INDONESIAN PETROLEUM ASSOCIATION
IPA
Newsletter

April 2005

http://www.ipa.or.id

A non-profit organization established March 1971 by the Steering Committee and Representatives of 28 founding companies

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OPEN FORVM ISSUE

Anisotropic Rocks Deepwater Interpretation Concepts

from the Editor

The March edition is the Open Forum Issue. Two excellent papers were submitted for publication, both coming from the field of geophysics.

The first is contributed by Dr. Heloise Lynn. Dr. Lynn is allowing the IPA to republish the expanded abstract of her SEG/AAPG Distinguished Lecture. This offering is a thoughtful and insightful presentation describing the state of seismic anisotrophy and its relevance to petroleum production. In the second article, Dr. Nick Hoffman discusses sedimentary clinoforms and their relationship to sea-level fluctuation and tectonic tilting. The membership should find both of these an interesting read.

Based on discussions with some member, in the November 2004 issue, I had proposed a new Letter to the Editor section. Unfortunately, over the last few months, I have received no letter or comment. Consequently, I am assuming that there is less interest in a letters segment than previously thought and that no vehicle for feedback is needed at this time.

The Newsletter is also in need of technical paper contributions, and I urge the readership to please consider writing either a paper or expanded abstract for the Newsletter.

The next issue of the newsletter will be printed in July. The topics for that issue will be carbonates and tectonics. Paper dealing with either of these subjects should be sent to *astawicki@id.kutpec.com*. I can also be reached at this e-mail address if you have any questions concerning rules. I look forward to hearing from you.

Alfred W. Stawicki
Editor

Indonesian Petroleum Association
Wisma Kyoei Prince, 17th Floor, Suite No. 1701
Jl. Jend. Sudirman Kav. 3, Jakarta 10220
Indonesia
Telp. (021) 572-4284 - 86
Fax (021) 572-4259
E-mail: ipa@cbn.net.id
http: //www.ipa.or.id
P.O. Box 1275 JKP/10012

Rig Visit for Students

Introduction to Wellsite Geology Melandong-1 Well, Indramayu

By Parvita H. Siregar

For the second time, IPA together with IAGI, conducted a course designed for geology students, which took place from 11-12 October 2004. Participants were 30 senior students from Institute Technology Bandung, University of Pajajaran Bandung, Trisakti University and Universitas Pakuan Bogor. The purpose of the course was to introduce students to rig procedures including the responsibilities of the wellsite geologist.

Figure 1, A group photo with the Meladong well in the background

Figure 2, And that thing up there is ....."

Senior oil company geologists, Muhammad Syaiful (ENI Indonesia), Shofiudin Thoha (Amerada Hess) and Irma Hermawati (VICO) gave the course. The first day ended with a dinner and Q&A session among the students and senior IPA/IAGI members. The discussions went on until after midnight.

The second day began at 05:30 with everyone ready to go to the wellsite. The students were divided into groups of five to make the visit more effective. Arriving at the Melandong-1 well, operated by Pertamina, around 08:50, the students were met by a very enthusiastic rig staff that explained rig operations. All of them had a good discussion with the Company Man, Operations Geologist, Wellsite Geologist, Drilling Engineer and others. Bp. Richard Mutalib (Project Leader of the Exploration Wells) was also present to explain to the students what they were about to see. They were able to observe the drilling rig floor, mudlogging unit and other places.

Figure 3, On the rig, taking a "pose-break"

After a lunch provided by the Pertamina staff, the students expressed great enthusiasm about learning more about the rig, which caused the return to Jakarta to be delayed.

The course was beneficial and the trip was very well organized. Hopefully, this activity will become a routine, as the student program tries to bridge the gap among new graduate students and the oil & gas industry so that one day they might pursue petroleum related careers.

Figure 4, Group photo with Ron Noble – Professional Committee Chairman and the IPA/IAGI lecturers

IPA Technical Symposium on

Deepwater and Frontier Exploration in Asia and Australasia

The much anticipated technical symposium on Deepwater and Frontier Exploration was held at the Four Seasons Hotel in Jakarta, December 7-8, 2004.

This was the 4th symposium of its type organized by the IPA over the past decade.

1995 "Sequence Stratigraphy of SE Asia"
1997 "Petroleum Systems of SE Asia and Australasia"
1999 "Gas Habitats of SE Asia"
2004 "Deepwater and Frontier Exploration in Asia and Australasia"

The focus of these symposia has been a little different from regular IPA Conventions, with audience attention being entirely directed towards the technical presentations and poster sessions.

Single oral sessions were held in the main ballroom of the hotel. Exclusive time was allocated to view and discuss the poster presentations, all of which were located in the foyer immediately outside the ballroom.

There were 8 oral sessions featuring 28 talks, including 3 keynote addresses. In addition, there were 18 poster sessions, making a total of 46 presentations in all.

The vast majority of presentations covered brand new material never presented before at other industry conferences. This made for an exciting program, with ample opportunity for in depth technical discussions.

All the presentations are documented in the conference proceedings volume, which is available from the IPA on CD or hard copy format.

A special evening technical session was held following the conference dinner. The presentation focussed on some beautiful outcrops of deepwater sediments in the Taranaki basin of New Zealand. The audience was treated to a spectacular field trip without having to leave the comfort of their dinner tables!

The demographics of people attending the conference was very interesting. A total of 250 people registered, plus several complimentary seats were provided to local university students and faculty members. Delegates came from several countries, including:

Australia, New Zealand, Malaysia, Brunei, Singapore, Thailand, India, USA, Canada, UK and Indonesia.

Representatives of 42 oil companies, 28 service providers and 10 universities and government organizations were present. This provided a remarkably diverse group of people. In addition to the technical content, attendees made good use of the networking opportunities for establishing new business contacts in the region.

Without doubt, it was a very successful event! Many thanks to all the delegates and organizers for their support and active participation.

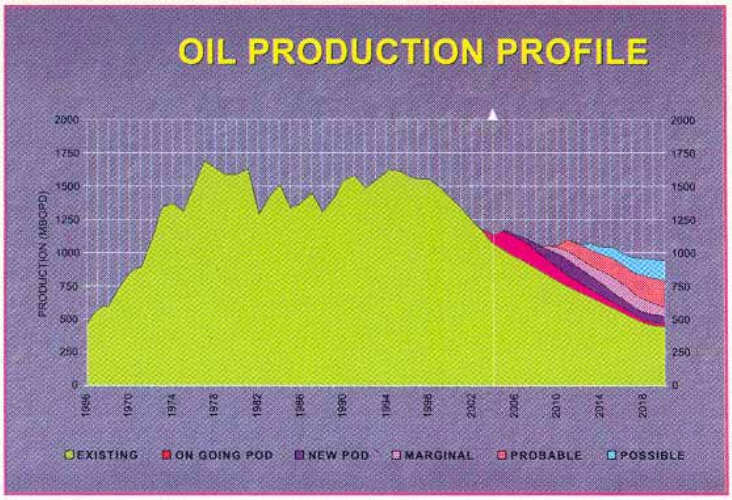
Ron Noble, Unocal.
General Chairman, Organizing Committee

Figure 1, The Organizing Committee of the 2004 "Deepwater and Frontier Exploration in Asia and Australasia" Symposium.

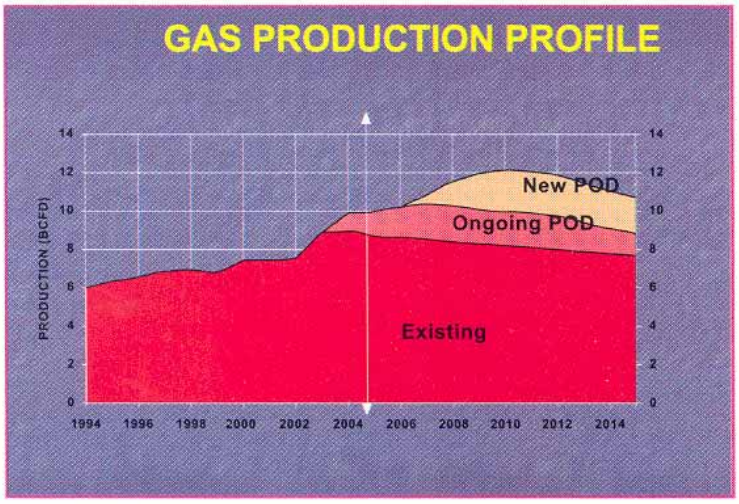
"2004 Summary & 2005 Focus of E & P Activities in Indonesia"

Dharmawan H. Samsu

The first of the 2005 IPA Luncheon Talks was held on February 17, 2005 and was a big success. The talk was entitled, "2004 SUMMARY & 2005 FOCUS OF E&P ACTIVITIES IN INDONESIA" and was presented by Mr. Kardaya Warnika, vice chairman of BPMIGAS. Due to space limitations, this event could only be attended by 210 of our members.



Mr. Kardaya Warnika presented the 2004 E&P activities in a concise report. He summarized past activities from 2000 to 2004, which mainly focused on the signing of new contracts, seismic and drilling activities, production performance, and gas marketing. Some of the most recent discoveries were also recognized. The presentation later dealt with the expectations of the current work programs and their impact on future production levels.



There are several major initiatives being undertaken in 2005. On the front line, the Government will support preparation of 20 New Acreages; while at the same time focusing its effort toward fulfilling domestic gas demand. Intensive seismic and drilling programs, both for exploration and delineation purposes, will characterize 2005. It was mentioned specifically that new exploration focus areas such as the deepwater Makassar Straits, offshore and onshore East & West Java, Central Sulawesi, South Sumatera, Riau, Jambi and Papua would command the major portion of BPMigas' time and attention. Consistent with the message delivered by BPMigas in 2004, Mr. Kardaya Warnika reiterated that the focus on marginal field development and on the increasing of brownfield production through negotiable incentive packages would continue. This could include the favorable consideration to recommendations for new terms and conditions, and/or new types of contracts.

The next luncheon program is March 24 when our speaker will be the President of IPA, Mr. Chris Newton.

Regards,
Dhar Samsu

INDONESIAN PETROLEUM ASSOCIATION

IPA

30th Annual IPA Convention and Exhibition

"The Urgency of Building Competitiveness to Attract Oil and Gas Investment in Indonesia"

Jakarta Convention Center, Jakarta, Indonesia
August 30 – September 1, 2005

Keynote Speech: *David O'Reilly, Chairman and CEO of ChevronTexaco Corporation*

Plenary Sessions: *The topics for each plenary session are "Implementing and Enabling Policies and Regulation for Oil and Gas Industry" and "Attracting Investment to Build the Oil and Gas Business". Distinguished representatives of Government, Industry, and Expert are invited to discuss issues relevant to the each topic.*

Technical Presentations: *Targeting approximately 100 papers from all aspects of the petroleum industry. The technical programme offers a unique opportunity for multi-disciplinary interaction amongst national and international participants and other hydrocarbon business entities.*

Exhibition: *2,000 sqm of exhibition booth space has been laid out, of which 80% has already been committed. 51 companies have so far signed up to exhibit the latest in technology and services. Sponsorship opportunities are also available.*

Registration: *Rp. 1.000.000,- for IPA Member / Rp. 1.200.000,-for Non-Member.*
For overseas participant IPA Member US$ 120 / US$ 150 for Non-Member.
Includes ice breaker, luncheon for 3 days, seminar, and cocktail party.

Field Trips:
1. *Baram Delta, Leaders: Angus Ferguson and Joe Lambiase - Universiti Brunei Darussalam.*
2. *Southern Mountains, SE Java, September 2nd-6th September 2005, Leaders: R. Hall and H. Smyth – University of London.*

Short Courses:
1. *Cenozoic Tectonics of Indonesia: Problems and Models; Prof. Robert Hall – University of London, August 28-29, 2005.*
2. *Evaluation of Reservoirs, Seals and Pay; Prof. John G. Kaldi – University of Adelaide, August 28-29, 2005.*

Golf Tournament: *Satelindo Golf Course, Sunday, August 28, 2005.*
Rp. 1.000.000,- for IPA Member / Rp. 1.200.000,-for Non-Member.

Accommodation:
1. *The Jakarta Hilton International; room rate/night.*
   Superior Room is US$ 80 net; Deluxe Room is US$ 90 net;
   Grand Deluxe US$ 110 net.
2. *Hotel Mulia; room rate/night. Mulia Splendor is US$ 105 ++*
3. *Hotel Atlet Century Park Jakarta; room rate/night*
   Superior Room is Rp. 400.000,- net;
   Deluxe Room is Rp. 470.000,- net;
   Executive Club Room Rp. 550.000,- net.

For details please contact the IPA secretariat, phones: (62-21) 572-4284, 572-4285, 572-4286, 0811-938776
or fax (62-21) 572-4259, e-mail ipa@cbn.net.id
For Exhibition please contact, Mr. Jeremy Dyer, e-mail: jnjdyer@cbn.net.id; phone cell: 0811 918-446

EXHIBITIONS, CONFERENCES & FORUMS

DATE	TITLE	LOCATION	CONTACT DETAILS	TELEPHONE/WEBSITE/FAX
Mar 28-29	Improved Oil Recovery Asia 2005	Kuala Lumpur	IQPC	http://www.iqpc.com.sg
Mar 29-30	Contract Risk Management for Production Sharing Contracts	Kuala Lumpur	IQPC	http://www.iqpc.com.sg
Apr 5-7	SEAPEX Exploration Conference & Farmout Forum	Singapore	SEAPEX	http://www.seapex.org
Apr 5-7	Asia Pacific Oil and Gas Conference and Exhibition (APOGCE)	Jakarta	SPE	http://www.spe.org
Apr 5-7	China International Petroleum & PetroChemical Technical Equipment Exhibition	Beijing	"Zhenwei Exhibition Co., Ltd"	http://www.cippe.net
Apr 10-13	APPEA 2005	Perth	APPEA (Conf' secretariat Julie Hood)	http://www.appea.com.au
Apr 19-21	The 6th China Oil Traders' Conference (COTC)	Hangzhou	C1 Energy	http://www.c1energy.net
Apr 26-27	Horizontal & Multilateral Wells Asia 2005	Kuala Lumpur	IQPC	http://www.iqpc.com.sg
Apr 26-27	Contract Risk Management in Indonesian Oil & Gas	Jakarta	IQPC	http://www.iqpc.com.sg
Apr 28-29	China New Energy Summit 2005	Shanghai	Quimice Consulting Corporation Ltd	http://www.qimice.com
May 8-13	Stagnation of e-Volution: Changing Production Management in 21st Century (Forum)	Phuket	SPE	http://www.spe.org
May 9-10	High Tan Crude Conference	Singapore	Conference Connection	http://www.cconnection.org
May 11-13	LNG Supplies for Asian Markets	Singapore	Conference Connection	http://www.cconnection.org
May 15-20	"Stimulation for the Future - Increasing Production, Reducing Cost (Forum)"	Phuket	SPE	http://www.spe.org
May 16-17	10th Annual Asia Upstream 2005	Kuala Lumpur	Global Pacific & Partners	http://www.petro21.com
May 16-17	Underbalanced Drilling Operations	Kuala Lumpur	Marcus Evans	http://www.marcusevans.com
May 17-18	Produced Water Management Asia 2005	Kuala Lumpur	IQPC	http://www.iqpc.com.sg
May-18	Africa-Asia Oil & Gas 2005	Kuala Lumpur	Global Pacific & Partners	http://www.petro21.com
May 18-21	"3rd Pakistan Oil, Gas & Energy Exhibition and Conference (POGEE 2005)"	Karachi	Pegasus Consultancy (PVT) Ltd	http://www.pogeepakistan.com
May 23-24	China Oil and Gas Summit 2005	Beijing	Allied Resources Allocator (ARA)	http://www.araworldwide.com
May 23-25	ICT 2005 Global Congress on Info & Communication Technology in Energy Sector	Bussan	ICT2005 Secretariat c/o Korean Gas Union	http://www.ict2005.com
May 24-25	3rd Hydrocarbon Asia Bottom Line Improvement Conference 2005	Kuala Lumpur	Hydrocarbon Asia (AP Business Publications)	http://www.safan.com
May 24-25	Global Oil & Gas Opportunities China 2005 (GoGo China)	Beijing	C5	http://www.C5-Online.com
May 24-25	The 2nd Annual China Oil & Gas Summit	Beijing	DGI Events	http://www.dgievents.com
Jun 12-14	Asia Oil & Gas Conference (AOGC 2005)	Kuala Lumpur	Conference Connection	http://www.cconnection.org
Jun 13-16	Oil & Gas Asia (OGA 2005)	Kuala Lumpur	Malaysian Exhibition Services Sdn Bhd	http://www.mesallworld.com
Jul 5-7	2nd International Hydrographic & Oceanographic Industry 2005 (IHOCE 05)	Kuala Lumpur	F&R Exhibition and Conference Sdn Bhd	http://www.fr-exhibitions.com.my
Aug 10-11	China Power Conference & Exhibition	Beijing	PennWell Corporation	http://www.pennwell.com
Aug 30-Sept 1	30th Indonesian Petroleum Assoc' (IPA) Convention and Exhibition	Jakarta	IPA Secretariat	http://www.ipa.or.id
Sept 8-9	New Zealand Oil and Gas Expo 2005	New Plymouth	Swan Exhibitions	http://www.swanexhibitions.com.au
Sept 13-15	Power-Gen Asia 2005	Singapore	PennWell Corporation	http://www.pennwell.com
Sept 14-16	18th World LP Gas Forum	Shanghai	MCI Group/World LPG Association	http://www.wlpgasforum2005.com
Sept 15-17	Gas Expo Shanghai 2005	Shanghai	Nationway Development Ltd & SIEC	http://www.gasexposh.com
Sept 19-21	"Asia Pacific Health, Safety and Environment Conference (APHSE)"	Kuala Lumpur	SPE	http://www.spe.org
Sept 21-24	Gas Indonesia 2005	Jakarta	PT Pamerindo Buana Abadi	http://www.pamerindo.com
Sept 21-24	Oil & Gas Technology Indonesia 2005	Jakarta	PT Pamerindo Buana Abadi	http://www.pamerindo.com
Sept 26-30	18th World Petroleum Congress	Johannesburg	ITE Group Plc	http:www.ite-exhibitions.com
Oct 27-29	CEPEX 2005 - China International Energy and Power Exhibition	Beijing	CWC	http://www.thecwcgroup.com
Oct 29-Nov 1	APIA 2005 (Australian Pipeline Industry Assoc) Convention and Exhibition	Adelaide	APIA	http://www.apia.net.au
Nov 2-Nov 4	China International Gas Exhibition & Conference (CIGEC 2005)	Shanghai	Energy Contents	http://www.energyasia.com
Nov 29-Dec 2	ASCOPE 2005	Manila	Malaysian Exhibition Services Sdn Bhd	http://www.mesallworld.com or www.ascope2005.com
Dec 5-6	International Improved Oil Recovery Conference in Asia Pacific (IIORC)	Kuala Lumpur	SPE	http://www.spe.org

TRAINING COURSES AND WORKSHOPS

DATE	TITLE	LOCATION	CONTACT DETAILS	TELEPHONE/WEBSITE/FAX
Mar 28-30	Production Sharing Contracts & International Petroleum Fiscal Regimes	Kuala Lumpur	Conference Connection	http://www.cconnection.org
Mar 28-30	Oil & Gas Accounting	"Nusa Dua, Bali"	IBC Asia Limited	http://www.ibc-asia.com
Mar 31-Apr 1	"LNG Contracts Drafting, Performance, Negotiations & Dispute Management"	Kuala Lumpur	IBC Asia Limited	http://www.ibc-asia.com
Apr-04	Asian Petroleum Future (Strategy Briefing)	Singapore	Global Pacific & Partners	http://www.petro21.com
Apr-04	Application of Stable Isotope Techniques in Gas and Oil Exploration and Production	Singapore	Intertek Testing	http://www.intertek.com
Apr 4-7	Offshore Pipeline Engineering	Jakarta	IBC Asia Limited	http://www.ibc-asia.com
Apr 25-29	Practical Investment Appraisal and Business Decision Analysis in Petroleum E&P	Bali	IPA (Dr H.L. Ong)	http://www.ipa.or.id
Apr 25-29	Basic Petroleum Economics with Accounting and Budgeting	Kuala Lumpur	OGCI	http://www.ogci.com OR www.petroskills.com
May-16	Advanced Natural Gas Processing Course	Kuala Lumpur	IBC Asia Limited	http://www.ibc-asia.com
Jul 4-5	Fundamentals of LNG (FLNG)	Australia	Conference Connection	http://www.cconnection.org
Jul 7-8	Fundamentals of LNG (FLNG)	Bangkok	Conference Connection	http://www.cconnection.org
Aug 22-24	Cargo Shortages in the Petroleum Industry (seminar)	Singapore	Abacus International	http://www.abacus-int.com
Aug 25-26	Petroleum Trading and International Law (seminar)	Singapore	Abacus International	http://www.abacus-int.com
Aug 28-29	Cenozoic Techtonics of Indonesia; Problems and Models	Jakarta	"IPA (Prof. Robert Hall, Univ. of London)"	http://www.ipa.or.id
Aug 28-29	"Evaluation of Reservoirs, Seals and Pay"	Jakarta	"IPA (Prof. John Kaldi, Univ. of Adelaide)"	http://www.ipa.or.id
Aug 28-Sept 2	Sand Management Strategies (ATW)	Hainan	SPE	http://www.spe.org
Sept 2-6	Southern Mountains of SE Java (Field Trip)	Java	"IPA (Prof. Robert Hall, Univ. of London)"	http://www.ipa.or.id
Sept 13-14	Upstream Government Petroleum Contracts (GPC 2005)	Singapore	Conference Connection	http://www.cconnection.org
Sept 15-17	Production Sharing Contracts & International Petroleum Fiscal Regimes (PSC 2005)	Singapore	Conference Connection	http://www.cconnection.org
Sept 16-17	Pacific Petroleum Insiders (PPI) 2005	Singapore	Conference Connection	http://www.cconnection.org
Sept 22-23	Crude Oil Marketing & Valuation (Crude Oil 2005)	Singapore	Conference Connection	http://www.cconnection.org
Dec 5-8	Offshore Pipeline Engineering	Kuala Lumpur	IBC Asia Limited	http://www.ibc-asia.com

Courtesy of Simon Crellin @ Deloitte Petroleum Services, Singapore

DRILLING highlights

October to January 2005

SUMATRA

PT Pertamina returned to exploratory drilling in its northern Sumatra acreage after an eight year hiatus and drilled gas exploration well Susu Selatan Deep 1ST. The well was suspended as a gas discovery in Belumai Formation carbonates in October 2004. Susu Selatan Deep 1ST was drilled as a sidetrack from the 1978 Susu Selatan 1 wildcat, that well being an unsuccessful test of Keutapang Formation clastics.

In Central Sumatra, Kondur drilled the deepening of Lasmo's 1992 MS BY-1 wildcat in the Malacca Strait PSC. This was designed to target Pematang Brownshale and Pematang Basal Clastics not reached by the original well and also to evaluate oil shows in the Menggala Formation. However, a blow-out and fire on 8 November 2004 during testing prevented the planned evaluation.

The South Sumatra Basin continued to be a busy area in terms of drilling but results were predominantly negative. PetroChina saw its success continue in November 2004 in the Jabung PSC with the Kabul 1 gas discovery in TAF sands. PT Medco followed up its Fariz 1 BRF carbonate gas/condensate discovery of April 2004 with the successful Fariz 2 delineation in January 2005. Unfortunately, the remainder of its wells were not so successful, namely the Pering 2 (dry) and 2ST (gas shows) tests of BRF carbonates.

All other wells reported for the basin were unsuccessful, these comprising PT Pertamina's Tika 2 appraisal, Petronas' Bagus 1 wildcat, the PT Pertamina/ConocoPhillips JOB's Kaliberau Dalam 1 deep wildcat (non-commercial gas) and ConocoPhillips' Rebonjaro Dalam 2 delineation.

JAVA

Offshore in the East Java Sea, two successful delineation wells were drilled during the period. Kodeco tested oil and gas at KE 7-3 (1,085 bo/d plus 10.5 MMcf/d from Kujung Formation carbonates) in November 2004, and in January 2005 ConocoPhillips tested oil and gas at Bukit Tua 4. ConocoPhillips also drilled wildcat Garit 1 in November 2004, but this encountered non-commercial oil and gas only.

In the Madura Strait, Santos followed up its Jeruk 1 oil and gas discovery of March 2004 with the Jeruk 2 appraisal. After six months of operations, three sidetracks and three DSTs, the well was successfully suspended in January 2005 after flowing almost 7,500 bo/d from the objective Kujung and proving a hydrocarbon column of at least 379m. Recoverable reserves are now likely to be greater than the pre-drill estimate of 170 MMboe. Drilling partner PT Medco quoted the cost of the well as almost US$ 33 million.

Onshore in eastern Java, Lapindo encountered non-commercial oil and gas with appraisal well West Wunut 2/2ST, while further to the west, Lundin's Padi 1 wildcat in the Blora PSC encountered non-commercial oil in Kujung Formation carbonates in November 2004.

WEST NATUNA

Two wells were drilled in the West Natuna Sea. Premier's Gajah Baru 2 appraisal in October 2004 encountered gas in both the objective Arang and Upper Gabus Formation sandstones, intersecting 35m net pay. In the Nila PSC, ConocoPhillips wildcat Menur 1 wildcat was dry.

Mark Harris
IHS Energy
mark.harris@ihsenergy.com
Tel +65 6225 4166 extn 104

MAKASSAR STRAIT/OFFSHORE TARAKAN

Unocal, both as operator and drilling on behalf of its partners in its non-operated acreage, continued targeting Mio-Pliocene turbidites using Diamond Offshore's "Ocean Baroness" S/S for deep water wells and established a new water depth record at over 2,330m in the process. However, drilling results were mixed. Following delineation well Sadewa 6 (oil and gas) in the East Kalimantan PSC, Zudavi took the rig for wildcat Pandu 1 (dry) in the Papalang PSC. Eni then drilled wildcats Aster 1 (oil and gas) and Padma 1 (dry) in the Bukat PSC in the politically sensitive Tarakan Offshore area before the rig was moved back to the Kutei Basin to drill the Rinjani 1 (gas shows) wildcat for Amerada Hess in the Tanjung Aru PSC.

PAPUA

By the end of 2004, two further wildcats had been drilled in the Salawati Basin by PetroChina, but both were dry, these being Klatoa 1 and Yosim 1.

2004 IN PERSPECTIVE

Statistically, 2004 ended with a marked improvement over 2003 in terms of number of exploratory wells drilled. At year end*, some 86 wells had been drilled to completion, as compared to just 58 in 2003. A further 11 wells continued into January 2005. With many single and multi-well drilling programmes scheduled for 2005, the outlook is becoming increasingly positive and estimates for 2005 show that considerably more than 100 wells may be drilled.

*Estimated totals as at time of writing.

First Technical Paper

New Deepwater Interpretation Concepts, Slopes, Sequences and Stacking Pateterns of Deepwater Clinoforms

Nick Hoffman[a], Daniel Palmowski[b]

Editor's Note

In 1977, the field of seismic interpretation took a leap forward with the publication of Memoir 26 by the AAPG. Section Two of that volume is devoted to seismic stratigraphic interpretation and contains a series of eleven articles by Dr. Peter Vail et al. In great detail, these papers explain the correlation of stratigraphy to global changes in sea level and their recognition on seismic reflection data. I am sure I am not the only interpreter who sees a clinoform on a seismic section and immediately jumps to conclusions about sand-prone facies, depositional environments and even ages of sedimentation.

At the IPA Deepwater & Frontier Exploration Symposium held last December, a poster was presented by Nick Hoffman and Daniel Palmowski on the interpretation of deepwater clinoforms and a summary paper was published in the proceeds. It is a "must read" for those involved in exploration in deepwater depositional environments. With the authors' permission, the paper is reprinted here. You may wish to insert a paper copy into your edition of Memoir 26.

Al Stawicki

Abstract:

Traditional shallow-water sequence stratigraphy acknowledges that deepwater systems are linked to shallow water processes, and suggests a framework to tie deepwater deposition into the shallow-water glacio-eustatic cycle. This connection is via sediment supply rate, rather than water depth. This model is of general use but lacks predictive power for localization of deepwater reservoirs in time and space. In addition, the model is devalued if the correlative shallow-water sequence is unavailable for study due to political, commercial, or geological reasons.

We offer instead a different way to view deepwater deposition – as an independent process occurring on the slope and dominated by a sequence stratigraphic framework which is driven by equilibrium slope, rather than eustatic base level. This framework maintains the tectonic and compactional subsidence component of traditional sequence stratigraphy and also utilizes sediment input. Collectively, these controls define deepwater accommodation space by changes of the balance of subsidence, sediment supply, and slope.

The stacking patterns of deepwater progrades and channel fills are significant for understanding deepwater tectonostratigraphy in a similar way that shallow water stacking patterns illustrate eustatic sea level history.

Retrogradational stacking reflects basin shallowing or landwards tilt. Progradational stacking reflects basin deepening or seawards tilt. Aggradational stacking reflects uniform conditions.

[a] 3D-GEO, Shcool of Earth Sciences, U. of Melbourne, Parkville, Australia
Phone : + 61 438 397 366, Fax: + 61 3 9011 6162, Email : nick@3d-geo.com

Examples are presented of the operation of deepwater sedimentary systems, as viewed in this paradigm, with predictions for areas of enhanced reservoir presence and quality.

Introduction

Since the original definition of the sequence stratigraphic paradigm, deepwater sequences have been seen as an appendage of shallow water sequences. The processes and events in shallow water related to eustatic changes have been seen as the dominant process controlling deepwater environment.

This link between shallow and deep water sequences, and hence of processes and events, is not necessarily useful. Whilst there is considerable value in exploring the links between closely associated shallow and deep water systems, there may be no such link, or the vital evidence may be missing.

It is quite common for a deepwater exploration prospect to be divorced from its shallow water equivalents and for the interpreter to be forced to analyze deepwater sequences in a stand-alone fashion. Examples of this include areas where the shallow water acreage is held by another licensee who refuses data access, or where the shallow water is in another country. At other times, the shallow water section may have been tectonised and be difficult to study due to poor onshore data quality and difficult terrain as well as the tectonic dislocation.

This paper explores ways in which a novel approach to deepwater process analysis and sequence stratigraphy can be carried out independently of shallow water sections. We show that prograding, aggrading, and retrograding deepwater packages can be analyzed in a very similar way to shallow water sequences, but independently. Our study area includes the Otway and Browse basins, offshore Australia where well-exposed deepwater sequences offer key insights into process.

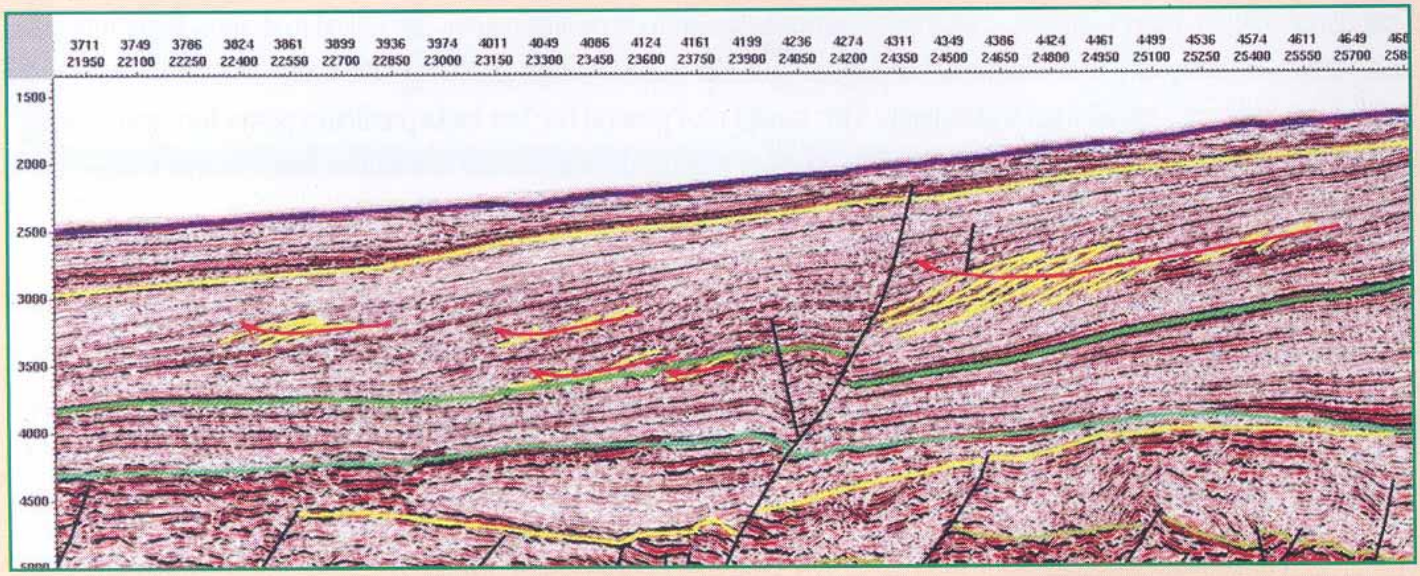


Figure 1: A deepwater seismic section from the Browse Basin, offshore northwest Australia. Here, a continuous megasequence of turbidites is deposited as a series of identical concave-up equilibrium surfaces. Each is a graded surface balancing transport and deposition. On the adjacent slope, bypass and erosion also occur. Water depth ~ 2000 m (3 sec twt).

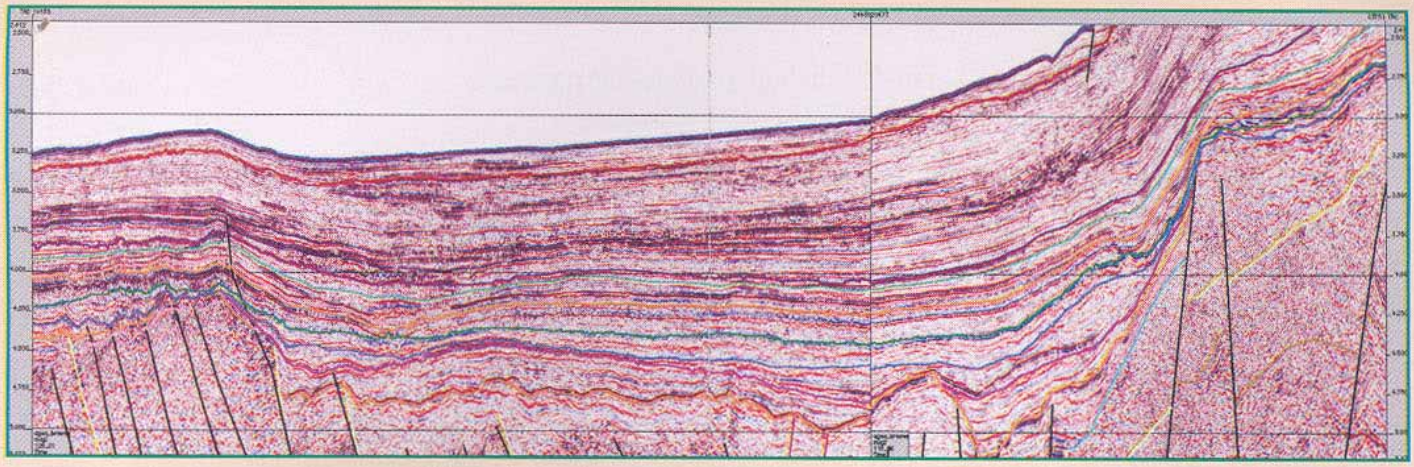


Figure 2: A deepwater seismic section from the Otway Basin, offshore southern Australia. A turbidite megasequence is deposited in 1500 m of water (2 sec twt) with detailed internal architecture. At least four deepwater systems tracts are developed, each with initial prograding parasequence sets, merging upwards into a more aggradational parasequence set before terminating with either a stepback or a step forward, believed to be triggered by tectonic tilting of the margin.

Theory

Deepwater deposition is a balance between sediment supply and accommodation volume in a very similar way to shallow water deposition. The drivers for sediment supply include all the "upstream" effects – climate, erosion in the hinterland, transport into the area and temporary storage en-route. The drivers for accommodation volume include local and regional subsidence through tectonics and thermal/plate effects, as well as base level variations.

However, "base level" in a deepwater setting is a rather subtle context. In shallow water, base level is clearly interpretable as the Eustatic sea level. In deepwater environments, a Eustatic sea level change may have no direct effect on transport and depositional processes, or the effect may be completely opposite to that in shallow water.

In shallow water, if base level falls, incision and erosion take place, and there is a seawards shift of facies belts. But in deepwater, there is little likelihood of erosion directly related to sea level fall. Instead, falling base level in shallow water often leads to accelerated sediment supply to deeper water, causing extra deposition.

Conversely, if base level rises in shallow water, accommodation volume is developed and sediment is deposited locally. From the viewpoint of deepwater systems, this represents temporary or permanent storage of sediment in an upstream cache. The deepwater system experiences sediment starvation due to Eustatic sea level rise.

This inverted link between shallow and deepwater effects of eustatic changes is expressed as the classic alternation of HST and LST in the sequence stratigraphic paradigm.

One problem in understanding deepwater processes has been this focus on high-frequency, short-lived events which have often obscured our view of longer-term and wider-scale processes. If we step back and look at a larger, whole-basin scale, we see a different style of response to the input drivers.

Whole-basin studies

We have studied deepwater areas at a regional scale in space and time whereby "normal" eustatic fluctuations are merely high frequency noise superimposed on more fundamental basin-filling processes. We use long record-length data shot

by Geoscience Australia for the purpose of understanding margin-scale processes.

In the Browse basin, offshore northwest Australia, a giant Tertiary carbonate shelf grew by massive prograding on the shelf edge into water depths of up to 1 km, perched inboard of a major crustal-scale normal fault system. The progrades accumulated from Upper Cretaceous through to Miocene times, when deposition became more aggradational. Post-Miocene, a number of major flooding events and thermo-tectonic subsidence have forced the shelf break landwards, but carbonate productivity has, if anything, increased (Hoffman and Hill, 2004).

The coeval deepwater sequence, beyond the crustal fault, is a classic turbidite section in ~ 2km water depth with accumulating layers of deepwater fan complexes (Figure 1). The layers form concave-upwards depositional surfaces that are the solution to the balance equation of transport and deposition. This equation is grain-size dependent (Robinson and Slingerland, 1998), and so the surfaces become asymptotically flatter as grain size decreases oceanwards.

This margin is our reference case. The changes on the shelf, both high-frequency eustatic and low-frequency subsidence, do not change the pattern of deepwater deposition. A single deposition megasequence spans the time from Mid-Cretaceous through to the present day.

Table 1: Deepwater vs. Shallow water Sequence Stratigraphic Paradigms

Deepwater Model	Conventional Shallow Water Model
Equilibrium is defined by SLOPE	Equilibrium is defined by Base Level
Increasing slope causes bypass/erosion	Increasing slope causes bypass/erosion
Decreasing slope allows sedimentation	Falling base level causes bypass/erosion
Equilibrium Slope is relative to subsidence and sediment supply	Rising Base Level allows sedimentation
Increasing subsidence allows deposition and vice versa	Eustatic base level is relative to subsidence and sediment supply
Increasing sediment supply encourages deposition and vice versa	Increasing subsidence allows deposition and vice versa
Deepwater progrades occur when supply is higher, slope is lower, subsidence is lower	Shallow water progrades occur when supply is higher, base level is higher, subsidence is higher

Although dominated by nett aggradation (deposition), the processes in this deepwater margin are essentially those of maintaining grade (sensu Robinson, Robinson and Slingerland, 1998). A parallel can be drawn to subaerial processes whereby erosional systems such as rivers develop graded profiles (thalwegs) through a balance of transport, storage, and erosion. In our next example, we will develop this analogy further in terms of Equilibrium Slope

In the Otway basin, the large-scale depositional history is a little different. Here, slow rifting of the margin began in Upper Cretaceous time (Palmowski et al., 2004). During the Palaeogene, a thick wedge of sediment was deposited in modestly deep water (< 1 km). In the mid Eocene, after the final break-up event and emplacement of first oceanic crust, more rapid spreading commenced, and was accompanied by rapid and extreme subsidence and oceanwards tilting. The deepwater

sequences today lie in water depths of 3-4 km. During this tilting, we have insight into deepwater processes as the grade of the seabed is altered tectonically and deposition processes attempt to restore a balance.

The most interesting observation is that during this time of tilting and subsidence, we see distinctive deepwater progrades developed. Deepwater clinoforms are not a new observation. They have been a feature of deepwater fan interpretation since the early days of sequence stratigraphy. However, due to the special circumstances of the Otway Basin, we are able to integrate the observation of these clinoforms into a new understanding of deepwater processes.

Up to four major systems tracts are developed in deepwater (Figure 2). Each one contains smaller-scale parasequence sets, defining an initial progradation of deepwater clinoforms, followed by a more aggradational parasequence set. These systems tracts are themselves arranged in a generally prograding sequence, although one major backstep is noted after the earliest systems tract.

We propose these as type examples of a new Deepwater Prograding Systems Tract. These are not responding to mere eustatic drivers, but to margin-scale thermo-tectonic subsidence and tilting.

In terms of process, we surmise that the DPST records a pulse of seawards tilting. The whole megasequence within which these four DPST are embedded records 0.5 degrees of seawards tilt and about 700 m of differential subsidence. Each individual DPST must represent a small fraction of this, perhaps 1/10 to 1/5 of the total. These are very subtle tilts, but the deepwater system is highly sensitive and responds appropriately.

We surmise that in the area of maximum tilt (inboard and updip of the DPST), the actual seabed slope is increased by tilting to something a little steeper than the equilibrium grade. As a consequence, more bypass (transport) occurs, and less deposition. Turbidite currents will flow with higher velocities down the steeper slopes, carrying relatively coarse particles further.

At the toe of slope, defined by the limit of tilting, these fast currents slow down and dump their load rapidly in a stack of deepwater fan complexes. Due to space considerations, these must necessarily prograde in a series of clinoforms. Note that although the formation of these deepwater clinoforms is triggered by oceanwards tilting of an updip portion of the slope, the local trigger is the flattening-off of that slope, so clinoforms are produced by *flattening* of slope, not steepening!

In the shallow water analogy, a lower base level leads to bypass and transport across the shelf and dumping at the shelf edge where transport slows and accommodation volume is available. Again, progrades are a necessary geometric consequence.

As the tilting event diminishes the rate of bypass and transport becomes marginally reduced, and the deepwater clinoforms cease to prograde. Instead, they aggrade, just as shallow water clinoforms transit from progradation to aggradation in the waning phase of the eustatic cycle.

The final element of the DPST may be developed as a nett landward shift of facies tracts, or may be aborted by the onset of a new pulse of tilting, and a new DPST, further oceanwards.

Summary and Conclusions

We have extended the sequence stratigraphic paradigm to new length and time scales in deepwater environments by studying rapid tectonic tilt in the Otway basin as an isolatable driver for Deepwater Prograding Systems Tracts. Of itself, this observation is relevant to changes in depositional fairways in deepwater environments undergoing rapid tectonic movement at both basin scale (as here) or at smaller scale where a related set of processes can generate local small-scale prograde-aggrade systems of deepwater clinoforms. An example of the smaller scale process is the fill sequence of Minibasins between salt diapirs or thrust ridges, where ponded turbidite sequences often exhibit local-scale clinoforms.

We also derive from this analogue a more fundamental insight. We believe that it is possible to describe deepwater environments in terms of a single dominant driver – depositional grade. Instead of modeling eustatic inputs, we convert to a model where all inputs are expressed as adjuncts to the prime driver (Table 1). Deepwater progrades occur at times and places of shelfal lowstands, concave slopes, and basinward tilt.

The Stacking Pattern of deepwater progrades is significant for understanding deepwater tectonostratigraphy in a similar way that shallow water stacking patterns illustrate eustatic sea level history. Retrogradational stacking reflects basin shallowing, sediment starvation, or landwards tilt. Progradational stacking reflects basin deepening, sediment supply, or seawards tilt. Aggradational stacking reflects uniform conditions.

Rather than being merely a deepwater tail, wagged by the eustatic dog in shallow water, we instead suggest that deepwater systems have an independent existence which can be measured in terms of local processes and inputs. The range of possible outcomes is wider than a simple shelf-driven approach would admit. In fact, in an extreme view, it is possible to consider the whole shallow water eustatic system as merely a high-frequency fluctuation in sediment input to deep water. It is the local and regional tectono-thermal chronology that drives deposition patterns and systems tracts in deepwater, except perhaps at the highest frequency.

Acknowledgements:

We recognize the assistance of Geoscience Australia in providing data over the Browse and Otway basins as part of on going studies of the Australian margin, and support of DP's Ph.D. studies.

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Hoffman and Hill, K.C., 2004 Structural-stratigraphic evolution and hydrocarbon prospectivity of the deep water Browse Basin, northwest-Shelf, Australia. In: Proceedings, Timor Sea Symposium, Northern Territory Department of Energy.

Palmowski, D.B., Hill, K.C. & Hoffman, N., 2004: Structural-stratigraphic styles and evolution of the offshore Otway Basin – a structural seismic analysis. In: Eastern Australasian Basin Symposium II, Petroleum Exploration Society of Australia Special Publication. IN PRESS.

Robinson, R.A.J. and Slingerland, R.L, 1998, Origin of grain-size trends in a foreland basin: the Pocono Formation of the Central Appalachian Basin: Journal of Sedimentary Research, 68, 473 – 486.

Field Seminars Carbonates

AAPG/IPA:
Equatorial Carbonate Systems - Modern and Miocene Analogs

INSTRUCTORS

Paul Crevello, Petrex Asia Reservoir & Stratigraphy Group, Kuala Lumpur, Malaysia;
Robert K. Park, Kodeco Energy Co Ltd., Jakarta Indonesia, Kristian Nurwedi, Institute of Technology, Bandung, Indonesia.

DATES

May 22 - 28, 2005

LOCATION

The trip will begin and end in Jakarta, Indonesia.
Participants should plan to arrive for an evening welcoming reception at 16.00 on May 21 and plan their departure for the evening of May 28.

TUITION

$2,225.00 SIGN UP NOW
Goes up to $2325 after 4/11/05. Includes, travel to/from the island resort of Pulau Putri, all meals on Pulau Putri,field refreshments, ground transportation to/from Bandung and night of May 21 hotel in Jakarta and 3 nights hotels in Bandung.

LIMIT

20 people

Who Should Attend

Exploration and Development geologists, geophysicists, reservoir and production engineers, log analysts and exploration and development managers who want a thorough working knowledge of productive carbonate reservoir systems.

Overview

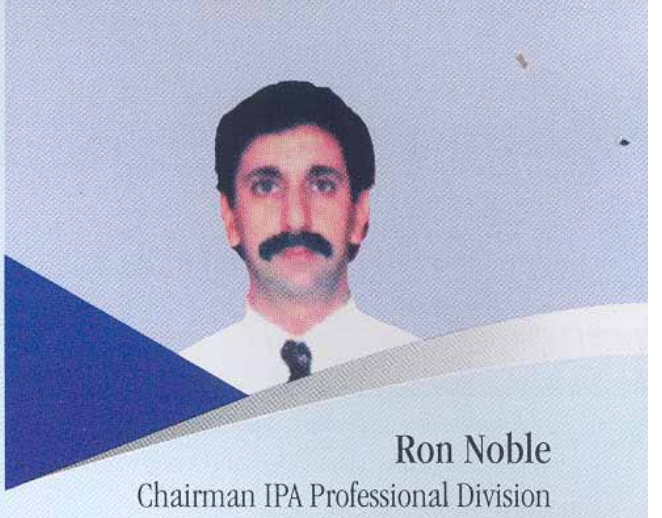
This six day field seminar will first examine the modern equatorial carbonate depositional environment of the Pulau Seribu island chain, offshore Jakarta then move inland to Bandung to examine some magnificent outcrops of a Late Miocene reef facies assemblage. The chain is located on the southern flank of the Sunda Basin within which the Miocene Batu Raja Limestone is a major producing reservoir and typical of the carbonate reservoirs found throughout SE Asia.

Objectives and Content

To understand the interplay of factors which influence carbonate sedimentation, biologic, atmospheric, oceanic, physiographic and others, which work together to dictate facies patterns, compositional elements and determine overall architecture, rates of growth, scale and style of expression. To consider the impact of fluctuations in relative sea level on evolving geometries, on diagenesis and how these factors will affect reservoir properties. The models derived here will be carried onshore and used as a guide to interpret outcrops of Late Miocene Rajamandala Limestone, the reefal members of which are much favored by Jakarta interior designers. With ancient and modern observations, develop appropriate reservoir models for exploration, development and full-field asset studies. Outcrop and subsurface Miocene analogs will also address shallow and hydrothermal karst systems and fractured dual-porosity reservoirs systems.
Format: The course will combine lectures and exercises with hands-on examination of modern and ancient carbonate systems together with seismic and log scale exercises and develop a methodology and strategy for investigating depositional, diagenetic and structural carbonate reservoirs aspects.

NOTE: Swimming is not a requirement for the first part of the trip, but it will allow you to appreciate many aspects of the reef environment. Snorkeling equipment is available for rent at theisland resort but we have made no provisions for diving. Water safety is a primary concern and you are asked to pay close attention to leaders' instructions.

CHAIRMAN'S CORNER



Ron Noble
Chairman IPA Professional Division
Unocal Indonesia Company

Dear IPA Members and Friends,

The Professional Division ended 2004 on a high note after organizing a number of very successful events during the course of the year. A technical symposium on "Deepwater and Frontier Exploration in Asia and Australasia" was held in December, with excellent attendance and positive feedback from delegates. Four educational fieldtrips were run during the year, two of which were held in conjunction with the IPA symposium. Eight luncheon talks were presented, with attendance exceeding 700 professionals in Jakarta and several more in Balikpapan and Riau. In addition, fourteen short courses were held on diverse technical topics and all were well received and attended. The 2004 short courses drew a total of 275 attendees, with per course figures ranging between 12 and 30. This represents a 60% increase over the previous year's attendance figures.

The student program for 2004 included a training class on wellsite geology and a visit to a Pertamina drillsite in west Java. This was a very popular event amongst university students and we plan to offer more programs like this in the future.

As with any volunteer organization, we have had to say goodbye to some of the committee chairpersons and welcome new members to the group. I will single one departing committee member, Mr. Chuck Caughey, who has been active with the IPA for many, many years. Most people who have been involved with the IPA know Chuck and his contributions. He has been involved in all aspects of the Professional Division, and was particularly active with the university student program. Many thanks to him and to all the IPA volunteers and staff for their efforts. We look forward to offering many more exciting events in 2005.

Ganti Wajah
(Changing Faces)

IPA COMPANY MEMBERS

AMOSEAS INDONESIA INC.
New name :
CHEVRON TEXACO ENERGY INDONESIA LTD.

ZODAN N.V./ZUDAVI N.V./TATELY N.V.
New address :
Bapindo Plaza
Mandiri Tower, 21st Floor
Jln. Jendral Sudirman Kav. 54-55
Jakarta 12190
Indonesia

Phones : (62-21) 527-8991; 527-8992
Fax. : (62-21) 527-8993; 526-7151

IPA ASSOCIATE MEMBERS

HORIZON OFFSHORE INDONESIA, PT
New address :
Graha Paramita, 10th Floor
Jln. Denpasar Raya Kav. 8 - Blok D2, Kuningan
Jakarta 12940

Phones : (62-21) 252-3242, 252-3240, 252-3241
Fax. : (62-21) 252-3243

INTERTEK UTAMA SERVICES, PT
New e-mail address :
john.fowler@intertek.com (company representative)

McDERMOTT INDONESIA, PT
New Representative :
Asan Sofian

PETROPEP NUSANTARA, PT
New phone number: (62-21) 739-2170

SCHLUMBERGER
New Representative :
Dr. Mohammed Badri

SEAMLESS PIPE INDONESIA JAYA, PT
New representative :
Raul Garcia-General Manager

WELLTEKINDO NUSANTARA, PT
New address :
Plaza Great River, 17th Floor
Jln. H.R. Rasuna Said Blok X-2, No.1
Jakarta 12950
Phones : (62-21) 5793-8938; 5793-8939; 5793-8940
Fax. : (62-21) 5793-8941

IPA INDIVIDUAL MEMBERS

Herman Sopandi
New e-mail address :
hsopand@chevrontexaco.com

James K. Forrest
New position :
Samarang FFR Project Manager
New address :
SCHLUMBERGER
BMPGeomarket
Rohas Perkasa, West Wing, 18th Floor
No. 8, Jalan Perak
50450 Kuala Lumpur - Malaysia

Phone : (603) 2166 7788 ext. 2894; (603) 2179 2894, direct
Fax. : (603) 2166 7000
E-mail : forest@kuala-lumpur.oilfield.slb.com
Mobile : 012 - 311 0392

Paul Cleek
New position:
Business Development Manager – SE Asia

Wahyu Sugiarto
New e-mail address:
wsugiarto@plasa.com

Tony Diemert
New Address
New Employer
Husky Oil (Madura) Ltd.
Park View Plaza, Lantai 5
Jl. Taman Kemang 27
Jakarta selatan 12730
Indonesia

Telephone : (+62-21) 7179-4777
Fax : (+62-21) 719-4650
E-mail : Tony.Diemert@huskyenergy.ca

The Winds of Change:

Anisotropic Rocks – Their Preferred Direction of Fluid Flow and Their Associated Seismic Signatures.

Dr. Heloise B. Lynn, Lynn Incorporated, Houston, Texas, USA, lynnearth1@aol.com

The Fall 2004 SEG/AAPG Distinguished Lecture: Expanded Abstract

The Context of our Community

All of us interact in the context of our community. SEG and AAPG have played major positive roles in the community wherein I have worked for the last 30 years. These two societies invited me to speak upon a topic of my choice, for the benefit of our joint communities, and so this paper came into existence. This is the "executive summary" version; the complete version is found in The Leading Edge (Nov. and Dec. 2005).

The "winds of change" refer to much more than just anisotropic rock whose seismic anisotropy provide insight into permeability anisotropy. The way we view our planet is changing: the planet is now being studied as the interaction of interlocking systems. The four systems are: the hydrosphere, the atmosphere, the lithosphere, and the biosphere, as all of us absorb energy from our sun. The planet and all its subsystems, like geology or the weather, are explicitly evaluated as inter-dependent and interacting within the context of the local community. The heterogeneity at the surface of our planet and the re-cycling of compounds and elements (water, nitrogen, sulfur, carbon dioxide, etc.) enable our planet to support life. (See Our Changing Planet, McKenzie and McKenzie, and James Lovelock on Gaia for a farther point of view). Those of us in our 50's have experienced two earth-science revolutions: the plate-tectonic revolution during the 1970s, and today's profound re-evaluation of "how our planet works" and what our role as planet-dwellers is.

The rocks that are the primary focus of most of our studies are best understood as, firstly, the result of the interactions of the climate, the water conditions, the depositional setting, the biosphere, and the provenance of the sediments, and secondly, the lithification and geologic history they have undergone. The biosphere shows up in our rocks as fossils, one of our key means of dating rocks. We understand any given stratigraphic facies in the context of its spatial neighbors – its community -- and its plate-tectonic setting. The climate includes the actions of gravity, sunlight, and atmosphere, but it is affected by where the land masses are, and how they are linked up together. The oil industry geoscientists are uniquely placed to have important data and tools to document the interaction of these four spheres throughout the last 660 million years and thereby track global climate change. The more-forward looking of our scientists and our oil companies are already doing just this.

Heterogeneous and Anisotropic Rocks: Do they veil or reveal the reservoirs we seek?

The sedimentary rocks, wherein reside most of our supply of hydrocarbons are neither homogeneous nor isotropic, but instead are heterogeneous and anisotropic. Heterogeneous means spatially variable in property value: velocity, porosity, permeability, shale volume, sand percent, etc., and so the issues of spatial resolution and temporal resolution come into play. Anisotropic refers to the measured value being dependent upon the azimuth in which the direction is made. Reservoir detection and reservoir characterization encompass the mapping of both the heterogeneity and the anisotropy, in the context of the structure setting. Therefore, it is necessary to depict in map form at least 3 numbers for any property "of interest":

1) the value itself (example: the large AVO gradient, the fast Interval Velocity, etc.)
2) the azimuth wherein the large value was measured.
3) The azimuthal difference in the value (Vfast minus Vslow; Large AVO gradient minus Small AVO gradient; etc.)

Proper geophysics would also include the error bars associated with the measurement, or the goodness of fit of the field data to the ellipse that we consider field data "ought to show" in the presence of azimuthal anisotropy, so now we are up to four values per measurement of interest, all of which would be co-rendered into one icon (glyph or symbol that holds 4 numbers). Amplitude, interval velocity, coherence, frequency, phase, etc., are just a few of the geologically-significant seismic properties that have an azimuthal dependence.

The scale (frequency) at which the measurement is made determines the value measured, as well as the whether the rock looks homogeneous or heterogeneous or anisotropic or isotropic.

Anisotropy -- like a Kitchen Sink

Anisotropy arises from the ordered heterogeneity(s) smaller than the wavelength. When the nature of the ordered heterogeneity replicates itself across different scale lengths (exhibiting fractal properties), then the anisotropy measured at one scale (the kilohertz frequencies – well logs) is similar to the anisotropy measured at another scale (the 10-100 hz reflection seismic). Just as a kitchen sink is a catch-all, so anisotropy as a term contains all the variety of the ordered heterogeneities smaller than the wavelength. What are the types or styles of order in the heterogeneities that we typically find in our rocks?

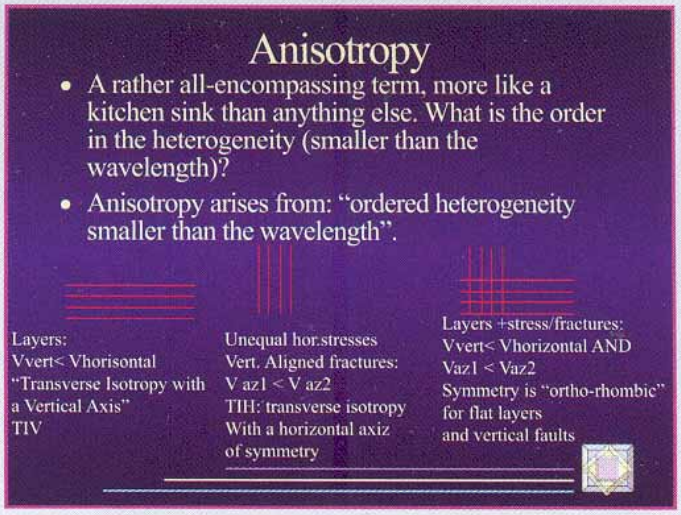


Figure 1 shows the various ordered heterogeneities.

The layers of the sedimentary rocks exert the first order effect upon reflection seismic data. The vertical velocity is usually less than the horizontal velocity. This is termed transverse isotropy with a vertical axis, or TIV (or VTI). (This is like plates stacked in the sink.)

Vertical aligned fractures and/or unequal horizontal stresses cause azimuthal anisotropy. The P-wave velocity parallel the fractures is faster than the P-wave velocity perpendicular to the fractures. This is termed transverse isotropy with a horizontal axis , or TIH (or HTI). This symmetry is like the plates in the kitchen sink being stacked on end. TIH ignores the effect of the layers, which is not a good idea when dealing with reflection seismic field data.

The most reasonable symmetry model that the *simplest* of our rocks exhibit is flat layers plus unequal horizontal stresses and/or vertical aligned fractures, which results in orthorhombic symmetry. If there are two sets of vertical aligned fractures at 90 degrees to each other, this is orthorhombic symmetry too. The reason that some geophysicists are fixated on symmetry patterns is that the seismic waves acquire the symmetry of the rocks through which the waves pass. (Winterstein, 1990, 1992). So, if you want to know about the rocks, we need to know about symmetries. Don Winterstein (1990) wrote an excellent paper in Geophysics on this. One good fact about orthorhombic symmetry is that after identification of the fast direction and the slow direction, and azimuth-sectoring into these directions, then most "isotropic" seismic processing code can function fairly well on azimuth-sectored data. This is one reason why some people azimuth-sector: they don't have to re-write their codes to use all the data all at once.

Many areas we explore in have dipping layers and/or dipping faults (dipping fractures). Therefore, monoclinic or triclinic symmetries would be expected. One consequence of monoclinic or triclinic symmetry is the mis-alignment of the azimuth of the fast P wave velocity and the fast shear wave polarization. Other consequences are less well understood, and more papers explaining to all of us what monoclinic and triclinic symmetries look like in field data would help.

Our complex earth contains a continuum of all scales of ordered heterogeneities, from which arise the three types of seismic responses:

1) reflections : arising from layers – ordered heterogeneity – 3/8ths wavelength thick or thicker. Widess (early 1970s) wrote "How thin is a thin layer?" and the answer is: 3/8ths wavelength thick gives us a discrete reflection from the bed top and another discrete reflection from the bed's base. These are the coherently reflected waves that comprise the classical "Signal" for processors.
2) Scattering (coda, trailing legs) and attenuation and dispersion (velocity is a function of frequency). When the ordered heterogeneities have scale lengths about 0.3 to 0.01 the size of the wavelength, then the seismic wave rattles around inside the fractured zone, with multiply scattered travelpaths. These are the "coda" or trailing legs that classical processors remove as Noise, using various forms of deconvolution.
3) Azimuthal variation in the traveltimes: effective media theory describes the change of velocity with azimuth and offset as though there were vertical aligned "penny shaped cracks" present, whose dimensions are much smaller than the wavelength.

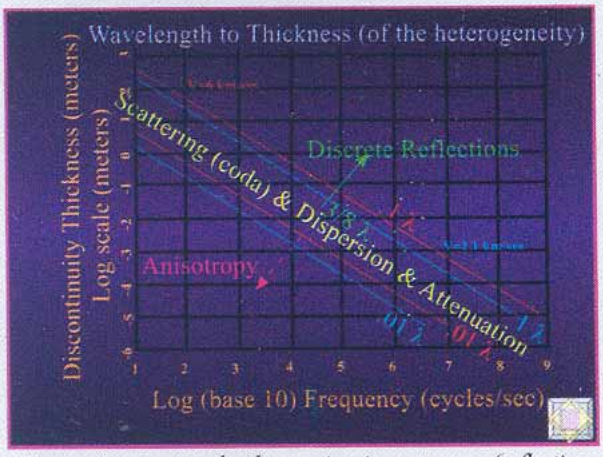


Figure 2 presents the three seismic responses (reflection, anisotropy, and scattering/dispersion/attenuation) as a function of frequency and discontinuity size on a log-log plot.

Figure 2 presents the three seismic responses (reflection, anisotropy, and scattering/dispersion/attenuation) as a function of frequency and discontinuity size on a log-log plot. Frequencies from 10 hz to kilohertz (sonic) to megahertz (laboratory) measurements are shown. Discontinuity thickness (or size) ranges from microns to mm to meters to kilometers. The principal focus of my work here is in the 10-100 hz realm, although it is important to fit into a Unified Theory all the other seismic measurements (crosswell, passive seismic monitoring, sonics, and laboratory). A given set of vertical aligned fractures will cause anisotropy within one (low) frequency measurement , dispersion/ scattering/attenuation to a (mid-) frequency, and reflections to the highest frequency seismic waves. The seismic response one measures is the result of the scale of the ordered heterogeneities relative to the wavelength used.

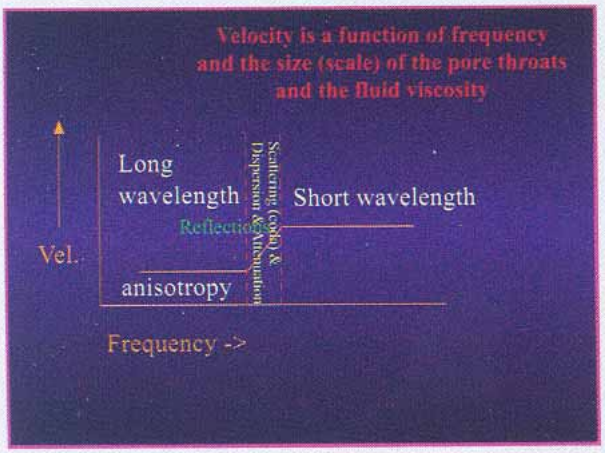


Figure 3 presents the well-known graph showing that velocity changes as a function of frequency.

Figure 3 presents the well-known graph showing that velocity changes as a function of frequency. The conventional wisdom of our community understands this type of observation to indicate that the high frequency, higher velocity region is the unrelaxed state of the rock, where the fluids in the pore space can not equalize their pressure (move) as the seismic wave passes through: the seismic wavelength is much too short to effectively move the fluid around, so the fluid acts as a stiffening agent. The low frequency, low velocity region is the relaxed state of the rock, wherein the fluids can move between the pore spaces as the long wavelengths pass through, equalizing the pressures, and thus a slower velocity results. The transition zone between the two states is the zone of Dispersion (for velocity changes with frequency), attenuation, and scattering (coda).

Therefore, it is possible to think about velocity being a function of frequency, as well as the scale (size) of the pore throats and the fluid viscosity, for the pore throat size and the fluid viscosity affect the flow rates through the rock. In the presence of high fracture density such that horizontal permeability anisotropy exists (preferred direction of fluid flow), then seismic anisotropy is present, as well as the potential to measure the dispersion, using surface seismic reflection data. The high

fracture density, with fractures of scale lengths approaching the wavelength have introduced pore throat sizes much much larger than those present in unfractured rocks. With or without this effect, may be the azimuthal scattering effect, wherein parallel the fractures whose scale lengths approach the wavelength there is less scattering, and perpendicular these fractures there is more scattering, attenuation, and dispersion. The next Great Challenge in seismic anisotropy is capturing, displaying, interpreting, and modeling these field data observations.

Reflections (from thick layers)

Every 3D- PP migrated volume displays focused imaged reflectors. Interpreted reflectors give us maps of horizon dip magnitude and dip azimuth, using various measurements of coherence. Lineations on these maps are commonly observed and related to macro-fracture lineaments. Prof. Kurt Marfurt at the Univ. of Houston and his colleagues have developed a way to calculate 3D volume curvature from 3D migrated PP seismic data. Their displays of curvature can highlight subtle lineations in the 3D data, and can provide additional information pertaining to the study of fractures and fluid flow in reservoirs.

Reflections+Anisotropy (azimuthal variation in PP traveltimes)

Figure 4 displays the well-known azimuthal variation in traveltimes of the far offsets (offsets about equal to target depths). The azimuths displayed are from 0 to 360, which is the correct way to view azimuthal variations in seismic signatures. The all-azimuth ellipse-fitting that uses all the data to determine the anisotropy is a powerful approach that captures the azimuthal variation in traveltimes and amplitudes. Sometimes people view the PP azimuthal traveltimes from 0 to 180, but too much information is lost that way. The variation of minimum time (fast) to maximum time (slow) over a 90 degree azimuthal variation is the classical signature of the "penny-shaped cracks" in the rocks above the reflectors that exhibit these azimuthal variations in traveltimes. The slide exhibits a "large" anomaly.

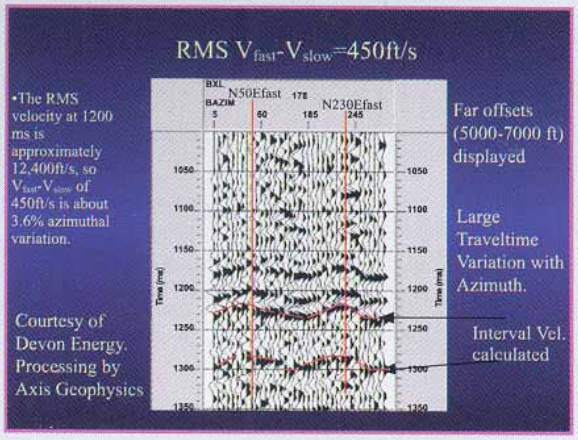


Figure 4

Not all Pores are Connected… Not all Fractures flow Fluids

We can find porosity (usually by inversion of amplitude into impedance). But how big are the pore throats? Pore throat size and fluid viscosity are involved with the effective permeability. The flow through a given length depends upon the cross section area (for flow), the pressure gradient, the fluid viscosity, and the permeability. A fractured reservoir with a horizontal permeability anisotropy has pore throats much larger than those normally encountered in conventional reservoirs.

We can find the relative density and orientation of "penny-shaped cracks" by mapping the azimuthal variation in PP traveltimes, or AVOaz, but do these fractured areas flow fluids?

There is additional information in our 3D wide-azimuth data, here-to-fore under-utilized, which should be captured and mapped, not removed in processing.

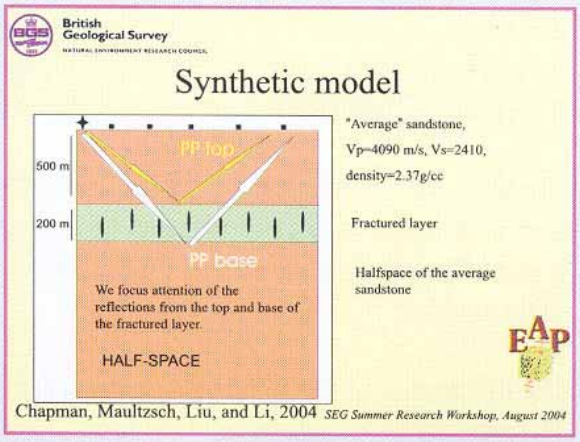


Figure 5

The Seismic Model Signature of Changing Permeability, from the Edinburgh Anisotropy Project

Chapman, Maultzsch, Liu, and Li, presented their work on frequency dependent anisotropy at the SEG/EAGE Summer Research Workshop, 2004, in Vancouver. They have been kind enough to let me show some of their slides. In Figure 5, we see their numeric model: a sandstone with VP=4090 m/s, VS=2410 m/s, density =2.37 gm/cc, with a fracture layer embedded inside it.

Figure 6 presents four different effective permeabilities, modeling from small fractures to large fractures (upper left to lower right). All four datasets are the fracture perpendicular direction, for the fracture parallel direction has minimal effect from the fractures. Only the mid- to far-offsets perpendicular to the fractures exhibit the effect of the fractures. As the fractures become larger, the effective permeability is greater, and the base of the fractured layer exhibits the dispersed signature that theory predicts. When the fractures are small, and not that permeable, then not much seismic effect is seen. The green box indicates the upper end of the modeled anomaly: the high frequencies have a faster velocity (less moveout), while the lower frequencies have a slower velocity (more moveout). The green box indicates the region to be enlarged and displayed in Figure 7.

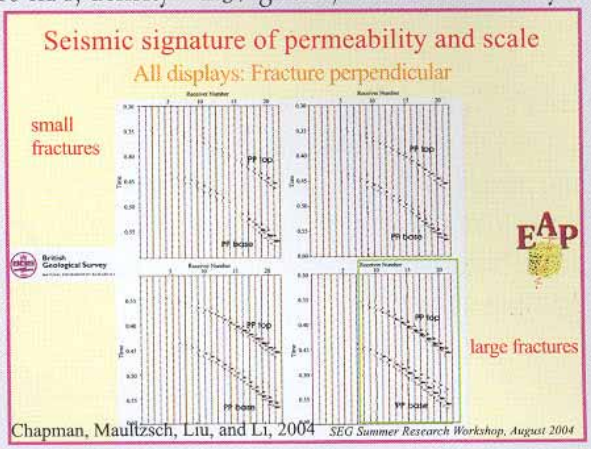


Figure 6

Now we can compare the fracture parallel and the fracture perpendicular signature, for mid- to far-offsets. Figure 7 displays on the left the fast azimuth, parallel to fractures, with its zero phase reflection from the top of fractured layer at the mid-offset. On the right, is the slow azimuth across the fractures, with its 90 degree phase wavelet at the top of the fractured layer, at a mid-offset. The Base of the fractured layer again is zero phase in the fast direction, while at the mid offsets, it is more like a 90-degree phase wavelet. At the far offsets, the low frequency and the high frequency reflections are distinctly different, showing different moveout curves.

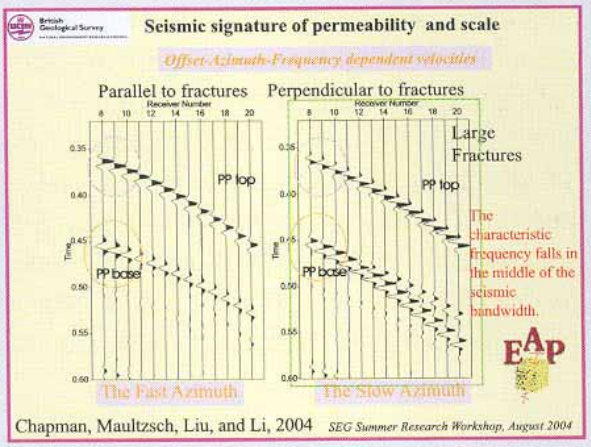


Figure 7

Obviously, what one would do to test for this phenomenon in field data is to acquire full azimuth full-offset PP 3D data, then separate by azimuths – fast and slow – and then band pass filter the SLOW direction into the low-half of the spectrum to run its own velocity scans. Then run a separate bandpass filter for the high-end of the spectrum, two octaves on each filter, please, and run its own velocity scan. While some might protest, "But this looks like a multiple!", I reply that this is model data and has no multiples. I believe that people are clever enough to figure out how to get rid of the multiples and preserve the dispersion. (How's that for optimism?) A good first step is to forget about trace-by-trace spiking deconvolutions, and to forget about spectral whitening, if you want to see the plumbing in your reservoir.

Of course, we have to get rid of the peg-leg multiples, the long-period reverberations that obscure our signal, but we just need to be careful how we get rid of them. Perhaps a surface-consistent gap deconvolution to remove reverberations could be considered, to leave the wavelet's phase alone. The opinions about deconvolution are equal to the number of geophysicists in the room.

The importance of the difference in phase between these two different-azimuth sections can not be over-emphasized . The necessity to compare phase by azimuth in our field data can not be over-emphasized. The non-unique interpretation step of azimuthal phase shall be discussed later in this paper.

Field Data: US Dept of Energy Wind River Project

Figure 8 displays some PP supergathers (3 CDP gathers combined to form one supergather, with offset increasing from left to right in each gather) for the East-West fracture parallel direction and in the North-South fracture perpendicular direction. The data come from the US Dept. of Energy Wind River project (naturally fractured gas reservoirs' study). The CDPs of these gathers are the same ground locations. Please note the high frequency nature of the fracture parallel, while the fracture perpendicular shows more energy in a lower frequency range. Moreover, the low-frequency reflections perpendicular to the fractures clearly exhibits a slower NMO on CDP 83 at 1.55-1.60 sec, while the higher frequency reflections are clearly flat, due to proper NMO.

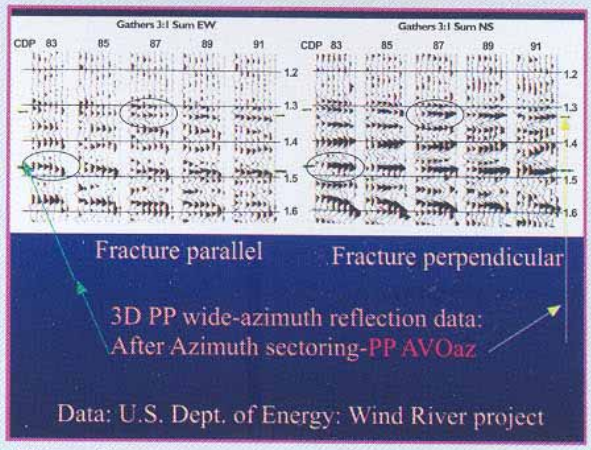


Figure 8

The arrows point to AVOaz anomalies studied in the earlier studies (Grimm et al., 1999; Lynn et al., 1996, 1997, 1998, etc.) At the time, we were not thinking about dispersion, but we should have been. Other geophysicists who viewed these slides, were: Dr. John Queen, who has been studying seismic anisotropy for over 20 years, asked perceptive questions when these slides were first shown. The low frequencies perpendicular to the fractures are indicating different moveout (slower) at 1.55 sec, while the higher frequencies are flat. This area also had different NMO velocities applied: E/W was faster and N/S was slower, just to get the gathers to appear as "flat" as they are.

Figure 9 shows the stacked migrated data for these gathers. In general, the E-W fracture parallel is higher frequency and lower amplitude; while the N-S fracture perpendicular is higher amplitude and lower frequency. Also please note the difference in apparent time structure for the CDPs presented here. The same ground locations (CMP bins) are presented, but the azimuths of their raypaths are different. Different velocity fields were used for moveout and migration, based upon the NMO curvature observed.

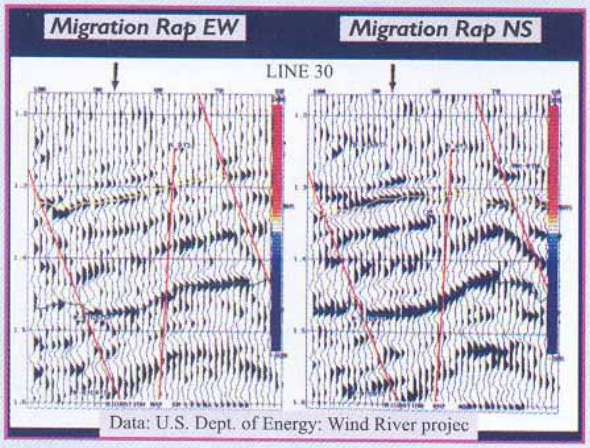


Figure 9

Other supergathers in this area showed dispersion in the PP reflection signatures on the order of 50 msec difference in traveltime at 4 seconds between the high frequency events and the low frequency events . (Lynn and Beckham, 1998).

These data were acquired in a naturally fractured gas reservoir, and it is probable that the cause of the dispersion is scattering off aligned vertical fractures whose scale lengths approach that of the wavelength. The fracture parallel direction is less scattered, while the fracture perpendicular direction is more scattered.

Where to Hunt

We don't have to hunt everywhere for offset-azimuth-frequency velocity (dispersion) effects. We only have to start the hunt where there is a good PP AVOaz anomaly. Why? Many publications have documented the log-log relationship of number of fractures to size (length or aperture) of fractures, from the scale of the micro-fractures to the scale of the San Andreas. Figure 10 illustrates the continuous range of all sizes in the ordered heterogeneities in the earth. The "**context of the community**" is revealed upon this slide: our friends the geologists have documented the various scaling properties of fracture populations and we would do well to heed their insights.

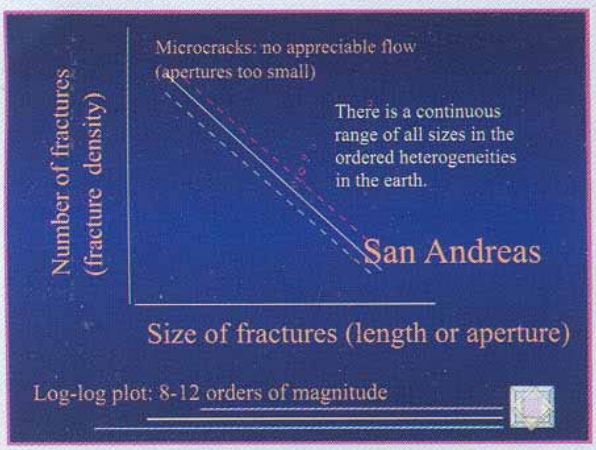


Figure 10

An upper and lower bound of the scaling relationship between size of fractures (length, aperture) and number of fractures (per unit volume, usually). The lower bound is a "relatively" unfractured rock mass, while the upper bound is the "fracture criticality" fracture density that Stuart Crampin has defined. Fracture criticality is the threshold fracture density which, when achieved, results in an interconnected network of fractures, and a significant permeability uplift. Fracture density less than fracture criticality implies a fracture network connected only to the matrix porosity, and not to all the other fractures in the rock volume.

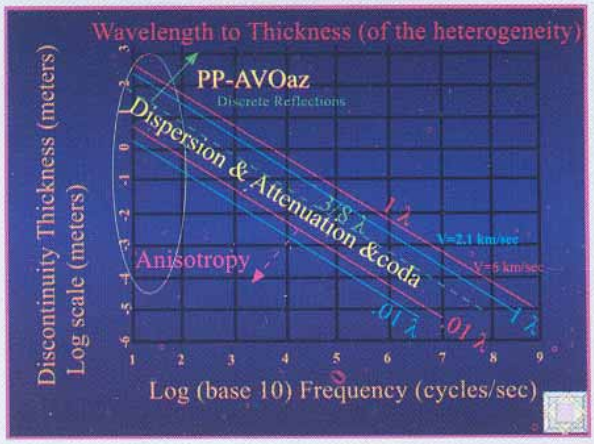


Figure 11

The magnitudes of the PP AVOaz anomaly are often 50-100% azimuthal variation on the far offset. This magnitude far exceeds the equivalent media theory (Ruger-Tsvankin, The Leading Edge, Oct. 1997) equations' predicted magnitudes. Therefore, it is appropriate to ask searching questions about "WHERE?" are these large magnitude AVOaz anomalies arising from. Since equivalent media theory can not explain the magnitudes of most AVOaz anomalies, new/better/broader theories are needed. I suggest that "the context of the local community", as demonstrated on Figure 10, 2, and 3, is a large part of the answer. Figure 11 displays the yellow oval of the PP-AVOaz response in the 10-100 hz bandwidth (our reflection seismic and VSP signals). It squarely overlays the zone of discrete reflections and anisotropy: already well-known as governing the nature of PP AVOaz responses. Right in the middle between the discrete reflection and the equivalent media theory regimes is the dispersion, attenuation, scattering and coda (trailing legs) regime: that are present but currently ignored or disliked in modern processing. Yet these are the signals that go with fracture scale lengths approaching the seismic wavelength and are therefore of even more importance to us than the penny shaped cracks of equivalent media theory.

The azimuthal variation in frequency is also garnering much interest. A method to present the wavelet's spectrum using color is found in Theophanis and Queen (2000). Color frequency displays of azimuthally-sectored data enable the evaluation of thin beds' reflections that exhibit azimuthally-variant tuning due to the presence of vertical aligned fractures.

Summary

The added dimension of azimuth for 3D PP (and PS) data provide additional information concerning aligned compliant connected pore space (Lynn, 2004). If you are interested in the "plumbing" of your reservoir, then you are interested in the azimuthal variation in seismic signatures. 3D PP wide azimuth field data ***habitually*** contain three major types of SIGNAL:

1) reflections from thick layers ($3/8^{th}$s wavelength thick and greater)
2) azimuthal variations in reflection traveltimes and amplitudes, that are to some part explainable by equivalent media theory, wherein our seismic traveltimes behave as though there were "penny-shaped cracks much smaller than the wavelength" that are influencing the velocity fields;
3) azimuthal attenuation, scattering (coda), azimuthal dispersion, wherein there is some property(s) of the fracture population (spacing, height, length, apertures, etc.) that is on the order of the wavelength. This means larger

than those penny shaped cracks of equivalent media theory. Any fracture set that has property scale lengths approaching the seismic wavelength are inherently of more interest than fracture sets with scale lengths much much smaller than the wavelength.

Items 1 and 2 above are routinely understood and honored in our data processing flows, with specialized and powerful software routines. Item 3 above is routinely destroyed in standard processing, even in some azimuthal processing sequences. Item 3 above should not be routinely destroyed in standard processing, but examined to see what useful insights are present. Furthermore, many of the PP AVOaz anomalies routinely observed are of much larger magnitudes than the 20-30% magnitudes that the Ruger-Tsvankin (equivalent media theory) equations predict: therefore, it is logical to ask, could some of item 3 above be influencing the magnitude of our PP AVOaz anomalies. While this paper has been focused upon the PP reflections, the comments also apply to PS reflections, which in general are far more sensitive to aligned ordered heterogeneities than PP waves.

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