STRUCTURAL EVOLUTION OF THREE GEOPRESSURED-GEOTHERMAL AREAS IN THE TEXAS GULF COAST[1]

Charles D. Winker, Robert A. Morton, and Deborrah D. Garcia

Bureau of Economic Geology, The University of Texas at Austin

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

distributary-channel and channel-mouth-bar deposits, and cover a relatively small area (approx. 4 mi^2). They are laterally in contact with thinner delta-front sandstones.

Blessing Area

The Blessing Prospect has a similar history to Cuero, but fault blocks are larger, fault traces are more sinuous, early growth ratios are much larger (maximum of 10), and rollover is substantial (Fig. 5). Growth ratios on most faults decrease steadily with time. Persistent structural highs on the basinward margins of fault blocks are probably underlain by residual shale masses (Bruce, 1973); elsewhere along the Frio trend, similar shale masses became diapiric.

Hydraulic isolation of geopressured Lower Frio sandstones near Blessing is similar to the Cuero area: downfaulted against Vicksburg slope shale on the landward side of the fault block, upfaulted against transgressive Middle-to-Upper Frio shale on the basinward side, and overlain by Middle Frio interbedded sand and shale (Fig. 4). Thick geopressured sandstones in the Blessing Prospect area (Fig. 6) are laterally more continuous than those in Cuero, and probably represent both distributary and delta-front facies. Individual thick sandstones tend to thin and pinch out basinward, whereas landward they tend to split up into numerous thin sandstones due to overall expansion of the section near the growth fault.

Pleasant Bayou

In the Pleasant Bayou Prospect, early structural development was characterized by widely spaced down-to-the basin faults with substantial rollover, conditions similar to that of Blessing. In post-Frio time, salt withdrawal and diapirism became active and superimposed substantial structural relief on earlier structures. Crestal faults developed over Danbury Dome, while growth rates on regional down-to-the-basin faults declined to less than 1.1. Post-Anahuac structures were entirely different from those active early in Frio time, in contrast to the persistent structural styles of Cuero and Blessing (Fig. 5). Changes in structural style with time are characteristic of salt tectonics in the Gulf Basin.

Isolation of deep structure sandstone reservoirs (Fowler, 1970) was virtually identical to that for Blessing, and was entirely a result of early fault growth. Thick geopressured sandstones in the Pleasant Bayou area are extensive and highly permeable; whole core analyses commonly report permeabilities in excess of 1000 md, and the producing sandstone (the "C" sand) covers approximately 25 mi^2 (Fig. 6). Variation in electric log character within individual sandstones is attributable primarily to three phenomena: (1) downdip pinchout, (2) splitting up of sandstones due to expansion into growth faults, and (3) lateral changes from channel facies to delta-front facies.

ABSTRACT

Detailed analysis of geological and seismic data from several geopressured geothermal areas (Cuero, Blessing, Pleasant Bayou) reveals similarities in structural-stratigraphic relationships that form geopressured aquifers as well as differences in structural complexity and evolution that characterize the different areas.

In these examples, geopressured sandstones are isolated on the updip side by downfaulting against shelf-slope shales, and on the downdip side by upfaulting against transgressive marine shales. Moreover, they are isolated above and below by thick sequences of transgressive shale or interbedded sandstone and shale.

Prospective reservoirs are found where deltaic and associated sandstones (distributary channel, delta front, barrier-strandplain) were deposited seaward of major growth faults and near the shelf margin. Structural development in these areas began with rapid movement of relatively straight to sinuous down-to-the-basin growth faults with narrow to wide spacings and varying amounts of rollover. Later structural movement was characterized by continued but slower movement of most growth faults. In the Pleasant Bayou area, late salt diapirism superimposed a dome-and-withdrawal-basin pattern on the earlier growth-fault style.

INTRODUCTION

Structural interpretation of geothermal prospect areas on a site-specific level is necessary to predict reservoir size and the potential volume of fluids that can be withdrawn from geopressured sandstones. Comparative structural interpretation on a regional scale is important (1) to understand the reasons for the accumulation of excess fluid pressure, (2) to identify factors which distinguish good quality prospects from poor quality prospects, and (3) to develop general models of structural style to aid exploration for and evaluation of prospects in areas of poor subsurface control.

The history of syn-depositional structures that create geopressured geothermal reservoirs can be reconstructed by means of sequential isopach maps. In the case of shallow-water deposition, it can usually be assumed that contemporaneous structural relief is much greater than the relief of depositional topography, so that an isopach map is essentially a paleostructural map as well, neglecting effects of compaction. By removing the horizontal component of post-depositional fault displacement from the isopach map, an approximately palinspastic reconstruction can be obtained. Relative rates of fault movement are quantified in terms of the <u>growth ratio</u> (or <u>expansion index</u>), defined as the ratio of downthrown thickness to upthrown thickness. This type of analysis is particularly useful for structurally complex areas such as Pleasant Bayou. Whereas deep structure maps may show the superimposed effects of different structural styles, individual isopach maps usually show a single style and are therefore easier to interpret.

STRUCTURAL DEVELOPMENT OF AREAS

Structure and stratigraphy of three areas (Figs. 1, 2) were studied in detail as part of the process of prospect evaluation. (1) The Cuero area (Bebout et al, 1979), in DeWitt County, is on the Eocene Lower Wilcox growth-fault trend, on the southwestern fringe of the Rockdale Delta system (Fisher and McGowen, 1967). (2) The Blessing prospect (Morton et al, 1981) in Matagorda County is on the Oligocene Frio growth-fault trend, within the Houston Delta system (Galloway et al, in press). (3) The Pleasant Bayou prospect (Bebout et al, 1978) in Brazoria County is also on the Frio trend and within the Houston Delta system, but is underlain by mobile salt which has complicated the structural development. A fourth area, the McAllen Ranch Field (Loucks, 1978; Berg et al, 1979), in Hidalgo County on the Vicksburg trend, has also been studied but in less detail; it was not a prospect but provides an interesting contrast in structural style.

A model for evolution of Tertiary growth-fault systems has been outlined by Winker and Edwards (in press), in which changes in structural styles and stress regimes are explained in terms of progradation of the continental slope. The major driving forces are gravitational instability of the continental slope and density inversions caused by sand-shale sequences overlying salt or undercompacted slope shale. Diapirs originate in a compressional regime at the base of the slope; once started, they continue to move because of the density inversion. Down-to-the-basin growth faults originate in an extensional regime at the shelf margin. After the shelf margin progrades farther basinward, growth faults and shale diapirs may continue to move, but at a greatly diminished rate. Salt diapirs, on the other hand, continue to be very mobile and therefore tend to dominate late structural development.

Cuero Area

In the Cuero area, faults are sub-parallel and fairly closely and evenly spaced (Fig. 3). Early fault movement was relatively slow, with small growth ratios (less than 2) and minor rollover (Fig. 4,5). This style is typical of the Lower Wilcox trend which represents the initial growth faulting in the Texas Gulf coast. The small amount of rollover suggests that the faults flatten out at considerable depth, and probably penetrate Lower Cretaceous carbonates. Decollement may occur in thin, non-diapiric Jurassic salt, similar to that which occurs along the southwestern margin of the East Texas Basin. In post-Wilcox time, growth ratios declined to less than 1.1, and regional basinward tilting was superimposed on the earlier structures (Fig. 5).

Geopressured sandstones occur in the second fault block downdip, and are isolated on the updip side by early downfaulting against older (Midway) slope shales, on the downdip side by upfaulting against Middle Wilcox transgressive shales, and above by an interbedded sand-and-shale sequence (Fig. 4). The best-developed geopressured sandstones (Fig. 6) appear, on the basis of electric-log patterns and whole core in one well, to be

McAllen Ranch Area

Evolution of structures in the McAllen Ranch area (Fig. 4) is similar to the Blessing area except that the faults flatten out at very shallow depth, resulting in extreme rollover and a very large horizontal component of displacement. Most of the Vicksburg section is geopressured due to downfaulting against Jackson slope shale, downdip pinchouts, and the overlying transgressive Upper Vicksburg shale wedge.

Additional structural complications which can be anticipated in areas of diapiric activity include (1) numerous faults of small displacement within major fault blocks (Bruce, 1973; Evamy et al, 1978); (2) "back-to-back" faults (Evamy et al, 1978) associated with diapirs; (3) major up-to-the basin (Spindler, 1977) or "counter-retional" (Evamy et al, 1978) faults, also associated with diapirs; and (4) salt diapirism contemporaneous with shelf-margin growth faulting (in contrast to Pleasant Bayou where diapirism post-dated growth faulting) in areas where salt is extremely mobile.

STRUCTURAL-STRATIGRAPHIC RELATIONSHIPS

Structural controls on sandstone quality and geometry are still a matter of speculation, because of the small number of areas which have been studied in sufficient detail. In general, however, it appears that the more proximal deltaic facies tend to make thicker and more permeable reservoirs than do the more distal facies. Conditions favorable for hydraulic isolation of proximal facies allowing for the accumulation of geopressure include: (1) large fault blocks where active faults probably extended considerable distances landward of the shelf break; (2) large fault displacement that effectively sealed high-permeability sandstones against slope shales; and (3) an overlying transgressive sequence, so that in the basinward bounding fault, reservoir sandstones are upfaulted against transgressive shales rather than sandstones which could drain the reservoir. Confirmation of these hypotheses will require a larger data set.

ACKNOWLEDGMENTS

This work was made possible through funding by the Department of Energy under contracts DE-AS05-76ET28461 and DE-AC08-79ET27111.

REFERENCES

Bebout, D. G., R. G. Loucks, and A. R. Gregory, 1978, Frio sandstone reservoirs in the deep subsurface along the Texas Gulf coast: their potential for production of geopressured geothermal energy: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 91, 92 p.

______ B. R. Weise, A. R. Gregory, and M. B. Edwards, 1979, Wilcox reservoirs in the deep subsurface along the Texas Gulf coast: their potential for production of geopressured geothermal energy: Univ. Texas, Austin, Bur. Econ. Geology, Rept. to U.S. Dept. of Energy, 219 p.

Berg, R. R., W. D. Marshall, and P. W. Shoemaker, 1979, Structural and depositional history, McAllen Ranch Field, Hidalgo County, Texas: Trans. Gulf Coast Assoc. Geol. Soc., v. 29, p. 24-28.

Bruce, C. H., 1973, Pressured shale and related sediment deformation: mechanism for development of regional contemporaneous faults: Amer. Assoc. Petrol. Geol. Bull., v. 57, p. 878-886.

Evamy, B. D., J. Haremboure, P. Kamerling, W. A. Knapp, F. A. Molloy, and P. H. Rowlands, 1978, Hydrocarbon habitat of Tertiary Niger Delta: Amer. Assoc. Petrol. Geol. Bull., v. 62, p. 1-39.

Fisher, W. L., and J. H. McGowen, 1967, Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas: Trans. Gulf Coast Assoc. Geol. Soc., v. 17, p. 105-125.

Fowler, W. A., 1970, Pressures, hydrocarbon accumulation, and salinities—Chocolate Bayou Field, Brazoria County, Texas: Jour. Petrol. Tech., v. 22, p. 411-423.

Galloway, W. E., D. K. Hobday, and K. Magara, in press, Frio Formation of the Texas Gulf Coast basin—depositional systems, structural framework, and hydrocarbon origin, migration, distribution, and exploration potential: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv.

Loucks, R. G., 1978, Sandstone distribution and potential for geopressured geothermal energy production in the Vicksburg Formation along the Texas Gulf coast: Trans. Gulf Coast Assoc. Geol. Soc., v. 28, p. 239-271.

Morton, R. A., H. S. Hamlin, C. D. Winker, B. R. Weise, A. R. Gregory, and D. D. Garcia, 1981, Prospectus for design well in the Blessing area, Matagorda County, Texas: Univ. Texas, Austin, Rept. to U.S. Dept. of Energy, 37 p.

Spindler, W. M., 1977, Structure and stratigraphy of a small Plio-Pleistocene depocenter, Louisiana continental shelf: Trans. Gulf Coast Assoc. Geol. Soc., v. 27, p. 180-196.

Winker, C. D., and M. B. Edwards, in press, Unstable progradational clastic shelf margins, <u>in</u> Moore, G. T., and Stanley, D. O. (eds), The shelf-slope boundary—a critical interface on continental margins.

Fig. 1 Regional trends of growth faulted shelf margins in the northwestern Gulf of Mexico, showing locations of geopressured-geothermal study areas.

Fig. 2 Approximate correlation of stratigraphic intervals used for construction of isopach maps (Fig. 5) and cross sections (Fig. 4).

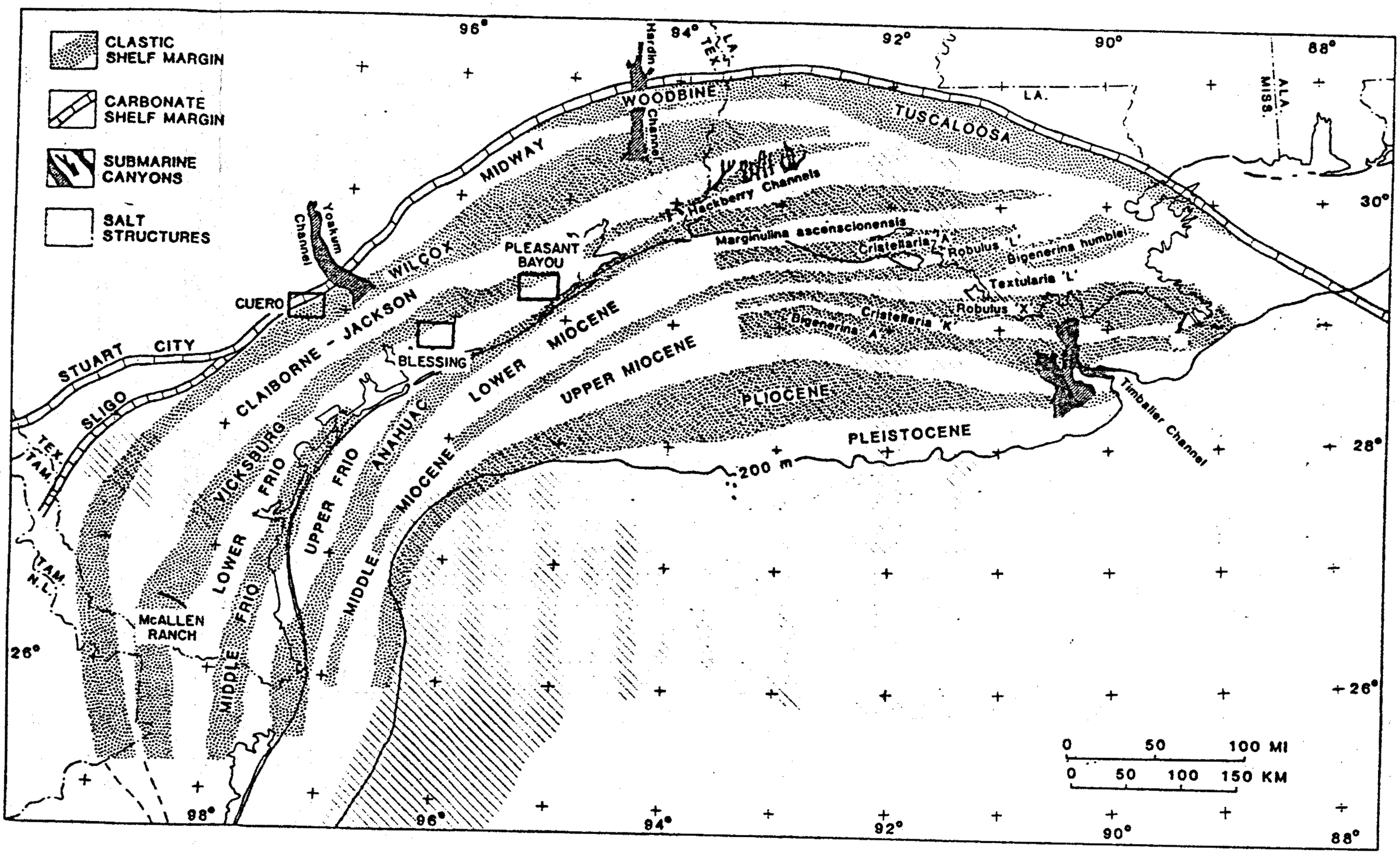
Fig. 3 Structure maps on tops of intervals of prospective geopressured geothermal reservoirs.

Fig. 4 Dip sections of four geothermal study areas, without vertical exaggeration. Numbers on stratigraphic units refer to Figure 2.

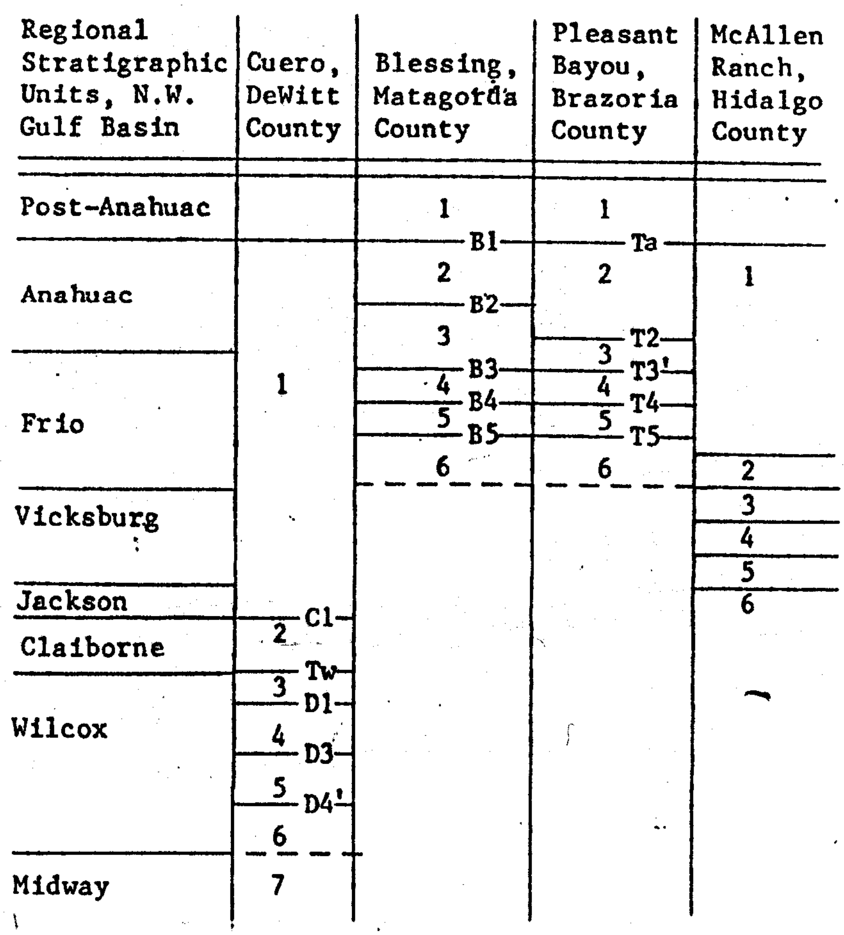
Fig. 5 Sequential isopach maps of three geothermal study areas with horizontal component of post-depositional faulting removed. Numbers of stratigraphic units refer to Figure 2.

Fig. 6 Extent of optimum sandstone development, based on electric-log patterns (thickness, absence of shale breaks, lateral continuity), for three geothermal study areas.

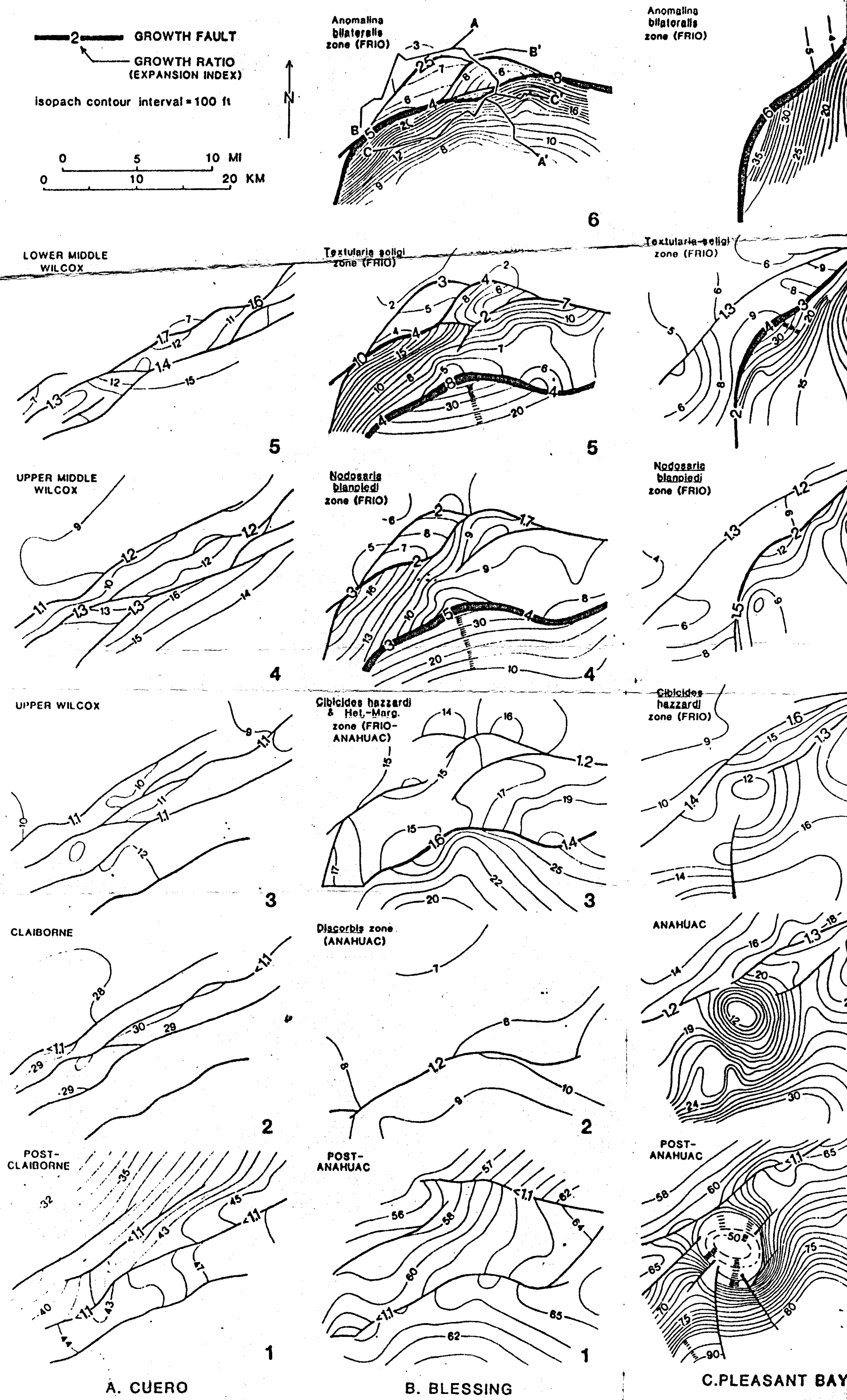
Fig. 2 Approximate correlation of stratigraphic intervals used for construction of isopach maps (Fig. 5) and cross sections (Fig. 4).



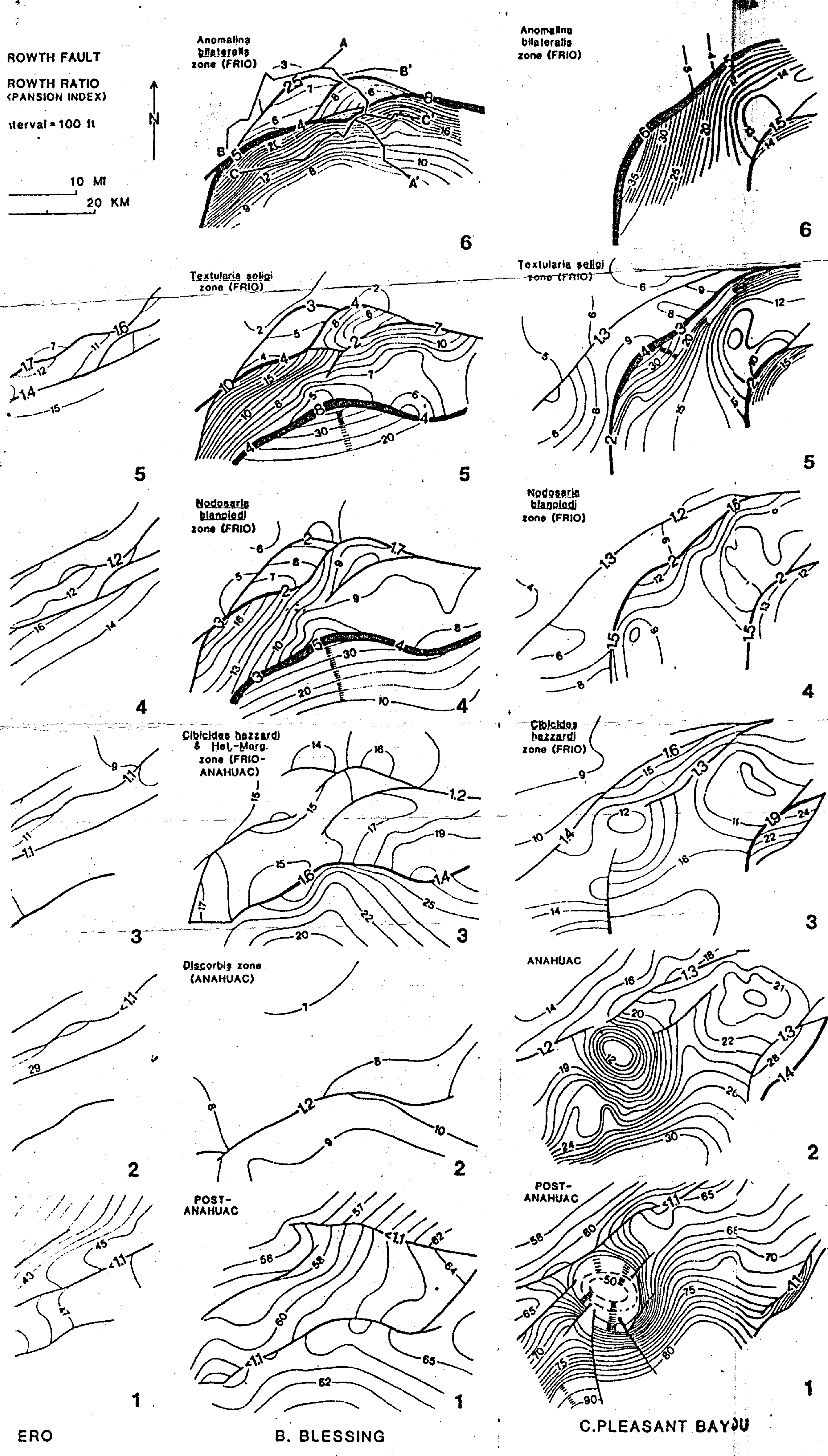
CLASTIC SHELF MARGIN
CARBONATE SHELF MARGIN
SUBMARINE CANYONS
SALT STRUCTURES
96°
94°
92°
90°
88°
98°
30°
28°
26°
Hardin Channel
LA. TEX.
LA.
ALA. MISS.
WOODBINE
TUSCALOOSA
MIDWAY
Yoakum Channel
Hackberry Channels
WILCOX
PLEASANT BAYOU
CUERO
CLAIBORNE - JACKSON
BLESSING
STUART CITY
SLIGO
TEX. TAM.
TAM. N.L.
VICKSBURG
LOWER FRIO
UPPER FRIO
MIDDLE FRIO
ANAHUAC
MIDDLE MIOCENE
LOWER MIOCENE
UPPER MIOCENE
PLIOCENE
PLEISTOCENE
200 m
McALLEN RANCH
Marginulina ascensionensis
Cristellaria 'A'
Robulus 'L'
Bigenerina humblei
Textularia 'L'
Robulus 'X'
Cristellaria 'K'
Bigenerina 'A'
Timbalier Channel
0 50 100 MI
0 50 100 150 KM



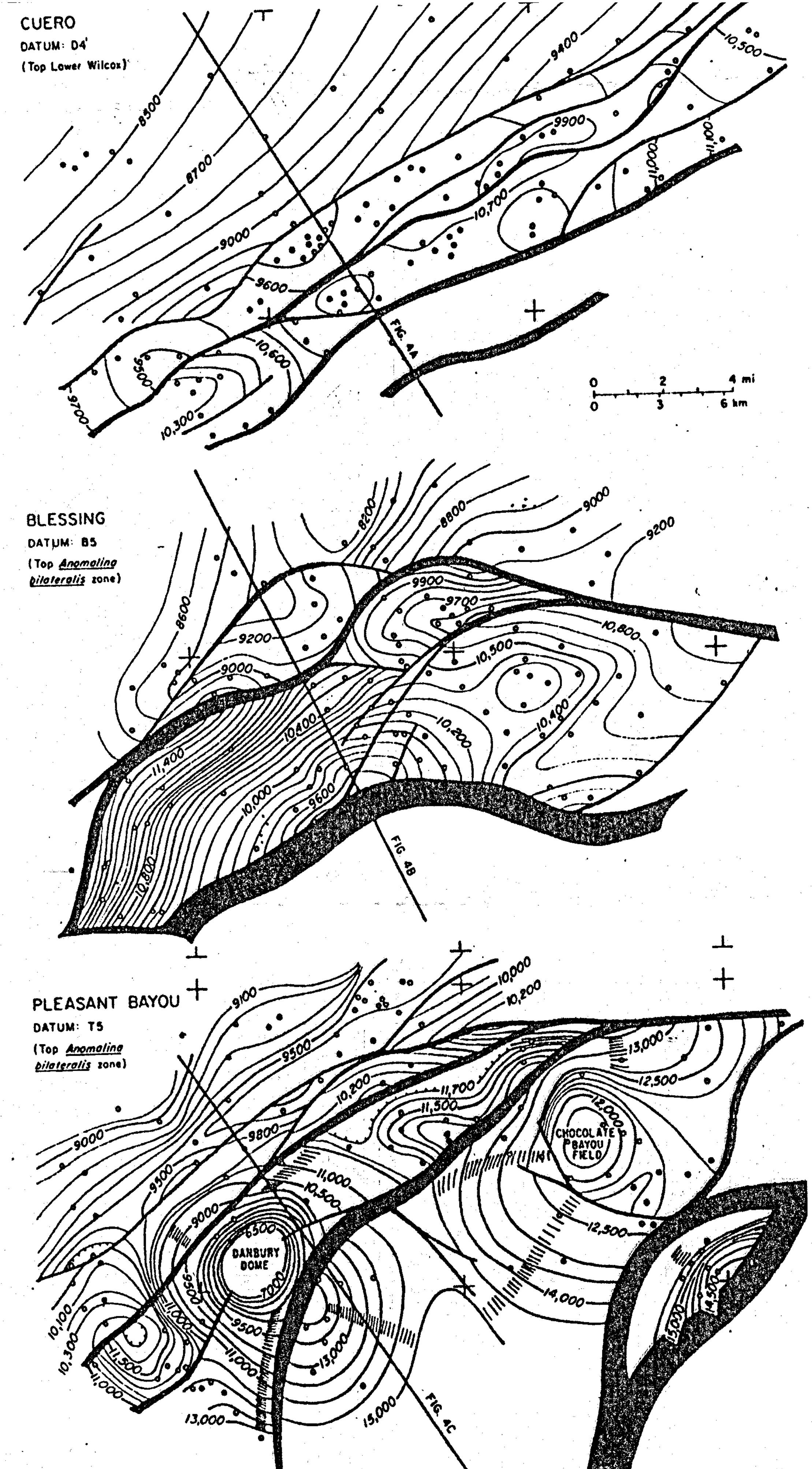
Regional Stratigraphic Units, N.W. Gulf Basin
Cuero, DeWitt County
Blessing, Matagorda County
Pleasant Bayou, Brazoria County
McAllen Ranch, Hidalgo County
Post-Anahuac
Anahuac
Frio
Vicksburg
Jackson
Claiborne
Wilcox
Midway
1
2
3
4
5
6
7
B1
B2
B3
B4
B5
Ta
T2
T3'
T4
T5
C1
Tw
D1
D3
D4'


GROWTH FAULT
GROWTH RATIO (EXPANSION INDEX)
isopach contour interval = 100 ft
N
0 5 10 MI
0 10 20 KM
Anomalina bilateralis zone (FRIO)
Anomalina bilateralis zone (FRIO)
6
LOWER MIDDLE WILCOX
5
Textularia seligi zone (FRIO)
5
Textularia seligi zone (FRIO)
UPPER MIDDLE WILCOX
4
Nodosaria blanpiedi zone (FRIO)
4
Nodosaria blanpiedi zone (FRIO)
UPPER WILCOX
3
Cibicides hazzardi & Het.-Marg. zone (FRIO-ANAHUAC)
3
Cibicides hazzardi zone (FRIO)
CLAIBORNE
2
Discorbis zone (ANAHUAC)
2
ANAHUAC
POST-CLAIBORNE
1
POST-ANAHUAC
1
POST-ANAHUAC
A. CUERO
B. BLESSING
C.PLEASANT BAY

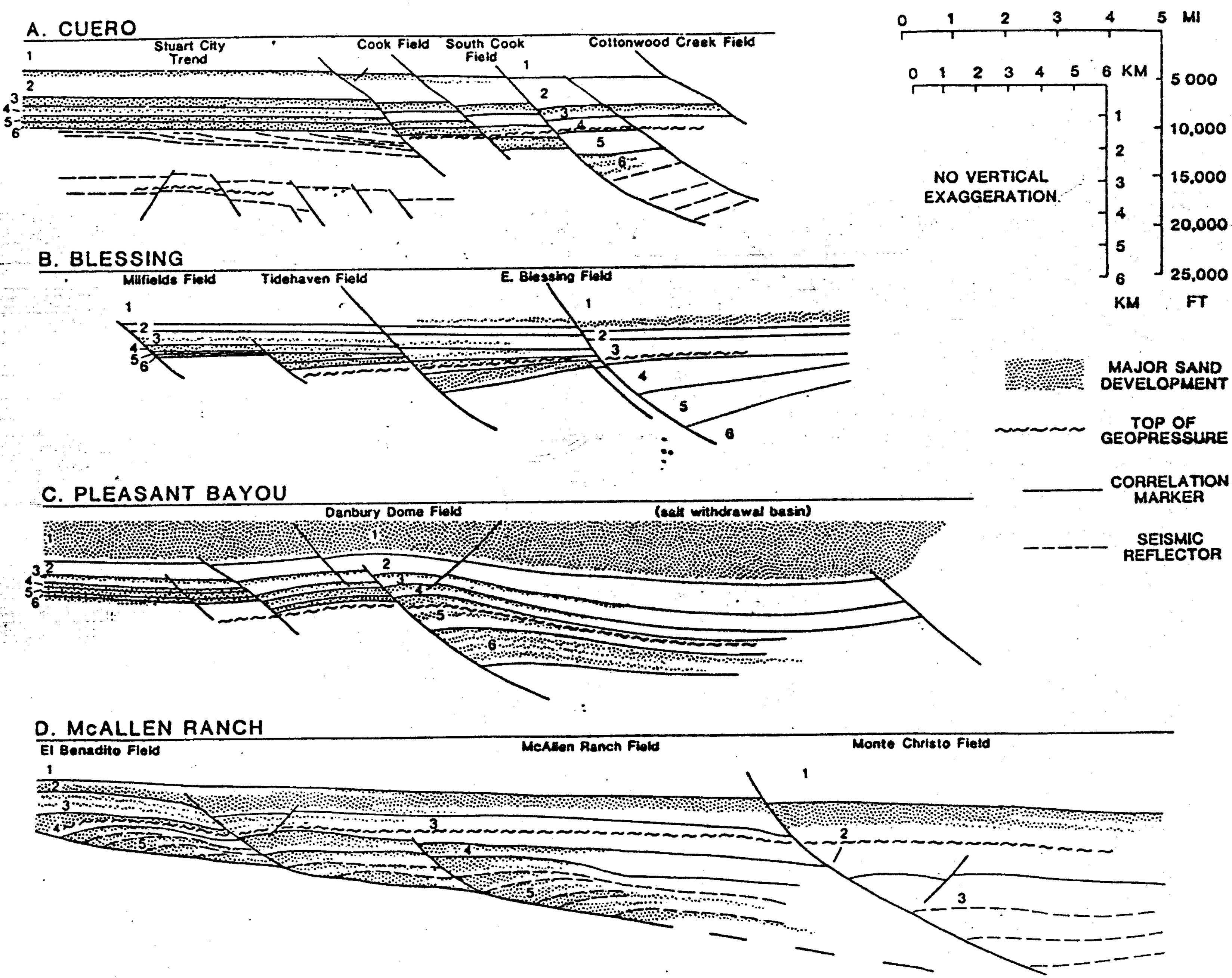
Fold B



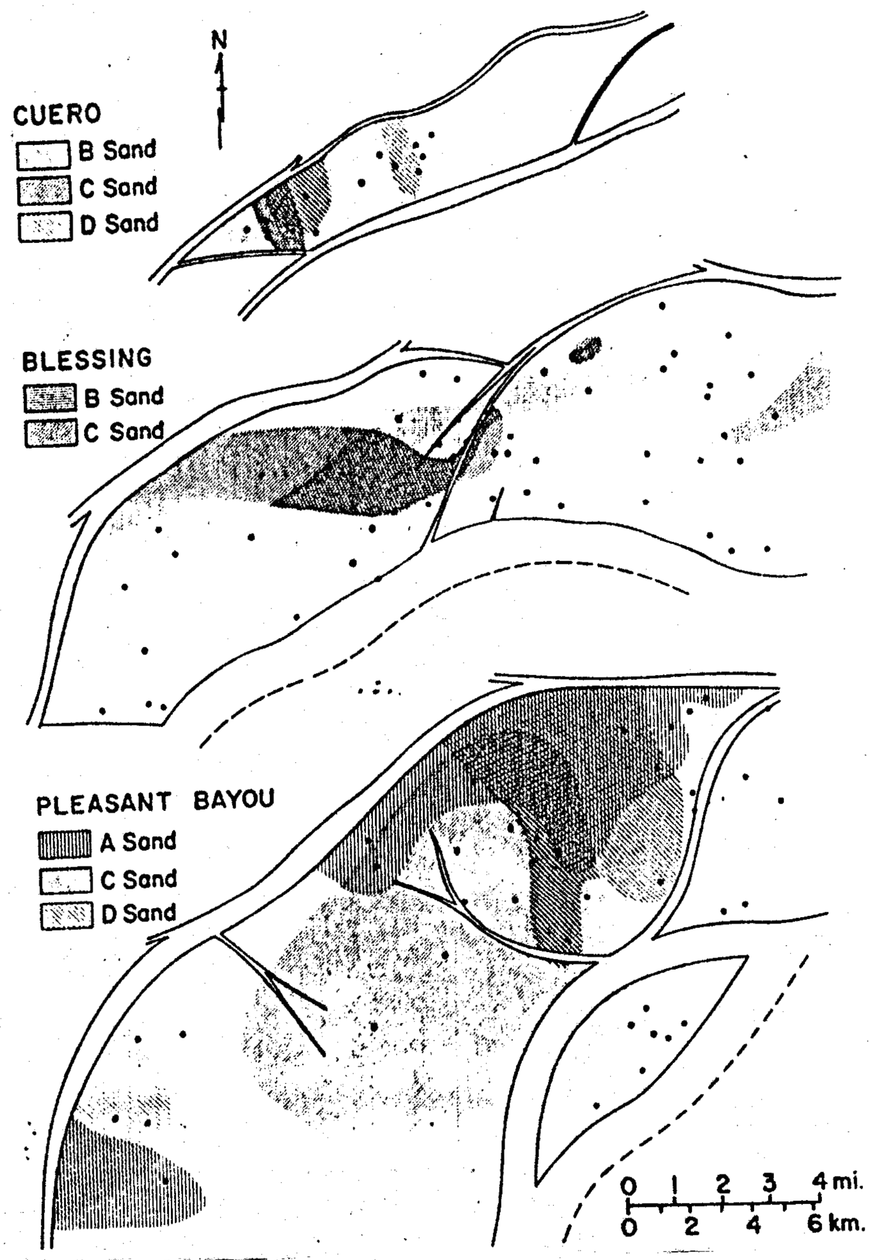
ROWTH FAULT
ROWTH RATIO
(PANSION INDEX)
ıterval = 100 ft
N
10 MI
20 KM
Anomalina bilateralis zone (FRIO)
Anomalina bilateralis zone (FRIO)
6
6
Textularia seligi zone (FRIO)
Textularia seligi zone (FRIO)
5
5
5
Nodosaria blanpiedi zone (FRIO)
Nodosaria blanpiedi zone (FRIO)
4
4
4
Cibicides hazzardi & Het.-Marg. zone (FRIO-ANAHUAC)
Cibicides hazzardi zone (FRIO)
3
3
3
Discorbis zone (ANAHUAC)
ANAHUAC
2
2
2
POST-ANAHUAC
POST-ANAHUAC
1
1
1
ERO
B. BLESSING
C.PLEASANT BAYOU



CUERO
DATUM: D4'
(Top Lower Wilcox)
8500
8700
9000
9400
9600
9700
9900
9900
10,500
10,600
10,700
10,300
11,000
11,000
FIG. 4A
0 2 4 mi
0 3 6 km
BLESSING
DATUM: B5
(Top *Anomalina bilateralis* zone)
8200
8600
8800
9000
9200
9200
9000
9900
9700
10,800
10,500
10,400
10,200
10,400
11,400
10,000
9600
10,800
FIG. 4B
PLEASANT BAYOU
DATUM: T5
(Top *Anomalina bilateralis* zone)
9100
10,000
10,200
9500
9000
9800
10,200
11,700
11,500
13,000
12,500
12,000
CHOCOLATE BAYOU FIELD
11,000
10,500
9500
9000
6500
DANBURY DOME
7000
9500
12,500
14,000
10,100
10,300
11,500
11,000
11,000
9500
11,000
13,000
13,000
15,000
15,000
14,500
FIG. 4C



A. CUERO
Stuart City Trend
Cook Field
South Cook Field
Cottonwood Creek Field
B. BLESSING
Milfields Field
Tidehaven Field
E. Blessing Field
C. PLEASANT BAYOU
Danbury Dome Field
(salt withdrawal basin)
D. McALLEN RANCH
El Benadito Field
McAllen Ranch Field
Monte Christo Field
0 1 2 3 4 5 MI
0 1 2 3 4 5 6 KM
5 000
10,000
15,000
20,000
25,000
KM
FT
NO VERTICAL EXAGGERATION
MAJOR SAND DEVELOPMENT
TOP OF GEOPRESSURE
CORRELATION MARKER
SEISMIC REFLECTOR


N
CUERO
B Sand
C Sand
D Sand
BLESSING
B Sand
C Sand
PLEASANT BAYOU
A Sand
C Sand
D Sand
0 1 2 3 4 mi.
0 2 4 6 km.