Handling Complex Stratigraphic Relationships Using Volume Based Modeling and Stair-Step Grids*

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Abstract

Traditional Corner Point Gridding (CPG) methods have limitations when dealing with very complex structural geometries resulting in distorted cells. The lack of cell orthogonality can lead to issues like convergence complications during the simulation stage. The challenge of the study was to model a complex carbonate's geology in a three-dimensional reservoir model representative enough of the reservoir's behavior and connectivity. For that purpose, the CPG methods were not appropriate and resulted in a simplified 3D grid with a large number of distorted cells which lead to problems during the simulation stage. The main objectives of this study were: (1) to build a structural 3D grid capturing both the structural and the stratigraphic complexities of a naturally fractured carbonate field using Stair Step Gridding (SSG), (2) to reduce the time spent on building the structural grids compared to CPG method, (3) to preserve volumetrics, below 10% difference, between the original corner point grid and the new stair-step grid, and (4) to assure the most optimal grid to run dynamic simulations.

The implemented methodology involved input data conditioning which was the key to achieving a successful structural model. The "tepee" shape of the reservoir meant that the fault modeling step was crucial for the boundary definition in order to create a watertight model constrained by the horizons within the structure. In addition, due to the stratigraphic complexity of the area, a logical stratigraphic relationship and proper horizons type definition were mandatory to be handled by the modeling algorithm. The final structural model was used as input to build a three dimensional stair-step grid ready for property population. Results showed that stair-step grids reduce the cell distortion and capture the structural and stratigraphic complexities. The good orthogonality of the final 3D grid reduces the run-time of dynamic simulations.

Introduction

The Western Mediterranean Area, offshore Spain, shows a complex set of sub-basins which comprise several rifting events during the late Oligocene and early Miocene (Navarro, 1997). A Mesozoic paleorelief fossilized by the Miocene defines the main structural NE/SW trend bounded by faults. In this area, the thickness of the Lower Miocene reservoir is not homogeneous and varies from 100 m down to 0 m. The thickest Miocene sediment column is found between culminations (or erosive depressions) where the accommodation space is greatest. The field studied is comprised of a SSW-NNE trending high of Cretaceous limestones in the hanging wall of a system of low-angle faults, with at least three distinct closures along strike. The northernmost and southernmost culminations have been drilled and are currently in production. Cretaceous beds are mostly tilted to the SE or NW and bounded at top and to the sides by erosional truncations and gravitational collapse surfaces. To reproduce this geological reality within a 3D model is quite complex. The final aim of this static model is to provide an input for simulation which will be used to predict the reservoir behavior under the current production scenario.

Technically, within a grid, the lack of cell orthogonality leads to issues of convergence and errors in the calculation of the fluid flow during the simulation stage (Aziz, 1993). Fault truncations (Figure 1) in Y, X and λ shapes, make the modeling process a challenge together with the carbonate deposit configurations in individual patches. In order to overcome these concerns, geo-modelers might have to simplify the structural interpretations trying to avoid cells distortion as much as possible. This simplification could restrict the ability to represent the key stratigraphic features (Branets et al., 2015). Also, the size and detail of the model depends heavily on the maturity (exploration, appraisal, development stages) of the reservoir (Iske et al., 2000). All the 3D models are a simplified view of the reality depending on: the scale of study, the quantity and quality of available information, and the computing limitations (Caumon et al., 2009; Thom and Höcker 2009). Comparing between gridding methods, the implementation of the SSG allowed the modeling of a complex structural and stratigraphic setting, assuring the proper three dimensional cell configurations. All types of faults can be represented and cells are less likely to be distorted, and orthogonality can be ensured using this type of grid (Gringartem et al., 2009).

Geological Setting

The field is located in the Tarragona sub-basin of the Valencia trough geological province. The study area is a structural high of five kilometers long and less that one kilometer wide divided into several minor structures. The Mesozoic paleorelief fossilized by the Miocene defines the main structural NE/SW trend bounded by faults. This trend is consistent with main productive structures in the area and it seems to be a regional trend.

The key events in the structural history of these Western Mediterranean fields are the uplift and faulting in the Late Cretaceous and early Tertiary together with the mid-tertiary collapse of the Gulf of Valencia (Bartrina et al., 1992). The basal Tertiary events are important because the basic structural outline of the Field was formed at this time and the Mesozoic carbonates were eroded and karstified. Following the Mid-Tertiary collapse of the Gulf of Valencia, the carbonates were buried beneath the Miocene and Pliocene shales preserving the trap.

Two reservoir rocks are present in the studied field, the basal Tertiary (generic BTG o basal tertiary group) and the Mesozoic limestones. The BTG (Base Tertiary Group) is a Lower Miocene age unit comprising dolo-sandstone and conglomerates, locally highly diagenetized (hydrothermally). This unit unconformably overlies Cretaceous limestones and marls. Both units are intensely fractured and affected by hydrothermalism and karstification (mostly in the Cretaceous).

The BTG (term proposed by Repsol in early 1993) (Maili et al., 2013) are mixed marine-clastic sediments which group different age lithologies from Oligocene to basal Miocene. The presence of coral relicts has been identified in this formation. The reefal depositional facies appear in some Mesozoic highs where the paleoenvironment was optimal (water level, position from the source, etc.) at the time of sedimentation. The conglomeratic materials are filling some of the semi-basins between culminations. The properties and amount of infill (materials from outer ramp and from erosion) depend on inclination and time of exposure, among some factors.

Methodology and Results

The main objective of this study is to illustrate the structural modeling workflow using the VBM method, applied to the study area. The methodology and obtained results were as follows:

A. Preparation of Input Data

Prior to model construction, the horizon interpretations had to be edited to avoid wrong-sided data that could lead to undesired extrapolations. The Volume Based Modeling (VBM) algorithm for horizon modeling is sensitive to “wrong sided” data which is input data present out of the boundaries of the desired geological model. If “wrong sided” data is not deleted, the model will be extrapolated out of the boundaries. As the limits for the model were defined by the faults, after the fault framework was generated, the horizon interpretations were deleted outside the fault framework extent (Figure 2).

B. Fault Framework

The fault framework process displays the faults on a grid and creates relationships between connected faults. The fault framework can be quickly updated with data from the new wells, reducing geomodeling cycle time and keeping the model “evergreen” (Maili et al., 2013). The resulting fault framework is shown in Figure 3.

C. Boundary Definition

The boundary definition is a key step during the creation of the structural framework, as it is crucial to define watertight models to avoid undesired extrapolations (Nuñez, 2015). The process is used to define the geometry of the new structural framework by specifying its coverage, the X-Y resolution, and the vertical limits (time or depth). In this case, the desired lateral extension of the model was determined by the two main SW-NE trend faults and by two smaller NW-SW faults. In order to avoid the extrapolation of the data outside these limits a watertight model was necessary. For that purpose and, after the fault framework was built, two surfaces with constant depths were generated in order to visualize the Z extents of the model. The Z values assigned to the surfaces were just above the shallowest point of the top of the model and just below the deepest point of the base (Figure 4).

When the fault framework was displayed along with the surfaces corresponding to the shallowest and deepest z extents values of the structural framework, there were some gaps present (Figure 5), these gaps would lead to extrapolation of the zones outside the fault boundaries during the Horizon Modeling process.

In order to eliminate these gaps, the fault extrapolation distance was increased to make a watertight model. Figure 6 shows all the faults that define the model limits crossing the top and base surfaces (Z extents) to make the gaps disappear. Also, and in order to constrain the extension of some horizons within the model, some faults were extrapolated to cut the top and base limits and create isolated compartments within the model itself (Figure 6).

D. Horizon Modeling

VBM is an algorithm for creating horizons in Structural Framework models. In VBM, input data (faults/horizons) are used to create a background tetrahedral mesh which represents the Volume of interest (VOI) of the model (10). An iso-stratigraphic function is calculated on to this to represent all of the input data stratigraphy in the model; this property field is calculated from a watertight representation of the fault network and horizon input data (10). This property defines interval boundaries which represent the iso-stratigraphic ages of these intervals with the oldest at the base and the youngest at the top.

The construction of this iso-stratigraphic property field is continuous across the entire structural framework and discontinuous across faults. It is designed to minimize dip and thickness variations while accounting for all input data (Souche et al., 2013). Once this calculation is completed, iso-surfaces of the attribute corresponding to the location of the original input data points are extracted as horizons in the structural framework and a zone model is computed. This yields a volume representation of geological layers. In the Horizon modeling process, it is very important to place the input data in the correct stratigraphic order and define the horizon types to handle the stratigraphic relationships.

The fault filtering distance for each fault side and for every horizon needs to be defined. The filtered data will not be taken into account as input when running the modeling process. For this model the default filtering distance of 50 meters was lowered to 5 meters and modified for some specific faults and horizons according to the results of the horizon modeling runs.

Based on the way that VBM works, some additional control points can be used when the extrapolation of some horizons cannot be controlled. The reason for this is that VBM extrapolation is guided by dip and thickness constraints so, where there is no input data, the algorithm will tend to continue the dip and thickness trends from areas where the input data is present. In order to change the extrapolation trends, some control points also called “In the air” interpretation are needed (Nuñez, 2015). A longitudinal cross section of the final structural framework is show in Figure 7.

E. Structural Gridding

The structural gridding process allows the quick and efficient generation of stair-stepped grids without the need to use the pillar gridding workflow. This process uses as input the structural framework generated in the previous step. The structural grid built using this workflow avoided the shortcomings and limitations of the pillar gridding approach when dealing with the complex stratigraphic relationships of the area (Figure 8).

After the creation of the 3D structural grid it is important to do a QC before populating it with properties.

A very useful property to use is the cell angle that can be used to identify non-orthogonal cells. The values calculated are angles representing the maximum deviation from 90 degrees at each corner. As a rule of thumb, values less than 15 are suitable for simulation; higher values can also be acceptable but they might cause problems during simulation. Other properties such as Cell Volume and Cell inside out are useful to detect cells with negative volumes that can impact volume calculations and simulation, and to detect extremely distorted cells.

The statistics of the calculated properties showed that the grid was suitable for simulation as 95.3% of the cells had an angle lower than 15^0 and 99.3 % lower than 25^0 (44^0 being the maximum). This was an important enhancement when compared to the initial pillar grid model where more than 70% of the cells presented an angle higher than 15^0 and the maximum angle was 75^0 . Also, no inside out and negative volume cells were present. Volumetric calculations in the 3D grid resulted in a difference of less than 2% when compared with the original corner point grid.

Discussion

The preparation of the input data was a crucial step for this study, as non-cleaned horizons are used by the VBM algorithm, as wrong-sided data when having a compartmentalized model. For the case study the preparation of the input horizons together with the fault filtering distance were important to avoid extrapolation inside the compartments of the models and out of the model area. Due to the fault angles (not vertical faults) and the fault network, the fault framework was simplified in the original corner point grid, but with the stair-step grid the angles and the relationship between the faults were honored.

The boundary definition was a key step of the workflow to avoid the extrapolation of the modeled horizons and zones out of the boundaries defined by the fault framework (Figure 9). The use of z-values to constrain the vertical size and the input horizons restricted only to the area of interest were crucial for the creation of the model inside of the volume of interest.

The density or resolution of the mesh is crucial when building the 3D grid, as an excessively dense model is inefficient to be visualized and processed, also very coarse models could be too rigid to account for complex 3D geometries. So, it is important to find the minimal resolution needed to reflect the geometric complexity of the structures.

For the horizon modeling the use of control points was needed in order to avoid extrapolation due to the way the algorithm works. Also the accurate definition of the horizon type was crucial when building the horizon model.

One cause of data misfit was the grid resolution, being too small at the beginning. Once the adequate size was found the hard data (well markers) was honored 100%. The seismic interpretation was highly honored based on the grid cell size.

Finally, after converting the structural framework to a structural grid, a QC of the grid showed a lot of improvements related to cell distortion, with a reduction of distorted cells by 94% which will improve the dynamic simulation. Based on the experience of this case study, the ideal workflow to follow when building a 3D grid is to start with the fault framework to compartmentalize the study area into fault blocks, then the stratigraphic horizons are created following stratigraphic rules.

Conclusions

From this technical evaluation using Structural Framework and Structural Gridding, it was proved that the stratigraphic and structural complexities of the area could be handled by stair-step grids. One of the key tasks during the project was the QC and editing of the input data, which showed the importance to have, as much as possible, clean input data to ensure a good result. Another important aspect to take into account when starting a model is to understand the geological framework to be able to adjust the input data based on the tool capabilities.

The results showed a good match between the final model and the input data. Some QC properties were calculated showing a huge improvement compared to the old model, reducing by 94% the number of cells with distorted angles higher than 15^0 , which improved the simulation process.

Finally, bulk volumetrics showed a similar value to the old model, with a difference of less than 2% in comparison with the corner point grid model. Results show that the Structural Framework and Structural Gridding processes helped to create a model ready for simulation while honoring the input data, solving the stratigraphic relationships found in the area, and modeling the faults keeping the dip and azimuth from the seismic interpretation. This case study demonstrates the importance of selecting the appropriate grid type based on the specific geological framework.

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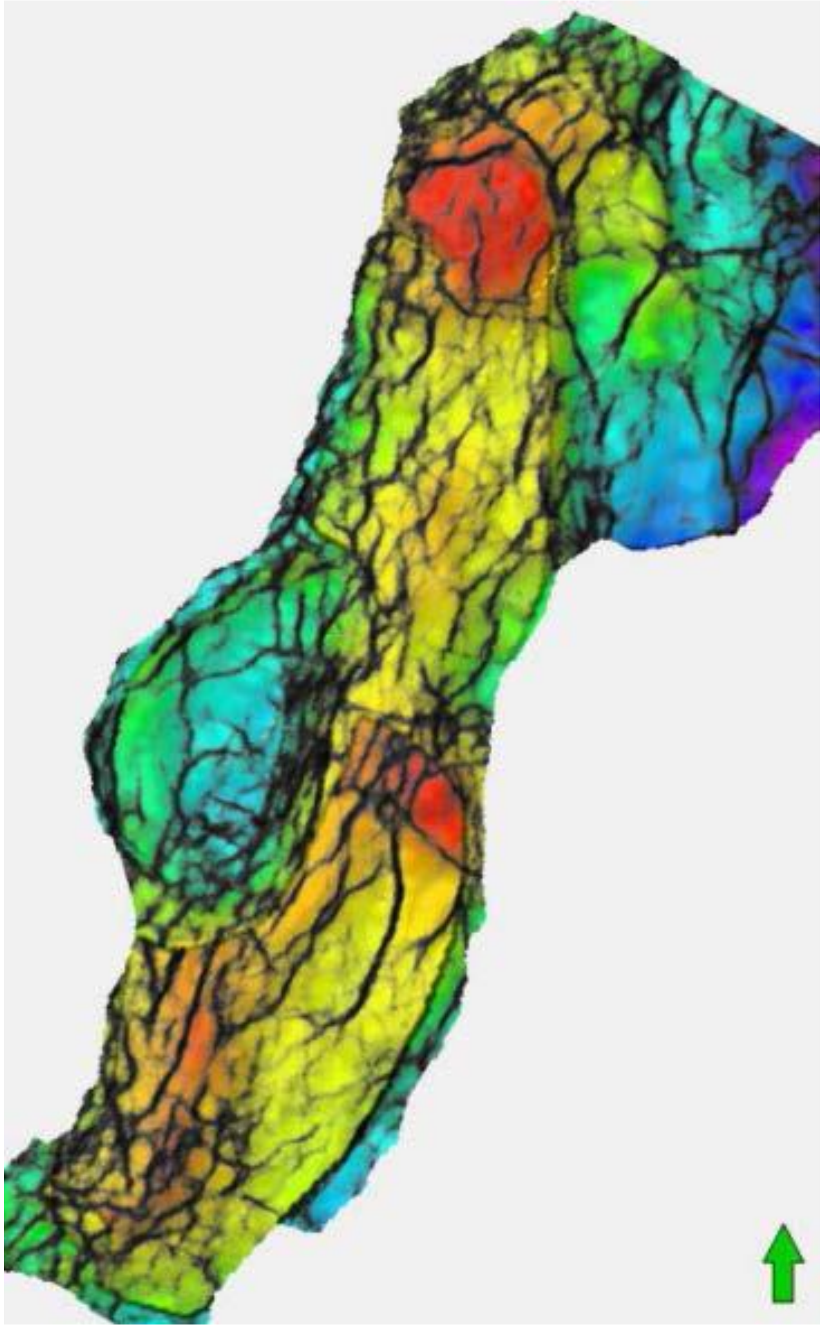

Figure 1. Top reservoir fault extraction from seismic enhancement.

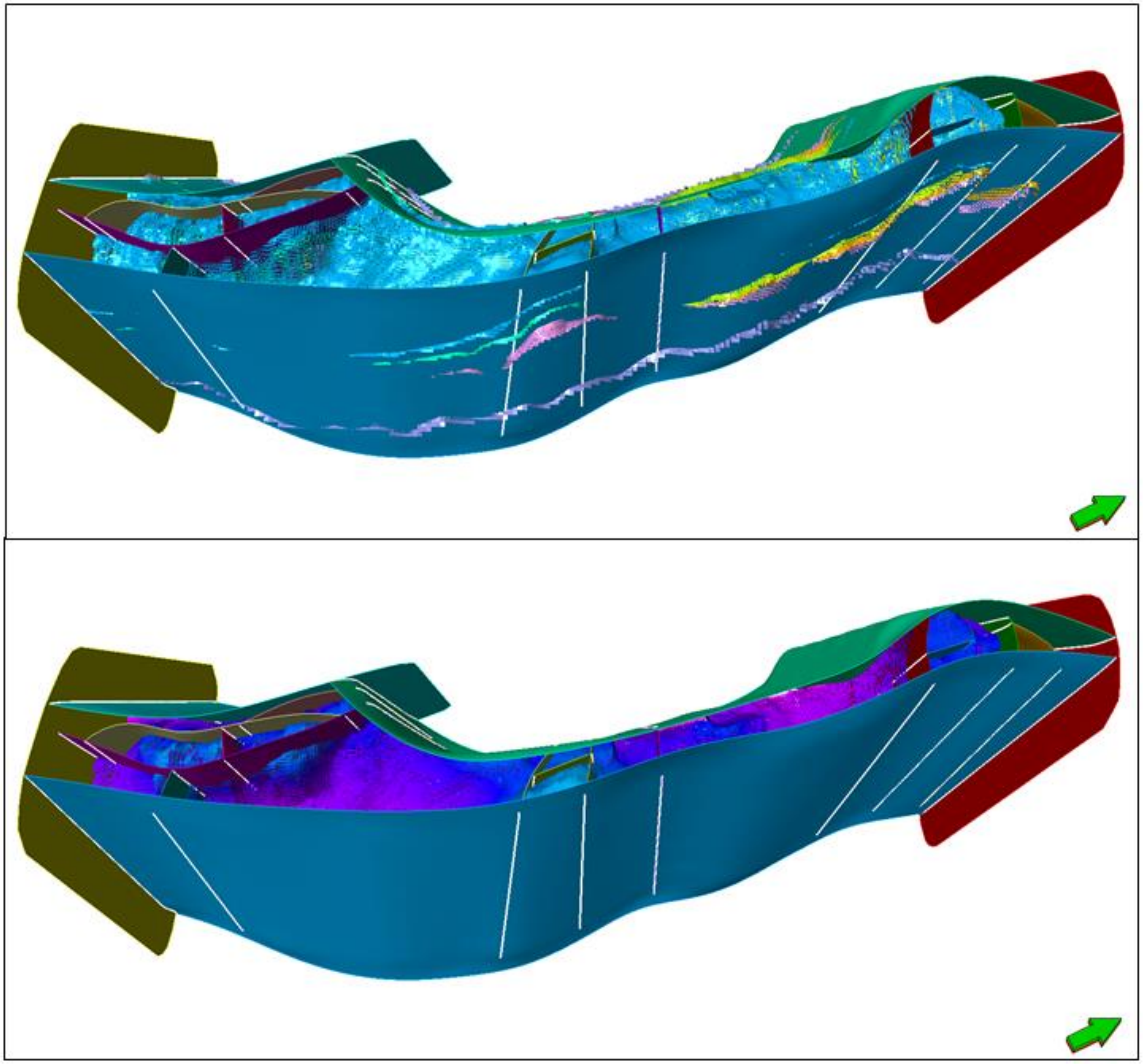

Figure 2. Original interpreted horizons (above), and cleaned horizons with no “wrong sided” data (below).

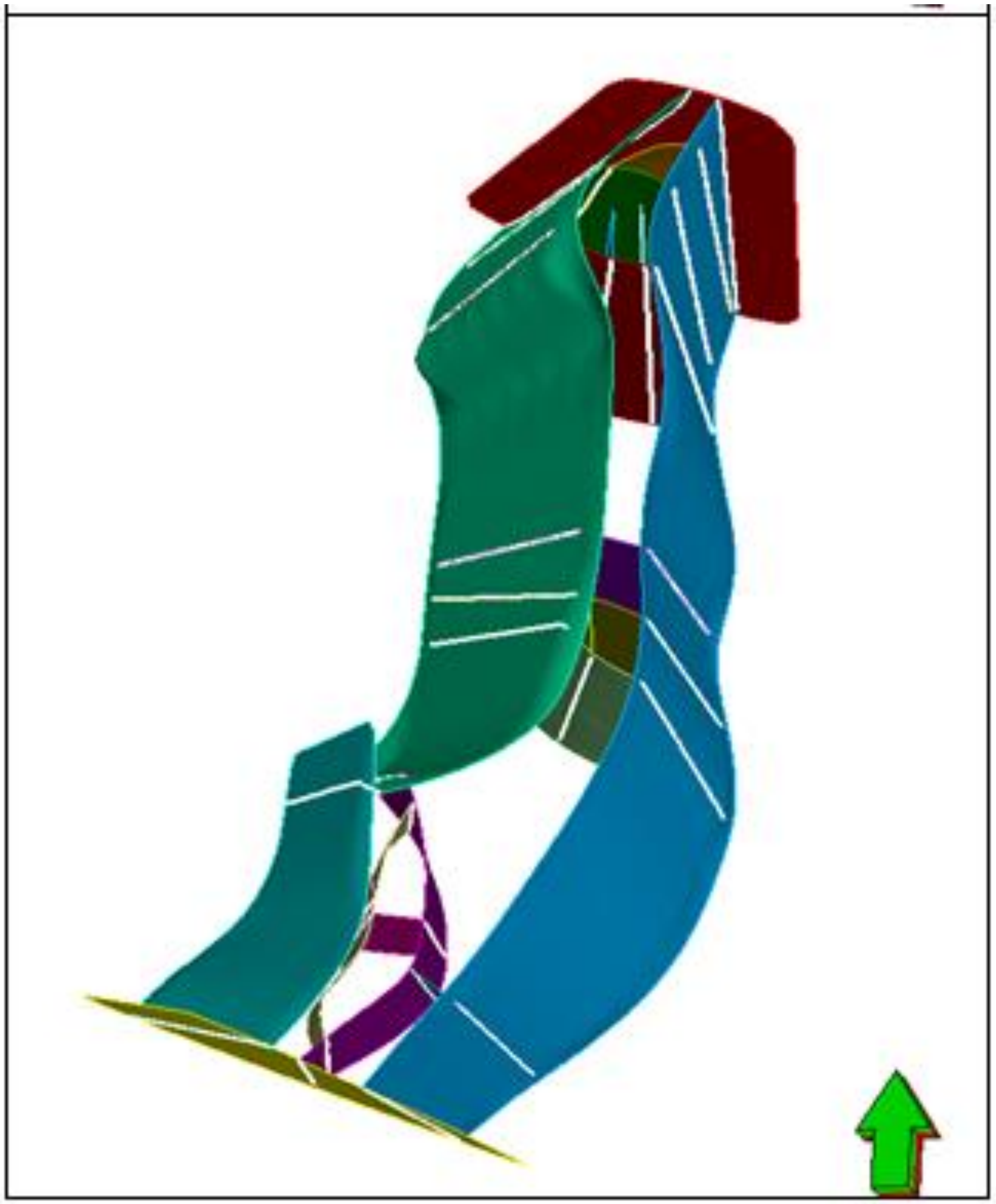

Figure 3. Final fault framework.

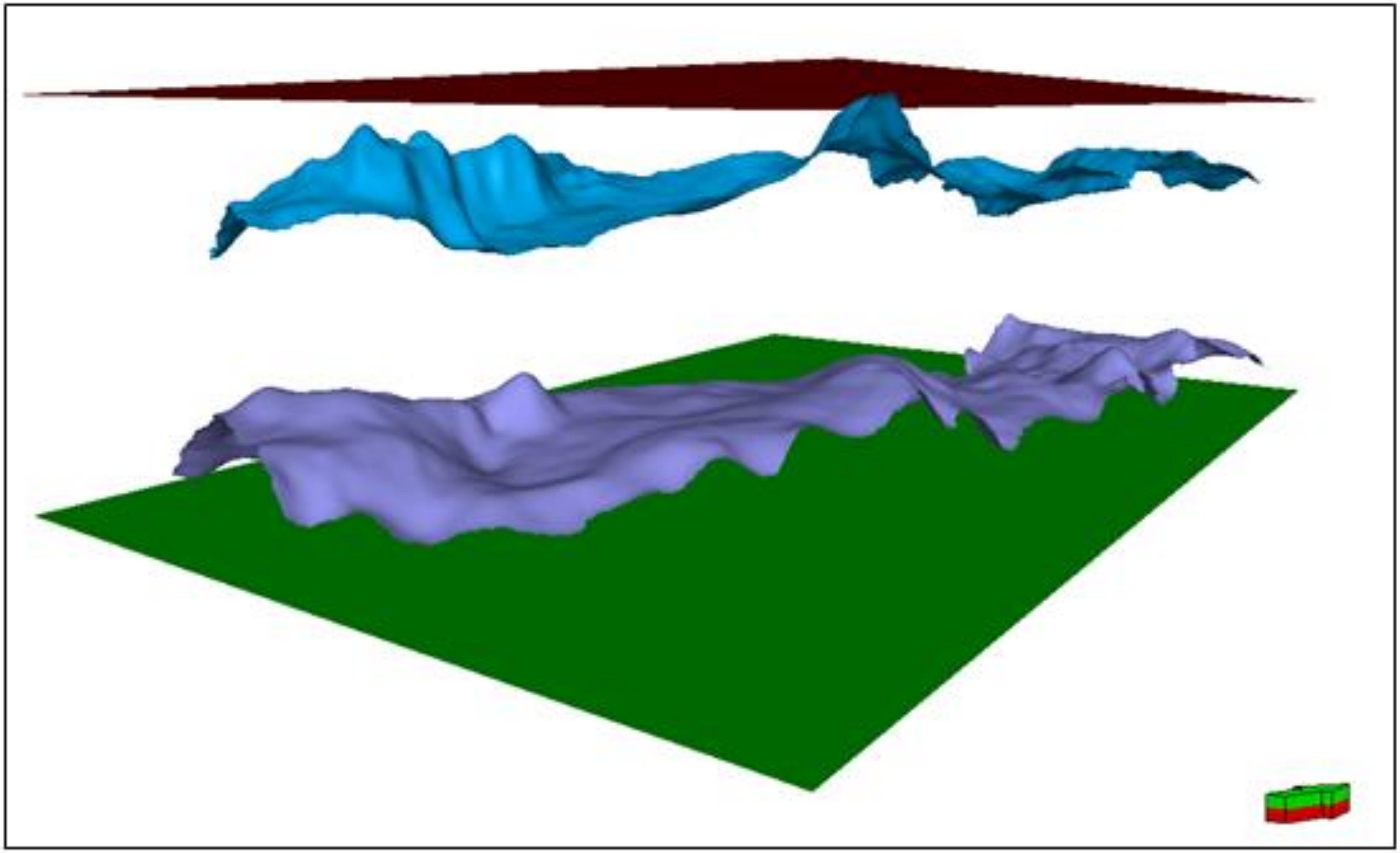

Figure 4. Reference flat surfaces representing the vertical limits of the structural framework.

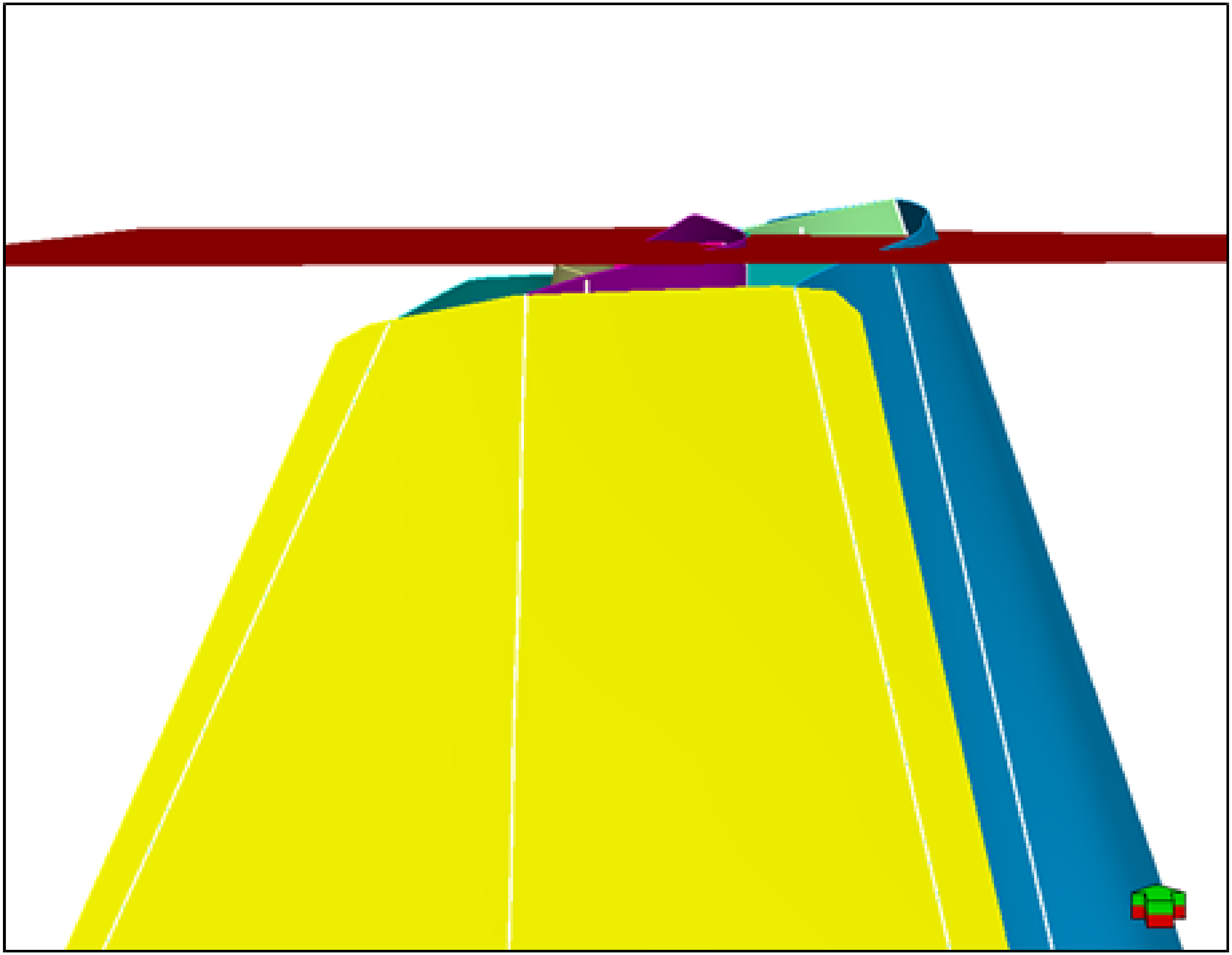

Figure 5.Void space between the fault framework and the vertical limits of the model.

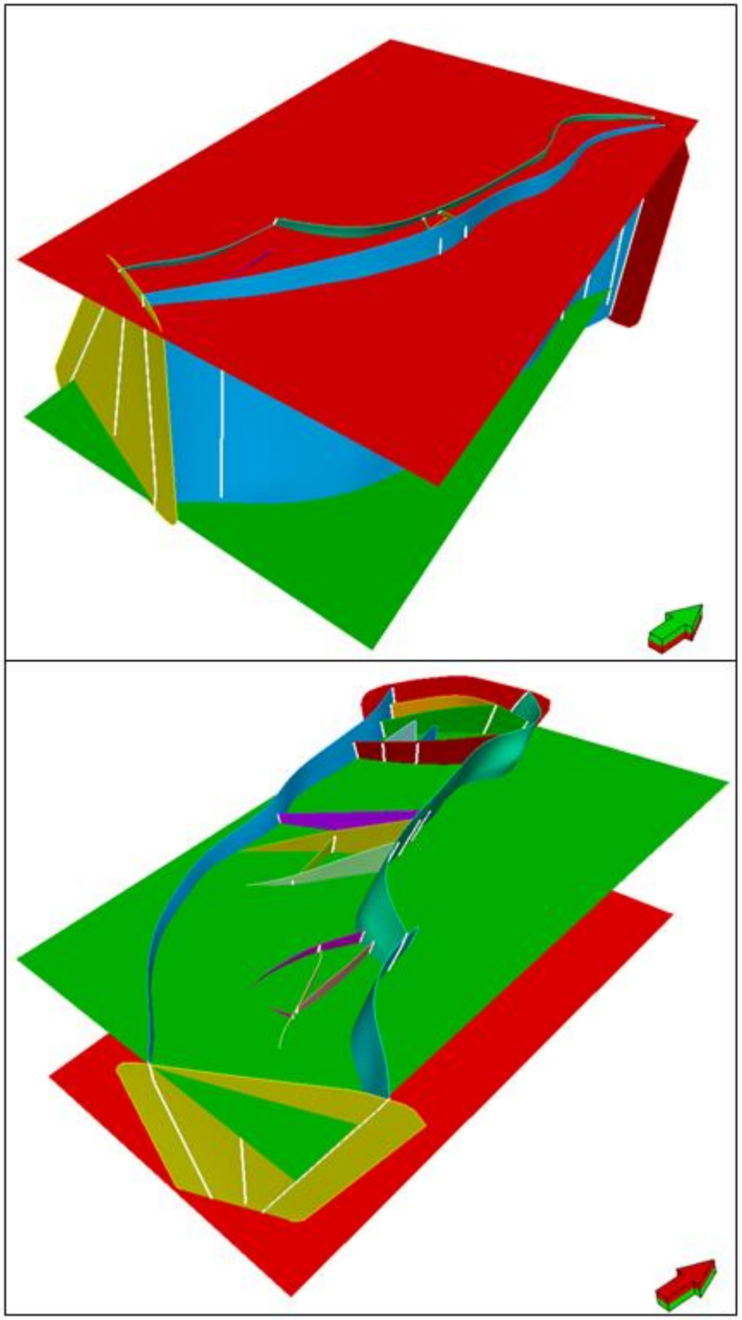

Figure 6. Faults crossing the vertical limits of the model after increasing the extrapolation distance.

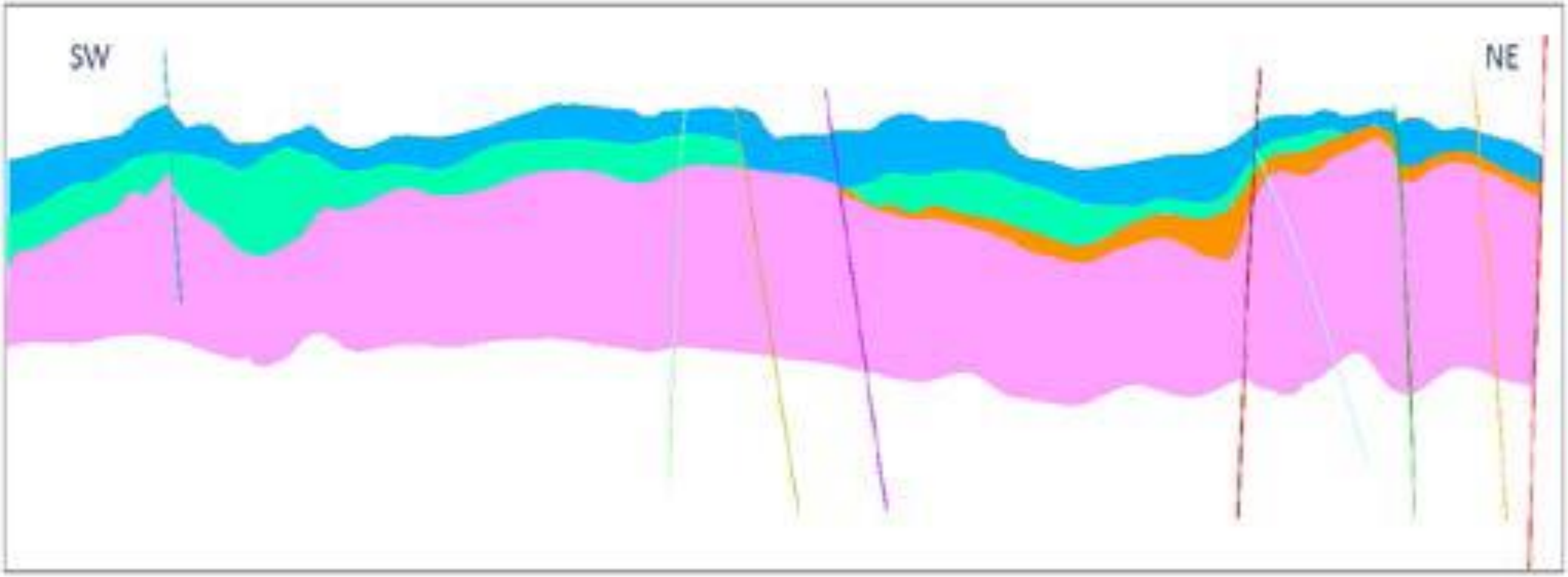

Figure 7. Cross section of the final structural framework.

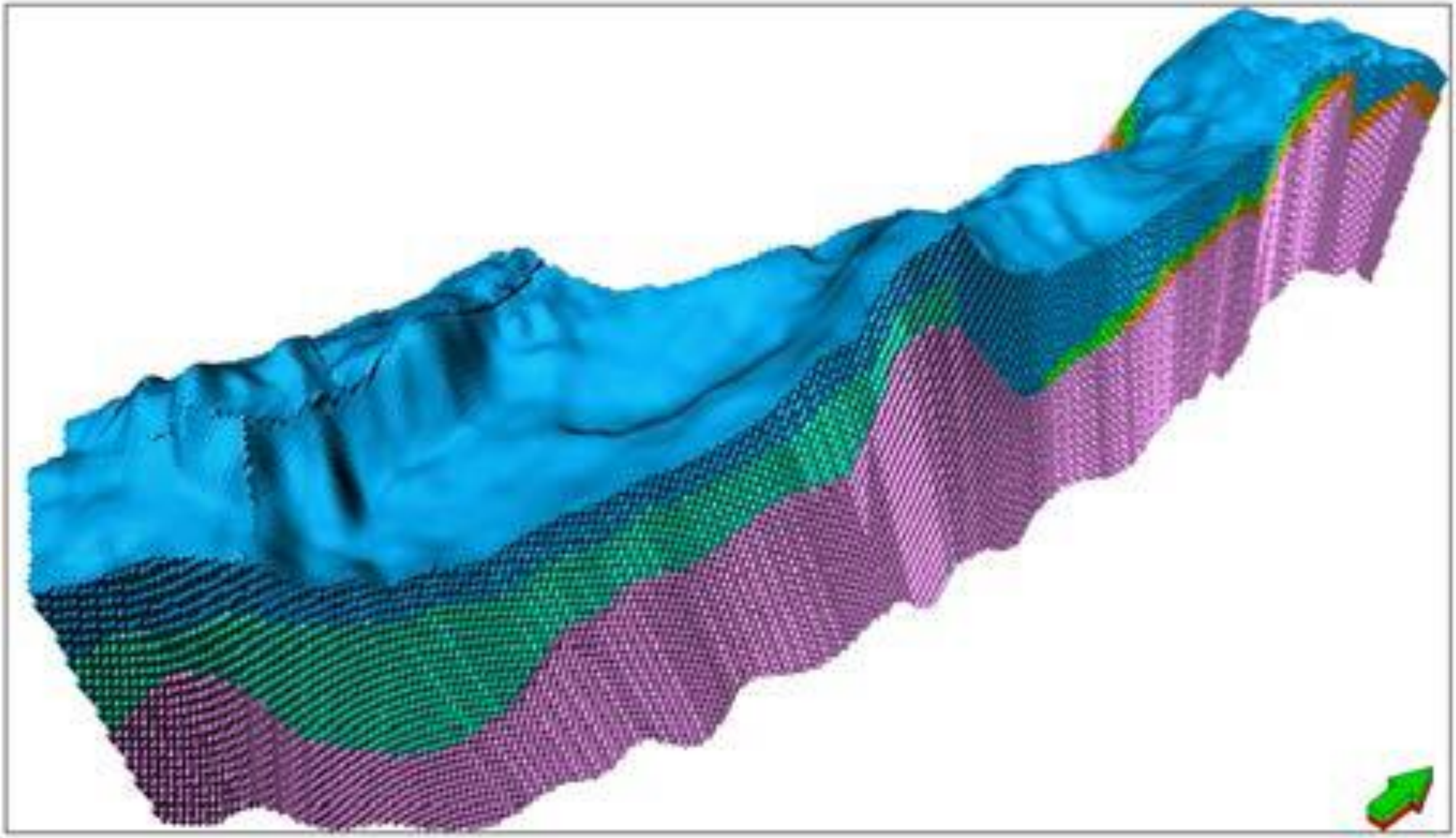

Figure 8. Final 3D stair-step grid.

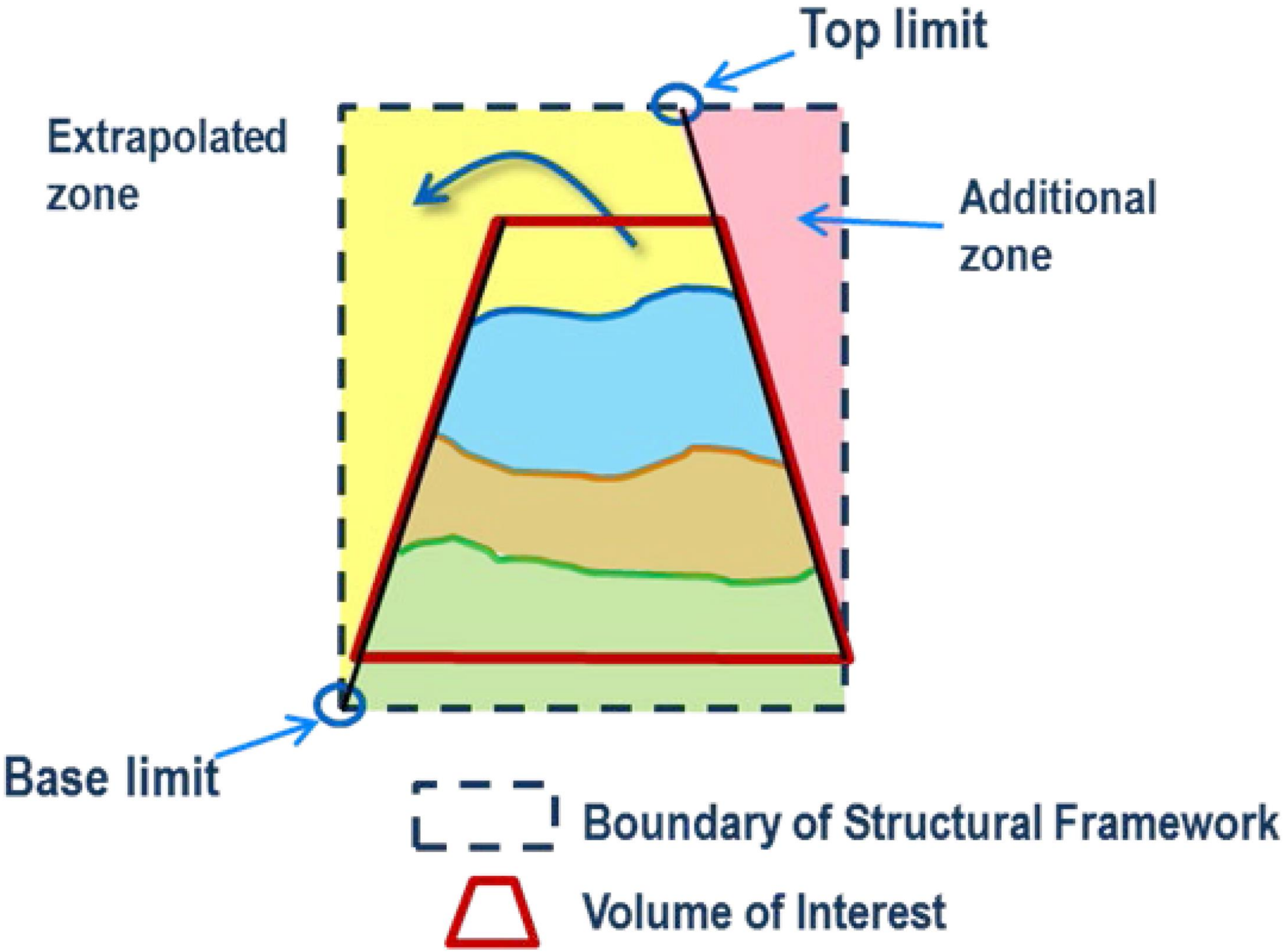

Figure 9. Example of found issues when defining the boundary.