At Long last! Regards and many thanks for an informative trip to your island! Richard H. Sams

Gulf Coast stratigraphic traps in the Lower Cretaceous carbonates

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Lagoonal rudistid patch reefs of Lower Cretaceous carbonates abound with facies change traps from Florida to Mexico and many of these contain extremely large but subtly hidden reserves of oil and gas.

To the imaginative explorationist these represent exciting targets for the drill bit.

But a workable geologic model that allows one to pinpoint an exploratory well location, a stratigraphic equivalent to the structural "Hickey," if you will, has not been forthcoming. Investigators of carbonate reef complexes have studied the rocks extensively in recent years on varying scales of observation from the regional to the petrofabric.

This has been done with an aim at producing useful depositional models, and although many models have been illustrated in the geological literature (Asquith 1979, Mazzulo 1980), few have indeed been of appropriate scale for the explorationist to confidently "aim his dart" at a drillable location reasonably expecting to make a discovery. Of those few models offered, or field examinations made, some consistent patterns emerge that have led this author to adopt what he terms as an "explorationist's model."

This article is therefore an attempt to demonstrate that model which in itself can be used as a prospecting tool upon which to locate a test well. I have started with the traps where the producible oil and gas are found and worked backwards to the geology of the depositional environment in an attempt to establish some rules as to where one should best direct his first test well efforts. Drawing from the relationship which the trap itself has to the regional and local environments of deposition, a fairly simple workable model relating facies change to a permeability barrier appears evident.

The explorationist's model has

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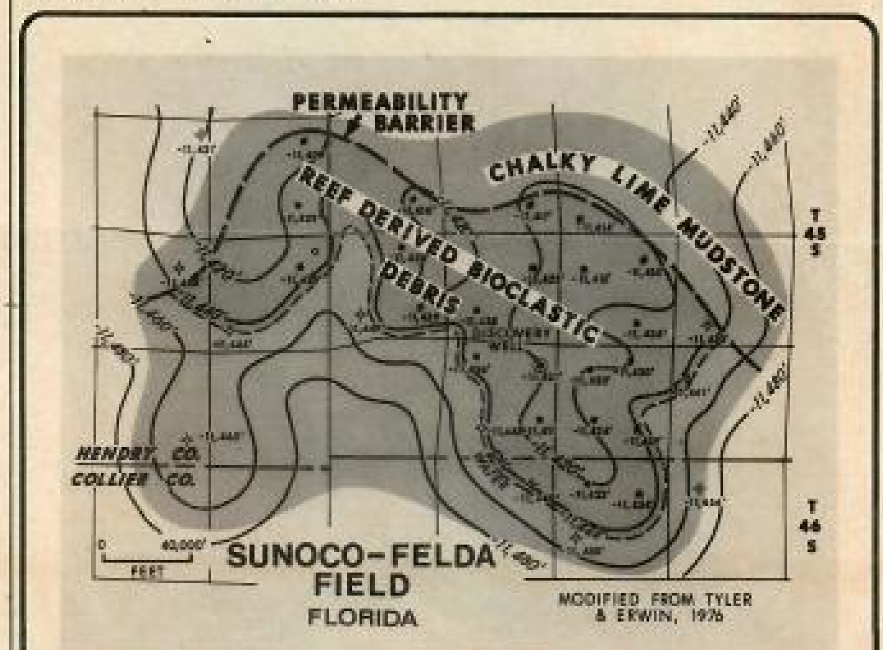
Fig. 1

Gulf Coast Lower Cretaceous*

*Carbonate shelves and basins (Modified from Bay, 1977). OGJ

Fig. 2

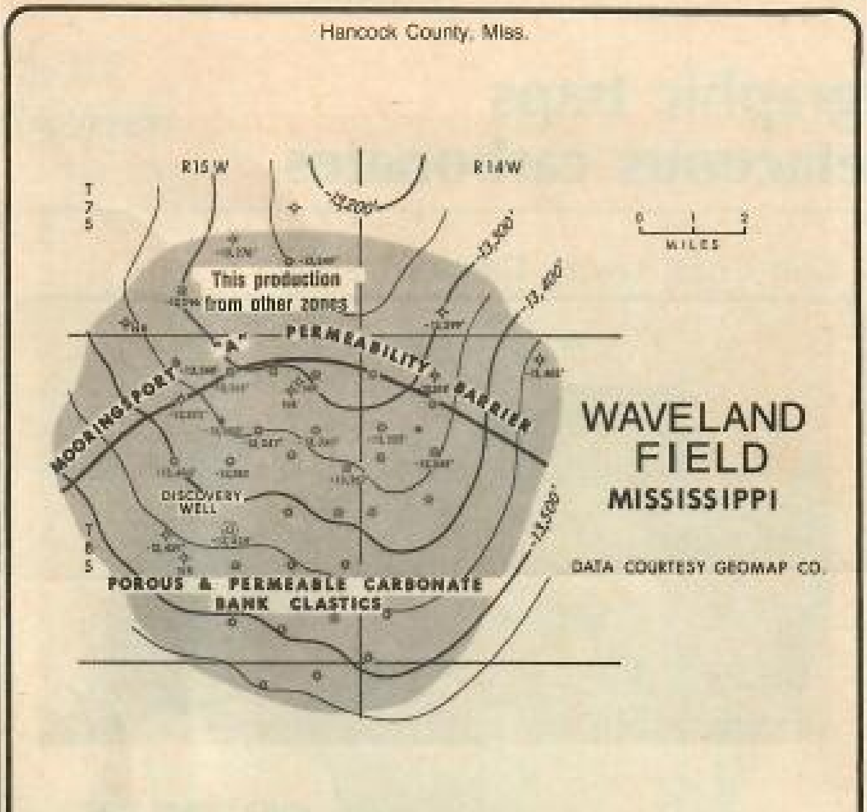
Sunoco-Felda field



Hendry County, Fla. (Modified from Tyler and Erwin, 1976). OGJ

Fig. 3

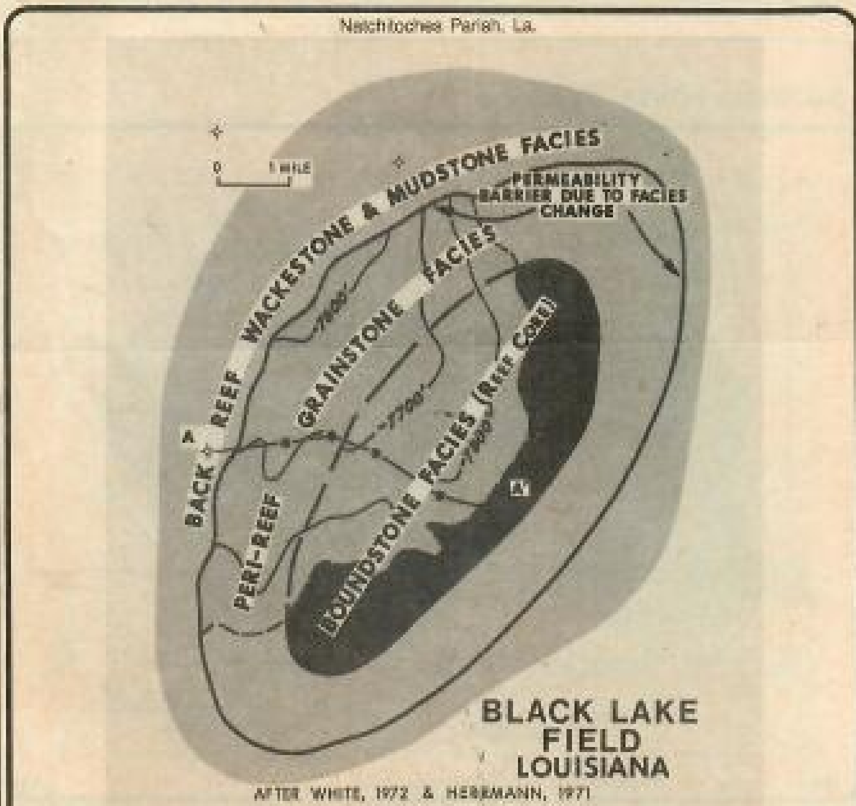
Waveland field



(Data courtesy GeoMap Co., also Sanneess, T., and Richard, Jr., personal communications)

Fig. 4a

Black Lake field



(modified from White 1921, and Herrmann, 1971)

been constructed from a review of those geologic occurrences of trapped oil and gas within carbonate units of the Lower Cretaceous along the Gulf Coast, particularly the patch reef banks and mounds, but an examination of the literature shows that most probably it has application in basins other than the Gulf Coast.

Descriptive carbonate terms among researchers also vary as the scale of observation varies from the regional to that of the borehole. Therefore, of necessity several excellent classifications of carbonate rocks have been applied by researchers depending upon their particular level of observation.

If one manages to correlate through the multiplicity of descriptive terms and learns to cross interpret such terms as "bioclastic" and "fragmental" or "plesparite" and "pelloidal grainstone," the mystery of it all begins to unravel into some relatively simple and therefore usable rules for reconstructing the depositional environment.

Among the classifications employed to describe carbonate rocks and their sedimentary facies, this author has found that the one derived by Dunham (1962) is to him the most useful from an explorationist's point of view, and it is therefore applied here.

That the trapping mechanism itself should be one related primarily to stratigraphy rather than structure is almost a foregone conclusion; otherwise the oil field to be discovered could more easily be delineated by the seismograph.

On the other hand, recent advances in seismic wavelet technology now indicate that the seismograph may be capable of delineating even these subtle traps if certain criteria are met.

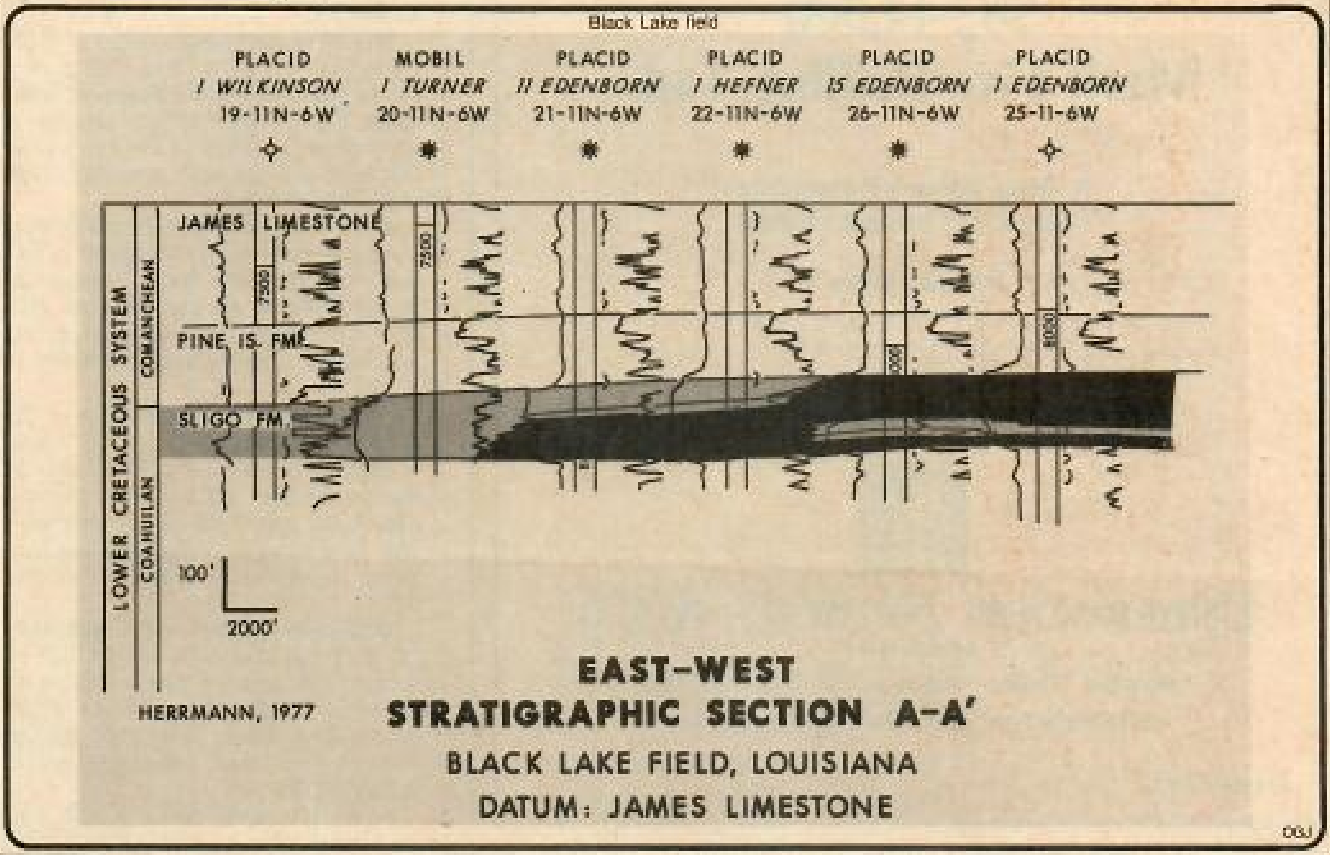
Patch reef, bank, and mound examples

The geological literature concerning oil and gas fields from Lower Cretaceous carbonates in the Gulf Coast describes a scattering of significant accumulations located from the southern tip of Florida all the way to central Mexico (Fig. 1). While the most significant Lower Cretaceous stratigraphic feature is the shelf edge barrier reef complex, the more prolific oil and gas fields of this scattering appear to be from patch reefs, carbonate banks, or debris mounds which were located on the shallow shelves behind the extensive barrier reef.

These isolated accumulations of reefal material are therefore perhaps a more attractive target for the explorationist than are the endless miles of

Fig. 4b

East-west stratigraphic section A-A'



barrier reef along the Lower Cretaceous shelf edge.

A brief summary of some of these examples follows in order to point out some significant similarities of the facies controlled stratigraphic traps.

Florida. Beginning at the southern tip of the Florida peninsula, there are 11 stratigraphically trapped oil fields producing from the Lower Cretaceous Sunniland limestone.

Tyler and Erwin (1976) document the entrapment of 44 million bbl of oil in place at Sunoco-Felda field (Fig. 2). They describe the reservoir as a "localized buildup of a part of a regional carbonate bank."

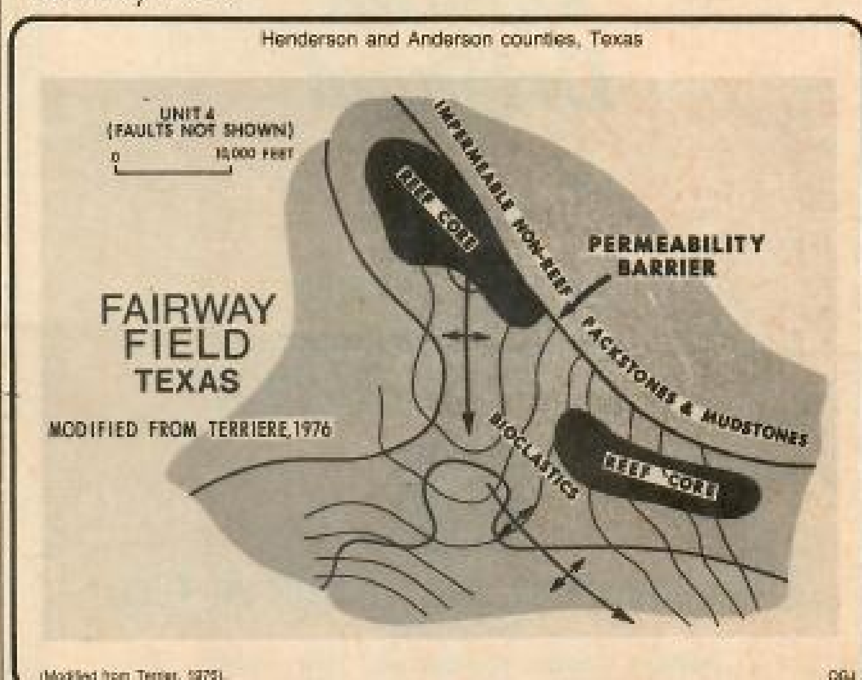
It is composed of highly porous and permeable reef derived pelletal grainstone. This rock type grades laterally into a miliolid chalky lime mudstone, and the facies change provides a permeability barrier which forms the updip limit of oil accumulation in the field.

Apparently, similar facies change permeability barriers account, at least in part, for the trapping mechanism in many of these other south Florida fields.

The bioclastic grainstones occur in individual reef pods or mounds whose dimensions are roughly 1½ miles wide by 3 miles long.

Fig. 5

Fairway field



Alabama-Mississippi. The Lower Cretaceous carbonate province touches only the southernmost tip of Alabama and very little more of southern Mississippi.

Only one significant field has been discovered in this region as yet; even though carbonates lie at depths of

10,000-12,000 ft and prolific production has been obtained from Lower Cretaceous sands of the Rodessa formation.

This field is Waveland field of Hancock County, Miss. (Fig. 3). It produces gas from the Morringsport limestone (Cate, et al. 1979) or possibly a downdip equivalent of the Ferry Lake (Richard and Sanness, personal communications 1981).

In 1979, an additional 14 Morringsport gas wells were completed in this field bringing the total number of completions to 30 gas wells on 640 acre spacing, thus demonstrating that it is indeed a major gas field (Cate, et al. 1979).

Two productive zones occur in the field and the uppermost or "A" zone is trapped across a structural nose as the productive, porous, and permeable facies gives way to an impermeable lime mudstone (Richard and Sanness, personal communications 1981).

Louisiana. In Louisiana, 669 billion cu ft of gas and 121 million bbl of recoverable oil were discovered in an apparent patch reef carbonate complex called Black Lake field (White and Sawyer 1966, Herrmann 1971, Bailey 1978).

Again the updip limits to the trap are provided by a permeability barrier formed by a facies change within the Pettet limestone (Fig. 4). A reef derived halo of porous and permeable oolitic grainstones changes laterally into lagoonal lime mudstones, and the permeability barrier is thus formed.

The patch reef boundstone core was encountered in several downdip wells.

It apparently is elongated having dimensions of roughly 3 miles by 5 miles, surrounded by 1 to 1½ miles of reef front beach grainstones and back reef washover grainstones.

Texas. In the East Texas basin, several notable oil fields have been found in the James limestone member of the Persall formation.

Terriere (1976) describes the huge Fairway field which has produced over 124 million bbl of oil since its discovery in 1960 and contains reserves estimated at 400 million bbl. While the trap at Fairway is a combination structural and stratigraphic trap (Fig. 5), the limit of production on the northeast edge of the field is a facies change to nonreef argillaceous limestone (Terriere 1976, p. 145). Thus, it is suggested that, here too, a facies change is responsible for a permeability barrier which forms part of the trap in the field.

In South Texas, significant production from permeability barrier traps has not yet been documented; although Loucks (1977) has described the presence of a favorable patch reef complex within the Cow Creek member of the Pearsall formation and oil and gas shows there are being evaluated (Fig. 6). On the other hand, the J.F.S. field in Dimmit County produces gas from a dolostone in the McKnight formation where porosity develops in the so called "transitional facies" along the edges of the Maverick basin (Fig. 7) (Jacka and Stevenson 1977).

It would appear that in this case a permeability or porosity barrier trap is present, but here it is affected by a facies change within the transition zone where the primary porosity of the grainstones has been occluded and a subsequent reversal of dip direction in response to Gulfward tilting now allows this barrier to become the updip seal.

Since its discovery in 1976, the J.F.S. field has produced approximately 18 billion cu ft gas from 11 wells.

Mexico. Rudistid patch reefs account for a significant amount of the 2 billion bbl of production from the El Abra limestone of the Golden Lane trend of Central Mexico (Fig. 8). The productive capacity and known trapping mechanisms, however, seem more related to postdepositional development of Karst topography and leached porosity than to the facies developed during deposition because known oil accumulations are confined to structural highs (Coogan, Bebout, and Maggio 1972).

Observed relationship

From these Gulf Coast examples, one can begin to see some common relationships among Lower Cretaceous patch reef production:

- Patch reef growth and development tends to favor pre-existing structural highs, even slight ones. The reefs tend to become elongated with a long axis normal to the direction of the basin.

Dimensions approximate 3-5 miles in width and length, respectively, but can vary greatly.

- Continued structural growth on these highs not only enhances further reef development but favors more prolific hydrocarbon accumulation by providing secondary leached porosity later on.

- Patch reef morphology favors three broad facies in a more or less concentric pattern. In the center is a reef core composed principally of boundstone facies of rudists growing in place.

This is covered and surrounded by a bank of bioclastic debris composed of grainstones and packstones, and yet further outward from the reef core lies the lower energy facies of wackestones and mudstones.

A modern day patch reef can be seen in Fig. 9.

This is an aerial view of Whale-Skate Island which is a part of French Frigate Shoals in the northwestern Hawaiian Islands.

While this island is only one of the 13 islets which form an atoll, it serves as an excellent Holocene analog of patch reef development. Note the island's position relative to the depositional basin which is in the background and to the right. Note also that it lies behind the fringing barrier reef of the atoll and is surrounded by many pinnacle reefs.

The aura of white carbonate sand beach is formed of bioclastic skeletal debris derived from the destruction skeletal debris derived from the destruction of the central coralline boundstone reef core and the surrounding pinnacle reefs.

The back reef washover zone illustrates the extensive influence from storm type high energy grainstone deposition combined with somewhat lower energy after storm packstone deposition.

One would imagine that the lower energy wackestone and mudstone deposition will occur here primarily in the final stages of burial when basinward tilting or subsidence reach a rate greater than the upward building rate of the coral boundstone reef core. (The ship located in the lee of the island suggests the present dimensions of this developing patch reef.)

When this patch reef dies through subsidence and is buried by low energy chalky lime mudstones and wackestones, the facies boundary established between these sediments and the high energy porous and permeable bioclastics will become a barrier to fluid migration early in the depositional history of the rocks formed. This early formed permeability barrier appears to provide the facies change stratigraphic entrapment which has been observed in the Gulf Coast examples cited above.

Basinward tilting of these early formed traps allows the back reef facies change to become the permeability barrier trap into which oil can migrate and become trapped during an early phase of burial. Therefore, the updip permeability barrier trap becomes the target for exploration efforts, and a geological model which predicts its presence becomes a useful exploration tool.

The explorationist's model

I, therefore, propose the following as a geologic model for a patch reef exploration (Fig. 10, 10a).

Briefly, the model is made up of (1) boundstone reef core, surrounded by (2) a halo of perireef grainstones. This is engulfed by (3) lower energy shelf and lagoonal in filled mudstones or wackestone.

The nucleus of the model is the reef core. This is made up primarily of the corals or rudistids growing in place and is what we generally associate mentally with the single term "reef" (Fig. 11a).

It may also be only a bank or mound of rugose debris where the reef framework once stood if the reef has been destroyed.

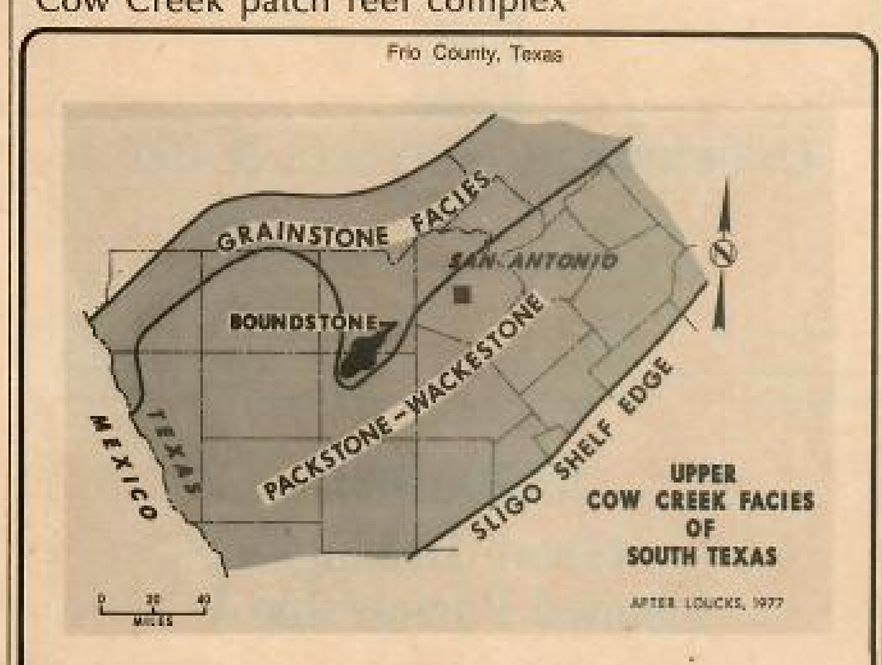
The reef core is rarely more than a mile wide and in length usually about 3-5 miles. Given sufficient time in a favorable environment reef cores may coalesce to form a fringing barrier reef which extends regionally hundreds of miles.

Under more hostile environments of subsidence or basinward tilting, however, they remain as isolated patch reefs of somewhat irregular, but elongated shape and more limited extent.

Loucks (1977) has shown that while

Fig. 6

Cow Creek patch reef complex



(Modified from Loucks, 1977)

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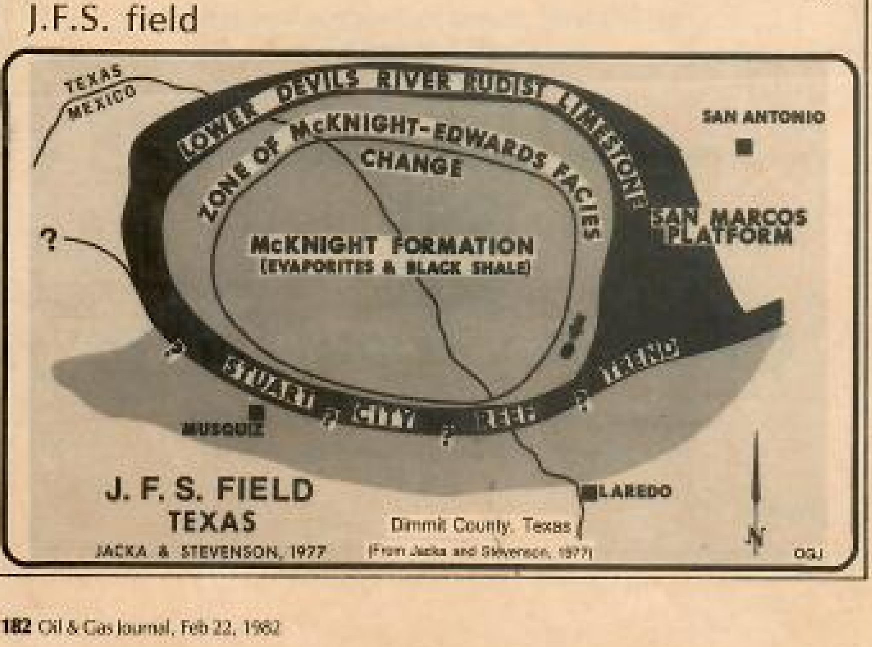
Fig. 7

J.F.S. field



(From Jacka and Stevenson, 1977)

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the boundstone facies has some porosity, it is often vuggy porosity and unless fractured or leached, it will have very little permeability.

It, therefore, generally represents a reservoir rock of only secondary importance.

The grainstones (Fig. 11b) are without doubt the most prolific and suitable reservoir rocks within the carbonate complex.

Their original porosities and permeabilities generally compare favorably to that of quartz sandstones unless altered diagenetically by secondary cementation.

In the barrier island reef complex, beach front grainstones commonly have been diagenetically altered so that the loss of porosity and permeability renders them unsuitable as reservoir rocks (Bebout and Loucks 1974).

On patch reefs, however, back reef and washover grainstones peripheral to the reef core may be more quickly buried by storm aftermath deposits of lagoonal mud if a source is present.

These have become the excellent reservoir rocks from which production is found as at Sunoco-Felda and Black Lake fields. Beyond the grainstones can be found the lagoonal lime mudstones, packstones, and wackestones or the basinal dark lime mudstones and low energy oncolite grain flats (Figs. 11c, 11d, 11e, respectively). While these rocks may have limited porosity, they rarely have much permeability unless it is due to fractures.

They, therefore, comprise an updip permeability barrier as the patch reef complex subsides or becomes tilted basinward.

This permeability barrier resulting from the facies change from grainstones to wackestones, packstones, or mudstones should follow the generally elliptical pattern and dimensions of the patch reef complex.

The prime target area for the exploratory effort should be the shaded area in (Fig. 10). These areas define zones in which maximum development of the grainstones should occur since both longshore current transport and storm washover transport occur together.

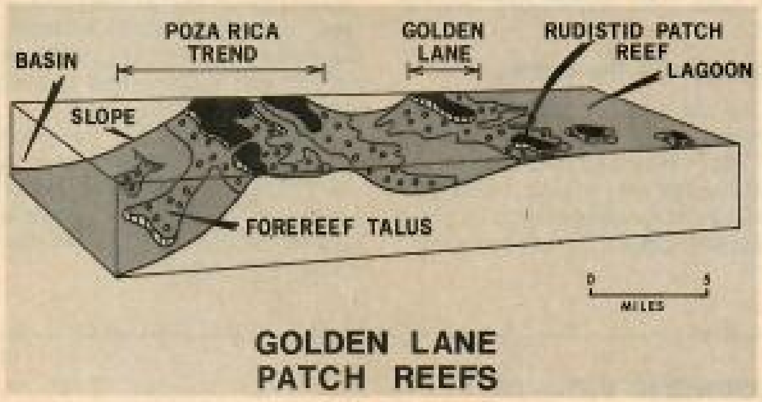
In addition, the close proximity to the boundstone facies affords a nearby abundant supply of material.

The present day structural attitude of the patch reef will determine which end of the elongated feature should lie updip and multiple oil/water or gas/water contacts in overlapping, but separated zones may exist.

While it may seem that this zone still leaves a rather broad target area for the drill bit, and the permeability

Fig. 8

Golden Lane patch reefs



(From Coogan, Bebout, and Maggio, 1972, Fig. 19).

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Fig. 9

Dip correlation

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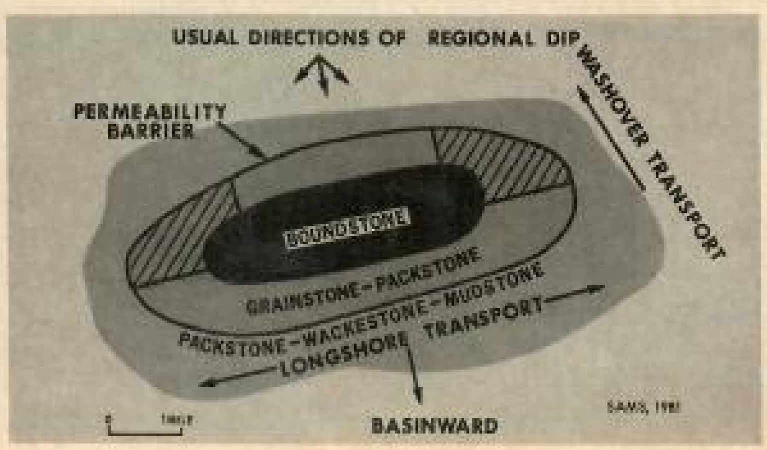
Fig. 10a

Map view of proposed model*



*For patch reef exploration

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barrier is difficult to pinpoint, the location of the permeability barrier was predicted with considerable accuracy (Fig. 12) with a minimum of well control prior to the discovery of the Black Lake field (White and Sawyer 1966).

Application of the model

As in the case of the Black Lake discovery, it is necessary to have some whole diamond core data showing fabric, texture, porosity, and permeabilities from wells nearby in order to precisely apply the model in exploration.

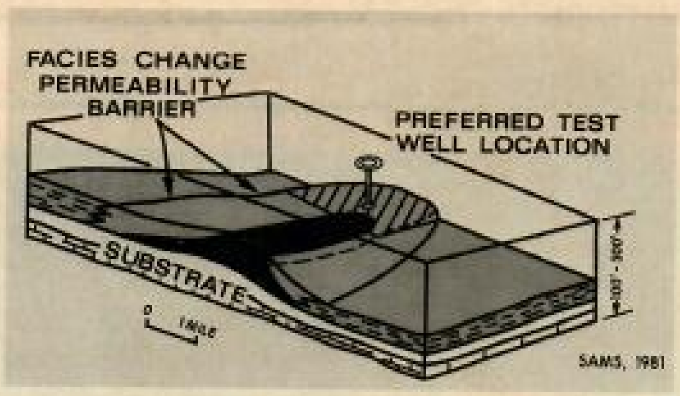
It is extremely desirable, though not imperative, to have at least one well which has penetrated the boundstone facies.

Lacking such knowledge, one must speculate on the presence of a patch reef through the use of isopachs of the substrata or the overlying interval together with a knowledge of the rate of regional basinward tilting.

Recent advances in the technology of seismic stratigraphy can be extremely helpful in identifying porosity zones of a patch reef complex because of the strong difference in acoustical impedance.

Fig. 11b

Isometric view of*



*Explorationist's model

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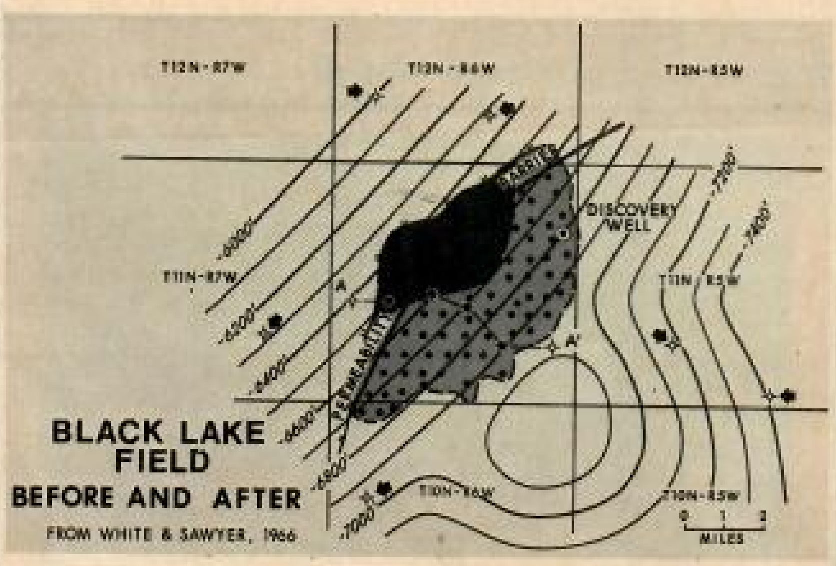
Fig. 12

Black Lake field



(modified from White and Sawyer, 1966)

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Assuming only regional basinward tilting and a half filled reservoir, the above geologic model might appear as in Fig. 13.

In the search for these subtle stratigraphic traps, one should realistically be prepared to conduct a multiple well exploratory program on each individual prospect.

The concept of a set number of expendable dry holes should be an accepted part of the total program, and these should be viewed in terms of finding costs weighed against the projected return on the overall investment.

If the target is an oil field of 10 million bbl or more as exemplified by the patch reefs found thus far in the Lower Cretaceous, then surely the projected return on the investment can carry more than one or two expendable dry holes.

Each time a well is drilled and cored, however, an adjustment to the orientation of the model may be in order and should be made before the next attempt to drill.

This is particularly true if a boundstone unit is cored.

Summary and conclusion

Clearly this model is simply another tool for the explorationist, and it represents no more than a synthesis of the author's understanding of oil and gas production from carbonates of the Gulf Coast Lower Cretaceous.

However, it is hoped that by applying it to a set of data in a particular area, in time, the drilling bit will show that rich rewards may be forthcoming in the search for this subtle stratigraphic trap.

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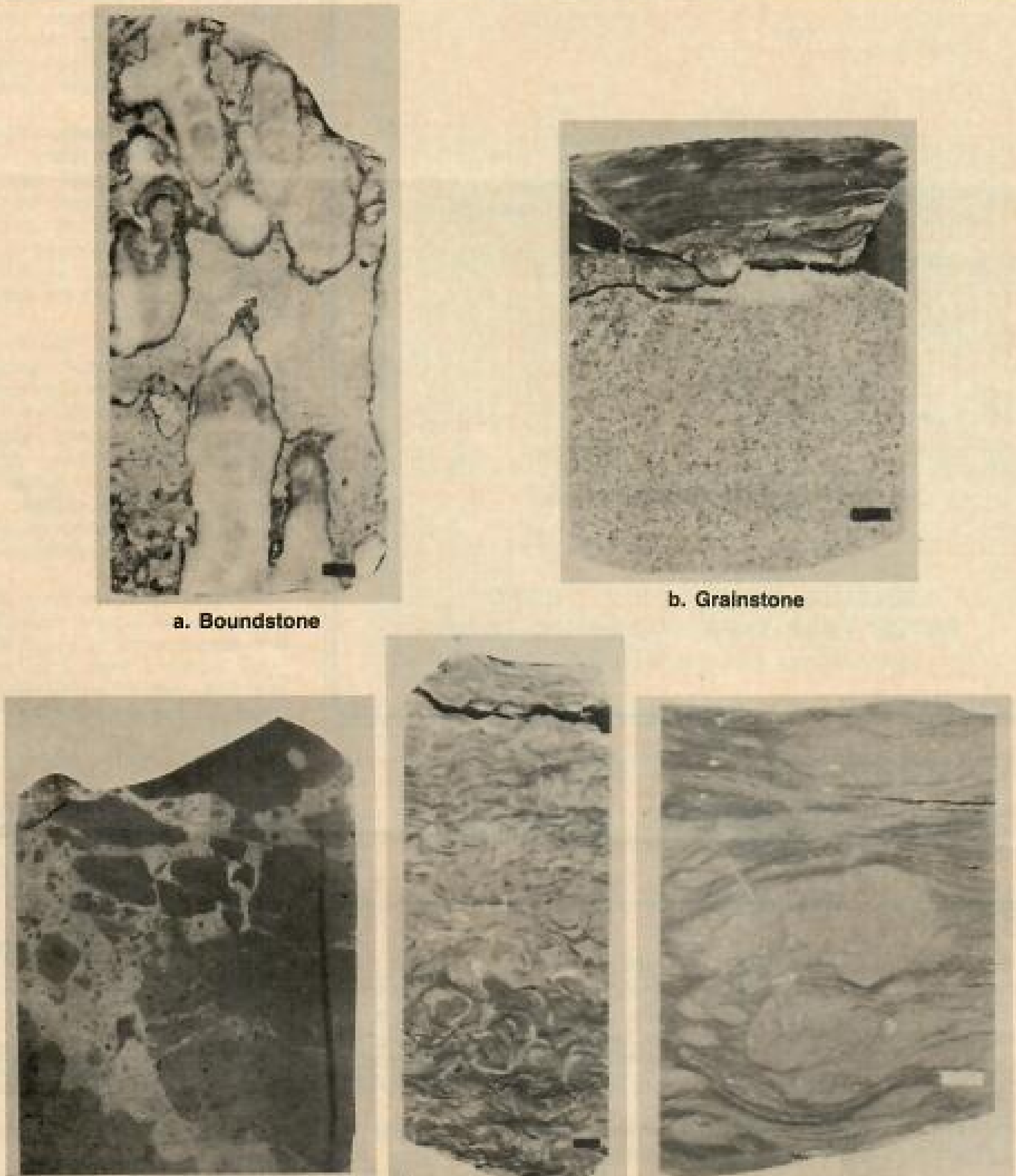
Fig. 11

Seismic line



a. Boundstone

b. Grainstone

c. Mudstone

d. Packstone

e. Wackestone

(Courtesy Bureau of Economic Geology, Texas University)

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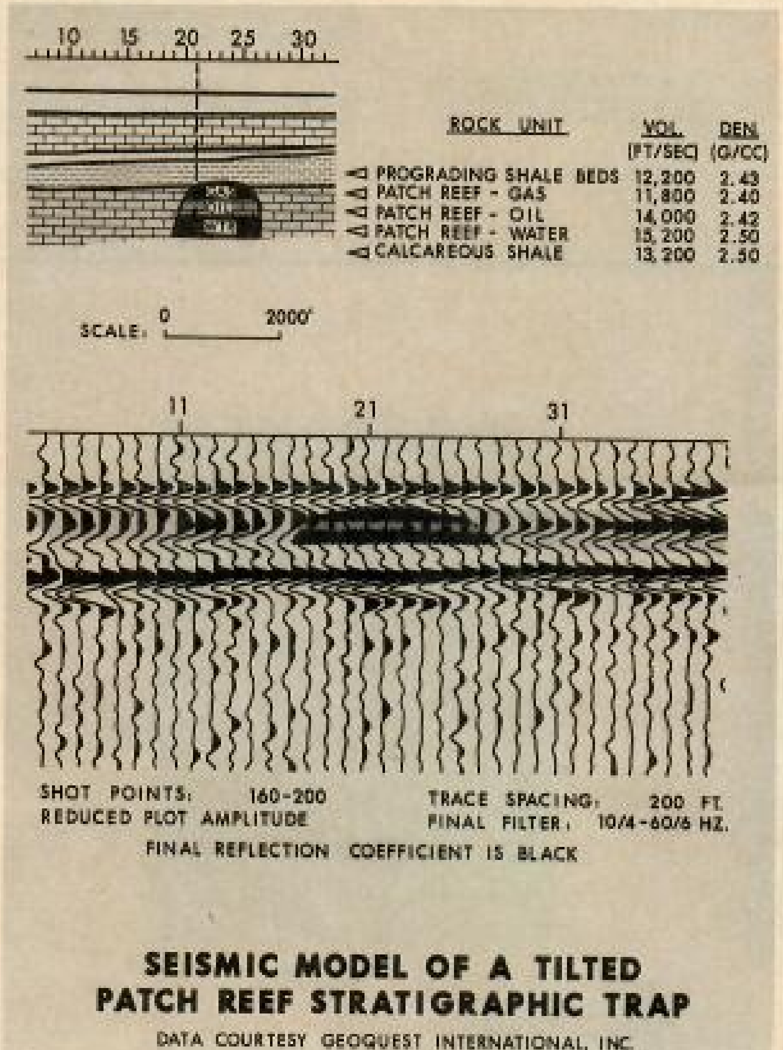
Fig. 13

Seismic model



(Courtesy GeoQuest International, Inc.)

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MISSISSIPPI

Upper Smackover Jurassic gas production has been opened on the north side of the West Heidelberg field in Jasper County, southeastern Mississippi.

Rosson & Layman et al. 1 Nathanial Jones, NW SE 22-1n-12e, flowed 1,225 Mcfd and 381 bc/d, 49.8°, on a 16/64 in. choke with tubing pressure 925 psi.

Production is from the top of the Jurassic Smackover through perforations at 16,344-16,465 ft. Total depth is 17,948 ft with 7 in. pipe run to 17,409 ft.

This field also has production in Chalk, Eutaw, Upper Tuscaloosa, Paluxy, Lower Cretaceous, Middle Hosston, and the Cotton Valley, according to Southeastern Oil Review, Jackson.

Other operators in the well are Omni and Coquina.

The operators control a block of more than 5,000 acres around the discovery well. An interest in the well and block is held by Louisiana Land & Exploration Co.

Gulf Coast SEPM sets conference dates, topics

The Gulf Coast section of the Society of Exploration Paleontologists & Mineralogists has announced its third annual research conference, entitled "The Jurassic of the Gulf Rim," to be held Nov. 28 through Dec. 1, 1982, in Baton Rouge, La.

Dr. Don Bebout, director of research of the Louisiana Geological Survey, and Dr. Clyde Moore, professor of geology at Louisiana State University in Baton Rouge, are the program co-chairmen.

This year's conference will be held in the Baton Rouge Hilton Hotel.

The two and a half days of the technical program will include the presentation of invited and volunteered papers representing all aspects of the entire Jurassic section of the circum-gulf area from the Cotton Valley to the Werner.

A wide range of papers is being solicited on regional stratigraphy, stratigraphic problems, paleontology, facies models, depositional environments, porosity evolution, diagenesis, engineering problems, structural framework, seismic studies, brine chemistry, and field studies.

As in the two previous conferences, there will be a comprehensive core workshop.

Being solicited are core presentations of classic Jurassic material along with supplemental data such as maps, cross sections, logs, core analyses, and thin section photomicrographs, which will support and enhance interpretations of depositional environments, burial history, and/or diagenesis.

Paper titles and informal summaries and core presentation summaries should be submitted to Clyde Moore and Don Bebout before Mar. 1, 1982.

Contact Moore or Bebout through Louisiana State University, Department of Geology, Baton Rouge, La. 70803.

The fee for the conference will be $100 with a special student rate of $25.

This fee will include admission to all sessions, one evening core workshop, reception, two lunches, a cocktail-buffet, and copies of the meeting papers.

Those interested in additional registration information can contact W.P.S. Ventress at Chevron, 935 Gravier St. in New Orleans, La. 70112, or phone 504-521-6761. ▪