amphiboles ↑ 27–32%
Quartz ↓ 8–27%

High-energy sorting at river mouth. Heavy minerals concentrated (magnetite, pyrite). Possible SNSM input via longshore drift from adjacent coast.

NE SECTOR C06–C10

Amphiboles 61–71% (C07–C08)

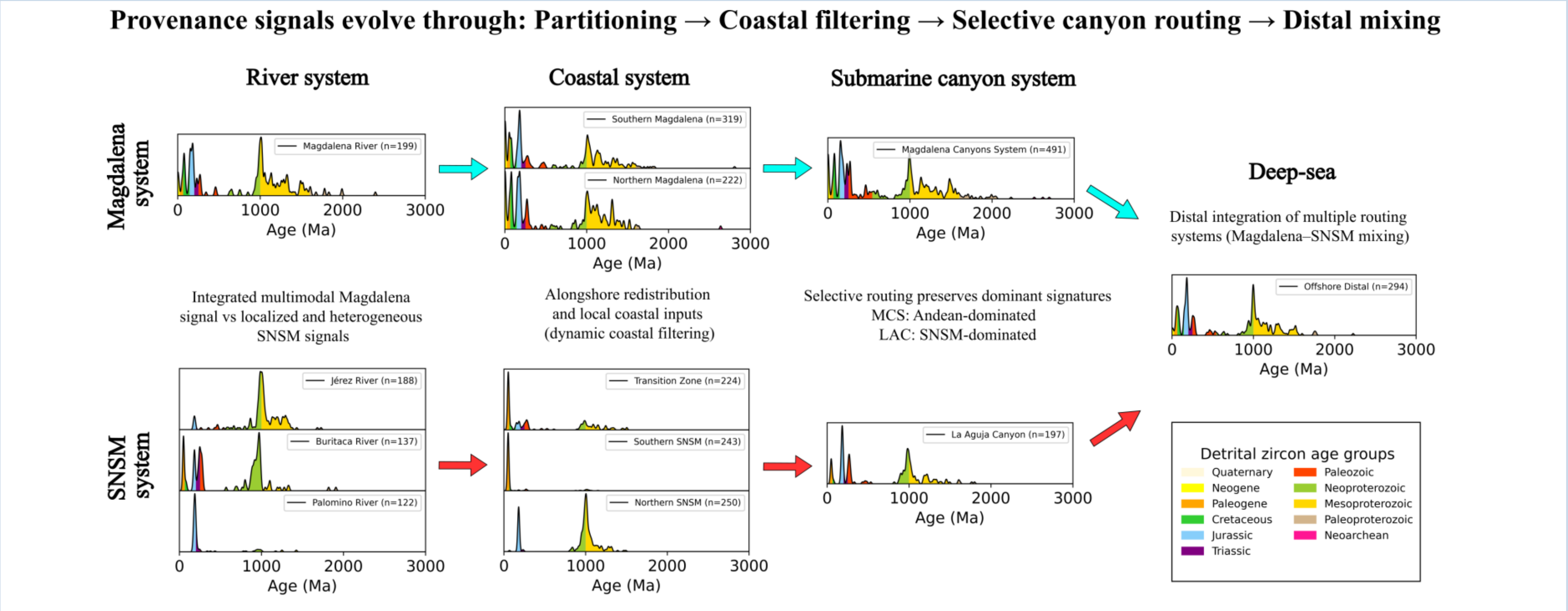
Enrichment from crystalline coastal erosion. There is another group - C09–C10: quartz recovery ~39% — NE SNSM gneisses. Clay illite ≥52% — proximal, limited weathering.

KEY TAKEAWAY Coastal mineralogy is NOT homogeneous — discrete compositional domains persist over tens of km, controlled by source proximity and lithology.

Zircon Age: Tracking the Provenance Signal from River to Deep Sea

RESULTS

Grouped KDE spectra — Magdalena system (top) vs. SNSM system (bottom) · River → Coast → Canyon → Distal



MAGDALENA SYSTEM Polymodal signal (Neogene + Jurassic ~180 Ma + Mesoproterozoic ~990 Ma) persists from river through coast into MCS canyon. Coastal domain acts as PASSIVE TRANSFER ZONE — high discharge overwhelms local inputs.

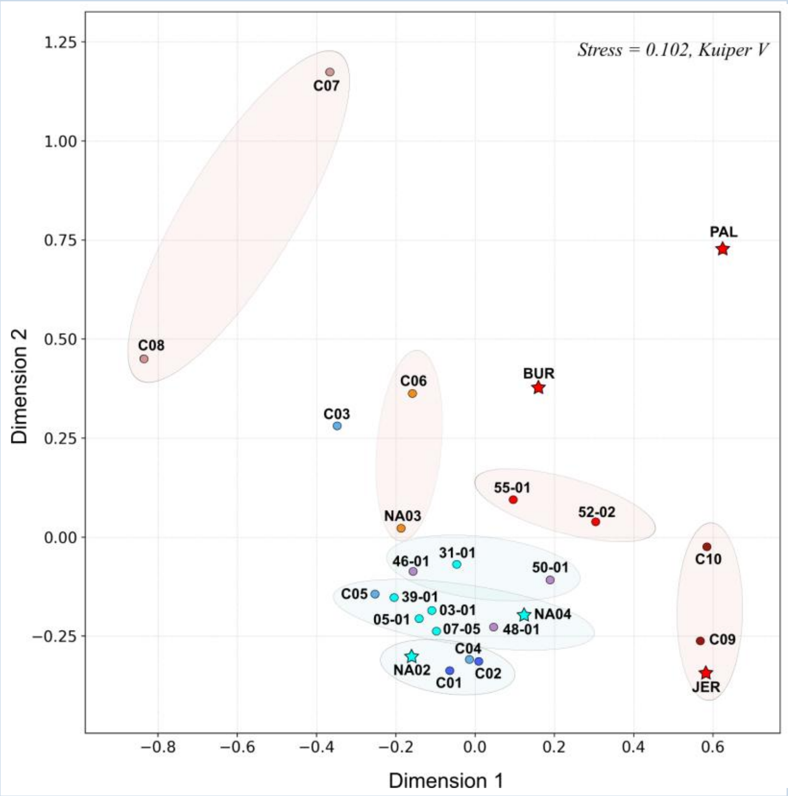
SNSM SYSTEM C07–C08 dominated by Paleogene ages (~50–54 Ma, >80–90% of grains) — ABSENT in most of the SNSM rivers (JER, BUR, PAL). Signal appears in LAC canyon. Source: direct erosion of Paleogene granitoids exposed at shoreline.

KEY TAKEAWAY The Paleogene peak in C07–C08 is absent from every fluvial sample — it can ONLY be explained by direct coastal erosion of Paleogene granitoids exposed at the SNSM shoreline.

Multivariate Statistics Confirm Systematic Domain Separation

RESULTS

MDS ordination (Kuiper V dissimilarity) · stress = 0.102 · n = 26 samples



Magdalena Cluster

C01–C05 + NA02, NA04 + MCS (39-01…31-01): tight grouping. High cross-correlation confirms signal continuity from river through coast into canyon.

Transition Zone — C06, NA03

Intermediate position between Magdalena and SNSM clusters. Mixed Paleogene + Mesoproterozoic signatures near Ciénaga Grande.

SW SNSM — C07, C08 (Paleogene)

Most isolated cluster — extreme dissimilarity from ALL other samples. Unique coastal-erosion-generated signature, not shared by any fluvial input.

NE SNSM — C09, C10, PAL, JER

Precambrian–Jurassic populations. Separate from SW SNSM cluster → internal massif segmentation preserved in coastal sediments.

Offshore Distal — 46-01, 48-01, 50-01

Intermediate between Magdalena and LAC clusters — progressive integration from both routing systems at basin scale. More similar to Magdalena system

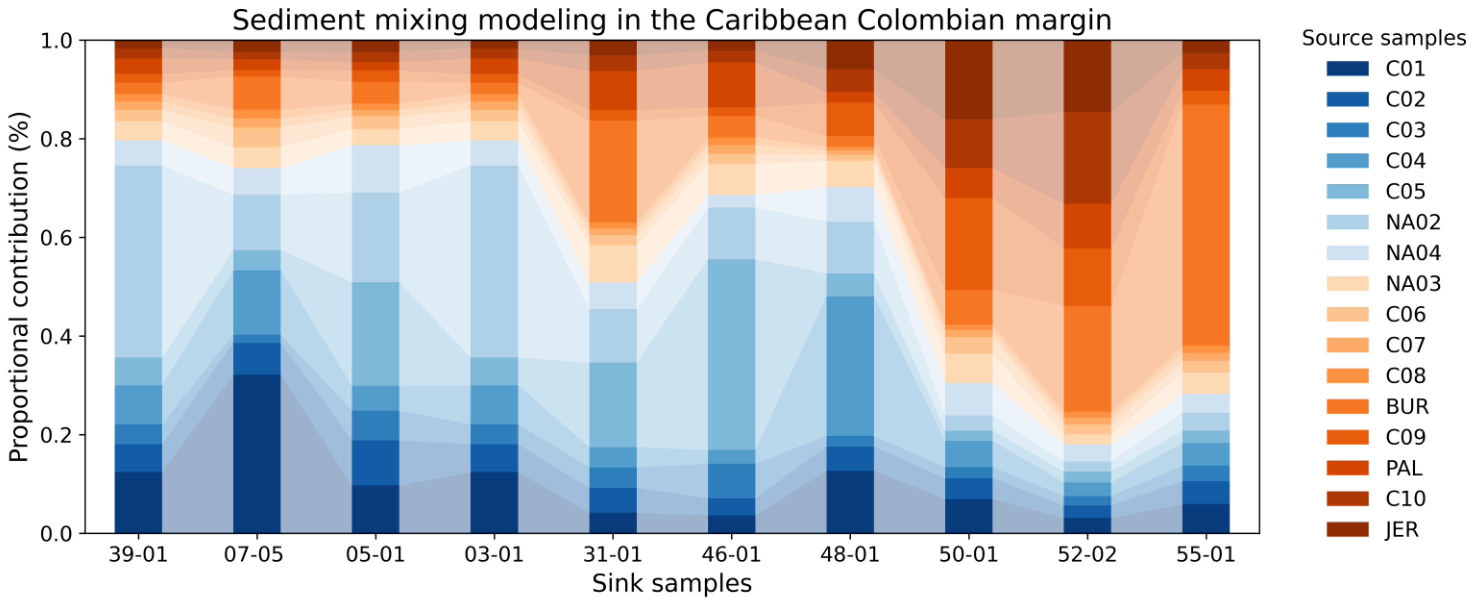
KEY TAKEAWAY Domain separations are statistically robust, not artefacts of sample size or metric choice.

08

Quantitative Mixing: River + Coastal End-Members to Offshore Sinks

RESULTS

DZmix Monte Carlo unmixing · all coastal + fluvial samples as independent end-members · Kuiper V objective function



MCS (39-01 → 03- 01)

65–85% Magdalena

NA02 alone contributes ~40% at proximal stations. SNSM sources remain <25%.

OFFSHORE DISTAL (31-01, 46-01, 48-01, 50-01)

Both systems detectable

No single source >39%. Variable contributions — full integration at distal scale only as 31-01.

LAC (52-02, 55-01)

>60% SNSM

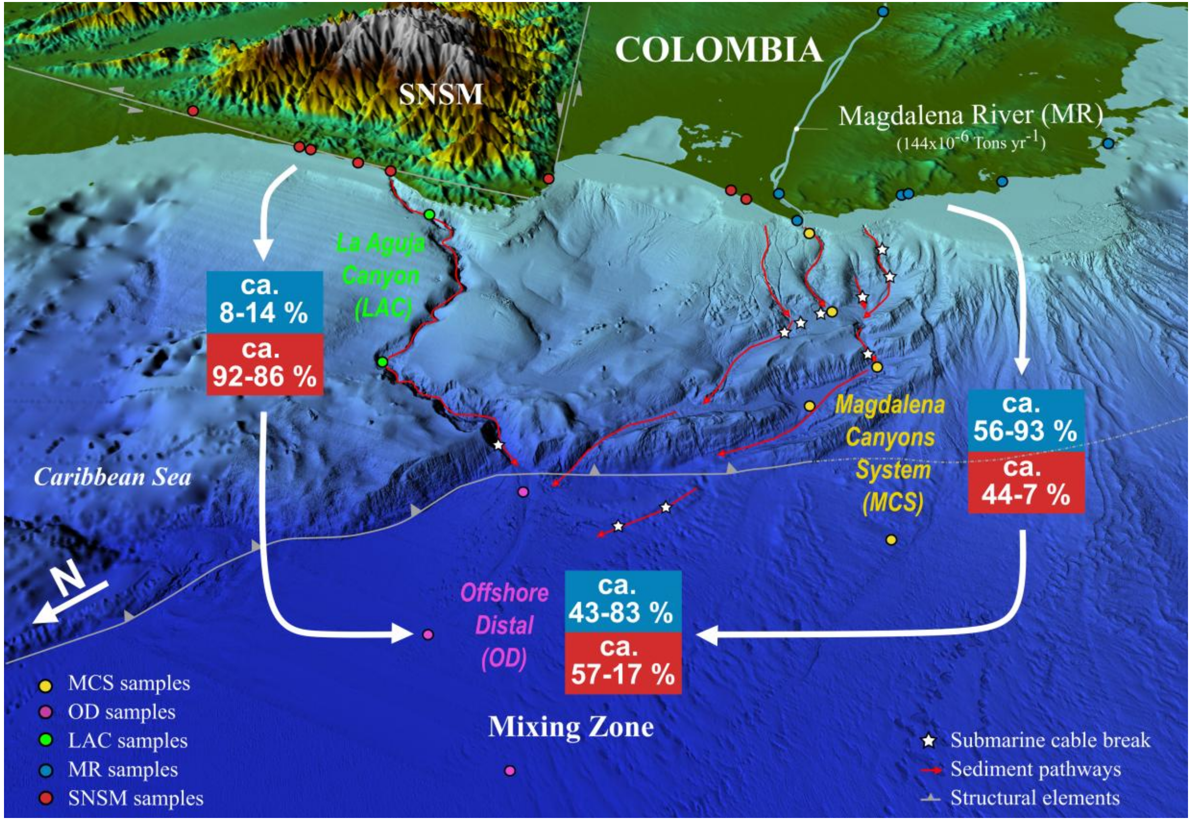
BUR contributes ~50% in 55-01. Magdalena-derived sources <30%. Selective routing confirmed.

KEY TAKEAWAY River-only models overestimate SNSM contributions and fail for LAC — the Paleogene coastal signal (C07–C08) is a REQUIRED component.

Sediment Routing in 3D: DZmix Proportions Mapped

GEBCO bathymetry · MCS vs. LAC vs. Offshore Distal mixing zone · Sediment pathways and structural controls

RESULTS



LA AGUJA CANYON (LAC)

SNSM: 86–92%
Mag: 8–14%

Fault-bounded conduit. Short path from crystalline shoreline. Selective routing confirmed.

OFFSHORE DISTAL (OD)

Magdalena: 43–83%
SNSM: 57–17%

Variable — both systems detectable. SCDB deflection drives NE transport of MCS turbidites promoting convergence.

MAGDALENA CANYONS SYSTEM (MCS)

Magdalena: 56–93%
SNSM: 44–7%

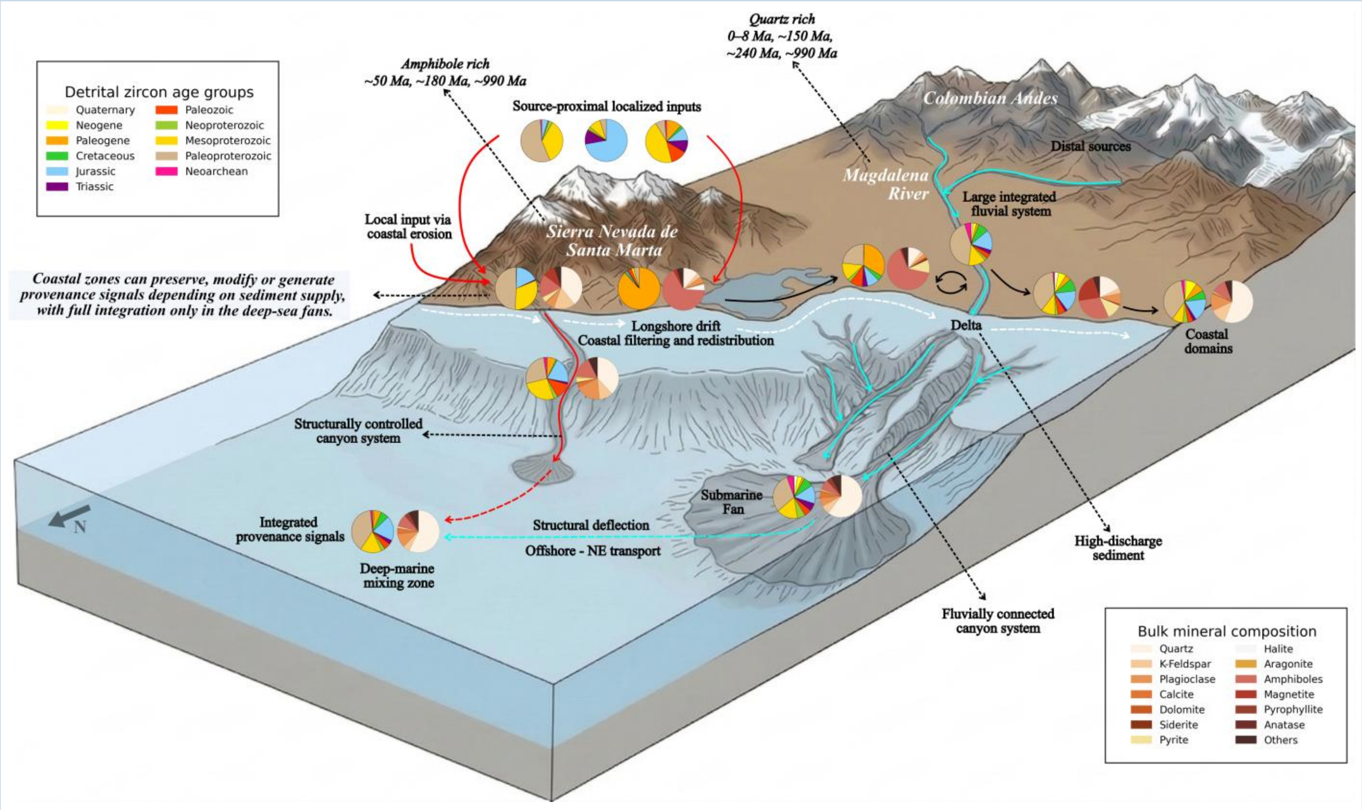
Fluvially connected, high discharge. Multiple canyon branches. Andean signal dominates throughout.

KEY TAKEAWAY Structural deflection of MCS turbidites by the SCDB front is the key mechanism driving convergence between the two routing systems in the distal mixing zone.

Synthesis: A Process-Based Framework for Coastal Provenance Transfer

CONCLUSIONS

Conceptual model + three key conclusions



Coastal Role is Supply-Controlled

Where fluvial supply dominates (~144 Mt yr^{-1}, Magdalena) → passive conduit.
Where fluvial input is minimal (~0.01 Mt yr^{-1}, SNSM) and crystalline rocks crop out at the shoreline → coastal erosion generates signatures ABSENT from the fluvial record.

Canyon Systems are Selective Routers

MCS records an integrated Andean signal (65–85% Magdalena). LAC reflects predominantly SNSM inputs (>60%). Full provenance mixing occurs ONLY in distal fan environments — not in canyons.

Coastal End-Members are Essential

The coastal domain can apport a extra signature and must be explicitly incorporated in any source-to-sink reconstruction — applicable globally to active margins with erosion-dominated coastal segments.

KEY TAKEAWAY The coastal domain is not a transparent window to source regions. It is a dynamic filter — and in erosion-dominated settings, a primary provenance source — that must be incorporated in source-to-sink models.

"The coast can change the signal."

Coastal erosion generates provenance signatures absent from fluvial records — and delivers them to the deep sea.

Thank you!

CONTACT

Estefany Villanueva-García

PhD Candidate · Institut für Geowissenschaften
Universität Heidelberg, Germany

Co-authors: **Y. Rojas-Agramonte** · D. Rincón-Martínez · D. Rösel · Ó. Álvarez-Silva · A. Mora · C. Winter

Funding & support: DAAD · Ecopetrol · Universität Heidelberg · Christian-Albrechts-Universität zu Kiel · Universidad del Norte · University of Gothenburg

✉ estefany.villanueva@geow.uni-heidelberg.de