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# Applications of Geomechanics in the Development of the Naturally Fractured Carbonates of the Mara Oeste Field, Venezuela

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## Abstract

A geomechanical study for naturally fractured carbonates was performed as part of an integrated study for the Mara Oeste field in Venezuela. The study included working with one paleomagnetically-oriented core in which natural and induced fractures were identified and oriented. Geomechanical static and dynamic laboratory tests were performed, to obtain strength, deformability and failure characteristics of the rocks. The in situ stress field orientation was determined in one well by using special core techniques such as ASR, DSA, AAA and SWAA. Regional information provided by focal mechanism data available in the Maracaibo basin was integrated together with image logs for eleven wells. Natural fractures and breakouts were studied and fracture orientation and in situ stresses were related with geological structures present in the field. A stress orientation map was built with all the available directional information. In situ stress magnitude was estimated by lost-circulation data, extended leakoff test and back-analysis from breakouts. A three-dimensional stress model of the field was performed using a lagrangian finite difference code. The model showed that stress orientation is dependent on geometry of the layers, and faulting can introduce jumps in stress magnitude. Out from the influence of the main faults the model reproduced the regional trend of stresses. Close to the main fault of Mara Oeste, stress rotation was evident both in depth and spatially, particularly at the crest of the folds. The model provided estimates of in situ stress magnitude that can be used to design new wells in blocks with little information.

## Introduction

The Mara field is located to the northwest of Maracaibo City (**Fig. 1**). The field produces low oil gravity (13° API) from the lower cretaceous carbonates of the Cogollo Group (Maraca, Lisure and Apón Formations). The field consists of two structural blocks separated by a thrust fault (the Mara Oeste fault) with a NE-SW trend, at the western part of the field, and changing to an ENE-SSW trend to the east. The southeastern part of the field is a fault-related fold with axis parallel to the fault. Several NW-SE normal faults dissect the area. Most of the wells (from a total of 17) have been drilled in this part. The northwestern part of the field lies on the footwall of the fault. To the north and northwest, the Cogollo group is totally eroded and the Eocene unconformity is found.

The Cogollo Group produces mainly from interconnected natural fractures, even though the dolomitization processes have enhanced the porosity and permeability at certain zones. Reservoir carbonate rocks are at an average depth of 6000 ft. Wells are completed open hole and are producing by natural flow and electro-submergible pumps.

In naturally fractured oil reservoirs production generally comes from a set of interconnected fractures. Directional borehole drilled to intersect open natural fractures is a common strategy in naturally fractured reservoirs. Also, fractures tend to close as reservoirs are depleted due to increases of effective stresses. It is therefore extremely important to know the magnitude and direction of in-situ stresses, azimuth, dip, spacing and aperture of fractures [1,2].

The determination of stress field is often limited to a few scattered points through the reservoir. But stresses can change spatially and in time. A tool like stress modeling to estimate the stress orientation and magnitude in areas of the field with no geomechanical information was considered necessary. There are problems in geomechanics that can be adequately faced with two-dimensional approximations, such as plane strain and plane stress conditions[3]. However, in the case of studying the stress distribution on a field including geological structures (faults and folds) and different rock layers, the problem is absolutely three-dimensional. For Mara Oeste field, a three-dimensional stress model was developed using a lagrangian finite difference code[4]. The geometry of the field, including rocks layers, faults and folds was discretized and mechanical and physical properties were assigned from laboratory and a calibrated sonic log. Geological and seismic information, core and log information, injectivity tests and focal mechanism data were used to build and calibrate the stress model.

## Core information

Only one core was available for testing, which is named in the paper well X. Detailed physical and geomechanical properties were obtained. The core was paleomagnetically oriented using a technique, which is published elsewhere[5]. Natural and induced fractures were described in the oriented core.

### Strength and deformability parameters

Two sample groups were tested at different depths (5935 ft and 6347 ft) with average porosity (2% and 15%, respectively)[6]. Coulomb criterion and Mohr´s circles at failure are plotted in **Fig**. **2** for these samples. Testing was developed with conventional procedures and tolerances published by the ISRM (International Society of Rock Mechanics). Different loading paths were followed to determine a) hydrostatic compressibility and Biot´s poroelastic coefficient; b) unconfined compression; and c) triaxial compression including dynamic measurements of acoustic velocities at different stages of the triaxial test. In Table 1, mechanical and deformability properties of the core are summarized.

### Natural and induced fractures observed in a paleomegnetically-oriented core of well X

The paleomagnetically oriented natural fractures observed in the core of well X, form a bimodal pattern[7] (**Fig. 3)**. Set 1 fractures probably originated as a conjugate set of shear fractures (or "hybrid/shear" fractures[8]) with a dihedral angle near 20 ° and opposite senses of dip. Sets 1a and Set 1b appear to alternate with depth. All fractures in Set 1a are open and exhibit an average strike of 144° while only 30 % of fractures in Set 1b are open and the average strike is 124°. Set 2 of fractures probably originated as an orthogonal set of extension fractures. Set 2a exhibit an average strike on N8°E. Open fractures Set 2a are striking more southerly, while healed fractures strike toward S20 W. There is a remarkably simple angular relationship with the nearby Mara Oeste and Oca faults: Set 1 fractures are perpendicular to the Mara Oeste Fault and Set 2 fractures are perpendicular to the Oca fault (**Fig. 4**).

Well X cores presented 4 fractures that probably represent coring-or drilling-induced fractures. It is generally thought that induced fractures strike parallel to present-day $\sigma_{Hmax}$[9]. As indicated in **Fig. 4** the induced fractures exhibit a preferred strike of 125°. The consistent SE trend of the 4 induced fractures suggests that the principal horizontal stress components are anisotropic and that the present-day $\sigma_{Hmax}$ may strike about 125°.

It is known that open natural fractures generally strike less than 45° from present-day $\sigma_{Hmax}$ and closed natural fractures generally strike more than 45° from $\sigma_{Hmax}$. On this basis, from open fractures determined in the core (**Fig. 4**) one "might" predict that present-day $\sigma_{Hmax}$ at well X location in Mara Oeste field is near 140° azimuth. A strike of 140° + 45°=185° divides open Set 2a fractures from closed set 2a fractures, and Set 1a fractures striking 144° can expected to be more open than Set 1b striking 124°, as is certainly seen in the cores.

A NW/SE present-day $\sigma_{Hmax}$ is geologically reasonable because the structural dip of the fold is toward 135°. Also, it is understand that folds in the region deform Miocene rocks, and hence the $\sigma_{Hmax}$ direction may have been NW/SE since at least the Miocene.

### In situ stresses from core testing at well X

The in situ stress orientation at well X was also determined by using techniques as Anelastic Strain recovery (ASR), Differential Strain Analysis (DSA), Acoustic Anisotropy Analysis (AAA) and Shear Wave Acoustic Anisotropy (SWAA) in cores of well X. Detailed description of the procedures of these techniques can be found in the literature[10]. A summary of directional information of the stress field nearby well X is presented in **Fig. 5,** showing the minimum horizontal or sub-horizontal, principal stress. Data points include measurements of DSA, ASR, AAA, SWAA and natural and induced fractures found in the core. The strongest trend for $\sigma_{hmin}$ is to the northeast. A weaker, secondary north – south trend is also evidenced, possibly reflecting a paleo-stress condition.

## Field and log data

2D seismic information was available in the field, which provided at some extent geometry of layers of interest, structural dip and fault shape. Structural maps for formation tops were available.

Recent focal mechanism studies in the western part of Venezuela[11] showed that for regions near Mara Oeste field, the regional trend of maximum in situ stress (compression) is oriented towards a NW-SE trend. Of course, this data corresponds to information from earthquakes occurring at about 40,000 ft deep but are still useful to show the regional trends.

### Image logs

Image data from 11 wells was analyzed and fractures observed were classified into open, partially open and closed fractures. The main trend of open fractures in the field is again NW/SE, although there is an ENE-SSW important trend present (**Fig. 6**). It is illustrated in **Fig. 7** that the ENE-SSW correspond to wells close to the crest of the fold and for wells located to the flanks, the striking trend is NW/SE. Partially open fractures present wider scatter. Partially open fractures might provide better ultimate hydrocarbon recovery because the partial mineralization can act as a natural proppant, keeping the fracture open during depletion.

**Breakouts**

Well-developed breakouts were detected in some of the wells in the field (**Fig. 8**). Breakouts are referred to extensively in the literature[12,13,14] and are considered directional localized failure at the borehole wall that can indicate the orientation of stresses causing such failure of the rock.

Breakouts well X, confirmed the information revealed by induced and natural fractures regarding orientation of in situ stresses.

Based on all the information available from core and image logs trends of in situ stress orientation were plotted over the structural map (top of Apón Formation) as illustrated in **Fig. 9**.

## In situ stress magnitude

The vertical in situ stress component was estimated by integrating several density logs from wells in the field. The resulting stress gradient was in average 1.02 psi/ft, which is a typical value for reservoir rocks. To estimate the minimum in situ stress magnitude, $\sigma_{hmin}$, a lost circulation data was used. Also an extended Leakoff test was available for well X, but unfortunately for upper layers, out of the formations of interest.

To use lost circulation data it is needed to determine whether the lost circulation is related to the presence of open natural fractures or if an involuntary hydraulic fracturing has occurred. In the former case, the mud weight will be close to the reservoir pressure. The mud weight corresponding to zones with closed fractures can be used to estimate $\sigma_{hmin.}$ For several wells it was possible to check in the image log, if there were open or closed natural fractures at the depth in which the lost circulation was reported. A $\sigma_{hmin}$ of 0.59-0.6 psi/ft was estimated. The extended leakoff available in well X at the 13 3/8" casing shoe was analyzes and the resulting closure pressure was 0.76 psi/ft. Even though this value is not representative of the producing zones, it is used as a bound of $\sigma_{hmin.}$

The maximum horizontal stress was estimated by back-analyses. Using tensile failure and elasticity to determine stress concentration around the borehole the breakdown pressure, $P_b$, of the formation is[10]:

$$P_b = 3\sigma_{Hmax} - \sigma_{hmin} - P_p + T_{o\,,} \qquad \text{Eq.(1)}$$

where $T_o$ is the tensile strength of the rock and $P_p$ is the reservoir pressure, then $\sigma_{Hmax}$ can be solved.

To perform a back analysis of a breakout considering shear failure at the borehole wall, a semi-analytical stress code[15] using Mohr-Columb failure criterion was used. This program determines the elastic stresses around the borehole and compare with the failure criterion. The values for were changed until a failure was predicted for the depth at which the brakout was observed. Rock strength and deformability properties were taken from core information, and the corresponding mud weight was used well pressure. Parameters used for the calculation and the results obtained are shown in Tables 2 and 3.

## 3-D stress modeling of the field

The stress model used is a commercial three-dimensional explicit finite-difference program based on a lagrangian calculation scheme. It has been design for engineering mechanics computations and especially for geomechanics and geothechnical engineering. Details of the program can be found in the literature[4].

The area used for the model is presented is squared in **Fig. 10-a,** which is the top of Apón Formation. Coordinate axis are shown (z is vertical and y-axis is oriented with a NW/SE trend of 140°). The area was discretized considering rock layers with the corresponding geometry; the main Mara Oeste thrust fault and dissecting normal faults were reproduced by linear segments and dips reflected by the 2D seismic. A number of 4500 quadrilateral elements and 5745 nodes were used. Elastic rock properties used in the model are presented in Table 3. Only rock properties from the lab were available for Apón formation, so the rest of the parameters were estimated with help of the calibrated sonic log available for Well X[16]. Fault properties were unknown, very few discontinuity properties are available in the literature[17,18]. High stiffness in comparison with surrounding materials was considered, preserving occurrence of shear under loading. An estimate to the discontinuity normal and shear stiffness can be estimated as 10 times the apparent stiffness of the surrounding rocks, given by[4]:

$$k_n = \max\left[(K+4/3\ G)/\Delta z\min\right] \qquad \text{Eq.(2)}$$

A friction angle of 30° was assumed with zero dilatancy and no tensile strength.

To decrease the size of the three-dimensional mesh depth range between 2950 and 11800 ft were modeled and overburden was imposed as a vertical load. Modeling followed two stages: a) Reach model equilibrium under self weight-of the rocks and pore pressure gradient. Lateral displacements in lateral nodes were restricted; base node displacements were completely restricted. This condition what is called geostatic stress conditions; b) Lateral nodes were freed and stresses were imposed at in x and y directions. These directions are coincident with regional principal in situ stresses, as has been discussed earlier. Magnitudes of $\sigma_x$ and $\sigma_y$ applied at the boundaries were increased in several stages until values estimated for minimum stresses at Well X were matched within 10 %. Effective stresses calculated by the model are presented in plane view (for Apón Formation) and a transverse section in **Fig. 10-b** and **10-c**.

The model showed that stress orientation is dependent on geometry of the layers, and faulting can introduce jumps in stress magnitude. Out from the influence of the main faults the model reproduced the regional trend of stresses. Close to the main fault of Mara Oeste, stress rotation was evident both in depth and spatially, particularly at the crest of the folds and near the fault plane.

In this modeling stress path actually followed by the rock during geological history is ignored and uncertainties over parameters and geometry of structures is still high. However, the model provided estimates of in situ stress magnitude that can be used to design new wells in blocks in which little stress information is available. For better estimates, more measurements of stress magnitude and better structural definition by 3D seismic is recommended.

## Conclusions and recommendations

- A detailed study of geomechanical properties was developed for a core in Mara Oeste. Deformability and strength parameters were obtained for two ranges of porosity.
- Natural fractures of a palleomagnetically oriented core presented two sets of natural fractures with trends NW/SE and NNE/SSW. Induced fractures with azimuth of 135° were observed. These trends are consistent with other observed in cretaceous cores studied in the Lake of Maracaibo.
- Present-day $\sigma_{Hmax}$ in the neighborhood of Well X is likely to be NW/SE (around 140°). This is confirmed by breakouts, open natural fractures, results of core testing (ASR, DSA, AAA, SWAA) and geological evidence (focal mechanism and orientation of structural dip of the fold).
- The most frequent orientation of open fractures on the field is NW/SE trend. Partially open fractures showed also this trend but with large scatter. Open fractures in wells near the crest of the fold strike parallel to the fold (trend ENE/SSW approximately). Wells far from the fault and crest of the fold maintain the regional tendency NW/SE.
- Breakouts were observed in several wells in the field. All the data gathered lead to a orientation stress map for the field.
- Stress magnitudes were estimated from density logs, lost circulation and leakoff data. Back-analyses studies were performed to obtain estimates of $\sigma_{Hmax}$. These are only estimates because a micro-frac test is not available for the rocks of interest.
- Once open and partially open fracture orientation and in situ stress field is known it is possible to determine the optimum well trajectory from the productivity point of view and a detailed study of fracture closure due to mechanical stresses and due to flow rate conditions. For example, the optimum trajectory for a deviated well near Well X would be perpendicular to 144° (if designed to maximize intersection with open Set 1a fractures) or perpendicular to 160° (if designed to “bisect” the open Set 1a and open Set 2a fracture patterns).
- Among Grupo Cogollo, the Apón Formation presented greater number of fractures. Apón is the widest Formation, though.
- Modeling results showed that stress orientation is dependent on geometry of the layers, and faulting can introduce jumps in stress magnitude. Out from the influence of the main faults the model reproduced the regional trend of stresses; while close to the main fault of Mara Oeste, stress rotation was evident both in depth and spatially, particularly at the crest of the folds and close to the fault surface.
- The model provides estimates of in situ stresses that can be used to design new wells in blocks with little information.
- Enhancement of structural interpretation of the field is recommended by a 3D seismic study.
- Local fracture density studies are to be made with relation to structural geology and sedimentary units, using geomechanical stress analysis.
- New cores with dynamic-static measurements, sonic logs, image logs and new stress magnitude data will greatly enhance the predictability of the stress model since more calibration points will be available.

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## References

1. Aguilera, R.: “Geologic Aspects of Naturally Fractured Reservoir”,Geologic Column”The leading Edge”, Dec, 1998
2. Nelson, R. “Geologic Analysis of Naturally Fractured Reservoirs”. Gulf Publishing Company, Houston, 1985.
3. Jaeger, J.C., “Fundamentals of Rock Mechanics”, Chapman and Hall, John Wiley & Sons, New York, 1976.
4. Itasca Consulting Group, Inc. FLAC , Fast Lagrangian Analysis of Continua, Versión 3.3, Minneapolis (1997).
5. Van Alstine, D. R., and Gillet, S. L.:”Paleomagnetic Orientation for the Multiwell Experiment: Sierra Geophysics Tech. Rept. SGI-R-82-066, 55pp, available from Sandia National La., 1982.
6. Terratek , Inc.: “Static and Dynamic mechanical properties and insitu direction. Maraven, Well DM-152”. TR98-11. September, (1997).
7. David R. Van Alstine and Joseph E. Butterworth, Feb.1997, “Paleomagnetic Orientation of Fractures & In Situ Stresses in Cogollo (Apon) Cores from well DM-152, Mara Oeste Field”.
8. Fransen, R.C.M.W., Vahrenkamp,V.C.,van de Graaf,W.J.E., and Muñoz,P.J.:”Optimizing field development of deep Cretaceous fractured reservoirs, Lake Maracaibo, Venezuela” SPE paper 23620,p.43-53 (1992)
9. Kulander, B.L., Dean, S.L. and Ward, B.J. , 1990, Fractured Core Analysis: Interpretation , Logging and Use of Natural and Induced Farctures in Core: AAPG Methods in Exploration Series, No. 8, Tulsa, Oklahoma, 88 p.
10. Fjaer, E., Holt, R., Horsrud, P., Risnes, R. “Petroleum Related Rock Mechanics”. Elsevier. (1992).
11. Malave, G., (1996), Sismicidad y tectónica en el Occidente de Venezuela. Mecanismos focales y su correlación con fallas activas, Informe Intevep, INT-03279,96.
12. Bell, J. S. and Gough, D. I., The use of borehole breakouts in the study of crustal stress, in Hydraulic Fracturing Stress measurements, edited by M.D. Zoback and B. C. Haimson, pp. 201-209, National Academy Press, Washington, D.C., 1983.

13. Gough, D. I. and Bell, J. S., Stress orientations from oil well fractures in Alberta and Texas, Can. J. Earth Sci., 18, 1358-1370, 1981.
14. Plumb, R. A. and Cox, J.W., Stress directions in eastern North America determined to 4. Km from borehole elongation measurements, J. Geophys. Res., 92, 4805-4816, 1987.
15. Pbore 3D, User´s Manual Version 2.0 The University of Oklahoma, Rock Mechanics Consortium.
16. VVA Consultores, C.A. ”Estudio Geomecánico del Area MaraOeste: Contribución a un estudio Multidisciplinario. Informe Final Marzo, 1998.
17. Bandis, S.C., Lumsden A.C. and Barton N.R., “Fundamentals of rock Joint deformation”, Int. J. Rock Mech. Min. Sci. & Geomech. Abstr., 20 (6), 249-268, 1983.
18. Kulhawy, F.H., “Stress Deformation Properties of rock and Rock discontinuities”, Eng. Geol., 9, 327-350, 1975.

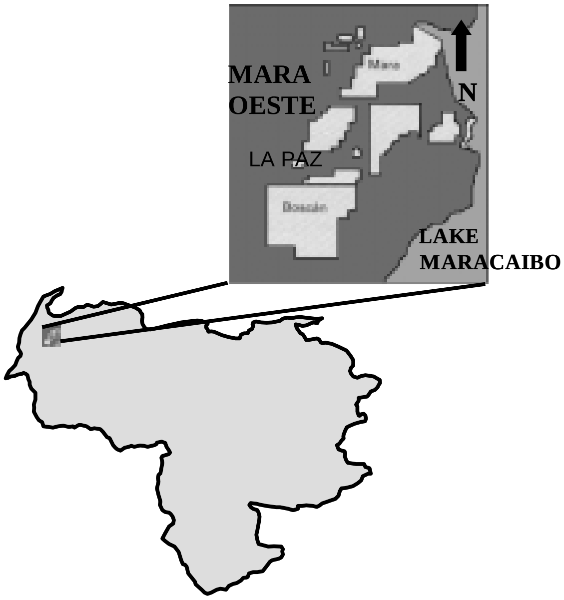


**Fig. 1 Location of Mara Oeste Field**

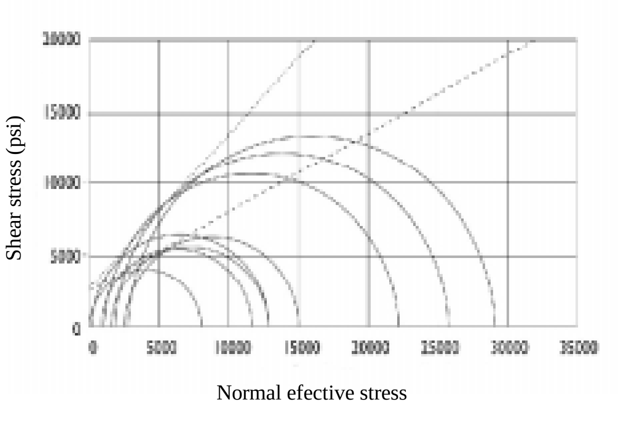


**Fig. 2 Mohr-Coulomb envelope for rocks from Apón formation at depths of 6347´and 5935´. Friction angle: 46.6° and 28.2°, respectively; linear cohesion: 2862 psi and 2544 psi, respectively.**

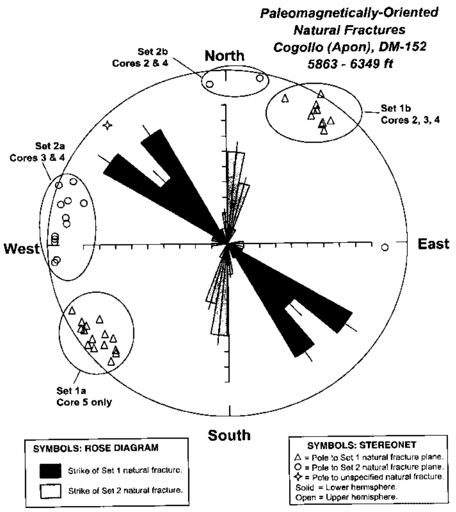


**Fig. 3. Paleomagnetically oriented poles (stereographic projection) and fracture strikes (rose diagram) of 41 natural fractures in Cogollo (Apón) cores from well X in Mara Oeste field.**

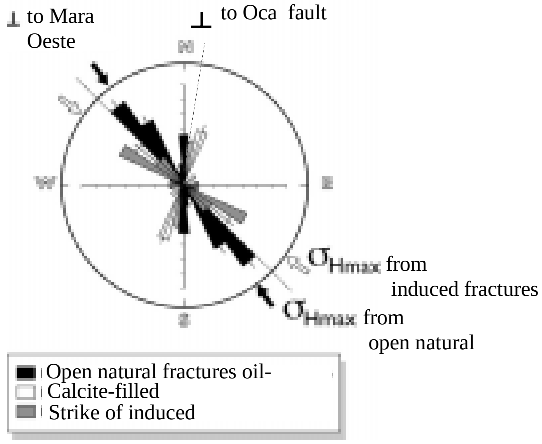


**Fig 4. Natural and induced fractures showing the present day $\sigma_{Hmax}$; also geometrical relationship with nearby faults is shown.**

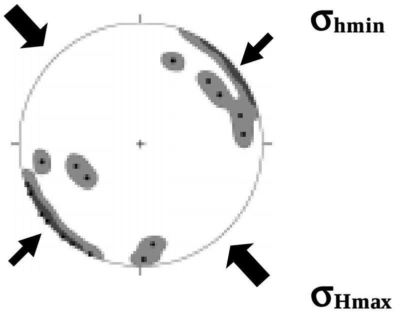
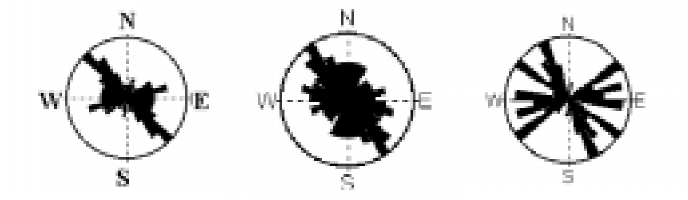
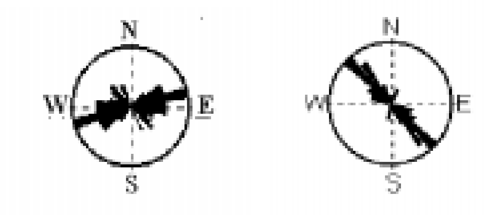


**Fig. 5 Orientation of $\sigma_{hmin}$ from core data (ASR, DSA, AAA, SWAA) and induced fractures in the core.**



**OPEN** **PARTIALLY OPEN** **CLOSED**

**Fig 6. Rose diagrams for natural fractures determined by image logs in 11 wells in the field (open, partially open and closed fractures)**



a) b)

**Fig 7. Structural control over open fractures: a) open natural fractures in wells near the crest of the fault related fold; and b) open fractures located far from the crest (to the flanks of the fold)**

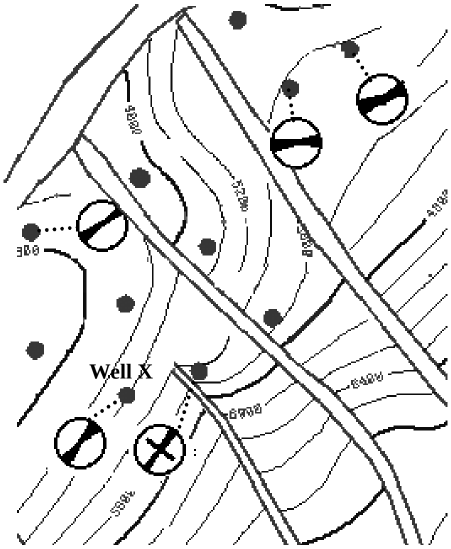


**Fig. 8 Orientation of breakouts observed at image logs for several wells in the area.**

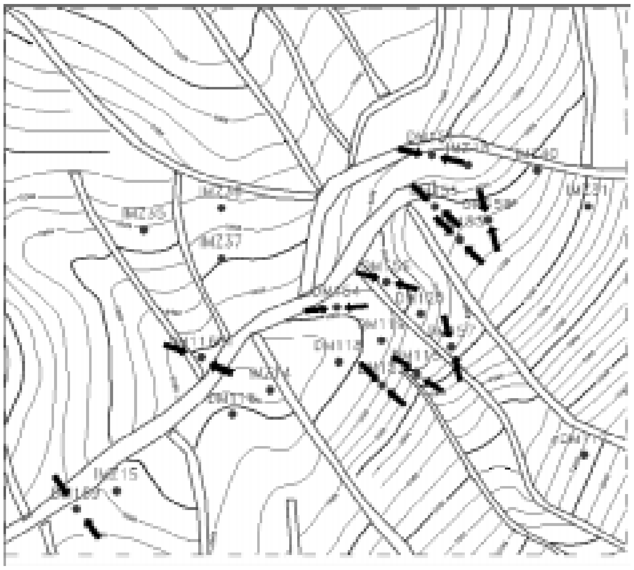


**Fig. 9 In situ stress orientation map built with core and log information.**

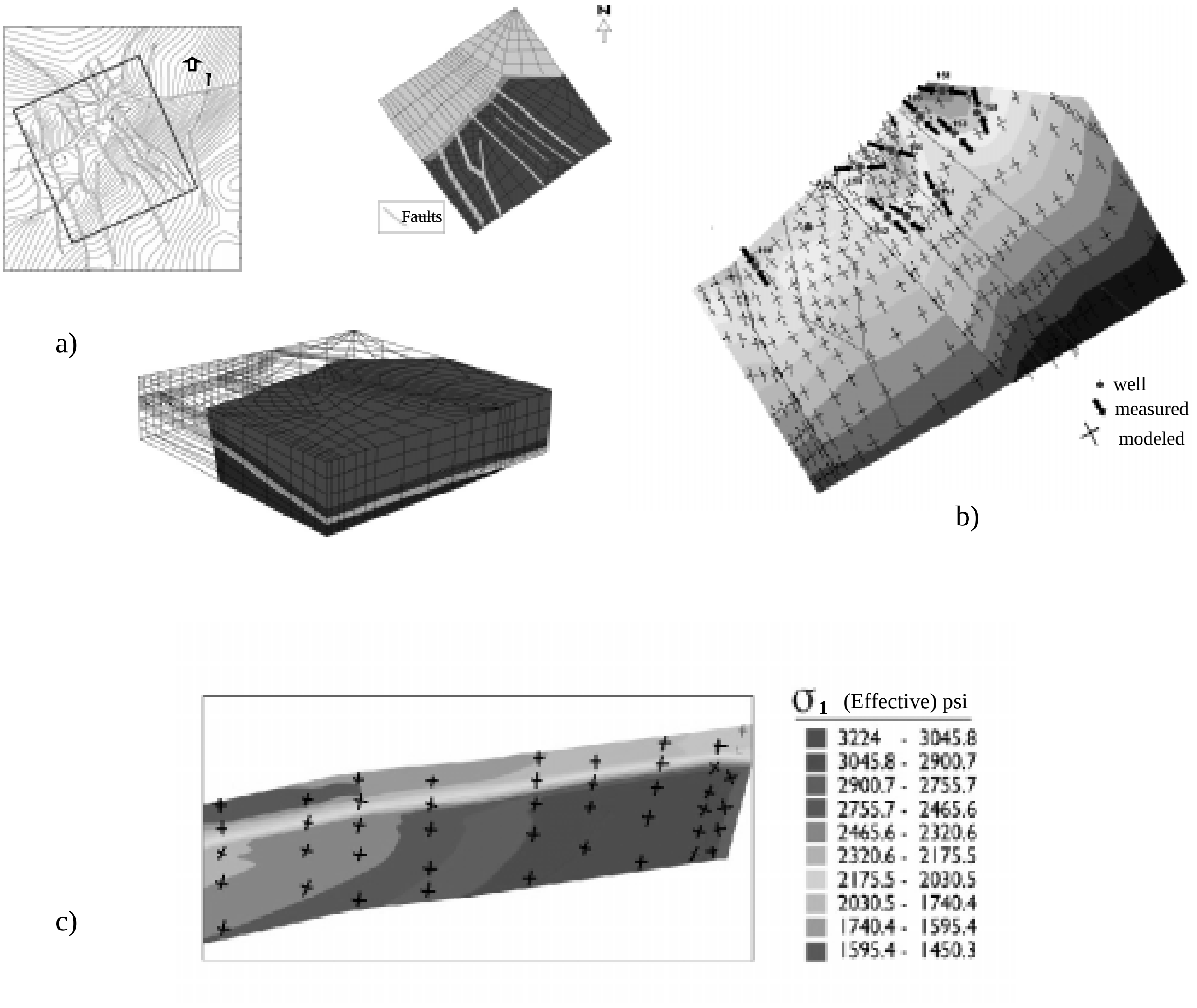


**Fig. 10 a) Structural map for top of Apón Formation showing the area that has been modeled, top and 3D views of the mesh, faults and layers are illustrated; b) Stresses determined for Apón Formation comparison is made between calculated and observed stress orientations; c) Cross section of the area modeled showing stress rotation near the fault plane.**

**Table 1. Static mechanical properties (Well X)**

| **Sample** | **Depth (ft)** | **Confining pressure (psi)** | **Pore press. (psi)** | **Effective compressive strength (psi)** | **Poisson ratio** | **Young´s Mod. ($10^6$ psi)** | **Bulk Mod. ($10^6$ psi)** | **Shear Mod. ($10^6$ psi)** |
|---|---|---|---|---|---|---|---|---|
| Z1-1 | 5935 | 0 | 0 | 7995 | 0.23 | 2.42 | 1.48 | 0.99 |
| Z1-5 | 5935 | 3740 | 2970 | 11555 | 0.28 | 2.96 | 2.28 | 1.15 |
| Z1-6 | 5935 | 4505 | 2970 | 12700 | 0.21 | 2.81 | 1.60 | 1.17 |
| Z1-4 | 5935 | 5400 | 2970 | 14950 | 0.24 | 3.24 | 2.11 | 1.30 |
| Z2-1 | 6347 | 0 | 0 | 12720 | 0.32 | 4.43 | 4.10 | 1.68 |
| Z2-2 | 6347 | 3995 | 3175 | 22025 | 0.21 | 4.89 | 2.79 | 2.02 |
| Z2-3 | 6347 | 4815 | 3175 | 25635 | 0.18 | 5.64 | 2.93 | 2.39 |
| Z2-4 | 6347 | 5775 | 3175 | 29000 | 0.20 | 5.93 | 3.33 | 2.47 |
| Z2-5 | 6347 | 7075 | 3175 | 34780 | 0.22 | 6.71 | 3.96 | 2.75 |

**Table 2. Parameters for Back-analysis of a shear failure with PBore 3D**

| | |
|---|---|
| Depth (ft) z | 6347 |
| Well radius (pies) | 0.35 |
| Young´s Modulus, E (psix$10^6$) | 5.6 |
| Poisson´s ratio | 0.22 |
| Vertical Stress gradient (psi/ft) | 1.02 |
| Minimum horizontal stress gradient (psi/ft) | 0.58-0.6 |
| Pore pressure (psi) $P_p$ | 2200 psi (0.35 psi/pie) |
| Constitutive model | Linear elasticity, impermeable |
| Failure criterion | Mohr-Coulomb |
| Failure parameters | C = 2500 psi $\phi = 25°$ |

**Table 3. Results for in situ stress magnitudes**

| **Source** | $\sigma_{hmin}$ (psi/ft) | $\sigma_{Hmax}$ (psi/ft) |
|---|---|---|
| Tensile Failure X-LOT | 0.6 | 0.91 |
| Tensile failure (Induced fractures during drilling) | - | 0.84 |
| Lost circulation | 0.58 | |
| Shear failure (breakouts) | - | 0.94 |

**Table 4. Elastic properties used for Flac 3D stress modeling**

| Layer (preferred lithology ) | E | | ν | ϕ (o) | c | | G | | K | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (Psi) | (Pa) | | | (Psi) | (Pa) | (psi) | (Pa) | (psi) | (Pa) |
| **Top** (sandstone) | 2.5E06 | 17.2E09 | 0.2 | 30 | 2500 | 1.7E07 | 1.04E06 | 7.16E09 | 1.39E06 | 9.5E09 |
| **Socuy** (sandstone shales) | 2.0E06 | 13.8E09 | 0.3 | 25 | 2800 | 1.9E07 | 0.77E06 | 10.6E09 | 1.76E09 | 11.5E09 |
| **Maraca** (limestone, dolomites) | 5.0E06 | 34.5E09 | 0.23 | 45 | 2862 | 1.98E07 | 2.03E09 | 14.0E09 | 3.08E09 | 21.3E09 |
| **Apon** (Limestone, dolomites) | 5.0E06 | 34.5E09 | 0.23 | 45 | 2862 | 1.98E07 | 2.03E09 | 14.0E09 | 3.08E09 | 21.3E09 |
| **Río Negro** (sandstone, basement) | 6.0E06 | 41.4E9 | 0.15 | 45 | 3000 | 2.07E07 | 2.61E06 | 18.0E09 | 2.86E09 | 19.7E09 |