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ABSTRACT

MIDDLE MIOCENE OROGENY IN TRINIDAD: RECORD OF CARIBBEAN COLLISSION AND TEMPLATE FOR YOUNGER DEFORMATION

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Three fundamentally different phases of tectonic development in Trinidad are widely recognised. Miocene orogeny, culminating at about 10.5-12 Ma, appears to have been dominated by SE-directed thrusting driven by the approach of the Caribbean Plate. The Late Miocene and early Pliocene is dominated by dextral strike-slip in the north, resulting in opening of the Gulf of Paria. In the south it is dominated by gravity-driven normal faulting related to west to east delta progradation. Finally, the Late Pliocene-Recent is dominated by both strike-slip and renewed folding and thrusting onshore, with gravity driven normal faulting migrating offshore to the southeast, ahead of the deformation front.

In this paper, we present results from four years of combined field studies and reinterpretation of an extensive seismic and well database. We focus on structure at top Cretaceous level, on the geometric relationship between deeper strata and the Late Miocene and younger normal-faulted package above, and on the relationship of Miocene foredeep and wedge-top fill to pre-Lengua-Cruse structures. Finally, we place these structures in their Miocene context. A map of the structures active at 12 Ma restores the effects of Late Miocene to Recent shortening and strike-slip, and a map of the structures active at 18 Ma attempts to restore the shortening and associated strike-slip recorded during the interval 18-12 Ma.

By 18 Ma, the deformation front had imbricated the Paleogene cover of the present-day Central Range (including Chaudiere, Pointe-a-Pierre and Central Range Nariva) which underlie Brasso and younger rocks with angular unconformity. As thrusting advanced to the southeast, it detached the thick Nariva foredeep section resulting in formation of the Nariva fold thrust belt, which includes thrust slices of Brasso-aged rock. Conventionally, this relatively thinly-detached thrusting is considered to have culminated to the south in the

Penal-Barrackpore trend, where Herrera through Lengua Formations are imbricated and overlain with angular unconformity or onlapped by Cruse and younger strata. The thrust front is placed in the vicinity of the axis of the Erin-Siparia Syncline.

However, a top Cretaceous map shows multiple, en-echelon, doubly-plunging culminations farther south, including the Rock Dome, Moruga, Guayaguayare and possibly Galeota structures. The relationship of these structures to the Late Miocene and younger section demonstrates that they must have been uplifted prior to deposition of the Cruse Formation.

The “10.5 unconformity surface” at the base of the Cruse in these areas has been reused as the basal detachment for younger gravity-driven listric normal faults which generally dip to the east. The overall thickness of the Cruse-Forest-Mayaro section deposited within this normal fault belt remains fairly constant (about 8000’) from the axis of the Erin-Siparia Syncline and into the Columbus Channel, suggesting that the base Cruse was not perched higher onshore than in the Columbus Channel. Thus, we can use the base Cruse surface as a structural datum. Furthermore, this surface is the only reliable structural datum that can be used to fully restore cross-sections in this area and understand the origin of the Cretaceous culminations.

The very steep dips recorded in the Cruse and Forest strata on the flanks of the southern anticline do not represent limb dips of the deeper structures and are generally not coaxial with those deeper structures. They result from the superimposition of two distinct tilts with different orientations. Late Miocene growth fault bounded sediment wedges generally roll towards the west, and the steepest bedding in these wedges had a more or less N-S strike and perhaps 30°-45° westward dip. These wedges were then refolded when the Cretaceous cored culminations were reactivated from the Late Pliocene to Recent. The refolding pattern is spectacularly clear in Kugler’s map of the south coast and Lizard Springs areas.

The only paleo-horizontals in the Cruse-Mayaro section are to be expected down dip from rollover sections, but these are hard to identify because we typically find the next downdip listric fault and associated rollover sediment wedge. The post-growth overlap section (Upper Forest and younger formations in the west and Palmiste and younger formations in the east) can be used locally as a paleo-horizontal but only show that significant reactivation of the Cretaceous culminations occurred during Late Pliocene and younger time. The available well and seismic data does not allow us clearly pick the exact equivalents of onshore formations in the Columbus Channel, so flattening on these young surfaces is subject to some error. In contrast, the seismic and well data do allow us to pick with confidence the surface into which the rollover faults detach both onshore and in the Columbus Channel.

Flattening on the “10.5 unconformity surface” datum reveals that top Cretaceous or Paleocene strata were exposed immediately below the surface at latest Middle Miocene time in the Lizard Springs and Moruga-Guayaguayare areas. The synclines between culminations preserve imbricated sections of Eocene (Navet or San Fernando) through Middle Miocene

(Retrench-Herrera-Karamat-Lengua) strata. This wedge of Pre-Cruse Cenozoic sediment reaches a maximum thickness of about 8000' thinning to zero over the Cretaceous anticlines. The thinning is too abrupt to be the southern pinchout of a foreland basin and this thick section is absent in the hanging walls of Cruse-aged normal faults. If it had been present, and removed in the hangingwalls of younger normal faults, the Cruse-Mayaro section would have to double in thickness in these areas, to about 16000', which it does not. Thus, the culminations must be late Middle Miocene in age. Only the Rock Dome thrust slice, in which Cretaceous through Cruse-aged strata are more or less parallel to each other, was emplaced later, since the Late Pliocene.

Cross-sections based on seismic data indicate that about 1.5-2s of Cretaceous and possibly older strata is involved in each thrust slice. The Cuche shale or base Gautier acts as an intermediate detachment level, and the deeper parts of the thrust slices may contain a section comparable to the Barranquín sandstones exposed in Venezuela, and drilled to the south of the Columbus Channel. Thus, the deep detachment level may be equivalent to the Couva evaporates drilled in the Gulf of Paria. The abrupt southern termination of the Cretaceous culiminations, and the fact that thrusting did not propagate farther south since the Late Miocene, suggests a fundamental stratigraphic control on thrusting, possibly the southern pinchout or fault truncation of an evaporite. The en-echelon geometry of the culminations suggests that they may be synchronous, and may have formed in a dextral transpressive setting.

Mapping the Cretaceous structures also provides an insight into the nature and origin of the Los Bajos Fault. There are no known analogues to the Moruga and Guayaguayare culminations on the west side of the fault, suggesting an origin as a dextral transpressive lateral ramp during Middle Miocene thrusting. This is supported by mapping in the Soldado area, where there is a Cretaceous-cored antiformal stack with an apparent >20 km offset across the Los Bajos Fault from a similar thrust stack in the Brighton area. These antiformal stacks are cored by Cretaceous thrust sheets which appear to drive Herrera-Karamat to the south prior to 10.5 Ma. They continued to tighten during Cruse time, separating the Cruse and Manzanilla basins. They could not have formed entirely since 10.5 Ma because we cannot account for the required shortening in Cruse and younger rocks were this the case. Much of this offset must have occurred when the Moruga and Guayaguayare culminations were forming, and matches well with our estimate of pre-Cruse shortening. Our mapping of young structures supports the "traditional" ca. 10 km Pleistocene offset, which matches with our shortening estimate for the Rock Dome thrust slice. We will explore the development of the Los Bajos Fault further in a companion paper.

Finally, this view of the culmination of Middle Miocene thrusting and its relation to shallower structures has several profound implications for petroleum systems of onshore southern Trinidad and adjacent offshore areas.

First, vitrinite reflectance and other data suggest that peak maturity was only reached in many areas after the deposition of the Cruse and younger section. Thus the southern basin source kitchen had already been compartmentalised by thrusts before peak maturity, and this should have prevented oil migration south of the Southern Range, into the Columbus Channel and on into Venezuela. Hydrocarbons generated after Middle Miocene orogeny were focussed towards the main culminations in the Cretaceous, and smaller culminations in Herrera and other potential reservoirs. The Columbus Channel has failed to produce oil because there is no way to migrate oil into it from onshore Trinidad, and there are no paleostructures at Cretaceous level to prevent migration to the south/southwest of oils generated within the Columbus Channel itself.

Second, the relationships of Herrera and Karamat sandstones to the Middle Miocene culminations can be deduced from seismic reflector terminations and from well data. These indicate that an "early Herrera" (7a,b zones) sandstone facies was deposited ahead of an advancing thrust front in a broad foredeep axis. This sandstone fairway is of fairly uniform thickness and may extend into the Columbus Channel. Heavy mineral and petrographic data indicate a provenance from the northwest or west, with chert and argillite fragments ("pepper") deriving from uplifted Cretaceous strata of the Venezuelan Serranía Oriental and exotic metamorphic minerals (e.g. chloritoid) coming from farther west via a proto-Orinoco river or being recycled from uplifted Nariva sands. Lateral ramps such as the Los Bajos Fault may have played a key role in allowing rivers to cross southward over the orogen: the coarsest Herrera facies are blocks entrained within mud diapir material exposed in the core of the Southern Anticline at Galfa Point. "Later Herrera" and Karamat sandstones and Lengua shales, in contrast, are confined to the synclinal axes between rising Cretaceous-cored anticlines, and show reflector pinchouts onto these structures, indicating deposition in a piggy-back or wedge-top context. We expect provenance to be recycled and sand continuity to be more localised for these slightly younger reservoirs. In particular, they may be thin to absent in the Columbus Channel.

Third, it is now clear that structural trends and dips in younger strata are not a reliable indicator of structure at Cretaceous to Herrera levels. This is particularly clear when all available strike-lines in the Southern Basin are integrated into the analysis, as in this study. Contrasts between adjacent widely spaced dip lines indicate that significant deeper structural and combined structural-stratigraphic traps in these deeper strata remain to be found that may hold significant volumes of non-biodegraded oil or late thermogenic gas.