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CERTIFICATE

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, DEHRADUN

This is to certify that Mr. S. Girrish Karthik and B. Raj Kumar, 2nd year student of M.Tech Petroleum Exploration at University of Petroleum & Energy Studies, Dehradun has successfully completed academic project training on "**STUDY OF RESERVOIR COMPARTMENTALIZATION USING STOCHASTIC MODELLING ASSISTED BY PRODUCTION DATA ANALYSIS**" during the period of 5th January , 2015 to 30th April, 2015 under the guidance of Dr. U. Kedareswarudu, Professor, University Of Petroleum And Energy Studies, Dehradun.

Project guide

Dr. U. Kedareswarudu

Professor

UPES, Dehradun

DECLARATION

This is hereby, declared that this project entitled "**STUDY OF RESERVOIR COMPARTMENTALIZATION USING STOCHASTIC MODELLING ASSISTED BY PRODUCTION DATA ANALYSIS**" is authenticated work done by S. Girrish Karthik and B. Raj Kumar of M.Tech (Petroleum Exploration) under the guidance Dr. U. Kedareswarudu of Department of Petroleum and Earth Sciences, UPES. This report work is submitted for the partial fulfilment for the award of degree of M.Tech (Petroleum Exploration) under UPES. This work done is not submitted to any other University or Institute for the award of any Degree or Diploma.

S. Girrish Karthik B.Raj Kumar

ABSTRACT

The reservoir compartmentalization is an important factor in analyzing the fault oriented reservoirs, where there are sealing blocks created due to the tectonic processes. The Suspicion of reservoir compartmentalisation often leads naturally to a discussion of faults and fault seal, particularly in clastic reservoirs and especially when sub-seismic faulting is anticipated. The problem can solved by the fundamental analysis of the reservoir upto the production and composition data analysis. The approach used here starts right from the seismic data interpretation to the subsurface modelling and finally the production data analysis to estimate the compartmentalization. The data acquired from the Rocky Mountain Oil Testing Center was used for this study which contains the required data of the Naval Petroleum Reserve-3, Wyoming in U.S.A. The data corresponds to the Teapot Dome and Salt Creek Oil field present there. The study is done using Petrel Platform 2013.2 and MBal software. The resultant model can be used to study the effects of compartmentalization on a reservoir right after drilling the appraisal wells.

Keywords: Reservoir Compartmentalization, fault seals, Static reservoir model, Production data analysis, Teapot Dome, Salt Creek field, Petrel

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1. INTRODUCTION

The area of study here is the Naval Petroleum Reserve-3, Wyoming in U.S.A. The Government of U.S had setup Rocky Mountain Oil Testing Center (RMOTC) to evaluate the petroleum prospects beneath the Teapot Dome and Salt Creek Oil fields. The RMOTC had acquired the geophysical and geological data all over the NPR-3 and announced the data to be non-proprietary and can be intended for scientific research purpose.

The data has been analyzed for the geophysical and structural processes that can be employed to estimate the petroleum system and the possible amount of reserves that can be recovered from the actual reserves.

As this Teapot Dome was familiar for the oil and gas production since 1880, the RMOTC have been employed to process the old vintage data from the papers that are analyzed manually to the digital format that can be analyzed using the computers.

1.1 Geological Significance of NPR-3, Wyoming

The U.S. geological survey has conducted a survey over NPR-3 in 1927. Manual mapping in scale of 1:1000 feet, was conducted with wells, faults and outcrops within productive part of the Teapot Field and adjacent parts of the Salt Creek Field.

1.2 History of Development

There were indications and Seepages of oil which had been found in the Salt Creek region prior to 1880. Also, in 1915 the presence of mineral wax or ozokerite within NPR-3 was identified.

Both the Salt Creek and Teapot were examined since 1879 and seepages were found in 1880. The prospect area was first drilled in 1889. Oil was first developed in Shannon Pool, were a small accumulation of oil was discovered in Shannon Sandstone on the northern flank of the Salt Creek Dome.

From the year 1889 to 1905 Shannon Pool was developed. During this period a total of 53,441 barrels of oil was produced and sold. The crude properties are described as Green crude with paraffin base, which had no gasoline. With an API of 24° and initial boiling point of 210°C.

Discovery of Shale Oil happened in 1906 and further deeper formations were considered thereafter. But, further developments were discontinued till 1920 due to legal issues.

The second sand formations were drilled and brought to completion on August 26, 1917. The formation depth was calculated to be 2,270 feet, which provided a commercial quantity of oil.

The major operator companies were Producers and Refineries Corporation till 1921 and Mammoth Oil Corporation till 1922.

The Map of Teapot area was made by Estabrook and Morley in 1920. The map indicated the structural saddle between Teapot and Salt Creek domes which lay within the naval reserve.

Wolverine Oil Corporation in 1918, drilled through “Second Wall Creek Sand” at a depth of 2,050 feet and showed commercial production. Mammoth Oil Corporation got lease on April 7, 1922 drilled wells and extracted at 100 percent capacity of reserves.

Government cancelled the lease on March 13, 1924 and the total control of reserves was turned over to Navy Department on December 29, 1927. The left out oil was given to Navy for future use.

Table 1 Various Oil Producers inTeapot

TABLE 1.—*Dates of completion of Mammoth Oil Co.'s wells along northwestern boundary line of reserve, as compared with dates of completion of wells on adjacent leased lands in Salt Creek oil field*

Wells in Salt Creek field				Mammoth Oil Co.'s offset wells		
No.	Location (T. 39 N., R. 78 W.)	Begun	Completed	No.	Begun	Completed
Argo No. 4	SW. ¼ sec. 16	July 5, 1922	Nov. 26, 1922	201–21	July 11, 1922	Jan. 27, 1923
Argo No. 3	SE. ¼ sec. 17	Oct. 12, 1922	Dec. 29, 1922	102–20	Sept. 19, 1922	Dec. 10, 1922
Argo No. 4	do	June 15, 1923	Aug. 28, 1923			
Argo No. 5	do	May 19, 1923	July 13, 1923	103–20	Mar. 31, 1923	June 4, 1923
Producers & Refiners No. 8	NE. ¼ sec. 20	Apr. 7, 1923	May 29, 1923			
Producers & Refiners No. 2	do	June 26, 1922	Sept. 6, 1922	101–20	Aug. 10, 1922	Dec. 20, 1922
				105–20	Apr. 27, 1923	July 27, 1923
Producers & Refiners No. 9	do	May 20, 1923	July 7, 1923	407–20	May 27, 1923	July 11, 1923
				408–20	May 30, 1923	Aug. 24, 1923
Producers & Refiners No. 5	do	Nov. 19, 1922	Feb. 3, 1923			
Producers & Refiners No. 7	NW. ¼ sec. 20	Mar. 8, 1923	May 8, 1923	401–20	Sept. 26, 1922	May 1, 1923
Argo No. 3	SW. ¼ sec. 20	June 11, 1923	July 28, 1923			
Argo No. 5	do	Mar. 25, 1924	June 3, 1924	409–20	May 15, 1924	June 30, 1924
Argo No. 6	do	Apr. 23, 1924	June 18, 1924	410–20	May 26, 1924	July 17, 1924
				402–20	Feb. 20, 1923	May 12, 1923
Argo No. 2	do	Mar. 19, 1923	May 17, 1923	101–29	Apr. 1, 1923	June 5, 1923
				201–29	July 20, 1922	Nov. 29, 1922
Argo No. 4	do	Apr. 4, 1923	June 2, 1923			
Ohio No. 4	do	May 2, 1923	Aug. 4, 1923	203–29	Mar. 23, 1923	June 24, 1923
Ohio No. 3	NW. ¼ sec. 29	Mar. 10, 1923	June 20, 1923			
Ohio No. 5	do	Apr. 10, 1923	June 15, 1923	204–29	Apr. 5, 1923	May 24, 1923

2 GEOGRAPHY

2.1 Location and Extent of Field

U.S. NPR-3 has a total area of 9300acres in Natrona County, Wyoming, which is 25-30miles N-NE of Casper and an equal distance SE of Big Horn Mountains. The map is provided in the following page.

2.2 Accessibility

Geographically and geologically, Teapot Field is closely related to the larger Salt Creek Oil Field. It is connected very well with Casper through highways and with railways. Several pipelines were constructed in the later part.

2.3 Topographic Features

NPR-3 lies near the western margin of the high plains or western part of the Great Plains region and characterized by the topographic features as per the climatic conditions of the region. The topographic map is provided below

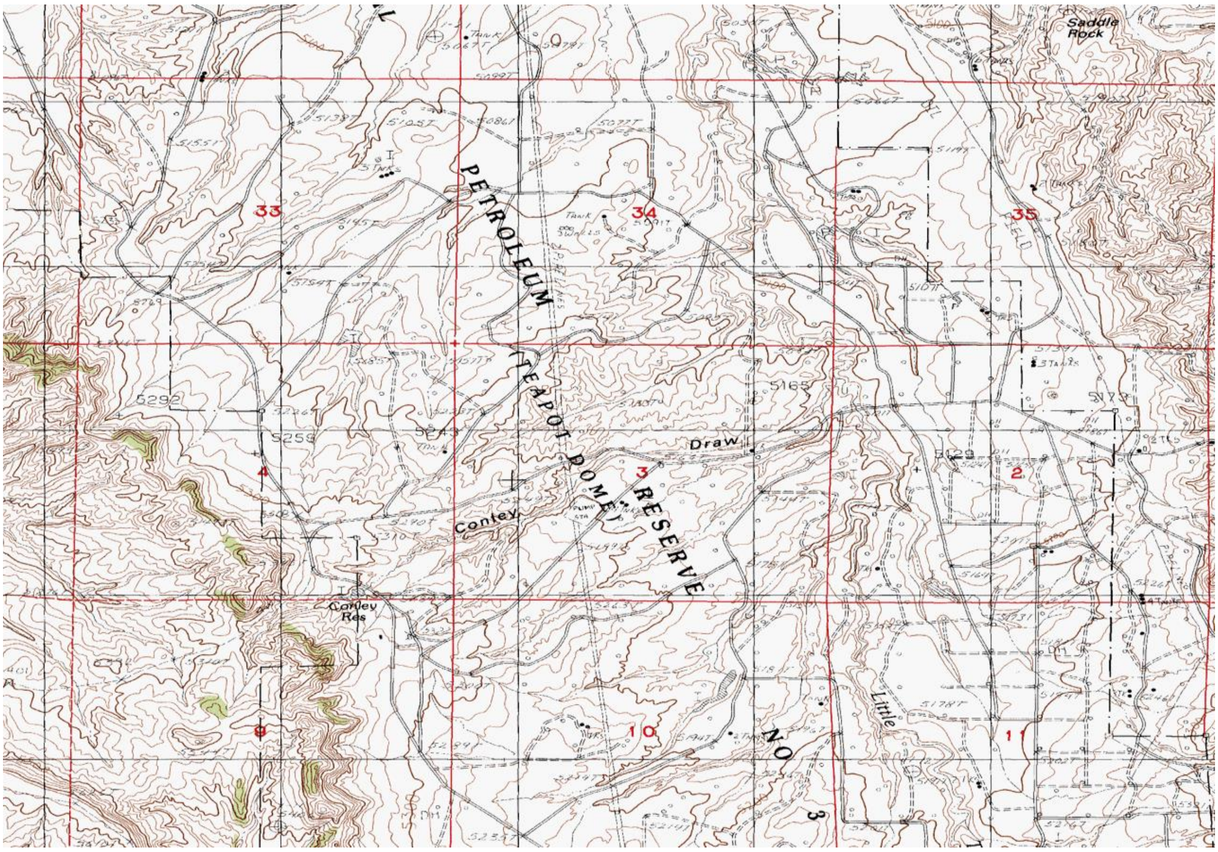


Figure 1Location of NPR-3

3 GEOLOGY

3.1 Stratigraphy

Sedimentary formations both exposed and underlying the Teapot and Salt Creek Oil fields are wide within eastern Wyoming and were deposited along or near the shores of a sea or gulf which in early cretaceous period extended over the Rocky Mountain region.

The deposits are cited along or near the shores of sea or gulf, which in early Cretaceous time extended over much of the Rocky Mountain region.

The stratigraphy related to the Powder River basin, which is a structural depression corresponding to the lowland area surrounded by the Big Horn Mountains on the west, the Black Hills on the east and Casper Mountains in the south Teapot and Salt Creek area lies along the western margin of this margin basin.

Formations consist of marine Shale's interbedded with beach and near-shore sands that grow thinner toward the East and North East, where progressively greater depths of water existed when the formations were being laid down. Some limy beds also underlie the Teapot domes, but thick limestones are present only in the sedimentary column far below the sands so far penetrated within the reserve.

3.1.1 Exposed Rocks

PARKMAN SANDSTONE MEMBER OF MESAVERDE FORMATION

The youngest rocks exposed within the reserve belong to the Parkman sandstone, which is the lowest member of the Mesaverde formation in this area

Upper sandstone -The upper part consists locally of massive yellow sandstone, which is not persistent but merges laterally, within short distances, into yellow sandy shale and thinner beds of sandstone.

Middle shale -The middle part of the Parkman member consists chiefly of dark carbonaceous shale containing layers of iron ore and thin coal beds developed in brackish coastal-plain swamps. The thickness of this unit is about 190 feet.

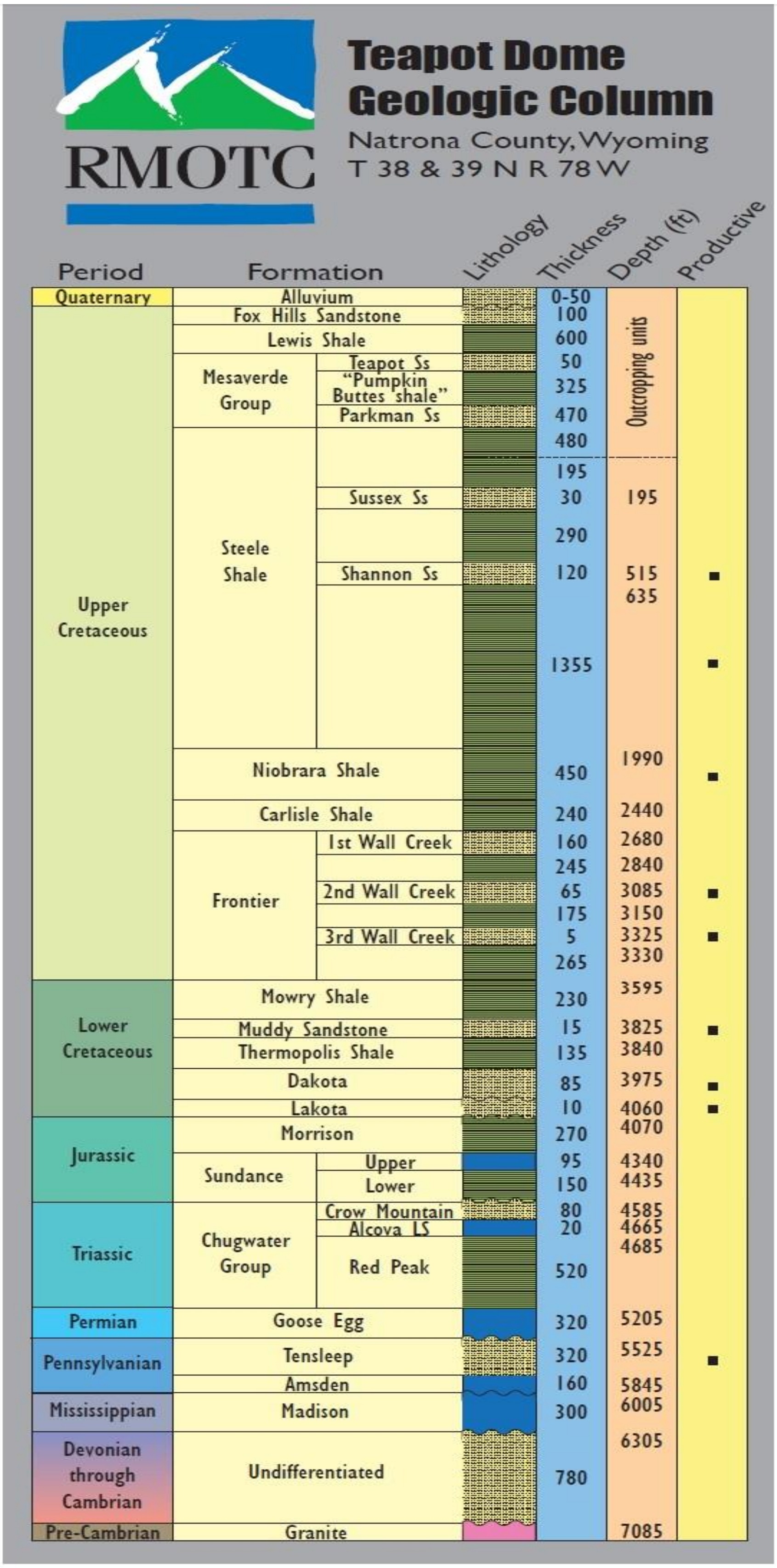


Figure 2Stratigraphic chart

Lower sandstones -The lower part of the Parkman member comprises the series of sandstone beds forming the inner face of the horseshoe shaped escarpment that borders the Teapot field.

The thickness of this white sandstone above the key bed ranges from 38 to 54 feet; and the aggregate thickness of the whole of the lower division of the Parkman ranges from about 170 to 190 feet,

STEELE SHALE

The Steele shale includes the beds between the Parkman sandstone member of the Mesaverde formation and the Niobrara shale and consists of upper and lower shale members separated by the Shannon sandstone member.

Upper member -The upper member of the Steele shale is about 1,450 feet thick and apparently underlies the Parkman conformably, the persistent series of thin sandstones in the upper part of the Steele, which form minor ledges beneath the Parkman rim.

Numerous beds of bentonite, are conspicuously developed in a zone between 400 and 550 feet above the base of the upper member of the Steele shale and afford one of the important guides for determining the structural details within the Teapot field.

Shannon sandstone member - The top of the Shannon sandstone is exposed along or just outside of the North Western edge of the reserve, and the whole member can be studied in detail along its escarpment a mile northwest of the reserve boundary. It is about 135 feet thick.

Thus normally the Shannon consists of two benches of sandstone capped by hard layers separated by an interval of dark clay containing large concretions of greenish sandstone. Water and minor amounts of oil have been found in the Shannon.

3.1.2 Unexposed Rocks

The sedimentary rocks below the Shannon sandstone are not exposed in the Teapot field, and their sequence and general character, are known either from well records, from partial exposures in the Salt Creek and Tisdale uplifts, or from outcrops along the flank of the Big Horn Mountains.

STEELE SHALE

Lower member.-The lower member of the Steele shale corresponds closely to the Telegraph Creek formation 20 of southern Montana, in the Salt Creek field, of about 1,000 feet of gray shale interbedded with thin ferruginous layers and a few bentonite beds. A thin conglomerate, commonly spoken of as the "fish-tooth conglomerate," occurs about the middle of the member and, besides shark teeth, contains fossil saurian bones.

FRONTIER FORMATION

The Wall Creek sandstone member ("**First Wall Creek sand**" of drillers) the top of the Frontier formation. The "Wall Creek sands" are at the present time of major importance as sources of oil in the Teapot and Salt Creek fields.

As a continuous sand with an average thickness of 136 feet, but it is really composed of two distinct parts separated by either a shale bed or a layer of hard limy sand. The upper layer, or bench, is 80 to 100 feet, and the lower about 20 feet thick. The lower sand contains water under high pressures and is sometimes sufficiently porous to yield an artesian flow of several thousand barrels per day when first tapped. In some places this bed seems to pinch out entirely, and only the inconsequential water of the upper layer will be encountered in a well, but usually water will fill the hole 1,000 feet or more as soon as the lower bench is tapped.

"Second Wall Greek sand."-The "Second Wall Creek sand" is the one of present importance in the Teapot field and has yielded the greater part of the oil obtained at Salt Creek. It is not over 20 or 25 feet thick in its massive part, although sandy shale above and below it may carry oil. It is the highest bed that carries pine trees and is a, massive medium-grained sandstone, with a calcareous cement, and would apparently form a good reservoir for oil. The Second Wall Creek sand varies in thickness from 20 to 100 feet.

"**Third Wall Creek sand**."- At its outcrop the "Third Wall Creek sand" comprises two benches, the lower one, from 30 to 40 feet thick, consisting of "medium-grained dirty-white sandstone" supporting a growth of pine trees, and the upper one, separated from the lower by 35 feet of gray shale, consisting of "25 feet of Shaly sandstone, also carrying a growth of pine."

The Third Wall Creek sand is found from 625 to 675 feet below the top of the First sand. At Powder River, the upper 20 feet and the lower 30 feet thick with a 35-foot shale bed between them. At Salt Creek the lower bench of sand is seldom found and the upper bench is very lenticular. 'Thirty wells have been drilled to the Third sand horizon [in the Salt Creek field

MOWRY SHALE

The Mowry shale is conspicuous at its outcrop because of its light colour, scarp-forming habit, and abundance of contained "fossil fish scales. It consists of hard dark shale that splits into thin plates and weathers a silvery gray, interbedded with several layers of bentonite, one of which rests upon the top layer of the "fish-scale" shale. The local thickness of the Mowry probably ranges from 230 to 280 feet.

THERMOPOLIS SHALE

The Thermopolis shale, which underlies the Mowry, consists chiefly of very dark soft shale containing plant. The lower part of the Thermopolis consists of 175 to 200 feet of dark shale containing plant fragments. Shark teeth are also found in the basal beds.

CLOVERLY FORMATION

The Cloverly formation underlies the Thermopolis shale and consists of two sands and an intermediate shale. The upper sand is called by the drillers the "Dakota sand" and the lower one the "Lakota sand".

"**Dakota sand**."-At its outcrop the "Dakota sand" consists of 14 feet of shaly sandstone which is strongly ripple-marked in its upper layers, and in the Salt Creek field it ranges from an inch or less to 14 feet in thickness and contains small amounts of oil and gas.

Middle shale member -The shale that underlies the "Dakota sand" is a varicoloured or dark massive shale 70 to 80 feet in thickness.

"Lakota sand"- as developed in the Salt Creek field is about 70 feet thick and consists' of sandstone beds separated by thin layers of shale. This multiple character is indicated by variations in the yield of oil and by the temperature of water encountered at different depths in the sand.

MORRISON FORMATION

In the Salt Creek field the Morrison appears to consist of about 300 feet of soft purple to green clay interbedded with hard fine-grained sandstone, especially between 110 and 225 feet above the base of the formation. At its outcrop the Morrison is about 250 feet thick and consists of shale interbedded with four or five hard thin sandstones which form conspicuous ledges along the outcrop. Oil seeps from at least two of these sandstones in the Tisdale anticline and fresh-water shells and the bones of dinosaurs have been found along the Morrison outcrops over wide areas.

SUNDANCE FORMATION

The Sundance formation, of Upper Jurassic age, underlies the Morrison conformably and as ordinarily identified in well records consists of a 100-foot upper bench of limestone and sandstone; a lower bench, feet thick, of sandstone, limestone, and shale and a middle member, 90 feet thick, of grayish shale, sandy shale, and soft sandstone. Part of the red rocks below the lower hard bench may belong either to the Sundance or to the Upper Triassic Jelm formation but definite evidence on this point is lacking.·

CHUGWATER FORMATION

The Chugwater formation ("Red Beds"), of Triassic age, as at present identified in Salt Creek Well records, consists of about 700 feet of massive red shale and sandstone, interbedded with some limestone beds and beds of gypsum.

EMBAR FORMATION

Beds tentatively correlated with the Embar formation, of Permian age, underlie the Chugwater and consist of 220 feet of ·alternating limestone and red shale, interbedded with a few layers of varicoloured sandstone.

TENSLEEP SANDSTONE

The Tensleep sandstone, of Pennsylvanian age, underlies the Embar and consists of about 270 feet of massive cross-bedded white sandstone, interbedded with a few thin layers of dark-brown limestone. This sandstone has been reached by a deep well just southwest of the town of Midwest, in the Salt Creek field, and there yields a flow of several thousand barrels a day of water having a temperature of about 170° F.

A second well drilled in 1930 reached the Tensleep at a depth of about 3, 780 feet and obtained an initial yield of about 1,900 barrels a day of heavy oil.

3.2 Structure of region surrounding Naval Petroleum Reserve no. 3

Naval Petroleum Reserve No.3 lies near the south western n1argin of the great structural depression commonly spoken of as the Powder River Basin, which is bordered by the Big Horn Mountain uplift on the west, by the Casper Mountains and Hartville uplift on the south and southeast, and by the Black Hills uplift on the east.

The position of this major basin is clearly indicated on the geologic map of North America and on the map of the coal fields of the United States by the oblong tongue of coal-bearing rocks which projects southward from Montana into the part of Wyoming between the Big Horn Mountains and Black Hills.

Near Kaycee an anticlinal spur projects south eastward from the Big Horn Mountains into the south western part of the Powder River Basin, on which the minor uplifts of the Kaycee, Tisdale (Powder River), and Salt Creek anticlines are superimposed.

The Salt Creek anticline extends at least from the northern part of T. 40 N., R. 79 W., into the south western part of T- 37 N, R-77 W, and upon this anticline the Salt Creek and Teapot domes are in turn superimposed.

The Salt Creek fold is not symmetrical, for its crest is much nearer its western than its eastern limit. The width of the eastern limb of the fold, measured from the crest to the bottom of the adjoining syncline, is about 20 miles, whereas the width of the western limb, measured from the crest to the bottom of the adjoining syncline, is only about a mile and a quarter. From northwest to southeast the Salt Creek anticline [including the Teapot field] is approximately 30 miles long.

Teapot uplift is shown as two complete domes instead of a single elongated uplift broken by faults into a number of segments. The Salt Creek dome lies upon the north end of the Salt Creek anticline, and its apex rises structurally about 1,200 feet above that of the Teapot uplift. It is much larger and less elongated than the Teapot Dome, but the two domes have similar steepening of the west flank and similar fault patterns.

The Teapot and Salt Creek domes lie, near the south and north ends of the Salt Creek anticline and are separated by the Castle Rock and other minor faulted uplifts.

The displacement along the local faults ranges from a few inches to about 280 feet. The arrangement of the faults with respect to the anticline and with respect to each other clearly shows that they were breaks which developed during the elevation and flexing of the anticline.

Compression was produced by forces applied, at once upward and north eastward, against the west flank of the Teapot Dome, causing breaks to develop across the axis of the fold, approximately in the direction of the forces applied. In places this faulting was accompanied by lateral crowding of one fault wall past the other, with consequent differential up bowing along parts of the anticlinal axis.

3.3 Occurrence of Oil, Gas, And Underground Water

Except beneath the higher parts of the Salt Creek and Teapot up folds the sands that yield oil in these fields contain water under strong hydrostatic or artesian pressure. Consequently the oil and gas present, being lighter than the water, have accumulated beneath the uplifts-free gas, being lightest, tending to occupy the tops of the domes.

4 LITERATURE SURVEY

Definition of compartmentalization Process

A reservoir is said to be compartmentalized, if the reservoir fluids cannot flow freely from one part of the reservoir to another over production time-scales.

(Reservoir Compartmentalization S.J.Jolley, Q.J.Fisher, R.B.Ainsworth, P.J.Vrolijk)

The Concept of Compartmentalization

Reservoir Compartmentalization – the segregation of a petroleum accumulation into a number of individual fluid/pressure compartments – occurs when flow is prevented across 'sealed' boundaries in the reservoir. These boundaries are caused by a variety of geological and fluid dynamic factors, but there are two basic types:

Static seals - that are completely sealed and capable of withholding (trapping) petroleum columns over geological time;

Dynamic seals- that are low to very low permeability flow baffles that reduce petroleum cross-flow to infinitesimally slow rates. The latter allow fluids and pressures to equilibrate across a boundary over geological time-scales, but act as seals over production time-scales, because they prevent cross-flow at normal production rates – such that fluid contacts, saturations and pressures progressively segregate into 'dynamic' compartments.

Mechanisms of compartmentalization

Faulting

Depositional heterogeneity

Various reservoir complexities

Effects of compartmentalization

Adverse effect on oil and gas recovery during the initial period of production.

Effective drilling of wells, if identified early.

Challenges

Limited data that are available during appraisal

Long-term production data is not available

Data Required

3D Seismic

Well log

Core

Hydrocarbon and water compositions and Contacts

Fluid Pressure data

Well test data (Maybe)

Earlier studies

Small range of fluid data used as an on/off compartmentalization indicator.

Identify the statistical differences in pressure or fluid composition between different parts of the field and hence conclude the compartmentalization.

May lead to false negatives or false positives.

Only just a prediction if compartmentalization is present or not, but not the probability and extent of compartmentalization.

Later studies

Wide range of different data types, including seismic and log data, oil and water chemistry, pressure, PVT properties and sedimentological and biostratigraphic data.

Integration of many fluid properties that all had different mixing rates made the interpretations much less prone to false negatives and positives.

Quantitative analysis of mixing rates using analytical models for fluid mixing and sometimes using numerical simulation.

4.1 Effects of compartmentalization on the hydrocarbon recovery

Study is done to codify the various elements of reservoir complexity that affects the recovery using a numerical scoring system called Complexity Index.

There are about 20 complexity factors that directly affects the recovery. The factors include the engineering and geological factors like:

- Structural complexity (e.g.: faulting, fracturing)
- Depositional complexity (e.g.: depositional continuity)
- Reservoir quality (e.g. permeability, heterogeneity)
- Fluid quality (e.g. viscosity)
- Reservoir energy (e.g. pressure, aquifer strength)

Other factors that affect recovery other than reservoir complexity are:

- Recovery process (Depletion, water-flooding, EOR)
- Well type and spacing

5 OBJECTIVE

- Identification and characterizing the compartmentalization in reservoir
- Prediction of compartmentalization through a static reservoir model and Primary dynamic data
- Maximum utilization of the low amount of appraisal data
- Effects of reservoir compartmentalization on hydrocarbon recovery

6 DATA ANALYSIS

The Rocky Mountain Oil Testing Center provides the set of non-proprietary data pertaining to the Teapot Dome area or Naval Petroleum Reserve 3, which can be intended to use in scientific research, testing and demonstration.

The dataset consist of:

6.1 Seismic Data

- **2D Seismic Data**
  - SEGY files for lines A-E
  - 2D data load sheet
  - 2D navigation data for lines A-E
  - 2D seismic base map
- **3D Seismic Data**
  - Interpreted 3D seismic horizons in .XYZ format
  - 3D SEGY file
  - 3D data load sheet
  - 3D processing parameters
- NPR-3 Field Boundary in ASCII format
- Select time/depth tables
- Teapot Dome reservoir information sheet

6.1.1 Seismic Data Quality Analysis

2D Seismic Data

The dataset is provided 5 number of 2D seismic lines present in the Teapot Dome, Natrona County of Wyoming State of USA. The seismic lines are of the datum NAD 1927 - North America Datum of 1927 (Mean) and the Coordinate System: SPCS27 - Wyoming East Central.

Project: NPR-3 1977 Heritage 2D Data

Client: Rocky Mountain Oilfield Testing Center

Area: Teapot Dome

County: Natrona

State: Wyoming

Reprocessed in 1977: Fenix and Scisson Data.

Navigation Digitized from Old Paper Maps (Oct 2005)

Load Parameters

Trace: Byte Number 5-9

Shots: Byte Number 21-24

Datum: 5500 feet

Velocity: 9000 ft/sec

Data Coordinate System Units: U.S. Survey Feet

Table 2: 2D seismic line information

Seismic Line	Shot Point Number	X Co-ordinate Start	Y Co-ordinate Start	X Co-ordinate End	Y Co-ordinate End	CDP	FFID
A	100 to 302	804635	935826	789561	976402	203-592	29-161
B	100 to 182	789024	963169	801074	976363	203-358	10-68
C	100 to 181	793467	958200	807516	968784	209-358	3-57
D	100 to 206	792850	946206	812982	956751	203-409	10-92
E	103 to 162	797844	953735	808695	960822	210-321	3-32

Provided Data is of seismic traces collected with the old technology where traces were in the paper maps, but then converted to the digital form of the computer processed and digitally interpretable seg-y format.

Although the data is very old, the traces collected corresponds to the shallow resources in the Teapot Dome, which are visualized better. Also, large number of shot-points and receivers were used to improve the Seismic Sound to Noise Ratio.

As the structure of investigation is a simple dome, the seismic sections are good enough for the interpretation.

The provided Segy data is ample to make horizon interpretation and fault interpretation.

The Synthetic seismogram provided with the seismic dataset is very helpful to study the Wellbore Seismic trace to that of areal seismic trace.

3D SEISMIC DATA

The 3D seismic data for the Teapot Dome area was acquired by Excel Geophysical Services, Colorado in January of 2001. The Post Stack Migration Data have the following Field Parameters:

ACQUIRED FOR	Rocky Mountain Oil Testing Center
ACQUIRED BY	Western Geco Crew 780
DATE RECORDED	January 2001
INSTRUMENT TYPE	I/O System II
FIELD FILTERS	OUT – ½ nyquist
NUMBER OF CHANNELS	1200
GEOPHONE ARRAY	6 Phones in 20 ft. dia circle
ENERGY SOURCE	4 AVH III 392 Vibrators
SWEEP	8-96 HZ 3 dB/Oct 12 Seconds
RECORD LENGTH	16 SECONDS
SAMPLE RATE	2 MS
GROUP INTERVAL	220 Feet 880 ft. line spacing
SOURCE INTERVAL	220 Feet 2200 ft. line spacing
SPREAD DIMENSIONS	10 lines of 120 channels
BIN SIZE	110 ft X 110 ft.
INLINE (LINE) BYTES:	17- 20 and 181-184
CROSS LINE (TRACE) BYTES:	13- 16 and 185-188
CDP X CO-ORDINATES BYTES:	81- 84 and 189-193
CDP Y CO-ORDINATES BYTES:	85- 88 and 193-196

PROCESSING PARAMETERS

Polarity: U.S polarity

Replacement velocity = 9000 ft/sec

Datum = 5500 ft

The 3D data provided can be utilized in creating a static reservoir model for the exploratory analysis.

The seismic volume generated is of a high quality. Yet, few data gaps are found in the data, which leads to the uncertainty of understanding the extent of the horizons interpreted from the data.

The provided data is in the SEGY format and the horizons are provided in .XYZ format. This horizon data cannot be utilized in the Petrel Platform for interpretation or modelling purposes.

6.2 Well log data:

- Teapot Dome Well Headers
- Directional Surveys
- Formation Log Tops
- Teapot Dome Base map
- LAS Files for deep and shallow wells at Teapot Dome
- Teapot Dome Geologic Column
- Teapot Dome Production Data

The well log data of both the shallow and deeper wells are provided. The wells intersecting with the seismic survey area very useful for correlation and the estimation of a synthetic trace that can be used for the verification of the structural and stratigraphic interpretation.

The well headers provide the information of the Well Number/Name, Location, Total Depth, Datum Type and Elevation, Well status, Spud date, etc.

The well tops provide information like top of Measured Depth (MD) of the formations present in the subsurface with respect to the corresponding wellbores that are located within various parts of the field or basin.

Provided well data contains a directional survey, which gives the Inclination and azimuth of the wellbore with respect to the subsurface Measured Depth.

The Teapot Geologic Column provides the stratigraphic sequence or order of the formations present in the survey area.

The well log files for all the wells are in the .LAS format that can be used for analysis in the Petrel Platform software.

The well log types present in the dataset include:

- Sonic Log
- Density Log
- Neutron Porosity Log
- Dip meter Log
- Spontaneous Potential log
- Resistivity log
- Caliper log
- FMS Log
- Mud log of few wells
- Cement Bond log

The well logs are provided with a base map in order to identify the location, Intersection with any Seismic section, Status of the well, etc.

The well logs can be upscaled and correlated to obtain a possible geological interpretation both structurally and stratigraphically. Here, the logs are very helpful in predicting the structure of the dome in various area of the basin.

6.3 Core Data:

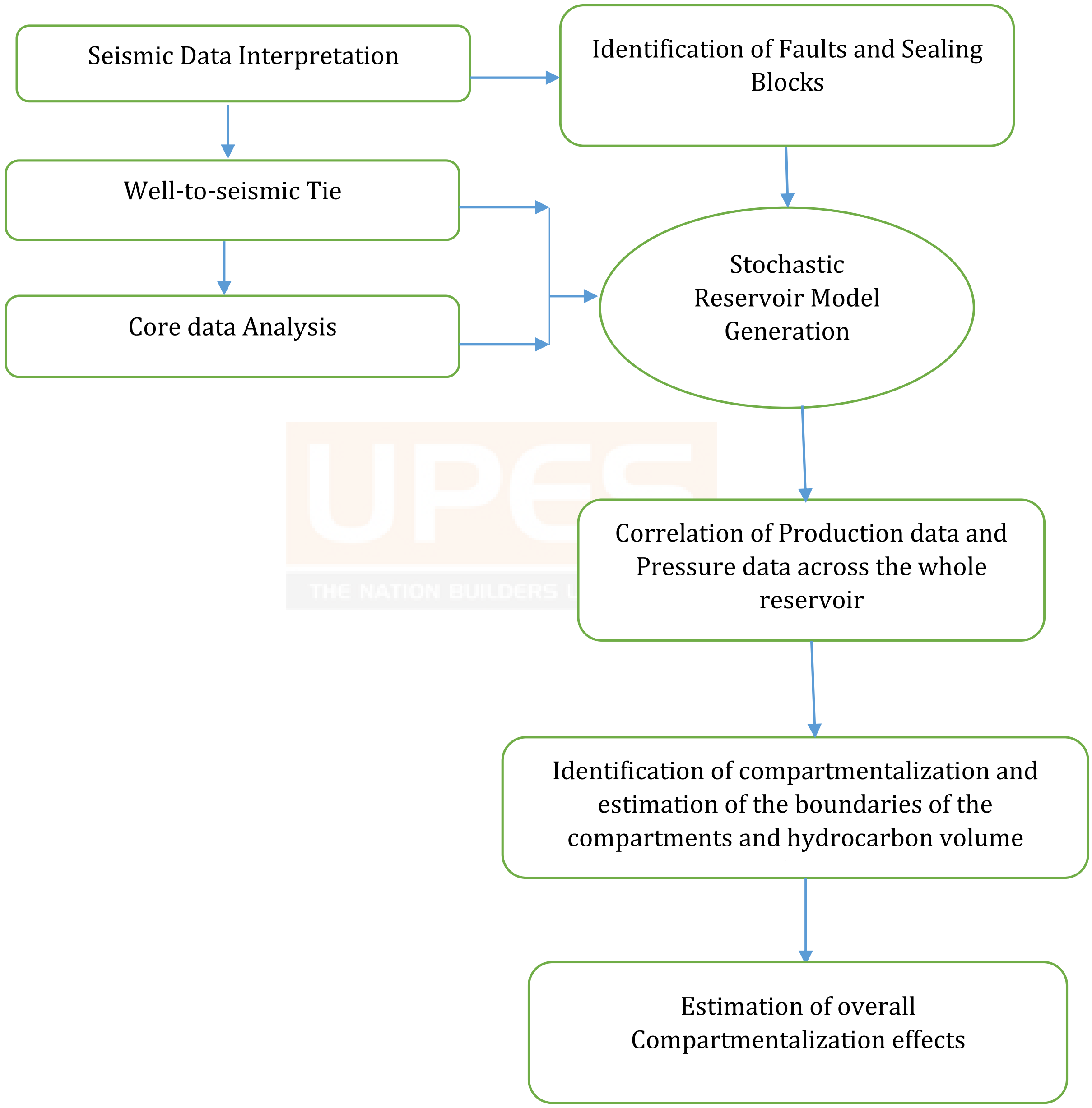
- Core Pore/Perm Analysis
- FMI Data
- LAS Files
- Mud Log
- Core Descriptions
- Core Photos

6.4 GIS Data:

- Feature Dataset - NPR3_Core_Data
- Feature Dataset - NPR3_Field_Data
- Feature Dataset - NPR3_Formations
- Feature Dataset - NPR3_Geology
- Feature Dataset - NPR3_Pipelines
- Feature Dataset - NPR3_Powerlines
- Feature Dataset - NPR3_Wells

7 METHODOLOGY

The Reservoir Compartmentalization can be inferred from the given data by starting from the simple Seismic Interpretation upto the production data analysis. The series of steps is provided by the flow sheet given below.



7.1 WORKFLOW:
Observations from available Appraisal Data

1. Seismic Mapping

- Faults present in a field, but does not provide direct information about the transmissibility of faults with the present static data.

2. Well Logs

- Show if there are low permeability Shales are present in the field. These shales may act as barriers to vertical flow if they are laterally extensive.
- Correlation across several appraisal wells.

3. Core data

- Lateral facies variation can be obtained, but difficult to prove without dynamic data.

4. Well Test data

- Pressure transient analysis
- Conclusion of the flow behaviour, Pressure variations across the field, SKIN factor, etc.

5. Production data

- Flow rates and pressure data are considered for predicting the production profile.

7.2 Observations of Compartmentalization

- Through non-equilibrium fluid-related properties indifferent parts of the reservoir, such as pressure, pressure gradients, water-oil or gas-oil contacts, fluid physical properties, and fluid composition.
- Through the various natural processes that occurs in the hydrocarbon reservoir and causes non-uniform fluid properties both vertically and laterally. Some of them are:
  - Reservoir filling causing changes in composition w.r.to time
  - In-situ biodegradation

- Regional or local hydrodynamic conditions affecting water chemistry, pressure and contact depth.
- Reservoir restructuring due to erosion and upliftment resulting in changes in pressure distributions and contacts
- Heterogeneity in mineral distribution and diagenetic processes can affect both hydrocarbon and water chemistry.

7.3 Precautions

Take into account the different time-scales of the fluid signals (pressure, contacts, density, composition in order to equilibrate, and to extrapolate to field production time-scales.

Avoid false negatives and false positives

Resolve apparently conflicting data

Complex, multiphase and multidimensional process of simulation of fluid equilibration.

7.4 To determine:

Generation of static reservoir model from the available data and identification of compartments along the reservoir.

Effective diffusion coefficient for each process from reservoir rock and fluid properties.

Comparison plot of different time-scales for each fluid property variation to attain equilibrium

For the known fluid perturbation for the time elapsed, analytical solution of the degree of compartmentalization should be estimated.

Development of simple practical assessment tool for compartments present.

8 SEISMIC INTERPRETATION

The seismic interpretation of the region has been explained in steps as shown below. The steps clearly defines the objectives and approach of the current study.

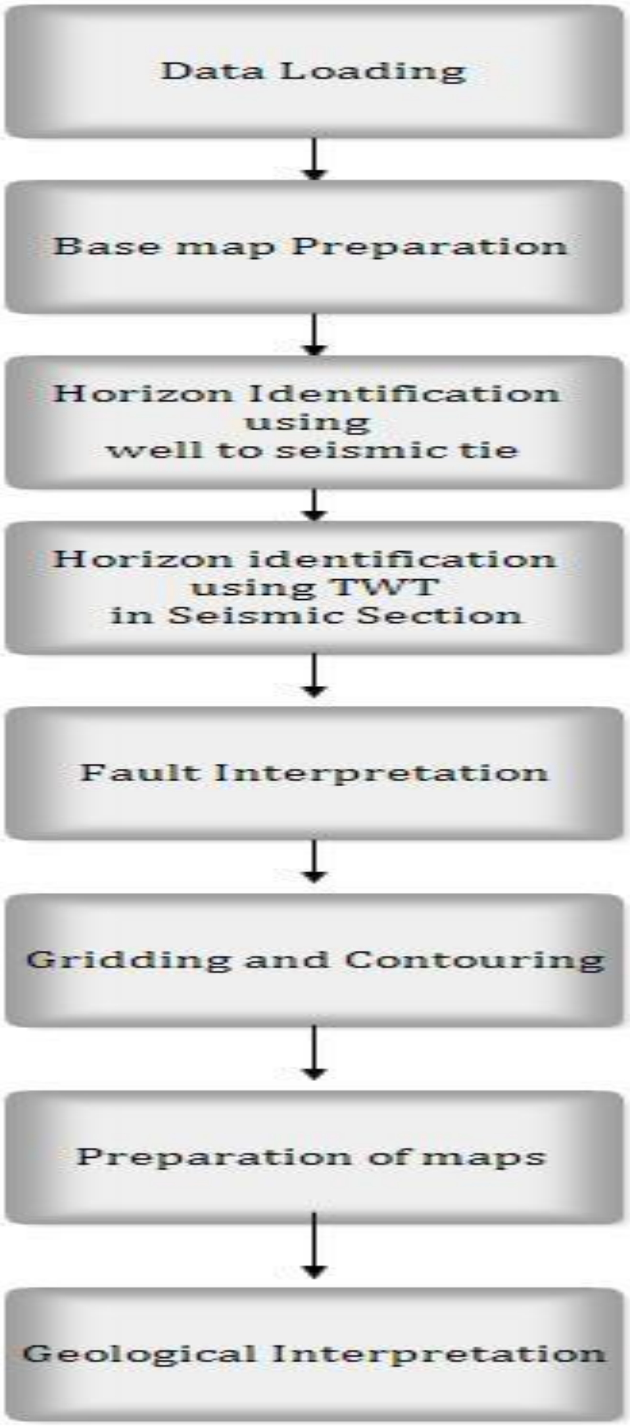


Figure 3 Workflow for seismic interpretation

The whole workflow is done using Petrel Platform software of the version 2013.2 with the following packages:

- Geoscience Core
- Reservoir Engineering Core
- Automatic Fault Extraction
- Seismic Volume rendering
- Surface Imaging

8.1 PROJECT CREATION AND DATA LOADING

- The project was created with Cardio graphic Reference System (CRS). CRS is prepared with spheroid NAD1927. The study area i.e. Teapot Dome lies under SPCS27 - Wyoming East Central division.
- Totally 5 lines of 2D seismic data of the Teapot Dome area in the NPR-3 (Line A, B, C, D and E) are given for correlation and interpretation.
- Also, 3D seismic data with inline 143 to 148 and cross line 93 to 94 are provided to create further interpretation and modelling.
- The trace and seismic cube parameters were set as provided above. The initial analysis is based on the variations in TWT of various layers.
- The 2D seismic data are saved as 'survey 1' and the 3D seismic survey is saved as 'Survey 2'. The interpretation were done in **Geoscience core module of Petrel and also in the Seismic Interpretation module** for specific geophysical processes.
- The well data are also loaded in order to provide log correlation and well intersection in the provided survey area.
- The velocity data (Dip Move Out) was provided, which can be loaded to the **Velocity model generation and Domain Conversion modules of petrel**. The data is of the format .VEL (NPR3_dmo.vel)
- The well logs and seismic data are correlated to generate Synthetic seismogram in the **Seismic to Well Tie module of Petrel**.

8.2 SYNTHETIC SEISMOGRAM

The main purpose of a synthetic seismogram is to generate TD curve function which is used in overlaying seismic section to identify seismic horizons with respect to well tops.

Sonic log is used as velocity function to convert depth domain to time domain. Well tops are converted to time domain. Moreover synthetic seismogram is used in the conversion of P-wave sonic velocity.

The procedures are listed below:

- Well seismic ties allow well data, measured in units of depth, to be compared to seismic data, measured in units of time.
- This allows us to relate horizon tops identified in a well with specific reflections on the seismic section.
- We use sonic and density well log to generate a synthetic seismic trace.
- The synthetic trace is compared to the real seismic data collected near the well location.

In this project work, the wavelet which has been extracted from the seismic data of following characters:

Length of Wavelet – 200 ms

Time window – 500- 1300 ms

Correlation window – 750-1200 ms

There are a few notable differences between seismic and well data. In a seismic data we collect area and volume samples. The frequency generally used is 5~60 Hz. The vertical resolution offered by a seismic survey is usually between 15 to 100m. The horizontal resolution is around 150 to 1000m. The attributes that we measure are seismic amplitude, phase, and continuity, horizontal & vertical velocities. The exact well intersections to seismic data was found to be difficult.

The well taken here is 48-X-28, located in the area where all the 10 horizons are present in the 3D seismic cross line 129. The replacement velocity is 2000 m/s. The synthetic seismogram was provided by the RMOTC Geophysicists as per our request. The horizons are marked with respect to the well tops in the synthetic trace.

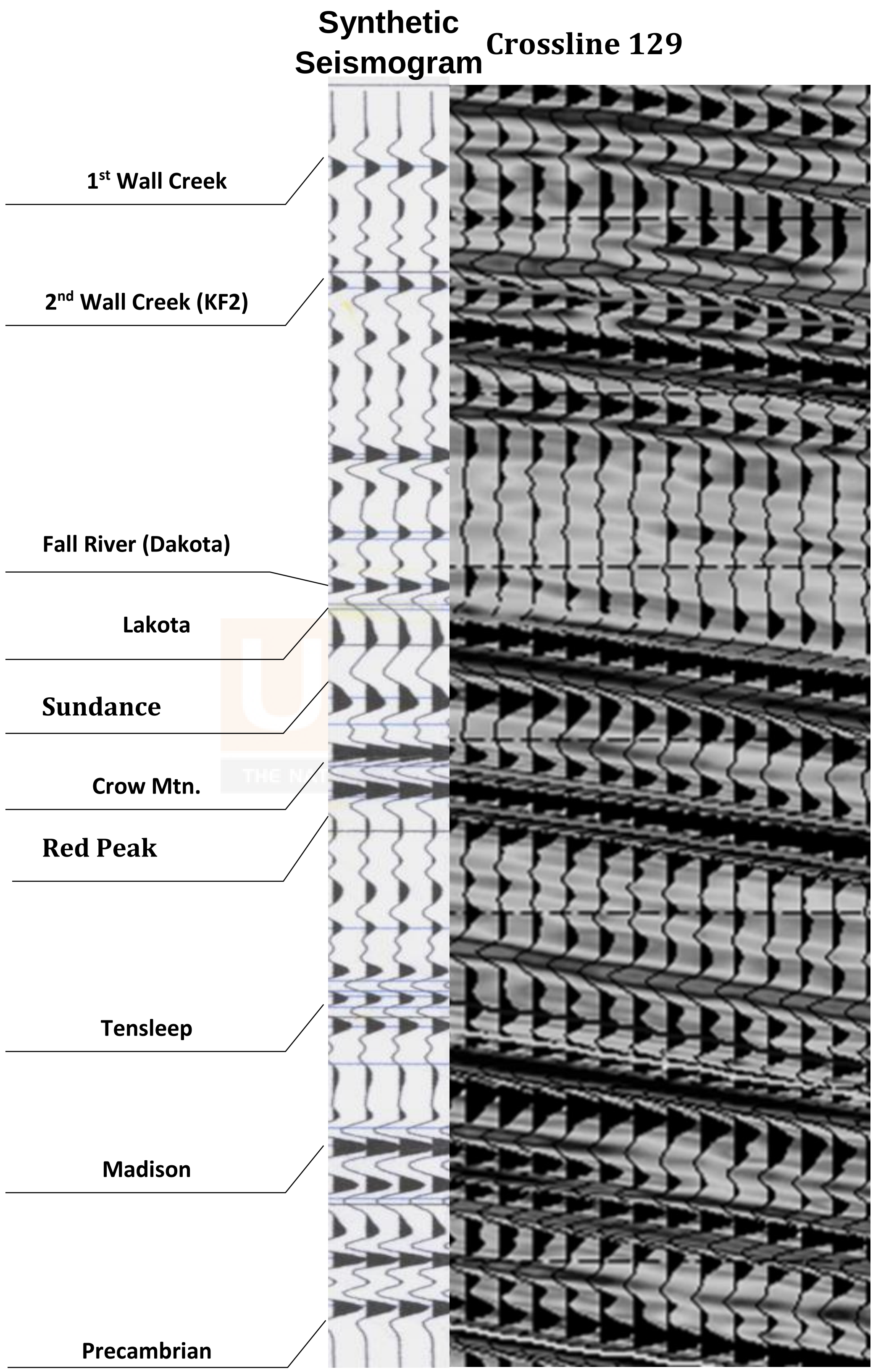


Figure 4Composite synthetic seismogram match to 3D seismic data at NPR-3.

8.3 SEISMIC HORIZON CORRELATION:

The 2D Seismic lines A to E are interpreted in the Seismic Interpretation module. The orientation of the lines and well 48-X-28(*) and other wells are provided by the base map shown below.

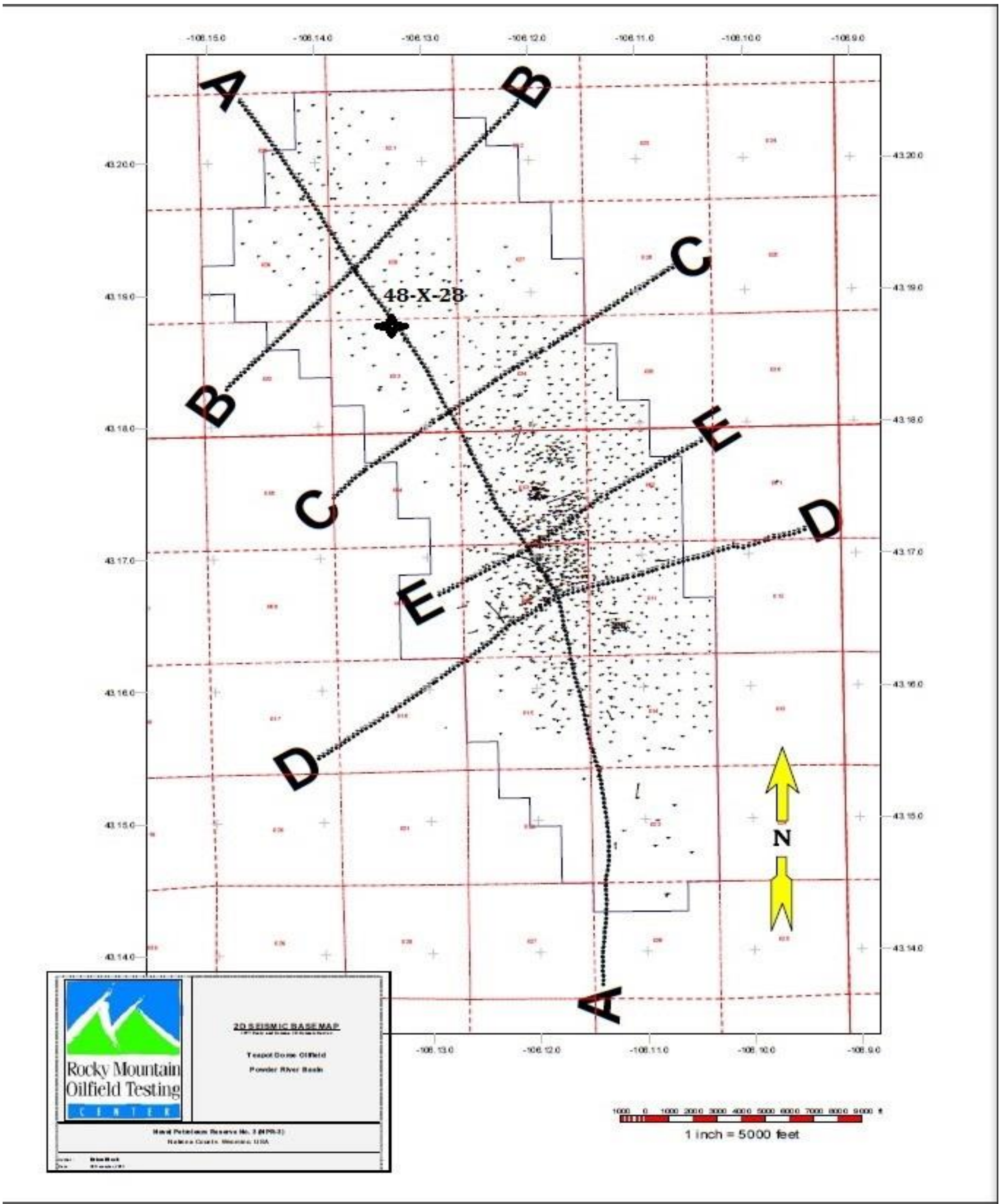


Figure 5 Seismic Base map

While correlating horizons internally in system we are recording the following.

1. X coordinate
2. Y coordinate
3. TWT
4. Amplitude attribute

In the current project the maximum has been correlated corresponding to the U.S. Polarity Scheme.

American polarity

Peak = increase in impedance = +ve (Black colour generally)

Trough = decrease in polarity = -ve (Red colour generally)

There are two possible modes of presenting seismic sections on the screen - as 'wiggle trace' or as 'Variable Intensity' displays.

On the seismic lines the principal surfaces has to be drawn. They are of the strong reflection character and hence bear the key to subsurface geology interpretation and their time map have been posted on the base map.

So as different formation encountered, different acoustic impedance contrast exists between them and correspondingly peak and trough. And accordingly the different horizon tops have been picked.

The Points mode in the Horizon interpretation of Petrel is used here.

A total of six major horizons out of the ten formations have been identified and are used in the current study. They are represented as:

Table 3Horizons Definition

HORIZON NAME	SCREEN NAME	COLOUR	POLARITY
Basement	H6	Blue	Blue (positive)
Tensleep	H5	Cyan	Blue (Positive)
Dakota	H4	Fluorescent Yellow	Blue (Positive)
Frontier	H3	Orange	Blue (Positive)
Niobrara	H2	Pink	Red (Negative)
Shannon	H1	Grey	Blue(Positive)

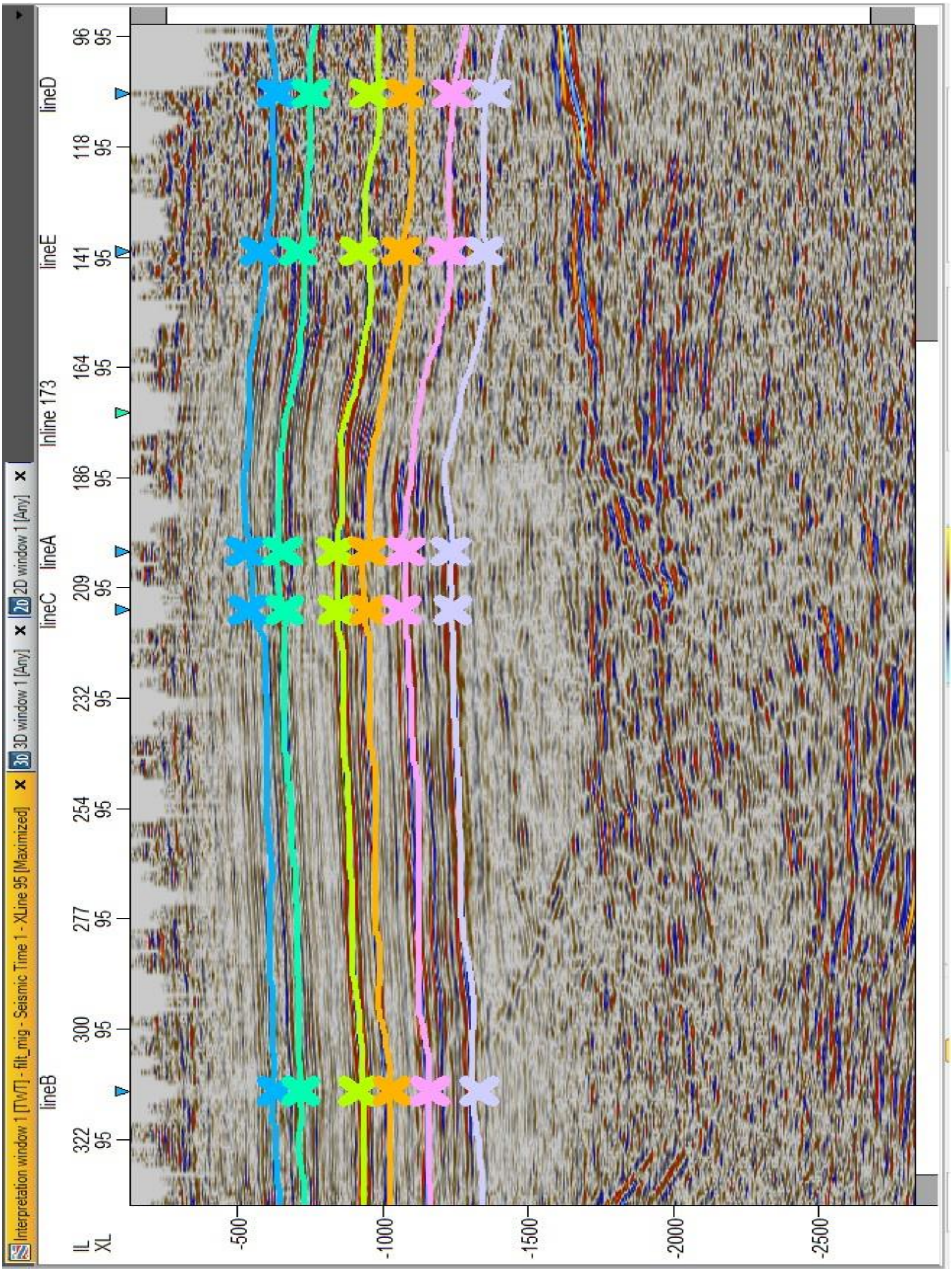


Figure 6Horizon interpretation of Xline 95

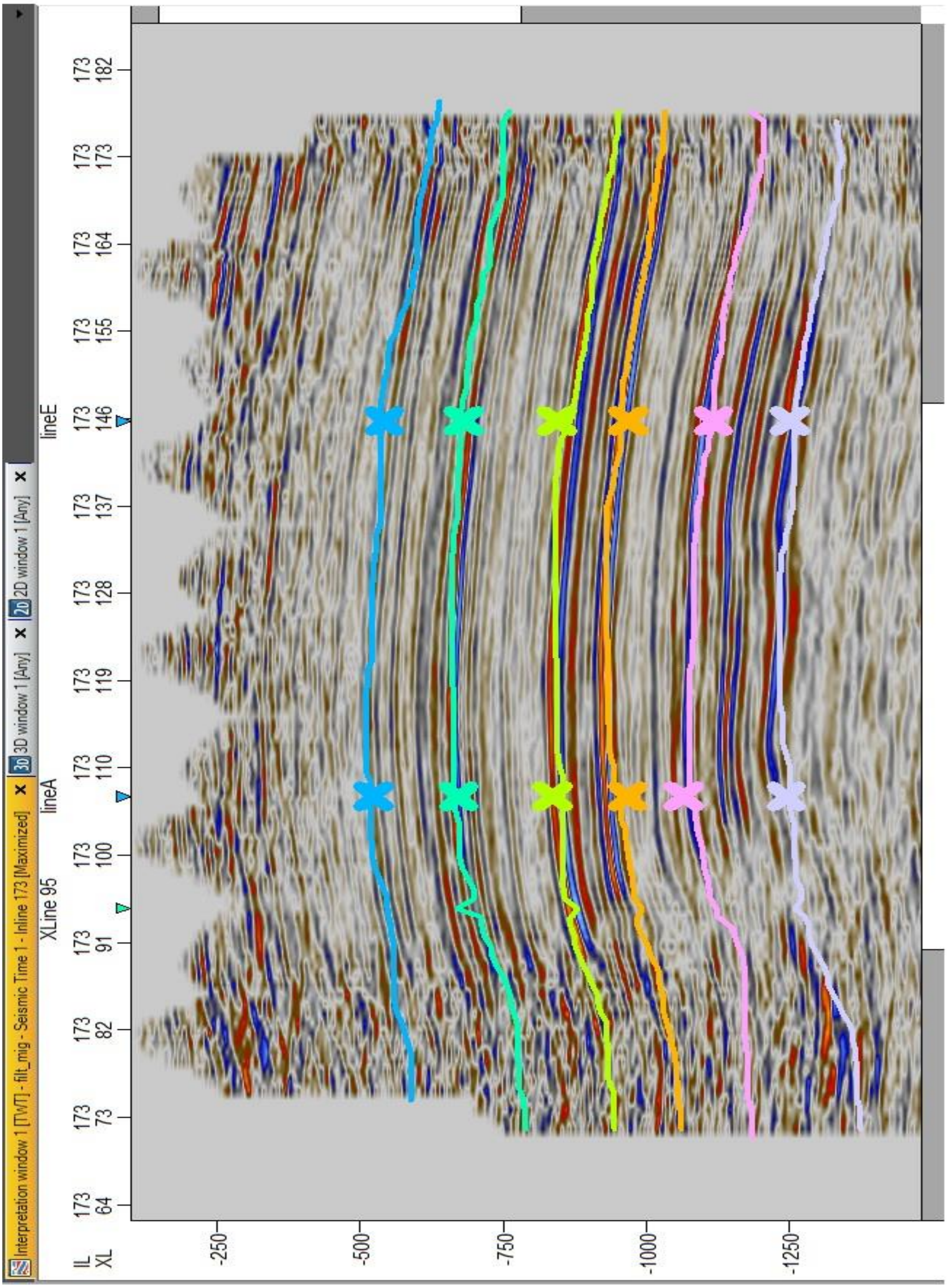


Figure 7Horizon interpretation of Inline 173

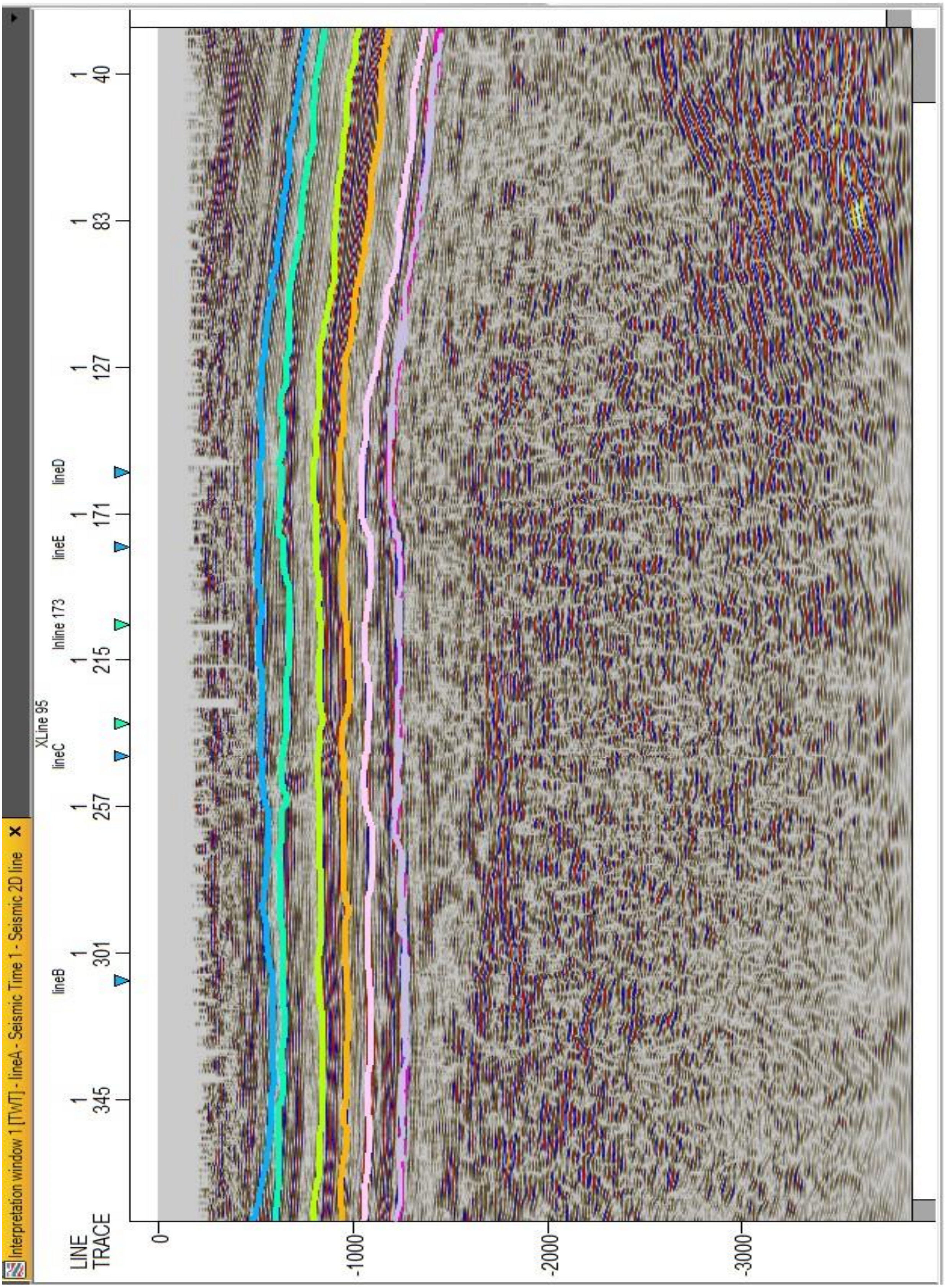


Figure 8Horizon interpretation of Line A

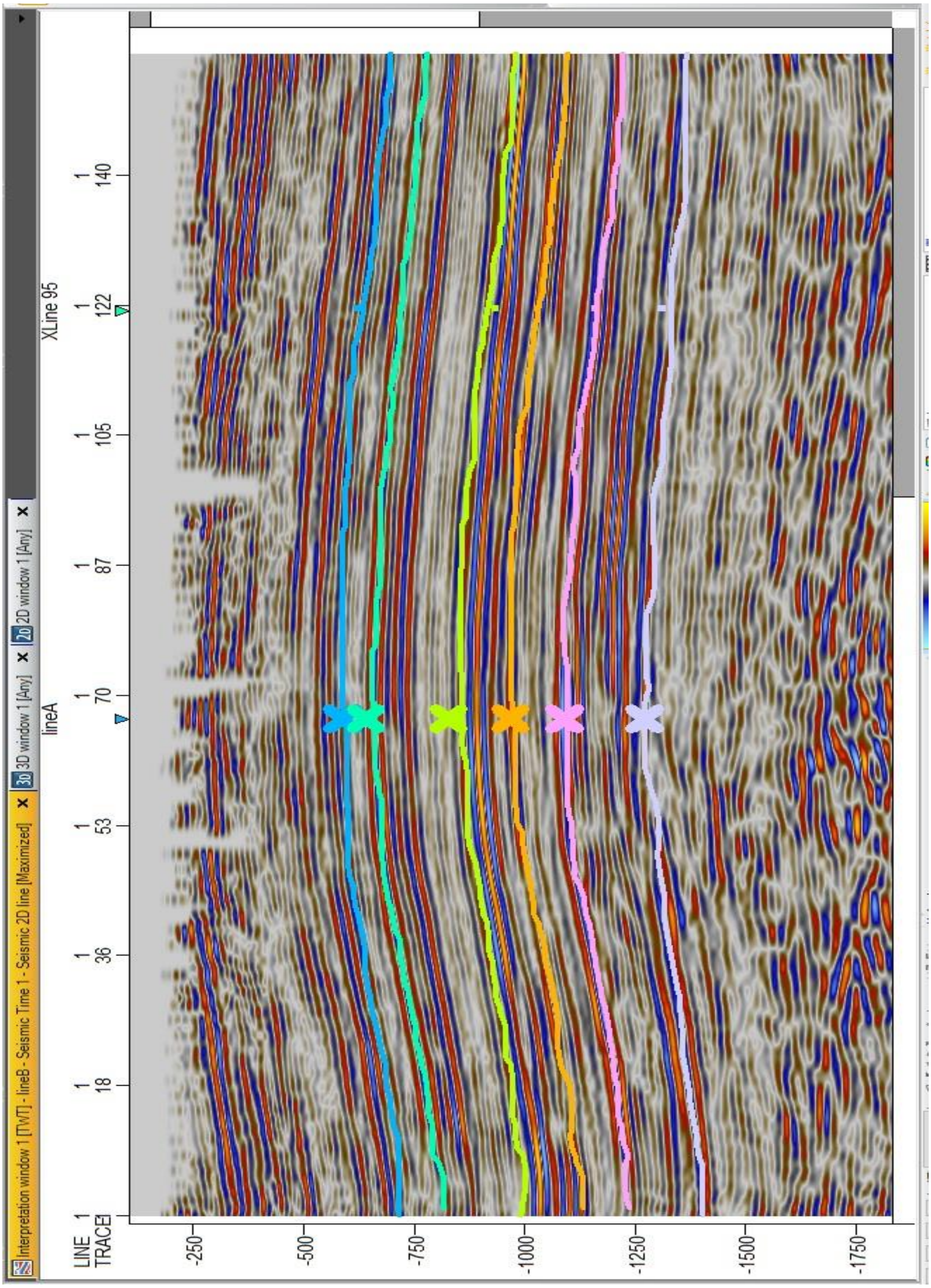


Figure 9Horizon interpretation of line B

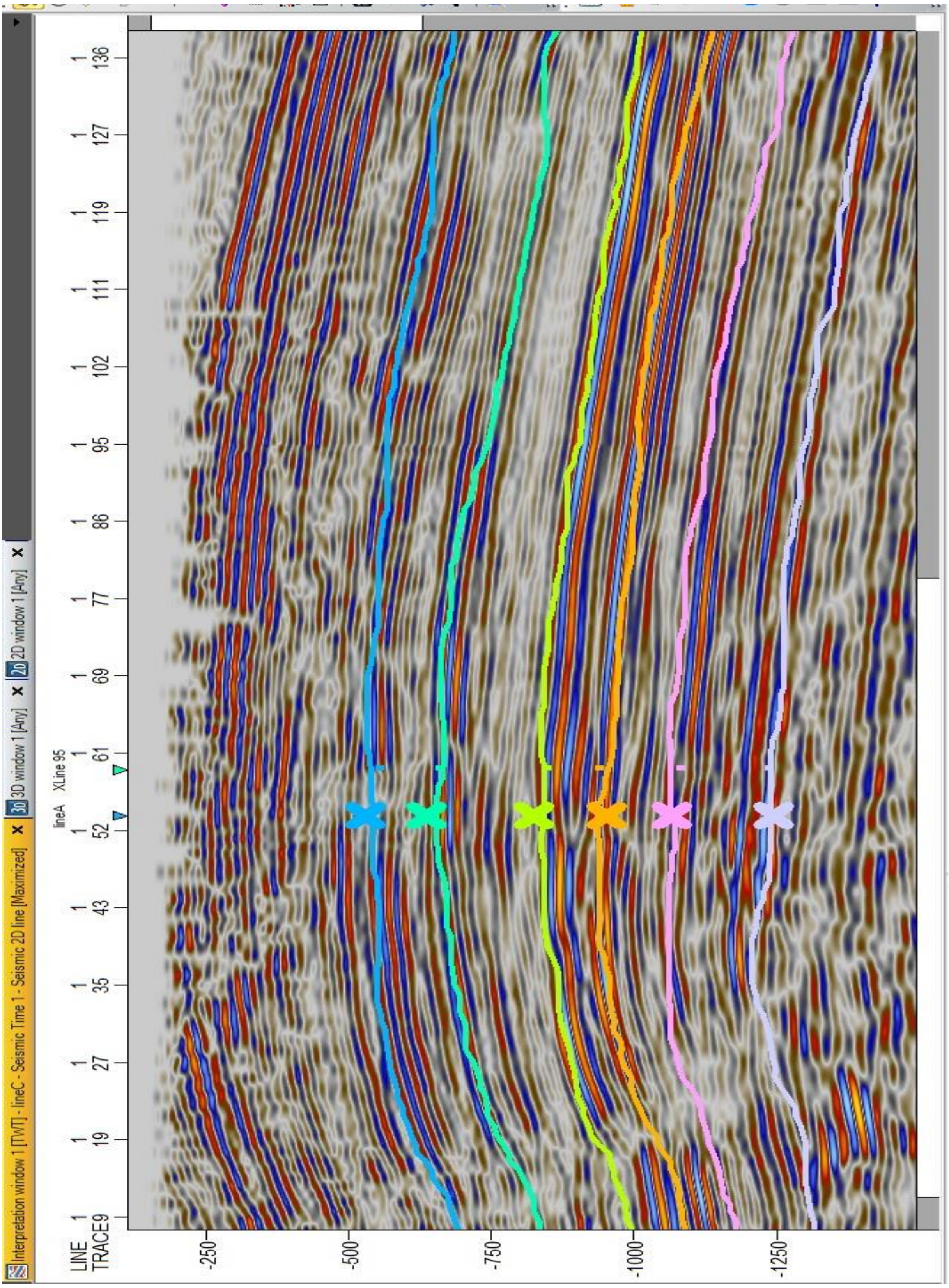


Figure 10Horizon interpretation of line C

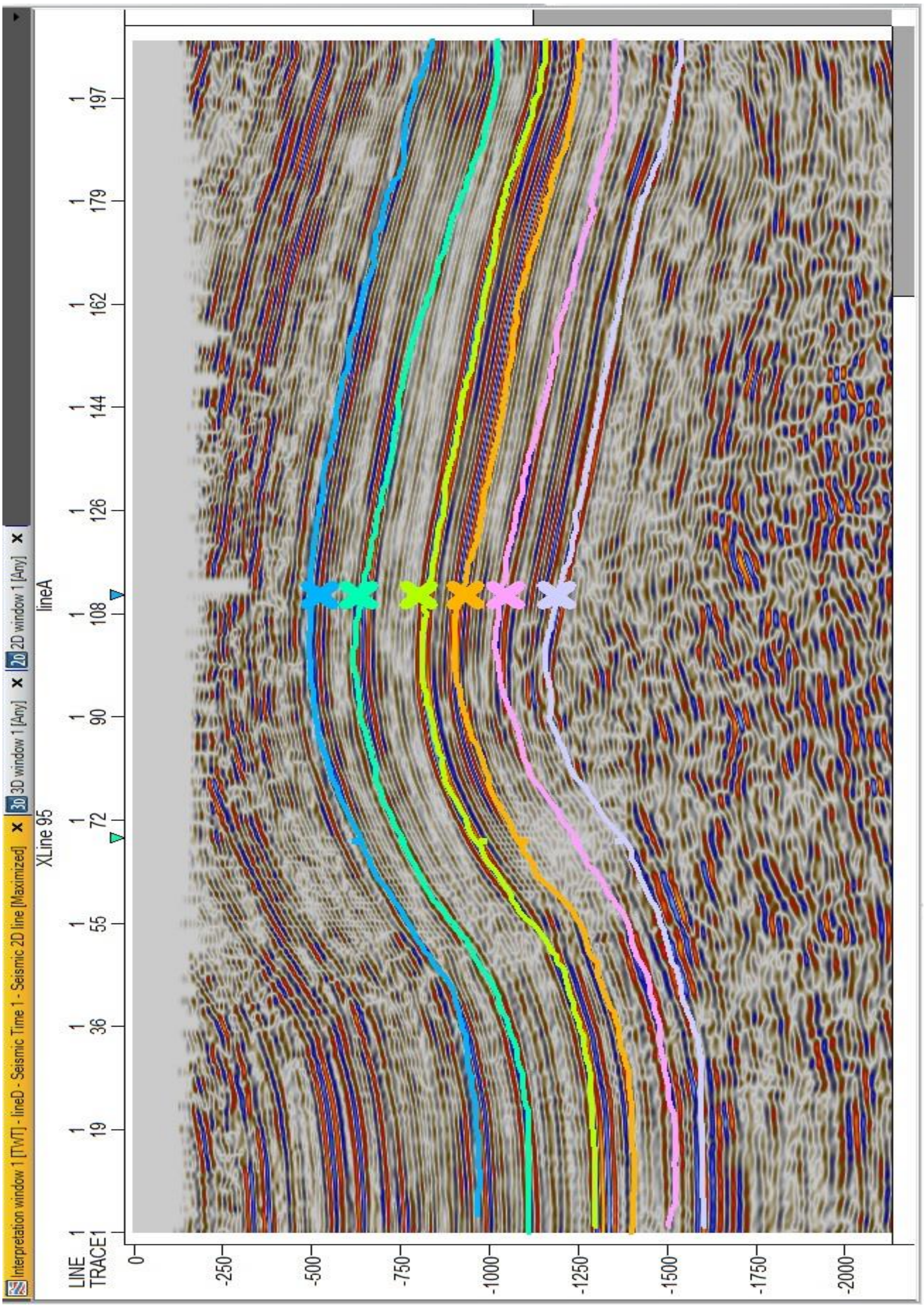


Figure 11Horizon interpretation of line D

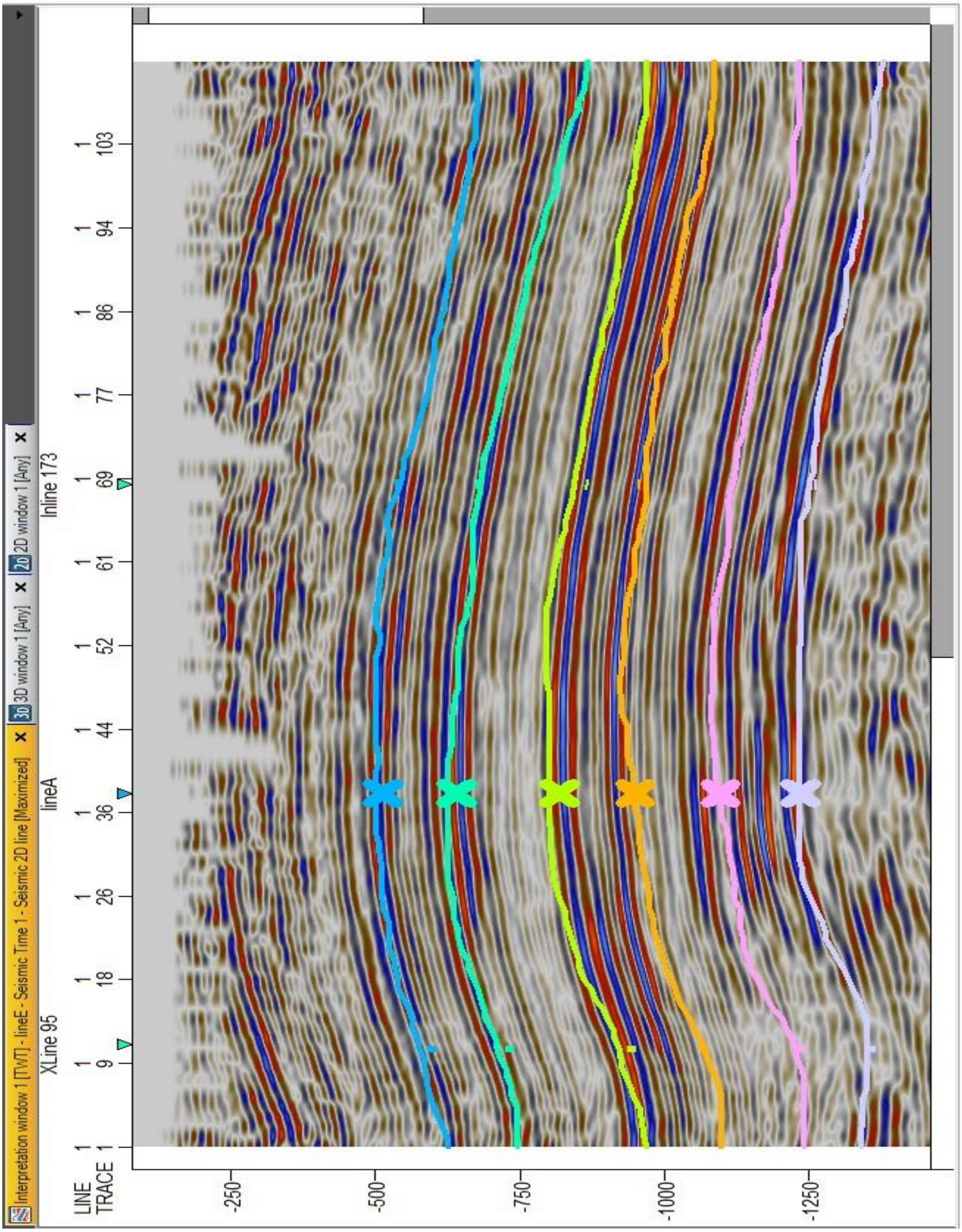


Figure 12Horizon interpretation of line E

9 FAULT INTERPRETATION

After the horizon marking, the seismic sections are subjected to the identification faults and then to the modelling of faults.

Interpreting all the faults can maximize our understanding of deformational history and the controls on trapping and flow of hydrocarbons. Generally faults have been mapped along with horizon simultaneously on the seismic sections. For better marking of the faults in the seismic sections, one technique can be used i.e. the sections can be squeezed.

One major fault has been identified which cut across all the section right from the basement to top of formations. Its direction is along **North-West to South-East**. Even some minor faults have also been marked in the section which cuts across some particular horizons.

The faults are first identified in the Seismic sections and then mapped to get the structural orientation within the basin.

The fault polygons are also created to visualize the faults in the 3D model and then gridded in order to interpret the volume of oil that may be trapped within the fault trap.

The process is explained as:

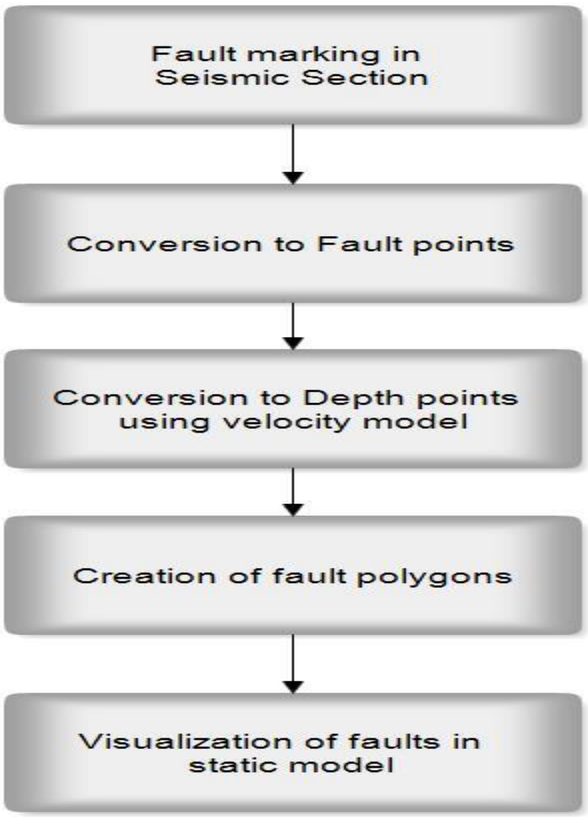


Figure 13Workflow for fault interpretation

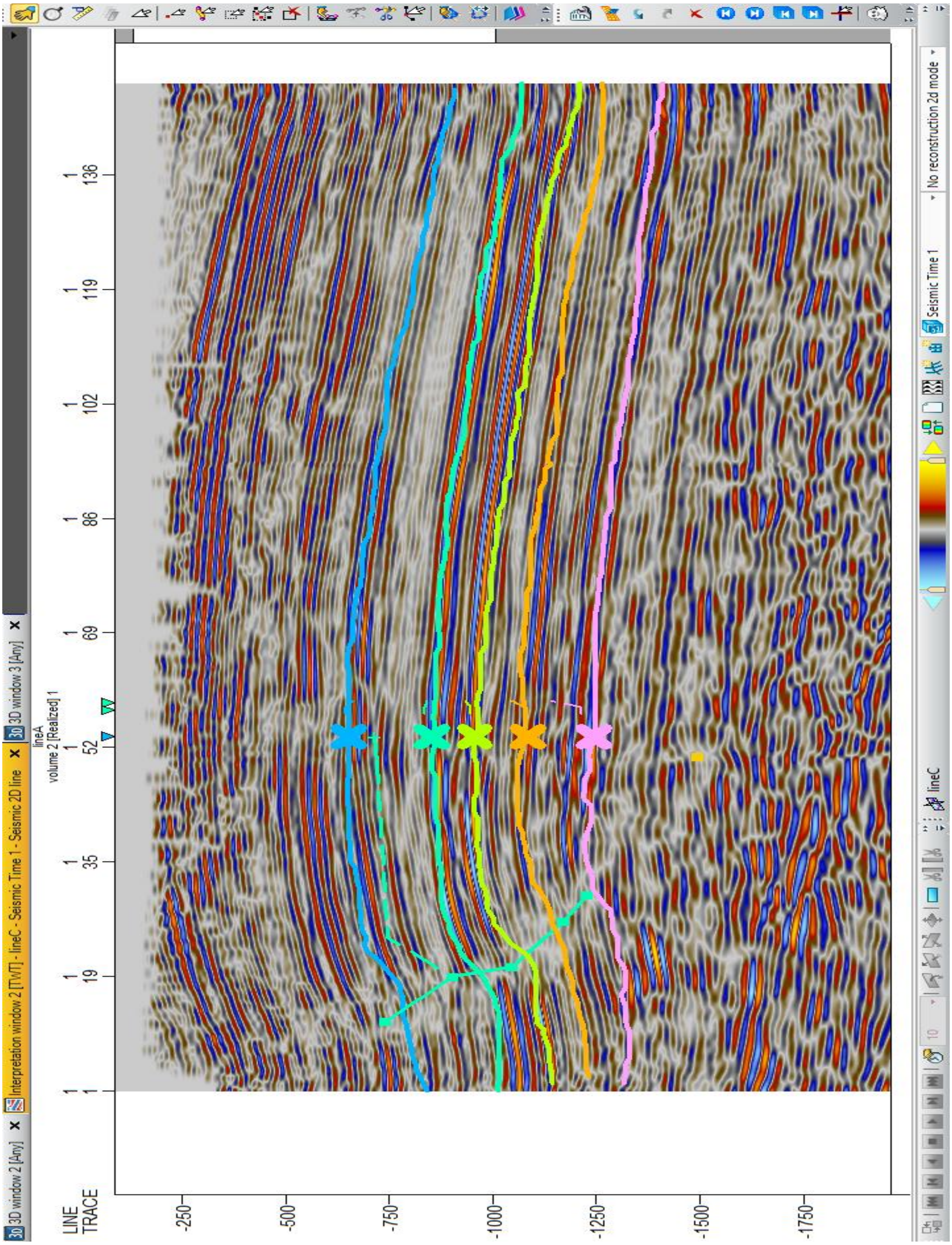


Figure 14Fault Interpretation on Seismic Section

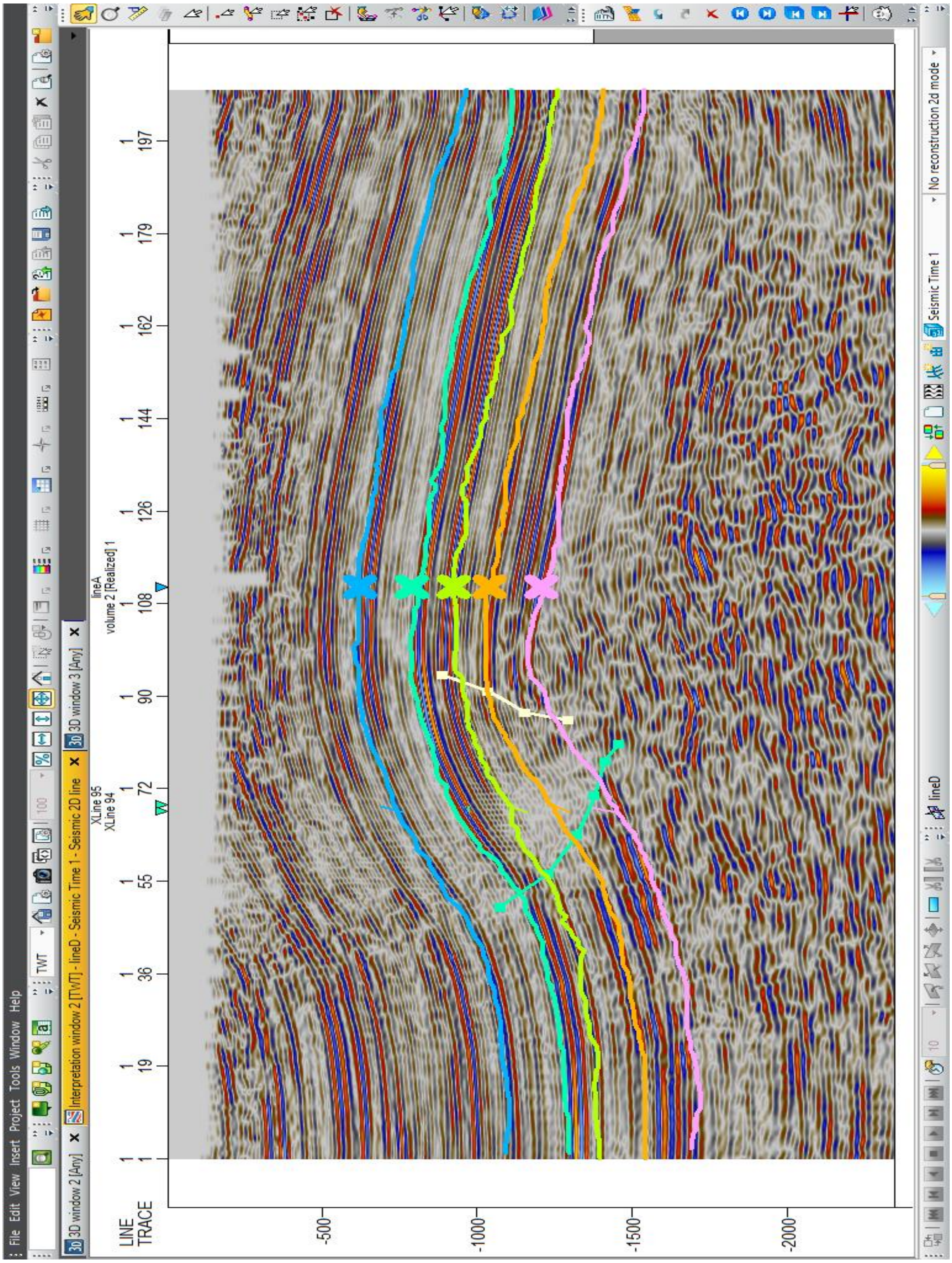


Figure 15Fault Interpretation on Line D

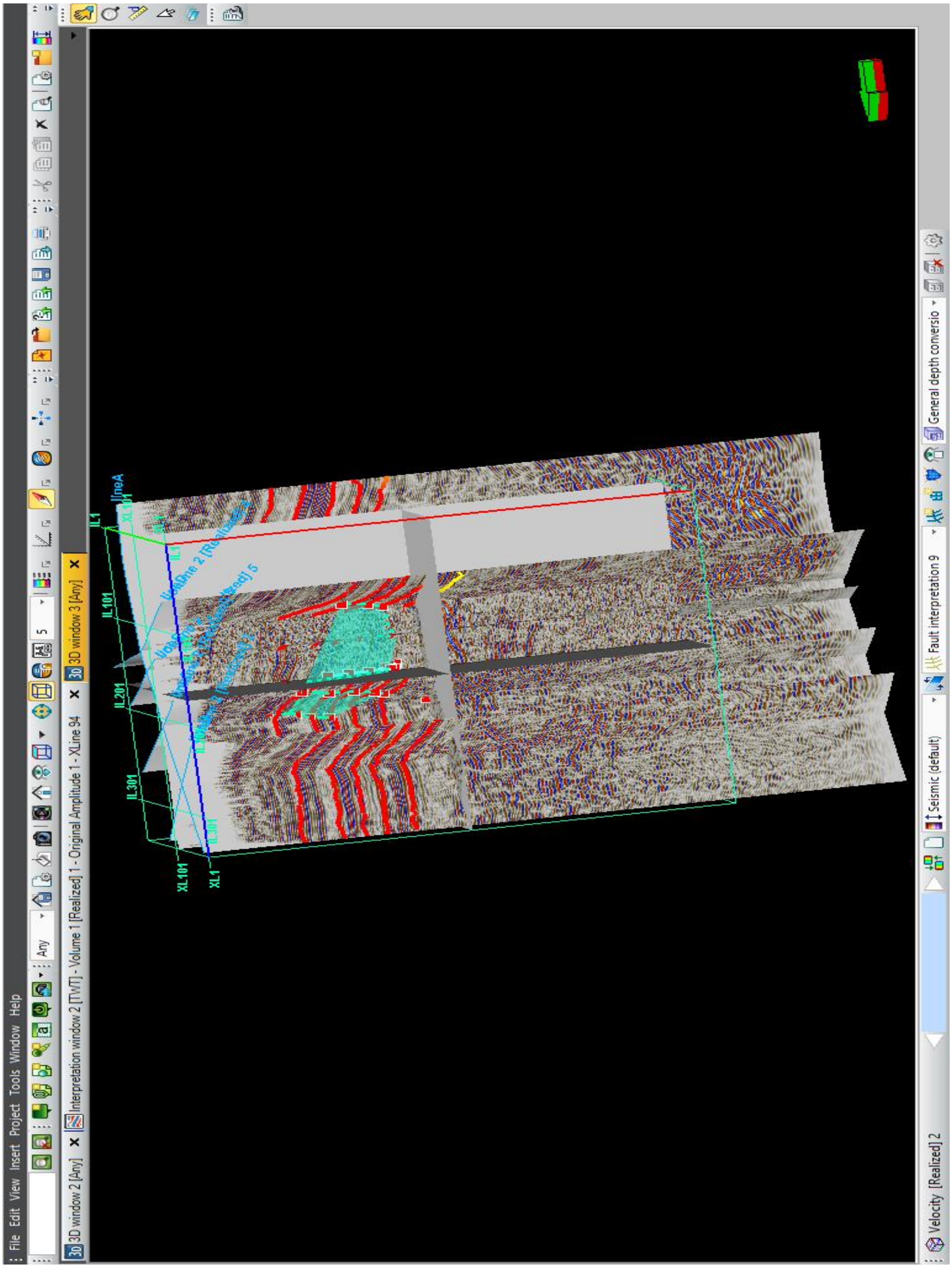


Figure 16Fault Display in 3D window

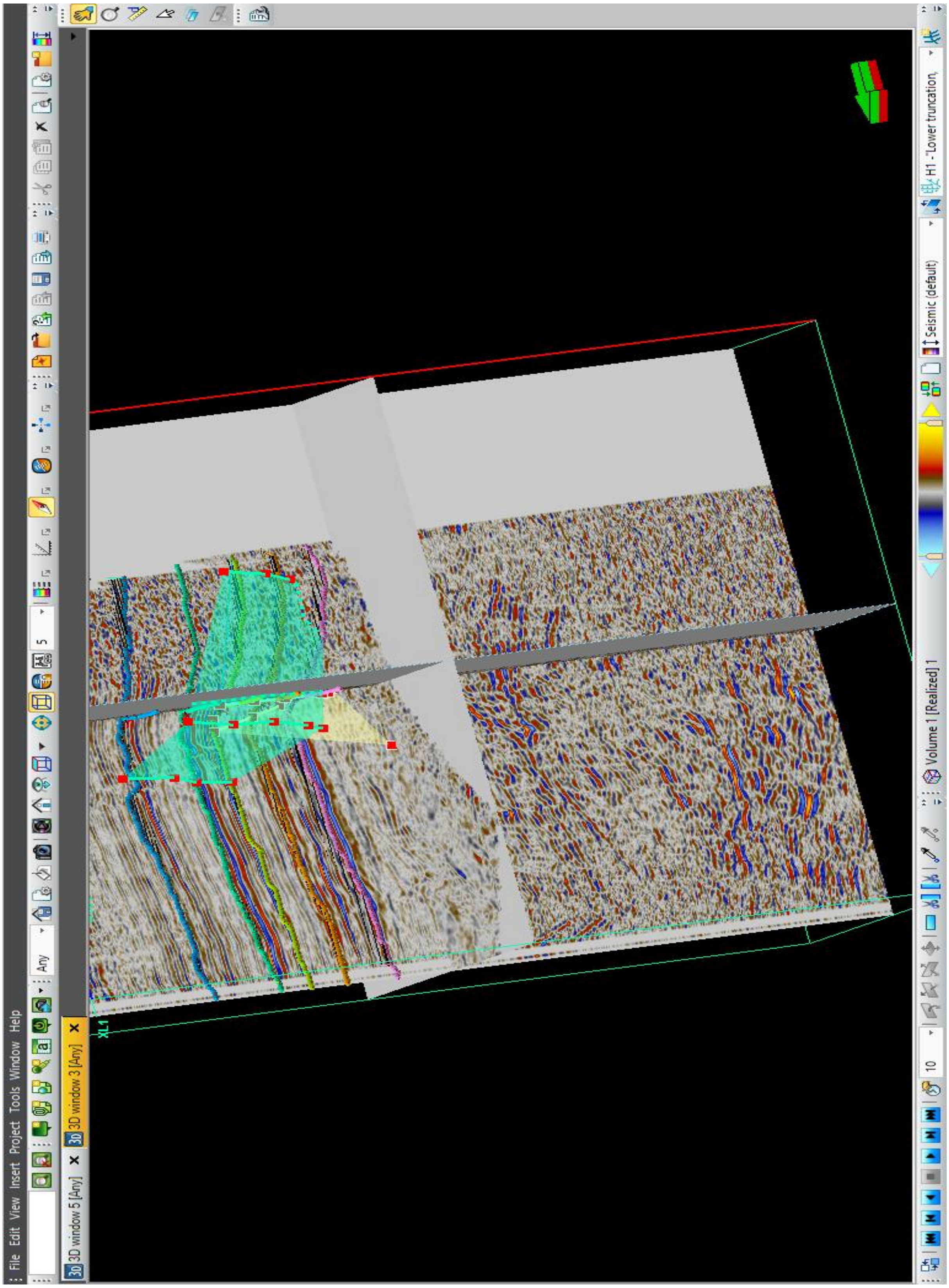


Figure 17Fault sticks in 3D view

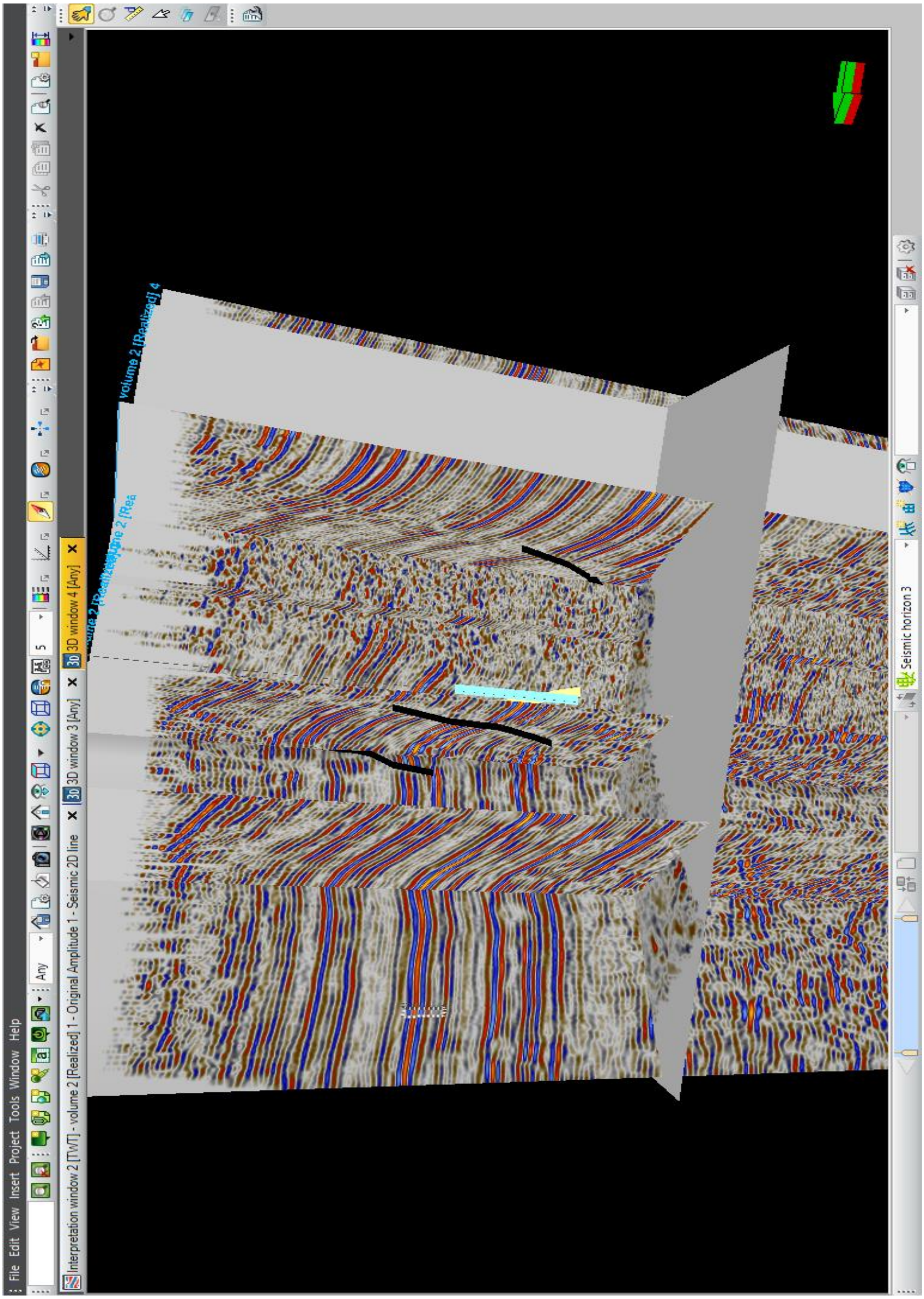


Figure 18Fault Polygon

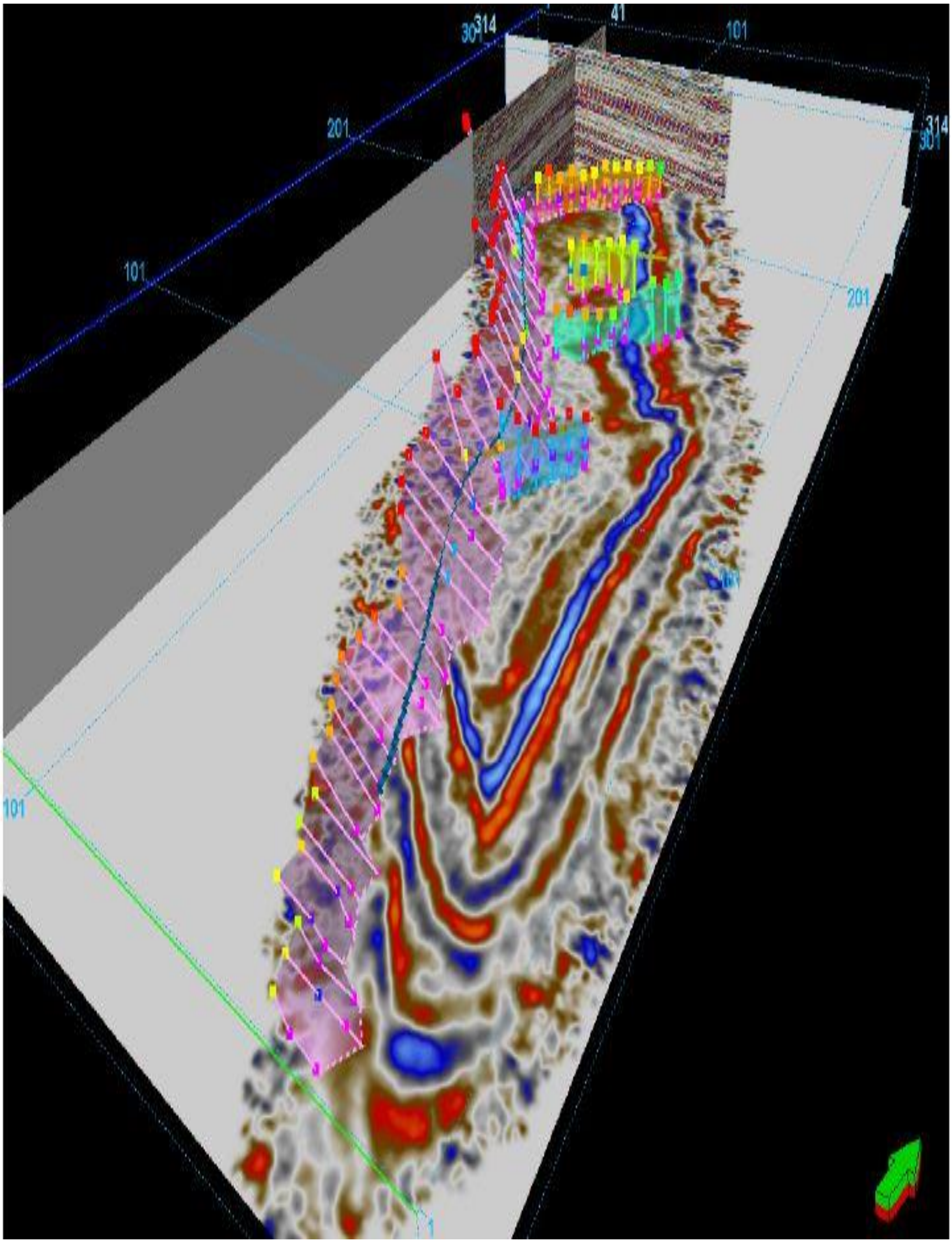


Figure 19Fault model over depth surface

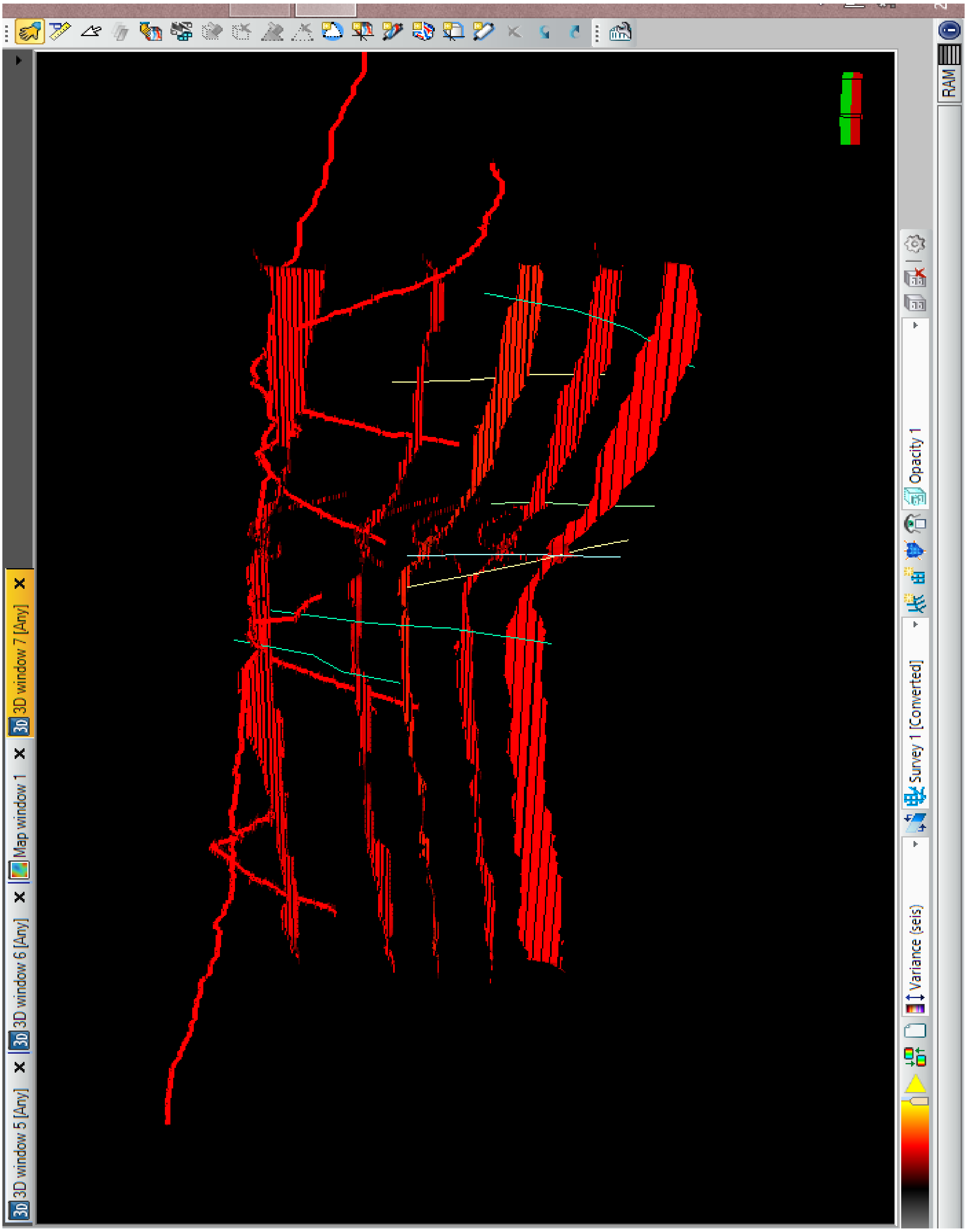


Figure 20Fault blocks in Tensleep layer

10 DOMAIN CONVERSION

The seismic interpretation is based on the TWT variations of seismic waves. But, the geology can be most interpreted when the TWT domain gets converted to the Depth domain. This can be done the application of a velocity pertaining to the particular location that can be obtained from either Well logs or seismic survey itself.

We have been provided with a velocity data file, which contains the velocity associated to a particular CDP that are present in the seismic survey.

Using the **Domain conversion** module of **Petrel**, theses velocities are made into framework that consists of the variation of velocity within the zone where the actual TWT data is present.

These velocities appear as peaks within the zone for a certain depth of the formation (i.e., formation velocity).

When the TWT horizons are provided as inputs to this velocity model, the horizons will be converted into the depth domain.

Also, the well logs are also viewed in the depth domain.

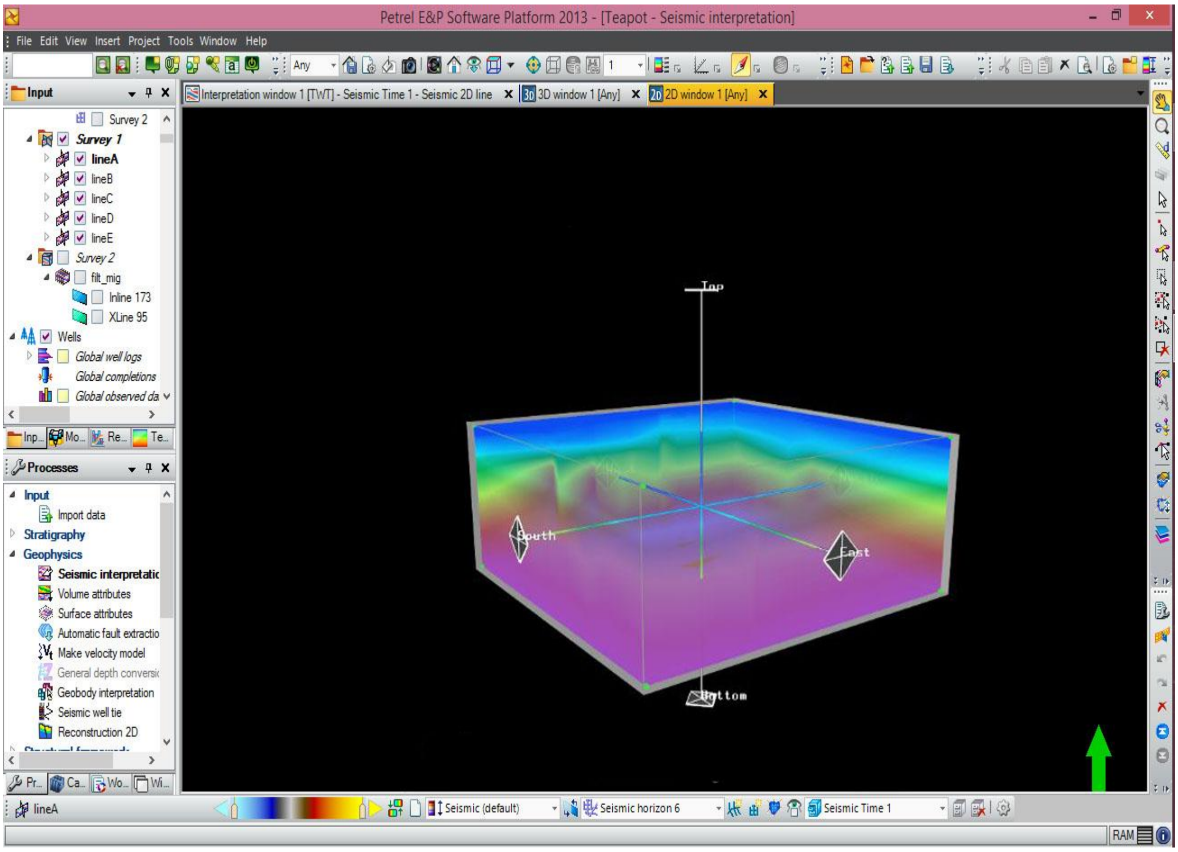


Figure 21 Velocity model

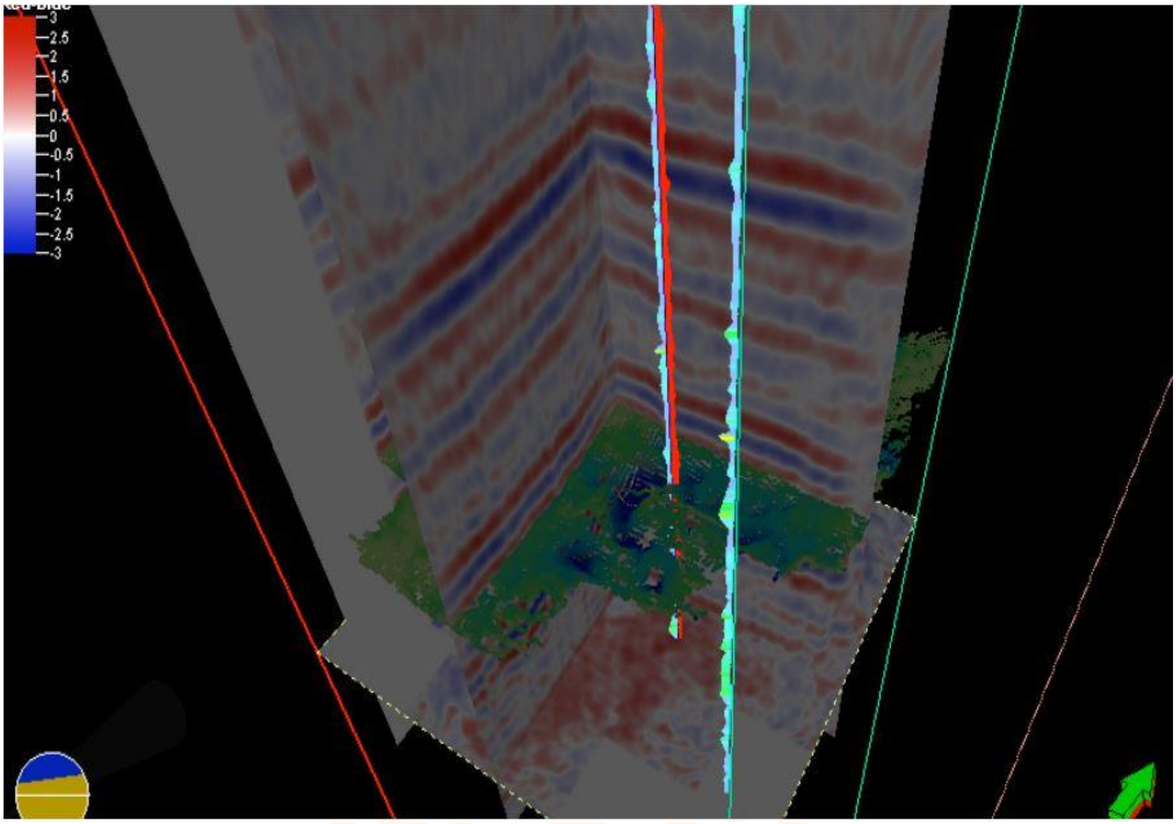


Figure 22Well Display before Depth Conversion

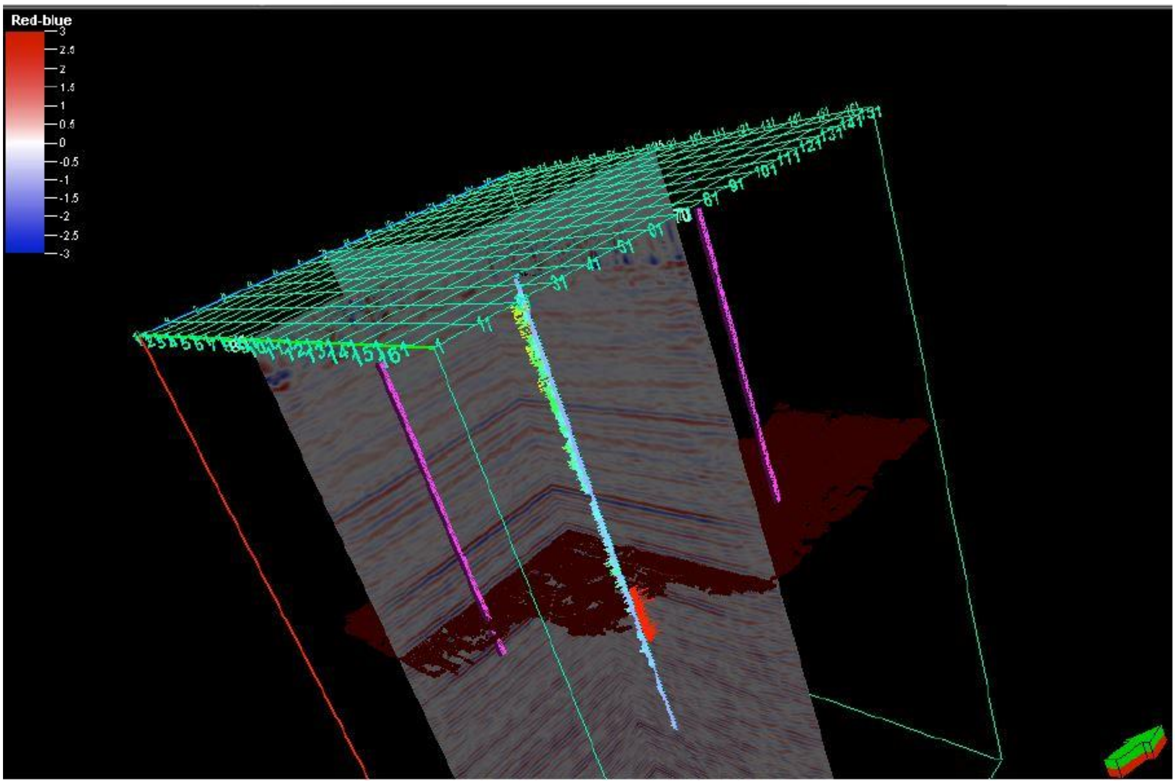


Figure 23Well display after depth conversion

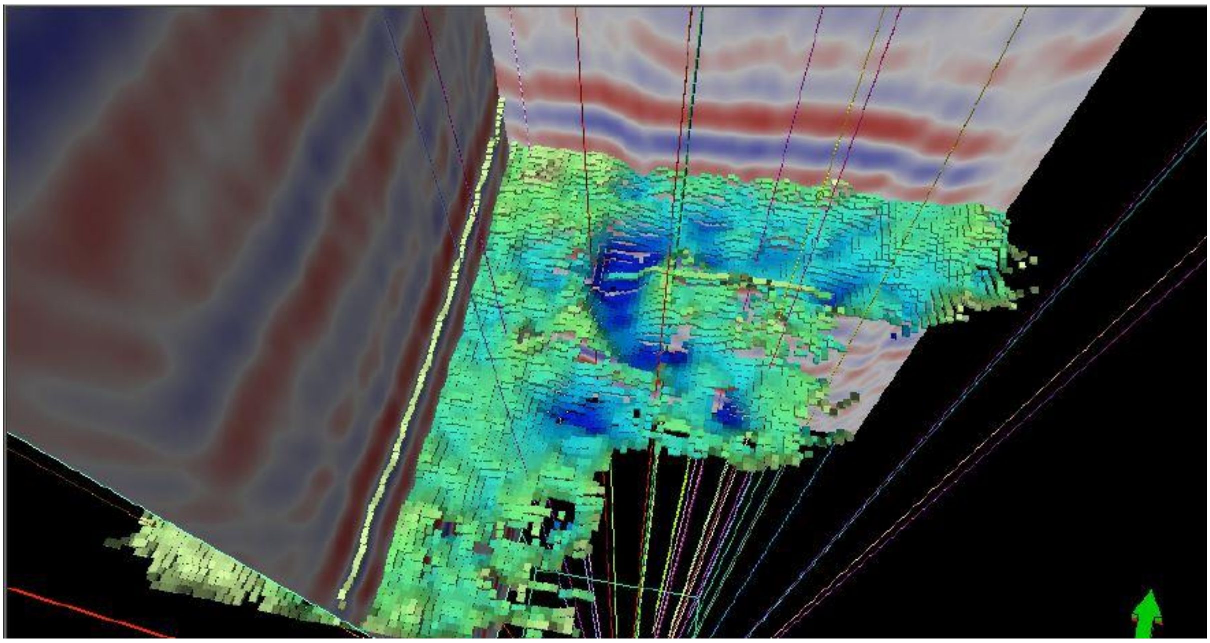


Figure 24Depth converted layer 1

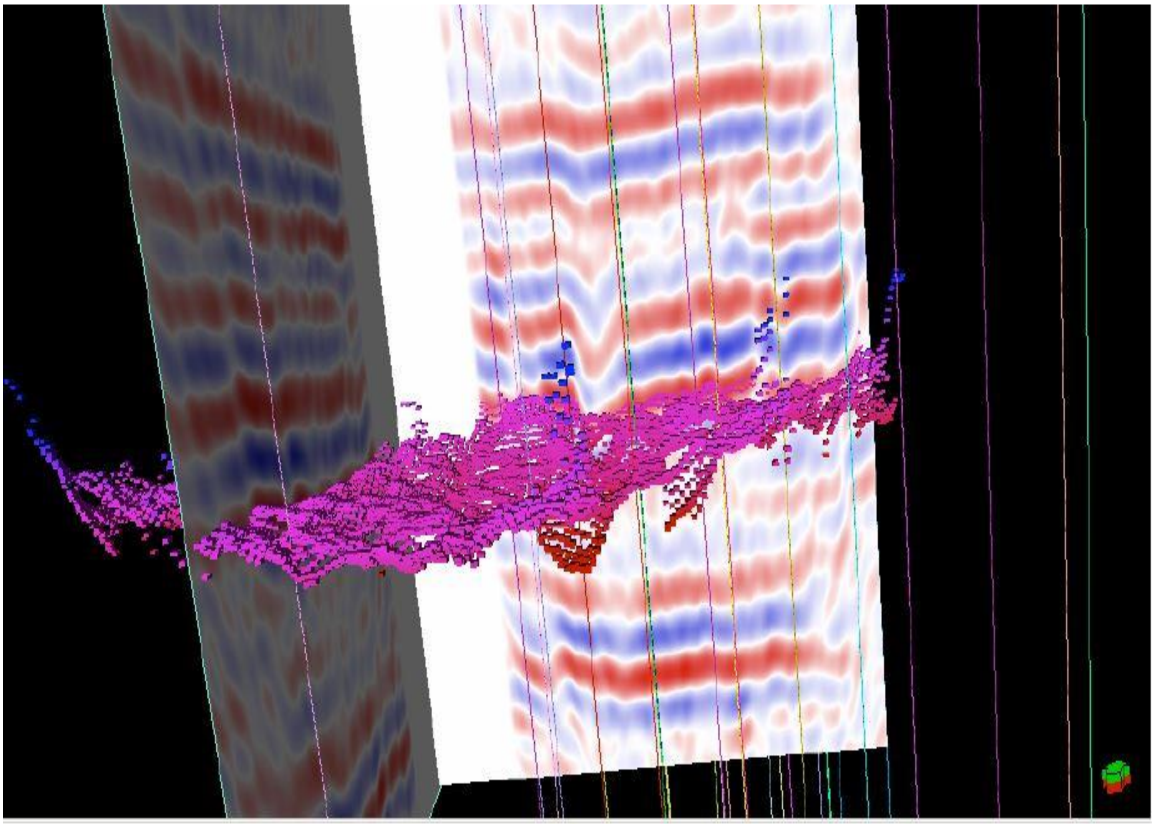


Figure 25Depth converted layer 2

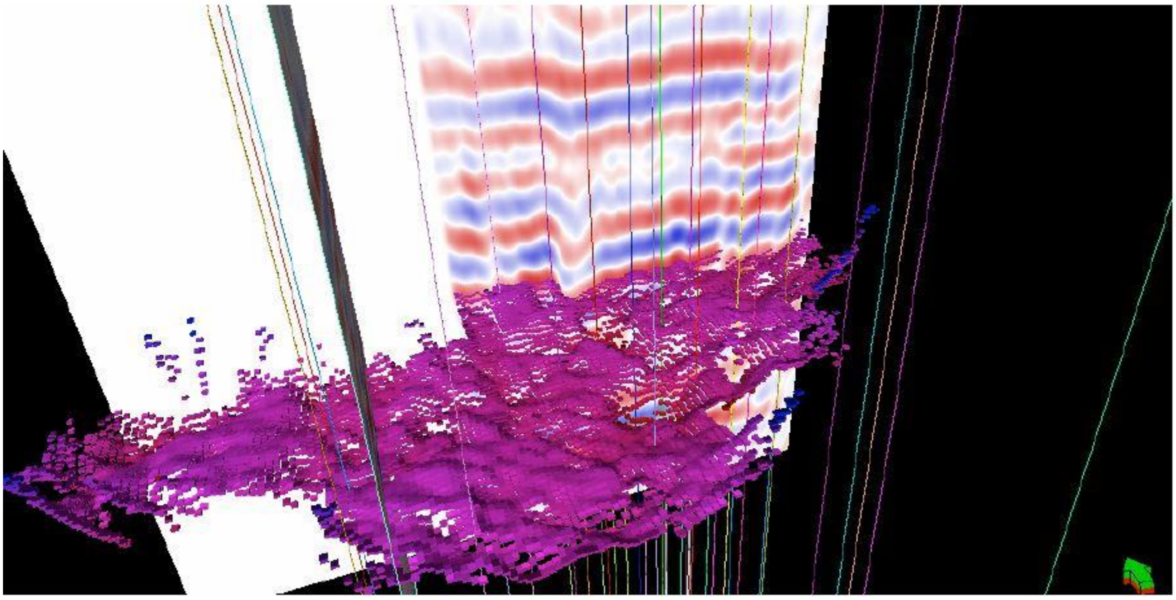


Figure 26Depth converted layer 3

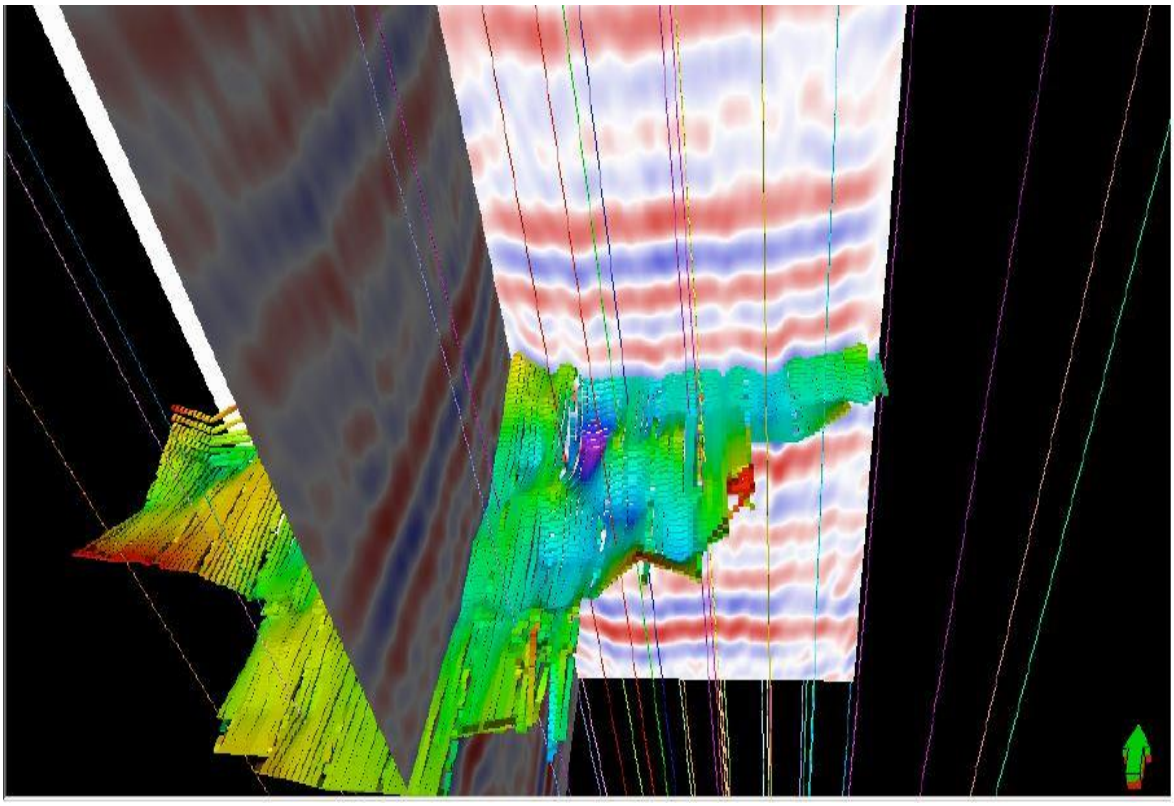


Figure 27Depth converted layer 4

11 GEOLOGICAL INTERPRETATION FROM SEISMIC INTERPRETATION

11.1 Structural Interpretation

The dominant structure in the NPR-3 is the Salt Creek dome and Teapot domes which is a Teapot Dome is an elongated asymmetric, basement-cored anticline.

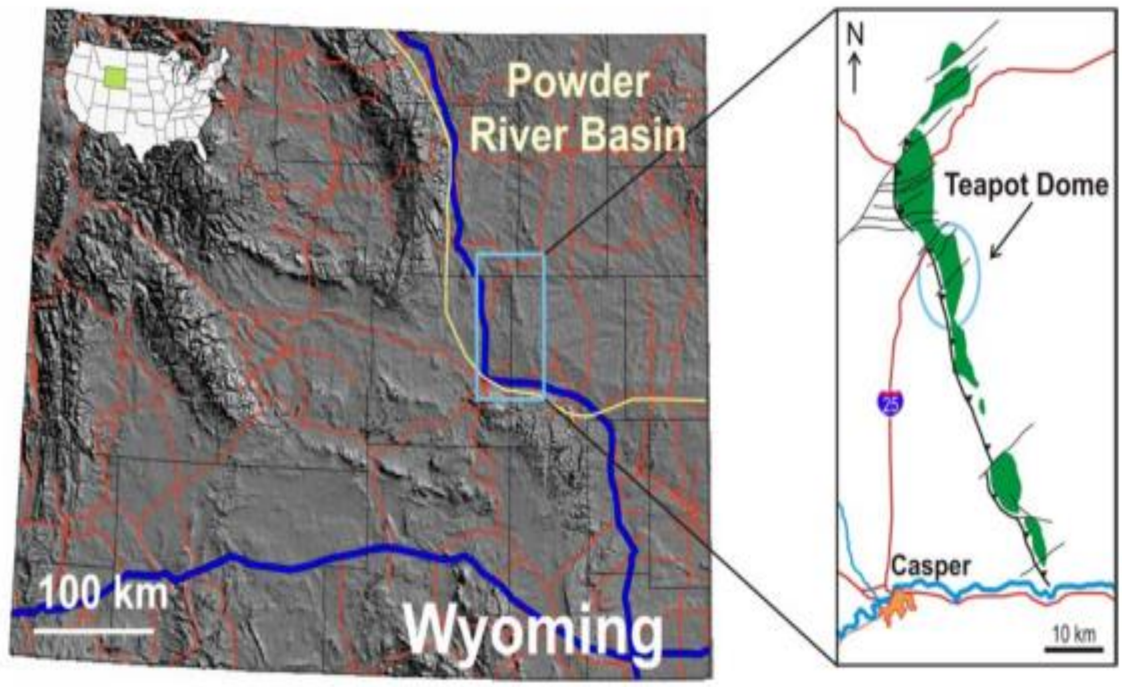


Figure 28Structural view of Teapot

In Teapot Dome, the west flank dips steeper (20-50^{0}) than the east flanks (<20). It is bound on the west by a main thrust fault, consisting probably of a series of high angle reverse fault of approximate 35° to 40° east northeast, offsetting the Precambrian igneous and metamorphic basement mapped in outcrop in adjacent ranges.

The anticline is compartmentalized in several blocks by major oblique strike-slip to normal faults that have been assigned arbitrary names S1, S2, S3, and S4. These faults are well defined in both the seismic data and in the outcrops. They offset the basement and are oriented along a NE-SW trend, parallel to both the vergence direction of the main fold and basement foliation in neighbouring outcrops. Their orientation and complexity varies locally, but generally have steep dips. At the surface, these faults have apparent lateral offsets, and sub-horizontal or oblique-slip striations have been observed, thus they have usually been interpreted as tear or accommodation faults. The thickness changes across the faults in Paleozoic and Mesozoic strata suggest that there were some earlier fault slip and growth strata events.

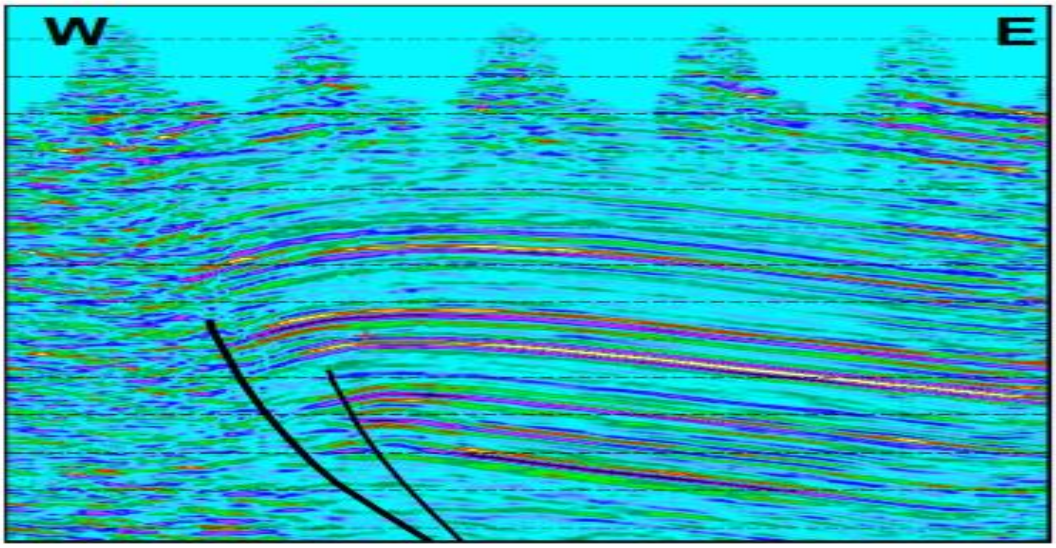


Figure 29Fault compartment beneath the Dome

11.2 Petroleum System

Up to the present time commercially valuable amounts of oil and gas have been found within Naval Petroleum Reserve No. 3 only in the "**Second Wall Creek" and "Third Wall Creek" sands and in fissures in the shale's above the "First Wall Creek sand."**

In the Salt Creek field, however, commercial oil has been yielded by the Shannon, the "First Wall Creek," the "Second Wall Creek," the "Third Wall Creek," the Muddy," the "Dakota," the "Lakota," the Sundance, and the Tensleep sands and by fissures in shale.

The "First Wall Creek sand" is exclusively water bearing in the naval reserve, but a possibility remains that the "Lakota sand" and lower sands may contain oil and gas within the reserve.

Shannon sandstone -The Shannon sandstone normally consists of two cliff-forming benches of sandstone overlain by a 25-foot bed of sandy shale or soft sandstone. An escarpment formed by the Shannon encircles the Salt Creek field, and the bed dips below the surface near the northern edge of the naval reserve and is within 400 feet of the surface over most of the productive part of the Teapot field. Some heavy oil has been prod need from the Shannon sand just north of the main Salt Creek field, and non-commercial quantities of oil have been found in it at places in or near the Teapot reserve.

"Second Wall Greek sand" -The "Second Wall Creek sand" which was opened by wells drilled at Salt Creek in 1917, has yielded the greater part of the oil produced in both the Teapot and Salt Creek fields and is the sand principally involved in present discussions.

The lack of pressure communication (or of interference) between nearby wells in parts of the Salt Creek field also suggests that the "Second Wall Creek sand" is there to a considerable extent divided into separate reservoir units by cementation along joint planes parallel to the crest of the fold, on which the crest has settled slightly, as the keystone of an arch settles when the sides of the arch are spread apart somewhat, or the independent performance (non-interference) may be due to composite bedding or crossbedding in the sand, which may consist of sand lenses overlapping shingle fashion.

"Third Wall Greek sand" -The "Third Wall Creek sand" lies 215 to 275 feet below the top of the "Second Wall Creek sand" and has yielded some oil in both the Salt Creek and Teapot fields.

"**Muddy sand" and "Dakota sand"** -The "Muddy sand" and perhaps other sandy beds in the Thermopolis shale and the "Dakota sand" have yielded considerable quantities of oil in the Salt Creek field and elsewhere in Wyoming. They have not .been completely tested at Salt Creek and are as yet wholly untested in the Teapot field, but in spite of their comparative thinness they appear to be of considerable potential importance within the naval reserve.

The "**Lakota sand**" of the drillers is a coarse conglomeratic sandstone, normally containing artesian water under strong pressure and also containing a considerable oil pool beneath the higher part of the Salt Creek dome. It is as yet untested within the naval reserve and may be found to contain, commercial quantities of oil and gas, although from the apparent strength of the water movement in the sand in the Salt

Creek field it is believed that there is less than an even chance that it will yield oil in the reserve.

Tensleep sandstone -The Tensleep sandstone yields large flows of artesian water in the Tisdale and Salt Creek fields, and because of the indicated strength of the water movement it is probably barren of oil beneath the Teapot dome, although the presence of an oil pool in this sand beneath the crest of the Salt Creek dome (revealed by drilling in 1930) indicates the possible existence of a similar pool in the Tensleep at Teapot. Because of its considerable thickness and high porosity, however, there is a bare possibility that it contains very large quantities of oil beneath the naval reserve possibility which it would be unwise to ignore.

11.3 MIGRATION AND ACCUMULATION OF OIL AND GAS

Much of the gas and a part of the oil escaped from the faults at surface seepages; but after a time the hydrostatic pressure exerted on the sand by the column of oil extending upward to the surface equalled the effective pressure in the sand, and the escape of oil and gas practically ceased.

During this period of quiet channels for upward migration were sealed off, owing either to plastic settling of the shale beds, to the hydration and swelling of the bentonite layers, to the settling and collection of mud in the constricted parts of the fault fissures, to local cementation of the sand by calcite, or to cementation of the fault walls and the development of the calcite fissure fillings which are so commonly found marking the fault planes in the Salt Creek, and Teapot fields.

After the faults were sealed local pressures were rebuilt or redistributed through regional hydrostatic and hydraulic adjustments, and gravitational readjustments went on within the folds, producing a segregation of gas above oil and of oil above water, as in the Teapot field.

With increasing pressure increased quantities of the free gas became redissolved in the oil, this process apparently going so far in the Salt Creek field as to cause the reabsorption of whatever free gas may have existed there after the initial accumulation had taken place.

The fact that nearly all the productive domes and anticlines in the Rocky Mountain fields are cut by fault fissures furnishes striking evidences that faulting and fissuring have played an important r6le in the migration and accumulation of oil into these entrapments.

Probably the best example of this is the petroleum geologist's paradise at Salt Creek, Wyoming. The huge Salt Creek structure and the somewhat smaller Teapot Dome are literally cut to pieces by fault fissures which are evidenced at the surface both by rock displacement and by calcite veins and stringers.

Evidence that the escape of small proportions of the gas and oil has continued practically to the present time is furnished by the occurrence of numerous seepages in the Salt Creek field.

11.3.1 Primary and secondary gas accumulation

Where the gas originally accompanying the oil and water (primary gas) has escaped through the fissures, the accumulated oil may be practically devoid of gas as at Soap Creek and Cat Creek, Maverick Springs, and other fields in Wyoming.

But where considerable gas under high pressure accompanies oil in faulted and fissured structures it seems probable that this gas is either primary gas retained by the early sealing of the fissures, or that it is secondary gas which formed in or migrated to the entrapment after the fissures were sealed.

It is possible that both phases of gas accumulation are represented in many structures, that there has been an enormous escape of gas incident to the migration and accumulation of oil in most fields is indicated by the high concentration of salts in the waters associated with the oil. This concentration has undoubtedly been brought about through the removal of water vapour in escaping gases

11.3.2 Retention of oil

The flow ceases when the propulsive force becomes inadequate to propel the oil to the surface. The complete escape of oil through open fissures has probably failed largely because of dissipated gas pressures, whereas the final retention of the oil is due to the sealing of the fissures before the gas pressures in the vicinity of the faults have again built up through regional adjustments.

11.4 Summary

1. Under favourable conditions, especially in firm consolidated strata, faulting that has yielded open fissures ·has been an important factor in the migration and accumulation of oil and gas.
2. Differential pressure, caused by the release of pressure through fault fissures,
3. The migration of gas and oil through fissures has been upward either to the surface or from one bed to another.
4. The propulsive force of expanding gas, more especially the gas absorbed in oil and water under high pressure
5. Oil is propelled more effectively than water by the propulsive force of absorbed gas
6. The migration and accumulation of oil and gas under the influence of differential pressures caused by faulting has been a comparatively rapid process, not the long drawn out process that is generally pictured.
7. The occurrence of faults in the Rocky Mountain and Mid-Continent fields is a valuable criterion in the search for petroleum. In these regions a closed structure that is faulted should generally be given preference to one that is not faulted. Further application of these facts may possibly be made in other fields.
8. Shallow sands have generally undergone more advanced drainage of oil and gas through fault fissures than have the deeper sands.

11.5 STRUCTURAL MODEL

Once the data is depth converted, the layers can be visualized using a structural model. Here, the dome is visualized. The petroleum system can be further visualized in the same model.

The structural model shows the variation of the domal structure with the elevation depth and also indicates the major fault running through the area and the wells that are flowing.

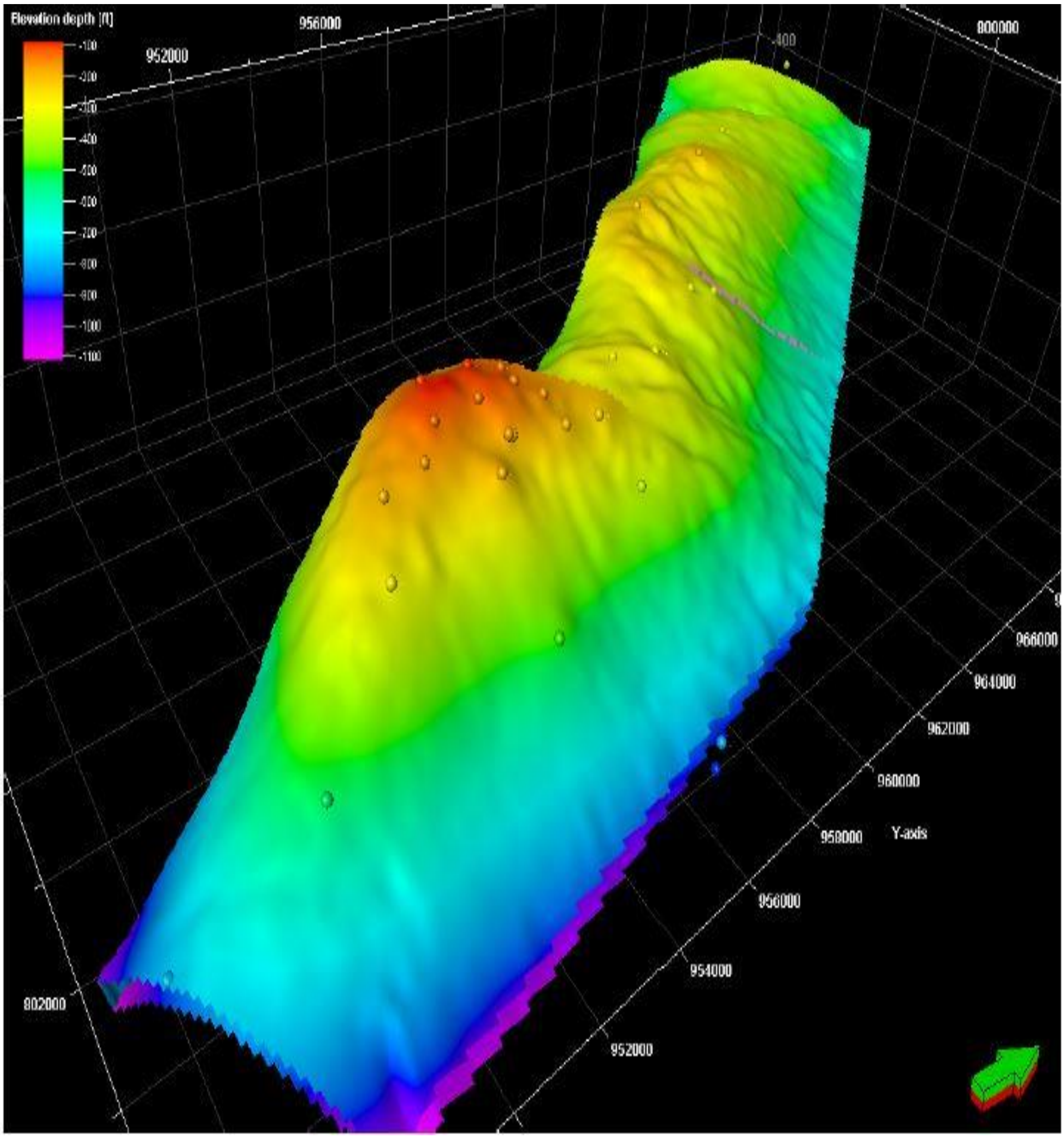


Figure 30Structural model

12 PLAY FOCUS

Besides the structure, the particular reservoir play is to be considered next. Of the above considered reservoirs, The Tensleep formation is containing the left out oil, which is produced the least within the Teapot oil field.

The properties of the Tensleep formation is studied from the various wells spudded through it. The core data provided the porosity and permeability, which are to be used in the Petrophysical property modelling.

Properties of Tensleep Formation:

Table 4 Description of Tensleep Formation

Formation Description	Dolomite-cemented dunal sand. 2 units separated by 10' - 15' dolomite. Strong H_2O drive.
Original Oil In Place 10^6 STB	33.4452
Original Gas In Place 10^6 SCF	11
Area , acres	320
Average porosity, %	8
Average permeability, md	80
Average Net Thickness, ft	50
Reservoir Pressure,	2350
Depth, ft	5500
Datum elevation, ft	-220
Cumulative oil produced, 10^6 STB	1.84
Cumulative gas produced, 10^6 SCF	0
Cumulative water produced, 10^6 STB	170.04
Reservoir temperature, deg F	190
Oil gravity, deg API	32
No. of wells	
Producing wells	13
Injection	
Shut in	4
Temporarily abandoned	1
Plugged and abandoned	4

The depth map of the Tensleep formation is shown below:

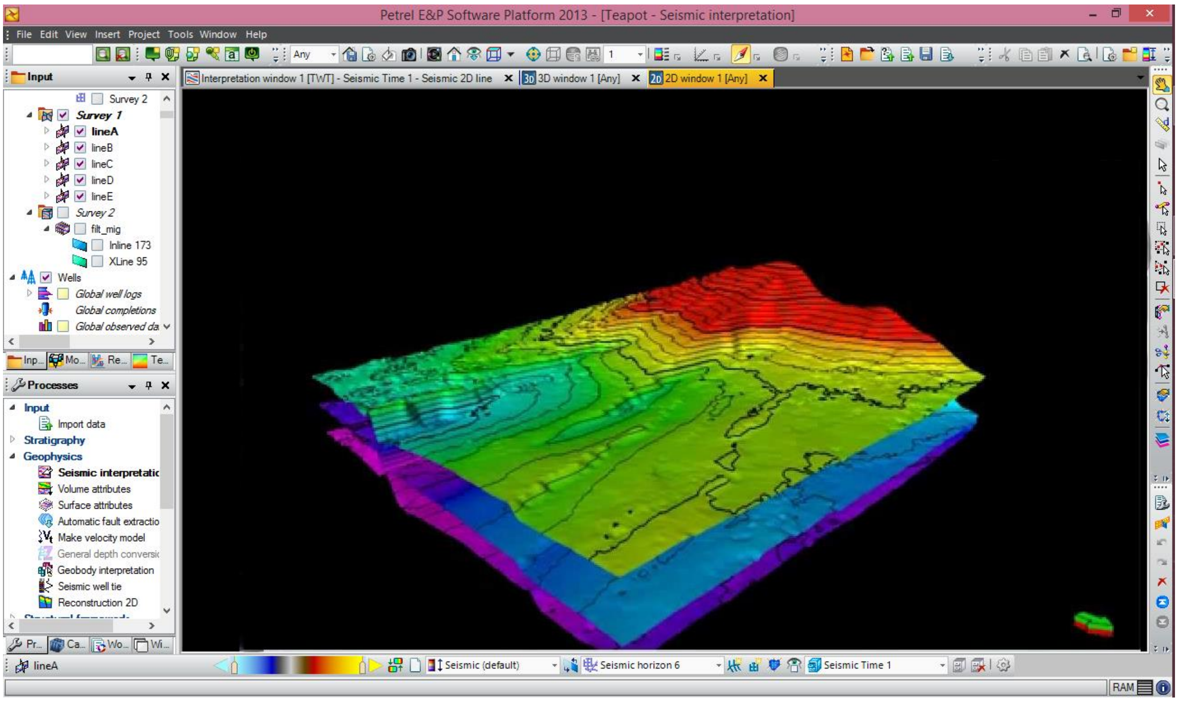


Figure 31Isopach map of Tensleep Formation

The properties of the Tensleep formation is analysed through the well 48-X-28, which contains all the information like mud log, core data, well logs, well tops, etc. The workflow is shown below.

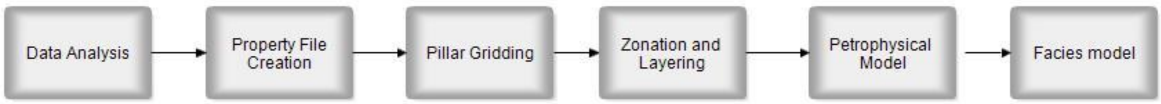


Figure 32Workflow for Play Focus

12.1.1 DATA ANALYSIS

The core data test results are used to estimate the porosity and permeability, which will be used in further steps. The core porosity is correlated to the well log porosity and corrections can be made.

The porosity and permeability are then made into files .por and .perm, which are then associated to the well and core data points on the particular location in the model.

The porosity and permeability plot with the Gamma Count is given below.

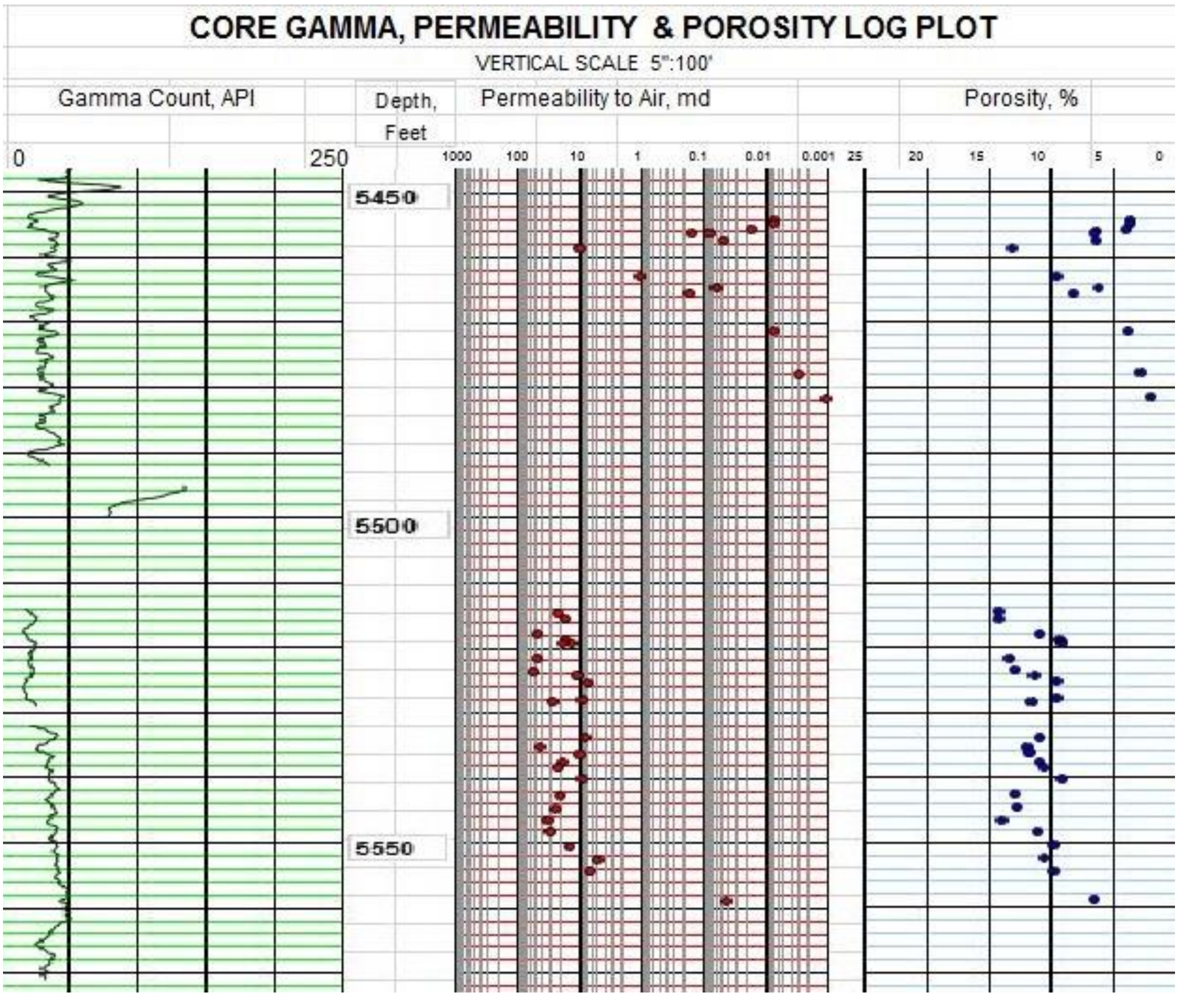


Figure 33Porosity Permeability Graph

12.2 Pillar Gridding

The play is made into 3d grids using the Pillar Gridding Process under Structural Modelling Tab.

The I and J increments are 100x100 for our current grid. The grid is then displayed in the 3D window. The input of the horizons and faults are provided to the grid and then visualized.

Then the grid boundary is created. The input data visualized should lie within the boundary. The faults are then fed into the grid.

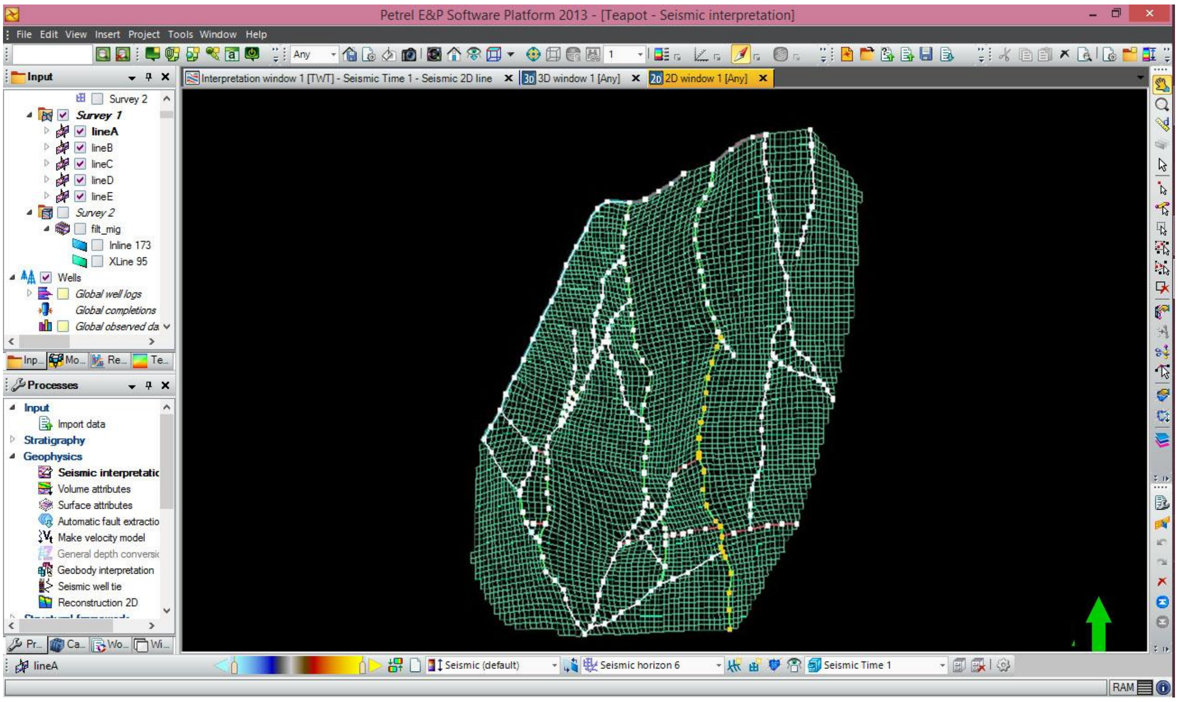


Figure 34Pillar Grid

12.3 ZONATION AND LAYERING

The grid, after completed will be fed with 3D horizons made earlier. The 3D horizon of the Tensleep formation will be layered based on the stratigraphic interpretation and the zones will be created based on the faults that separate the layers into small blocks.

The blocks will be taken into consideration while we have to choose particular location to drill a well for maximum production.

In Petrel, under Structural modelling tab, the Vertical layering Process is chosen for this operation. The input Grid mentioned above is fed along with the 3D horizons to this process.

The zones in the Tensleep are taken as per the recommendations taken from Geologists in RMOTC, Wyoming, U.S.A. The 5 different zones of the Tensleep formation are shown above. The known fluid holding volume of the layers are presented along with intersecting faults and layers.

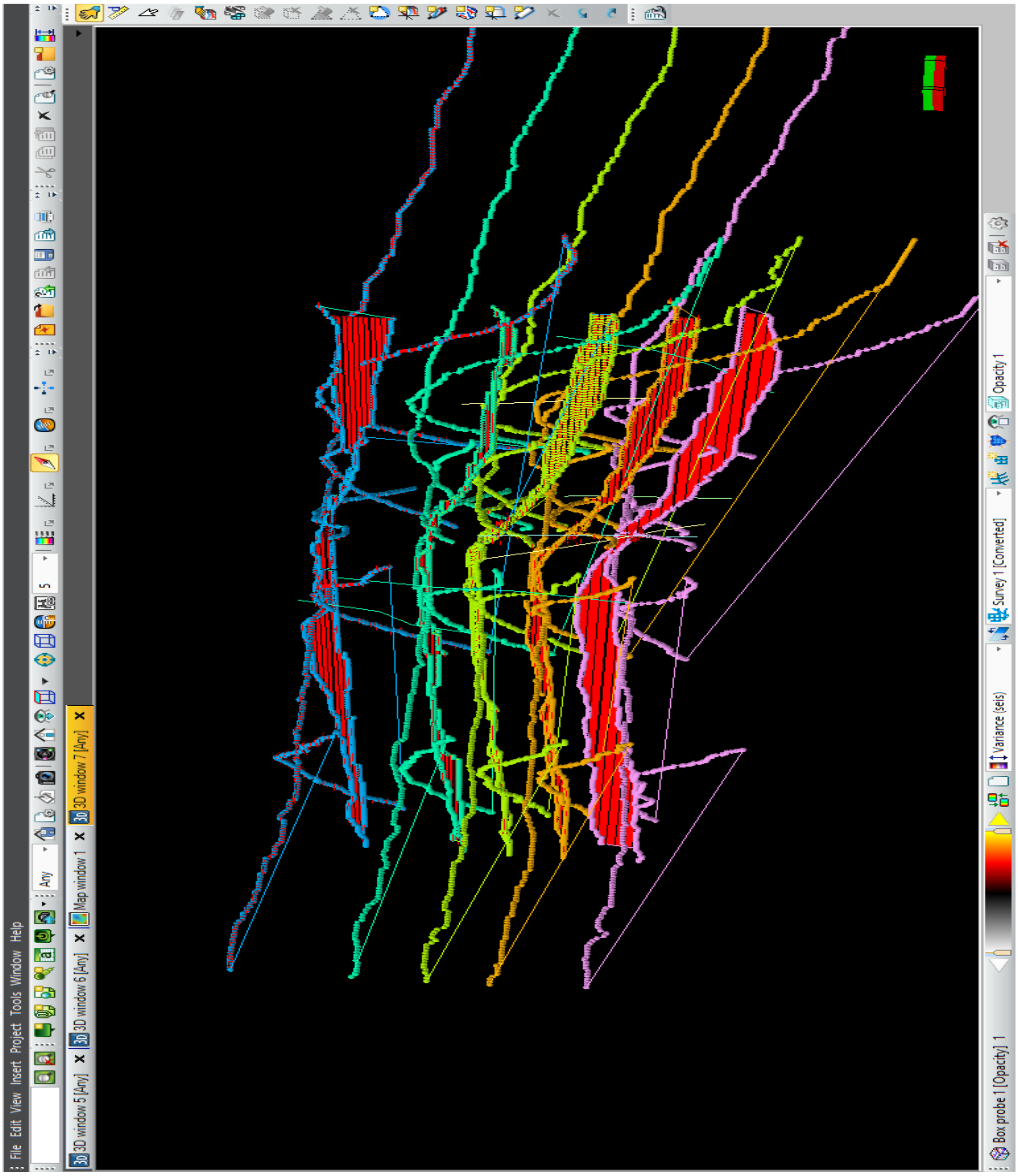


Figure 35Zonation and layering within Tensleep formation

13 PROSPECT FOCUS

Within the zones, the smallest stratigraphic unit can be visualized using the Facies model. The model is developed with the intra-layer properties which are taken into account with the help of scanning and imaging logs in the particular producing intervals.

The Facies model comes under the Prospect focus, where the exact Pay zone is modelled with the known properties of the layers.

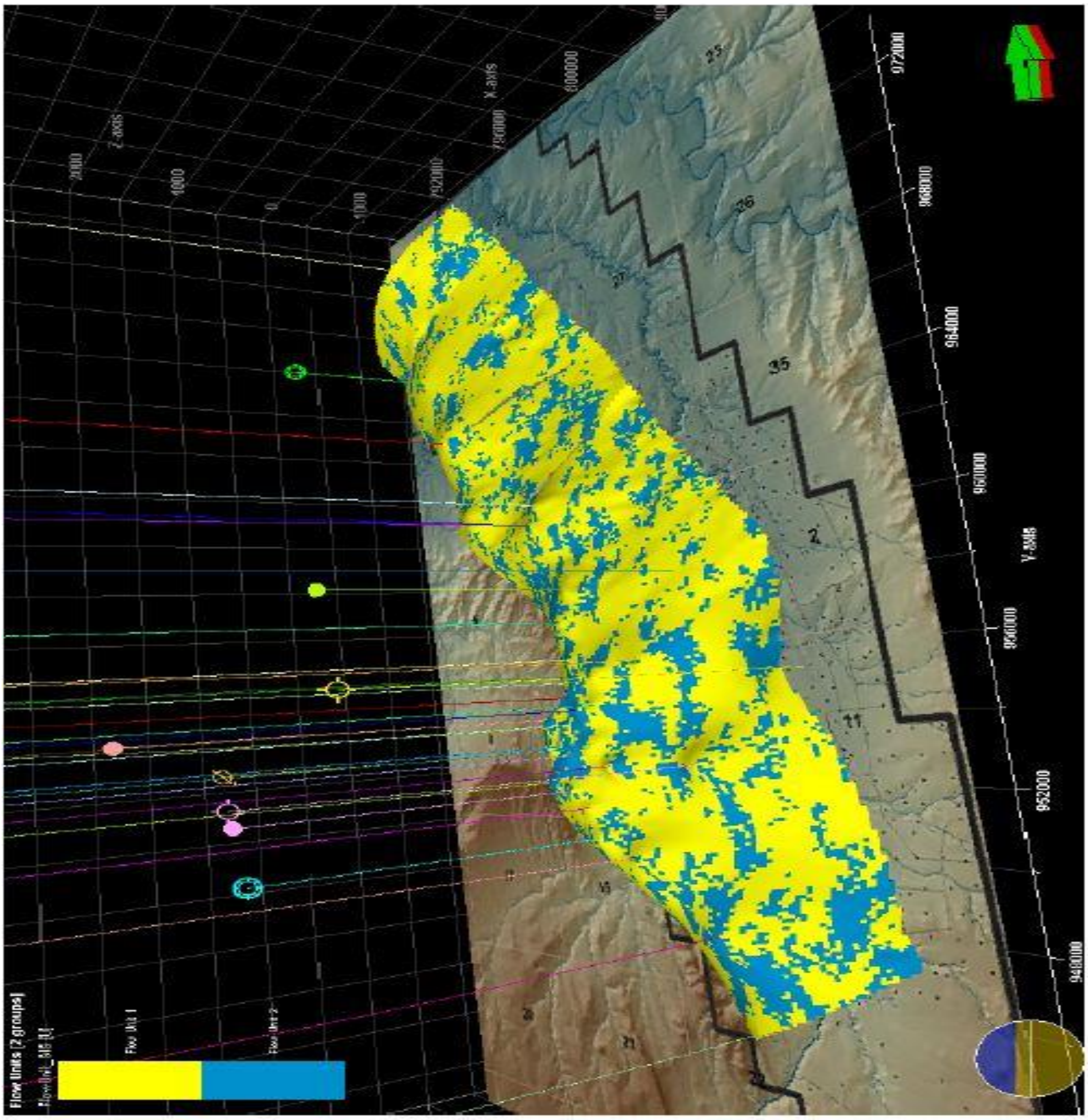


Figure 36Facies Model

The Volume of oil contained in the Tensleep is already determined and the Well data of this formation is also known. As the fault sealing blocks are modelled, the remaining oil in the formation can be determined by the Production data analysis in order to identify and estimate the Reservoir compartmentalization and its effects.

14 PRODUCTION DATA ANALYSIS

Field Data

To carry out this research, data was collected from the U.S. Department of Energy Rock Mountain Oilfield Testing Center on the Teapot Dome oil field as well as other free access sources. A base map was constructed with layers depicting various natural features and fault lines as well as a layer containing the location and attributes of each oil well studied.

Depth

Oil production volume was summarized by well depth. A total of 7,760,700 barrels of oil were produced by the 663 shallow wells which are defined as less than 1,004 feet in depth and a total of 13,995,227 barrels of oil produced by 655 deep wells for an oil field total production of 21,755,927 barrels.

While Figure indicates the majority of both shallow and deep wells individually produce less than 90,000 barrels of oil. The mean or average production for deep wells is almost double that of shallow wells. Yet the median production of deep wells is 60% that of shallow wells. With the sample sizes of both shallow and deep wells being nearly equal to each other, collectively, deep wells produce almost double that of shallow wells.

Depth	Mean	Median	Sum
Deep	21,367	4,209	13,995,227
Shallow	11,723	7,150	7,760,700
		Total	21,755,927

Formation

The two formations which dominate the oil field production are the 2 with 40.3% of the production and Shannon with 39.5% or 8,583,263 bbls. All other formations combined account for only 20.2% of the overall production.

The Tensleep formation has produced less than 20% of its reserves. The number of wells drilled are just 13 only. In order to produce more effectively, various factors should be considered:

- Structural complexity (e.g.: faulting, fracturing)
- Depositional complexity (e.g.: depositional continuity)

- Reservoir quality (e.g. permeability, heterogeneity)
- Fluid quality (e.g. viscosity)
- Reservoir energy (e.g. pressure, aquifer strength)

These factors, when estimated will provide the effect of reservoir compartmentalization on the production from the Tensleep formation.

The Structural, Depositional and Reservoir complexities are estimated already through the static model. The Production data analysis helps to determine remaining factors.

14.1 DATA ANALYSIS

We were able to obtain reservoir data for two wells (x and y) which we analysed using MBAL Software for data interpretation. The following screenshots were taken while working on the software.

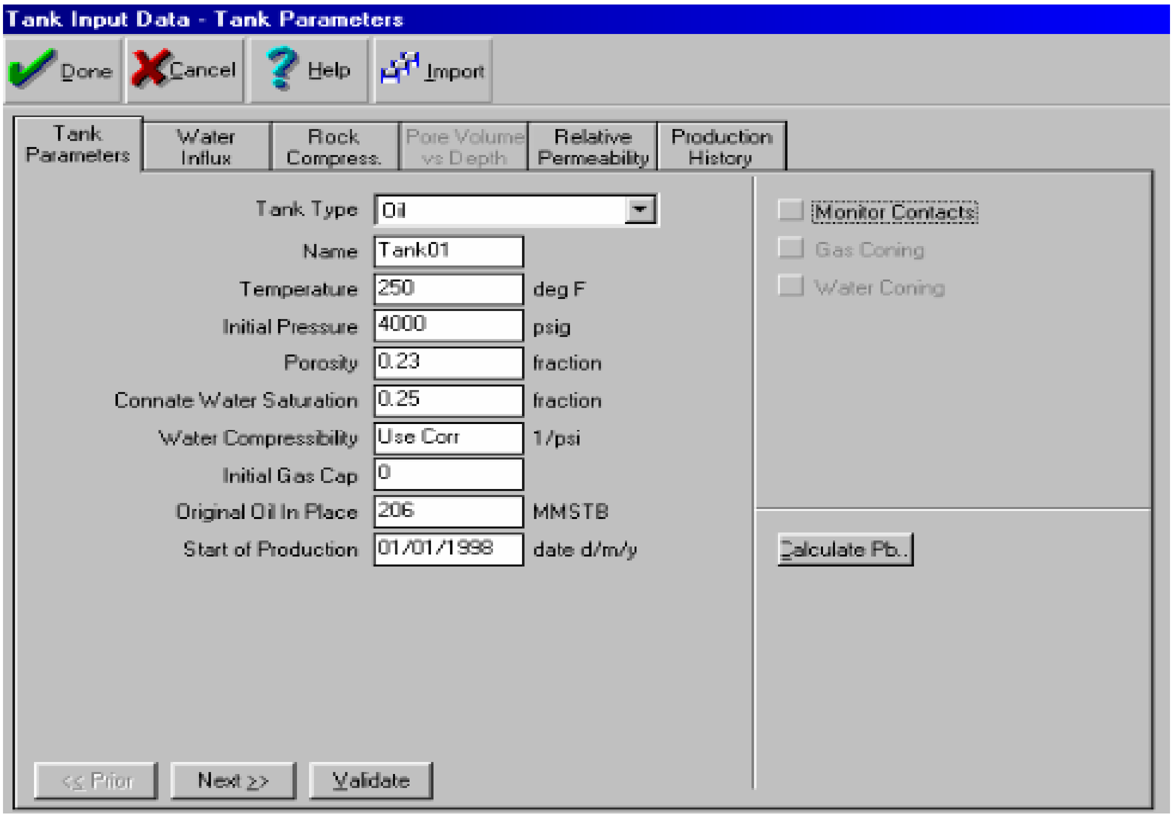


Figure 37-Input data dialog for well- 48-x-28

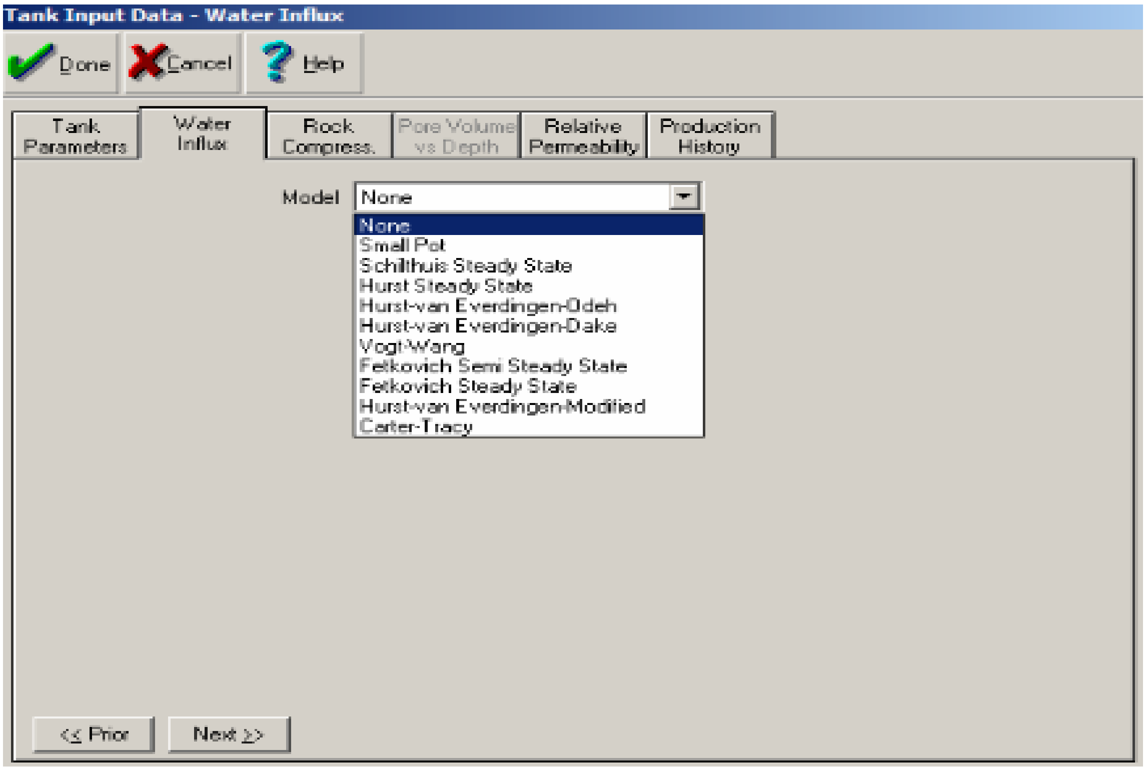


Figure 38- Input dialog for well-48-x-28

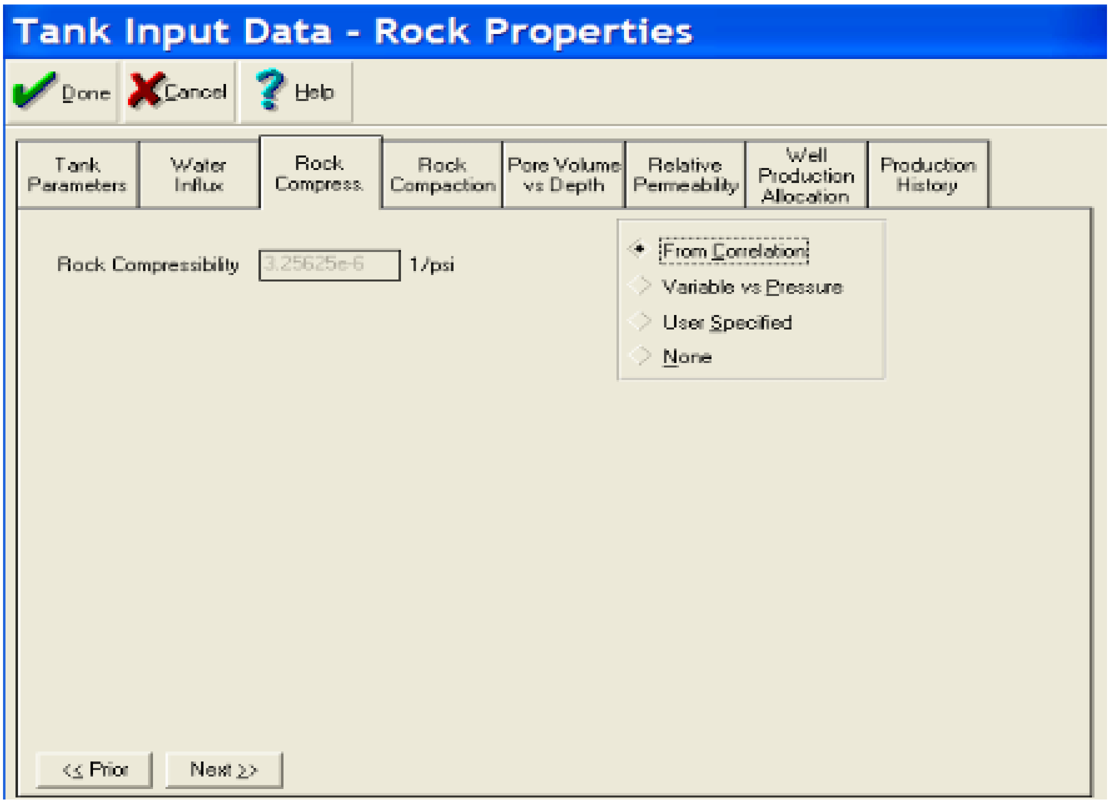


Figure 39- Input dialog for well-48-x-28

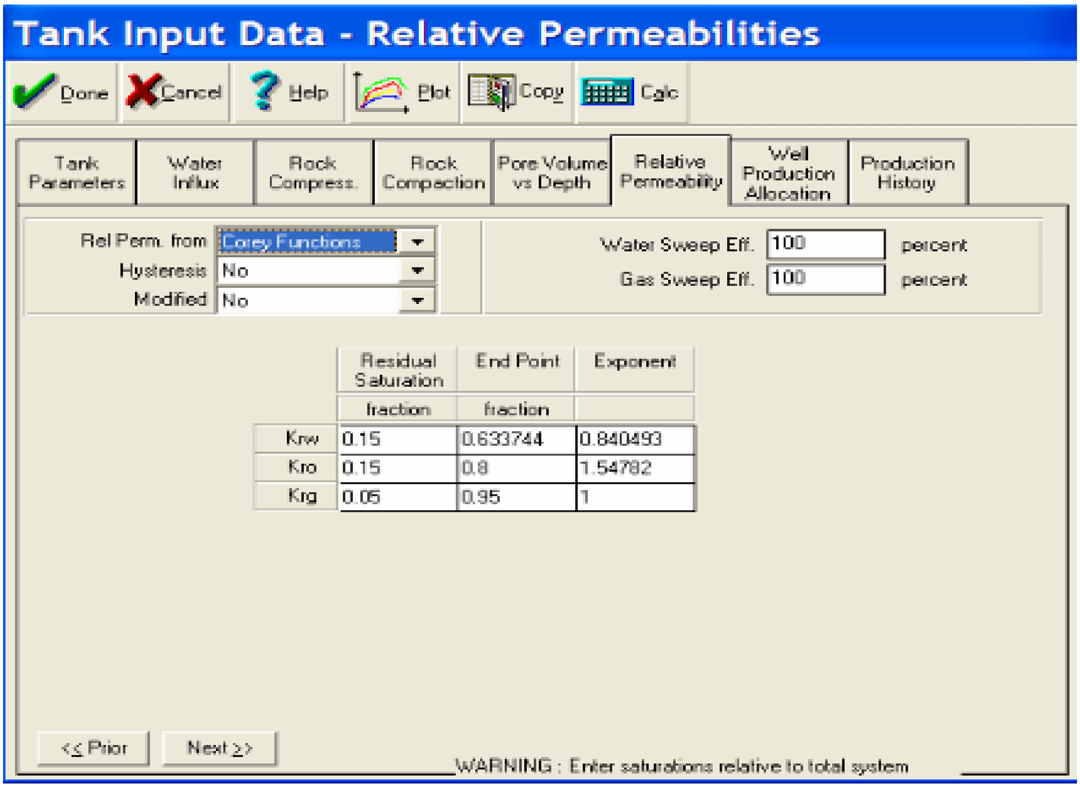


Figure 40 Input dialog for well-48-x-28

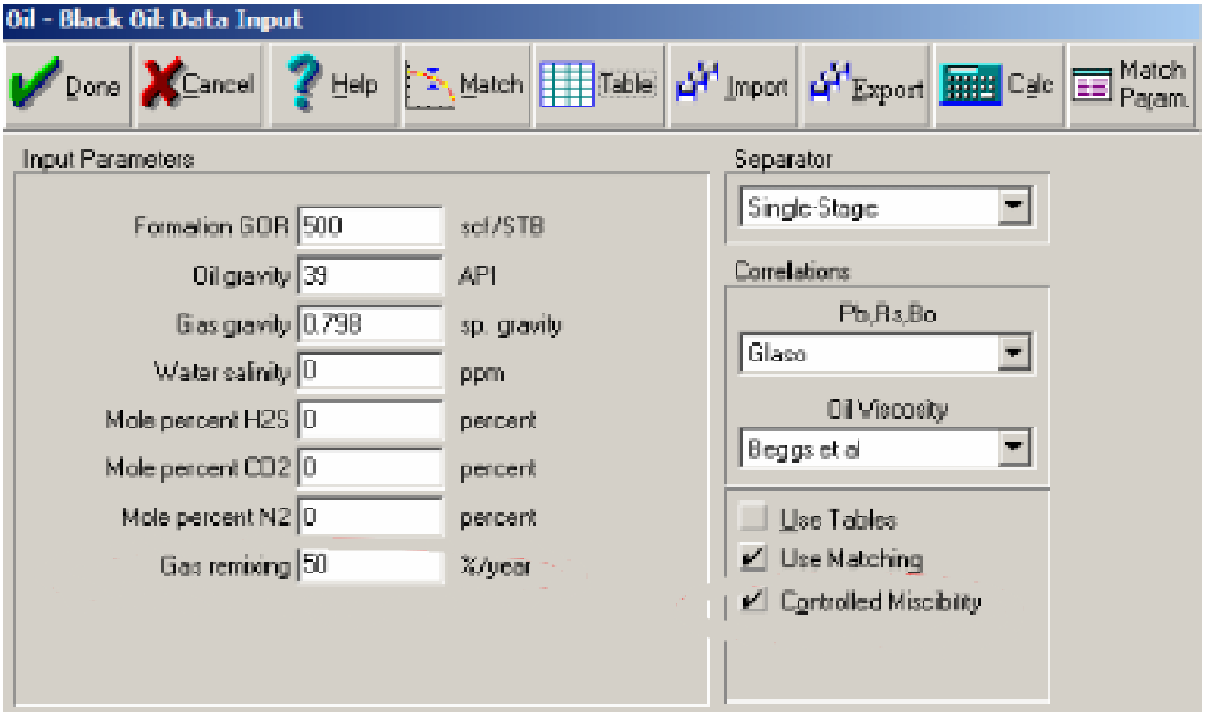
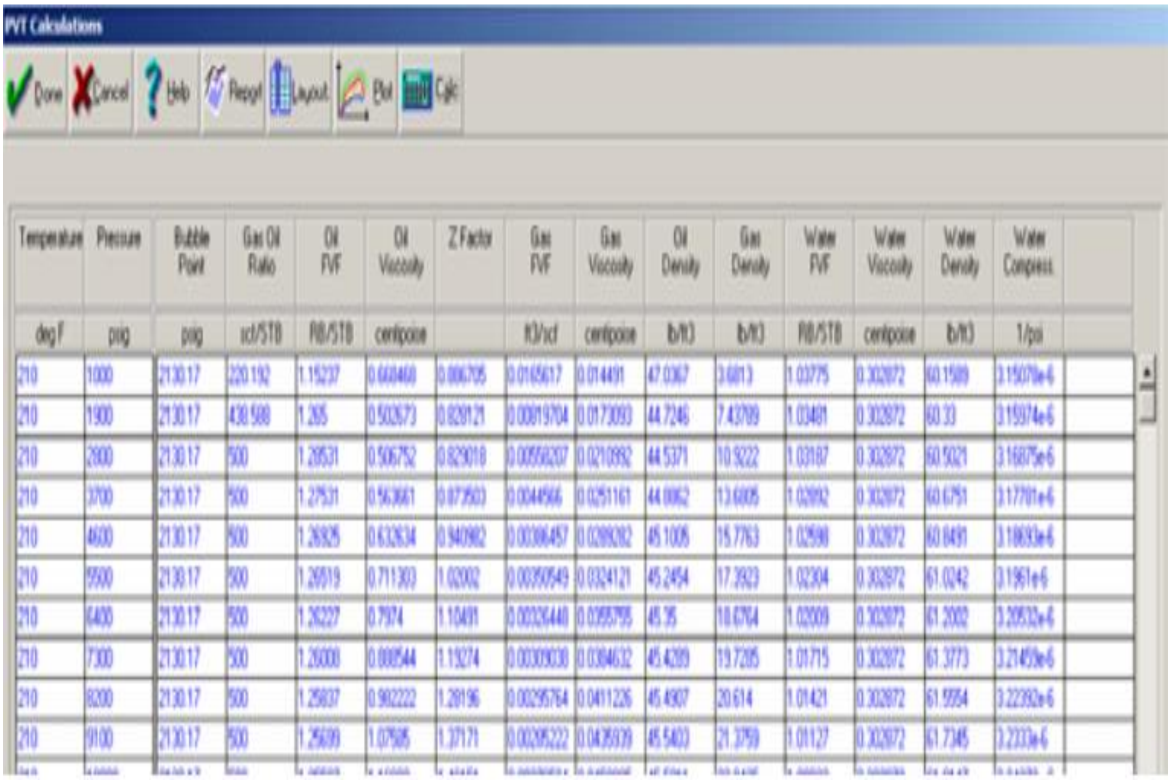


Figure 41 Input dialog for well-48-x-28



Temperature	Pressure	Bubble Point	Gas Oil Ratio	Oil FVF	Oil Viscosity	Z Factor	Gas FVF	Gas Viscosity	Oil Density	Gas Density	Water FVF	Water Viscosity	Water Density	Water Compress
deg F	psig	psig	scf/STB	RB/STB	centipoise		ft3/scf	centipoise	lb/ft3	lb/ft3	RB/STB	centipoise	lb/ft3	1/psi
210	1000	2130.17	220.192	1.15237	0.668460	0.886705	0.0165617	0.014491	47.0367	3.6813	1.03775	0.302872	60.1509	3.15079e-6
210	1900	2130.17	438.588	1.265	0.503673	0.828121	0.00819704	0.0173093	44.7246	7.43709	1.03481	0.302872	60.33	3.15974e-6
210	2800	2130.17	500	1.28531	0.506752	0.829018	0.00558207	0.0210992	44.5371	10.9222	1.03187	0.302872	60.5021	3.16875e-6
210	3700	2130.17	500	1.27531	0.563661	0.873503	0.0044566	0.0251161	44.0062	13.6005	1.02892	0.302872	60.6751	3.17701e-6
210	4600	2130.17	500	1.26925	0.632634	0.940982	0.00386457	0.0289282	45.1005	15.7763	1.02598	0.302872	60.8491	3.18693e-6
210	5500	2130.17	500	1.26519	0.711303	1.02002	0.00350549	0.0324121	45.2454	17.3923	1.02304	0.302872	61.0242	3.1961e-6
210	6400	2130.17	500	1.26227	0.7974	1.10491	0.00326440	0.0355795	45.35	18.6764	1.02009	0.302872	61.2002	3.20532e-6
210	7300	2130.17	500	1.26008	0.888544	1.19274	0.00309038	0.0384632	45.4289	19.7285	1.01715	0.302872	61.3773	3.21459e-6
210	8200	2130.17	500	1.25837	0.982222	1.28196	0.00295764	0.0411226	45.4907	20.614	1.01421	0.302872	61.5554	3.22392e-6
210	9100	2130.17	500	1.25699	1.07585	1.37171	0.00285222	0.0435939	45.5403	21.3759	1.01127	0.302872	61.7345	3.2333e-6

Figure 42- PVT data for well 48-x-28

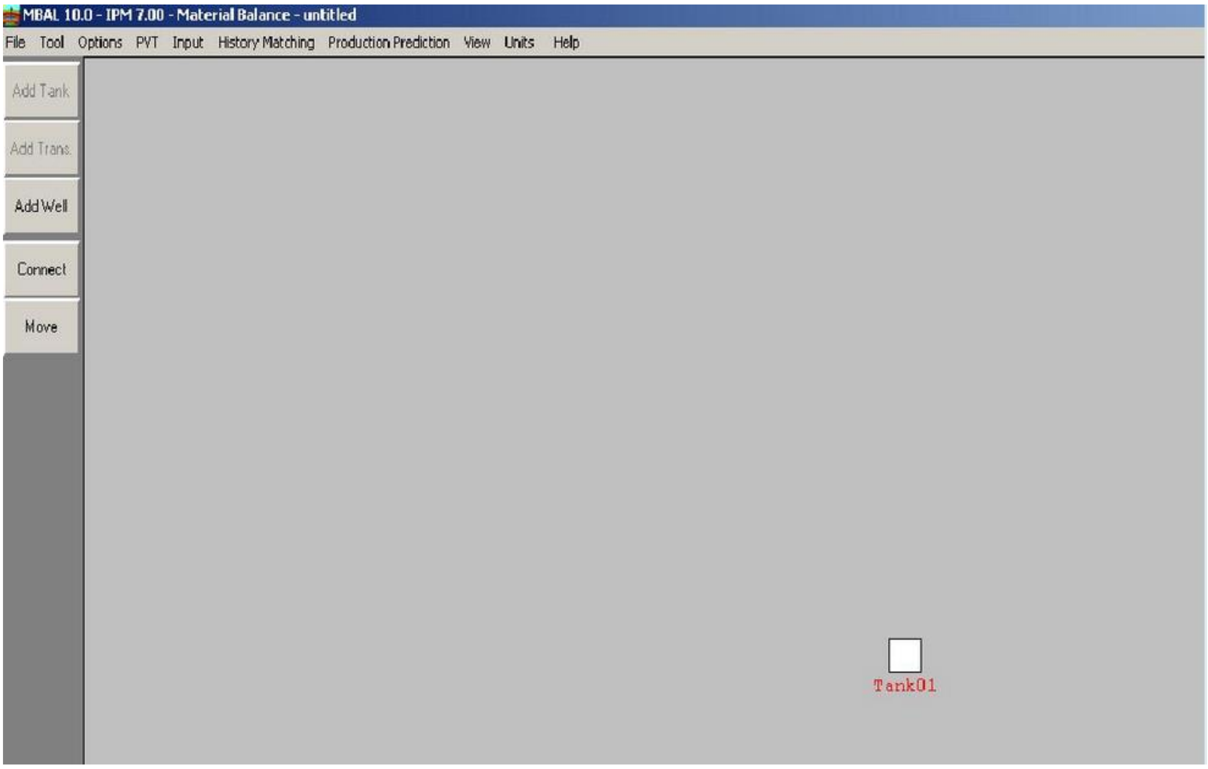


Figure 43 input dialog box for well 26-x-16

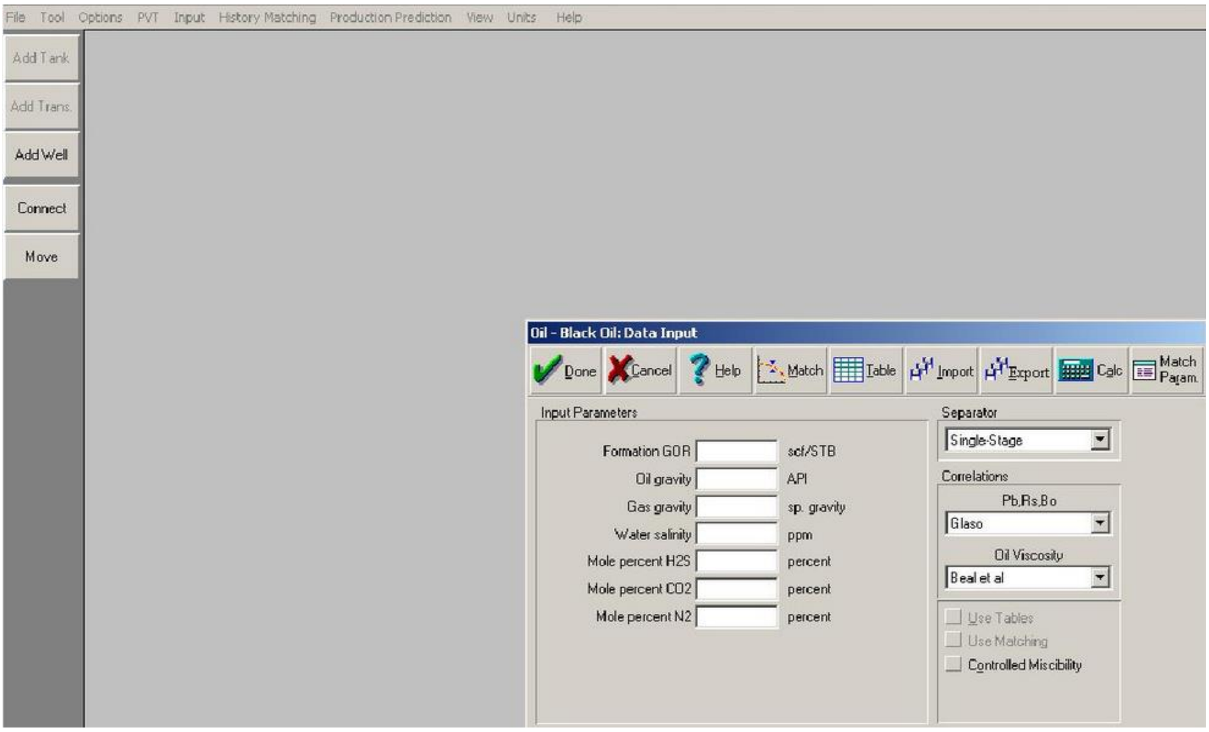


Figure 44 Input dialog box for well-26-x-16

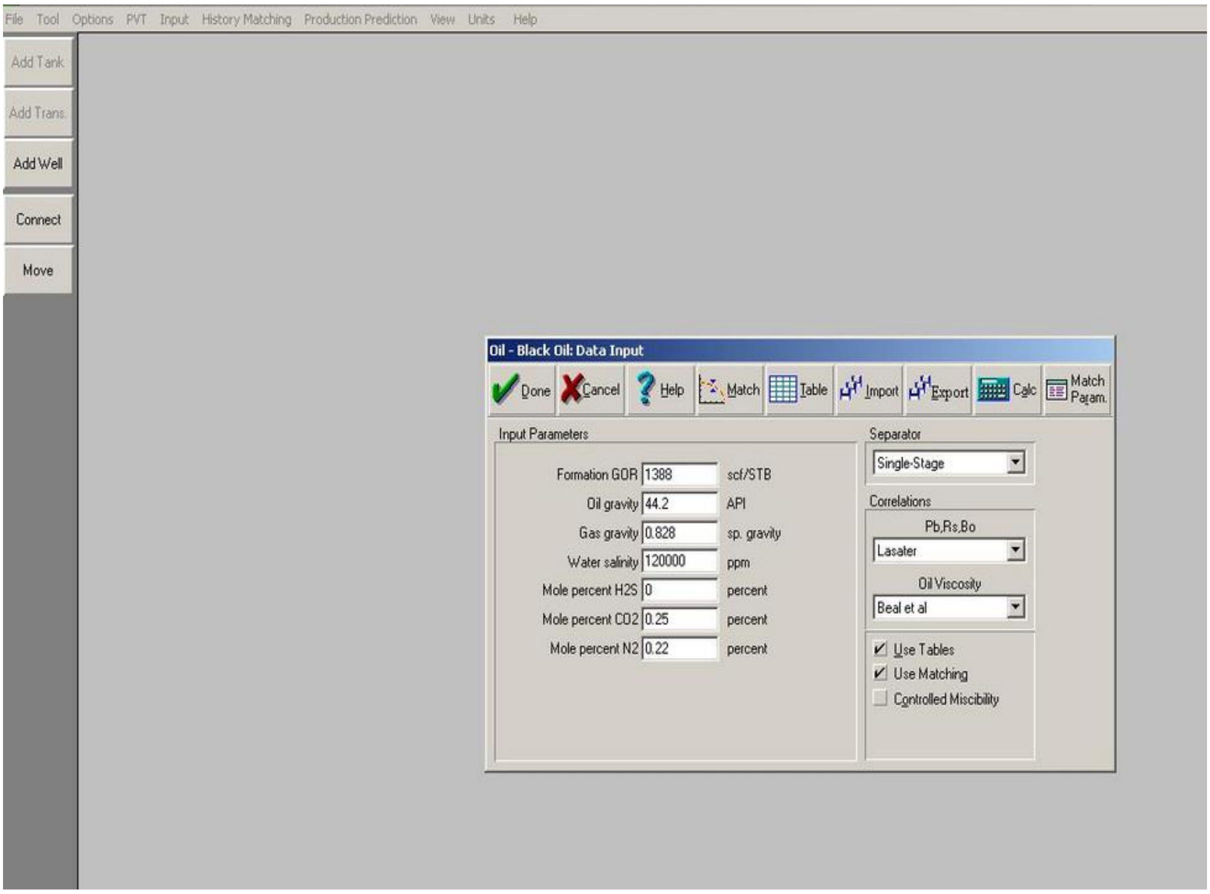


Figure 45Input dialog box for well- well-26-x-16

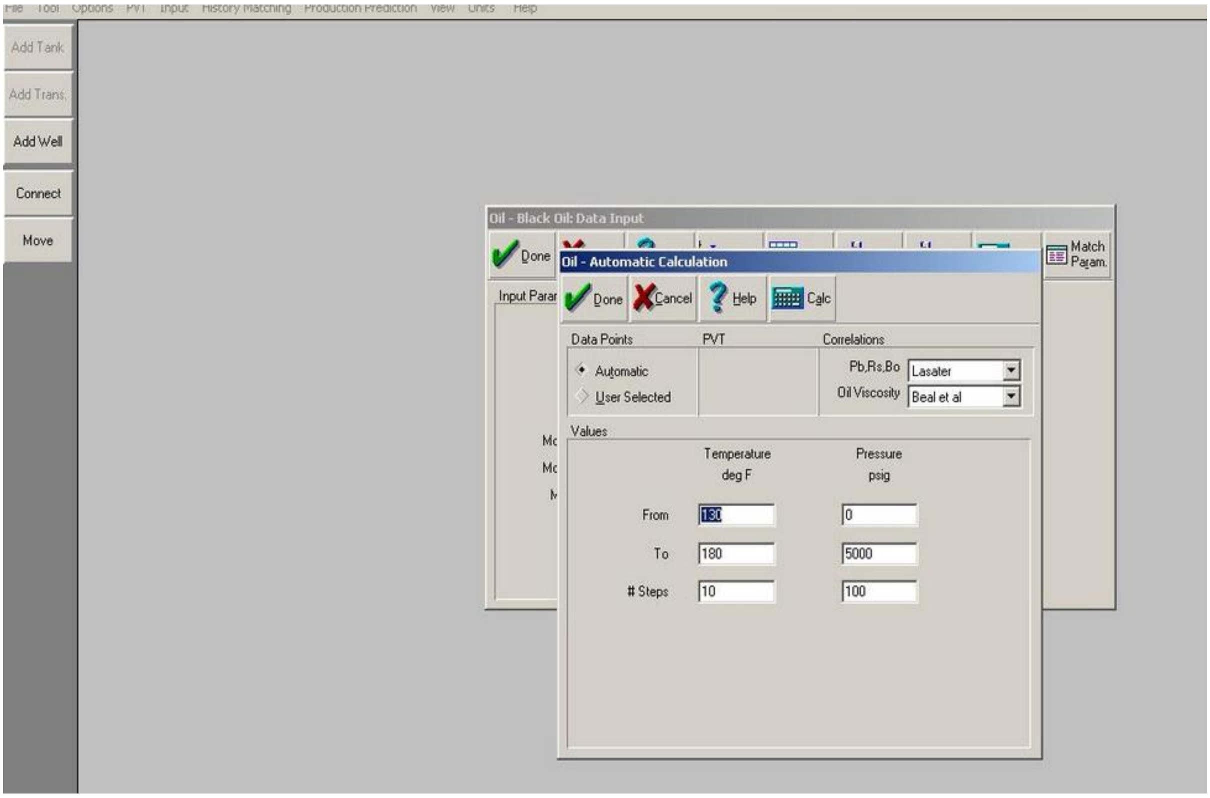


Figure 46Input dialog box for well- well-26-x-16

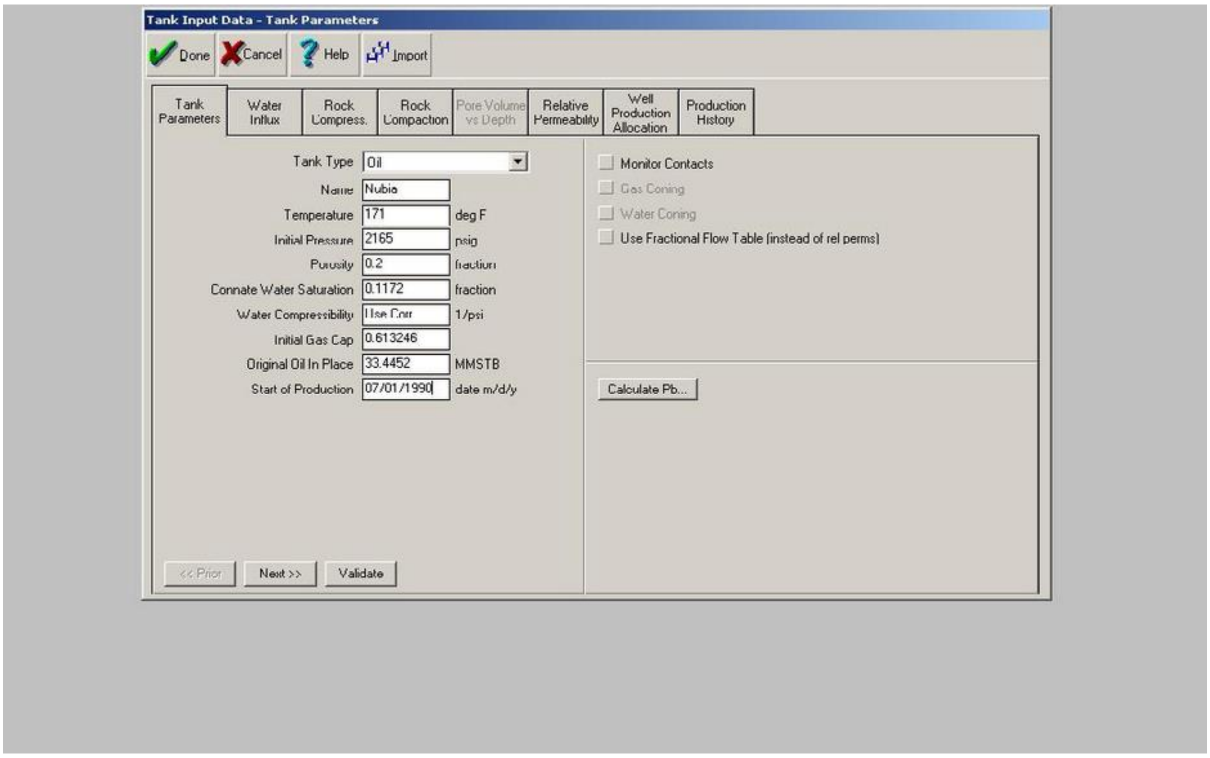


Figure 47input dialog for well-26-x-16

PVT Calculations

Done Cancel Help Report Layout Plot Calc

Temperature	Pressure	Bubble Point	Gas Oil Ratio	Oil FVF	Oil Viscosity	Z Factor	Gas FVF	Gas Viscosity	Oil Density	Gas Density	Water FVF	Water Viscosity	Water Density	Wa Comp
deg F	psig	psig	scf/STB	RB/STB	centipoise		ft3/scf	centipoise	lb/ft3	lb/ft3	RB/STB	centipoise	lb/ft3	1/p
130	0	2165	0.00516804	1.054	0.993999	0.0067518	0.00766502	0.0112839	47.702	0.0558841	1.01282	0.693022	66.7362	2.88465
130	50	2165	64.6006	1.10028	0.97654	0.028586	0.00737371	0.0113201	46.3575	0.248386	1.01267	0.693022	66.7458	2.88507
130	100	2165	129.201	1.14656	0.959081	0.0486762	0.00708238	0.0113688	45.1215	0.444771	1.01253	0.693022	66.7554	2.88549
130	150	2165	193.802	1.19284	0.941621	0.0670208	0.00679106	0.0114266	43.9813	0.64516	1.01238	0.693022	66.7651	2.8859e
130	200	2165	258.402	1.23912	0.924162	0.0836197	0.00649973	0.0114923	42.9264	0.849692	1.01224	0.693022	66.7747	2.88632
130	250	2165	323.003	1.2854	0.906702	0.0984728	0.0062084	0.0115651	41.9474	1.05851	1.01209	0.693022	66.7843	2.88674
130	300	2165	387.603	1.33169	0.889242	0.11158	0.00591707	0.0116449	41.0364	1.27176	1.01194	0.693022	66.794	2.88715
130	350	2165	452.204	1.37797	0.871783	0.122942	0.00562575	0.0117316	40.1867	1.48959	1.0118	0.693022	66.8036	2.88757
130	400	2165	487.65	1.39973	0.854323	0.132558	0.00533442	0.0118251	39.8475	1.71215	1.01165	0.693022	66.8133	2.88799
130	450	2165	512.854	1.41287	0.836864	0.140428	0.00504309	0.0119256	39.6779	1.93958	1.01151	0.693022	66.8229	2.8884e
130	500	2165	538.057	1.42601	0.819404	0.146553	0.00475176	0.0120331	39.5114	2.17201	1.01136	0.693022	66.8326	2.88882
130	550	2165	563.26	1.43916	0.801945	0.150932	0.00446043	0.012148	39.348	2.4096	1.01121	0.693022	66.8422	2.88924
130	600	2165	588.463	1.4523	0.784485	0.153565	0.00416911	0.0122703	39.1875	2.65246	1.01107	0.693022	66.8519	2.88966
130	650	2165	613.667	1.46544	0.767025	0.154453	0.00387778	0.0124005	39.0299	2.90071	1.01092	0.693022	66.8615	2.89007
130	700	2165	638.87	1.47859	0.749566	0.153594	0.00358645	0.0125387	38.8751	3.15445	1.01077	0.693022	66.8712	2.89049
130	750	2165	663.343	1.4913	0.732106	0.153526	0.00335045	0.0126853	38.7288	3.41375	1.01063	0.693022	66.8809	2.89091
130	800	2165	686.517	1.50324	0.714647	0.156845	0.00321281	0.0128406	38.5951	3.67867	1.01048	0.693022	66.8905	2.89133
130	850	2165	709.691	1.51517	0.697187	0.159339	0.00307517	0.013005	38.4634	3.94924	1.01034	0.693022	66.9002	2.89174
130	900	2165	732.865	1.52711	0.679727	0.161008	0.00293753	0.0131788	38.3338	4.22542	1.01019	0.693022	66.9099	2.89216
130	950	2165	756.039	1.53905	0.662268	0.161853	0.00279989	0.0133622	38.2062	4.50717	1.01004	0.693022	66.9196	2.89258
130	1000	2165	779.213	1.55099	0.644808	0.161873	0.00266225	0.0135558	38.0805	4.79436	1.0099	0.693022	66.9292	2.893e-(
130	1050	2165	802.388	1.56293	0.627349	0.161068	0.00252461	0.0137596	37.9568	5.08683	1.00975	0.693022	66.9389	2.89342
130	1100	2165	825.915	1.57497	0.609889	0.160358	0.00240073	0.0139741	37.8349	5.38434	1.00961	0.693022	66.9486	2.89384
130	1150	2165	850.563	1.58737	0.59243	0.161947	0.00232045	0.0141994	37.7145	5.68658	1.00946	0.693022	66.9583	2.89425
130	1200	2165	875.211	1.59976	0.57497	0.163056	0.00224017	0.0144356	37.596	5.99317	1.00931	0.693022	66.968	2.89467
130	1250	2165	899.859	1.61216	0.55751	0.163684	0.00215989	0.014683	37.4793	6.30367	1.00917	0.693022	66.9777	2.89509
130	1300	2165	924.507	1.62455	0.540051	0.163831	0.00207961	0.0149414	37.3644	6.61756	1.00902	0.693022	66.9874	2.89551

Figure 48PVT data for well well-26-x-16

14.2 INFERENCE

It is observed from the reservoir data that both wells producing from the same formation (Tensleep formation) have different reservoir fluid characteristics. This effectively proves with a high degree of certainty that the Tensleep formation are in fact compartmentalized.

Here, the fault seal blocks are also provided to visually infer the compartmentalization.

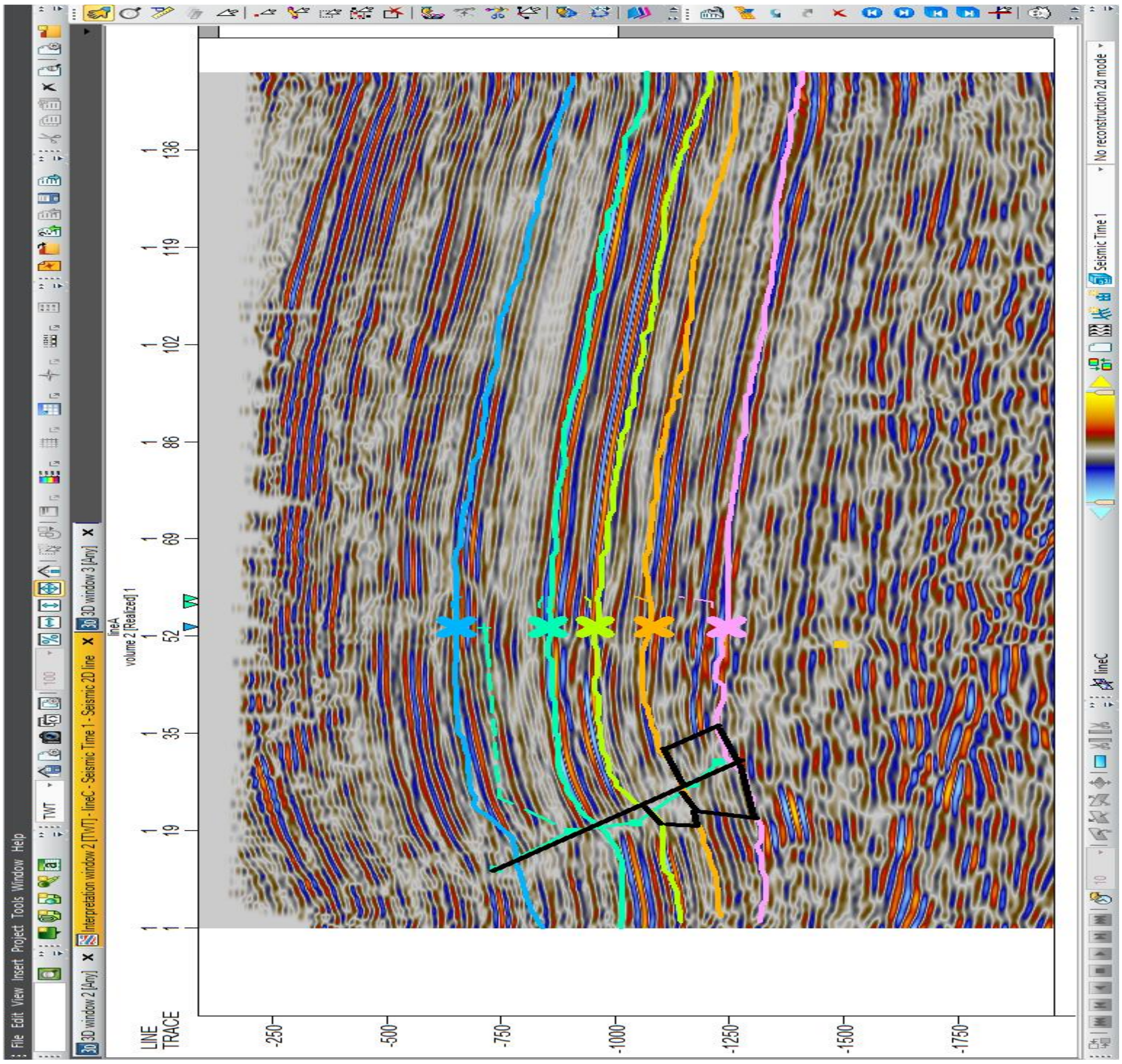


Figure 49Seismic Section Showing Compartments

Also in the zonation and layering, we have seen the layers of Tensleep have been sealed off into three parts, from where we have taken up the well data for the Production data analysis.

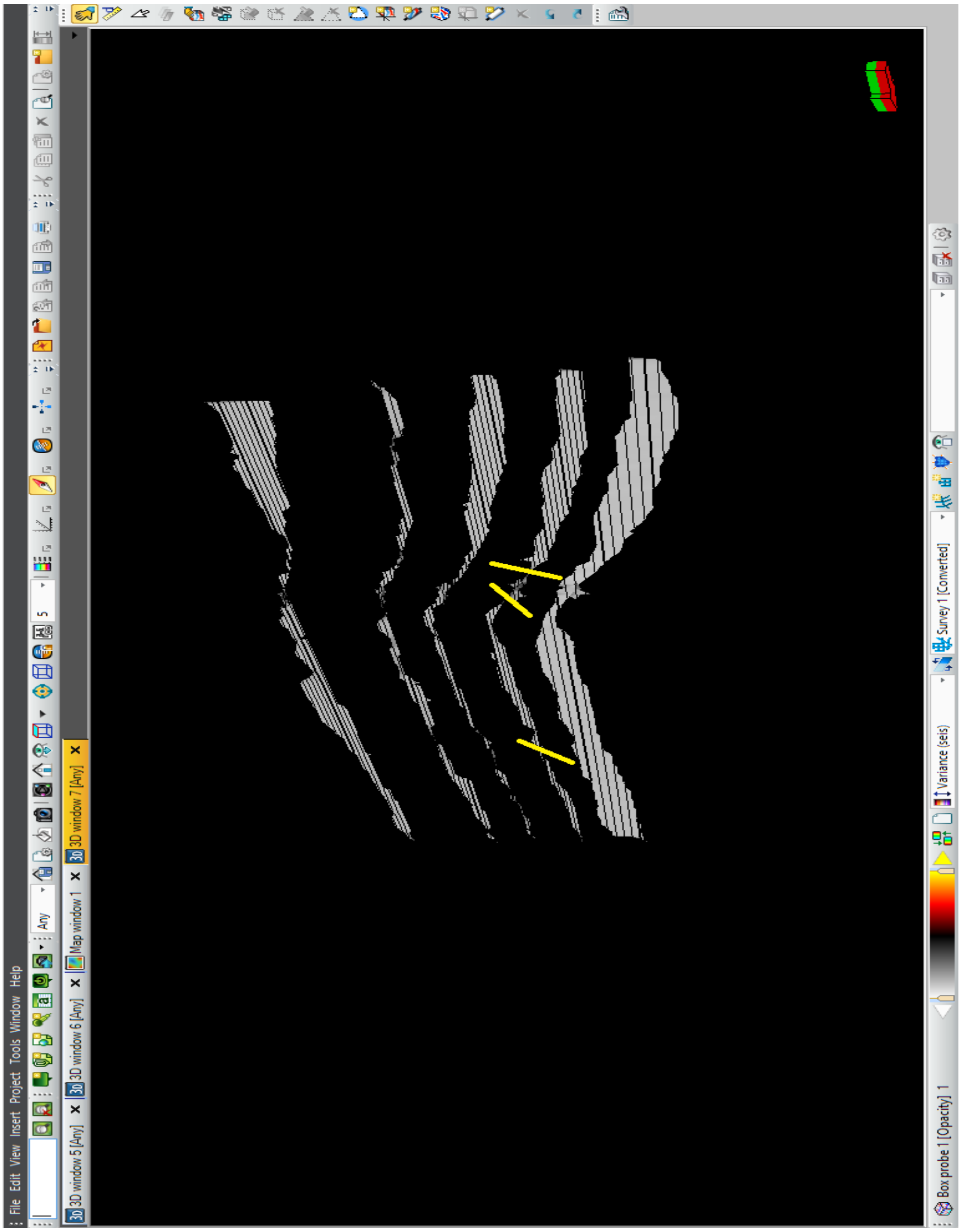


Figure 50Comaprtments in the layers of Tensleep

15 CONCLUSION

Investigation regarding the possibility of compartmentalization in the Teapot Dome reservoir was carried out in two phases;

1. Seismic data analysis
2. Production data analysis

During the first phase, the geometry of the subsurface strata is examined in order recognize structures with a potential trapping mechanism within the reservoir's confines. By thorough analysis of the seismic section and the static model prepared, we were able to establish a fault within the reservoir which created isolated zone of hydrocarbon accumulation.

During the second phase, we chose two wells located on either side of the fault and evaluated the production data and fluid properties from those wells. It came to our notice that properties of produced fluids from either well had considerable levels of disparity.

Thus further supporting our concept of existence of compartmentalization in the Tensleep formation.

Proper and early knowledge regarding the reservoir compartmentalization will aid in preparing the appropriate field development plan for optimally and economically production.

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