EFFECTS OF INHERITED PRE-JURASSIC TECTONICS ON THE U. S. GULF COAST

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ABSTRACT

The Triassic separation of North America from South America resulted in an irregular fragmented arc which now extends from Central America to South Florida. Stranded blocks of continental crust control the location of major basins over the attenuated crust between the stranded blocks, permitting early thick evaporite precipitation and thicker than normal sediment deposition.

Post-rifting tectonic patterns retain an inherited fabric reflecting the Triassic rifting. Triassic horsts, grabens, and half-grabens localized and delineated later "microbasins," herein defined as a limited area of deposition, the boundaries of which reflect, or can be presumed to reflect, buried basement-related faulting.

Mapping of trend offsets indicate that NW-SE linear patterns exist and imply the presence of small-scale strike-slip "transform" faults within these basins that control the lateral position and size of individual microbasins. Mapping of these microbasins is essential to the understanding of exploration play concepts within a geologic province. It is inferred that many Gulf Coast growth-fault basins are at depth related to basement block-faulting and thus fit this definition of microbasins.

Irregular thicknesses of Louann salt have resulted from salt precipitation on a block-faulted basement. The uneven thickness of salt within individual grabens and half-grabens has controlled the spatial distribution and size of the resultant salt domes, pillows, and withdrawal areas. This salt movement is one link between the original basement block faults and the resultant growth fault basins.

INTRODUCTION

A simple descriptive model is proposed to explain the post-Triassic tectonic framework of the U. S. Gulf Coast. Cycles of rifting, quiescence, and ocean closure have been repeated along NW-SE paths from the Precambrian to the Recent (Feldman, 1986; Burgess, 1976; Wood and Walper, 1974; Rankin, 1976; and others).

The latest cycle begins with Triassic rifting along the Atlantic and Gulf Coast margins of the United States. The zone of basement block-faulting along the U.S. Gulf Coast is inferred to be equivalent to the area of transitional crust (Pilger, 1981). Major basins are located over attenuated crust thinned during Triassic rifting (Worzel and Watkins, 1973; Burke et al, 1984; and Pilger, 1981). River delta systems are associated with most of these basins. Along the Gulf Coast, these basins are separated by stranded blocks of continental crust. The Sabine uplift, Monroe uplift, and Wiggins arch are examples of such blocks (Worzel and Watkins, 1973; Wood and Walper, 1974). The former position of the Yucatan Peninsula is now occupied by the salt dome basins of Southeast Texas, South Louisiana, and Central Mississippi (Pindell, 1985).

Within these basins, microbasins formed over Triassic grabens and half-grabens (Adams, 1989). Small-scale transform faults define the strike limits of these microbasins. Cretaceous reefs developed over the leading edges of certain horsts and counter-rotated half-grabens in response to bathymetric conditions influenced by the pre-Jurassic fabric. Breaks in the reef margin are localized over the small scale transform faults. These breaks define pathways for later sediment transport and sites for preferential sand deposition.

Farther basinward, salt deposition filled in irregularities in the fragmented bottom topography comparable to the Danakil area of Ethiopia (Halwerda and Hutchinson, 1968). Resultant salt thicknesses were inversely proportional to topographic relief on the post-rift block-faulted surface. The initial irregular salt thickness influenced the size, shape and spatial distribution of the resultant salt pillows and piercement features.

TECTONIC FRAMEWORK

Late Precambrian rifting (800 Ma) separated North America from South America and Africa along a zone of alternating inward and outward facing aulacogens (Rankin, 1976). The Delaware, Southern Oklahoma and Reelfoot rift systems are integral parts of the U.S. Gulf Coast and reflect orthogonal tectonic patterns along northwest-southeast and northeast-southwest patterns (Fig. 1).

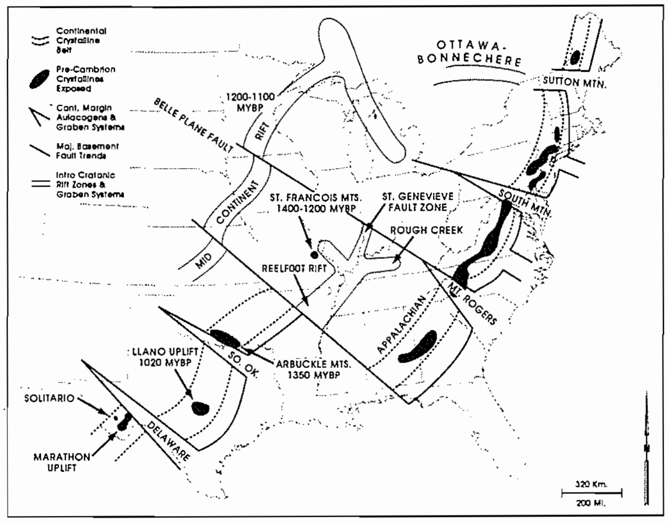

Figure 1: Precambrian tectonic features of the U.S.

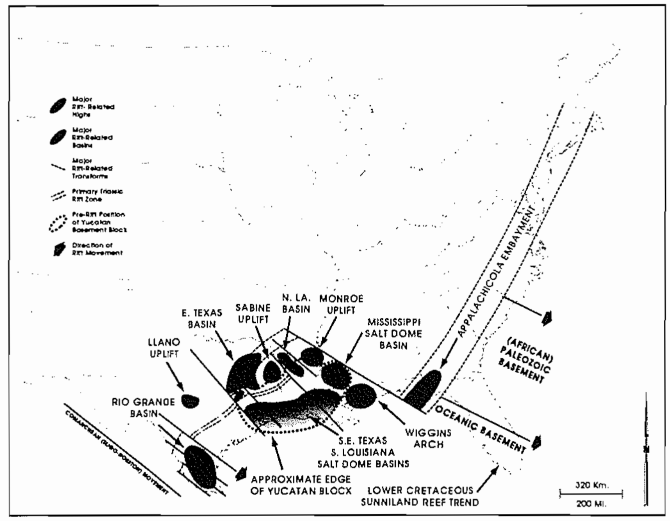

Figure 2: Triassic Tectonic Features of the U.S.

The Acadian-Alleghenian-Ouachita-Marathon orogeny records the closure of the Proto-Atlantic in a scissor-like motion from northeast to southwest; beginning in the Devonian in the northeastern U.S. and ending in the Permian in the Huastecan structural belt of Mexico.

During Pennsylvanian time, the zone of active sedimentation and deformation shifted 300 to 400 miles (420 to 580KM) northwest from the southern Appalachians to the Ouachita area of Arkansas and Oklahoma. This major northwest translation in the collision zone coincides with the end of North America-Africa collision and the start of North America-South America collision.

Coincident with this change of collision site came a change in the structural style of deformation. The large Precambrian granitic masses of the Appalachians acted as buttresses that concentrated the thrusting and deformation into a relatively narrow, straight zone from New England to Alabama. But from Arkansas to the Big Bend area, smaller localized basins are separated by small, mostly northwest-southeast highs.

The supercontinent Gondwanaland began to break up into its former components during the Triassic. The opening of the Gulf-Atlantic took place by a scissor action from southwest to northeast, an exact reversal of its closure in the late Paleozoic (Fig. 2). This rifting, with its attendant axial uplift and block faulting, took place in an arid climate. Resultant evaporite sedimentation was similar to the Danakil area of Ethiopia where evaporite wedges filled in rotated half-grabens along the flanks of the Red Sea Rift Zone (Halwerda and Hutchinson, 1968).

As North America scissored away from South America and Africa, a restricted sea formed over the rift sag. The restricted sea covered only the area being vacated by South America (Pindell, 1985). The pull apart rift motion was probably oriented northwest-southeast, parallel to the transform line from Little Rock, Arkansas, to Pensacola, Florida. The area southwest of this line was being vacated by South American (and Yucatan) crust and outlines the margins of the current Gulf Coast Basin.

The Gulf Coast margin is a fractured remnant having deep basins floored by new oceanic crust or thin transitional crust, separating large blocks of continental crust which moved early in the rifting process and were stranded as spreading centers jumped south (or southeast). The Sabine uplift, Monroe uplift, Wiggins arch and Yucatan are such blocks of stranded continental crust. The presence of rift structures north of these blocks supports the early movement and later stranding as spreading centers jumped to the south.

An outline of the continental crust under the Yucatan covers nicely the area between the Sabine, Monroe, and Wiggins positive elements, and represents the site of the thickest salt deposits on the Gulf Coast (Fig. 2).

The presence of a north-dipping wedge of red beds of probable Triassic age on the north edge of the Yucatan block is supportive of a pre-rift interpretation with the Yucatan tucked into what is now South Louisiana (Nairn, 1975).

Data suggest that post-rift tectonic activity along the U.S. Gulf Coast has been minimal. South and West Texas record evidence of Laramide reactivation of faults associated with the Delaware aulacogen (Fig. 3). This is expressed in Texas as the Frio River line (Ewing, 1987), the Texas lineament (O'Driscoll, 1979) or the Texas corridor (Pindell and Dewey, 1982). The resultant northwest-southeast aligned linear features are important to the understanding of South Texas geology. Of equal or greater importance is the implication that northwest-southeast linear elements are present across the entire U.S.Gulf Coast, and that they are a critical part of the structural-stratigraphic relationship (Fig. 4).

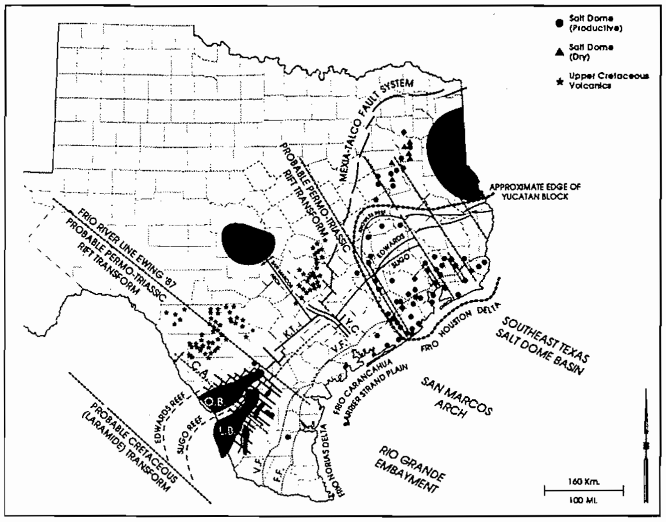

Figure 3: Tectonic Features of the Texas Gulf Coast. Major linears divide the Texas Gulf Coast into three provinces; the Rio Grande Embayment, the San Marcos Arch (in an expanded sense), and the Southeast Texas salt dome Basin, each with separate and distinct structural and stratigraphic histories. Stratigraphically, the San Marcos Arch has remained a predominantly strandplain complex throughout much of the Tertiary, separating major delta systems in Southeast Texas and the Rio Grande Basin (Galloway et al, 1982).

Abbreviations: C.A.= Chittum Anticline; O.B.= Olmos Basin; L.B.= Lobo Basin; K.T.= Karnes Trough; V.F.= Vicksburg Flexure; F.F.= Frio Flexure; Y.C.= Yoakum Channel.

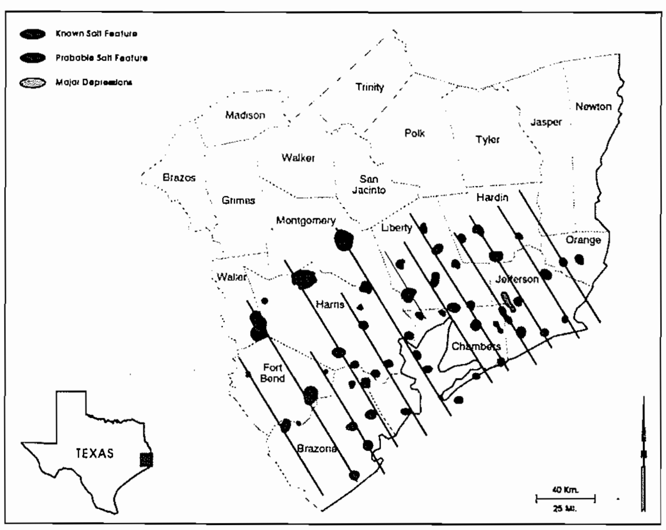

Figure 4: Southeast Texas Salt Feature Map- Nearly all of the salt domes and ridges in the Southeast Texas salt dome Basin can be mapped to fall along sets of NW-SE parallel lines, matching the direction of elongation on salt ridges such as Stowell and Fig Ridge. Spacing of the lines is remarkably uniform across the basin and supports an ordered origin for these linear features.

The post-rift sequence is a typical passive trailing margin sequence that records the non-marine (Triassic) to marine (Cretaceous to Recent) development of the Gulf Basin. The Cretaceous to Recent sediments form a major regressive clastic wedge that is filling the Gulf Basin from the north and northwest.

The influence of dip-oriented northwest-southeast linear features on this sediment package is critical to the microbasin model presented in this paper.

MICROBASINS

Evidence of a block-faulted "Pre Jurassic" basement is present from Texas to Florida. Zamboras (1988) shows Paleozoic blocks underlying ooid grainstone shoals in the Cotton Valley Lime in Limestone County of East Texas. The basement highs are critical to the formation of seafloor highs over which the ooid shoals develop, and to the post-depositional movement that induced fracturing of the reservoir rocks. Sigsby (1976) notes that differential deposition of salt across pre-salt faults is a key to syndepositional faulting that influenced the depositional pattern of facies in the Smackover Formation in the Big Escambia Creek-Jay-Blackjack Creek area of Southern Alabama and the Florida Panhandle. Fowler (1964) demonstrated a structural relationship between the Smackover structure of certain fields in the Ark-La-Tex area and presumed wrench fault movement on basement faults.

The presence of a demonstrable relationship between pre-Jurassic tectonic elements and Jurassic sedimentation patterns around the northern rim of the Gulf of Mexico suggests the presence of a comparable relationship in younger sedimentary sequences; eg, major rivers such as the Mississippi and the Rio Grande occupy positions within Precambrian aulacogens much as their precursors have since the Paleozoic (Fig. 1).

Inferences from seismic data, regional structure mapping, and surface lineament analysis suggest that northwest-southeast trending linear features are present in the basement below the Jurassic to Recent sedimentary wedge along the U.S. Gulf Coast. They also imply that apparent transform-like offset exists across these northwest-southeast oriented features. Transform offset by these faults of a terrain comprised of NE-SW trending horsts, grabens and counter-rotated half-grabens will generate a linear fault having a large components of dip slip offset that can change dip direction from side to side along its strike based on the precise juxtaposition of individual horsts, grabens, and half grabens across the fault. The South Texas regional seismic line demonstrates what this terrain looks like in a dip direction (Fig. 5).

The resultant topographic surface would have rows of horsts, grabens and half-grabens striking northeast-southwest with individual fault block terminations lined up along the northwest-southeast trending transform faults (Fig. 6). These transform faults would be expressed in the overlying section as inflection points or offsets in the strike of regional faults, as dip-oriented

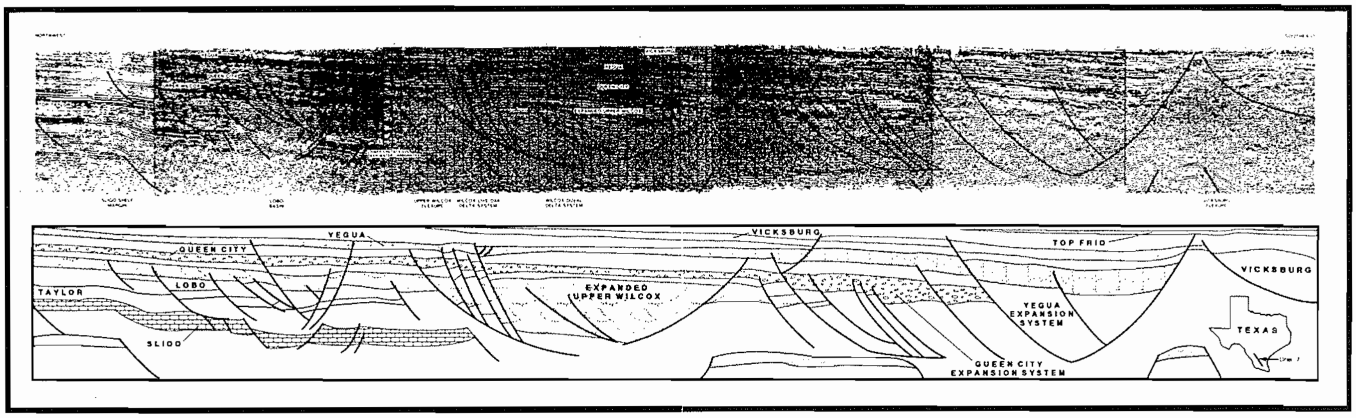

Figure 5 : South Texas Regional Seismic Line- Pre-Jurassic block faulting is reflected in younger sediments as a dip progression of fault-bounded basins separated by narrow horst blocks. Carbonate reefs such as the Sligo shelf margin are located over the leading edge of basement horst blocks. Microbasins; such as the Olmos basin, Lobo basin, upper Wilcox flexure, expanded Queen City trend and Vicksburg flexure are located over basement grabens or counter-rotated half-grabens. Deep reflectors near the bottom of the section are probably Jurassic and are not the Pre-Jurassic basement. Special thanks to P & L Seismic, Seismic Exchange and American Seismic for granting permission to publish this section.

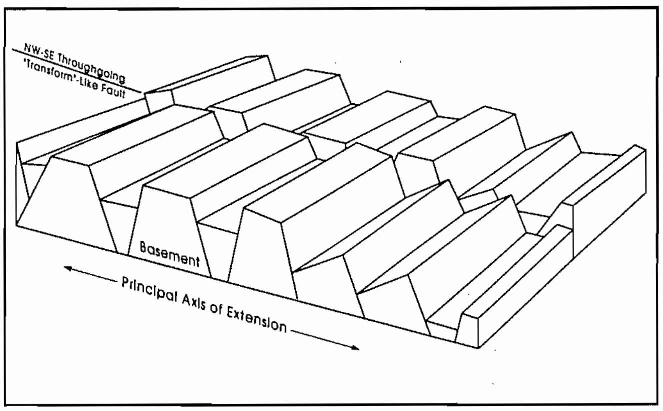

Figure 6: Immediate Post-rift block-faulted basement, South Texas model. A block-faulted basement with relief up to 1000' (305m) or more is used as a starting point. A NW-SE 'transform' is present separating two similar, but not necessarily identical, terrains with an apparent right-lateral offset.

linear patterns of salt features (Fig. 4), as faults striking perpendicular to the normal trend of faults (Van den Bold et al, 1987), or as "coincidental" changes in stratigraphy that affect several different ages of sediments in nearly the same location or along a single dip-oriented line.

The term "microbasin" is herein defined as a limited area of deposition, the boundaries of which reflect, or can be presumed to reflect, buried basement-related faulting. In this context a microbasin could overlay one or possibly more than one basement graben or half-graben, or; in the case of the Lower Cretaceous Edwards or Sligo reefs it may be defined by the highest edges of basement horst blocks.

The microbasin concept allows models to be constructed and compared to known areas along the Gulf Coast. The use of proper models will allow prediction of reservoir patterns in undrilled areas. Many more models can be made by altering the type and amount of sedimentation through time, by varying fault throws, or by basement fault reactivation.

Three microbasin models are presented which demonstrate basement-sediment pattern relationships for the South Texas Wilcox, the North Louisiana Smackover, and the Southeast Texas salt dome basin Miocene/Frio. Consistent elements exist for basement rock types and basement structural style. Each begin with a block-faulted terrain of horsts and grabens with occasional counter-rotated half-grabens. Northwest-southeast transform faults divide the models with apparent right lateral offset. In the South Texas Wilcox model and the North Louisiana Smackover model, the basement blocks are horizontal in a strike direction, for simplicity. In the Southeast Texas model, the basement blocks dip in a strike direction to demonstrate the effects of tilted basement blocks on the formation of salt domes.

The thickness of post-rift salt deposition varies from place to place with the salt generally thinner to the north and west and thicker to the south. Original salt thickness is an important variable in the microbasin model. Original salt thickness, coupled with the thickness of deep marine shales determines to a great extent the magnitude and timing of sediment-loading induced deformation (West, 1989).

SOUTH TEXAS WILCOX MODEL

The South Texas Wilcox Model combines clastic and carbonate reef deposition. Cretaceous Rudist reefs formed over the leading edge of some basement horst blocks, and clastic-filled basins formed over basement grabens and half-grabens.

Figure 5 demonstrates three of the fundamental elements of the microbasin model.

1) The presence of "deep" continuous reflectors interpreted to be later (Jurassic?) sediments that image the location of basement horst blocks.

2) The presence of major regional basins between the basement horst blocks.

3) The location of a carbonate shelf-margin over the leading edge of a basement horst block. This supports the relationship between basement block faulting and submarine topography.

The immediate post-rift topography (Fig. 6) is interpreted to be a block-faulted terrain of horsts, grabens, and counter-rotated half-grabens; all striking northwest-southeast. A transform fault having apparent right lateral offset crosses the model from northwest to southeast. The fault is shown having relief of 1000 feet (305m) or more. Actual relief probably varies greatly as some faults no doubt have much greater throws. Basement rock types are probably Upper Paleozoic Ouachita facies with basic igneous contributions increasing to the southeast.

Eagle Mills type alluvial fans are shown in some basement grabens (Fig. 7). These sediments are probably present in most, if not all, of the grabens and half grabens as a result of arid environment erosional processes. Partial coverage by Louann Salt precipitation filled the lowest parts of grabens and half-grabens with progressively thinner salt updip to the northwest. Salt precipitation is not as widespread as in the later models, but sufficient salt is still present to core such features as Palangana and Piedras Pintas salt domes in Duval County and Gyp Hill dome in Brooks County, among others (Posey, 1986; Raring, 1986). This evaporite section is covered by a thick section of marine shales and mudstones of presumed Jurassic age. This sediment thickness may have been sufficient for loading to initiate salt mobility.

The Lower Cretaceous Sligo reef (Fig. 8) is located over basement horst blocks. The reef front is offset along strike from basement block to basement block resulting in a "stairstep" map shape for the shelf margin (Fig. 3). Reef breaks are postulated to preferentially occur at the

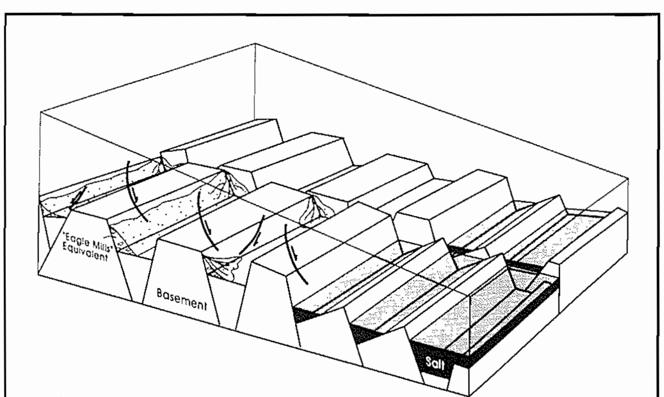

Figure 7: Early post-rift sedimentation, South Texas model.

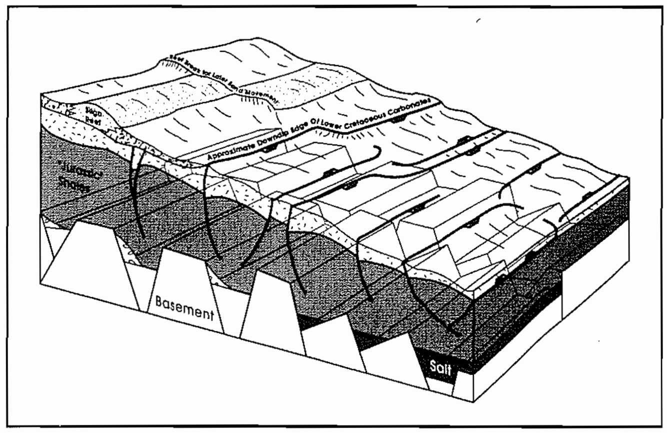

Figure 8: Lower Cretaceous Reef Deposition, South Texas model.

steps in the map pattern over the basement transforms. Later sands should be funnelled through these reef breaks into basins located over basement grabens in front of the shelf margins. In South Texas, the Olmos and Lobo basins are examples of this type of microbasin.

Laramide orogenic activity in the Western U.S. caused reactivation of some South Texas "transform" faults. Additionally, large volumes of sediments were shed from the newly emergent Rocky Mountains into the Rio Grande Basin. These sediments sequentially filled microbasins from NW (oldest) to SE (youngest). Rapid sedimentation and its resultant sediment loading combined with salt flowage to form regional growth faults in the upper Wilcox, Queen City, Yegua and Vicksburg sections (Fig. 5). Major sediment transport systems continued to be located over the basement transforms (Fig. 9). Longshore current activity will tend to elongate sediment patterns in a strike direction within each microbasin.

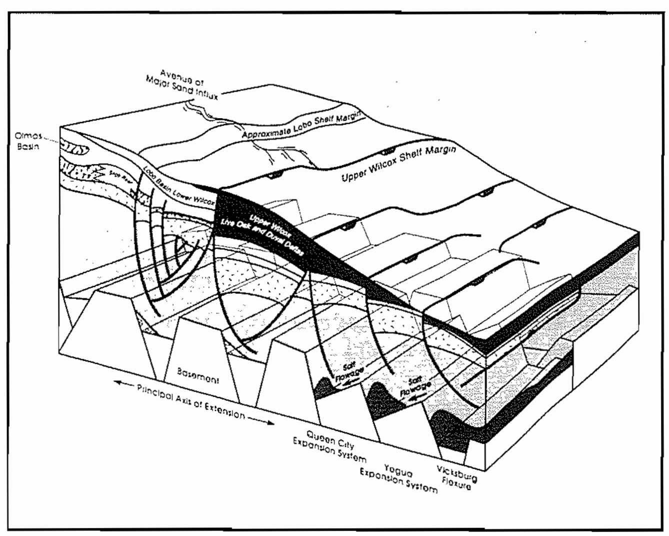

Figure 9: Eocene to Oligocene clastic deposition, South Texas model.

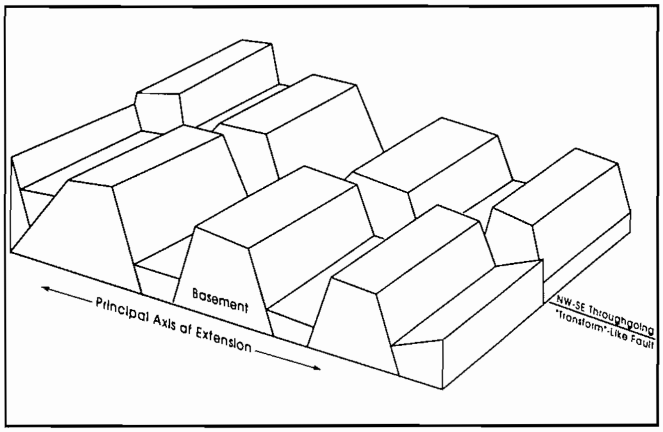

Figure 10: Immediate post-rift block faulted basement, North Louisiana Smackover model.

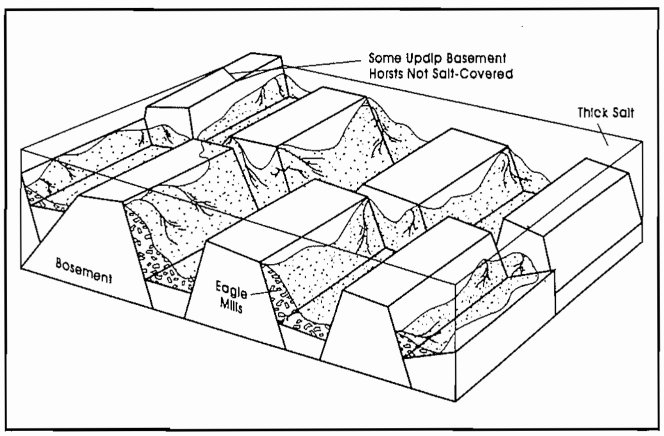

Figure 11: Post-rift Evaporite Deposition, North Louisiana Smackover model.

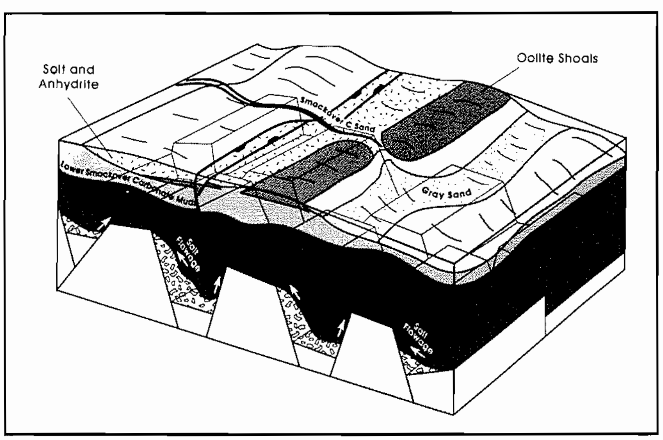

Figure 12: Smackover-Haynesville Deposition, North Louisiana Smackover model.

NORTH LOUISIANA SMACKOVER MODEL

Observations and data from studies in the Mesozoic trend from Florida to Texas imply certain similarities exist between producing fields in widely divergent geographic areas (Fowler, 1964; Sigsby, 1976; Zamboras, 1988).

The assumption is made that a block-faulted terrain resulted from Triassic rifting. Dip-oriented transforms cut through the series of horsts, grabens, and half-grabens producing linear trends that are oriented NW-SE (Fig. 10). Like the South Texas Wilcox model the transform is shown having apparent right lateral offset.

Erosion of basement horst blocks in an arid environment (Fig. 11) produced extensive alluvial fans, wadis, and eolian deposits in the adjacent grabens and half-grabens. Steeply dipping alluvial facies are thickest along the flanks of the eroding horsts. The later evaporite section of Werner Anhydrite and Louann Salt was precipitated in nearly all of the grabens and completely covered many of the downdip horst blocks. Original salt thickness was inversely proportional to pre-depositional topography.

Sediment loading initiated salt movement near the end of Smackover deposition (Fig. 12). Oolite grainstone shoals developed on the subtle topographic highs that formed over the basement horsts and the leading edges of certain counter-rotated half-grabens. Where offsets occurred along strike from basement horst to basement horst an equivalent offset occurred in the overlying grainstone shoals. Clastic influx entering the system was moved along dip-oriented dispersal channels that formed over the basement "transform" faults. Smackover "C" sands and the downdip Gray sand demonstrate these patterns (Judice and Mazzullo, 1982). Lateral facies changes can be very abrupt in carbonate depositional systems where bottom topography is affected by basement faulting.

SOUTHEAST TEXAS SALT TECTONICS AND GROWTH FAULT MODEL

As with the two previous models, this model begins with a block-faulted terrain of horsts, grabens, and counter-rotated half-grabens cut by a northwest-southeast trending "transform" fault having apparent right-lateral offset (Fig. 13). Unlike the previous models, the individual fault blocks also have a tilt in the northeast-southwest strike direction. This adds another component of realism to the later block diagrams of this model.

As before, a very uneven salt isopach results from salt precipitation on a block-faulted basement (Fig. 14). The direction and magnitude of dips on the pre-salt surfaces plus the salt isopach values will determine the location and type of resultant salt features.

Deep water shales of Jurassic to Eocene age spread in a nearly uniform interval across the top of the Louann Salt (Fig. 15). Critical sediment loading thickness was probably reached during this time and initiated salt flowage. With dip vectors in both a dip and strike direction on the pre-salt surface it is most probable that salt domes, pillows, etc. began to form over the corners of basement grabens and half-grabens. If this hypothe-

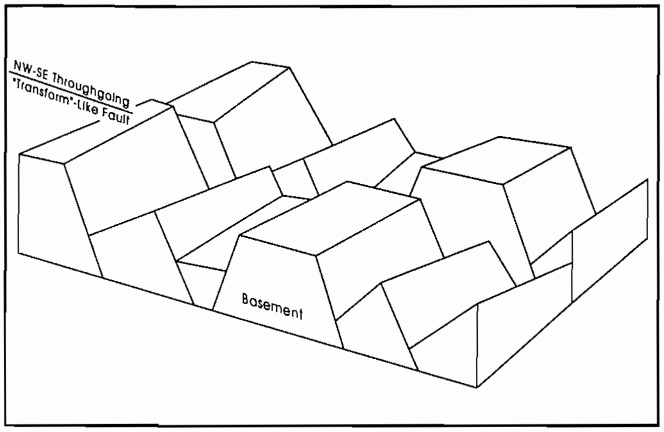

Figure 13: Block faulted basement terrain, SE Texas model.

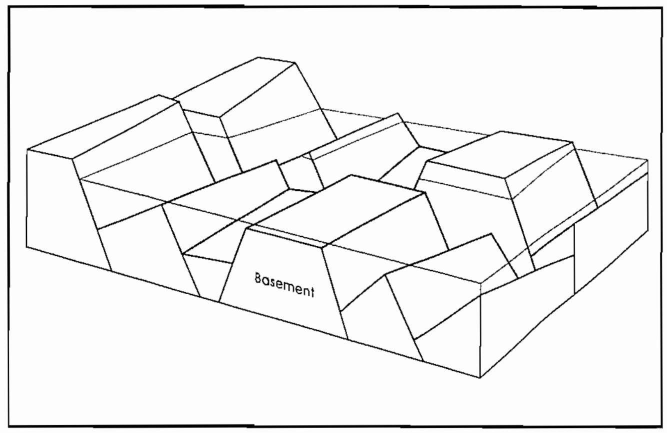

Figure 14: Salt precipitation, SE Texas model.

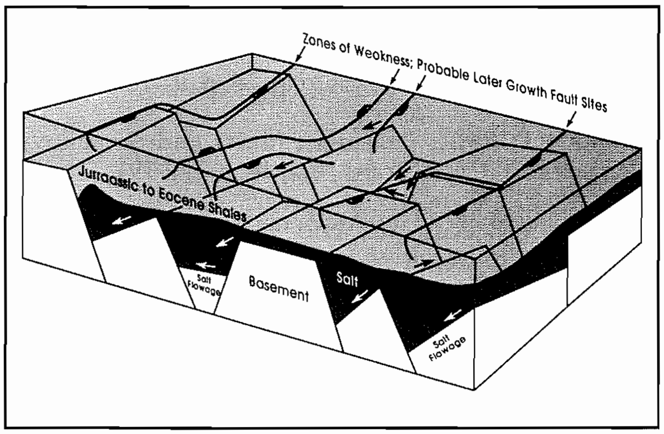

Figure 15: Jurassic to Eocene Shale Deposition, SE Texas model.

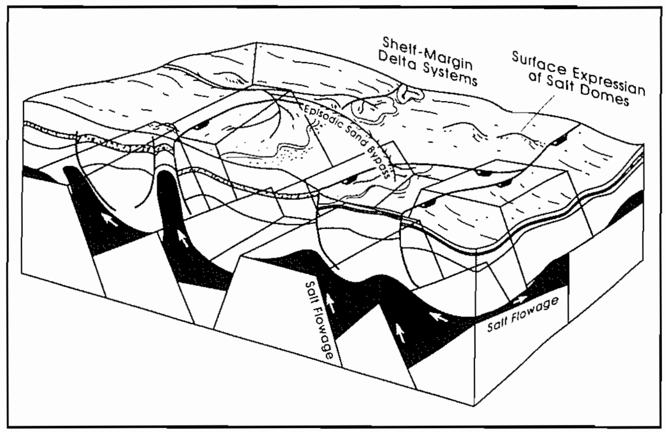

Figure 16: Oligocene to Recent Growth Fault Systems, SE Texas model.

sis is true, it would be expected that mapping of the current location of salt piercement features in the Southeast Texas salt dome basin would result in northwest-southeast linear trends. Figure 4 shows that in fact a case can be made for these northwest-southeast linear trends. Zones of weakness above the moving salt initiate at what will later be sites of major growth fault systems. The salt piercement features are frequently found at the nodes where arcuate growth faults meet.

Large volumes of clastic sediments were shed east and southeast from the Rocky Mountains as a result of Laramide Orogenic activity. In Southeast Texas and its adjacent offshore areas, these sediments range in age from Oligocene to Recent. Salt mobility had reached the point where some salt features had developed a topographic expression on the sea floor which influenced sedimentation sites and distribution paths (Fig. 16). At the same time, the sediment loading from this influx activated the earlier zones of weakness into growth faults which developed sub-parallel to the basement blocks beneath the salt.

Individual growth fault basins developed into discrete microbasins in response to both sediment loading and salt mobility. This explains the difficulty of correlating well logs which appear to be from similar areas, but in fact are in different growth fault basins. Individual growth fault basins filled with discrete ages of sediments, and were then bypassed in favor of a new sedimentation site. Primary growth fault sedimentation sites were generally near the shelf margin and secondary sites were normally in the upper and middle slope environment.

Major faults in the offshore are normally considered to run northeast-southwest. However Van den Bold et al (1987) demonstrate faults oriented northwest-southeast in the Banks area on the Louisiana upper continental slope based on high-resolution seismic data. It is possible to infer that these anomalous fault alignments are also related to basement, or at least salt-presalt features.

The study of the distribution of these salt features and growth fault patterns will help delineate basement transforms and help predict the distribution of sands in lightly drilled areas.

SUMMARY

Repeated and continued movement of crustal elements in North America along NW-SE paths resulted in rift and thrust features forming at right angles to that orientation. These linear elements can be seen from the Precambrian to the Recent in various parts of North America. Triassic rift features of the Atlantic and Gulf Coasts show the same underlying motion vectors. Along the Atlantic Coast, the Triassic rift took place along a single, straight zone. Along the Gulf Coast the rift area is fragmented and numerous stranded blocks of continental material are surrounded by transitional to oceanic crust. The areas between the stranded blocks of continental crust became the major depositional sites of the Gulf of Mexico basin. The former position of the Yucatan Peninsula is now marked by the location of the salt dome basins of Mississippi, South Louisiana, and Southeast Texas.

Within these major depositional basins, post-rifting tectonic patterns retain an inherited fabric from the Triassic rifting. Triassic horsts, grabens, and half-grabens localized and delineated later "microbasins," herein defined as a limited area of deposition, the boundaries of which reflect, or can be presumed to reflect, buried basement-related faulting. Mapping of depositional trends and trend offsets imply the presence of northwest-southeast linear patterns controlled by small-scale strike-slip or 'transform' faults in the basement which control the size and lateral extent of individual microbasins. Mapping of these microbasins is critical to an understanding of detailed depositional patterns. Sands may be continuous over an entire microbasin but have no counterpart just a short distance away in a different microbasin. It is implied that many growth-fault basins are at depth related to basement faults and thus fit this definition of microbasins.

Salt deposition on a very irregular block-faulted basement resulted in an original salt isopach which was an exact cast of the pre-salt topography. This uneven salt thickness controlled the spatial distribution and size of the resultant salt domes, ridges, pillows, and withdrawal areas.

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