

3D and 2D Lithostratigraphic Modelling of Carbonate Formations: The Case of Songololo Limestone and Its Surroundings

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How to cite this paper: Sapa, R. L., Kabulu, B. M., Kingoma, C. M., Kisaka, B. M., Nzemba, E. E., Paul, M. B., Mambwiya, J. L., Kakene, J. S., Malobo, F. M., Onanga, G. B., & Kisonga, E. M. (2026). 3D and 2D Lithostratigraphic Modelling of Carbonate Formations: The Case of Songololo Limestone and Its Surroundings. *Journal of Geoscience and Environment Protection*, 14, 192-207.

<https://doi.org/10.4236/gep.2026.1410007>

Received: July 13, 2026

Accepted: October 20, 2026

Published: October 23, 2026

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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 focuses 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 the best understanding of it. To study carbonate deposits such as limestone we use some principles of stratigraphy and analysis sequence. Carbonate rocks are sedimentary rocks with dip and direction also cyclicity of layers. The present article consists of creating cross-sections to visualize different types of lithofacies of carbonate formations and analyze the layout contact based on lithostratigraphy principles using 3D model to visualize their contacts underground.

Keywords

Cross-Sections, 3D Model, Songololo, Limestone, West-Congo

1. 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 ge-

ological data available generally consist of documents such as cross-sections or geological maps and point data such as borehole logs or outcrop descriptions (Kaufmann & Martin, 2008). 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 (Kedzierski, 2017). 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.

2. Methods and Equipment

2.1. 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 (Vancutsem et al., 2006). It straddles the Kimpese and Luima sectors in the Songololo Territory, in the Province of Kongo Central (Figure 1). It is bounded by 15°5'00" and 15°25'00" east longitude and 5°0'00" and 5°30'00" south-latitude.

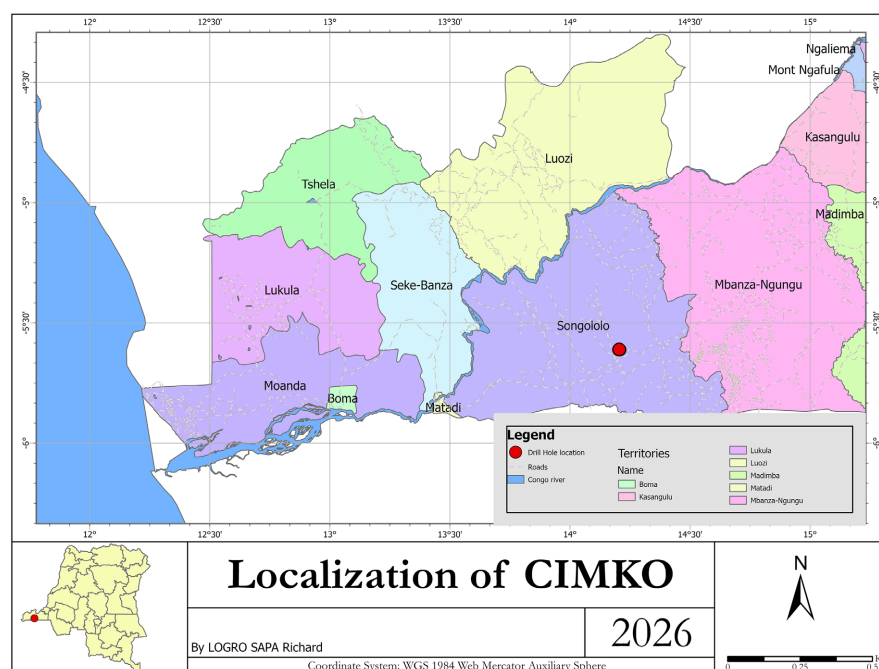


Figure 1. Map showing the location of the study area in Kongo Central Province.

2.2. 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 strati-

graphic 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 patterns in a manner that is independent of the 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 can be observed at the scales afforded by the resolution of the data available. 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 (Catuneanu, 2022). 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 area belong to the Neoproterozoic schist-limestone group within the Bulu and Luanza formations of the Kwilu Unit (Logro et al., 2024). The superposition from the top to the bottom is LF1, then LF2 and ends with LF3.

2.3. 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 created a 3D model of different lithofacies on Leapfrog software.

2.4. Methods

The exploration and mining phases of the CIMKO mine generated a significant amount of information about this deposit (Table 1). This made it possible to create a database that was used in the models presented in this study (Salama et al., 2016). 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 (Cao et al., 2024). To address these

modeling challenges, numerous methods have been explored. One such method is automated modeling using multipoint geostatistics of drilling data (Guo et al., 2022). 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 finally 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.

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

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 (Qin et al., 2018). To draw those different model 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 (Kesse, 2024). 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.

3. Results

The surveys overlaid on the topographic map (Figure 2) show the locations of the holes in the field.

3.1. Structural Measurement

Following Table 2 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 designed (Figure 3).

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: flat bed boundaries (dips rarely exceed 45 degrees) and fractures steeply dipping (Figure 3).

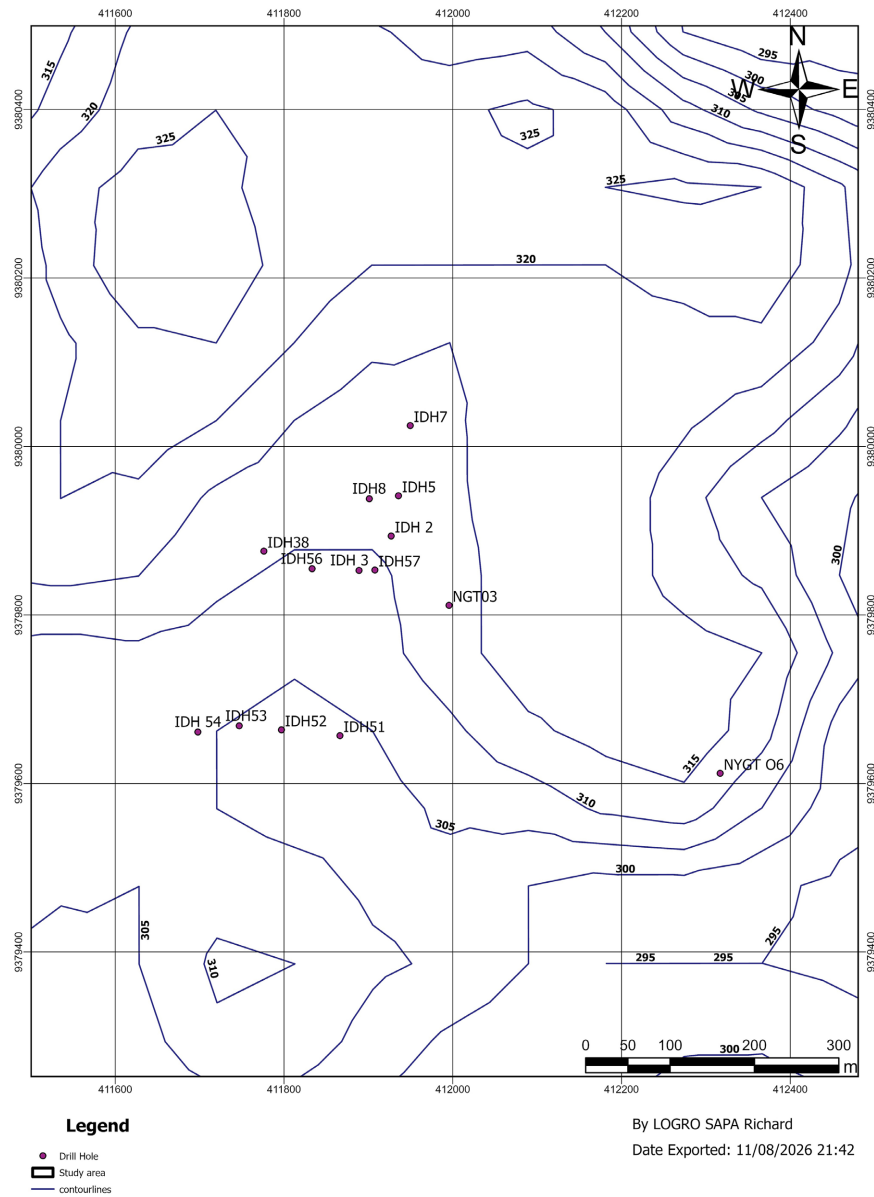


Figure 2. Base map showing the locations of the bore holes.

Table 2. Structural measurement of bored hole NYGT03.

HOLE ID	NORTHING (UTM Zone 33M)	Easting (UTM Zone 33M)	Elevation
NYGT03	9379811.54 m	412310.694 m	315 m
Structure	Dip	Dip direction	
Bedding	31	272	
Bedding	31	270	
Bedding	38	252	
Bedding	39	295	
Joint	31	250	

Continued

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 azimuth 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).

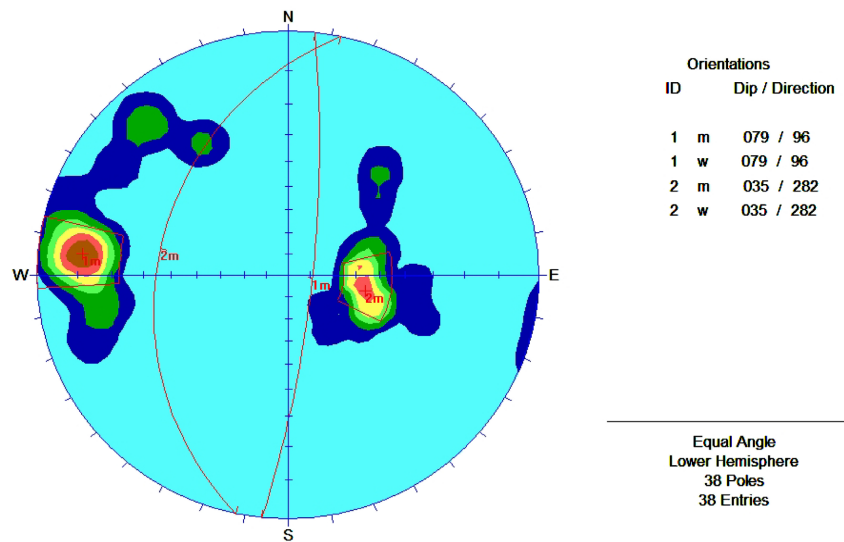


Figure 3. Stereonet sketch of drill hole NYGT03.

3.2. Lithological Correlation Cross-Sections

Table 3 provides lithological data recorded in 13 drilled holes which set 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	Coordinates UTM (33M)			Depth		Description lithologies	
	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

Continued

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	Massive light grey limestone	LF3
IDH 54	9379661	411698	306.516				
				0	63	Laterite	LF0
				63	90	Massive light grey limestone	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 O6	9379.612	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 (**Figure 7**), **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**).

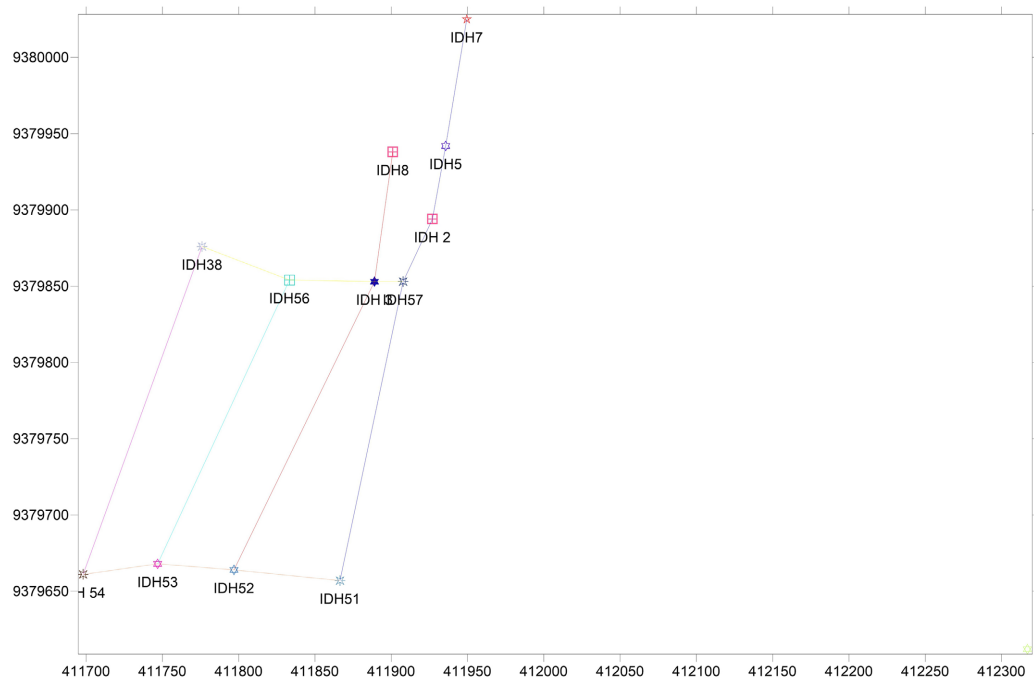


Figure 4. Base map of drill holes which present Cross-section lines from North to South and from West to East.

A. Cross-section 1

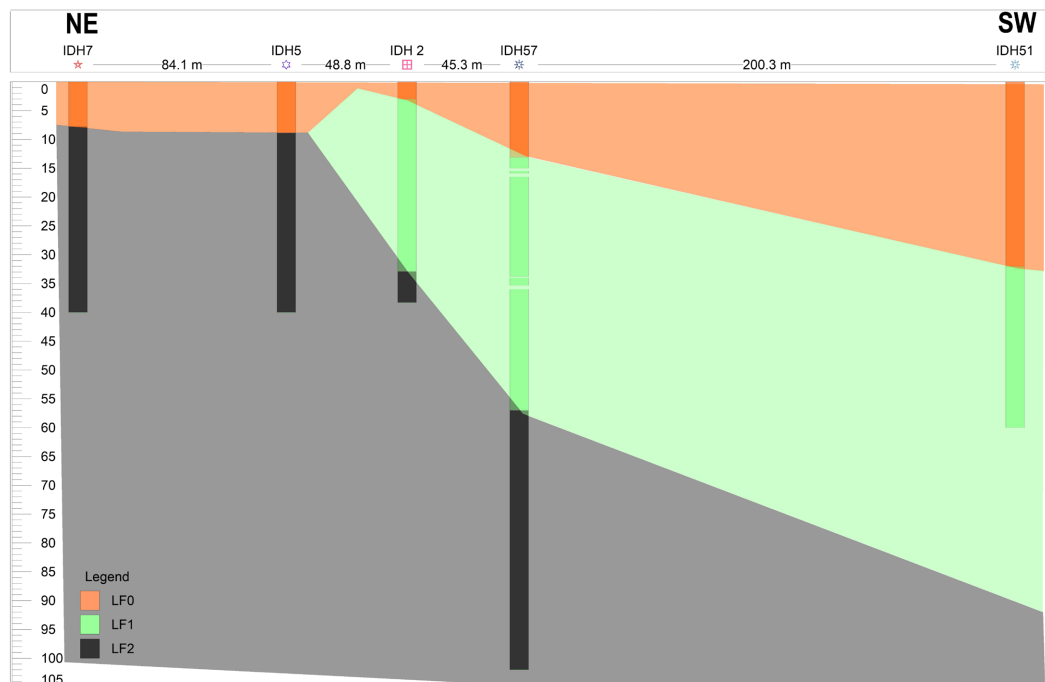


Figure 5. Correlation of the drill holes IDH7, IDH5, IDH2 and IDH57.

B. Cross-section 2

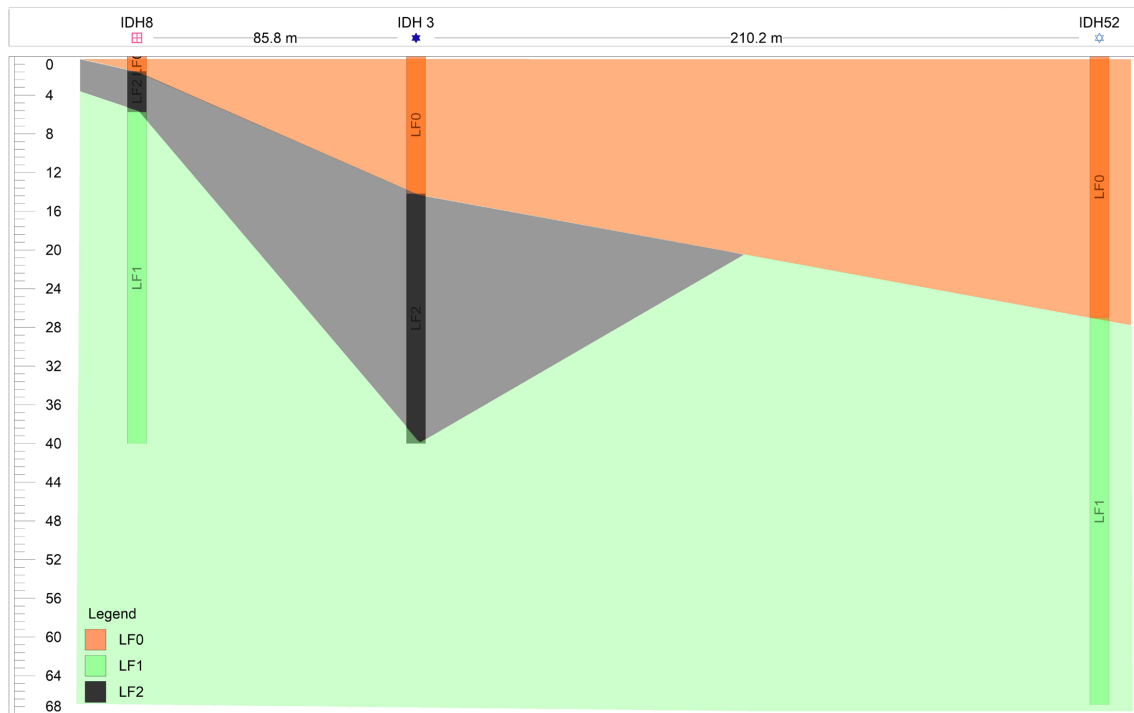


Figure 6. Cross-sections IDH8, and IDH3 and IDH52.

C. Cross-section 3

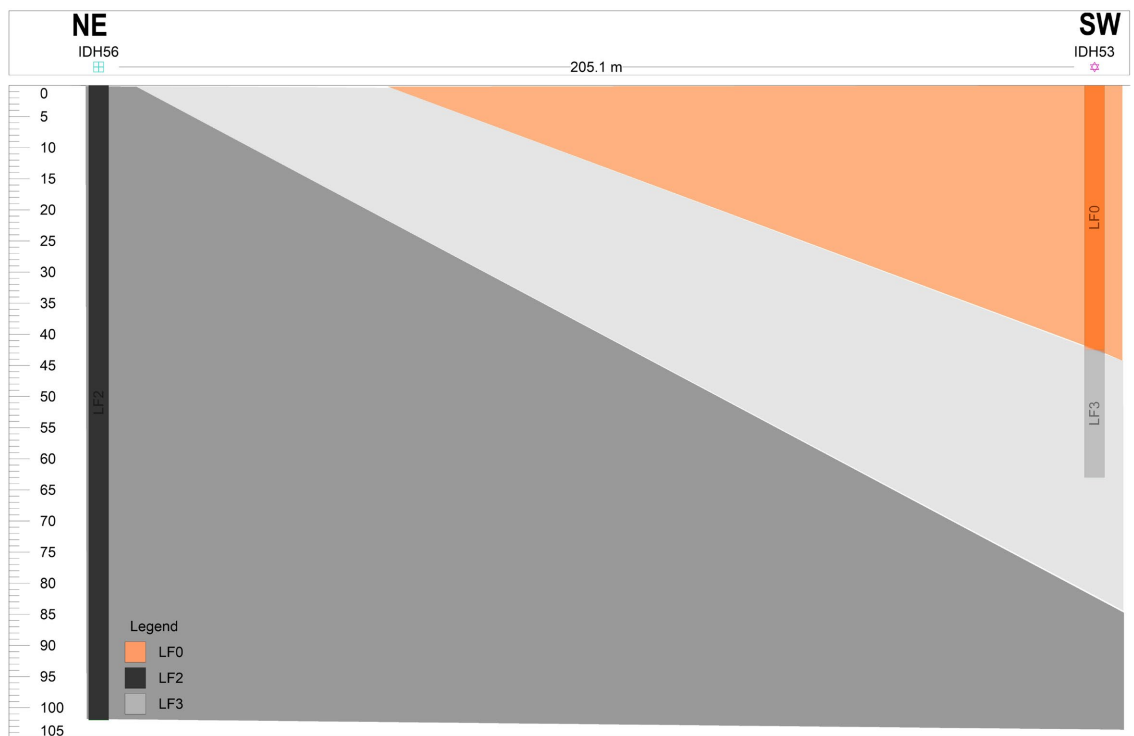


Figure 7. Correlation of the drill holes IDH56 and IDH53.

D. Cross-section 4

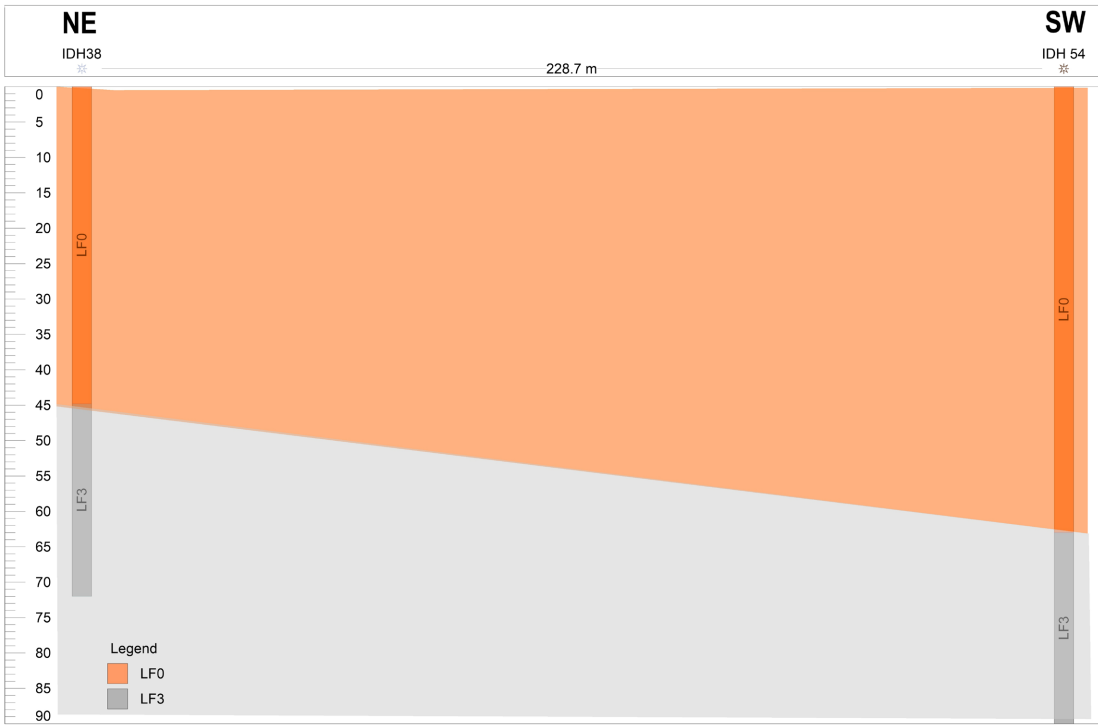


Figure 8. Cross-section IDH38 and IDH54.

E. Cross-section 5

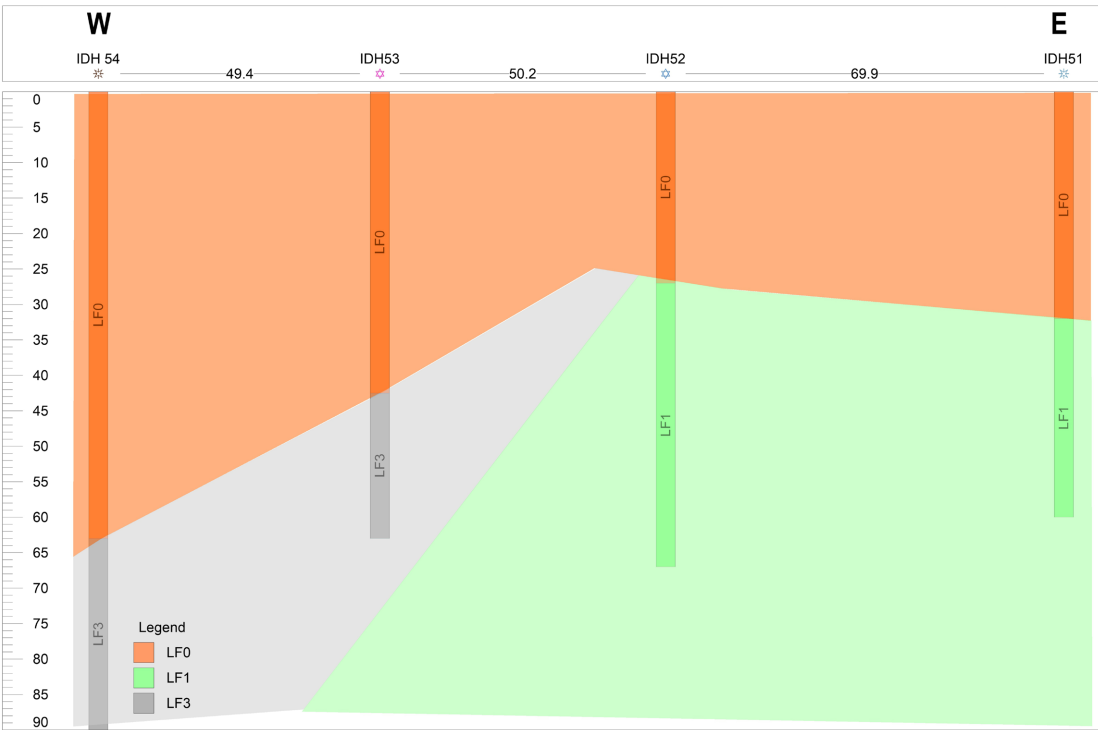


Figure 9. Cross-section of IDH54, IDH53, IDH52 and IDH51.

F. Cross-section 6

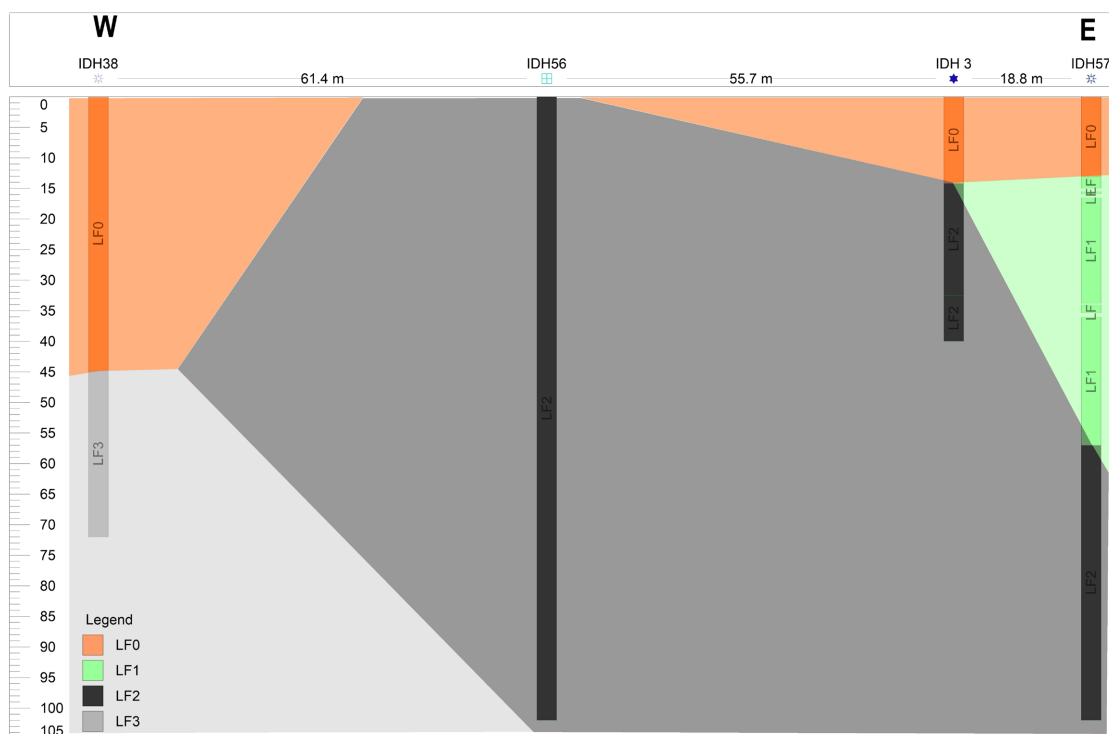


Figure 10. Cross-section of IDH38, IDH56, IDH3 and IDH57.

3.3. 3D 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 (Cui et al., 2017). Three model images have been produced; 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 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.

4. Discussion

The development of an automated geological modeling system—including data entry, database creation, data processing, method selection, and model optimization—remains crucial (Wu et al., 2022). 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 (Richet, 2011).

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

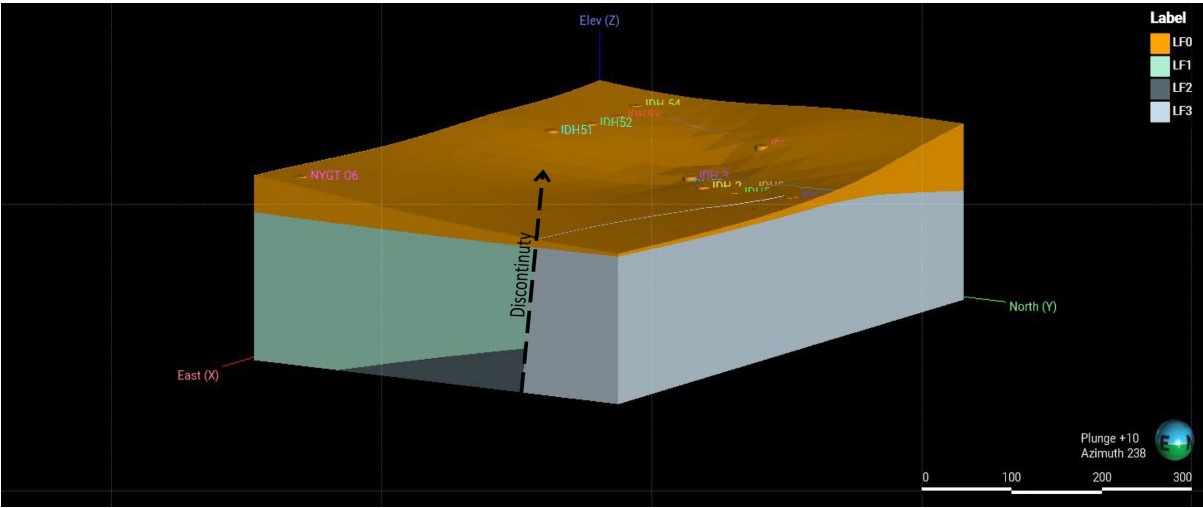


Figure 11. The block model North-East side.

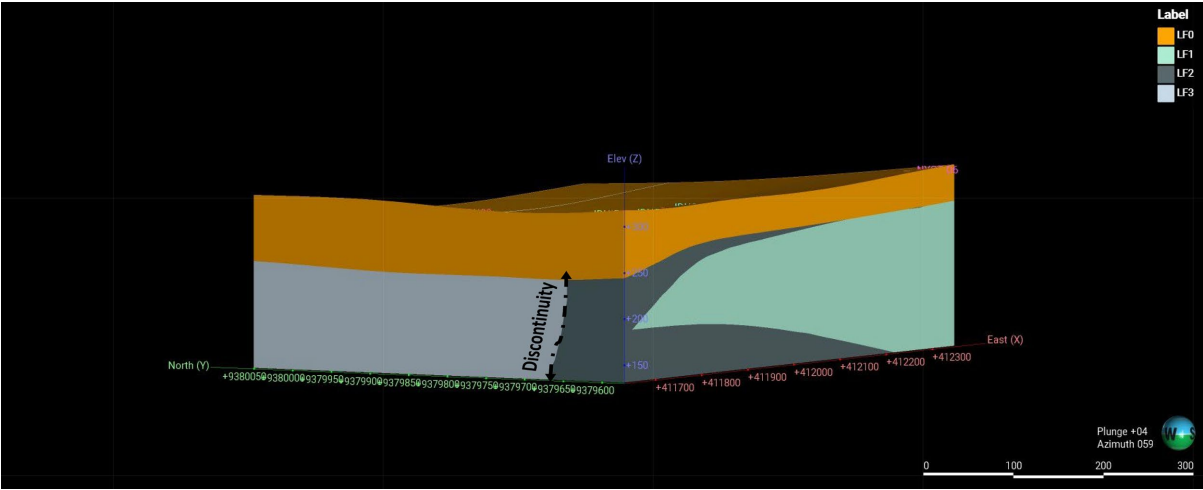


Figure 12. The block model viewed from the North-East side.

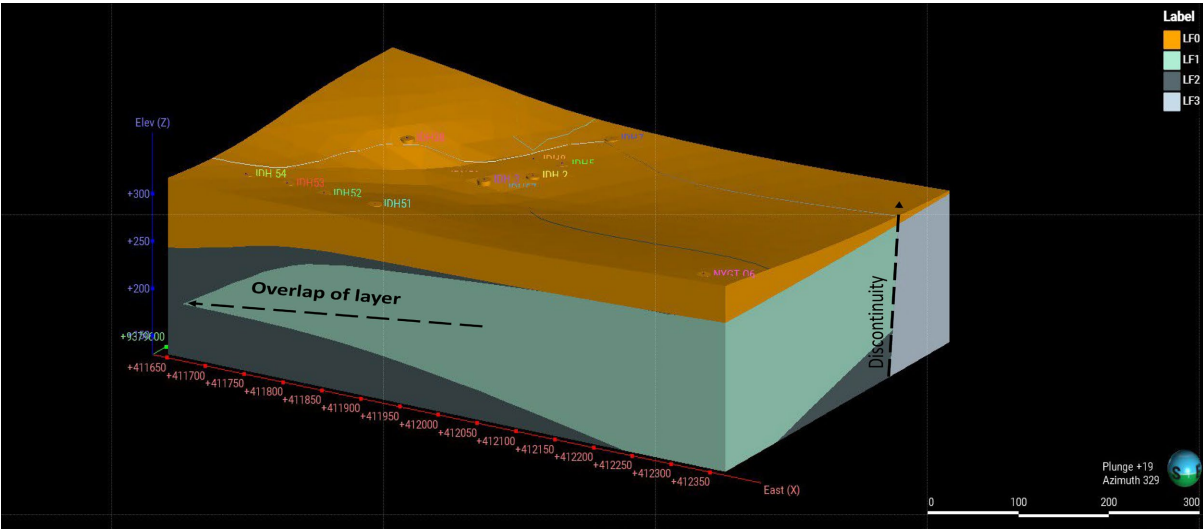


Figure 13. The block model viewed from the South-East side.

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

On the cross-section 1, the layer LF1 overly the layer LF2, but the cross-section 2 shows the reverse situation. The cross-sections 3 and 5 show also the reverse of layers deposit (LF2 - LF3 and LF1 - LF3). The cross-section 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 (Clari et al., 1995). The 3D model made from the GA-Kriging interpolation method produced 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 (Hillgaetner, 1998) and the discontinuity between LF1 - LF2 and LF3 is clearly a fault contact.

5. Conclusion

From the following paragraphs, we retain that 3D design is very important to observe lithology covering the alteration layer underground. From cross section lines designed by Strater software using extrapolation method, we observe abnormal 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.

Author Contributions

Conceptualization, Richard LOGRO SAPA. and Guyghens Bongwele Onanga; methodology, Eric Manuku Kisonga; software, Richard LOGRO SAPA; validation, Erci Manuku Kisonga, Guyghens Bongwele Onanga, Christian Mabua Kingoma and Blaise Mutombo Kabulu; formal analysis, Junior Lele Mambwiya and Paul Mupepele Batubenga; investigation, Joseph Sefu Kakene; resources, Fabrice Mutamba Malobo; data curation, Guyghens Bongwele Onanga; writing—original draft preparation, Bob Mayemba Kisaka; writing—review and editing, Richard LOGRO SAPA; visualization, Eno Ekita Nzemba; supervision, Guyghens Bongwele Onanga; project administration, Blaise Mutombo Kabulu; funding acquisition, Christian Mabua Kingoma. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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