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A Planetary View of Mesozoic Plate Tectonics in the Gulf of Mexico

In many respects the geology of the Gulf of Mexico is better understood than other comparable marginal seas due primarily to its long history of drilling and reflection seismic acquisition by the petroleum industry. However, the petroleum accumulations and thick Tertiary section that attract industry also restrict scientific ocean drilling. To date only the carbonate margin of the southern Gulf and Quaternary fans in the deep eastern basin have been targeted. Discovering new details of the nature and timing of the opening of the Gulf basin, therefore, presents a considerable challenge. The goal of this ongoing study is to determine whether the opening of the Gulf of Mexico is a predictable manifestation of the planetary-scale superswell-related mantle stresses that drive the movements of major plates and to evaluate implications for Gulf of Mexico petroleum systems.

Predicting microplate kinematics within the poorly defined boundary zone that separates North Atlantic and South Atlantic spreading is pivotal in this analysis. It is postulated that the movements of continental microplates in the Gulf of Mexico are driven by mantle stresses that move first North America and then South America away from Africa.

While there is a considerable volume of published seismic and biostratigraphic data that provides credible evidence of Triassic - Jurassic rifting around virtually the entire Gulf margin, compelling evidence of significant pre-Berriasian (Jurassic) plate movements related to seafloor spreading and ocean crust formation is lacking. Although several seismic stratigraphic studies that transect the northeastern and western margins of the deep Gulf Basin suggest a Jurassic age for the oldest basin-filling sediments, interpreting Callovian (late Middle Jurassic) Louann Salt as autochthonous. It is equally plausible that the salt is allochthonous, having been included in the base of large superficial detachments containing post-synrift - pre-drift strata of late Jurassic and earliest Cretaceous age deposited originally on attenuated continental crust of Gulf Rim. The Sea of Cortez (Gulf of California) provides a well documented analog for this type of margin failure during early opening. Observations of Jurassic strata overlying undated oceanic crust therefore do not directly imply a Jurassic crustal age.

Outcropping and drilled Mesozoic strata of the Gulf rim, the presence of buried plume-related alkalic basaltic volcanoes of middle and Late Cretaceous age, and the geometric requirement that the Yucatan Platform be rotated into a position along the Texas - Louisiana margin to allow the reassembly of Pangea are the principal constraints on the origin of the Gulf of Mexico. There is general agreement among researchers that the opening of the western basin of the Gulf of Mexico reflects the counterclockwise rotation of a Yucatan microplate. Following recently published paleomagnetic evidence the Chiapas portion of the Maya Block is treated as a separate microplate in this study. It is recognized that the rotation of a Yucatan microplate about the relatively well-known Euler rotation poles that open the North Atlantic Ocean cannot account for the most probable trajectory of Yucatan. Published opening solutions designed to provide an ideal Yucatan trajectory are purely kinematic, not addressing the implications of a unique Gulf of

Mexico stress field on planetary scale mantle processes that drive plate motions.
Departing from a purely kinematic solution for Yucatan microplate motion, this study focuses on a rotation geometry linked to the stresses that move the major North and South American plates. Details of the predicted timing and direction of Yucatan microplate rotation thus depend on the changing relative positions of the well known North Atlantic and South Atlantic Euler (rotation) poles. Comparison of North and South Atlantic rotation poles and the history of Berriasian to Barremian (Neocomian) rifting between South America and Africa, which heralded development of a South Atlantic stress field, directly imply a post-late Berriasian (Cretaceous) opening of the western Gulf of Mexico. Application of the South Atlantic opening pole positions and angular velocities to the opening of the western Gulf of Mexico further predicts that Yucatan microplate rotation is mostly complete by early Aptian time (~109 Ma BP).

The new Gulf of Mexico microplate kinematics proposed here predict that most Gulf of Mexico seafloor (~60 %) was created during the Early Cretaceous period of stable geomagnetic polarity (120.4 - 83.5 Ma BP). The absence of obvious magnetic lineations in the deep western basin is therefore a predictable element of Gulf evolution. A further consequence of post-Berriasian opening of the western Gulf of Mexico is that the thick succession of Norphlet to Cotton Valley sediments that build up on thick Louann Salt (Callovian) in Oxfordian to early Berriasian time is likely to destabilize as Yucatan moves away from the Texas-Louisiana margin. The movement of large superficial detachments into the nascent Gulf Basin would cover virtually all of the oldest (Berriasian to earliest Aptian) oceanic crust located nearest the basin margin. Magnetic spreading anomalies M10N to M0 would thus be strongly diminished or completely destroyed. In applying a Gulf of California model, the superficial detachment phase in the western Gulf of Mexico Basin begins with the first plate movements initiated by mantle stresses and therefore very likely coincides with the development of the deeper crustal detachments that are characteristic of the early stages of asymmetric continental fragmentation.

Analysis of dated oceanic plateau basalt accumulations and the inferred tracks of related mantle plumes indicate that two hotspots transit the central Gulf of Mexico basin during the late Mesozoic. By holding mantle plumes fixed relative to Africa, a procedure considered valid for Atlantic hotspots, tracks are predicted that pass through the Gulf of Mexico at critical times in its evolution. One hotspot, recorded in conjugate oceanic plateau basalts of the Ceara and Sierra Leone Rises in the Central Atlantic, is traced to a Triassic position within the Central Atlantic Magmatic Province underlying the Bahamas and central Cuban microplates. The Ceara-Sierra Leone Rise hotspot exits the Gulf through South Florida in the Jurassic as North America begins moving away from Africa.
The second important Gulf of Mexico hotspot is recorded in accumulations of oceanic plateau basalts that comprise the Beata and Aves Ridges in the Eastern Caribbean. The Beata-Aves Ridge hotspot enters the Gulf region through West Texas, passing beneath the Rio Grande Rift in the Barremian. It is centered in the western Gulf basin in the middle Cenomanian and exits the basin beneath Yucatan in the early Campanian. The Bermuda hotspot is also important for explaining regional geology. It transits north of the Gulf basin proper, passing beneath the Mississippi Embayment in Turonian through Campanian time. Alkalic basalts of the northern Gulf Rim, which date between 110 and

60 Ma BP, probably record the combined effects of the Beata-Aves Ridge and Bermuda hotspots. The northern end of the modern Caribbean Arc may be pinned at the present location of the Beata-Aves Ridge hotspot.

Examples of Gulf Basin evolution constrained by this new planetary view of microplate motion are provided in a series of plate reconstructions that begin with the development of a rift valley system that breaks the Yucatan Platform off the North American Plate (Fig. 1) and ends with a fully opened Gulf of Mexico Basin (Fig. 2). Implications for the petroleum systems of the Gulf Basin are outlined in Table 1.

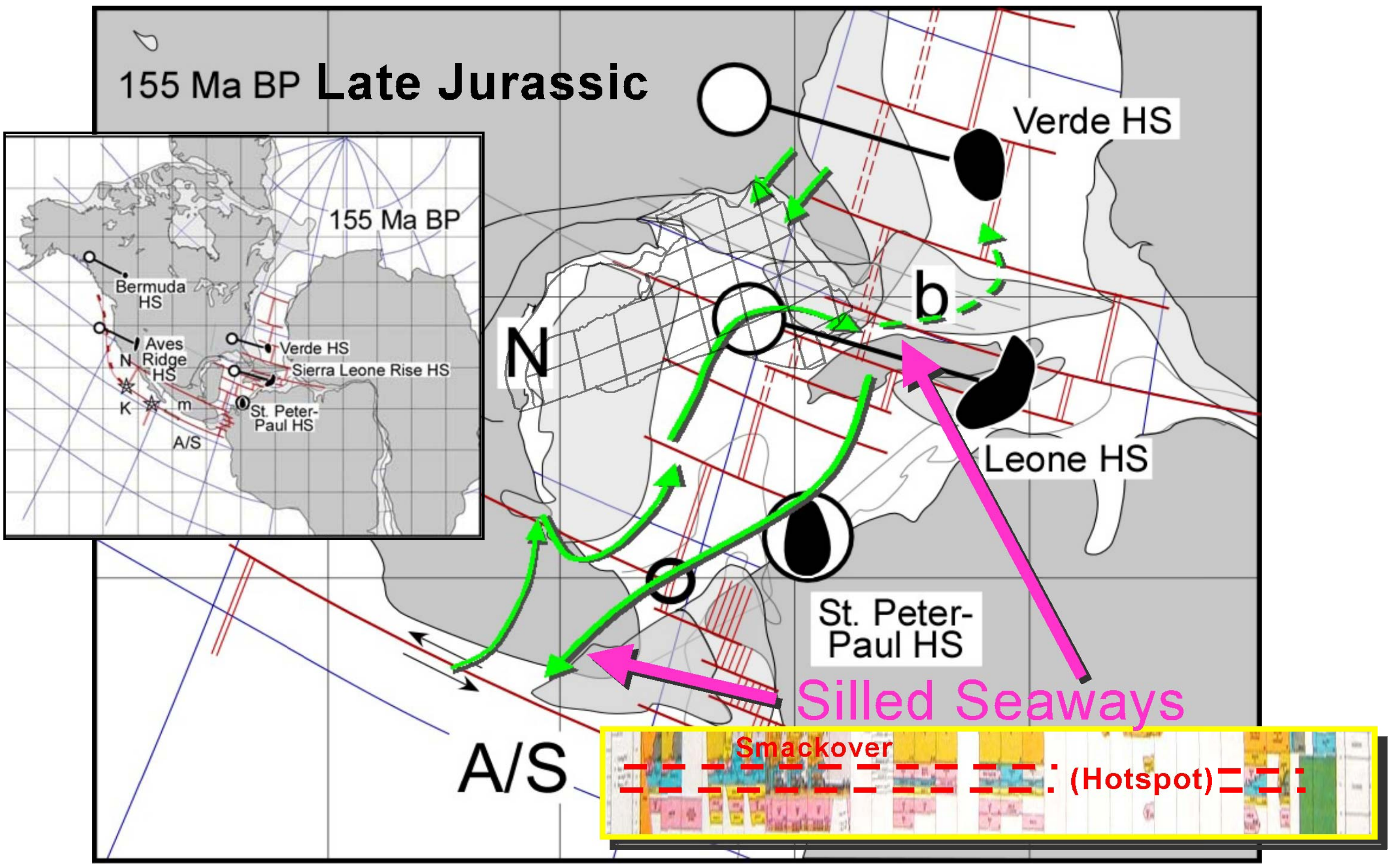

Figure 1. Plate tectonic reconstruction for the Late Oxfordian (inset at left) showing plate boundaries and hotspot tracks (fixed positions with respect to Africa). A/S= the African/South American Plate; N= the North American Plate; b= the Bahamas Microplate; K= the Kula Plate; m= Mexican block. The Yucatan Rift Valley which evolved in the Jurassic between North America and Yucatan received marine incursions from the south supporting shallow-water Smackover carbonate source-rock deposition. A center of Smackover source-rock deposition active in the eastern Gulf Basin was separate as indicated in the AAPG COSUNA correlation chart for the northern Gulf Basin (inset lower right). Smackover equivalent strata from South Texas (at left) to northern Florida (at right) is bracketed between dashed lines.

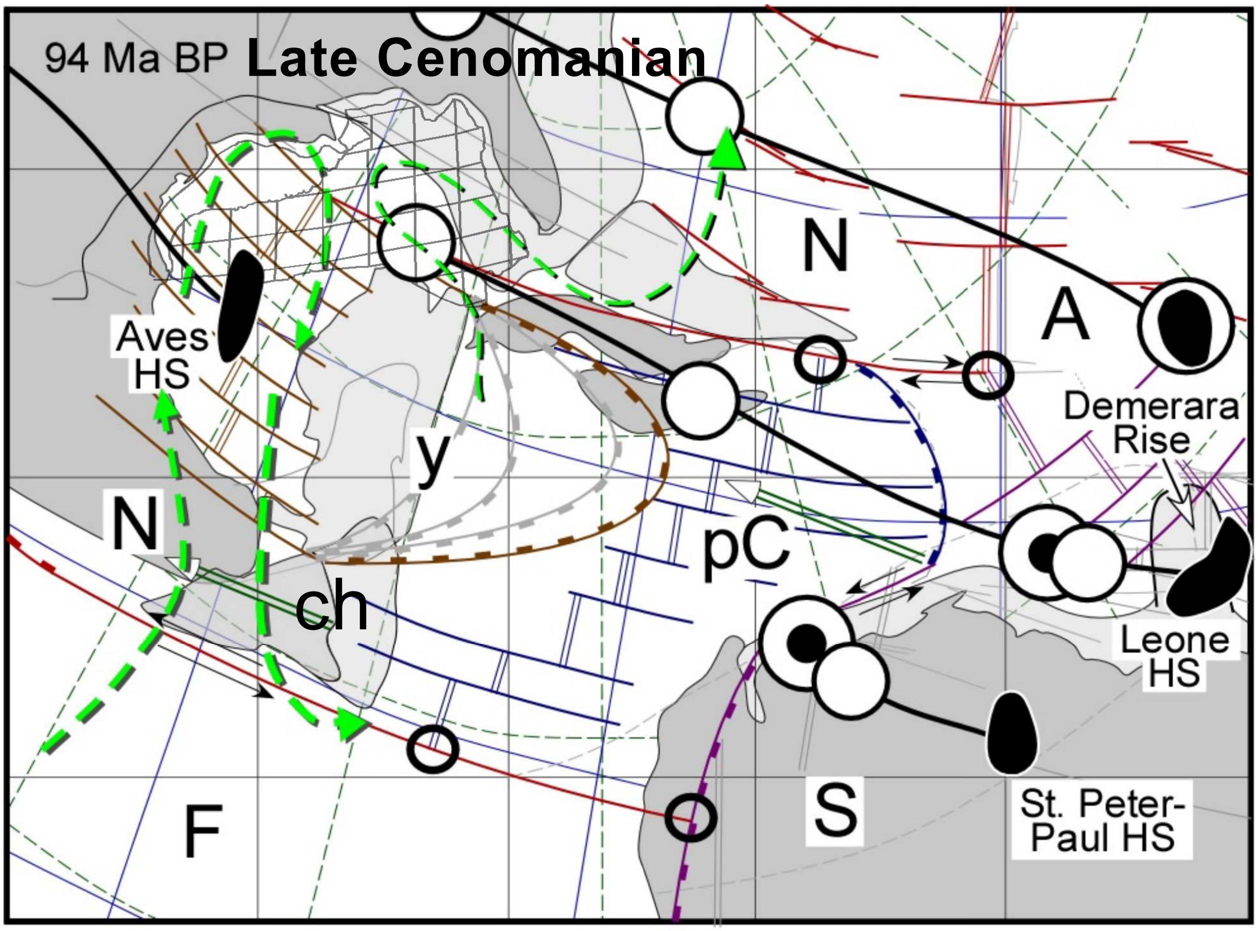

Figure 2. By about 94 Ma BP (late Cenomanian ~MCSB time) the western Gulf of Mexico is fully open. However, in the Late Aptian - Cenomanian the predicted passage of a Beata-Aves Ridge Hotspot beneath the western basin and implied subduction between the Yucatan microplate and South Florida may have elevated existing Greater Antillean blocks, thus restricting interchange with the Proto-Caribbean and Atlantic. Restricted circulation would have favored source-rock deposition. In this figure ch= the Chiapas Microplate; F = the Faralon Plate; pC= the Proto-Caribbean Plate; A= the African Plate; S= the South American Plate. The familiar modern outlines of Cuba and Hispaniola, provided for reference, include exotic terranes that came together in the Cenozoic.

Table 1. Implications for Gulf of Mexico petroleum systems.

Age	Epoch	Tectonic Activity	Paleo-Environment		Paleo-Water Depths	Heat Flow	Thermal Con-ductivity	Sediment Surface Temp-erature	Kerogen Type	Matur-ation Effect
			Western Basin	Eastern Basin						
>200 Ma	Norian - Rhaetian (Late Triassic)	Early rifting and attenuation of continental crust. Development of a Yucatan Rift Valley in the west and several rift valley systems in the east.	Arid Yucatan Rift Valley basins, some containin hypersaline lakes (Eagle Mills Fm.).	Complicated rift valley terranes with arid rift basins, some containing hypersaline lakes.	0-500m (along rift axes)	High heat flow in evaporite and sediment-starved basins, lower in basins with thick siliciclastic alluvial-lacustrine sediments.	High conductivity in evaporites low conductivity in alluvial-lacustrine section.	Warmer (25-35 oC) in dry basins, slightly cooler (20-30 oC) in lakes.	Predominantly Type I, possibly some Type III and IV.	
200 -155 Ma	Hettangian - Oxfordian	Late rifting in the west. Late rifting, early spreading, and developing transform margin in the east.	Arid rift basins in the Yucatan Rift Valley with frequent marine incursions through tortuous silled passages lead to accumulation of thick Callovian evaporites (Werner Fm., Louann Salt).	Accumulation of thick evaporites in rift valleys in the Callovian, followed by transgression and deepening at the edge of a rapidly widening Proto-Caribbean seaway which connected the early Atlantic basin with the Pacific across shallow silled Antillean and Mexican passages.	0-1000m (along western basin axis), 0-1500m (in eastern basin)	High heat flow in evaporite and sediment-starved basins, lower in basins with thick siliciclastic alluvial-lacustrine sediments.	High conductivity in evaporite basins, low conductivity in basins with thick alluvial-lacustrine sediments	Warmer (25-35 oC) in dry basins, slightly cooler (20-30 oC) in lakes.	Predominantly Type I and IIS, some Type III and IV.	Slower
155 - 135 Ma	Kimmeridgian - Berriasian	Early spreading in the western basin with active detachment faulting of raised Jurassic strata along the basin margins. Subduction of Proto-Caribbean seafloor begins with development of a trench-arc system in the southeast.	Narrow Salton Sea- like isolated dry and marine basins with narrow silled entrances, locally thick siliciclastic deposits (Lower Cotton Valley Gp.).	Development of a deepening trench off South Florida and local emergence of volcanic islands may have restricted the connection between the eastern Gulf and the Proto-Caribbean .	0-1000m (along western basin axis), 0-2000m (in eastern basin)	High heat flow in a narrow zone along the ridge axis and above evaporite section, low in areas of high siliciclastic accumulation rates and above detachments.	High conductivity where ridge is exposed, in hydrothermal areas and in thick evaporite section, low conductivity in thick siliciclastic section and within detachments	Warmer (25-35 oC) in isolated arid basins, cooler (15-20 oC) in marine basins.	Predominantly Type I and IIS.	Faster along margins and beneath detachments.

135 - 125 Ma	Valanginian - Hauterivian	Rapidly spreading basin with continued detachment faulting along margins. Persistent subduction along a trench-arc system in the southeast.	Sea of Cortez-like early Gulf with locally thick siliciclastic deposits (Upper Cotton Valley Gp.), connected by silled seaways to the Pacific and Proto-Caribbean	Continued development of the trench and island arc off South Florida with increased potential for isolation of the connected eastern and westewrn Gulf basins from the Proto-Caribbean.	500-1000m (along western basin axis), 0-2000m (in eastern basin)	High heat flow in a narrow zone along the ridge axis and above evaporite section, low in areas of high siliciclastic accumulation rates and above detachments.	High conductivity where ridge is exposed, in hydrothermal areas and in thick evaporite section, low conductivity in thick siliciclastic section and within detachments	Normal marine (10-15 oC)	Predominantly Type IIS and II.	Faster along margins and beneath detachments.
125 - 115 Ma	Barremian - Middle Aptian	Development of a mature spreading basin with widespread thermal subsidence away from the spreading center. Minor detachment faulting continues along basin margins in the north and west while subduction continues in the southeast.	A broad, recognizable Gulf of Mexico probably connected by silled seaways to the Pacific. Locally thick siliciclastic and carbonate deposits (Hosston and Sligo Fms.). The continued development of a trench off southern Florida causes shoaling in the eastern Gulf basin, with increased potential for isolation of the connected eastern and western basins from the Proto-Caribbean and Atlantic.		1000-2000m (along western basin axis), 0-2000m (in eastern basin)	High heat flow in a broader zone along the ridge axis and above evaporite section, low in areas of high siliciclastic accumulation rates and above detachments.	High conductivity where ridge is exposed, in hydrothermal areas and in thick evaporite section, low conductivity in thick siliciclastic section and within detachments	Normal marine (8-10 oC)	Predominantly Type IIS and II.	Faster along margins and beneath detachments.
94 - 80 Ma	Turonian - Early Campanian	Thermal subsidence resumes in the western and eastern Gulf basins following passage of the Beata-Aves Hotspot into the western Caribbean and the cessation of arc volcanism in the southeast. Passage of the Bermuda Hotspot beneath the Mississippi Valley Embayment, however, leads to continued volcanism in the north-central Gulf basin.	Local volcanism in north-central Gulf basin creates a series of islands. Locally thick siliciclastics and later carbonates in the east (Upper Tuscaloosa, Eutaw, Selma Fms.) and mixed siliciclastic and carbonate deposits in the west (Eagle Ford, Austin, Taylor Fms.).The deepening eastern and western Gulf basins are connected by shallow silled seaways to the Atlantic and Proto-Caribbean (Gulf Loop Current) with tectonic isolation less likely. A tortuous connection to the Pacific through a developing Middle America arc system is possible.		1000-2000m (along western basin axis), 1000-2000m (in eastern basin)	Locally high heat flow in the western Gulf due to residual effects of the Beata-Aves Hotspot and passage of the Bermuda Hotspot through the northern Mississippi Valley Embayment. Locally high heat flow in eastern Gulf above evaporite section and low heat flow in areas of thick siliciclastic section and above detachments.	High conductivity in volcanic and hydrothermal areas and in thick evaporite section, low conductivity in thick siliciclastic section and within detachments.	Normal marine (6-10 oC)	Predominantly Type II and IIS.	Slower in response to reduced accumulation (and erosion). Faster later in the period along margins and beneath detachments.