Advanced Reservoir Modeling in Poor Seismic; October Field, Northern Gulf of Suez, Egypt*

William J. Sercombe[1], Leon Thurmon[3], and James Morse[2]

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[1]Consultant, Orlando, FL (ontario_blue@yahoo.com)
[2]Computational Geology, Weybridge, VT
[3]Consultant, Grand Junction, CO

Abstract

October field OOIP on discovery was 1.5 billon barrels in the Cretaceous Nubia and 500 million barrels in the overlying Cretaceous Nezzazat. Previous models had not been successful owing to very poor 3D seismic resolution. After 15 years of production a new model build was initiated. This model obtained a perfect predictive match of oil, water and pressure for six years in the Nubia and was the basis for 30 new wells drilled on prognosis. The success of the new static model was based on the integration of re-correlated model layer datums, quantitative dipmeter analysis using SCAT and related principles, and depth stripping the 3D seismic volume to extract subtle conjugate fault patterns. The interpreted fault patterns match fault patterns that can be seen in surface outcrops and were subsequently confirmed by field outcrop observation. The dipmeters were critical as they dispelled a number of existing myths, e.g., that the field was unfaulted and unfolded. The dipmeter azimuths varied widely from well to well but the simple contouring of model layer datums did not indicate much departure from smooth homoclinal dip. The azimuth changes rather suggested no or low fault throws for numerous compartments at different dip azimuths. The 3D seismic volume had been re-processed 50 times, but was still considered poor in resolution. The depth converted 3D volume was depth stripped at short intervals and breaks in amplitude in the horizontal depth slices were digitized. A collection of breaks was then reinterpreted in vertical sections and any consistent collections of breaks were triangulated as a fault. A conjugate fault set across the field was the result. The fault style was consistent with the conjugate faults observable in outcrop onshore. The new model made a perfect dynamic model after years of models that never worked. The perfect model was made through the integration of new top datums, old dipmeters, outcrop study and a previously unusable low resolution 3D seismic volume.

ADVANCED RESERVOIR MODELLING IN POOR SEISMIC; OCTOBER FIELD, NORTHERN GULF OF SUEZ, EGYPT

- William J. Sercombe, 1
- Leon M. Thurmon, 3
- James Morse, 2

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OCTOBER FIELD
BIG FIELD !
BIG PROBLEMS !

- OLD MAPS NOT WORKING!!!
- MODELS DIDN'T WORK
- 20 % ANNUAL DECLINE
- WATERFLOOD NOT WORKING
- MULTI SIDE TRACK DRILLING FIASCOS

WHAT WE DID

- BUILT MULTI -DISCIPLINE RESERVOIR MANAGEMENT TEAM

- NEW GEOSCIENCE TOOLS
REMADE ALL OF THE MAPS !

- NEW ENGINEERING TOOLS
REMADE THE MODEL !

INTEGRATED ALL DATA FOR RESOLUTION IN POOR SEISMIC

DIPMETERS

TOPS

OUTCROP ANALOGS

SATELLITE IMAGERY

+

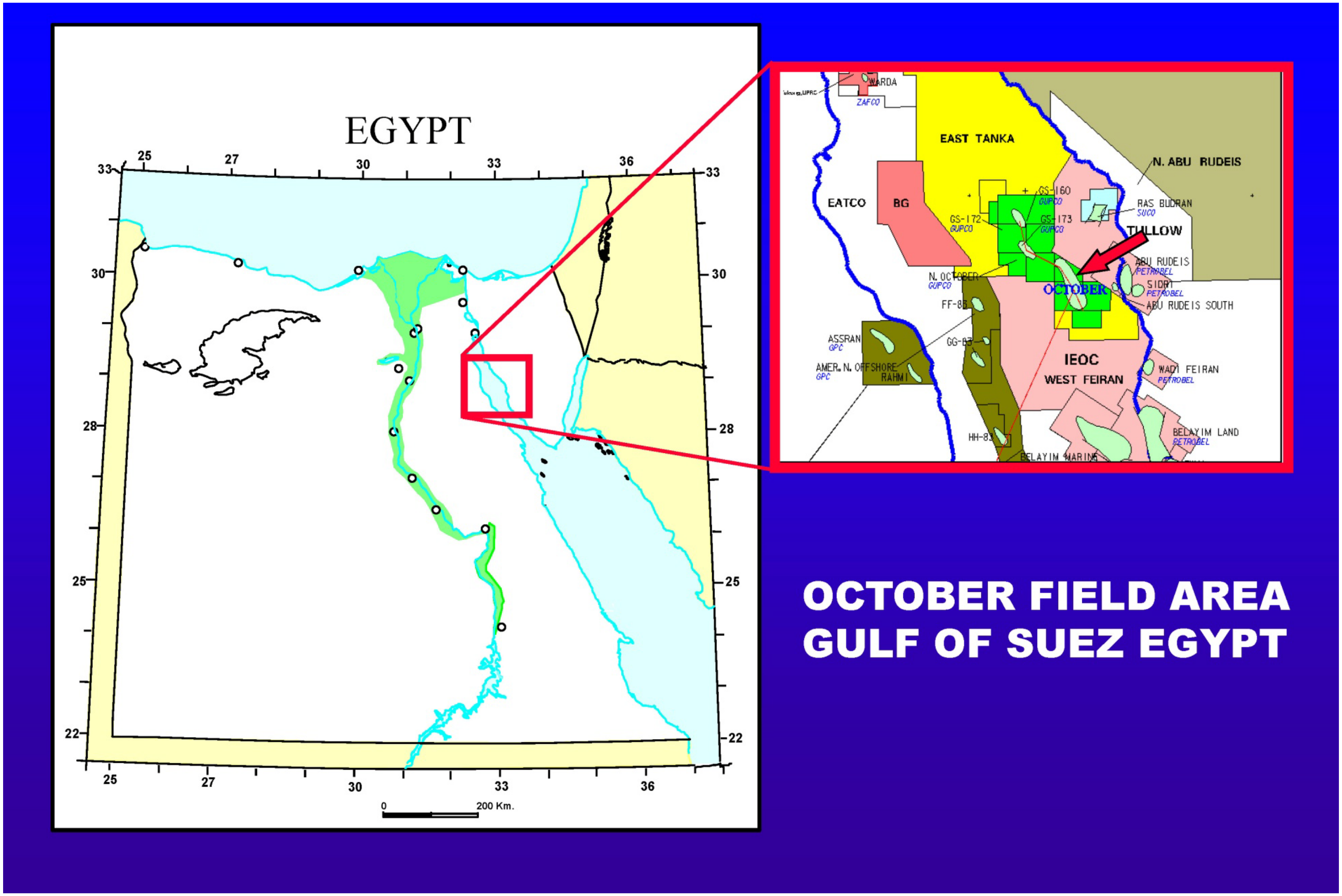
DEPTH STRIPPED 3D SEIMIC VOLUME

RESULTS:

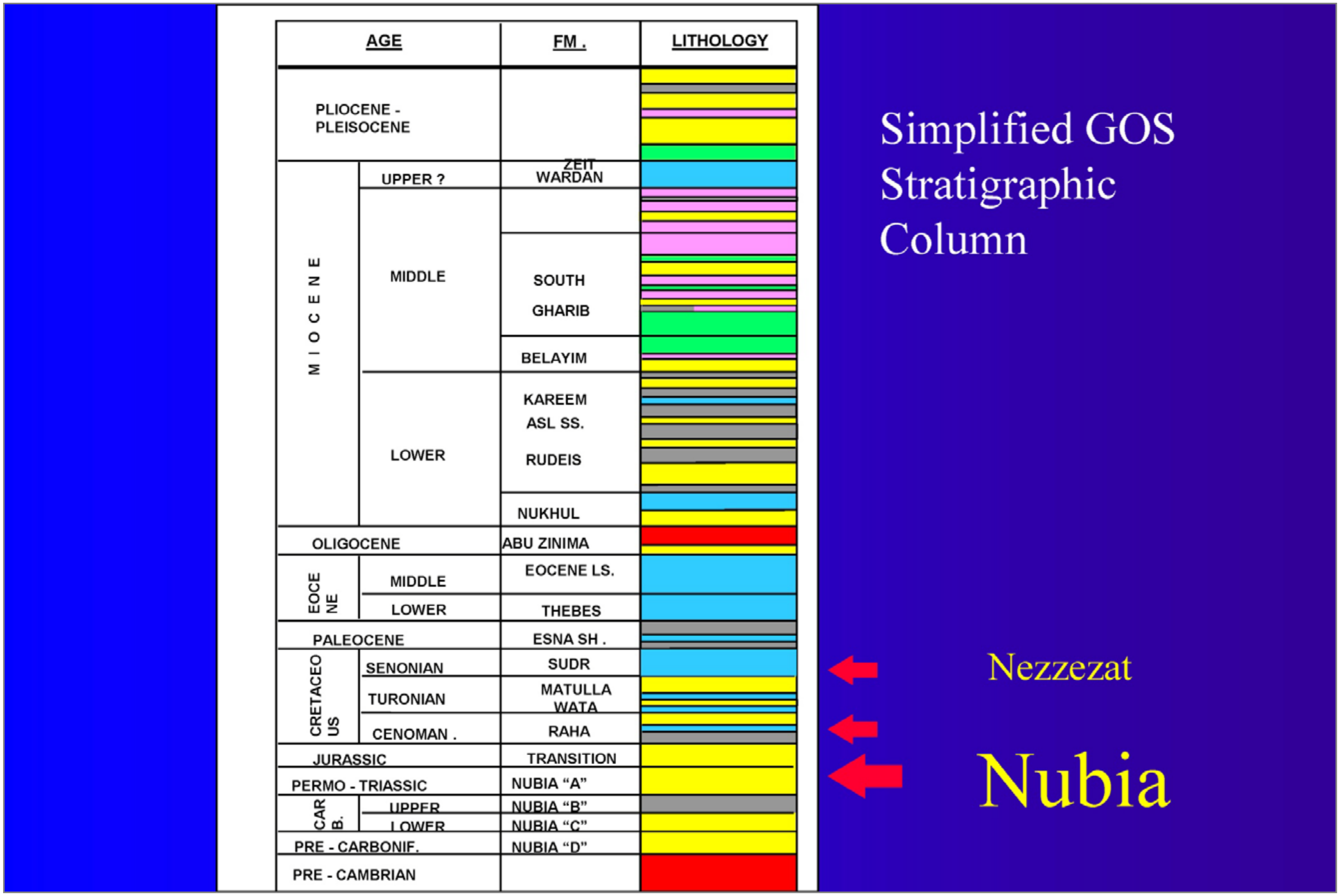
6 YEAR PREDICTIVE HISTORY ABSOLUTELY PERFECT

30 WELLS DRILLED ON PROGNOSIS

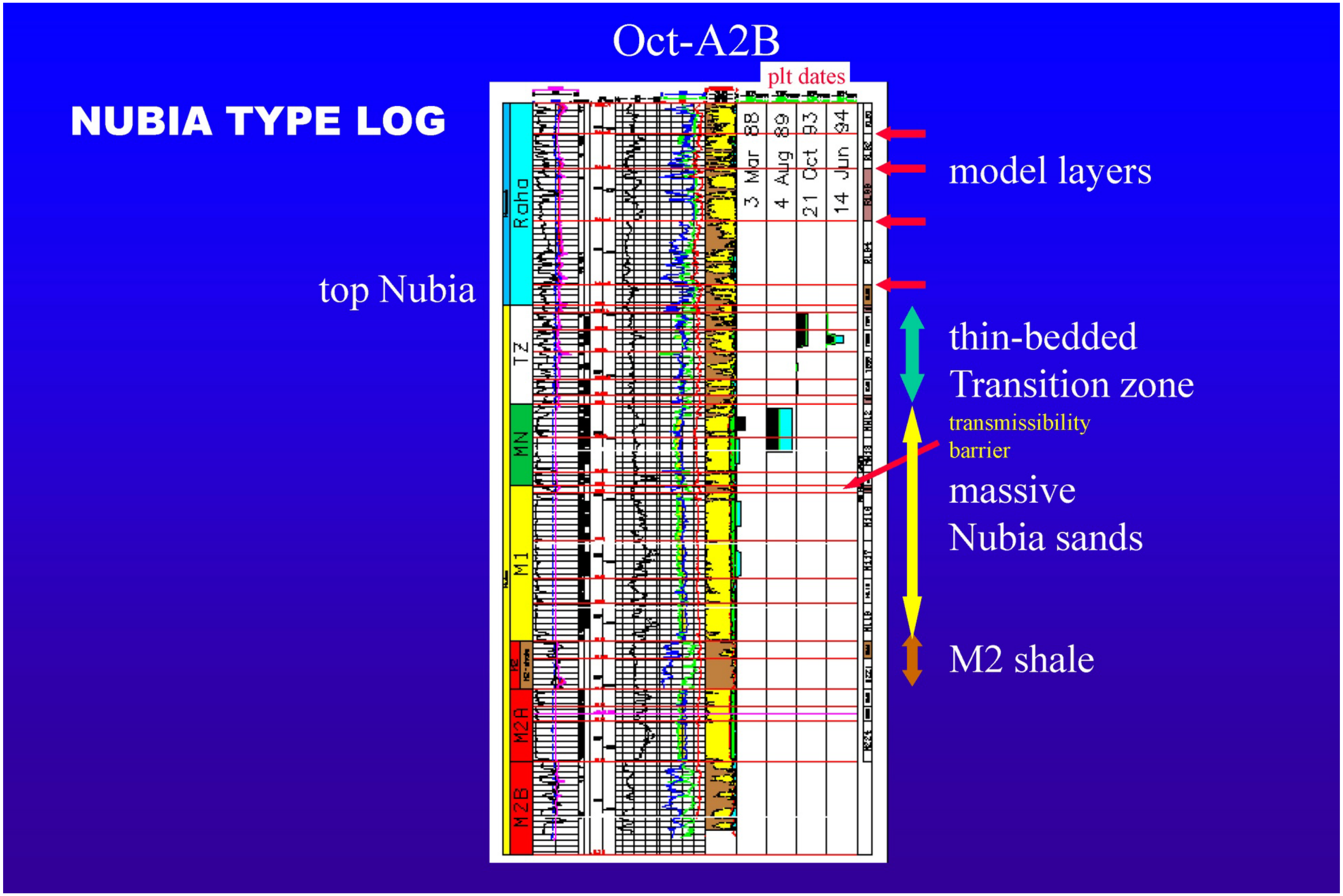
NO FURTHER DRILLING PROBLEMS



Presenter’s notes: The Gulf of Suez is located between the Sinai Peninsula and the Eastern desert of Egypt. Amoco has been producing oil from the Gulf of Suez, in conjunction with GUPCO, since 1967. The Amoco/GUPCO GOS oil fields produce over 300,000 barrels of oil per day and the October Main field produces about a third of this total at 105,000 barrels per day. The October Main Field was discovered in 1978 and has reached the mature stage where detailed geology and geophysics, engineering models, secondary recovery schemes and innovative drilling, completion and cost control are all critical to the future success of the field. The geological setting of the GOS is basically an extensional rift with structural traps producing from tilted and faulted blocks sealed by fault juxtaposed shales.

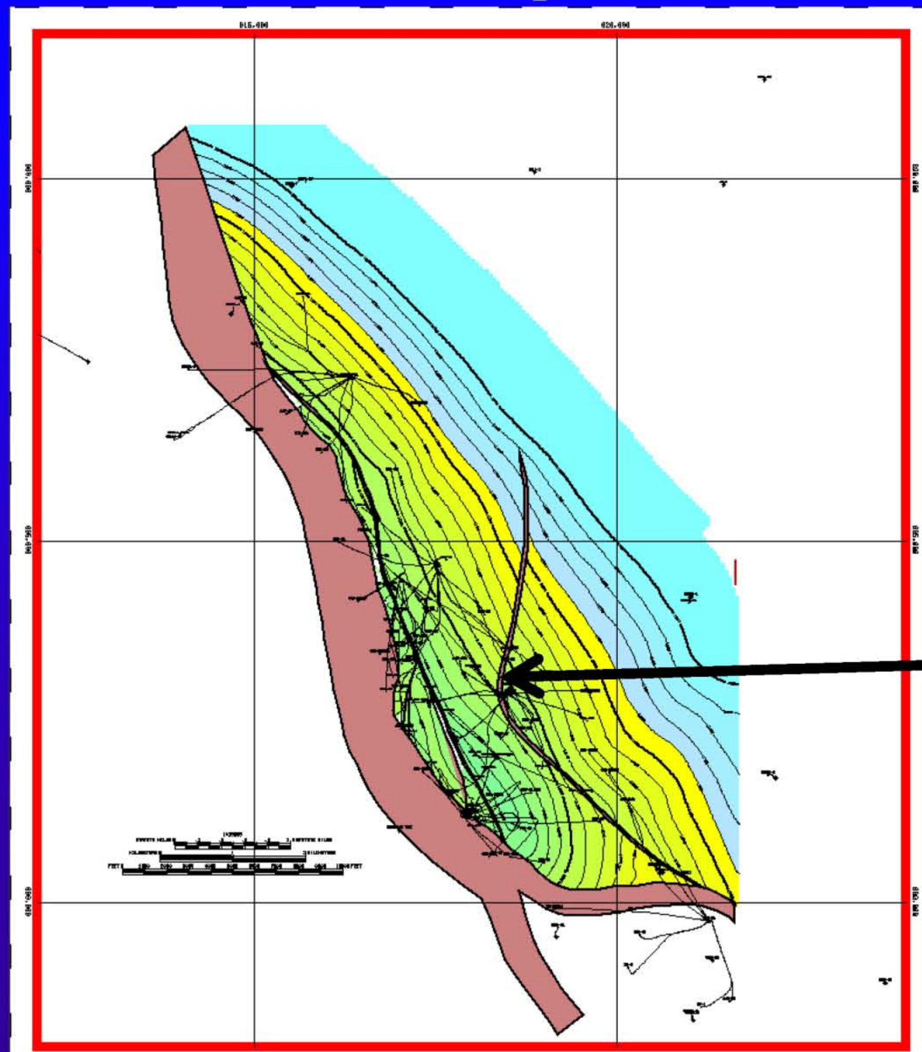


Presenter's notes:The GOS stratigraphic column displays the Upper Cretaceous Nezzazat Group; made up of Matulla, Wata and Raha reservoirs producing about 25,000 BOPD and the Cretaceous to Paleozoic "Transition" and "Nubia" sands of the Nubia reservoir package which account for 80,000 BOPD. The oil is sourced from the overlying SUDR formation. The majority of the extensional tectonics occurred in the Miocene during the "Clysmic-Rift Event". The post-rift sequences include thick evaporites that historically reduced seismic image quality. The Nezzezat and transition reservoirs are thinner-bedded than the massive Nubia fluvial sandstones that have the bulk of the storage capacity.



Presenter's notes:The example Nubia composite log depicts the non-marine fluvial Nubia reservoir package with the model layers used in the study shown as red horizontal lines. Nubia reservoir analysis emphasized vertical and lateral permeability variations for the GCOMP model. Petrophysical analysis for the Nubia was completed using standard GOS parameters. The difficult pay determination for the Nezzezat resulted in a BULK VOLUME OIL (BVO) pay determination that eliminates static pay cutoffs. This technique subtracts the porosity multiplied by the water saturation from the bulk porosity to obtain the residual bulk volume oil. This technique allows the dynamic assessment of the porosity - water saturation interaction on a foot-by-foot basis and, when combined with accurate Archie parameters, allows pay recognition improvement in zones that were not calculated as pay using static cutoffs.

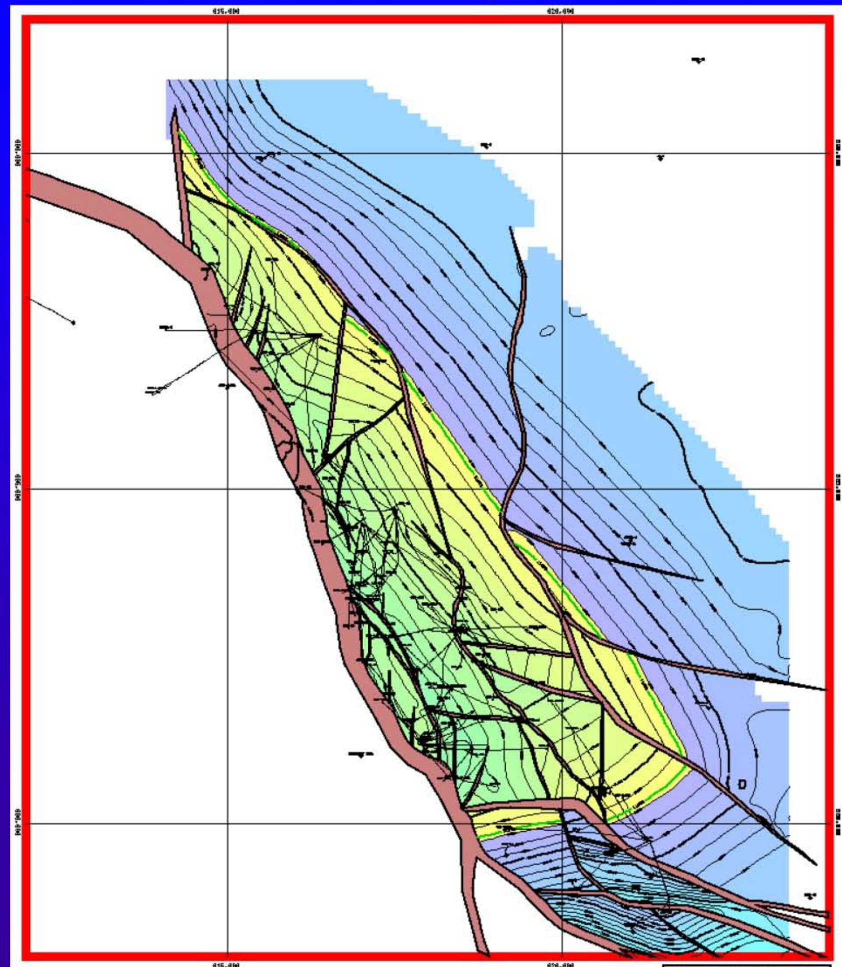
1992 Nubia structure map based on 2D seismic



FAULT GOING WRONG DIRECTION: CAUSED MODEL FAILURE

Presenter’s notes:The October Nubia Reservoir was modeled in GCOMP in 1992 with older vintage 2D seismic data and a very simplified map. Only two or three major north-south faults were interpreted on the structure map. The map does portray the essential elements of the field with an east-dipping homoclinal back flank, the western Clysmic fault termination and a Clysmic synthetic sliver block on the western margin of the field. After this study, a 3D seismic program was authorized and acquired by December 1992 in order to improve structural mapping in the field. This began the new strategy for GUPCO that changed our approach to exploration and production in the GOS.

1994 Nubia structure map based on 3D seismic



PROBLEMS!!

DIPMETERS ALL GOING IN DIFFERENT AZIMUTHS

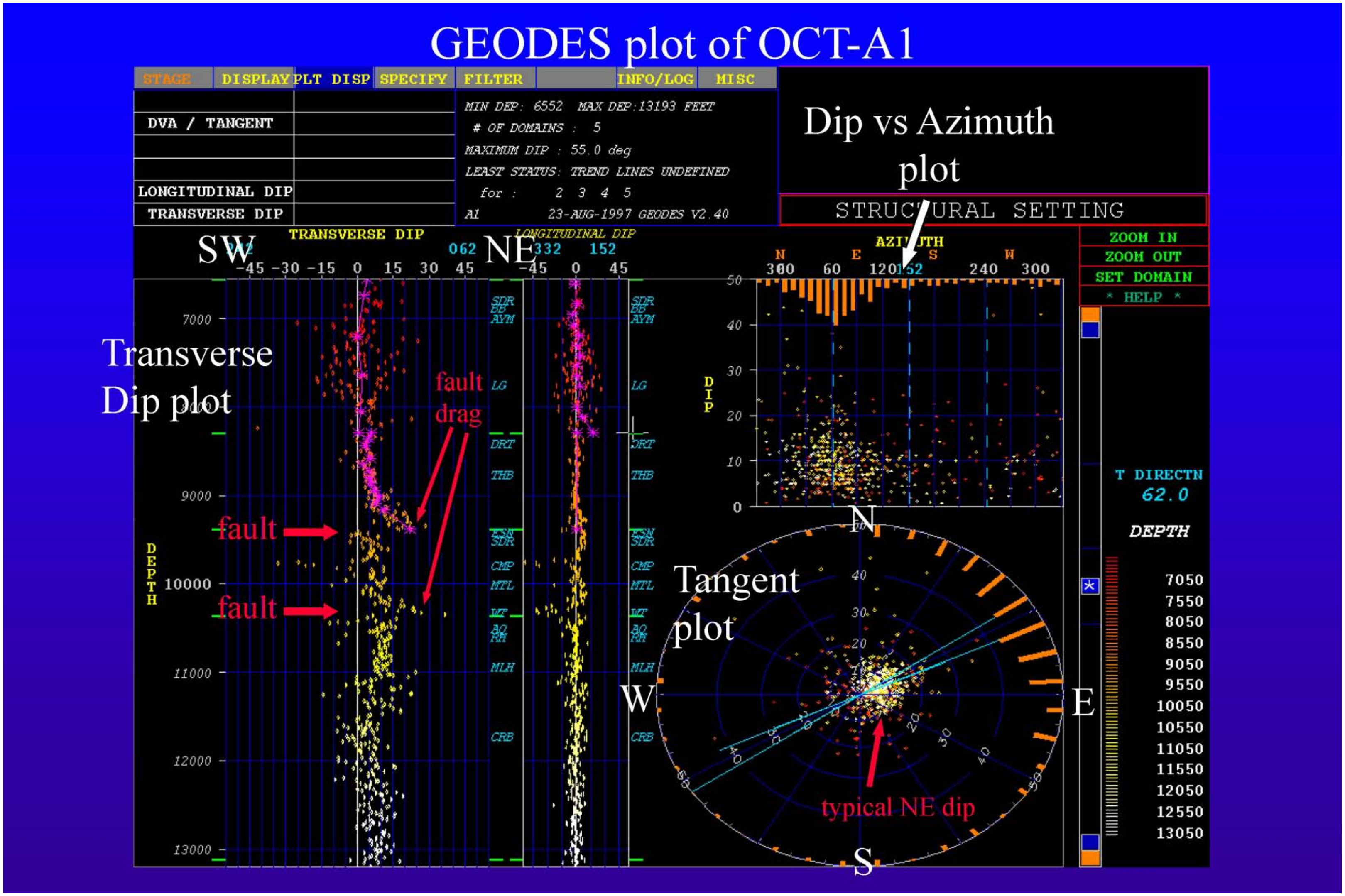
SEISMIC DIDN'T LOOK CORRECT

MODEL STILL WOULDN'T INITIATE

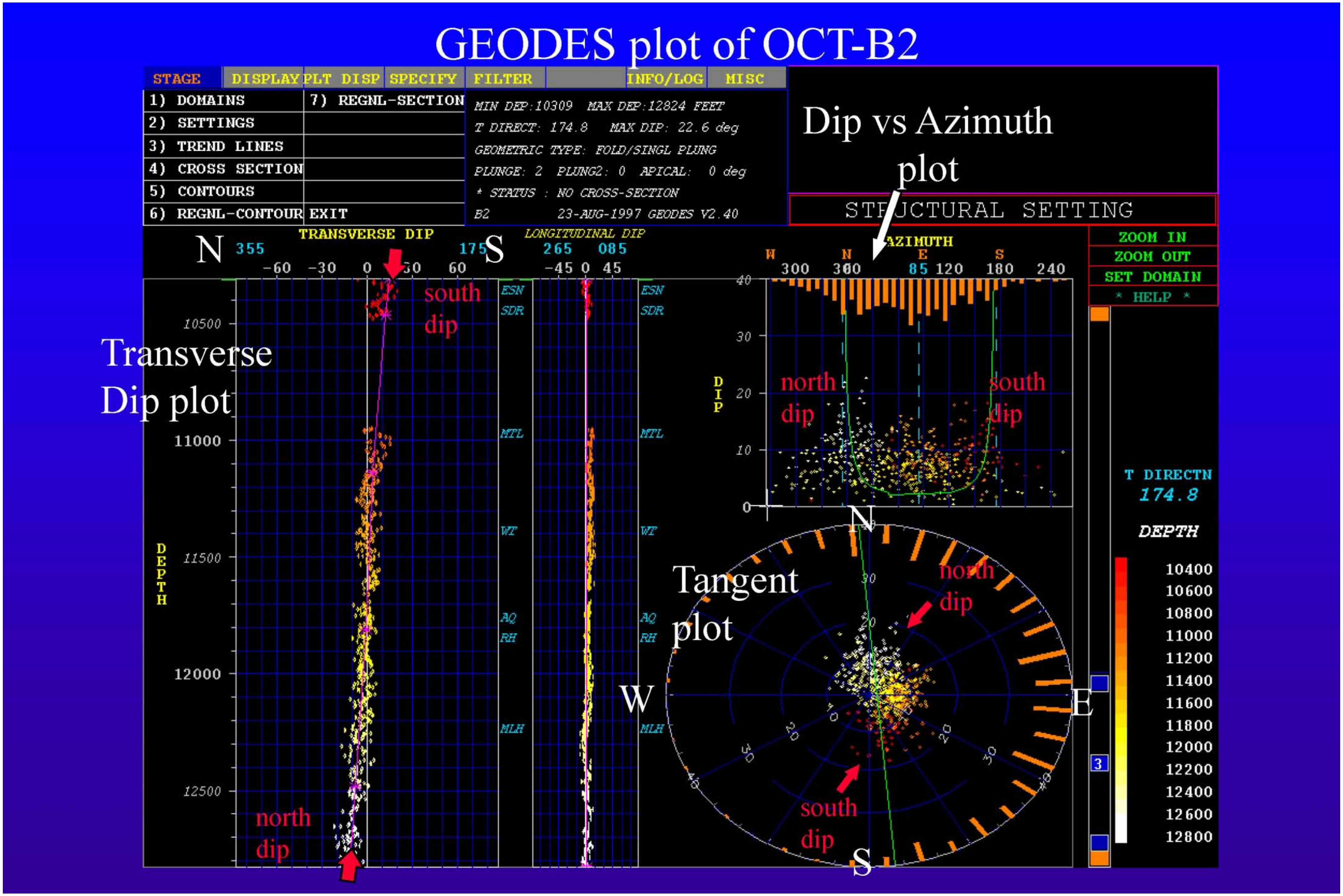
Presenter's notes:In 1994 a very detailed October Nubia model study was undertaken in order to integrate the newly shot 3D seismic, recent drilling, and advanced software such as the GEODES dipmeter evaluation software, the Openworks platform and Earthvision 3D analysis and visualization. The study was to incorporate 26 model layers. This intermediate stage map was made on the top of the Nubia using the early processing and the dipmeters interpreted in GEODES. The dipmeter evaluation, critical to this study and now an integral part of GOS evaluations, revealed not simple planar surface topologies but complex faulting and seemingly random dip variations between even closely spaced wells. This implication of complex faulting was important for any models and secondary recovery programs, especially in the thinner-bedded Nubia Transition and Nezzazat reservoirs. The seismic was difficult to interpret at this early stage due to low signal-to-noise and strong multiples obscuring the weak Pre-Miocene events.

STEP 1

RAN ALL DIPMETERS THROUGH SCAT

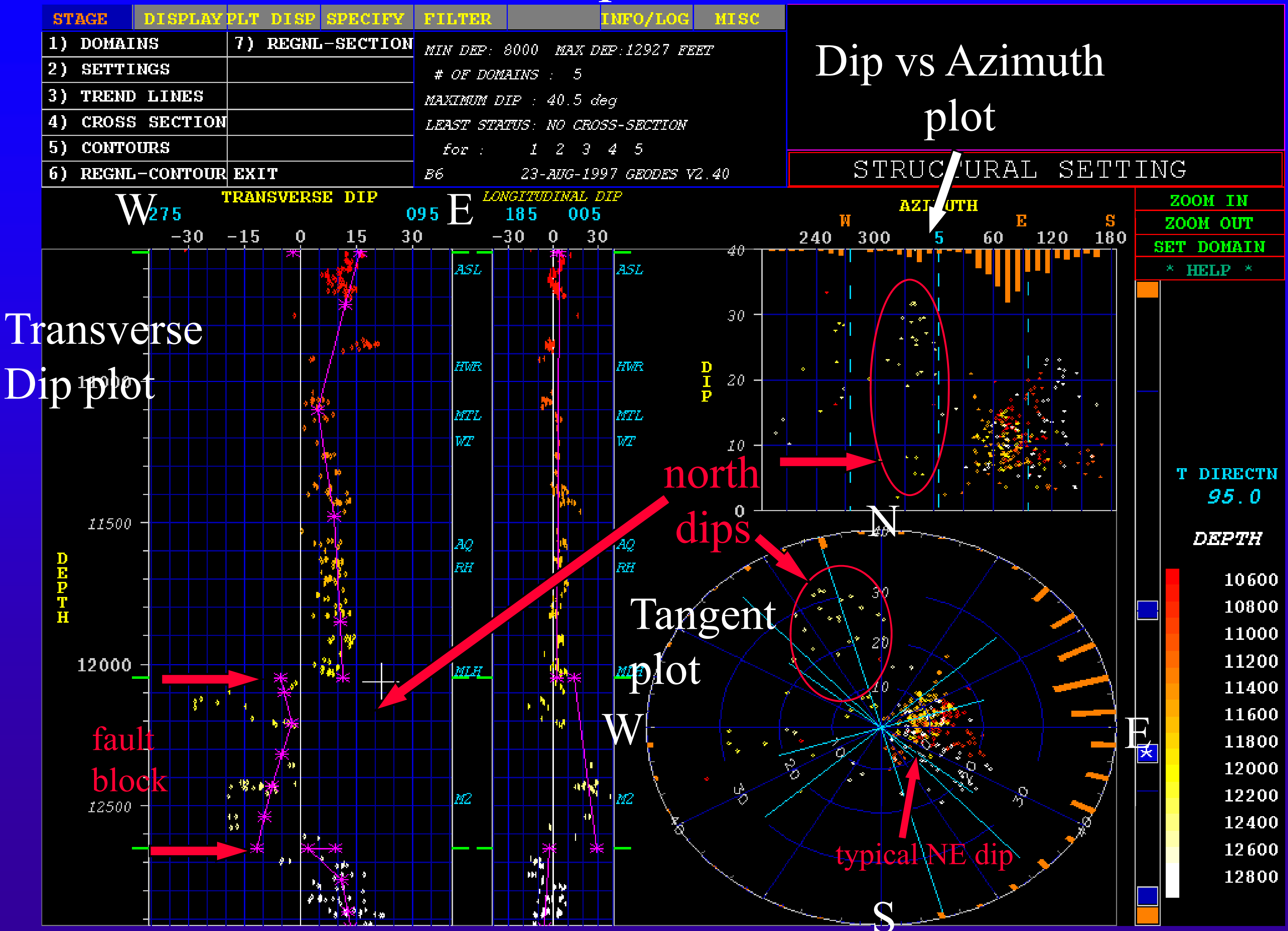


Presenter's notes:The GEODES dipmeter software utilizes the principles of statistical curvature analysis to break apart the dip and azimuth components and then continue with a series of calculations that permit detailed structural analysis. For further details on this technique the August 1997 issue of The Leading Edge contains a paper on the use of this technique in the October field. The A1 plot of Transverse dip or the dip maxima or true dip direction (left side of slide) shows two fault cuts displaying fault drag at 9,300 feet and 10,300 feet as shown by the red arrows. The Dip vs. Azimuth plot and Tangent plots display the same data and show a NE dip azimuth to the bulk of the data set. The lower fault at 10,300 feet has north drag, but it was also the old north-south fault that cut the A1 well. The pre-1997 processing did not resolve the fault direction. This north drag on the lower fault proved to be correct and was a piece of evidence that changed the entire fault pattern of the field. The next two slides illustrate other types of structures in the October field that indicated the structure was not a simple east-dipping tilted block.



Presenter's notes:The GEODES plot for the B2 well shows a gradual dip azimuth change between the Matulla at 11000 feet and the Nubia at TD. The dips rotate from the red, south-dipping points on the plots to the white north dipping points. This is interpreted as a fold that leaves the Nubia dipping north in contrast to the usual northeast dip on the back homoclinal flank.

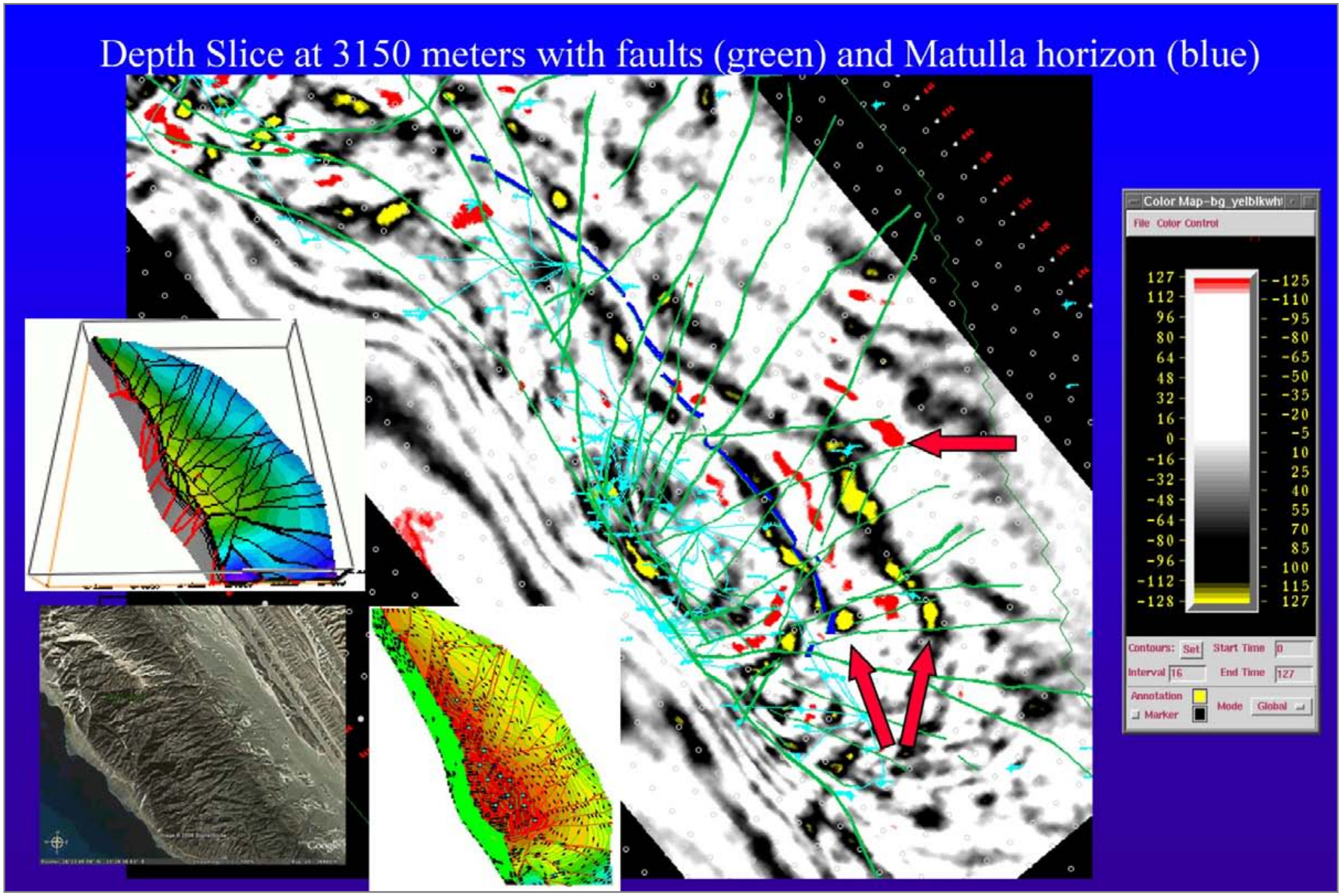
GEODES plot of OCT-B6



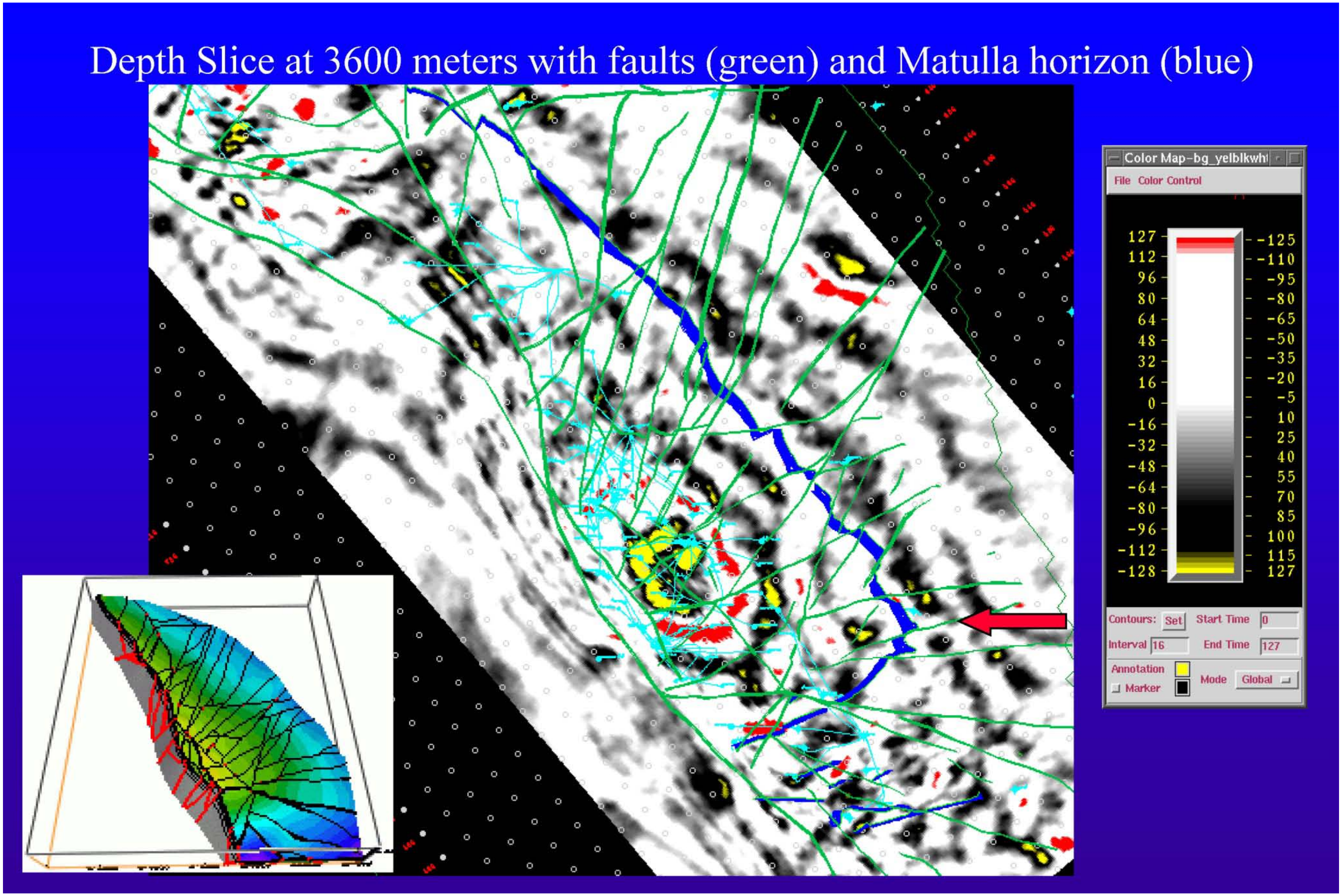
STEP 2

DEPTH STRIPPED SEISMIC

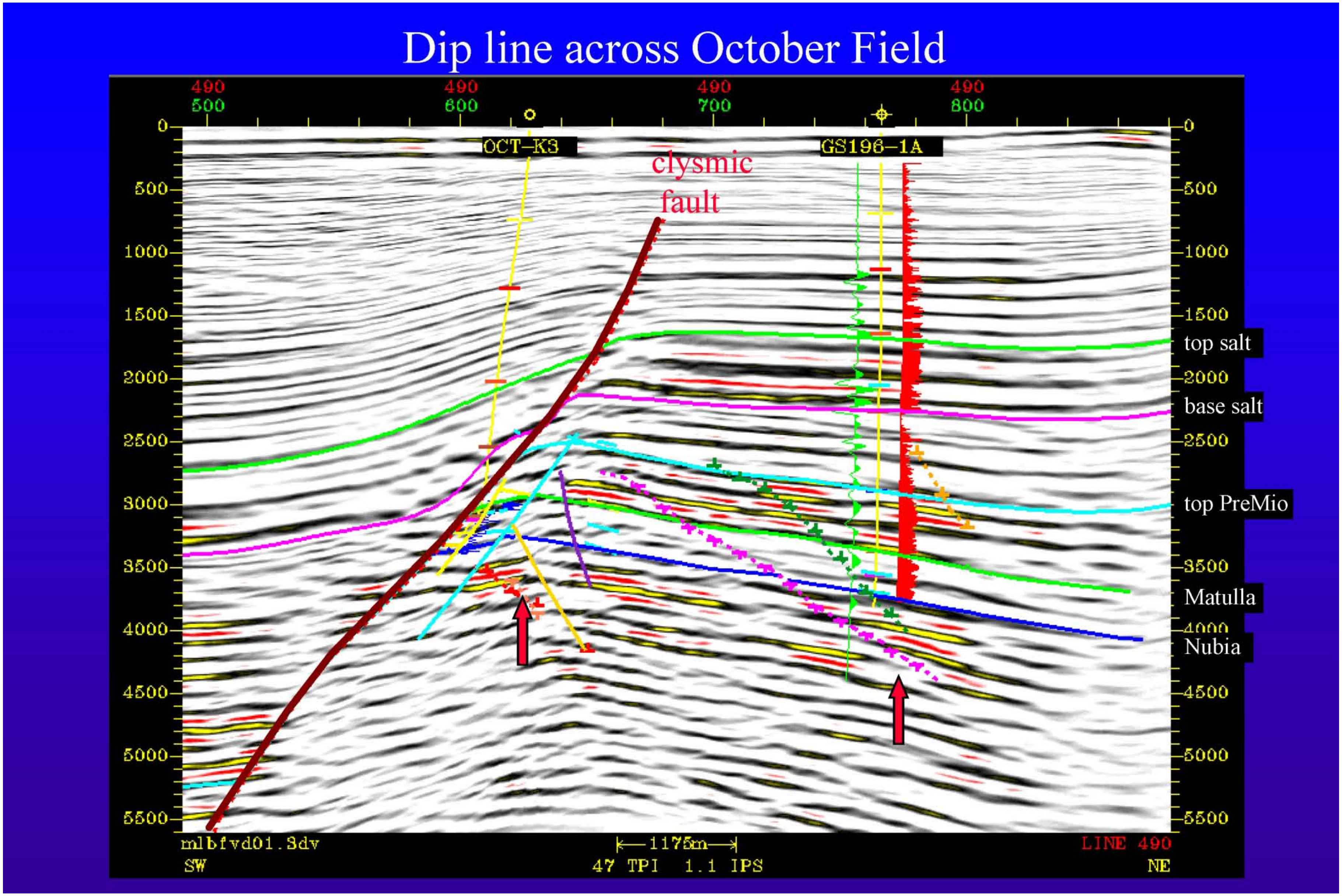
Presenter's notes:The GEODES plot for the B6 well shows a major fault break between the Matulla and M2 model layer in the Nubia. The overall dip is northeast but the isolated fault block has a north dip-azimuth similar to the nearby B2 well shown on the last slide. The north dip made the interpretation of an east-dipping Clysmic parallel block difficult. The remaining dipmeters for the field had the same multi-variant dip and azimuth changes between wells that made the mapping difficult without better seismic resolution.



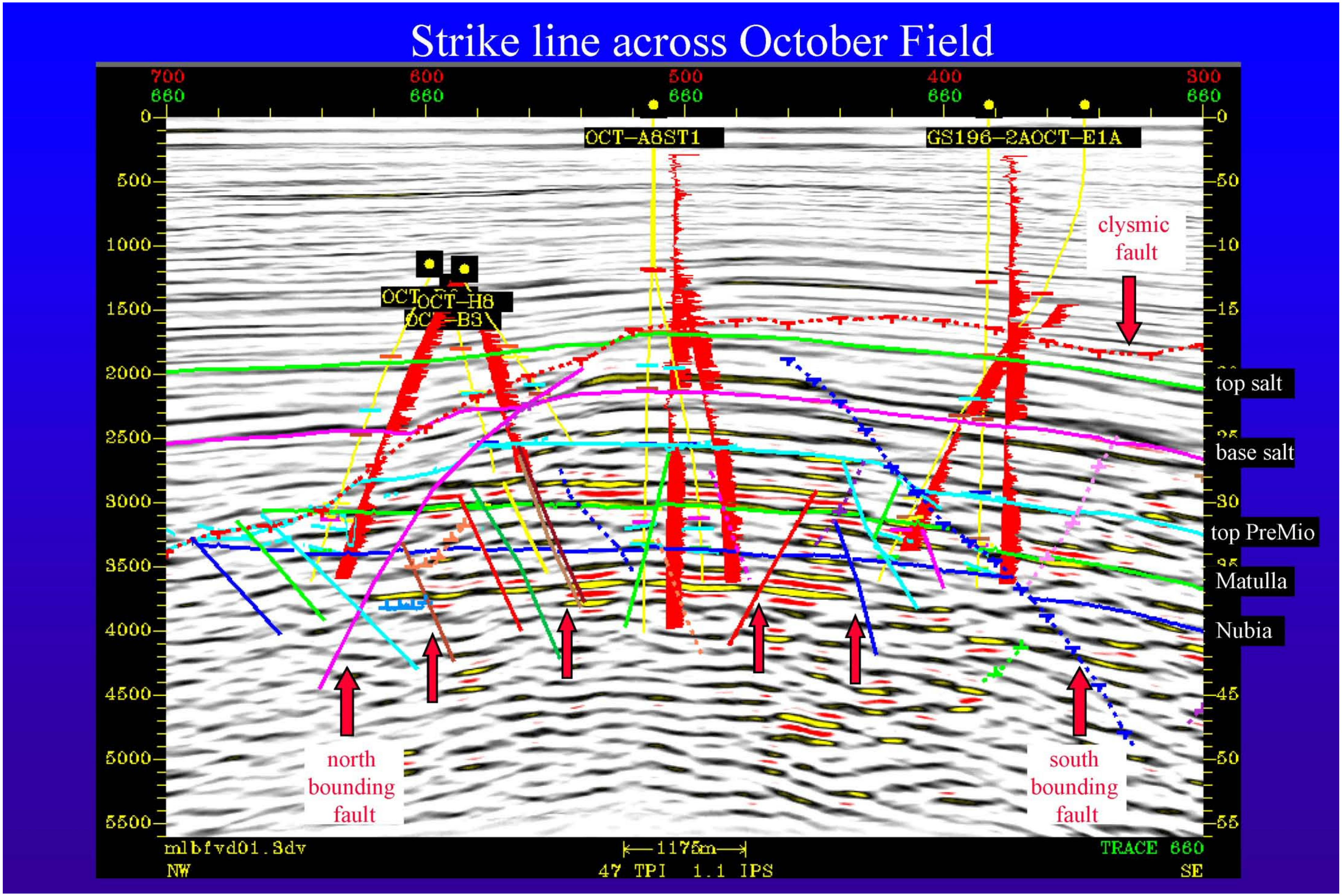
Presenter's notes:In 1996, Lonnie Blake, Mohammed Sadek and others at GUPCO began to make great strides in improving the sign-to-noise in the pre-salt section of the October 3D data. Model-driven multiple removal techniques, time-slice filters and surgical velocity filtering reduced the noise while improved velocity modeling focused the 3D depth migration. The result of this interpreter-driven in-house processing is dramatically improved seismic resolution over what was available in 1994 and laid the groundwork for completely changing the fault pattern of a 20-year old "mature" oil field. This depth slice at 3150 meters is an example of this new data. The interpreted faults, shown here in green, are based on sharp amplitude terminations as shown by the red arrows. At each depth slice the process was to objectively mark any structural discontinuity with an unassigned fault. These discontinuities produced consistent locations of fault traces in map view. The process was similar to picking lineaments on remote sensing images.



Presenter's notes:This deeper depth slice illustrates the same interpreted fault pattern as the previous slide. The unassigned fault picks that were consistent as good fault planes were triangulated in SeisWorks and later gridded for the 3D Earthvision model. The green-colored fault traces on this view are where the triangulated faults intersect the slice, and illustrate their conjugate nature. These faults were consistent with the fault pattern seen in the underlying Precambrian. This fault pattern now fits the dipmeter data and the missing sections from correlations, while also helping to explain the multi-variant dip-azimuth changes between closely spaced wells.



Presenter's notes:This dip-line illustrates the main components of the interpretation through the K3 (on the left) to the downdip 196-1 well. The main Clysmic fault, the Matulla and Nubia reservoirs, Pre-Miocene unconformity, (base salt) Ras Budran and (top salt) South Gharib surfaces are shown. The dip-line also illustrates the new conjugate faults, previously identified geologically but unrecognized in seismic. The subtle amplitude differences are highlighted through color variance and are shown by the red arrows.

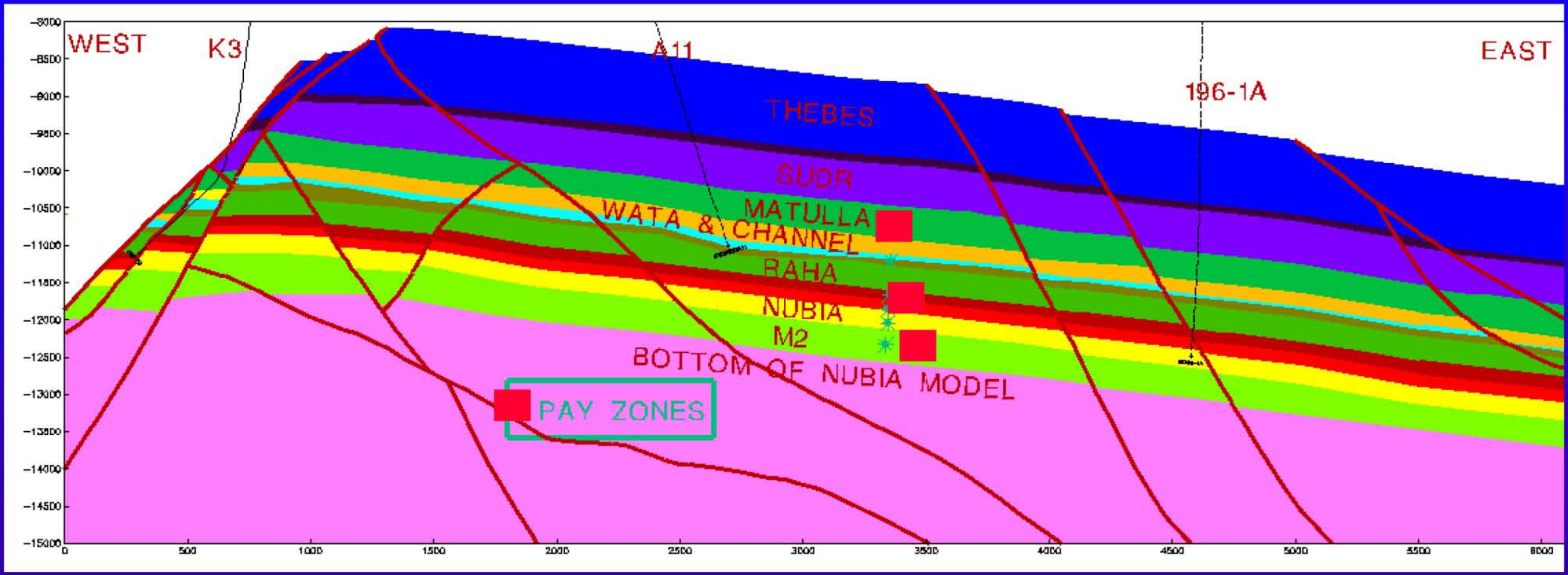


Presenter’s notes:The strike line with north on the left shows the major bounding faults which are essentially major conjugate faults. The Pre-Miocene section shows the cross-cutting nature of the conjugate faults that are cross-cutting in both map and cross section view. Again, subtle amplitude changes can be seen in this view and are shown by the red arrows.

STEP 3

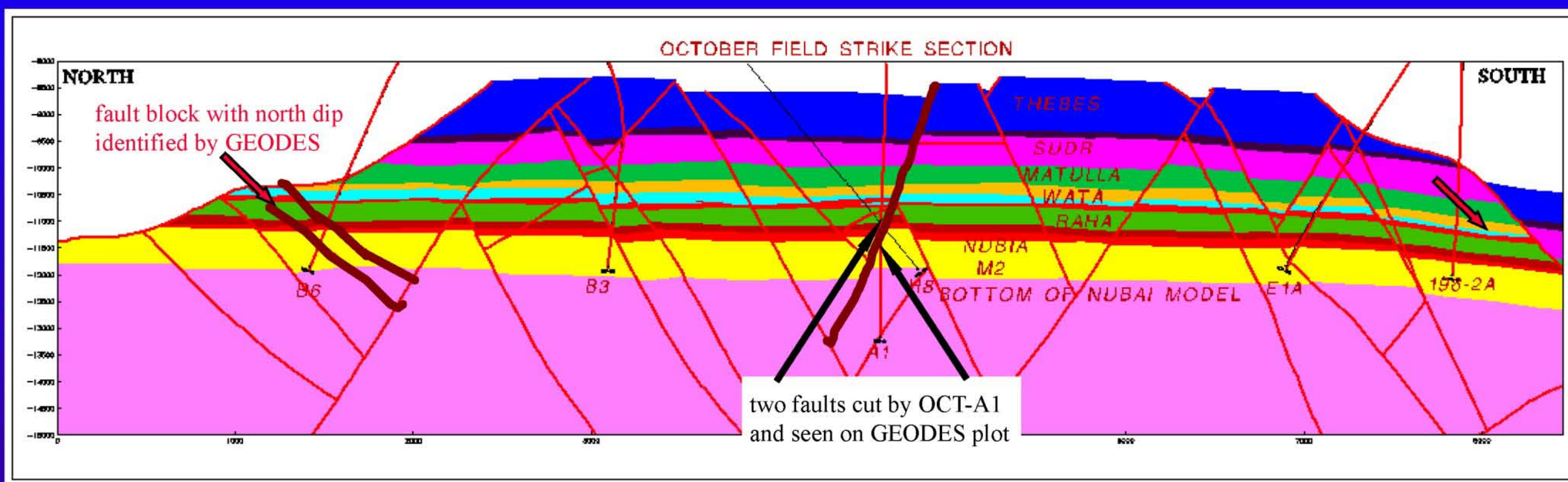
CONVERTED SEISMIC , DIPMETRS AND TOPS INTO SOLID EARTH MODEL

October Field - East-West Dip Cross-Section



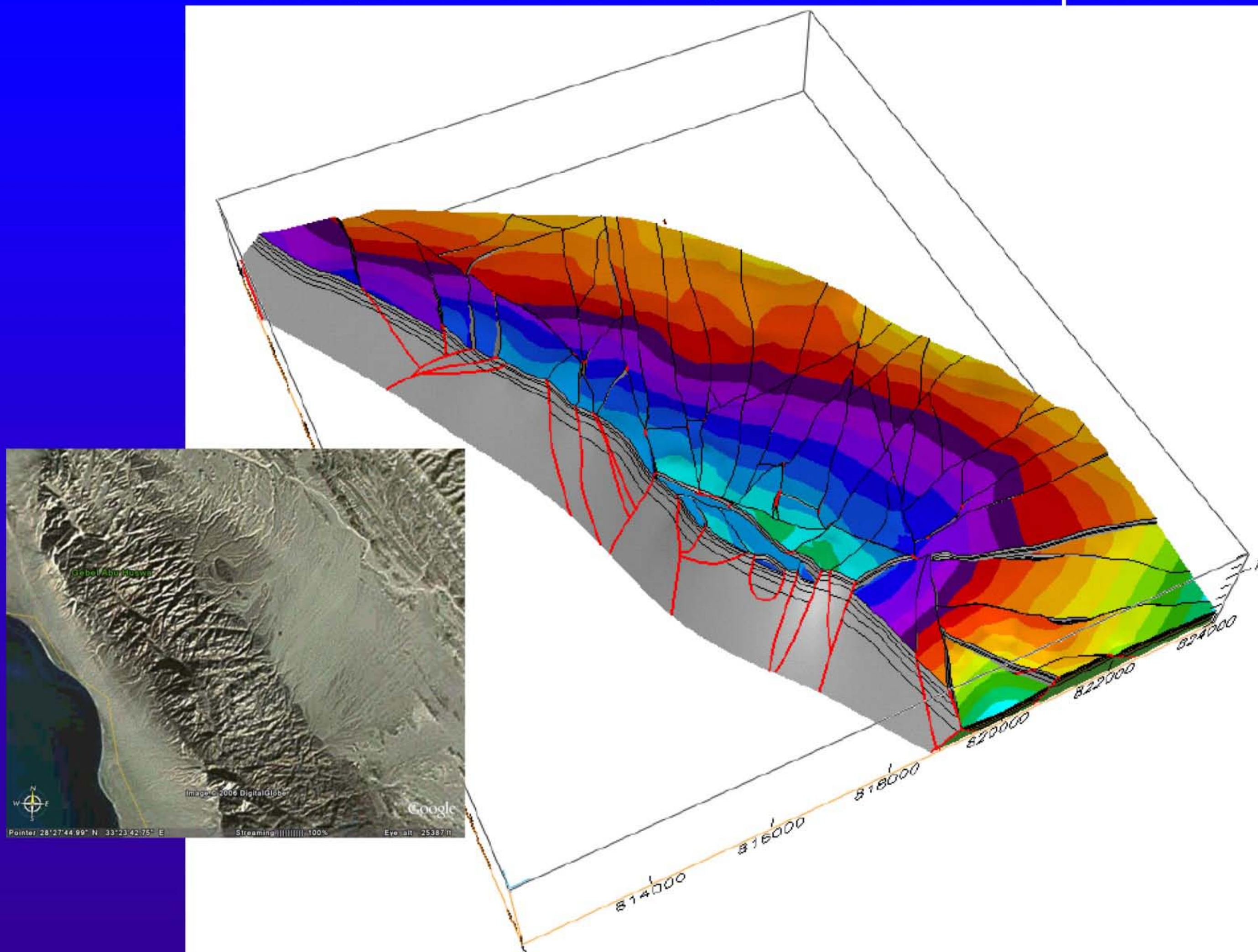
Presenter's notes:This is a one-to-one cross sectional slice through the 3D geologic model, not a drafted cross-section. The seismically derived fault planes were gridded in EarthVision and snapped to the well fault-cuts identified from correlated missing sections and dipmeters. The faults resulted in a model with 71 fault blocks indicating that the field is far more complex than originally thought. The major pay zones are shown with asterisks.

October Field - Strike Cross-Section



Presenter’s notes:This cross sectional model slice is the geologic equivalent of the seismic strike line. The north-bounding fault on the keystone pop-up block in the middle of the line is <u>the</u> major east-west fault identified from GEODES in well A1. The Turonian-aged Wata channel incised valley fill system, a major Nezzazat reservoir objective shown in light blue, thins dramatically over and around this triangular block, suggesting that the faulting was partly pre-Nezzazat and reflecting the Precambrian fabric seen on satellite imagery.

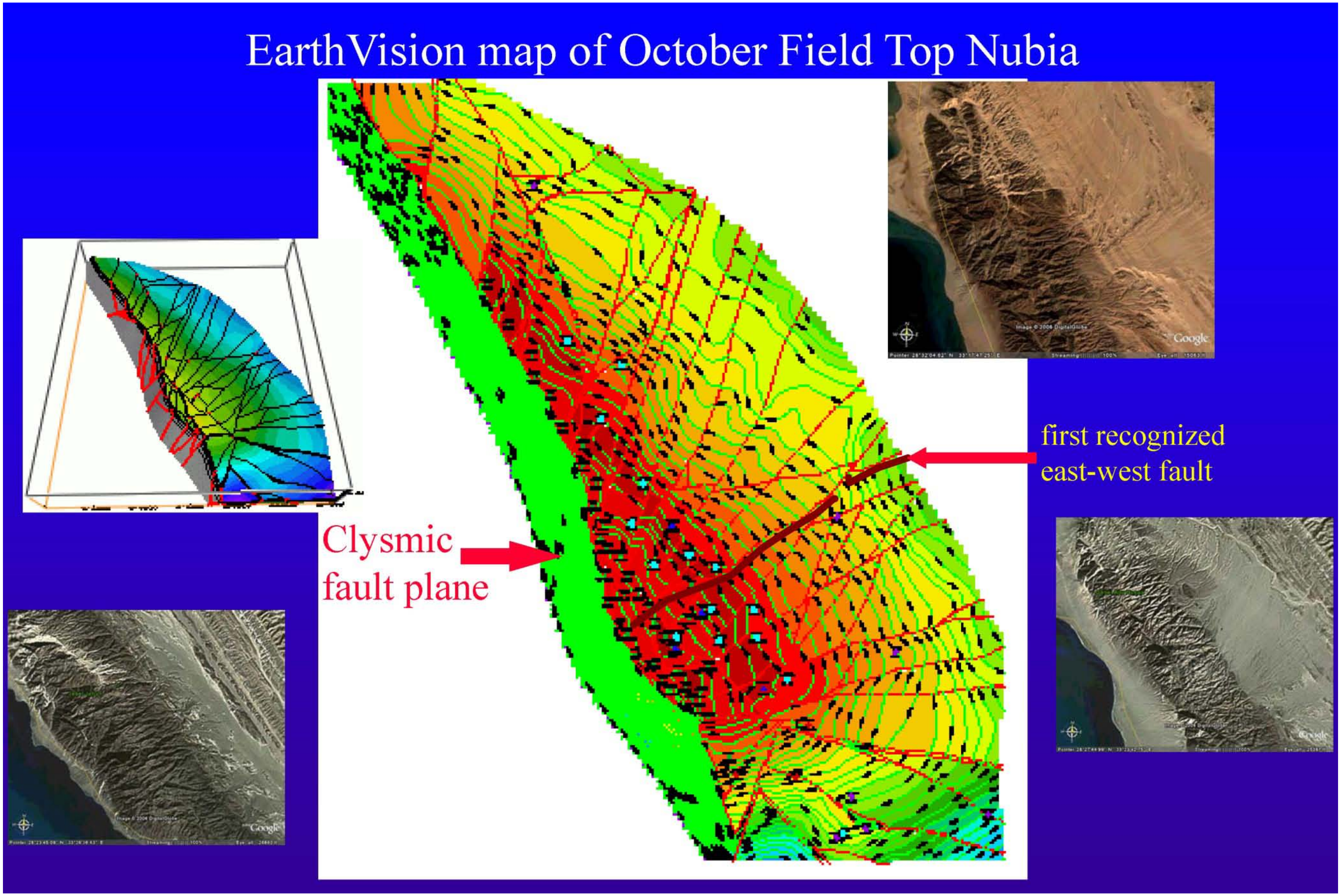
EarthVision model of October Field Top Nubia



Presenter's notes:The top of the Nubia is contoured on this 3D image looking northeast. This is a one-to-one image and illustrates the conjugate faults in map view and along the frontal Clysmic fault plane which is colored in gray. The Nubia portion of the EarthVision model was further subdivided for modeling purposes into 20 layers. The construction of the 3D model was interrupted in 1996 by serious software shortcomings because of the size of the model; which consists of about 2,000 individual 2D grids. Cooperative efforts with the vendor corrected the problems. CPU time for the creation of the 3D model for October has been reduced from 5 days to two hours or less with Dynamic Graphic's release of EarthVision version 4.0. The full model, as shown in the cross section slices, was built from Eocene Thebes to the bottom of the Nubia for a total of 28 layers in 71 fault blocks. The model is currently being utilized for both GCOMP modeling and operations.

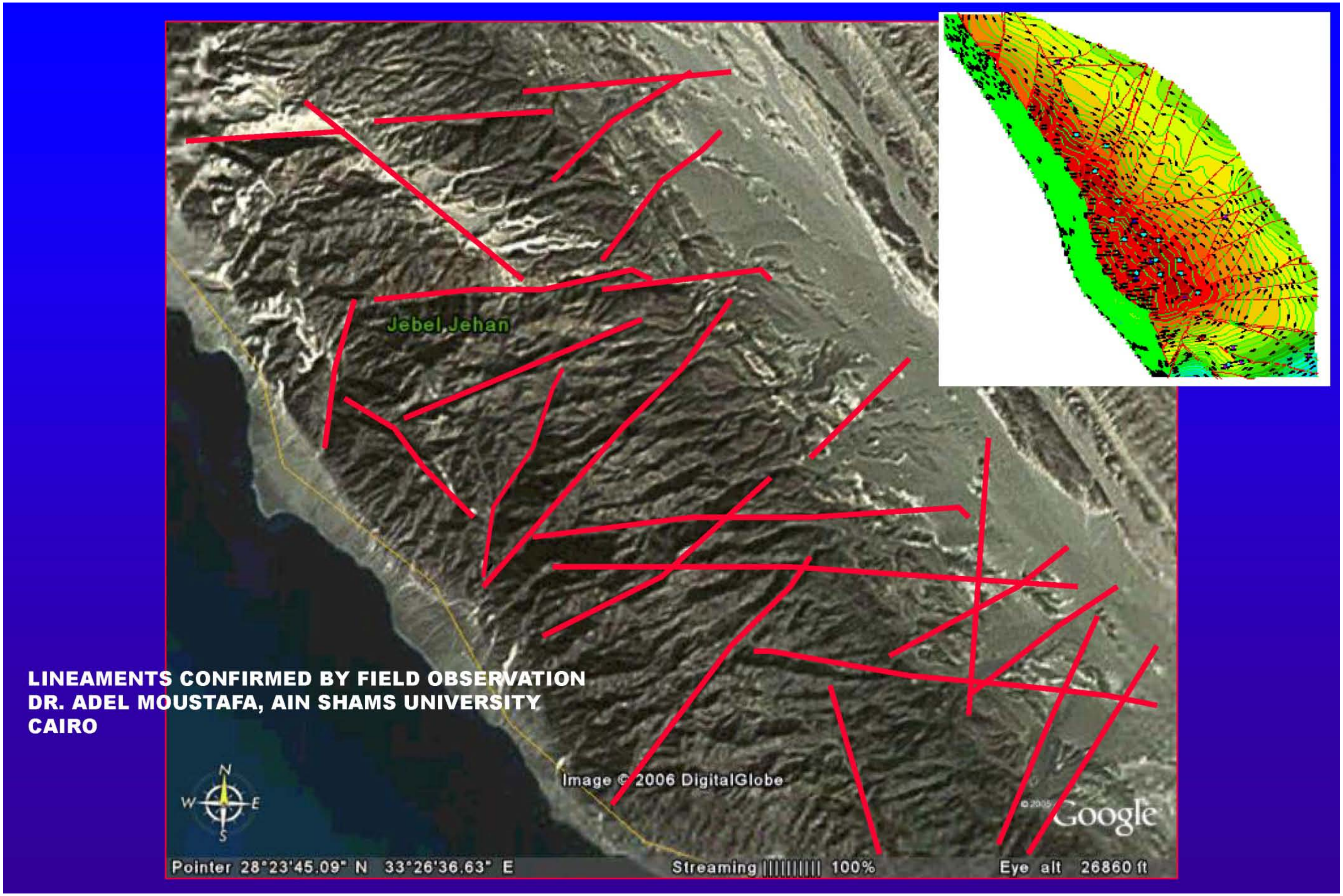
STEP 4

TIED IN REGIONAL GEOLOGY
FAULT SYSTEM EXACTLY
ANALOGOUS TO OUTCROP



Presenter’s notes:This slide is the two dimensional map of the new Nubia surface that resulted from an integrated evaluation of all the data. Poor initial waterflood response caused a re-evaluation of the back-block structure. New seismic processing, Seismic Sequence Attribute Mapping (SSAM), and coherency studies suggested east-west faulting in this area. GEODES evaluations of the dip meter data in A1 (shown in previous slide) also pointed to a east-west fault pattern. This fault, highlighted on this slide in brown, was later confirmed near the crest of the field with the drilling in late 1996 of the H11.

Presenter's notes:The Landsat image of the central GOS and the western side of the Sinai near the October field area shows the dark colored Precambrian metapelites on the right. The lighter colored Nubia and younger sediments cover the Precambrian where not exposed. The Precambrian, sitting just below the Nubia section exhibits a pronounced east-west conjugate fracture and fault system that can be observed in the field. The recognition of this pattern in the Precambrian was important collaboration in the new, seismically defined fault pattern.



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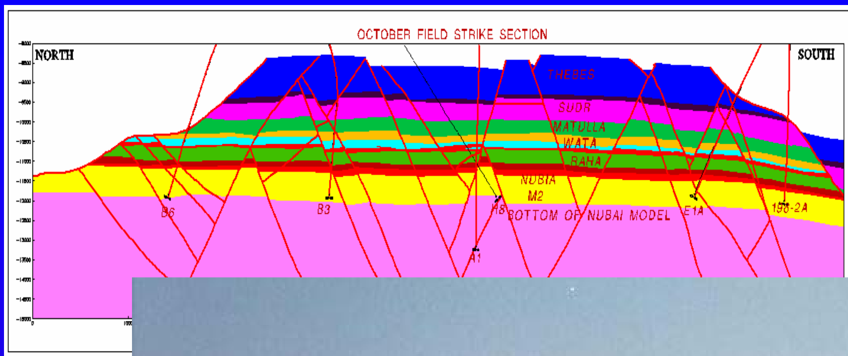
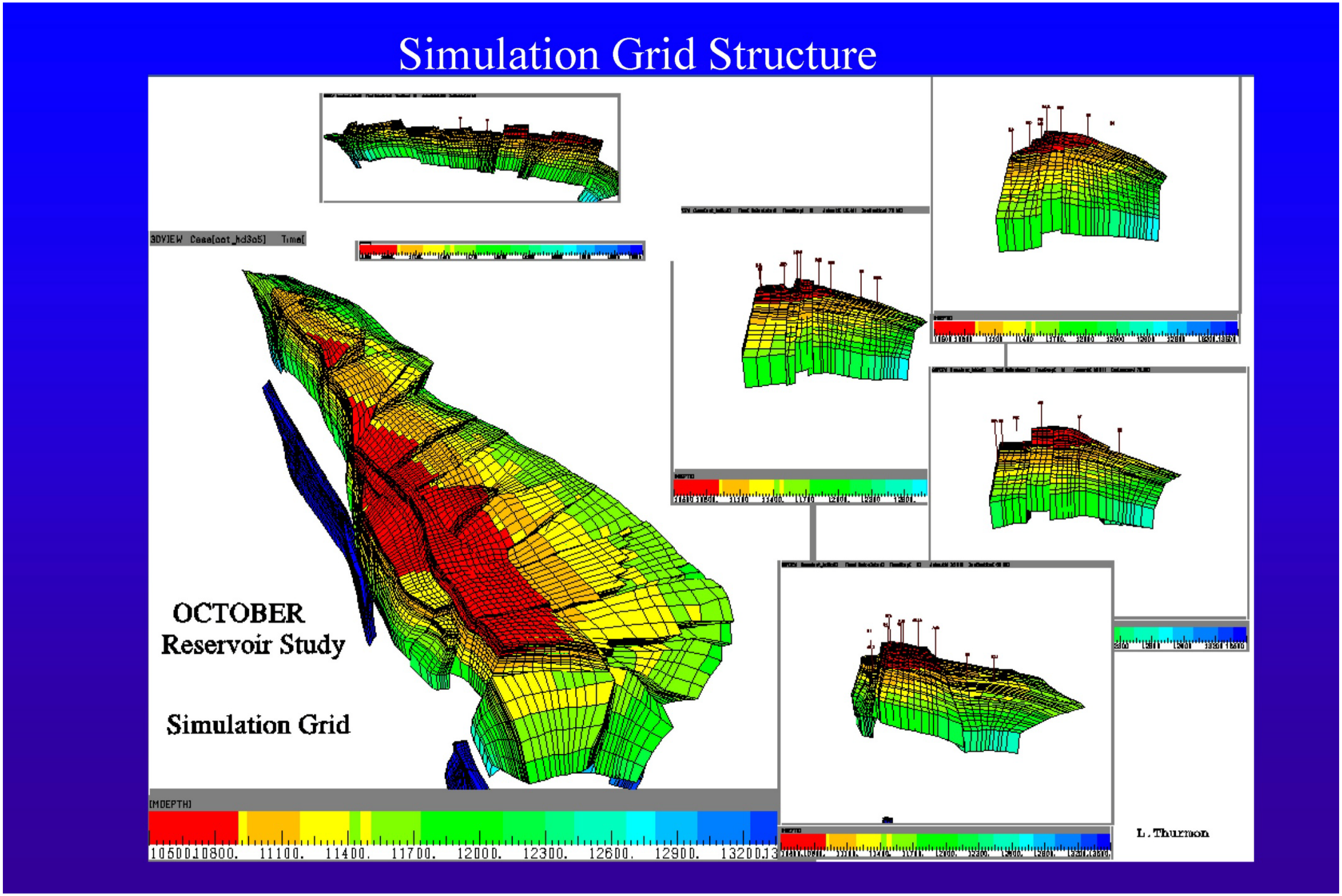
Outcrop Cross-Section



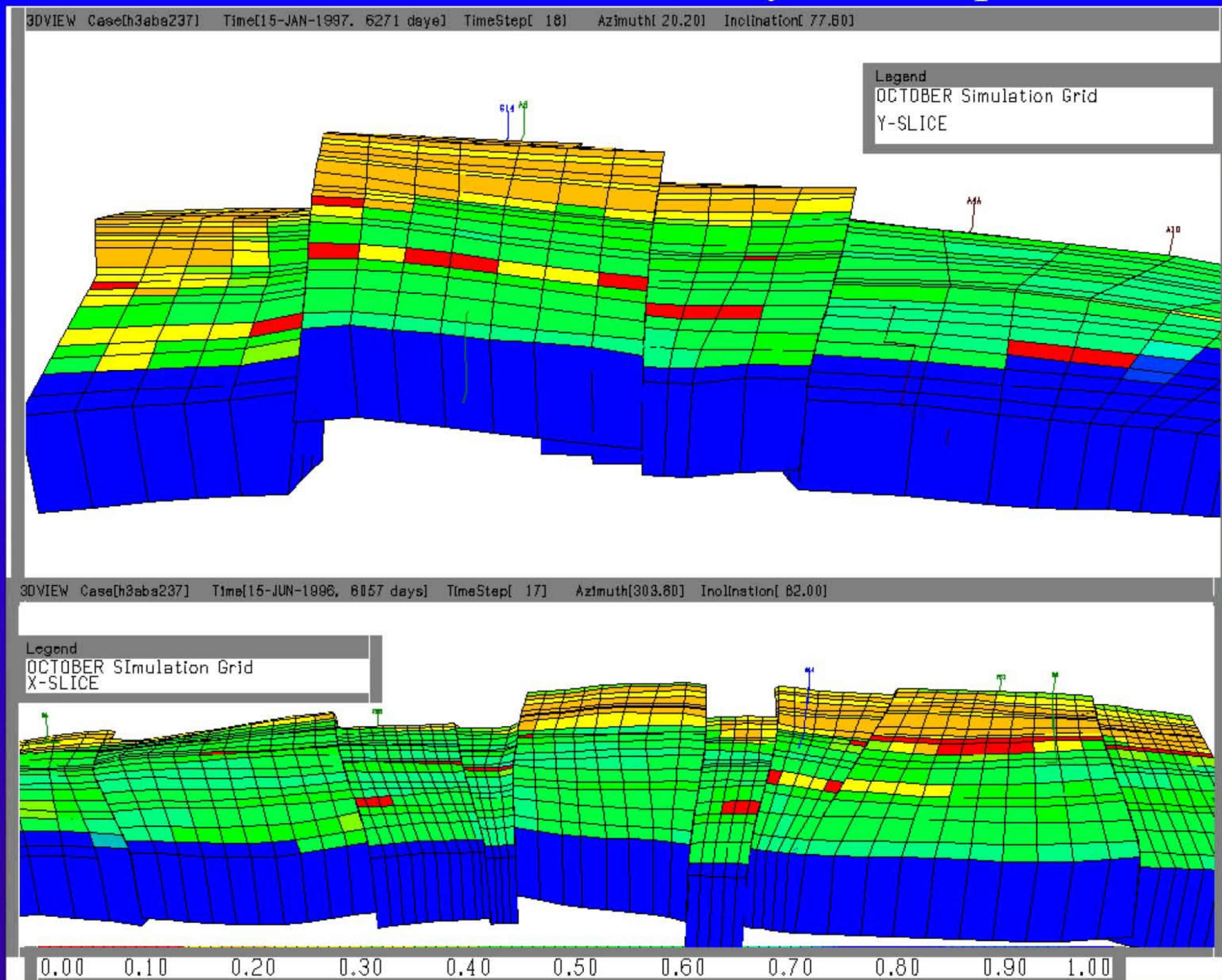
STEP 5

BUILT DYNAMIC MODEL
OLD FAULT
PATTERN:WOULDNTINIATE AT
ALL
NEW FAULT PATTERN:
PERFECT MATCH UPON FIRST
INITIATION

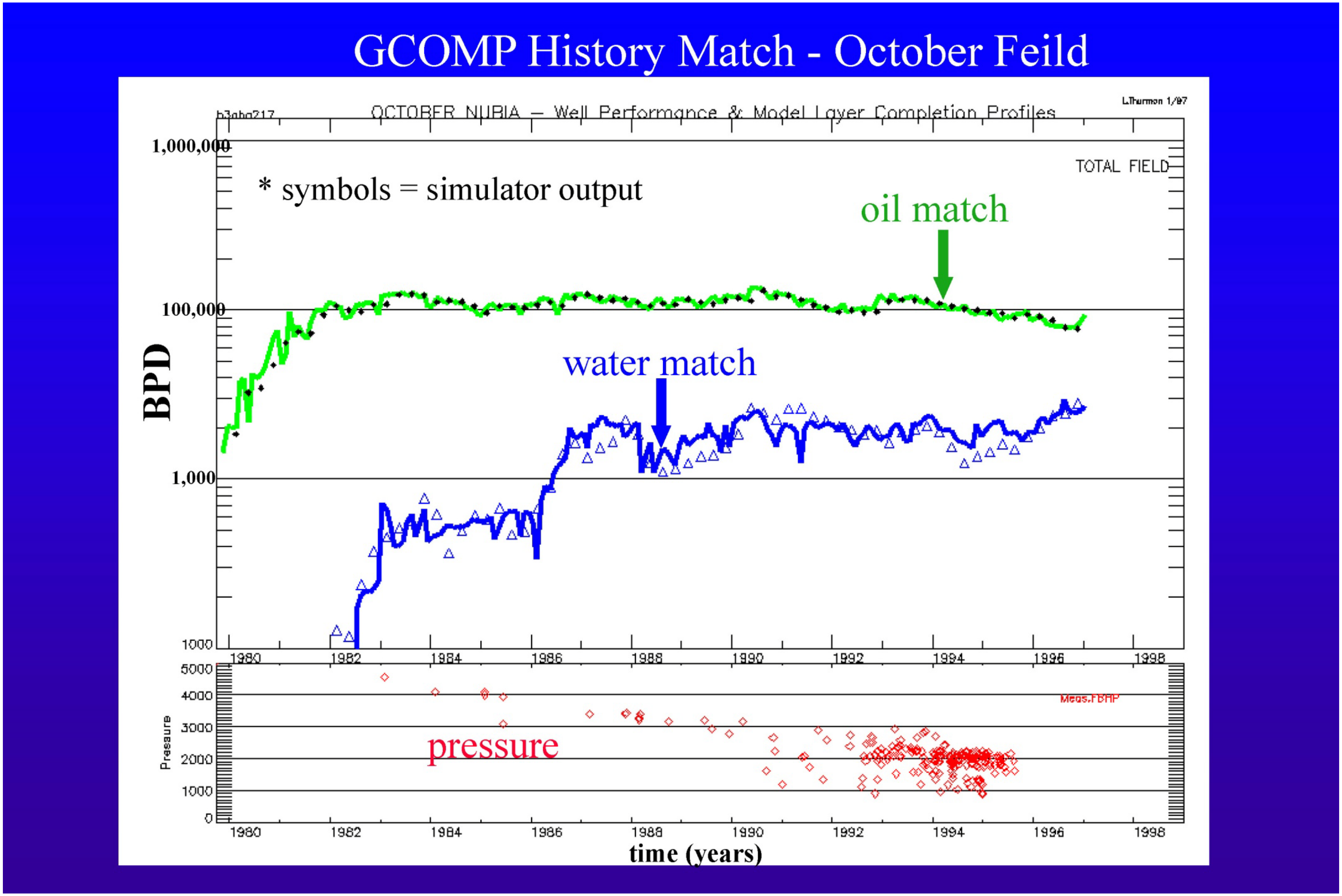


Presenter's notes:Two major goals of the October Reservoir Simulation effort were to incorporate the structural complexity - many non-vertical faults, and incorporate the deviated wellbores accurately. Approximately 30 of the mapped faults and about 60 wells as deviated wellbores were built into the Simulation Grid. This slide shows the Simulation Grid conforming to the non-vertical fault planes.

GCOMP Simulation Grid Layer Juxtaposition



Presenter’s notes:Plugback workovers have historically been very successful in the October Nubia Reservoir in reducing or shutting off water production, yet pressure continuity has been seen throughout the Nubia Column above the Heavy Oil. The combination of a Heavy Oil Barrier and the many layer juxtapositions resulting from the extensive faulting appear to be the controlling factors. These physical features have been incorporated in the current simulation grid. This slide of east-west and north-south cross sections in the Simulation Grid, provide a sample of the extensive model layer juxtapositioning across faults. The cross sections are colored with Saturation at time t(o).



Presenter’s notes:This slide shows the full field History match portion of the reservoir simulation. The solid lines are actual production rates; blue is water and green is oil. The symbols are the simulator calculated values, blue triangles are simulator water rates and the black solid symbols are simulator oil rates. The individual well matches, not shown here, do a good job of predicting the plugback workovers. The rather complex simulation grid, we feel, is responsible for the good history matches.