

**Geological evolution of Venezuela-Trinidad reassessed:
Protocaribbean-Caribbean foreland basins (Campanian-Recent)
and Neogene wedge-top halite-dissolution basins**

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EXECUTIVE SUMMARY

In the popular "Pindell Model", the Jurassic-Cretaceous passive margin of Trinidad and northern Venezuela was destroyed by diachronous Caribbean Arc collision and foreland-basin initiation, from Paleocene in the west (Maracaibo) to Miocene in the east (Trinidad). In contrast, an exhaustive synthesis presented here of the Spanish and English literature published since 1860 clearly shows a S-verging, S-migrating non-diachronous Maracaibo-Trinidad foreland basin, from Campanian time. This basin can be attributed to the published concept of slow (amagmatic) Protocaribbean subduction under the N-facing former passive margin, from Campanian time, pushing a "Slope Nappe" (former passive-margin slope and underlying rift fill and continental basement) up onto the former outer shelf, metamorphosing the shelf and rift succession there, and driving the foreland basin. In turn these metashelf and metarift strata were later uplifted as an in-sequence "Shelf Nappe" (present Coastal Cordillera-

Araya-Paria-Northern Range; Oligo-Miocene cooling ages), further eroding the covering Slope Nappe and forcing the basin south. Nappe mountains fed olistostromes and turbidites southward to this foreland basin from late Campanian to early Late Miocene time; these were deposited as submarine fan-deltas on the northern "active slope" of a flysch trough, facing a mud-rich "passive slope" and (beyond) a sandy southern shelf.

A second problem with the Pindell Model is that, as shown here, the Caribbean Arc began its 1,100 km ESE (relative) transit along the Venezuela-Trinidad margin much later than the model asserts, starting from Guajira in the far west at 30 Ma (mid-Oligocene) rather than 60 Ma (Paleocene). This ESE motion along the Protocaribbean coastal mountains caused Late Oligocene pullapart (with volcanism) in the western sector of the margin, due to its parallel (ESE) orientation, forming the Gulf of Venezuela-Falcón Basin. In contrast, the different orientation of the eastern sector (ENE) caused oblique obduction of a Caribbean Arc nappe (incorporating the Villa de Cura Complex, Margarita and Tobago) onto the Slope-Shelf Nappe stack, through Early Miocene to Recent time (still in progress at Tobago); thus the Caribbean took over diachronously (progressively later eastward) as the foreland-basin driver. The presently active Caribbean foredeep is confined to the Deltana Basin (east of the San Francisco Fault SE projection) and contiguous Columbus Basin; W of here all former Protocaribbean-Caribbean foredeep regions of E and C Venezuela are rebounding, because their Caribbean-nappe drive has been cut off by eastward migration of the nappe "suture point" (now at Margarita), lying on the San Francisco-Roques Canyon transform, that connects NW to an E-tearing, S-dipping (Caribbean) subduction zone, namely the South Caribbean Marginal Fault.

Late Miocene (post-11 Ma) to Recent basins on the Caribbean Nappe (*i.e.* lying north of the "Cura-Margarita-Tobago line"; Tuy Basin, northern Gulf of Barcelona, Cariaco Trough, northern Carúpano-North Coast Basins), interpreted in the literature as extensional or transtensional despite lacking volcanics, grew during and after nappe emplacement. These are reinterpreted here as "pseudo-extensional" basins, formed by

subsurface dissolution of a formerly unknown, thick (km), synrift, diapiric, lowermost Cretaceous halite interval in the underlying Slope Nappe, here named the "Carib Halite". Similar halite-dissolution supraorogen basins were also growing to the south, on the active Shelf Nappe and adjacent parautochthonous S-verging thrust belt (*e.g.* southern Carúpano-North Coast Basin, Morichito, Gulf of Paria, Caroni, South Trinidad Basins). All of the halite-dissolution basins are syn-orogenic wedge-top basins, in which halite-dissolution subsidence outweighed tectonic (shortening) uplift; subsequent reduction or cessation of halite dissolution (due to halite exhaustion?) locally in Trinidad allowed uplift to overtake subsidence in Quaternary time (*ca* 1 Ma), forming the Central and Southern Ranges. Massive underground halite dissolution coincided with the 11-0 Ma long-term glacioeustatic low (Haq), and reflects prodigious rainfall during each post-glacial recovery (present interglacial climate is relatively arid in parts of Venezuela, such as Falcón), supplying fresh water to the subsurface along orogenically fractured aquifers connected to nappe- and thrust-belt mountain recharge areas.

Halite dissolution on such a scale is globally unique and is attributed to a fortuitous combination of three factors: (1) orogenic uplift, producing a large hydraulic head and extensive fracturing, both of which promoted meteoric-water infiltration and deep hydrothermal circulation; (2) tropical glacially affected climate with extreme rainfall; and (3) fractured aquifers in contact with the Carib Halite (*e.g.* in Trinidad, fractured metamorphics below and fractured limestones locally above).

The Carib Halite dissolution "weld" can be identified in wells and exposures, but the halite itself is nowhere exposed, and where thought to be preserved is beyond drilled depths. The halite or its weld occurs in the Slope and Shelf Nappes, and in the parautochthon/autochthon at least as far south as the present frontal thrust in Trinidad, eastern Venezuela and central Venezuela, as well as under the Falcón highlands and in the Mérida-Perijá ranges, as shown by supraorogen basins, saline springs, gypsum veins and other indicators of buried-halite dissolution.

The Carib Halite was deposited during the late-rift stage in a graben system that reached westward from Trinidad across northern Venezuela to Falcón, and in connecting grabens coinciding with the present Mérida and Perijá mountains, linking with a halite-bearing graben in Colombia (Bogotá halite). The age of the Carib Halite, constrained by fossils in strata below and above the dissolution weld, is early Neocomian (specifically late Berriasian and early Valanginian); this age is consistent with the lack of any indisputably Berriasian faunas among the recorded Jurassic-Cretaceous fossils ever found in Venezuela and Trinidad, and coincides precisely with a major eustatic sea-level low (Haq chart), that provided the halite-depositing graben with the required isolation from the world ocean. The deduced Neocomian age of the halite indicates that rifting in Venezuela and Trinidad persisted much later than proposed by Pindell and co-workers, who argued that Protocaribbean rifting ended (sea-floor spreading began) 20-30 m.y. earlier in the Jurassic (Oxfordian).

The missing halite explains, among many other diverse phenomena, the well known metamorphic-grade discontinuity (at the weld) in the Northern Range, and also in Paria Peninsula, separating (A) the Güinimita-Laventille-Lopinot-Toco post-rift suite, showing incipient metamorphism only (shales locally converted to slate and phyllite; limestones locally recrystallized, impeding dating due to alteration of fossils), from (B) metamorphic older rocks (Macuro, Cariaquito, Maracas, Maraval, *etc.*), showing prehnite- to greenschist metamorphism (including Sans Souci rift volcanics), with shales entirely converted to phyllite and schist.

Since 5 Ma, the Maracaibo-Bonaire Microplate (limited by Roques and South Caribbean Faults) has been moving ENE relative to South America, along the San Sebastián Fault (Caracas coast), pushed by Caribbean subduction in the west, forming the Mérida Andes oblique bivergent thrust mountains and the flanking Maracaibo and Barinas foreland basins. Most previous workers consider the Mérida Andes to be at least twice this age. Uplift of the Sierra de Perijá and of mountains throughout Falcón-Guajira also occurred. The Falcón-Guajira mountains subsequently collapsed in the

west by subsurface dissolution of the Carib Halite, causing the Gulf of Venezuela to resubside.

These three "new" concepts, namely early northern orogeny (in fact a 1970s idea), "late" Caribbean Arc arrival (1980s), and massive halite dissolution, will profoundly affect exploration, changing interpretations and predictions of subsidence history, paleogeography, structure (halite décollement), traps (thrusting; dissolution collapse structures), heat flow (high thermal conductivity of halite), seismicity, previously unsuspected evaporitic source rocks, seals, *etc.* For example, rejecting the popular Gulf of Paria pullapart model, in favor of halite-dissolution subsidence, negates both a supposed 11Ma change in Caribbean relative motion vector, from ESE to ENE, and major dextral slip (10s km) on mythical east-west master faults in Trinidad that have never been found and that cause drastic dextral palinspastic disruption, with vital implications for oil exploration.

This report presents the Campanian to Recent evolution of the whole Venezuela-Trinidad region, covering every basin, and detailing the diverse evidence for deep-halite dissolution (from outcrops, wells and seismic profiles) and for long-lived northern provenance (based on southward fining, olistolith compositions and heavy minerals). The report is a painstaking synthesis of the literature, with the added benefit of the the author's 15 years of experience in the region, conducting outcrop and subsurface studies throughout Venezuela and Trinidad, including three years as clastic-sedimentology consultant to Petróleos de Venezuela. No previous report or publication has described and interpreted both of these countries as a unified entity, or in such detail. Several enigmatic formations are discussed in particular detail and demystified (*e.g.* Patos Conglomerate, "basal Vidoño limestone", "Corazón limestone", Caratas, Tinajitas, San Fernando, "Lecherías Beds"). The report integrates and interprets a vast amount of published data, enhanced by outcrop observations by the author. Products include 8 new and original tectonogeographic maps (Maastrichtian to Pliocene) and various tables of data (olistolith compositions, heavy minerals, evaporite occurrences by formation, Venezuela-Trinidad halite-dissolution basins, and analagous basins

worldwide). Aside from these benefits, the report can be used as a computer-searchable encyclopedia and literature source of Venezuela-Trinidad basins and formations. With onshore and onshore bid rounds scheduled in Trinidad for 2005-2006, and the strong likelihood of land offerings in Venezuela over the next five years (change of president?), plus the recently demonstrated continued potential for giant oilfield discoveries (*e.g.* Angostura, discovered 1999), no exploration company interested in this prolific petroleum province can afford to be without this report.

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