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# *3D and 2D Stratigraphic Modelling of Carbonate Formations : The Case of Songololo Limestone and its Surroundings*

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## *Abstract*

*Nowadays to visualize the geological model of layers, there are several methods. Those methods are sometimes indirect such as geophysical survey and others are direct such as drill holes survey. This study is focus on direct method using 13 bored holes assessment drilled by Nyumba ya Akiba for Cimenterie Kongo (CIMKO). Cimenterie Kongo (CIMKO) plant mines carbonate rock for cement production. The technology progress set software to design the field reality and make best understanding of it. To study carbonates deposits such as limestone we use some principles of stratigraphy and analysis sequence. Carbonates rocks are sedimentary rocks with dip and direction also cyclicity of layers. The present article consists in creating cross-sections to visualize different types of lithofacies of carbonate formations and analyze the layout contact based on litho-stratigraphy principles using 3D models to visualize their contacts underground.*

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## Introduction

The Songololo area in the Central Kongo Province of the Democratic Republic of the Congo consists of carbonate rock formations covered by thick layers of weathering. Mining survey data constitute an important source of geological information. In a range of applications involving geological modeling, the low-cost geological data available generally consist of documents such as cross-sections or geological maps and point data such as borehole logs or outcrop descriptions [1]. The description of drill cores from the limestone quarry at the Cimenterie Kongo plant serves as the source of geological information for this study. Sedimentary modeling, which focuses on the geological system comprising sedimentation, transport, and erosion of sediments, can adopt two perspectives: the study of the arrangement of sedimentary units (stratigraphic modeling) and that of the nature and distribution of sediments. Sedimentary models can also be distinguished based on their use, which depends on the scale of the study area and the maturity stage of the exploration/production project [2]. The use of Stratigraphic modeling for different lithofacies allows us to visualize the layers at depth and highlight the shape of the contact between them.

## Methods

### Study Area

The study area is located in the western part of the Democratic Republic of the Congo, approximately 220 km from the city of Kinshasa [3]. It straddles the Kimpese and Luima sectors in the Songololo Territory, in the Province of Kongo Central (Figure 01). It is bounded by 15° 5' 00'' and 15° 25' 00'' east longitude and 5°0'00'' and 5°30'00'' south-latitude.

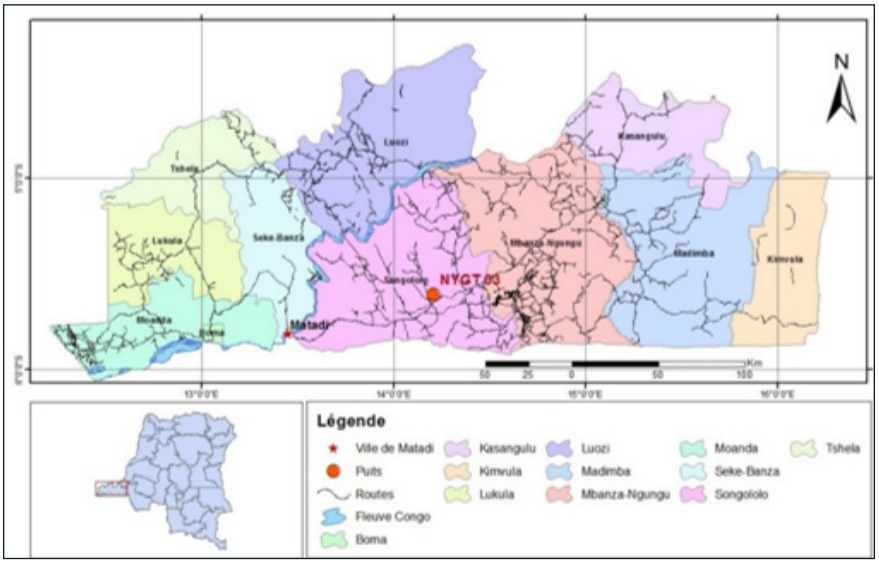



**Figure 1:** Map showing the location of the study area in Kongo Central Province

### Geological Context of the Area

The evolution of sequence stratigraphy involved advances in understanding of the array of possible controls on sequence development, improvements in stratigraphic resolution, revisions to the definition and classification of sequences, and ultimately the emergence of standard approach to methodology and nomenclature. The methodology is based on the observation of stratal stacking pattens in a manner that is independent of the is interpretation of the underlying controls. Beyond the purpose of the methodological workflow, the modeling and testing of possible control on sequence development can continue indefinitely after the construction of a sequence stratigraphic framework. Sequence stratigraphy is a type of stratigraphy that relies on stacking patterns for the definition, nomenclature, classification and correlation of stratal units and bounding surfaces. The method examines the stratigraphic cyclicity and the related changes in sedimentation regimes that ca be observed at the scales afforded by the resolution of the data avaible. Sequence stratigraphic units are bodies of sediment or sedimentary rocks defined by stratal stacking patterns and their bounding surfaces, and sequence stratigraphic are

stratigraphic contacts which mark changes in stratal stacking pattern [4]. The geology of our study area is best documented in the previous publication by Richard LOGRO SAPA titled: "Contribution to the Petrographic Study of Carbonate Rocks of the Kwilu Group in the West Congo Supergroup: The Case of the Songololo Limestone and Its Surroundings." This study, conducted on the wells of the Kongo Cement Plant, we note that the Kongo Cement Plant quarry extracts three limestone lithofacies, namely: greenish-gray limestone, light gray limestone, and dark gray limestone. The lithofacies in our study aera belong to the Neoproterozoic schist-limestone group within the Bulu and Luanza formations of the Kwilu Unit [5]. The superposition from the top to the bottom is LF1, then LF2 and ends with LF3.

## Equipment

All of the fieldwork we conducted focused primarily on the petrographic descriptions of the core samples. We used an Excel spreadsheet and a notebook to record the data and information collected from the core bins; we used a ruler to measure the thicknesses of the beds; the Garmin Map 64 GPS allowed us to locate the wells and create maps using GIS tools (ArcGis); the main layers direction was treated by Dips software and the stratification models of the layers were processed by creating cross sections using 2D Strater software. Finally, we create 3D model of different lithofacies on Leapfrog software.

## Methods

The exploration and mining phases of the CIMKO mine generated a significant amount of information about this deposit (Tab.1). This made it possible to create a database that was used in the models presented in this study [6]. The primary objective of 3D geological modeling is to generate accurate and comprehensive models for geological and mining exploration and prospecting. This involves capturing crucial aspects such as topography, rock distribution, structural characteristics, and mineral deposits [7]. To address these modeling challenges, numerous methods have been explored. One such method is automated modeling using multipoint geostatistics of drilling data [8]. We mapped the holes onto a topographic background using GIS software (QGIS), then we defined the main dip/direction using geotechnical drill hole (NYGT3) with Dips software to determine the orientation of the cross-sections and we finely created six lithological cross-sections of the lithofacies where four of them are oriented North-East to South-West and two oriented East to West using 2D modeling software with Strater and 3D modelling with Leapfrog using techniques such as GA-Kriging interpolation.

GAs are finally employed to find the best solution by searching on the whole design space of updating parameters selected based on a sensitivity analysis [9]. To draw those different models we started by creating base map of holes using collar table, then we downhole from collar, survey and lithology tables. The cross-sections correlations had been designed by extrapolation of lithology limits. The methodology implemented by the software is based on interpolating the geological layers traversed by the boreholes outward to create a 3D model [10]. This approach allows for the construction of surfaces representing the top and sides of each lithofacies. The arrangement of the layers allows us to discuss about the results and draw a conclusion.

**Table 1:** Data from CIMKO deposit, used in the models developed in this study

| Data used | Total data used |
|---|---|
| Bore hole | 13 |
| Structural measurement of bored hole | 38 |
| Cross section lines | 6 |
| Lithofacies | 4 |

## Results

The surveys overlaid on the topographic map (Figure 02) show the locations of the holes in the field.

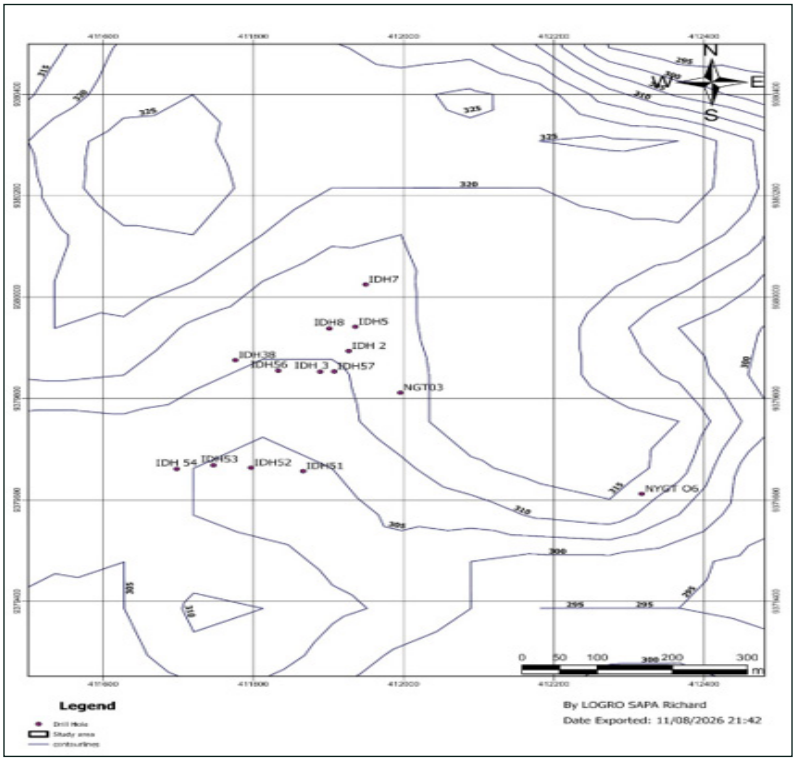



**Figure 2:** Base map showing the locations of the bore holes.

## Structural Measurement

The following table (Table 1) provides information about Structural measurement of bored hole NYGT03 which contains information about structure type, Dip angle and dip direction angle. From those data Stereonet sketch of drill hole NYGT03 has been design (Figure 3).

**Table 2:** Structural measurement of bored hole NYGT03

| HOLE ID | NORTHING (UTM Zone 33M) | Easting (UTM Zone 33M) | Elevation |
|---|---|---|---|
| **NYGT03** | **9379811,54m** | **4123.10.694m** | **315 m** |
| Structure | Dip | Dip direction | |
| Bedding | 31 | 272 | |
| Bedding | 31 | 270 | |
| Bedding | 38 | 252 | |
| Bedding | 39 | 295 | |
| Joint | 31 | 250 | |
| Joint | 72 | 100 | |
| Bedding | 39 | 277 | |
| Joint | 81 | 95 | |
| Joint | 76 | 95 | |
| Joint | 80 | 90 | |
| Joint | 81 | 95 | |
| Joint | 79 | 100 | |
| Joint | 64 | 150 | |
| contact | 39 | 289 | |

| | | | |
|---|---|---|---|
| Joint | 80 | 138 | |
| Joint | 78 | 123 | |
| Joint | 66 | 145 | |
| Bedding | 48 | 232 | |
| Joint | 76 | 95 | |
| Contact | 61 | 219 | |
| Joint | 54 | 272 | |
| Bedding | 20 | 312 | |
| Bedding | 43 | 254 | |
| Joint | 70 | 81 | |
| Bedding | 34 | 270 | |
| Joint | 86 | 99 | |
| Joint | 29 | 269 | |
| Joint | 39 | 307 | |
| Bedding | 44 | 289 | |
| Joint | 59 | 289 | |
| Joint | 39 | 289 | |
| Joint | 29 | 289 | |
| Joint | 86 | 109 | |
| Joint | 55 | 223 | |
| Joint | 79 | 71 | |
| Joint | 75 | 81 | |
| Joint | 31 | 328 | |
| Joint | 80 | 138 | |

Core were only marked from where was intersected the fresh rock, and only the survey (dip and azimut at that depth were considered to convert the alpha and beta values) deviation was taken in account due to low;

All measurements were taken from the bottom of the core;

As per results presented, most of the structures (either beddings or joints) are rough and planar with some coating material infill/or only staining due to fluid flowing through open joints;

Logging procedure is based on Optimising Geotechnical Logging to Accurately Represent the Geotechnical Environment by Dempers GD as presented at the second Australasian ground control in mining conference;

Bedding : breaks along bedding planes(open fractures)
Contours near edges of the diagram indicate steeply dipping fractures while those in the centre of the circle indicate horizontal fractures;

According to the stereonet and visual core observations, two types of geological features are easily differentiated : flatbed boundaries (dips rarely exceed 45 degrees) and fractures steeply dipping (Figure 3).

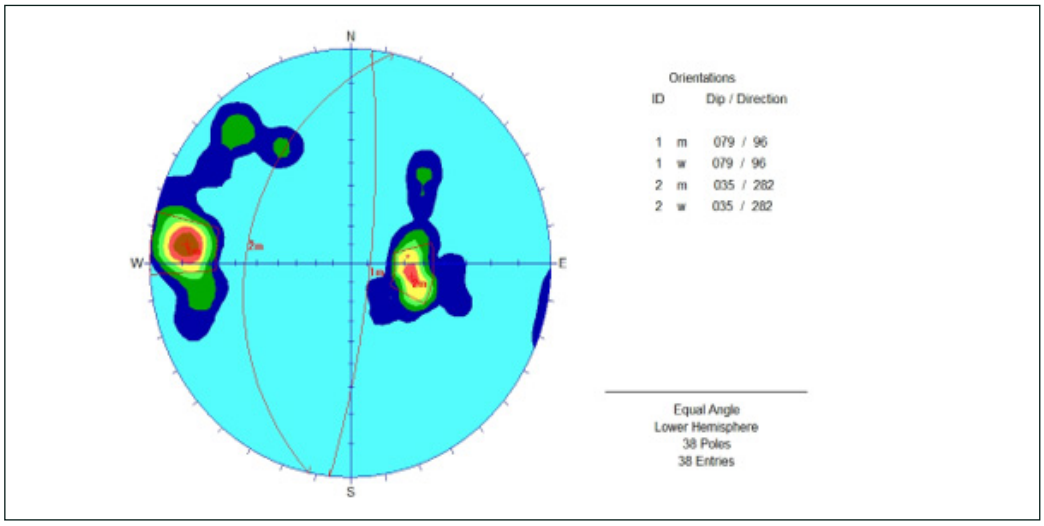



**Figure 3:** Stereonet sketch of drill hole NYGT03

## Lithological Correlation Cross-Sections

The table (Table 2) provides lithological data recorded in 13 drilled holes which sets on 3 lithofacies (LF1, LF2 and LF3) covered by the alteration layer (LF0).

**Table 3:** Table of lithological data recorded in 13 drilled holes

| Hole ID | Coordinats UTM (33M) | | | Depth | | Description lithologique | |
|---|---|---|---|---|---|---|---|
| | South | East | Alt | From (m) | To(m) | Limestone | Label |
| IDH 2 | 9379894 | 411927 | 278 | 0 | 3 | Laterite | LF0 |
| | | | | 3 | 32,9 | Greenish grey limestone | LF1 |
| | | | | 32,9 | 38,3 | Dark grey limestone | LF2 |
| IDH 3 | 9379853 | 411889 | 279 | 0 | 14,18 | Laterite | LF0 |
| | | | | 14,18 | 32,5 | Dark grey limestone | LF2 |
| | | | | 32,5 | 40 | Dark grey limestone | LF2 |
| IDH5 | 9379942 | 411935,7 | 278,1 | 0 | 8,9 | Laterite | LF0 |
| | | | | 8,9 | 40 | Dark grey limestone | LF2 |
| IDH7 Dip 90° | 9380025 | 411949,5 | 283,5 | 0 | 7,8 | Laterite | LF0 |
| | | | | 7,8 | 40 | Dark grey limestone | LF2 |
| IDH8 | 9379938 | 411901 | 278 | 0 | 1,54 | Laterite | LF0 |
| | | | | 1,54 | 5,75 | Dark grey limestone | LF2 |
| | | | | 5,75 | 40 | Greenish grey limestone | LF1 |
| IDH38 | 9379876 | 411776 | 296,576 | 0 | 44,8 | Laterite | LF0 |
| | | | | 44,8 | 72 | Light grey | LF3 |
| IDH51 | 9379657 | 411866,4 | 305,38 | 0 | 32 | Laterite | LF0 |
| | | | | 32 | 60 | Greenish grey limestone | LF1 |
| IDH52 | 9379664 | 411796,9 | 302,802 | 0 | 27 | Laterite | LF0 |
| | | | | 27 | 67 | Greenish grey limestone | LF1 |
| IDH53 | 9379668 | 411746,9 | 303,516 | 0 | 42,5 | Laterite | LF0 |
| | | | | 42,5 | 63 | calcaire gris claire massif | LF3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| IDH 54 | 9379661 | 411698 | 306,516 | 0 | 63 | Laterite | LF0 |
| | | | | 63 | 90 | Calcaire gris claire massif | LF3 |
| IDH56 | 939854,8 | 411833,3 | 273,4 | 0 | 102 | Dark grey limestone | LF2 |
| IDH57 | 9379853 | 411907,8 | 273,1 | 0 | 13,1 | Laterite | LF0 |
| | | | | 13,1 | 15 | Greenish grey limestone | LF1 |
| | | | | 15 | 15,5 | Cavity | |
| | | | | 15,5 | 15,9 | Greenish grey limestone | LF1 |
| | | | | 15,9 | 16,5 | Cavity | |
| | | | | 16,5 | 33,8 | Greenish grey limestone | LF1 |
| | | | | 33,8 | 34 | Cavity | |
| | | | | 34 | 35,35 | Greenish grey limestone | LF1 |
| | | | | 35,35 | 36 | Cavity | |
| | | | | 36 | 57 | Greenish grey limestone | LF1 |
| | | | | 57 | 102 | Dark grey limestone | LF2 |
| NYGT 06 | 9379612 | 412317 | 322 | 0 | 37,5 | Laterite | LF0 |
| | | | | 37,5 | 38,4 | Greenish grey limestone | LF1 |
| | | | | 38,4 | 114 | Greenish grey limestone | LF1 |

The base map (Figure 4) presents the sections lines. We selected the sections line from North-East to South-West of the **Cross-section 1**: IDH7, IDH5, IDH2, IDH57 and IDH 51 (Figure 5), **Cross-section 2**: IDH56 and IDH53 (Figure 6), **Cross-section 3**: IDH8, IDH3 and IDH52 (Figure7), **Cross-section 4**: IDH38 and IDH54 (Figure 8) and two sections lines-oriented West to East; **cross-section 5**: IDH54, IDH53, IDH52 and IDH51 (Figure 9), **cross-section 6**: IDH38, IDh56, IDH3 and IDH57 (Figure 10).

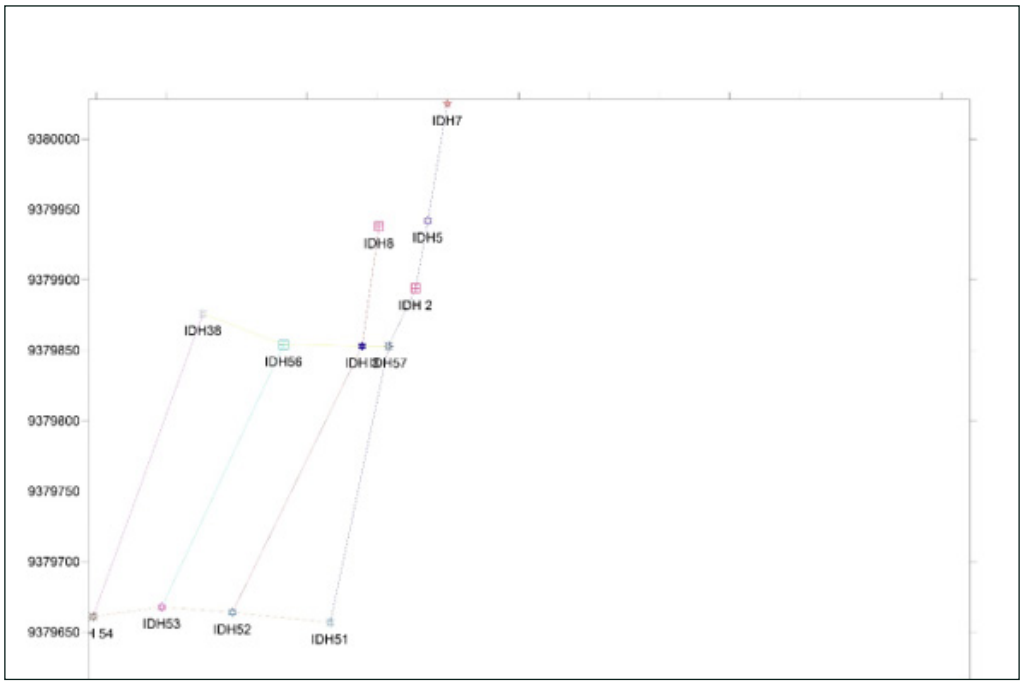



**Figure 4:** Base map of drill holes which present Cross-section lines from Noth to South and from West to East.

**Cross-section 1**

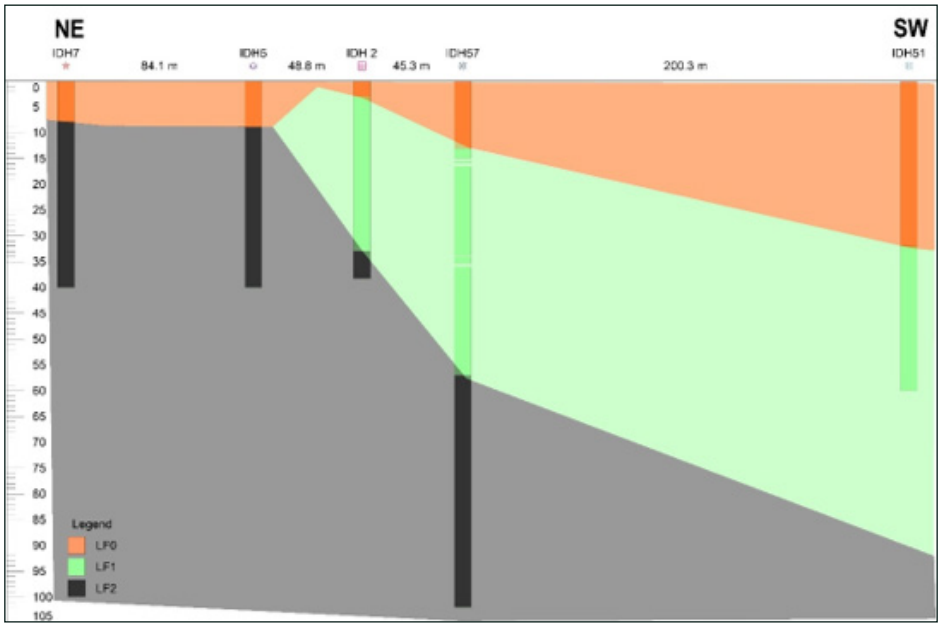



**Figure 5:** Correlation of the drill holes IDH7, IDH5; IDH2 and IDH57

**Cross-section 2**

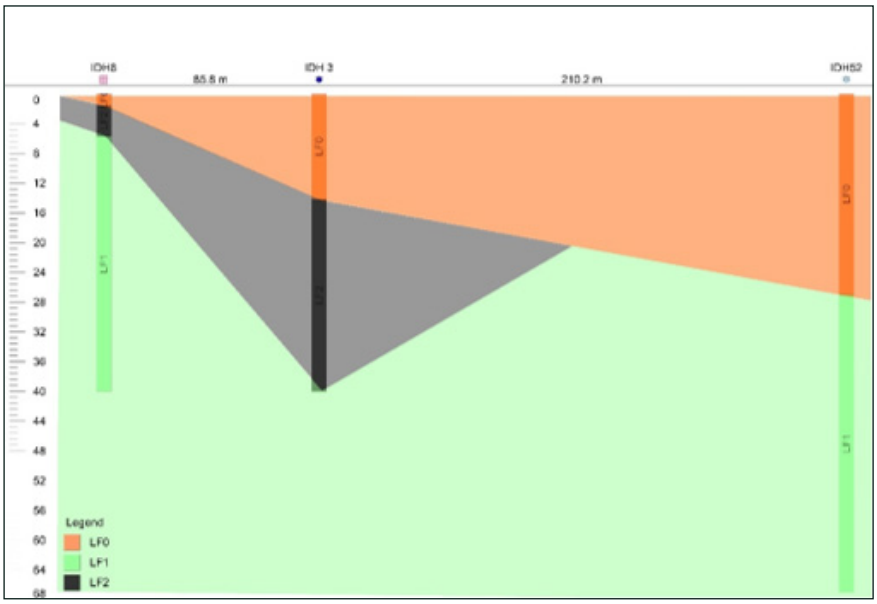



**Figure 6:** Cross-sections IDH8, and IDH3 and IDH52

**Cross-section 3**

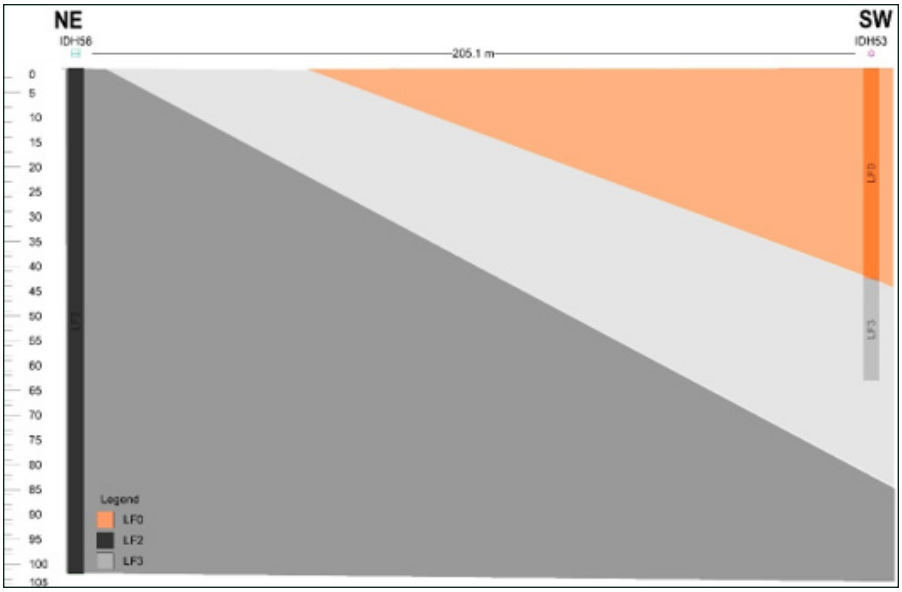



**Figure 7**:Correlation of the drill holes IDH56 and IDH53

**Cross-section 4**

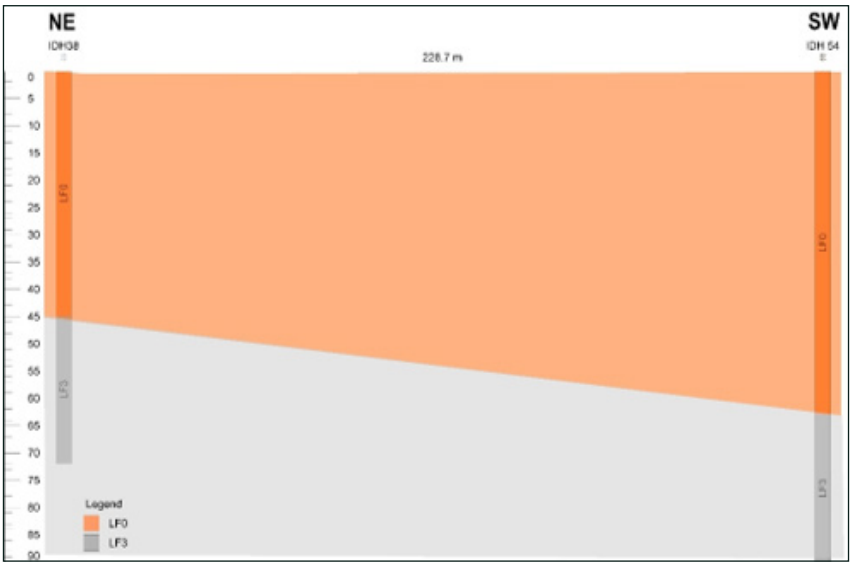



**Figure 8:** Cross-section IDH38 and IDH54

**Cross-section 5**

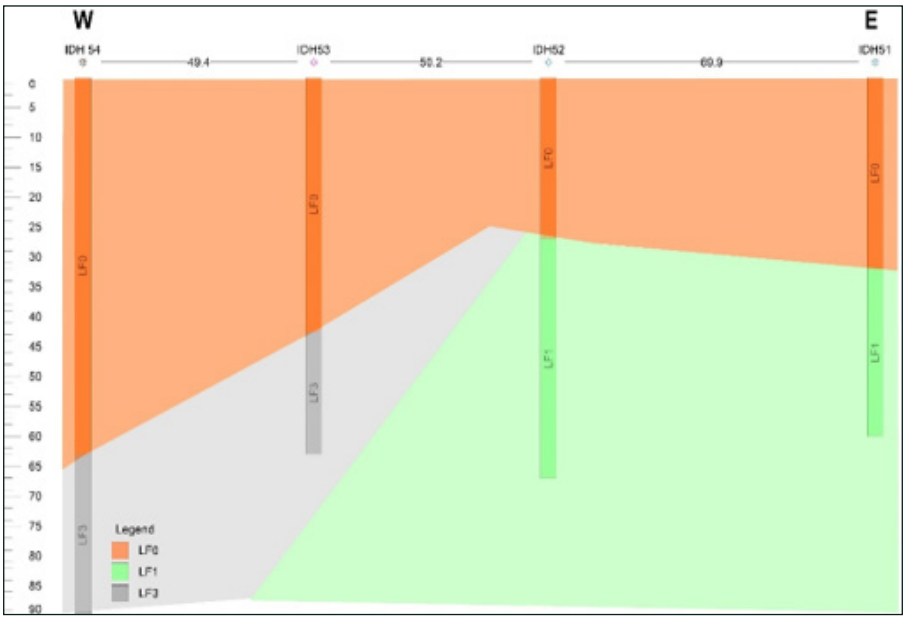



**Figure 9:** Cross-section of IDH54, IDH53, IDH52 and IDH51

**Cross-section 6**

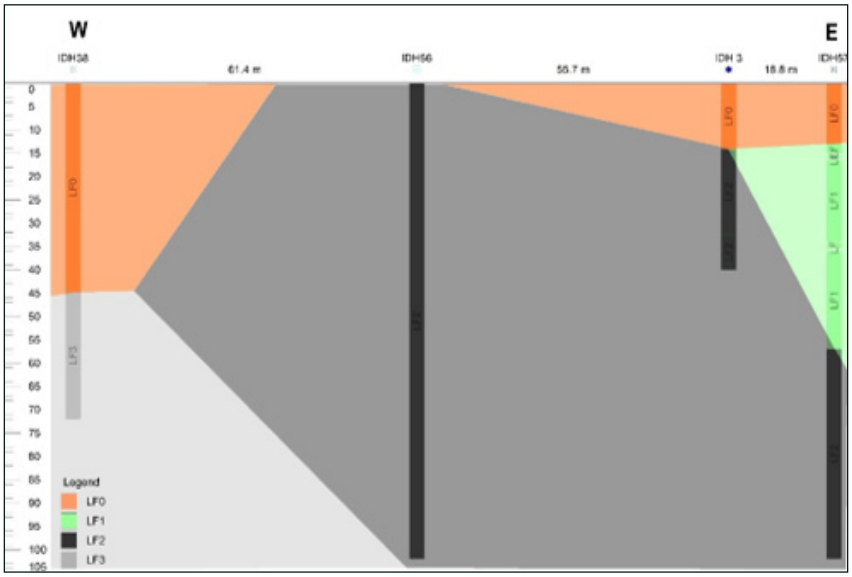



**Figure 10:** Cross-section of IDH38, IDH56, IDH3 and IDH57

## D Models of the Lithology of the Layers

This approach not only solves geological modeling problems related to complex geometric and topological relationships, but also introduces a new method and concept for 3D geological modeling. In addition, techniques such as GA-Kriging interpolation [11]. Three model images has been product; the perspective view (Figure 11) shows the superposition of the different lithofacies from the North-East of the block model. The second view (Figure 12) shows the South-West view of the block model and the last view (Figure 13) shows the An overlap can be observed between the dark gray and greenish-gray limestone lithofacies. The bottom perspective view (Figure 7) shows the superposition and overlap of three lithofacies.

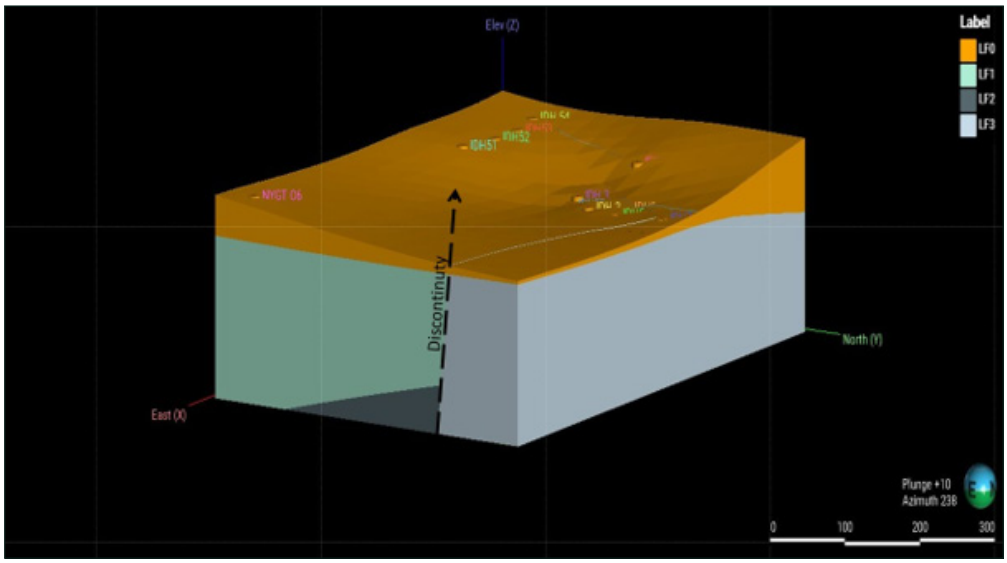



**Figure 11**: The block model North-East side

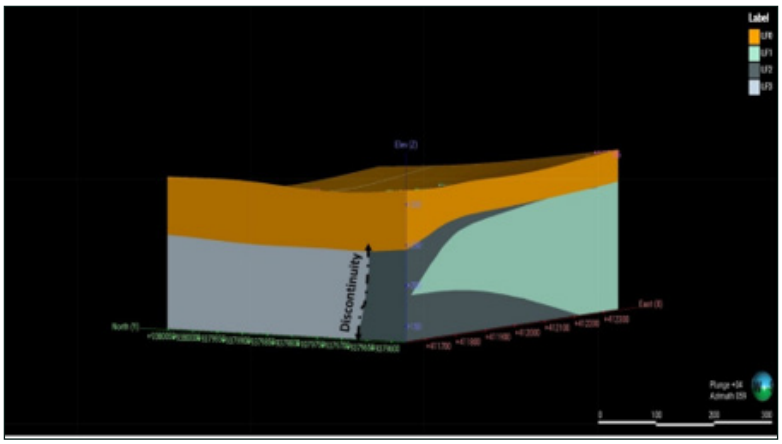



**Figure 12:** The block model viewed from the North-East side

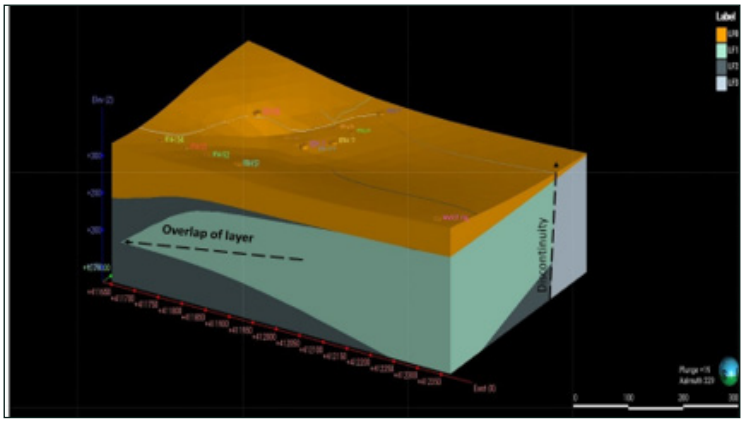



**Figure 13**: The block model viewed from the South-East side

## Discussion

The development of an automated geological modeling system—including data entry, database creation, data processing, method selection, and model optimization—remains crucial [12]. The resulting geological model demonstrates that digital outcrop data and 3D geological modeling are effective tools for testing the characterization of carbonate outcrops and conceptual models of carbonate platform systems [13].

The structural measurements of the bore hole NYGT03 shows breaks along bedding planes (open fractures) steeply dipping and flatbed boundaries (dips rarely exceed 45 degrees).

From 2D model of underground lithofacies (cross-sections) designed by Strater software , we observe this following:

On the cross-section 1 the layer LF1 overly the layer LF2 but the cross-section 2 show the reverse situation. The cross-sections 3 and 5 show also the reverse of layers deposit (LF2-LF3 and LF1-LF3). The cross-sections 6 shows the normal deposit of layers LF1, LF2 and LF3. Such deposition model mean we are in a part of sequence stratigraphy. Some of unconformities like the gap between LF1 and LF3 means the period of marine erosion and we are in a part of the sequence cycle in the stratigraphic unit of Kwilu.

A discontinuity surface is defined as follows: a surface which separates younger from older sedimentary rocks where evidence based on geometric, sedimentological, diagenetic, or biostratigraphic criteria, enables to infer a break in sedimentation, of whatever length [14]. The 3D model made from the GA-Kriging interpolation method product by Leapfrog shows overlap layers between the lithofacies LF1 and LF2 and the discontinuity between LF1-LF2 and LF3.

The overlap layer is commonly expressed as surface in bore holes sections and is due to rapid and substantial environmental changes and the discontinuity between LF1-LF2 and LF3 is the clearly a fault contact [15].

## Conclusion

From those followings paragraphs we retain that, 3D design is verry important to observe lithology cover underground the alteration layer. From cross sections lines designed by Strater software using extrapolation method we observe unnormal contacts between lithofacies using principles of sequence stratigraphy. The 3D modelling with GA-Kriging interpolation method using Leapfrog software shows clearly the overlap of layer and the discontinuity structure interpret as fault surface between lithofacies.

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