Takutu Basin Rift as a Late Cretaceous Conduit for Continent-Interior Drainage into the Guyana Basin

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Abstract

The Takutu basin of Guyana and Brazil is known as a Jurassic to Early Cretaceous (pre-Aptian) age non-marine continental rift basin associated with the initial opening of the North Atlantic Ocean. However, in Guyana a previously unrecognized thin section of claystone, sandstone, and anhydrite above the Lower Cretaceous was drilled in the 1993 Turantsink-1 well. This was dated as a Late Cretaceous (probably Turonian) restricted marine unit by a biostratigraphic study. Tentatively correlated to the deltaic Tucano Formation in Brazil, it demonstrates that a marine embayment of the Atlantic Ocean extended at least this far south along the Takutu rift during a Late Cretaceous highstand.

In addition, although the Takutu basin is today separated from the coast by a broad expanse of Precambrian basement rocks, seismic data show that the rift once extended further northeast. This is supported by the NE-SW orientation of numerous faults cutting the Precambrian. The Takutu sedimentary section did not pinch out depositionally, but rather was truncated by post-depositional uplift and erosion. Uplift probably occurred during a Miocene regional tectonic event, related to the Andean orogeny, which also caused internal structural deformation in the Takutu basin.

In the offshore Guyana basin, the head of the submarine Berbice paleocanyon is just offshore from the relatively minor Berbice river, with its headwaters near the northeast end of the Takutu basin. This giant shelf-incised canyon system, over 80 km long, was cut over several million years during the late Coniacian to Santonian, following the Turonian transgression into the Takutu, and filled during Campanian to Maastrichtian time. It served as a conduit for transporting vast amounts of sediment from the continent across the shelf into deep water as channel deposits and submarine fans. The modern Berbice river is incapable of transporting this volume of sediment, but a much larger proto-Berbice river system must have then existed, draining northeastward from the South American interior across the Guiana Shield through the topographic low of the Takutu rift. The Miocene uplift caused drainage re-alignment and stream capture of the upper proto-Berbice river by the Amazon river system, thus greatly reducing sediment input. This scenario provides the most logical source-to-sink explanation of the formation and subsequent abandonment of the Berbice paleocanyon and of the associated deep-water deposits that comprise hydrocarbon reservoirs of the Guyana basin.

Introduction

The Takutu basin is a continental rift basin or graben, straddling the Brazil-Guyana border, that splits the Precambrian basement rocks of the Guiana Shield into northwest and southeast segments (Lujan and Armbruster, 2011). It initiated in the Early Jurassic, or possibly latest Triassic, and accumulated up to 7,000 m of volcanic and sedimentary fill by Late Cretaceous time (Berrangé, 1977; Crawford et al, 1985; Eiras and Kinoshita, 1990). Despite being located some 300 km inland from the Atlantic coast, the basin is believed to have formed in association with the initial opening of the North Atlantic Ocean as the failed arm of a triple junction (Berrangé, 1977; Griffith, 2017). The present-day extent of the basin covers an area of about 11,200 km², being some 280 km long, 40 km wide, and elongate in the ENE-WSW direction (Figure 1). It forms a topographically low corridor between the Pakaraima Mountains to the north and the Kanuku Mountains to the south.

The Guyana (or Guyana-Suriname) basin is the mostly offshore passive margin shelf and deep water depocenter shared by both Guyana and Suriname, encompassing an area of some 257,000 km². It first developed in Jurassic time as the southern North Atlantic Ocean began to open with the rifting of the North American from the Gondwana craton, prior to the separation of South America and Africa in Early Cretaceous time (Yang and Escalona, 2011). Jurassic age graben structures filled with syn-rift sediments have been identified geophysically in the basin (Griffith, 2017), beneath a prominent base Cretaceous unconformity, but these have not been tested by wells. Above the syn-rift section, or the Precambrian basement where the syn-rift is absent, lies a mostly unstructured Early Cretaceous to Recent passive margin sedimentary section. The most striking feature in the Guyana basin is the Berbice paleocanyon (Kean, 2014; Wood et al, 2019), a shelf-incised canyon system with dimensions similar to the Grand Canyon cut over several million years during late Coniacian to Santonian time, and filled during the Late Cretaceous. It served as a conduit for transporting vast amounts of sediment from the continent across the shelf into deep water as channel deposits and submarine fans, which form most of the recently discovered stratigraphically-trapped hydrocarbon reservoirs. A large proto-Berbice river system, draining the Guiana Shield highlands and possibly beyond through the Takutu graben, is the logical continental source for this massive Upper Cretaceous sediment influx.

Takutu Basin

Six oil exploration wells have been drilled in the Takutu basin without commercial success (see Figure 4 for locations), which together with 2D seismic programs shot by Petrobras, Home Oil Company, and Hunt Oil Company serve to define basin structure and stratigraphy (Crawford et al, 1985; Eiras and Kinoshita, 1990; Webster and Murdock, 1995; Webster, 2004). Basin fill in Guyana includes the latest Triassic to Early Jurassic Apoteri Volcanic Formation tholeiitic basalt overlain by continental alluvial to lacustrine sediments of the Manari, Pirara, and Takutu formations, from oldest to youngest, with the Upper Takutu dated as Early Cretaceous (Barremian) (Figure 2). In the Brazilian sector, the Aptian to Upper Cretaceous (?) fluvial-deltaic Tucano (or Serra do Tucano) Formation also occurs (Scaramuzza do Santos, 2016), and the entire basin has a thin Cenozoic veneer of laterite and/or alluvial deposits.

Takutu basin stratigraphy is well detailed by prior workers (Crawford et al, 1985; Eiras and Kinoshita, 1990) and also in a biostratigraphic study of the Hunt Oil Company Turantsink-1 well (Lester, 1993). Prior to the drilling of the Turantsink-1, data indicated that the entire basin fill above the Apoteri basalt was non-marine fluvial-deltaic to lacustrine in origin, including thick halite in the lower to middle Jurassic Pirara

Formation, deposited in the Lake Marakanata evaporite basin. However, biostratigraphic data from this well indicate there were probably two or three brief marine incursions into the basin in Early Jurassic Sinemurian to Hettangian time (Figure 3). In addition, a previously unrecognized shallow 19 m (63') thick section of claystone, sandstone, and anhydrite above the Barremian-age upper Takutu Formation was identified. This was dated as a Late Cretaceous (probably Turonian) restricted marine unit and tentatively correlated to the Tucano Formation in Brazil. The Tucano Formation crops out in the Tucano Hills and was penetrated in the Petrobras Serra do Tucano-1, as well as in the Turantsink-1. Only fluvial-deltaic (non-marine), dominantly sandstone, facies have been described in Brazil, however, and an Aptian-Albian to possibly lower Upper Cretaceous age (Eiras and Kinoshita, 1988) was assigned based on the unit's position above the Takutu Formation. The marginal marine facies identified in Turantsink-1 demonstrate that a marine embayment of the Atlantic Ocean extended at least this far south along the Takutu rift during a Late Cretaceous highstand. This also indicates that the area between the Takutu and Guyana basins must have been topographically low and implies that the Takutu rift system probably extended further northeast during the Mesozoic. This interpretation is further reinforced by the fact that only fresh water lacustrine deposits have been identified in the Takutu Formation, unlike the evaporites found in the underlying Pirara Formation, suggesting that the basin had filled to a spill point and that riverine outflow was northeastward toward the Atlantic Ocean, initiating the proto-Berbice river. Paleogeographic maps of three key intervals, the Lower Pirara, Upper Takutu, and Tucano formations, are shown (Figures 4-6) to illustrate interpreted depositional environments and facies distribution.

Present day structural configuration of the basin is shown at the top of the Apoteri Basalt (Figure 7). This is a composite map, with the Guyana side represented by a time depth structure map based on the Hunt Oil Company interpretation (Webster and Murdock, 1995; Webster, 2004) and Brazil side being a depth map following a Home Oil Company/Petrobras interpretation (Crawford et al, 1985).

Two seismic lines and a composite cross section demonstrate the occurance of the Tucano Formation and the fact that deformation took place subsequent to Upper Cretaceous deposition. A northeast-southwest seismic line acrosss the Tucano High in Brazil (Figure 8), as tested by the Petrobas Serra do Tucano-1 well, shows the Tucano thickening up to 2,200 m in the adjacent low. Similarly, a NNW-SSE line through the Hunt Turantsink-1 in Guyana (Figure 9), located 105 km northeast of the Serra do Tucano-1, also shows the Tucano Formation thinned by erosion over the structural high at the wellsite. At the eastern end of the Takutu graben, basin strata rise structurally and are terminated by erosion, not by depositional thinning and pinchout. This is demonstrated by a composite cross section (Figures 10a, b) from the Turantsink-1 area through the deep Rupununi Trough to beyond the Rewa High at the northeast end of the basin. The cross section follows multiple seismic lines to the end of the data in the northeast, beyond which it is based on outcrop control. The Tucano Formation reaches a thickness of over 1,000 m in the Rupununi Trough, and it and the older units maintain near-constant thickness until being erosionally truncated. This indicates that the basin originally extended further northeast during Jurassic and Cretaceous time. How far it extended is uncertain, but it is likely that the original Jurassic graben system was a rift valley complex, possibly segmented by transfer zones, that formed a structurally low corridor from the Guiana highlands to the coast.

The major structural features in the basin such as the Savannah Arch and Rupununi Trough were developed during a regional, probably middle Miocene, tectonic event including right lateral transpression (Eiras and Kinoshita, 1988) linked to subduction of the Nazca Plate and uplift of the Andes Mountains. As shown on the tectonic map of South America (Cordani et al, 2016) (Figure 11), the Guiana Shield is split into northwest and southeast segments by the Takutu graben. Eastward-directed regional compression generated by the eastward thrusting of the Andes Mountains, particularly the Eastern Cordillera, must have caused the northwest shield area to shift slightly in a right-lateral sense along the crustal zone of weakness of the Takutu rift. The ENE-WSW trending central rift area experienced internal structural deformation, while the northeast and posssibly southwest extensions, being at higher angles to the regional compressive stress, suffered compression and uplift. Their Mesozoic sections were subsequently removed by erosion so that only Precambrian basement rocks are present today. The northeast-southwest orientation of faults and dikes cutting the exposed basement rocks, as shown on the geologic map of Guyana (Guyana Geology and Mines Commission, 2010), supports the concept of the rift having extended northeastward from the present day Takutu basin toward the offshore Guyana basin.

Proto-Berbice River System

The Guiana Shield highlands have sourced the headwaters of major regional river systems such as the Orinoco, Amazon, and others throughout Mesozoic and Cenozoic time, although paleo-drainages have changed substantially over time. In particular, one of the largest rivers draining the central shield area was the proto-Berbice, a northeast flowing river that ran through the Takutu graben toward the coast. During Early to Middle Jurassic time, as the Pirara Formation was deposited, endorheic Lake Marakanata served as a local depocenter, receiving predecessors of the modern Ireng, Cotinga, Takutu, Uraricoera, Rupununi, Rewa, and Essequibo rivers (Lujan and Armbruster, 2011) (Figures 4, 12). From Late Jurassic through Early Cretaceous time, as the Takutu Formation was deposited (Figure 5), the Lake Marakanata basin filled with sediment to a spill point and transitioned to a fluvial environment. A trunk stream, the proto-Berbice, flowed northeastward through the northeast extension of the Takutu rift to exit to the Atlantic Ocean near the mouth of the modern Berbice river. A marine highstand event during Turonian time pushed a marine embayment as least as far inland as the Turantsink-1 well location (Figure 6), followed by retreat of the sea and the initiation of a period of extensive upland erosion and transport of sediment seaward by the proto-Berbice river in Coniacian, Santonian, and later Cretaceous time. How far to the southwest the headwaters of the proto-Berbice extended, in the direction of the modern Rio Branco, is uncertain, but it is possible that it drained a sizeable portion of the modern Solimões/Rio Negro basin between the Purus and Vaupes arches (Figure 11).

Probably beginning in mid-Miocene time, with the uplift and erosion of Takutu basin sedimentary fill described above (Figure 10), the headwaters of the proto-Berbice river were reduced through stream capture by the southward-flowing Rio Branco, a tributary of the Rio Negro and the newly formed Amazon river. The Cotinga and Uraricoera rivers were captured at the end of the Pliocene, followed by the Ireng and Takutu in the early Pleistocene (Lujan and Armbruster, 2011). The modern Berbice is a minor river, with headwaters near the northeast end of the Takutu graben, having also lost its former tributaries of the Essequibo and Corentyne rivers later in the Pleistocene (Figure 12).

Guyana Basin and Berbice Paleocanyon

The Guyana basin is the Atlantic passive margin depocenter shared by both Guyana and Suriname, encompassing a total area of about 257,000 km^2, including 125,000 km^2 in deep water seaward of the continental shelf edge, between the Waini arch to the northwest and the Demerara plateau to the southeast. As the southern North Atlantic Ocean began to open during Jurassic time, sediments time-equivalent to those in the Takutu graben accumulated in rift basins such as the Nickerie graben and the probable offshore extension of the Takutu rift (Yang and Escalona, 2011; Griffith, 2017). This section shows up as dipping reflectors on seismic lines below a regional Early Cretaceous unconformity

(Figures 2 & 13) but has not yet been drilled in wells. A seismically-defined Neocomian age carbonate bank with down-dip organic-rich shale also occurs in the deeper water part of the basin (Nibbelink et al, 2019).

Above this section, or the Precambrian basement where the syn-rift is absent, lie mostly unstructured Early Cretaceous to Recent passive margin sedimentary units that have been identified in wells (Figure 2). A transgressive basal clastic unit of Barremian to Aptian age, the Stabroek Formation, is overlain by the Albian carbonate section of the Potoco Formation. Above this is the Canje Shale, a Cenomanian-Turonian age hydrocarbon source rock, deposited during a maximum transgressive event that extended into the Takutu graben, as described above. The uppermost Cretaceous unit is the New Amsterdam Formation, a prograding sand-rich clastic wedge on the shelf that transitions to a series of submarine fans and gravity flows in the deeper water to the north. These form the hydrocarbon reservoirs recently discovered in Santonian to Maastrichtian age sands in the ExxonMobil Liza-1 and subsequent deep-water discoveries in both Guyana and Suriname. Overlying Paleogene and Neogene strata complete the sedimentary package, including a thick, rapidly-deposited, post-mid-Miocene clastic section derived from Amazon river discharge and transported by longshore currents (Mapes and Torres, 2017).

The trans-shelf conduit for most of the New Amsterdam deep-water sands is the most striking feature in the Guyana basin, the Berbice paleocanyon (Kean, 2014; Wood et al, 2019). This is a shelf-incised canyon system over 80 km long with dimensions similar to the Grand Canyon, cut over several million years during late Coniacian to early Santonian time (Figure 13). With the canyon head just offshore the modern Berbice river, it served as a conduit for transporting vast amounts of sediment from the continent across the shelf into deep water as channel deposits and submarine fans (Nibbelink et al, 2019). Cut through six major phases of incision, fill, and re-incision (Wood et al, 2019), the canyon was incised through the Canje Shale to the top of the Potoco Limestone, which was apparently sufficiently indurated to resist further downcutting. The modern rivers draining into the offshore basin, including the Essequibo, Demerara, Berbice, and Courantyne, appear inadequate to have transported the volumes of sediment required. Rather, the large proto-Berbice river system, draining the Guiana Shield highlands and probably beyond through the Takutu graben, is the continental source for the massive Upper Cretaceous sediment influx that accumulated in the deep waters of the Guyana basin.

Conclusions

The evolution of the Takutu basin, the proto-Berbice river system, and the Berbice paleocanyon in the Guyana basin follows this timeline:

- Late Triassic(?)- Early Jurassic: Initial Takutu basin rifting associated with opening of the North Atlantic Ocean. Extrusion of Apoteri Volcanic Formation tholeiitic basalt.
- Early-Middle Jurassic: Deposition of Manari shale and Pirara Formation evaporites and basin-margin clastics in a fluvial/lacustrine environment in the endorheic Lake Maracanata rift basin. Two or three brief marine incursions into the basin occur.
- Late Jurassic-Early Cretaceous (Barremian): Deposition of Takutu Formation clastics in a fluvial to fresh-water lacustrine environment; proto-Berbice river initiated from the Takutu basin to the Atlantic Ocean.

- Mid-Late Cretaceous (Aptian-Turonian): Deposition of Tucano Formation in fluvial/deltaic to marginal marine environments; Turonian marine transgression extends into the basin; proto-Berbice river system continues to evolve.
- Late Cretaceous: Large proto-Berbice river system flows from SW to NE from interior South America through the Takutu rift to the Atlantic. Submarine Berbice Canyon is cut (Coniacian-Santonian time) and giant submarine fans are deposited in the offshore Guyana basin through Maastrichtian time.
- Paleocene-Early Miocene: Tectonic quiescence and reduced erosion; reduced offshore deposition.
- Mid-Late Miocene: Tectonic reactivation due to Andean orogeny; right-lateral wrench faulting along Takutu boundary faults; internal structural deformation in Takutu graben; uplift and erosion of northeast and southwest graben areas; headwaters of proto-Berbice river captured by Amazon river tributaries.
- Pliocene-Pleistocene: Capture of additional upper proto-Berbice tributary rivers by Rio Branco in Brazil; Essequibo river system becomes dominant drainage in Guyana; Berbice river reduced to a minor drainageway. Continued Guyana basin sedimentation derived mostly from Amazon river discharge.

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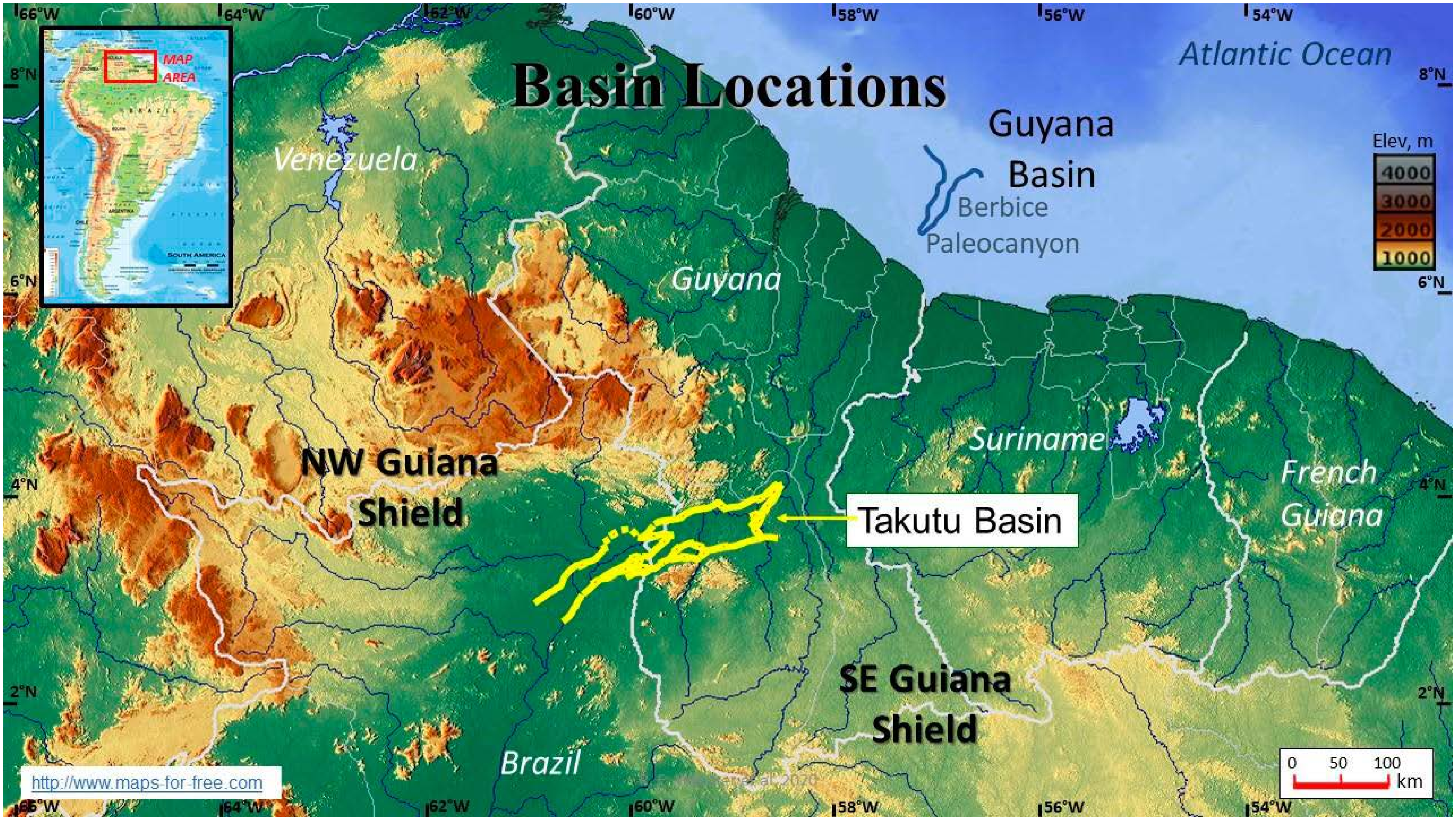


Figure 1. Map showing northeast South America topography and Takutu basin location. Yellow lines depict major present-day graben-bounding faults. The Takutu graben splits the Guiana Shield into northwest and southeast segments. The offshore Guyana basin and Berbice Paleocanyon outline are also shown. Topographic base from www.maps-for-free.com.

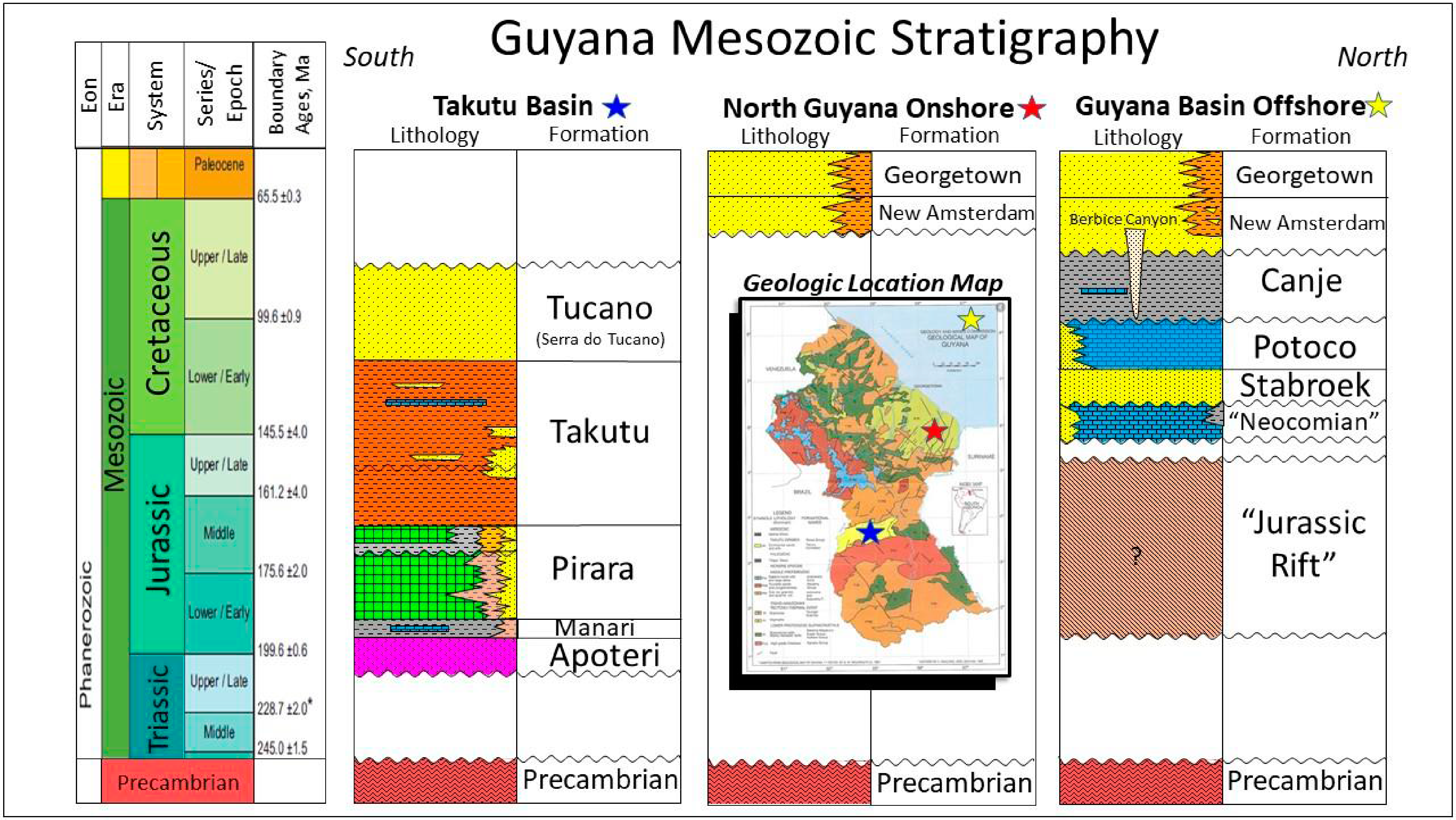


Figure 2. Guyana Mesozoic Stratigraphy. Takutu basin units are separated from the offshore Guyana basin by an expanse of Middle Proterozoic basement rocks.

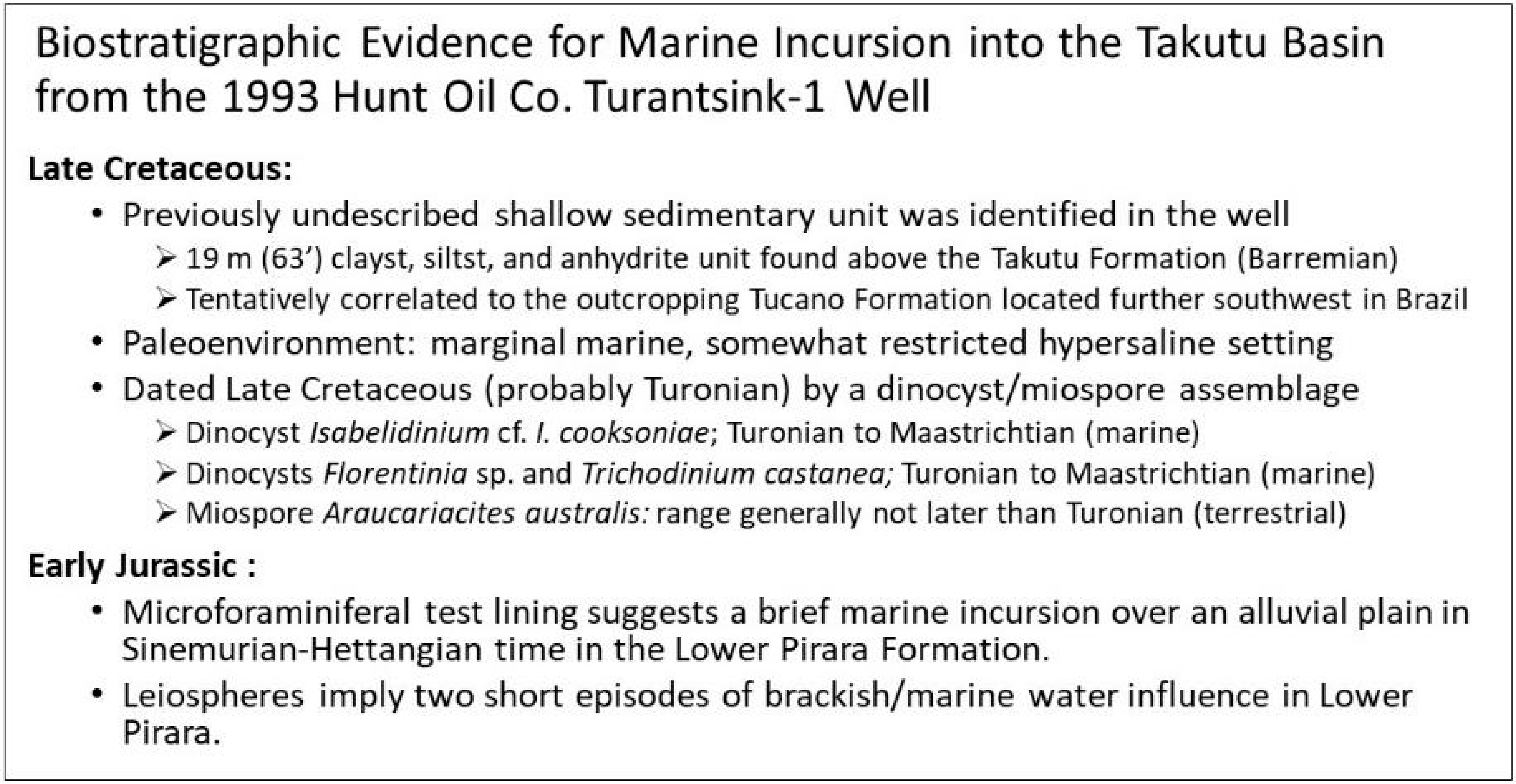


Figure 3. Biostratigraphic data from the Turantsink-1 well (from Lester, 1993).

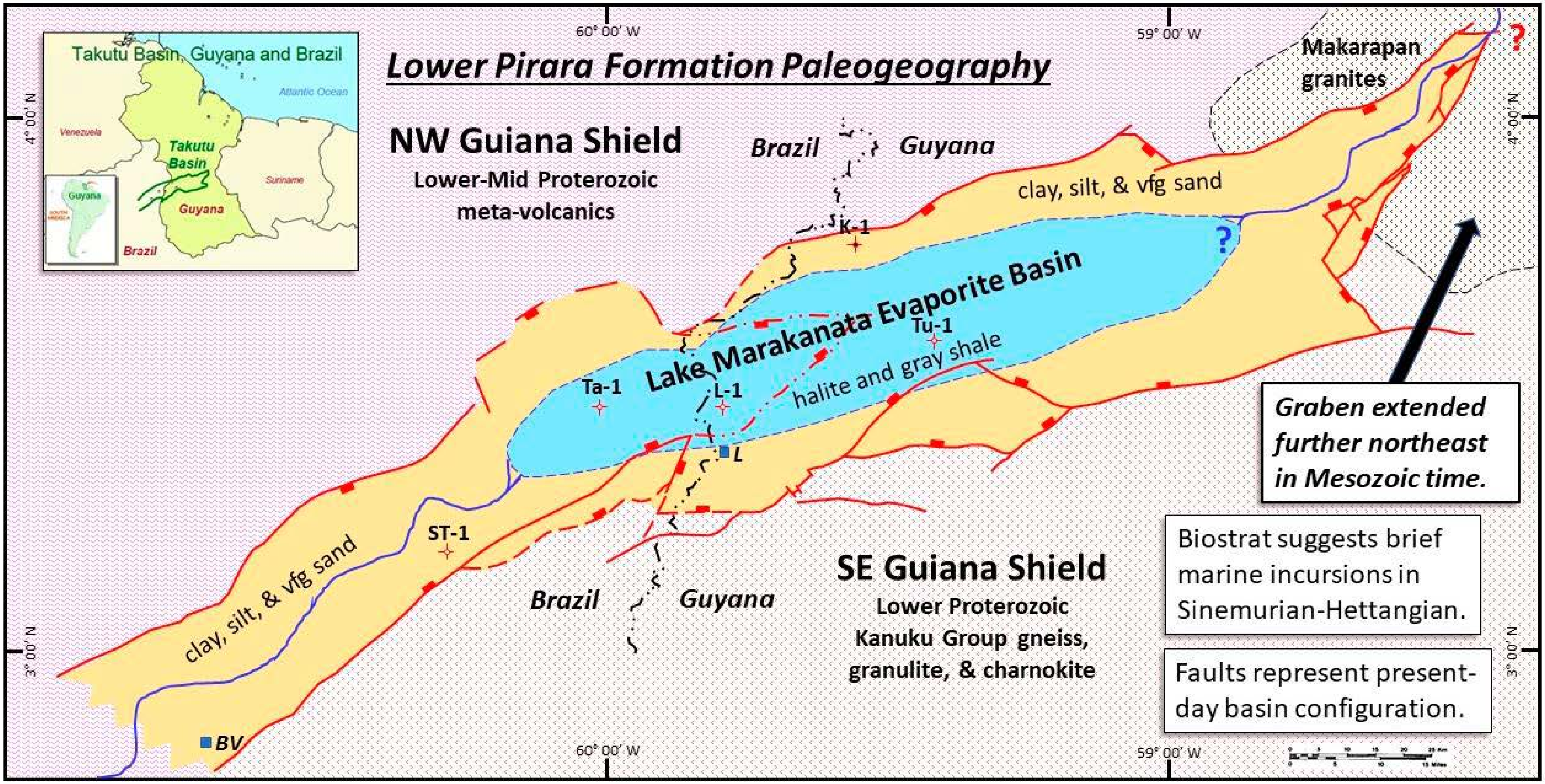


Figure 4. Early Jurassic Paleogeography (Pirara Formation), Takutu Graben. Biostrat data indicating brief marine incursions into this otherwise continental setting implies the graben system extended further northeast during this time. Thick evaporites were deposited in endorheic Lake Marakanata. Wells: Ta-1: Tacutu-1, ST-1: Serra do Tucano-1, L-1: Lethem-1, K-1: Karanambo-1, Tu-1: Turantsink-1 (not shown: Apoteri K2 offset to K-1). Towns: BV: Boa Vista, Brazil; L: Lethem, Guyana.

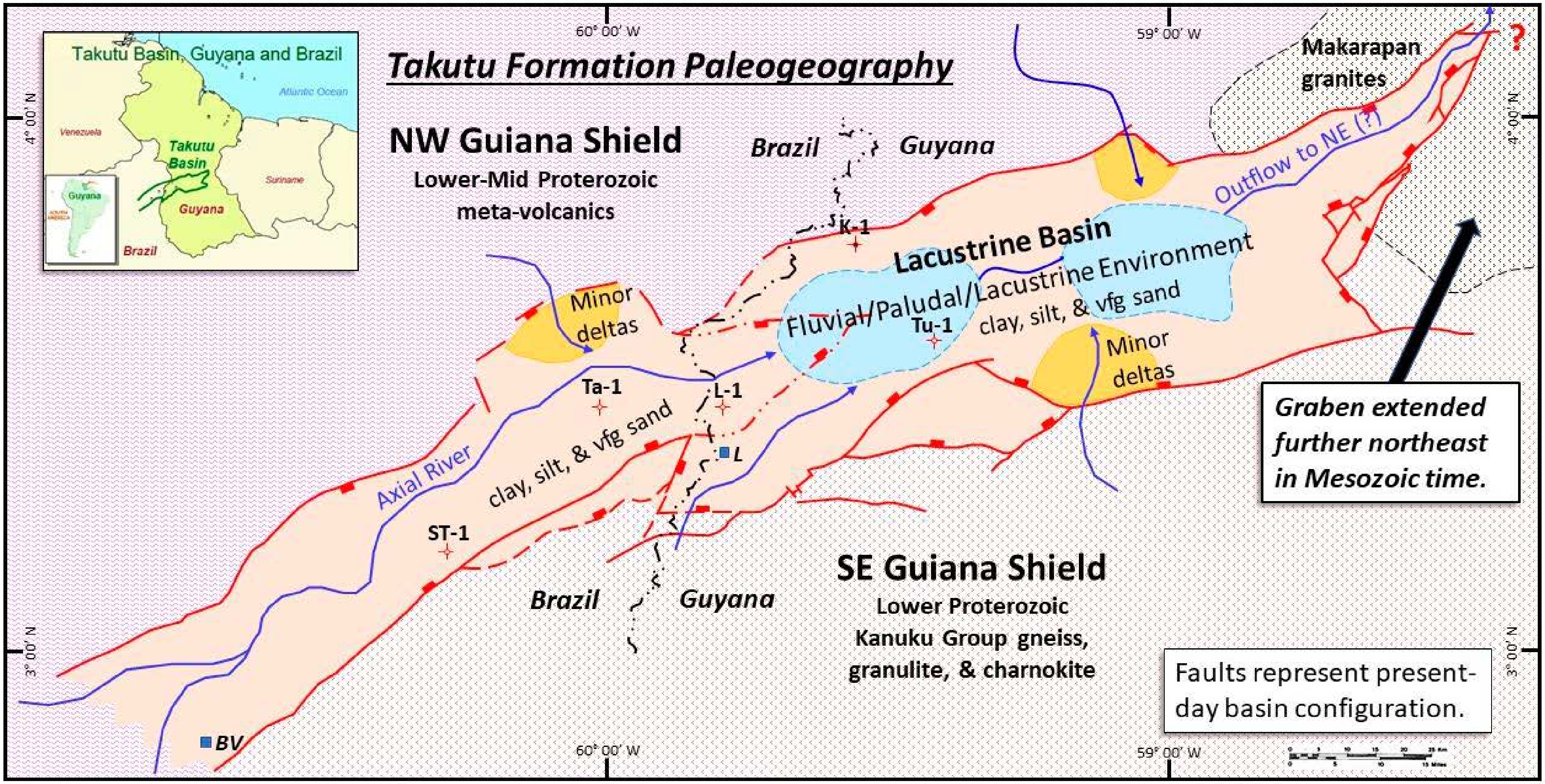


Figure 5. Late Cretaceous Barremian Paleogeography (Takutu Formation), Takutu Graben. Lack of evaporite deposits in the lacustrine setting indicates there was not a closed endorheic lake as during Pirara Formation deposition, but that there was probably drainage outflow northeastward toward the Atlantic Ocean initiating the proto-Berbice river.

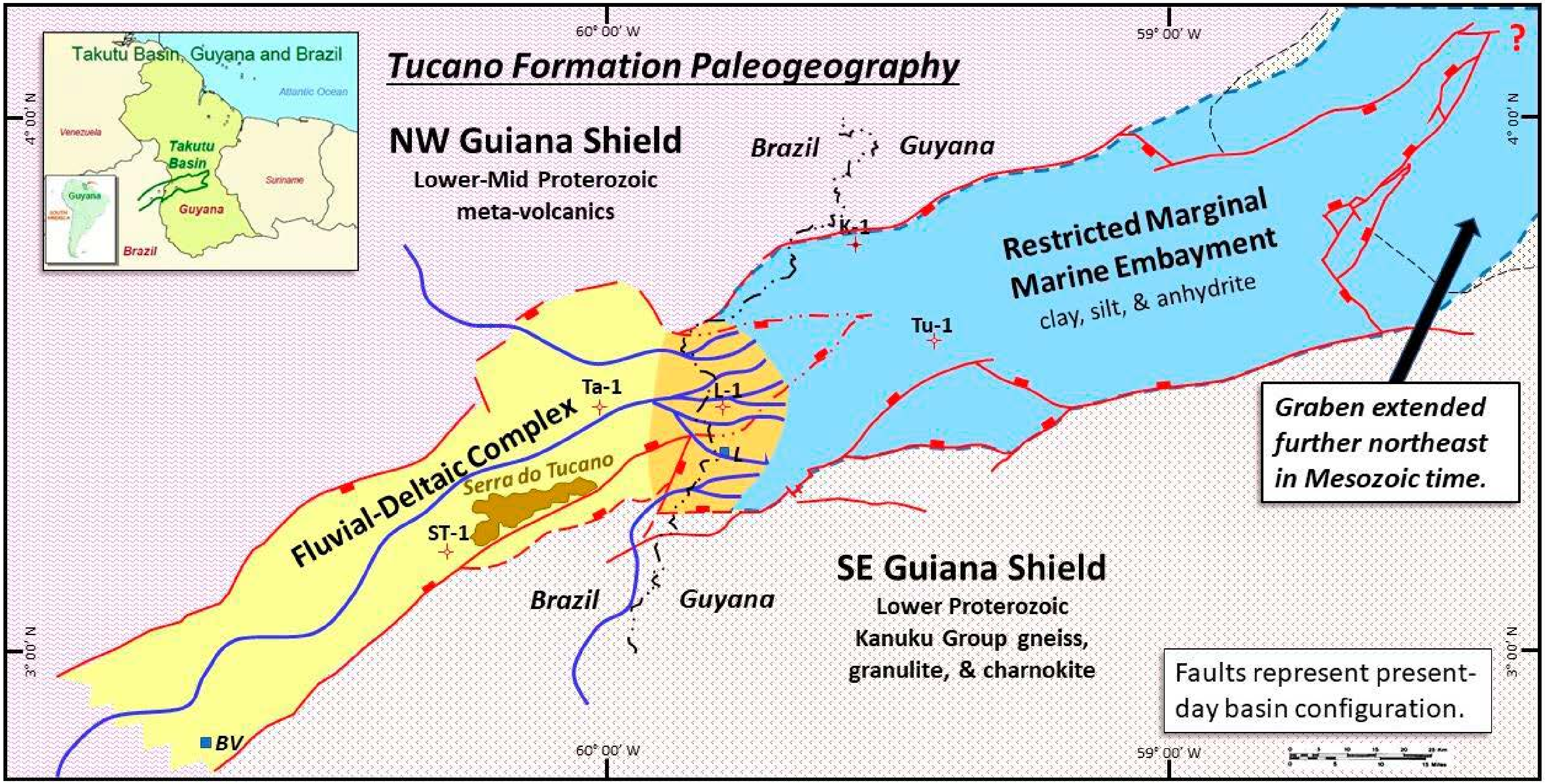


Figure 6. Upper Cretaceous Turonian Paleogeography (Tucano Formation), Takutu Graben. Restricted marginal marine sediments are documented at the Turantsink-1 (Tu-1) location, while fluvial-deltaic deposits occur further southwest. Serra do Tucano outcrop area shown (after Eiras and Kinoshita, 1990). Following this Turonian highstand, a major regional drainage system developed (proto-Berbice River) directed through the graben to the coast.

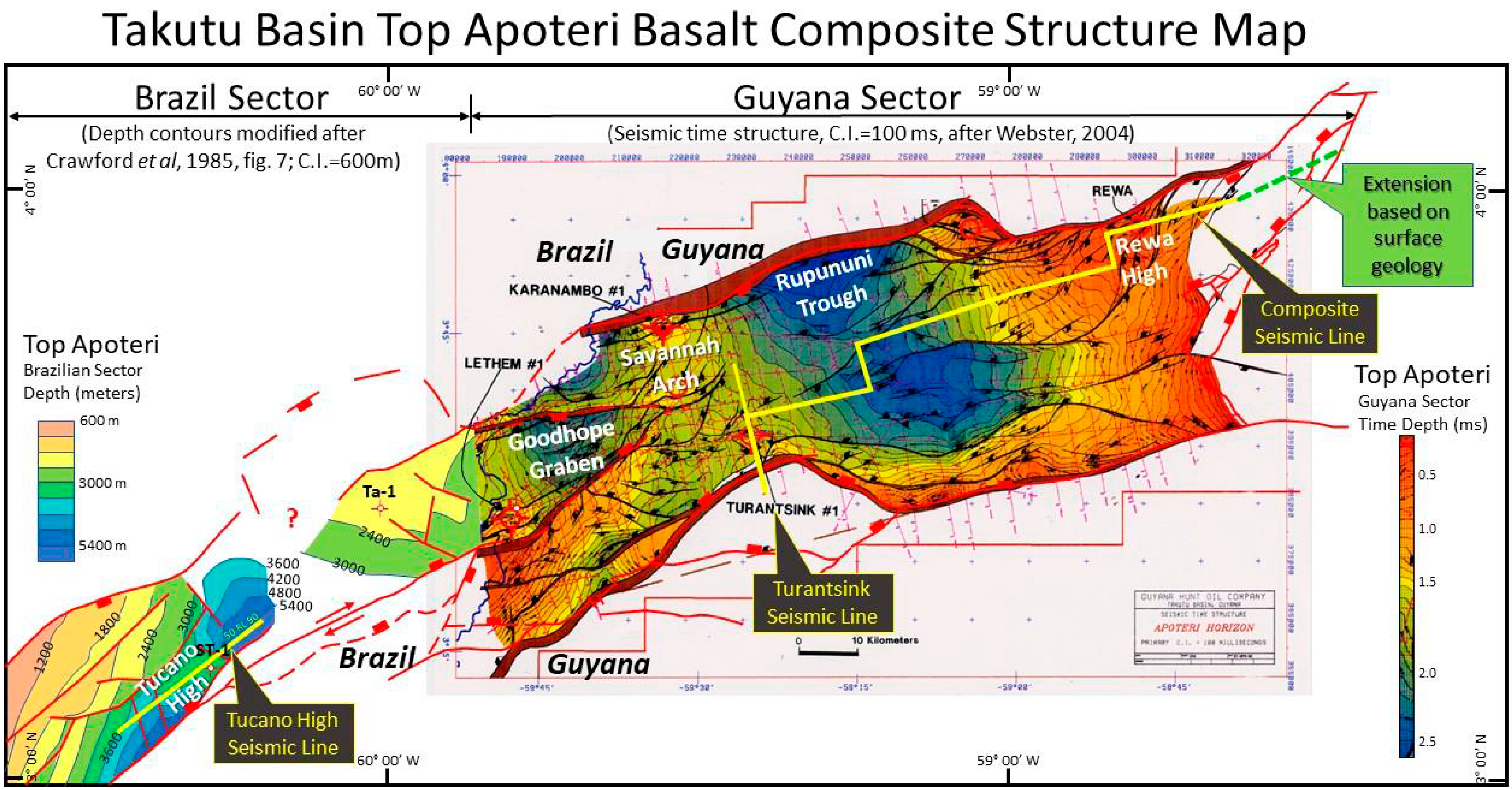


Figure 7. Composite Structure Map, Top Apoteri Volcanic Formation (Early Jurassic). Major intra-basinal structures are identified, as developed during a Miocene tectonic event involving right lateral transpression. Yellow and yellow/green lines show locations of Figures 8-10.

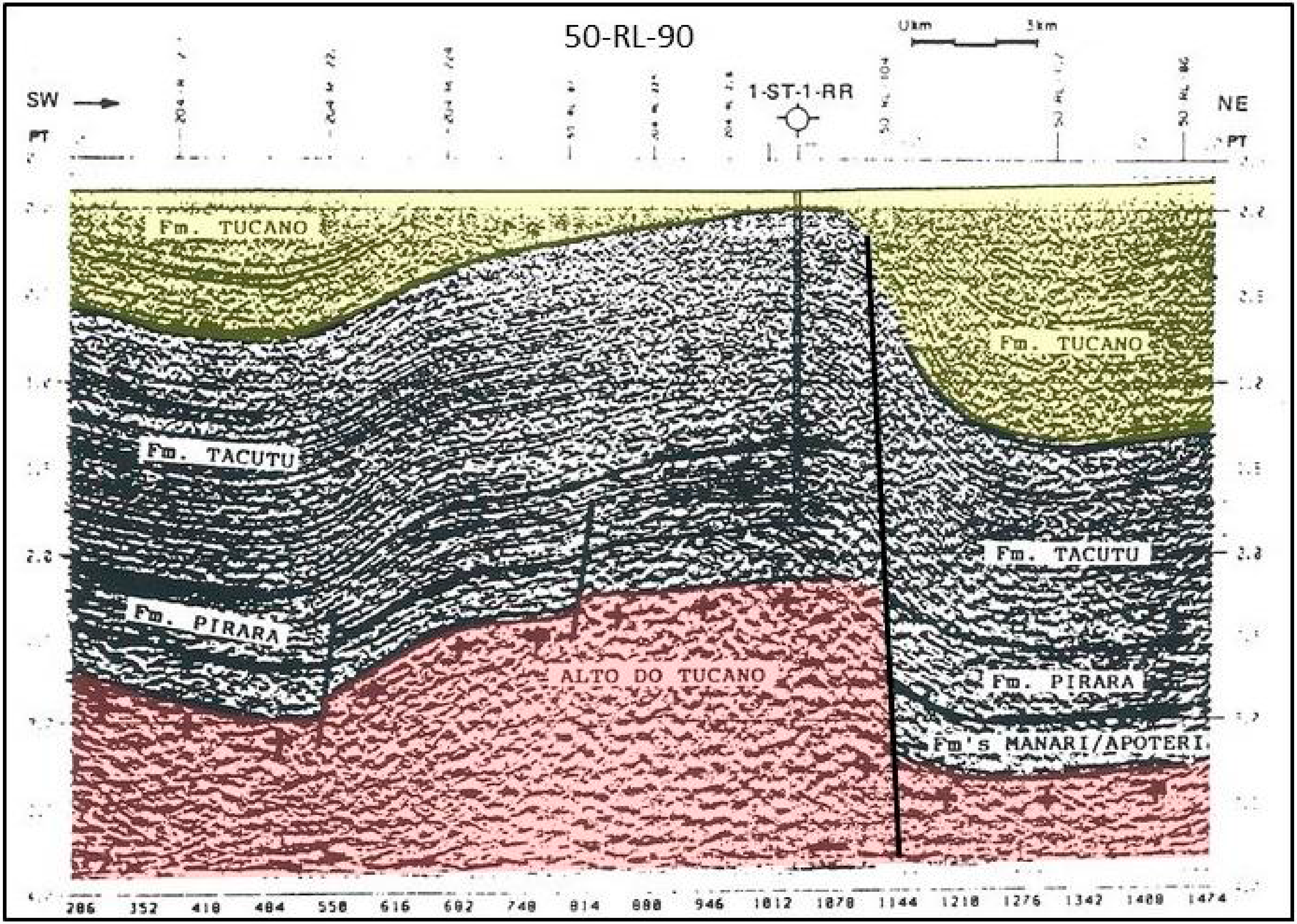


Figure 8. Petrobras seismic line 50-RL-90 across the Tucano High and the Serra do Tucano-1 well (modified after Eiras and Kinoshita, fig. 18).

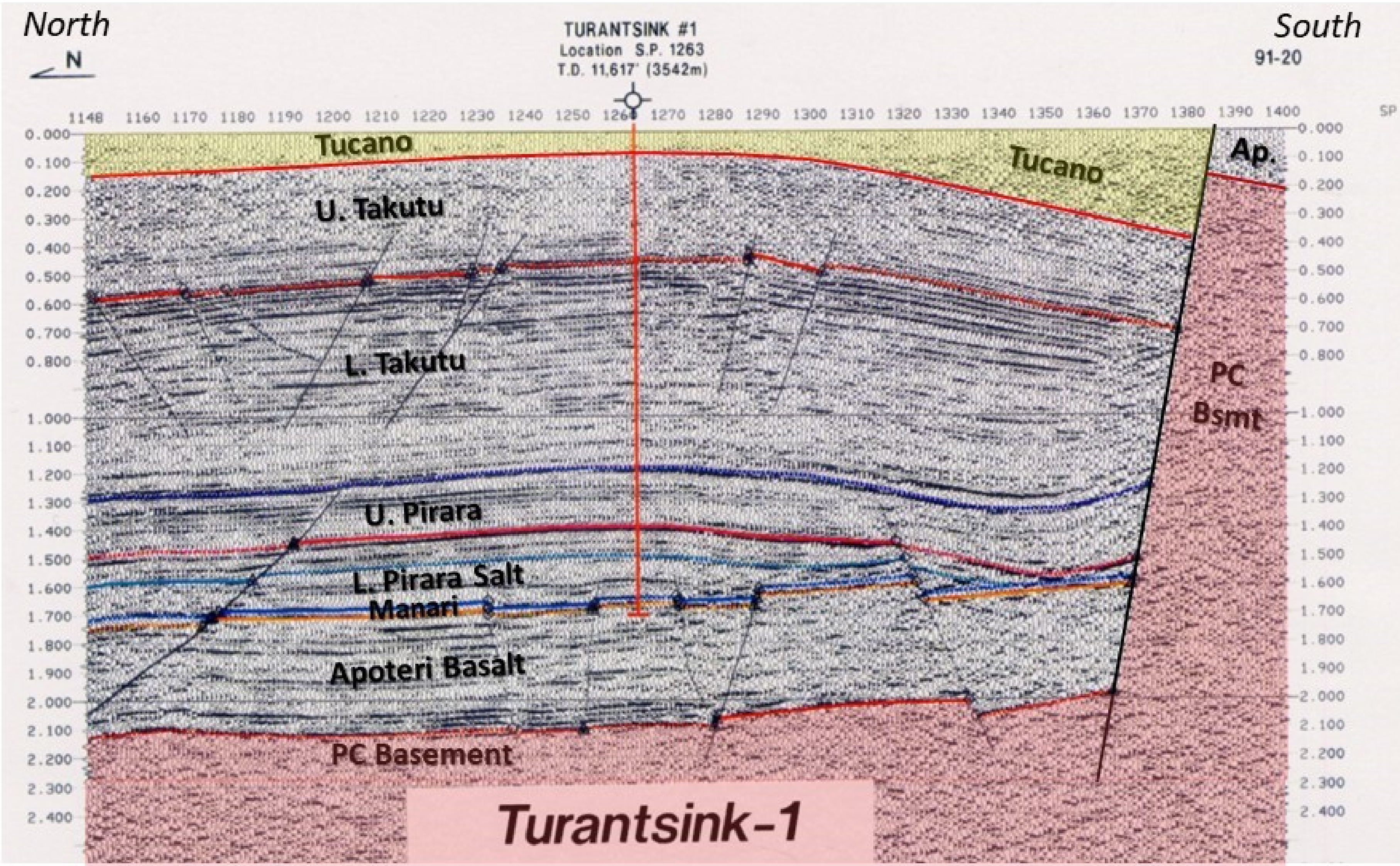
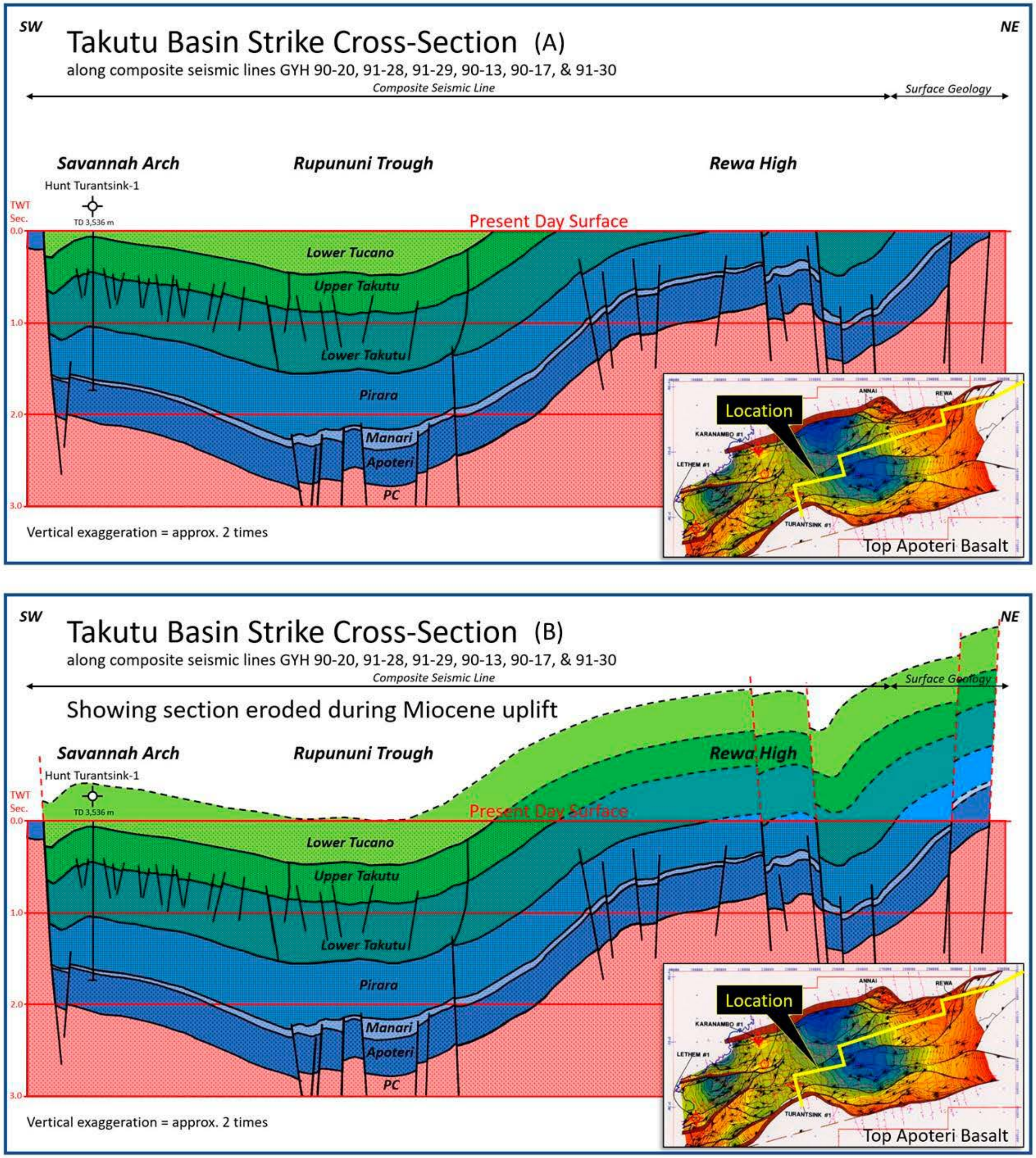


Figure 9. Hunt Oil Co. seismic line GYH-91-20 through the Turantsink-1 well (modified after Webster, 2004). Vertical scale same as Figure 8.



Figures 10A and 10B. A. Composite cross-section across the Takutu basin, Guyana, showing present day structure and erosional truncation of stratigraphic units. B. Identical cross-section showing the probable section uplifted and eroded during the Miocene tectonic episode.

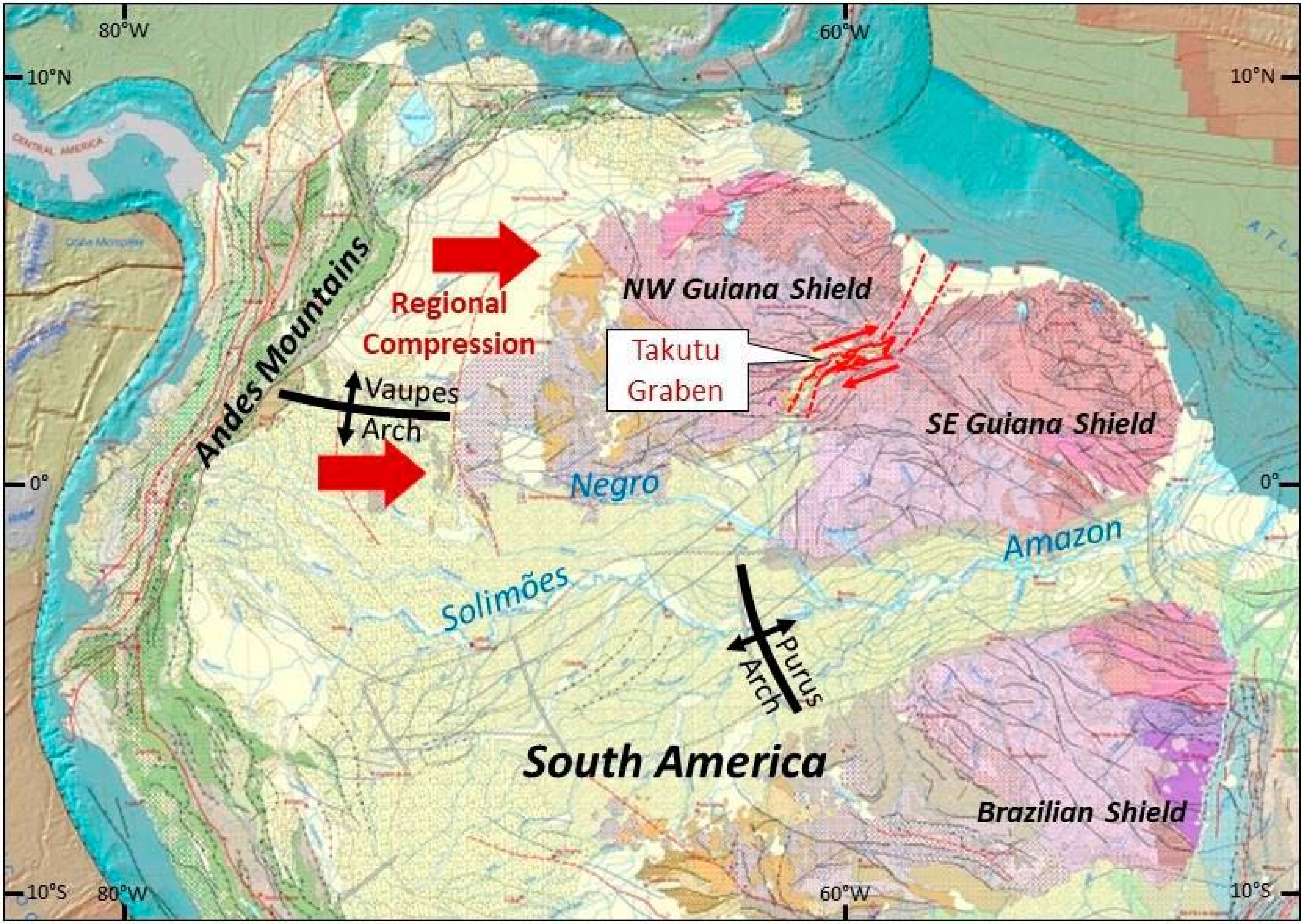


Figure 11. Regional compressive stress generated by the Andean Orogeny in mid-Miocene time caused right-lateral transpression along the crustal zone of weakness of the Takutu graben, which splits the Guiana Shield into northwest and southeast segments. Solid red lines: present day graben bounding faults; dashed red lines: probable Mesozoic extent of Takutu rift system. Proto-Berbice river flowed from the interior through the Takutu graben to the Atlantic. Archean to Proterozoic basement rocks crop out in the shield areas. Base Map: Tectonic Map of South America showing modern rivers (Cordani et al, 2016).

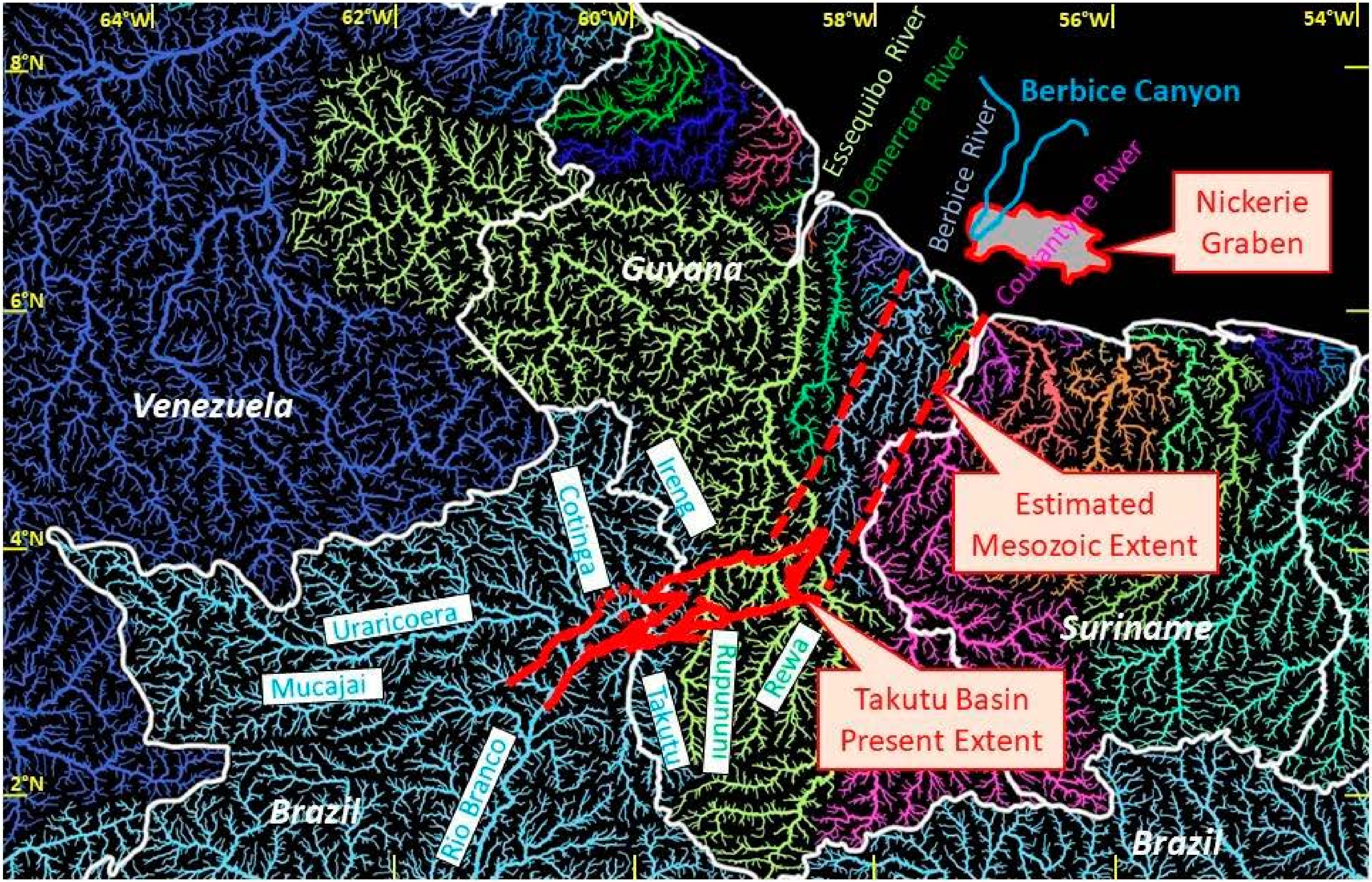


Figure 12. Modern rivers, northeast South America. Takutu basin bounding faults in red; estimated Mesozoic northeast extent of the rift shown by dashed red lines. Outline of Upper Cretaceous Berbice submarine canyon shown in blue. Nickerie graben (Griffith, 2017) is a geophysically-defined Jurassic rift in the Guyana basin that aligns with the Takutu rift trend. River map from https://www.grasshoppergeography.com/River-Maps/

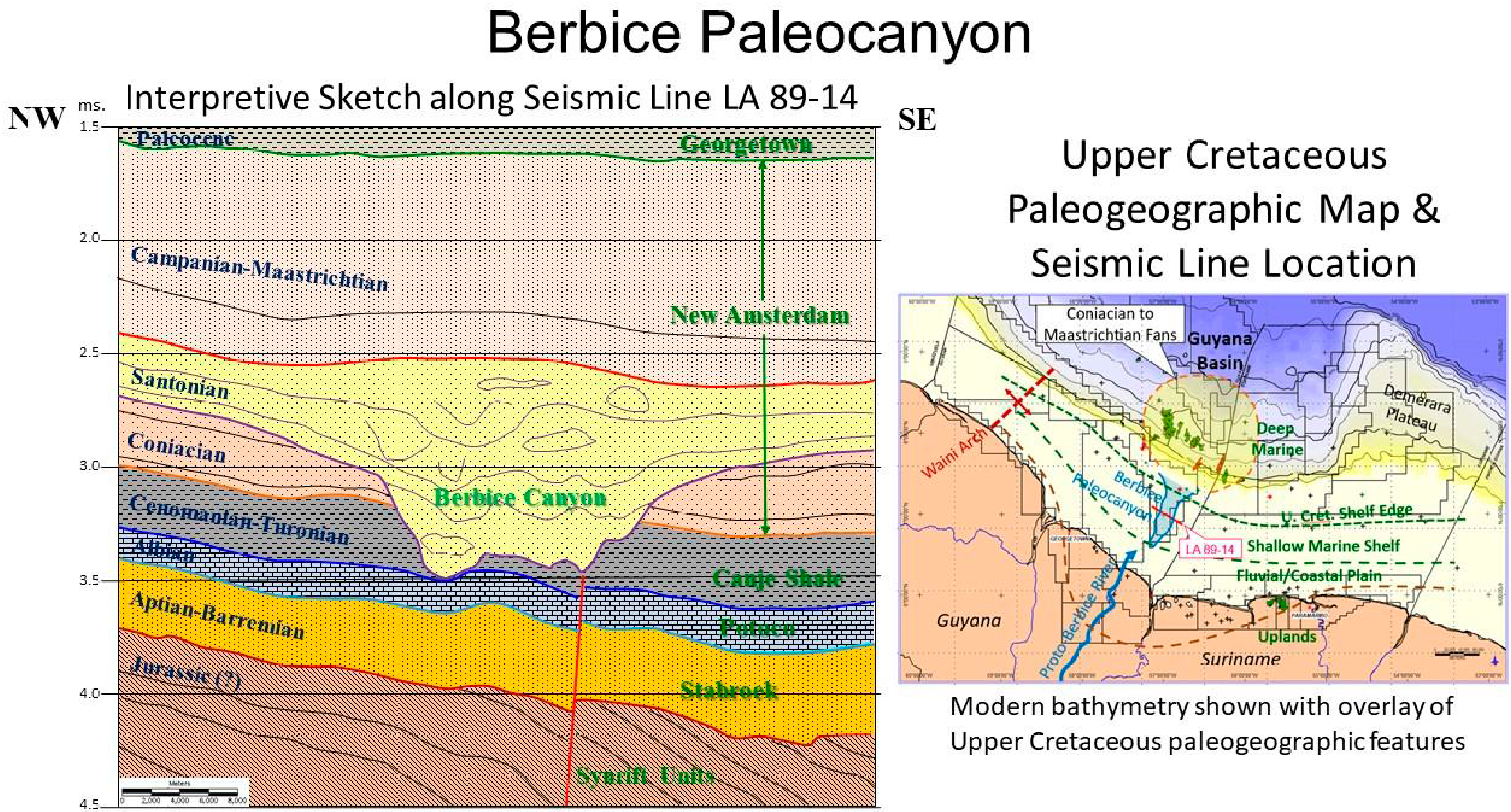


Figure 13. Berbice Paleocanyon interpretive drawing along strike line LA 89-14. Location map shows generalized paleographic setting during Late Cretaceous Santonian-Campanian time.