ORIENTED FRACTURING – A PRACTICAL TECHNIQUE FOR PRODUCTION OPTIMIZATION

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ABSTRACT

Understanding of the near wellbore stress distribution is critical to implement effective fracturing strategies. Reservoir quality variations, mixed lithologies with plastic behavior will alter the near wellbore stress distribution reducing the compressive stress of the rock. Thus, constant stress gradients (0.1 psi/ft.) are misleading and rock mechanical properties measurements may prove to be of extreme importance. This work discusses the development of criteria for orienting perforating/fracturing strategies. We present, an improved completions methodology that couples a systematic and enhanced geomechanical reservoir characterization with effective fracture placement and increased production results.

Case-specific examples demonstrate the advantages of using detailed stress profiles and accurate reservoir description as key components of a GeoMechanical Model. Orientated Perforation strategies are suggested to address different and complex issues; multiple fractures, near-wellbore tortuosity, maximum proppant concentration, vertical coverage, natural fractures, tortuosity and erosional effects, with subsequent impact on improved reservoir performance and well deliverability. Net pressure matches and geomechanical data indicate that effective oriented fracturing stimulation treatments can be implemented where others have failed or unacceptable production changes occurred.

The technique can be selectively applied to: 1) **A** "smart completion" approach can be implemented; zone determination. design and placement of perforations are based on detailed geomechanical description. 2) Perforations are placed were they are needed the most based on input from the geomechanical model, fully accounting for the formation mechanical properties, 3) Methods to obtain principle stresses to determine optimum phasing with the preferred fracture plane, 4) More efficient placement of fracture stimulation treatments optimizing fracture geometry and treatment volumes.

Based on a detailed geomechanical model an effective perforation strategy can be implemented to ensure vertical coverage and proper placement of hydraulic fractures. The advantage of such approach reflects in the improved efficiency of the perforating/fracturing strategies, minimization of treatment failures, treatment design/redesign and the significant impact on production optimization. Recommendations for strategic placement of perforations (density and phasing) and the mechanics for fracture initiation from vertical, deviated and horizontal wellbores are also discussed.

AN INTEGRATED METHODOLOGY

The perforating for fracturing methodology discussed in this work uses the results of building a GeoMechanical model to place the set of perforations where they are needed the most; oriented along the Preferred Fracture Plane (PFP) and accounting for stress contrasts, variable pressure effects, fracture initiation mechanics and optimum production-development strategy. The improved completions methodology and criteria for perforating/fracturing is based on systematic and enhanced geomechanical reservoir characterization as discussed by Manrique et.al.[1,2] and Kordziel et.al.[3] as part of an integrated methodology for stimulation treatment optimization.

As demonstrated by field and production results, the improved efficiency of the perforating/fracturing strategies minimizes treatment failures and has significant impact on treatment implementation and production enhancement strategies. This technique has proven to be especially applicable in tectonically stressed areas with high fracture gradients ($\tilde{N}_g > 1$ psi/ft.) where placement is a problem, and in situations where near-wellbore complexities, excessive friction pressure losses (tortuosity, pinch points, misalignment, multiple competing fractures) and premature screen-outs need to be addressed.

Oriented perforating helps to minimize or even eliminate these situations, allowing for more aggressive fracture treatments (higher proppant concentrations and/or larger proppant sizes), higher sand concentrations (improve conductivity), reduce the shear placed on the fracturing fluid, less damaging fluids, etc.

Oriented Perforating/Fracturing

During placement of a hydraulic fracture, the fracture takes the path of least resistance or Preferred Fracture Plane (PFP). The reservoir state of stress is defined by the maximum (s_H) and minimum (s,) horizontal stress. The PFP lies in the direction of maximum horizontal stress **(Figure 1).** When perforations are misaligned with respect to the PFP, hydraulic fracturing requirements often result in increased near-wellbore complexity (tortuosity, friction pressure). **Fig. 1** illustrates the various possibilities of fracture initiation when perforations are aligned and when they are not. In such cases, multiple competing fractures (possibly continuing far-field), microannulus pathways (creating pinch points), fracture initiation at the tip or base, or both, of the perforations or combination of these scenarios may lead to near-wellbore proppant bridging, premature screenout and incomplete fracture placement. Various operational remedial techniques are implemented to overcome these near-wellbore challenges such as proppant slugs, higher viscosity fluids (more damaging), higher rates and minimal gun phasing.

By having all perforations aligned along the same PFP the number of holes directly open to the fracture are increased-optimized **(Figure 1).** Near-wellbore complexities are minimized and energy is now focused on optimal placement and fracture geometry rather than on proppant transport through the near-wellbore region. In cases where perforations are misaligned with respect to the PFP, energy is dissipated and wasted dealing with increased friction pressures, creating fractures that may result in asymmetric fractures, multiple competing fractures, fractures with not enough conductivity and pinch out points.

In almost all cases, higher treatment pressures are required to deal with friction pressure losses and near-wellbore tortuosity, which calls for remedial techniques such as sand slugs and even reperforating. However, production response is usually reduced due to limited effective fracture length, conductivity, stress on proppant and field evidence of conductivity degradation.

Geo-Mechanical Model & Fracture Modeling

Reservoir description, stress profiles, stress distribution, preferred fracture plane, fracture orientation as well as elastomechanical data and interpretation may suggest important changes in perforation strategy and fracture procedures to improve vertical coverage and ensure proper fracture placement. The integrated approach for oriented perforating/ fracturing relies on the determination of the stress profile, stress magnitude/contrast between layers.

The GeoMechanical model uses reservoir and rock mechanics data (elastomechanical properties) for the layered model: Young's modulus, stress profile and stress contrast, Poisson's ratio, ***k, f***, fluid saturations, toughness, gross, net and leakoff thickness for zones above and below the pay zone to determine fracture propagation, growth and geometry. Pore pressure is an important factor affecting the stress state and distribution as to account depletion and over-pressured effects. Because of its flexibility many optimization scenarios can be created to fine-tune the optimum design and create perforating and fracturing strategies.

Figure 2 illustrates the potential stress distribution within a defined zone of interest. Each scenario posses a different completion alternative that needs to be integrated with the field development strategy. Since different stress profiles may be present different perforation/fracturing approaches may be applicable; a) Linear stress behavior - Fracture treatment will tend to grow upward. **A** point source approach placed at the bottom of the zone may be applicable, b) In the case of a depleted zone the treatment will tend to grow into the depleted zone - it will act as a sump for any fracture treatment. Fracture design and placement need to take this into consideration c) competent stress barriers will favor treatment containment provided that enough stress contrast is present between low and high stresses - point source blanket perforation within the interval may be used variable stress profile; d) intercalated high and low stress zones - a selective perforation approach may follow

PFP Determination

Orientation of the preferred fracture plane (PFP) can be determined with:

- Crossed Dipole Shear Sonic Imager Tool; for Shear speed anisotropy determination
- Fullbore Formation MicroImager Tool; to Visualize drilling induced fractures
- Ultrasonic Borehole Imager Tool; to Visualize breakout

The effective use of the Dipole Sonic Imager (Cross-Dipole), measures Compressional and Shear needed to provide accurate in-situ stress measurements, establish local stress direction and to calculate elastomechanical properties. In-situ stress profile measurements will provide dynamic and static in-situ measurements ***(E, n)***. These data is required for fracture design, post treatment evaluation and optimization and determination of the PFP orientation.

The Crossed Dipole Shear Sonic Imager Tool, can be used to detect shear speed anisotropy and measure elastomechanical properties. This shear speed anisotropy is often a result of differences in the horizontal stress directions (s_{max}/s_{min}).

The Fullbore Formation MicroImager tool provides a circumferential electrical image of the wellbore and offers quantitative information for the analysis of fractures. This tool is used to visualize drilling induced fractures and wellbore breakout and the orientation of these anomalies.

Figure 3 illustrates the capabilities of the Formation MicroImager tool at showing both wellbore breakout and drilling induced fractures. Wellbore breakout is shown on the upper portion of the image and drilling induced fractures are on the lower portion. Drilling induced fractures normally occur while the drilling the hole overbalanced and are usually in the maximum horizontal stress direction (PFP). Wellbore breakout occurs when the stress concentrations near the borehole wall exceed the strength of the rock. When this occurs, small pieces of rock are broken off and the wellbore is elongated in the minimum stress direction. The PFP is 90° from the direction of wellbore breakout.

The Ultrasonic Borehole Imager Tool provides a circumferential acoustical image of the wellbore and can be run in open hole and in oil-based mud. This tool can be used to characterize borehole deformations such as breakout and induced fractures (Figure 4).

Fracture Modeling

Numerical modeling and fracture design was done using Schlumberger's in-house fracturing simulator FracCADE. The P3D and Multilayered fracture model is a finite difference model that rigorously solves the fundamental rock mechanics equations using a 3-D poroelasticity model that includes 2-D flow within the fracture. The model allows seamless integration of log data with zoning capability that permits sensitivity and multiple optimization runs. Because the FracCADE deals with a layered system a GeoMechanical model that describes the reservoir system is created based on the log information. Near wellbore effects are considered: perforation friction, deviation tortuosity, and phasing misalignment.

Multlayered Fracturing module simulates the instantaneous initiation and extension of multiple hydraulic fractures in multiple layers. This option integrates a single fracture model with a set of constraints that couples the behaviors of the individual fractures. This can be used to investigate proppant bridging and premature fluid dehydration can be investigated for each layer. Proppant and fluid fronts as well as perforation friction are tracked and calculated for each layer, allowing the analysis of the limited entry design.

Fracture Width / Proppant Concentration

One of the main advantages of implementing an oriented perforating/fracturing strategy is that it allows focusing the fracture initiation pressure and energy to create a hydraulic fracture into generation of the fracture width necessary to create a good proppant pack that guarantees the hydraulic communication between the reservoir-fracture-wellbore.

Normally the largest width is present at the wellbore, where the proppant achieves enough critical velocity to erode the formation, relieving the stress load (and pressure) in the near wellbore area, that weakens as the proppant laden fluid keeps eroding the rock until reaching a maximum threshold.

Such a threshold, limits the fracture growth at the wellbore. The extent of this growth is determined by a combination of shot density, perforation diameter, erosion effects, cement compressive strength, near wellbore stress and the plastic condition of the rock given by the measurement of its deformation (E and n). If a clear path does not develop (i.e., not enough width) then the narrow fracture conduit will be restricted and would not have enough clearance for the sand laden fluid to flow within the fracture. The friction pressure losses will increase as well as the net pressure. Proppant will bridge and a sand bank will develop forcing premature slurry dehydration (a screen-out in the making).

Figure 5 (Behrmann[4]) shows the relation between the dimensionless perforation/proppant diameter and channel width/ average proppant diameter vs. sand concentration, to investigate the effects of fracture width restrictions due to increase on proppant concentration. The experimental data corresponds to measured results for water and polymer based fluid with a viscosity of 100 cp.

It is interesting to note the agreement between field evidence and experimental results. As suggested in Fig. 5, a proppant laden tluid is injected into the fracture and sand concentration increases, a threshold for critical sand concentration around **4** ppa defines a bridging region (screenout zone). Once the threshold is reached it appears that sand concentration effects are minimal, since the channel is well developed and there are less chances for a screenout within the bridging region (bridging parameter is around 2.5 and **3)**

Although the experiment does not take into consideration the presence of natural fractures or severe leakoff, but suggests which mechanism is most affecting the premature screenouts in natural fractures. Once the high concentrations hit the very narrow channels of the natural fissures we are in the bridging region.

Natural Fractured

SystemsWhen natural fractures are present and shooting phased perforations, those perforating tunnels that are not aligned with the PFP and will steal the energy (net pressure) necessary to create a fracture (with enough width), will generate high friction pressures (tortuosity), will drink fluid faster and will tend to screen out easily. In this case sand placement and conductivity become issues. In addition it and will not generate an effective fracture length that will contribute significantly to production as compared to those aligned with the PFP. Thus having all perforations aligned will minimize these effects.One may argue that in a natural fractured system you will have multiple denditric fractures (more like fissures) initiating at the oriented perforations. These fractures cannot propagate independently in multiple directions but will eventually propagate along or turn into the direction of the PFP and are likely to coalesce in the reservoir due to the effects of the **far** field stress. Many of these fissures will dehydrate prematurely and will bridge out as the proppant stages hit them, thus the ones we propagate will preferentially be oriented along the PFP.

It has been our experience that when dealing with the naturally fractured or fissured system, the GeoMechanical model (DSI/FMI) allows to determine the location, fracture aperture, frequency and density of the fracture system. With the main objective being the connectivity, the design incorporates this information and provisions are made in the fracture fluid and fracture design to account for increased or pressure dependent leakoff and the amount of confinement from formations adjacent to target zone.

Misalignment and Dipping Beds

Wellbore misalignment and dipping beds generate a unique near wellbore stress condition that forces changes in fracture geometry and direction as they propagate from the near wellbore to the far field stress regimes (Figure 6). The relatively high net pressures observed in some cases may be associated with complex geology, additional local tectonics and near wellbore stresses. This may result in high breakdown pressures due to abnormal near wellbore stress conditions, difficult fracture designs and optimization, premature screenouts and asymmetric fracture wings. In this case an alternative would be to use a high performance or extreme overbalance perforation (EOBP) to achieve deeper penetration and maximum reservoir contact. High shot density with 120°-60° phasing, will reduce tortuosity effects and enhance hydraulic communication between well and reservoir. However, is in this situation that oriented fracturing will minimize friction pressures and develop enhanced fracture conductivity.

In addition, further characterization of the dipping beds is needed and the use of advanced formation evaluation logs to determine the effect of formation dip and faulting on fracture azimuth. It is also recommended to perform a calibration and step rate test prior to the main treatment. With this information a decision can be made regarding friction pressures in general.

WIRELINE ORIENTED PERFORATING TOOL (WOPT)

The WOPT assembly in Figure **7,** is used to orient the wireline conveyed perforating guns in 5° increments. An essential component in the tool string is the specialized wireline swivel. The swivel provides complete independence between the wireline cable and the tool string. This minimizes the detrimental effects any cable torque would have on the natural lie of the tool string in the wellbore.

In near vertical wellbores (<5° deviation), at least two runs are required to complete the operation. The first run is performed to find the natural lie of the string in the wellbore and includes the gyro. Weighted spring positioning devices (WSPD), located above and below the gun, help rotate the string to the low side of the hole. The second run, without the gyro, is the perforating run. The gyro run may not be required in wellbores with deviations greater than 5° in the zone to be perforated if reliable open hole directional survey data is available.

During the gyro run, the deviation and relative bearing are recorded with the Wireline Perforating Inclinometer Tool (WPIT). The WPIT also has a casing collar locator (CCL) included in the tool. The gyro is used to determine the azimuth of the tool string, i.e., the direction the tool face (high side) is pointing with respect to true North. The gyro also provides an independent reading of relative bearing and deviation. Once the azimuth is determined, the guns can be indexed around to point in the desired perforating direction. This is done manually at the surface by using the indexing adapters located above and below the gun as shown in the schematic at the right.

On the perforating run, the gyro is removed from the gyro carrier because it would be damaged by the perforating shock. The WPIT remains in the tool string and is used to confirm the string's orientation (repeatability) prior to shooting the gun. Repeatability of the relative bearing data on the second run verifies that the tool string's azimuth has not changed and that the guns are in the desired orientation. The WOPT tool has an orienting accuracy that places perforations as close as ± 3" from the PFP. Surveys run after perforating indicate this technology consistently places perforations within ± 10" of the desired perforating azimuth.

The WOPT tool assembly orients the wireline-conveyed perforating guns in 5° increments. An essential component in the tool string is the wireline swivel, which provides complete independence between the wireline cable and the tool string to minimize detrimental effects of cable torque.

ORIENTED FRACTURING FIELD EXAMPLES

Oriented perforating utilizes 180° phasing in the direction of the maximum horizontal stress (PFP) to ideally create a single, bi-wing fracture. Such an approach allows for larger proppant sizes and/or higher proppant concentrations, thus resulting in a more aggressive stimulation, a better proppant pack, larger conductivity and less chance of premature screenout. Also, by reducing the near wellbore tortuosity, lower viscosity fluids can more effectively place proppant compared to conventional perforating techniques.

California Diatomite – The following generic example illustrates the benefit of oriented fracturing. The targeted formations are the Upper Brown Shale and Diatomite. Wells were fractured with the Fiber Assisted Transport (FAT) fluid. The log suite included data necessary to construct a GeoMechanical model to determine the stress profile and PFP orientation (~N55° E to N65° E); PEx/CMR/DSI/GPIT and RFT were run to optimize fracture design.

Wellbore deviations ranged from 0.20-1.5 degrees. A total of seven stages were fractured (oriented) between the two wells. The well was successfully perforated with as little as 0.4° deviation. The Oriented Perforating deviation record is 0.1° . Multiple intervals were perforated and fractured. On site interpretation and real time analysis indicate that the lowest zone (Upper Brown Shale) treated at reduced pressures (1600 psi less). Diatomite Stages also treated at 1500 psi less than previous wells.

Near wellbore pressure differences ranging from 150 to 500 psi as compared to offset wells. In all cases it was observed a reduction in friction pressures of 50% on average and as high as 87%. Treatment pressures were reduced by as much as 31% (15% on average) (Fig 8). Real-time data suggested minimal to no near-wellbore pressure losses on any of the proppant stages, during the fracture treatment. Post-fractured well test indicated a Xf– 600 feet, matching the FracCADE design.

Granite Wash Formation - This Oriented Fracturing treatment was performed in the Granite Wash formation of the Panhandle of Texas. The fracture treatment optimization began with interpretation of a Crossed Dipole Shear Sonic Imager and a Formation MicroImager for determination of the horizontal stress orientation. Elastomechanical properties were computed as input for the fracture design.

Drilling induced fractures were clearly observed throughout the zones of interest as shown in Fig 9. The PFP orientation was determined to be N85° E – S85° W. Perforation scheme was a 2 SPF with 180° phasing. Wellbore deviation ranged between 1.5° and 2" . An UltraSonic Imaging tool used for both cement evaluation and casing inspection was run to verify the location and orientation of the perforations. Results indicate that the perforations were accurately placed in the desired orientation with the PFP.

A post-fracture well test indicated that the fracture half-length was 600 feet, matching the FracCADE design, the economic sensitivity analysis and the post-treatment pressure transient analysis (Fig. 9). Real-time data acquisition during the fracture treatment indicated that minimal near-wellbore pressure losses were encountered on the initial stepdown test, and that no near-wellbore pressure increases were encountered on any of the proppant stages.

Table 1 illustrates the results and applicability of oriented fracturing in several wells and different types of formations. In all cases near-wellbore complications were reduced (tortuosity, pinch points and multiple competing fractures). In general as a direct result of the oriented fracturing, we have observed a reduction or elimination of near wellbore friction reflected in DPnet of 200 to 600 psi and an increase in amount of proppant placed ranging from 25% to 200 % and a production increase of 30% to 500% as compared to offset wells and preferred completion practices.

CONCLUSIONS

- Oriented fracturing helps to minimize or even eliminate near wellbore pressure losses, allowing for higher proppant concentrations and/or larger proppant sizes, higher sand concentrations for improved conductivity and higher production response.
- When perforations are misaligned with respect to the PFP, energy is dissipated and wasted dealing with increased friction pressures, creating fractures that may result in asymmetric fractures, multiple competing fractures, fractures with not enough conductivity and pinch out points. Thus, by having all perforations aligned along the same PFP and directly open to the fracture the energy is now focused on optimal placement and fracture geometry rather than on proppant transport through the near-wellbore region.
- The use of a GeoMechanical model allows for integration of reservoir and rock mechanics data (elastomechanical properties), stress profile, fracture orientation determination, PTA. With this information in mind, Oriented perforat ing design is made with fracture treatment in mind
- The integrated approach provides flexibility to investigate many optimization scenarios can be created to fine-tune the optimum design and create perforating and fracturing strategies. In particular, orientation along the PFP.
- Oriented fracturing along the preferred fracture plane (PFP) results in
- Fracture optimization: reduction of near-wellbore complexities (tortuosity) minimization of multiple competing fractures. Resulting in lower treatment pressures, reduced friction losses, Minimized **risk** of premature screenouts
- Treatment Optimization: Good Proppant pack: higher proppant concentrations, larger proppant sizes, larger Conduc tivity and increased production results

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2. Manrique,J.F., Bjornen,K. and Economides-Ehlig,C..; "Systematic Methodology for Effective Perforation and Fracturing Strategies," SPE 38630, presented at the 1997 ATCE, San Antonio, Texas, 5–8 October 1997.
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4. L.A. Behrmann, "Perforating Requirements for Fracture Stimulation," internal presentation, Schlumberger Perforat ing & Testing Center, Feb. 20, 1997.

Table 1 – Summary of Oriented Fracturing Treatments

								Propped Fracture				
Well #	Completion Option	Perforating	Proppant	Formation ft	P_{r} Psi	Frac Grad psi/ft	Comments	xf ft	w	hf	FCD	Conductivity
Well # 1 - Brown Shale / Diatomite												
Many wells (10+), Multiple Stages (3+)	Point Source/Limited Entry	4 to 8 spf / 45° to 60° / 0.22" to 0.32"	25,000+ lbs; 20/40 Jordan	2000 - 3000	2500 - 3000		Guar: 30#-35#	114.84	0.157 in	93.8 ft	41.9 - 52	2917 - 4300 md-ft
1 well, 3 Stages	**Oriented Perforating/Fracturing**	**4spf / 180° / 0.4"**	130,000 - 300,000+ lbs; 20/40 Jordan	1700 - 3000	1000 - 1500	0.65 - 0.72	Low Guar 25#	986.4 - 1901	0.12 to 0.23 in	1401 - 310	35.0 - 35	2853 - 3500 md-ft
Well # 2 - Morrow Formation												
Many wells (10+)	Traditional Completion - Limited Entry	4spf / 45 - 60° / 0.32"	25,000 - 40,000 lbs; 20/40 CarboLITE	11909 - 11850	4800	0.68 - 0.7	WF240 70Q FOAM / q_{gas} ~ 1.5mmcfd @ 500 psi	516	0.15	76	1.5	773
2 Stages	**Oriented Perforating/Fracturing**	**6spf / 180° / 0.32"/Underbalanced**	50,000 - 80,000 lbs; 20/40 CarboLITE	12290 - 12300	3800	0.62 - 0.65	WF240 70Q FOAM / q_{gas} ~ 3.0+ mmcfd @ 1200 psi	271	0.332	305	1.5	414
Well # 3 - Rockies/Tight Gas Sands												
	Traditional Completion - Limited Entry				8000	0	From qgas~0.0 MMSCFD to qgas~0.1+ MMSCFD	400.3	0.103	390.5		736
	Traditional Completion - Limited Entry				7800	2.8	From qgas~2.5 MMSCFD to qgas~4.5+ MMSCFD	286.6	0.261	183.4		1579
	Oriented Perforating/Fracturing	**6spf / 180° / 0.32"/Underbalanced**			7800	6.8	From qgas~1.0 MMSCFD to qgas~3.5+ MMSCFD	97	0.134	132.8		1105
Well # 4 - North Sea	Skin Frac / Oriented Perforating/Fracturing	**6spf / 180° / 3 3/8" PowerFlow Underbalanced**	45,000 lbs; 20/40 RC LWP	12,500+	8000	0.87	Borate System 40#, HTD, Pressure ~ 10,000+ psi From qoil~150 BOPD, to qoil~3000+ BOPD, 34% WC	306	0.1	180	1	800
Well # 5 - Tight Oil Sand / California												
Many wells (10+)	Traditional Completion - Blanket/Selective	4 to 8 spf / 60° to 90° / 0.32" to 0.5"	0 lbs; 20/40 Ottawa	6000 - 8800	Screenout	0.7 to 1.2						
5 wells	**Oriented Perforating/Fracturing**	**4spf / 180° / 0.4"**	**300,000+ lbs; 20/40 Ottawa**	6200 - 8800	~5500							
Well # 6 - Tight Oil Sand / California												
10 wells	Traditional Completion - Limited Entry	4 spf / 90° / 0.4" to 0.5"	0 - 20,000 lbs; 20/40 Ottawa	6600 - 7800	6600+/Screenout	0.75+						
5 wells	**Oriented Perforating/Fracturing**	**4spf / 180° / 0.38"-0.4"-0.5"**	**170,000 - 275,000+ lbs 40/70-20/40 Ottawa**	**6400 - 6800**	**5400 - 7000**	0.6 to 0.72						
Well # 7 - Lobo Fm / South Texas												
Many wells (10+)	Traditional Completion - Limited Entry	4 to 8 spf / 45° to 90° / 0.22" to 0.32"	300,000+ lbs; 20/40 Jordan	**9300 - 9600**	**9000+/Screenout**	0.75 - 0.95		200 - 250	0.05 - 0.1	100 - 150		< 20
1 Stage	**Oriented Perforating/Fracturing**	**4spf / 180° / 0.4"**	**202000 lbs; 20/40 Econoprop 50000 lbs; 20/40 SHS**	9500 - 9550	8163	0.846	YF330HT w/10# J553 High tortuosity completely eliminated	300	0.055	100 - 150		Target Enhanced Conductivity
Well # 8 - Granite Wash Fm / Mid-Continent												
	Traditional Completion - Limited Entry											
	Oriented Perforating/Fracturing	**4spf / 180° / 0.32"**	114800 - 20/40 Jordan	13060 - 13150	3557	0.544 - 0.575	2.5% & 0.5% ClearFRAC	305	0.024 - 0.1	125	11 to 45	1080 - 2045
Well # 9 - Atoka Fm / Mid-Continent												
	Traditional Completion - Limited Entry				5508 psi							
	Oriented Perforating/Fracturing	**4spf / 180° / 0.38"**	92250 - 20/40 Ottawa	7800 - 8000	6891 psi	0.7 - 0.72	50Q YF125 - Energized Low Gel 25# High wellbore deviation ~ 28°	460.0 ft	0.104 in 0.051 in	312.4 ft	2.4	286
Well # 10 - Moken Sand; Gas Reservoirs												
	Oriented Perforating/Fracturing	**4spf / 180° / 0.32"/Clustered Perfs**	55290 - 20/40 Econoprop	11200 - 11250	4060 - 5000	0.68 - 0.75	YF340LPH 65Q FOAM	q_{gas} = 2.0 MMCFD (FTP 1300#)				
	Traditional Completion - Limited Entry	4 spf / 90° / 0.35"	15,000 - 20/40 sand		11,100 8000+ / Screenout			q_{gas} = 600 MCFD (FTP 700#)				
Well # 11 - Gething Fm. / Canada												
	Oriented Perforating/Fracturing	**4spf / 180° / 0.32" - 0.42"**	43933 - 20/40 Jordan	7000 - 7200	5270	0.74 - 0.78	Calibrated ClearFRAC Foam ΔP_{net} = 200 - 500 psi less than offset Near-wellbore pressure losses minimized	420	0.241 - 0.84	171	2.2	801

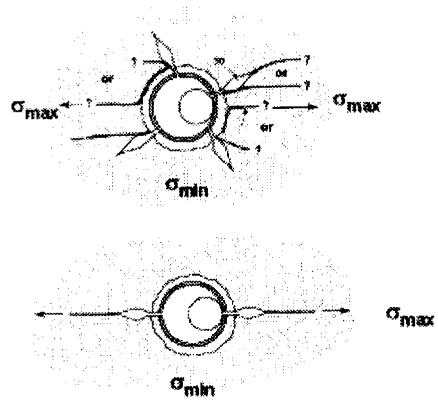

Figure 1 - Perforations Aligned and Misaligned with Respect to the Preferred Fracture Plane

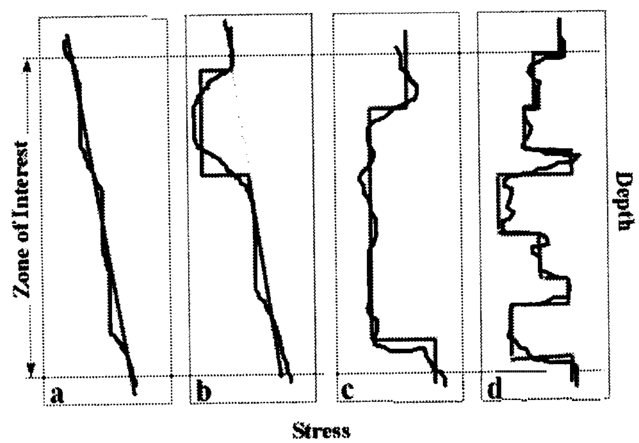

Figure 2 - Potential Stress Distributions within Zone of Interest
After Manrique[2]

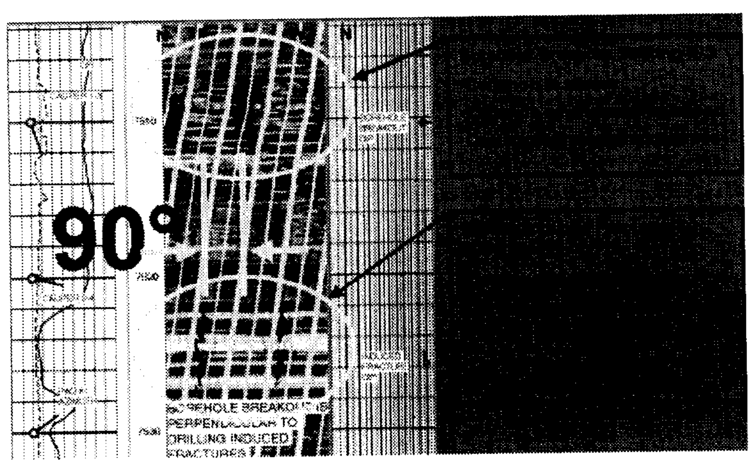

Figure 3 - Wellbore Breakouts and Drilling Induced Fractures Detected by the Fulbore Formation MicroImager Tool
Note: Orientation is about 90".

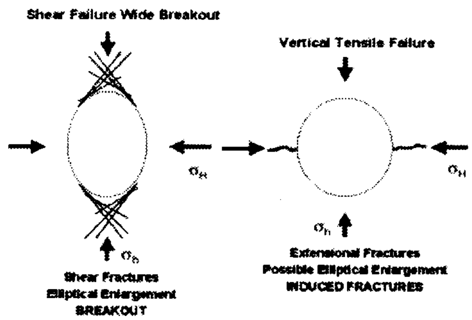

Figure 4 - Borehole Breakouts and Drilling Induced Fractues as a Result of Failure Mode

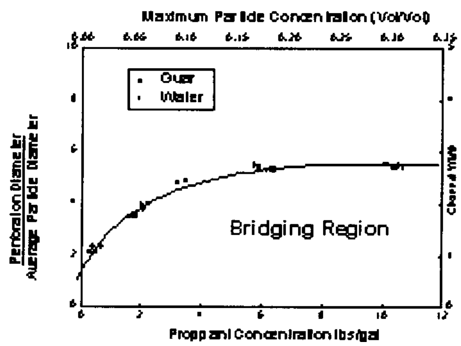

Figure 5 - Bridging of Particles in Perforations
After L. Behrman[4]

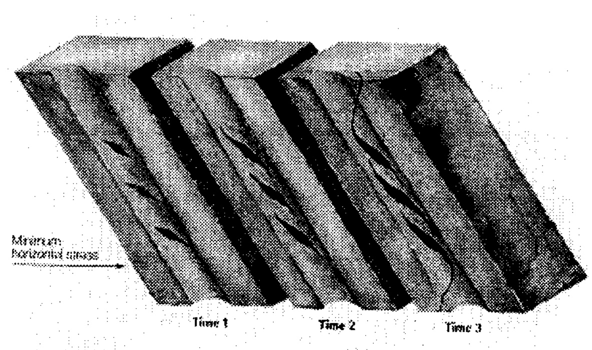

Figure 6 - Fracture Propagation in Dipping Beds

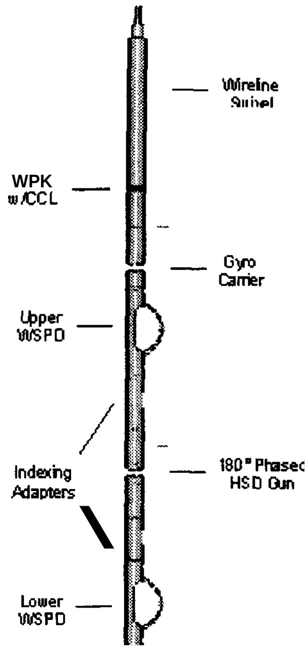

Figure 7 - Wireline Oriented Perforating Tool (WOPT)

Figure *8* – Near Wellbore Pressure Comparisons – Offset Wells and Oriented Fracturing Techniques

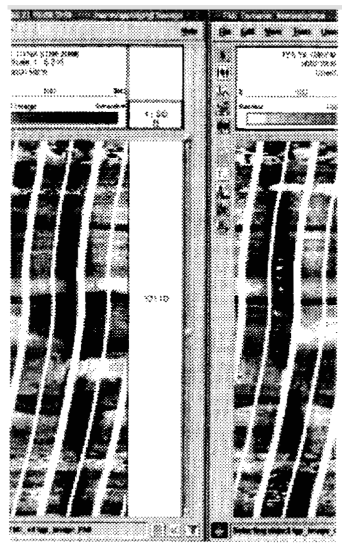

Figure 9 - Drilling Induced Fracture Identification - GeoMechanical Model Application

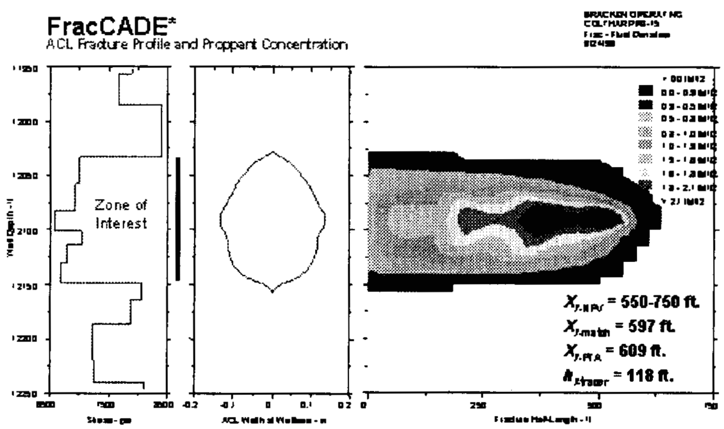

Figure 10 - Pressure Matching Results - Comparison Production Matching, Pressure Matching and PTA Analysis Results