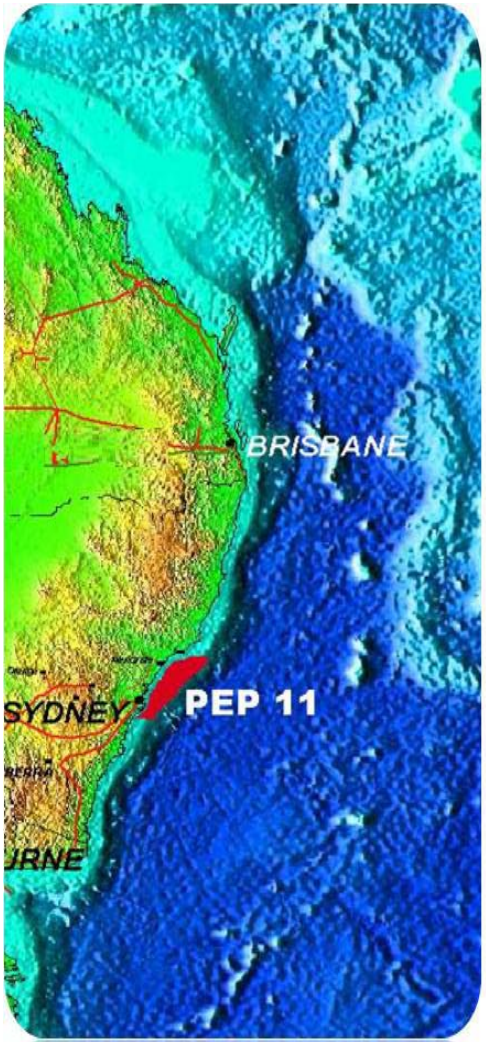
OFFSHORE SYDNEY BASIN : PEP11 OPPORTUNITY

- NSW/PEP 11 covers 8100+ sq km, 20 km from Australia's largest energy market, excellent infrastructure
- Permit Prospective Recoverable Resources estimated at up to 16.3 Tcf; mean = 7.5 Tcf
- Excellent analogies with world class producing fields
- Active thermogenic hydrocarbon system demonstrated offshore
- Possible gas/condensate-charged Permian + Triassic reservoirs / excellent potential for gas & oil discovery
- Prospective resources and proximity to infrastructure infer potential for LNG
- Advent – right to earn 85%; JV partner Bounty Oil & Gas reducing from 75% to 15%
- Robust Economics: NPV_{10} >A$12 billion potential at P50 level => potential >170 x uplift in equity value
- Evaluating tenders for provision of rig, environmental approvals nearing completion and conceptual well engineering design complete



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Offshore Sydney Basin – A Proven Petroleum Basin With Potential Huge Gas Reserve – Prospective Recoverable Resources of 16.3 Tcf (P10) estimated for the Permit.

Cornea, Browse

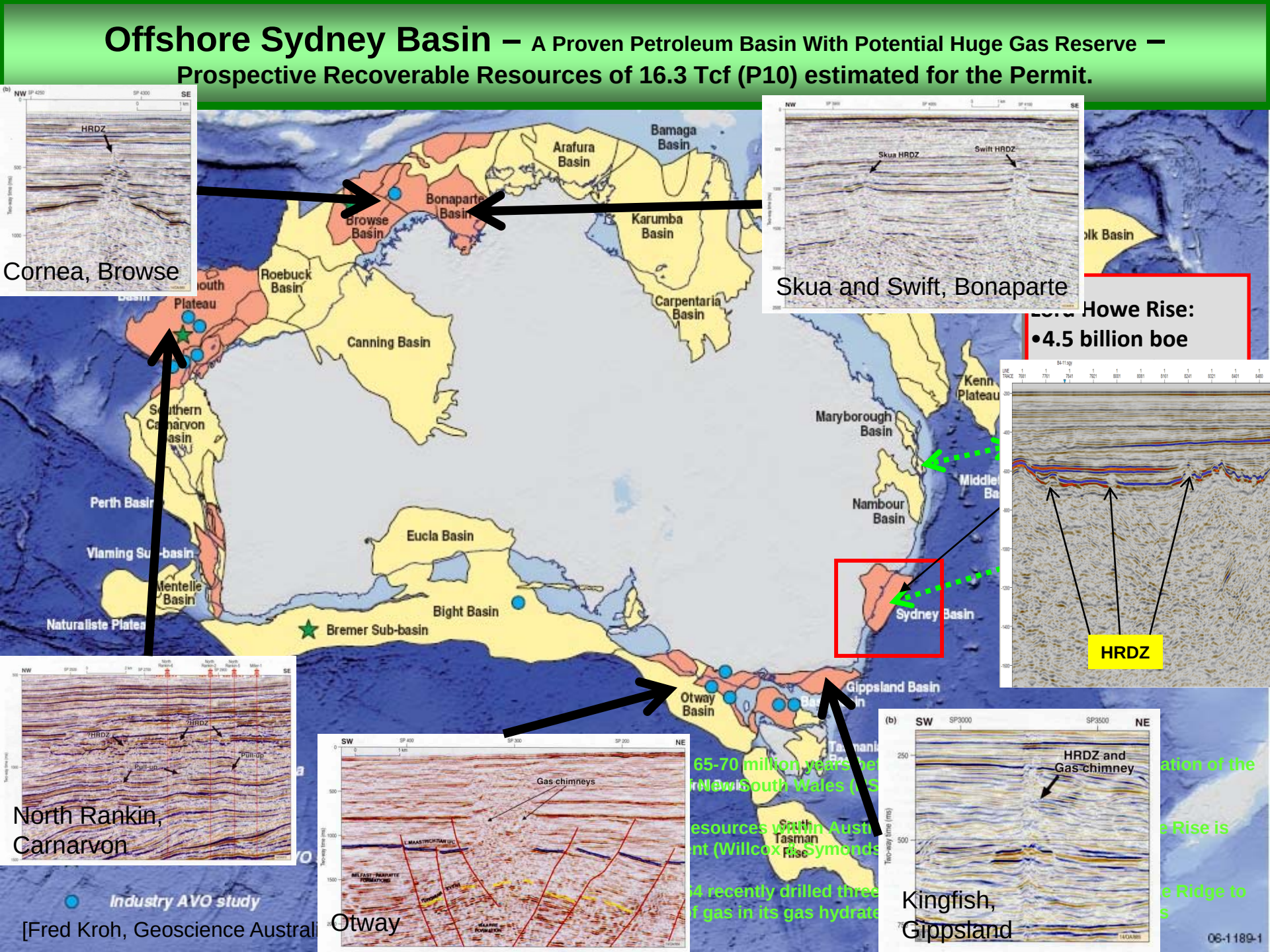
Skua and Swift, Bonaparte

Lord Howe Rise:
•4.5 billion boe

North Rankin, Carnarvon

Otway

Kingfish, Gippsland



[Fred Kroh, Geoscience Australi

Offshore Sydney Basin – Santos and Government Reports

- **"Ampolex**, assuming a somewhat different objective stratigraphy, **estimated unrisked reserves at 1560 Bcf**. **Santos (1993)** had identified a total of 10 structural leads, two on the flank of the Newcastle Syncline being estimated **to each contain 975 Bcf of gas-in-place**."(Alder, 1998)

- **"**Although the high inertinite and vitrinite content of the coals indicate that they are primarily a potential source of gas, the **Upper Permian coals of the Sydney Basin compare favourably as a potential source for both oil and gas with the Toolachee Formation, the main late Permian source in the Cooper Basin of southwest Queensland and South Australia.** The Late Permian coal measures attain a thickness of about 1600m at the coast between Newcastle and Terrigal-1, and thicken and dip offshore.**"** (Alder, 1998)

- **"**Maximum depth to magnetic basement in NSW/P10 is greater than 9km in the southern Macquarie Syncline and south of the New England Fold Belt at the continental margin. Recent seismic reprocessing and aeromagnetic surveying have focused the exploration effort on northern NSW/P10 **where thick (greater than 1600m) Upper Permian section containing source and reservoir facies is predicted."** (Grybowski, 1992)

- **"**This area is the most prospective in NSW/P10 because **the primary source and reservoir section**, the Upper Permian coal measures, attain its greatest thickness, and **structural closures potentially containing this section have been mapped on the reprocessed 1981 seismic."** (Grybowski, 1992)

- **"**Depth to magnetic basement exceeds the seismically determined depth to the base of the Permian sediments across the offshore uplift and its flanks. Leaman (1990); also interpreted from gravity data that shallow magnetic basement across the offshore uplift may not be crystalline basement but a thick Upper Carboniferous/Lower Permian volcanic pile with Carboniferous sediments below. **It seems that a sub-Permian basin lies below the Sydney Basin near the coast and offshore."** (Grybowski, 1992)

Offshore Sydney Basin – Geoscience Australia and NSW Government Reports.

[Maung et al, (Australian & NSW Govt Report) Petroleum Resources Branch/Bureau of Research Sciences,**1997**]

- **"**Whilst the Basin is considered gas-prone numerous significant shows, including both bleeding oil and gas flows, have been reported, supporting the assessment **that the Basin contains an active petroleum system**."

- **"**Reconnaissance and semi-detailed seismic reflection coverage identify the Offshore Sydney Basin as a region of structural complexity, **the style of which appears to be quite different from that of the adjacent onshore areas**."

- **"**Several structural prospects and leads identified by previous explorers lie within areas **now considered optimal for source rock and reservoir development. Previous explorers have estimated one prospect, associated with the Offshore Uplift, to potentially contain over 1 Tcf of gas**. Additional leads have also been identified, across the eastern flank of the Uplift, where geological control is minimal **and analogies to onshore geology tenuous. Many of these additional leads lie on regional structural fairways which have the potential to trap significant commercial quantities of hydrocarbons**."

- **"**Whereas Ampolex (Bradley, 1993) interpreted structural reactivation of this orogen as having commenced in the Middle to Late Permian and Santos interpreted it to be entirely related to Tasman Sea rifting (Grybowski, 1992), we link its structural reactivation to the development of the Sydney Basin from the earliest Permian."

- **"**Areas around and adjacent to the emerging Offshore Uplift, and particularly its shallowing eastern flank, were subjected to greater wave-base, barrier and strand bar deposition **(environments favourable to enhanced reservoir development) than comparable onshore areas**. This is an extremely important aspect for it has been the absence of perceived suitable reservoirs within the Permian that has impeded further exploration effort throughout the Sydney Basin generally."

- **"**According to the Santos interpretation Triassic and Late Permian sediments had been stripped off the crest of the Offshore Uplift, an interpretation that restricted the potential for reservoir involvement across the structural crest of the Uplift. This is reflected in the style of structuring interpreted by Santos. **Our interpretation differs markedly from those of both Santos and Ampolex."**

Offshore Sydney Basin – Prospectivity Studies to 2004

- **"**The Sydney Basin was subjected to late-stage episodes of **compression, which caused brittle deformation, fracturing** and high angle reverse faults probably during the Late Oligocene to Mid-Miocene **(as seen in the Gippsland and Otway Basins)."** (Bradley, 1993)

- **"**More recent **drilling results demonstrate a currently active gas-generative petroleum system (both carbon dioxide free and ethane enriched)**, probably sourced from both the Wandrawandian Siltstone and Berry Siltstone. The Nowra Sandstone (sealed by Berry Siltstone) and the Snapper Point Formation (sealed by Wandrawandian Siltstone) **present widespread target horizons** for deep petroleum exploration wells within the southern, central western and central northern Sydney Basin.**"** (Arditto, 2001)

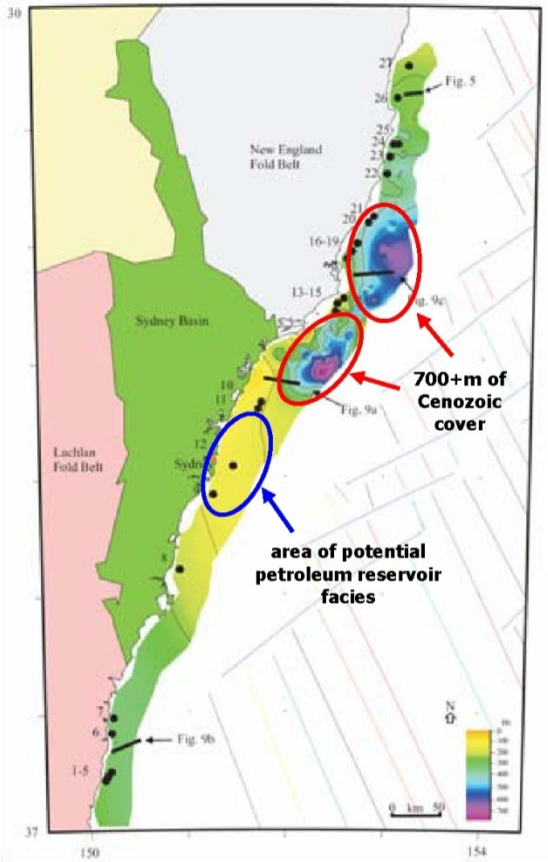
- **"**Several new structural targets have been added to the existing inventory of prospects and leads, including some now considered **optimally located with respect to source rock and reservoir development**. It was during another foredeep loading episode in the Late Permian that the **economically significant and regionally extensive, petroleum source rock**, coal bearing faces of the Tomago, Newcastle and Illawarra Coal Measures were deposited.**"** (Alder, 1998)

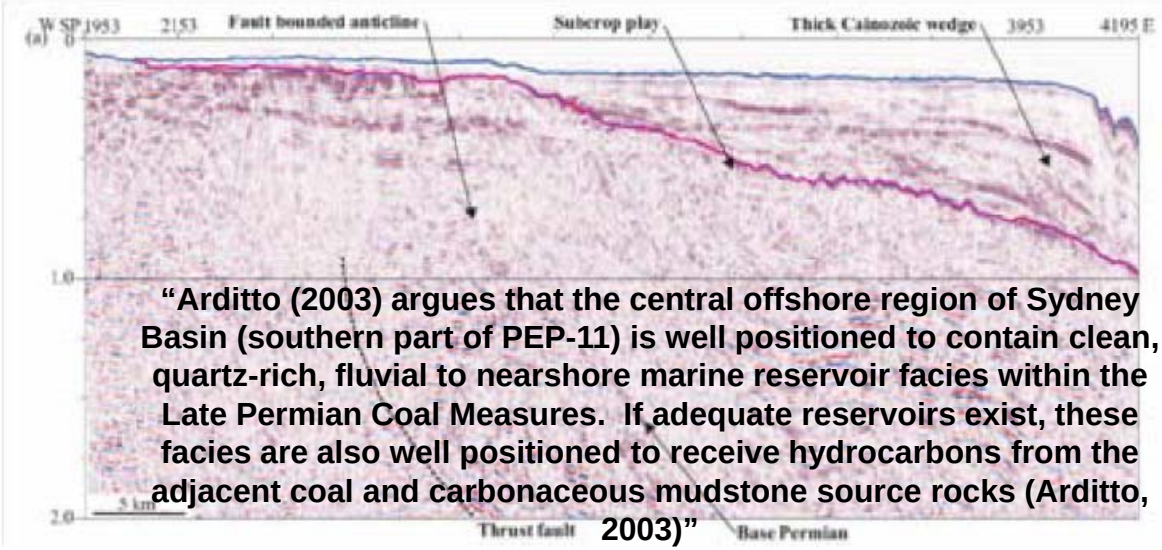
- **"The Sydney Basin contains the necessary ingredients for hydrocarbon accumulations, namely abundant source and seal rocks** (Early Permian marine shales/siltstones and later Permian Coal Measures)**, adequate thermal history, and untested traps."** (Hamilton and Galloway, 1989; Alder).

- **"Structural traps are believed to be widespread with Late Permian and Late Triassic anticlines and fault traps combined with Tertiary rejuvenation of older structures thought to be the major plays."** (Stewart and Alder, 1995).

- **"**Towards the top of these cycles thick coal measure facies were deposited, particularly in the late Permian; **supporting our assessment that the basin contains an active petroleum system."** (Stephenson & Burch, 2004)

- **"**The Sydney Basin contains at least 6km of Permo-Triassic marine and non-marine sequences, and is the **southernmost part of an eastern Australian super-basin that extends from the hydrocarbon producing Bowen Basin in Queensland through the Gunnedah and onshore Sydney Basins."** (Stephenson & Burch, 2004)





"Arditto (2003) argues that the central offshore region of Sydney Basin (southern part of PEP-11) is well positioned to contain clean, quartz-rich, fluvial to nearshore marine reservoir facies within the Late Permian Coal Measures. If adequate reservoirs exist, these facies are also well positioned to receive hydrocarbons from the adjacent coal and carbonaceous mudstone source rocks (Arditto, 2003)"

Figure 7: Diagram from Sayers et al (2004) showing seismic line SY91-15a in the offshore Sydney Basin. The diagram shows the relationship of the Cenozoic wedge as a possible sealing facies the underlying Permian subcrop play.

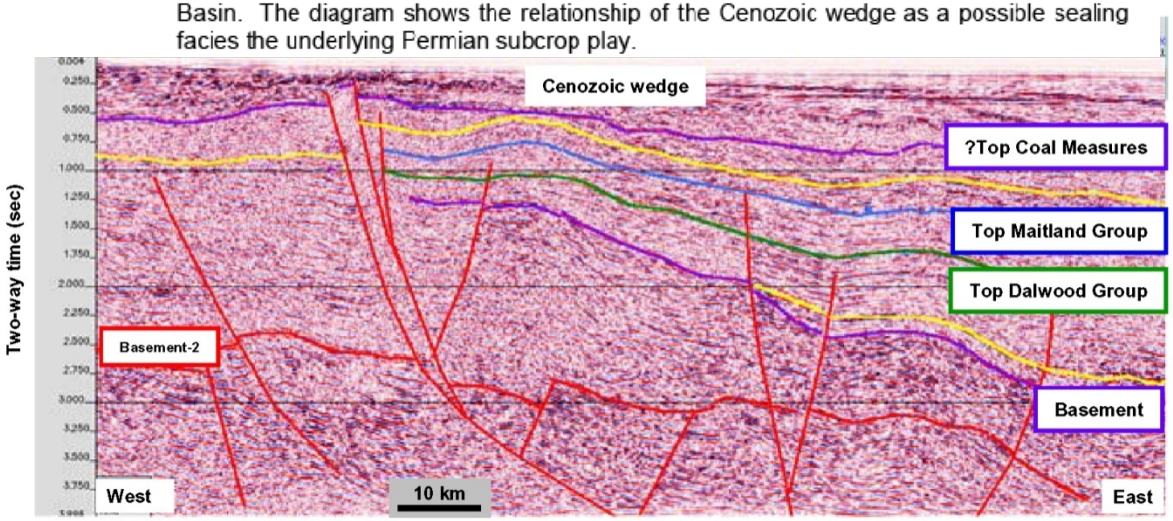


Figure 84 (above):
Isopach map of the Cenozoic cover in the Sydney Basin (from Sayers et al., 2004)

Figure 85 (right):
Interpreted seismic line 91-014 across the northern offshore Sydney Basin. The line location is shown on the adjacent map, along with the East Maitland-1 well and the Hunter Valley Domes structural domain (**red** shading).

Offshore Sydney Basin – Seep Features – a Key Exploration Tool

- **“**Gulf of Mexico: Active bubble discharge areas increase gradually to the south **reaching a peak over the southern most reservoirs** and suggests these are diagnostic ✱of much earlier stage of gas generation & movement **diagnostic of active present day reservoir charging**.**”** (Whelan)

- **“Active seeps** occur where **gas bubbles, pockmarks, or bright spots are visible on seismic profiles** and where chemosynthetic communities are present in conjunction with **large concentrations** of migrated hydrocarbons (macroseeps). These generally occur where **generation and migration of hydrocarbons from source rocks are ongoing today**.**”** (Abrams)

- **“Active** seeps are easily detected as acoustic anomalies (e.g., wipe-out zones and bottom simulating **reflector) on conventional and high-resolution seismic profiles. Also active seeps may be seen as gas** bubble traces and pockmarks on subbottom profiler and sidescan sonar records.**”** (Hovland and Judd, 1988, in Abrams).

- **“Active** seeps typically occur in basins that are now actively generating hydrocarbons or that **contain excellent migration** pathways.**”** (Abrams)

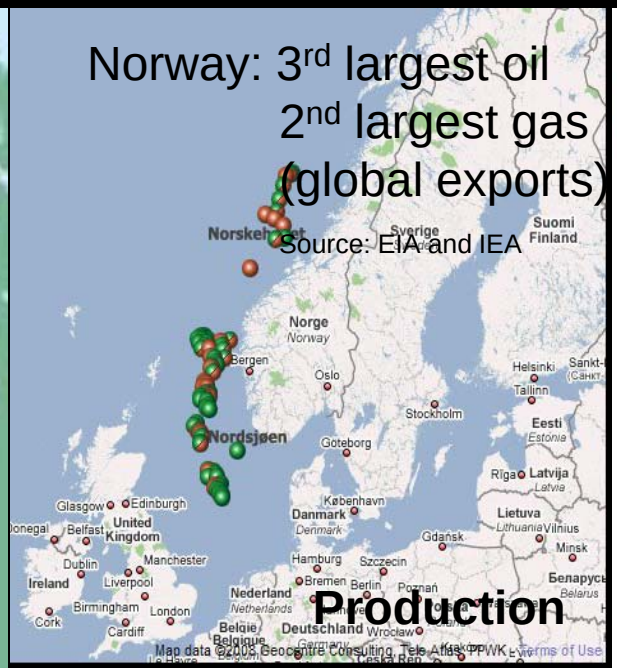
- **“**It also demonstrates that **regional chimney mapping provides a robust framework** with which to **high-grade** areas for exploration.**”** (O’Brien et al, Geoscience Australia)

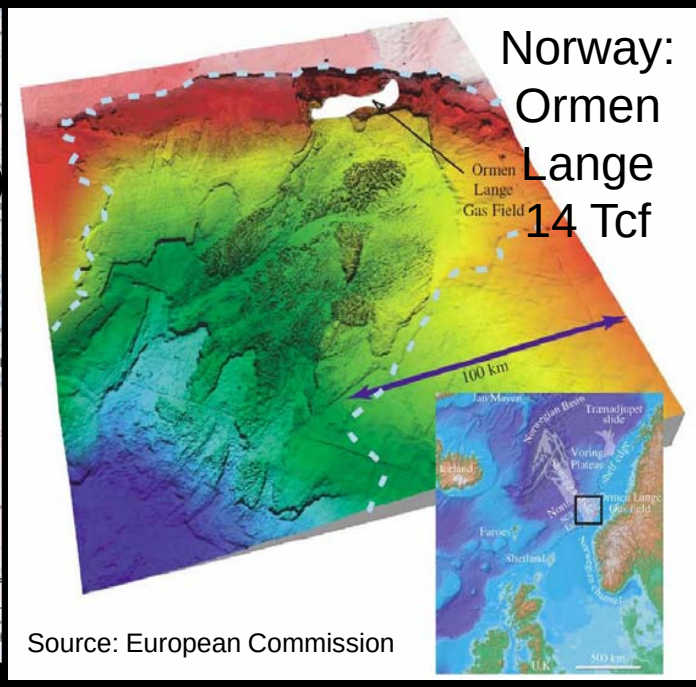
- **“**Whilst these chimneys appear as strong events on seismic data (Figure 7), the total amount of hydrocarbons passing through them to the seafloor can be fairly insignificant, at least at the present day. This suggests that even **quite low amounts of gas can produce strong chimneys on seismic data**.**”** (O’Brien et al, Geoscience Australia)

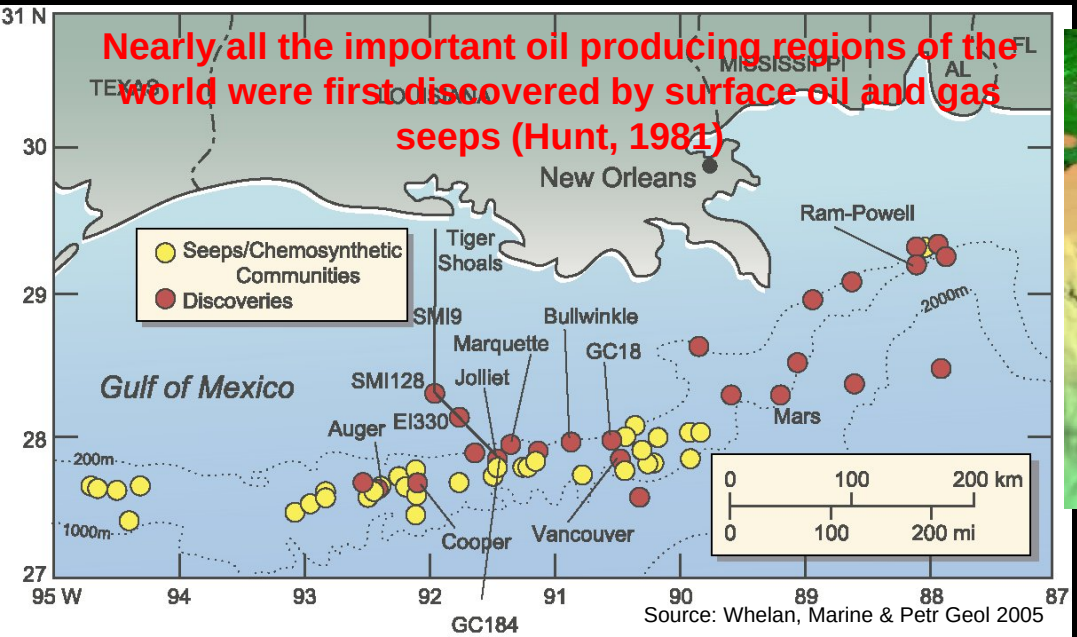
- **“**These **small slicks are, however, absolutely critical in identifying the location of the most prospective structures** within a province such as the Yampi Shelf.**”** (O’Brien et al, Geoscience Australia)

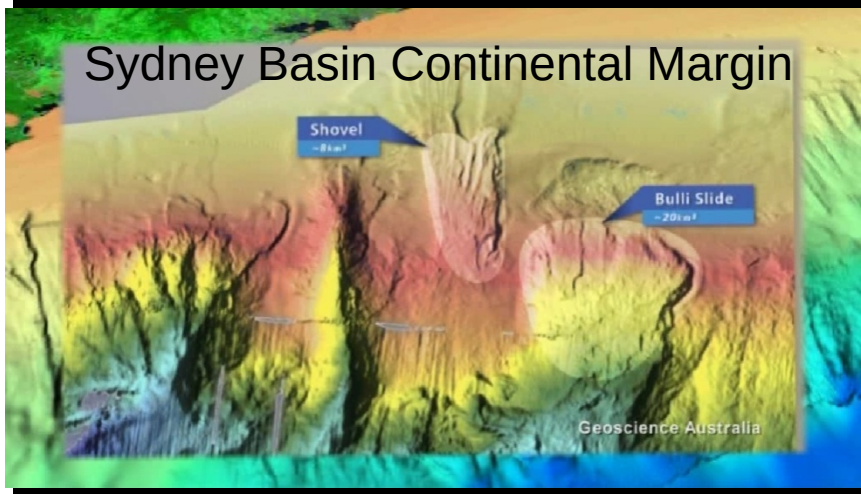
- **“**From an exploration viewpoint, it would appear that a hierarchical approach is the most appropriate. Firstly, seafloor features such as **pockmarks** and biological build-ups should be identified, and **shallow direct hydrocarbon indicators (DHIs)**, **gas chimneys and HRDZs** etc should be mapped using available 2D, and preferably 3D, seismic data. These data should be combined with regional charge history modelling (2D and 3D) and structural mapping, and analysis of the distribution of the regional sealing facies. These data should be combined with regional SAR data to identify any areas with clear liquids seepage - such as the inboard edge of the Yampi Shelf.**”** (O’Brien et al, Geoscience Australia)

Slope failure, Gas seepage. Major HC Provinces









Slumps: over 28 cu. km

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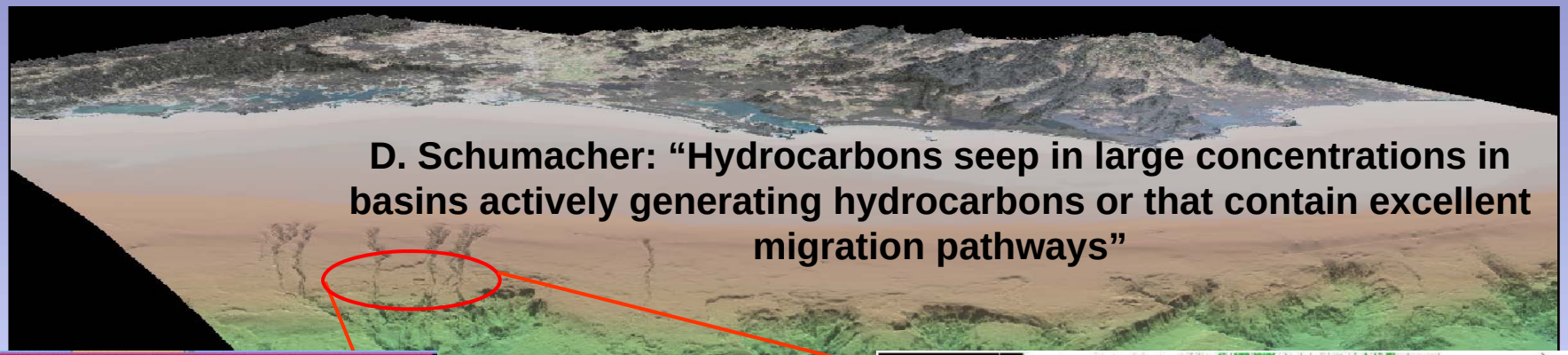
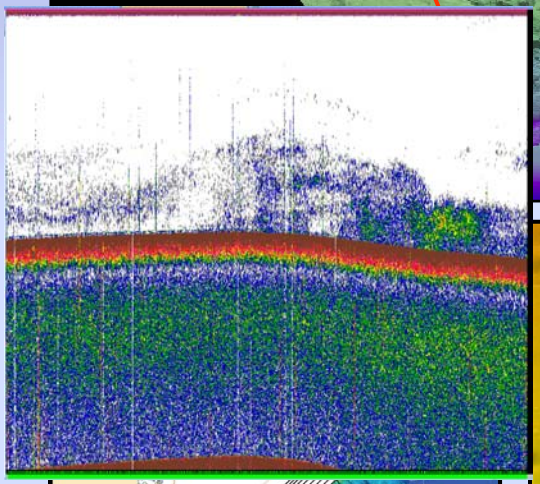
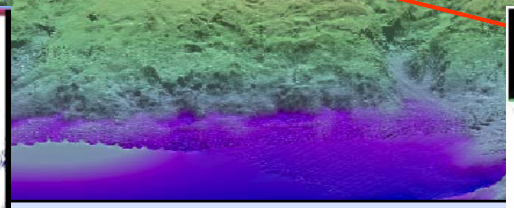
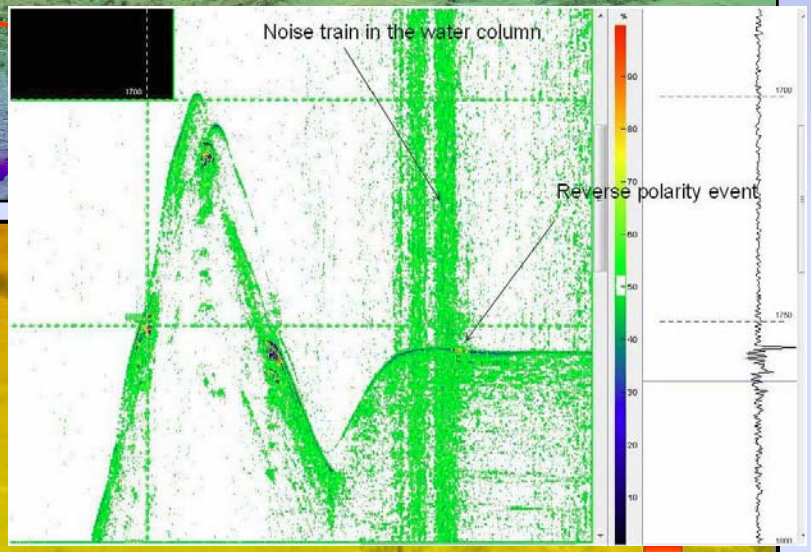
Swath Survey 2006

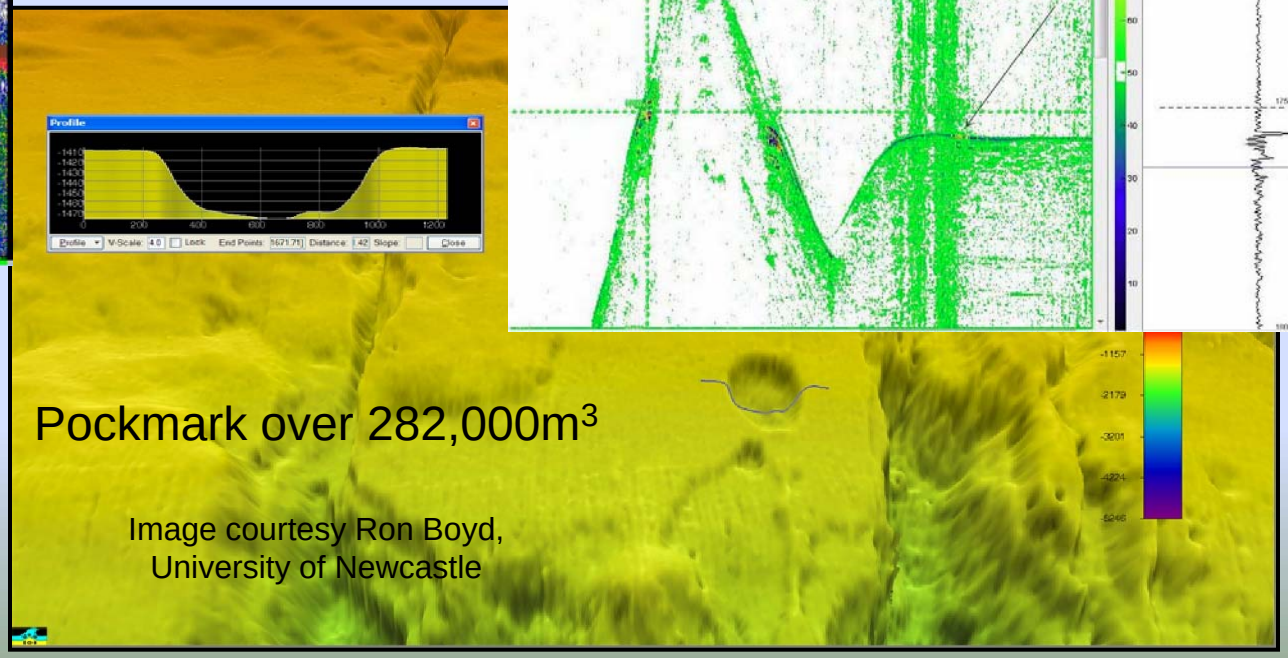


D. Schumacher: "Hydrocarbons seep in large concentrations in basins actively generating hydrocarbons or that contain excellent migration pathways"



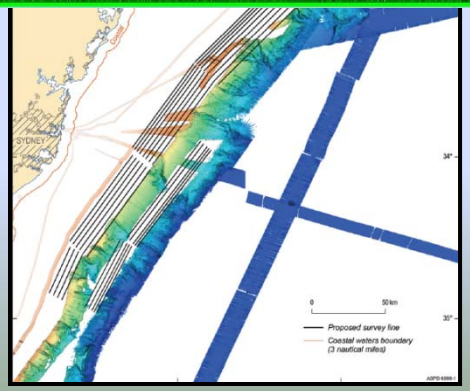




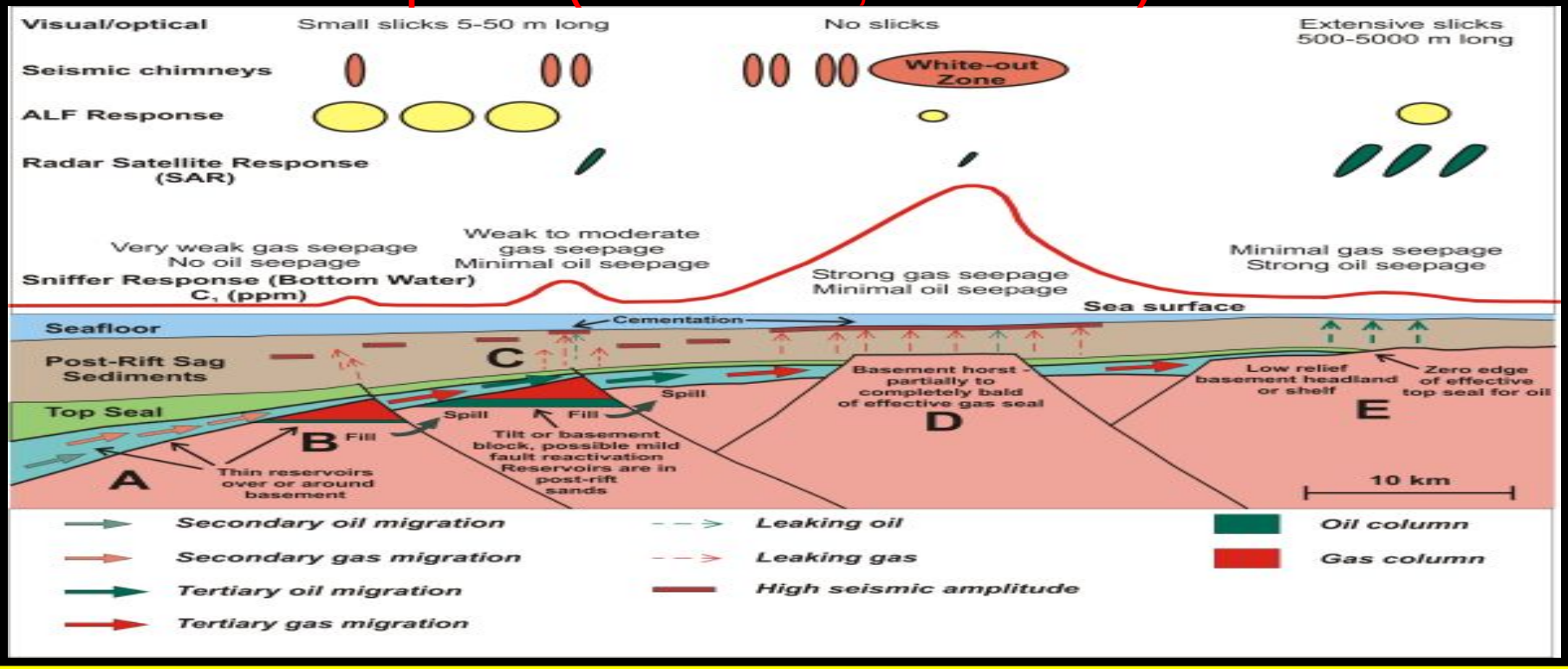


Pockmark over 282,000m^3

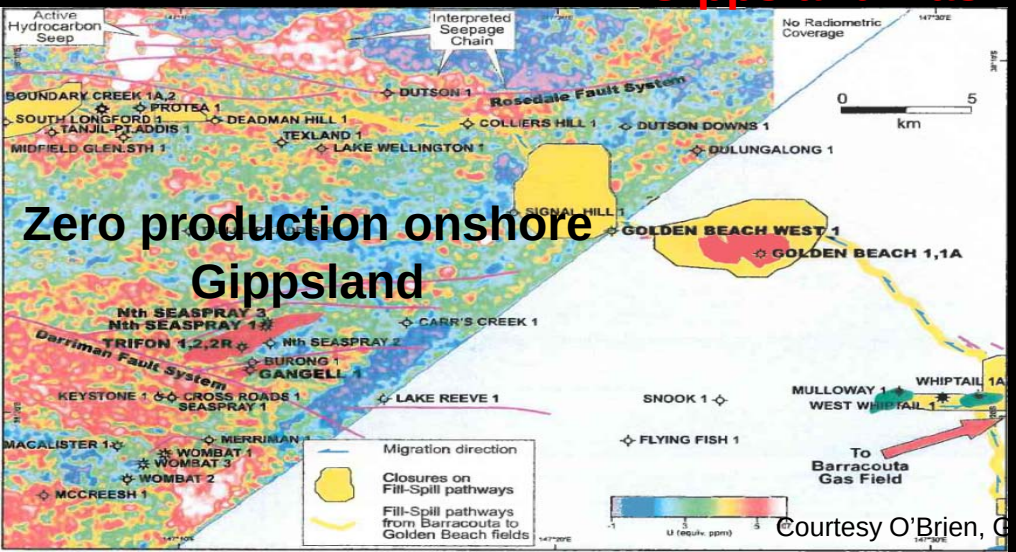
Image courtesy Ron Boyd,
University of Newcastle



Yampi Shelf (Browse Basin, NW Australia) Model

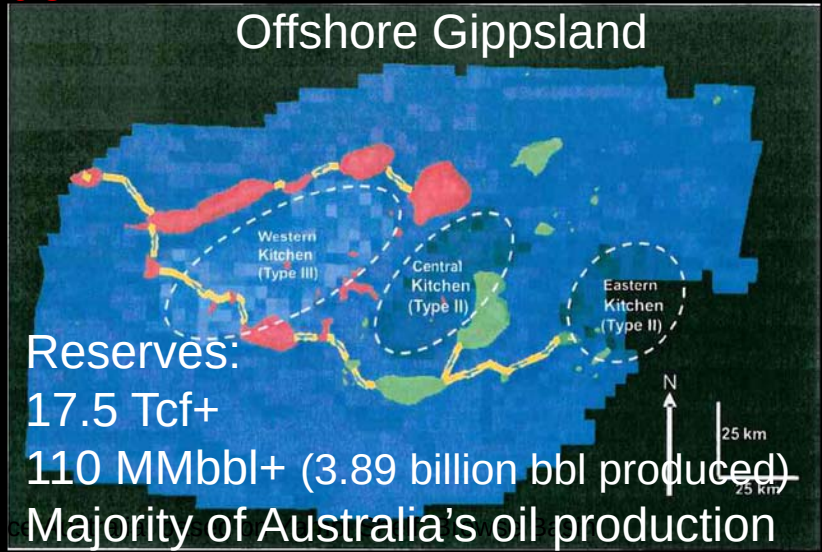


Gippsland Basin Model



Zero production onshore Gippsland

Courtesy O'Brien, C

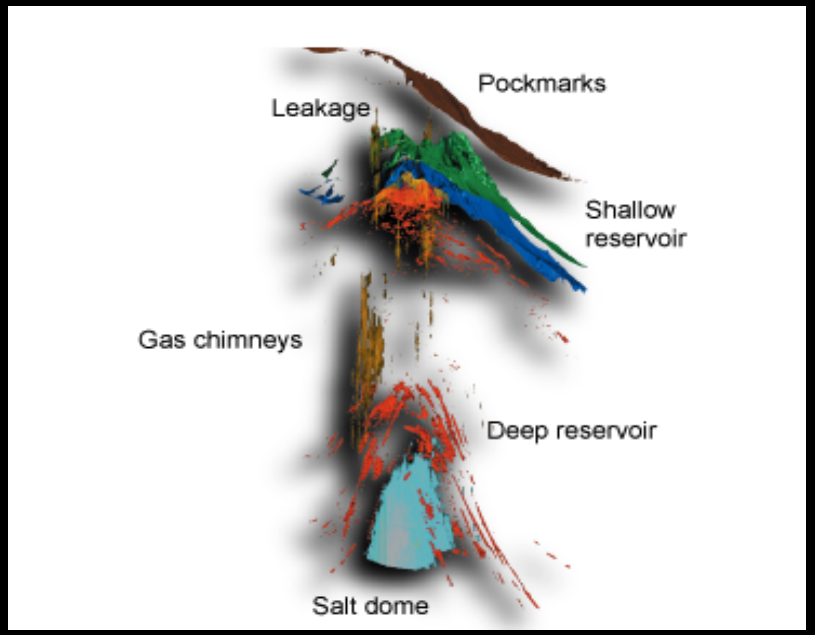


Reserves:
17.5 Tcf+
110 MMbbl+ (3.89 billion bbl produced)
Majority of Australia's oil production

Chimneys and pock marks indicating focus areas of fluid flow above the top reservoir

"From the many studies performed in hydrocarbon basins from all over the world we have learned that seismic chimneys are visible in 90% of all Mesozoic and Tertiary basins."

Norway – Gullfaks South Field



Judd and Hovland, 2007. *Seabed Fluid Flow.*

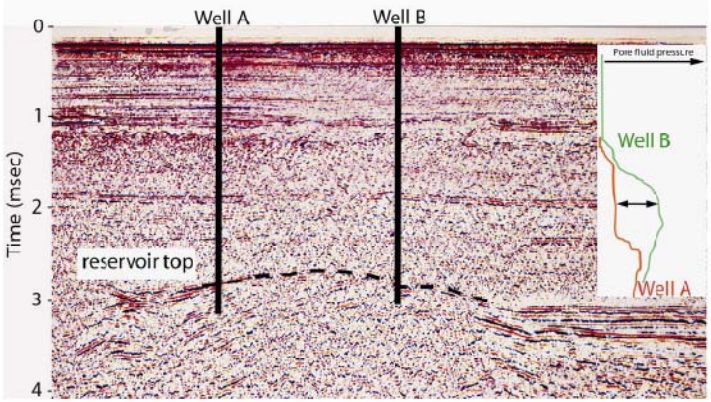
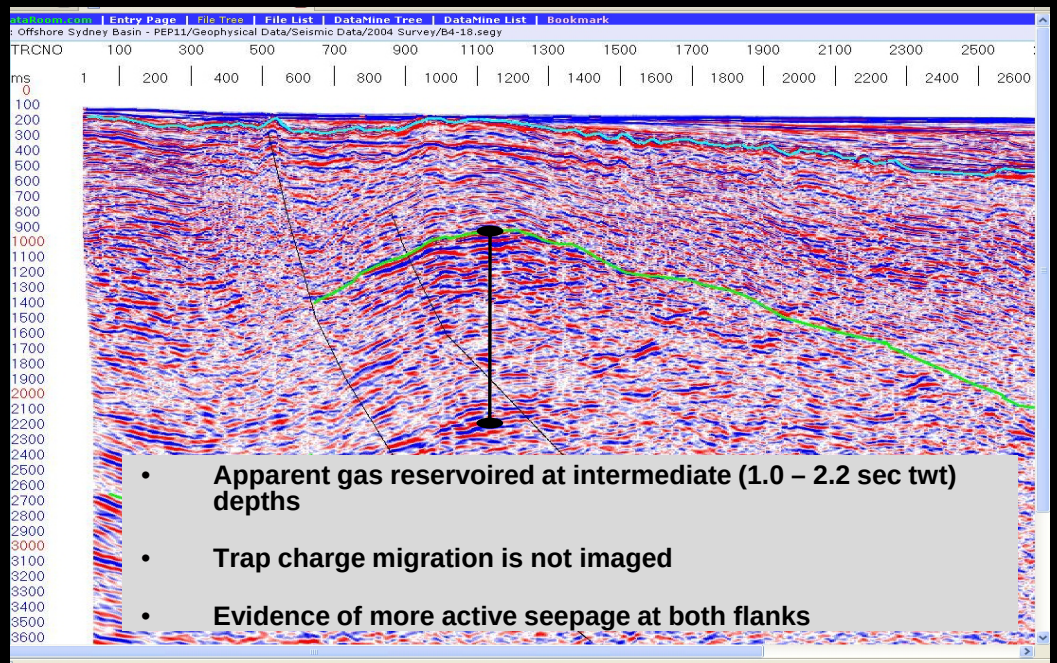


Figure 6.8: Seismic section across the Gullfaks South field (Norwegian North Sea) showing a gas cloud (a zone in which the acoustic layering is obscured by the presence of gas) above the petroleum reservoir. Well A lies outside the gas cloud, Well B passes through it. In Well B mud gas readings were found to be much higher, there more higher hydrocarbon gas components (C2 to C5), more gas shows, and higher pore fluid pressure (see inset) than Well A, outside the chimney; there was a 10.2 MPa pore fluid pressure difference between the two wells at the depth indicated by the two-ended arrow on the inset diagram. N.B. The vertical scale of the seismic section (in seconds, two way time), does not match the vertical scale (depth in km) of the pressure diagram. [Courtesy of Helge Løseth, Statoil.]



- **Apparent gas reservoired at intermediate (1.0 – 2.2 sec twt) depths**
- **Trap charge migration is not imaged**
- **Evidence of more active seepage at both flanks**

Judd and Hovland, 2007. *Seabed Fluid Flow.*

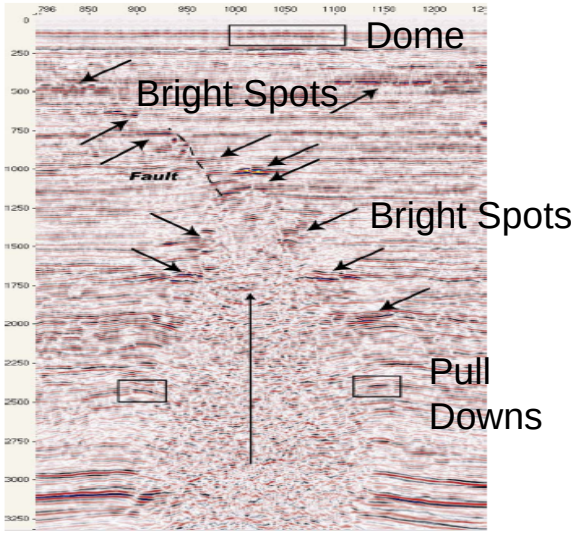
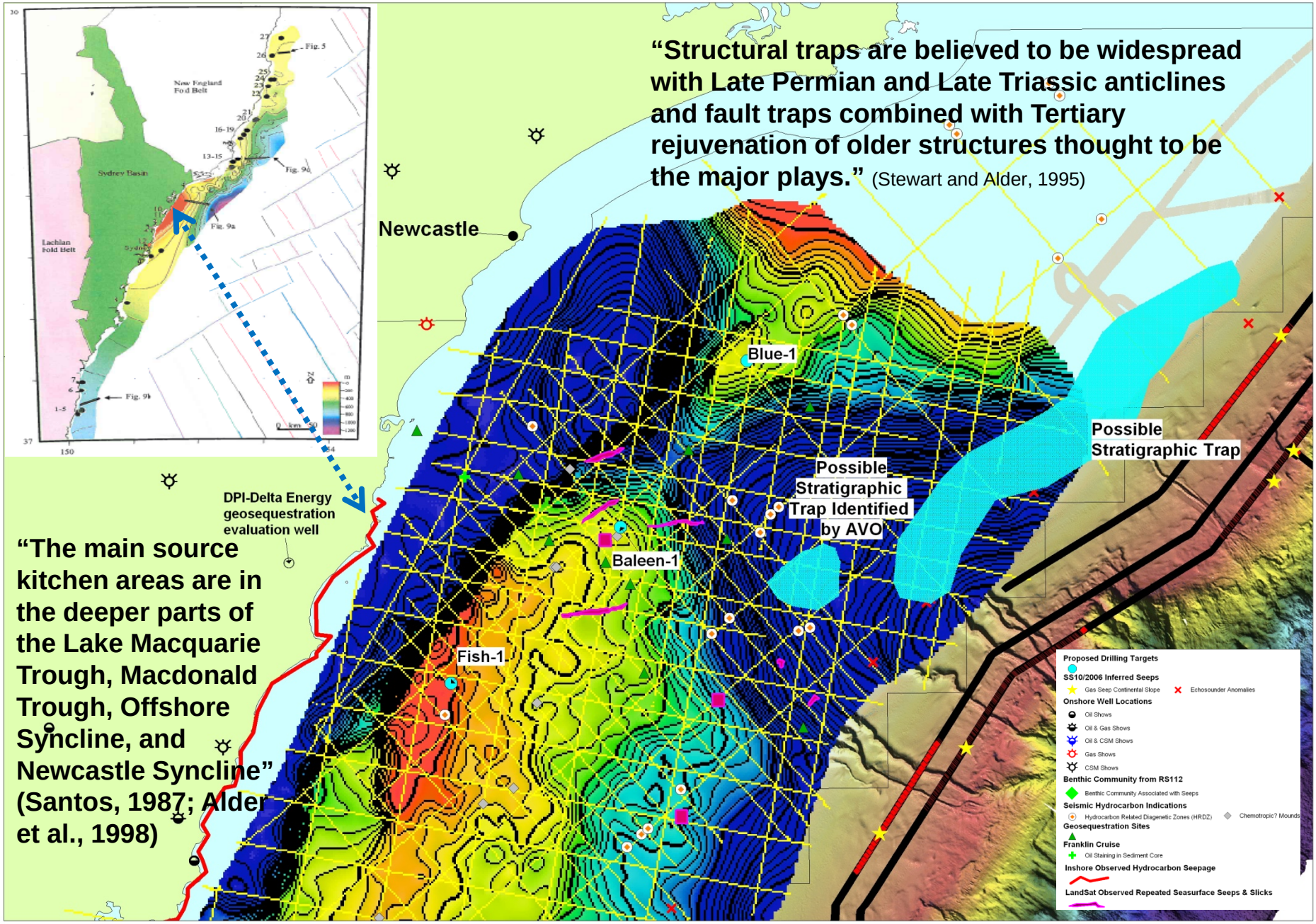


Figure 2.21: Seismic section across the Tommeliten Delta structure, a salt piercement diapir. The noisy zone is interpreted as a gas chimney through which gas rises vertically (as indicated by the large arrow). Some gas escapes laterally to produce brightening of adjacent reflectors, and reducing the acoustic velocity (v_p) to produce 'pull down' (examples are in the rectangles). A fault rising from the top of the gas chimney, from about 1,200ms to about 750 ms, provides a gas migration pathway; bright spots adjacent to this fault and elsewhere (examples are arrowed) indicate shallow gas accumulations. Reflection enhancement near the seabed (in the rectangle) occurs where the near-seabed sediments are slightly domed upwards; it is above this feature that gas seeps into the water column. [Image courtesy of Helge Løseth.]



"Structural traps are believed to be widespread with Late Permian and Late Triassic anticlines and fault traps combined with Tertiary rejuvenation of older structures thought to be the major plays." (Stewart and Alder, 1995)

"The main source kitchen areas are in the deeper parts of the Lake Macquarie Trough, Macdonald Trough, Offshore Syncline, and Newcastle Syncline" (Santos, 1987; Alder et al., 1998)

Offshore Sydney Basin:

Horizon E Structure Frame Indicating Huge Offshore Anticline

Mean prospective recoverable resources: 7.5 Tcf

Baleen Prospect:
Prospective rec. res:
P10: 5.78 TCF
P50: 1.79 TCF
P90: 0.22 TCF

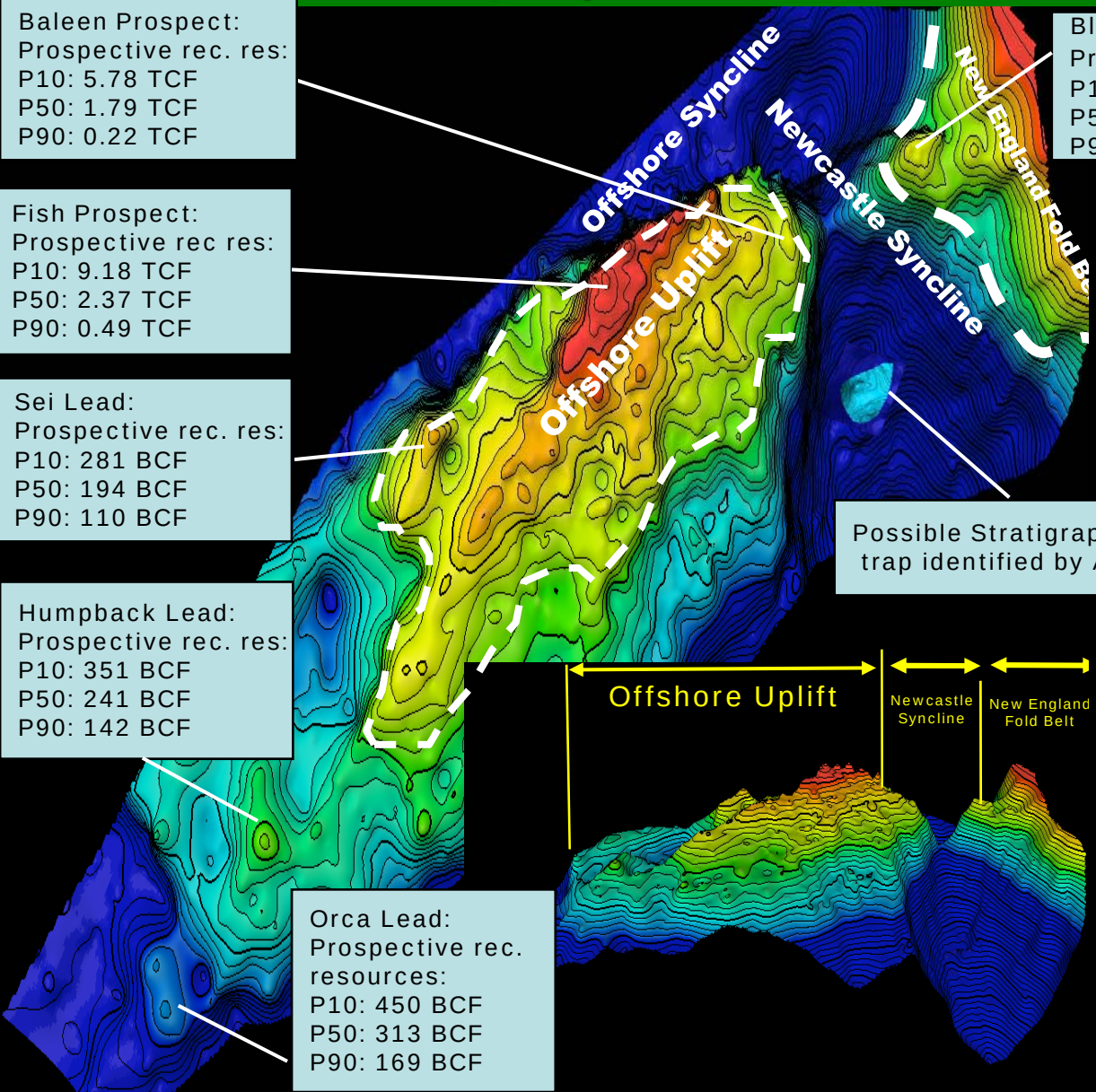
Fish Prospect:
Prospective rec res:
P10: 9.18 TCF
P50: 2.37 TCF
P90: 0.49 TCF

Sei Lead:
Prospective rec. res:
P10: 281 BCF
P50: 194 BCF
P90: 110 BCF

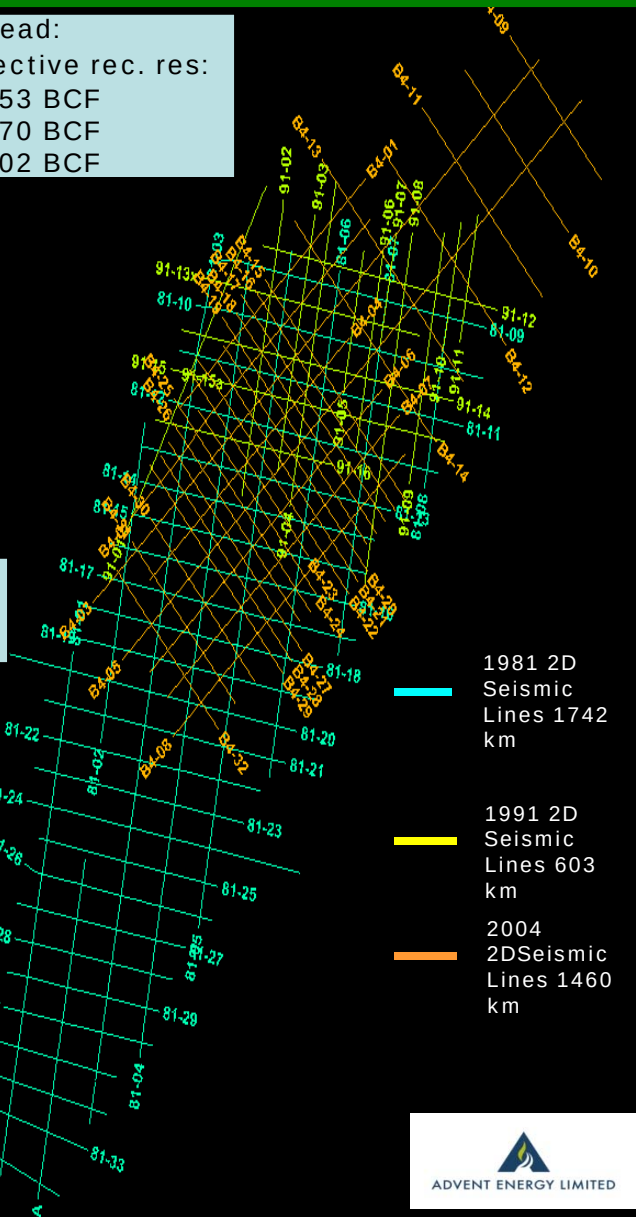
Humpback Lead:
Prospective rec. res:
P10: 351 BCF
P50: 241 BCF
P90: 142 BCF

Orca Lead:
Prospective rec. resources:
P10: 450 BCF
P50: 313 BCF
P90: 169 BCF

Blue Lead:
Prospective rec. res:
P10: 253 BCF
P50: 170 BCF
P90: 102 BCF



Possible Stratigraphic trap identified by AVO



1981 2D Seismic Lines 1742 km

1991 2D Seismic Lines 603 km

2004 2DSeismic Lines 1460 km

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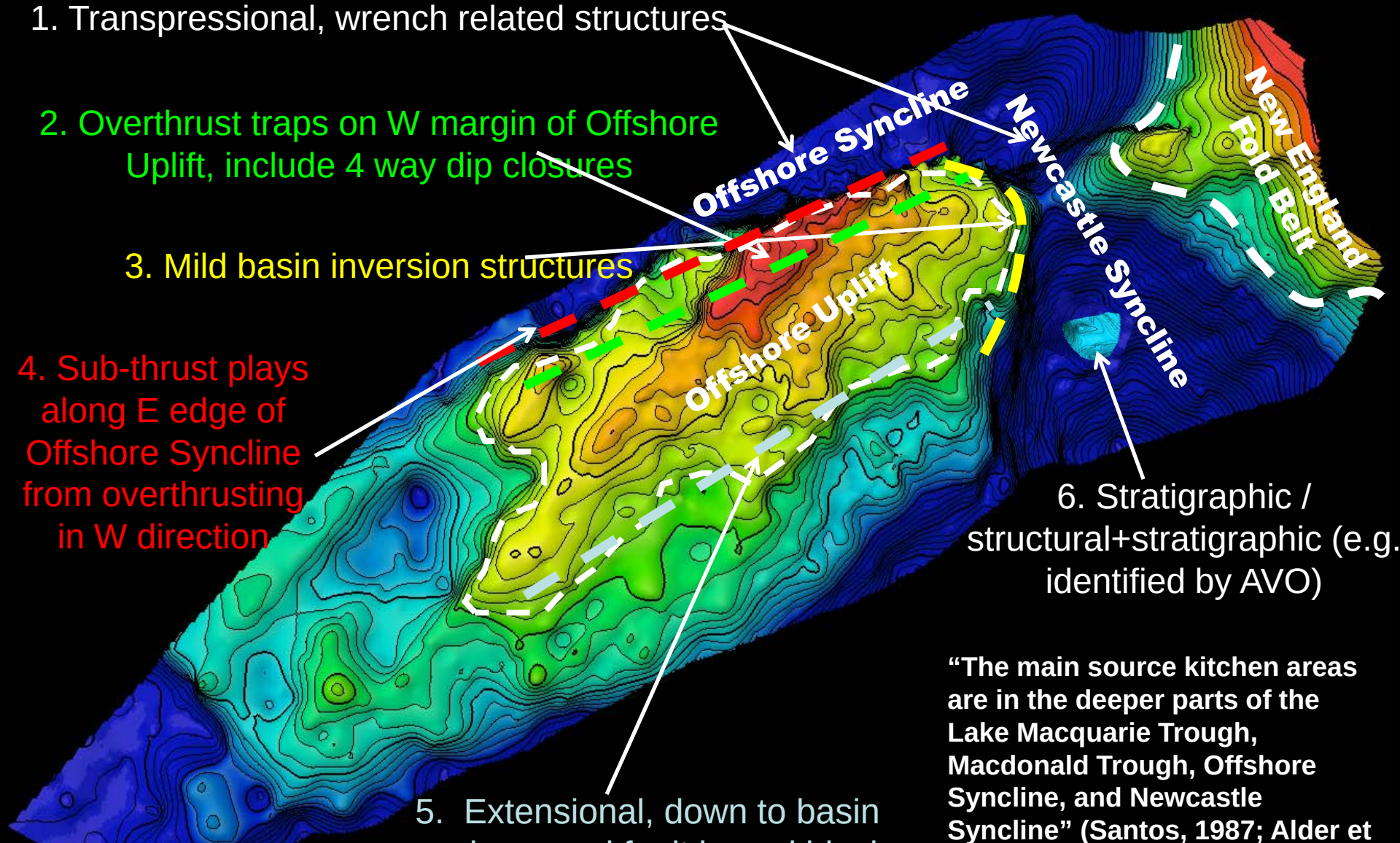
Offshore Sydney Basin: Possible Trap Styles



1. Transpressional, wrench related structures

2. Overthrust traps on W margin of Offshore Uplift, include 4 way dip closures

3. Mild basin inversion structures

4. Sub-thrust plays along E edge of Offshore Syncline from overthrusting in W direction

5. Extensional, down to basin margin normal fault bound blocks (E flank of Offshore Uplift)

6. Stratigraphic / structural+stratigraphic (e.g. identified by AVO)

"The main source kitchen areas are in the deeper parts of the Lake Macquarie Trough, Macdonald Trough, Offshore Syncline, and Newcastle Syncline" (Santos, 1987; Alder et al., 1998)

From Maung et al, 1997, and Stephenson & Burch, 2004, Preliminary Evaluation of the Petroleum Potential of Australia's Central Eastern Margin (GA12988)

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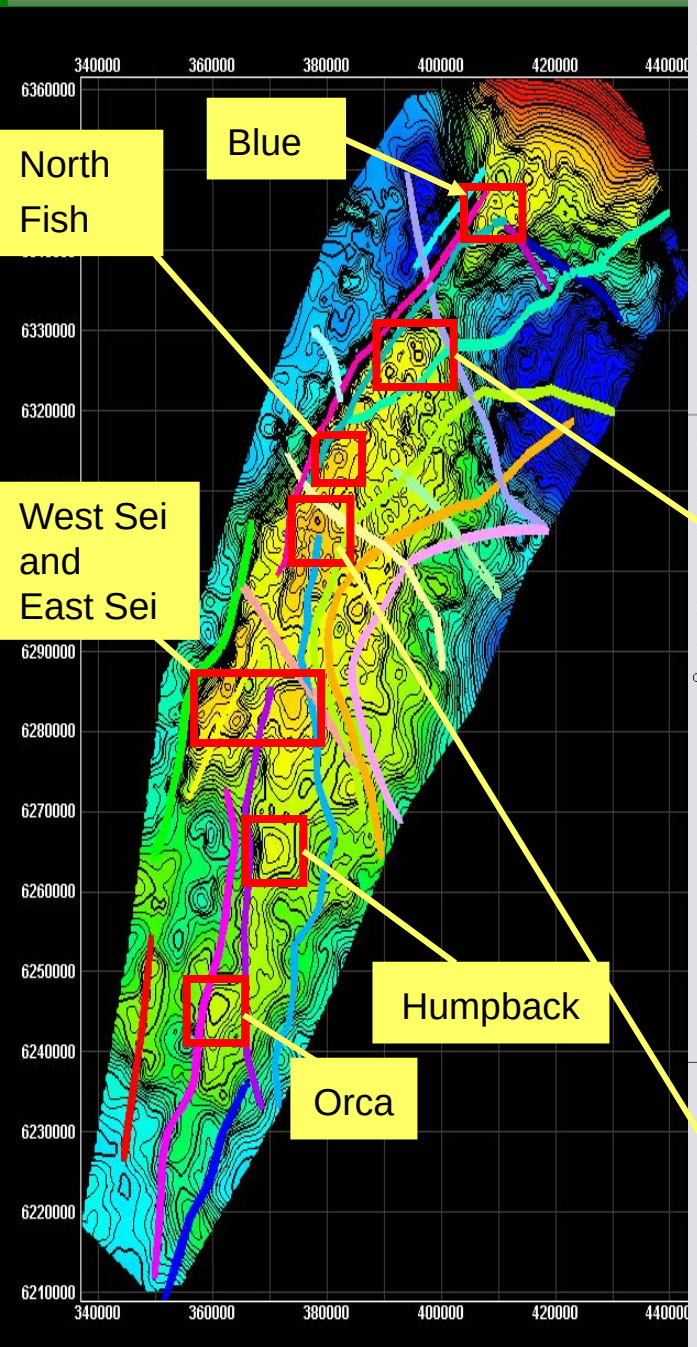
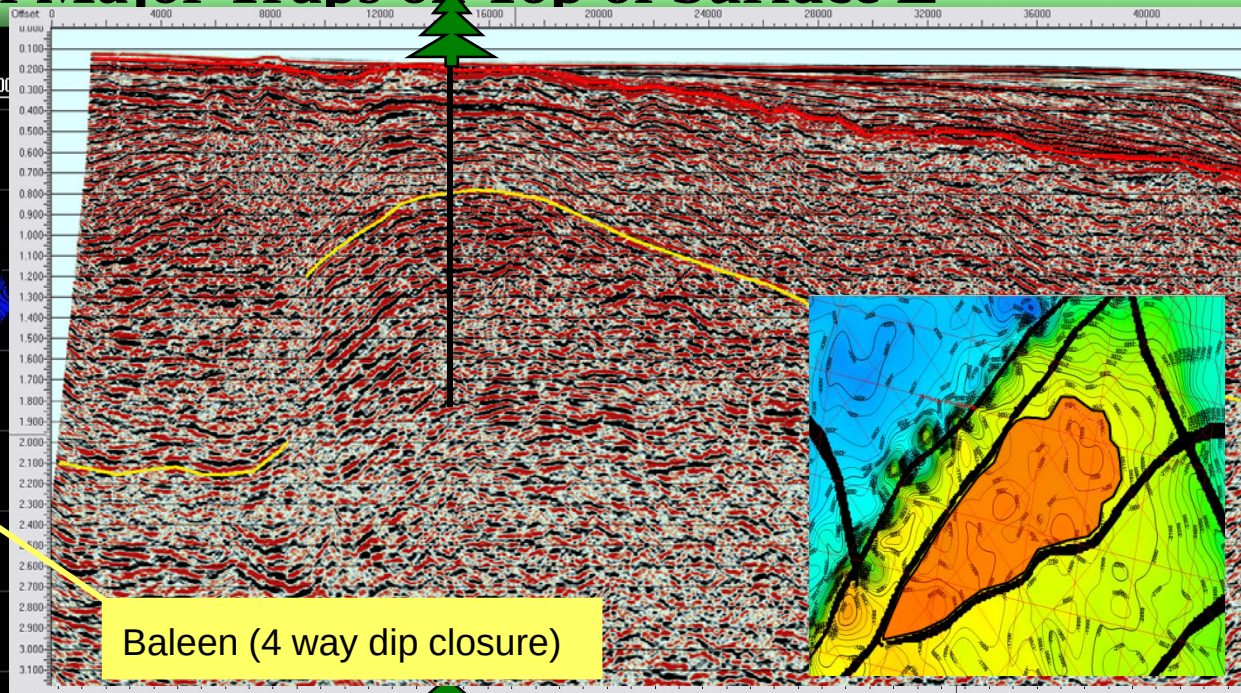
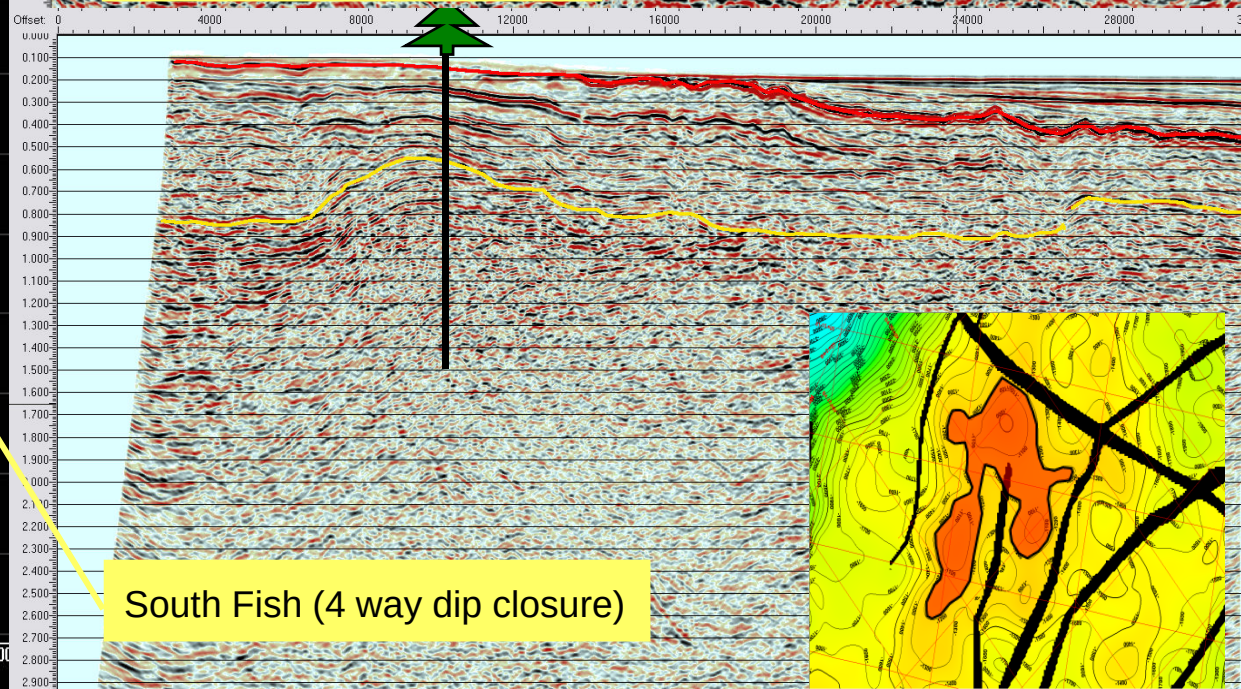
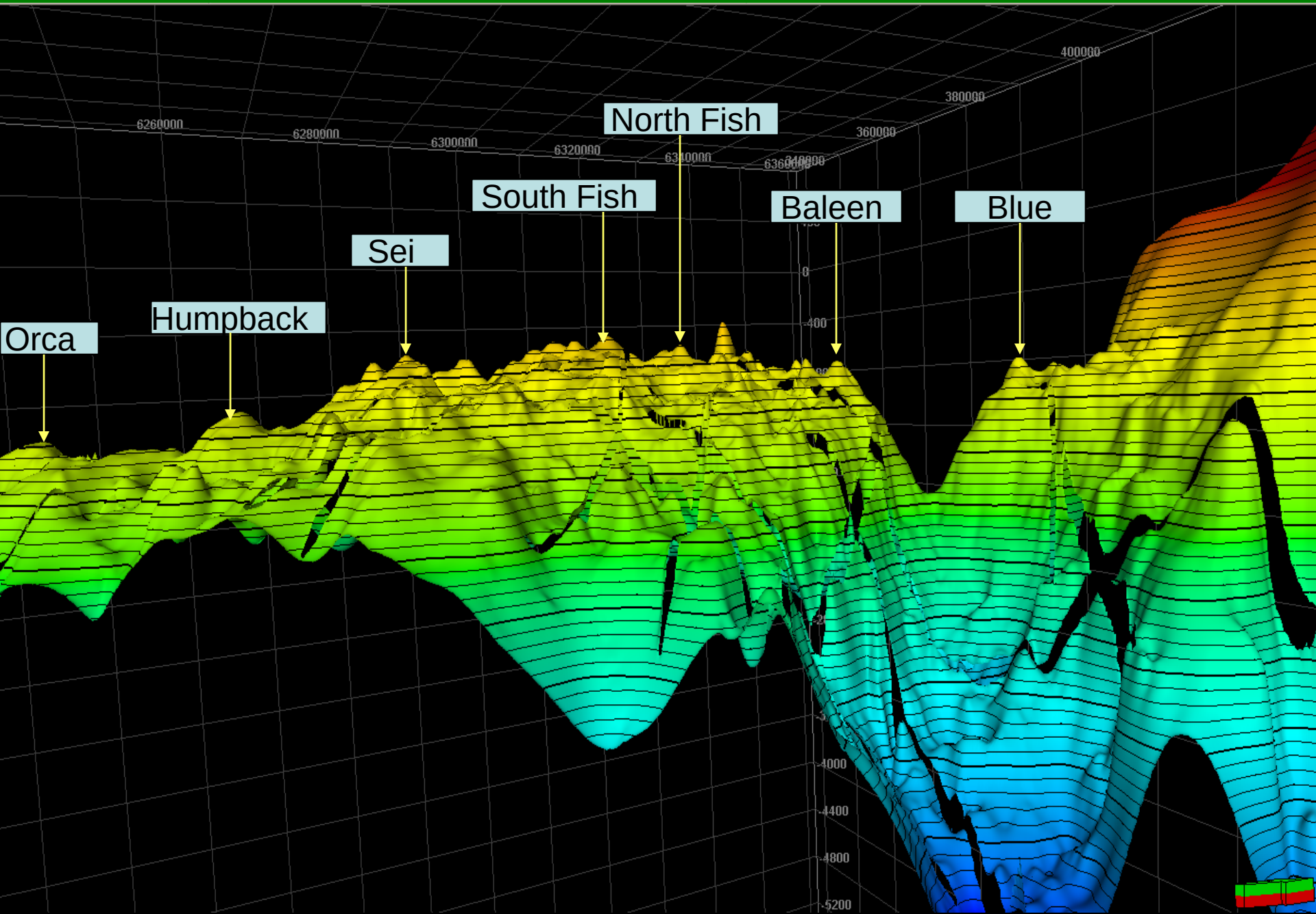
Distribution of Major Traps on Top of Surface E



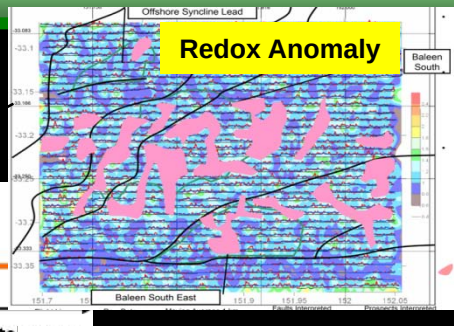


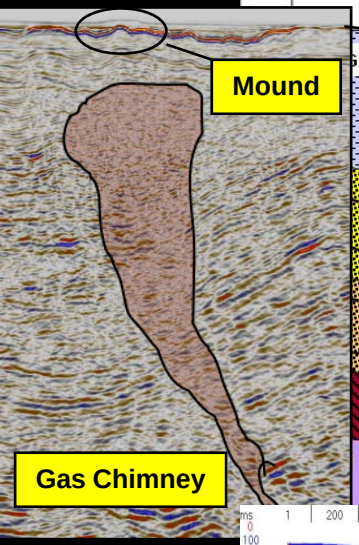


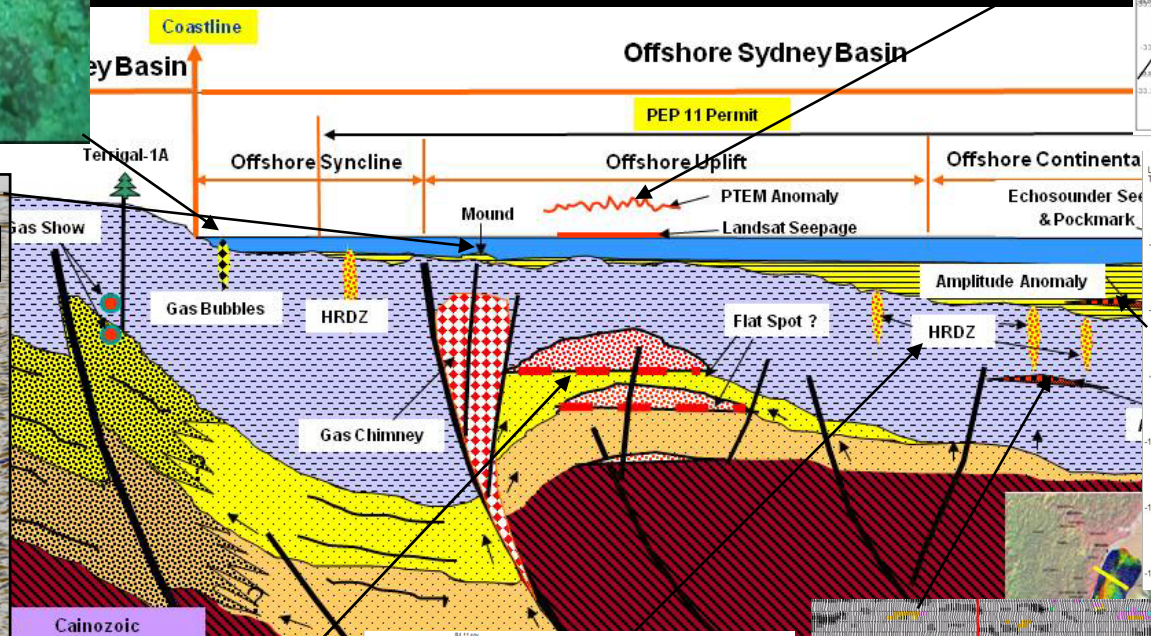
Surface E Side View From East to West

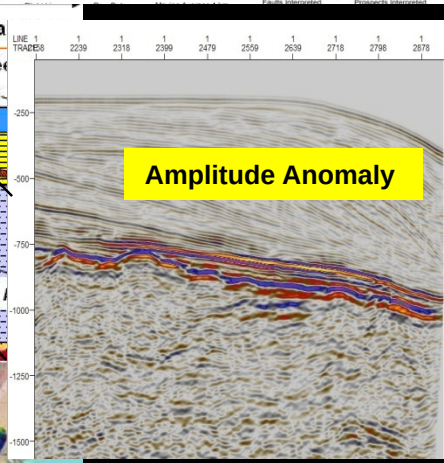


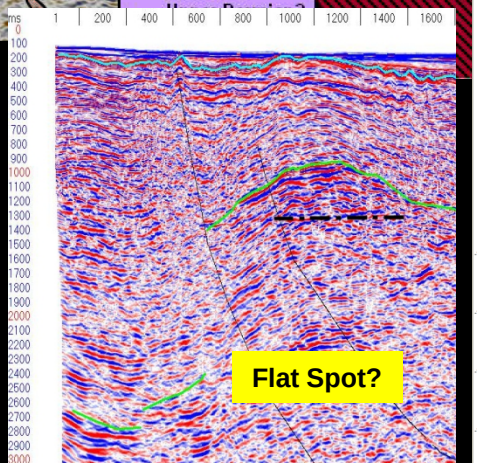
Petroleum Association and Reservoir Model

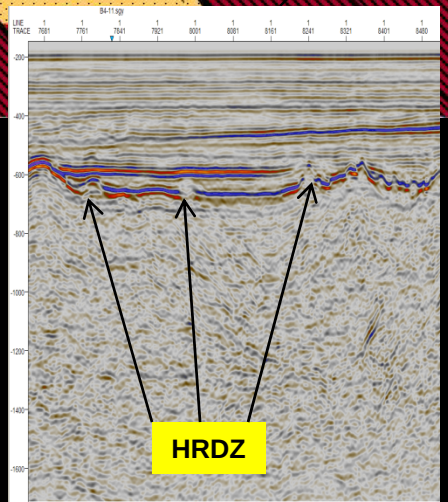


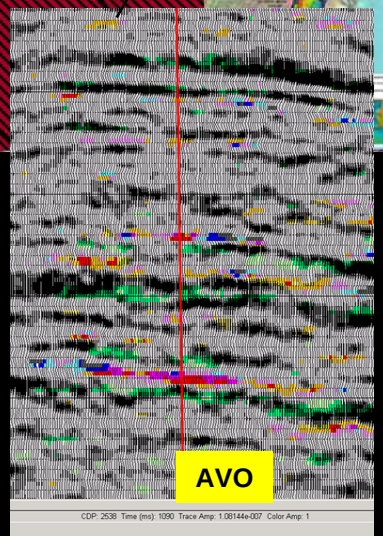


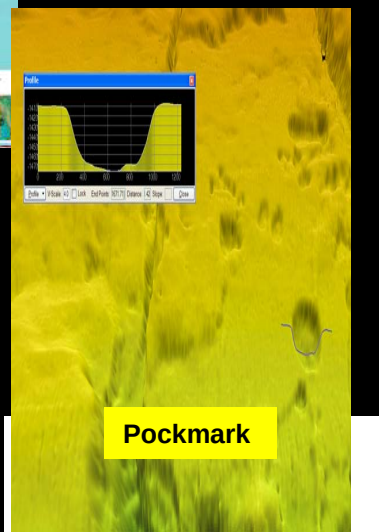




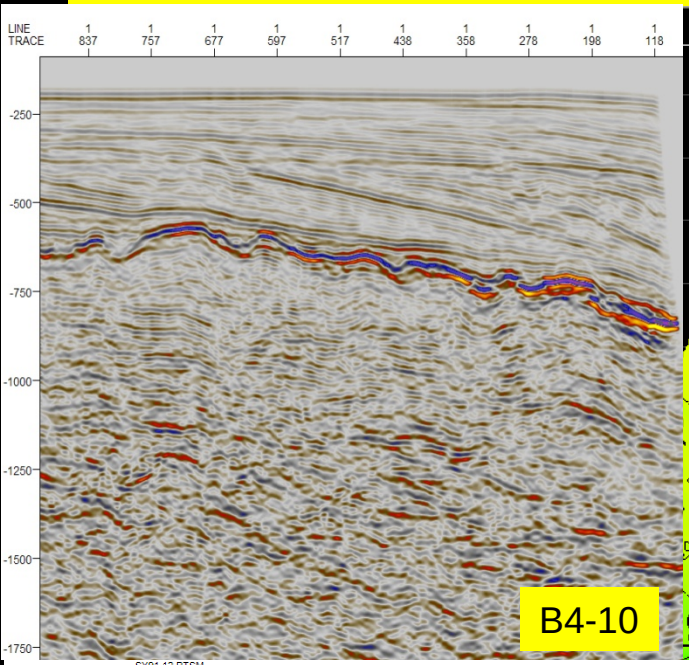


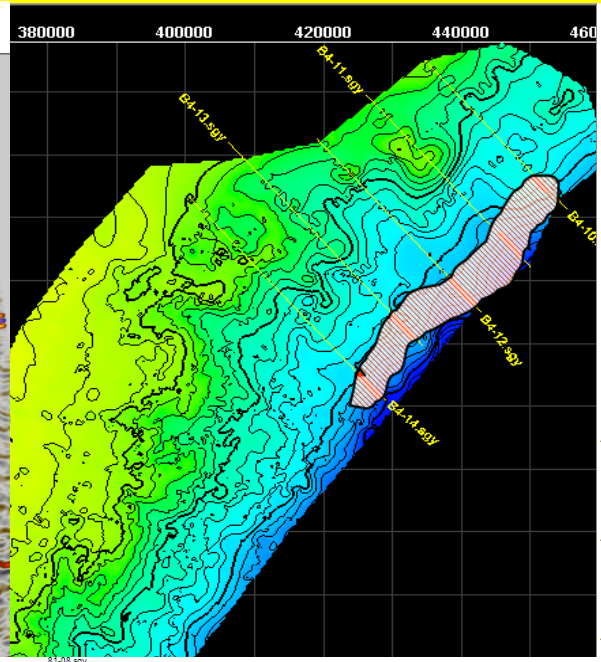


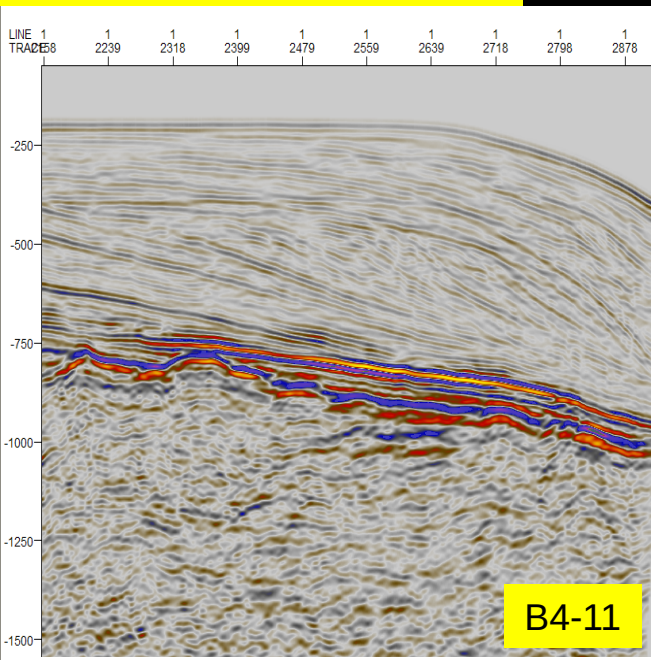


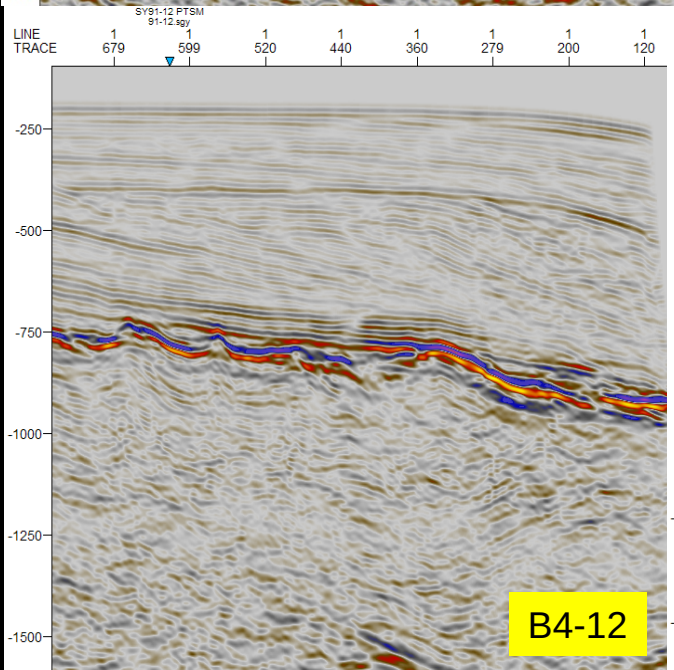


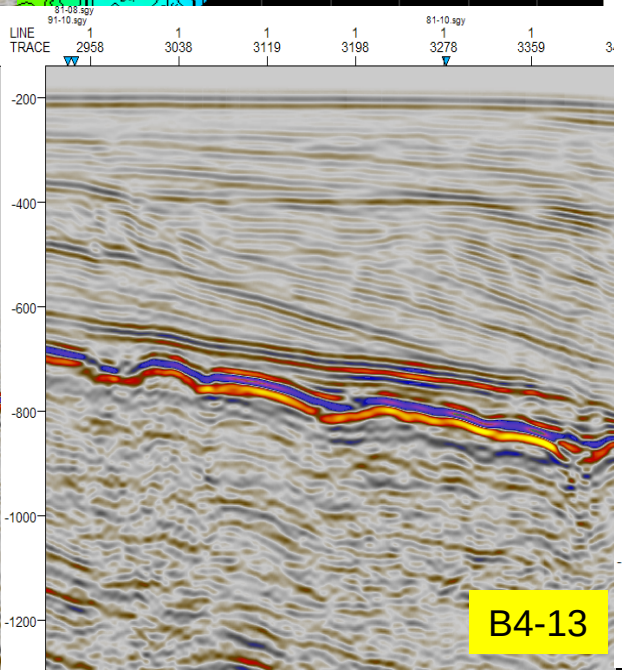
Amplitude Anomaly Along Continental Margin

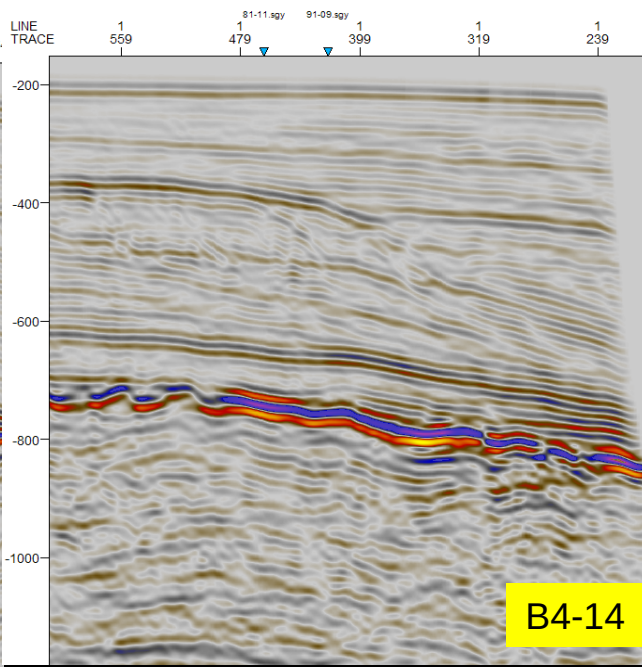




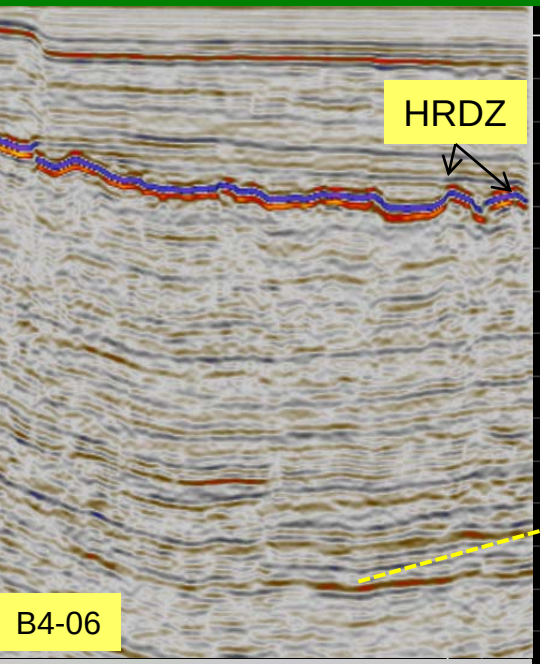


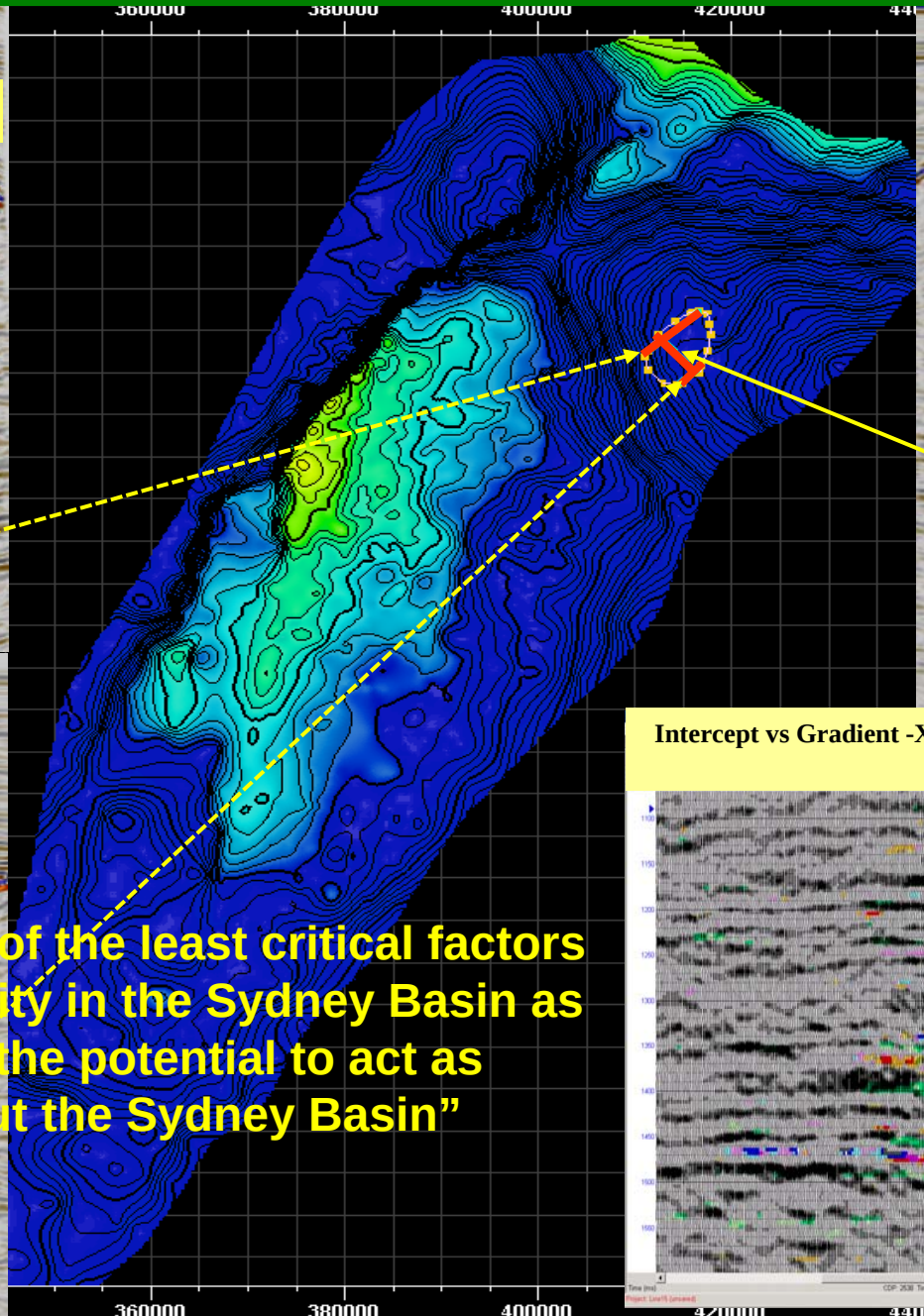


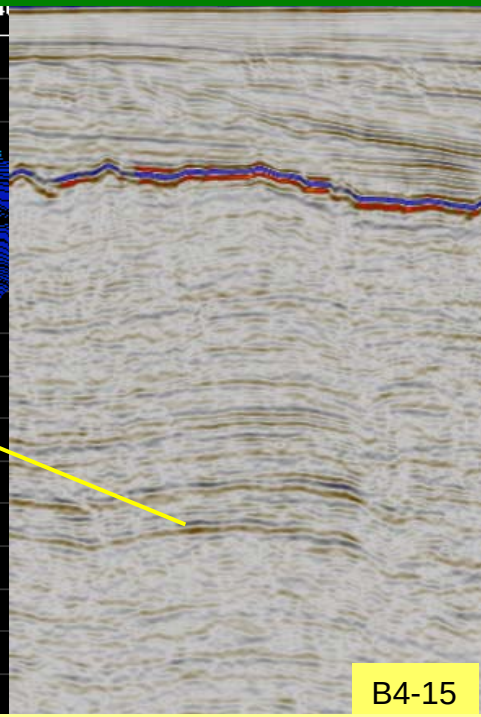


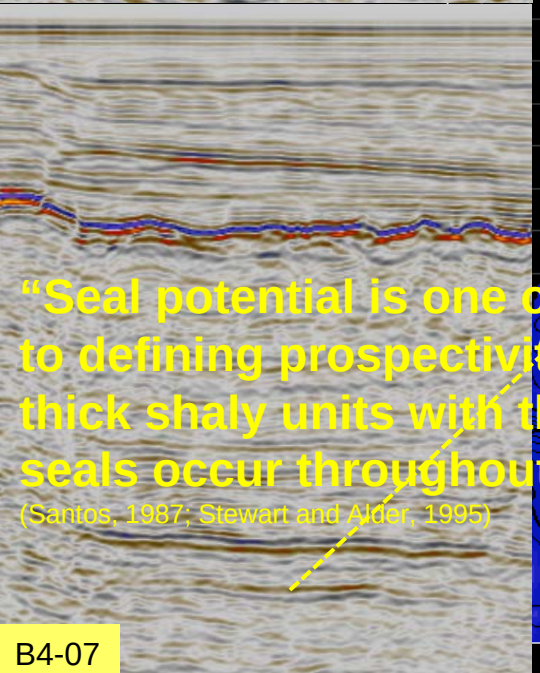


Direct Hydrocarbon Indicators - Possible AVO





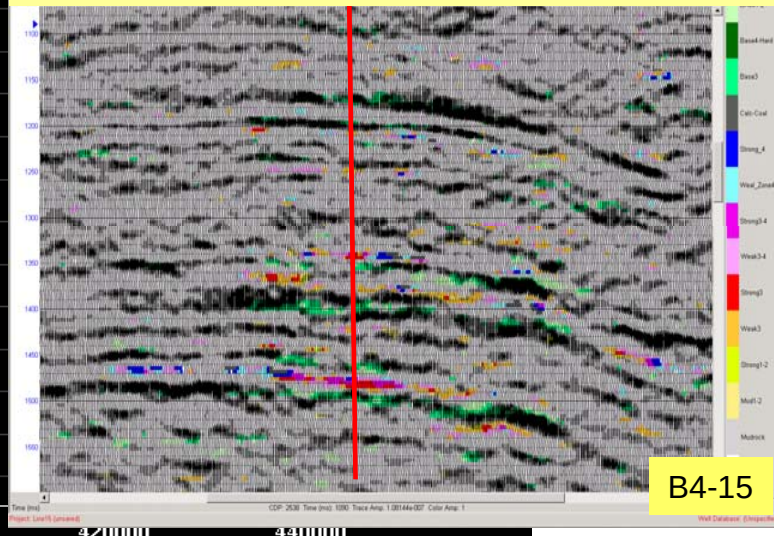




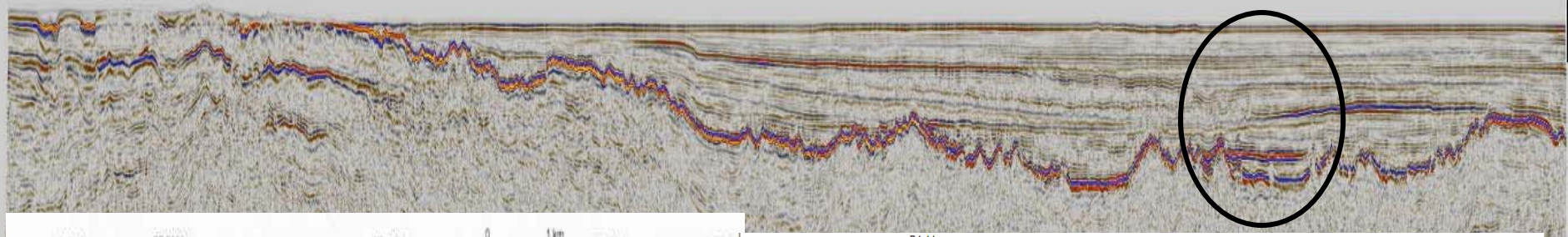
"Seal potential is one of the least critical factors to defining prospectivity in the Sydney Basin as thick shaly units with the potential to act as seals occur throughout the Sydney Basin"

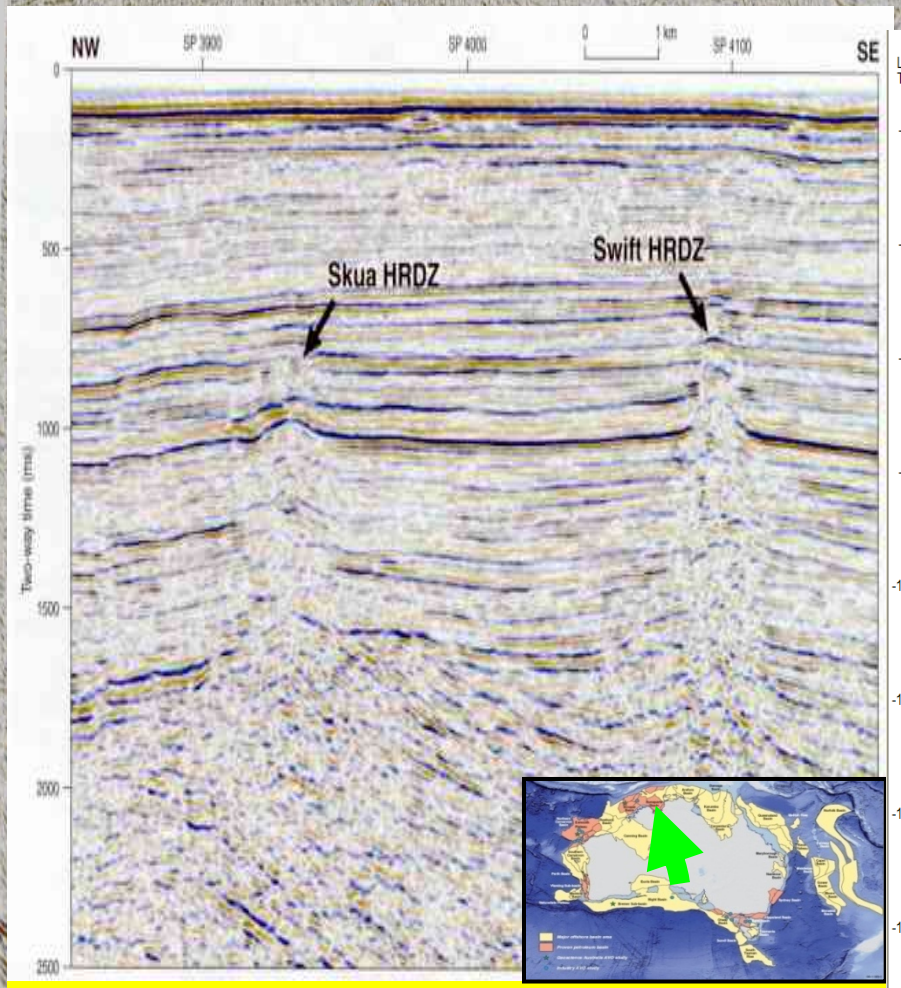
(Santos, 1987; Stewart and Alder, 1995)

Intercept vs Gradient -Xplot Colour Scheme - CDP 2200-2800 on stack

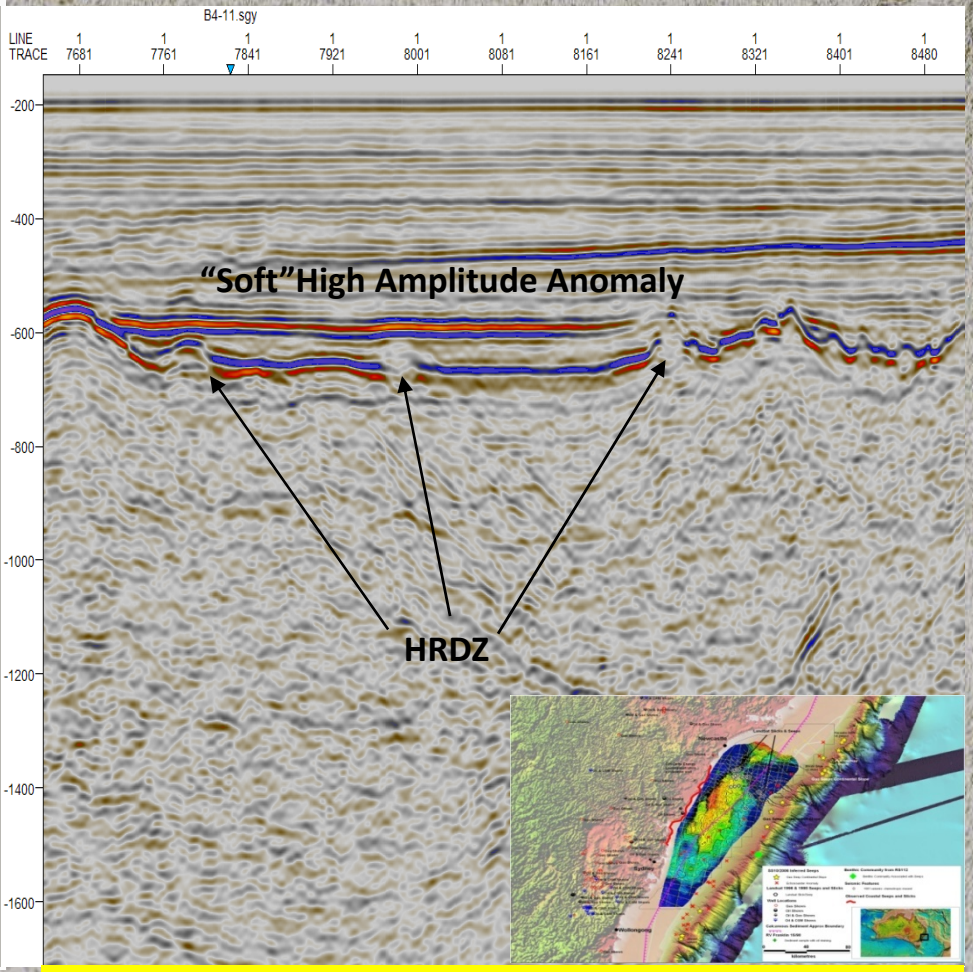


HRDZ comparison between PEP11 Line B4-05 and Bonaparte Basin



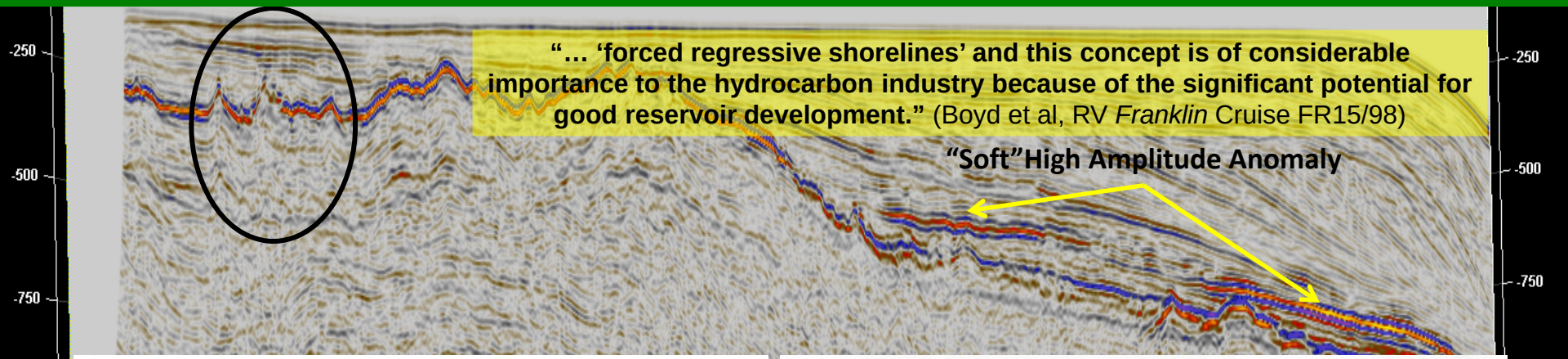


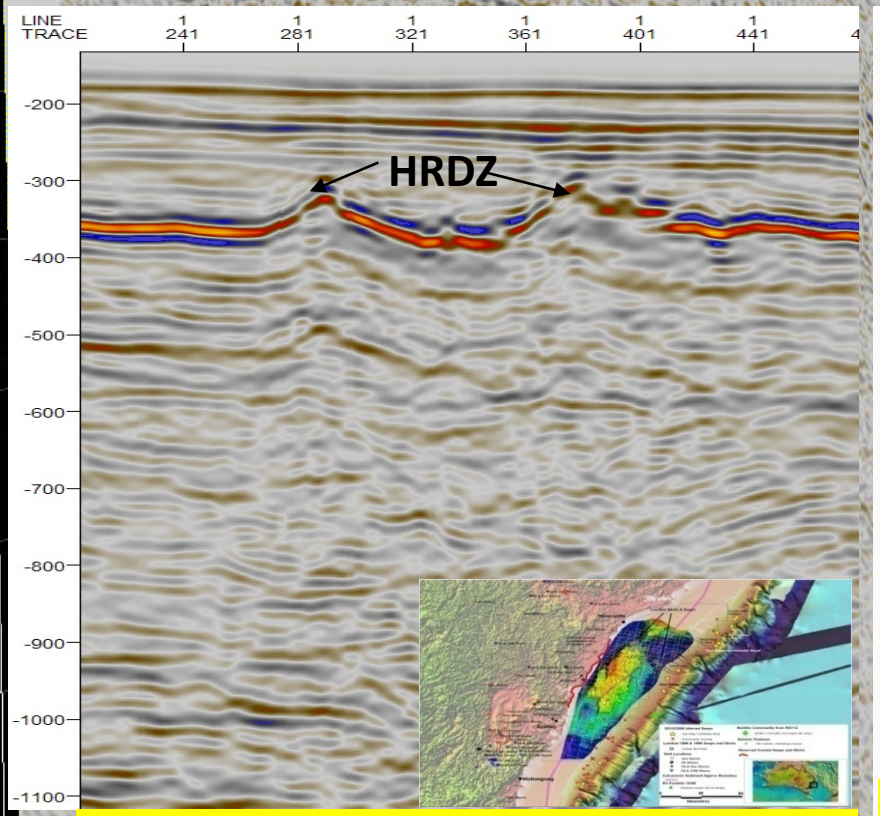
HRDZs over the Skua and Swift fields, Bonaparte Basin
[Source O'Brien, Geoscience Australia]



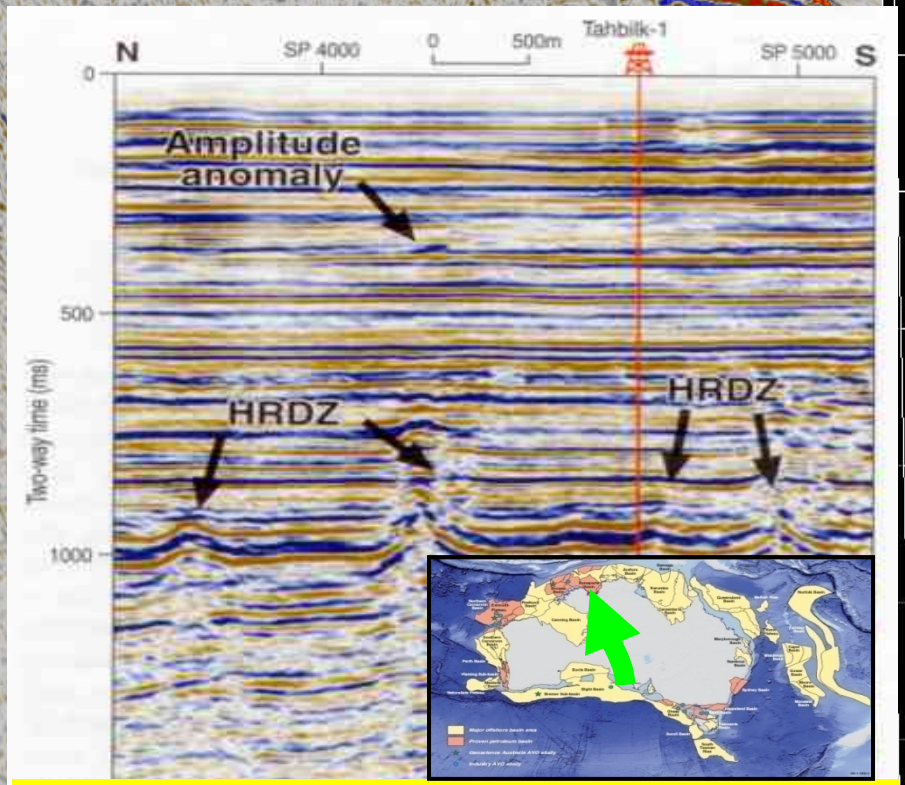
HRDZs on PEP11 seismic line B4-05

HRDZ comparison between PEP11 Line B4-11 and Vulcan Sub-basin



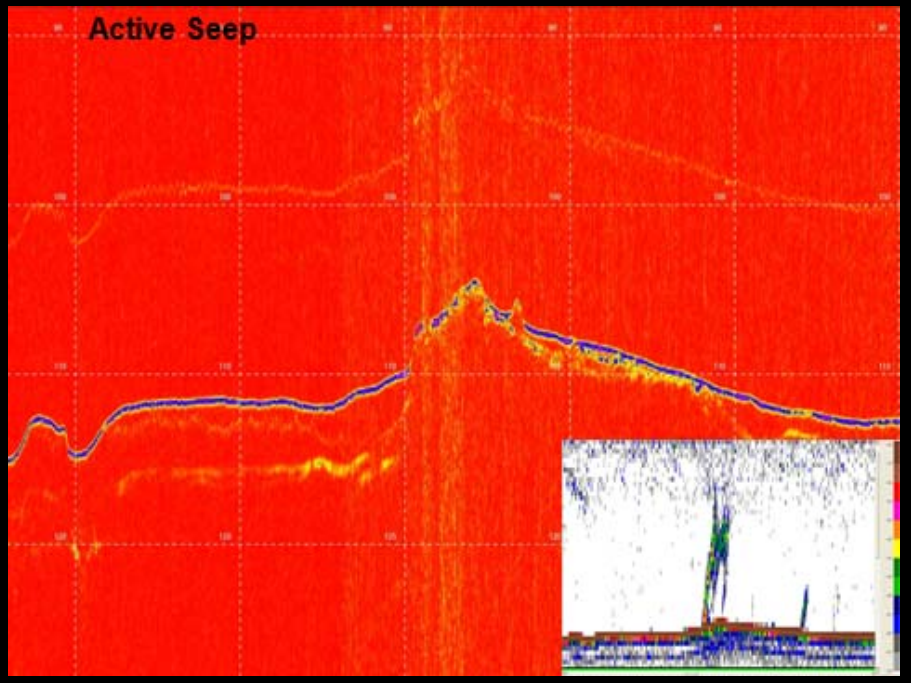


HRDZs on PEP11 seismic line B4-11



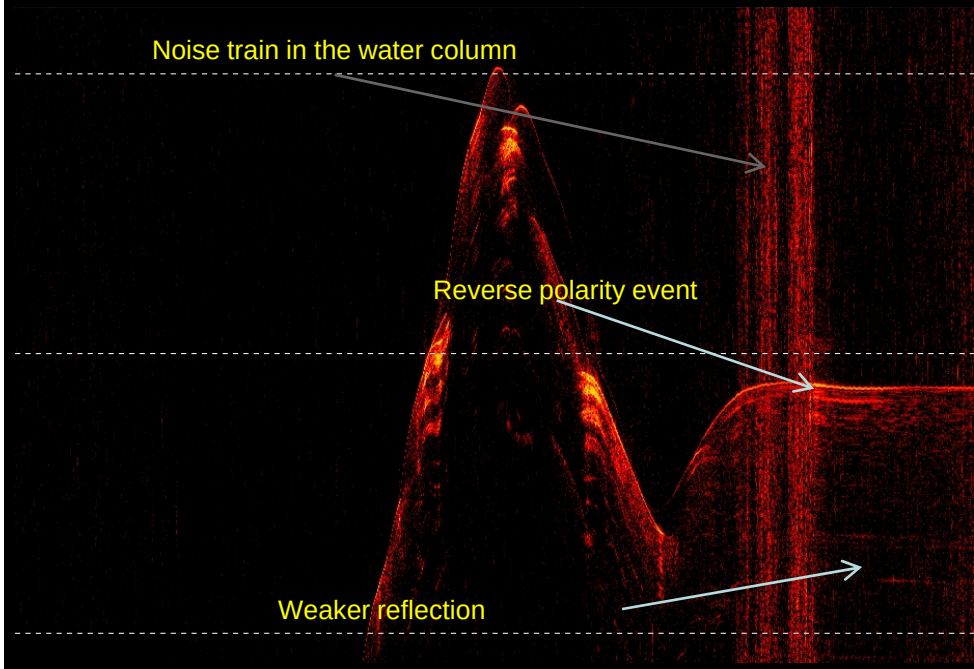
High intensity, large and linear HRDZs are present near the Tahbilk gas accumulation, located in the southern Vulcan Sub-basin [Source O'Brien, Geoscience Australia]

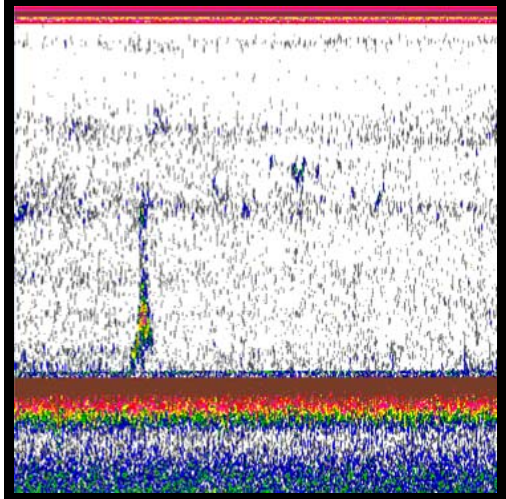
"A recent review of more than 850 wildcat wells – all drilled after geochemical surveys finds that 79% of wells drilled in positive anomalies resulted in commercial oil and gas discoveries"
D. Schumacher



Cornea seep, over Cornea oil/gas field, Browse Basin

Offshore Sydney Basin





Gas in water column and shallow sediments identified in Sub-Bottom Profiles by Fred Kroh from SS10/2006 survey

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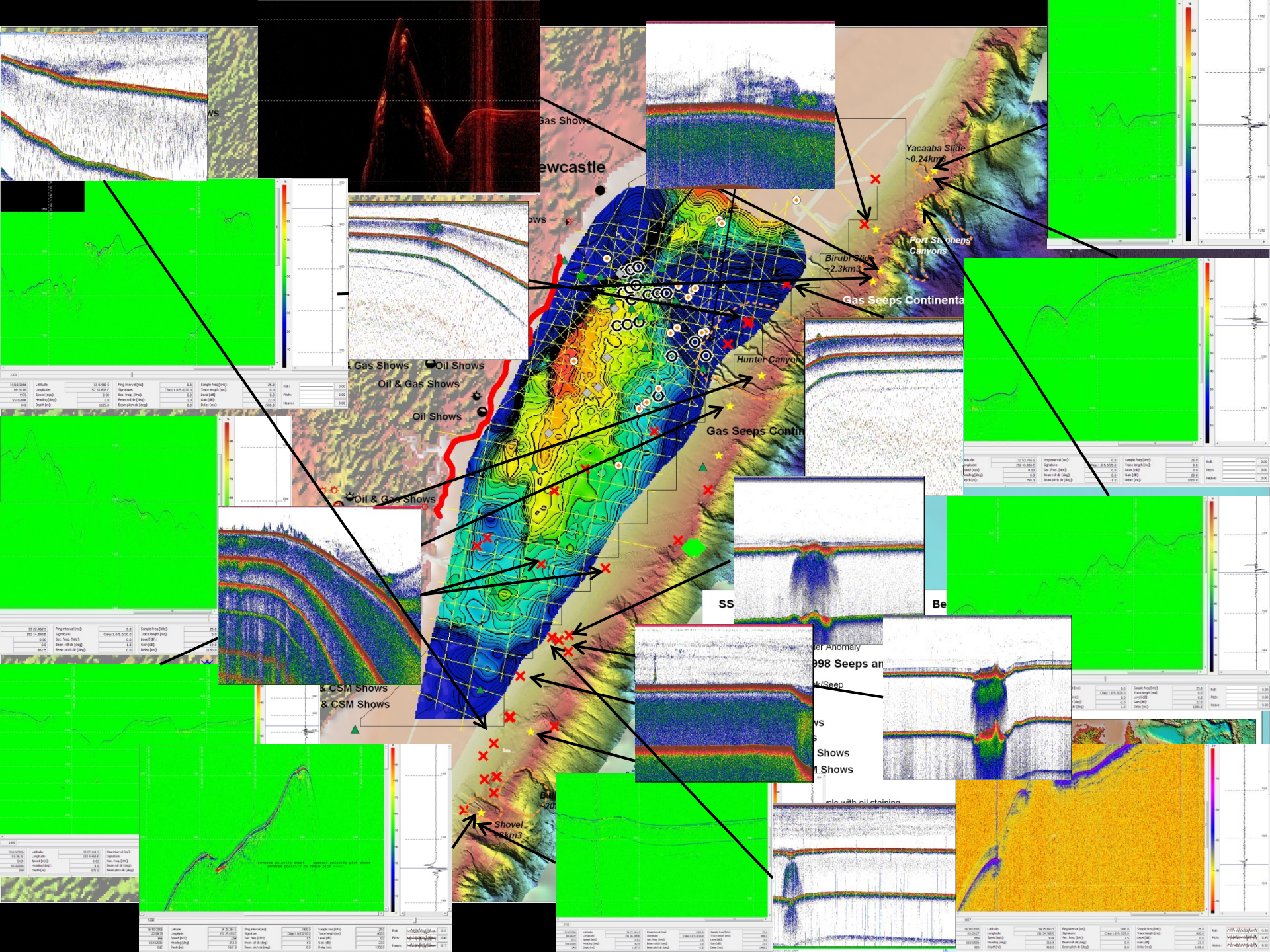
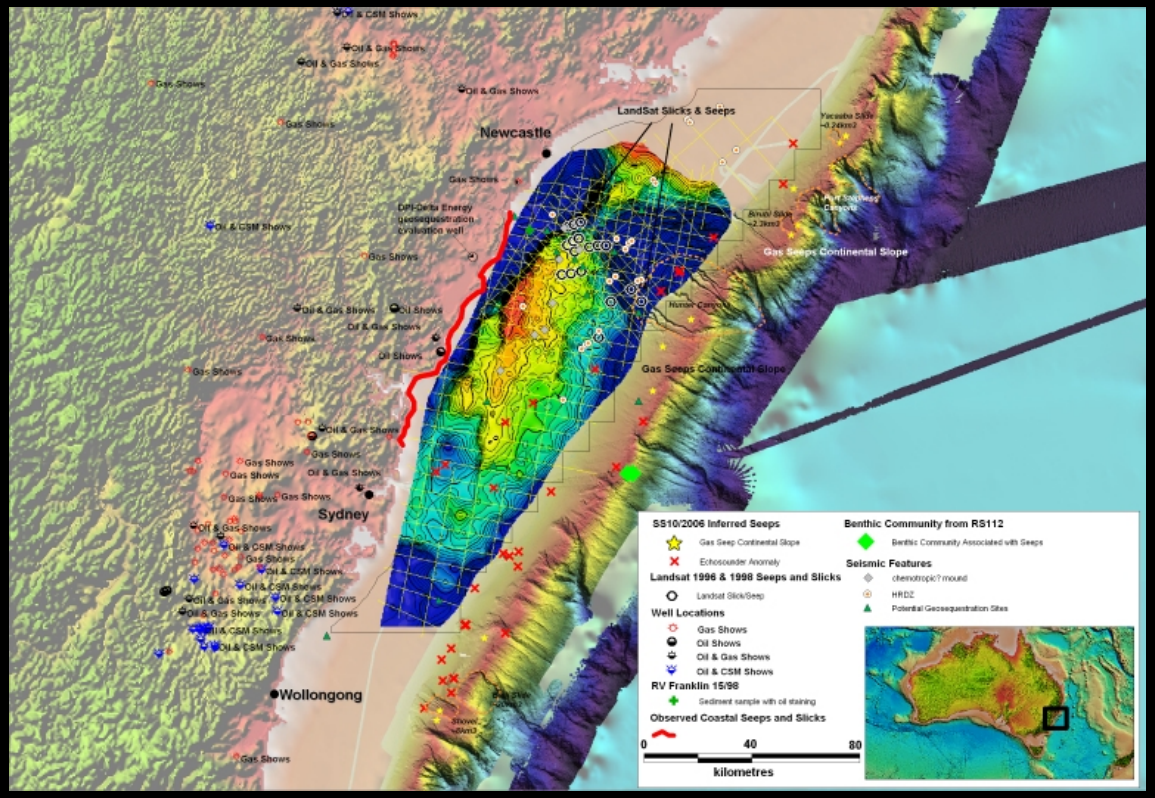

Gas Shows
ewcastle
Yacaaba Slide
~0.24km3
Port Stephens' Canyons
Birubi Slide
~2.3km3
Gas Seeps Continenta
Hunter Canyon
Gas Seeps Contin
Oil Shows
Oil & Gas Shows
Oil Shows
Oil & Gas Shows
& CSM Shows
& CSM Shows
Shovel
~6km3

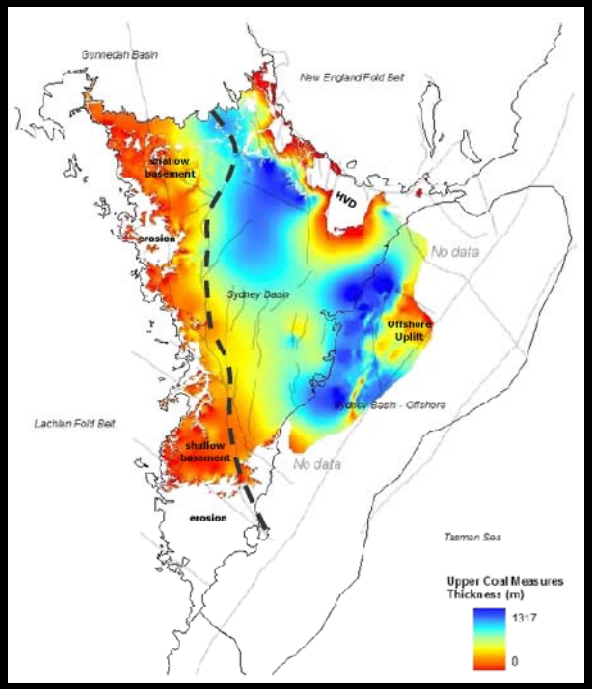
Analysis of Gas from Offshore Sydney Basin

Repeated Hydrocarbon seep samples show a thermogenic source
- Liquids component indicated -



Hydrocarbon Seep Gas Analysis:

- Methane 90.69%
- Oxygen 1.58%
- Carbon Dioxide 4.12%
- Nitrogen 3.7%



"It is generally assumed that maturation and migration began relatively early and hence early structures are favoured as hydrocarbon traps"
(Stewart and Alder, 1995)

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Petroleum Systems Summary - Sydney Basin

> 100 onshore, 0 offshore wells

Northern area

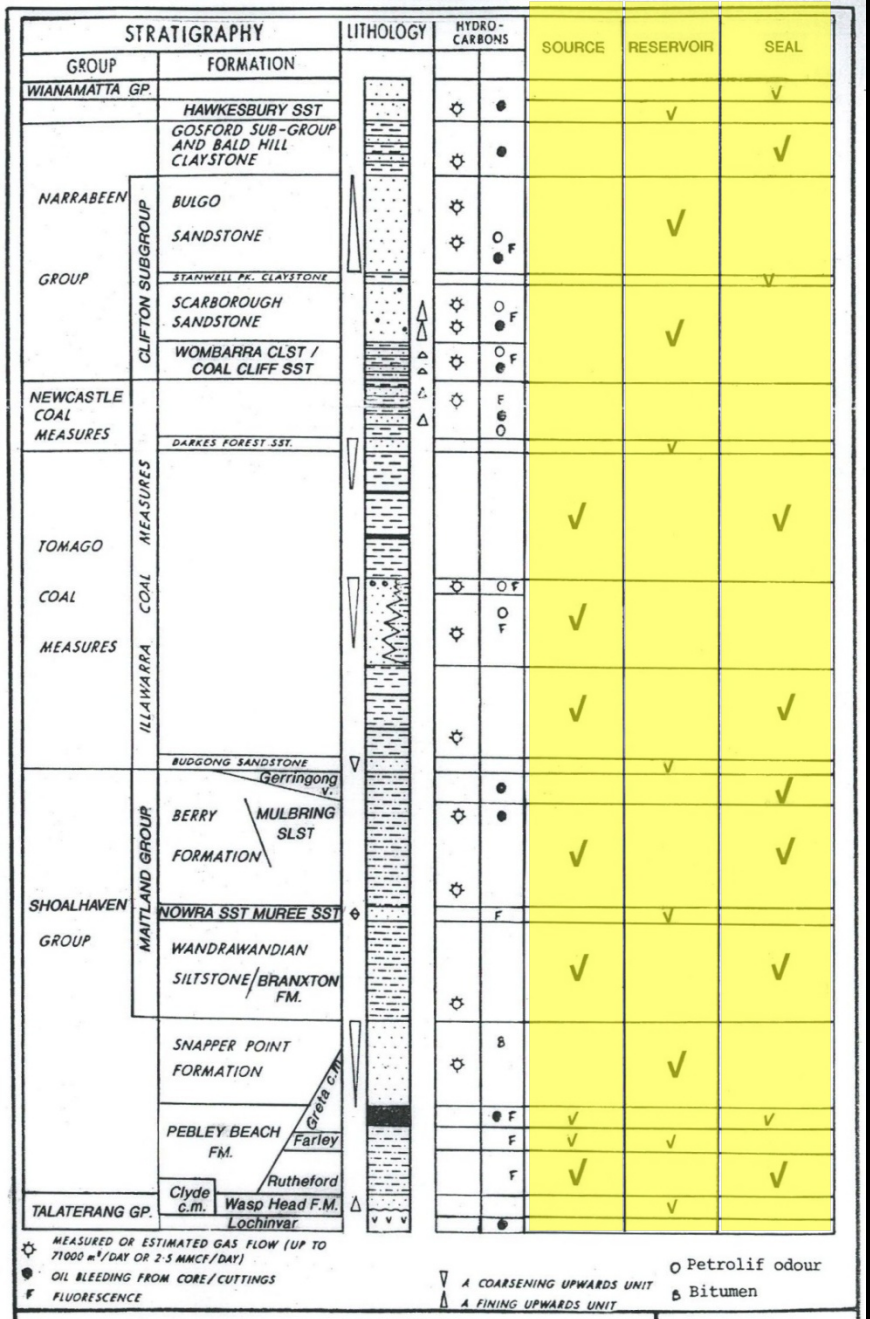
Period	Rock unit	Source	Reservoir	Seal	Shows
TR	(not preserved)				
	Wianamatta Group		OIL & GAS	regional	
	Hawkesbury Sandstone		good		gas,oil
	Narrabeen Group	?	good	intraformational	gas,oil
	Narrabeen Group	?	good		gas,oil
P	Newcastle Coal Measures	oil window	OIL & GAS		gas,oil
	Tomago Coal Measures	oil window	intraformational	intraformational	gas
	Mulbring Siltstone	(?) late oil window	gas, minor oil	regional	gas,oil
	Muree Sandstone		diagenesis risk		minor
	Branxton Formation	(?) late oil window	gas	regional	gas
	Greta Coal Measures	overmature for oil	intraformational	intraformational	oil
	Farley Formation	gas	poor		minor
	Rutherford Formation	gas	gas	regional	minor
	Lower Dalwood Group		poor		oil

Southern area

Rock unit	Source	Reservoir	Seal	Shows
(not preserved)				
Wianamatta Group		GAS	regional	
Hawkesbury Sandstone		good		gas,oil
Gosford Subgroup	?	GAS	intraformational	gas,oil
Clifton Subgroup	?	good		gas,oil
Illawarra Coal Measures	overmature for oil	intraformational	intraformational	gas
Budgong Sandstone & eq.		diagenesis risk		
Berry Siltstone	gas	gas	regional	gas,oil
Nowra Sandstone		diagenesis risk		minor
Wandrawandian Siltstone	gas	gas	regional	gas
Snapper Point Formation		diagenesis risk		gas
Pebbley Beach Fm & equiv.	gas	poor	intraformational	minor
Clyde Coal Measures & eq.	gas	poor		

Figure 12. Petroleum systems summary, Sydney Basin

From Stephenson & Burch, 2004, Preliminary Evaluation of the Petroleum Potential of Australia's Central Eastern Margin (GA12988)



STRATIGRAPHIC DISTRIBUTION OF RESERVOIRS, SEALS & SOURCE ROCKS

Figure 6.4

PLAN 586

- **Source Rocks：Late Permian Coal Measures, mainly Greta and Tomago groups；**
- **Reservoir Rocks：Fluvial Sandstone in Permian and Triassic**
- **Seals：Siltstone in Wandrawandian and Branxton group**
- **Onshore: 8 wells - oil shows & 16 – oil + gas shows**

NSW Dept of Mineral Resources:

"41% wells flowed gas on test"

"The Sydney Basin contains an active petroleum system"

"Potential source and seal sequences occur extensively…"

"Reservoir potential should increase to the east, in the offshore"

"Early Permian sands are likely to / have good initial primary porosity and permeability."

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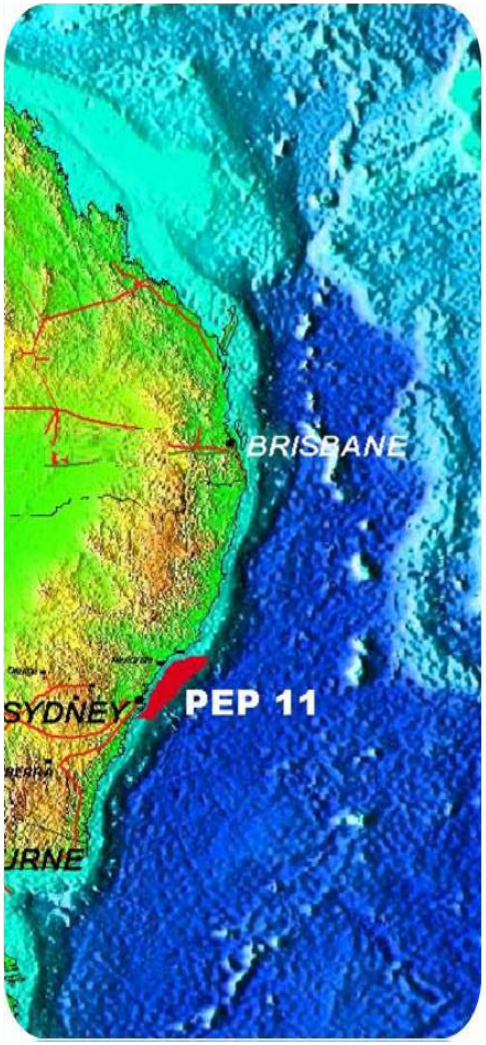
OFFSHORE SYDNEY BASIN : PEP11 ECONOMICS

- **Gas price of A$7 (US$5) per MCF,**
  - **Initial well productivity of 30MMcfd,**
  - **Development well cost of US$17MM / well,**
  - **Facilities & pipeline Capex of US$240MM Opex of US$0.3/MCF**
  - **Fish (P50) 2.37 TCF has an NPV_{10} of A$5.156 billion and an IRR of 177%**

- **Minimum economic size is considered to be 200BCF**
- **RPS Group completing environmental approvals / Du-El Engineering completing well construction + project management**
- **Evaluating tenders for provision of jackup rig to drill Fish prospect; TD 2096 – 4496m.**
- **Seeking equity and/or farmin partners**



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•Fred Kroh –Formerly Project Leader of Geophysical Processing and Data Access Project - Geoscience Australia
•Tim Berge –Geophysical Consultant -
•Deet Schumacher -Terraliance
•Dan Orange
•Fred Aminzadeh
•David Connolly
•Michael Abrams
•Professor Ron Boyd –Newcastle University
•Andrew Mayo –Macquarie Oil –
•Kriton Glenn –Geoscience Australia
• Ben Clennel , Asrar Talukder and team (CSIRO Subsurface Prediction and Description)
•Geoff O'Brien –Formerly Geoscience Australia
•Ding Gui Ming –Principal Geological Consultant
•Associate Professor Jock Keene –Sydney University
•Kevin Ruming - School of Environmental and Life Sciences University of Newcastle
•BOS
•Oil Hunters
•Bounty Oil
•RPS
•BGP
•John Cant
•Allan Williams -NPA
•Mike Rego – Aminex
•Tom Fontaine
•Fugro
•Geosience Australia
•Crown Minerals NZ
•Kieth Woolard
•David Orth
•David Remus

Publications

•AAPG Memoirs "Hydrocarbon migration and its Near surface Migration"
•Judd A and Hovland M "Seabed Fluid Flow"
•Whelan J Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution "Dynamic gas driven petroleum systems" and Whelan J et al "Surface & subsurface manifestations of gas movement through a N-S transect of the Gulf of Mexico"
•Government of NSW "New South Wales Petroleum Potential"
•NSW Department of Mineral Resources
•Alder et al "Prospectivity of the Offshore Sydney Basin –A New Perspective"
•Frog Tech Pty Ltd
•Aftenbladet Multimedia
•The European Commission "The Deep Sea Frontier"
•Aminzadeh, F., de Groot, P., Berge, T. et al "Determining Migration Pathway from seismically derived Gas"
•Geoscience Australia –Patchett.A and Langford. R."New South Wales –Deep Saline Aquifer Storage Potential"
•Geoscience Australia Glenn. K "Revealing the continental Shelf off New South Wales"
•Aminzadeh F Connolly D and Ligtenberg H "Hydrocarbon Phase detection and other applications of Chimney Technology"
•Dietmar Schumacher, Surface geochemical exploration for oil and gas: New life for an old technology Geo-Microbial Technologies, Ochelata, Oklahoma, U.S. The Leading Edge
•Michael A. Abrams "Significance of hydrocarbon seepage relative to petroleum generation and entrapment" Marine & Petroleum Geology
•AAPG Conference Geoffrey W O'Brien, Andrew Barrett, and Megan Lech ."Integrating 3D Seismic data and multiple, independent remote sensing technologies to constrain near-surface Hydrocarbon Migration and Seepage Rates and Leakage Mechanisms on the North-western Australian Margin"
•Journal of Geophysical Research, The world's most spectacular marine hydrocarbon seeps (Coal Oil Point, Santa Barbara Channel, California):
•Marine & Petroleum Geology N. Rollet, GA Logan, JM Kennard, PE O'Brien, AT Jones, M Sexton Characterisation and correlation of active hydrocarbon seepage using geophysical data sets: An example from the tropical, carbonate Yampi Shelf, Northwest Australia
•Daniel Lewis Orange The implications of Hydrocarbon seepage, gas migration and fluid overpressures to frontier exploration and geohazards
•Dietmar Schumacher AAPG Hedberg Conference Near Surface Hydrocarbon Migration; Mechanisms and seepage rates The Dynamic Nature of Hydrocarbon Microseepage: An Overview
•O'Brien et al "Yampi Shelf Brows Basin –Northwest Shelf "
•Cowley R & O'Brien "Identification and interpretation of leaking hydrocarbons using seismic data"
•Kroh F Reprocessing shows AVO potential for petroleum exploration Geoscience Australia

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