Sedimentary basin evolution and conventional and unconventional petroleum system development

Autor(en): **Doust, Harry**

Objekttyp: **Article**

Zeitschrift: **Swiss bulletin für angewandte Geologie = Swiss bulletin pour la géologie appliquée = Swiss bulletin per la geologia applicata = Swiss bulletin for applied geology**

Band (Jahr): **16 (2011)**

Heft 2

PDF erstellt am: **26.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-327745

Swiss Bull. angew. Geol. Vol. 16/2, 2011 S. 57-62

Sedimentary basin evolution and conventional and unconventional petroleum system development

Harry Doust[1]

Introduction

Sedimentary basins have proven to be frustratingly difficult to compare with each other, particularly when it comes to the evaluation of resource potential. Many petroleum geologists will be able to recall, perhaps to their cost, examples of apparently similar basins that have turned out to contain significantly different quantities of oil or gas. It is my belief, however, that in attempting to compare basins we are approaching the subject at too large a scale: We need to dig deeper and consider the building-blocks from which the basins are constructed, as reflected in the phases or cycles they passes through during their evolution.

We are all familiar with basin types – they include rifts, passive margins, epi-continental seas, foreland basins, etc. These are, however, not static things; the majority of basins represent the present-day expression of an evolution through a number of phases or cycles in basin evolution. Basin cycles are the building-blocks from which sedimentary basins are formed and, like bricks, we can make use of the fact that they are relatively consistent in their development. Basins on the other hand have distinct, unique architectures; they are built up in different ways.

I believe that in order to better understand how basins work and make use of them for predictive purposes, we need first to understand how the cycles work – these can be more easily and more meaningfully compared from basin to basin, and thus learned from, than the basins themselves. I hope to show that this approach can help us to think in a more structured way about sedimentary basin development and resource potential.

[1] Faculty of Earth and Life Sciences, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands.
Presentation to VSP/ASP, June 2011, Yverdon-les-Bains, Switzerland: Extended Abstract

Basin development

The processes governing sedimentary basin creation and evolution include (figure 1):

- Crustal extension and faulting: These result in the development of rift, graben or fracture cycles. The sediments they contain usually form the synrift cycle.
- Thermal relaxation and subsidence. This results in sag cycles without faults, in which the sediments belong to sag, postrift sag and passive-margin cycles.
- Compression and uplift. This results in inversion, flexural subsidence and forearc cycles, with sediments belonging to syntectonic and foreland/fold-belt cycles.

These processes and their associated cycles give rise to different basin histories and geometries, depending on the stage of evolution, timing and relative development. Thus we have a number of relatively typical evolutionary «trajectories», as shown in figure 2.

Some basins actually comprise one cycle only. Some rift basins, for instance, comprise just a synrift cycle – a good example would be the Phitsanulok Basin in Thailand – but there are very many, particularly those that were created recently. Other basins have evolved through two or more cycles – we call these multi-cycle basins. In Southeast Asia (Doust & Sumner 2007) we can see

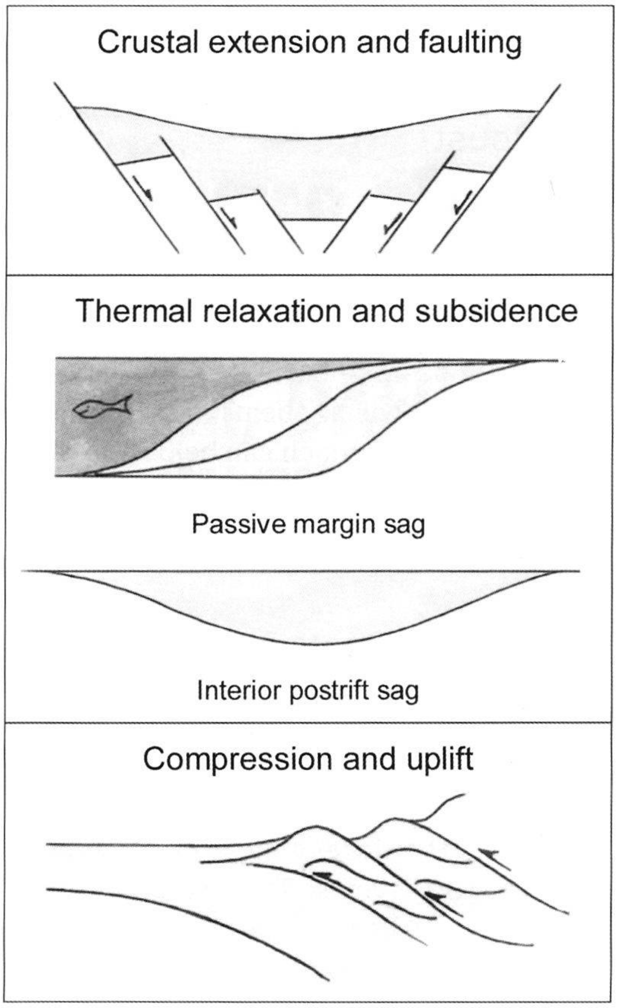

Fig. 1: Processes governing sedimentary basin creation and evolution.

representatives of basins which, during the same period of geological time, experienced different evolutions through rift, post-rift sag and inversion or compressive cycles depending on their reaction to the local stress evolution. These basins all developed within the same overall geodynamic and sedimentary framework, however, and the cycles have *similar sedimentary characteristics*: In them we recognise (i) an *early synrift*, in which the sediments are commonly lacustrine (ii) a *late synrift*, which is commonly deltaic (iii) an *early postrift*, commonly open marine in character and (iv) a *late postrift*, which is commonly deltaic again. This similarity in facies allows us to compare cycles and stages, even where the tectonic histories differ.

Petroleum Systems

Here we can make the jump from sedimentary basin cycle to petroleum system development. The latter are by definition dependent on the presence of source, reservoir and

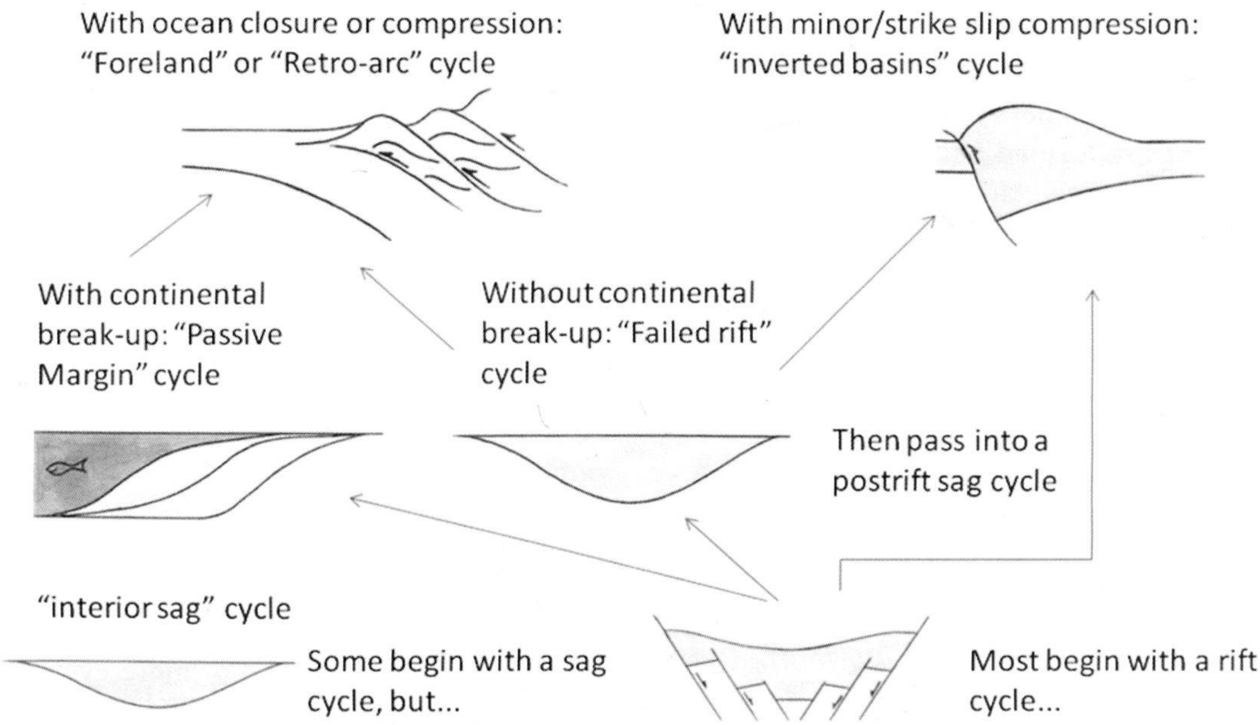

Fig. 2: Typical evolutionary «trajectories» in basin histories.

seal rocks, traps and fields. In the many Tertiary rift to post-rift basins in Southeast Asia, with their similar tectono-stratigraphic evolution (although with variable expression of cycle development) we can recognise a pattern of recurring types of petroleum systems (which we may call petroleum system types or PSTs):

1. An early synrift PST, receiving charge from lacustrine source rocks, very oil-prone.
2. A late synrift PST, receiving charge from a transgressive sequence of deltaic coals and coaly shales, with mixed oil and gas charge.
3. An early post-rift PST, receiving charge from marine shales, poor in quality, or from highly mature synrift PSTs, gas prone.
4. A late post-rift PST, receiving charge from a regressive deltaic sequence with coals and coaly shales, mixed oil and gas prone, but often immature for oil or gas generation.

The advantage of this is that we can look at each of these petroleum systems separately, compare them from basin to basin in their basin evolutionary (cycle) context and analyse the basin prospectivity in greater detail with the help of a larger number of analogue situations. Having done this, we can then reassemble our basin and address the original question; what is the potential of this area?

In the figure below (from Doust & Sumner 2007) a plot of total ultimate recovery of oil and gas for Southeast Asia Tertiary basins is shown. It reflects clearly what we have noted above in terms of PST development and oil and gas mix. We might be surprised by the low volume in the oil-prone early synrift PST, but this can be readily accounted for by the fact that a lack of regional mid-synrift topseal has allowed much of the oil to leak into late synrift reservoirs.

West African salt basins, cycles, petroleum systems and play types

The sedimentary basins of the South Atlantic margin comprise a family of multicycle basins which, as in SE Asia, evolved through a similar history. In this case it involved early Cretaceous rifting to form a synrift cycle, followed by a mid Cretaceous to Recent marginal sag cycle represented by a passive margin. In these basins we recognise the following cycle-bound PSTs:

(i) a synrift lacustrine petroleum system: In the synrift here we see the same *basin cycle type* and the same oil-prone *petroleum system type* as in the SE Asian Tertiary basins, although they are of different age and in different continents. We can thus use the one as analogue for the other and exchange experience from the two areas (which we

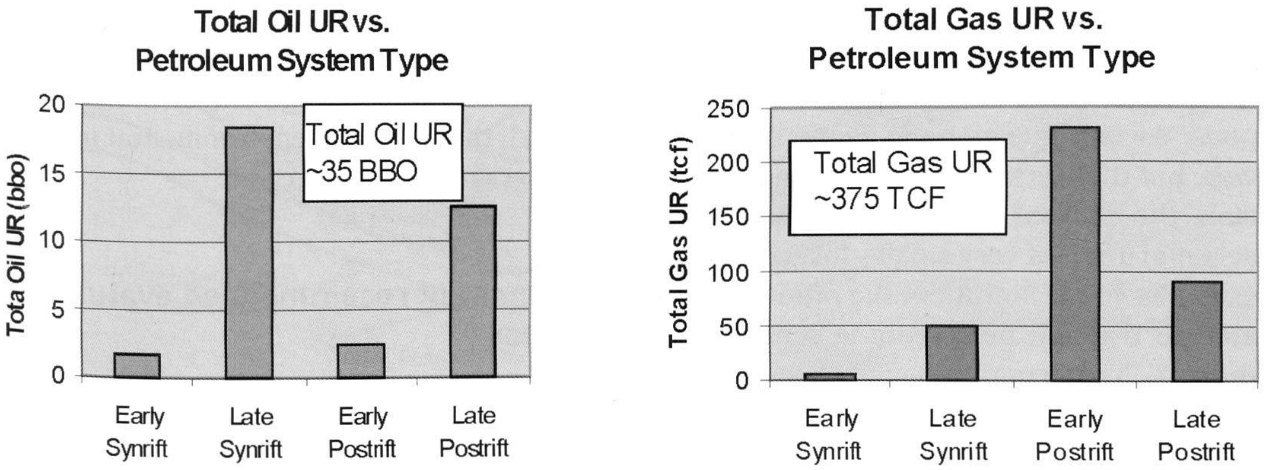

Fig. 3: Total ultimate recoveries (UR) of oil and gas for Southeast Asia Tertiary basins.

could not do considering the basin as a whole).
(ii) a postrift marine petroleum system: In the postrift here we have a good oil-prone PST related to a period of Late Cretaceous ocean anoxia, which is not present in the Tertiary of SE Asia. Although it cannot be used in this context, therefore, this PST represents a valuable analogue *petroleum system type* (PST) for passive margin cycles elsewhere in the world.

In addition to analysing the petroleum system development in various cycle types, we can note that trap types – the plays we explore for – are often characteristic of the various phases in basin development. Basin evolution often appears to follow a history from extension, through thermal sag and subsidence into inversion and/or compression (see above) and this is in part reflected in the type of structures we encounter: Tilted and faulted blocks are typical of pre- and synrift cycles, while a greater variety of structural and stratigraphic trap types occur in postrift and compressional cycles.

Efficiency of the system and unconventional potential

Petroleum systems are defined as «*natural systems encompassing a pod of active source rock and all related oil and gas – including all the necessary processes*» (Magoon & Dow 1994). Geochemists sometimes can provide us with estimates of the amount of petroleum that may have been generated from such pods. We may question the figures they provide, but there is little doubt that in comparison, the amount trapped in conventional accumulations is very small – In a number of examples in the literature, the ratio of generated to trapped petroleum is rarely more than 5%. The generation-migration-accumulation process appears to be very inefficient, therefore.
So what happens to all of the rest? A lot certainly leaks to the surface during secondary migration (as evidenced by petroleum seepages), but increasingly the question is being asked: What is the chance that a substantial amount is actually trapped in the subsurface by unconventional processes in unconventional accumulations, and can we access such resources?

Exploration for and production from unconventional petroleum resources like Basin Center Gas (BCG), Shale Gas & Coal-bed Methane (CBM) are becoming increasingly important and, as with conventional resources, they belong to petroleum systems that can be related to basin cycles too. The difference is that they are trapped in low permability reservoirs, which do not allow gas to move through buoyancy-driven migration (as shown in figure 4). Critical to the trapping mechanism is the fact that gas is immobile in such reservoirs (< 1 mD) except at extremely high saturations – over a large range of water saturations, gas is essentially caught in what is commonly referred to as the «permeability jail».
While exploration for conventional accumulations is aimed at evaluating the chances of success and the volumetric uncertainty at field and prospect scale, unconventional gas resources actually fill the reservoir formation. The technical chance of finding gas is thus very high, but because only a fraction of it can be produced, the focus is on the identification of «sweetspots» and the drilling of individual wells that can produce well under stimulation. Because the number of wells required is large and stimulation is needed, the potential environmental impact may become a serious issue.

Summary of recommended evaluation process

This abstract outlines a process by which resource evaluation in sedimentary basins can be facilitated by breaking the basins down into the tectono-stratigraphic cycles that form them. This procedure helps us to understand not only how basins develop, but also how and where types of petroleum systems develop. The following steps summarise this process:

1. Analyse and describe the (standard) *cycles* and *stages* in basin evolution and group them into *cycle types*.
2. Identify the *petroleum systems* present, relate them to the basin cycles and group them into *petroleum system types*.
3. Carry out a systematic description of the *plays* present and their location in the basin, geographically and in the cycles.
4. Rebuild the *basin*, by preparing a trajectory plot summarising the above, allowing for the comparison of tectonostratigraphic basin evolution and identification of appropriate analogues.

Figure 5 illustrates the relationships between basins, cycles, petroleum systems and plays. Let us assume we have a sedimentary basin that can be divided into three cycles (for instance prerift, synrift and postrift, as we have, for instance, in the North Sea), each hosting a petroleum system (i.e an active source rock), the most important of which, in this case, is in the second cycle. Let us assume further that the latter charges a number of different reservoir horizons in all three of the cycles – these we can call play levels (again, we see such a situation in the North Sea, where a synrift Late Jurassic petroleum system charges reservoirs from Devonian to Eocene age). We can expect that at each of these play levels, a variety of trapping geometries will be developed – and these represent the plays we explore. The geodynamic, sedimentary and tectonic processes that govern cycle, petroleum system and play development are shown on the figure also: They indicate when and where the emphasis of the basin and prospectivity analysis will be placed.

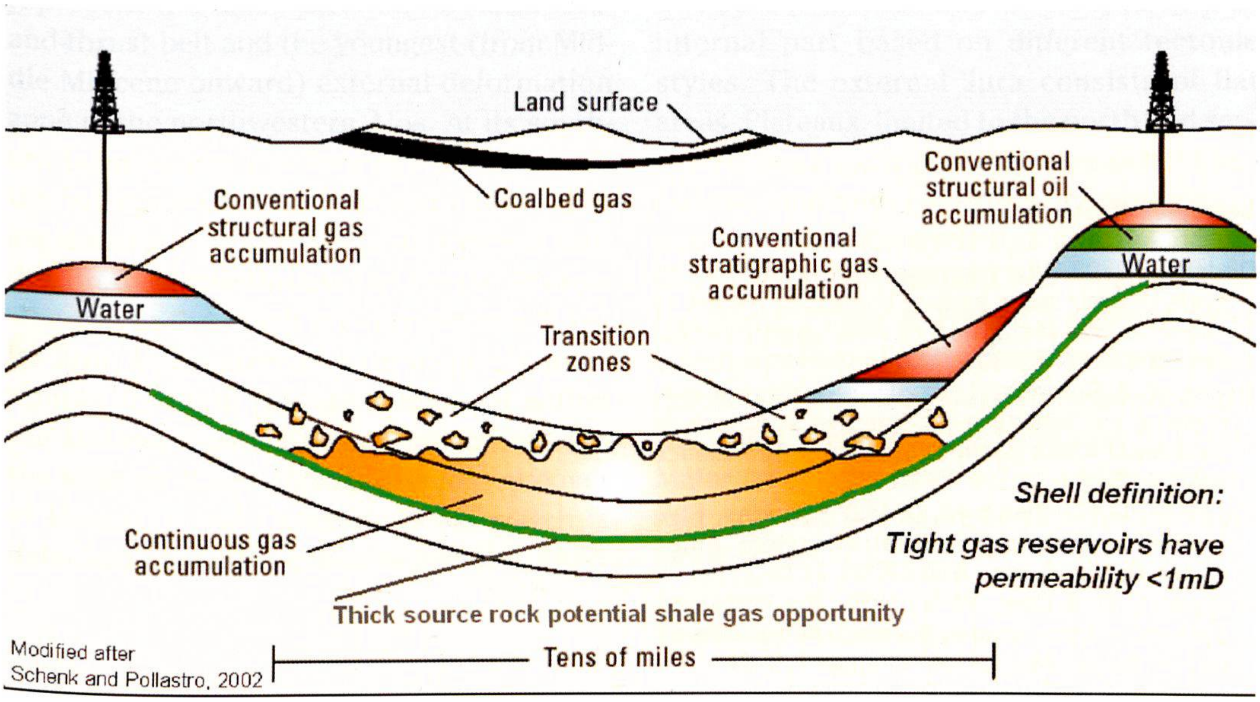

Fig. 4: The basin context of trapping in unconventional gas petroleum systems like BCG, shale gas and CBM compared with that of unconventional petroleum systems.

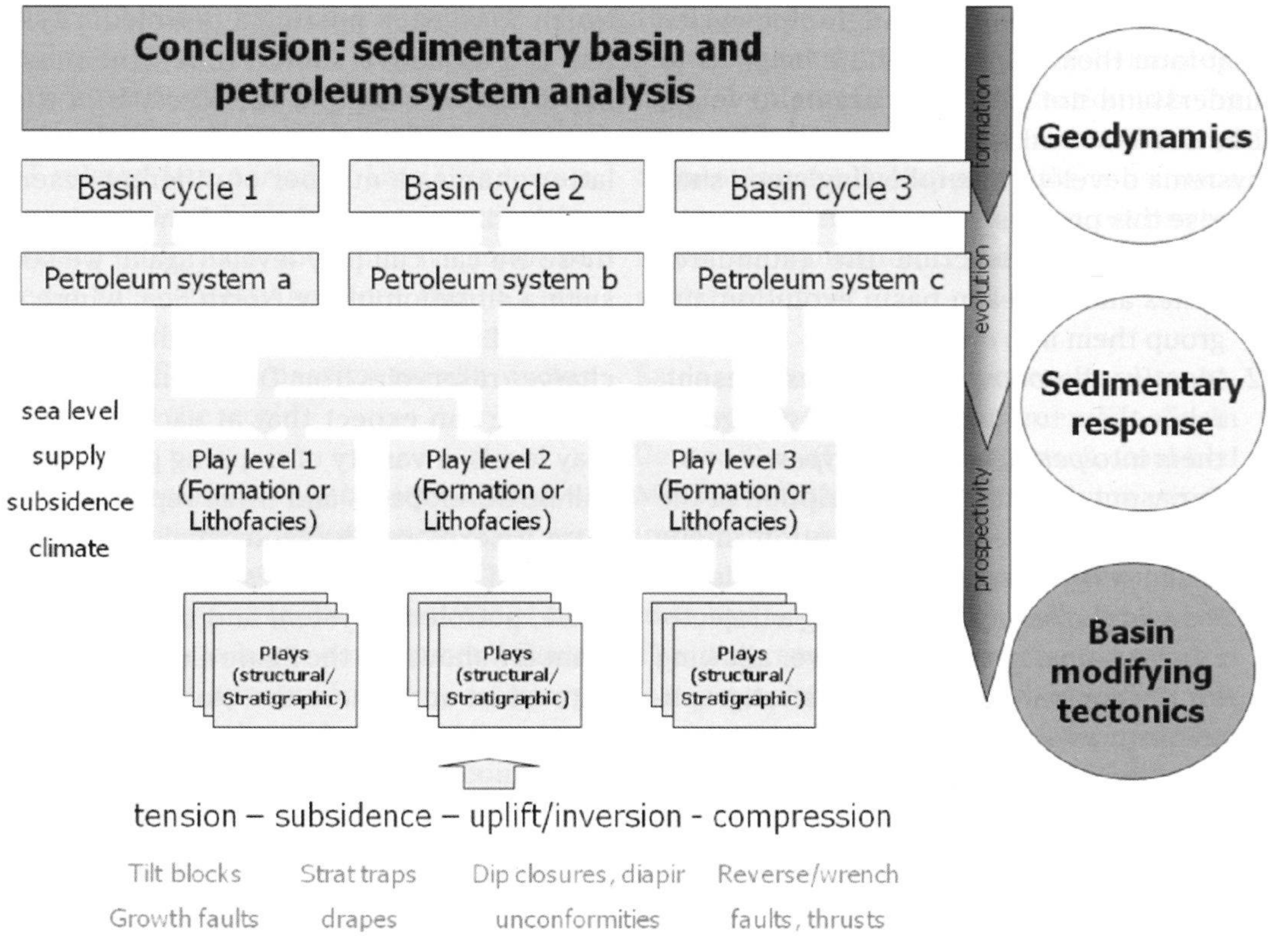

Fig. 5: Relationships between basins, cycles, petroleum systems and plays.

Selected references

Doust, H. 2003: Placing petroleum systems and plays in their basin history context: a means to assist in the evaluation of new opportunities. First Break 21, 73–83.

Doust, H. & Sumner, H. S. 2007: Petroleum systems in rift basins – a collective approach in Southeast Asian basins. Petroleum Geoscience 13(2), 127–144.

Kingston, D. R., Dishroon, C. P. & Williams, P. A. 1983: Global basin classification system. Amer. Assoc. Petrol. Geols., Bull 67(12), 2175–2193.

Magoon, L. B. & Dow, .W. G , 1994: The Petroleum System – from source to trap. Amer. Assoc. Petrol. Geols., Memoir 60. Chapter 1, 3–24.

Schenk, C. J. & Pollastro, R. M. 2002: Natural Gas production in the United States. US Geol. Surv. Fact Sheet 113–01.