Fractured Intrusion and Extrusion Reservoirs: Play Concept and Hydrocarbon Potential*

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Abstract

Fractured intrusion and extrusions of tectonic origin form prolific reservoirs with substantial hydrocarbon reserves in many mature basins. Fractured basement reservoirs are commonly thick with irregular porosity and permeability distribution. A proper study of these reservoirs begins by recognizing the stress regimes, diagenesis processes and attributes of the matrix, and fracture networks.

Fields of hydrocarbon production from fractured basement are well known in numerous basins that are generally formed and dominated by convergent stresses of strike slip tectonics and related structures. Strike-slip fault related fractures associated with dissolution porosities formulate the permeability and storage capacity of granitic reservoirs in Bach Ho, Ran Dong, La Paz, Habban, and Bongor oil fields. Extensional tectonics is responsible of creating normal-fault related fractured reservoirs in El Zeit Bay and Augela-Nafoura oil fields. Production from fractured extrusion rocks has been established in West Java basin, Deccan play over west India, and Neuquén basin- South Argentina. Fields of fractured extrusion reservoirs include Jatibarang, Padra, Lumas Las Yeguas, Loma La Lata and Aguada San Roque oil fields.

It has been found that fracture geometry faithfully depicts the stress regime that dominated the fracturing process. The rock facies and ductility control the vertical fracture density and the areal distribution of discrete fracture networks. The vertical density is highly biased by the resolution of measuring tools, well diameter, fracture dip, and the trajectory of boreholes. Since open fractures are mostly vertical, deviated wells drilled normal to fracture planes are likely to intersect more fractured than a vertical one. Defining the areal distribution of discrete fracture network over the field or the reservoir is extremely difficult. Hydrocarbon migration path ways, the entrapment mechanism, and seal vary between basins as the geologic setting differs. Structural bounding faults in hard rocks tend to be open which facilitates hydrothermal solution and overlying aquifers to invade and percolate the fractured reservoirs. Dissolution effect and diagenesis processes tend to alter the permeability of fractures and the productivity of oil fields. When depleted, fractured reservoirs may drain juxtaposed hydrocarbon and water bearing formations. Hydrocarbon resources can be estimated using volumetric calculation at early stages of development. After a certain period

of production, material balance calculation tends to provide more reliable results. This presentation offers insight on integration approaches that applied on fractured reservoirs in fields with distinct structural styles and facies.

References Cited

Anderson, E.M., 1951, The Dynamic of Faulting and Dyke Formation, With Applications to Britain: 2nd edition, Oliver and Boyd, Edinburgh, 206 p.

Adnan, A., Sukowitono, and Supriyannto, 1991, Jatibarang Sub Basin - A Half Graben Model in the Onshore of Northwest Java: Proceedings of the Twentieth Annual Convention, Indonesian Petroleum Association, v. 1, p. 279-297.

Bingian, L., W.Z. Embong, and M.A. Taha, 2012, The Well Trajectory Impact on Hydrocarbon Discovery in Fractured Basement Reservoirs - A Case Study from Cuu-Long Basin, Vietnam, AAPG International Conference and Exhibition, 16-19 September, Singapore.

Bone, G., N.T. Giang, D.N. Quy, V.N. An, D. Pham, J. Sun, and Q. Tang, 2008, Improvements in Seismic Imaging in Fractured Basement, Block 15-1, Offshore Vietnam: Fractured Basement Reservoir: *Petrovietnam Rev*iew, v. 4, p. 63-69.

Cuong, T.X., 2001, Reservoir Characterization of Naturally Fractured and Weathered Basement in Bach Ho Field, Technical Forum 2001.

Cuong, T.X., 2000, Reservoir Characterization of Naturally Fractured and Weathered Basement in Bach Ho field, Vietnam: Master's Thesis, Universitii Brunei Darussalam, Bandar Seri Begawan.

Nelson, R.A., 1985, Geologic Analysis of Naturally Fractured Reservoirs: Gulf Publishing Co., Houston, 320 p.

Noble, R.A., K.H. Pratomo, K. Nugrahanto, A.M. Ibrahim, I. Prasetya, N. Mujahidin, C.H. Wu, and J.V.C. Howes, 1997, Petroleum Systems of Northwest Java, Indonesia, *in* J.V.C. Howes and R.A. Noble (eds.), Proceedings of an International Conference on Petroleum Systems of SE Asia and Australasia: Indonesian Petroleum Association, p. 585-600.

Nurmi, R., and M. Taha, 1988, Fractured Types Detected in Eastern Mediterranean Reservoirs: AAPG International Convention and Exhibition, Nice, France.

Phon, N.V., and N.A. Duc, 2006, Characteristics of Basement Fractured Reservoirs in Cuu Long Basin and Consideration on Modelling: Fractured Basement Reservoir International Conference, Petrovietnam and Vietsovpetro, Vungtau, Vietnam.

Stearns, D.W., 1968, Certain Aspects of Fractures in Naturally Deformed Rocks, *in* R.E. Riecker (ed.), Rock Mechanics Seminar: Terrestrial Sciences Laboratory, Bedford, p. 97-118.

Sruoga, P. and P. Rubinstein, 2007, Processes Controlling Porosity and Permeability in Volcanic Reservoirs from the Austral and Neuquen Basins, Argentina: American Association of Petroleum Geologists Bulletin, v. 91, p. 115-119.

Sylvester, A.G, 1988, Strike-Slip Faults: Geological Society of America Bulletin, v. 100/11, p. 1666-1703.

Tachalenko, J.S., and N.N. Ambroseys, 1970, Structural Analysis of the Dashte Bayaz (Iran) Earthquake Fractures: Geological Society of America Bulletin, v. 81, p. 41-66.

Taha, M, W. Sharif, S. Illias, S. Dawning, and M.T. Sanek, 2009, Hydrocarbon Potential of Strike-Slip Related Fractured Metasediments and Basement Reservoirs, Offshore and Cut Long Basins: Petroleum Geoscience Conference and Exhibition, Kuala Lumpur , Malaysia.

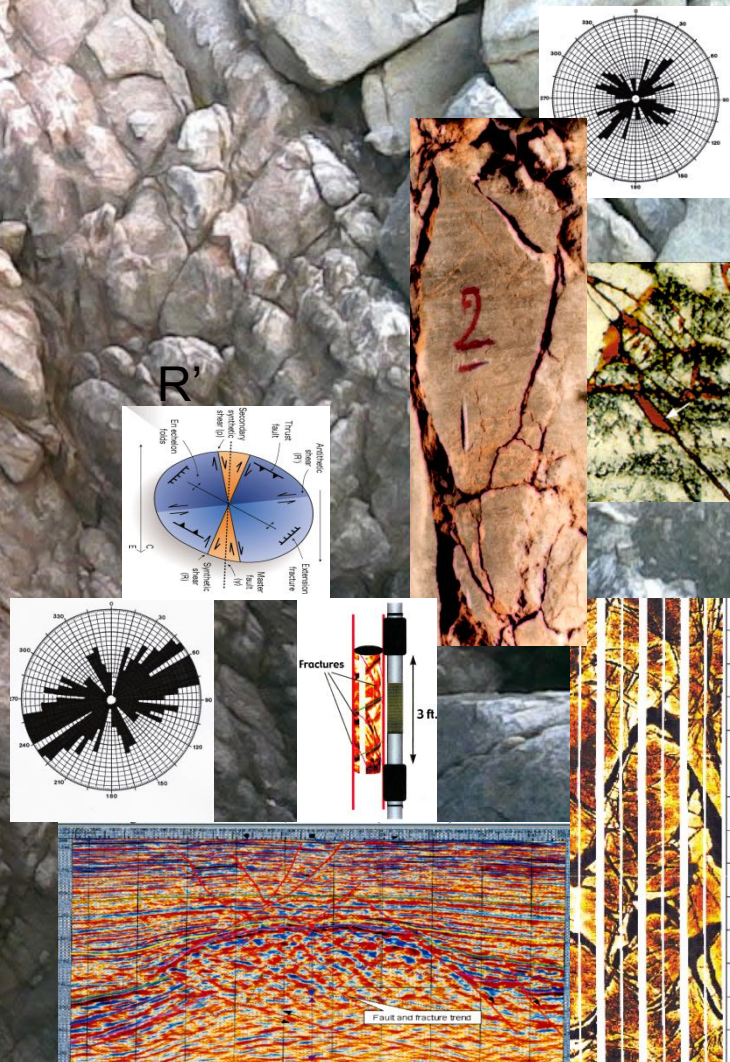
Taha, M., 2001, Characterisation of Fractured Basement Reservoirs; An Integrated Approach, Cuu Long Basin: Exploration- Keys of Success Technical Forum, Ho Chi Minh City, Vietnam.

Wilcox, R.E, T.P. Harding, and D.R. Seely, 1973, Basic Wrench Tectonics: American Association of Petroleum Geologists Bulletin, v. 57, p.74-96.

Witte, J., M. Bonora, C. Carbone, and O. Oncken, 2012, Fracture Evolution in Oil-Producing Sills of the Rio Grande Valley, Northern Neuquen Basin, Argentina: American Association of Petroleum Geologists Bulletin, v. 96/7, 1253-1277.

Zubiri M., and J. Silvestro, 2007, Fracture Modeling in a Dual Porosity Volcaniclastic Reservoir: A Case Study of the Precuyo Group in Cupen Mahuida Field, Neuquén, Argentina: AAPG Annual Convention, Long Beach, California, April 1-4, 2007, Search and Discovery Article #20045 (2007). Website accessed November 2017.

Fractured Intrusions and Extrusion Reservoirs : Play Concept and hydrocarbon Potential



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Common Igneous Rock Types and Log Response

Volcanic or Extrusive	Trachyte	Rhyolites	Dacite	Andesite	Basalt	Limburgite	Dense (Porphyritic)
				Dolerite/ Diabase			
Plutonic or Intrusive	Syenites	Granites Monzonite	Granodiorite	Diorite	Gabbro	Peridotite	Grained

Heavy minerals Content Increases

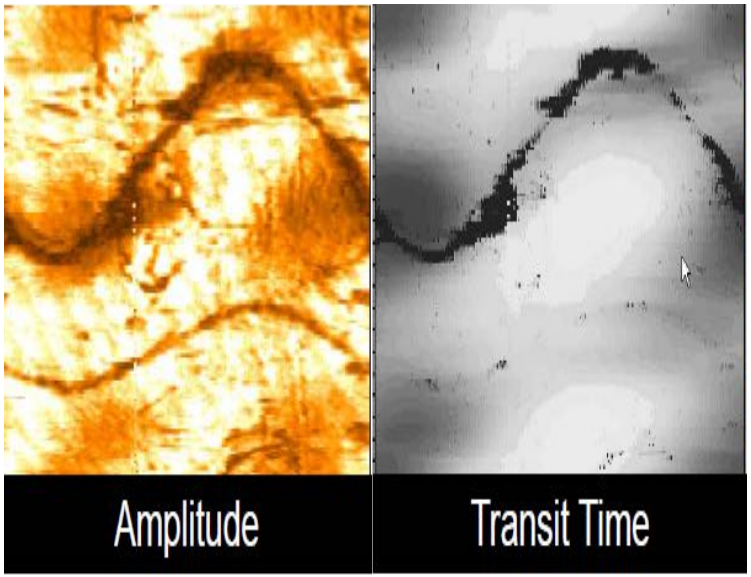
Silica Content Increases

Acidic Basic

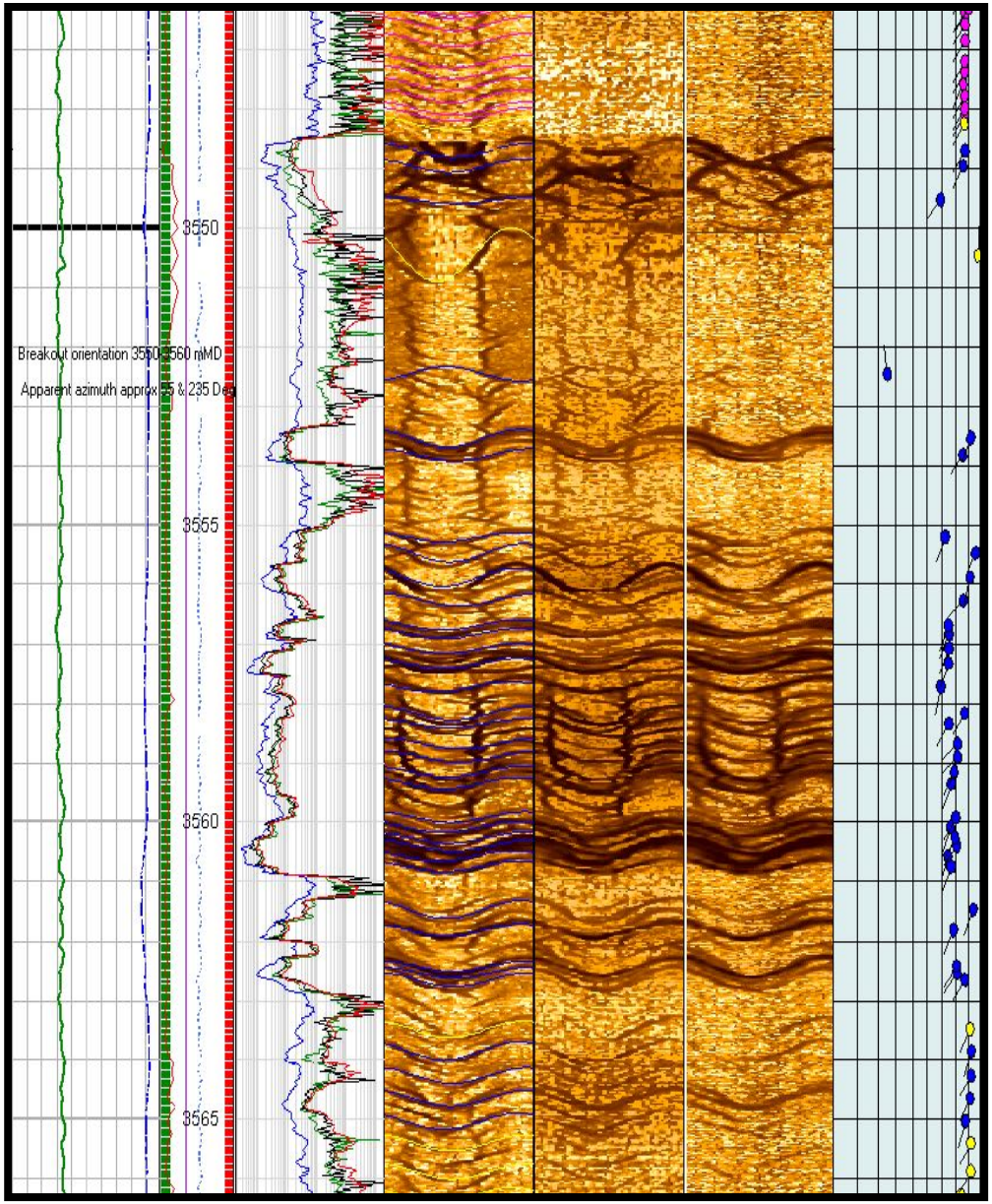
K-Feldspars

GR

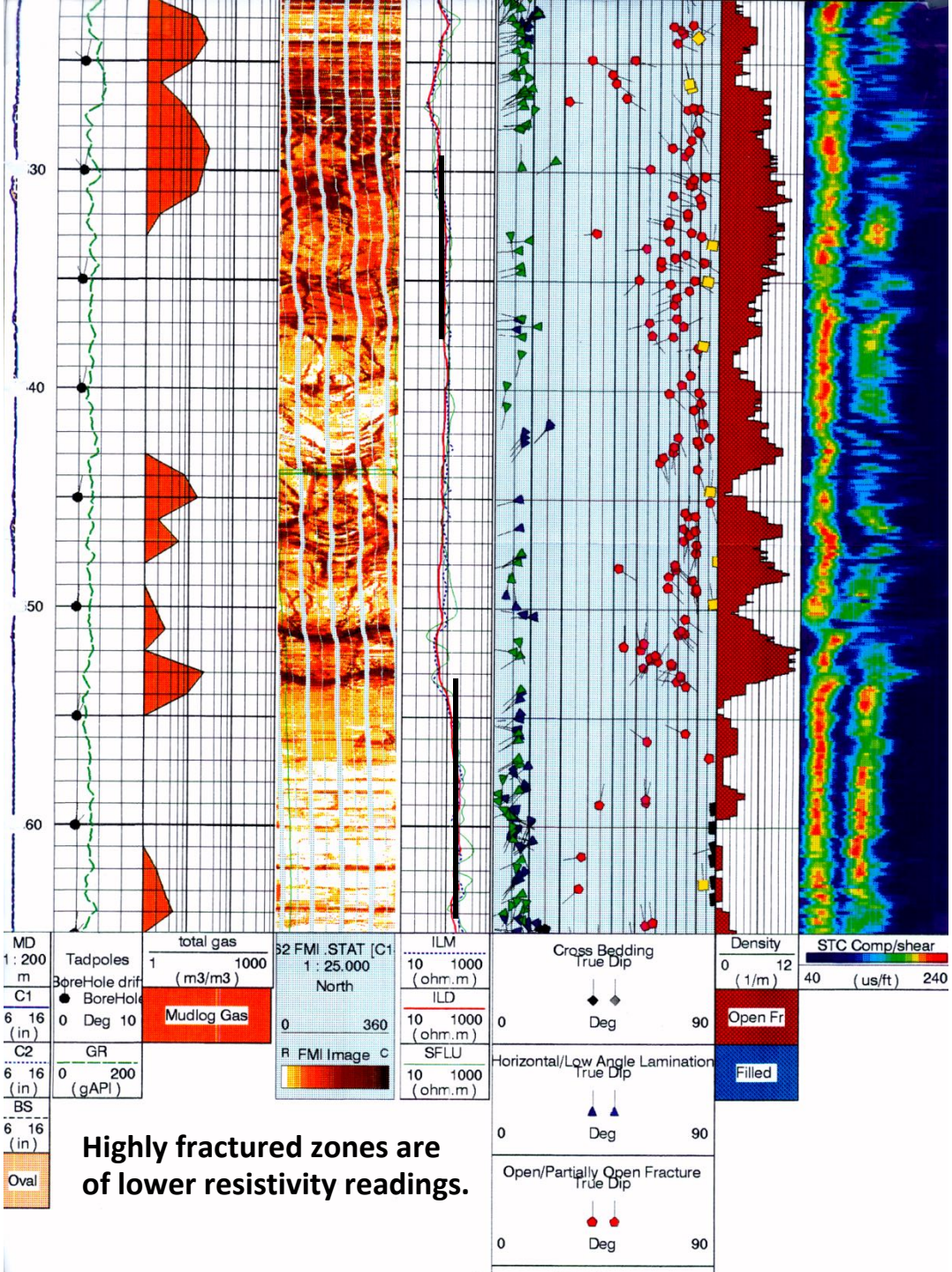
NPHI&RHOB



Fracture detection by Amplitude and Transit time of the Ultrasonic Borehole Imager. All fractures will be detected by amplitude while only open fractures will be recognized by transit time,



GVR Image data over the fractured basement in RRR well

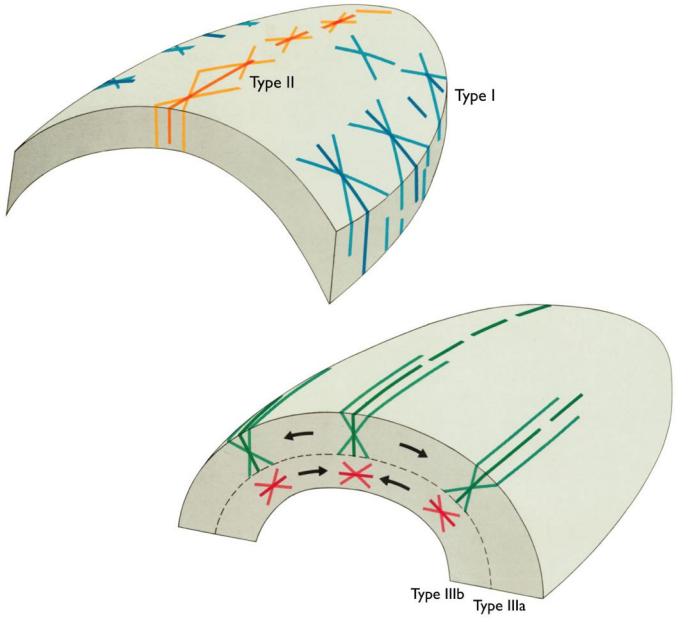


Highly fractured zones are of lower resistivity readings.

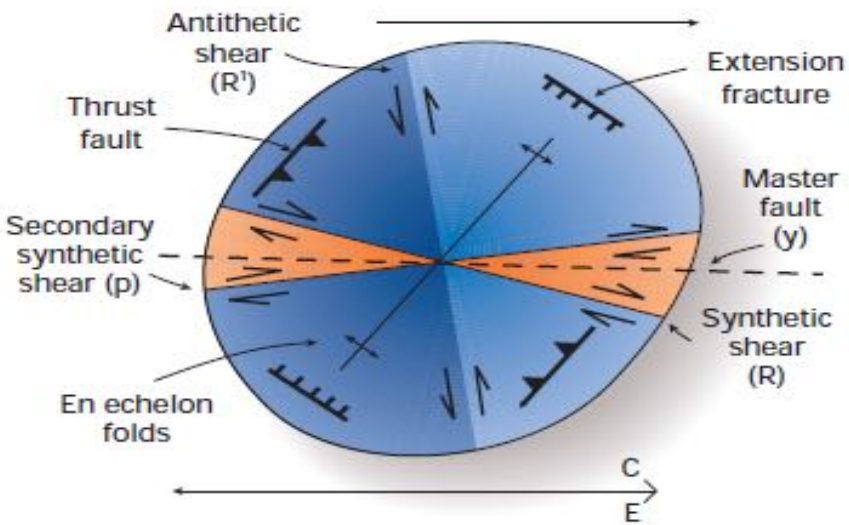
STC (Slowness Time Coherence) employs a full waveform analysis technique to define propagation mode of waveforms that are acquired by the DSI (Dipole Sonic Imager) tool. Red indicates the maximum coherence (Compression arrival) green designate attenuated coherence (Shear arrival) as blue displays mud arrival or Stoneley waveforms.

Compression waveforms are the least affected by fractures as they are capable to propagate in solids and fluids. Shear waveforms tend to be attenuated as they split when crossing open fractures filled with mud/oil or gas.

Taha et al., 1999



Stearn's (1968) Fold-related Fractures



Strike-slip structural elements angular relationship (after Wilcox et al.,1973; Tachalenko & Ambroseys, 1970 ; Sylvester, 1988)

Different Types of Fractures:

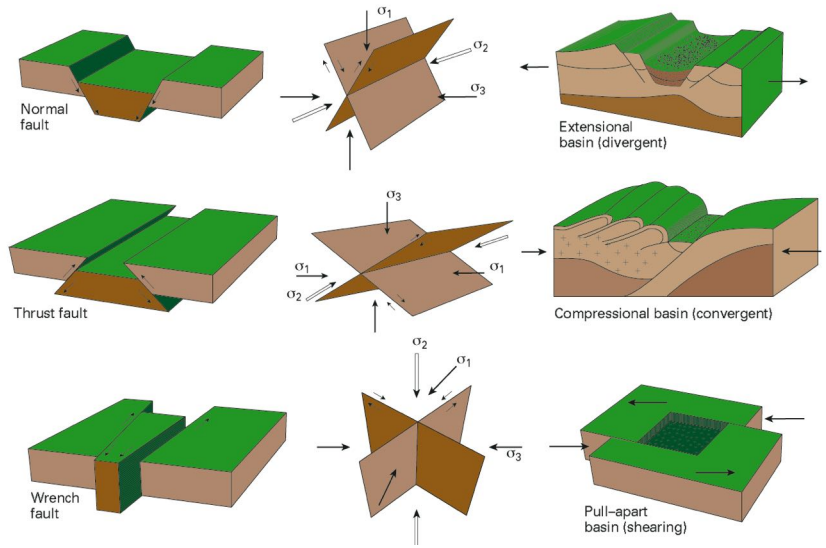
Tectonic Related:

- **Unloading/Sheet fractures**
- **Fold-related fractures**
- **Normal and reverse fault-related fractures**
- **Strike slip/Wrench fault-related fractures**
- **Fault-related fold fractures**

Non-tectonic Related*

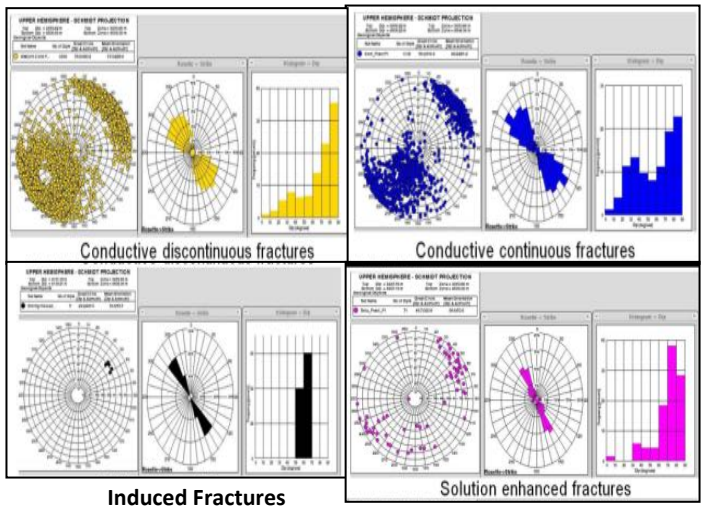
- **Syneresis fractures (volume reduction by subsurface dewatering)**
- **Chicken-wire fractures (mineral phase changes)**
- **Cooling/quenching fractures (contraction of hot rocks as it cools)**
- **Gravity related fractures (roof collapse….)**

*** Modest and/or of limited economic value**



Dynamics of faults (Anderson, 1951)

Fractured Basement in Well A



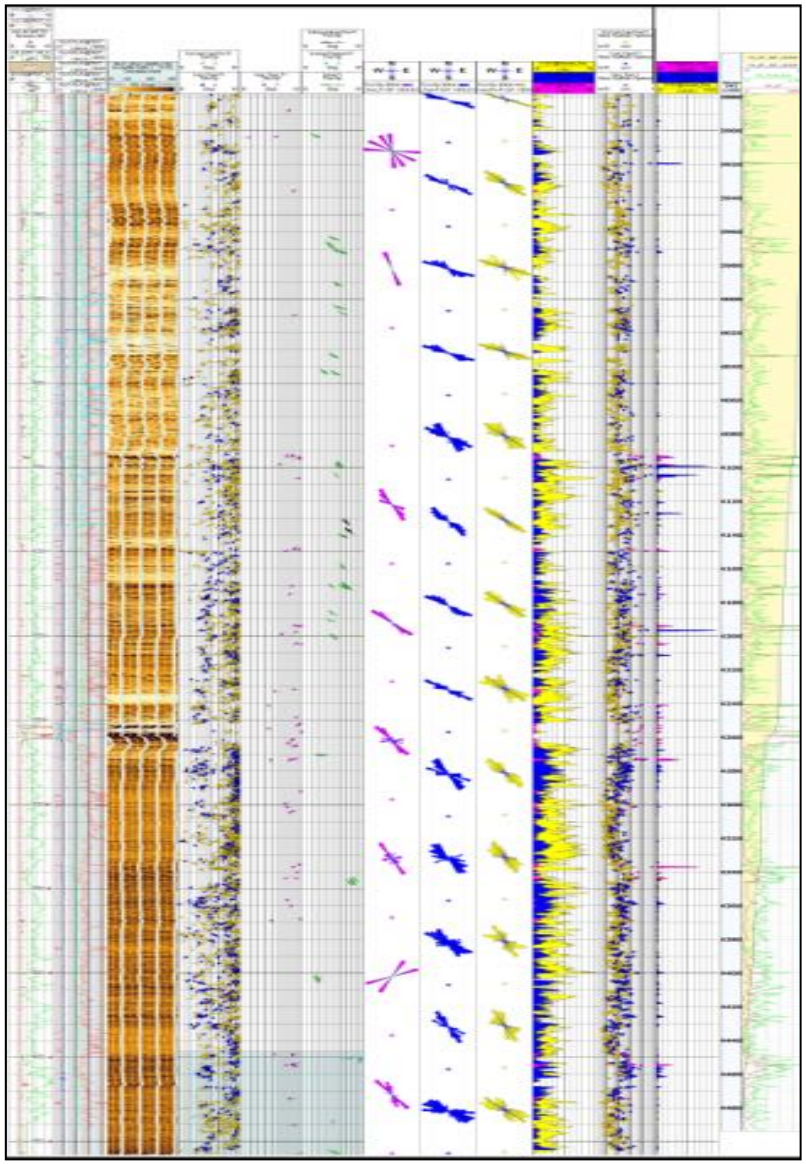
Induced Fractures

Fractures consistently strike NW-SE throughout the penetrated basement section and parallel to the contemporary maximum horizontal stress.

Legend

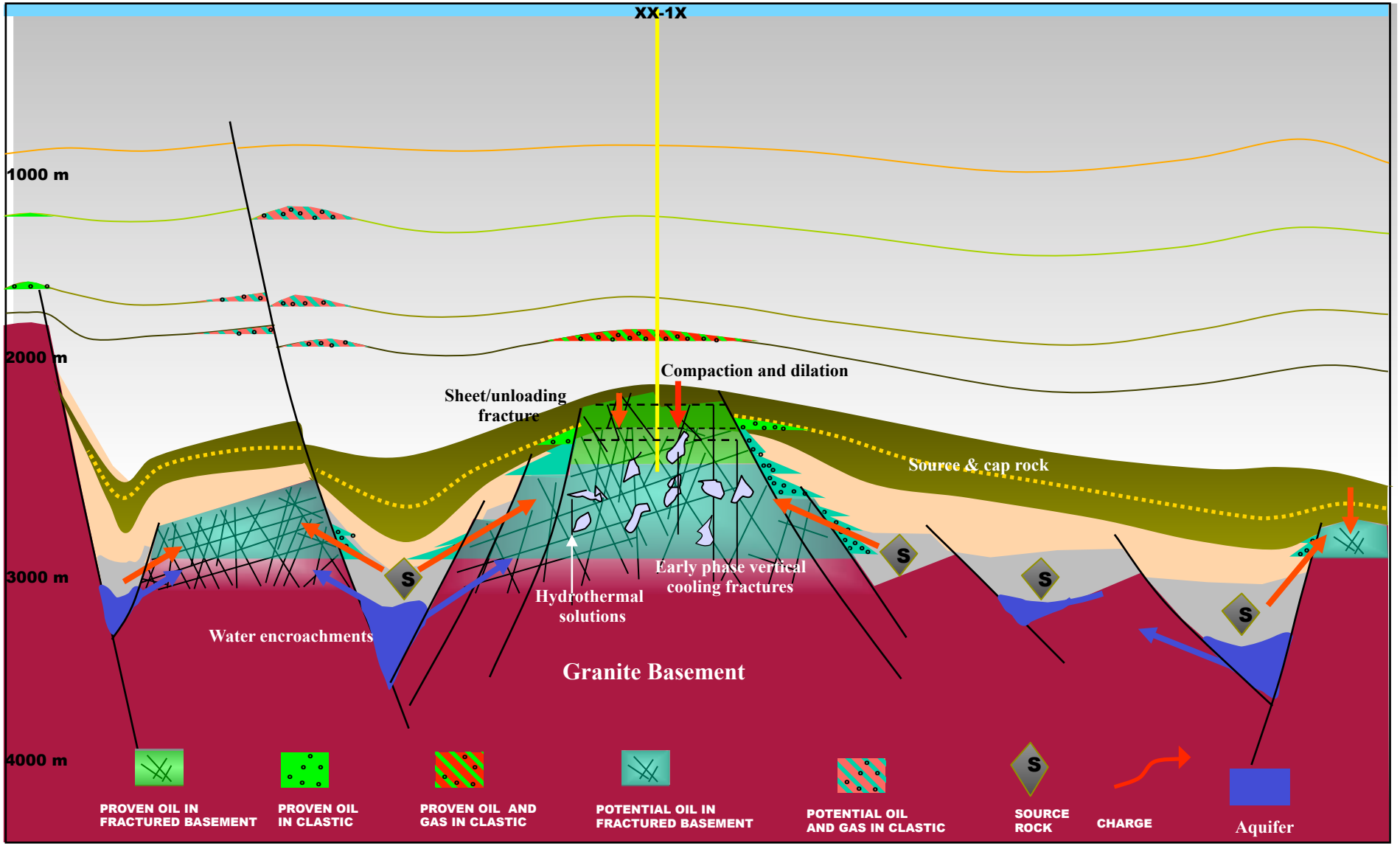
- Conductive continuous fractures
- Solution enhanced fractures
- Discontinuous fractures

FMI data of well A

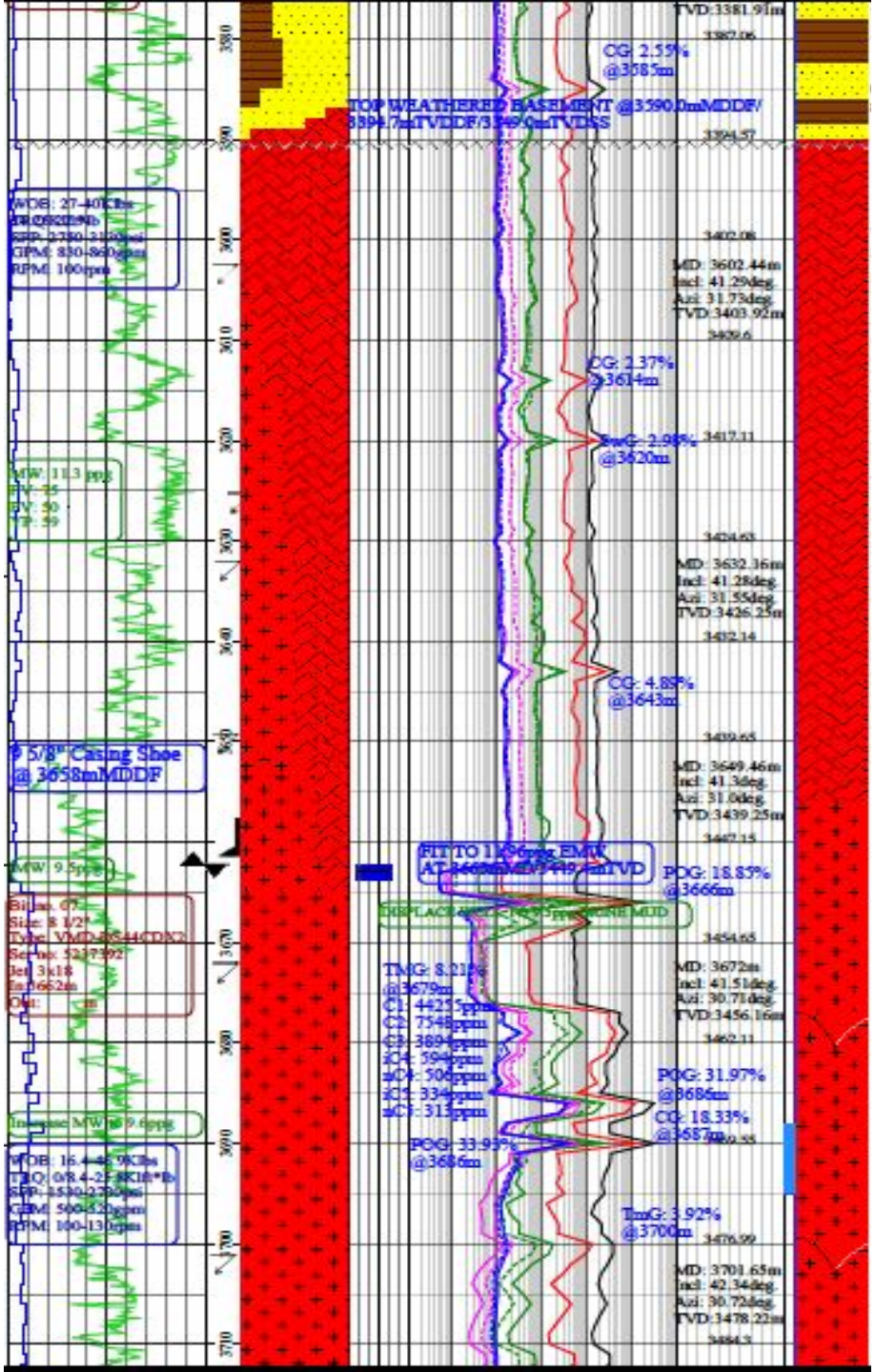


Fractures Detection Is Biased By :

- Tool’s sampling
- Borehole Diameter
- Well Trajectory
- Fracture Types and Dip



Natural Fractured/ Cavernous Reservoirs Conceptual Play Setting. (Taha et al., 2009)

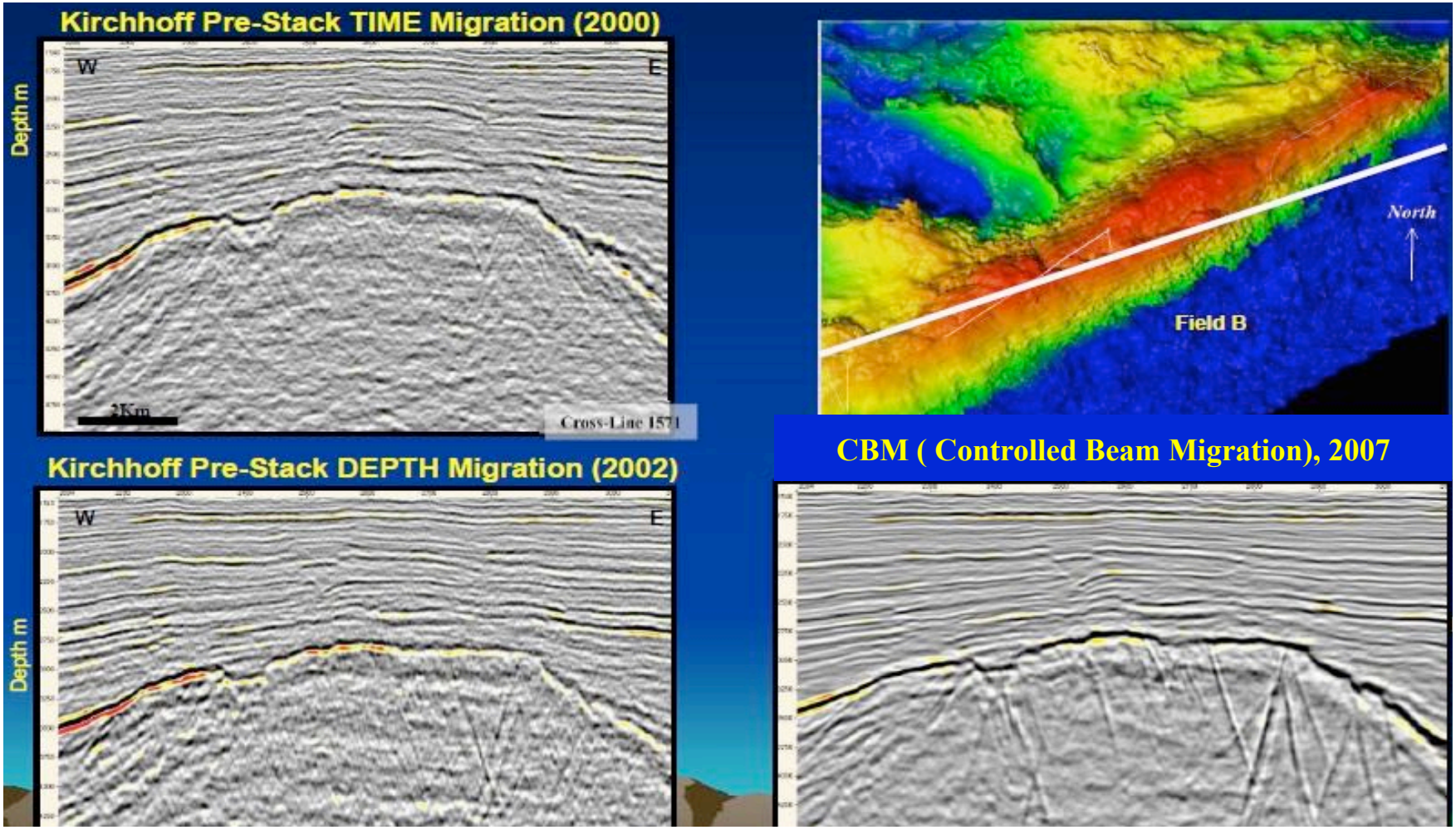


Top Weathered Granite

Weathered granite is of poor reservoir quality. (Cuong,2001; Phone and Duc, 2006)

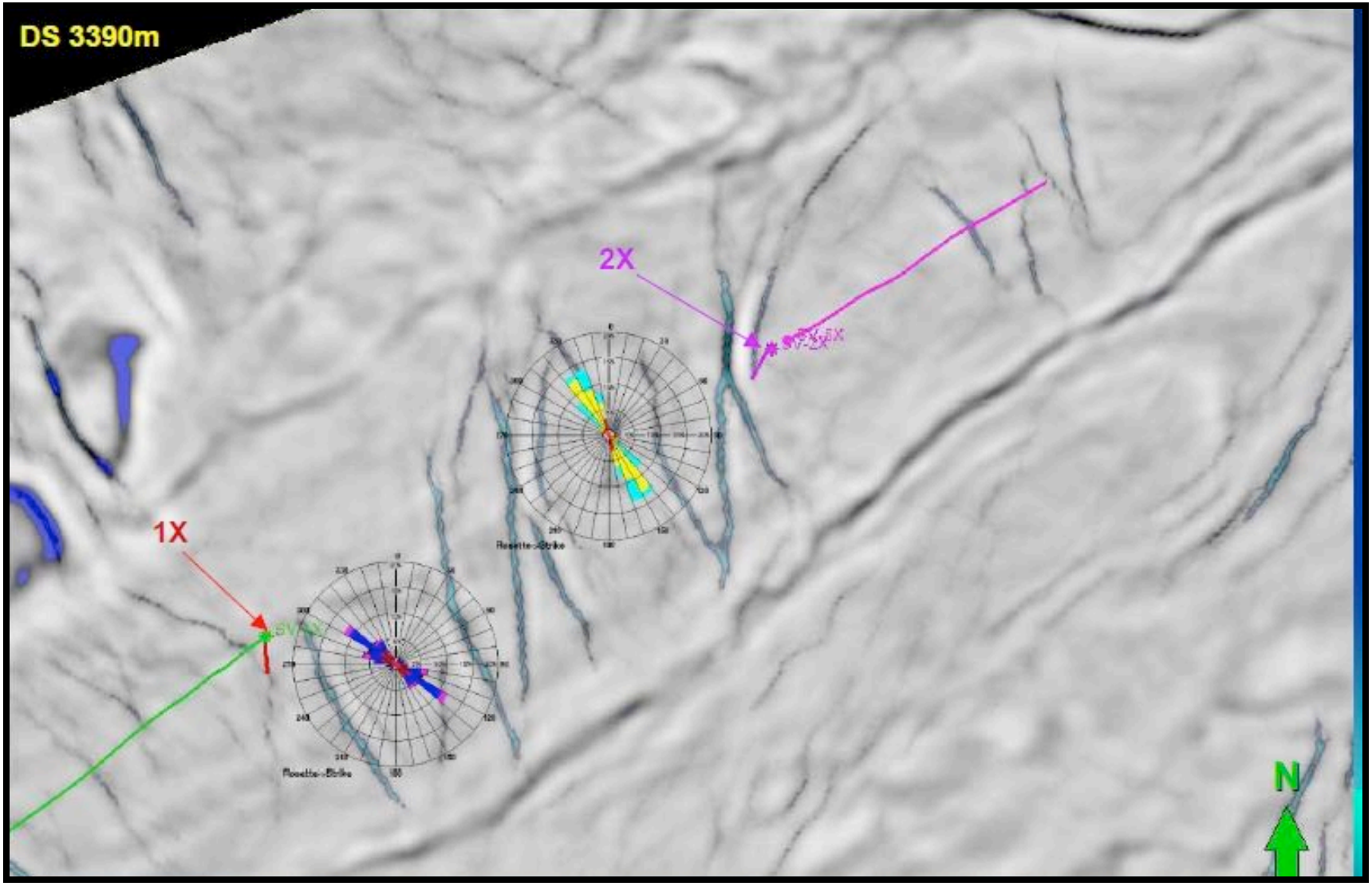
Top Fractured Granite

Total losses of 500,000 BBLS of sea water were reported. The well flows 100% oil after three days of cleanup

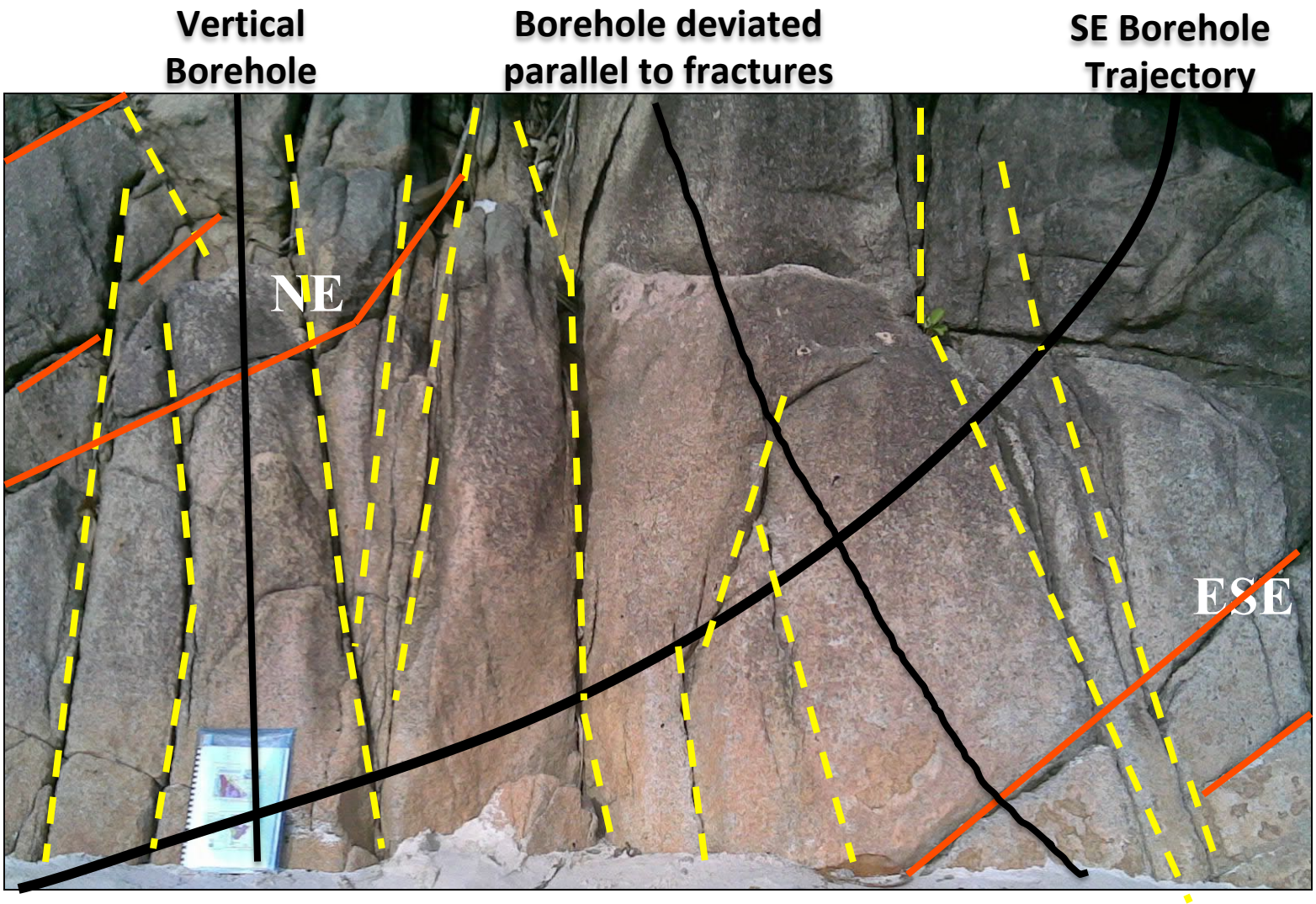


Steeply dipping fractures (more than 60°) within reservoir rocks are difficult to image.
Poor signal to noise ratio in deeper reservoir sections with strong multiple interference.
Sharply lateral varying contrast in velocity.
Complex faulting creates fault-shadow at deeper levels.

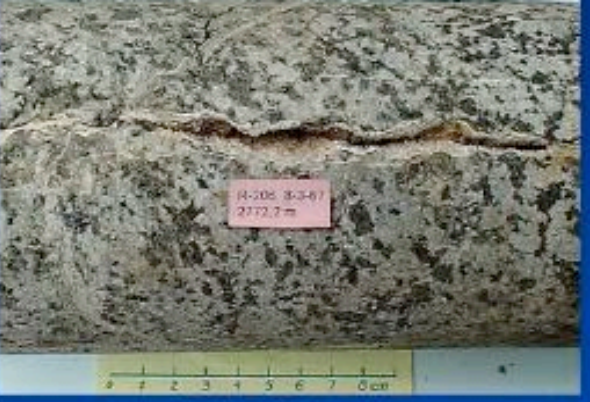
Enhancement in seismic imaging PSDM_CBM technique (Bone and Giang, 2008)



Correlation between fracture orientations from FMI and Ant-Track data of field B (Bone and Giang, 2008)

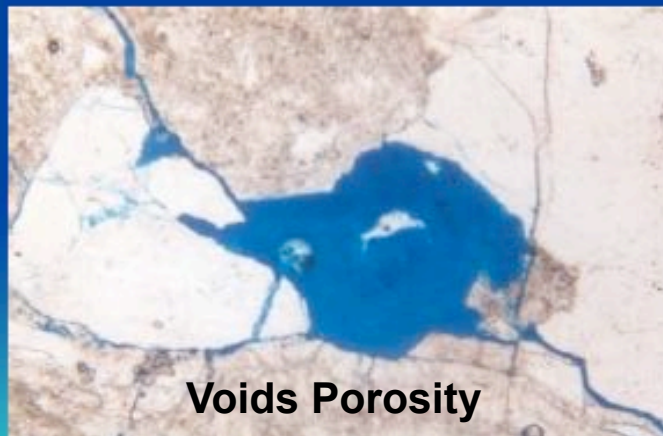


Redang Island; NE-SW (yellow) open fractures with idealized SE borehole trajectory.



Macro-Fracture

Micro-Fracture

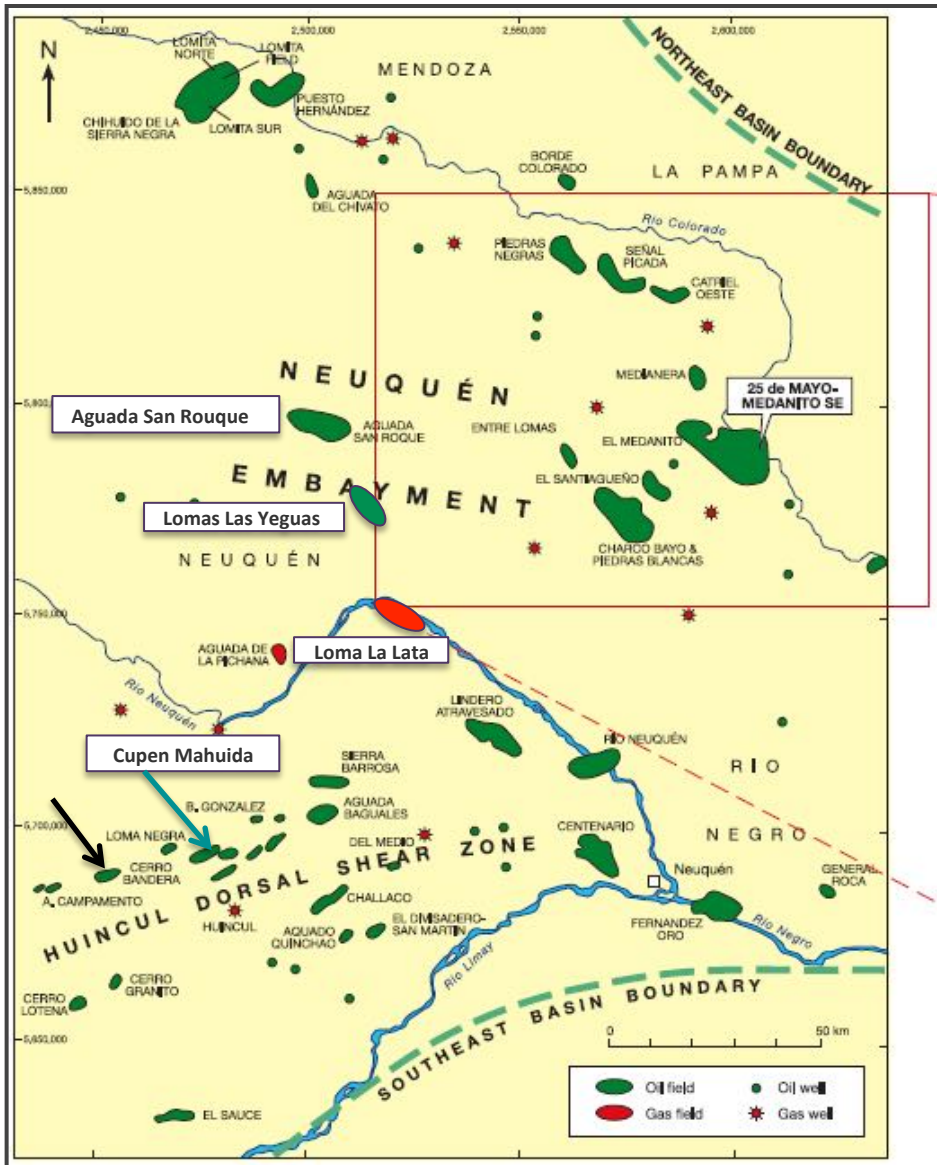


Voids Porosity

Different Types of Porosity:

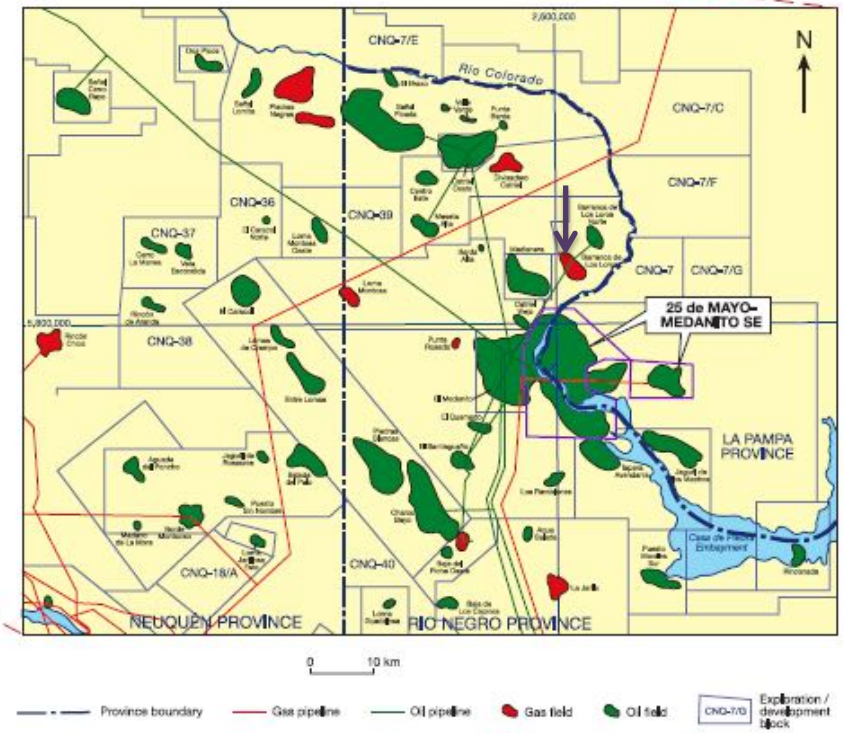
- Stress-Related Porosity; Macro-and micro-fractures
- Temperature Related Porosity; Cooling fracture and shrink porosity
- Erosion and Weathering Related Porosity; Physical and chemical dissolution and leached porosity
- Diagenesis Related Porosity; Mineral-phase change fractures and voids
- Induced Porosity; Induced fractures, spall- and breakouts

(Modified after Cuong, 2001 and others)



Medanito-25 de Mayo field has a daily production of 12,000 BO and 17 MMCFG. Estimated reserves of the field is about 400 million bbls. Over the period of 1962-2001 Cumulative production reached 352 million bbls

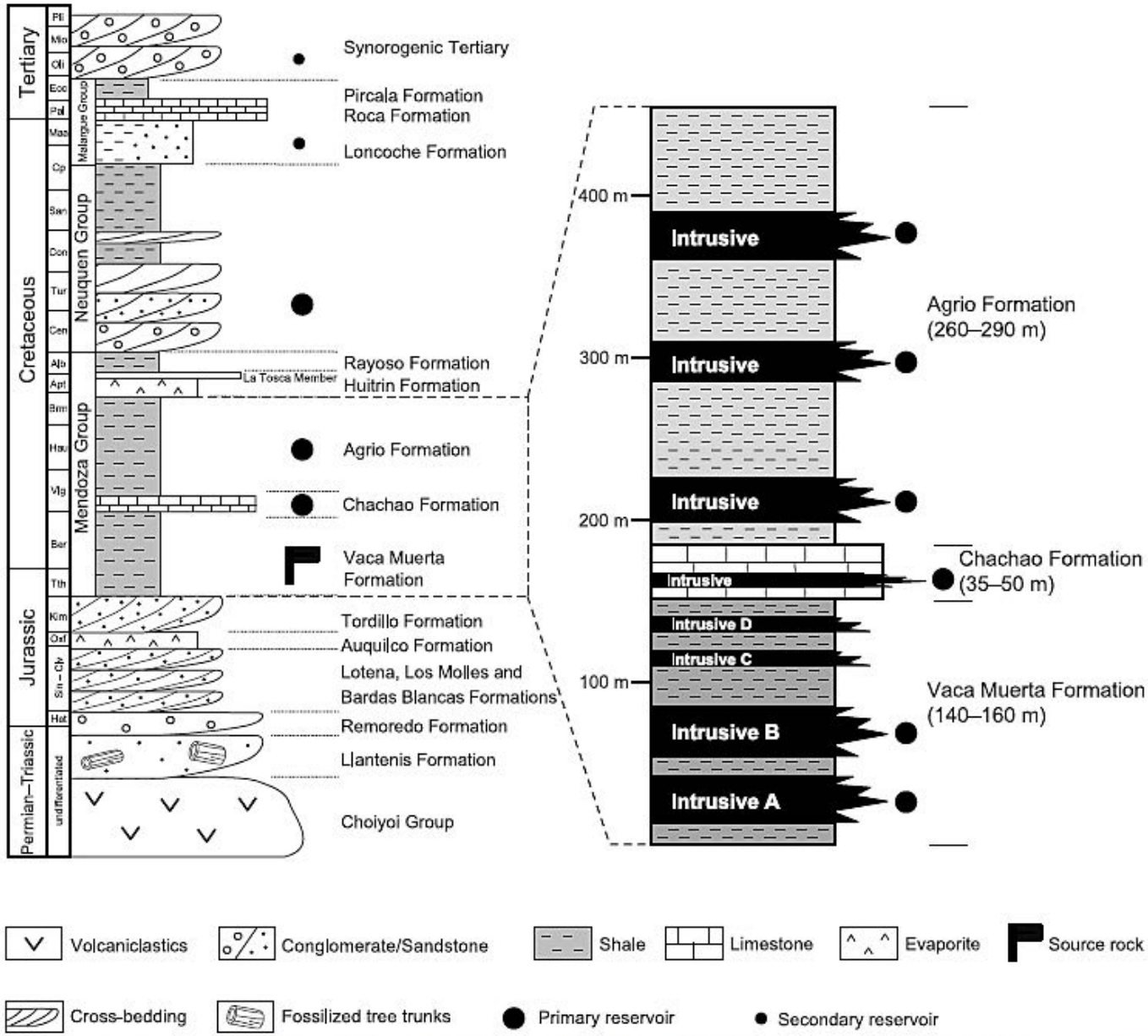
B



- Arrows show the Cerro Bandera, Barranca de los Loros and Cuoen Mahuida field locations of the studied cores and Images

Location map of the oil and gas fields in the central Neuquén basin

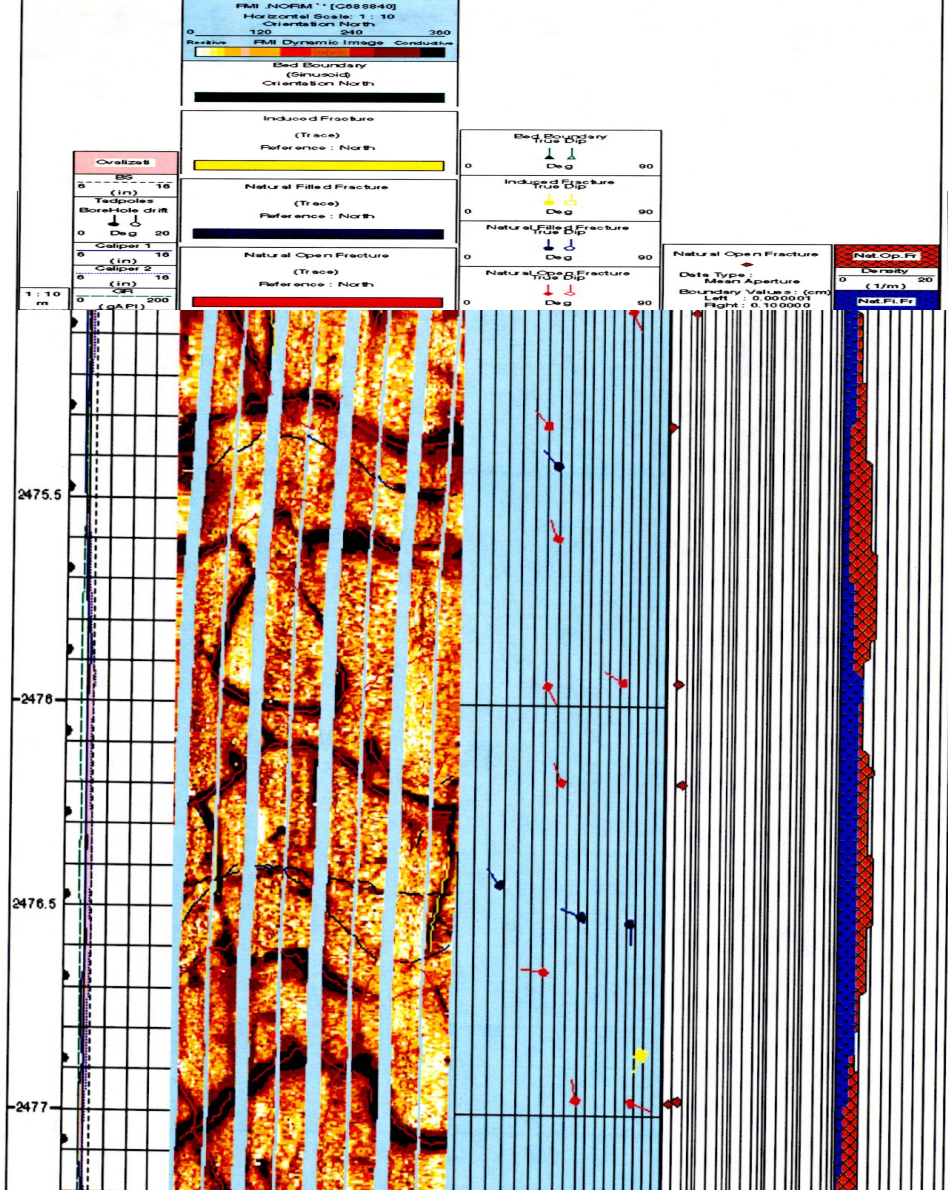
Fractured Permo-Triassic tuffaceous formation of the Choiyoi group. It is one of the main reservoirs in the Medanito field.



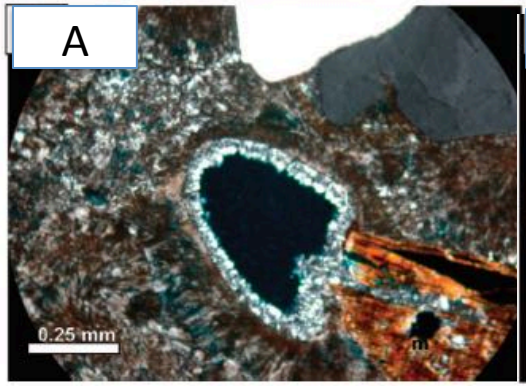
Intrusive reservoirs embedded within the Vaca Muerta source rocks in Neuquén basin, Argentina (Witte et al., 2012)

Fracture and Vesicle Porosity in Basalt, Near Great Salt Lake, Utah (courtesy of Ron Nelson)

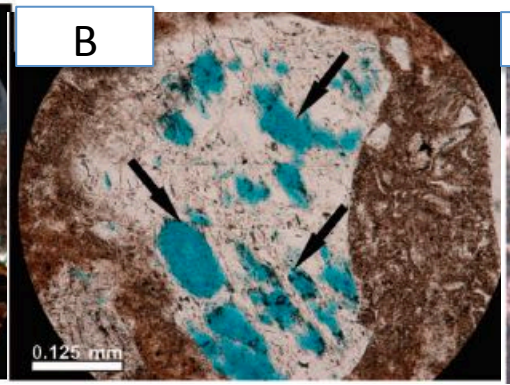
Zeolite filled the cavities of vesicles in extrusion .(Courtesy of Colorado College



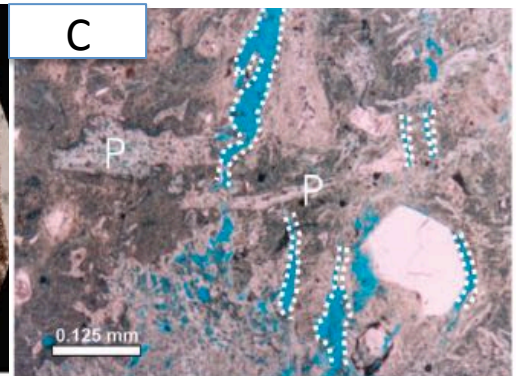
Borehole imagery over Diabase intrusion in Loma la Lata field, Neuquén basin. Horizontal and inclined fractures were generated by cooling and flexures. Mottled patterns reflects gas escape vesicles.



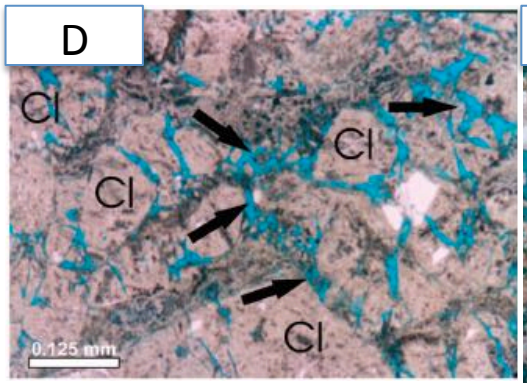
Vesicular with vapor-phase crystals .



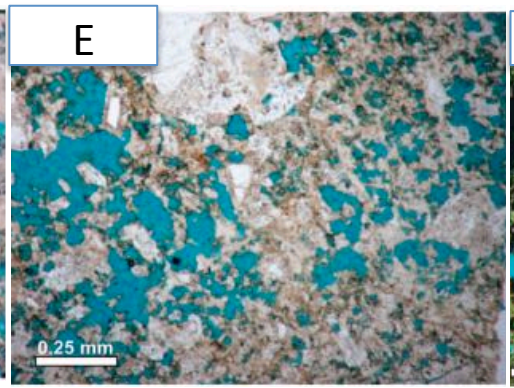
Interacrystalline porosity



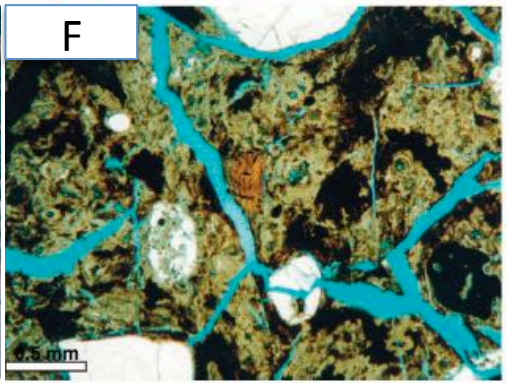
Gas pipe porosity



Intraclast porosity

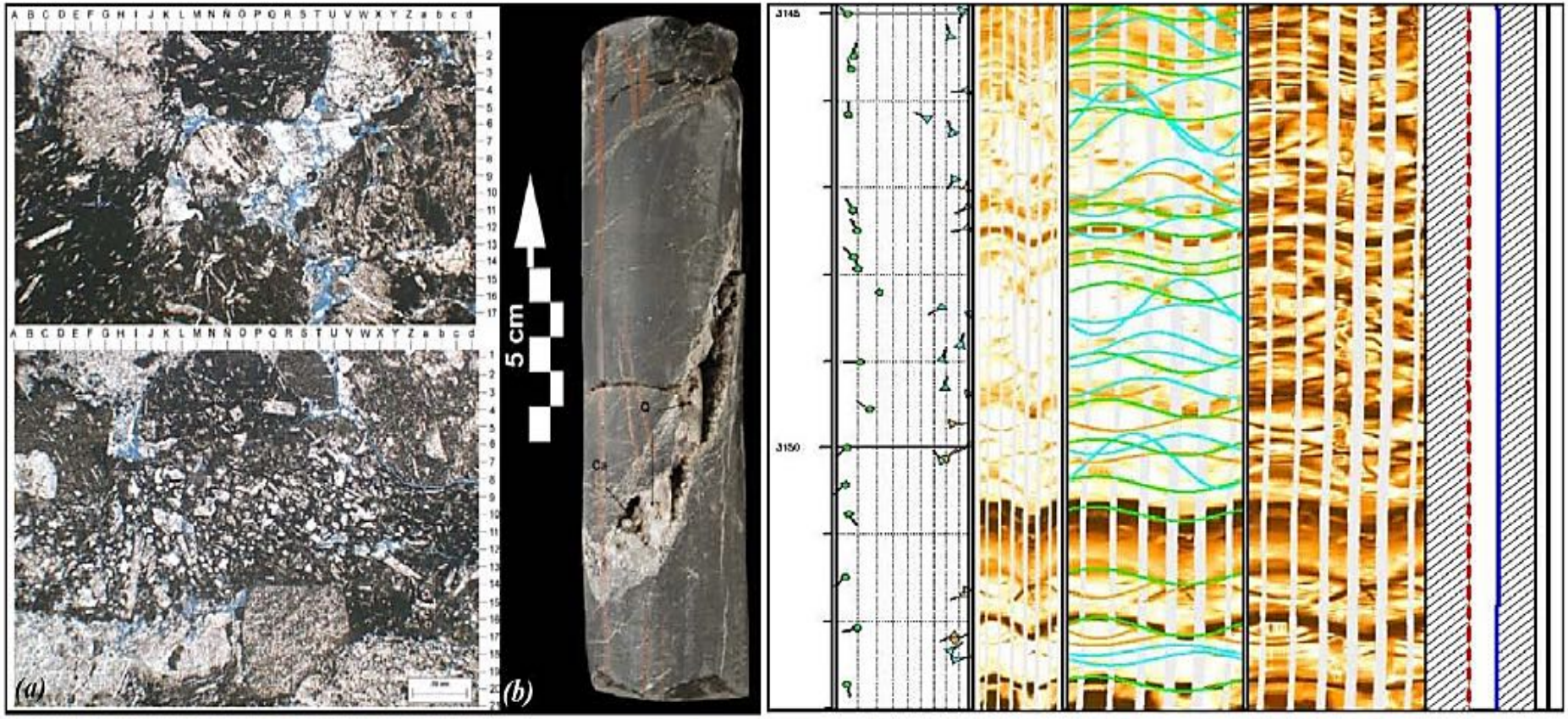


Void porosity



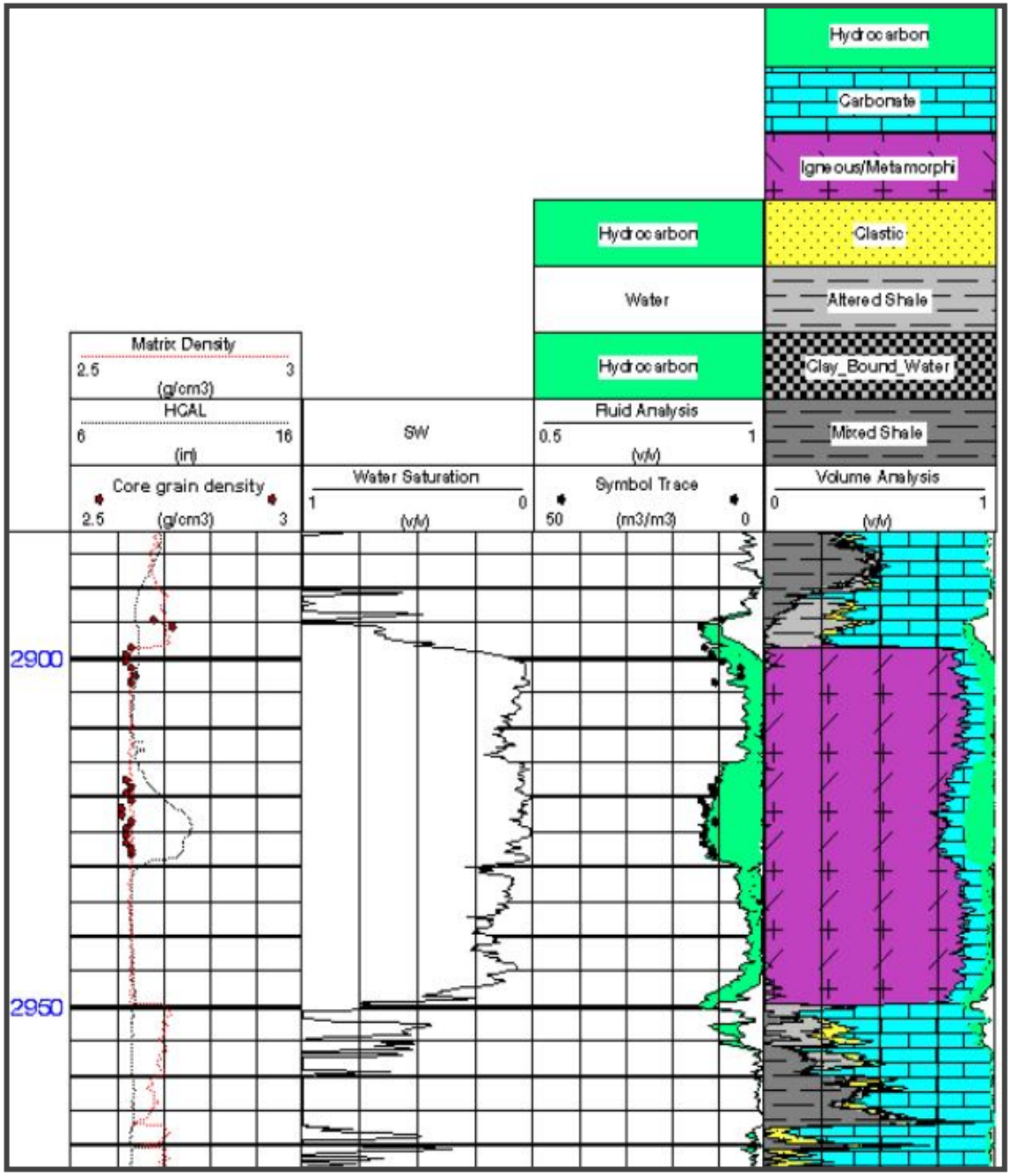
Network of quench/ cooling fractures

Porosity and permeability in Volcanic Reservoirs in Cerro Bandera and Barranca de Los Loros fields, Neuquén Basins (Sruoga and Robinstein, 2007)



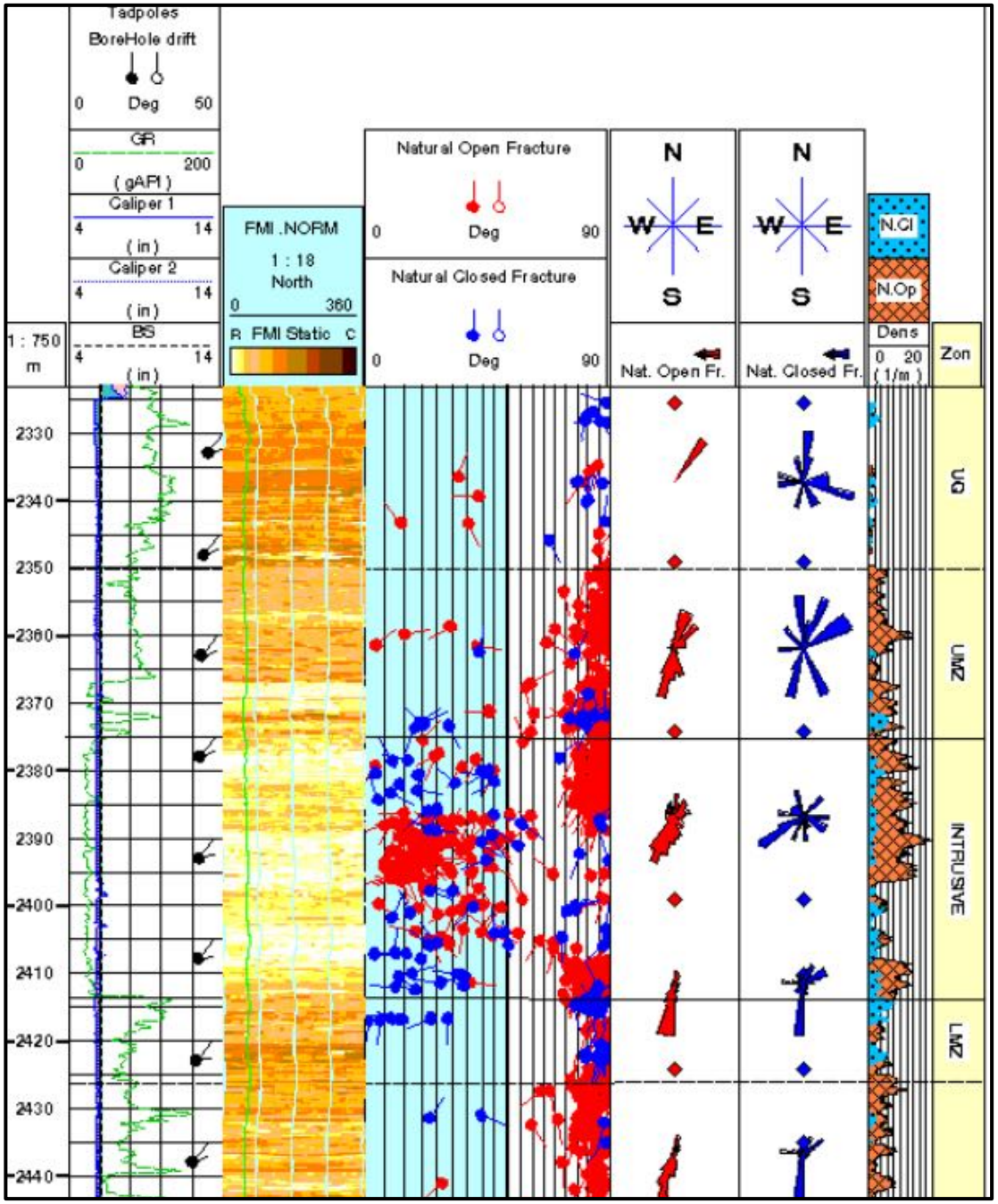
Fractured tuffaceous facies in Cupen Mahuida gas field; a) thin section showing micro-fractures with alteration and dissolution of minerals where porosity reaches 9% with a permeability of 42 mD , b) open fractures in core partially filled by calcite and silica crystals and c) interpreted borehole image log showing open fractures (orange), closed fractured (blue) and bed boundaries (green) (Zubiri and Silvestro, 2007)

ASR-103; Integrated petrophysical interpretation and core data over the intrusion and metamorphic zones (courtesy of Schlumberger)

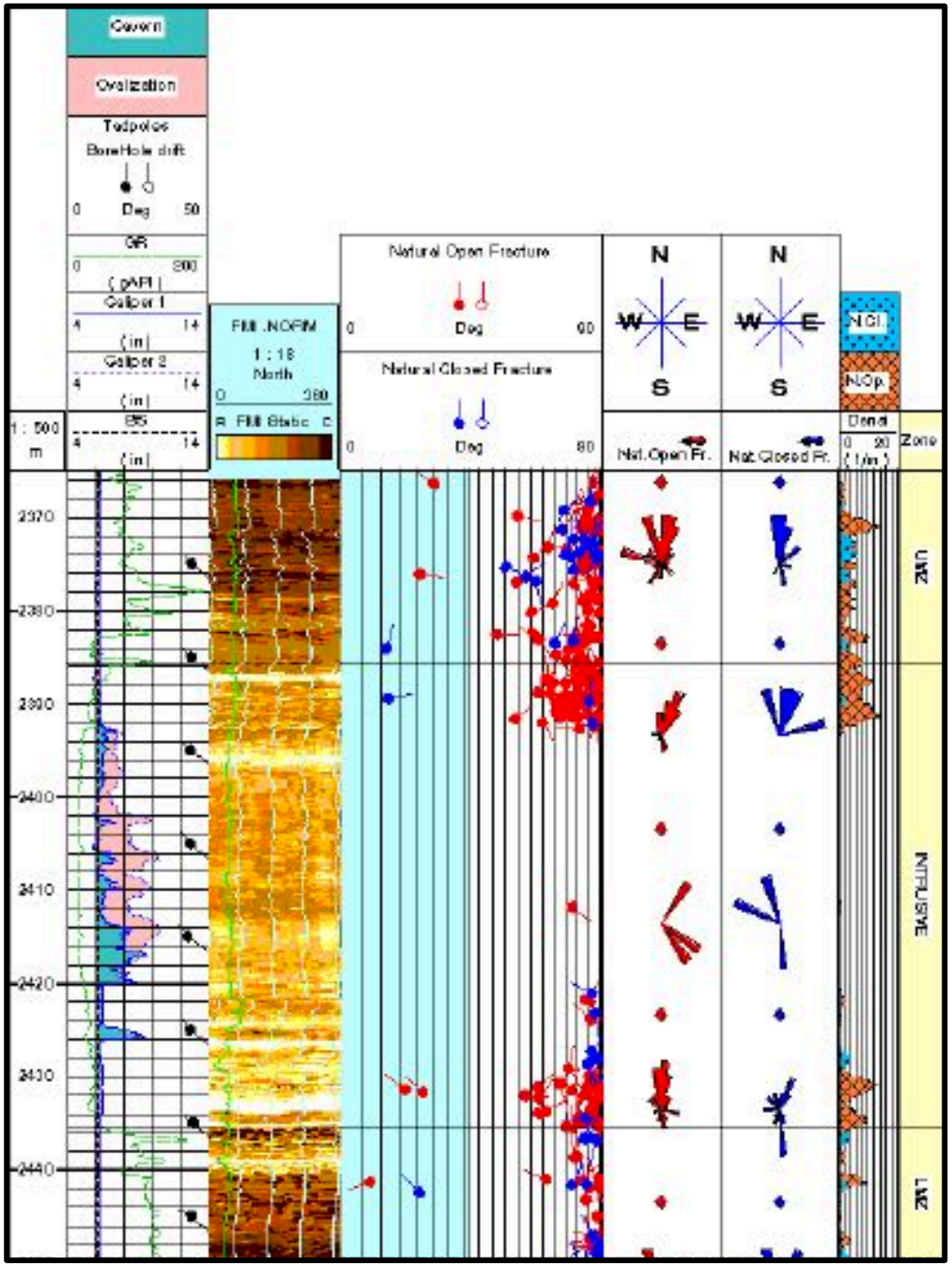


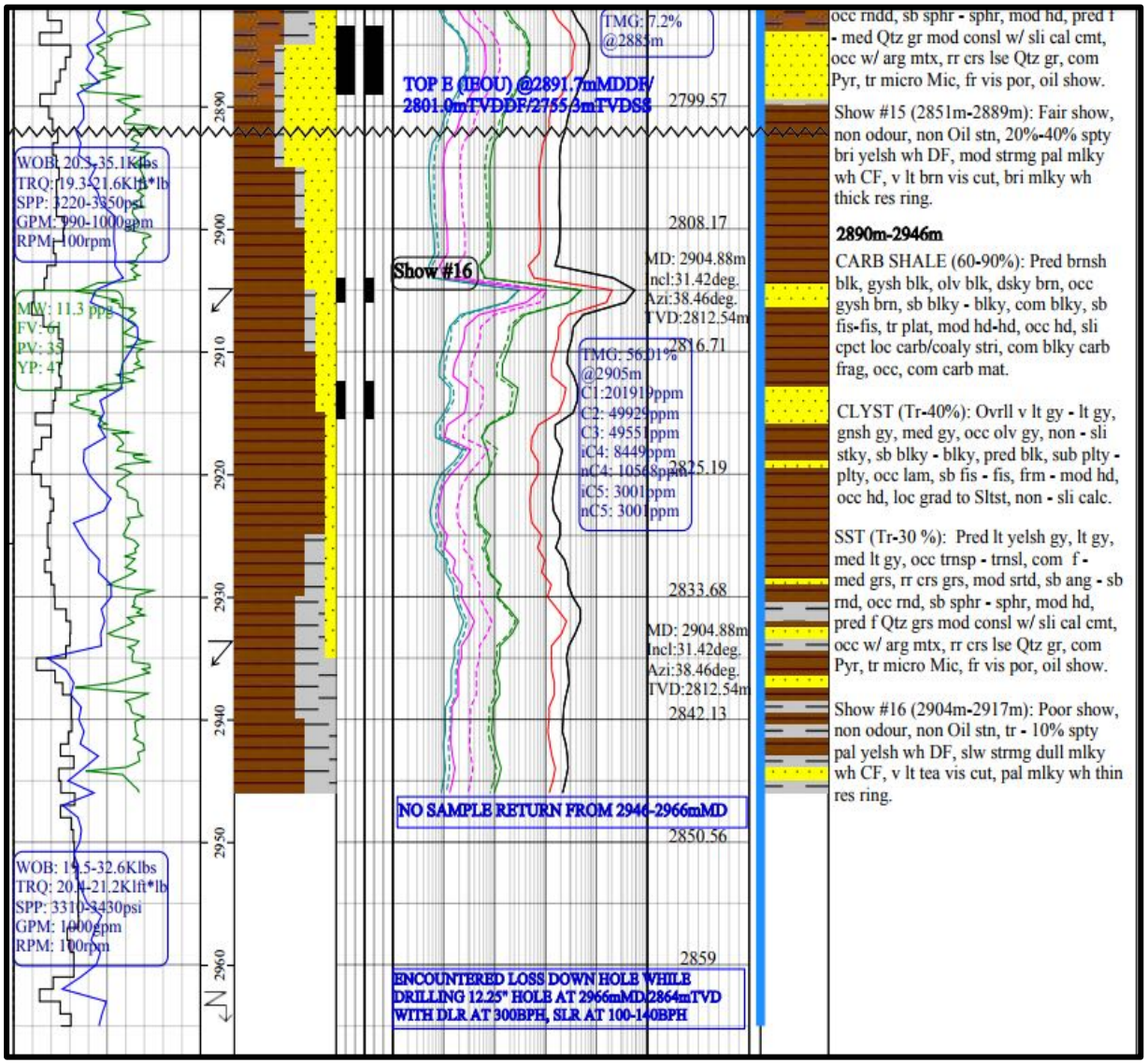
LLY-220; The well was drilled deviated 45 degree to the NE. Highly and low angle fractured U &L metamorphic and intrusive were intersected. Tectonic related fractures strike NW-SE with subordinate NE-SW partially open and cemented fractures.

The well tested 700 BO/d from the L. metamorphic and Lower intrusion and 35 MMCFG/d from the U metamorphic and U intrusion (courtesy of Schlumberger)

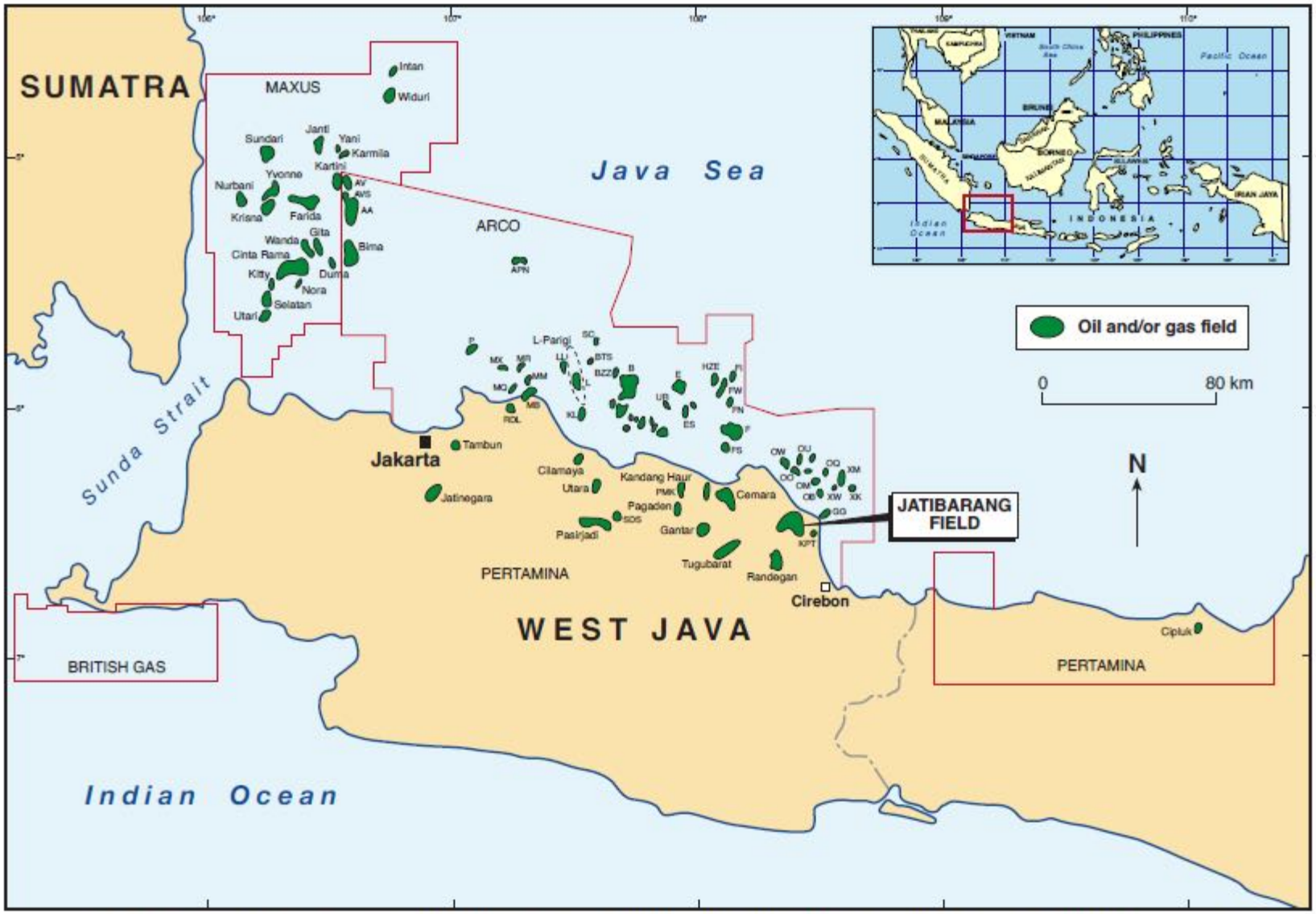


LLY-213; The well was deviated 45 degrees to the NE. High numbers of highly dipping fractures along the upper and lower metamorphic zones were intersected. The caliper data shows that the Borehole is spalling out over the intrusion suggesting the presence of high density fractures. The well tested 1500 BOPD and 17 MMCFGD (Courtesy of Schlumberger)

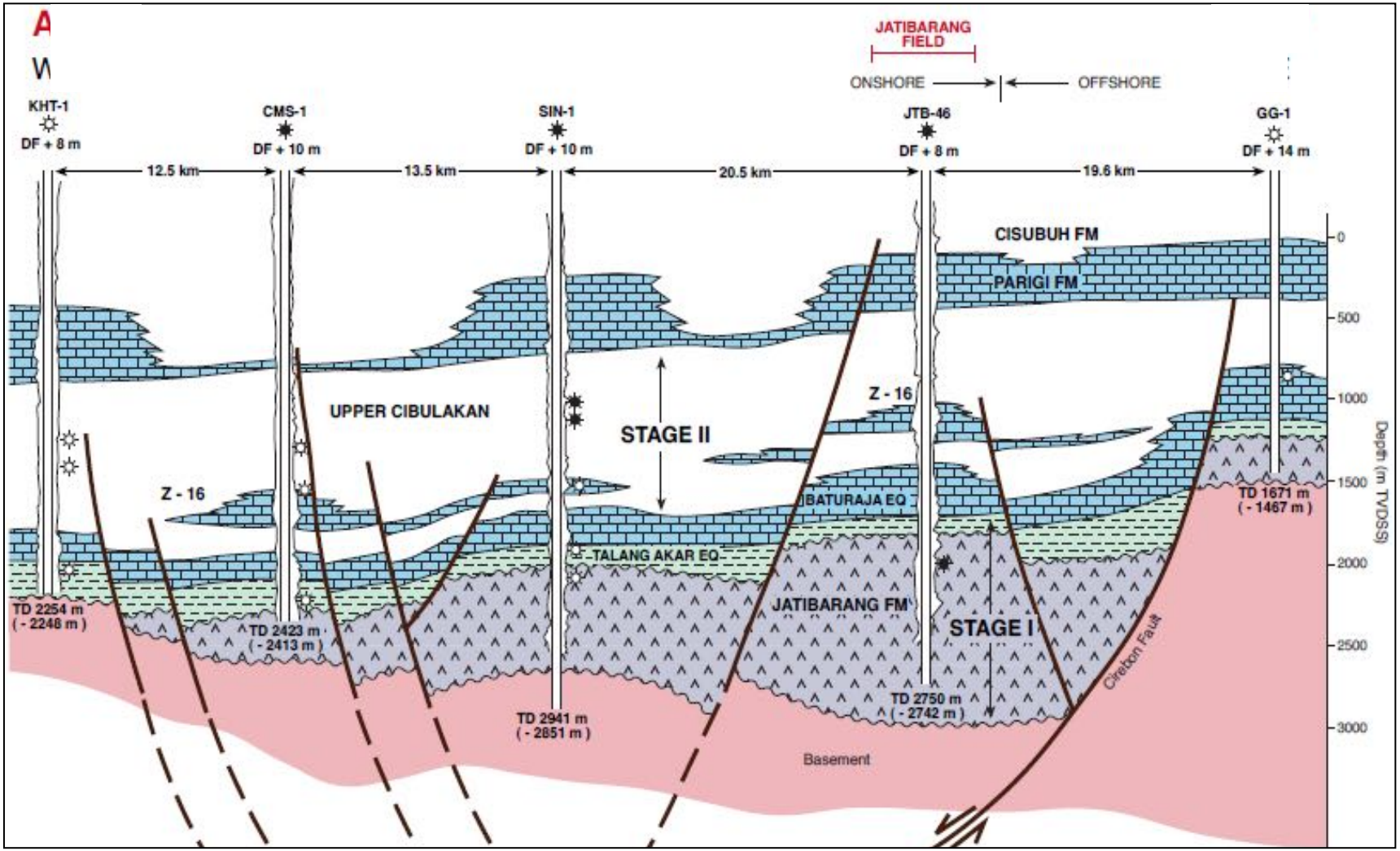




Complete mud loss loss with no return occurred when the well intersected highly fractured intrusion. It was side tracked due to stuck pipes.



Oil and gas fields of the NW Java basin (Noble et al., 1997)



The tuffaceous sandstone and basaltic/andesitic rocks of Jatibarang formation is the main reservoir in Jatibarang field which was discovered in 1969. The field went on production in 1975 and reached the production rate of 40,000 BOPD of 30° API in 1987. The field produced 80 million bbls in 2003 with an estimated contingent resources 500 million bbls. In 2008 the reservoir watered out. (After Adnan et al., 1991)

Prescription of Success

- Understanding the Structural setting, stress regime and fracture geometry.
- Defining the proper seismic imaging of lineaments, joints and fractured zones.
- Setting well trajectories and drilling fluids.
- Planning for Borehole logging, coring, sidewall coring, formation evaluation, testing and completion.
- Recognizing Fracture and matrix attributes.
- Awareness of Reserve calculations pros and cons.
- Strategizing Development Plans and Exploitation
- Utilizing data integration and multidisciplinary approaches


Thank you!