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3D Seismic Data Interpretation in Gumry Field, Melut Basin

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Abstract: This work describes interpretation of 3D seismic data of Gumry area which is located in Blocks 3 & 7 in Melut Basin the South of Sudan. The data used in this study was acquired by Blue Nile Geophysical Company (BGC) in 2004. The 3D data was interpreted by the author at the SUDAPET CO. LTD in Khartoum – Sudan, Vertical Seismic Profiling data (VSP) and Check-Shot data of the Gumry-1 well were used. The data quality is good and adequate for the objectives. Geoframe software has been used which enables to display inline, cross line and time slice and also enables checking of the consistency of the interpretation from line to line. Synthetic seismogram has been generated for Gumry _1 well for seismic data tie. Time and depth maps have been generated for the top of Yabus Formation. The 3D data interpretation clarifies that there are many oil structures found in study area such as normal faults, faulted trap, graben, half graben, and faulted anticline. Faults system in Gumry area consists of normal faults, trending NW-SE, with some of them dipping SW and others dipping NE. Gumry oil field prospects are mainly fault block structure, located at the block up thrown side of the normal Fault block.

Keywords: Melut Basin, Gumry Field, Rift Basin, Normal Fault, Grabens, Half Graben

1. Introduction to Geology of Melut Basin

1.1. Overview

In this work seismic exploration of Melut Basin and interpretation has been carried out. The Melut Basin is a Mesozoic-Cenozoic rift basin related to the formation and development of the Central African Shear Zone (CASZ) on the Pre-Cambrian crystalline and metamorphic basement of lower relief [4]. Three stages of rift development and fracturing have been identified, stronger in the Early Cretaceous and Paleogene and weaker in the Late Cretaceous. Source rocks are the Lower Cretaceous lacustrine shales, whereas reservoirs and seals are both Paleogene and Upper Cretaceous. Dominant structural styles are large-scale anticlines in the Paleogene sequences and antithetic normal fault-blocks in the Upper Cretaceous and Paleogene [4].

Vail and Whiteman investigated Melut basin and the neighbouring area s in the general context of the geology of the Sudan being a target for hydrocarbon exploration [15, 16]. Yabus and Samma Formation are the main reservour in Melut basin these formations are interbeds of sandstones with thin beds of mudstones, with fining-upward pattern. The sandstones dominate the mudstones. The latter ones are generally brown to light brown in colour, sometimes light grey or pinkish. The sandstones are variable in grain size ranging from fine to coarse. They are mostly yellowish to greyish brown. The sandstones are variable in grain size ranging from fine to coarse. They are mostly yellowish to greyish brown, Yabus and Samma Formations are fluvial in origin and they act as reservoir rocks for oil in the Melut basin assigned a Lower Paleocene [10].

The Melut Basin is characterized by flat plains, composed of older alluvial, sand plains, lacustrine deposits and alluvial fans. This plain area is surrounded by regionally metamorphosed Precambrian and Paleozoic rocks and minor syn-late to post- tectonic. Mesozoic/Cenozoic intrusive igneous rocks [6]. These rocks are exposed northeast and northwest of the Melut Basin in the Ingessana Hill and the Nuba Mountains respectively. [6] The Nuba Mountains are made of high–grade gneisses and low-grade Greenschist. The tectonic contact between the two groups is marked by the Kabus ophiolitic mélange zone [6]. Based on previous investigations [2], the stratigraphic and tectonic subdivisions of the Basement Complex of the NE Nuba Mountain can be summarized as follows:

Post-orogenic granites, syn-late orogenic granites, Kabus ophiolitic mélange rock assemblage and low–grade volcano-sedimentary sequence.

1.2. Location & Accessibility

Melut basin lies in southeast Sudan and it trends generally in NNW direction. The basin extends about 400 km from the Ethiopian border into Sudan. The maximum width of the basin is about 200 km. It is approximately bounded by longitude 32° 00' and 34° 00' E and the latitude 8° 00’ and 11° 00’ N Figure 1. The area is accessible by air from Khartoum, by river boats from Kosti to Malakal and also via seasonal roads and tracks.

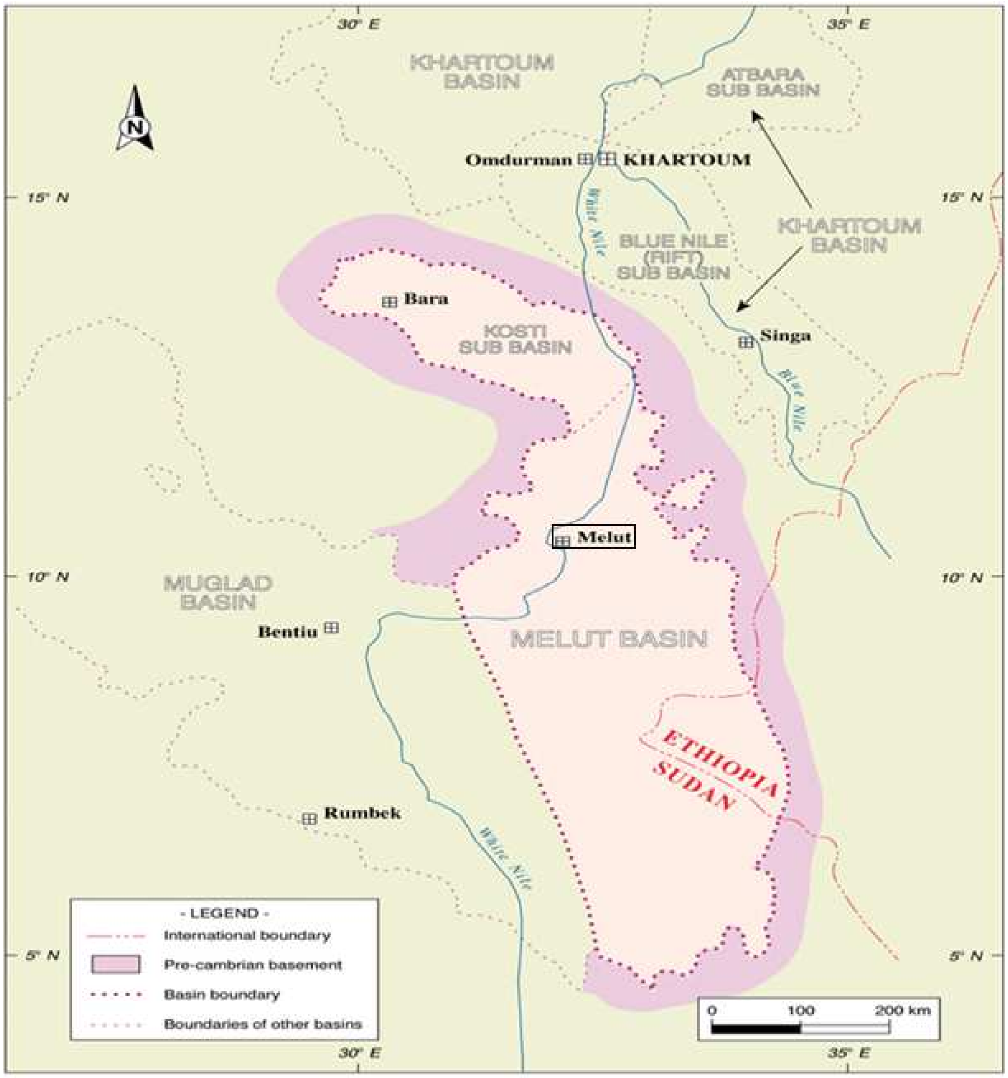

Figure 1. *Location map of the study area (PDOC, 2006) [9].*

1.3. Ahistorical Note on Petroleum Exploration

Melut basin and the adjacent territories have long become a target for hydrocarbon exploration. In November 1974 Chevron signed a concession area agreement with the Sudan covering a (516,000 sq km) in southern Sudan. In 1975 the agreement was converted to a production – sharing agreement. The original agreement area is 204,000 sq km of the Muglad and Melut blocks. In 1979 Chevron and government entered an agreement providing for an additional (73,200 sq km) to be added to the contract area. [7], presented details of a seismic operation in the Sudd. During the seismic operation Chevron crews have recorded over 58.000 km of seismic data plus one extensive three –

dimensional survey (3D) [6].

In 1995 (GPCS) signed a production – sharing contract other companies and started work in South Sudan. In 2001 GPCS replace the agrement by other company called PDOC, its comprised of may firms such as CNPC which is woned the biggest share, Malaysian company Petronas, Sudapt, Gulf Oil and Althani company. PDOC holds the rights for the exploration and development of the contract areas Blocks 3 and 7 located in the south east of the Republic of the Sudan. Petrodar is currently engaged in oil exploration and production in Blocks 3 and 7, which are oil concession areas located in the Melut Basin in Southern Sudan. The company's production in this area reportedly accounted for almost half of Sudan's total crude oil output in late 2006 [4].

1.4. Petroleum Exploration in Melut Basin

Petroleum Exploration in this basin was investigated by Chevron. (1975). Geophysical surveying was has been done covering almost parts of the area. Many exploratory wells were drilled in Melut Basin by Chevron from June 1981 to May 1982 in which oil was discovered in some of the wells.

Browne et al carried out geophysical work in what was called the White Nile Rift that includes the northern part of the Melut basin [3], Salama investigated the evolution of of River Nile and suggested that the area of the Melut basin was occupied by closed saline lakes. These lakes were connected together in Tertiary time to from the River Nile [11-13]. Lawyer and Kay evaluated Chevron's work and published geological work regarding the central Sudanese rifts basins [7]. Mohr discussed the stratigraphy, sedimentology, geophysics, tectonics, and significant oil accumulation in Sudan rift basin including Melut basin [8]. ElTayeb investigated the sedimentary sequence of the Melut Basin (Kordofan group) [5].

2. Tectonic History of Melut Basin

Eisawi suggested that the area occupied by the central Sudanese Rift basins represented an extensive continental platform since the Cambrian till the Mesozoic. By the end of Pan-Africa Orogeny 500 Ma this region had become a consolidated and stabilized platform and there were no great regional tectonic activities (Figure 2). At the Jurassic–Cretaceous time, the separation of Gondowana Land created a considerable amount of shear and extensional force which produced a number of rift basins in central Africa including the Sudan and Melut Basin is one of them. These basins subsided by normal faulting parallel and sub-parallel to the basinal axes and margins. Tertiary subsidence continued in the Melut Basin Complex and was accompanied by uplift of the volcanic areas of Ethiopia. The main dyke direction around Jebel Gemi volcano is ENE providing further evidence for the repeated reactivation of Pan–African structures. This represents the first rifting phase that took place in late Jurassic to Early Cretaceous and ended near the end of Albian [6]. This initial rifting phase was followed by another two phases. The second one occurred during the Turonian, Late Senonian and ended in Paleocene, while the third began in the Late Eocene – Oligocene [14]. This rifting phase reached its peak during the Oligocene and resulted in a marginal marine transgression that invaded the area from the south. The formation of Lau and is deposited under saline conditions and include intercalations of beach sandy units accompanied with waning phase at the early Miocene. At the top of Kordofan Group coarse alluvial and fluvial braided river sedimentary rocks of Agor and Daga Formations were deposited as result of source uplifting. This uplifting took place in post Miocene time [8, 1].

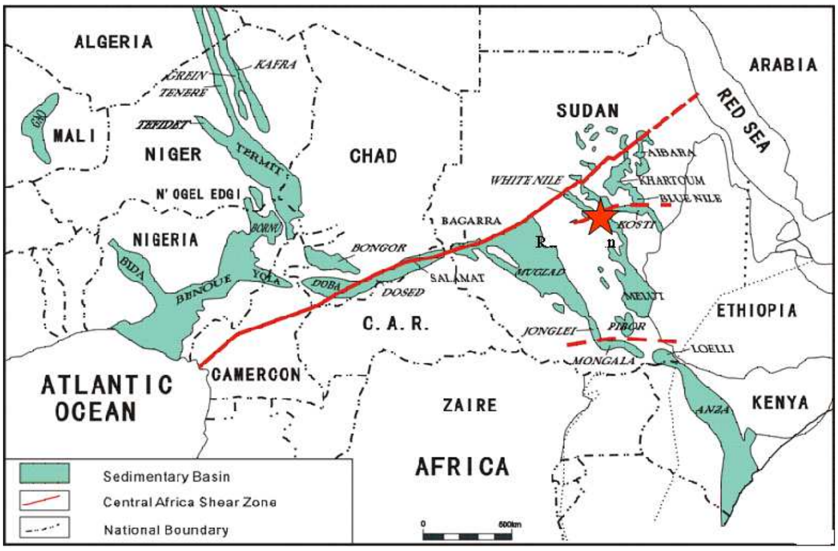

Figure 2. *Major rift basins of Sudan and adjacent countries (modified after Wycisk. et al). [17]*

3. Objective of the Study

The study aims to investigate the nature of the subsurface structures of the oil in Gumry Field, Block 3 & 7, Melut basin. This is to be carried out by interpretation of 3D seismic data and well data from the area using Geoframe Software reference.

4. Methodology

The data used in this work includes seismic processed data of 3D PSTM of Gumry Field located in Melut Basin in Sudan. The work contains 154 sq km of 3D seismic data. Vertical Seismic Profiling data (VSP) and check shots data were provided in digital format.

The interpretation was carried out by the author at Sudapet Company Ltd, using Interpretation and Exploration Software Generation -X (IESX) and Contouring and Plotting Software generation-3 (CPS-3) under Geoframe 4.2. Interpretation is started with the well logs and synthetic seismograms generated for Gumry well. After correlations between well and seismic data, the interpretation by picking minor and major faults on the Yabous horizon in 3D data volume, the horizon is relatively consistent and recognizable and allows for defining the structures of interest. Time and depth maps have been generated for the top of Yabus Formation and then we converted the time map to depth map using the steps of depth conversion and software techniques.

4.1. Interpretation of 3D Seismic Data

The objectives of 3D seismic interpretation are as follows:

To map Gumry field in order to have a clear definition of the structures that embrace the target layers of Yabus tops' reservoirs.

To resolve the structural uncertainties.

Better reservoir determination.

4.1.1. Horizon Identification

One horizon is targeted (top of Yabus Formation), using the 3D seismic data, to define the structural configuration of Gumry prospects formation. Synthetic seismograms and check shots are used to tie the well top to the 3D seismic data. The synthetic seismograms generated for Gumry-1 as shown in Figure 3.

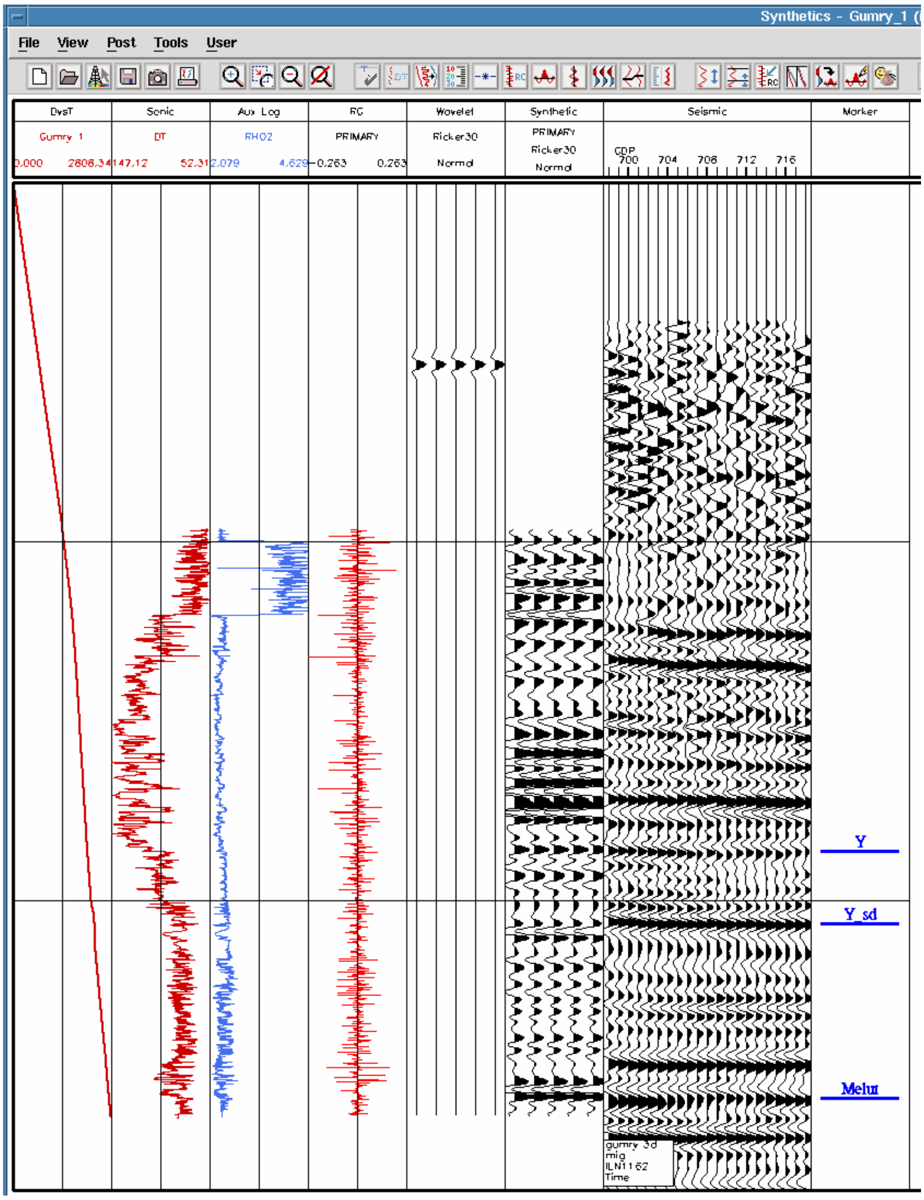

Figure 3. Synthetic seismogram showing Gumry-1 well and the corresponding seismic data.

4.1.2. The Synthetic Seismograms

The synthetic seismogram is generated by convolving the reflectivity derived from digitized acoustic and density logs with the wavelet derived from seismic data. By comparing marker beds or other correlation points picked on well logs with major reflections on the seismic section.

4.1.3. Horizon and Fault Picking

Horizons and fault picking Figure 4 are main factors contributing to the seismic resolution of uncertainties. The 3D seismic data is of good quality at least at the zone of interest, and the horizon and faults are picked with high level of confidence resulting in a clear definition of Gumry structures. The high confidence level is due to the fact that the horizon is picked on seismic section on the work station.

4.2. Fault Identification

The identification of faults is based on their individual fault characters and on advanced techniques such as variance cube geo-feature mapping.

4.2.1. Variance Cube

It is an attribute that can be used to highlight faults and subtle stratigraphic features in 3D seismic volume. In the output cube the high amplitudes are displayed in high contrast. This operation works best with data that is incoherent over the restricted areas. The variance cube can be calculated at every time or depth sample within the area of interest (Figure 5).

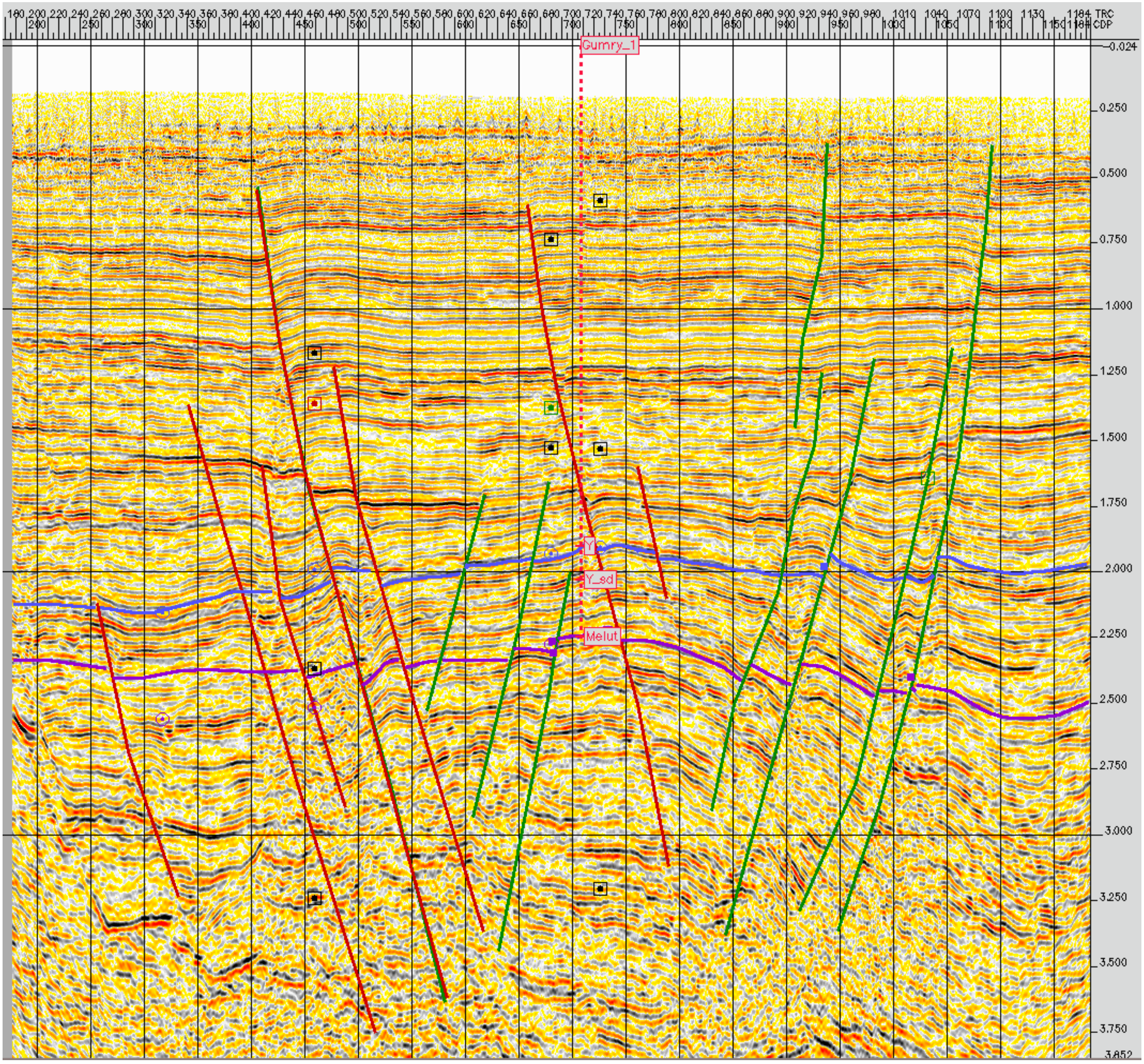

Figure 4. *3D seismic section showing faults and horizons picking.*

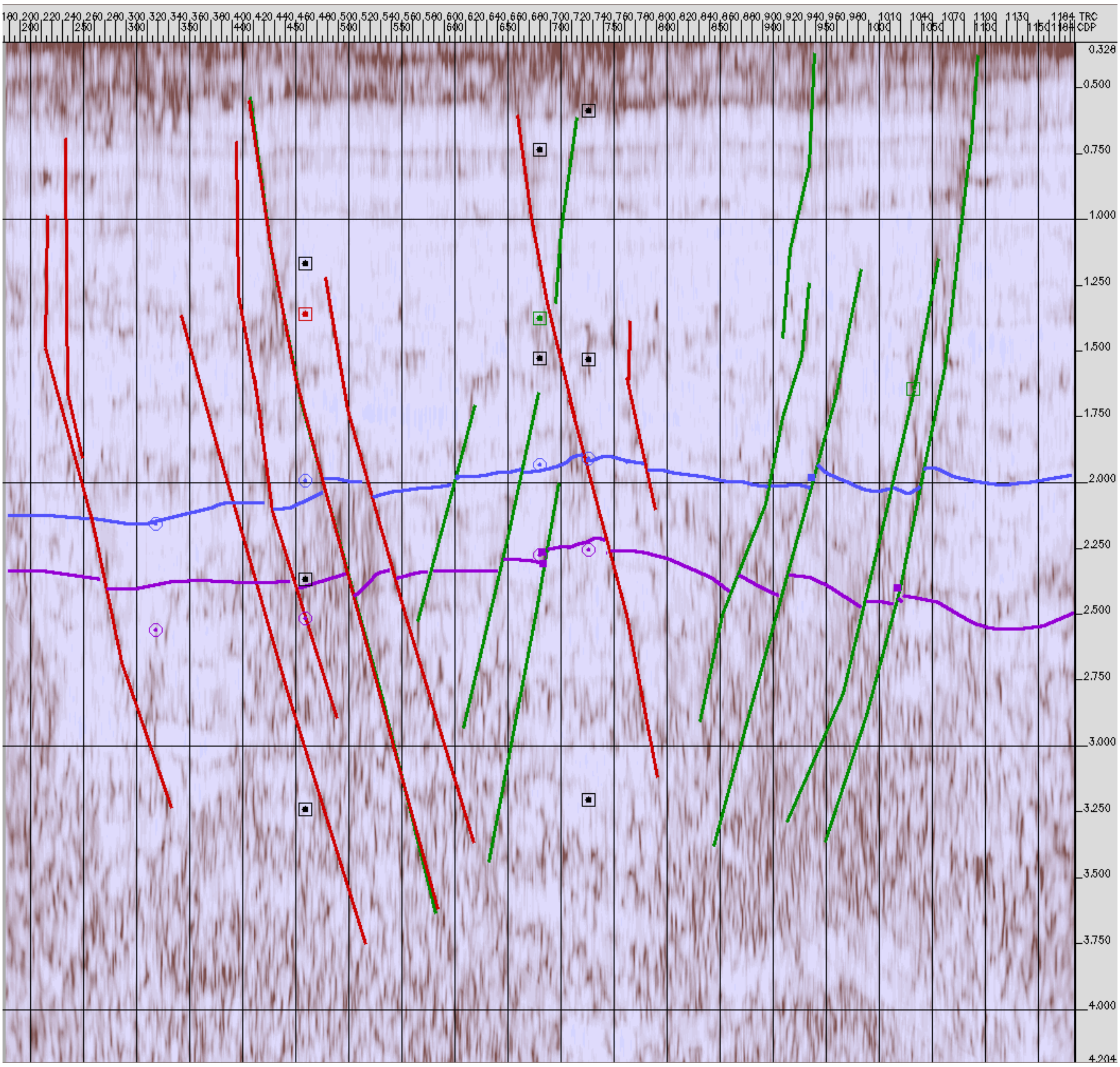

Figure 5. *Variance Cube at 1900 ms with faults and horizons.*

4.2.2. Geo-Feature Mapping

It is a seismic tool to computes attribute providing a measure of similarity between the traces being compared. A high correlation indicates that the traces mach well;

A low correlation indicates that they are dissimilar. Anomalies are delineated based on wavelet shape. In geo-feature mapping attributes the amplitudes are calculated to further confirm the major and minor fault patterns and also it is used to scan the distribution of faults throughout the 3D area Figure 6 shows the result of geofeature mapping.

4.2.3. Fault Boundaries

In this stage all faults contacts are connected together with smooth lines called fault boundaries and then fill them with red color as shown in Figure 7.

4.2.4. Horizon Mappping

Time horizon is picked from image volume obtained from 3D prestack time migration. After interpretation of faults and horizons, a number of sets of time structure maps and depth structure maps are generated for top Yabus Formation as shown in Figure 8 and Figure 9 respectively. In the next pages, these maps are considered as the last step in the interpretation which represent structure traps including (anticline, graben, half graben, horst and faults) but in this study we have only faults in different classification such as normal faults, fault blocks, graben and half graben and also there is faulted anticline has been seen in some sections.

The relation between time map and depth map Figure (8 and Figure 9) in the next pages respectively represent the structures of Yabus Horizon. The first one displays the structures with contour lines in time, second one displays the structures in depth and also includes the prospect area (A) which in green color (Figure 9).

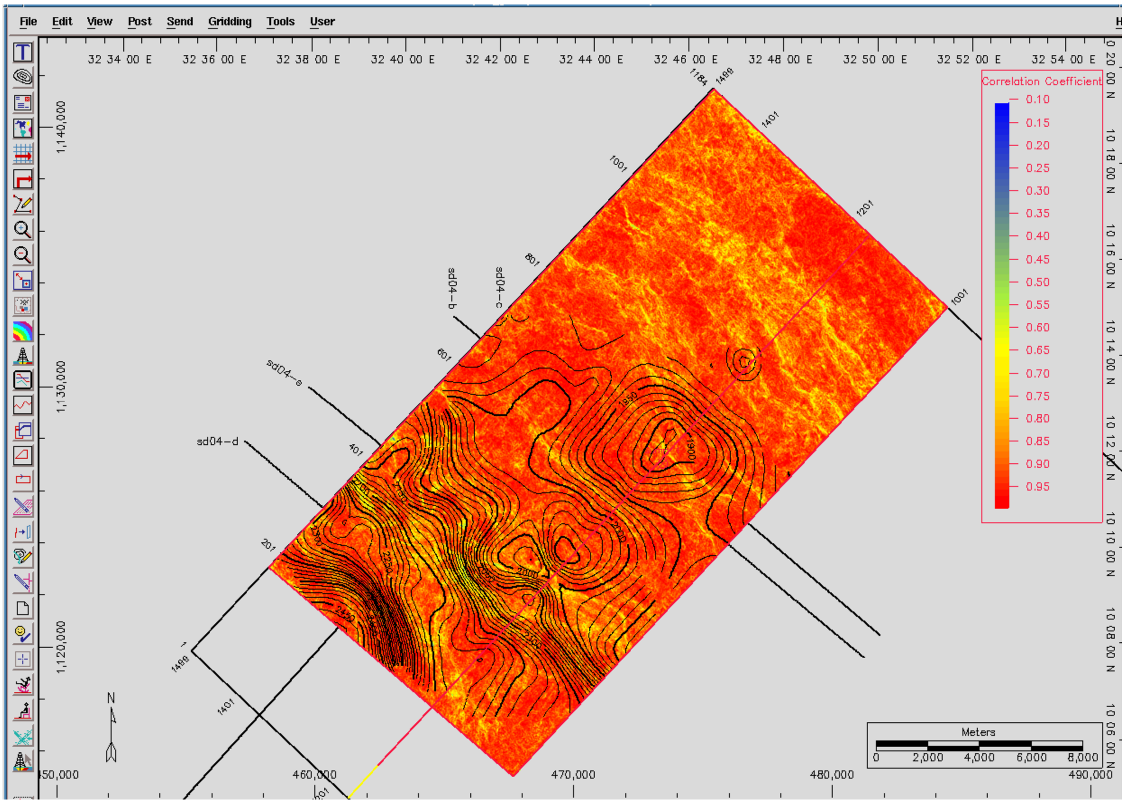

Figure 6. *Geofeature map with contour lines of 2D (black lines) inside 3D.*

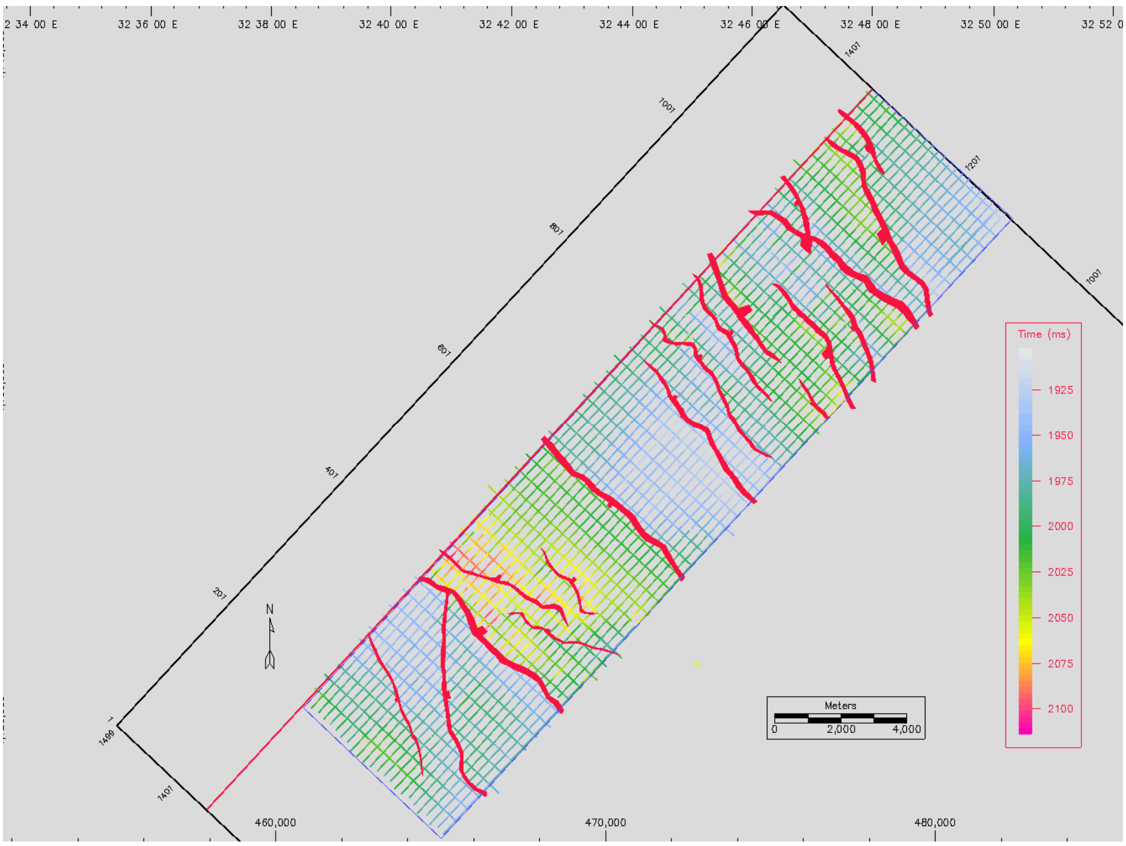

Figure 7. *Showing Fault boundaries.*

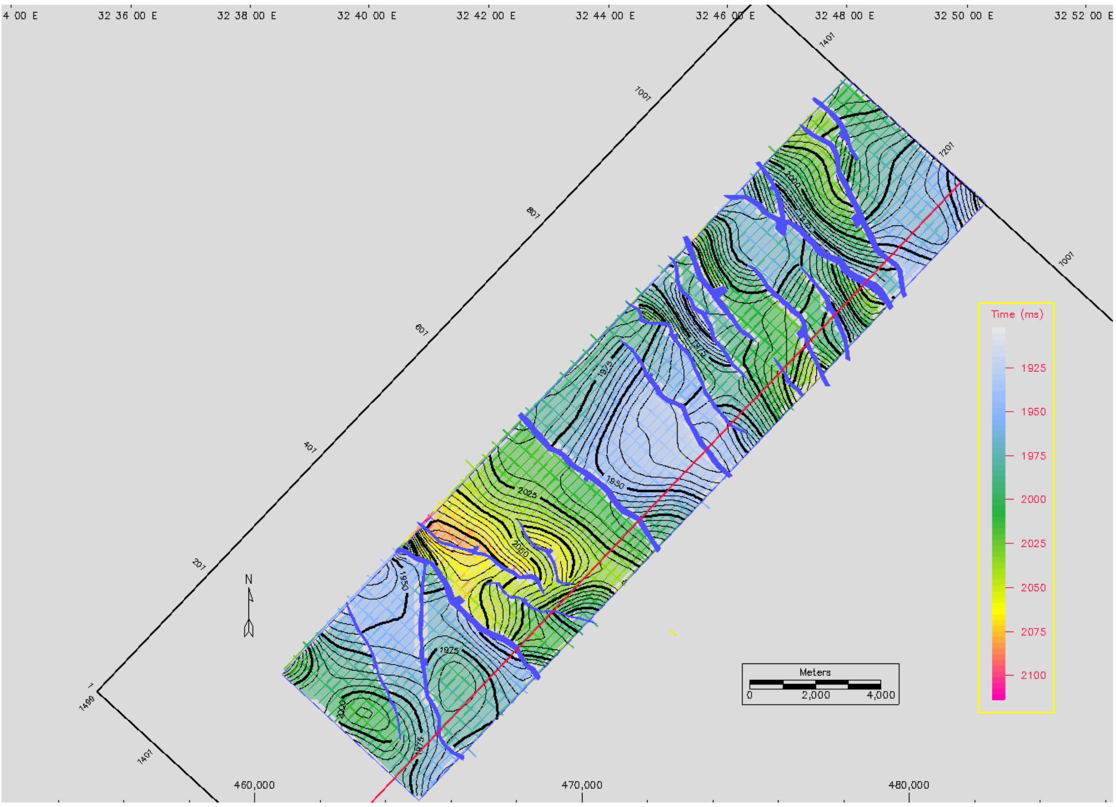

Figure 8. Top Yabous Two Way Time (TWT) Structural Map.

4.2.5. Two Way Time Structural Map of Yabus Formation Top Yabous Depth Structural Map

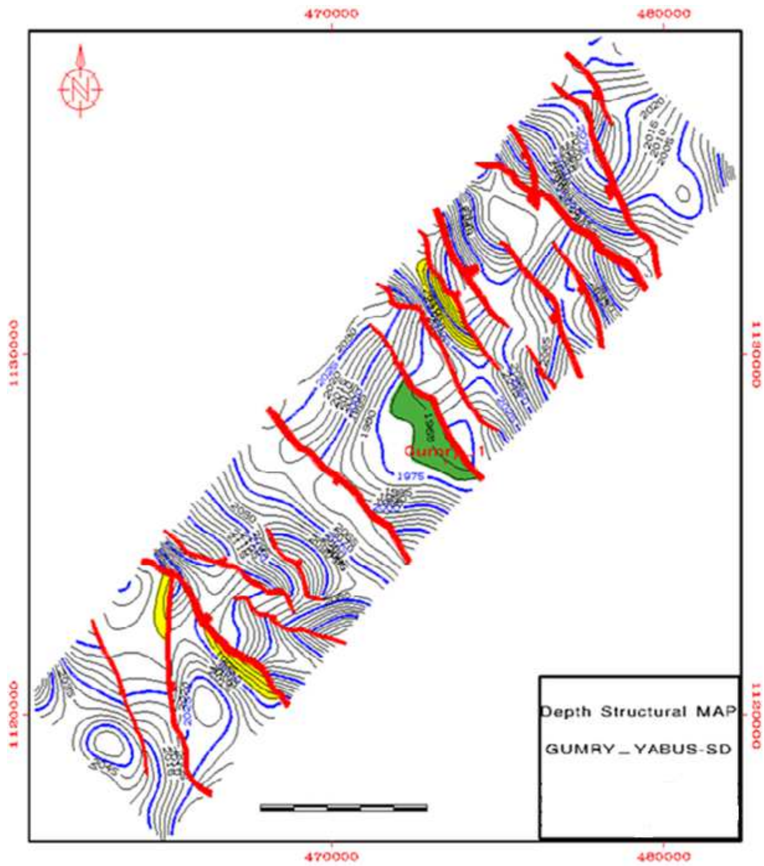

Figure 9. Top Yabous Depth Structural Map.

4.2.6. Time to Depth Conversion and Prospects Generation

The time-to-depth conversion procedure involves the following steps:

(a) Interpret a set of time horizons from an image volume derived from time migration; these time horizons are usually associated with layer boundaries with velocity contrast or geological formations of interest. [19].

(b) Intersect rms velocity functions picked at specified analysis locations over the survey area with the time horizons from step (a) to derive horizon- consistent rms velocity maps. The rms velocity functions are preferably picked from gathers derived from prestack time migration or VSP check shot. [18].

(c) Albeit rarely, a third option is to use normal- incidence rays for depth conversion. Time horizons interpreted from the time-migrated volume of data may first be forward-modeled to derive 3-D zero- offset travel times, which are then depth-converted using normal-incidence rays. Dix conversion still is the robust method for interval velocity estimation [19].

Time to depth conversion was performed using Contouring and Plotting Software Generation-3 (CPS-3) software. Two approaches of time to depth conversion techniques were attempted to see the impact of velocity to the structural closures. These approaches are as follows:

(i). Time (T) Versus Depth (Z) Single Function

In order to tie well information to seismic data it is important to know the relationship between depth and two-way travel time at the well. The sonic log is used to define time/depth points. The time / depth (T-D) curve can be used to determine travel time of a given marker in the well and then compared with the seismic line Table 1. shows the time to depth table.

Table 1. *Time to depth table.*

No	TWT (ms)	DEPTH (m)
1	500	1300
2	1000	2200
3	1500	2800
4	2000	3200

(ii). Check Shots

A type of borehole seismic data designed to measure the seismic travel time from the surface to a known depth. A check-shot-corrected sonic log also makes it easier to determine interval velocities between key formations, since familiar formation boundaries can be readily recognized from the sonic log. If density log information is also available, more accurate synthetic seismogram log integration usually results. Borehole seismic data that include the check shot velocity survey and the VSP (Figure 11) can measure large volumes of rock and will indicate the presence of velocity anomalies which may be totally missed by the sonic log. These velocity anomalies must be measured and dealt with accurately when mapping the velocity fields that are so critical to an effective surface-seismic time to drill-depth conversion process.

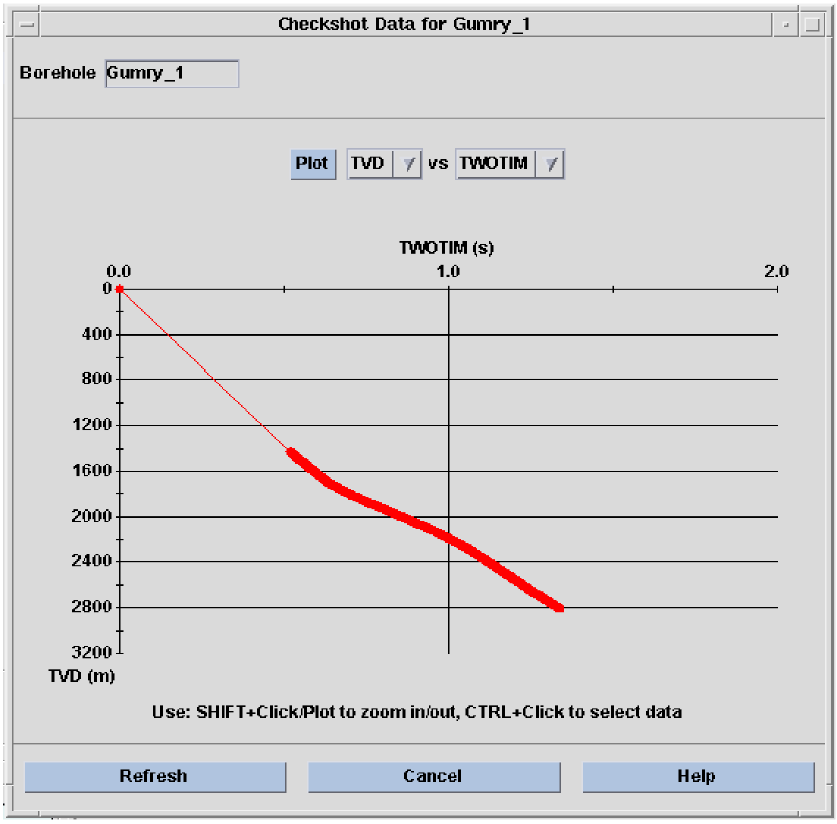

Figure 10. *Time (T) to Depth (Z) curves of Gumry well.*

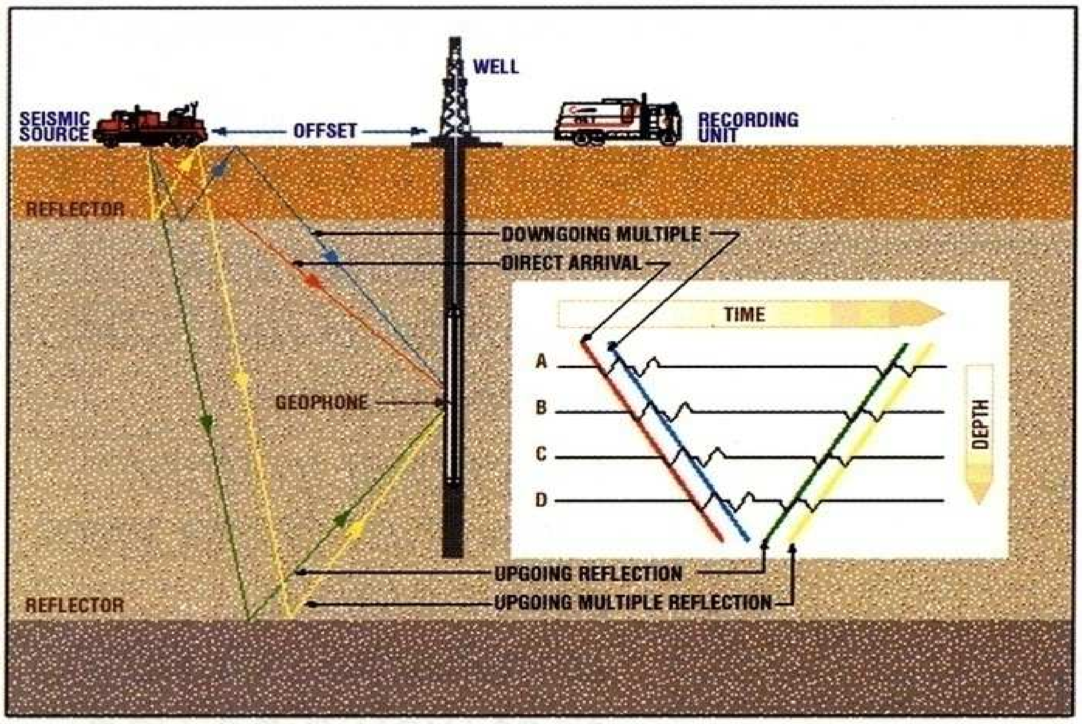

Figure 11. *Check-shot borehole seismic survey.*

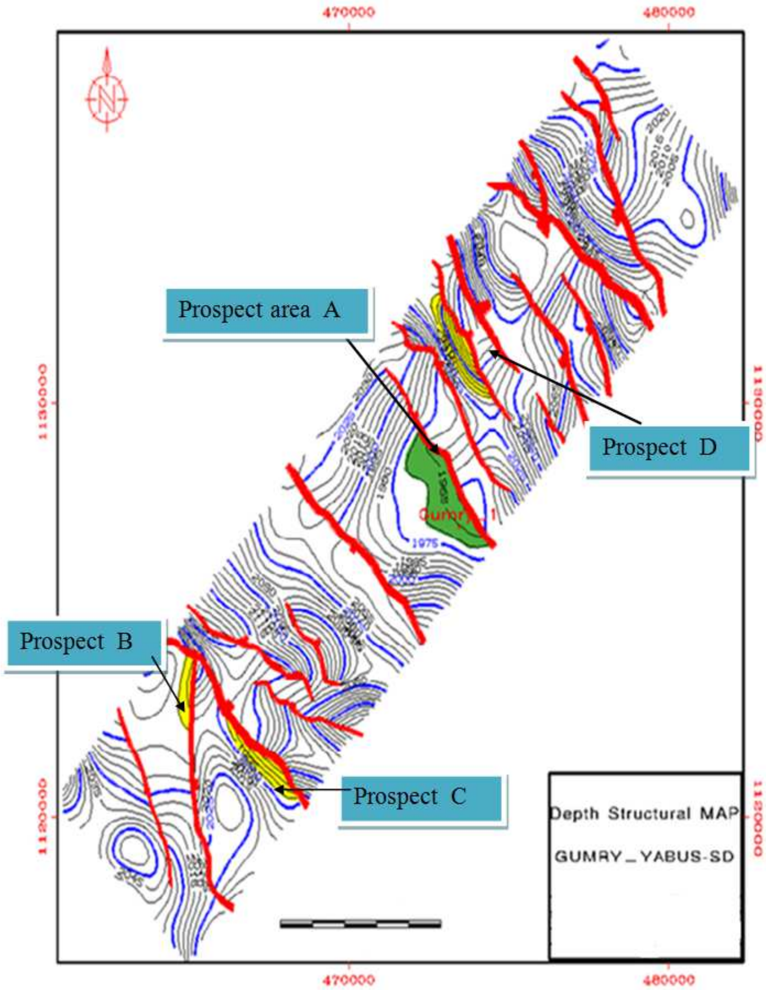

Figure 12. *Top Yabous Depth Structural Map showing the prospects.*

Table 2. *Showing prospects area at top Yabous Depth Map.*

No	Trap Name	Trap Area (sq k)	Burid Depth (m)	Closure Relief (m)	Strike
1	Prospect A	1.25	2359	15	NW-SE
2	Prospect B	1.00	2010	30	NW-SE
3	Prospect C	0.6	1795	20	NW-SE
4	Prospect D	1.68	1995	15	NW-SE

There are three other prospects which A, B, C and D with trap ares (1.25, 1.00, 0.6, 1.06) with depth (2359, 2010, 1795, 1995), reliefs (15, 30, 20, 15) and their strike NW-SE.

5. Result and Discussion of Structural Features

Based on gravity data, Melut Basin is formed of four sub-basins named: North Melut Sub-Basin, East Melut Sub-Basin, West Melut Sub-Basin and South Melut Sub-Basin. They are mainly controlled by NW-SE and/or NNW-SSE-striking normal faults. The sediments infilling these basins are characterized by thick nonmarine clastic sequences of Cretaceous, Tertiary and Quaternary Period. More than 15,000 ft of sediments were deposited at the deepest parts of the sub-basins. The basin was formed as a result of multi-structural system of the Sudanese rifts which was developed during late Jurassic to Cretaceous, and appears to have been activated several times since the Paleozoic. A variety of structures have been created in Melut basin, some of which are effective hydrocarbon habitats primarily or secondarily.

Gumry basin is a highly faulted belt with many small faults. Most of the said faults are of the SW and NE dipping. The trap analysis of Gumry structural setup indicates that Gumry oil field prospects are mainly fault block structures, located at the hanging wall of the normal fault block or fault nose. The fault throws are approximately 10 km (at Yabus horizon). The maximum trap areas of the said prospect is, approximately 1.25 sq.km (Figure 12). There are also other structures such as graben and half graben referred to as block faulting, fault trap and faulted anticline as shown in seismic section (Figure 13).

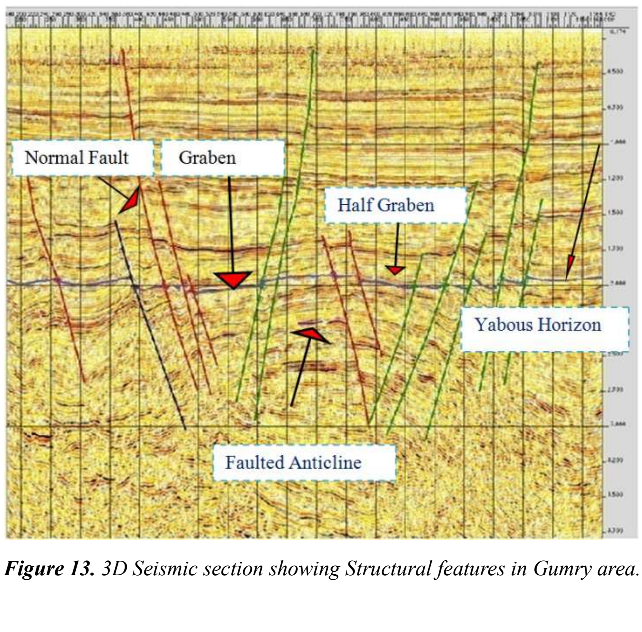

Figure 13. *3D Seismic section showing Structural features in Gumry area.*

6. Conclusions

The 3D data interpretation results of top Yabus horizon confirmed the structures of Gumry oil field. Different approaches in interpretation using geofeature mapping, variance cube techniques are adopted in an effort to support the accuracy and expedite the interpretation. The study of the area indicates that Gumry area is characterized by different oil structures such as grabens, half graben, fault trap and faulted anticline. In Yabus, prospects are mainly, fault trap structure, located at the up thrown side of the normal Fault. The fault throw is approximately 10 m (at Yabus horizon). The length of the fault is 10.84 km. The maximum trap area of the said prospect is approximately 1.25 sq. km with buried depth 2359 m, likewise there are other three prospects have been observed in depth map such as prospect B, C & D without wells and other faults.

The depth map in 3D shows that the structures controlled by NW and SE dipping and NW-SE or NNW-SSE-striking normal faults.

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