Application of Advanced Exploration Technologies for the Development of Mancos Formation Oil Reservoirs, Jicarilla Apache Indian Nation, San Juan Basin, New Mexico

Final Report

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Executive Summary

The Jicarilla Apache Indian Nation is located largely within Rio Arriba County, north-central New Mexico, along the eastern margin of the San Juan basin. The Mancos, a thick, organic-rich Upper Cretaceous marine shale, and a confirmed unconventional continuous-type oil play, is productive on and just to the south of the northern lands. Four fields, East Puerto Chiquito, West Puerto Chiquito and Gavilan (off the Nation lands), and Boulder (within the Nation boundary), have produced 27 million barrels of oil and 85 billion cubic feet of gas since 1960, and account for about three-quarters of all production from this formation in the San Juan Basin. However, the United States Geological Survey estimates that the technically recoverable remaining resource from the Mancos shale is about 189 million barrels of oil, suggesting considerable exploration and development potential still exists for the play.

Specialized exploration and development approaches are required to successfully locate and produce new unconventional, continuous-type oil fields. Specifically, while the thermal maturity for the Mancos indicates widespread oil generation, natural fracture development appears to be a prerequisite for commercial oil accumulation and flow capacity. In addition, due to an absence of "external" reservoir energy (e.g., gas cap or water drive), the primary drive mechanisms are solution-gas drive and gravity drainage. As a result, field development practices critical for economic success include wide well spacing and reservoir pressure maintenance via produced gas re-injection.

A statistical review of well performance reveals a play-average reserve yield of 164 thousand barrels per well. However, as expected in any play of this type, variability is high. The standard deviation from this mean is 343 thousand barrels, and the top 20% of wells account for 75% of the total reserve base. The best well in the play has a projected oil reserve of almost 3 million barrels of oil, implying that significant upside exists if naturally fractured "sweet spots" can be found.

Considerable variability also exists in field performance, believed primarily due to different development and operating practices. The West Puerto Chiquito field, which adopted a "best practice" approach of wide well spacing and pressure maintenance via produced gas re-injection, has an average reserve yield of 300-400 thousand barrels per well. The Gavilan, Boulder and East Puerto Chiquito fields, developed on tighter spacing and with limited pressure maintenance, have average reserves of 100-150 thousand barrels per well.

A study has been performed to identify Mancos shale exploration leads in the northern Jicarilla Nation lands, based on the concept of natural fracture development. Using a combination of satellite imagery, potential fields, seismic data, and structural interpretation, four such leads have been identified. One is considered a Gavilan field analog (+/- 7,000 feet), in a relatively deep, flat-lying section of the Mancos. This lead area covers approximately 43,000 acres (67 square miles). The other three leads are considered West Puerto Chiquito analogs (5,000 – 7,000 feet), on the lowermost flank and basal flexture of the basin-margin monocline. These leads range in size from 12,000 to 18,000 acres (19 to 28 square miles).

Based on various exploration and development assumptions, and accounting for the upside associated with the drilling of (a small percentage of) high-reserve wells, the leads appear to hold excellent opportunity for economic exploitation. Lead I (Gavilan analog) is projected to support the drilling of about 40-50 production wells, which could yield 16 million barrels of oil reserves. The pro-forma financials assume an exploration cost of $1.9 million, and a total capital investment of $22 million, to yield a net present value (15% discount rate) of $57 million. Leads II/III/IV (West Puerto Chiquito analogs), are each projected to support the drilling of 12-18 production wells, yielding oil reserves of 9 million barrels each. For these leads, pro-forma financials assume an exploration cost of $0.9 million, and a total capital investment of $7 million, to yield a net present value (15% discount rate) of $34 million.

In aggregate (four leads combined), the potential exists for the drilling of 90-100 production wells which could yield 43 million barrels of oil reserves. In such a (best-case) scenario, pro-forma financials assume a total exploration cost of $4.6 million, and a total capital investment of $43 million, to yield a net present value (15% discount rate) of $159 million.

Table of Contents

List of Tables

List of Figures

List of Exhibits

List of Acronyms and Abbreviations

AAPL	American Association of Petroleum Landmen
API	American Petroleum Institute
ARI	Advanced Resources International
bbl	barrel
Bcfg	billions of cubic feet of gas
DOE	Department of Energy
EUR	estimated ultimate recovery
ft	foot
JAIN	Jicarilla Apache Indian Nation
MBO	thousands of barrels of oil
Mcfg	thousand cubic feet of gas
MMBO	million of barrels of oil
NAPE	North American Prospect Expo
NPTO	National Petroleum Technology Office
OGA	Oil and Gas Administration
psi	pounds-per-square-inch
USGS	United States Geological Survey

1.0 Introduction

1.1 Play Overview

The Mancos in the San Juan basin is a thick, organic-rich, Upper Cretaceous marine shale. It is a confirmed, unconventional, continuous-type oil play, as established by the United States Geological Survey (USGS), being play #2208 in their 1995 National Assessment of United States Oil and Gas Resources[1]. It is a dual-porosity, naturally fractured play, and due the tight nature of the shale matrix, reservoir development is dependent upon extensive natural fracturing. The USGS has estimated that 189 million barrels of technically recoverable oil resource remains to be discovered and produced from the play.

The Jicarilla Apache Indian Nation (JAIN) is located largely within in Rio Arriba County, north-central New Mexico, on the eastern margin of the San Juan Basin (Figure 1). Four oilfields have been discovered and developed in the Mancos in the vicinity of the Nation: the East Puerto Chiquito, West Puerto Chiquito, and Gavilan fields (just south of the northern Nation lands), and the Boulder field (within the Nation boundary), Figure 2. These four fields have produced 27 million barrels of oil (MMBO) and 85 billion cubic feet of gas (Bcfg) since 1960, and account for approximately three-quarters of all production from this formation in the San Juan basin (Table 1).

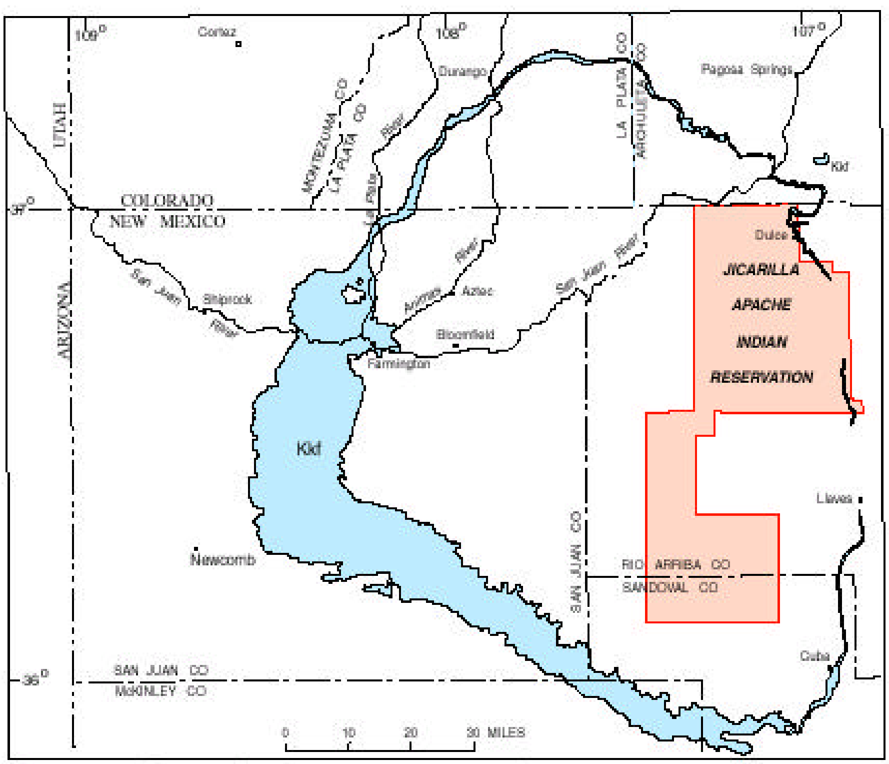


Figure 1: Basin and Nation Outlines
(reproduced from reference 3)

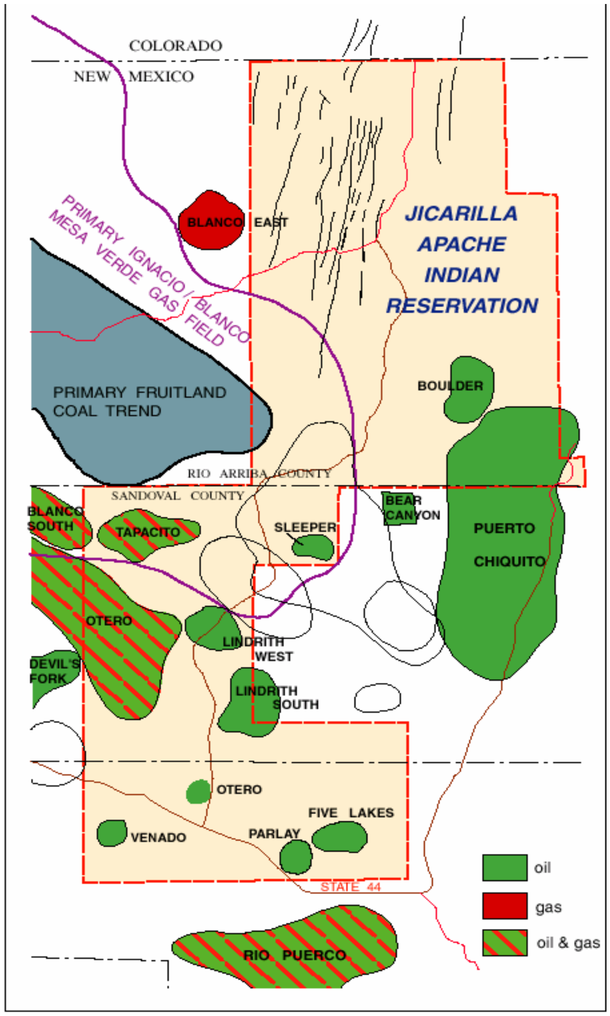


Figure 2: Major Oil/Gas Fields On/Near Nation Lands (reproduced from reference 3)

Table 1: Field Summaries

				As of Mid-2000		
Field	**Year of Discovery**	**Total Wells**	**Currently Active Wells**	**Cumulative Oil Production (MMBO)**	**Cumulative Gas Production (Bcfg)**	**Cumulative Water Production (million barrels)**
E. Puerto Chiquito	1960	42	14	4.4	2.6	0.4
Boulder	1961	24	4	1.9	1.3	0.2
W. Puerto Chiquito	1963	49	30	13.6	43.7	0.1
Gavilan	1982	84	48	7.1	37.5	0.3
		199	96	27.0	85.1	1.0

Due to the continuous nature of the play, and the potential for natural fracture (reservoir) development northward along the basin margin onto the Jicarilla Nation lands, an opportunity exists to extend the productive Mancos trend in this direction. The technical challenge is to understand the geologic mechanisms underlying natural fracture development in the Mancos, calibrate that understanding to the existing fields, and then to extrapolate the resulting model along strike to identify new exploration leads to the north (onto the Nation lands).

1.2 Project Objectives and Work Plan

1.2.1 Project Objectives

To facilitate the exploitation of that opportunity and to simultaneously contribute to both the welfare of the Nation and the U.S. national energy supply, the U. S. Department of Energy (DOE), National Petroleum Technology Office (NPTO), funded this study with the following objectives:

- Develop an exploration rationale for the Mancos shale in the north-eastern San Juan basin.
- Assess the regional prospectivity of the Mancos in the northern Nation lands based on that rationale.
- Identify specific leads in the northern Nation as appropriate.
- Forecast pro-forma production, reserves and economics for any leads identified.
- Package and disseminate the results to attract investment in Mancos development on the Nation lands.

1.2.2 Work Plan

The proposed work plan to accomplish the above objectives was as follows:

Task 1: Develop Exploration Rationale

The proposed exploration rationale, approach and data requirements are provided in Table 2. The rationale considered source rock, reservoir seal, and natural fracture development, as well as the existence of structural relief to facilitate gravity drainage – an important field development consideration.

Table 2: Proposed Exploration Rationale

Key Element	**Approach**	**Data Requirements**
Source Rock	Organic content, thermal maturity of shales	Core data, literature
Reservoir Seal	Thickness of overburden	Well log data, literature
Natural Fractures •Folding •Faulting	• Second derivative mapping •Geomechanical modeling	Seismic, well logs
Gravity Drainage	Structural relief	Seismic, well logs

Task 2: Collect, Quality-Control and Organize Data

The data collected and utilized for the study included:

- Regional geologic studies and background literature
- Satellite and potential fields data
- Seismic surveys
- Well data (as available)
    - Drilling and completion information
    - Well logs
    - Results of core tests
    - Results of pressure transient tests
    - Production

Task 3: Perform Regional Partitioning and High-Grading

This task was to be accomplished through the analysis of satellite imagery and potential fields data. The objective was to identify large regions that appeared favorable for extensive natural fracture development.

Task 4: Lead Identification

Leads were then to be generated in the northern Nation lands based on the exploration rationale, regional partitioning information, more detailed structural interpretation, and analogy with existing fields. If data availability and quality was sufficient, geomechanical modeling was also proposed to assist in the identification of naturally fractured "sweet spots".

Task 5: Estimate Production Potential, Reserves & Economics

For each lead identified, pro-forma production, reserves and economics was to be estimated. Reservoir simulation was proposed as the method by which production and reserves were to be estimated, based on a history-match of one of the existing fields.

Task 6: Technology Transfer (End Products)

The technology transfer component of the project was to consist of:

- Final report, which would also serve as the "lead book" for distribution to potential investors in Mancos exploration on the Nation lands.
- Publication of that report in summary form in an industry trade journal of professional symposia proceedings.
- One-day workshop to present the results.

1.2.3 Deviations from Original Work Plan

For a variety of reasons, the actual work plan deviated in certain respects from that proposed. A summary of the major deviations, and the reasons for them, are listed below:

- Due to a lack of seismic coverage on the northern Nation lands, geomechanical modeling could not be performed. In its' place, a more detailed structural and remote sensing analysis was employed.
- Due to variations in lead characteristics, a reservoir simulation study of only one analog field would not have been sufficient to capture the intricacies of the different leads. In its' place, a more thorough statistical evaluation of geologic properties, development practices and production was performed on each of the four existing fields, which served as the basis for forecasting production and reserves for each of the new leads.
- The workshop was replaced with a display booth at the 2002 American Association of Petroleum Landmen (AAPL) North American Prospect Expo (NAPE). This was believed a better venue to reach the target audience for the study.

These deviations to the originally proposed work plan were necessary to achieve the stated project objectives (which remained unchanged), in light of the amount and quality of actual data available.

2.0 Background

2.1 Geologic/Reservoir Setting

2.1.1 Geologic Setting

The Jicarilla Apache Lands lie along the northeastern margin of the San Juan basin in Rio Arriba and Sandoval Counties, New Mexico, where Laramide activity along the northern edge of the Nacimiento Uplift has deformed the basin's eastern flank (Figure 3). Oil fields are found along and on the southern margin of the Tribal holdings where oil from mature Upper Cretaceous Mancos shales has accumulated in fractured reservoirs of the same age (Figure 4).

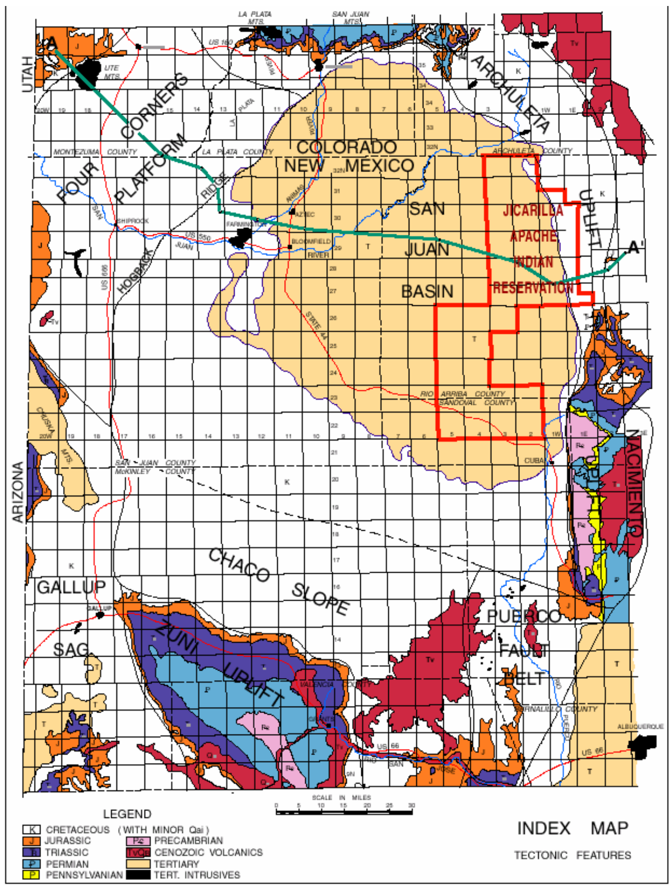


Figure 3: Major San Juan Basin Structural Elements (reproduced from reference 3)

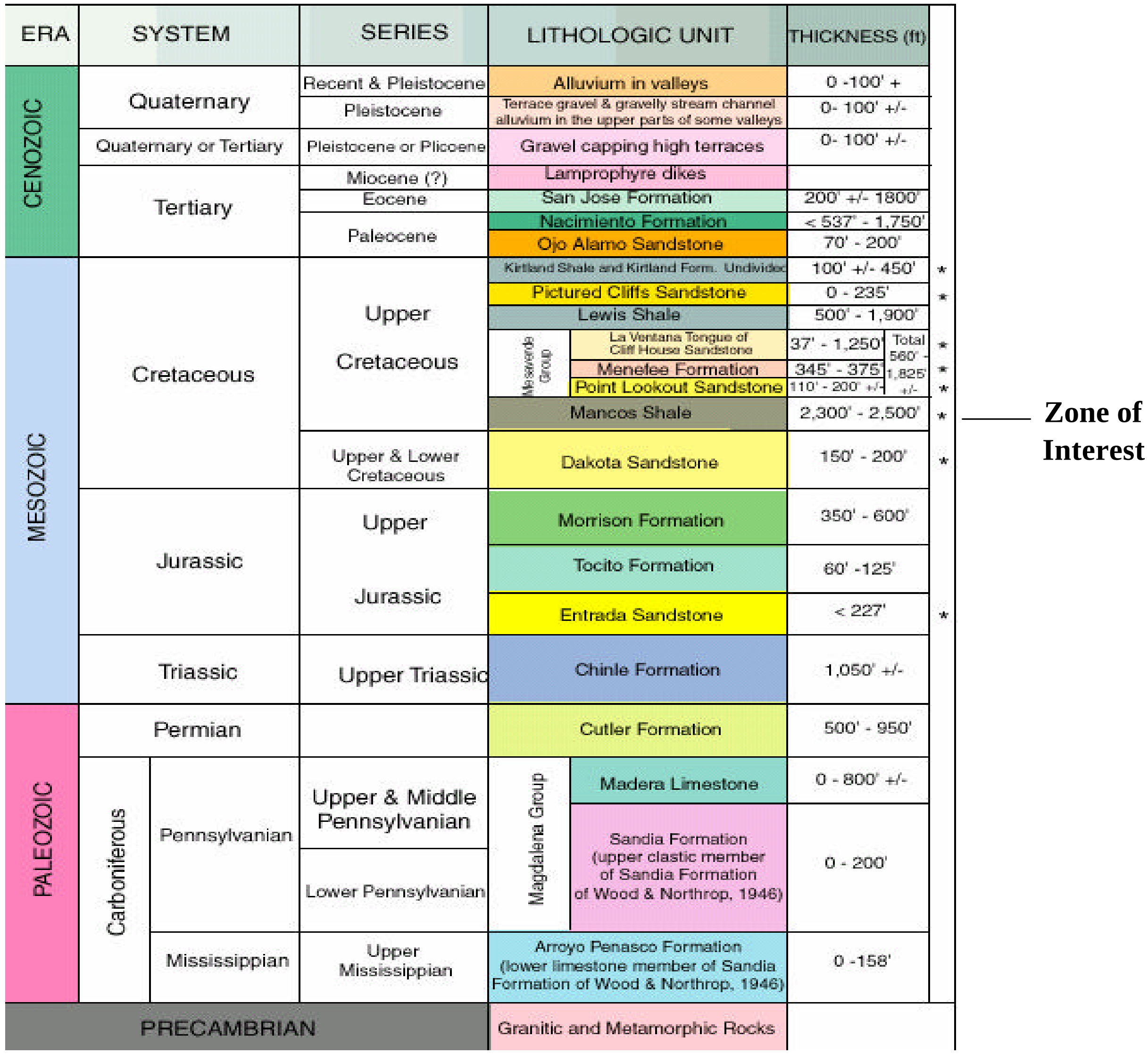


Figure 4: Stratigraphic Chart, Eastern San Juan Basin (reproduced from reference 3)

The San Juan Basin is a broad, topographic basin with a pronounced structural asymetry to the north and northeast (Figure 5). Cretaceous strata dip gently to the northeast along the southern flank and quite steeply to the south and west in a prominent monocline that bounds the basin along the northern and eastern flanks. The productive areas in and adjacent to the Jicarilla lands lie at the base of the monocline (locally known as the Hogback) where strata of Upper Cretaceous age have been deformed by impingement of the Naciemento Uplift along the eastern flank of the basin during Laramide tectonic activity. A series of north to northwest trending, out of the basin reverse faults and anticlines lie along the west edge of the Naciemento Uplift and on trend with its concealed extension to the north, the Archuleta uplift (Figure 3). This margin has been interpreted as transpressive in nature, related to northeastward directed Laramide compression (Figure 6). Oil production in fractured Mancos Shale reservoirs was found in several fields at the basinward limit of this structural belt that extends for several tens of miles along the east flank of the basin.

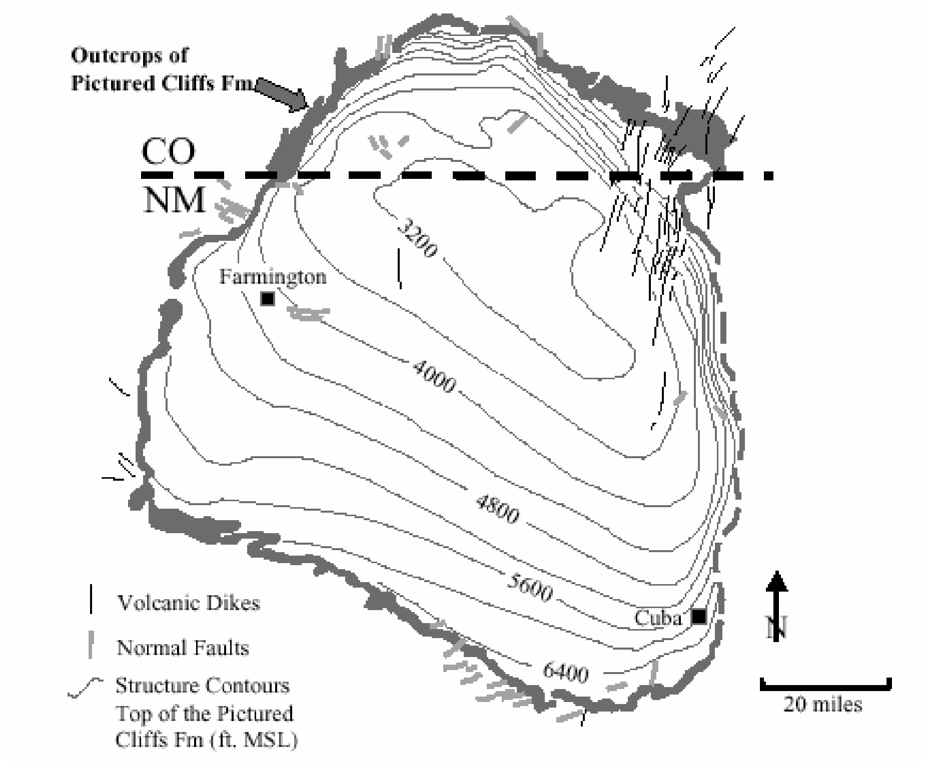


Figure 5: General Structure of the San Juan Basin (reproduced from reference 11)

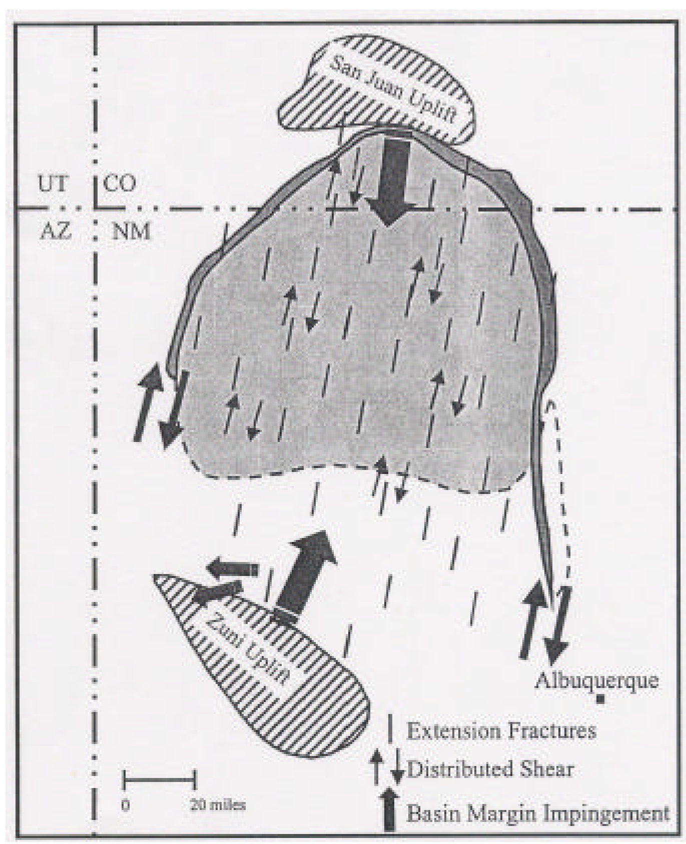


Figure 6: Tectonic Fracture Model, San Juan Basin (reproduced from reference 11)

The primary reservoir objective for the oil play on Jicarilla lands is the Niobrara Member of the Upper Cretaceous Mancos Shale (Figure 7). The Niobrara is approximately 800 feet thick across the area and contains three (possibly more) silty, dolomitic intervals that form fractured reservoirs as a result of fault and fold related deformation along the west dipping, monoclinal, basin margin (Figure 8). Ridgely[13] performed a thorough stratigraphic review of the Jicarilla lands and concluded the majority of the area contained silty facies similar in nature (although in some cases, younger) to the productive areas along the southern margin of the Lands. Source rock studies undertaken as part of the overall evaluation indicated most of the Reservation lies within an interpreted oil window and should have charge readily available for local fractured reservoir development, negating the need for long distance migration through extremely tight host rock.

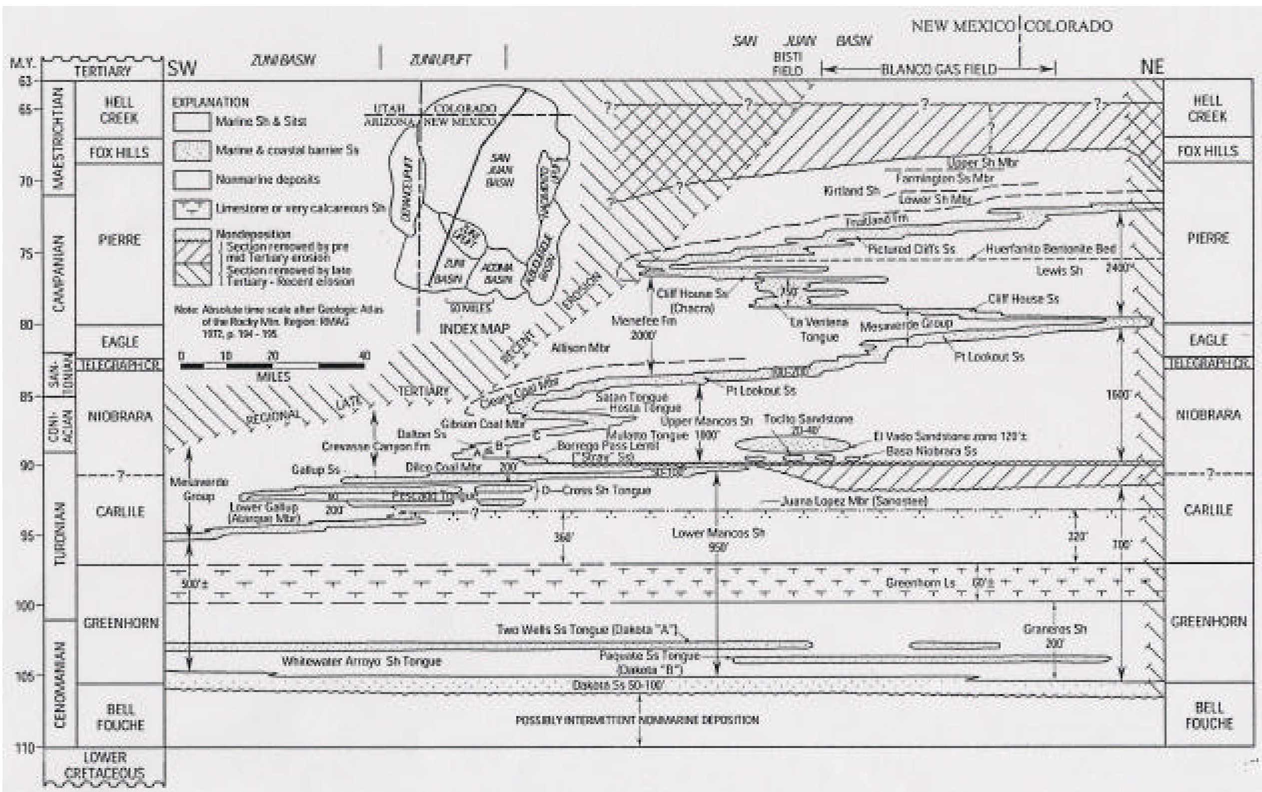


Figure 7: Time-Stratigraphic Sequence across San Juan Basin (reproduced from reference 13)

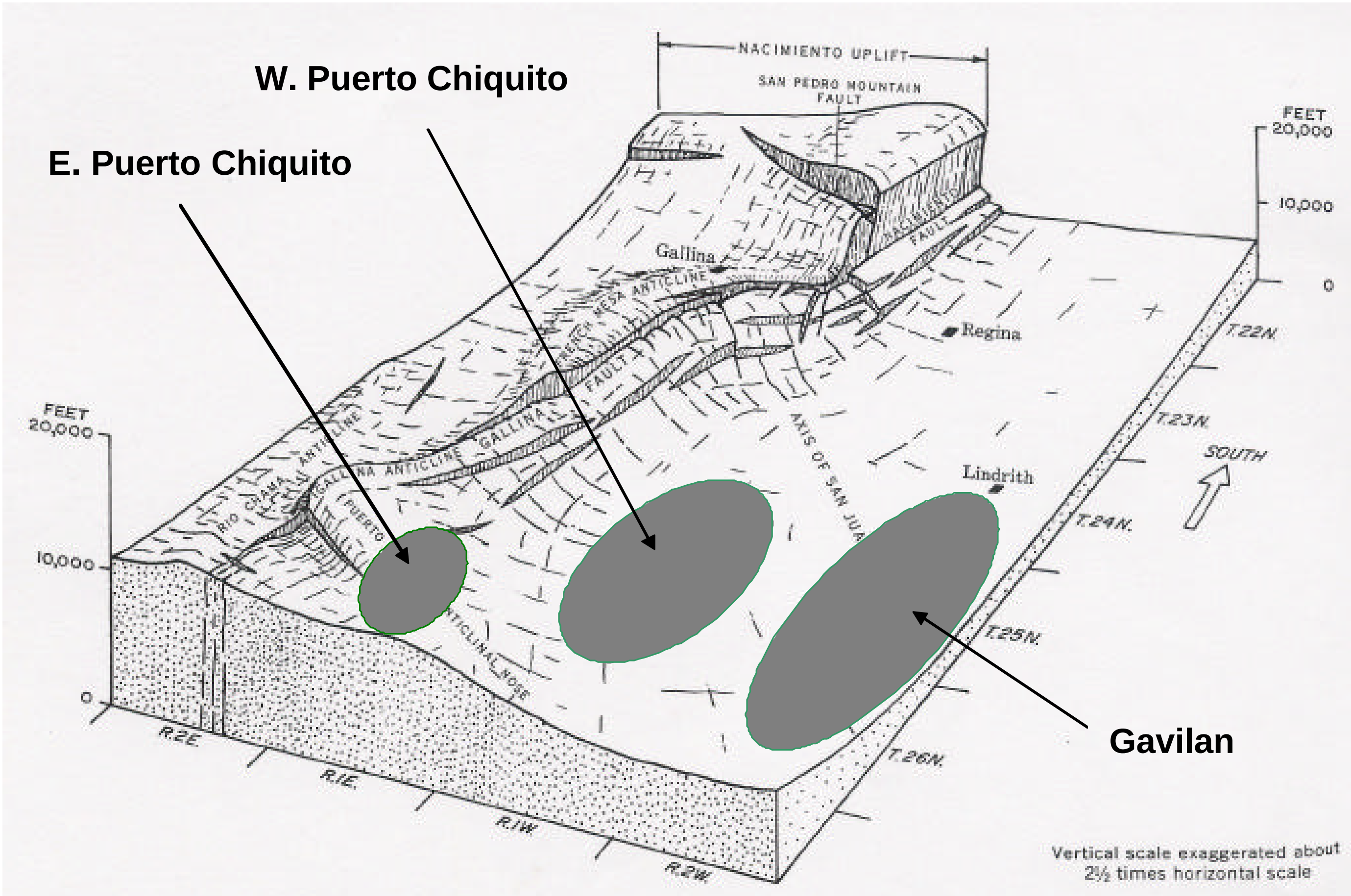


Figure 8: Block Diagram Showing Location of Mancos Oil Fields (reproduced and modified from reference 2)

The structural geology of the area is complex. Outcrop patterns of en echelon appearing folds and faults along the front of the Nacimiento uplift gave rise to the transpressive margin hypothesis of Baltz (1967) and others (Figure 9)[2]. Lorenz[11], using citations from several authors, recount a complex history for the Nacimiento uplift involving initial strike slip and later compression to form a slight overhang. Regardless, several folds and faults are observable along the west flank of the Archuleta uplift immediately to the east of the reservation (Figure 9). Available seismic from previous operators was reprocessed and interpreted by Taylor[17] to improve resolution and understanding of the structure along the eastern margin of the Reservation. Coverage is sparse and ambiguous. Westard verging thrusting is visible on some lines, as is eastward backthrusting. A seismic line drawing from the report is shown in Figure 10. Using Figure 10 as the basis for a working hypothesis, the surface anticlines and synclines mapped in Figure 9 can be visualized as the surface manifestations of subtle backthrusts related to deeper basinward thrusting and can be expected to die out basinward. These observations will form the basis for the interpretation of the surface remote sensing and the related subsurface inferences.

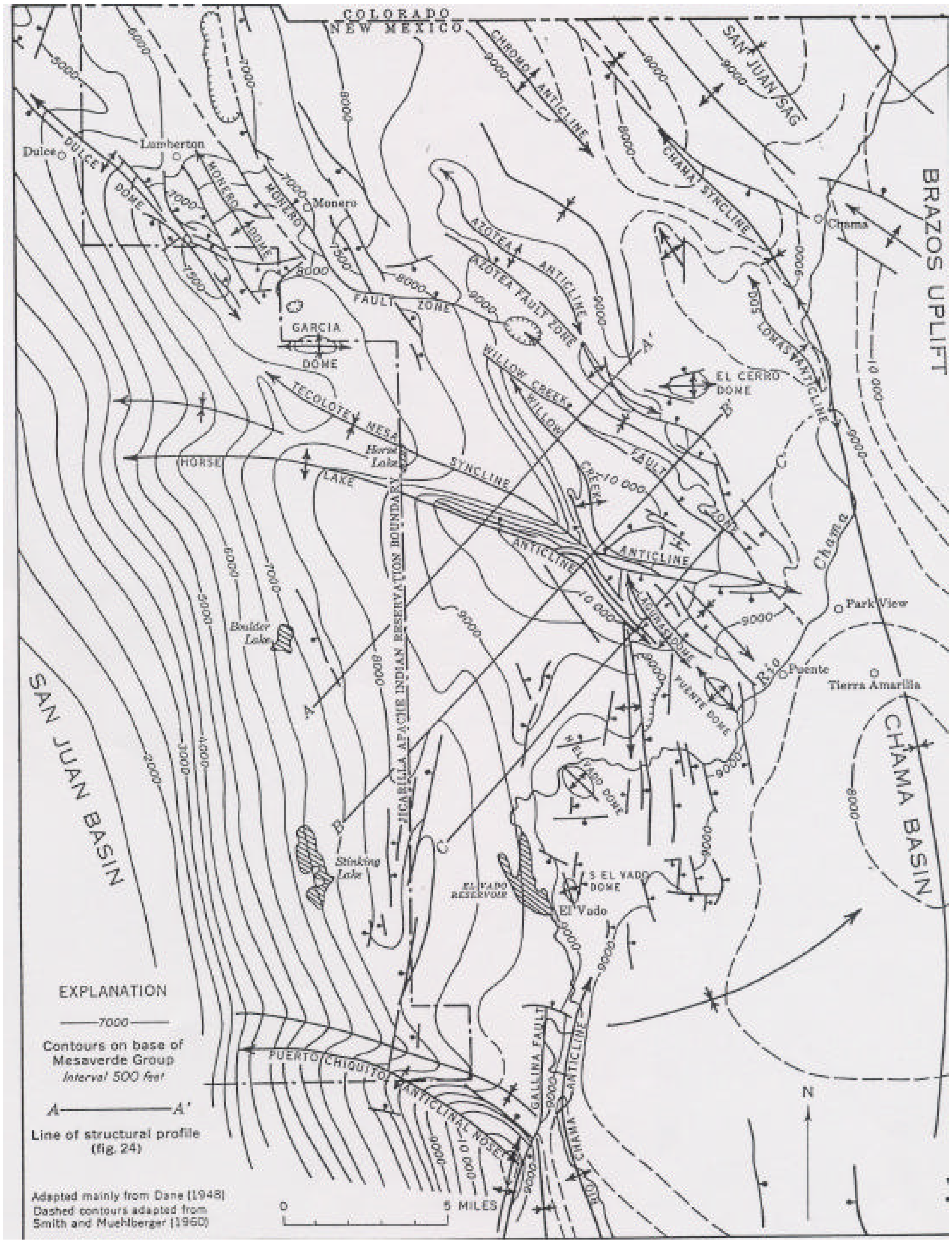


Figure 9: Local Structure, East of Study Area
(reproduced from reference 2)

Available literature, geologic mapping, and remote sensing indicates the productive geologic trends present along and on the southern Jicarilla lands are present to the north in the more sparsely explored northern areas of the Reservation and should be prospective for similar types of hydrocarbon accumulations.

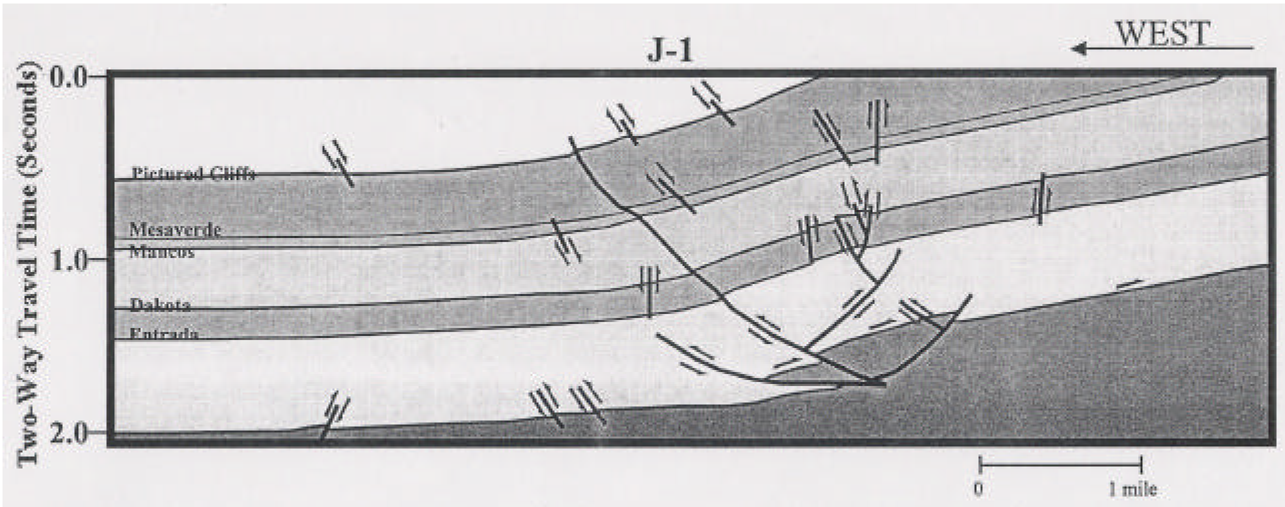


Figure 10: Line Drawing Interpretation of Line J-1 (reproduced from reference 17)

2.1.2 Reservoir Properties

The Mancos shale can be subdivided into five individual units, as follows:

- Upper Shale member (+/- 650 feet)
- Niobrara member (+/- 800 feet)
- Carlisle Shale member (+/- 440 feet)
- Greenhorn member (+/- 70 feet)
- Graneros Shale member (+/- 100 feet)

The oil reservoirs are contained within three fractured dolomitic siltstone beds within the Niobrara member. Specifically, these reservoirs are called the “A,” “B,” and “C” zones (Figure 11), each of which are 5-20 feet in thickness. These more brittle rocks fracture more easily when bended, folded or faulted to create the permeability conduits needed for commercial production than the more plastic encasing shales.

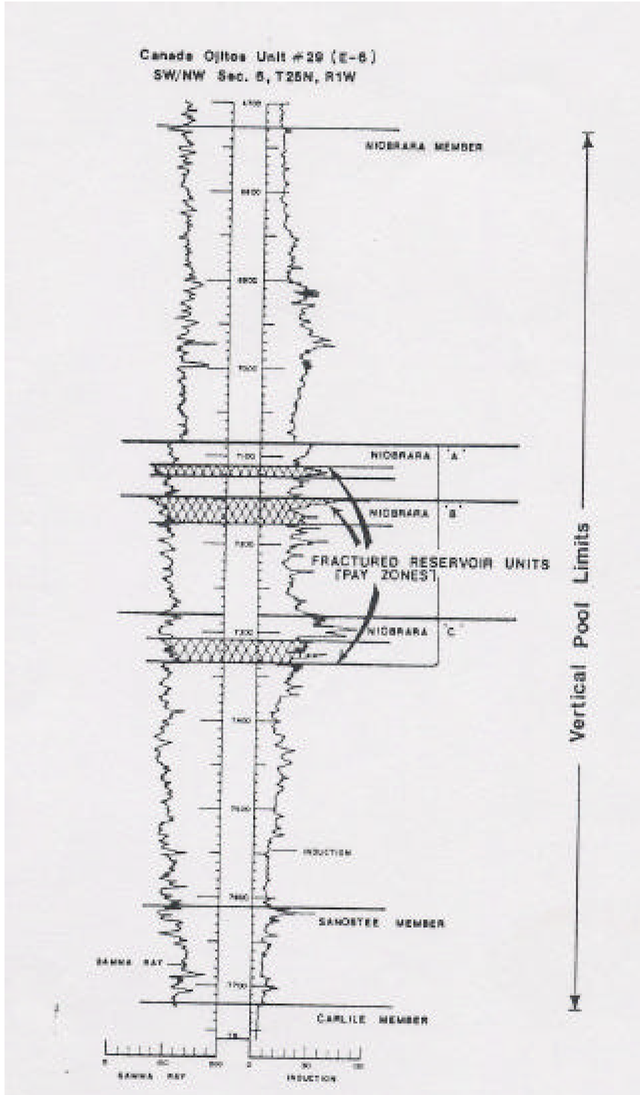


Figure 11: Type Log Showing Fractured Reservoir Units within the Niobrara (reproduced from reference 7)

Core tests suggest that the Mancos exhibits almost no matrix porosity (<1%), with high irreducible water saturations (>90%). Matrix permeability is also low (0.05 to 0.1 microdarcies). Hence, all reservoir porosity and permeability is associated with natural fracturing. Natural fracture systems typically exhibit low bulk porosities (<1%) and high reservoir permeability (10's to 100's of millidarcies). As such, wide well spacings are logical in such environments; large spacings provide the pore-volumes needed to store commercial quantities of oil in the low porosity reservoir and; high permeabilities suggest these porosities can be drained from a considerable distance.

Reservoir depths range from shallow in the east (towards the basin margin), and on the order of 2,000-3,000 feet, to deeper in the west on the order of +/- 7,000 feet. Approximate depths to the producing horizons for each field, and implied original reservoir pressures based on a 0.33 psi/ft gradient are provided in Table 3. Reservoir temperatures are in the 150 –170 degree (Fahrenheit) range.

Table 3: Reservoir Depths and Pressures

Field	Average Depth (ft)	Average Surface Elevation (ft)	Estimated Original Pressure (psi)
E. Puerto Chiquito	2,750	7,120	570
Boulder	3,950	7,260	920
W. Puerto Chiquito	6,450	7,430	1,690
Gavilan	7,000	7,330	1,900

The reservoir oil has an API gravity ranging from 33 – 43 degrees, a viscosity of about 0.6 centipoise at reservoir temperature, and is considered a sweet, low-sulphur, paraffin-base crude. Importantly, the bubble point pressure is estimated to be about 1,535 psi. Since Mancos reservoirs do not have water drives or gas caps to provide reservoir energy, the primary drive mechanisms are pressure depletion and solution gas drive, both of which are relatively inefficient. Along the flank of the monocline however, gravity drainage has also been proven effective and, as will be presented later, pressure maintenance appears to be an essential practice for successful field development.

2.2 Historical Development

Table 1 lists the four productive Mancos fields near or on the Nation lands in the eastern San Juan basin, along with the discovery year for each. For the most part, these fields were developed using vertical wells, which were cased, perforated and hydraulically fractured in the Niobrara (reservoir) zones. In some cases the wells were pumped later in life. The approved and actual well spacings adopted for each field are presented in Table 4, as determined by Sage[14]. In addition, the three eastern-most fields, East Puerto Chiquito, Boulder, and West Puerto Chiquito, being on the flank of the monocline, probably benefited from gravity drainage (the relative position of each field along the monocline is illustrated in Figure 12). Lastly, the Canada Ojitos Unit (within the West Puerto Chiquito field) was formed almost immediately after field discovery, and an active program of pressure maintenance via produced gas re-injection was immediately implemented.

Table 4: Approved and Actual Well Spacings

Field	Approved Spacing (acres/well)	Actual Spacing (acres/well)
E. Puerto Chiquito	160	193
Boulder	80	98
W. Puerto Chiquito	320	511
Gavilan	40	335

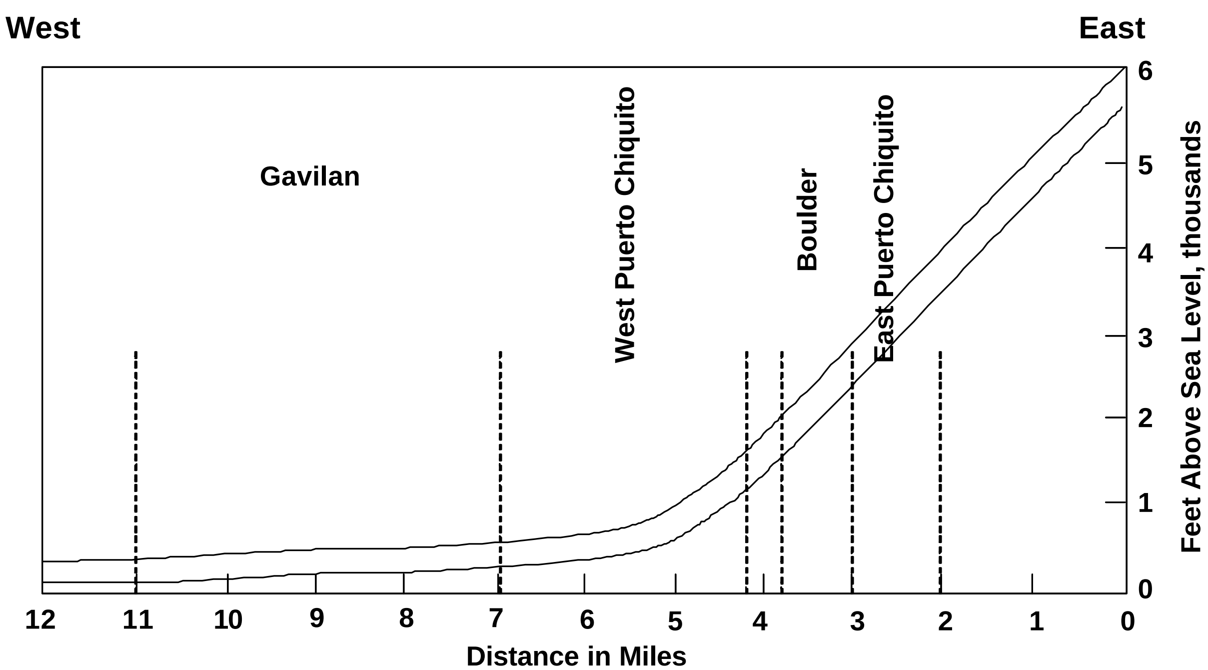


Figure 12: Relative Position of Each Field along Monocline

Table 5: Estimated Ultimate Recoveries

Field	Cum Production (MMBO)	Remaining Production (MMBO)	EUR (MMBO)
E. Puerto Chiquito	4.4	0.1	4.5
Boulder	1.9	<0.1	1.9
W. Puerto Chiquito	13.6	0.8	14.4
Gavilan	7.1	0.6	7.7
TOTAL	27.0	1.5	28.5

Estimated ultimate recoveries (EUR) for each of the fields are provided in Table 5. What is readily apparent is the significant difference in performance between each of the fields.

Work by Greer[7] sheds some light into these performance differences. Table 6 lists variations in pore volumes, per-well recoveries and per-acre recoveries for the play. While there does not appear to be a significant variation in pore-volume density across the play, there can be two orders-of-magnitude in difference in per-well recoveries. One of the reasons for this difference, however, can be attributed to the various well spacings employed. This might account for one order of magnitude difference in well performance.

Table 6: Variations in Recovery

	Low	High	High/Low
Pore Volume per Acre (bbls):	1,500	3,000	2
Per-Well Recoveries (bbls):	15,000-20,000	1,500,000-2,000,000	100
Per-Acre Recoveries (bbls):	80	800	10

However, as also noted by Greer, gravity drainage (and more importantly pressure maintenance), can account for another order of magnitude improvement in field performance (Table 7). Hence a combination of wide well spacing, being on the flank of the monocline to take advantage of gravity drainage, and a pro-active pressure maintenance program via produced gas re-injection, appear critical to maximize production from Mancos reservoirs.

Table 7: Efficiency of Recovery Mechanisms

Method	Recovery (Efficiency)
Pressure depletion/Solution gas drive	5-6%
Gravity drainage/Pressure maintenance	55-60%

It should also be noted that deeper on the flank of the monocline, the reservoir pressures are greatest, and the oil is more likely to be saturated with gas (an important reservoir energy consideration). One implication is that spacing wells too closely, and producing them too quickly, reduces reservoir pressure rapidly (via rapid liberation of solution gas), thus leading to poor recoveries. This is illustrated in Figures 13 and 14. Well recoveries appear to increase at a relatively constant gas-oil ratio until pressure is reduced to the point where solution gas is rapidly released, at which point the reservoir energy needed to sustain production is quickly dissipated, resulting in almost no further recovery.

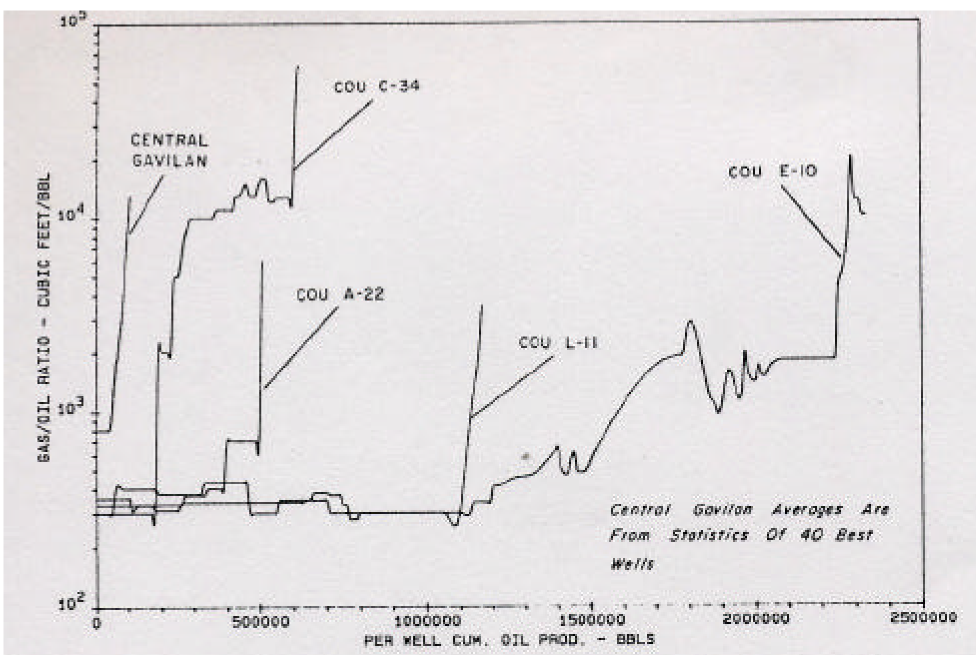


Figure 13: Comparison of West Puerto Chiquito and Gavilan Well Performances (reproduced from reference 7)

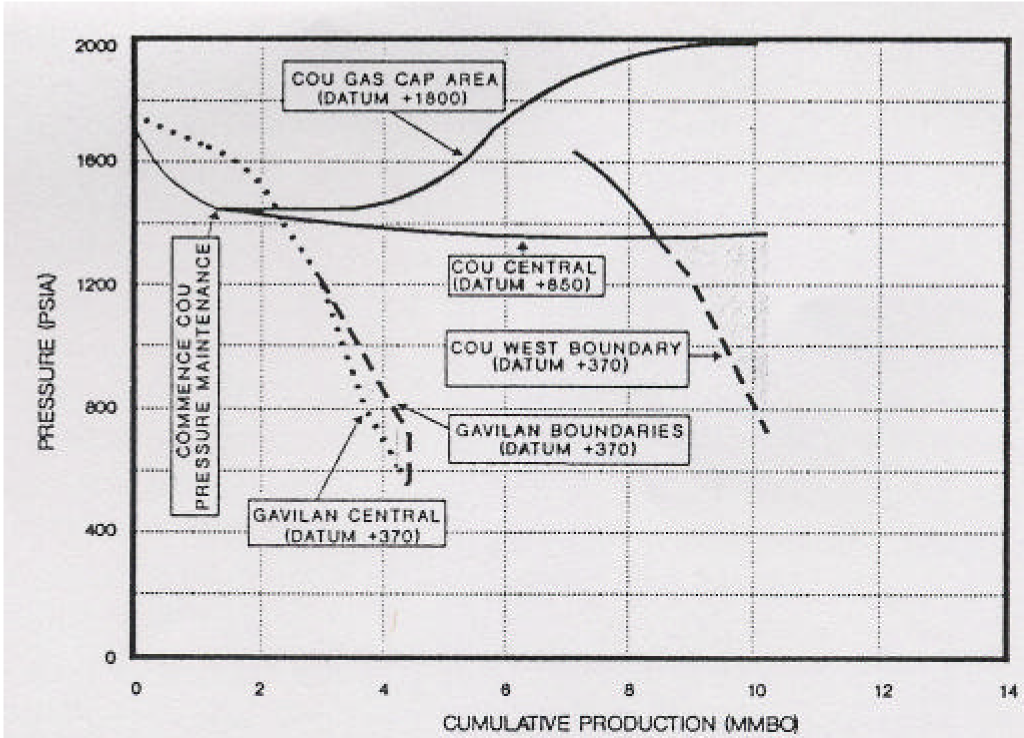


Figure 14: Reservoir Pressure Comparison – West Puerto Chiquito and Gavilan (reproduced from reference 7)

In addition to these four main producing fields, in 1992/93 Amercian Hunter shot about 100 line-miles of (two-dimensional) seismic, and drilled five (mostly) horizontal wells testing the Mancos in the area to the north of the Canada Ojitos Unit in the West Puerto Chiquito field. The relative positioning of these wells along the monocline is illustrated in Figure 15. The most notable success was the Jicarilla 3-F horizontal well, located on the basal flexture of the monocline. This well has a projected ultimate recovery of over 230 MBO.

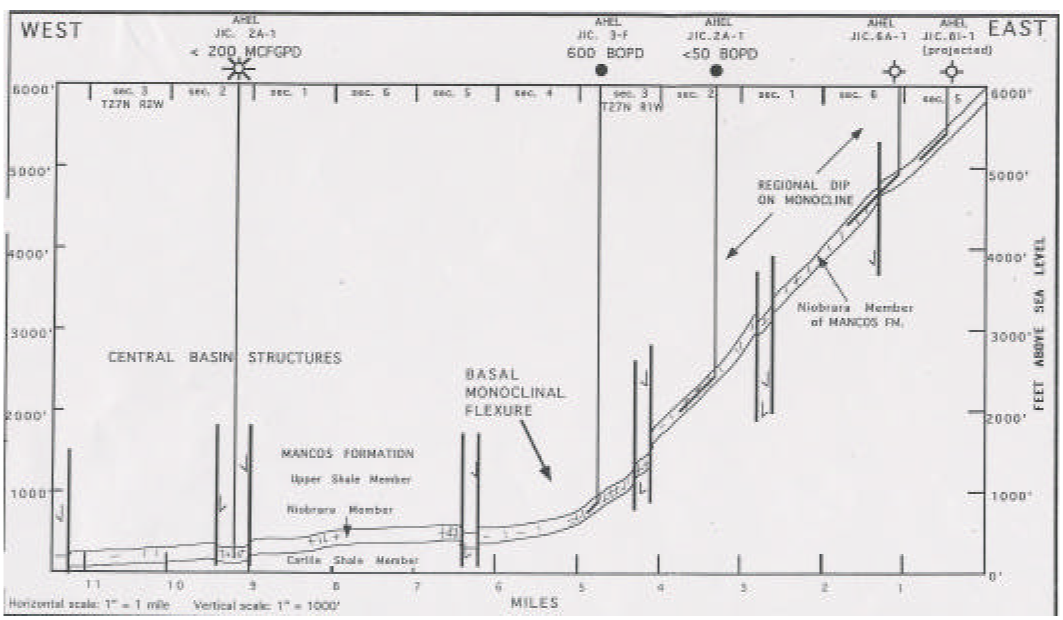


Figure 15: Structural Positioning of American Hunter Wells (reproduced from reference 14)

Subsequent to this program, one of Amercian Hunter's partners in this play, Enre, assumed operatorship and drilled an additional six wells, most of which were vertical. These wells primarily offset existing production, and did not yield any notable new discoveries.

2.3 Production and Reserves

A statistical review of well performances was conducted to determine if any obvious, relationships might exist between various geologic parameters and ultimate recoveries. It would also serve as the basis for estimating production from any new leads identified in the northern Nation lands.

The procedure was to estimate the EUR's of as many wells as possible via decline curve analysis. A breakdown of the number of wells analyzed, by field, is provided in Table 8; poor data quality necessitated eliminating some wells from the analysis dataset. Despite this restriction, 165 out of 199 total wells were analyzed.

Table 8: Wells Analyzed via Decline-Curve Analysis

Field	Total Wells	Currently Active Wells	Study Wells
E. Puerto Chiquito	42	14	30
Boulder	24	4	12
W. Puerto Chiquito	49	30	43
Gavilan	84	48	80
	199	96	165

The resulting distribution of EUR's is provided in Figure 16. The average Mancos shale well has an EUR of 164 thousand barrels of oil (MBO). Approximately 87% of all wells have an EUR of less than 300 MBO. However, similar to many naturally fractured plays, the remaining 13% of the wells, that have an EUR greater than 300 MBO each, account for two-thirds of total Mancos reserves. In fact, the top 20% of wells account for 75% of total Mancos reserves in the eastern San Juan basin. The best well in the play, the Canada Ojitos Unit #11, has an EUR approaching 3 MMBO; the best five wells in the play are all located in the Canada Ojitos Unit, and suggest that the development/operating practices there have had an important influence on well performance.

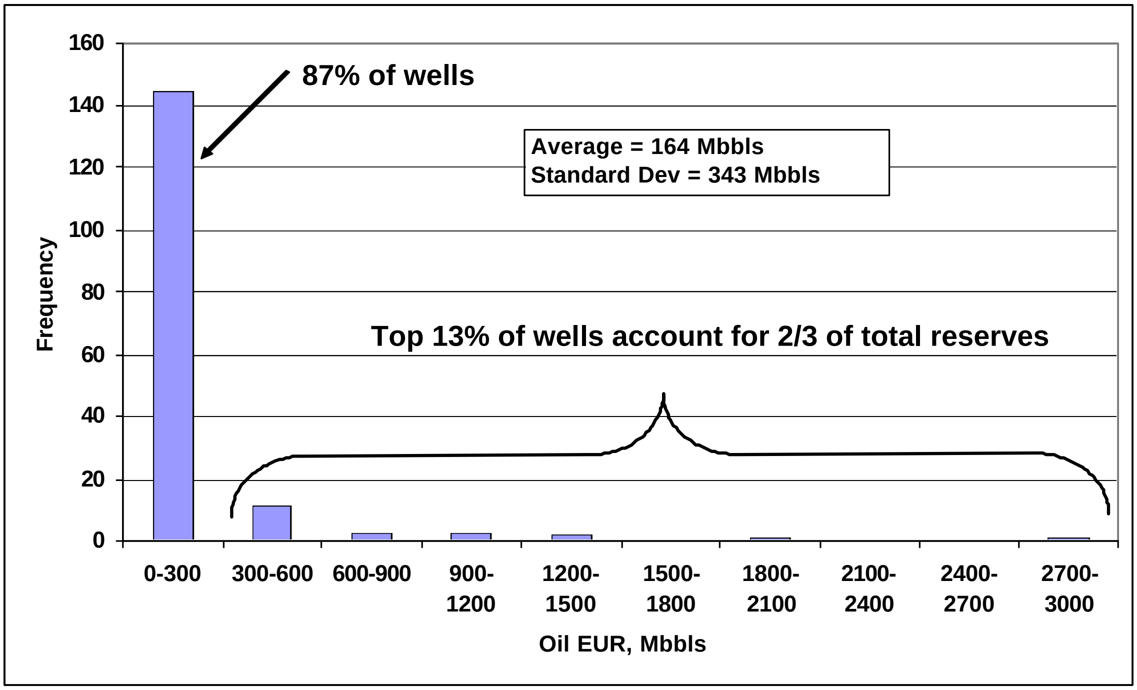


Figure 16: EUR Distribution, All Study Wells

Time-zero production plots for each field were constructed and are illustrated in Figure 17. Only wells that had come on production since 1970 were included in this analysis since that is first date for which continuous data is available. Note that no Boulder field wells met this criterion, and therefore a time-zero plot for this field could not be constructed. It is starkly clear from this figure that Puerto Chiquito West is the most prolific field in the play, followed by Gavilan, and finally Puerto Chiquito East.

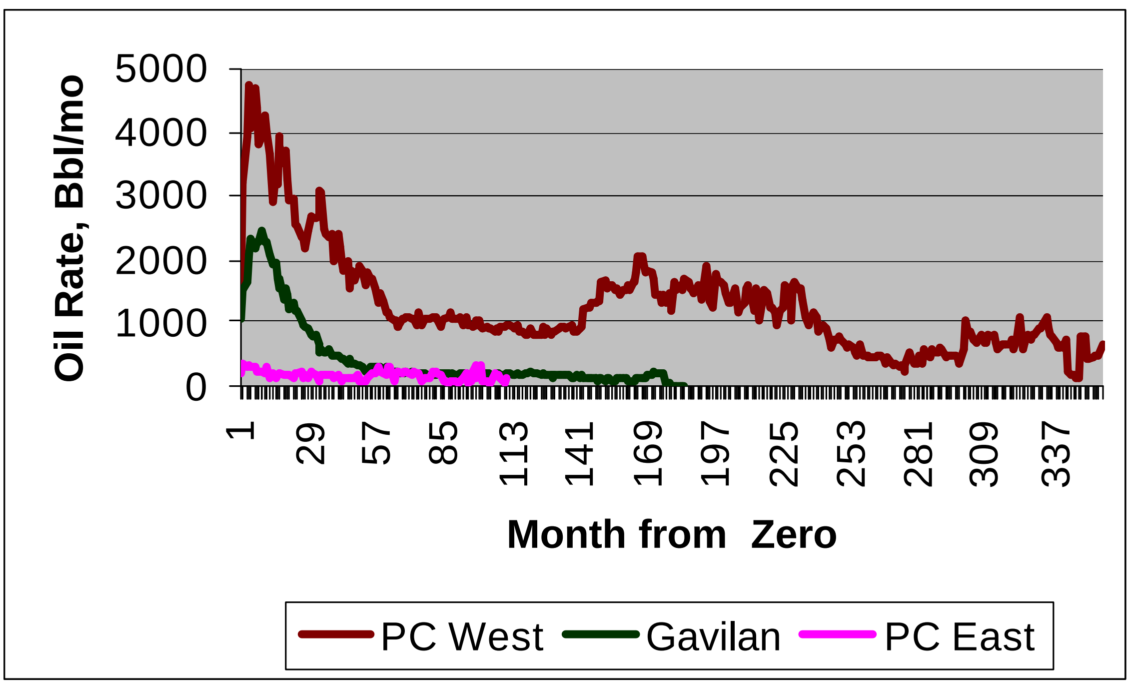


Figure 17: Comparison of Time Zero Profiles

A comparison of EUR's based on several different methods is presented in Table 9. Again, the superior performance of Puerto Chiquito West is evident. This is believed strongly dependent upon the fact that this field was developed on wide well spacing, with an active pressure maintenance effort via produced gas re-injection.

Table 9: EUR Comparisons (MBOE)

Field	Study Well Average	Field Basis*	Time Zero**
PC East	137	107	43
Boulder	121	79	***
PC West	334	294	428
Gavilan	90	89	104

*field EUR divided by total wells
**only for wells drilled since 1970
***no wells drilled since 1970

2.4 Exploration Rationale

A successful exploration rationale for extending production into non-producing areas incorporates the observed characteristics of established production with reasonable hypotheses regarding the nature and geology of the exploration area to identify prospective areas for new drilling. The eastern San Juan basin oil play represented by Gavilan, Puerto Chiquito and E. Puerto Chiquito fields as productive analogs is not characteristic of conventional oil plays in general and has been classified as a confirmed "continuous" type play by the USGS. Ridgeley[13] in her analysis also notes the unconventional characteristics of the Niobrara production as a "continuous" type deposit where charge is locally generated, nearly uniform in distribution and dependant more on sporadic occurences of permeability than a typical charge, migration and trapping scenario. In this area, in order to be successful, many of the more conventional exploration practices must be questioned and potentially reordered or discarded.

Evaluation of the local producing fields indicates gravity drainage is an important, perhaps even key, source of reservoir energy. Production analysis of existing fields shows better production at the topographic base of the accumulation. In order to maximize the potential for gravity driven reservoir energy, the prospect should be located at the base of steeply dipping structure to achieve maximum potential column height. Areas along the base of the monocline where the steeply dipping beds flatten out should be quite prospective.

Reservoir engineering concepts for fractured reservoirs indicate fractured reservoirs with tight reservoir rock require at least two directions of fracturing to achieve the greatest permeability impact from the natural fracturing. Borehole fracture logs presented by

Emmendorfer[5] (Figure 18) clearly indicate the greatest angular diversity of fracture direction in the synclinal areas of Gavilan Field. Production bubble mapping indicated the wells with the greatest cumulative productivity lie in synclinal areas. Conjugate natural fracture sets are frequently ascribed to stresses from folding along anticlines and synclines as described by Sage[14]. However, such fracturing would normally be expected to yield a relatively uniform diversity of fracture azimuth. Emmendorfer's map (Figure 18), to the extent it reflects true fracture statistics, seems to indicate the synclines have greater breadth of angularity than the anticlinal areas where fracture populations seem more undirectional. This is best seen in the west half of T25N R1W, a synclinal area of the field, versus the east half of T25N R2W which contains the crest of the structure. The production bubble map (Figure 19) indicates significantly higher productivity where fracture diversity is greatest, in the western half of T25N R1W. A better explanation of this phenomenon might lie in interpreting the synclines as footwall structures associated with fault propagation, where shear failure of rock in conjugate sets is common. E-W seismic lines shot by American Hunter show the presence of both backthrusting and tensional normal faults along the monocline. In the absence of high quality seismic, many small fault features and associated folds will simply contour as anticlines and synclines on widely spaced well control. A reasonable exploration rationale built on this hypothesis would be to preferentially target synclines, both for higher reservoir energy in a gravity drainage system and higher permeability as the area most likely to contain localized shear fracture systems.

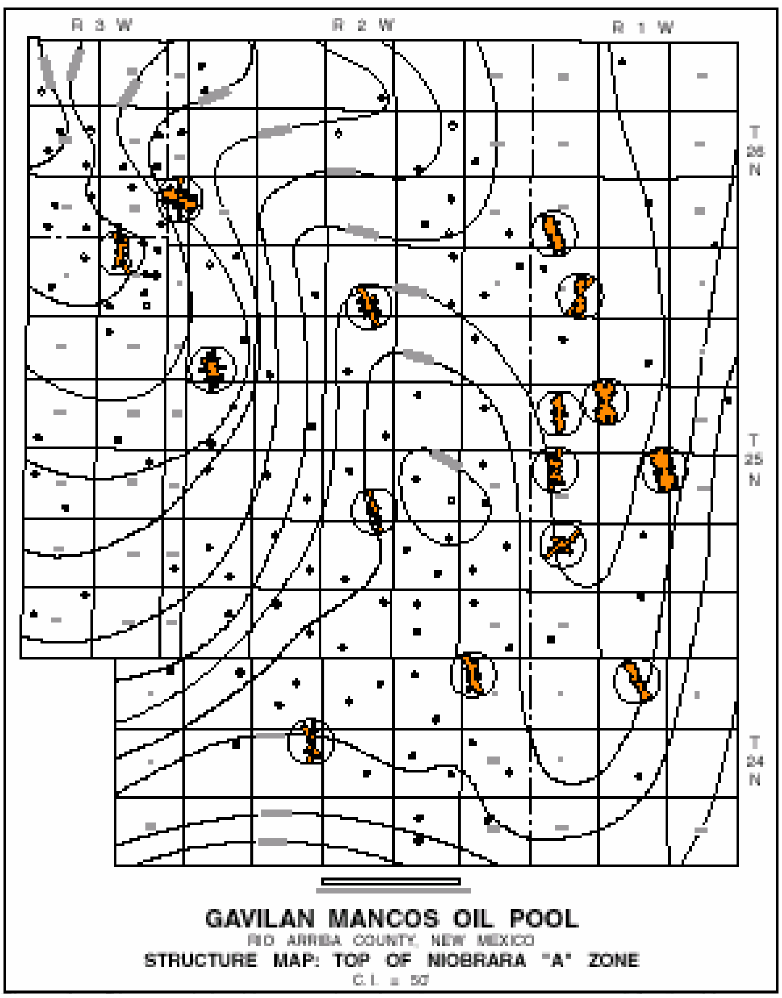


Figure 18: Gavilan Mancos Oil Pool
(reproduced from reference 3)

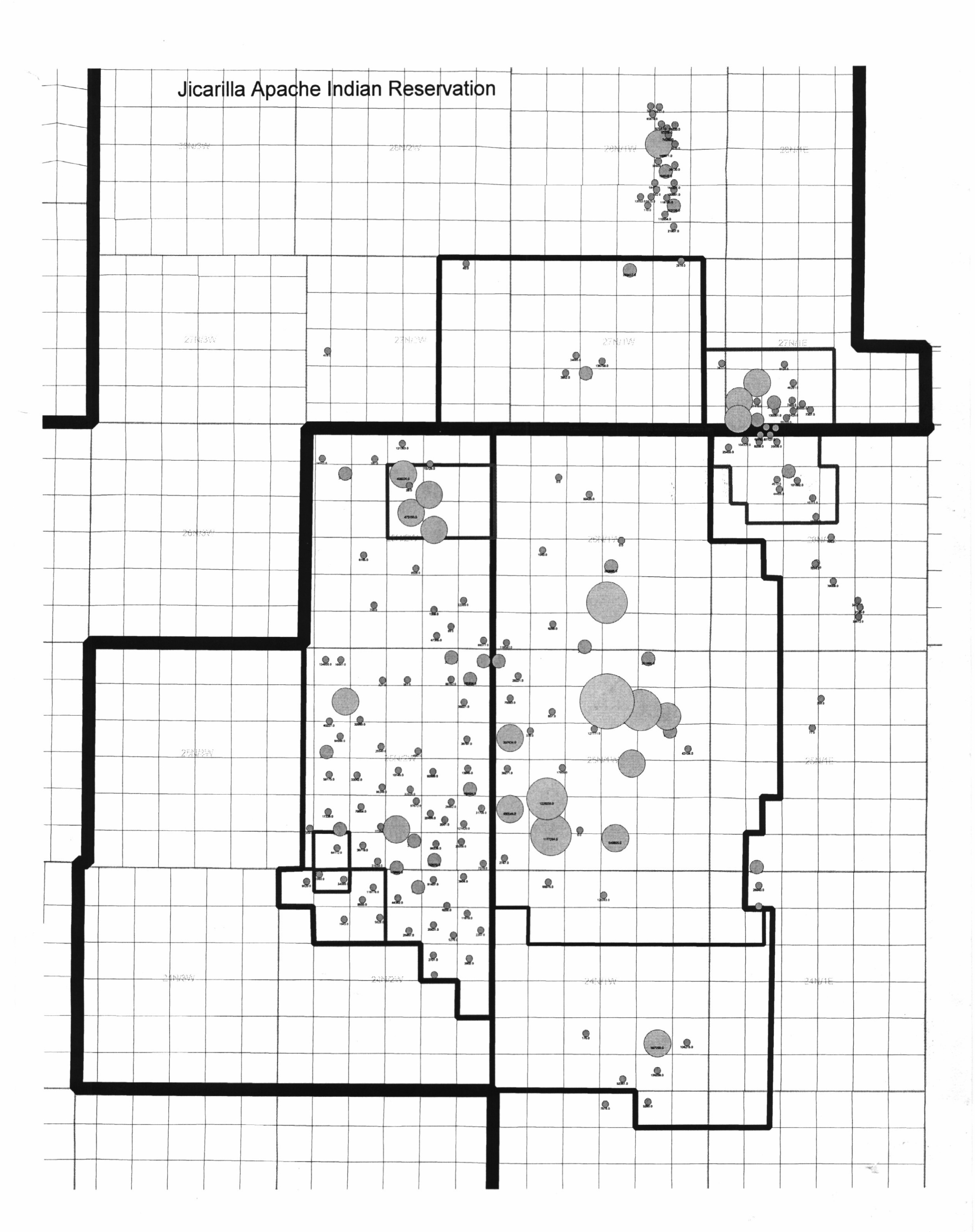


Figure 19: Production Bubble Map

Computer models of stresses around fault systems indicate areas of greater and lesser extensional stress and strain depending on position of the observation point relative to the fault. For most reverse or normal faults this seems to localize around the downthrown side of the shallow fault tip. In an exploration terrane practically devoid of primary porosity and relying upon fracture porosity and permeability for both storage and deliverability, it is a reasonable projection to target such areas preferentially as a way to maximize potential volume and productivity.

Assembly of reservoir characterization information, regional geology and theoretical understanding of fracture systems in faulted terranes indicates exploration efforts in the Jicarilla Apache lands area should focus on the downdip tips of synclinal areas near the base of steep dip as they die out basinward or synclinal areas off the flank of intrabasinal highs. These areas are interpreted as the most likely places to encounter multiple fracture directions (good permeability), strong extensional fracturing (better storage potential), and better reservoir energy (low in the gravity well). They should be key elements of a successful exploration rationale.

3.0 Identification of New Leads

3.1 Natural Fracture Analysis

The exact nature of natural fractures in the Mancos oil reservoirs of the northeastern San Juan basin and their relationship to productivity is poorly understood. There is very little high quality, publicly available core and log data from the reservoir upon which to base an interpretation. Determination of the fractured nature of the Mancos play rests almost entirely upon the reservoir behavior (engineering aspects), the near total lack of discernable porosity on logs, and early use of dipmeters for fracture detection in the Gavilan area. No detailed characterization of the fractures at the reservoir scale in the Mancos fields exists. Lorenz[11] discusses the tectonic setting and characteristics of Mesaverde and Dakota fractures in the San Juan basin as a whole but no Mancos core material was available for their interpretation. Indeed, there is a total lack of oriented core and recent image logs upon which to build a coherent fractured reservoir characterization targeted towards the Jicarilla Lands. Hence the attempts to use remote sensing techniques in this project to extrapolate areas of higher than average reservoir fracturing onto the Jicarilla Lands.

Lorenz discusses the nature and distribution of fractures in outcrops of Jurassic to Cretaceous sediments along the eastern flank of the basin. His discussion spans a defacto geologic transect from Jurassic and Dakota sediments near the edge of the Nacimiento Uplift upwards through the section into the Mesaverde sediments, younger and structurally higher in the sequence. Through field observations and measurements they document the following points:

1) There is a strong dependence of fracture characteristics on lithology. More brittle rocks are fractured.
2) Three sets of conjugate deformation bands exist in the Jurassic sediments. These bands strongly compartmentalize the Jurassic as a potential reservoir but are expressed as fractures in the overlying, cleaner, more brittle Dakota sands.
3) Fault related fractures exist in conjugate sets within the downthrown blocks, striking subparallel to the minor faulting in the area. The faults and their associated fractures exist in zones up to 30 feet wide and contain evidence of fluid conductivity unless/until plugged by crystalized minerals.

The outcrops examined by Lorenz represent a stratigraphic and mechanical transect that spans the structural and stratigraphic setting of the Mancos oilfields. The Mancos immediately overlies the Dakota and underlies the Mesaverde. The exhumed outcrops of the Jurassic sediments along the edge of the Nacimiento Uplift are interpreted to be representative of the structural environment along the leading edge of the uplift and its associated faulting, seismic transect tracing J-1(Figure 10).

The conjugate fracture patterns observed in the San Ysidro area, shown on the diagram below (Figure 20, labeled SY), compare favorably with the patterns observed by Emmendorfer (Figure 18) in the Gavilan oilfield. Analysis of surface imagery trends agrees well with the simpler trends measured on the Mesaverde outcrops but lacks the complexity in detail of the older Jurassic and Dakota sediments caught up in the frontal fault propagation zone of the Nacimiento Uplift. Thus, the surface remote sensing trends, while they reflect basement structure in general, do not reflect the detailed fracture patterns of the actual Mancos oil reservoirs in the leading edge deformation zone of the Nacimiento Uplift. This observation, together with the gravity drive character of the reservoirs, best explains the poor correlations found during efforts to relate surface fracture density (expressed by lineament density) to oil production in the established fields (discussed in the next section).

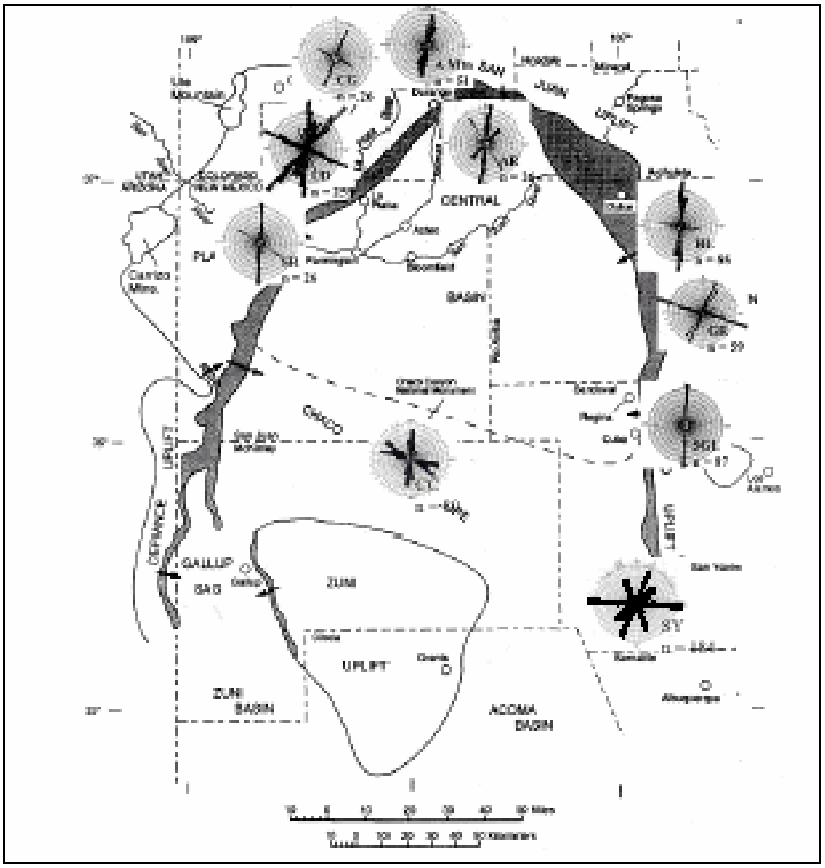


Figure 20: Outcrop Fracture Orientations
(reproduced from reference 11)

Extrapolating limited core and outcrop to the established oilfields indicates the reservoir consists of multiple, fault related, conjugate sets of fractures in brittle dolomitic siltstones of the lower Mancos. These reservoirs, by analog to outcrops, are best developed in the downthrown blocks of faulting associated with the propagation into the basin of the basal reverse fault carrying the Nacimiento Uplift and zones of faulting, both normal and reverse, that exist along the leading edge monocline.

3.2 Production Correlations

In an attempt to gain further insights on geologic controls for natural fracture occurrence, a statistical analysis was performed to determine of any of the measured geologic parameters could be correlated to production performance. If such relationships exist and could be identified, then presumably those parameters could also be incorporated into the exploration rationale.

The parameters tested for correlation with the EUR's included:

- Second derivative of structure
- Lineament density
- Depth
- Dip
- Gravity
- Aeromag
- Others

The results of the first two, considered likely to be the most influential, are shown in Figures 21 and 22. These figures do not suggest that any simple statistical relationship exists with production performance. In fact, no uni-variate statistical relationship was found between EUR and any of the above parameters. The obvious conclusion is that well performance in the Mancos is highly complex, influenced by a combination of geologic, development and operating conditions, and cannot be explained via simple (uni-variate) statistical analysis.

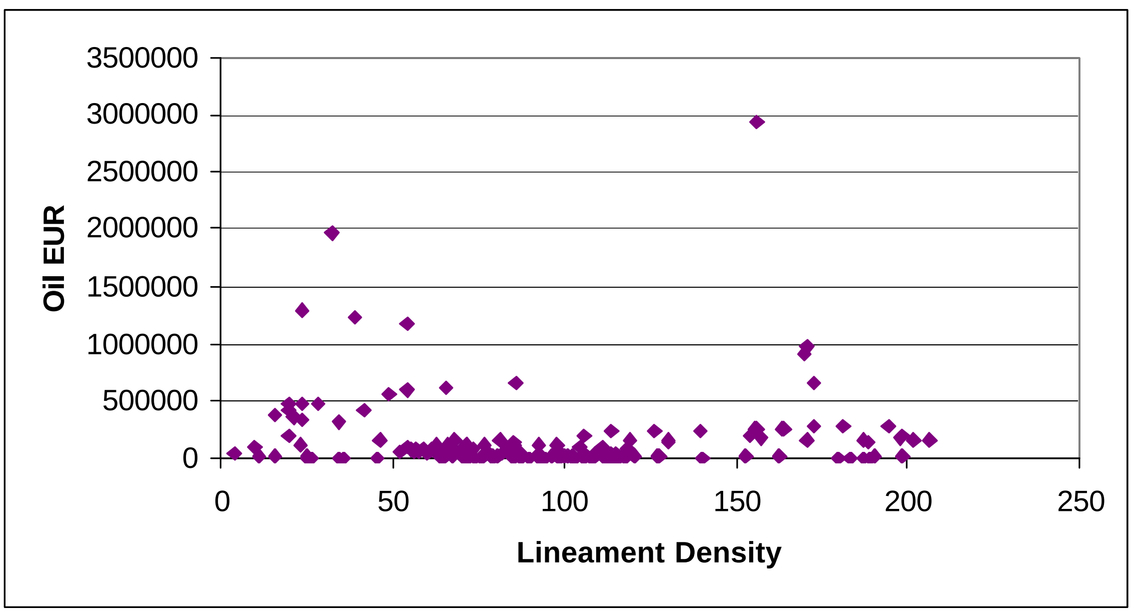


Figure 21: Lineament Density Crossplot

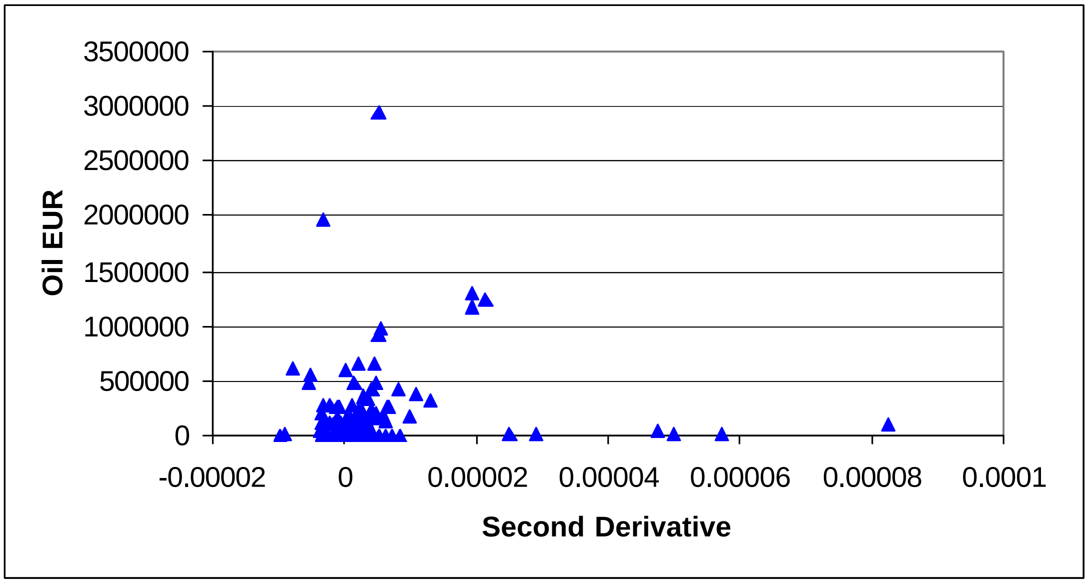


Figure 22: Second Derivative Crossplot

3.3 Lead Area Identification

Four lead areas on the Jicarilla lands have been identified on Exhibit 13. These four leads fall into two general analog types, Gavilan(1) and Puerto Chiquito(3), based on the production and geologic analyses presented previously. The Gavilan-type lead is located in the general area of T29N3W. The three Puerto Chiquito-type leads are located along the northward extension of the monocline west and north of Boulder Field in Townships 28, 29 and 30 North; Range 1W. Drilling depths and possible economic scenarios for the leads are presented in the economic section of this report.

The leads are highly scoping in nature because there is little data available in the area upon which to base Mancos mapping. The primary sources of information used to identify the leads were geomorphic interpretation of the remote sensing images in the low relief areas, projecting surface mapping of faults along the monocline and crude shape mapping of sparse well control.

The imagery from which the Gavilan-type lead was identified is presented in Figure 23. The high productivity synclinal area of Gavilan, northeast quarter of T26NR2W, underlies a pronounced dendritic drainage anomaly indicating a subtle syncline(confirmed by subsurface mapping, Exhibit 13) plunging to the NW(red circle). The lead, green circle, shows a similar, but larger, surface anomaly. Shape contouring of sparse Mancos top data for the area seems to confirm the potential presence of a synclinal area. As stated previously, exploration targets for oil in the Mancos of this area should target synclinal features near the base of the Monocline to maximize reservoir energy and potential for fracturing in the reservoir. This lead lies in a similar position with respect to the Monocline as Gavilan and seems to show similar surface expression, justifying its lead status and further investigation.

The three lead areas identified on the eastern portion of the Jicarilla lands all lie on or near the base of the Monocline. Figure 24 shows the imagery of the eastern flank area where the backthrusts and their associated synclines(blue circles) have expression at the surface. These subtle structures have been used in the past to justify the left lateral sense of shear along this margin. Another possible interpretation, favored here, would make the reverse faults and synclines backthrust systems forming, fan-like, off the north flank of the Naciemento Uplift. Under this scenario, the exploration target would be the leading edges of the backthrusts where Coulomb shear fractures associated with the fault propagation would provide the multiple directions of fracturing necessary for high permeability and low structural position along the Monocline would provide reservoir energy.

The lead areas identified here would require significantly more study to properly design a seismic program or identify test well locations. Suggestions for further work would include more detailed photogeologic interpretation using high resolution aerial photography combined with outcrop field mapping to generate a very detailed surface geologic map of the area. Surface fracture characterization would likely also improve potential for exploratory success.

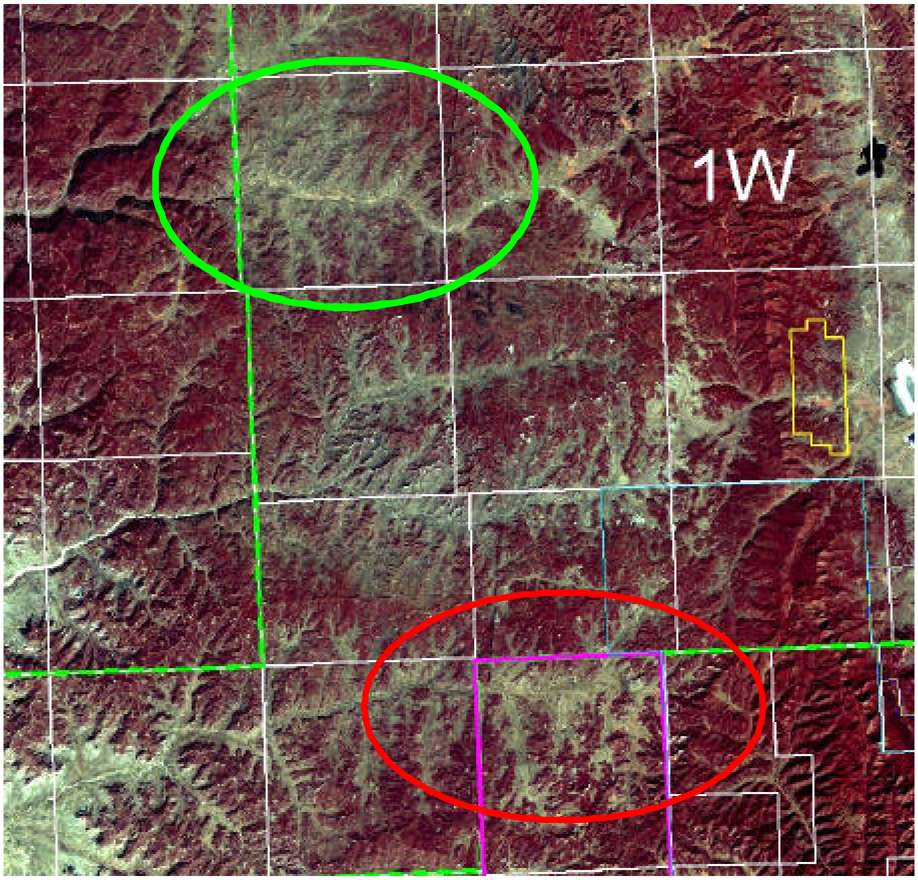


Figure 23: Gavilan – Analog Lead

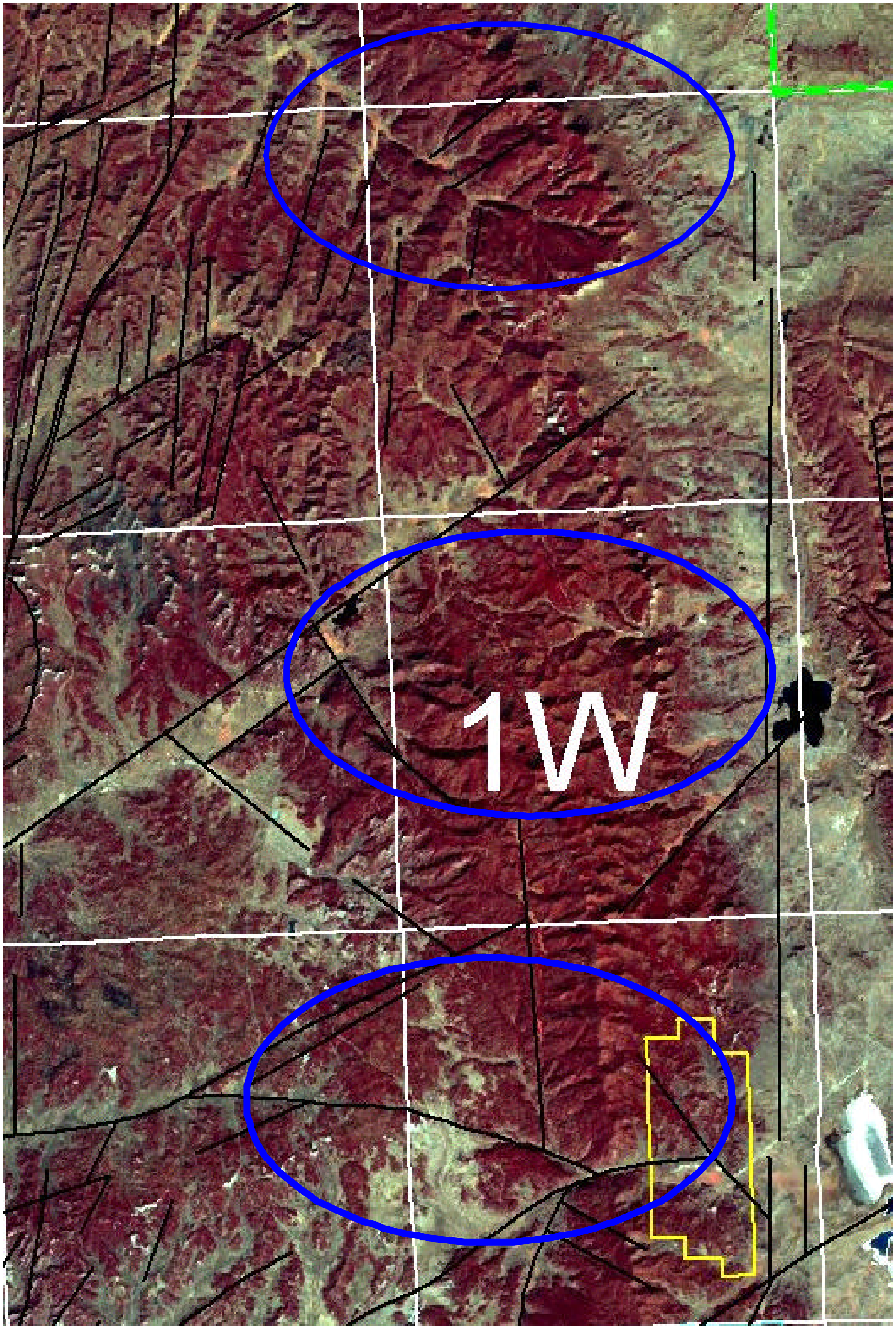


Figure 24: West Puerto Chiquito Analog Leads

3.4 Reserves and Economics

The final component of this study was to estimate pro-forma production, reserve and financial performance of the leads identified. This was accomplished using the following methodology:

- Describe leads
- Establish exploration/development approaches and costs
- Forecast production performances
- Assume financial/economic parameters
- Perform reserve/economic analysis
- Run Monte Carlo simulation of results

Each of these elements of the reserve and economic analysis are presented below:

3.5 Lead Descriptions

The four leads are illustrated in Exhibit 13, one of which (Lead I) is considered a Gavilan field analog (low-relief environment, base of monocline) and the other three (Leads II/III/IV) are considered analogs to the West Puerto Chiquito field (high-relief environment, along flank of monocline). The geographic size of each lead is presented in Table 10, along with the comparative size of each analog. Note that Leads II/III/IV are each much smaller than the Canada Ojitos Unit. Two economic analyses were performed – one for Lead I and one for Lead II/III/IV (an individual lead, not all three combined).

Table 10: Description of Leads

LEAD	AREA	ANALOG
I	43,000 acres 67 mi^2	Gavilan (78 mi^2)
II	18,000 acres 28 mi^2	West Puerto Chiquito (COU – 101 mi^2)
III	12,000 acres 19 mi^2	West Puerto Chiquito (COU – 101 mi^2)
IV	14,000 acres 22 mi^2	West Puerto Chiquito (COU – 101 mi^2)

3.6 Exploration/Development Assumptions and Costs

The following schedule of exploration/development activities was assumed:

- Year 1: Seismic surveys, geological analysis
- Year 2: Exploration drilling
- Year 3: Begin development

For the seismic program, it was assumed that 75% of the lead area would be surveyed (two-dimensional), at a density of 1-mile spacing on the dip lines and 2-mile spacing on the strike lines. The cost of seismic acquisition and processing was assumed to be $8,000/line-mile. In addition, a geological and geophysical analytic cost of $150,000 for Lead I and $75,000 for Lead II/III/IV was assumed (to identify specific, naturally fractured prospects).

In year two, the number of exploration wells drilled, which were assumed to be disposable (i.e., not converted to production wells), were three for Lead I and two for Lead II/III/IV. Estimated well costs and assumptions are provided in Table 11.

Table 11: Well Cost Summary

	Exploration	Production	Injection
Drilling/Completion			
Site Prep	Y	Y	Y
Drilling	Y	Y	Y
Logging	Y	Y	Y
Casing/Cementing	N	Y	Y
Perforating	N	Y	Y
Stimulation	N	Y	Y
Production Equipment			
Tubing/Packer	N	Y	Y
Surface Plumbing	N	Y	Y
Oil Storage	N	Y	N
Gathering/Compression/Distribution			
Low Pressure	N	Y	N
Compression	N	N	Y
High Pressure	N	N	Y
Cost	$200,000	$400,000	$800,000

Development was assumed to begin in year three, with wells drilled at an average pace of 9/year until fully developed (fewer in earlier years, more in later years). It was assumed that 70% of the lead area would be developed at 640-acre spacing. This resulted in an estimated well count of 46 for Lead I and 16 for Lead II/III/IV. It was also assumed that the dry-hole rate would be 20%, meaning that only 37 wells would be productive for Lead I and 13 for Lead II/III/IV (the dry-hole costs were allocated to the remaining production wells).

It was assumed that all produced gas would be re-injected for pressure maintenance purposes. The ratio of production wells to injection wells was assumed to be 10:1, resulting in a total injection well count of four for Lead I and one for Lead II/III/IV. A low-pressure gas gathering system from the production wells, a central gas compression and dehydration facility, and a high-pressure redistribution system were assumed, and are reflected in the allocated well costs.

Fixed operating costs were assumed to be $1000/month, to account for overhead, workovers, etc. In addition, variable operating costs of $1.00/bbl of oil (transportation) and $0.20/Mcfg (compression, dehydration), were also assumed.

3.7 Production Forecasts

Production forecasts for Lead I and Lead II/III/IV were based on the time-zero plots for the Gavilan and West Puerto Chiquito fields respectively (Figure 17). Curve-fits for each are provided in Figures 25 and 26. The average Lead I well yields an EUR of 81 MBO; however, this estimate has been increased by a factor of two, to 162 MBO, to account for the larger well spacing and the implementation of pressure maintenance, which are not reflected in the actual time-zero plot for Gavilan. This value is about average for the play. The average Lead II/III/IV well yields an EUR of 343 MBO; similar to that at West Puerto Chiquito. Gas rates were computed based on a gas-oil ratio versus time plot (Gavilan) and gas-oil ratio versus cumulative oil production plot (West Puerto Chiquito). Note that gas production was not valued as it was assumed that are produced gas was reinjected (although at some time in the future some value would be captured during reservoir blowdown). Gas rates were still computed to estimate gathering and compression costs.

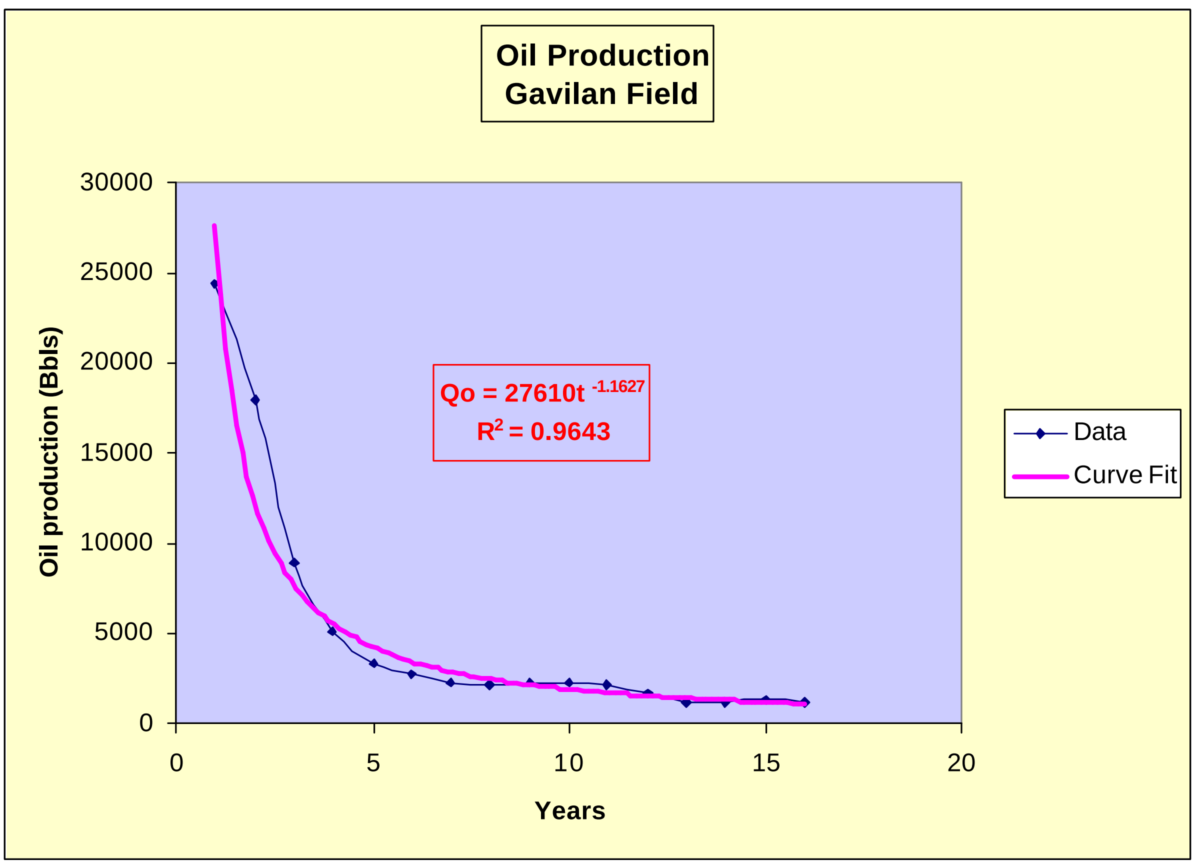


Figure 25: Production Assumptions – Gavilan Field

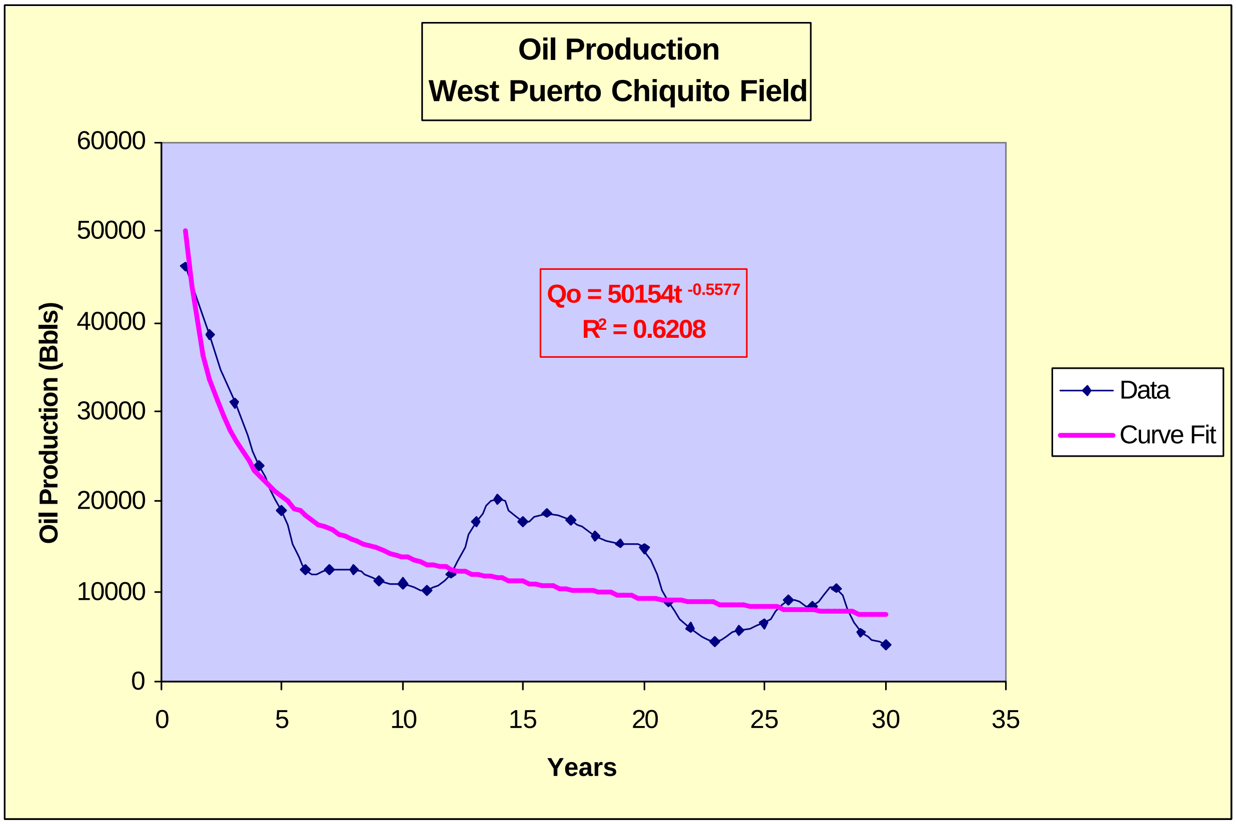


Figure 26: Production Assumptions – West Puerto Chiquito Field

3.8 Financial/Economic Assumptions

The financial and economic assumptions for the analysis are presented in Table 12 below.

Table 12: Financial Assumptions

Acreage Payment ➢ $25/acre
Disbursement of monies ➢ Interests • Working Interest: 100% • Net Revenue Interest: 80% ➢ Taxes • 16% (State-4%, Nation-12%)
Oil and Gas Prices ➢ Oil Price: $20/Bbl ➢ No (real) price escalation
Discount Rate ➢ 15%

3.9 Results

The results of the analysis based on the previously-stated assumptions are presented in Table 13 below. For Lead I, a total exploration cost of $1.9 million is estimated, and a total capital investment of $22 million, to yield an oil reserve of 6.0 MMBO and a net present value (15% discount rate) of $13 million. The profitability ratio for this case is 0.6. For Lead II/III/IV, a total exploration cost of $0.9 million is estimated, and a total capital investment of $7 million, to yield an oil reserve of 4.5 MMBO and a net present value (15% discount rate) of $13 million. The profitability ratio for this case is 1.8. Note that if all four leads (II/III/IV) were developed, these economic results would have to be scaled up accordingly (see total column).

Table 13: Preliminary Results (20-year time frame)

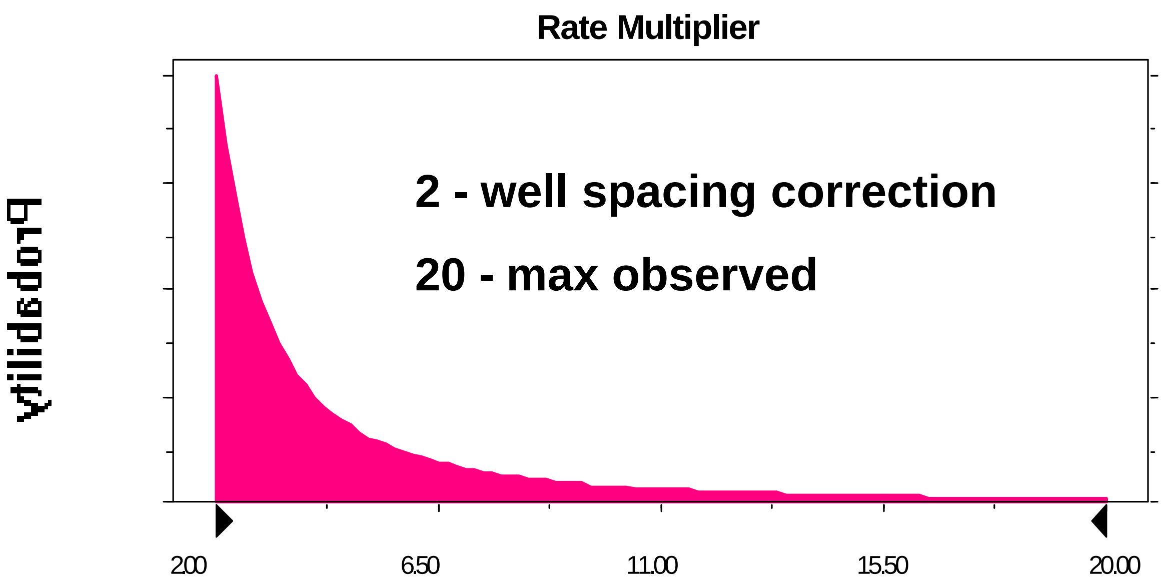
	Lead I	**Leads II/III/IV (each)**	**Total**
Exploration Costs (Acreage, Seismic, G&G, Exploration wells)	$1.9 million (43,000 acres)	$0.9 million (15,000 acres)	$4.6 million (88,000 acres)
Capital Investment (Production/Injection wells)	$22 million (46/4)	$7 million (16/1)	$43 million (94/7)
Gross Oil Reserves **Gross Gas Production** (not valued)	6.0 MMBbls 47.6 Bcfg	4.5 MMBbls 16.2 Bcfg	$19.5 MMBbls 96.2 Bcfg
NPV_{15} **	$13 million	$13 million	$52 million
Profitability Ratio (NPV/Capex)	0.6	1.8	1.2

It is clear that, although not large in scale, development of these leads could be attractively profitable. While there is no doubt considerable risk and uncertainty remains, a tailored exploration program (to identify specific, naturally fractured prospects), and sound development practices (i.e., wide well spacing, pressure maintenance via produced gas re-injection), these risks should be minimized.

3.9.1 Monte Carlo Simulation

To examine the sensitivity of the economic results to the assumptions made, a Monte Carlo simulation the results was performed. The base-case values and probability distributions assumed, for each parameter are provided in Tables 14 and 15 for Lead I and Lead II/III/IV respectively. Noteworthy is the inclusion of an “oil rate multiplier”. In the case of Lead I, an initial value of 2 is used to account for increased spacing, as described above. Beyond that, a Parreto distribution was employed to account for the possibility of drilling a “high yield” well, presumably as a result of an improved exploration strategy (Figure 27). The maximum limit of the Parreto distribution was set at the maximum observed reserve for a Mancos well. Hence this is the technique employed to account for the upside associated with an advanced exploration strategy.

(a) **Lead I**



(b) **Lead II/III/IV**

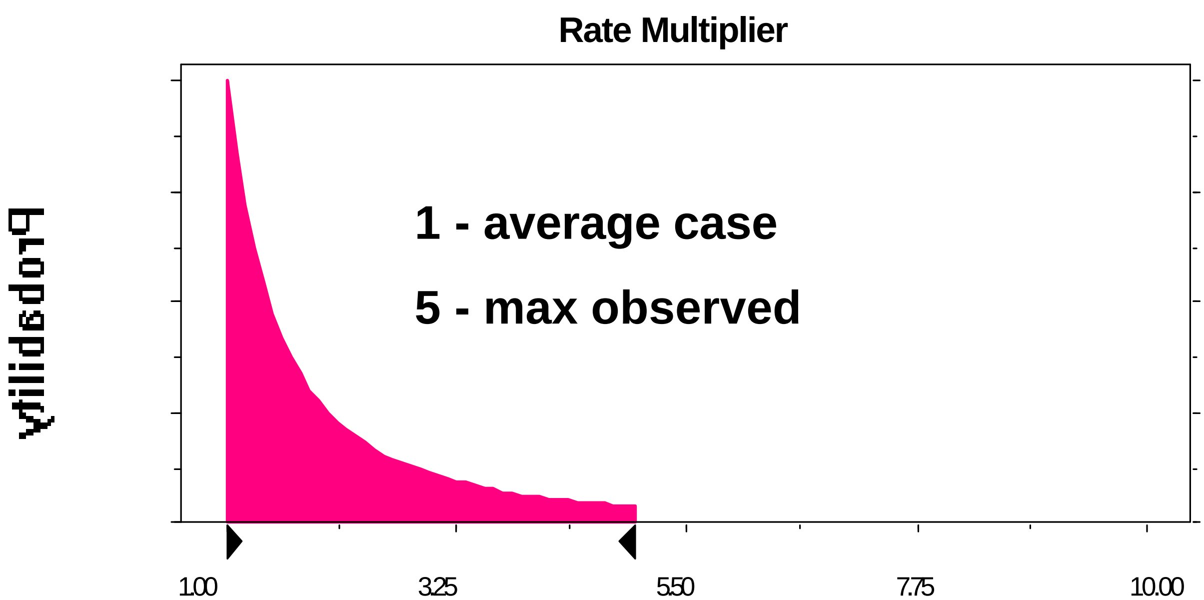


Figure 27: Oil Rate Multiplier

Table 14: Monte-Carlo Simulation Input – Gavilan Field

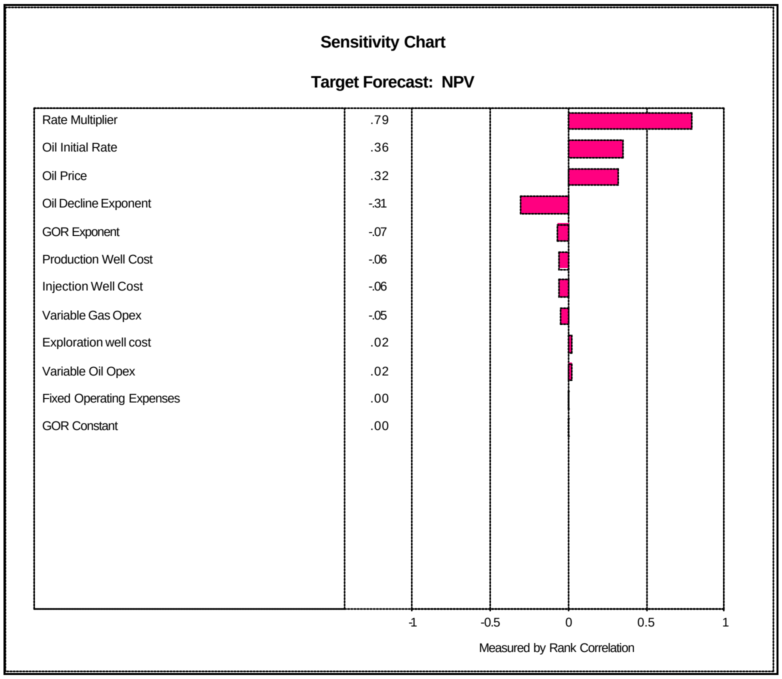
PARAMETER	ORIGINAL VALUE	DISTRIBUTION
Well Cost - Exploration - Production - Injection	 - $ 200,000 - $ 400,000 - $ 800,000	 - Normal, +/- 25% StdDev - Normal, +/- 25% StdDev - Normal, +/- 25% StdDev
Fixed Operating Costs	$ 1000 / well / month	Normal, +/- 25% StdDev
Variable Operating Costs - Oil - Gas	 - $ 1 /Bbl - $ 0.20 / Mcf	 - Normal, +/- 25% StdDev - Normal, +/- 25% StdDev
Oil Initial Rate	28 MBbls / yr (76 Bbls / day)	Normal, +/- 25% StdDev
Oil Rate Multiplier	2	Pareto, Shape 1, Min 2,Max 20
Oil Curve Fit Exponent (Power law)	1.1627	Normal, +/- 25% StdDev
GOR Initial Rate	2438 scf / Bbl	Normal, +/- 25% StdDev
GOR Curve Fit Exponent (time)	0.8166	Normal, +/- 25% StdDev
Oil Price	$ 20 / Bbl	Normal, +/- 25% StdDev

Table 15: Monte-Carlo Simulation Input- West Puerto Chiquito Field

PARAMETER	ORIGINAL VALUE	DISTRIBUTION
Well Cost - Exploration - Production - Injection	 - $ 200,000 - $ 400,000 - $ 800,000	 - Normal, +/- 25% StdDev - Normal, +/- 25% StdDev - Normal, +/- 25% StdDev
Fixed Operating Costs	$ 1000 / well / month	Normal, +/- 25% StdDev
Variable Operating Costs - Oil - Gas	 - $ 1 /Bbl - $ 0.20 / Mcf	 - Normal, +/- 25% StdDev - Normal, +/- 25% StdDev
Oil Initial Rate	50 MBbls / yr (137 Bbls / day)	Normal, +/- 25% StdDev
Oil Rate Multiplier	1	Pareto, Shape 1, Min 1, Max 5
Oil Curve Fit Exponent (Power law)	0.5577	Normal, +/- 25% StdDev
GOR Initial Rate	802 scf / Bbl	Normal, +/- 25% StdDev
GOR Curve Fit Exponent (cum oil)	7E-06	Normal, +/- 25% StdDev
Oil Price	$ 20 / Bbl	Normal, +/- 25% StdDev

The first step in the analysis was to evaluate which parameters has the greatest impact on the end result. The result of those analyses, in "tornado plot" form, are shown in Figure 28 (a) and (b). As one might expect, oil rate and price assumptions are the most important to the outcome. Hence, by using relatively conservative assumptions in this regard, the forecast economic performance is also conservative.

(a) <u>Lead I</u>



(b) <u>Lead II/III/IV</u>

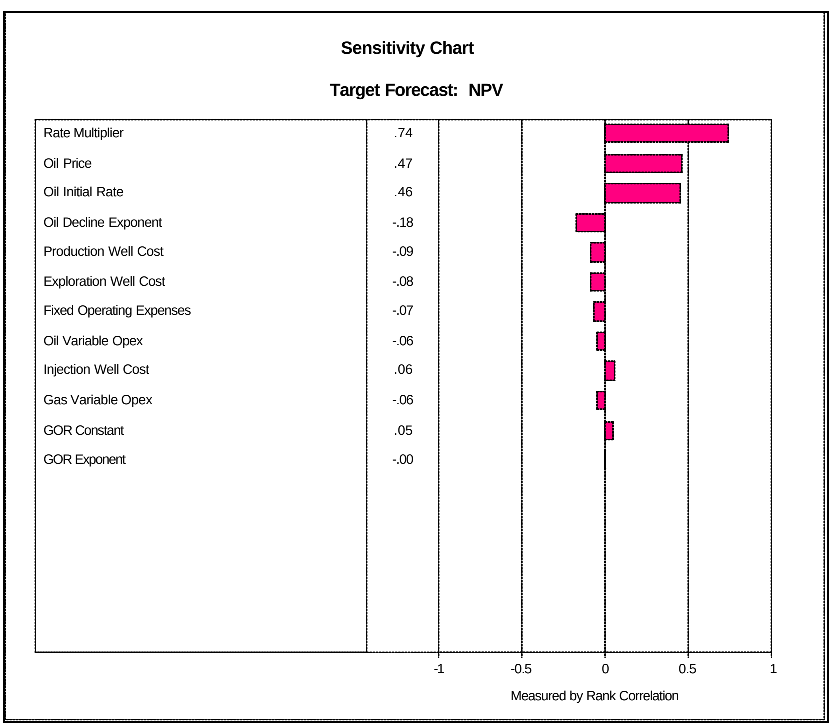
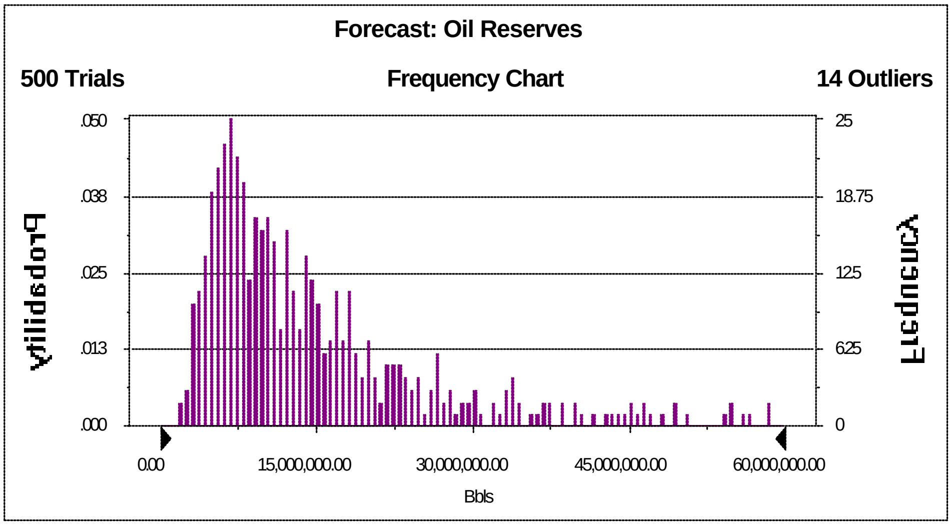


Figure 28: Sensitivity Analysis

Results of the Monte Carlo simulations themselves are presented in Figures 29 and 30 for Lead I and Lead II/III/IV respectively, anad are summarized in Table 16. Based on the various assumptions in the analysis, there is an 80% probability that Lead I would yield an EUR of 6.4 MMBO, and an NPV_{15} of $13 million. Similarly, Lead II/III/IV would yield an EUR of 47 MMBO, and an NPV_{15} of $13 million. These new economic results begin to illustrate the value that can be assigned to an advanced exploration strategy; the NPV_{15} for the total project (all four leads combined) is increased by $107 million, or over 100%, as a result of improved exploration success.

(a) <u>Oil Reserves</u>



(b) <u>NPV</u>

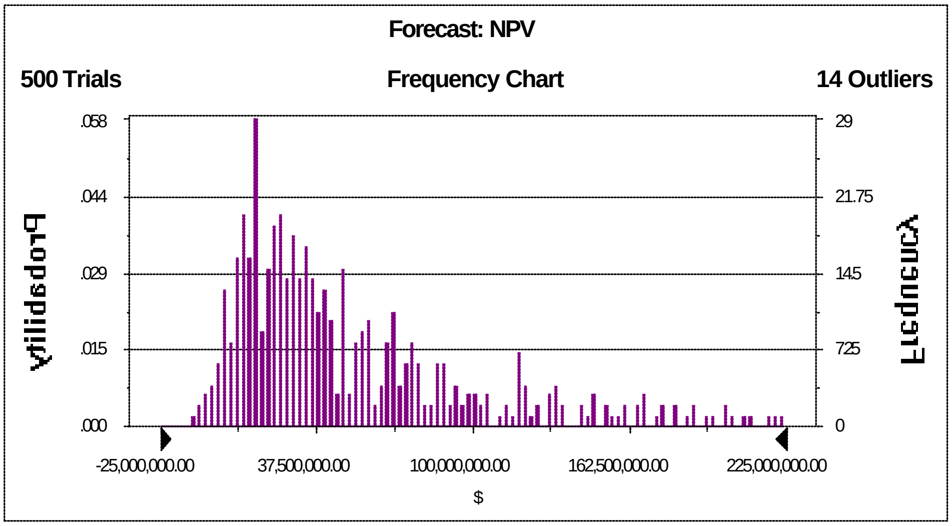
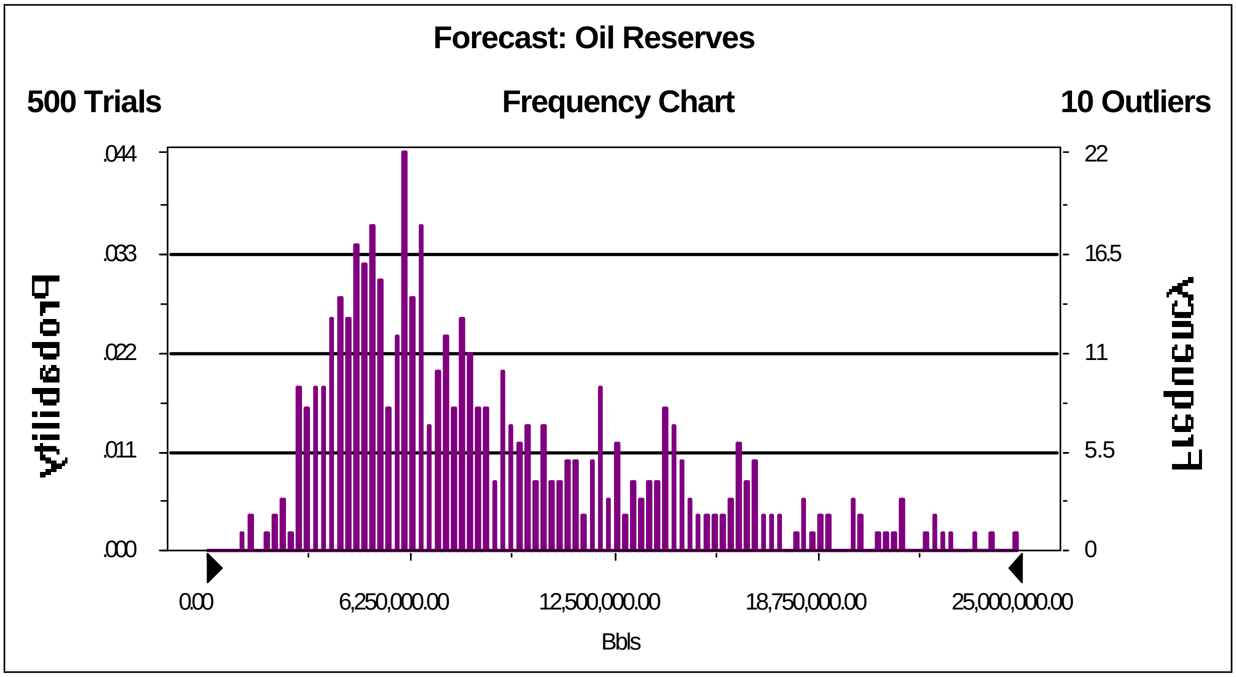


Figure 29: Monte-Carlo Simulation Results – Lead I

(a) Oil Reserves



(b) NPV

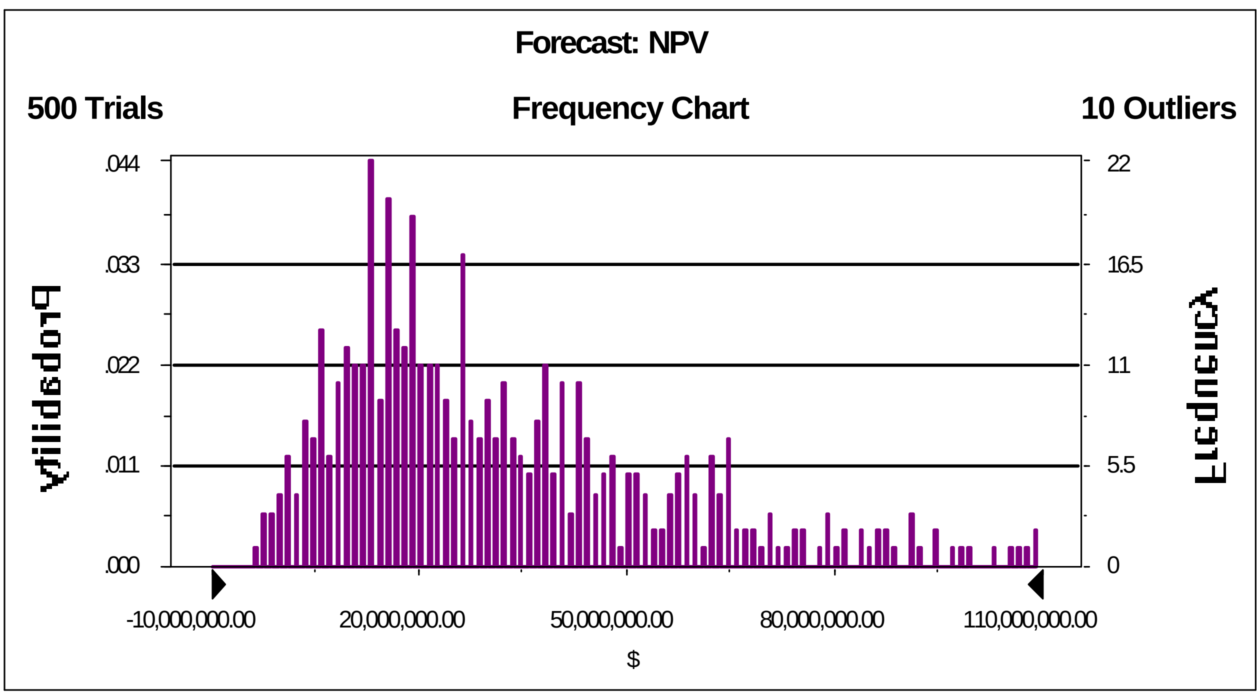


Figure 30: Monte Carlo Simulation Results- Lead II, III, IV

	Lead I	**Leads II/III/IV (each)**	**Total**
Exploration Costs (Acreage, Seismic, G&G, Exploration wells)	$1.9 million (43,000 acres)	$0.9 million (15,000 acres)	$4.6 million (88,000 acres)
Capital Investment (Production/Injection wells)	$22 million (46/4)	$7 million (16/1)	$43 million (94/7)
Gross Oil Reserves **Gross Gas Production** (not valued)	16 MMBbls 62 Bcfg	9 MMBbls 18 Bcfg	43 MMBbls 116 Bcfg
NPV_{15}	$57 million	$34 million	$159 million
Profitability Ratio (NPV/Capex)	2.6	4.8	3.7

Table 16: Summary of Monte-Carlo Simulation Results

4.0 Information Dissemination

The following technology transfer activities were performed as part of the project to disseminate the results to industry and potential investors:

- Hosting a booth at the AAPL-sponsored NAPE on January 30 & 31, 2002 at the George R. Brown Convention Center in Houston to present the leads to prospective investor companies. This is the premiere annual event for property transactions in the U.S., and hence targeted the precise audience sought for presenting the results. In attendance were three representatives from the JAIN - OGA, and two representatives from ARI. Over 40 companies stopped by the booth and expressed some level of interest in working with the Nation to develop the Mancos. A summary of those contacts was prepared separately and distributed to the JAIN-OGA and the U.S. DOE – NPTO.

- Preparation of this final report. Copies of this report have been distributed to the JAIN - OGA, the U.S. DOE - NPTO, and each region of the Petroleum Technology Transfer Council. Copies are also being mailed to each company that visited the display booth at NAPE. In addition, presentations of the final results were made to JAIN-OGA, DOE-NPTO (Tulsa), and the Bureau of Indian Affairs (Denver). Included in this final report is an accompanying presentation, which also summarizes the project results, and all the Exhibits (full-scale maps) in electronic form.

- While not completed at the time of this writing, a summary version of this final report will be published in an industry trade periodical or symposia proceedings to broaden the audience reached.

5.0 Conclusions/Recommendations

5.1 Conclusions

- The Mancos shale is highly complex, non-conventional oil play.
- Considerable further development potential exists.
- Successful exploitation requires a combination of specialized exploration and proven operating practices.
  - Natural fractures (“Sweet Spots”)
  - Wide Spacing
  - Gravity drainage/pressure maintenance

- New leads have been identified base on structural interpretation concept.
- Combined NPV_{15} of leads, if discoveries are made and development proceeds, are estimated at over $150 million on a $43 million capital investment.

5.2 Recommendations

- Attract venture partner.
- Perform seismic survey & geomechanical modeling to establish high-potential prospects.
- Drill & evaluate results.

6.0 References

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Appendices

Appendix A: Thermal Maturity Information

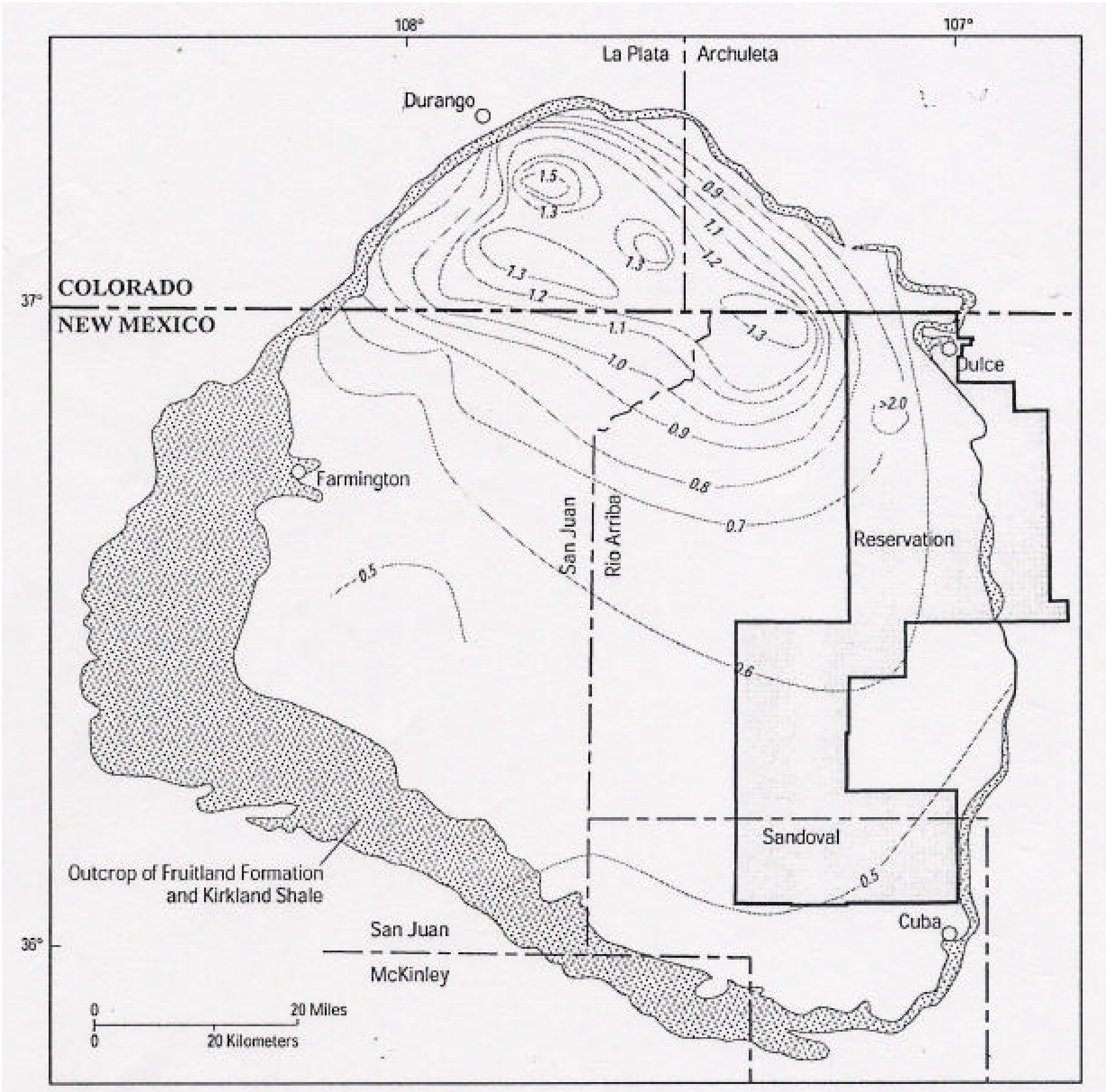

Figure A-1: Thermal Maturity Map of the Fruitland Coal (reproduced from reference 13)

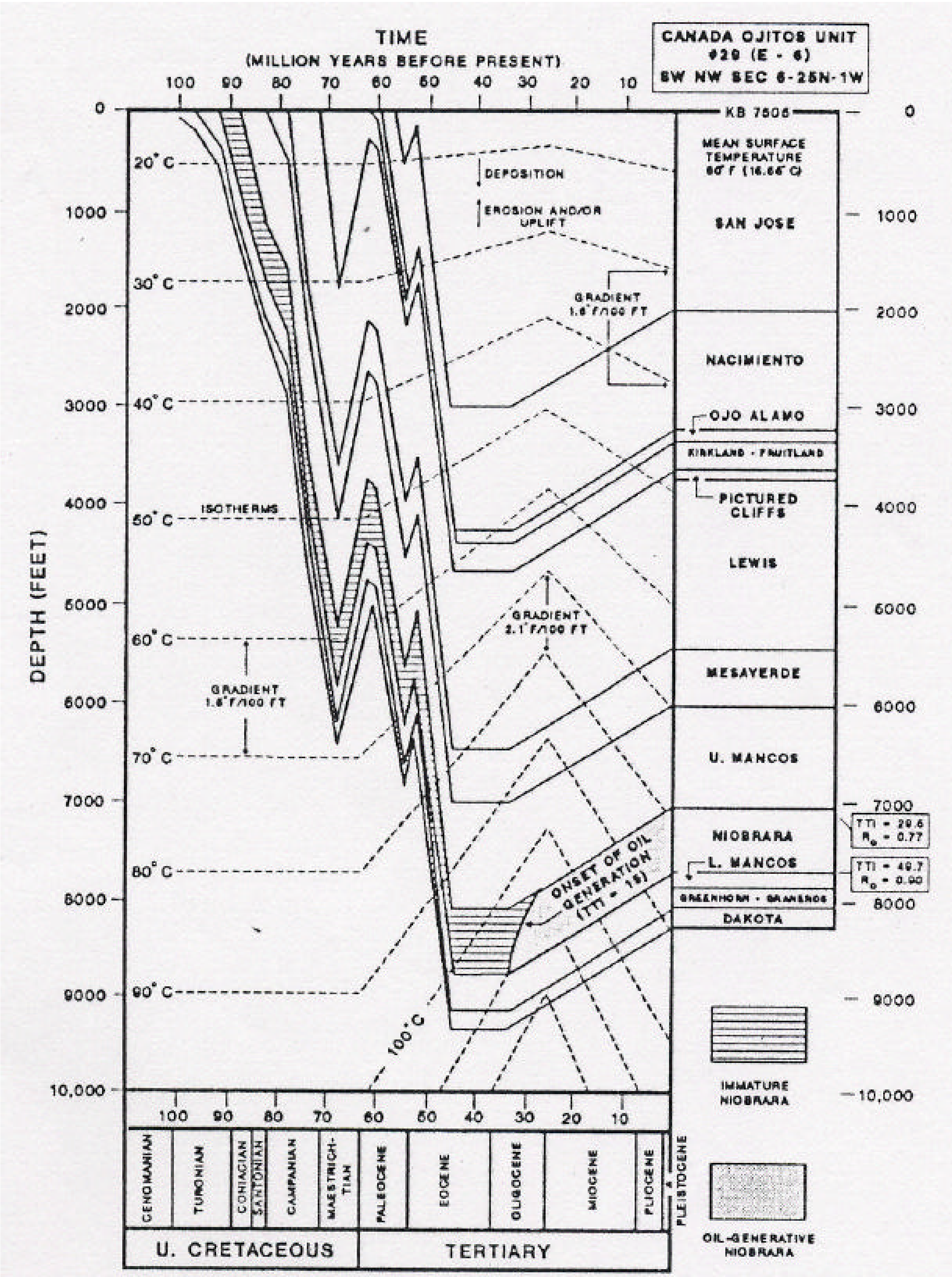

Figure A-2: Burial and Thermal History Reconstruction of the Canada Ojitos Unit 29 Well (reproduced from reference 7)

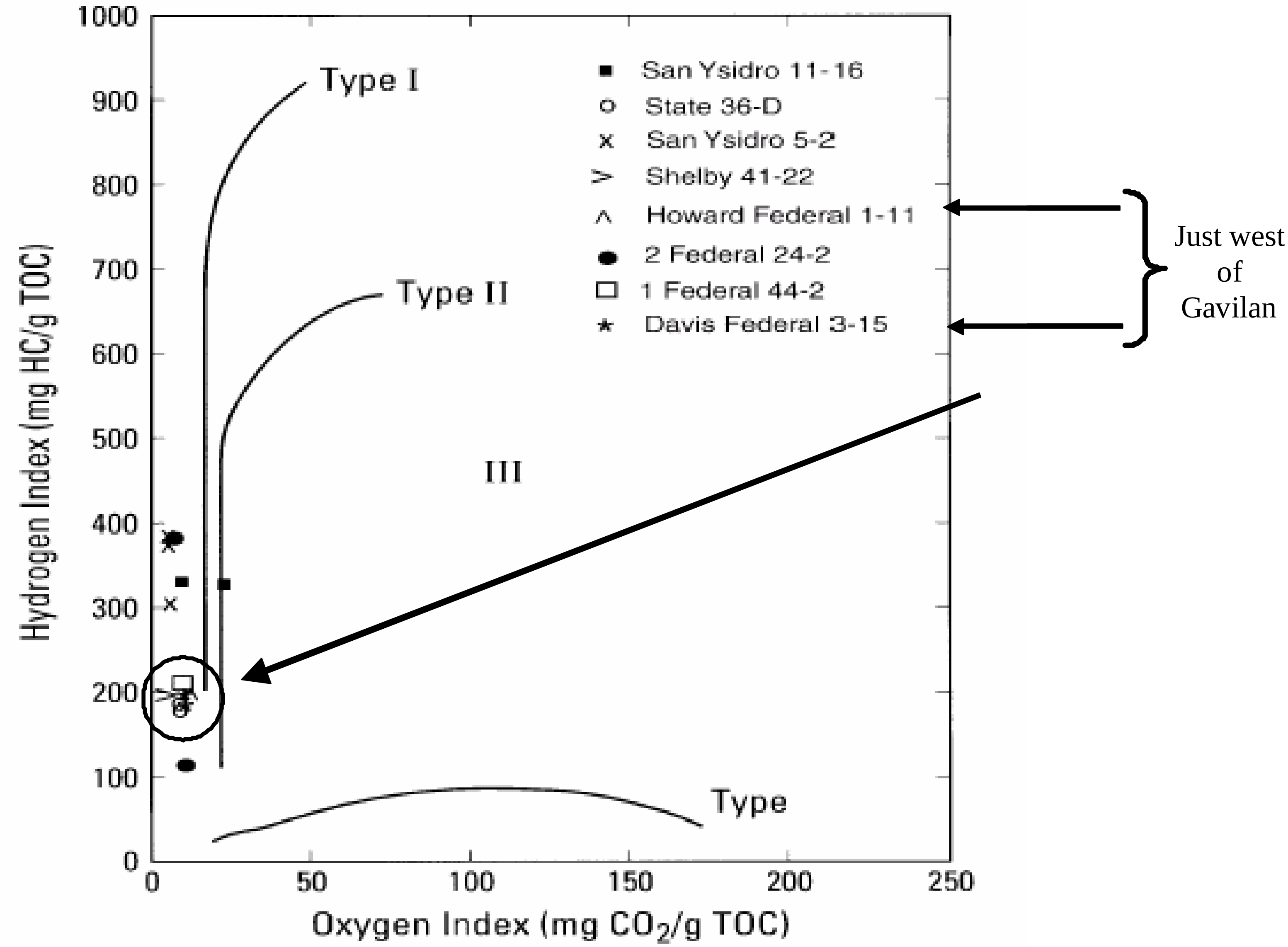

Figure A-3: Van-Krevelan Diagram of Mancos Rock Chips (reproduced and modified from reference 13)

Appendix B: Economic Spreadsheets

Lead I

	WELLS SCHEDULE							STUDIES			Total Cost
	Exploration	Cost/Well	Production	Cost/Well	Injection	Cost/Well	Total	G and G	Seismic	Total	
Price		200,000		400,000		800,000					
Year 1							-	150,000	576,000	726,000	726,000
Year 2	3	200,000					600,000			-	600,000
Year 3			8	500,000	1	800,000	4,800,000			-	4,800,000
Year 4			8	500,000	1	800,000	4,800,000			-	4,800,000
Year 5			8	500,000	1	800,000	4,800,000			-	4,800,000
Year 6			8	500,000	1	800,000	4,800,000			-	4,800,000
Year 7			5	500,000			2,500,000			-	2,500,000
Year 8							-			-	-
Year 9							-			-	-
Year 10							-			-	-
Total	3	600,000	37	18,500,000	4	3,200,000	22,300,000	150,000	576,000	726,000	23,026,000

Lead II/III/IV

	WELLS SCHEDULE							STUDIES		
	Exploration	Cost/Well	Production	Cost/Well	Injection	Cost/Well	Total	G and G	Seismic	Total
Price		200,000		400,000		800,000				
Year 1							-	75,000	224,000	299,000
Year 2	2	200,000					400,000	-	-	-
Year 3			8	500,000	1	800,000	4,800,000			-
Year 4			5	500,000			2,500,000			-
Year 5							-			-
Year 6							-			-
Year 7							-			-
Year 8							-			-
Year 9							-			-
Year 10							-			-
Total	2	400,000	13	6,500,000	1	800,000	7,700,000	75,000	224,000	299,000

Lead I

	REVENUE						
	GROSS PRODUCTION		NET PRODUCTION		PRICE ($)		TOTAL GROSS REVENUE ($)
Year	Oil (Bbls)	Gas (Mcf)	Oil (Bbls)	Gas (Mcf)	Oil	Gas	
1						NOT SOLD	
2							
3	441,760	1,077,099	353,408	861,679	20	-	7,068,160
4	639,084	1,924,462	511,267	1,539,569	21	-	10,736,603
5	762,234	2,660,879	609,788	2,128,703	20	-	12,195,750
6	850,374	3,327,506	680,299	2,662,005	20	-	13,605,984
7	752,712	3,540,675	602,169	2,832,540	20	-	12,043,387
8	457,624	3,129,072	366,099	2,503,258	20	-	7,321,982
9	334,097	2,872,561	267,278	2,298,048	20	-	5,345,559
10	263,446	2,686,755	210,756	2,149,404	20	-	4,215,130
11	217,190	2,542,200	173,752	2,033,760	20	-	3,475,046
12	184,437	2,424,732	147,549	1,939,786	20	-	2,950,985
13	160,000	2,326,384	128,000	1,861,107	20	-	2,559,996
14	141,068	2,242,215	112,854	1,793,772	20	-	2,257,089
15	125,975	2,168,953	100,780	1,735,162	20	-	2,015,603
16	113,668	2,104,319	90,934	1,683,455	20	-	1,818,681
17	103,445	2,046,664	82,756	1,637,332	20	-	1,655,125
18	94,825	1,994,761	75,860	1,595,809	20	-	1,517,200
19	87,461	1,947,671	69,969	1,558,136	20	-	1,399,384
20	81,102	1,904,659	64,882	1,523,727	20	-	1,297,633
21	75,557	1,865,143	60,446	1,492,115	20	-	1,208,914
22	70,682	1,828,654	56,546	1,462,923	20	-	1,130,911
Total	5,956,741	46,615,364	4,765,393	37,292,292			95,819,120

DEDUCTIONS ($)								
INVESTMENT	ACREAGE AND RENTAL PAYMENTS	OPERATING EXPENSES		PRODUCTION TAXES	NET INCOME	CUMULATIVE NET INCOME	NPV	CUMULATIVE NPV
		Fixed	Variable					
726,000	592,000		-		(1,318,000)	(1,318,000)	(1,318,000)	(1,318,000)
600,000			-	-	(600,000)	(1,918,000)	(521,739)	(1,839,739)
4,800,000		96,000	657,180	1,060,224	454,756	(1,463,244)	343,861	(1,495,878)
4,800,000		192,000	1,023,976	1,610,490	3,110,137	1,646,893	2,044,965	549,087
4,800,000		288,000	1,294,410	1,829,363	3,983,977	5,630,870	2,277,852	2,826,939
4,800,000		384,000	1,515,875	2,040,898	4,865,211	10,496,081	2,418,870	5,245,809
2,500,000		444,000	1,460,847	1,806,508	5,832,032	16,328,113	2,521,348	7,767,157
-		444,000	1,083,438	1,098,297	4,696,246	21,024,360	1,765,493	9,532,650
-		444,000	908,610	801,834	3,191,115	24,215,475	1,043,181	10,575,832
-		444,000	800,797	632,269	2,338,064	26,553,539	664,624	11,240,455
		444,000	725,630	521,257	1,784,159	28,337,698	441,017	11,681,472
		444,000	669,383	442,648	1,394,954	29,732,652	299,836	11,981,308
		444,000	625,276	383,999	1,106,720	30,839,372	206,854	12,188,162
		444,000	589,511	338,563	885,015	31,724,387	143,840	12,332,002
		444,000	559,766	302,340	709,497	32,433,883	100,272	12,432,274
		444,000	534,531	272,802	567,347	33,001,230	69,724	12,501,998
		444,000	512,778	248,269	450,078	33,451,309	48,098	12,550,095
		444,000	493,777	227,580	351,842	33,803,151	32,695	12,582,790
		444,000	476,996	209,908	268,481	34,071,632	21,695	12,604,485
		444,000	462,034	194,645	196,954	34,268,586	13,839	12,618,324
		444,000	448,586	181,337	134,991	34,403,577	8,248	12,626,572
		444,000	436,413	169,637	80,862	34,484,439	4,296	12,630,868
23,026,000	592,000	8,064,000	15,279,814	14,372,868	34,484,439		NPV	12,630,868

Lead II/III/IV

Year	REVENUE: GROSS PRODUCTION Oil (Bbls)	GROSS PRODUCTION Gas (Mcf)	NET PRODUCTION Oil (Bbls)	NET PRODUCTION Gas (Mcf)	PRICE ($) Oil	PRICE ($) Gas	TOTAL GROSS REVENUE ($)	DEDUCTIONS ($): INVESTMENT	ACREAGE AND RENTAL PAYMENTS	OPERATING EXPENSES Fixed	OPERATING EXPENSES Variable	PRODUCTION TAXES	NET INCOME	CUMULATIVE NET INCOME	NPV	CUMULATIVE NPV
1	-	-	-	-		NOT SOLD		299,000	208,000	-	-	-	(507,000)	(507,000)	(507,000)	(507,000)
2	-	-	-	-			-	400,000		-	-	-	(400,000)	(907,000)	(347,826)	(854,826)
3	401,232	444,353	320,986	355,483	20		6,419,712	4,800,000		96,000	490,103	962,957	70,653	(836,347)	53,423	(801,403)
4	523,361	673,365	418,689	538,692	20		8,373,772	2,500,000		156,000	658,034	1,256,066	3,803,673	2,967,325	2,500,977	1,699,574
5	387,792	639,163	310,234	511,330	20		6,204,672	-		156,000	515,625	930,701	4,602,347	7,569,672	2,631,407	4,330,981
6	321,083	639,860	256,867	511,888	20		5,137,330	-		156,000	449,055	770,600	3,761,676	11,331,348	1,870,218	6,201,198
7	279,270	645,282	223,416	516,225	20		4,468,314	-		156,000	408,326	670,247	3,233,741	14,565,088	1,398,035	7,599,234
8	249,916	642,048	199,933	513,638	20		3,998,653	-		156,000	378,325	599,798	2,864,529	17,429,618	1,076,883	8,676,116
9	227,866	639,464	182,293	511,571	20		3,645,861	-		156,000	355,759	546,879	2,587,223	20,016,840	845,768	9,521,884
10	210,534	645,189	168,427	516,151	20		3,368,538	-		156,000	339,571	505,281	2,367,686	22,384,527	673,044	10,194,928
11	196,455	653,345	157,164	522,676	20		3,143,279			156,000	327,124	471,492	2,188,663	24,573,190	541,004	10,735,932
12	184,732	663,404	147,786	530,723	20		2,955,712			156,000	317,413	443,357	2,038,943	26,612,133	438,257	11,174,189
13	174,779	675,294	139,823	540,235	20		2,796,461			156,000	309,838	419,469	1,911,154	28,523,287	357,208	11,531,398
14	166,195	694,757	132,956	555,805	20		2,659,112			156,000	305,146	398,867	1,799,099	30,322,386	292,404	11,823,801
15	158,695	739,684	126,956	591,747	20		2,539,112			156,000	306,631	380,867	1,695,614	32,018,000	239,639	12,063,440
16	152,071	811,924	121,656	649,539	20		2,433,128			156,000	314,455	364,969	1,597,704	33,615,704	196,349	12,259,789
17	146,166	889,893	116,933	711,915	20		2,338,655			156,000	324,145	350,798	1,507,713	35,123,417	161,121	12,420,911
18	140,861	976,023	112,689	780,818	20		2,253,773			156,000	336,065	338,066	1,423,642	36,547,058	132,293	12,553,204
19	136,061	1,072,205	108,849	857,764	20		2,176,978			156,000	350,502	326,547	1,343,929	37,890,987	108,596	12,661,800
20	131,692	1,167,413	105,354	933,930	20		2,107,077			156,000	365,175	316,062	1,269,841	39,160,828	89,226	12,751,026
21	127,694	1,262,872	102,155	1,010,298	20		2,043,109			156,000	380,269	306,466	1,200,374	40,361,202	73,343	12,824,369
22	124,018	1,362,674	99,214	1,090,139	20		1,984,289			156,000	396,553	297,643	1,134,093	41,495,295	60,255	12,884,624
Total	4,440,471	15,938,209	3,552,377	12,750,568			71,047,538	7,999,000	208,000	3,060,000	7,628,113	10,657,131			NPV	12,884,624.26