Fault Analysis, Stratigraphic Discontinuities and 3D Structural Modeling of Tb-Field, Offshore Niger Delta*

Odunayo F. Bamidele and Olugbenga A. Ehinola[1]

Search and Discovery Article #40526 (2010)
Posted April 30, 2010

*Adapted from extended abstract and slides prepared for oral presentation at AAPG International Conference and Exhibition, Rio de Janeiro, Brazil, November 15-18, 2009

[1]Geology, University of Ibadan, Ibadan, Nigeria (obamidele2000@yahoo.com; ehinola01@yahoo.com)

Abstract

The patterns of production, hydrocarbon entrapment and migration require detailed fault analysis. Facies distribution, petrophysical properties and fault analysis of TB-Field offshore Niger Delta were modeled using high-resolution geo-cellular grids of 88920 cells. The data comprised of seismic volume, log suites and check shot data with the use of geological based software, PETREL[TM] Workflow tools. Three horizons and Twenty-two (22) faults were interpreted from within the range of 2100 and 2610 ms. The facies distribution was done using semi-variogram analysis and Sequential Gaussian Simulation. The fault properties, transmissibility multiplier, fault displacement and fault permeability were also modeled.

Well correlation results from the depths of 7612 ft (2537 m) to 10,000 ft (3333 m) show Channel sand, Background floodplain and Levee. The shale volume and permeability models reveal values 0-0.65 and 600-5000 mD as reservoir rocks, respectively. The water saturation model is within 0.40-0.90 and graphically presented. The results from the fault permeability and displacement reveal the communication abilities of these faults as the transmissibility multiplier values indicate areas with values 1 (one) as 'open', those of 0s (zeros) as 'closed' and from between 0 and 1 as variably sealing.

The fault and facies models have served as pointers in locating targets and depositional environment in TB-Field and would also be useful for dynamic modelling in reservoir engineering.

Introduction

Faults can both be a channel of hydrocarbon migration and barrier that aid hydrocarbon accumulation. The patterns of production, hydrocarbon entrapment and migration require detailed fault analysis (Allan, 1989; Aydin, 2000). Element of risk is a an important element in which hydrocarbon exploration and exploitation strategies must be involved. Geologic risk minimization should start with the mindset of having a successful target, such as a fault may seal, if it has undergone deformation processes which has created a membrane seal or if there has been juxtaposition against reservoir rocks (Koledoye et al. 2000, 2003).

The Tb-Field is situated offshore southwestern Niger Delta (Figure 1) and is complexly faulted within the basin. The arcuate destructive and wave-dominated type Cenozoic Niger Delta believed to be one of the world largest deltas is situated at the northeastern margin of the Gulf of Guinea on the west coast of Africa in the southern part of Nigeria on the south Atlantic Margin. The Okitipupa Ridge separates the Niger Delta in the west from the Dahomey Basin. To the North, the Niger Delta is linked to the Benue Trough by the Cretaceous Anambra Basin.

The Niger Delta covers an area of approximately 75,000km^2 and consists of a regressive sequence whose maximum thickness is about 12 km thick in the central part (Short and Stauble, 1967). The Delta consists of Tertiary (Cenozoic) sediments deposited in a high-energy-constructive deltaic environment. These sediments range in age from Eocene to Recent (Reijers et al., 1997). The sedimentary fill of the Delta encompasses the Tertiary, during which it was fed by the drainage system of the Niger, Benue, and Cross rivers. The present-day delta is a complex of fluvio-marine systems that have succeeded one another in a stepwise fashion as the delta prograded towards the southwest (Bowen et al., 1994).

The three stratigraphic sequences of Niger Delta, starting with the basal unit are: the marine shales of Akata Formation, middle paralic Agbada Formation and the topmost Benin Sands (Figure 2) (Short and Stauble, 1967; Reijers et al., 1997). The main reservoir in the Niger Delta is the sands of the Agbada Formation while the shales provide lateral and vertical seals (Krusi and Idiagbor, 1994). The Benin Formation is about 2000 m in thickness, and it consists mainly of fresh-water fluvial sands and gravels which are occasionally interspersed with shale beds towards the base of the rock units. The sands are generally fine- to coarse-grained and very poorly sorted. Occasional streaks of lignite and thin scattered grayish brown shale beds are intercalated with the sands and gravels, while the grains are subangular to well rounded with most clear white, the yellowish brown quartz with subordinate hematite and feldspar grains (Short and Stauble, 1967).

The deformation encountered in the entire delta sequence by syn-sedimentary faulting and folding gave rise to the formation of traps where hydrocarbon accumulations are found in the present-day Niger Delta. Growth faults and the associated rollover anticlines are the predominant structures of the Niger Delta (Corredor et al., 2005). This study aims at structural and facies interpretations, and creation of 3D models of Tb-Field.

Methodology

The software PETREL^{TM} tool was used under different modules during the course of this research work. These modules (on PETREL^{TM} workstation) are designed to specifically undertake distinct operations which include: visualization, seismic interpretation, well correlation, 3D grid design for geology and reservoir simulation, depth conversion, 3D reservoir modeling and others. The datasets (seismic volume, well logs, check shot and well header) used for this study were imported into PETREL (via a CD-ROM containing information of about 590 megabytes) in their various formats. Each data set was assigned with a specific format that can be imported into user-defined folders either as line data or point data. Three horizons were mapped in the seismic sections, which were designed to skip at the rate of 4 ms. The three horizons were picked within the range of 2000 and 2500 ms after the seismic section had been realized. Cropping exercise, which is a process where area(s) of interest are cut or carved out from the whole seismic section, was also carried out.

Fault sticks were defined in the seismic section to indicate the dip of the faults. Series of key pillars were joined laterally to indicate the shape and the extent of the faults. The horizons generated were converted to surface using Convergence Algorithm method. The surfaces were edited and smoothed and form 2D stratigraphic framework of modeling. During the pillar gridding the 3D mesh was defined. A 3D grid is a 2D grid mesh extended into the third dimension. A 2D mesh is defined in 'x' and 'y' directions as rows and columns. The pillar gridding therefore reveals the 3D grid in 2D grid stacked on top of one another. The faults generated served as input for the pillar gridding process, and these resulted in the framework of the model that includes faults, the size of the cell and where the surface was later inserted. The faults and the 3D grid, which were in time-domain, are converted to depth. This must be done because abrupt lateral velocity variation may result in false structures, thereby leading to misinterpretation of the subsurface (Antonellini and Aydin, 1994; Bailey et al., 2006; Larue, 2004).

The depth conversion was done using Linvel formula:

$$V = V_0 + KZ\text{......................................}1$$

Where V_0 = initial velocity of a particular surface or reference datum, e.g., the seabed
$\quad$ V = final velocity
$\quad$ K = constant or surface
$\quad$ Z = depth

The logs utilized for the model include the Gamma Ray log (GR), the Spontaneous Potential log (SP), permeability log, resistivity log and volume of shale. The logs were upscaled as the depth converted grid was made to undergo zonation and layering processes which compartmentalize the 3D grid or reservoir model into units. Stochastic methods, which are used in the Sequential Indicator Simulator, were used in the geostatistical analysis in the modeling of the facies and petrophysical parameters. The modeled fluvial facies were interpreted during the well correlation exercise. The fault permeability was calculated using a displacement-weighted average under Lithology-

Dependent option. The displacement of each of the faults in the 3D grid was measured, and it is independent of the faults in project units, hence no unit is given. The transmissibility multiplier was computed by comparing the permeability on each side of the fault. The permeability used was taken along the 'I' and 'J' directions from the grid permeability already generated during the petrophysical modeling process after upscaling the logs (Figure 3).

Results and Discussion

The facies identified are channel sand, background floodplain and levee (Figure 4). There is alternation in deposition of channel sands and background flood plains apparent in the well bores (wells 1, 2 and 3) from within the depth of 7612 ft *(2537 m)* to 10,000 ft (3333 m). The occurrences of four (4) units of levee sand were also identified (Figure 4). Four sequence boundaries (SB) were identified within the interpreted area of interest in the well logs and seismic section (Figure 5). The first sequence boundary occur at the depth of about 10,580 ft and terminate at the depth of 9564 ft. The second, third, and fourth sequence boundaries occur at the depths of 7100 ft, 7525 ft , and 8384 ft, respectively. The discrete facies are distributed throughout the depth-converted model grid (Figure 6) after it has been upscaled. This defined the trends within the reservoir 3D grid. The Bulk Volume model defined the entire volume used for the petrophysical and facies models built and expresses the entire model in 88920 cells.

The fluvial facies model indicated areas covered by the channel sands, background floodplains and levee (Figure 7). Three petrophysical properties which include permeability, volume of shale, and water saturation were modeled (Figure 8). The distribution of permeability property gives clues to the petrophysical potential of the Tb-Field. The areas with high permeability values (yellow and red colours) of 500-6500 mD are potential area for hydrocarbon prospecting (Figure 8a). The areas with low levels of permeability are areas which allow little or no flow of hydrocarbons. The volume of shale (Figure 8b) represents the distribution of these petrophysical properties from the upscaled version of the well logs. The grid is calibrated into fractions, which define the 3D model into various depositional environments, as the part which captures values of 0-0.65 signifies potentially reservoir rocks. The water saturation model (Figure 8c) in turn gives a guide to the hydrocarbon-producing capacity of the reservoir. Each cell in the grid represents a value of the water saturation in the Tb-Field. The areas with blue colour, which capture 0.40-0.90, shows high level of water saturation while the other part of the model indicate regions in Tb Field with low water saturation values.

The fault property transmissibility multiplier (TM) displayed shows various values of TM as indicated (Figure 9a). The portions with red values are indicative of the fault(s) being open or close (0.9-1.0 in value). The colour values, for example blue at the point of 0.2, indicates the fault has reduced the communication efficiency to 20% across the fault zone. The internal fault products are the fault properties resulting from displacement (Figure 9b). These fault properties affect the communication ability of the faults in this area of investigation. A fault which divides the flow unit's portions of high permeability (yellow/red colours) would have a lesser TM value than the ones with similar properties that divides the flow unit's low permeability units (Figure 9c).

Conclusion

These models are pointers to the environments of deposition in the field, which in turn could be used to reconstruct the past environments, and even as a palaeoecologic guide. This model could be used to build several other models which are cost effective in oil production and reservoir management. The model also defined the reservoir and non-reservoir rocks in the Tb-Field. The petrophysical models, which involve the Bulk volume, Volume of shale, Permeability and Water saturation give the petrophysical properties or set of information vital in volumetrics/reservoir volume and producibility. The model built has provided information on the lithofacies, geometry, orientation, spatial distribution, proportion and connectedness of the permeable and impermeable rock units within the Tb-Field.

References

Allan, A.S., 1989, Model for hydrocarbon migration and entrapment within faulted structures: AAPG Bulletin, v. 73, p. 803-811.

Aydin, A., 2000, Fractures, faults, and hydrocarbon entrapment, migration and flow: Marine and Petroleum Geology, v. 78, p. 797-814.

Koledoye, B., A. Aydin, and E. May, 2000, 3-D visualization of fault segmentation and shale smearing in the Niger Delta: Leading Edge, v. 19, p. 692-701.

Koledoye, B.A, A. Aydin, and E. May, 2003, A new process based methodology for analysis of shale smear along normal faults in the Niger Delta, AAPG Bulletin, v. 87, no. 3, p. 445-463.

Short, K. C., and A.J. Stauble, 1967, Outline of geology of Niger Delta: AAPG Bulletin, v. 51, p. 761–779.

Reijers, T.J.A., S.W. Petters, and C.S. Nwajide, 1997, The Niger Delta Basin, *in* R.C. Selley, ed., Africa Basins-Sedimentary Basin of the World 3: Amsterdam, Elsevier Science, p. 151-172.

Bowen, B.E., D.J. Hall , R.N. Rosen, and B.L. Shaffor, 1994, Sequence stratigraphic and structural framework of southeast Niger Delta shelf, NAPE Bulletin v. 9, no. 1, p. 51-58.

Krusi, H.R., and C. Idiagbor, 1994, Stratigraphic traps in Eastern Niger Delta - inventory and concepts, NAPE Bulletin, v. 9, no. 1, p.,76-85. Corredor, F., J.H. Shaw, and F. Bilotti, 2005, Structural styles in the deepwater fold and thrust belts of the Niger Delta, AAPG Bulletin, v. 89, no. 6, p. 753-780.

Antonellini, M., and A. Aydin, 1994, Effect of faulting on fluid flow on porous sandstones; Dordrecht, Kluwer Academy publisher, p. 10.

Bailey, W.R., J. Underschultz, D.N. Dewhurst, G. Kovack, S. Mildren, and M. Raven, 2006, Multi-disciplinary approach to fault and top seal appraisal; Pyrenees-Macedon oils and gas fields, Exmouth Sub-basin, Australian Northwest Shelf, Marine and Petroleum Geology, v. 23, p. 241-259.

Larue, D.K., and H. Legarre, 2004, Flow units, connectivity and reservoir characterization in a wave dominated deltaic reservoir: Meren reservoir, Nigeria, AAPG Bulletin, v. 88, no. 3, p. 303-324.

Figure 1. Map showing location of the study area (Tb-Field).
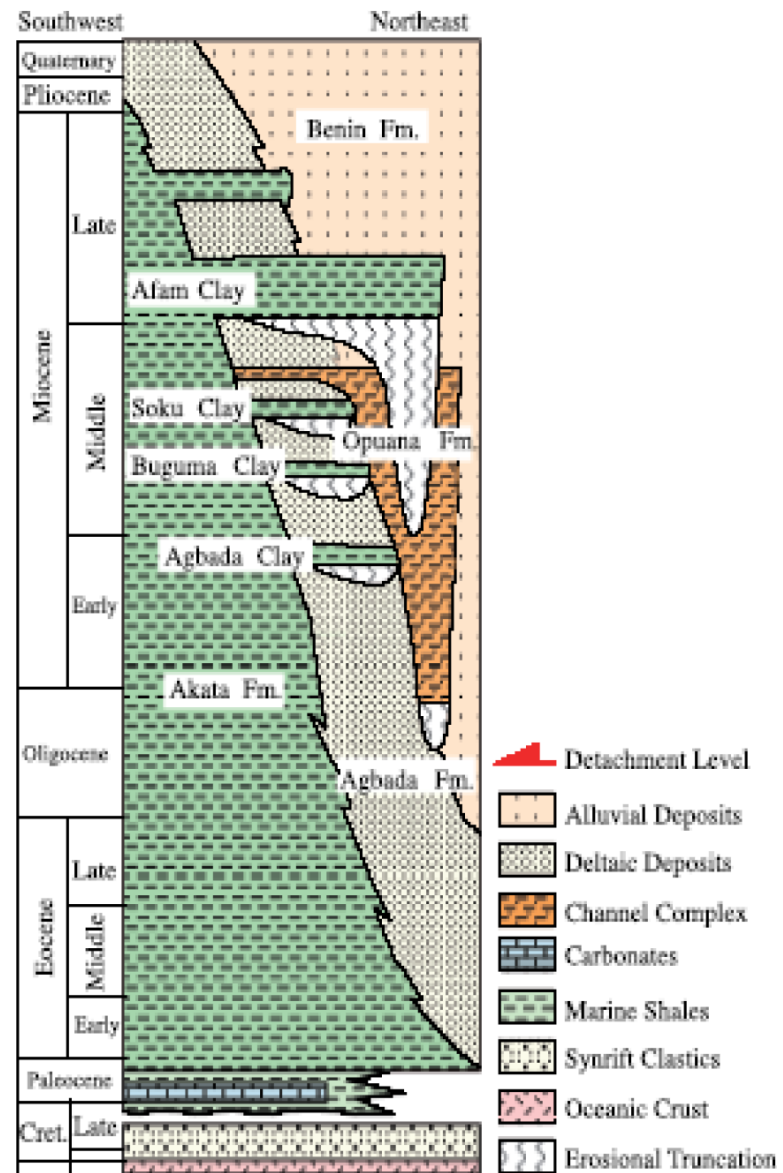
Figure 2. Regional stratigraphy of Niger Delta.
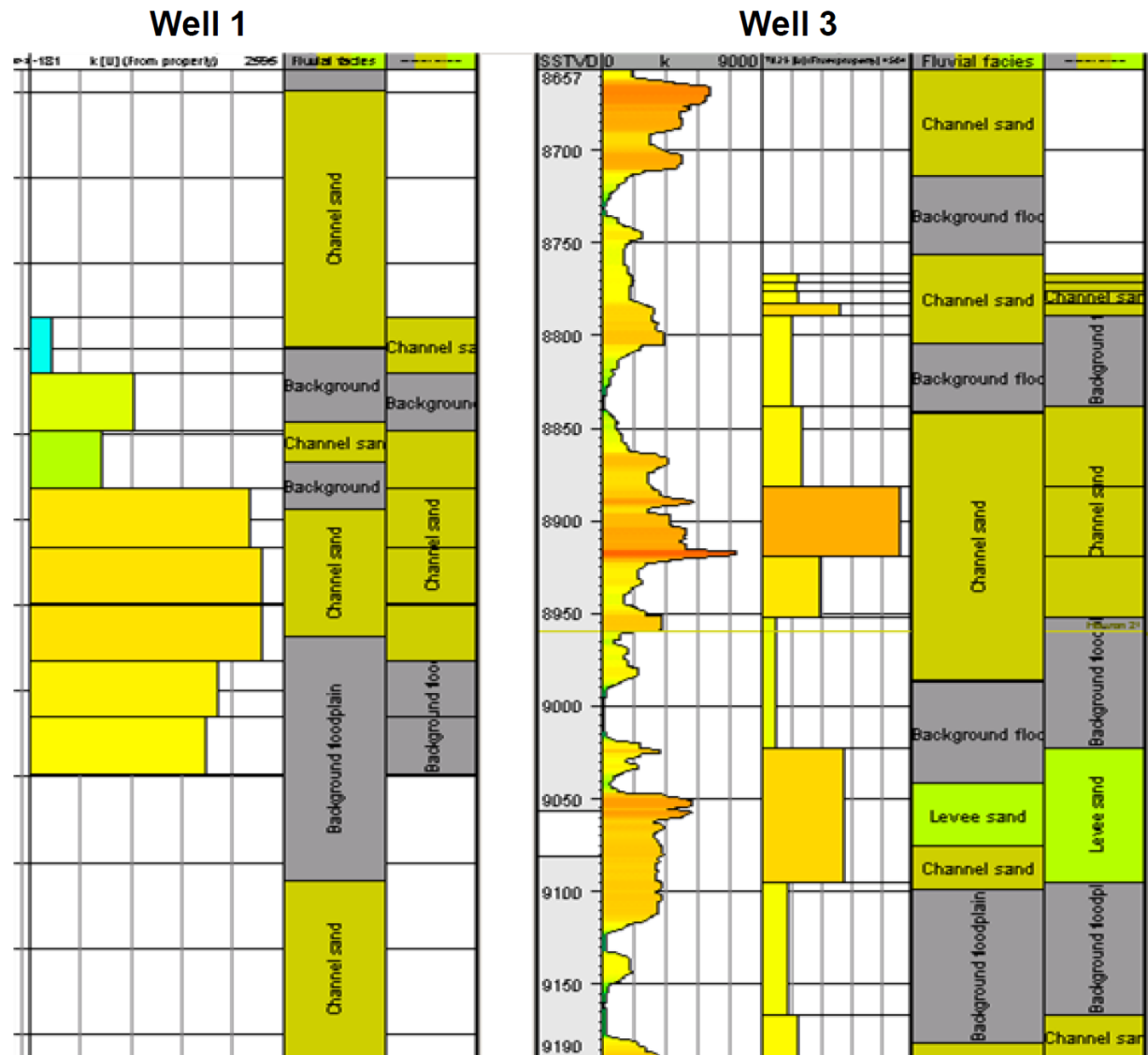
Figure 3. Upscaled logs of wells 1 and 3.
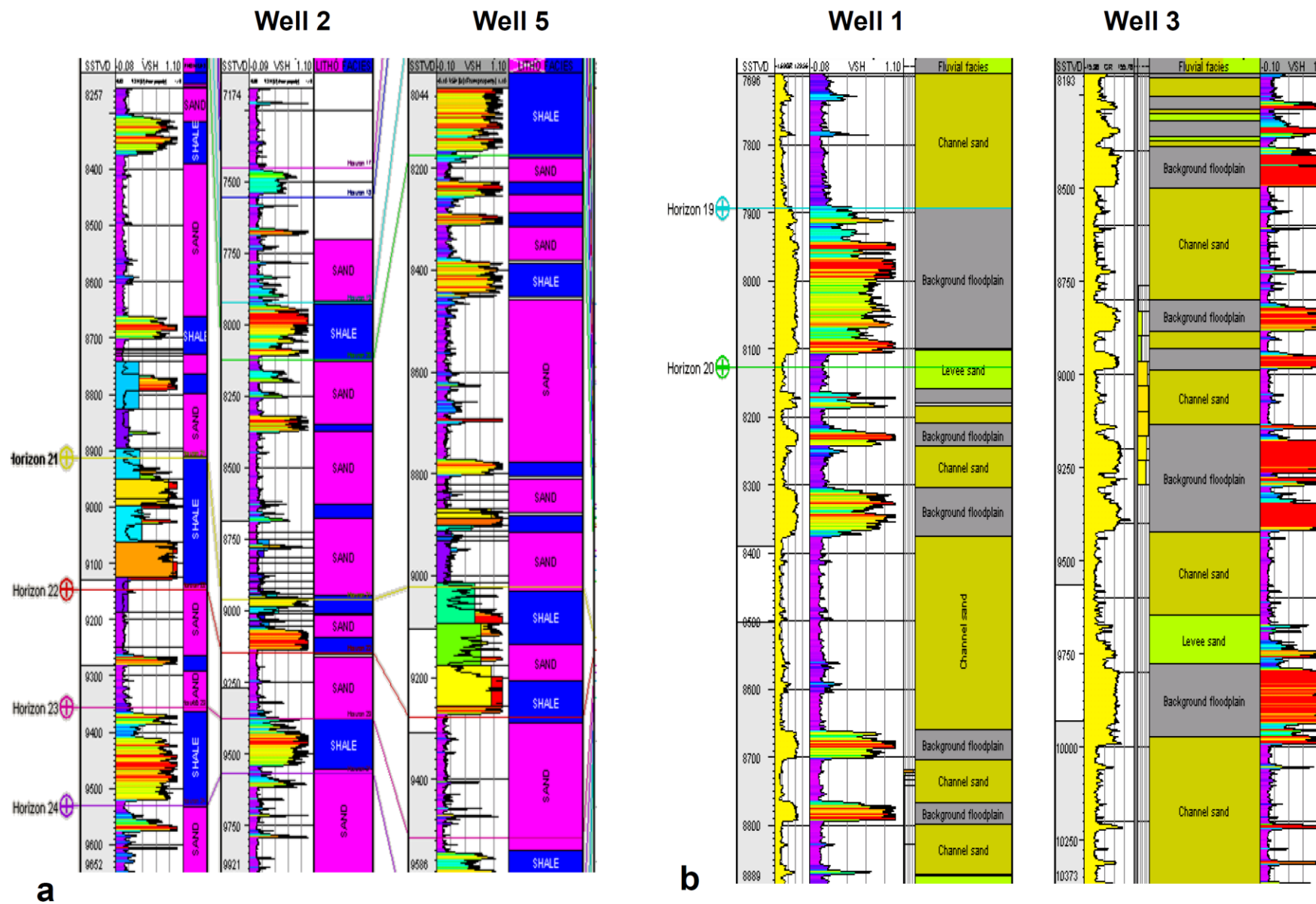
Figure 4. Interpreted facies: (a) lithofacies and (b) fluvial facies.
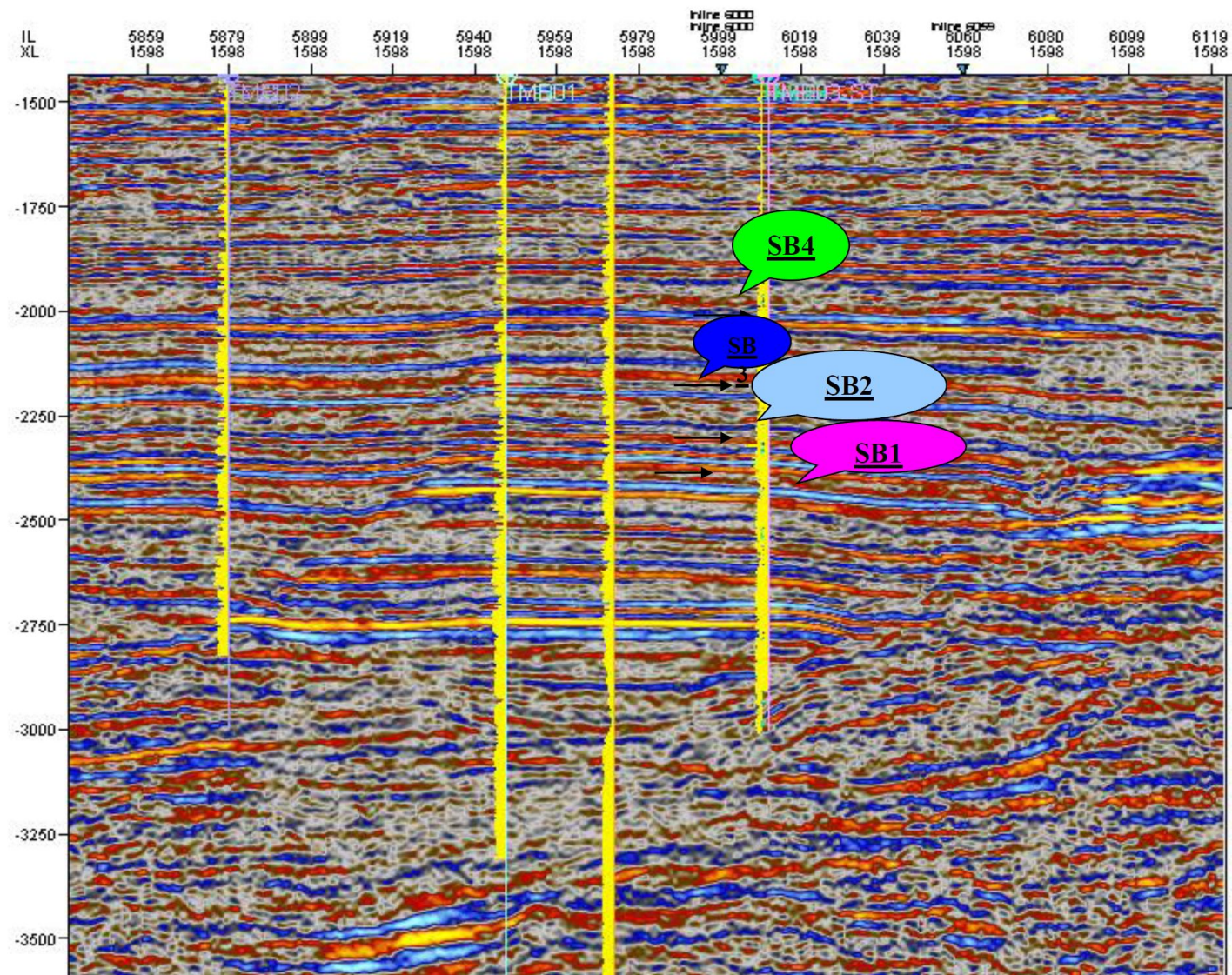
Figure 5. Sequence boundaries identified in the Tb-Field.
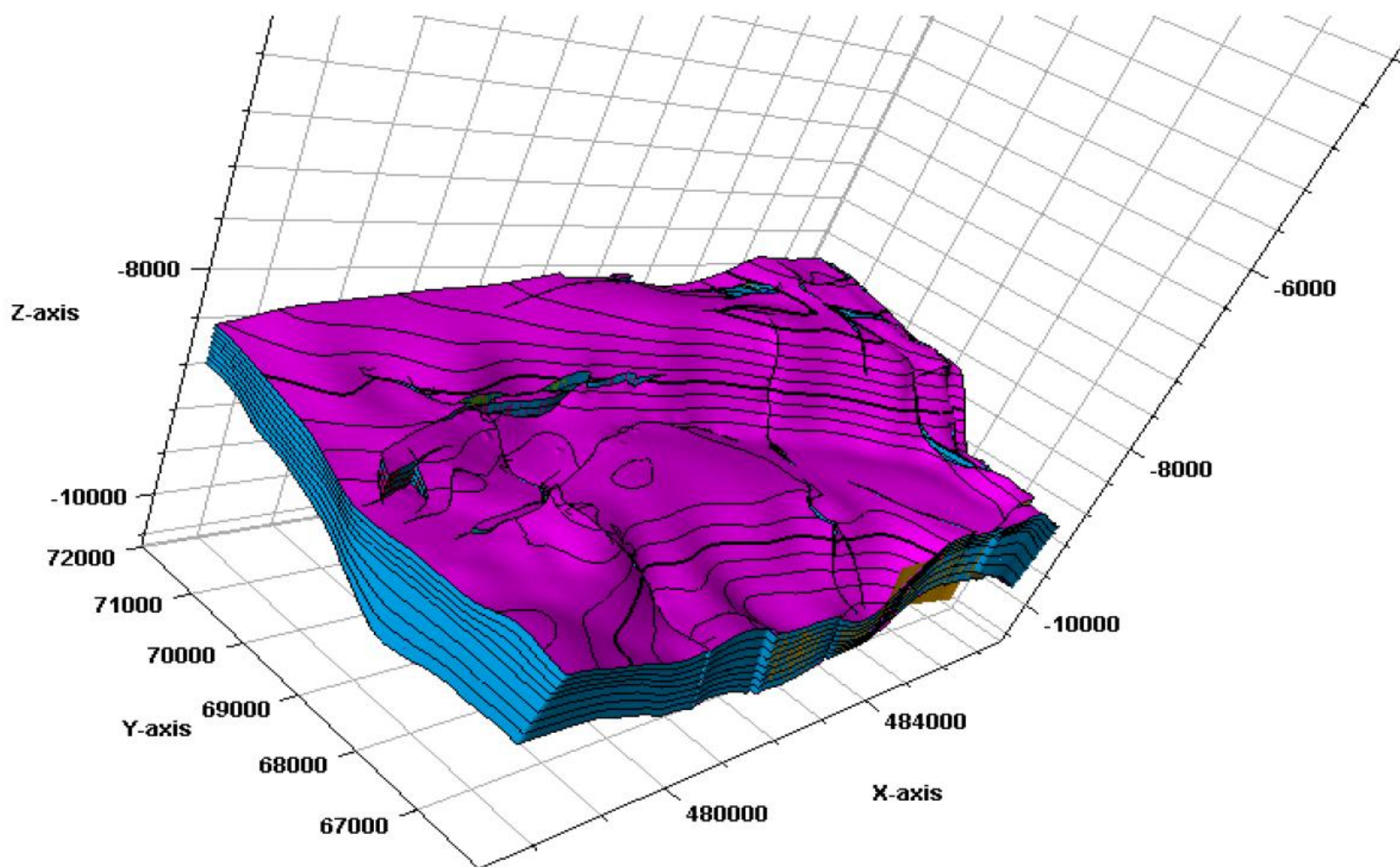
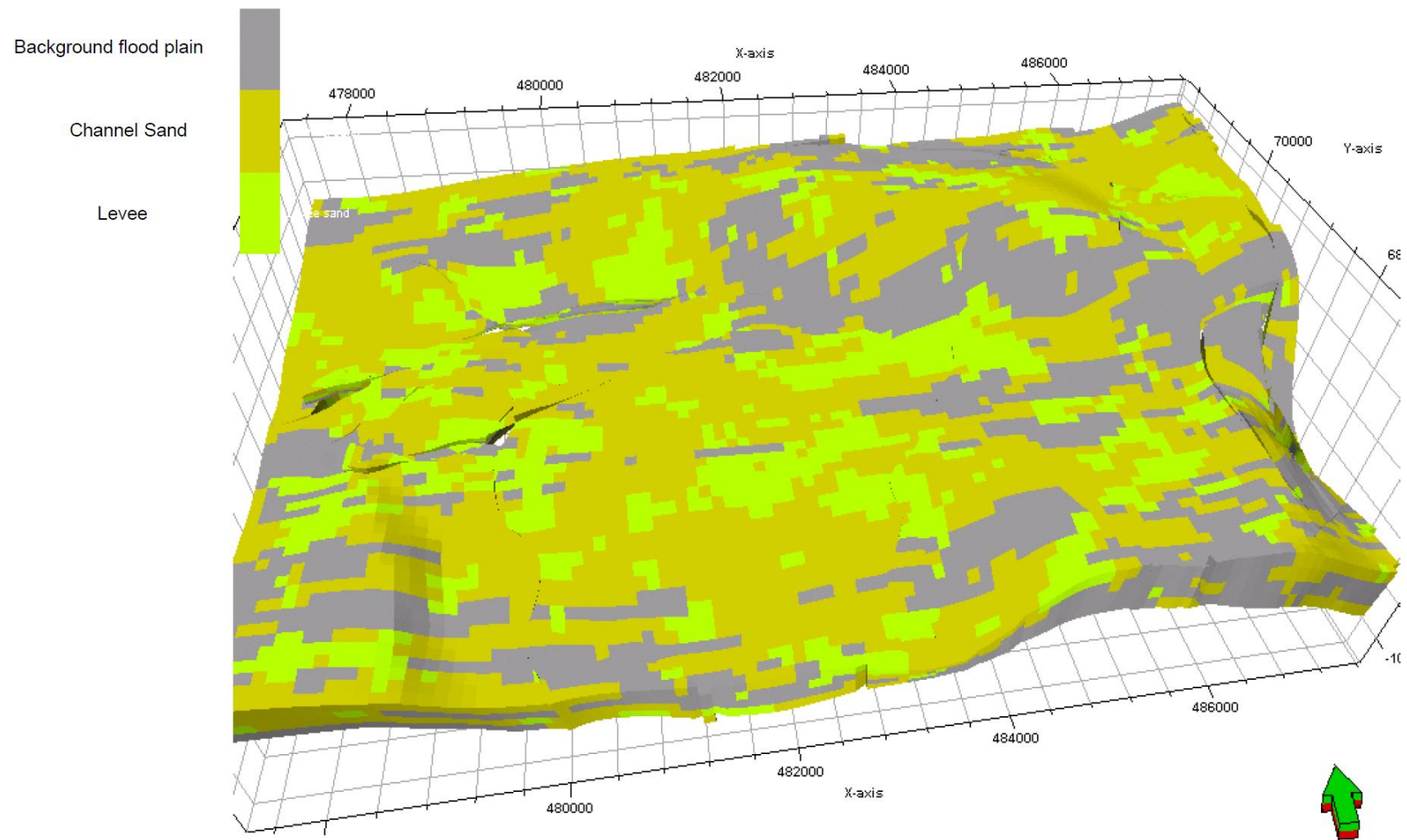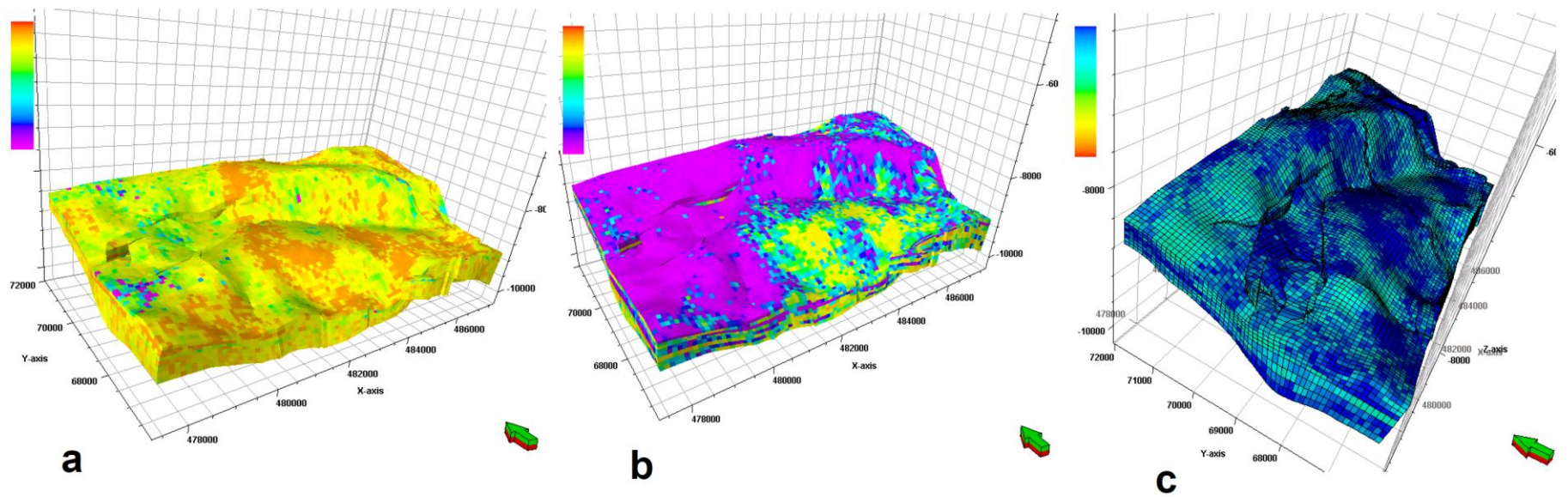Figure 6. Depth-converted 3D grid.

Figure 7. Fluvial facies model.

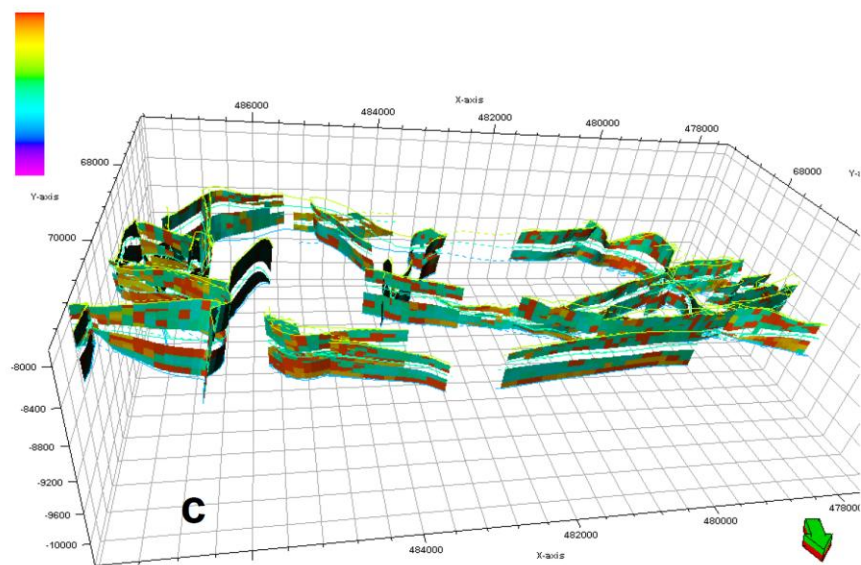Figure 8. a. Permeability, b. volume of shale, and c. water saturation models.
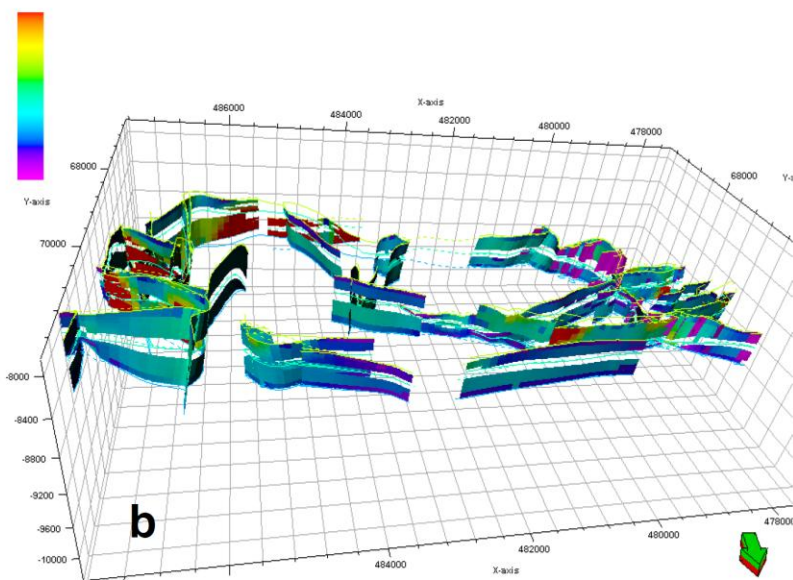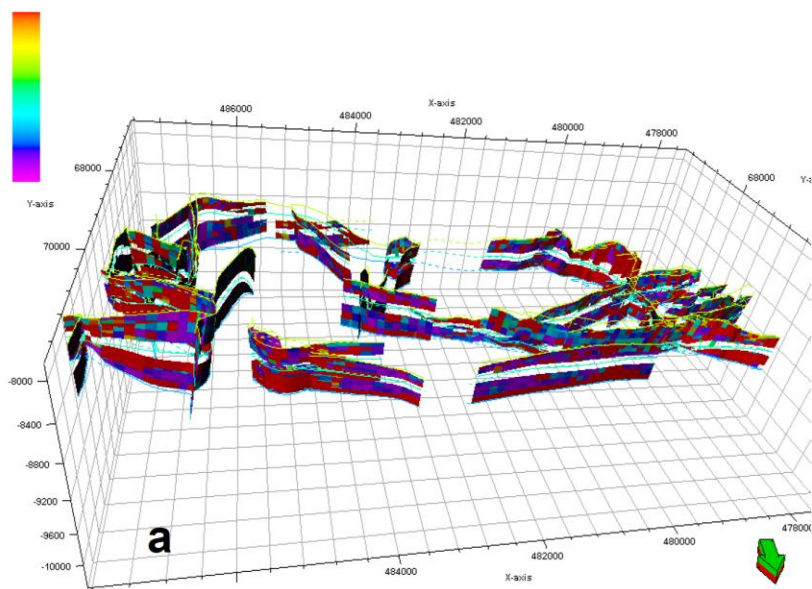
Figure 9. a.Transmissibility multiplier, b. fault displacement, and c. fault permeability models.