addition to remaining abreast in their traditional disciplines, are now required to develop novel and still mostly undiscovered ways of validating their models and theories.

The challenge is to understand humanity's global environment, formed of interacting systems (atmosphere, ocean, land surface, biosphere) whose combined complexity exceeds that of any system previously considered by the physical, life, or social sciences.

One can only applaud AGU and the European Geosciences Union for paving the way with their respective focus group and section in "nonlinear geophysics" which cut across traditional geophysical disciplines, and for nurturing their connections with societies representing mainstream physics. Departments of geography, geophysics, meteorology, and environmental, atmospheric, and/or oceanic sciences are already networking in support of Earth system science to become the ultimate interdisciplinary program when linked with social sciences.

Maybe the time has come to reach out to other departments: physics of course, but also computer science, economics, sociology, and anthropology to develop a super-system approach integrating both the coupled Earth processes and the complex social organization which will be crucial to address the future challenges.

For more information about the World Year of Physics, visit the Web site: http://www.physics2005.org/

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Seafloor Margin Map Helps in Understanding Subduction Earthquakes

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Ecuador and southwest (SW) Colombia suffered widespread damage during the twentieth century as a result of some of the greatest subduction earthquakes and associated tsunamis ever recorded. In 1906, the Ecuador-SW Columbia margin, located at the transition between the continent and deep ocean, ruptured over a 500-kilometer length as a single great (M_w = 8.8) subduction earthquake (Figure 1a) [*Kelleher*, 1972]. The 1906 rupture zone was partially reactivated in 1942, 1958, and 1979 by earthquakes of M_w 7.7 to 8.2 (Figure 1b), with 100–200 kilometer-long rupture zones [*Beck and Ruff*, 1984].

Such considerable variation in earthquake rupture length and magnitude in this area's seismic cycles during the last century has raised questions about the nature and enduring significance of the boundaries that exist between rupture zones and about the long-term recurrence interval between earthquakes.

Turbidites, which are detrital sediment, deposited from gravity-induced current with high particle concentration, in the Ecuador-Colombia trench and adjacent fore-arc basin potentially record Holocene (<10 Ka) subduction seismic activity. Analyzing turbidite sequences helps determine the recurrence of earthquakes, because earthquakes are the most likely mechanism for triggering turbidity flows. Major northern Andean rivers transport large amounts of terrestrial sediment derived from the vigorous erosion and strong volcanic activity of the Andes to the trench and basin.

Characteristics such as robust tectonic activity and high sedimentation rates make the Ecuador-SW Colombia subduction margin a region of focus for studying key para-meters that control large subduction earthquake behavior.

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In 2000 and 2001, the French Sisteur cruise and the joint French-German Salieri cruise collected vertical and wide-angle seismic data to explore the deep structure of the Ecuador-SW Colombia plate boundary. However, it became clear that information about long-term tectonic deformation, sediment nature, and sediment distribution were critical for the development of a geodynamic model that characterizes short-term deformation in the region of the great Colombia-Ecuador subduction earthquakes.

In a joint project, a team that included scientists from France, Canada, Columbia, and Ecuador completed the Amadeus cruise on board the research vessel *L'Atalante* in February–March 2005.

The cruise collected 55,000 square kilometers of contiguous swath bathymetry coverage, extensive marine geophysical data, sedimentary cores, and dredged rocks, as well as the first sediment heat probe measurements collected off southwestern Colombia (Figure 1b).

The new bathymetric map created from the cruise provides evidence for major margin tectonic contrasts and active crustal faults which correlate with earthquake rupture zones and their boundaries. The bathymetric map, complemented by sediment cores, also reveals a complex canyon-channel system that distributes two types of turbidites with river flood and earthquake origins, respectively. The heat flow data obtained along the trench decrease globally southward according to well-established relations between plate age and oceanic heat flow. Heat flow data collected across the margin toe will help discriminate the causes of the variation in transverse extent between the 1958 and 1979 rupture zones (Figure 1b).

Crustal Faults and Earthquake Rupture Zones

The region where rupture zones of the 1958 and 1979 Colombia-Ecuador subduction earthquakes meet have been shown previously to correlate with a lateral change in the fore-arc tectonic regime from compression to subsidence and with transverse crustal faults that segment the Ecuador-SW Columbia margin [*Collot et al.*, 2004].

These authors suggested that the fault-bounded basement Manglares high located between the fore-arc basin and the trench, and a major fault that branches upward from the landward dipping fault contact between the plates, might control the seaward limit of the 1958 earthquake rupture zone.

The new bathymetric map created from the Amadeus cruise reveals the tectonic contrast between the fold-and-thrust belt of the Patia Promontory-Tumaco high—which is associated with the 1979 rupture zone—and the largely subsident Manglares fore-arc basin, which roughly correlates with the 1958 rupture zone.

The newly-discovered trace of the Manglares fault that cuts northwesterly through the Manglares basement high, and the northeast-trending Ancon fault (Figure 1c) correlate with northward and seaward limits, respectively, of the 1958 rupture zone. These relations suggest that the fault activity on the long term may reflect tectonics of the seismogenic zone.

Esmeraldas and Patia-Mira Canyon-Channel System

A spectacular, 330-kilometer-long, submarine, meandering canyon-channel system was mapped off northern Ecuador-SW Colombia during the Amadeus cruise. The system is comprised of the Esmeraldas and Patia-Mira canyons and their associated deep-sea turbidite system, which is dammed to the south by the Galera seamounts (Figure 1b). The turbidite system consists of a maximum 3.5-kilometer thick fan of sediments, a channel that meanders northeastward for at least 230 kilometers, and areas of recent sandy lobe deposits.

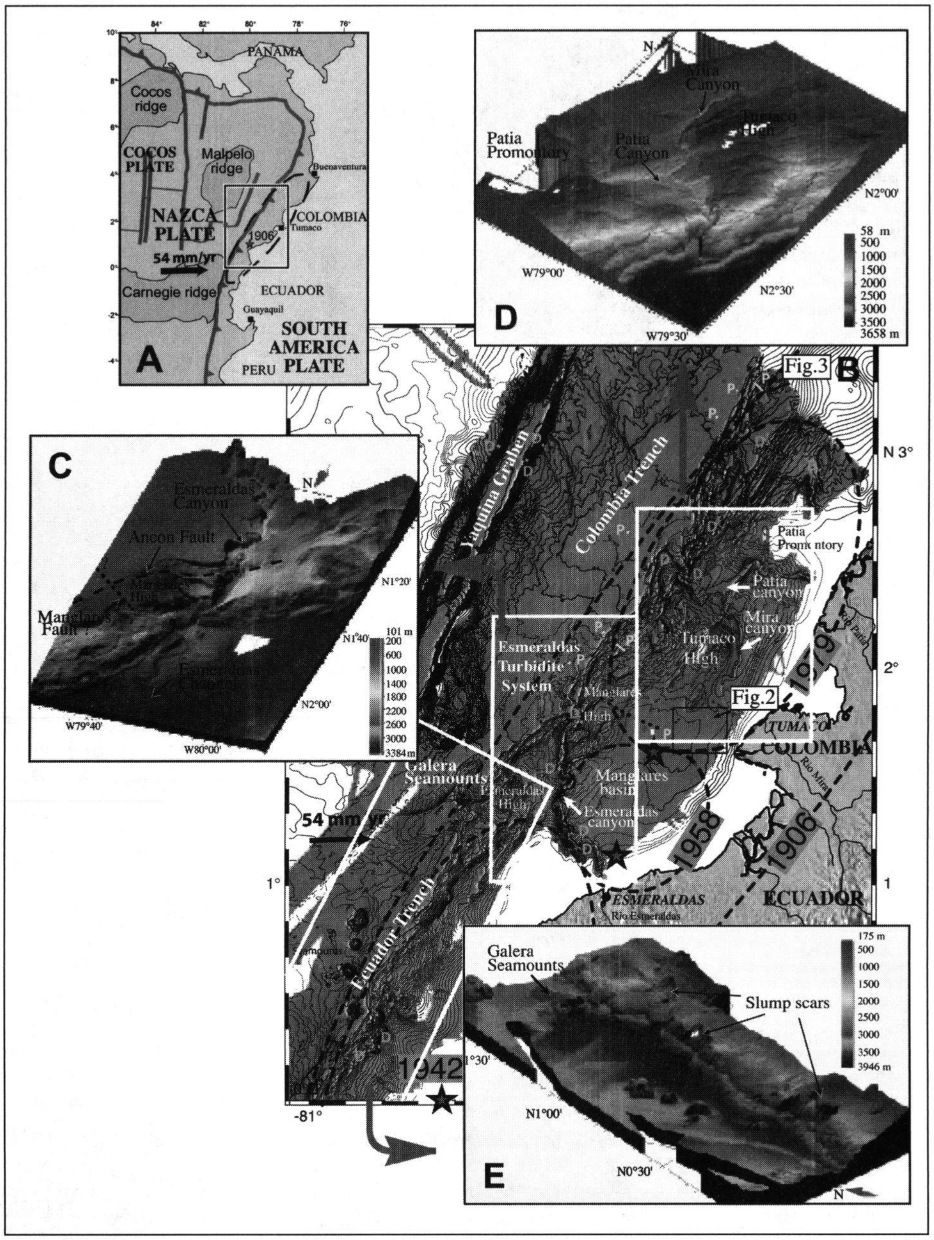

Fig. 1. Multibeam bathymetry of the region of the great 1906 subduction earthquake at the North–Ecuador-SW Colombia convergent margin. (a) Location of the study area. (b) Shaded relief of the bathymetric map with locations of core sites (red dots), dredge sites (blue letters D), and heat flow measurements (yellow letters P). Dashed black lines indicate earthquake rupture zones. Red stars indicate earthquake epicenters. White dotted lines are faults shown in three dimensional view (c–e) Three-dimensional views of the Esmeraldas canyon, Patia-Mira canyon, and North Ecuador margin, respectively. Note the different color scales for the various 3-D views. Original color image appears at the back of this volume.

The Esmeraldas canyon extends over a length of 130 km, from near the mouth of the Esmeraldas River in Ecuador, down to a depth of ~2750 meters (Figure 1c). The canyon is highly sinuous, V-shaped in cross section, and sharply cuts the tectonic deformation front at the margin toe, thus indicating that erosion processes are currently active. The canyon incises the fore-arc basin seafloor by 300 to 1200 meters. Abandoned meanders perched on both sides of the canyon indicate the emplacement of its initial course, and terraces in the canyon suggest that phases of sediment fill and erosion alternated in relation to climatic changes and vertical tectonics.

The Patia canyon and its main tributary, the Mira canyon, were discovered during the cruise off Tumaco in Colombia (Figure 1d). The Patia canyon was mapped over a length of 120 kilometers, from water depths of 250–3400 meters at the margin toe, where a growing anticline has forced the canyon mouth to deviate northward. The canyon, which incised the lower margin by up to 700 meters, is Z-shaped in map view and U-shaped in cross-section. This suite of evidence suggests that during the Holocene Epoch the Patia-Mira canyon has been less active than the Esmeraldas canyon.

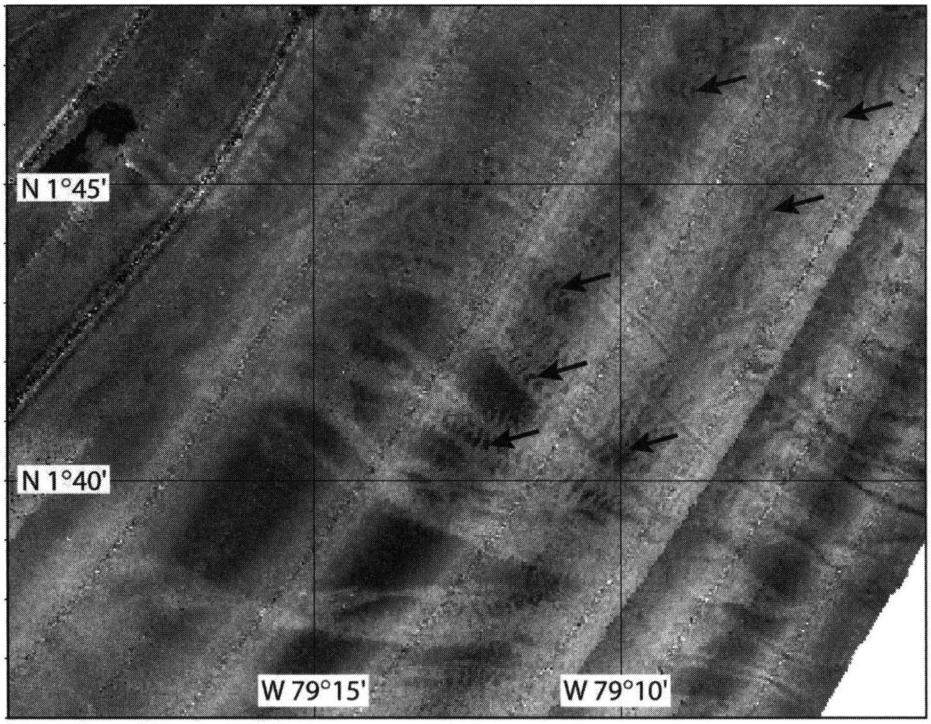

Fig. 2. Backscatter imagery of the fore-arc basin showing tiny, darker stripes (arrows) perpendicular to low-reflective channels, thus pointing to possible liquefied structures generated during earthquakes. Location is that shown in Figure 1b.

Sediment Partitioning in the Trench Fore-Arc System

The many 5- to 30-centimeter thick sand turbidites recovered during the cruise from the deep-sea turbidite system, including those from terraces and levees ~200 meters above the channel/canyon floor, suggest thick gravity flows with high particle concentration. The most frequent type of turbidite contained abundant wood fragments, which suggests a link with river floods and, possibly, El Niño events. The less frequent type was devoid of wood fragments, which suggests slump-induced turbidity currents initiated during earthquakes.

In contrast, fore-arc basin sediment, including levees of the Patia canyon, consists almost exclusively of mud churned by organisms. However, one core collected in a fore-arc pounded basin with a transparent acoustic-facies exhibits a very homogeneous mud, which suggests in situ homogenization during earthquake shaking, or emplacement of co-seismic turbidite with homogeneous top related to contemporaneous oscillation of the water column as proposed by *Cita et al.* [1984].

Submarine Slides

Numerous 5- to 10-kilometer-wide, arcuate slump scars and steep linear scarps associated with debris toes indicating unstable slopes were identified along the margin and canyon flanks (Figure 1e and 1d). Some scarps appear to have formed by incremental slip, whereas others resulted from catastrophic collapses.

Near latitude 0°20'N, a group of 5- to 6-kilometer-wide, lower slope indentations correlate with subducting seamounts. Abundant creeping and slide structures were discovered along the fore-arc basin flanks and upper margin slope, where numerous rectilinear, headless gullies might be related to gas or fluid seeps. Very narrow reflective stripes oriented perpendicular to these gullies may reflect co-seismic liquefaction structures (Figure 2).

In Situ Heat Flow and BSR-Derived Heat Flow

The downdip width of the seismogenic zone, which is the shallow portion of the plate boundary interface where an earthquake can nucleate, is thermally controlled [*Hyndman and Wang,* 1993], and the primary constraints for thermal modeling are seafloor heat flow measurements. Thermal modeling constrained by heat flow calculated from the depth of the "bottom-simulating reflector" (BSR), a seismic reflector that characterizes the pressure/temperature dependent base of a gas hydrate layer beneath the seafloor, indicates that along-strike heat flow variations match the structural segmentation of the margin [*Marcaillou,* 2003]. Repeated heat probe measurements, obtained seaward of the deformation front, average 95 and 121 milliwatts per square meter in the north of the Amadeus survey, 65 and 54 in the center, and 56 in the south, in good agreement with BSR-derived values landward of the deformation front.

Two 5-kilometer-long heat flow profiles at a spacing of 200-250 meters were collected along seismic lines where BSR-derived heat flow indicated large localized variations. Along seismic line SIS-40, three large heat flow peaks in the BSR-derived heat flow were also detected in the heat probe measurements (Figure 3). The peaks are generally associated with bathymetric inflections, and they may represent thrust faults that provide high-permeability channels for warm fluids to reach the seafloor.

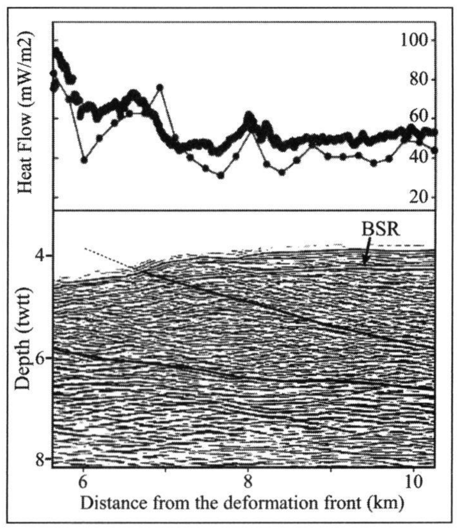

*Fig. 3. Heat flow values along line SIS-40. Location is that shown in Figure 1b. Curve with solid dots shows sediment heat probe values. Bold curve is BSR-derived values [*Marcaillou, *2003].*

In conclusion, sub-seafloor geological and geophysical data collected during the Amadeus cruise provide valuable information to understand great subduction earthquakes. Dating the margin's crustal fault activity from sediment deposited along the faults, together with establishing the chronology of the recurrence of earthquake-related turbidity flows in the trench, will help in determining the long-term rhythm of seismic activity.

Moreover, newly acquired heat flow values will be used to constrain thermal modeling of the frontal part of the margin, to define the temperatures associated with the depth-variable updip limit of the seismogenic zone. A detailed comparison of heat probe and BSR-derived heat flow peaks may provide constraints for quantitative estimates of fluid flow along margin faults.

Acknowledgments

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NEWS

Expansion of U.S. Coastal Barriers System Receives Support

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The extent of lands included in the U.S. Coastal Barriers Resources System should be expanded in order to protect more people, property, and natural resources in vulnerable coastal areas, according to several witnesses at an 8 November U.S. congressional hearing.

However, the witnesses disagreed as to whether sections of Louisiana should be included in that expansion. Louisiana received attention at the hearing due to the extent of damage caused by recent hurricanes; the U.S. Geological Survey has estimated that 100 square miles of Louisiana marsh became open water during the storms.

The Coastal Barriers Resources System is comprised of approximately 1.25 million hectares of undeveloped lands along the U.S. Atlantic, Gulf of Mexico, and Great Lakes coasts. The system encourages conservation of coastal barriers—which can provide protection against storms and habitat for aquatic species—by denying federal expenditures, such as flood insurance, for new development. The reauthorization of the law that created this system—the Coastal Barriers Resources Act (CBRA)—was the subject of the hearing by the U.S. House of Representatives' Resources Subcommittee on Fisheries and Oceans.

In recent years, damage from hurricanes, including Katrina, has highlighted the danger to both life and property from building on coastal barriers. A 2002 study by the U.S. Fish and Wildlife Service (USFWS) estimated that by 2010 the CBRA will have saved the federal government $1.2 billion that would have been spent on disaster relief and infrastructure if these coastal barriers had been developed and supported by federal programs. The study noted that CBRA had become an effective tool in limiting development along coastal areas.

At the hearing, Robert Young, associate professor of geology at Western Carolina University in Cullowhee, N.C., argued that while CBRA should be extended for the cost savings alone, the benefits of ecosystems protection are an important added value.

Young suggested that Congress consider expanding CBRA to include all vulnerable coastal barriers and shorelines, regardless of their stage of development, and he proposed the formation of an independent commission that could identify vulnerable shorelines that would be removed from federal assistance.

"We should take a free market approach," Young said. If insurance in these areas is too costly, then building there is impractical, he said.

Robert Twilley, director of the Wetland Biogeochemistry Institute at Louisiana State University, noted that the effects of Hurricane Katrina were compounded by nearly 100 years of degradation of the Louisiana coastal wetland landscape caused, at least in part, by poor government policies.

"Rebuilding ... must address the ongoing and dynamic changes in this landscape and the fundamental importance of river resources that once supported [these] coastal wetlands," said Twilley. "If restored properly, the Gulf Region will develop new paradigms as to how coastal communities deal with risks and hazards of the coastal landscape."

Subcommittee Chair Rep. Wayne Gilchrest (R-Md.) said that he and many members of Congress think that "if you could save coastal Louisiana, you could save any coast." He suggested that Louisiana could be a "laboratory" to study how people can "become more compatible with nature's design."

The CBRA reauthorization would support an inventory and assessment of undeveloped coastal barriers. Reauthorization also would extend the USFWS' digital mapping program, which to date has transferred maps of 60 out of 856 CBRA areas from paper to digital format.

Benjamin Tuggle, acting special assistant to the USFWS director, said digital maps will help to save taxpayers money and preserve coastal habitat by making it easier for local communities to quickly determine if properties are within the CBRA system. He estimated that transferring the maps of all CBRA units to digital format would cost $15–16 million over seven to eight years.

The reauthorization was approved by the U.S. Senate Committee on Environment and Public Works on 26 October, but no date has been set for its consideration by the full Senate.

—SARAH ZIELINSKI, Staff Writer

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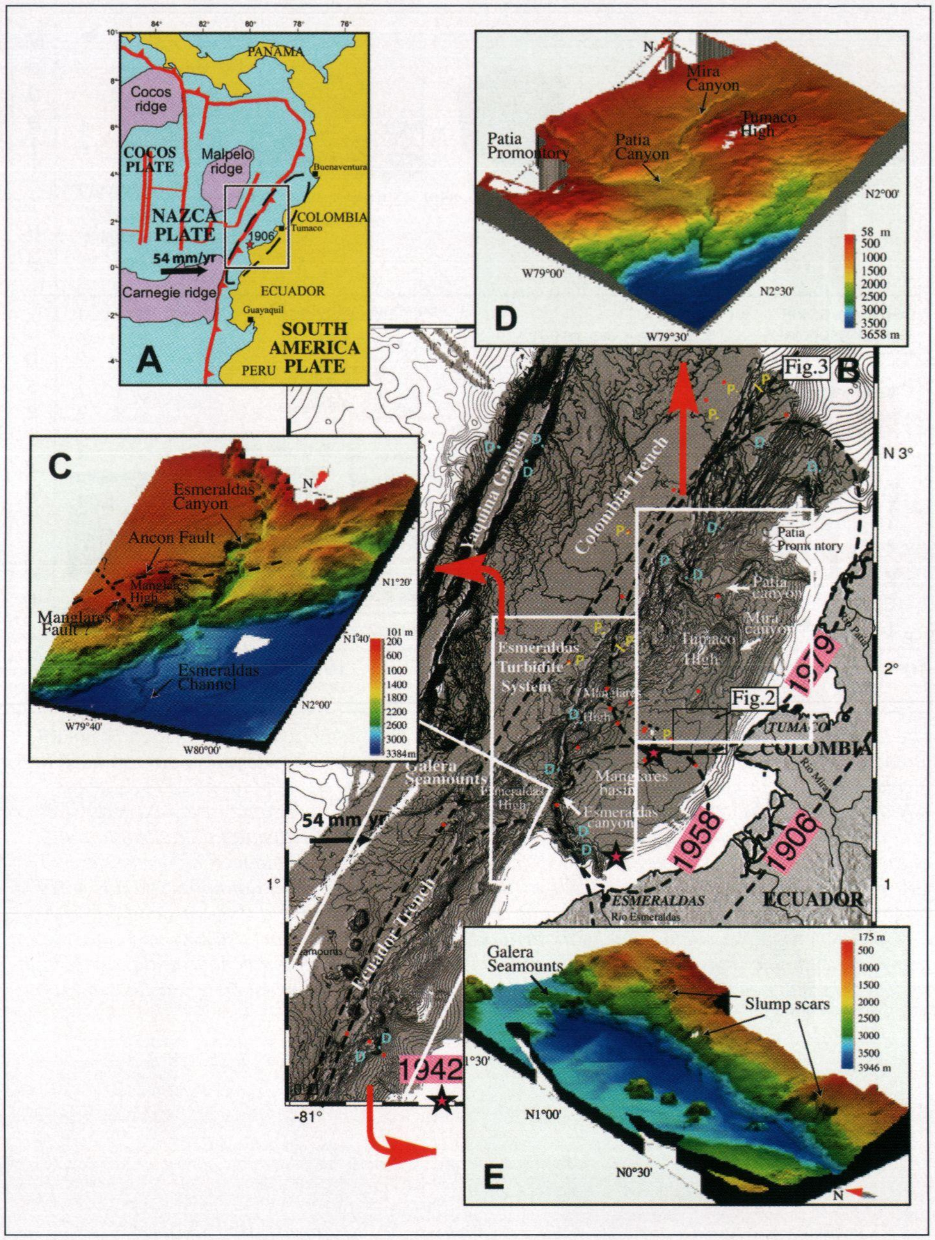

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