

# Supra-Salt Stacked Condensed Sections (SCS): Potential Indicators of Subsalt Stratigraphy\*

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\*Adapted from presentation and accompanying extended abstract at GCS SEPM 16<sup>th</sup> Annual Research Conference, December, 1995, p. 195-196.

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## Abstract

The development and understanding of allochthonous salt sheets has been the focus of intense scientific (McGuinness and Hossack, 1993, and others) and economic (Moore and Brooks, 1995) interest in recent years. Concurrently enhanced techniques in biostratigraphic analysis have advanced the comprehension of depositional and structural interaction to a level of greater precision. Depositional sequences of clastic sediments can be identified by the occurrence of bioevents and abundance patterns (Armentrout and Clement[1990] and others) in microfossil assemblages. Recognition and correlation of these patterns can be translated into useful techniques of subsalt stratigraphic prediction.

Reservoir prediction is a critically important component of subsalt petroleum exploration. It is dependent upon paleoenvironments of deposition, structural development (both pre- and post-salt sheet emplacement), and the impact of salt movement upon sediment transport fairways. This interaction of salt tectonism and sedimentation creates complex systems of potential subsalt hydrocarbon traps.

Over thirty wells have now penetrated allochthonous salt sheets on the offshore Louisiana and Texas continental shelf and slope and have encountered significant thicknesses of subsalt sedimentary section (Moore and Brooks, 1995). In addition, several hundred wells have been drilled into the tops of these sheets, yielding not only useful salt sheet well control, but also delineating useful stratigraphic information which can be used to interpret salt mechanics and subsalt stratigraphy. Most of these wells contain non-condensed normal sedimentary sections deposited during the evacuation of the salt after sheet emplacement. These sections are often expanded intervals associated with large regional listric faults and have been laterally displaced over significant distances on a decollement surface along the top of the sheet. However, in upwards of forty of these salt top wellbores, multiple condensed sections, stacked conformably in thin sequences on top of each other, are encountered in various thicknesses above the salt. Each of these condensed sections represents a time period of slow sediment accumulation marking an extended period of hemipelagic sedimentation. It is important to realize the significant time period represented by these thin stratigraphic intervals. Often four or five of these condensed sections, representing approximately 2-3 million years (Paleo Data, 1992), are encountered stacked on top of each other above the top of salt, and they represent a period of minimal clastic deposition. These intervals can be termed as stacked or mega-condensed sections, and their occurrence offers an opportunity to better understand both the suprasalt and subsalt stratigraphy. They are unique and offer an invaluable point of stratigraphic control when encountered.

Within the wells that penetrated the top of salt and subsalt wells, at least four types of supra-salt sequence occurrences are evident. They are: 1) stacked condensed sections conformably deposited upon and coupled to the salt (coupled SCS), 2) stacked condensed sections that have decoupled from, and extended along, the top of the salt (decoupled SCS) as a unit, 3) coupled or decoupled normal thicknesses of individual sequences resting

conformably upon the salt, and 4) coupled or decoupled normal sequences that are significantly younger than the surrounding salt flank intervals, suggesting subaqueous erosion, non-deposition, or overthrusting.

Thus, three scenarios exist for the age relationship between supra- and subsalt sediments. First, a large sedimentary time gap may be present. This most often occurs along the updip edge of salt sheets where a large listric fault system formed above the salt. Second, the section can be conformable with little apparent missing section. Third, a prominent repeated section can occur when a stacked condensed section is present above the salt sheet. These repeated sections are of primary interest in understanding subsalt stratigraphy.

The most notable repeated sections occur in the publicly released South Marsh Island 200 #1 and Vermilion 356 #1 wells, but several other unreleased wells have also encountered repeated section (McGuinness and Hossack, 1993). All of these wells encountered stacked, condensed sections above salt and then penetrated subsalt time equivalent sediments that were from five to ten times as thick as the supra-salt sediments. In each of these two released wellbores, at least one of the repeated subsalt sedimentary sequences contained thick reservoir quality sandstone.

McGuinness and Hossack (1993) concluded that repeat sections demonstrated the extrusive glacier model of sheet development. They stated that these sediments can only be translated laterally with the sheet as it lengthens and they could not be preserved during sill-styled injection. These initial supra-salt sediments are deposited on sheet inflated highs, which minimizes the deposition of significant sediment thicknesses above the salt.

This is evidenced in models of supra-salt, bypassed-sand deposition from Simmons and Bryant (1992) on the modern day salt-supported continental slope. High resolution sonar-derived physiographic images demonstrate intrabasinal paleo structures underlain by inflating salt structures. These structures have only thin layers of subparallel sediments on top and are surrounded by deep interlobal and supralobal mini-slope basins filled with thick sand-rich sediments (i.e., Keathley Canyon 255 and Green Canyon 908 wells). Subsequent periods of salt canopy remobilization can extend the sheet fronts and edges over an ancestral mini-basin, carrying the equivalently aged, thin-stacked condensed sections (SCS) with it. It is significant that these thick sands encountered beneath salt are deposited in a lower bathyal (or deeper) paleoenvironment, which appears similar to some recently detailed accounts for significant deepwater GOM discoveries (Mahaffie, 1994; McGee, 1994). Sand-rich subsalt sediments can thus be penetrated after identifying the positions of the updip depocenters and upper slope fairways from where sediments can be transported downdip to lower slope-abyssal depocenters.

McGuinness and Hossack (1993) demonstrated a reconstruction-dependent method of subsalt age-prediction in which sediment extension was equivalent to sheet lengthening and the translational fault extension could be used to determine the footwall cutoff "by measuring back from the hangwall cutoff on top of the sheet a distance equal to the amount of extension." This is not always easily determined in the contorted, deeply buried salt environment of the present-day shelf and upper slope, but is a refined valid reconstructive technique, and reconstructions are useful in fully understanding these sediment/salt relationships.

### **Conclusion**

In conclusion, when stacked condensed sections are penetrated by wellbores directly above the top of an allochthonous salt sheet, limited subsalt biostratigraphic evidence demonstrates that the stacked condensed time section may be encountered in a repeated and thicker section of subsalt sediments. The subsalt section has a greater propensity for sand because of the ancestral paleotopographic relief associated with the salt sheet which results in sand-prone sediment-gravity deposits to bypass the inflated salt highs and accumulate in the basins surrounding salt scarp edges and fronts. Wellbores have confirmed these scenarios and suggest favorable conditions for subsalt sand deposition. It is important that subsalt explorers recognize stacked condensed sections (SCS) and implement these concepts in the future wells of the play. A significant thickness (4000+ ft) of subsalt section needs to be penetrated in future subsalt wells to adequately evaluate trapping opportunities below the salt in multiple sand potential sequences indicated by stacked condensed sections above the salt.

# **SUPRA-SALT STACKED CONDENSED SECTIONS (SCS):** *Potential Indicators of Subsalt Stratigraphy*

**DWIGHT "CLINT" MOORE**



**FRANK C. SNYDER**



**STEFAN "STEVE" RUTKOWSKI**



## ***ACKNOWLEDGEMENTS***

***The Authors express their appreciation to our managements and fellow colleagues at Anadarko Petroleum and Phillips Petroleum for their encouragement and support in preparing this presentation. The efforts of Art Waterman and his colleagues at Paleo Data, Inc. in partial review of this work and their contribution of biostratigraphic data are gratefully appreciated and acknowledged.***

## *INTRODUCTION*

- *Depositional sequences of clastic sediments can be identified by the occurrence of bioevents and abundance patterns in microfossil assemblages*
- *Recognition and correlation of these sequences is a critical component of subsalt petroleum exploration*

*Reservoir Prediction is a critical component of subsalt petroleum exploration.*

■ **Occurrence dependent on:**

- **Paleoenvironments of Deposition**
- **Structural Development  
(Pre & Post Salt Sheet Emplacement)**
- **Impact of Salt Movement on Sediment  
Transport Fairways**



## SIGNIFICANT SUB-SALT WELLS - FEDERAL OFFSHORE GULF OF MEXICO (MAJOR SHEET WELL PENETRATIONS)

WELL NAME	DATE DRLD (TD)	TOP OF SALT	BASE OF SALT	TVD THICKNESS OF SALT	DRLD MD WELL (TD)	DRLD TVD SEDIMENT THICKNESS BELOW SALT
Garden Banks 171 #1 Marathon	05/84	-8,400'	-9,510'	1,110'	10,597'	997'
West Cameron 505 #2 Gulf	09/84	-13,900'	-15,590'	1,690'	18,500'	2,820'
S. Marsh Island 200 #1 Diamond Shamrock	02/86	-8,730'	-9,720'	990'	13,500'	3,700'
Vermilion 356 #1 Amoco	12/87	-8,400'	-10,500'	2,100'	17,000'	6,360'
Lake Washington #1 Amoco (Onshore)	04/90	-9,350'	-13,410'	4,075'	21,241'	7,781'
Miss. Canyon 211 #1 Exxon	06/90	-5,750'	-8,780'	3,030'	14,670'	5,820'
Bay Marchand #1 Amoco	05/91	-9,820'	-14,160'	4,340'	18,277'	4,260'
Garden Banks 165 #1 Chevron	04/92	-5,765'	-12,715'	6,950'	18,000'	5,200'
South Marsh Is. 169 #1 Amoco	12/93	Confidential	Confidential	Confidential	18,020'	Confidential
Ship Shoal 349 #1 Phillips	10/93	-7,603'	-11,428'	3,825'	16,500'	4,990'
South Timbalier 260 #1 Phillips	05/94	Confidential	Confidential	Confidential	16,610'	Confidential
Ship Shoal 349 #2 Phillips	06/94	Confidential	Confidential	Confidential	18,603'	Confidential
Vermilion 349 #1 Anadarko	06/94	-9,550'	-12,010'	2,460'	16,146'	4,046'
Ship Shoal 360 #2 Unocal	08/94	Confidential	Confidential	Confidential	19,000'	Confidential
Ship Shoal 250 #1 Japex	09/94	-12,246'	-13,202'	956'	17,750'	4,447'
South Timbalier 289 #1 CNG	11/94	-12,078'	-13,003'	925'	18,034'	4,934'
Garden Banks 127 #1 Shell	05/95	Confidential	Confidential	Confidential	14,730'	Confidential
Vermilion 308 #1 Amoco	07/95	Confidential	Confidential	Confidential	20,399'	Confidential
Mississippi Canyon 292 #1 Texaco	08/95	Confidential	Confidential	Confidential	17,976'	Confidential

## SIGNIFICANT SUB-SALT WELLS - FEDERAL OFFSHORE GULF OF MEXICO (SHEET EDGE/FLANK AND SUB-WELD WELL PENETRATIONS)

WELL NAME	DATE DRLD (TD)	TOP OF SALT	BASE OF SALT	TVD THICKNESS OF SALT	DRLD MD WELL (TD)	DRLD TVD SEDIMENT THICKNESS BELOW SALT
S. Marsh Isl. 153 #3, Phillips	8/73	NA	NA	NA	14,000'	NA
Cameron Parish Peltex #1	10/79	-20,330'	-20,415'	85'	21,530'	1,085'
S. Marsh Isl. 119 #1, Shell	7/81	NA	NA	NA	17,700'	NA
Vermilion 292 #1, Shell	3/83	NA	NA	NA	16,000'	NA
Ship Shoal 366 #2, Placid	10/83	-7,040' -7,329' -7,605'	-7,281' -7,355' TD in Salt	241' 26' 513'+	8,203'	305' Between Salts
Eugene Island 324 #1, Gulf	03/84	NA	NA	NA	15,000'	NA
Green Canyon 98 #1, Conoco	06/84	-10,320'	-11,700'	1,380'	12,121'	340'
Green Canyon 39 #1 ST1, Placid	09/84	-11,675' -12,005'	-11,815' TD in Salt	140' 185'+	12,294'	190' Between Salts
Mississippi Canyon 400 #1, Amoco	01/85	-10,710'	-14,160'	3,450'	16,000'	1,840'
East Breaks 170 #1, Amoco	08/85	-16,075'	-16,325'	250'	17,500'	1,100'
Mississippi Canyon 400 #2, Amoco	09/85	-14,230'	-15,220'	1,290'	17,010'	1,700'
High Is. A-374 #1, Mobil	09/85	-7,575'	-7,825'	250'	15,000'	7,100'
Green Canyon 152 #1STH1, Marathon	12/85	-11,350'	-12,470'	1,130'	16,281' MD	1,623'
Ewing Bank 790 #1, Placid Oil	6/86	NA	NA	NA	15,143' TVD	NA
Vermilion 412 #1, Mobil	01/87	-7,705'	-9,020'	1,315'	9,502'	402'
Eugene Is. 385 #A-12, Union Texas	07/88	-12,450'	-12,510'	60'	14,104'	74'
Eugene Is. 371 #B-4, Union Texas	08/88	10,650' MD	13,000' MD	1,875'	13,038'	30'
S. Marsh Isl. 148 #1, Chevron/Tenneco	12/88	NA	NA	NA	19,500'	NA
Green Canyon 184 #A-12, Conoco	12/90	-8,300'	-8,600'	300'	12,564'	3,964'
Garden Banks 260 #1STH2, Amerada Hess	05/93	-14,098	-16,108	2,010'	18,848' TVD	2,658'
Garden Banks 128 #1, Shell	7/94	Confidential	Confidential	Confidential	17,477' TVD	Confidential
Ship Shoal 368 #1, Amerada Hess	02/95	NA	NA	NA	15,774' TVD	NA

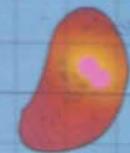


EAST CAMERON

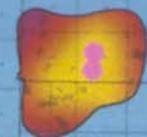
VERMILION

SOUTH MARSH  
ISLAND

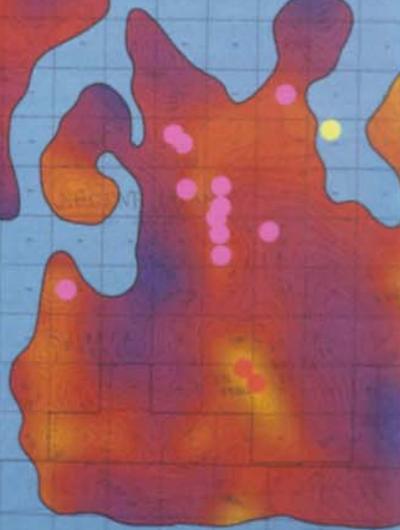
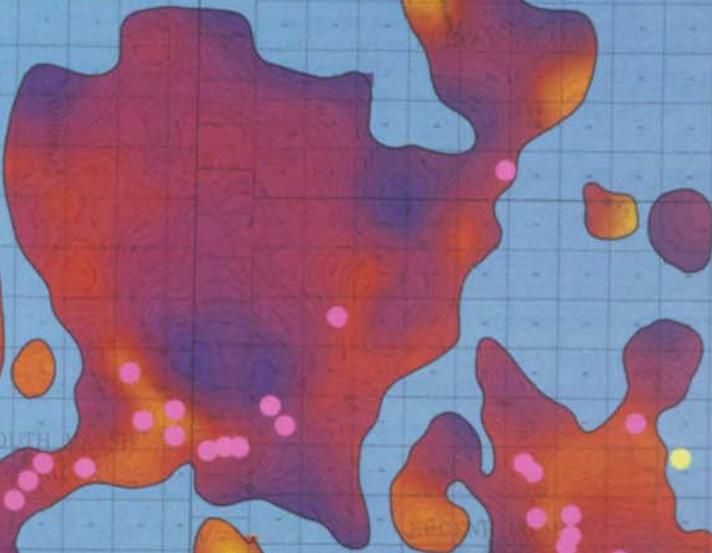
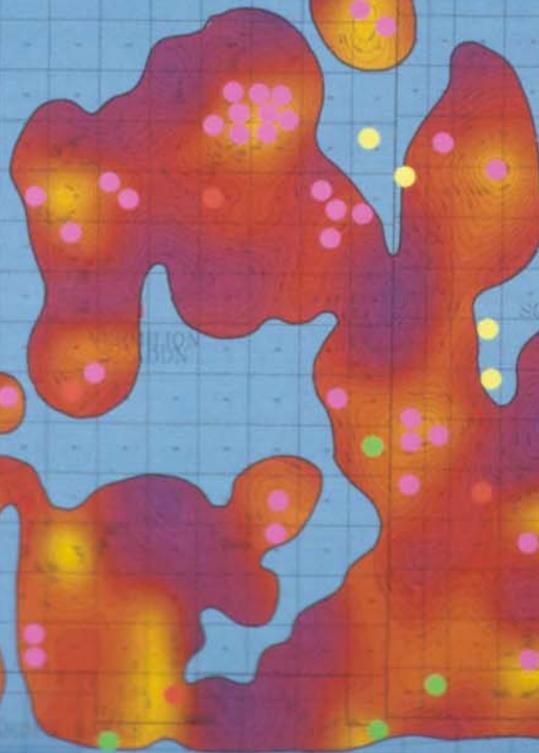
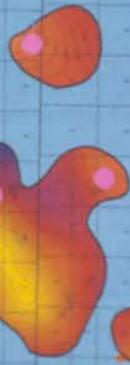
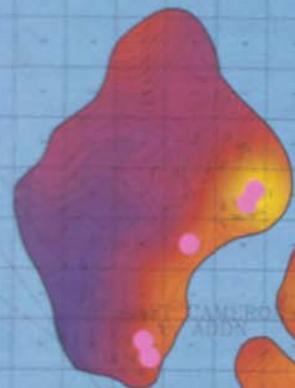
EUGENE ISLAND



VERMILION



ISLAND



- SCS IN SALT TOP WELL
- SUBSALT WELL
- SUBWELD WELL
- SALT TOP WELL

# SHIP SHOAL

# SOUTH TIMBALIER

GRAND ISLE

WEST DELTA  
ADDN

SHIP SHOAL

SOUTH TIMBALIER

GRAND ISLE

MISSISSIPPI CANYON

SOUTH TIMBALIER

E. W. BAY

ATWATER VALLEY

GREEN CANYON

- SCS IN SALT TOP WELL
- SUBSALT WELL
- SUBWELD WELL
- SALT TOP WELL

NORTHWEST

TGS LINE 1464-41

SOUTHEAST

S  
S  
3  
2  
4

SHIP SHOAL 339

S  
S  
3  
4  
8

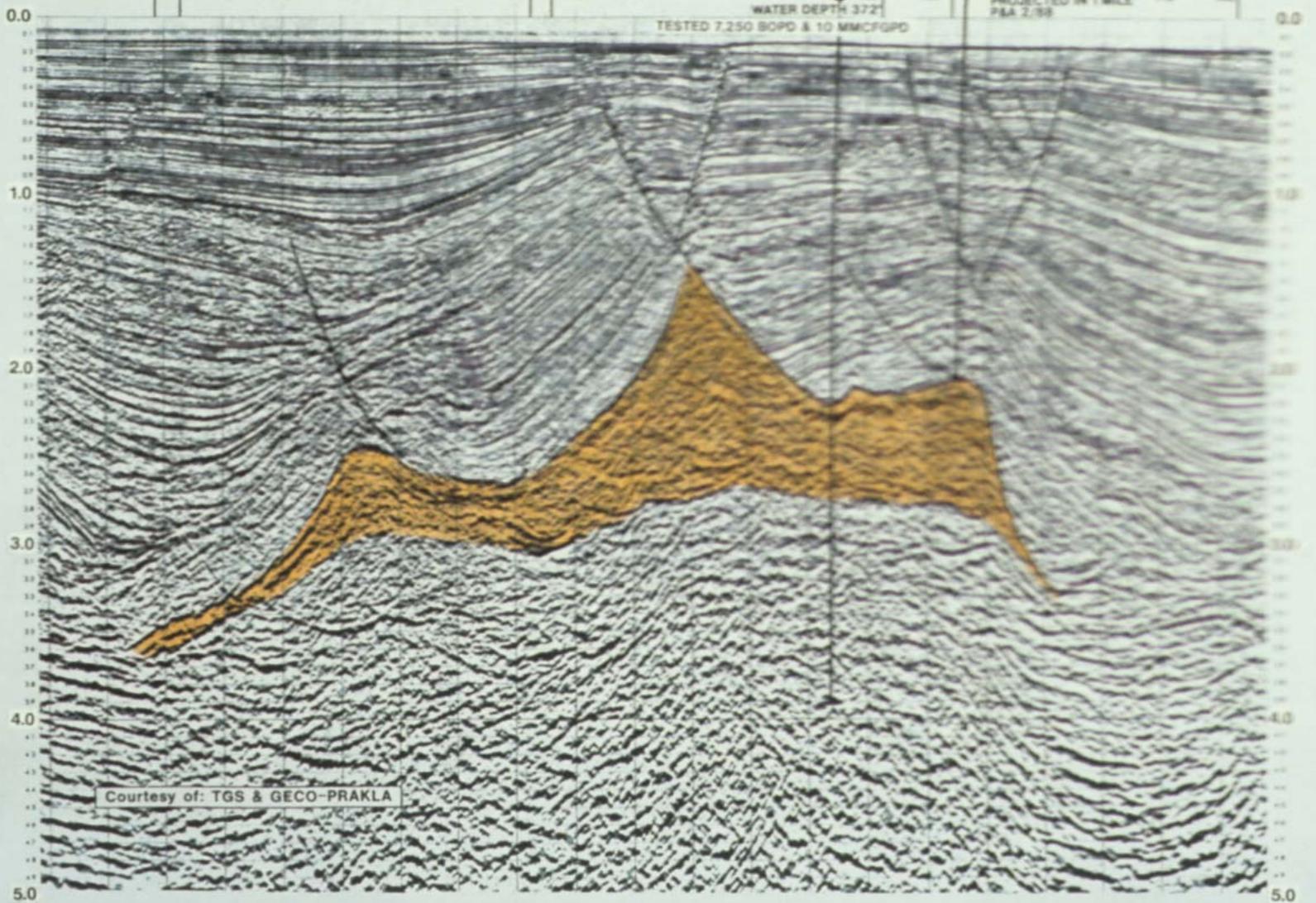
"MAHOGANY"  
SHIP SHOAL 349  
PHILLIPS/ANADARKO/AMOCO  
OCS-G-12008 #1  
TOP/SALT ?  
BASE/SALT ?

S  
S  
3  
5  
9

SHIP SHOAL 358  
TOP/SALT -7230'  
TD IN SALT  
AT 7363'TVD

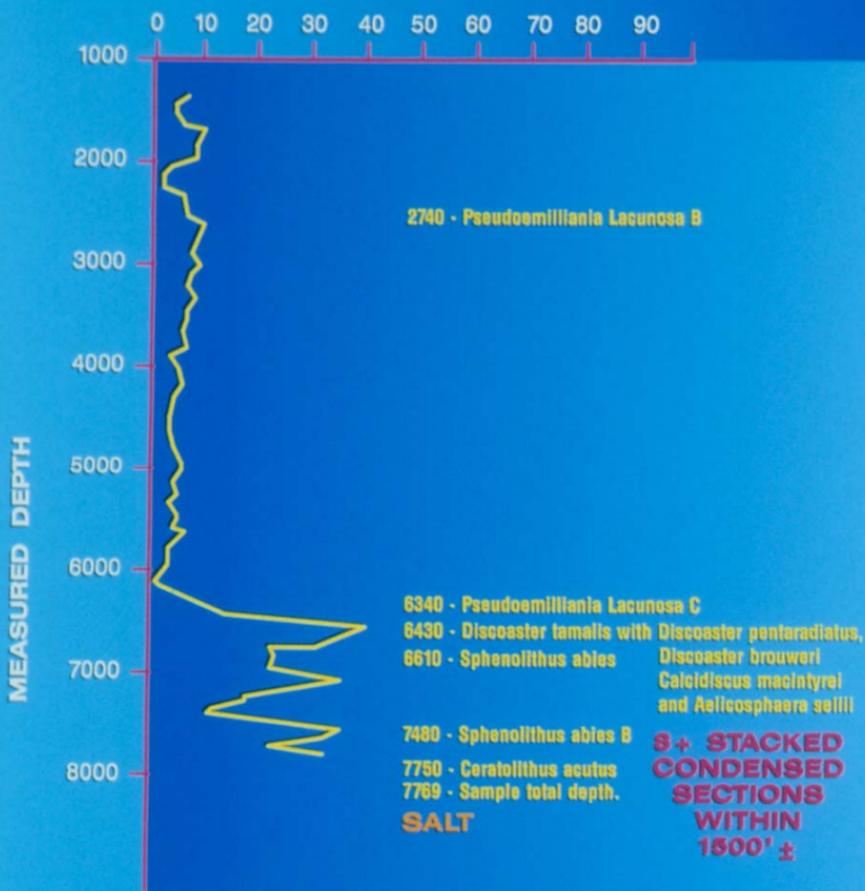
DTD 16,500'  
WATER DEPTH 372'

MOBIL #1  
SS 359  
PROJECTED IN 1 MILE  
P&A 2/98



**MOBIL OIL CORPORATION - GULF OF MEXICO  
BLOCK 359 - #1 OCS-G-5586 - SHIP SHOAL AREA**

**CALCAREOUS NANNOFOSSILS**



WEST

TGS LINE 245-12

EAST

GREEN CANYON 38

GREEN CANYON 39  
PLACID OCS-G-5883#1  
TOP/SALT -11,670'  
BASE/SALT -11,810'

GREEN CANYON 40

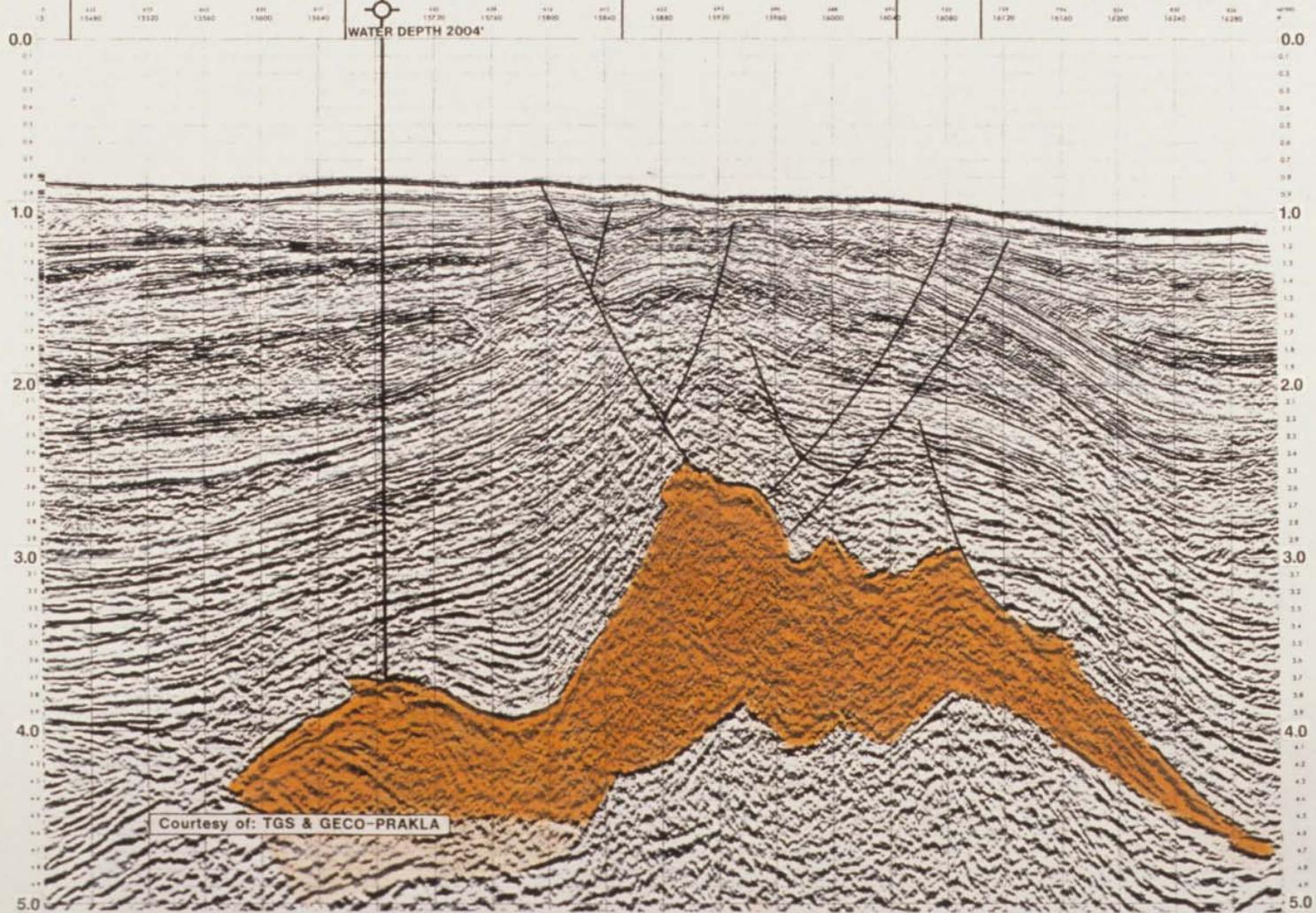
GREEN  
CANYON  
41

ATWATER 1

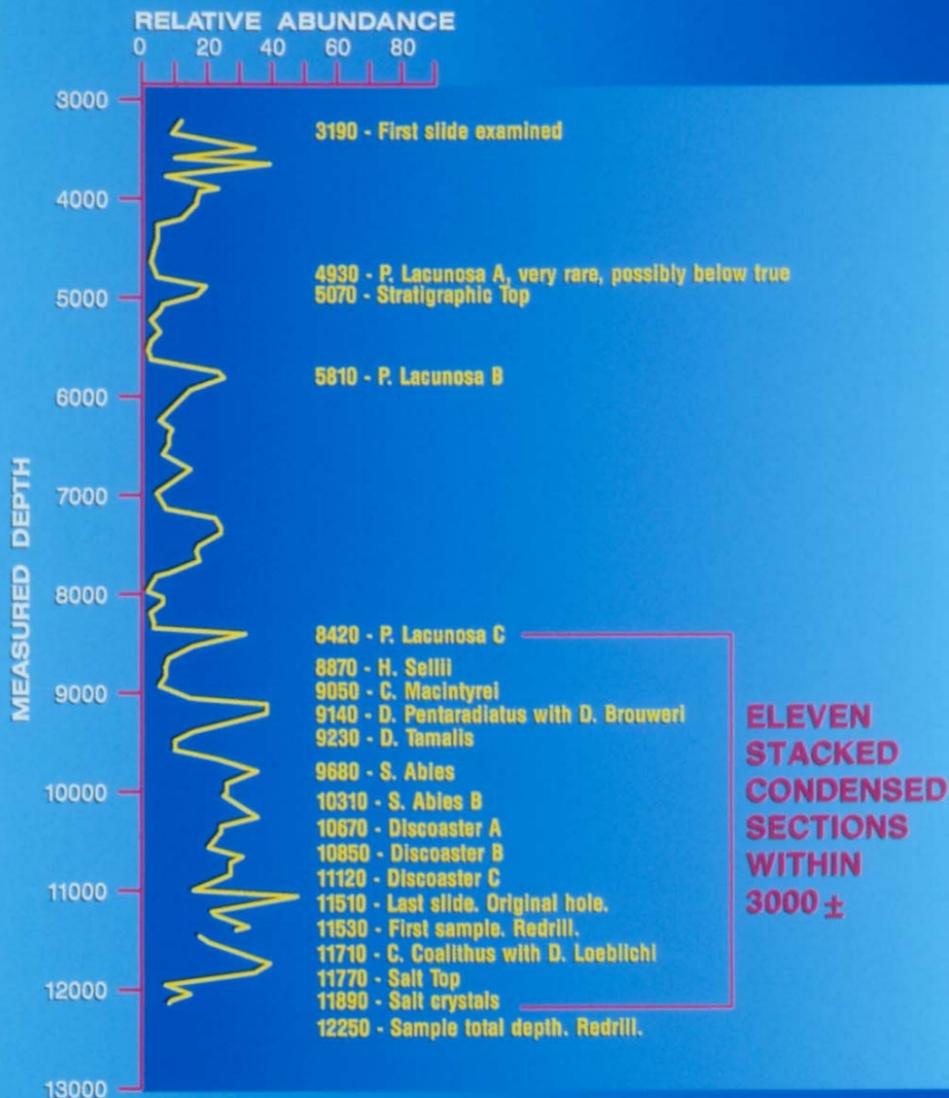
TD 12,294' TOP/2<sup>nd</sup> SALT -12,010'



WATER DEPTH 2004'



**PLACID OIL COMPANY – GULF OF MEXICO  
BLOCK 39 - #1 OCS-G-5883 - GREEN CANYON**



94 00

92 00

90 00

88 00

29 00

28 00

27 00

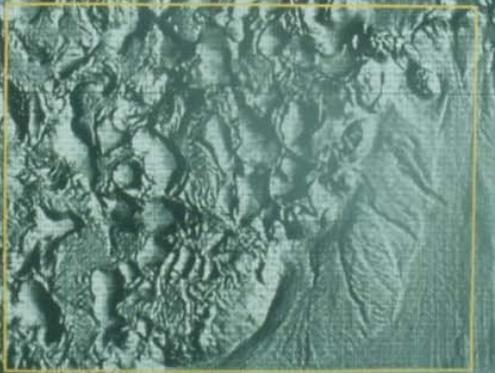
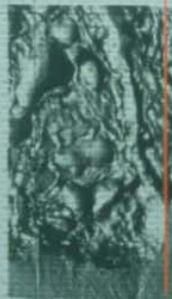
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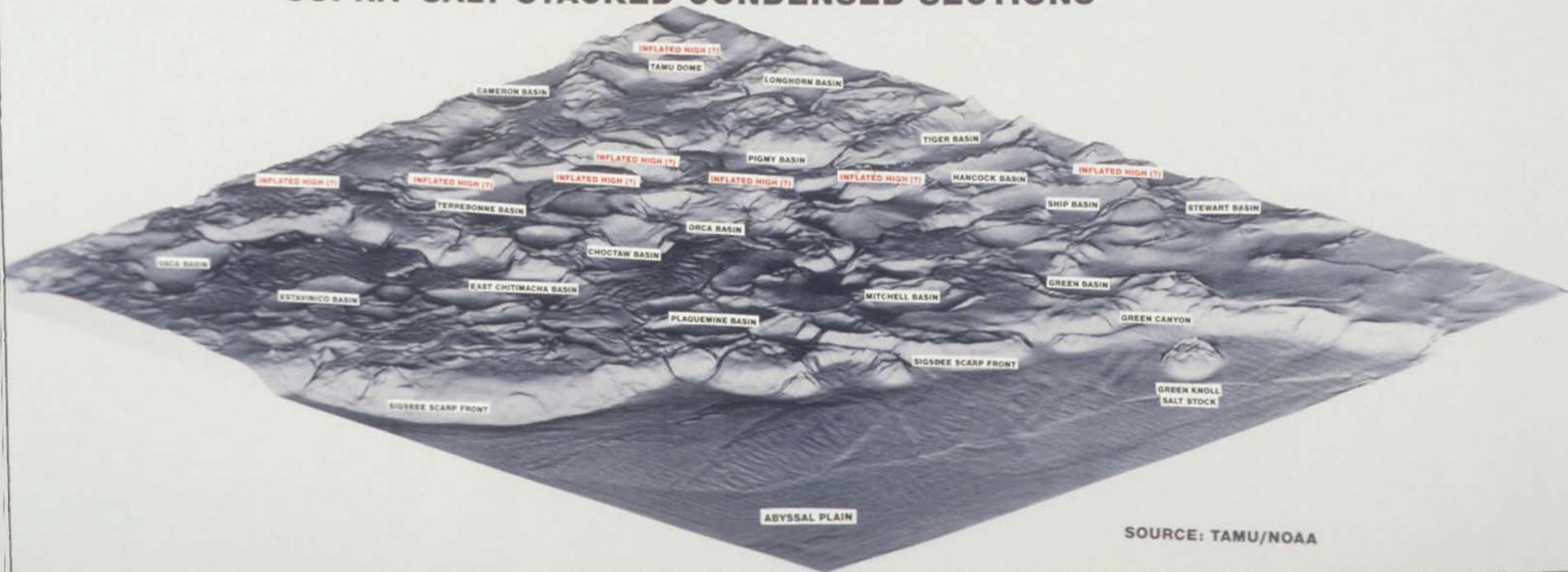
GARD

R VALLEY

LUND

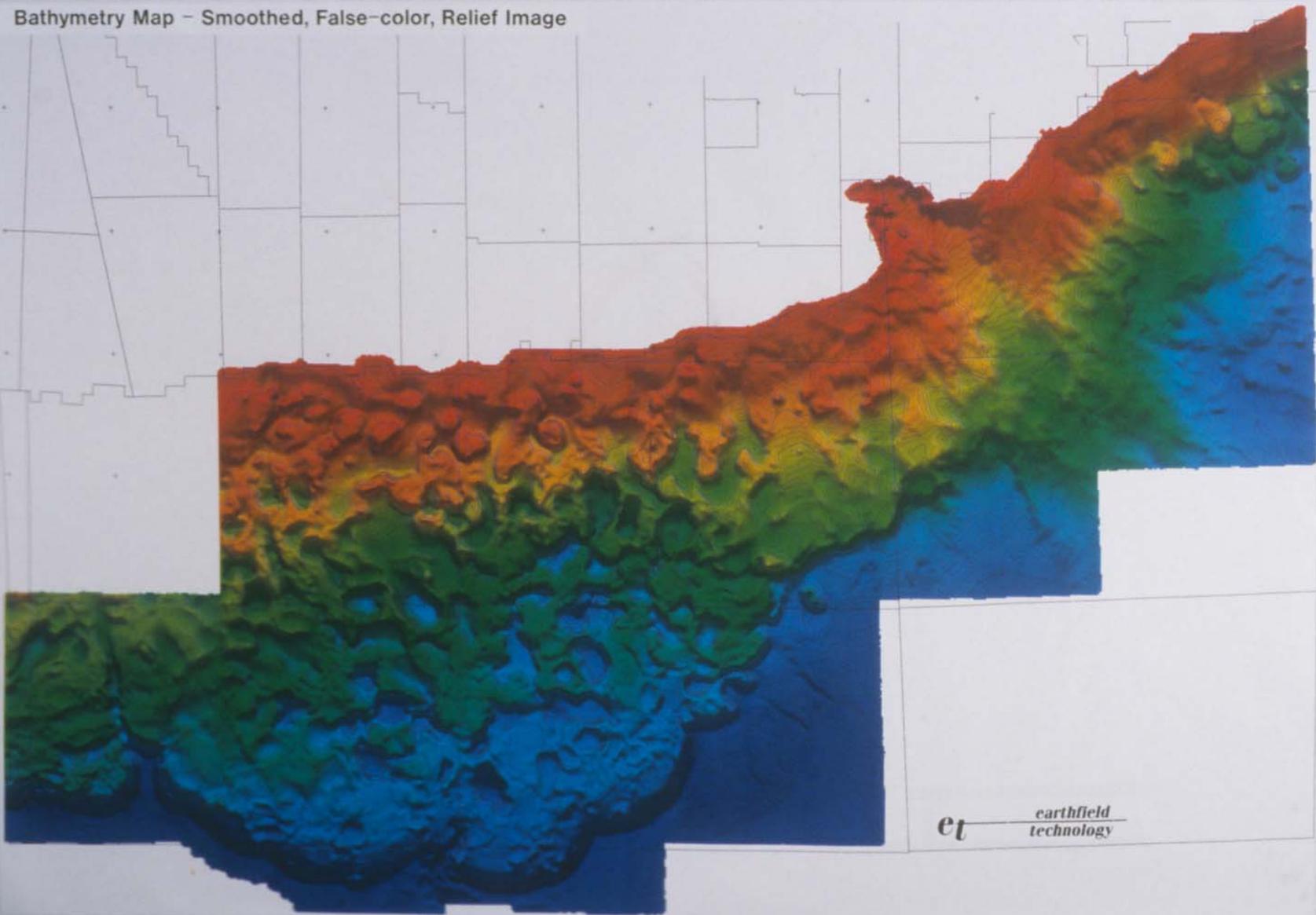


**OVERTHRUST SIGSBEE SALT SHEET / PLATFORM  
PRESENT DAY - WALKER RIDGE/GREEN CANYON  
INTRA-BASINAL SALT INFLATED HIGHS WITH POSSIBLE  
SUPRA-SALT STACKED CONDENSED SECTIONS**



SOURCE: TAMU/NOAA

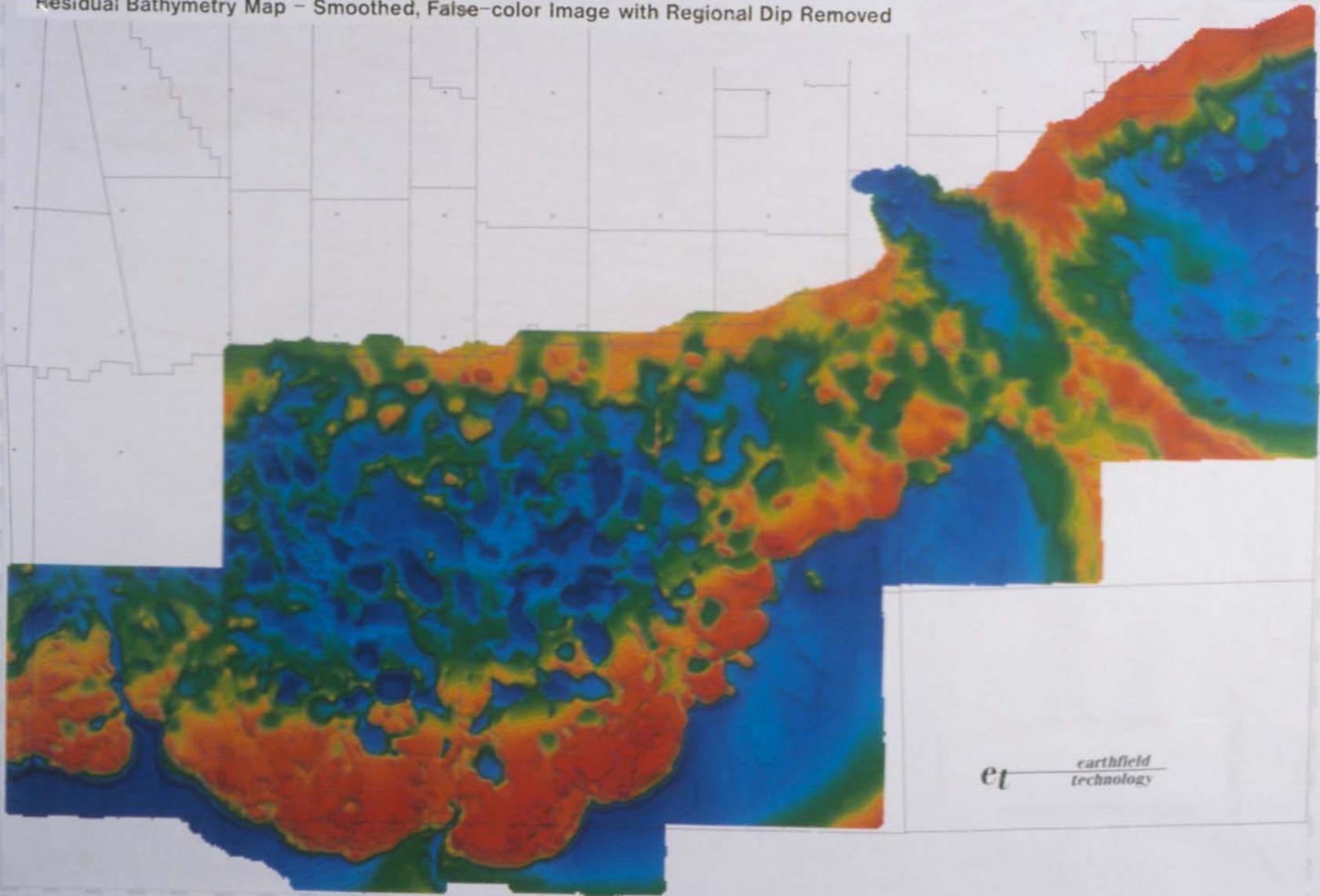
Bathymetry Map - Smoothed, False-color, Relief Image



*et* earthfield  
technology

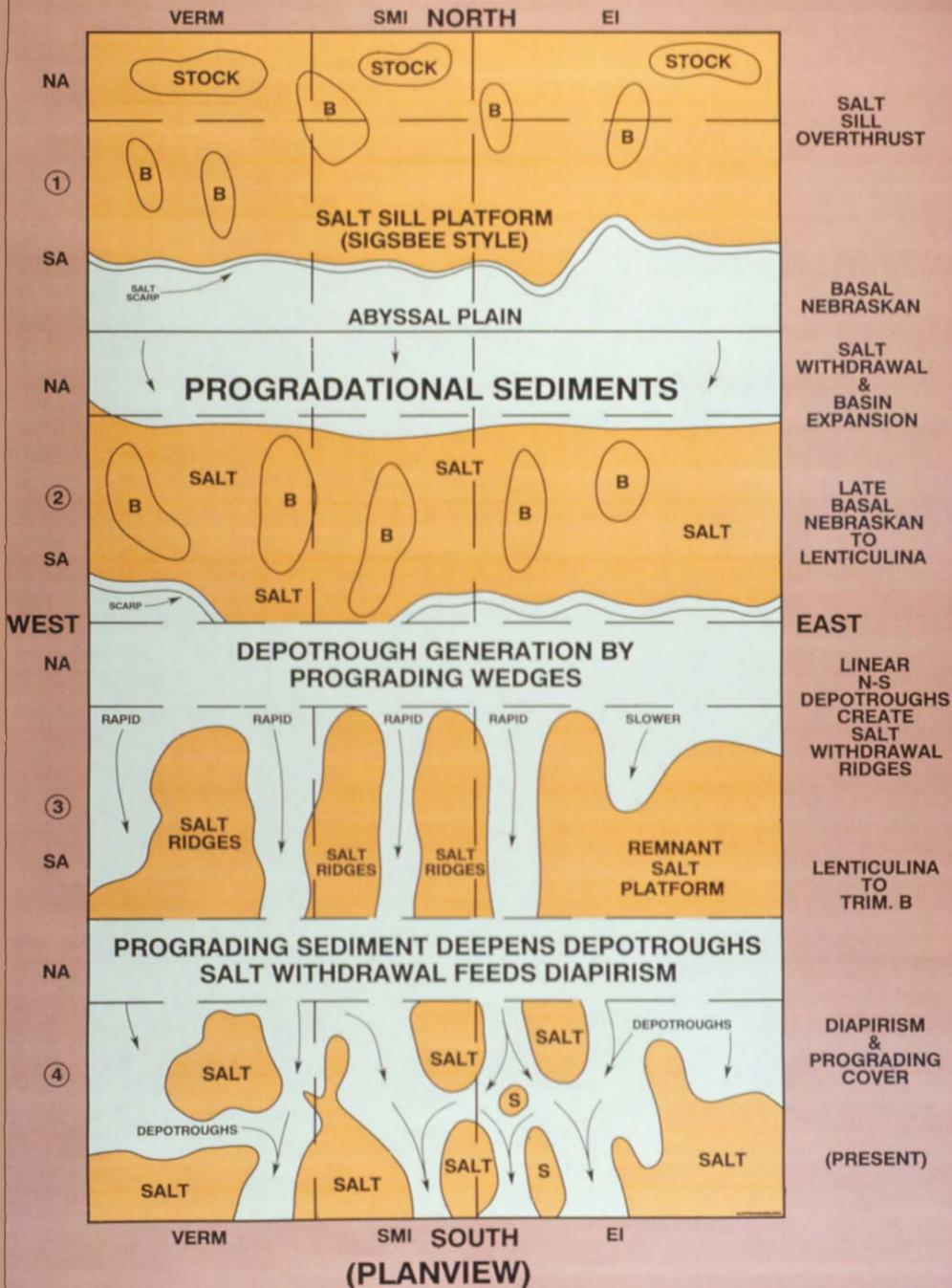
© 2000 Earthfield Technology, Inc. All rights reserved. This map is a derivative work of the Earthfield Technology, Inc. bathymetry data. The bathymetry data was collected by the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS). The bathymetry data was processed by Earthfield Technology, Inc. using the Earthfield Technology, Inc. bathymetry processing software. The bathymetry data was smoothed and false-colored to create this relief image. The bathymetry data was collected from 1998 to 2000. The bathymetry data was collected from the following sources: NOAA, USGS, and Earthfield Technology, Inc. The bathymetry data was collected from the following sources: NOAA, USGS, and Earthfield Technology, Inc. The bathymetry data was collected from the following sources: NOAA, USGS, and Earthfield Technology, Inc.

Residual Bathymetry Map - Smoothed, False-color Image with Regional Dip Removed



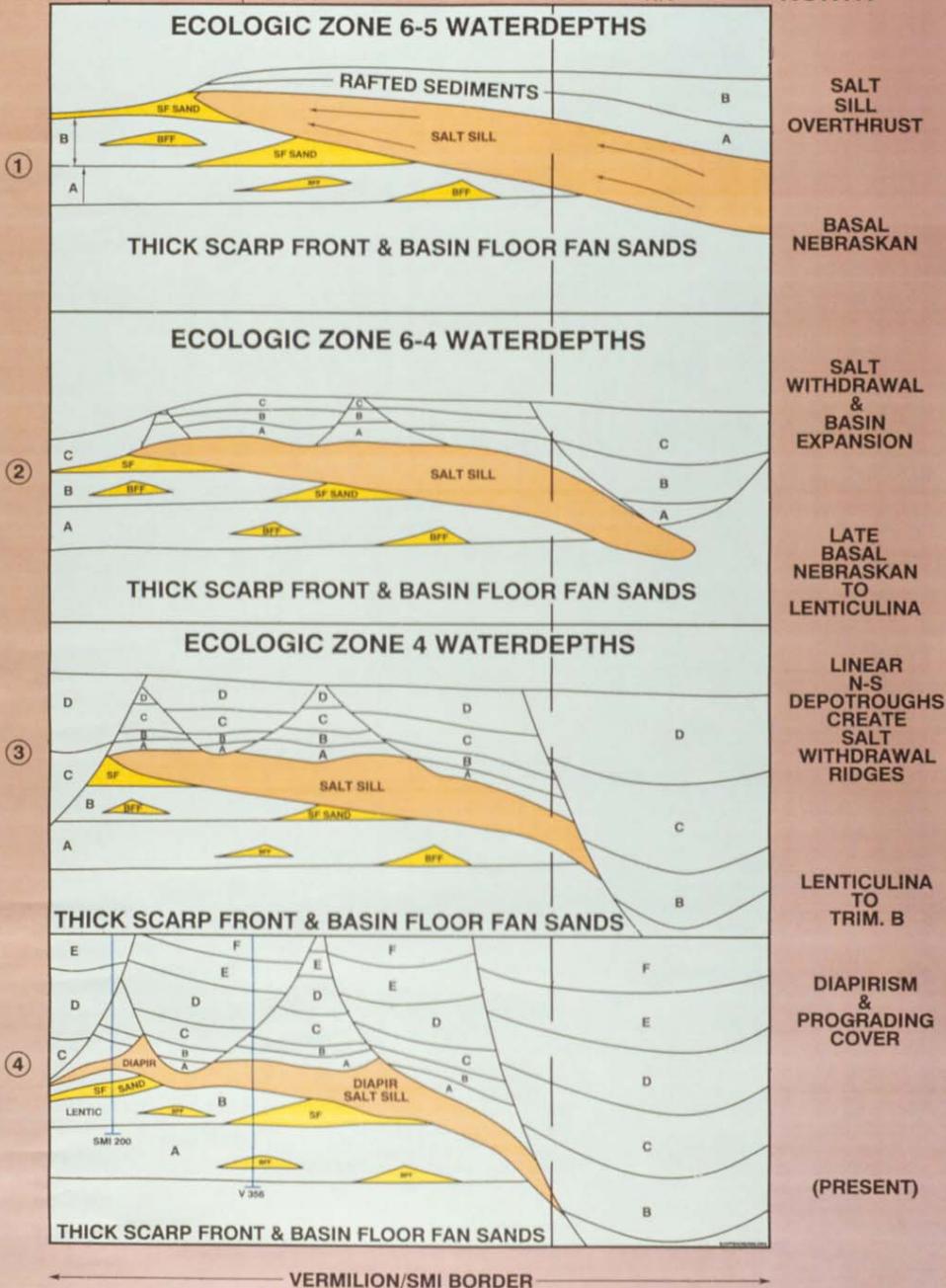
*et* — earthfield  
technology

# EVOLUTION OF SALT STYLES



# EVOLUTION OF SALT STYLES

SOUTH SMI 200#1 V 356#1 SA NA NORTH



## *Four Types of Supra Salt Sequence Occurrences:*

- 1 Stacked Condensed Sections (SCS) coupled and conformably deposited upon the salt**
- 2 Stacked Condensed Sections (SCS) decoupled from and extended along the top of salt**
- 3 Normal thickness of individual sequences coupled or decoupled that set conformably upon the salt**
- 4 Normal thicknesses of individual sequences coupled or decoupled that are much younger than the surrounding salt flank intervals suggesting subaqueous erosion or non-deposition**

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**NORMAL SUPRASALT SECTION**

**STACKED**

**CONDENSED**

**SECTIONS (DEPOSITIONAL CONTACT)**

**SALT SHEET**

**"JUMBALAYA"**

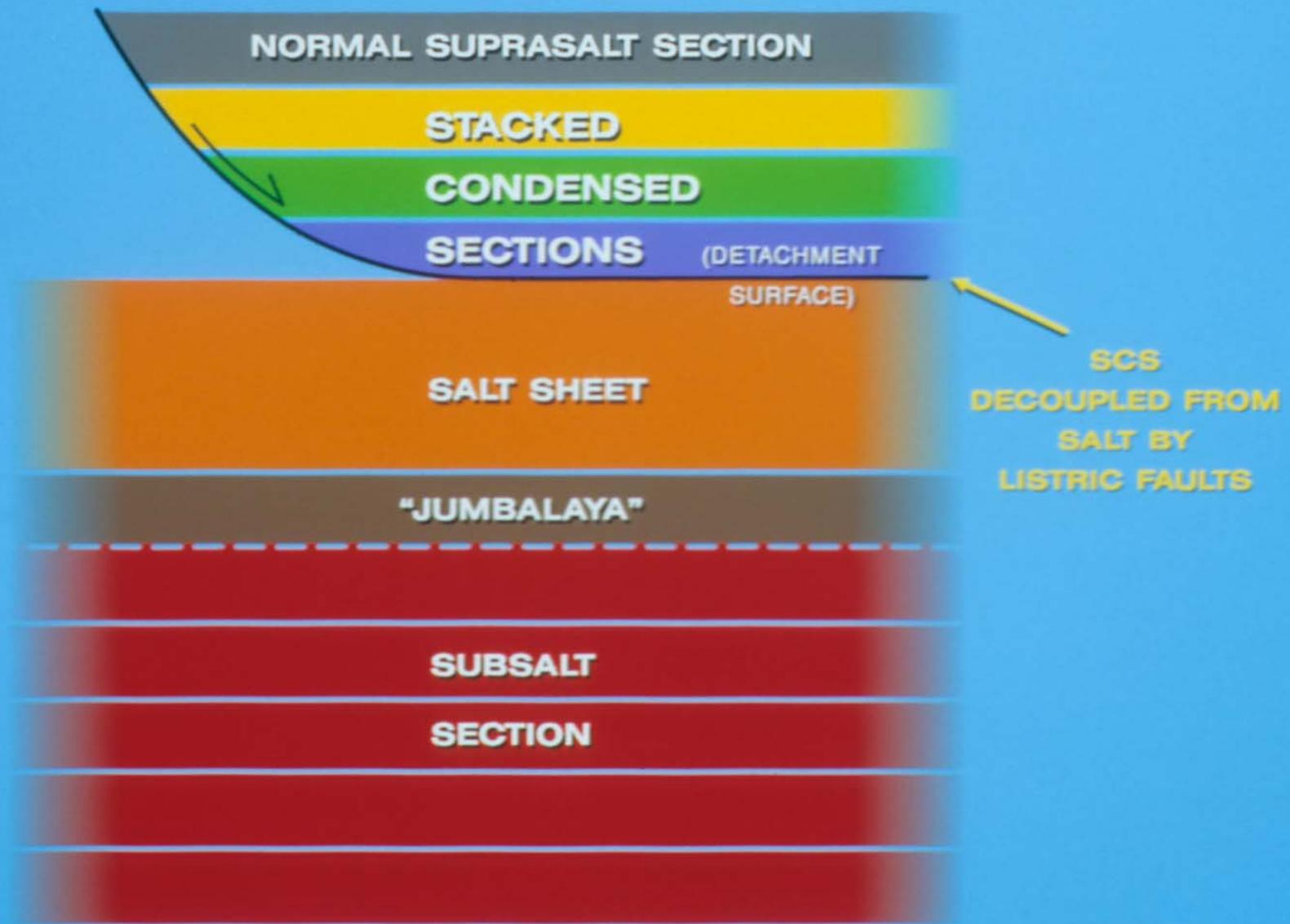
**SUBSALT**

**SECTION**

**SCS  
CONFORMABLE  
AND  
COUPLED TO  
SALT**

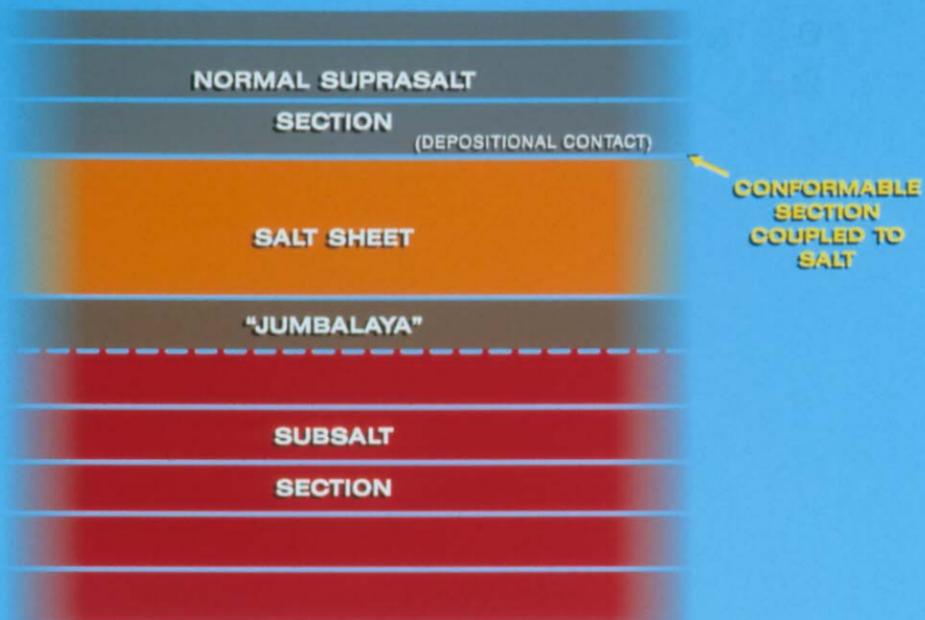
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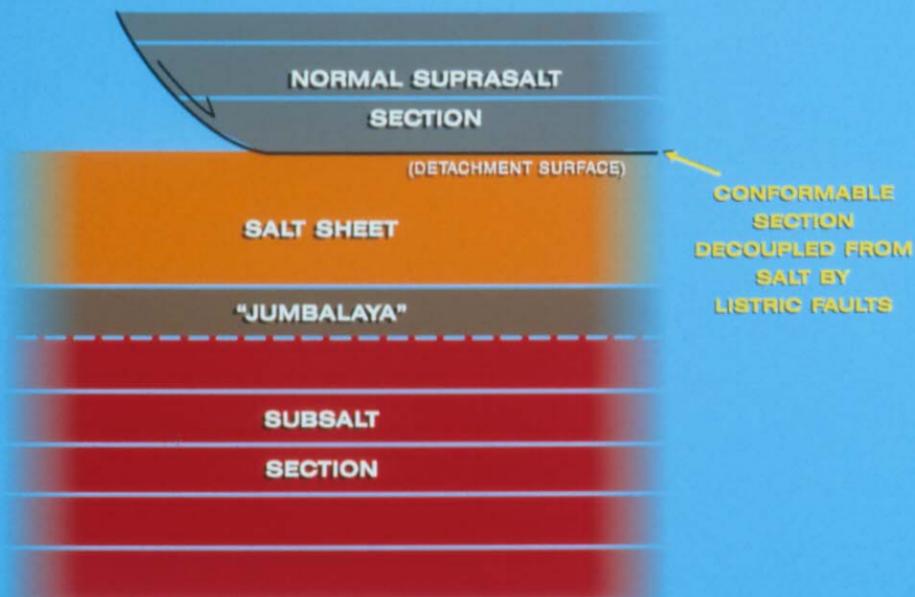


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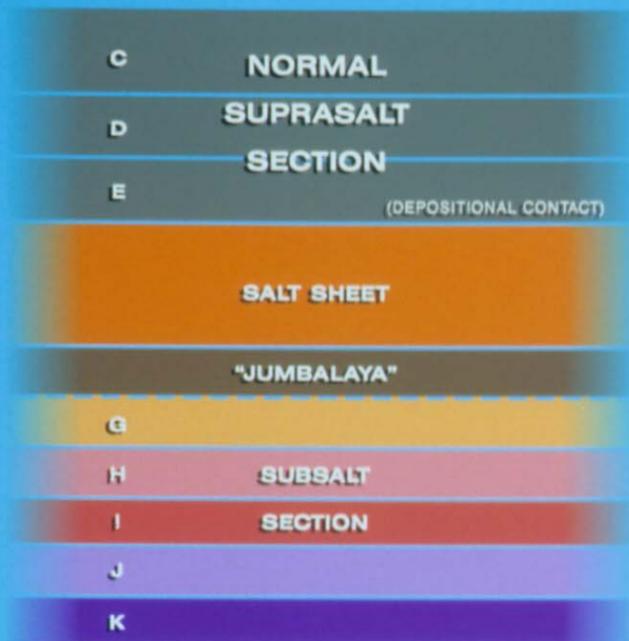
3A



3B

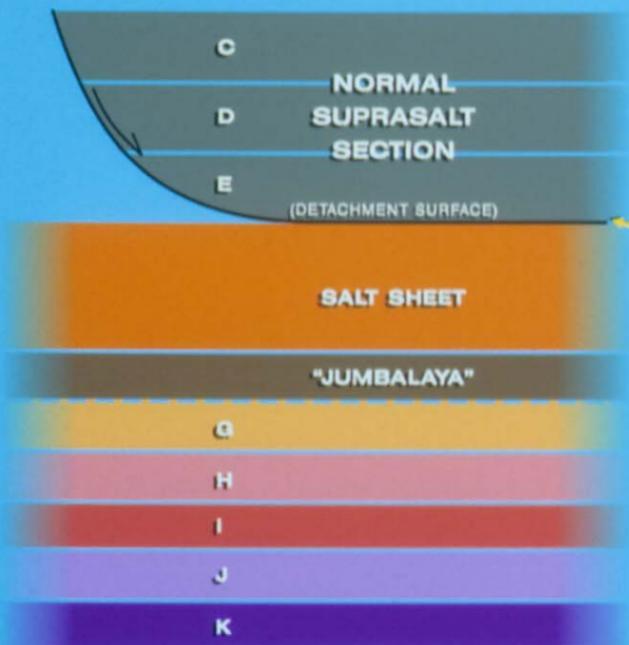
## *Four Types of Supra Salt Sequence Occurrences:*

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- 4** *Normal thicknesses of individual sequences coupled or decoupled that are much younger than the surrounding salt flank intervals suggesting subaqueous erosion or non-deposition*



*Younger non-SCS sequences coupled to salt suggest subaqueous erosion or non-deposition.*

4A



*Younger non-SCS sequences decoupled from salt suggest subaqueous erosion, non-deposition or overthrusting.*

4B

*Results in three significant scenarios for age relationships between supra and subsalt sediments:*

- 1 Large sedimentary time gap**
- 2 Conformable, with little apparent missing section**
- 3 Significant Repeat Section below salt, occurring when SCS is present above salt**

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**NORMAL SUPRASALT SECTION**

**A** **STACKED**  
**B**  
**C** **CONDENSED**  
**D** **SECTIONS**  
**E** (DETACHMENT SURFACE)

**SALT SHEET**

**"JUMBALAYA"**

**H**

**I** **SUBSALT**

**J** **SECTION**

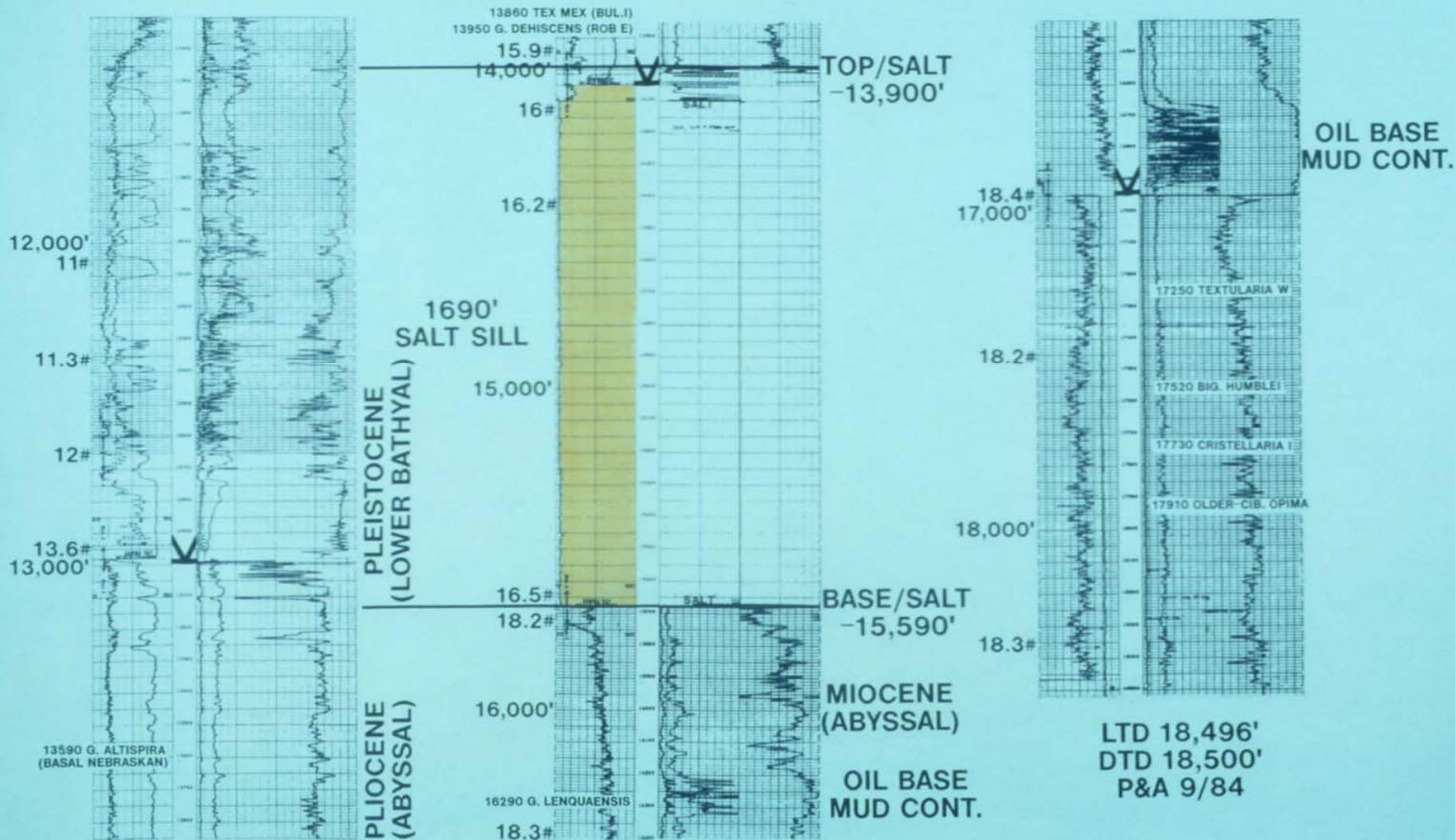
**K**

**L**

**LARGE  
SEDIMENTARY  
TIME GAP**

*Most often occurs along  
the updip edge of salt  
sheets where a large  
listric fault system  
formed above the salt.*

**GULF #2  
OCS-G-5337  
WEST CAMERON 505**



NORTHWEST

TGS LINE 1180-41

SOUTHEAST

WEST CAMERON 488

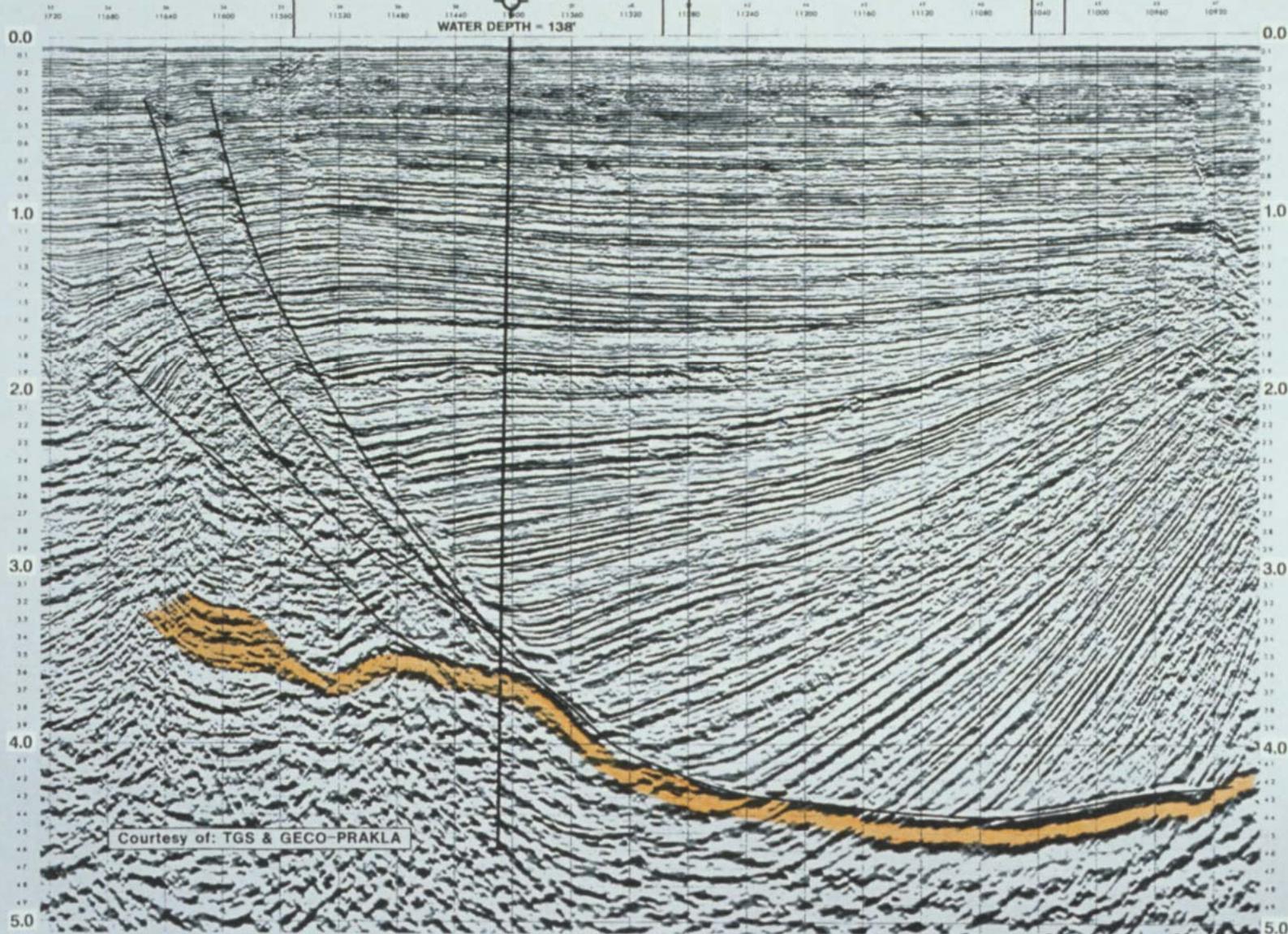
WEST CAMERON 505  
GULF OCS-G-5337 #2  
TOP/SALT -13,900'  
BASE/SALT -15,590'  
TD 18,500'

W  
C  
5  
0  
6

WEST CAMERON 511

W  
C  
5  
1  
0

WEST CAMERON 531



Courtesy of: TGS & GECO-PRAKLA

*Results in three significant scenarios for age relationships between supra and subsalt sediments:*

- 1 Large sedimentary time gap**
- 2 Conformable, with little apparent missing section**
- 3 Significant Repeat Section below salt, occurring when SCS is present above salt**

## NORMAL SUPRASALT SECTION

A **STACKED**  
B **CONDENSED**  
C **SECTIONS**  
D

(DEPOSITIONAL  
CONTACT)

**SALT SHEET**

**"JUMBALAYA"**

E

F **SUBSALT**

G **SECTION**

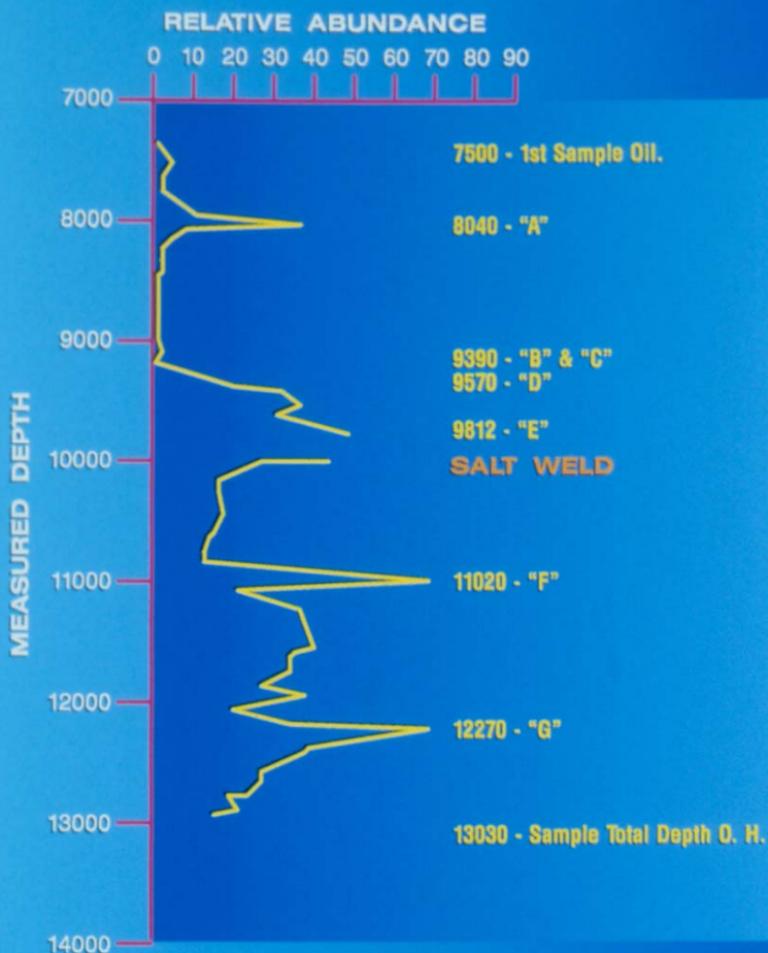
H

I

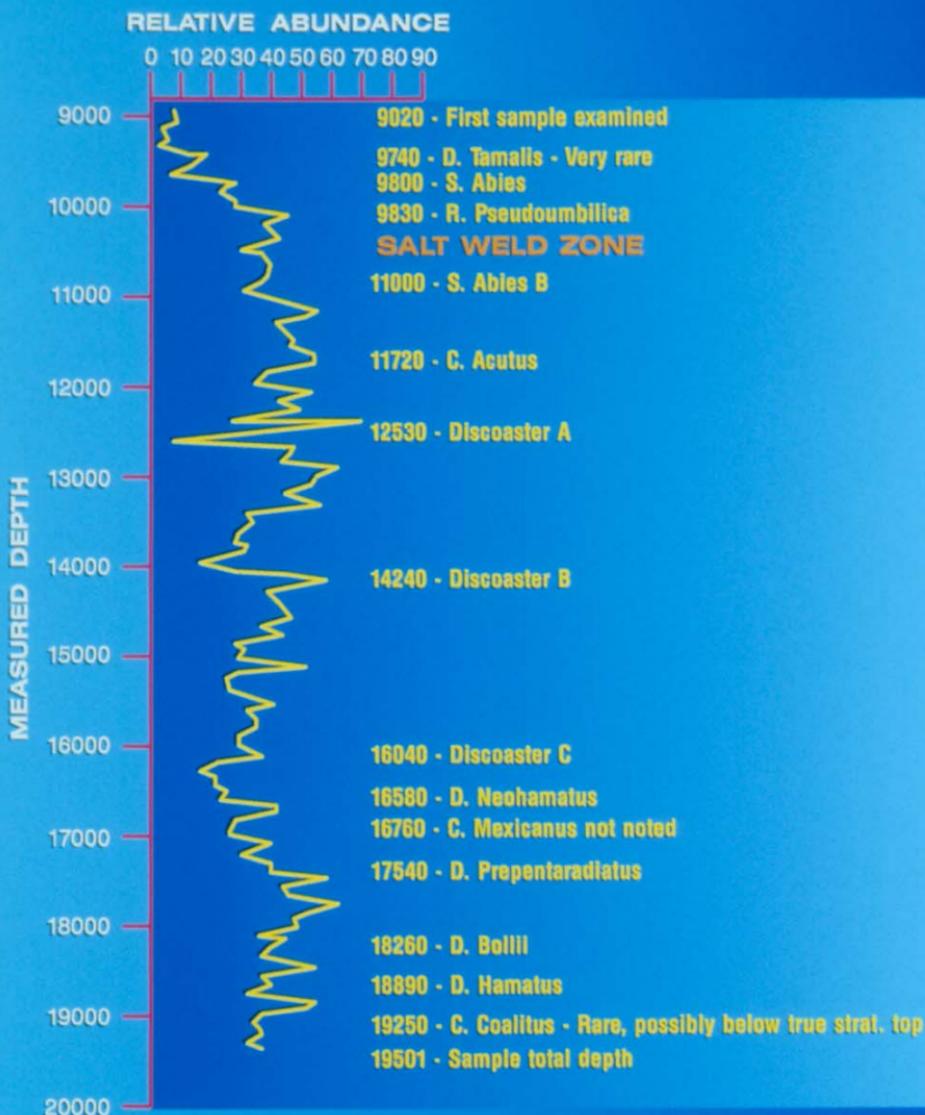
**CONFORMABLE  
NO MISSING  
SECTION**

*The section can be  
conformable with little  
apparent missing  
section.*

**GULF OIL COMPANY – GULF OF MEXICO  
BLOCK 324 - #1 OCS-5816 - EUGENE ISLAND**



**CHEVRON/TENNECO – GULF OF MEXICO**  
**BLOCK 148 - #1 OCS-G-8685 - SOUTH MARSH ISLAND**



*Results in three significant scenarios for age relationships between supra and subsalt sediments:*

- 1 Large sedimentary time gap**
- 2 Conformable, with little apparent missing section**
- 3 Significant Repeat Section below salt, occurring when SCS is present above salt**

## NORMAL SUPRASALT SECTION

A STACKED  
B CONDENSED  
C SECTIONS (DEPOSITIONAL CONTACT)

SALT SHEET

"JUMBALAYA"

A

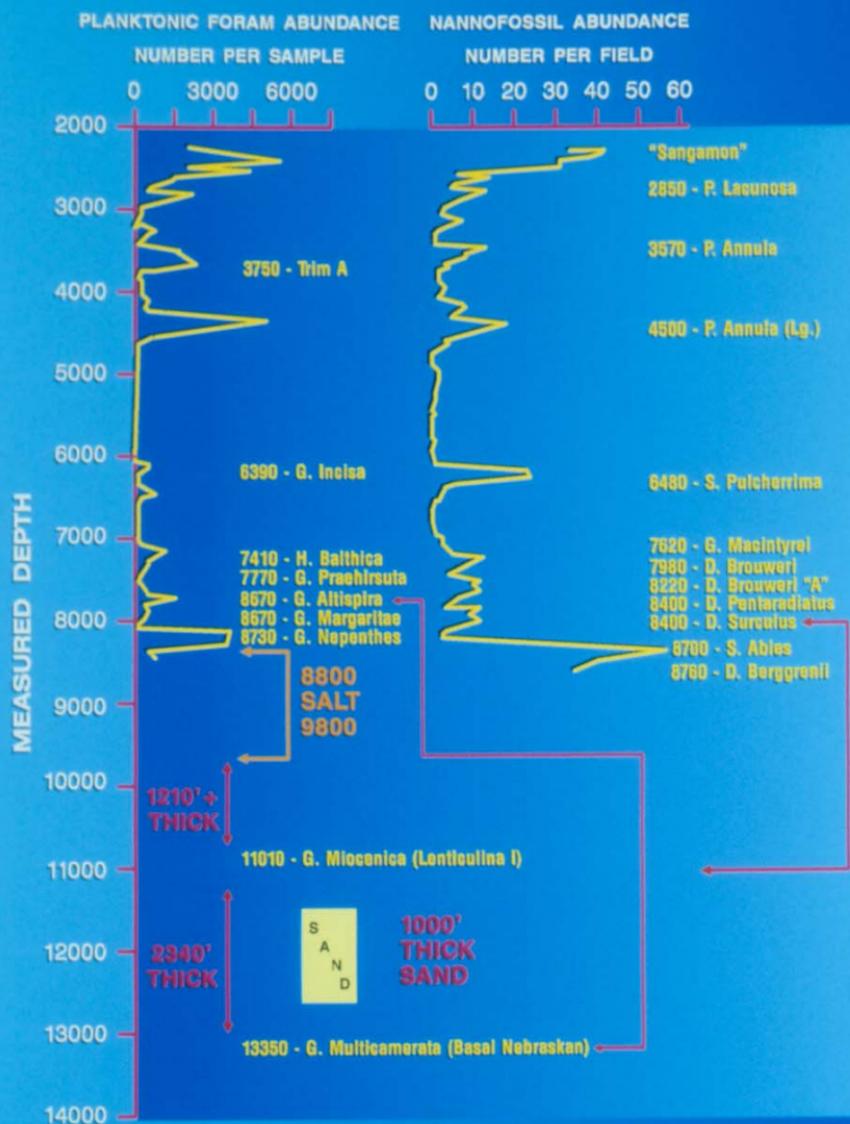
B SUBSALT SECTION

C

REPEATED SECTION

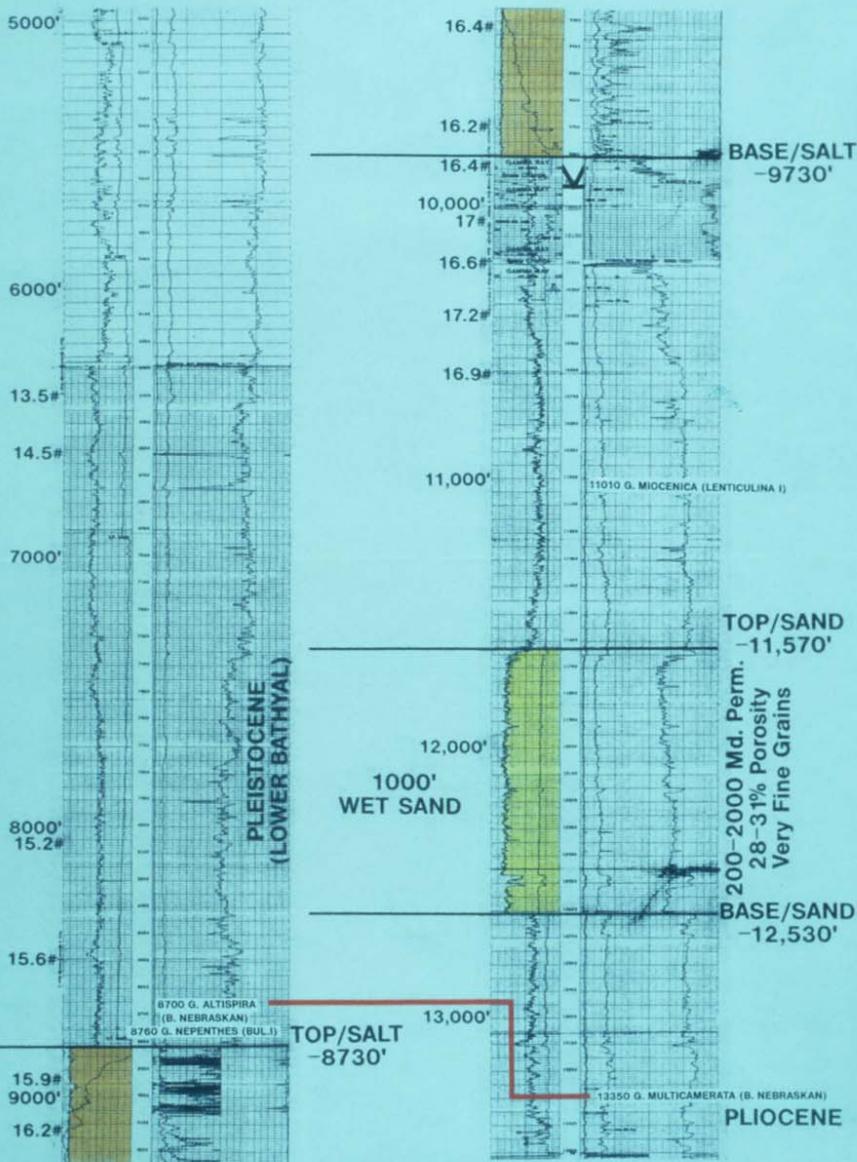
*A prominent repeated section can occur when a stacked condensed section is present above the salt sheet with "5 to 10" time expansion below salt.*

**DIAMOND SHAMROCK - GULF OF MEXICO**  
**BLOCK 200 - #1 OCS-G-7719 - SOUTH MARSH ISLAND**



SOURCE: ABOVE SALT - TGS  
 BELOW SALT - PALEO-DATA

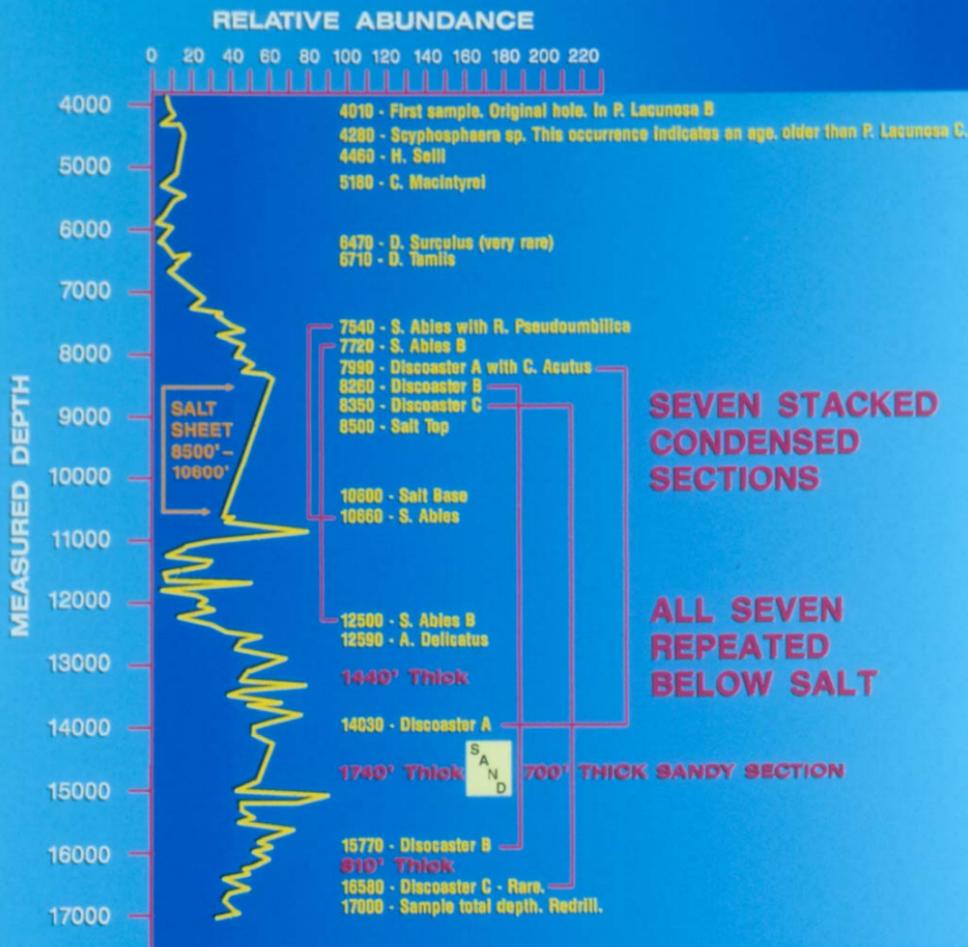
**DIAMOND SHAMROCK #1  
OCS-G-7719  
SOUTH MARSH ISLAND 200**



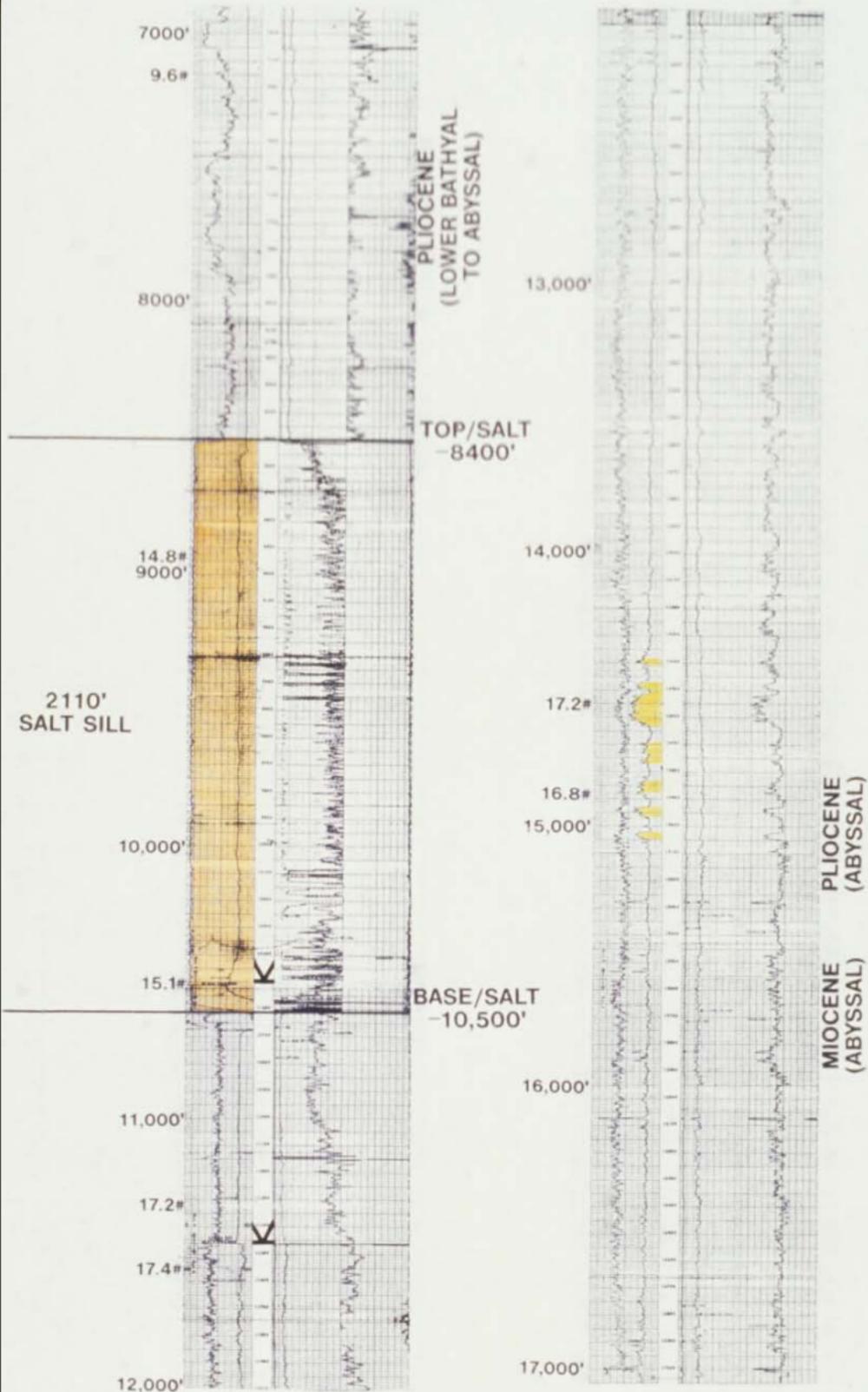
**1000'  
SALT  
SILL**

LTD 13,500'  
DTD 13,500'  
P&A 2/86

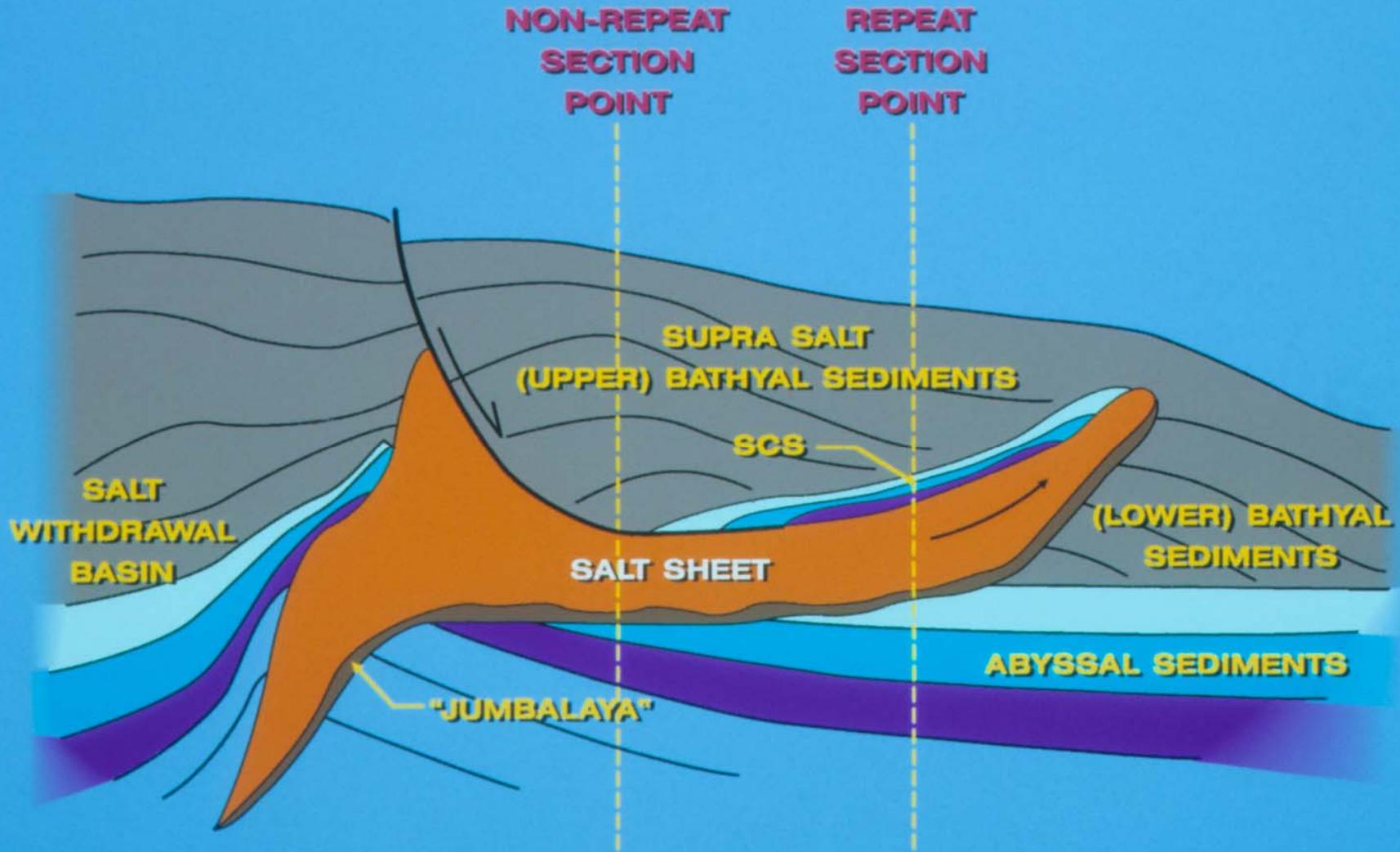
# AMOCO PRODUCTION COMPANY – GULF OF MEXICO BLOCK 356 - #1 OCS-G-7690 - VERMILION



AMOCO #1  
OCS-G-7690  
VERMILION 356



LTD 17,034'  
DTD 17,000'  
P&A 12/87



**NON-REPEAT  
SECTION  
POINT**

**REPEAT  
SECTION  
POINT**

**SUPRA SALT  
(UPPER) BATHYAL SEDIMENTS**

**SCS**

**SALT  
WITHDRAWAL  
BASIN**

**SALT SHEET**

**(LOWER) BATHYAL  
SEDIMENTS**

**"JUMBALAYA"**

**ABYSSAL SEDIMENTS**

## ***CONCLUSIONS***

- ***Stacked Condensed Sections(SCS) or “Mega-Condensed Sections” encountered above allochthonous salt sheets suggest that thicker and “repeated” sequences of age equivalent sediments may be encountered below the salt sheet.***
- ***Subsalt sediments below SCS may have greater propensity for sand due to sand prone gravity driven deposition bypassing these salt inflated highs and accumulating around salt scarp edges and fronts. All prior to sheet thrusting with rafted SCS on sheet surface.***
- ***Thick intervals of subsalt sediments (4,000+) should be penetrated in future wellbores below salt sheets to encounter all subsalt age equivalent sequences seen in the rafted SCS supra salt.***

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**TGS, Geco-Prakla, Amoco, Earthfield Technologies  
and Western Geophysical**

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