A New Direction for Asian Stratigraphy

Peter Lunt
What is it about?

1. There is still a lot we do not know about the geology of SE Asia
2. We have been using over-simple techniques
   - SE Asia is a complex area explored using geological techniques developed in simple basins.
   - Passive margin-type sequence stratigraphy is model-based or deductive.
   - If the model is not true we **must** shift to an inductive method
Late 1970’s. Evidence driven (Inductive) geological model

- LCP, source rock & reservoir
- Marine, not a source rock
- This is not a eustatic-type change in sea level
- Good seal
- Poor seal
Same area, same ages, 2000’s.

“Snap to Fit” - Model-driven
This is *Nitendo-Geology*

How can we find new hydrocarbons with simpler ideas than our predecessors?

In other sciences this is known as a **“Spherical Cow”** approach

Geology has shifted from integration of diverse data to being dominated by one data type, and a **one size fits all** process
SE Asia has been basing its exploration on a convenient but over-simple and flawed model: a *Deductive* approach.
What is Stratigraphy?

Stratigraphy is the division of sedimentation into packages within which Walther’s Law can be used to predict facies (facies=elements of petroleum systems).

Sequences are bounded by unconformities: the contacts at which Walther’s Law breaks down (either due to changes in r.s.l. or tectonics).

Across a bounding unconformity an altered set of sedimentary conditions is established and a new sequence begins.
What is a “Megasequence”? 

- In most global basins “megasequences” are the large scale basin readjustments seen at 10-100 million year intervals (Miall, 2010)
- The boundaries are large scale Non-Waltherian Contacts
- In tectonically active SE Asia they occur at about 3 to 5 Ma intervals and hence they overshadow and replace the “3rd Order” Sequence concepts.
So why not eustasy?

Or even the anodyne relative sea-level change?

- Simple: The founders of the eustatic or r.s.l. “depositional sequence” models predicted the technique will not work here
In order to develop generally applicable depositional models, it was assumed that the following conditions would be present:

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The rate of seafloor subsidence at any single location on a profile was held constant. Seafloor subsidence is primarily a function of lithospheric cooling and sediment loading (together they compose total subsidence). Geo-historical analyses from a variety of sedimentary basins suggest that eustatic variations occur with greater frequency than subsidence variations. Thus, over a limited interval, the assumption of constant subsidence rate seems acceptable. Nonetheless, when the general model is modified to account for local conditions, nonuniform subsidence can be accommodated. Total subsidence increases in a basinward direction. This seems to characterize most divergent basin margins.

Deposition was occurring along a divergent continental margin characterized by a shelf, slope, and basin, where sediment supply remains constant. In the real world, differing rates of sediment supply affect primarily the seaward extent of deposition. In the landward direction, stratal patterns will usually show onlap and aggradation as the space between sea floor and base level is filled, whereas the basinward limit of progradation is a function of sediment supply and basin margin geometry. Thus, in the landward direction, where base level (sea level or graded-stream profile) is the controlling factor, the stratal patterns on the landward side of identical basins will be the same regardless of the sediment supply. When local sediment supply parameters are incorporated into the model, the effect will be observed primarily at the seaward limit of deposition.

The trend of eustatic change is curvilinear, approaching sinusoidal. Although the actual trend of eustatic change is clearly not sinusoidal, the eustatic curve may nonetheless be resolved by a series of sine curves. It will be shown that depositional stratal patterns are directly related to inflection points on this curve.

Again, it must be emphasized that, although these models are generally applicable, the overprint of local factors must be considered in order to utilize them in a predictive mode for a particular basin. By incorporating local factors, one can readily refine the models to simulate local conditions.

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Not in SE Asia, or rather tectonics strongly and repeatedly overprints the weak eustatic signal until the mid Pliocene

Not in SE Asia: the proximal to distal dimension of sedimentation can have many changes through time

Posamentier et al. 1988

SEPM Spec. Pub. 42

Not in SE Asia, or rather tectonics strongly overprints the curvilinear profile at an average of 3 to 5 Ma intervals.
Eustasy as a significant influence on play level stratigraphy

Rift-sag basin geometry

The two “sacred cows” of SE Asian stratigraphy... are in fact spherical cows

<table>
<thead>
<tr>
<th>Time (Ma)</th>
<th>Magnetic Chrons</th>
<th>System/Epochs</th>
<th>Standard Stages / Ages</th>
<th>Global Mean Sea-Level Changes</th>
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Sea-Level Curve

1.0 0.5 0.0

300 200 +100 -100

C1 ... n60

C4
C5
C6
C7
C8
C9
C10
C11
C12
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
C27
C28
C29
C13-
C16

The two “sacred cows” of SE Asian stratigraphy... are in fact spherical cows

Eustasy as a significant influence on play level stratigraphy
Inductive vs deductive reasoning

**Inductive**

- Observation
- Pattern
- Hypothesis
- Test & confirmation / refutation

**Deductive**

- Paradigm
- Observation
- Description of observation in light of paradigm.

- Description of observation in light of paradigm.
Deductive vs. Inductive approaches

<table>
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<tr>
<th>Sequence model</th>
<th>Depositional Sequence</th>
<th>Genetic Sequence</th>
<th>T-R Sequence</th>
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<tbody>
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<td>end of transgression</td>
<td>HST</td>
<td>early HST</td>
<td>HST</td>
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<td>end of regression</td>
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<tr>
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<td>late LST (wedge)</td>
<td>LST</td>
<td>late LST (wedge)</td>
</tr>
<tr>
<td>onset of base level fall</td>
<td>early LST (fan)</td>
<td>late HST (fan)</td>
<td>FSST</td>
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<td></td>
<td>HST</td>
<td>early HST (wedge)</td>
<td>HST</td>
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</tbody>
</table>

- Depositional Sequence models require specific conditions not met by most SE Asian basins
- They assume and require
  1. A single proximal to distal dimension and eustatic or epeirogenic relative sea-level fall.
  2. Curvilinear, approaching sinusoidal, changes in relative sea level.
- The T-R Sequence model reduces the sequence approach to basics, including avoiding CC and MFS proxies on seismic in favour of observed MRS proxies.

In the absence of an inductive workflow, people been applying the deductive model where it should not have been used.

Embry & Johannessen, 2017
The “Cycles” scheme of Sarawak; a neglected inductive T-R model

At each event the basin changes, with faulting and folding somewhere on seismic

As defined by Posamentier et al. each of these is a Sequence above & outside eustatic / rsl influence and models

RED are events that correlate with major Sabah events (“B” are focused on the Bunguran Trough in the far west)
Based on seismic without analytical input, the facies above the reef at this location was published as “fluvial”.
Excellent deep outer neritic to upper bathyal faunas below casing, above reef. Analyses are required to obtain this crucial data. It cannot be interpreted on a workstation.

This boundary is a “non-Waltherian Contact”.

However these model-based “Picks” were carried into exploration areas and cross-checking well analyses were greatly reduced.

Excellent deep outer neritic to upper bathyal faunas below casing, above reef.

Inductive (tectonic) sequence boundary, initiates reef
End of one major sequence
Main subsidence began c. 12 Ma

Sequence Boundary, flood of marine carbonate over thick clastics,

Major Sequence Boundary, magnitude determined by microfossils as well as the need to create accommodation space for subsequent clastic sequence. This magnitude is far greater than any candidate eustatic sea-level fall and probably occurred in less that a million years...

Same site: geo-history plot
Locations c 30-150km away, have the main subsidence event at the previous sequence boundary, and minor subsidence at the event shown here. It is not in a simple 2D proximal-distal setting.
Reconstructing the foundations of PBE

It's all there in the pyramid, but it requires geology, esp. stratigraphy
Reconstructing the foundations of PBE
Its all there in the pyramid, but it requires geology, esp. stratigraphy

We have abandoned this part!

We have bought software and are locked into this part!

Low value, creaming curve exploration

BASIN FOCUS

Petroleum Systems

Sequence Stratigraphy

4D Basin History

Data Management

Plate Setting

Tectonostratigraphic Frame

Megasequences Basin Fill

Key Maps -structure -isopach

Mining Legacy knowledge

PLAY FOCUS

Lead inventory

Play Risk

-CRS Maps, Uncertainty -Success rates

Basin Statistics
-field size ditributions -Analogs

Bone / play level understanding

Modified after D. Roberts 2005
We have abandoned this part!

Reconstructing the foundations of PBE

Its all there in the pyramid, but it requires geology, esp. stratigraphy

We have bought software and are locked into this part!

Low value, creaming curve exploration

“Streetlight” observational bias

This is where you lost your wallet?

No, I lost it in the park. But this is where the light is.
PBE has rules related to scale

Without new ideas PBE is just chasing the creaming curve.

In the mature basins of SE Asia only small specialists can make money chasing creaming curves, but there are new concepts.
"We usually find gas in new places with old ideas. Sometimes we find gas in an old place with a new idea, but we seldom find much gas in an old place with an old idea. Several times in the past we have thought that we were running out of gas, whereas actually we were only running out of ideas."

Parke A. Dickey 1958

[* Surely we know all about Asian basins?*

揭牌 No. For decades we have simplified the complex geology to fit our basic models. **The area is ripe for innovation**

[* The reason is the “spherical-cow” approach to stratigraphy*

In the past few years several wholly new or very strongly re-risked SE Asian plays have been identified in “mature” basins.
So what comes next?

- T-R sequence stratigraphy lacks the jargon & intricacy of the still hotly debated deductive models. But being inductive (evidence-based) it is robust and reliable.
- A large-scale inductive approach has unified (nearly) all the major unconformities around Sundaland and makes a solid foundation.
- Testing intra-sequence facies with Walther’s Law. Testing sequence boundaries with plate tectonics.

(real example far west South China Sea)
Revising basics

In an area with a hundred year exploration history

North Sumatra / West Thailand
1 Minute Summary; North Sumatra

Variations on this scheme are in all papers from 1970’s (post Arun) until now

The classic Bampo-Preutu(!) Petroleum system (>15 TCF, 600 MMB condensate)
The source of the super-giant Arun field has never been proven, but it is not the low TOC “Bampo” black shales.

This is a very large subsidence event, covering thousands of sq. km. over western N. Sumatra and W. Thailand. An undocumented tectonic event of magnitude
The source of the super-giant Arun field has never been proven, but it is *not* the low TOC “Bampo” black shales.

This is a very large subsidence event, covering thousands of sq. km. over western N. Sumatra and W. Thailand. An undocumented tectonic event of magnitude...
This onlap surface was onto their P21SB. Beginning a marine flood within their syn-rift sequence. This was noted in Tsukada et al. (1996) to be a “catastrophic subsidence”, but little else was said about it.
In north Sumatra this is a huge non-Waltherian contact. It went un-remarked in the 1996 paper on the area except it was noted as a “catastrophic tectonic subsidence”.

Non-Waltherian contacts must obey Walther’s Law in the same fault block or terrane.

These events are the same age and same contrast as the wells with “catastrophic tectonic subsidence”. It was not a local event.
Using geohistory plots

The model does not match reality

Note scale contrast between eustatic curve and subsidence curve

Not one “catastrophic unconformity”, but three!
The bottom line

Better to chase this creaming curve in a different basin, different petroleum system, with c. 1/20th the well density.

Two distinct basinal areas with very different petroleum systems are incorrectly combined, but one area is leaky with hundreds of wells and the other, larger, area with the more prolific PS has only 20 wells. So YTF extrapolations for a single N. Sumatra Basin are massively biased by the old onshore data.

Massive statistical weighting of this data is the creaming curve in IHS, WoodMac etc!

Much lower well density, mis-understood stratigraphy and contains the super-giant Arun hydrocarbon source.

Heavily explored, high well density.
Revising basics

ANOTHER area with a hundred year exploration history
Multiple basins, multiple Petroleum Systems

* Yet just one stratigraphy: 2011 and 2016 published summaries

Just because it gets repeated over and over again doesn’t mean it’s true!
This correlation illustrates the tectonic controls on sedimentation - both carbonate and clastic.

In this example there was considerable uplift and slight tilting at the end Eocene (black horizon), followed by severe subsidence, tilting and seismically recognisable extensional faulting within the Early Oligocene (at the time of the pale blue horizon). …

Note uplift to seed new reef. This happened 3 times in the history of E. Java basins. Each uplift in different areas and all outside the expected simple rift to sag model.
The Ngimbang problem

* There are so many things called *Ngimbang Formation* it is useless.
* **Five or six very different megasequences.** Sands, biohermal limestone, baythal clays, multiple source rocks of very different quality and distribution, ditto for reservoir sands and carbonates. Megasequences identifiable to an integrated T-R, evidence-based approach
* Instead we use a Popperian “pseudoscience” term: so flexible that it can be used to contain any deeply drilled sedimentary facies. As Confucius famously said “One can not have intelligent discussions until one has precisely defined the terminology”

And as Humpty Dumpty said; “*When I use a word it means just what I choose it to mean.*’ ‘The question is,’ said Alice, ‘whether you can make words mean so many different things.”

Lewis Carroll. Alice in Wonderland
Sibaru; not a graben
Sibaru; not a graben
1. Intra-horst lows lack syn-rift facies
2. Reefs not required to be over basement highs but can be over uplifted petroleum systems

Analyses are required to obtain this crucial data. It cannot be interpreted on a workstation.
Unraveling the history of the South China Sea
Cross-discipline impact

* Just as stratigraphy impacts risks on the elements of a Petroleum System it also impacts regional tectonic reconstructions.

* Accurate dating of changes and regional mapping of Non-Waltherian Contacts will test, and be tested by, tectonic models.
Emerging regional models

- The popular slab-pull model for the South China Sea needs to be heavily modified or abandoned.
- Things just don’t happen in the right order in the rights places. Seismic alone won’t tell you this. You need analyses, especially micropalaeontology and petrology (sometimes Vr or fission track analyses etc)
XK-1, simple subsidence

Haq & Al-Qahtani 2005 onlap curve and sea-level (to scale)

Benthic marine environment compiled from Hedgeseth (1957) and Ingle (1980)

CNOOC XK-1 (Xisha Isl.)

Upper T.e (Te5)
Lower T.f (Tf1)
Lower T.f (Tf2)
Upper T.f
"T.h"

(Ma et al. 2017)
Mulu-1, a complex and confused history

- Like XK-1, the event on the Oligo-Miocene boundary is very strong here (but has been confused in literature).
- There is also a second “break-up” like unconformity at about 16 Ma

A large non-Waltherian contact, but you need to look at the rocks under a microscope to see it. No microscope, no data.
Conclusions

- In a few years time there will be a new geological model for the South China Sea and Sundaland.
- Many new concepts will not impact exploration, but chances are somewhere a new play / creaming curve will appear and give someone a very high reward.
- Seismic and geology will be tied to a single inductive (evidence-based) model.