Geomechanical Approach for Cores Analysis of Jurassic Manusela Carbonate Fractured Reservoir from Oseil Field*

Anggoro S. Dradjat[1] and Christian Sony Patandung[1]

Search and Discovery Article #20149 (2012)**
Posted June 11, 2012

*Adapted from oral presentation given in Bali, Indonesia at the Geoscience Technology Workshop (GTW) on Reservoir Quality of a Fractured Limestone Reservoir, 15-17 February 2012. Please refer to companion article by A.S. Dradjat et al. (Search and Discovery Article #20157(2012)).

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Abstract

The geomechanical relationship between lithology and rock strength reveals a new method for fracture study and analysis. This practical geomechanical application is also valuable for drilling parameter design and could create a new way of development of field development. In order to simplify complications in the Jurassic Manusela carbonate fractured reservoir, we used the geomechanical as approach.

The method of geomechanical core interpretation and analysis of our carbonate fractured field is as follows:

- stress in the earth is simplified by using Smax and Smin system;
- all failure is simplified into shear and tensile fracture;
- tensile strength of rock is much smaller compared to compressive strength;
- evidence of multiple tectonic phases, such as extension, surface exposure and compression, are key for fracture development; diagenesis (e.g., cementation and compaction) creates higher rock strength;
- rock strength of Manusela carbonate is calculated from sonic log by using equation, drilling well data and triaxial test;
- direct relationship between helium porosity and rock strength is found in Oseil-1 well.

In the core workshop we are proposing new ways for fracture analysis by combining calculated rock strength and lithology. Higher rock strength has fewer fractures and less porosity, whereas less rock strength has more fractures and more porosity. In E Nief-1 well, compacted dolostone core has the highest rock strength (average 10500 PSI), less fracture, and is non-reservoir. Oolitic limestone core at this well has less rock strength (average 7200 PSI), more fractures and is good reservoir.

In Oseil-1and 4, Oolitic limestone dissolution core zone has less rock strength (average 6800 PSI), and dolostone is slightly stronger (8800 PSI); both zones of limestone and dolostone are highly fractured and highly porous.

Selected References

Jaeger, J.C., and N.G.W. Cook, 1979, Fundamentals of Rock Mechanics, Third Edition: Chapman and Hall, London, 593 p.

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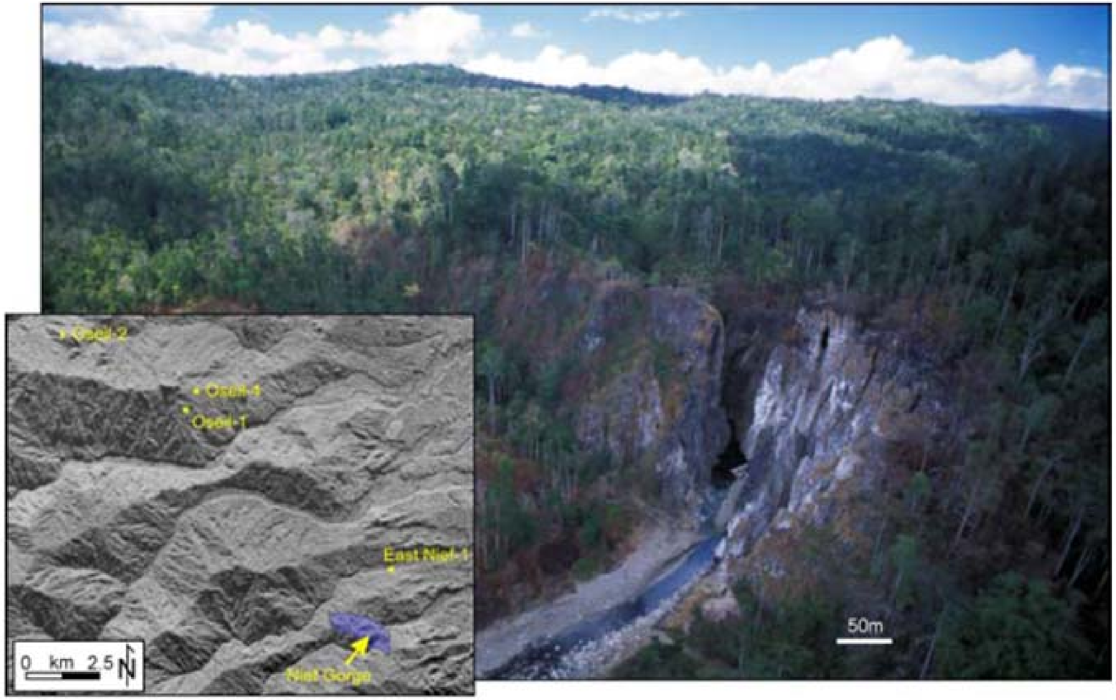

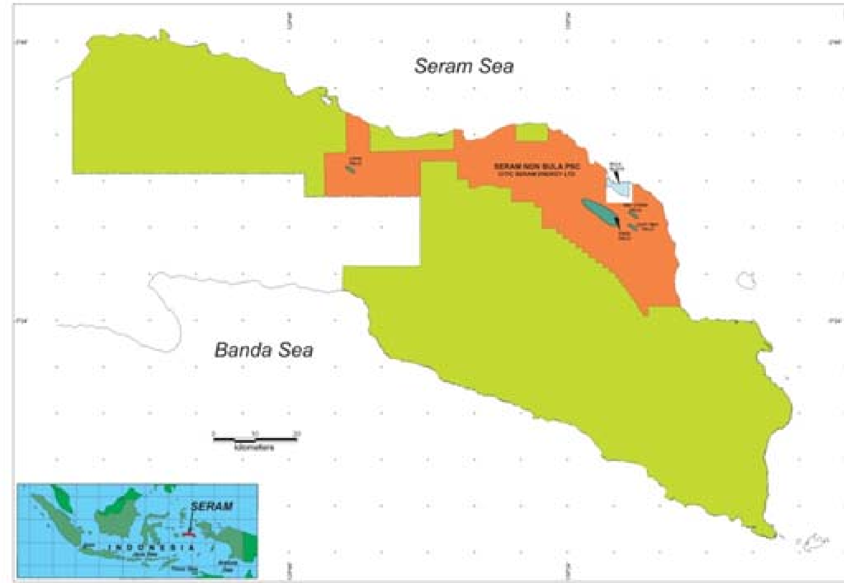

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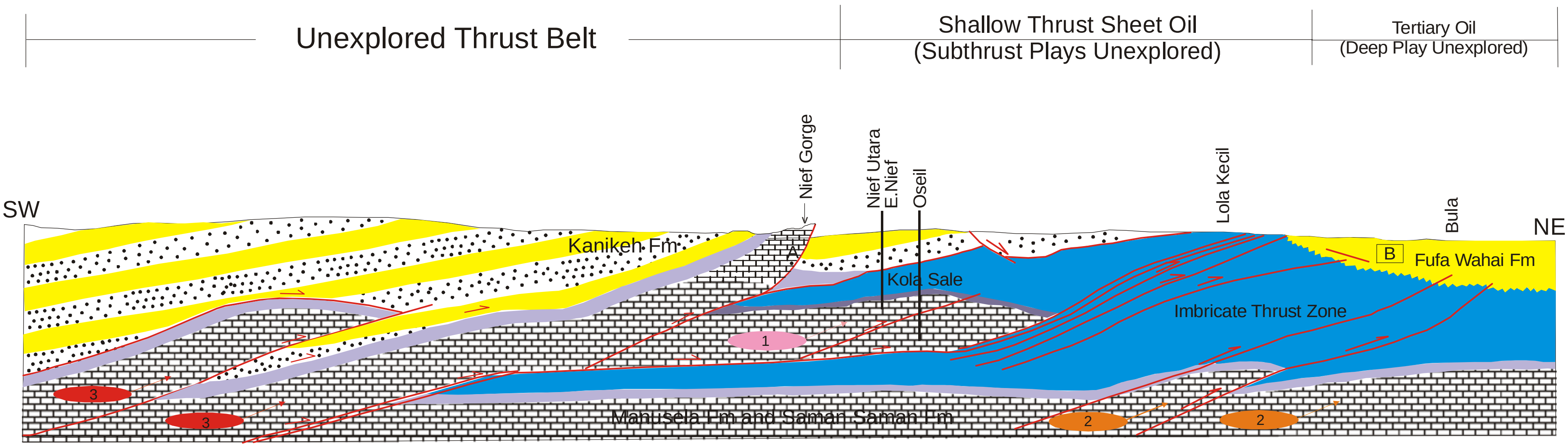
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Geosciences Technology Workshop

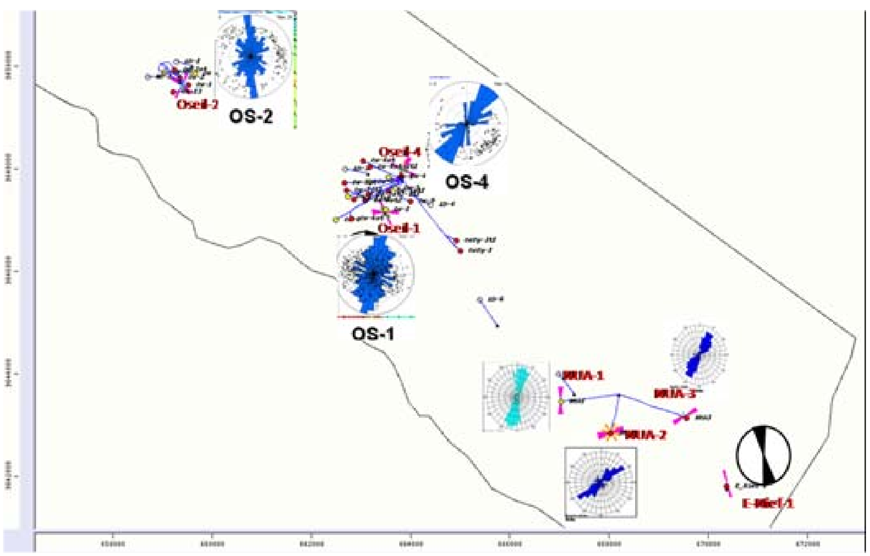
CITIC Seram Energy Ltd

Fractured Carbonate Reservoirs
15-17 February 2012 | Bali, Indonesia

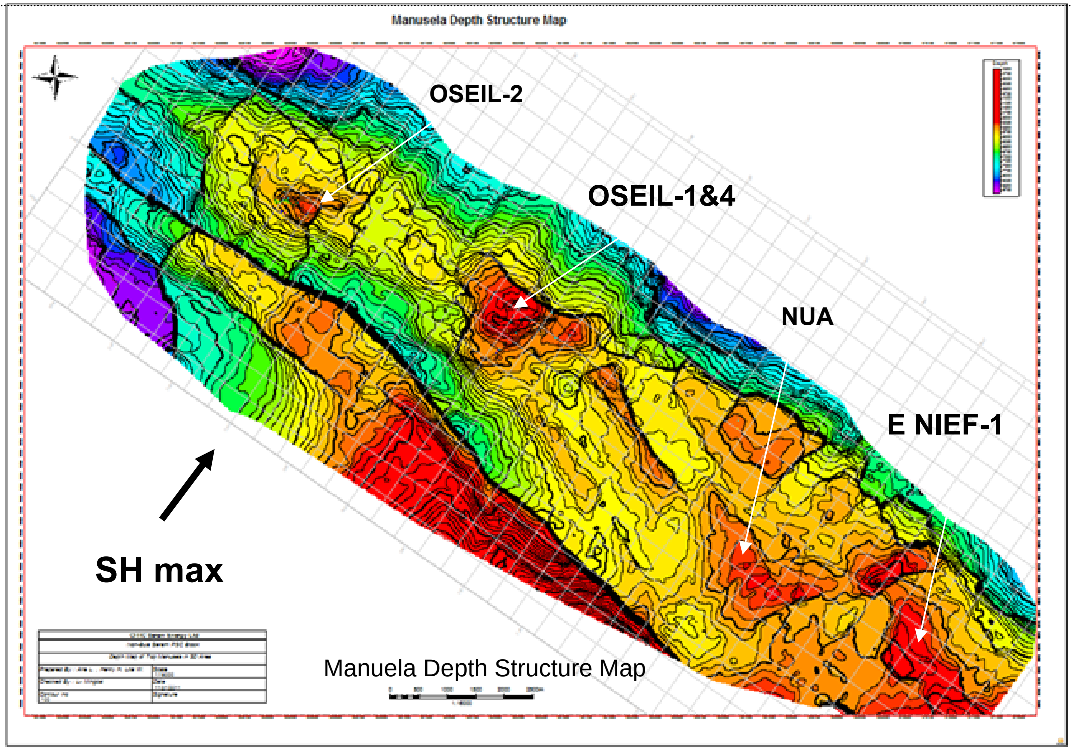
Regional Tectonics



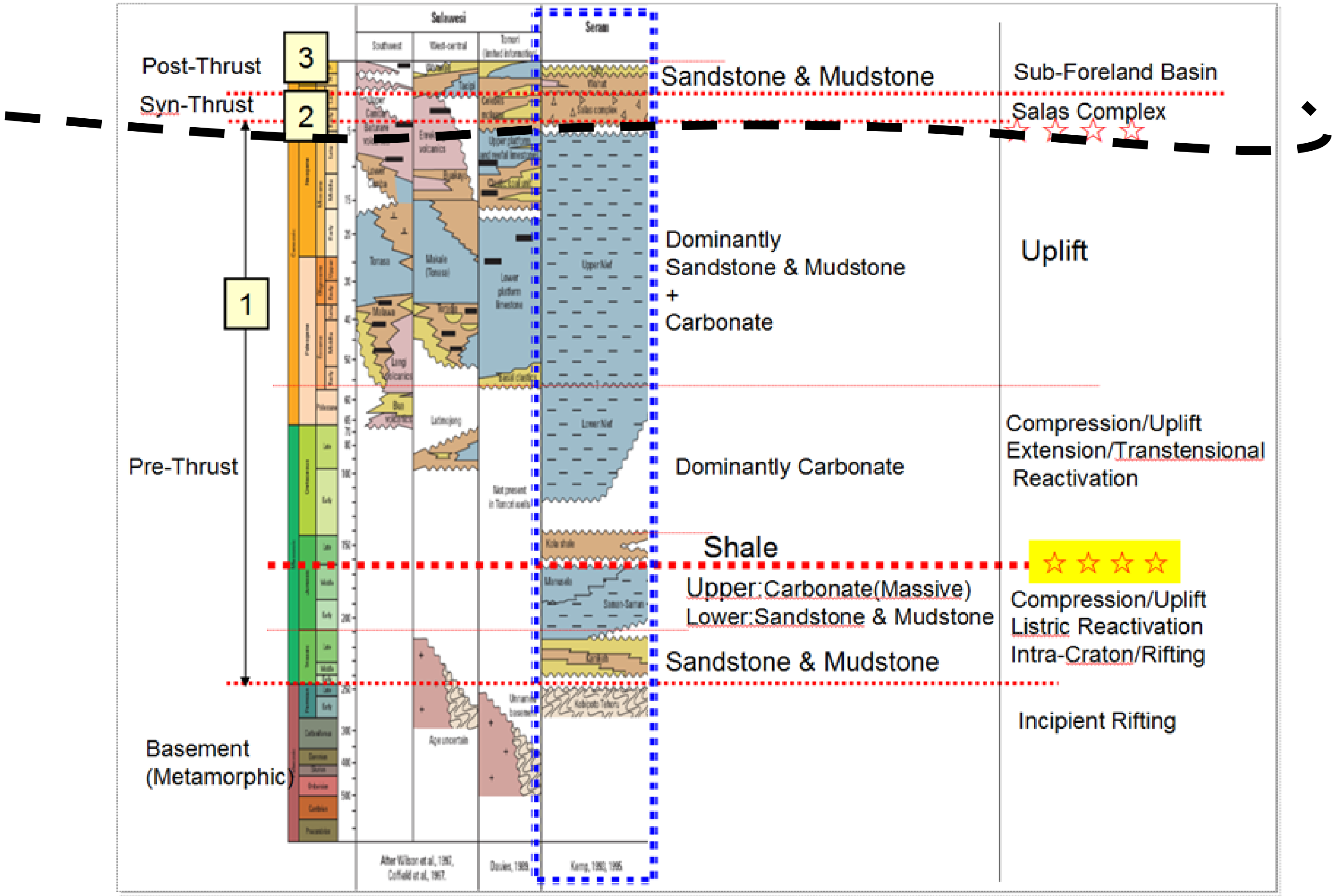
Regional Structural Cross Section of Oseil Field



Fracture strikes from FMI log



Manuela Depth Structure Map



Stratigraphy of Oseil field

- Manusela fracture carbonate reservoir-- Jurassic age.
- Tectonic extensional fracture was generated during Early Jurassic.
- Uplift of listric fault reactivation followed by karsting, dissolution and cementation caused by phreatic water.
- From Jurassic to Late Neogene's Manusela carbonate was compacted.
- Late Neogene's compression rectified the extensional fracture and compression fracturing was generated.

Mechanical Stratigraphy

Geomechanical approach for Oseil field

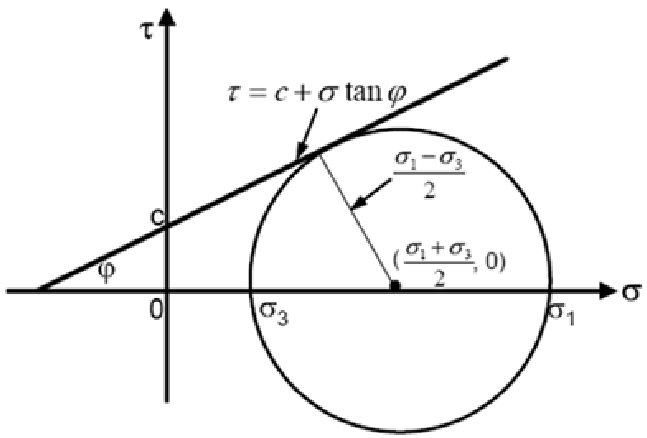


Fig. 4.11. Mohr circle and strength envelope for dry materials.

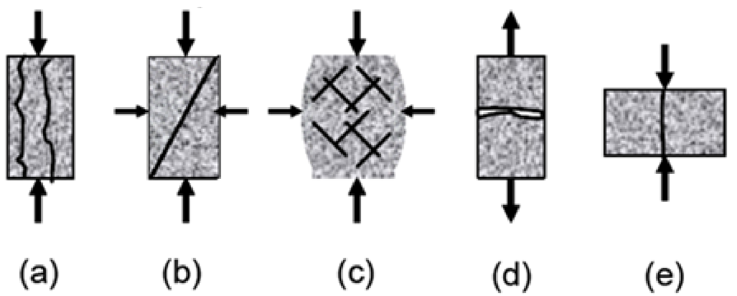


Fig. 4.16. Rock failure types. **a.** splitting; **b.** shear failure; **c.** multiple shear fractures; **d.** tensile failure; **e.** tensile failure induced by point loads.

Jaeger, J. C., and N. G. W. Cook, 1979. *Fundamentals of Rock Mechanics*, Chapman and Hall, London.

- *Stress in the earth is simplified by using Smax and Smin system.*

- *All the failures are simplified into shear and tensile fracture*

- *Tensile strength of rock is much smaller than compressive strength*

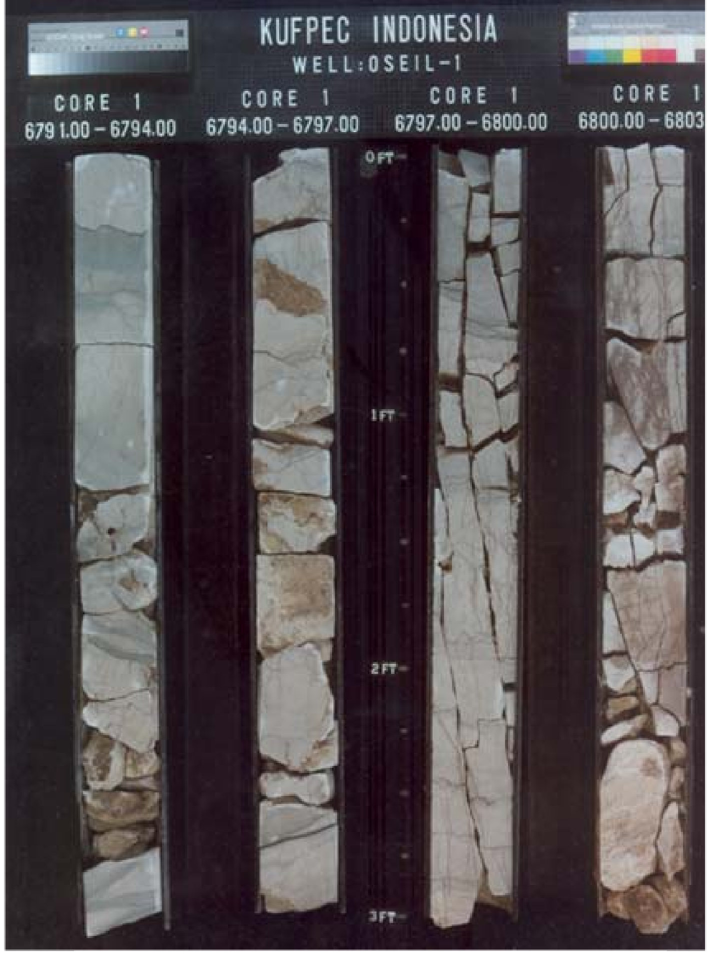
- *Multi-phase of tectonics, such as extension, surface exposure and compression, are key for development of fractures; extension is good for fracture and compression good for structure.*

- *Diagenesis changed lithology and rock strength properties of the rock.*

- *Rock strength of Manusela carbonate facies is calculated from sonic log by using Militzer and Stoll equation (1973), drilling data and core triaxial test.*

- *Porosity is calculated using helium porosity measurement; direct relation of Helium porosity versus rock strength found in Oseil-1 well.*

- *Geomechanics core measurement:*
  a. Poisson ratio b. Rock strength c. Thomsen parameter



Os-1 Rock Strength Calculated Using Militzer and Stoll E

Core no:1 depth 6791 to 6803 feet

MD DEPTH (FEET)	DT	7682/DT	(7682/DT)^1.82
6791.00	52.39	146.67	8765
6791.50	56.08	137.02	7744
6792.00	58.99	130.26	7062
6792.50	59.62	128.88	6927
6793.00	58.36	131.67	7202
6793.50	55.99	137.24	7766
6794.00	52.96	145.09	8594
6794.50	50.20	153.07	9473
6795.00	48.89	157.17	9940
6795.50	49.23	156.08	9815
6796.00	50.34	152.64	9425
6796.50	51.05	150.52	9188
6797.00	50.56	151.98	9351
6797.50	48.89	157.17	9940
6798.00	46.94	163.70	10704
6798.50	45.70	168.14	11239
6799.00	45.81	167.74	11190
6799.50	47.41	162.08	10512
6800.00	49.89	154.02	9580
6800.50	52.40	146.64	8762
6801.00	54.69	140.50	8105
6801.50	56.81	135.26	7563
6802.00	58.29	131.82	7218
6802.50	58.67	130.97	7133
6803.00	58.40	131.58	7193
Average Rock Strength OS-1 core no:1			8816

KEY TO FRACTURES :

Filled fractures (fractures filled with breccia, rock flour or porous matrix)

Large open fractures

Microfractures or fractures which are healed with calcite cements

Stylolites

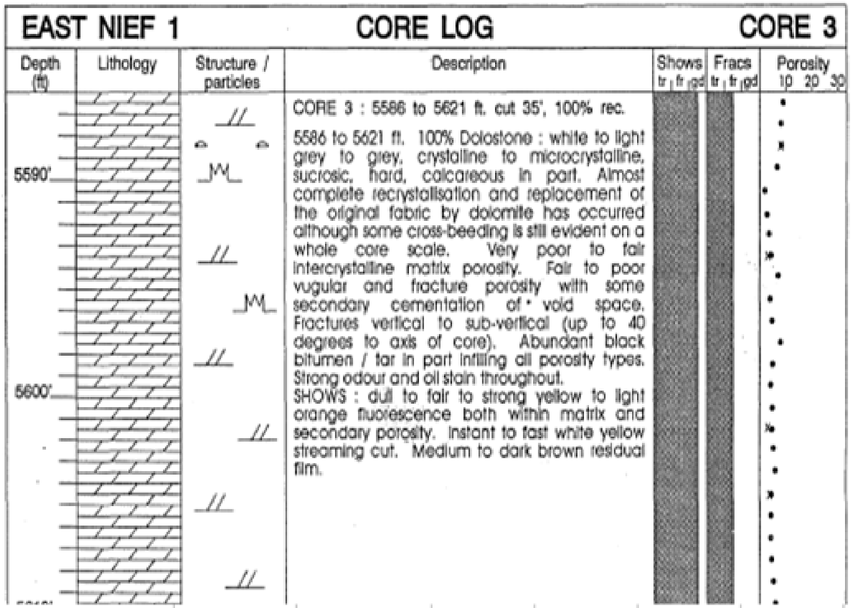
Vugs or isolated pore spaces

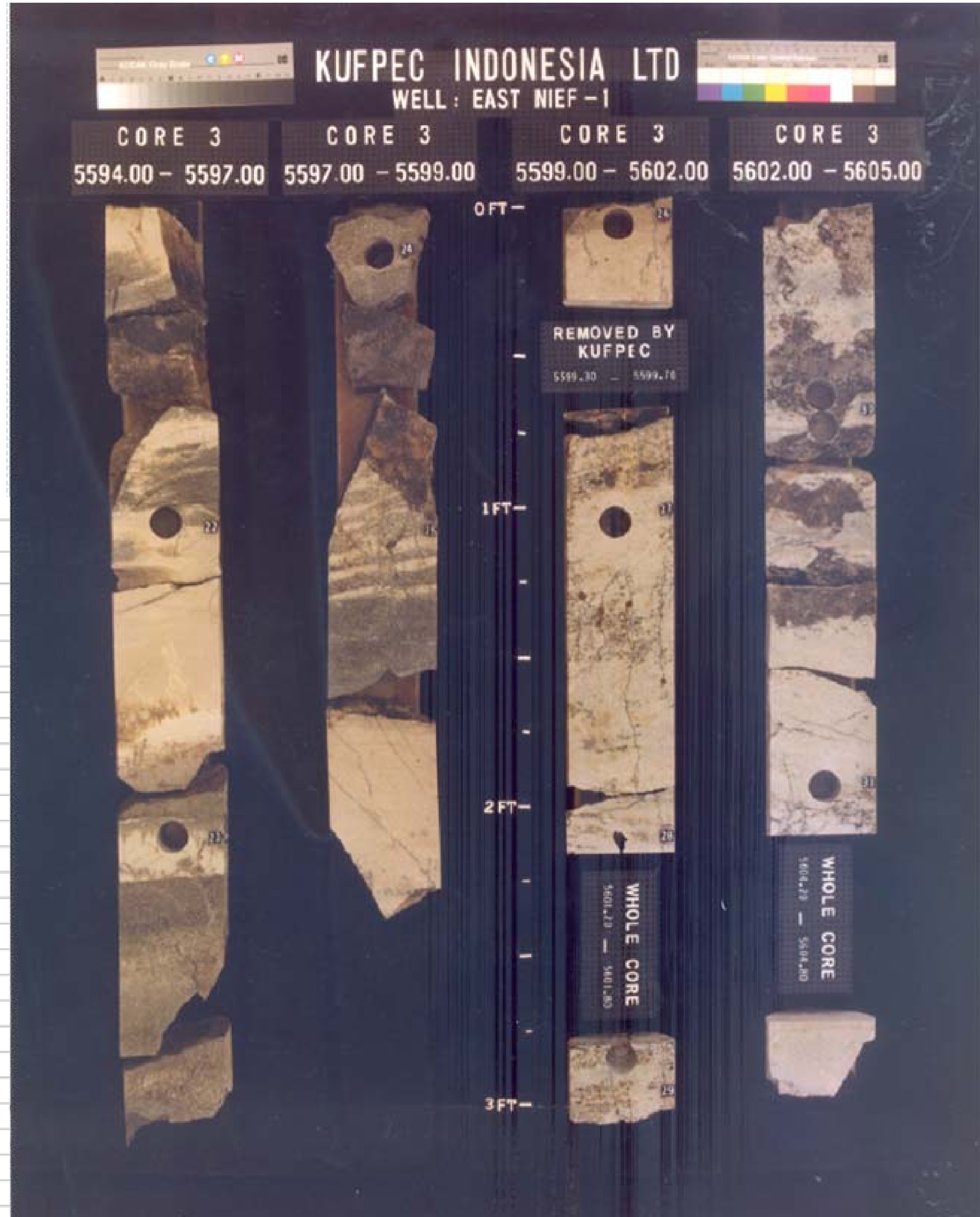
FACIES	DESCRIPTION
A	OOLITIC GRAINSTONE

Lithology: Limestone

Low-rock-strength lithology has more fractures and is porous.

DOLOSTONE



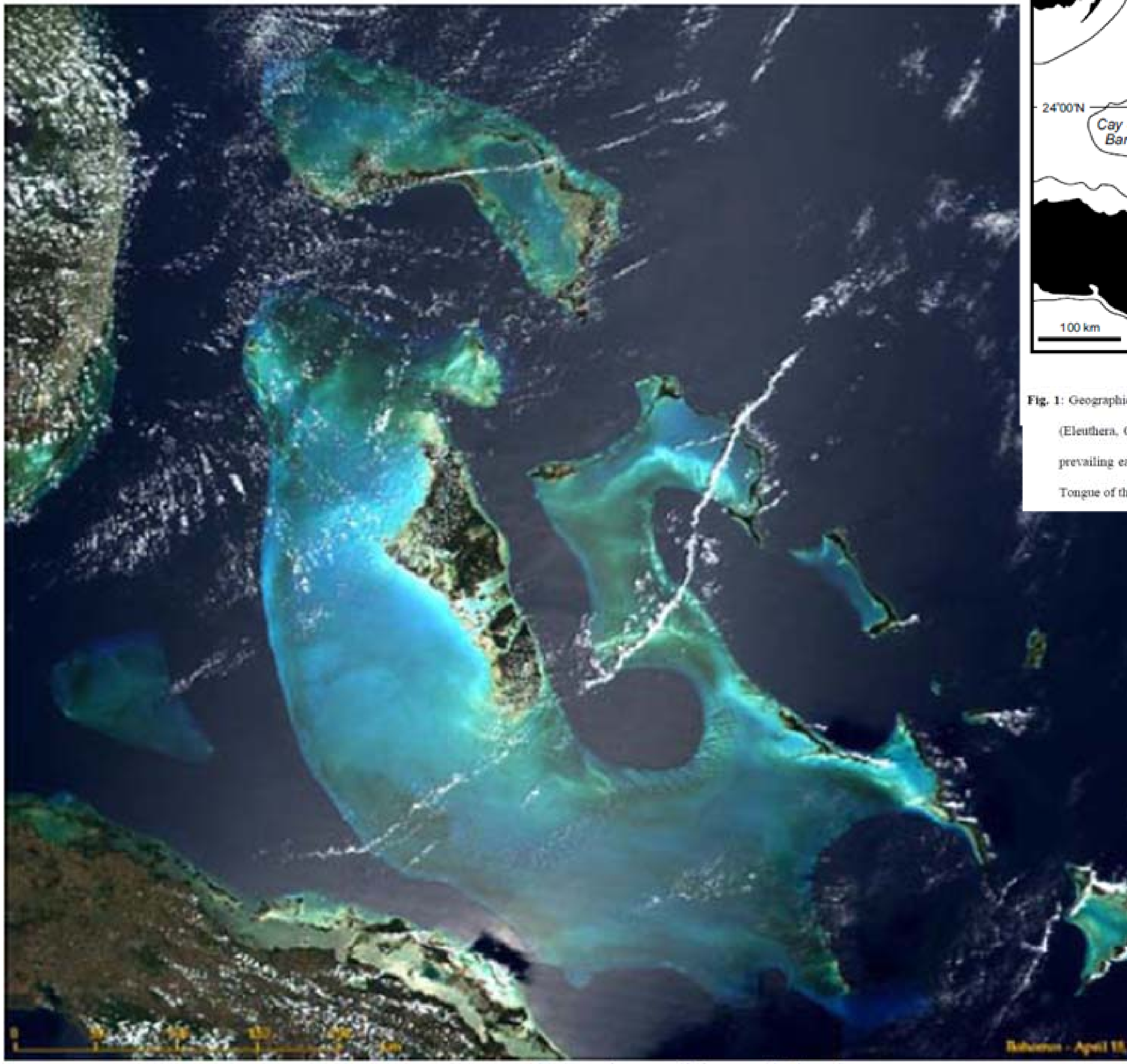


E Nief-1 Rock Strength Calculated Using Militzer and Stoll Equation (1973)
Core no:3 depth 5594 to 5605 feet

MD DEPTH (FEET)	DT	7682/DT	(7682/DT)^1.82
5594.0	45.88	167.48	11159
5594.5	**46.91**	163.80	10717
5595.0	47.77	160.85	10368
5595.5	48.78	157.52	9981
5596.0	49.8	154.30	9612
5596.5	50.5	152.16	9371
5597.0	50.7	151.56	9304
5597.5	50.43	152.37	9395
5598.0	48.82	157.39	9966
5598.5	47.46	161.90	10492
5599.0	46.75	164.36	10784
5599.5	46.52	165.18	10881
5600.0	46.51	165.21	10885
5600.5	46.72	164.47	10796
5601.0	47.13	163.04	10626
5601.5	47.1	163.14	10638
5602.0	46.93	163.73	10709
5602.5	46.49	165.28	10894
5603.0	46.31	165.93	10971
5603.5	46.19	166.36	11023
5604.0	46.13	166.57	11049
5604.5	46.07	166.79	11075
5605.0	46.05	166.86	11084
Average Rock Strength E Nief core no:3			**10512 PSI**

Higher-rock-strength lithology--fewer fractures and lowerporosity.

Great Bahama Oolitic Limestone as an analog for Oseil field



Bahamian oolitic sand shoals.

The Symphony of the Spheres: Oolitic Sand bodies, Bahamas*

Gene Rankey[1]

Search and Discovery Article #50250 (2010)
Posted March 25, 2010

*Adapted from 2008-2009 AAPG Distinguished Lecture.

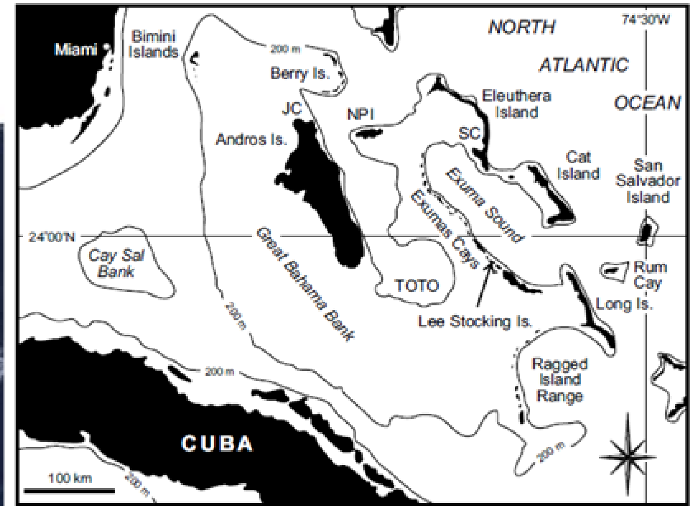
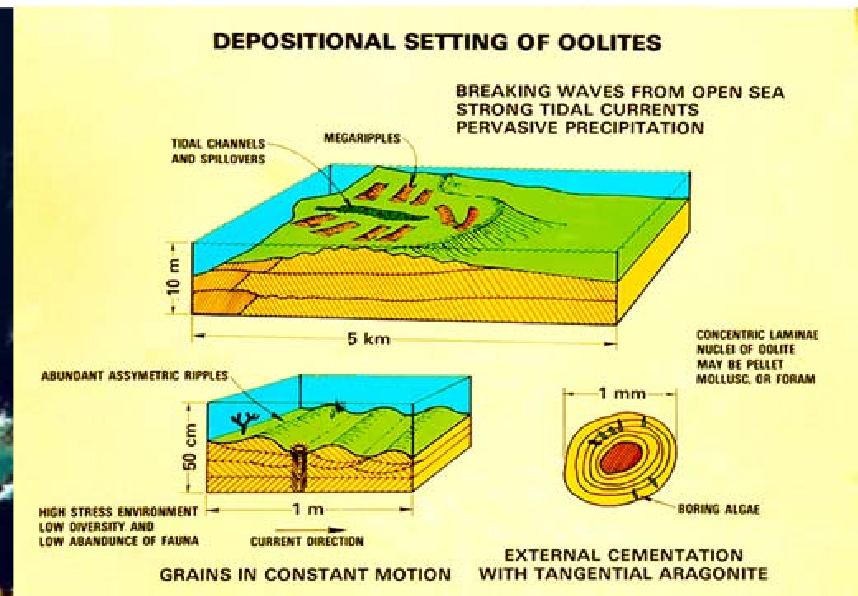


Fig. 1: Geographical situation of the Great Bahama Bank (GBB). The occurrence of islands (Eleuthera, Cat, Exumas, Long) on the eastern margin of GBB is likely related to the prevailing easterly winds. JC = Joulters Cays, NPI = New Providence Island, TOTO = Tongue of the Ocean, SC = Schooners Cays.



The paradoxical occurrence of oolitic limestone on the eastern islands of Great Bahama Bank : where do the ooids come from ?

PASCAL KINDLER[1] and ALBERT C. HINE[2]

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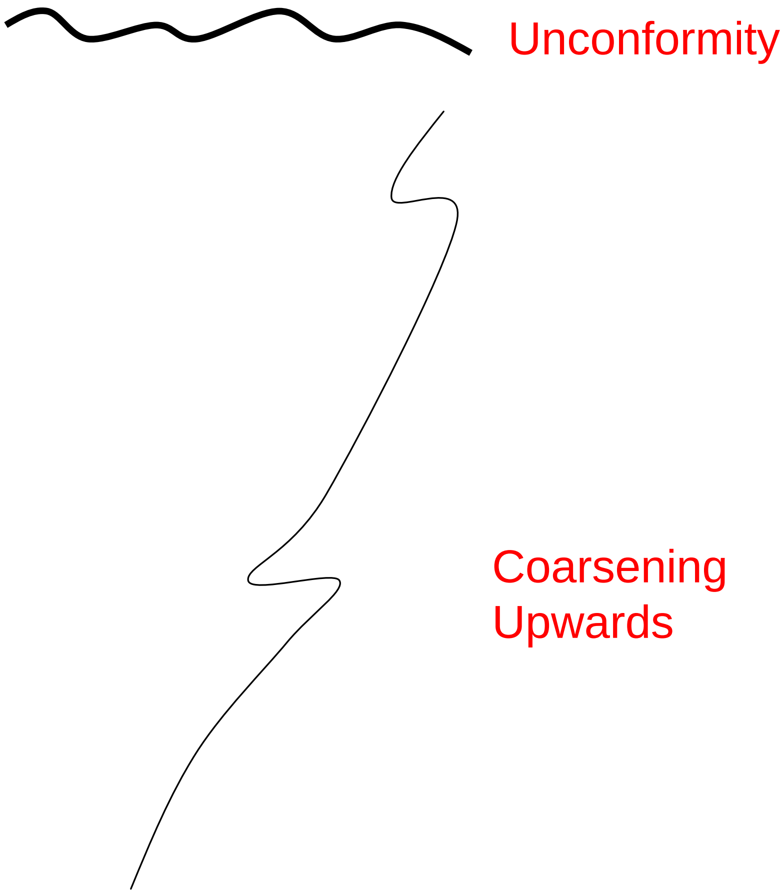
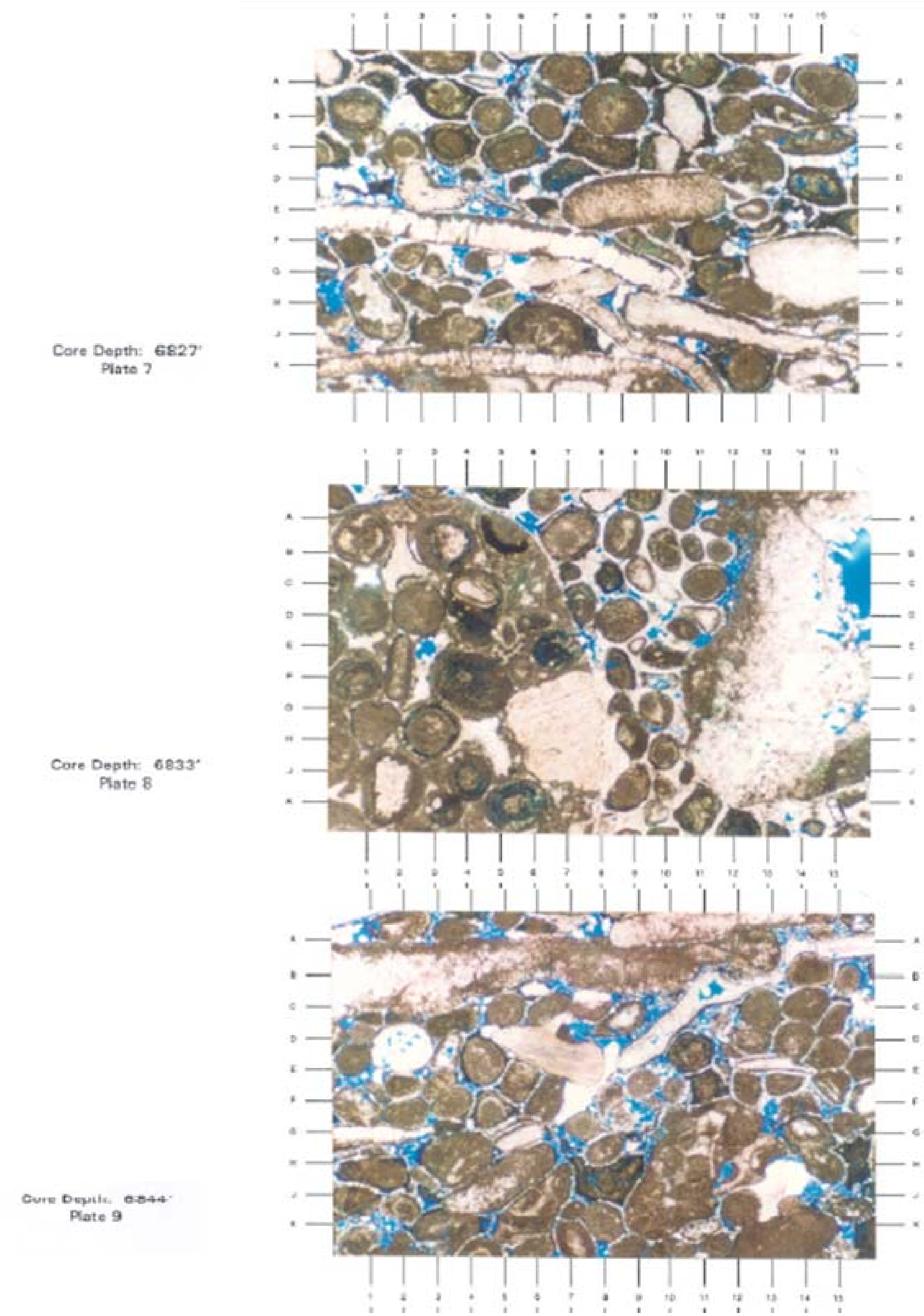
[2]College of Marine Science, University of South Florida, St. Petersburg, FL 33701, USA

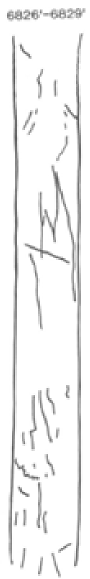
Depositional Environment

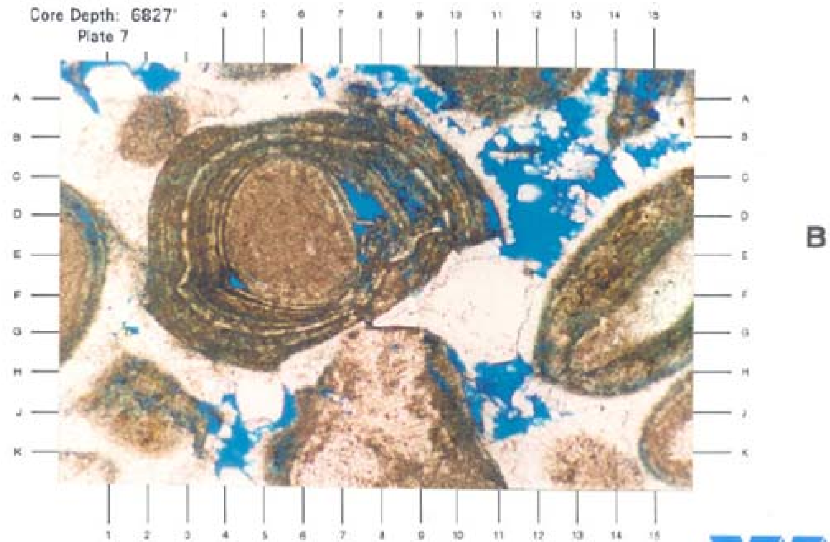




Oolitic carbonate deposited in regressive cycle of shallow-marine environment, from low-energy restricted marine to high-energy marine sand shoals.

Dissolution and Breccias Alteration





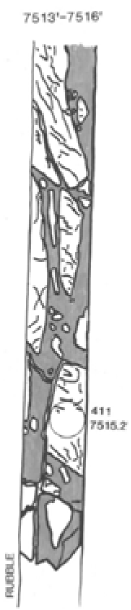
Micritisation of molluscan fragments has resulted in micrite-envelops. Isopachous rims of calcite cement is evident (Pl.B: C15). Dissolution of molluscs was followed by compaction that has distorted some ooids (Pl.B: D9), the precipitation of equant calcite cement, infilling primary and secondary porosity.

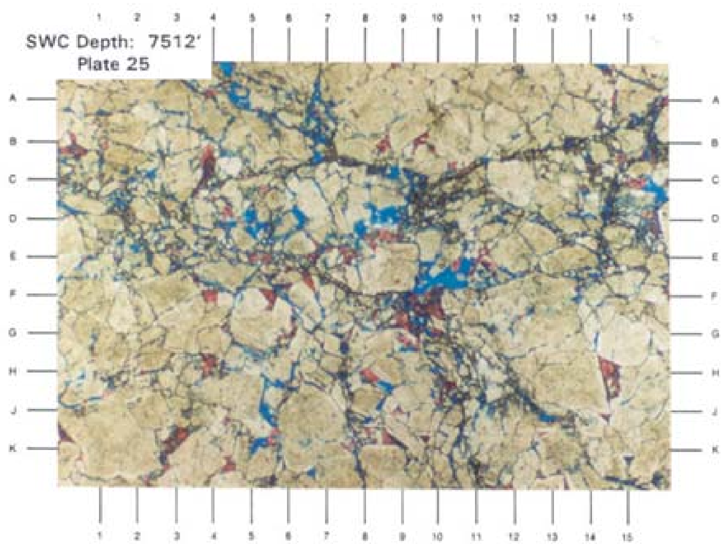
Western Atlas International

Corelab Indonesia

Early Jurassic extension followed by uplift and surface exposure has generated dissolution, brecciation of Limestone and Dolostone.

Thin section and core of dissolution zone from OS-1 well occur in Oolitic limestone; dissolution of Mollusk has distorted some Ooids and created better porosity.



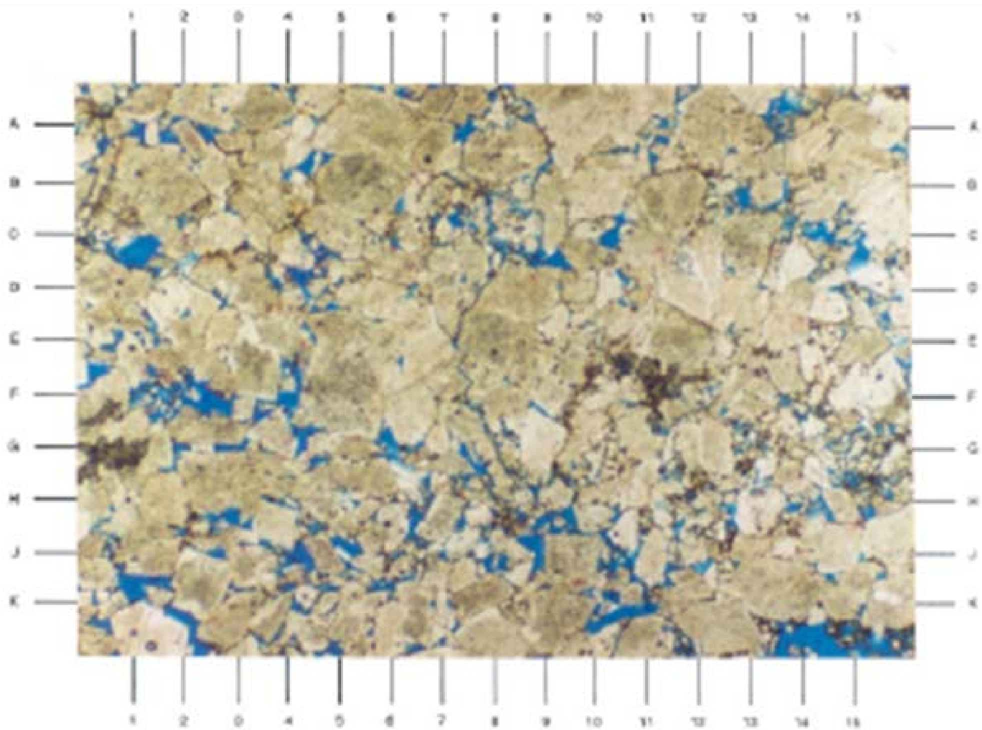


A dolomudstone? is heavily fractured (brecciated) and composed of hypidiotopic dolomite crystals that forms a mosaic fabric. The diameter of dolomite crystals ranges from 80 to 600 microns, with an average of 180 microns. No grains were evident.

Heavily fractured (brecciated) Dolostone is clearly seen in core and thin section.
Brecciation with high angle fracture could create very high vertical permeability that could connect reservoir to aquifer.

Diagenetic Compaction

Less compacted Dolostone (Oseil-1well)



Dolomitisation has destroyed the original rock (?precursor limestone).

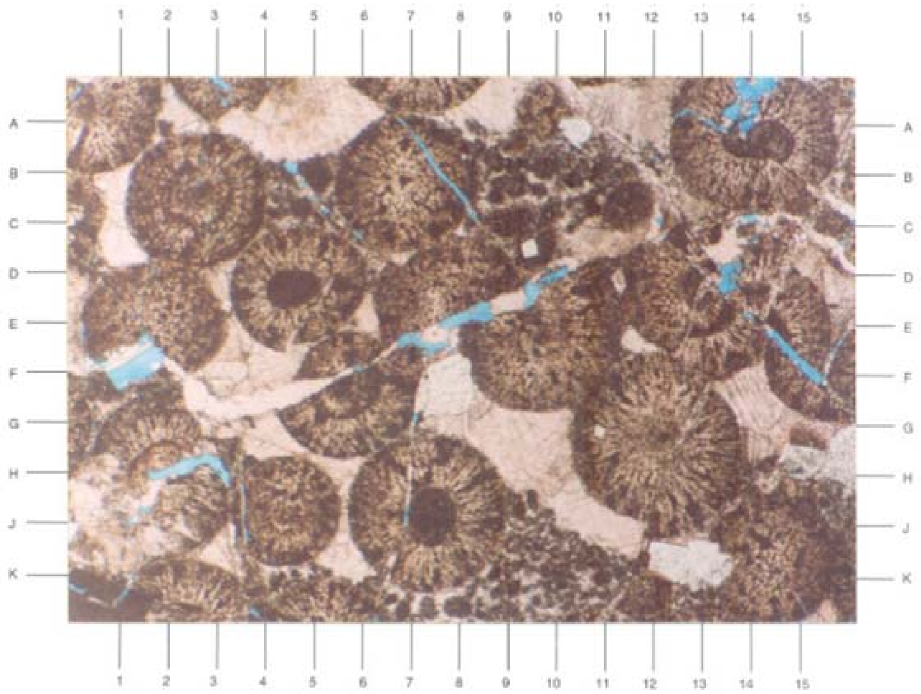
Intercrystalline porosity is good and well connected. Oil staining is locally observed (Pl.B: G7).

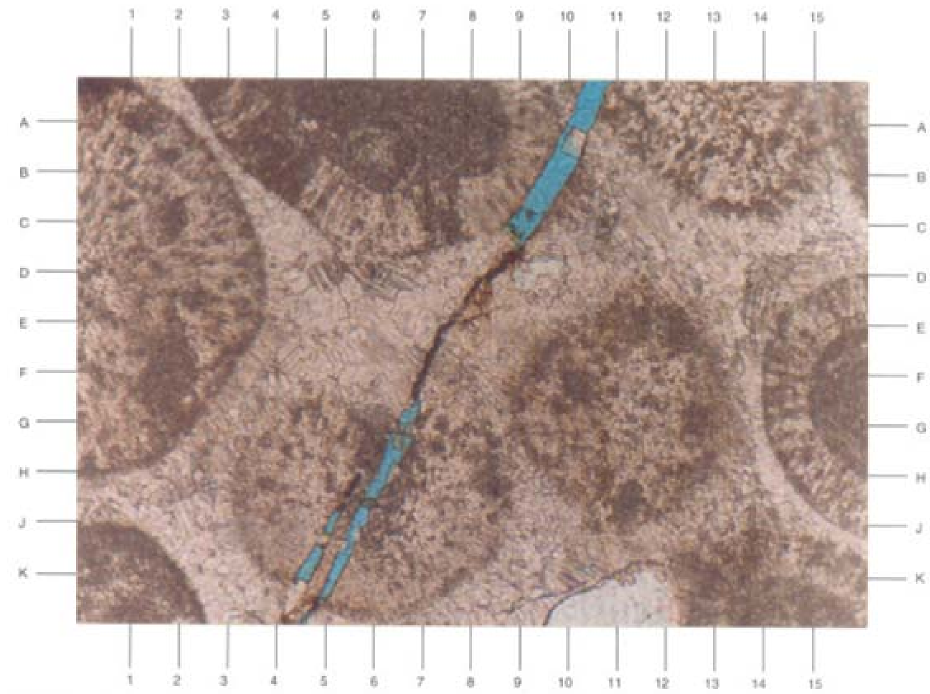
More compacted Dolostone (E.Nief-1 well)

FIGURE 12b - Thin section of Manusela Formation showing total replacement of grainstone by dolomite. Sample from East Nief 1 well at depth of 5594' (RKB)

Compaction diagenetic alteration caused by burial will destroy dolostone porosity; Oseil-1 dolostone is less compacted, compared to E,Nief-1.
Rock strength is also increased by compaction; rock strength of dolostone in E.Nief-1 area is much greater, compared to OS-1.

Fracturing History

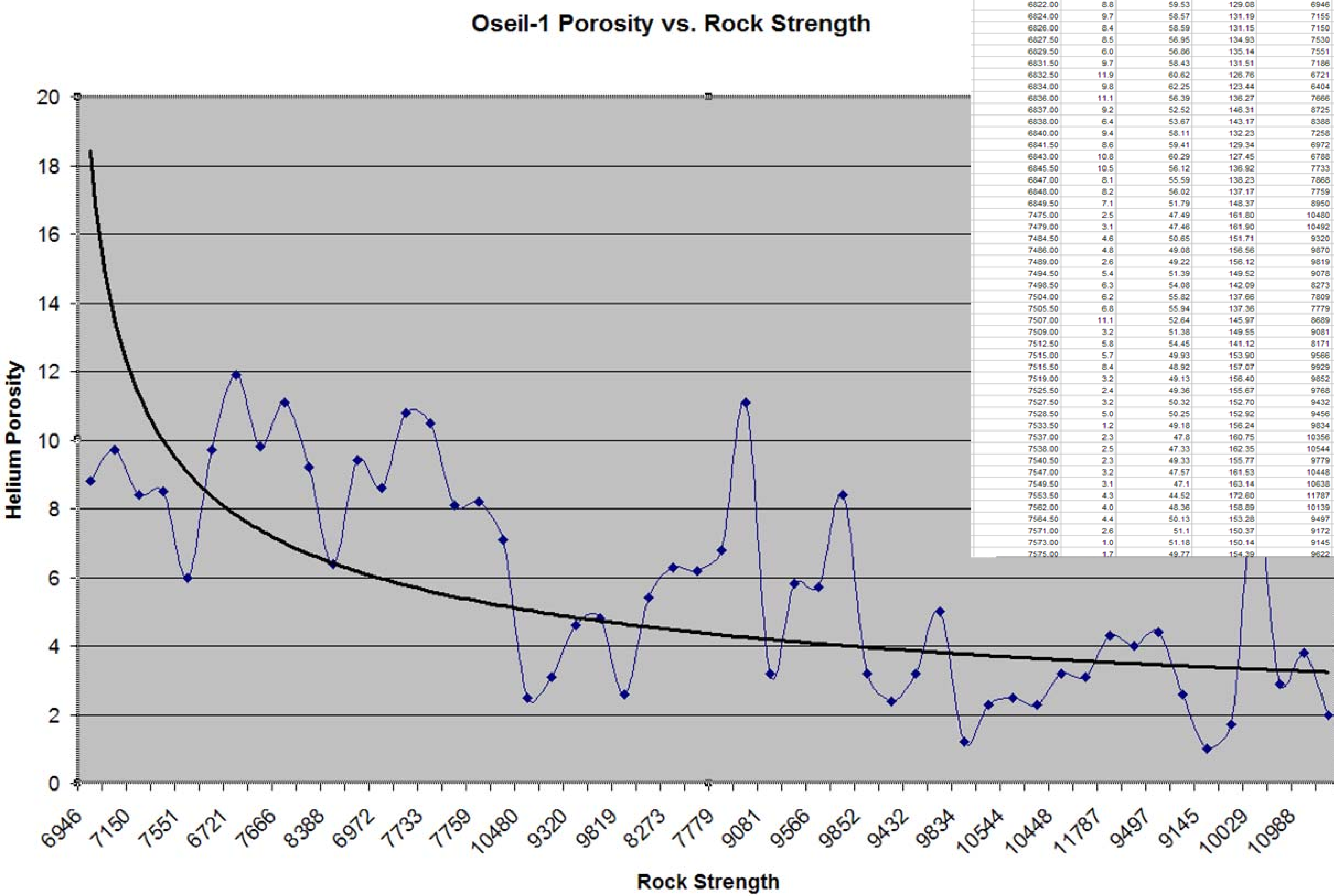




Intergranular porosity is mostly filled with blocky calcite cement (G9). Later stage of fracturing caused millimeter-scale displacement.

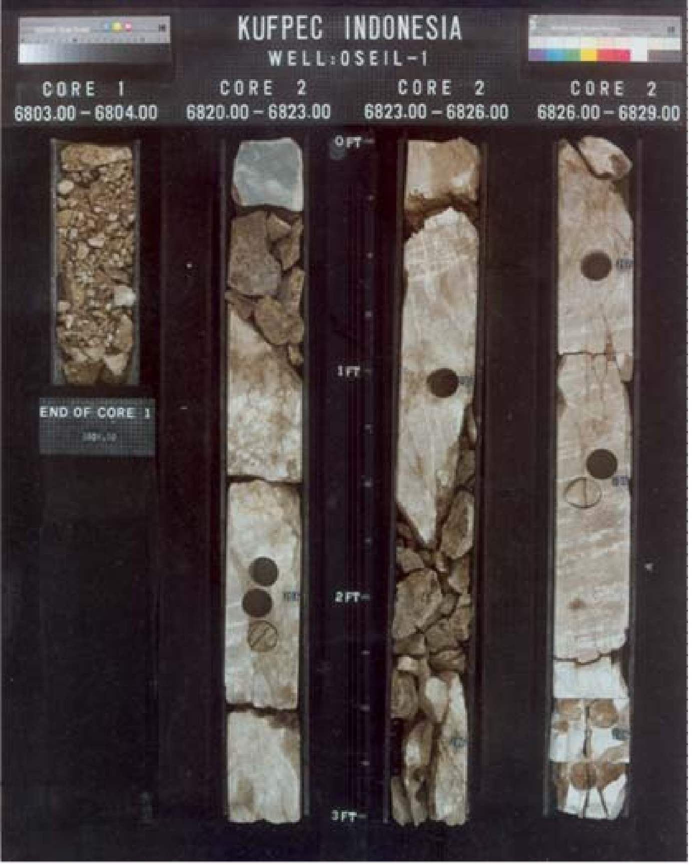
Early fractures are cemented by calcite; later fractures are open and contain calcite and bitumen (E8).

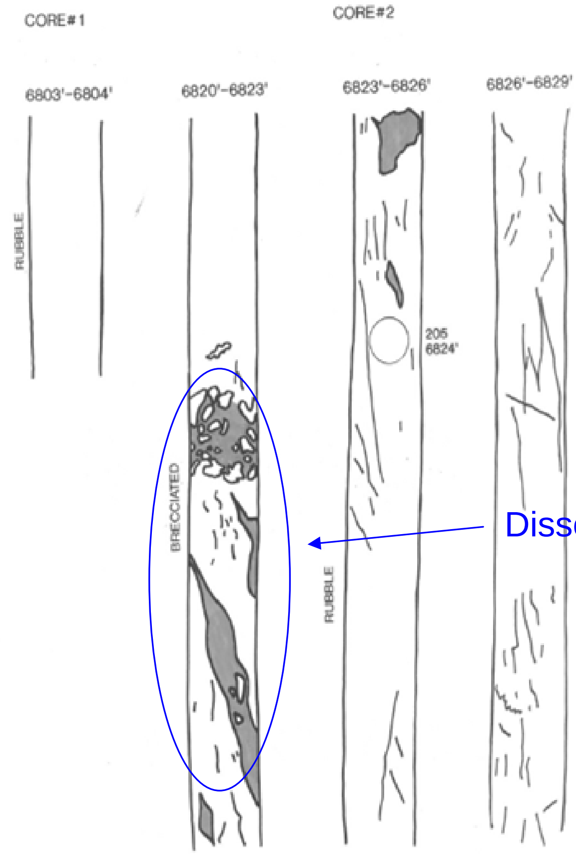
Compression began in late Neogene and rectified early fractured rock that had been cemented by calcite and caused millimeter-scale displacement; younger fractures are open and could contain oil.



Helium Porosity				
Depth (feet)	Porosity	DT (msec/feet)		UCS (PSI)
		DT	7682/DT	(7682/DT)^1.82
6822.00	8.8	59.53	129.08	6946
6824.00	9.7	58.57	131.19	7155
6826.00	8.4	58.59	131.15	7150
6827.50	8.5	56.95	134.93	7530
6829.50	6.0	56.86	135.14	7551
6831.50	9.7	58.43	131.51	7186
6832.50	11.9	60.62	126.76	6721
6834.00	9.8	62.25	123.44	6404
6836.00	11.1	56.39	136.27	7666
6837.00	9.2	52.52	146.31	8725
6838.00	6.4	53.67	143.17	8388
6840.00	9.4	58.11	132.23	7258
6841.50	8.6	59.41	129.34	6972
6843.00	10.8	60.29	127.45	6788
6845.50	10.5	56.12	136.92	7733
6847.00	8.1	55.59	138.23	7868
6848.00	8.2	56.02	137.17	7759
6849.50	7.1	51.79	148.37	8950
7475.00	2.5	47.49	161.80	10480
7479.00	3.1	47.46	161.90	10492
7484.50	4.6	50.65	151.71	9320
7486.00	4.8	49.08	156.56	9870
7489.00	2.6	49.22	156.12	9819
7494.50	5.4	51.39	149.52	9078
7498.50	6.3	54.08	142.09	8273
7504.00	6.2	55.82	137.66	7809
7505.50	6.8	55.94	137.36	7779
7507.00	11.1	52.64	145.97	8689
7509.00	3.2	51.38	149.55	9081
7512.50	5.8	54.45	141.12	8171
7515.00	5.7	49.93	153.90	9566
7515.50	8.4	48.92	157.07	9929
7519.00	3.2	49.13	156.40	9852
7525.50	2.4	49.36	155.67	9768
7527.50	3.2	50.32	152.70	9432
7528.50	5.0	50.25	152.92	9456
7533.50	1.2	49.18	156.24	9834
7537.00	2.3	47.8	160.75	10356
7538.00	2.5	47.33	162.35	10544
7540.50	2.3	49.33	155.77	9779
7547.00	3.2	47.57	161.53	10448
7549.50	3.1	47.1	163.14	10638
7553.50	4.3	44.52	172.60	11787
7562.00	4.0	48.36	158.89	10139
7564.50	4.4	50.13	153.28	9497
7571.00	2.6	51.1	150.37	9172
7573.00	1.0	51.18	150.14	9145
7575.00	1.7	49.77	154.39	9622

Exponential relationship of laboratory measurements of Helium porosity (taken from cores) versus rock strength (derived from sonic log).





Dissolution zone

Os-1 Rock Strength Calculated Using Militzer and Stoll Ec

Core no:1 depth 6820 to 6829 feet

MD DEPTH (FEET)	DT	7682/DT	(7682/DT)^1.82
6816.50	59.68	128.75	6914
6817.00	59.65	128.82	6921
6817.50	59.85	128.39	6879
6818.00	60.49	127.03	6747
6818.50	61.48	124.98	6550
6819.00	62.52	122.90	6354
6819.50	63.36	121.28	6201
6820.00	63.68	120.67	6144
6820.50	63.17	121.64	6235
6821.00	62.02	123.90	6447
6821.50	60.71	126.57	6702
6822.00	59.53	129.08	6946
6822.50	58.69	130.93	7128
6823.00	58.36	131.67	7202
6823.50	58.4	131.58	7193
6824.00	58.57	131.19	7155
6824.50	58.8	130.68	7104
6825.00	59.05	130.13	7049
6825.50	59.08	130.06	7043
6826.00	58.59	131.15	7150
6826.50	57.7	133.17	7352
6827.00	57.06	134.67	7503
6827.50	56.95	134.93	7530
6828.00	57.03	134.74	7510
6828.50	56.98	134.85	7522
6829.00	56.86	135.14	7551
Average Rock Strength OS-1 core no:2			6963 PSI

KEY TO FRACTURES :

Filled fractures (fractures filled with breccia, rock flour or porous matrix)

Large open fractures

Microfractures or fractures which are healed with calcite cements

Stylolites

Vugs or isolated pore spaces

FACIES	DESCRIPTION
A	OOLITIC GRAINSTONE

R. Barraclough.
G. Kemp.
February 1996.

Petrographic Data 6827' MD

Lithology: Limestone

Company : Kufpec
Well : Oseil-1

File No.: PET-93.131

PETROGRAPHIC DATA SHEET

Core Depth: 6827'
Plate 7

Lithology : Limestone
Classification : Oolitic-molluscan grainstone

GRAINS			68%	CEMENTS	21%
Ooids			51%	Calcite	21%
Peloids			4%	REPLACEMENTS	0%
Intraclasts			1%		
Molluscs			9%		
Echinoderms			3%		
MATRIX			0%	VISIBLE POROSITY	11%
				Intergranular	9%
				Mouldic	2%
	Min	Mode	Max	TEXTURE	
Grain size	V.fine	Medium	V.coarse	Sorting : Moderate	
Pore Size (mm)	0.01	0.13	0.24	Grain Contacts : Floating > Tan	
				Abrasion : Moderate	

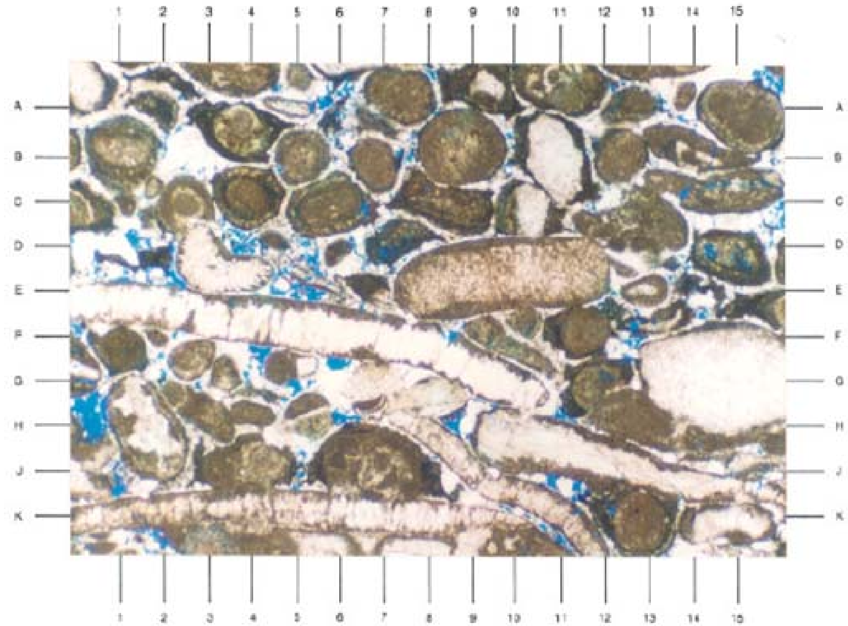
Summary :

A medium-grained oolitic-molluscan grainstone is laminated and contains abundant ooids, accompanied by common imbricated molluscan fragments (Pl.A: bottom) and minor peloids, echinoderms and intraclasts. Some ooids have very thin concentric laminae (superficial, Pl.A: B7).

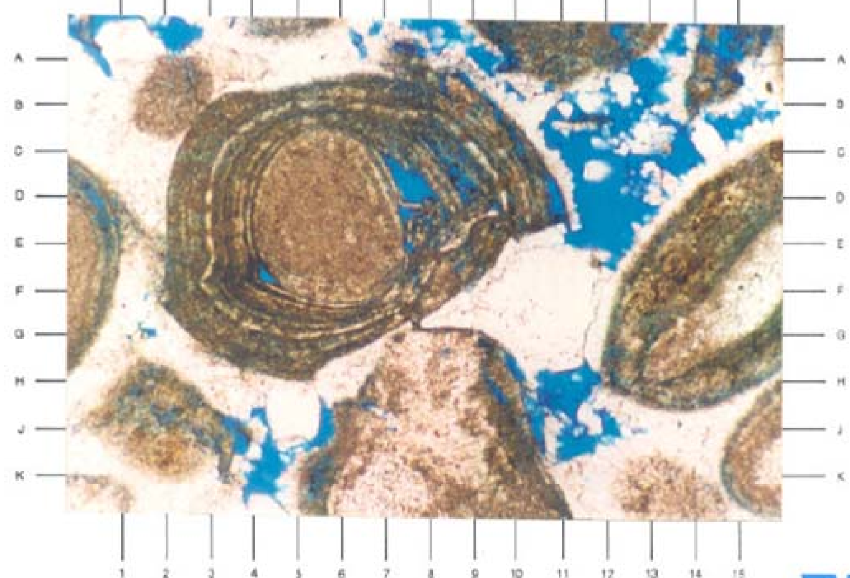
Micritisation of molluscan fragments has resulted in micrite-envelops. Isopachous rims of calcite cement is evident (Pl.B: C15). Dissolution of molluscs was followed by compaction that has distorted some ooids (Pl.B: D9), the precipitation of equant calcite cement, infilling primary and secondary porosity.

Visible porosity is fair, comprising widespread calcite reduced intergranular porosity and localised mouldic porosity.

Plate A: 1cm = 0.24mm, Plane polars
Plate B: 1cm = 0.06mm, Plane polars



A



B

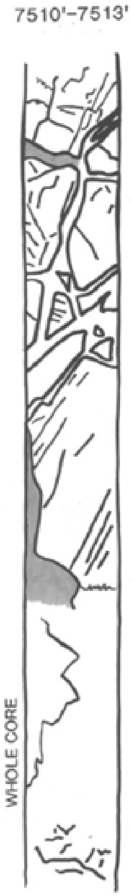
Western Atlas International

P.T. Corelab Indonesia

Os-1 Petrography Data 6827' MD

Lithology: Limestone

Lithology: Dolostone



Company : Kufpec
Well : Oseil-1

File No.: PET-93.131

PETROGRAPHIC DATA SHEET

SWC Depth: 7512'
Plate 25

Lithology : Dolostone
Classification : Dolomudstone?

Full Diameter Porosity : 5.8%
Full Diameter Permeability : 0.58 md

GRAINS			0%	CEMENTS	21%
				Calcite	21%
				REPLACEMENTS	0%
MATRIX			0%	VISIBLE POROSITY	11%
				Intergranular	9%
				Mouldic	2%
	Min	Mode	Max	TEXTURE	
Grain size	-	-	-	Sorting : -	
Pore Size (mm)	0.01	0.17	0.7	Grain Contacts : -	
				Abrasion : -	

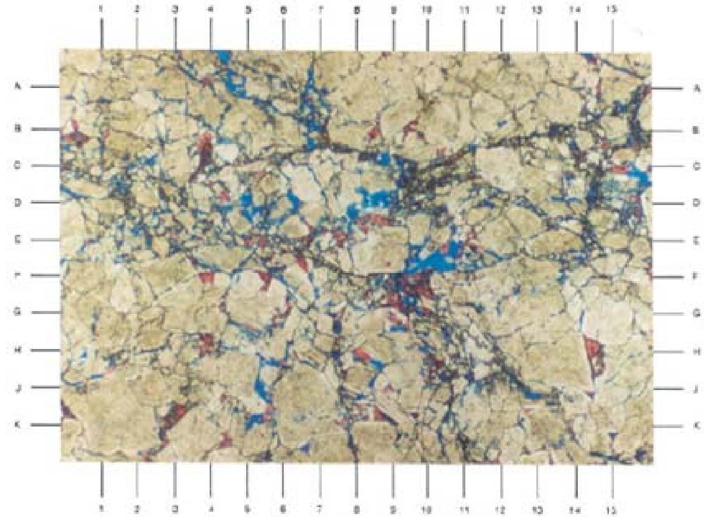
Summary :

A dolomudstone? is heavily fractured (brecciated) and composed of hypidiotopic dolomite crystals that forms a mosaic fabric. The diameter of dolomite crystals ranges from 80 to 800 microns, with an average of 180 microns. No grains were evident.

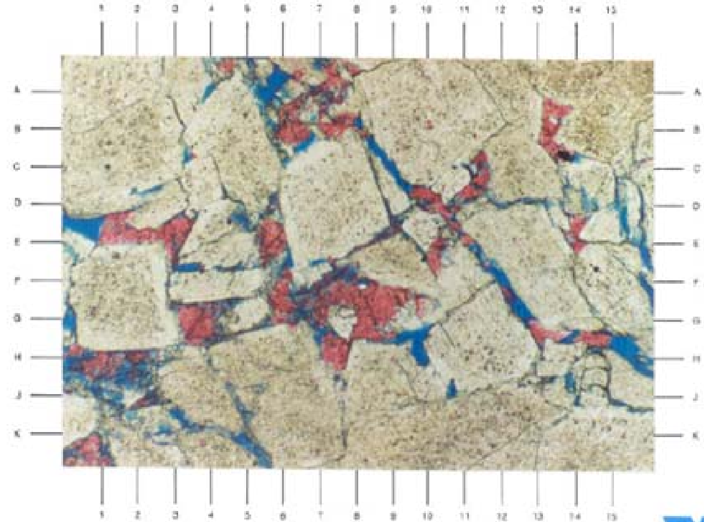
Dolomite replaces the former lithology. Fracturing was succeeded by calcite (Pl.B: E3) cementation that also infills intercrystalline porosity.

Excellent porosity is visible and consists mainly of fractures with lesser intercrystalline pores (Pl.A: J5.5).

Plate A: 1cm = 0.24mm, Plane polars
Plate B: 1cm = 0.06mm, Plane polars



A



B

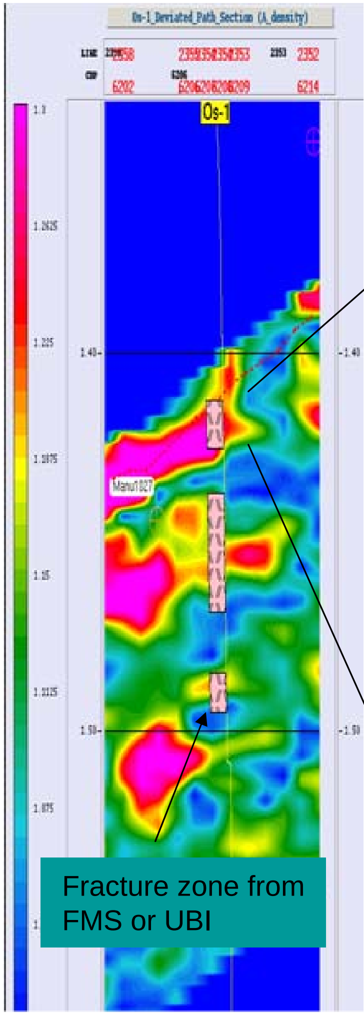
Western Atlas International

P.T. Corelab Indonesia

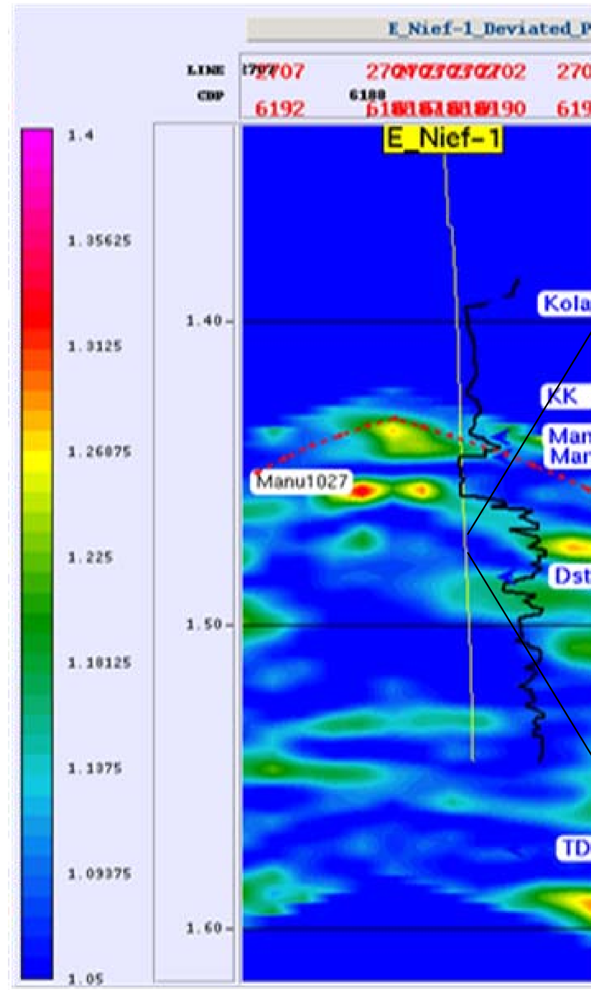
Os-3 Rock Strength Calculated Using Militzer and Stoll Equation (1973)				
Core no:3 depth 7510 to 7513 feet				
7610.00	51.44	149.38	9062	
7610.50	51.37	149.58	9084	
7611.00	51.48	149.26	9049	
7611.50	52.06	147.60	8866	
7612.00	52.59	146.11	8704	
7612.50	52.65	145.94	8686	
7613.00	52.52	146.31	8725	
Average Rock Strength			8882	PSI

Seismic Anisotropy and Oseil Cores

SEISMIC ANISOTROPY



SEISMIC ANISOTROPY



Core and seismic anisotropy of Oseil-1 upper zone showing high intensity of Manusela carbonate fractured reservoir.

High fracture intensity = High seismic anisotropy

E Nief-1 core and seismic anisotropy showing Manusela carbonate fractured reservoir not developed.

Low fracture intensity = Low seismic anisotropy

Future research on Geomechanical and AVAZ

Static geomechanical cores measurement for the following physical properties:

1. Poisson ratio
2. Rocks strength, unconfined compressive strength (UCS)
3. Thomsen parameter using ultrasonic stiffness at 0, 45 & 90 degrees to fracture planes.

CORE#4

In the case of anisotropy ,Vs shear wave is polarized into Vs fast and Vs slow, shear wave traveling parallel to fractured zone will have faster velocity, while shear wave traveling perpendicular to fractured zone will have slower velocity, γ Thomsen parameter will be:

$$\gamma = \frac{Vs\,fast - Vs\,slow}{Vs\,slow}$$ crated significant positive value **0.15**

If in the case of dissolution or brecciation and P wave velocity changes dependent on fracture strike and direction, ε and δ of Thomsen parameter may change:

$$\varepsilon = \frac{Vp\ 90\,deg - Vp\ 0\,deg}{Vp\ 0\,deg} = -0.05$$

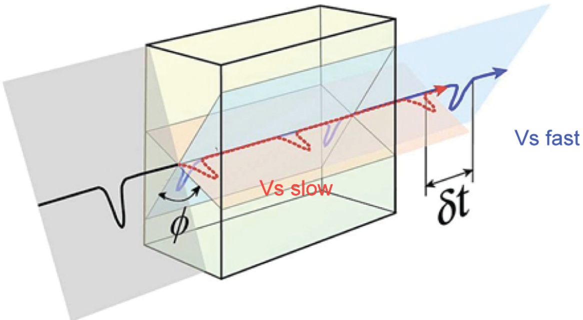
$$\delta = \frac{Vp\ 45\,deg - Vp\ 0\,deg}{Vp\ 0\,deg} - \varepsilon = -0.05$$

and coefficient AVO Fracture anisotropy

$$B_{an} = -0.05 + 1.2[\frac{Vs}{Vp}]^2$$

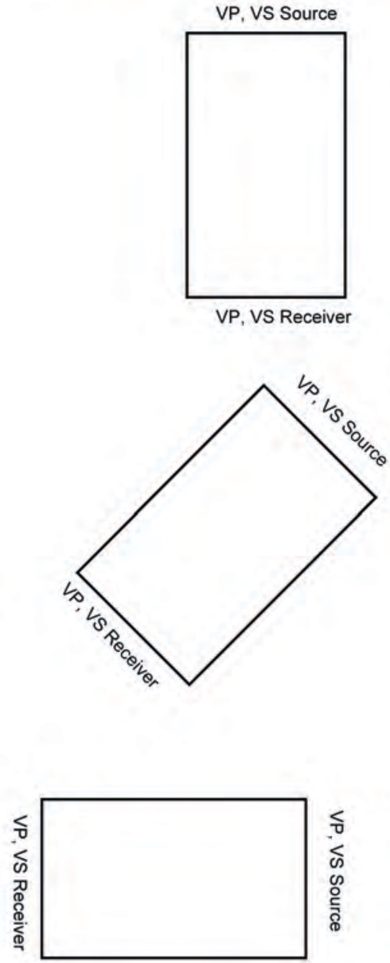
$$C_{an} = \frac{1}{2}[-0.05 \sin^2 \emptyset + 0.05]$$

Shear wave splitting in anisotropic media



FRACTURE ANISOTROPY FROM CORES

Thomsen parameter using ultrasonic stiffness at 0, 45 & 90 deg to fracture planes.



$$\gamma = \frac{Vs\ fast - Vs\ slow}{Vs\ slow}$$

$\gamma =$ 0.15

$$\varepsilon = \frac{Vp\ 90\ deg - Vp\ 0\ deg}{Vp\ 0\ deg} = -0.05$$

$$\delta = \frac{Vp\ 45\ deg - Vp\ 0\ deg}{Vp\ 0\ deg} - \varepsilon = -0.05$$

and coefficient AVO Fracture anisotropy

$$B_{an} = -0.05 + 1.2\left[\frac{Vs}{Vp}\right]^2$$

$$C_{an} = \frac{1}{2}\left[-0.05 \sin^2 \emptyset + 0.05\right]$$

Oseil-1 Cores Anisotropy Measurement

Conclusion

- *G&G Problems for carbonate fracture reservoir are lithology heterogeneity and fracture distribution.*
- *Combining cores, well data and seismic will be valuable to predict reservoir heterogeneity and fracturing.*
- *Rock strength is used because simple approach to heterogeneity of reservoir and AVAZ are used for fracture prediction.*
- *Low-rock-strength lithology will have more fractures, more porosity and more anisotropy. High-rock-strength lithology is less fractured, less porous and isotropic.*