3D Structural Evolution of the Salt Controlled Frampton Anticline, Atwater Valley Fold Belt, Deep Water Gulf of Mexico*

Gianluca Grando[1], Zsolt Schleder[1], Ryan Shackleton[1], Graham Seed[1], Tim Buddin[2], Ken McClay[3], and Francesco Borraccini[1]

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[1]Midland Valley Exploration, Glasgow, United Kingdom (francesco@mve.com)
[2]BP Exploration, Sunbury, United Kingdom
[3]Royal Holloway University of London, London, United Kingdom

Abstract

The salt-controlled Frampton anticline is part of the Atwater Valley/Southern Green Canyon frontal fold belt system in the deep water Gulf of Mexico. A kinematic model and structural evolution of the growth fold are proposed based on the interpretation of high quality 3D depth migrated seismic data and 3D structural restoration.

2D and 3D restoration is frequently used as a tool to validate structural models and to examine the evolution of structures. In this study, results of structural restoration have been integrated with true thickness map analysis because isopach maps of unrestored models can provide insight to the structural evolution with a smaller number of iterations normally required in restoration. Restoration was performed using the 4DRestore tool box developed by Midland Valley Exploration, which is a full 3D surface and volume restoration tool based on a mass-spring geophysical solver.

Mapping and structural restoration show that small wavelength salt pillows separated by minibasins formed soon after deposition of the Middle Jurassic Louann Salt during an early contractional event. These precursor structures controlled the geometry and location of Tertiary folding. The main phase of fold amplification occurred during the late Miocene and early Pliocene synchronous with basal salt withdrawal and formation of synclinal welds.

3D sequential restoration techniques applied in this study could be used to infer the fold kinematics for less well imaged hydrocarbon-bearing growth folds in the deep water province of the Gulf of Mexico; particularly those that result from non-plane strain deformation.

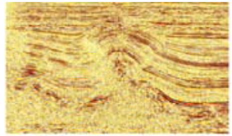
3D STRUCTURAL EVOLUTION OF THE SALT CONTROLLED FRAMPTON ANTICLINE, ATWATER VALLEY FOLD BELT DEEP WATER GULF OF MEXICO

Gianluca Grando[1], Zsolt Schleder[1],, Ryan Shackleton[1], Graham Seed[1] , Tim Buddin[2], Ken McClay[3], and Francesco Borraccini[1]

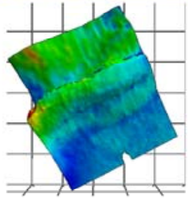
[1] Midland Valley Exploration, Glasgow, UK
[2] BP Exploration Sunbury, London, UK
[3] Royal Holloway University of London, UK

AIMS

- **Determine the structural evolution of the Frampton Anticline**



- **Integration of isopach maps analysis and non plane strain restoration to unravel fold history**



- **3D Restoration to analyse progressive evolution and timing**

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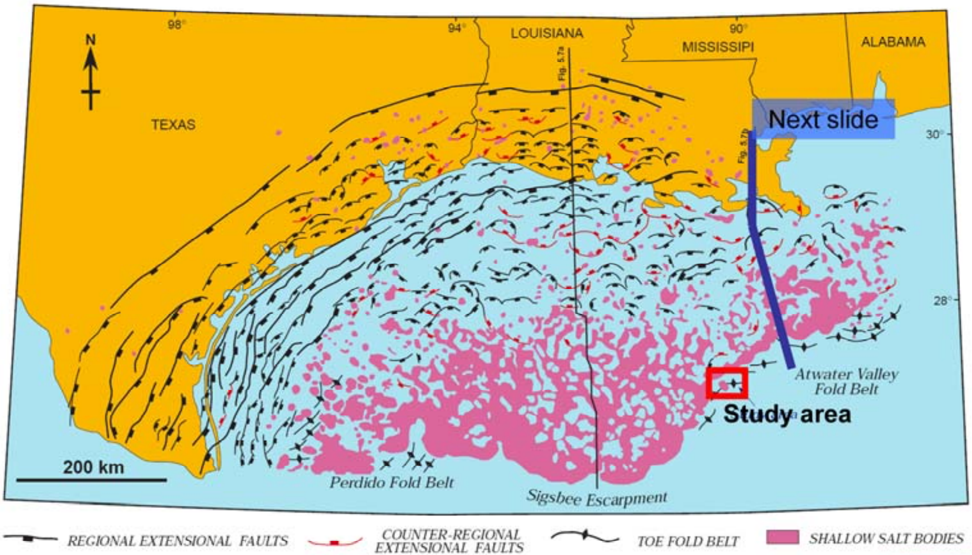
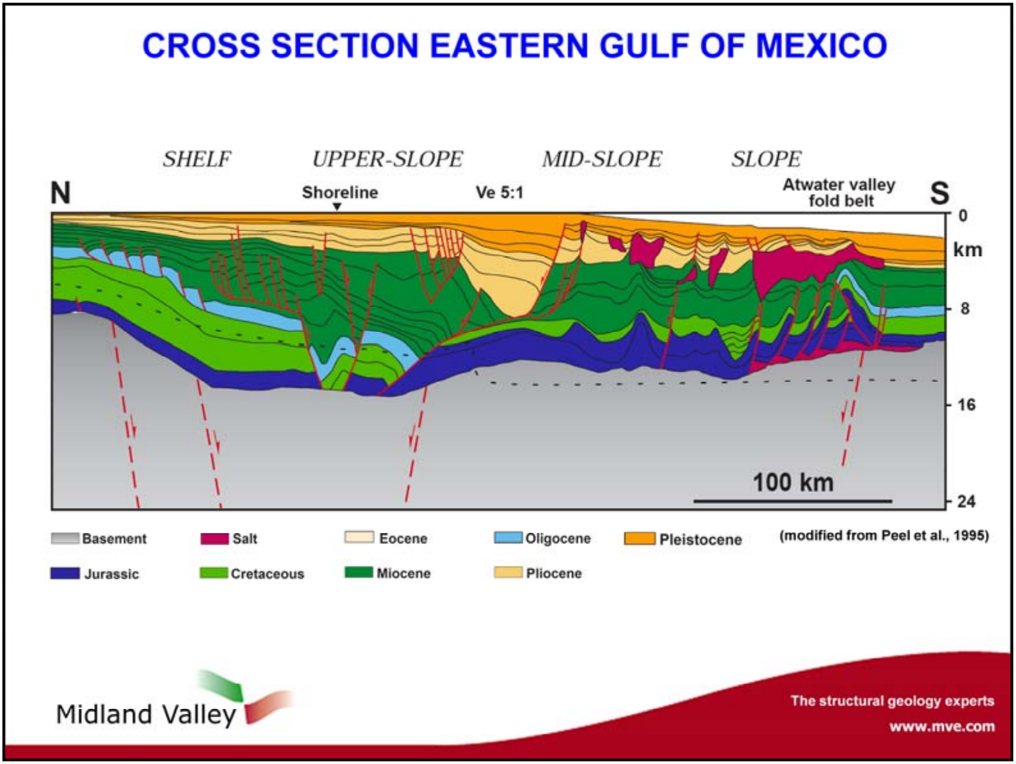
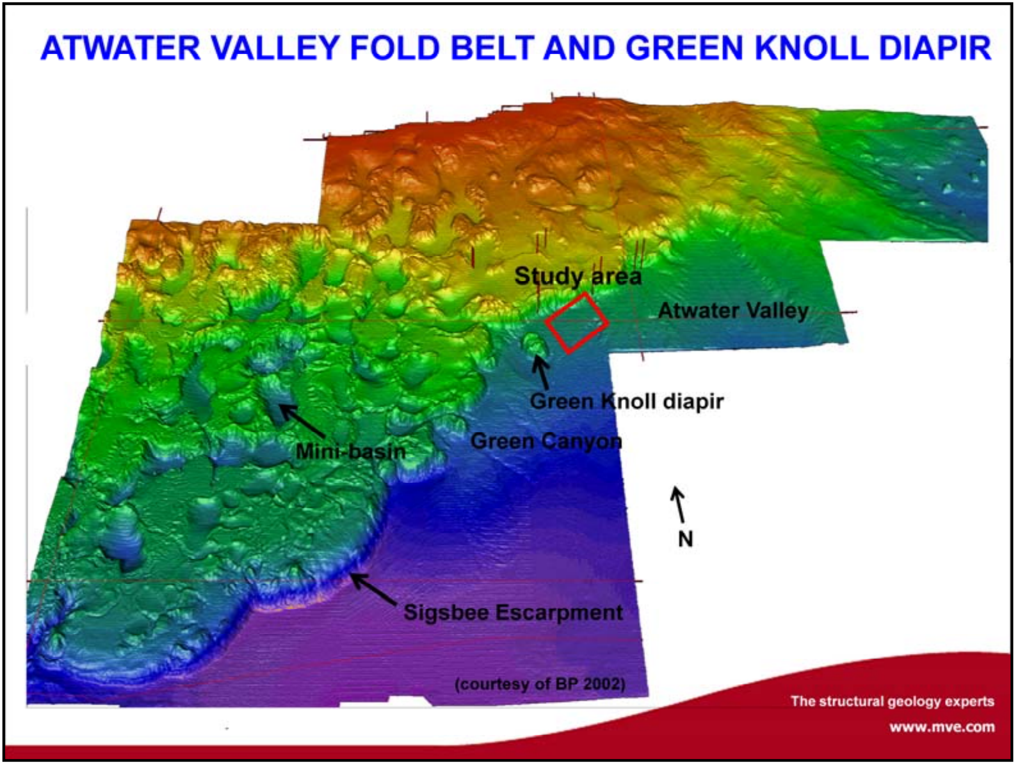
This study was part of the PhD work of Gianluca Grando at Royal Holloway; in particular we used the 3D Model of the Frampton Anticline and have done some analysis which was not previously performed.

STRUCTURE - NORTHERN GULF OF MEXICO

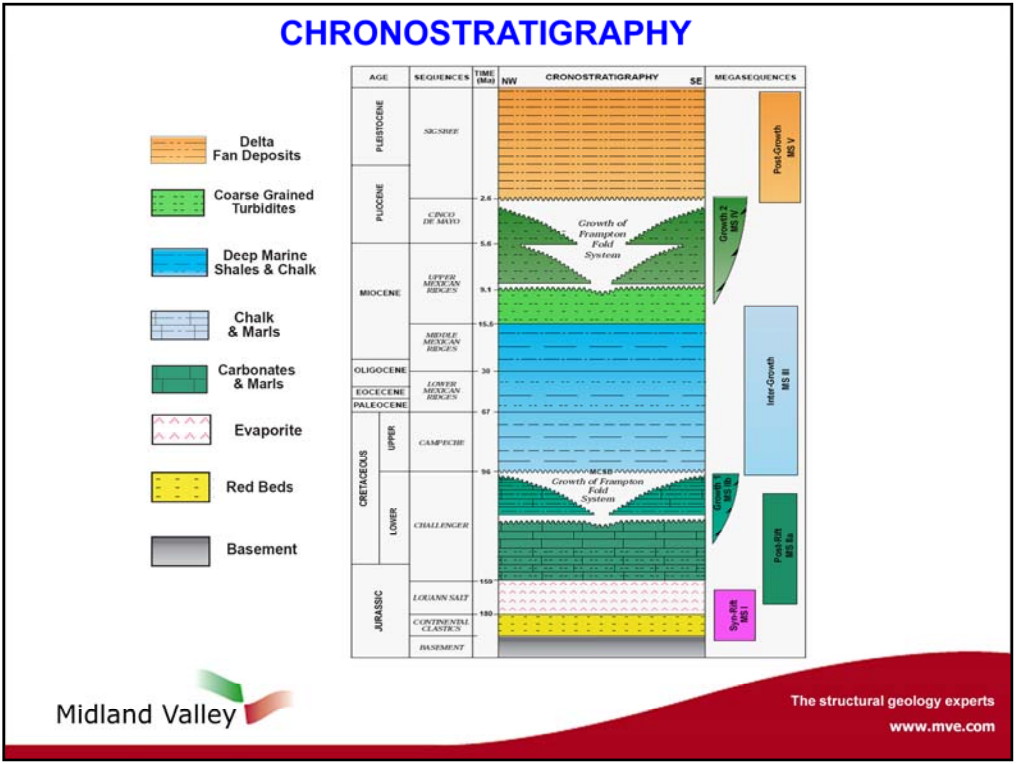




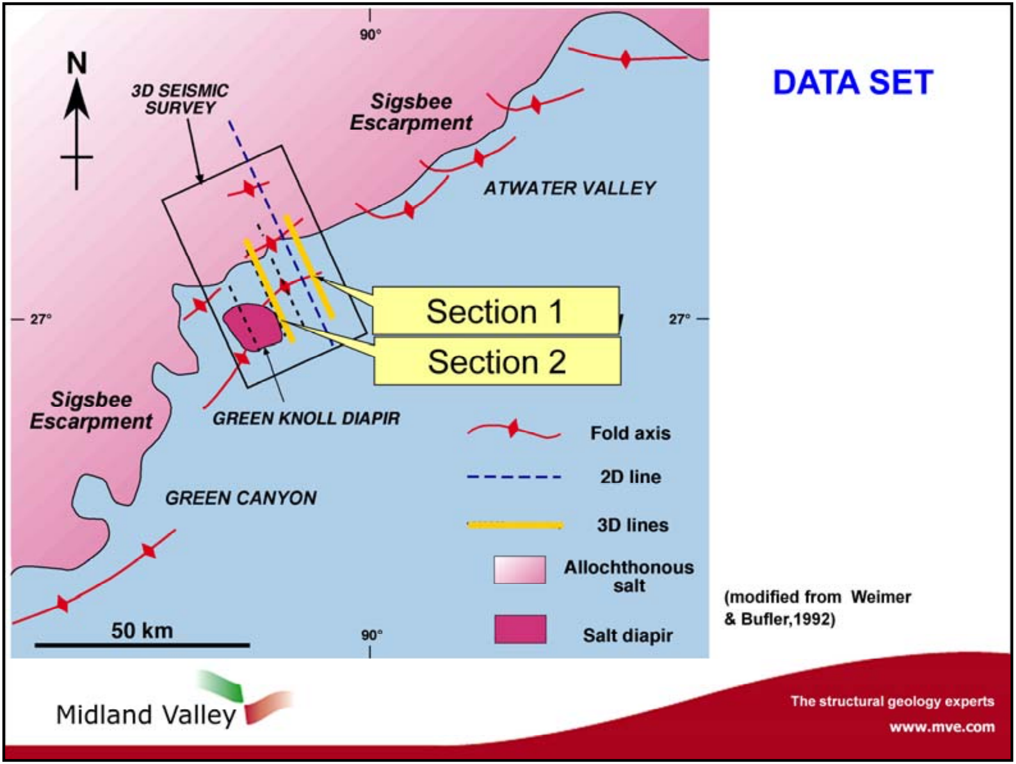
This is the classic geological cross sections of Frank Peel, one of the first which help to unravel the complex history of this salt basin. It crosses the eastern GOM showing the main structural elements. Note the compressional structures at the toe of the slope cored by the Louann Salt and the allochthonous salt sheet in the upper part of the sections sitting right above the fold belts. The salt has completely evacuated from the up dip section inflating the downdip structures.



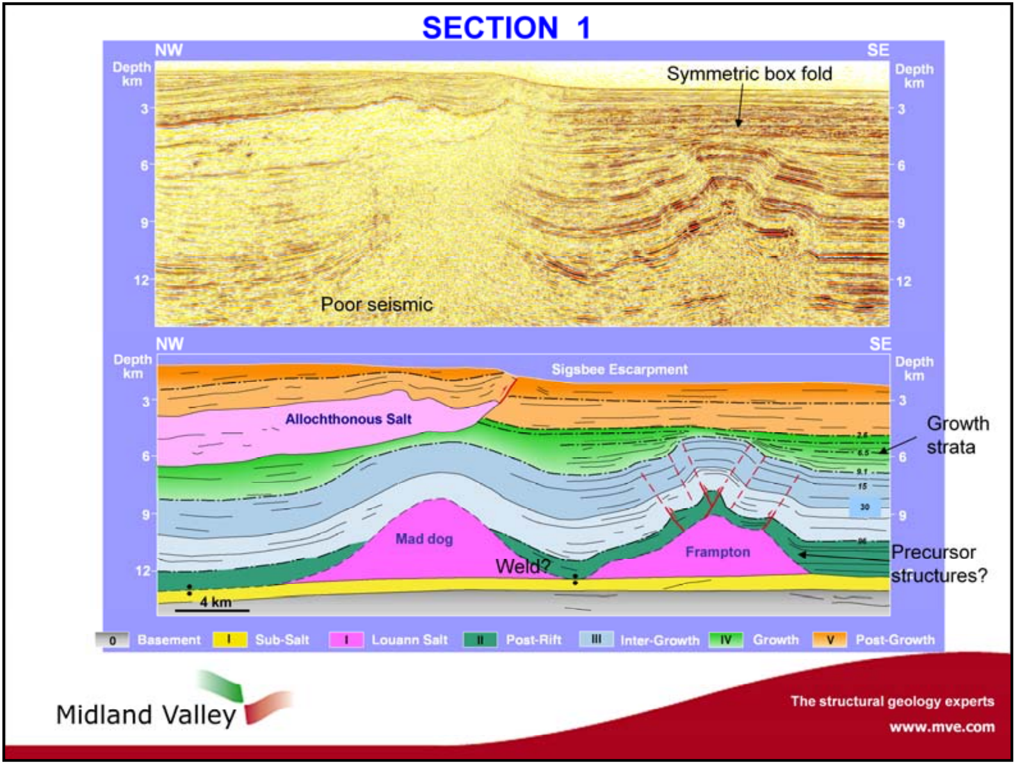
DEM of the study area, showing the location of the Frampton Anticline in the Atwater Valley fold belt and the Green Knoll diapir. The Frampton Anticline sits right below the Sigsbee Escarpment, which corresponds to the seaward edge of the allochthonous salt sheet.



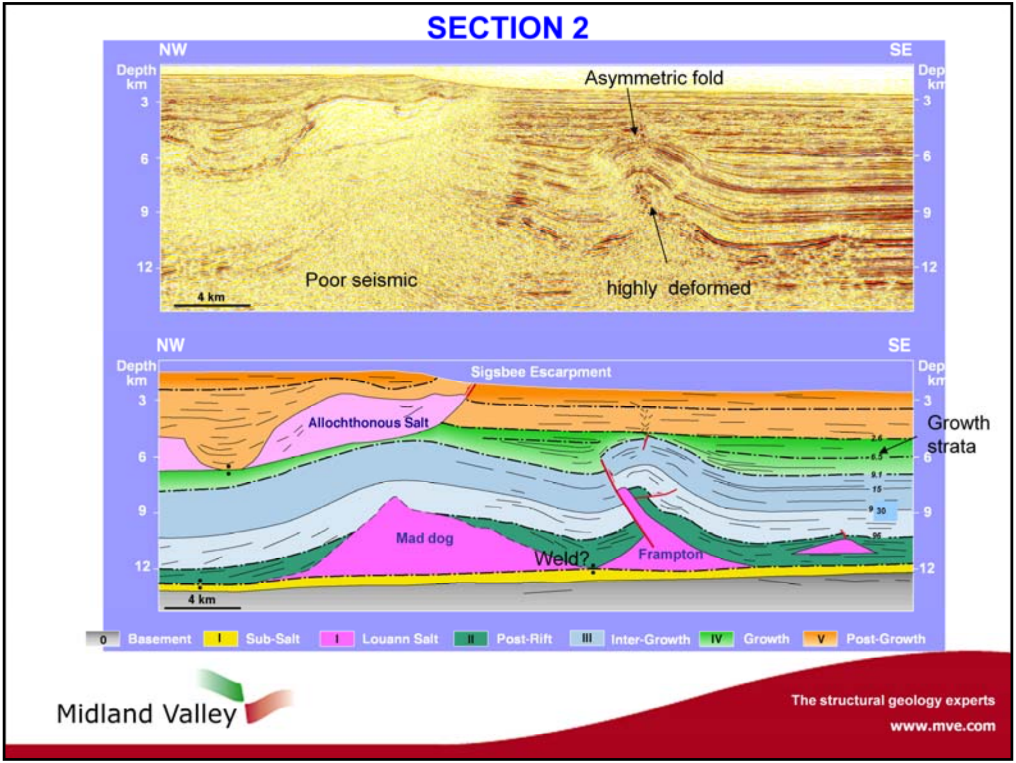
Chronostratigraphic diagram, showing major megasequences related to main tectonic events. Note the two phases of growth of the structure: an early deformation phase (salt inflation), following the deposition of the Middle Jurassic Louann Salt and a main compressional phase in the Miocene-Pliocene. The Tertiary sequence is mainly characterized by turbidites.



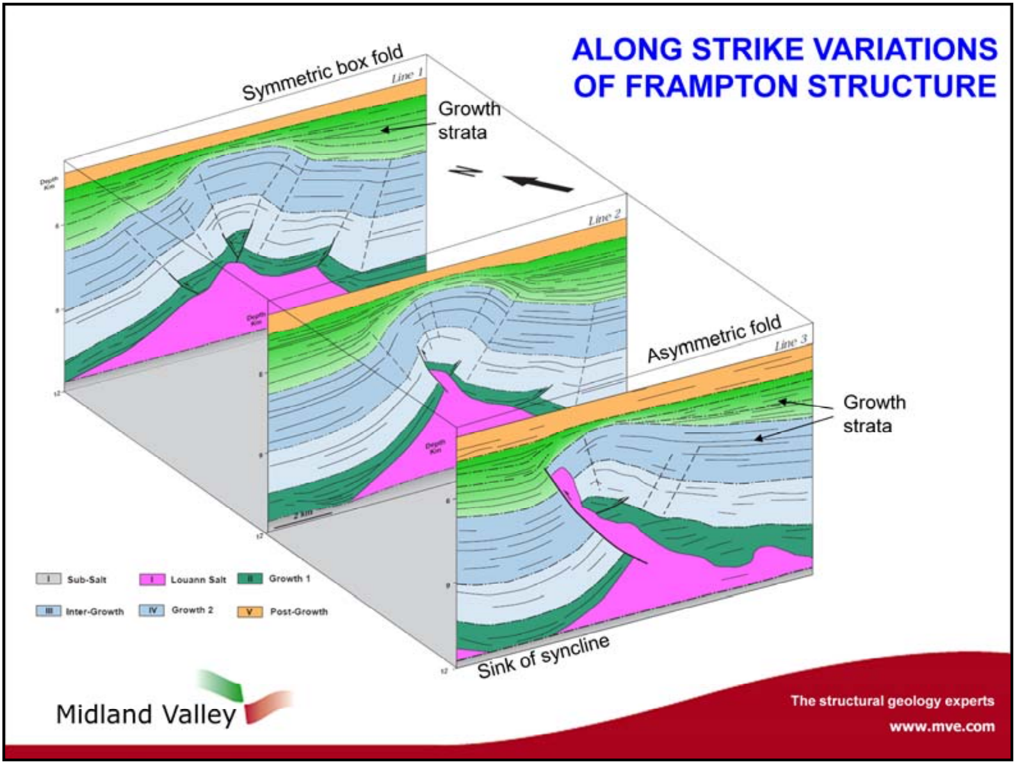
Structural map and location of the 3D survey which contains the 3D Model that was made. Yellow lines shown on next slides.



Frampton symmetric box fold in the east, away from the Green Knoll diapir. Note Mad Dog Anticline masked by the allochthonous salt and Frampton farther down slope.



Closer to the Green Knoll diapir to the west, the structure is more asymmetric and thrusted and is characterized by the development on the back thrust. The core of the structure is highly deformed.

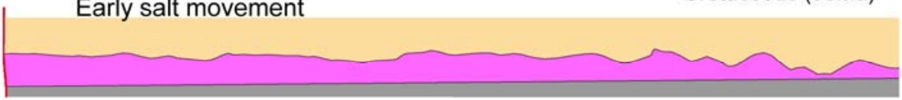


This cartoon shows the variation of structural styles along strike of Frampton. In proximity of the Green Knoll diapir the anticline is faulted and the sinking of the syncline more evident than in the eastern part of the structure. The diapir acted as nucleating site for deformation. The earlier structure growth in proximity of the diapir.

Structural evolution - 2D restoration

Early salt movement

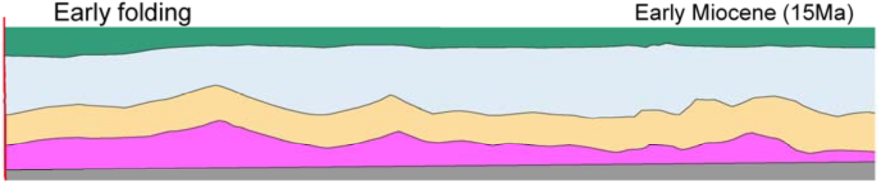
Cretaceous (96Ma)



Initial inflation of basal salt, pre-existing salt pillow

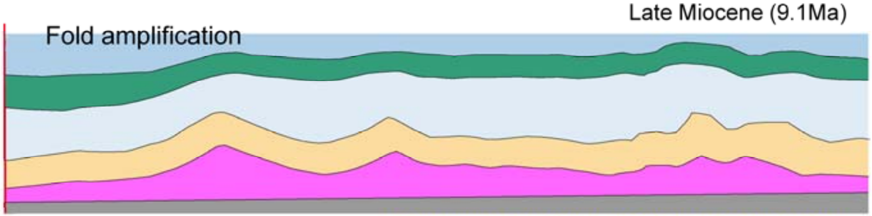
Early folding

Early Miocene (15Ma)

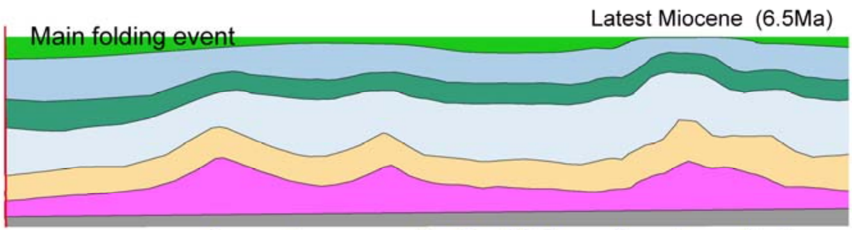


Frontal fold growth – initially short, shallowly dipping limbs

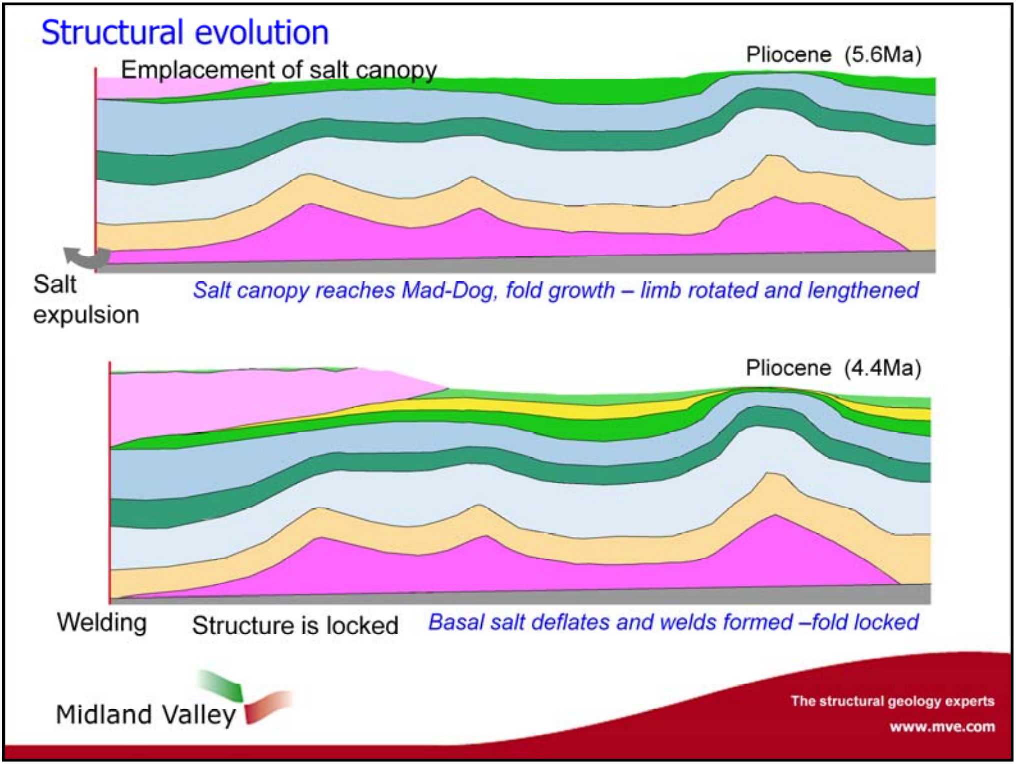
Structural evolution



Fold growth and amplification by limb rotation



Increasing compression Rapid fold growth-main growth phase



Structural evolution
Emplacement of salt canopy
Pliocene (5.6Ma)
Salt
expulsion
Salt canopy reaches Mad-Dog, fold growth – limb rotated and lengthened
Pliocene (4.4Ma)
Welding
Structure is locked
Basal salt deflates and welds formed –fold locked
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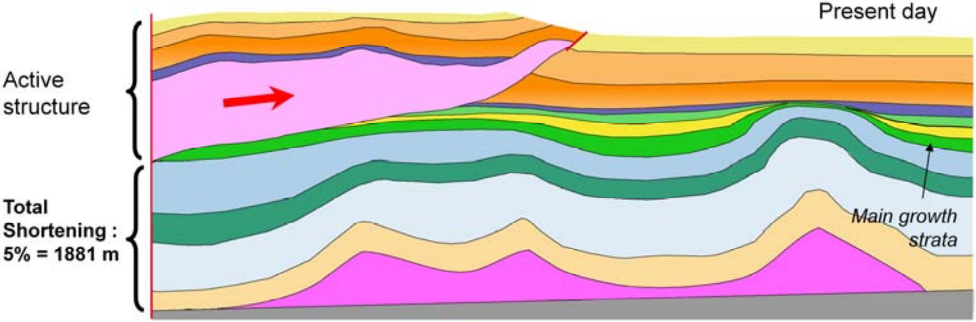
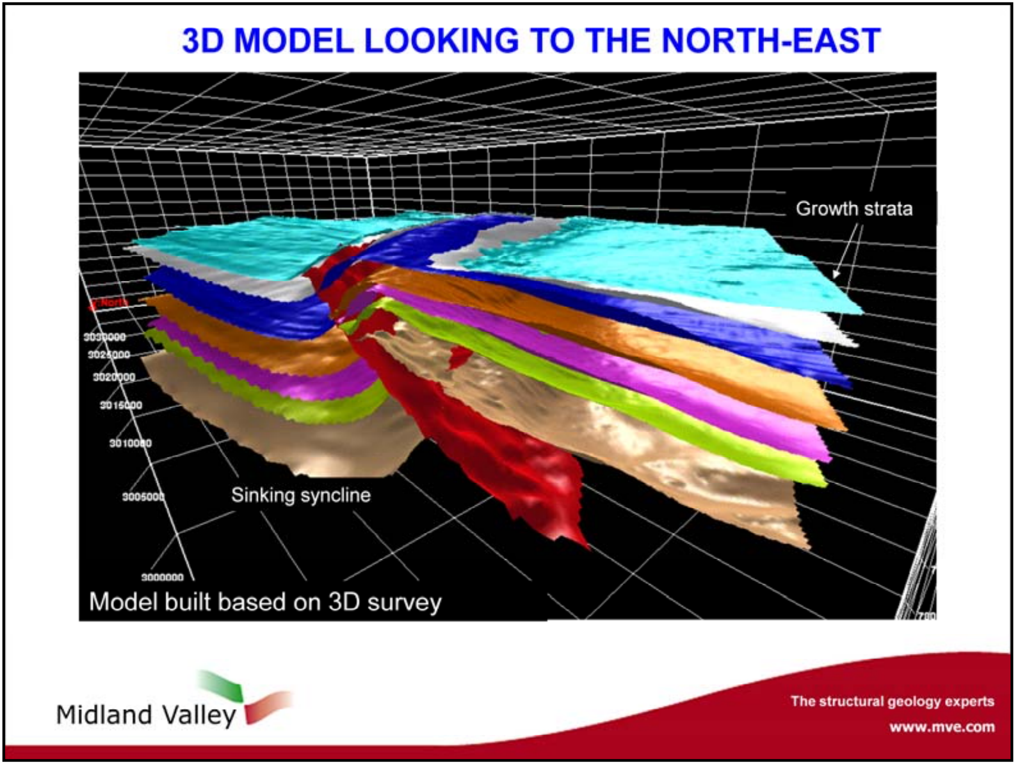
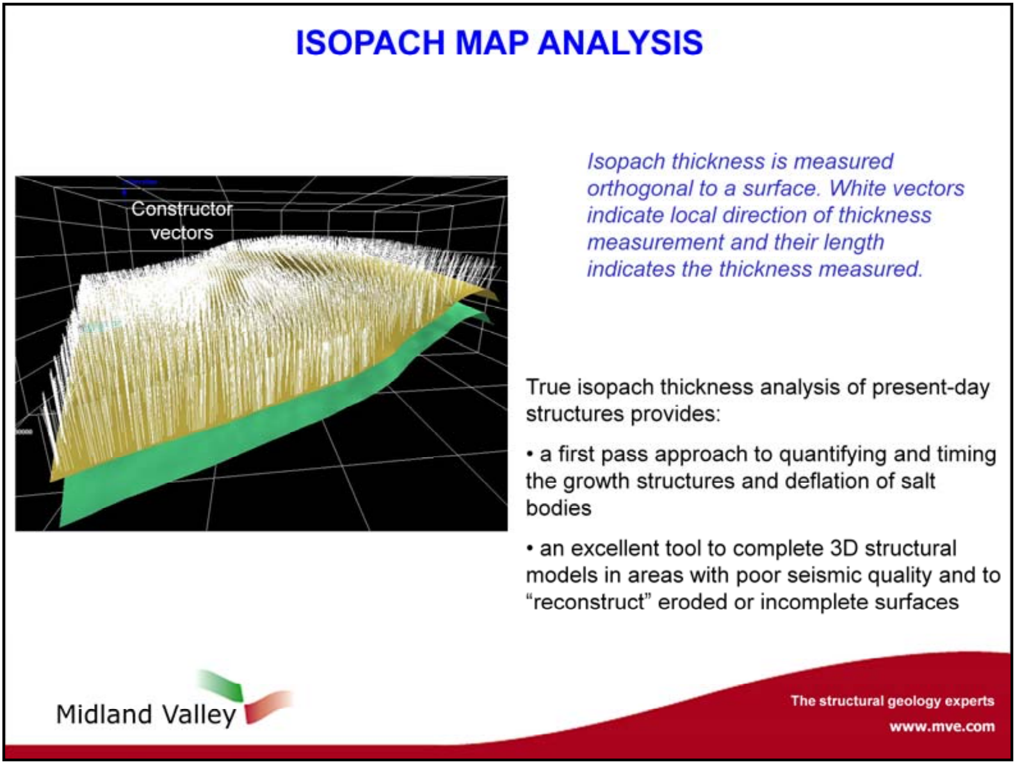
Structural evolution



Passive Pleistocene burial of frontal folds, basinward extrusion of salt canopy

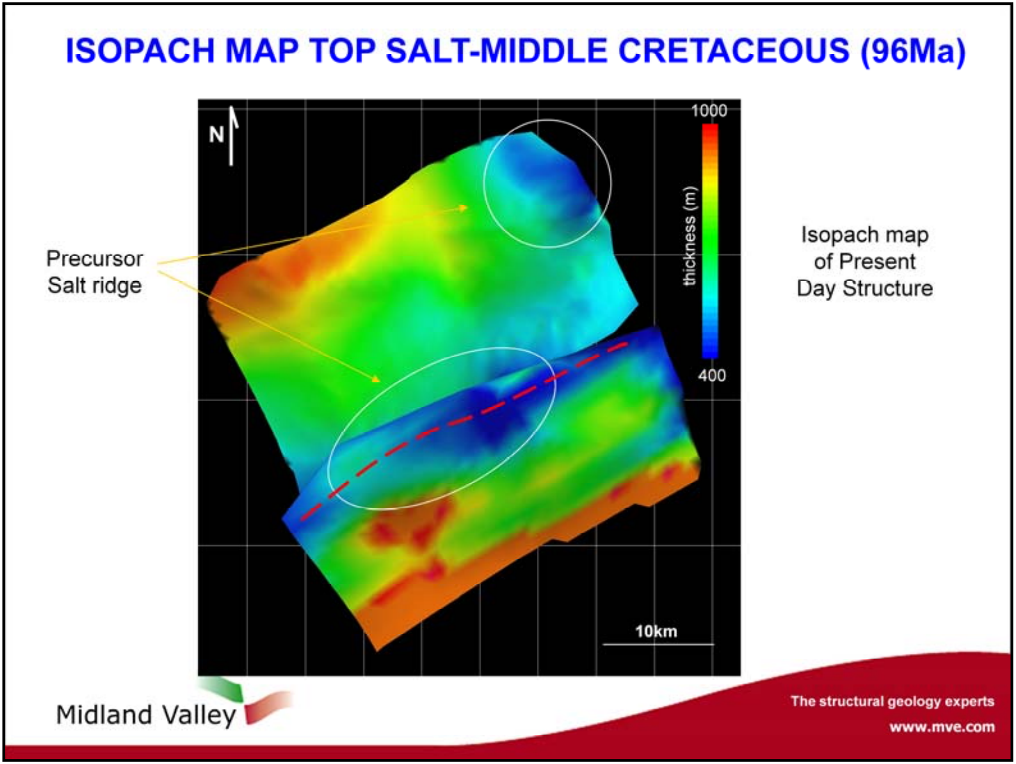


3D Model built using 3D seismic from Frampton survey. This image shows the western faulted asymmetric flank of the structure in proximity of the Green Knoll diapir. Note the latest Miocene-Pliocene growth strata onlapping the fold limbs.

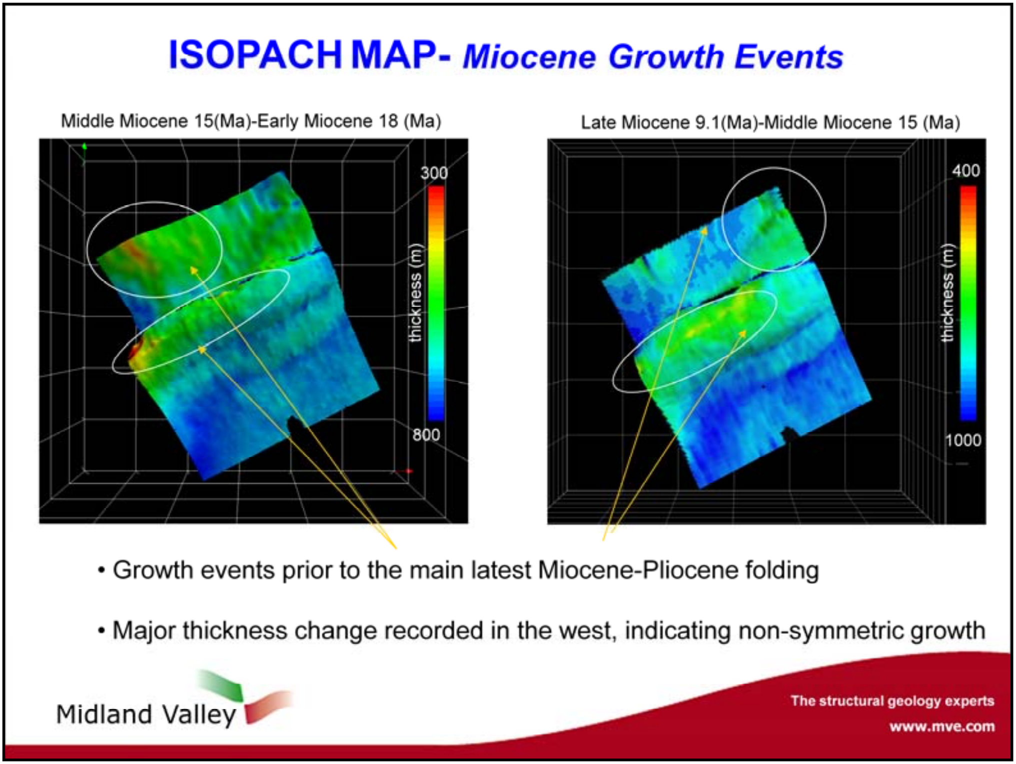


The use of 3D real-thickness maps on present-day 3D models makes it possible to:

1) Validate interpretations.
2) Complete 3D interpretation in areas of poor seismic data (e.g., around salt stems, diapirs or below salt bodies).
3) Complete 3D interpretation for improved results in restoration.
4) Perform preliminary analysis of structure growth history.



Pre-Tertiary structures controlled the evolution of the structure and were amplified through time. Early deformation occurred soon after deposition of the Louann Salt.

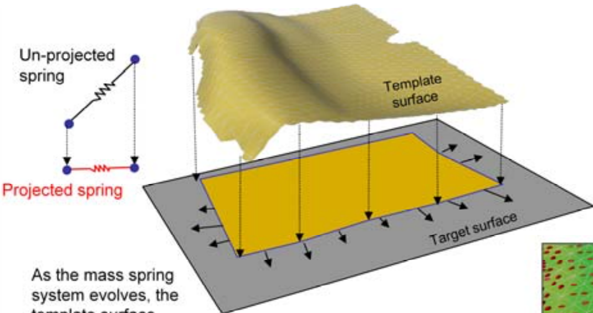


Thickness map indicates growth from the early Miocene. Maximum growth occurred from latest Miocene-Pliocene recorded by the growth strata onlapping the flanks of the anticline. This is in accordance with the 3D Restoration performed with 3DMove. The structure growth (asymmetrical and earlier in the west) affected by the diapir.

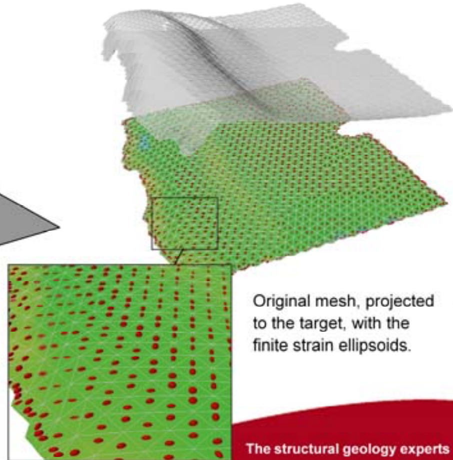
THE MASS-SPRING RESTORATION

The goal is to restore a surface or volume to a target

- maintaining area/volume
- minimising strain

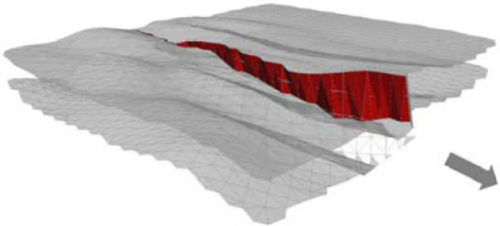


As the mass spring system evolves, the template surface spreads out along the target surface

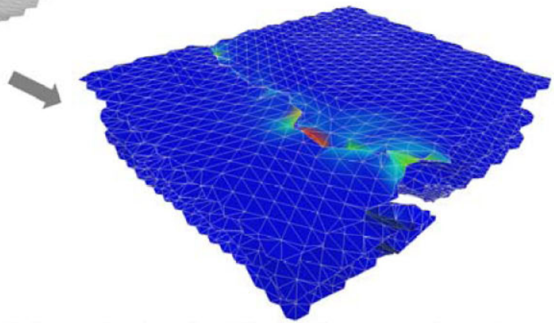


Original mesh, projected to the target, with the finite strain ellipsoids.

MODEL CONDITIONING



The fault scarp is filled with virtual springs (red triangles).



During restoration the virtual springs are collapsed and the hangingwall and the footwall are restored. Colour map is the residual energy and implicates edge affects.

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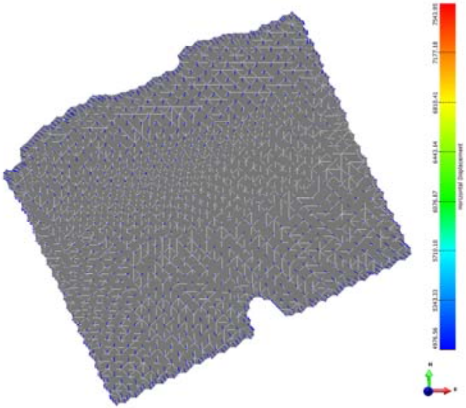
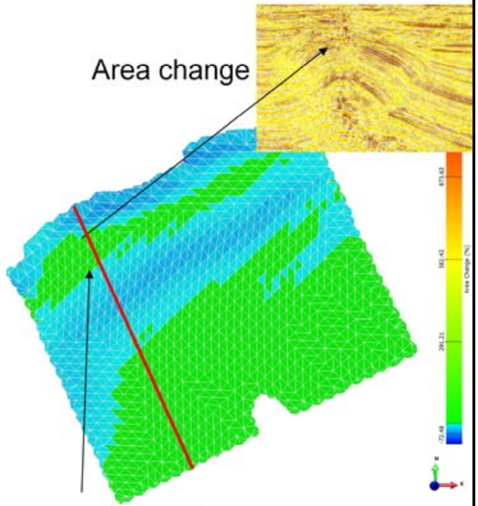
RESTORATION OF THE MIDDLE MIOCENE

Horizontal displacement



Non-cylindrical structure, plane strain restoration methods would give erroneous result

Area change



Extension over the crest of the structure (triangles shrink during restoration)

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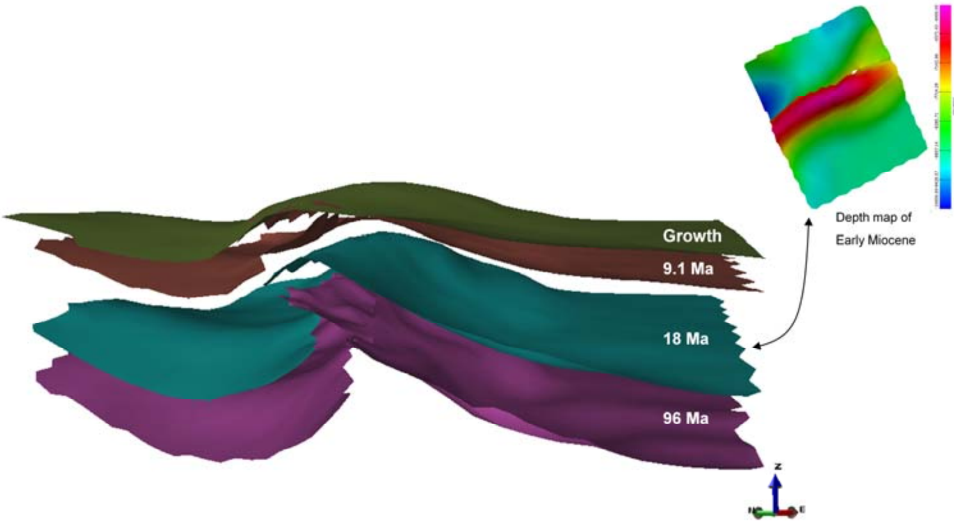
PLEISTOCENE-PLIOCENE BACKSTRIPPED



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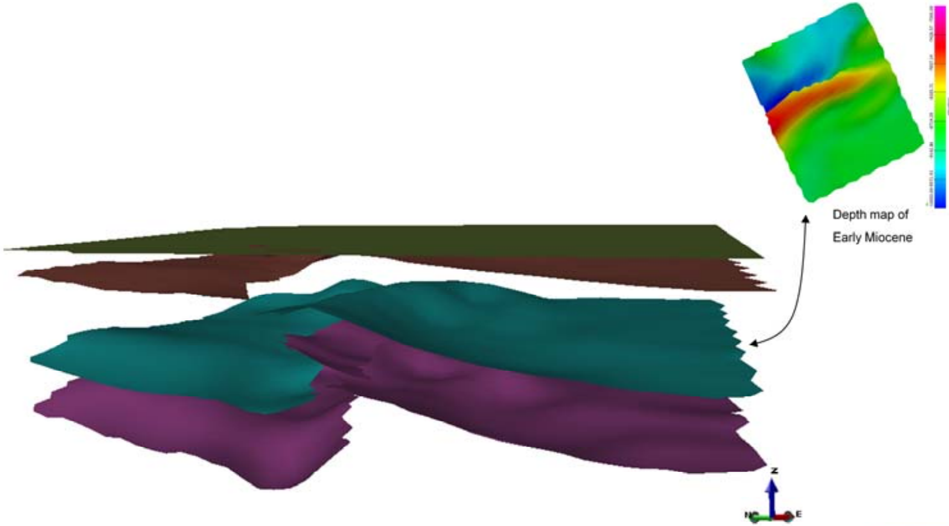
RESTORATION OF THE EARLY PLIOCENE GROWTH STRATIGRAPHY



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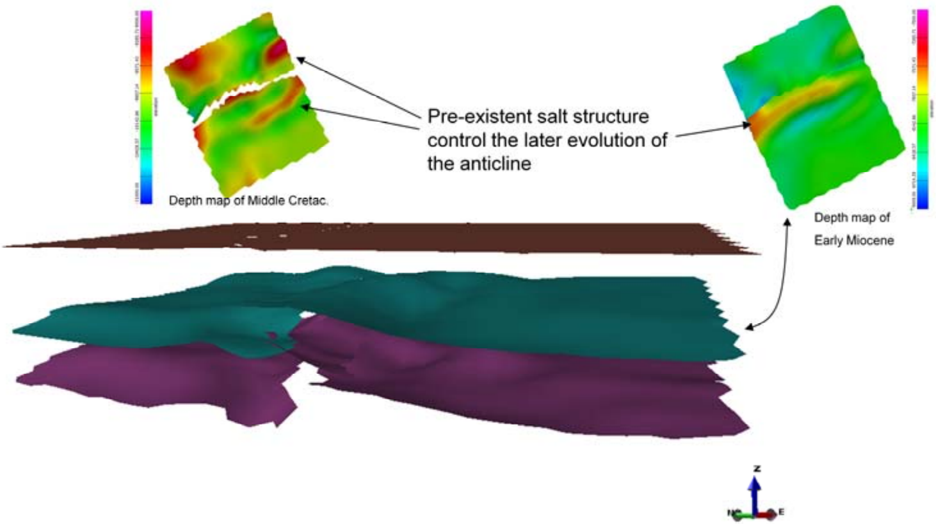
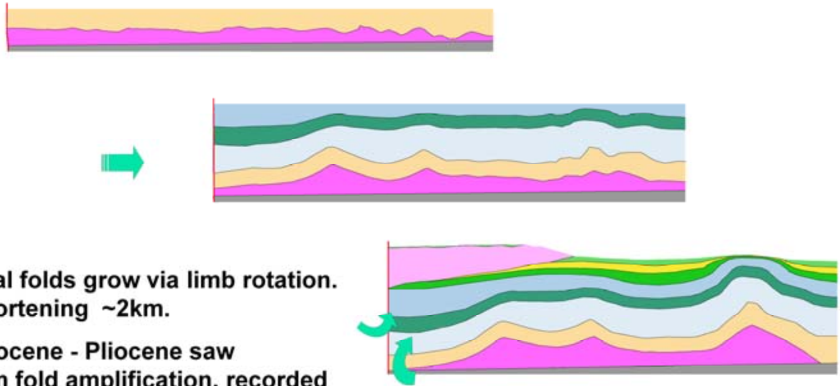
RESTORATION OF THE LATE MIOCENE



CONCLUSION I

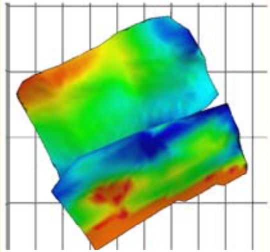


- Frontal folds grow via limb rotation. Total shortening ~2km.
- Late Miocene - Pliocene saw maximum fold amplification, recorded by growth strata on fold limbs
- Salt withdrawal and welding during Sigsbee canopy emplacement.

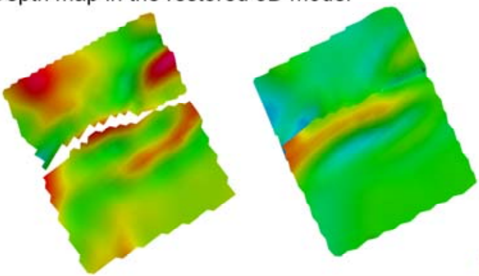
CONCLUSION II

- **Subtle early salt structures existed by the Cretaceous.**
- **The geometry of early basal salt ridges control the growth of later frontal fold.**

Thickness analysis on present day structure



Depth map in the restored 3D model



- **The fold growth is not symmetric and coeval along strike due to the presence of the diapir.**

Selected References

Peel, F.J., C.J. Travis, and J.R. Hossack, 1995, Genetic structural provinces and salt tectonics of the Cenozoic offshore U. S. Gulf of Mexico; a preliminary analysis, *in* Salt tectonics; a global perspective: AAPG Memoir 65, p. 153-175.

Weimer, P., and R.T. Buffler, 1992, Structural geology and evolution of the Mississippi Fan fold belt, deep Gulf of Mexico: AAPG Bulletin, v. 76/2, p. 225-251.