Future trends in oil and gas exploration

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Global trends influencing exploration

Future resource trends

- Deepwater: the drill out of passive margins and deltas
- Arctic: ice-bound offshore
- Re-exploration of onshore basins and shallow waters
  - Unexplored Rock Volume
  - Tight oil giants, Shale plays & EOR

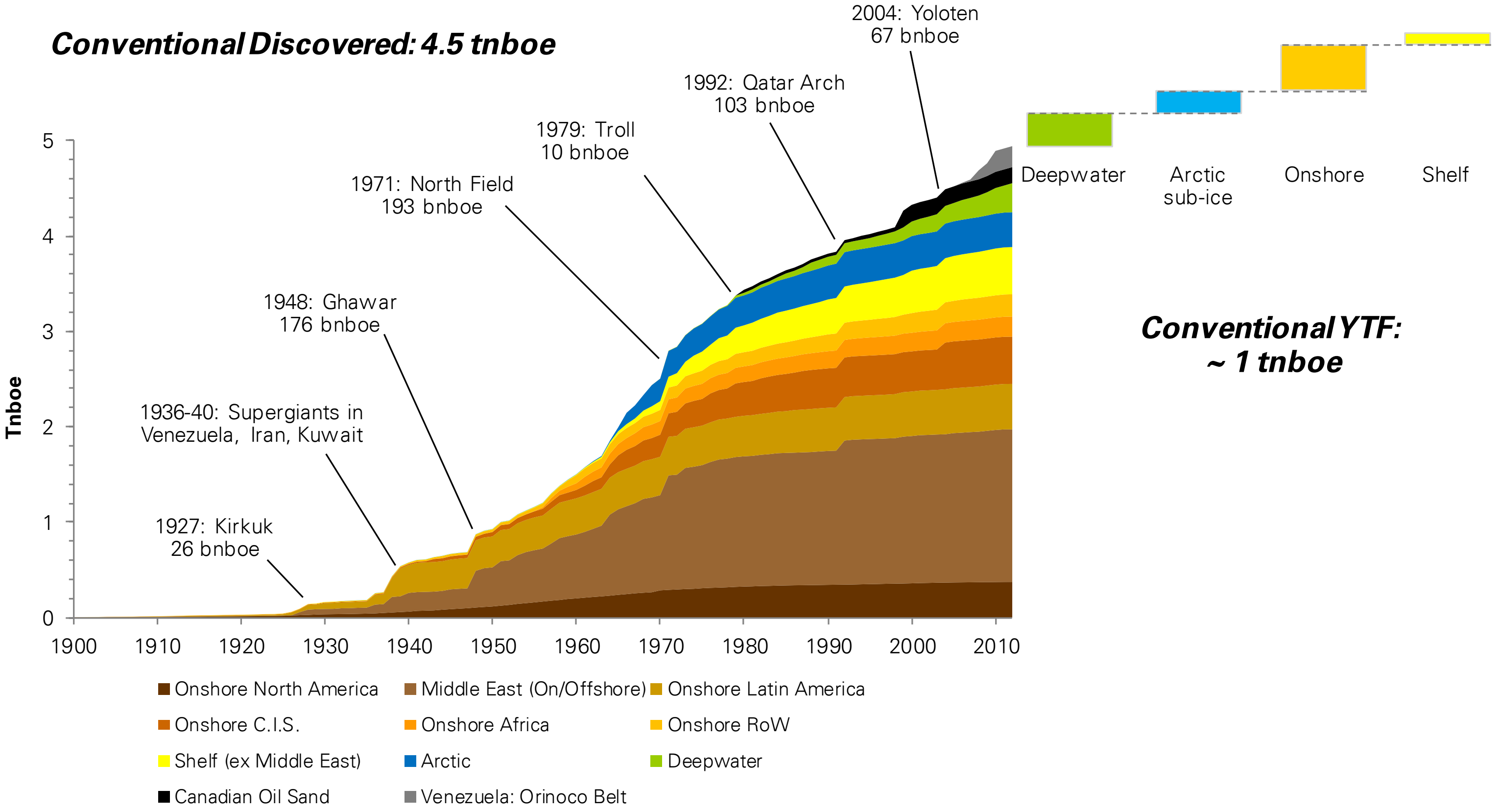
Future technology trends

- Striving for the perfect seismic image
- Ice management, arctic spill response and reduction of environmental impact
- Transformation of K_h and μ & characterisation of unconventional pay
- Digitisation of everything

Future geopolitical trends

- Mexico, Venezuela, Iran, KSA…

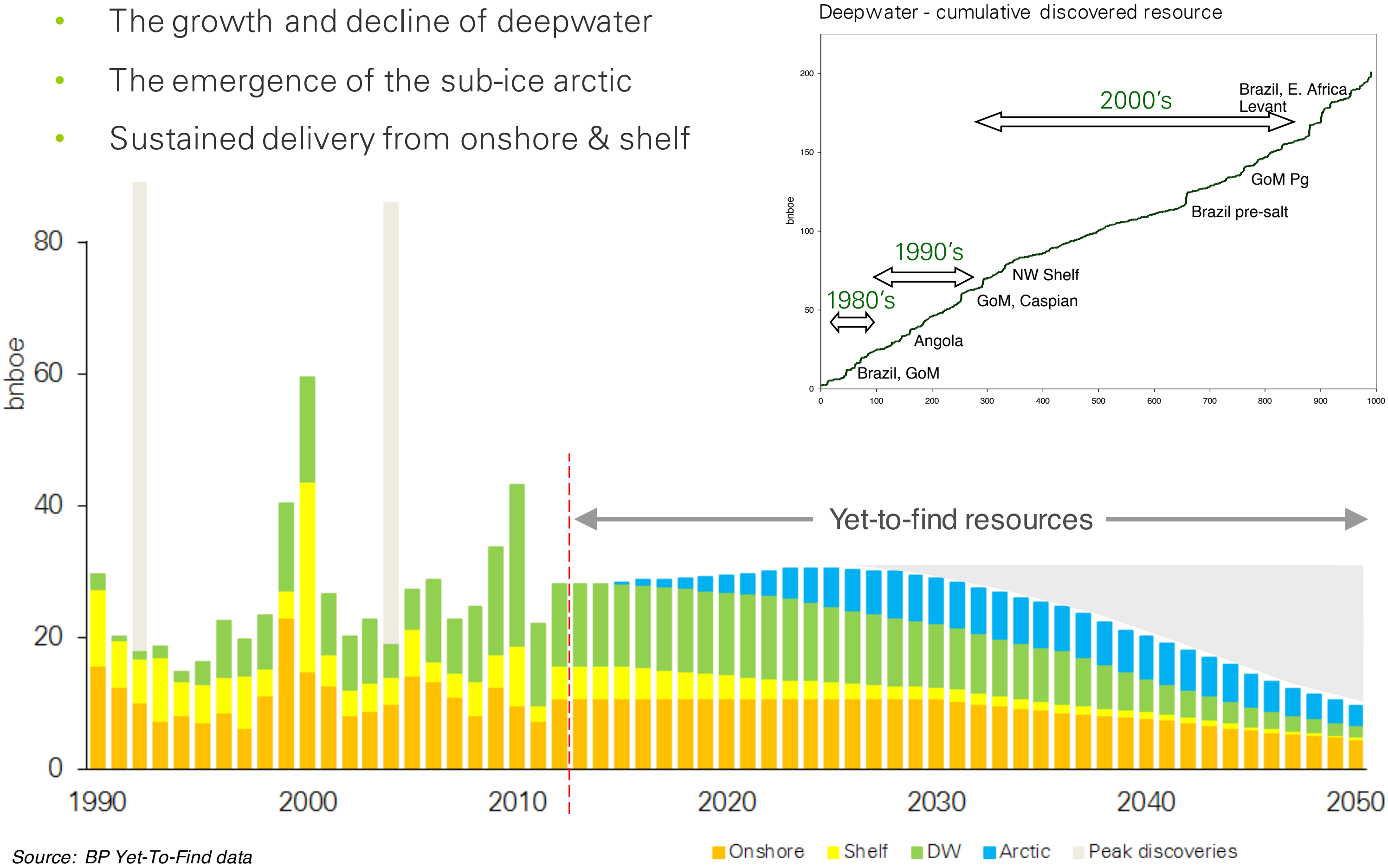
Global discovered resource and yet-to-find



Source: IHS, EIA and CAPP (Canadian Association of Petroleum Producers) for onshore North America data

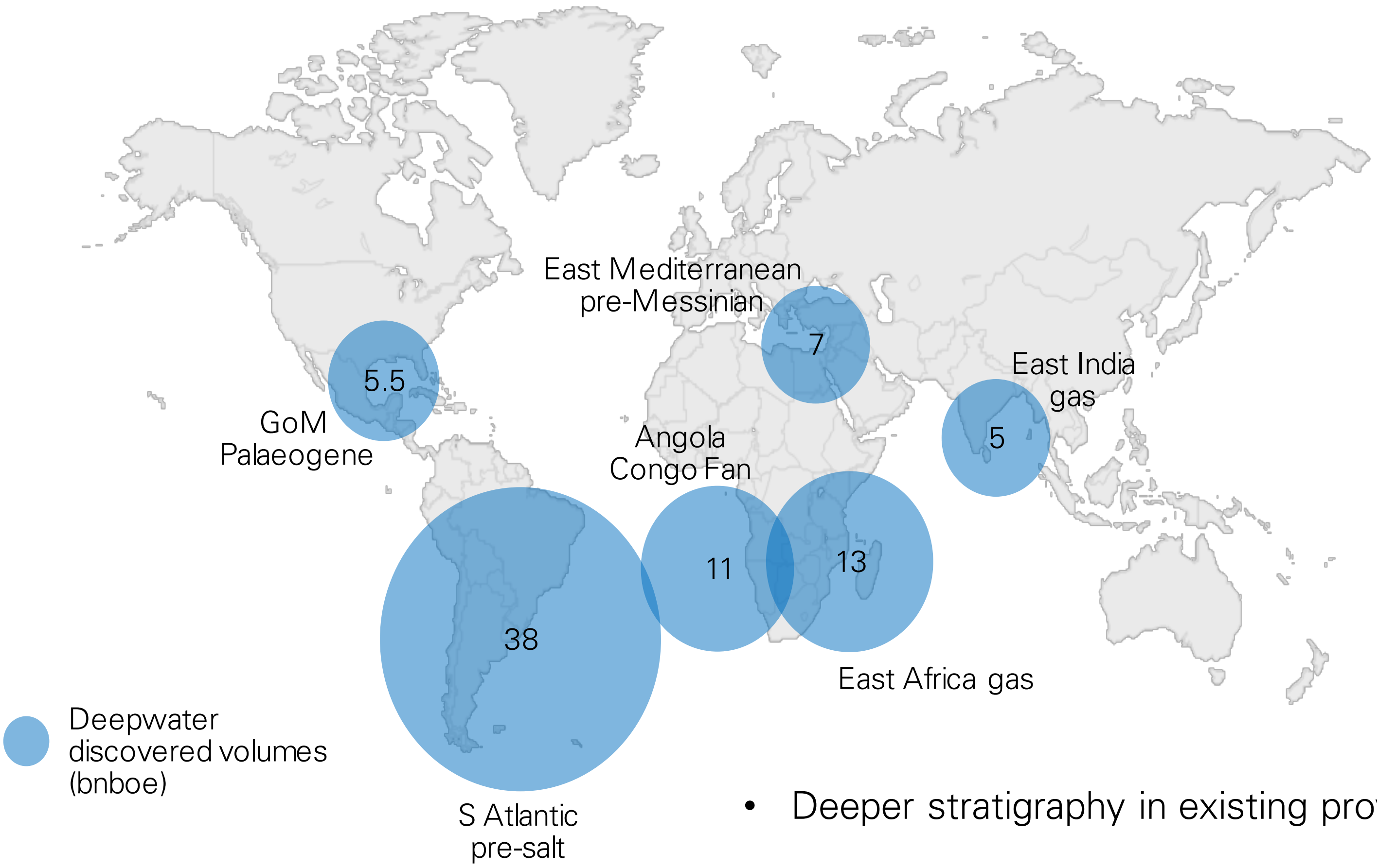
Exploration delivery – past and future

- The growth and decline of deepwater
- The emergence of the sub-ice arctic
- Sustained delivery from onshore & shelf



Source: BP Yet-To-Find data

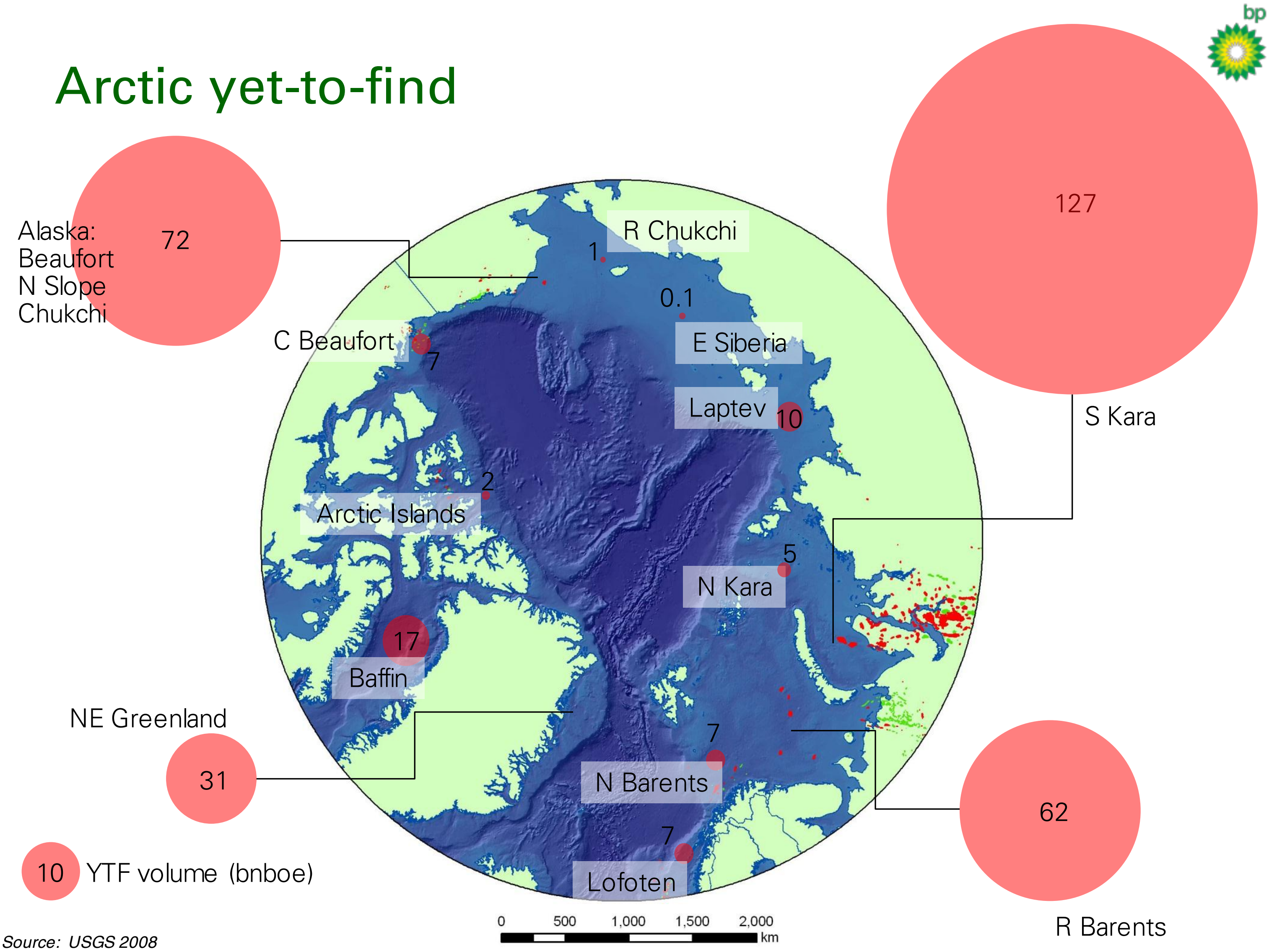
Material new plays of the past decade – all deepwater



Source: IHS EDIN / BP

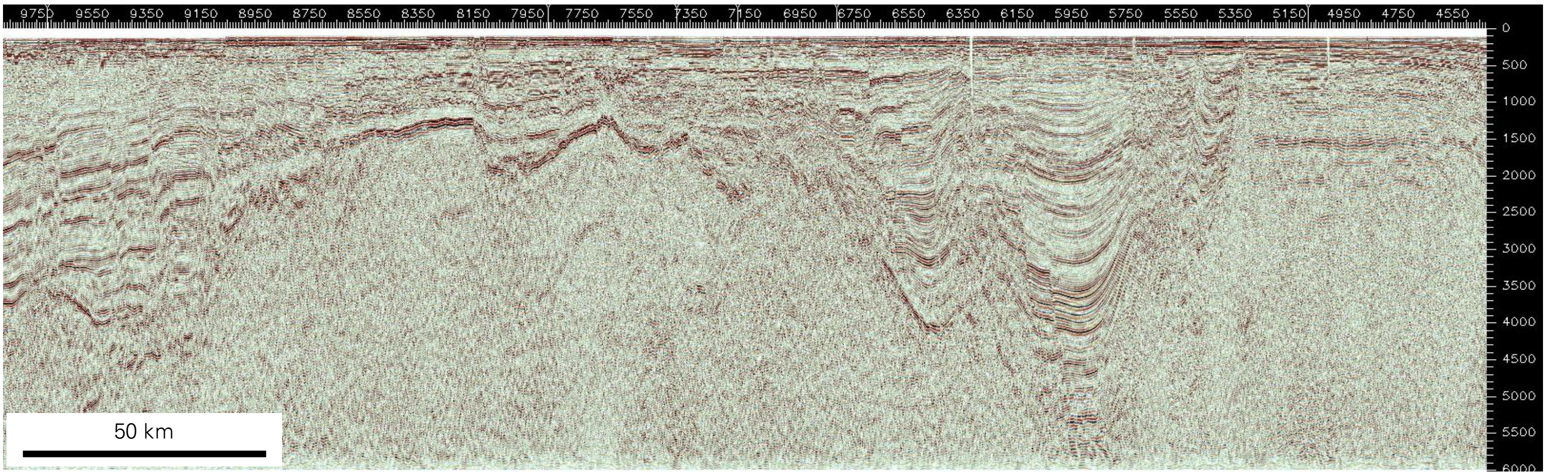
- Deeper stratigraphy in existing provinces
- Delta's medial and distal fans

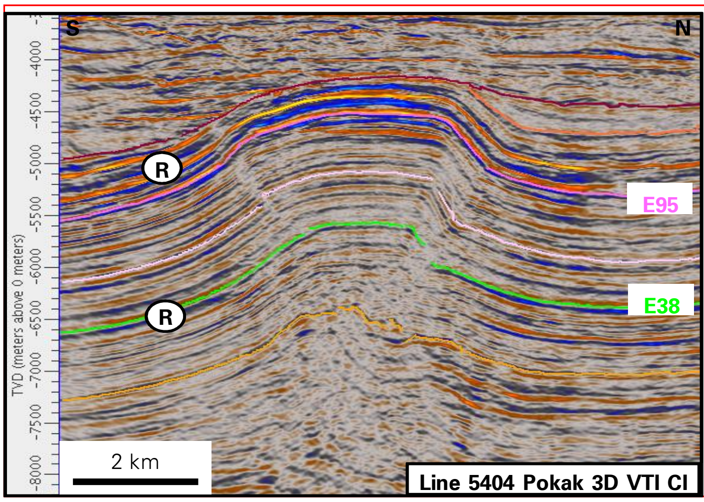
Arctic yet-to-find

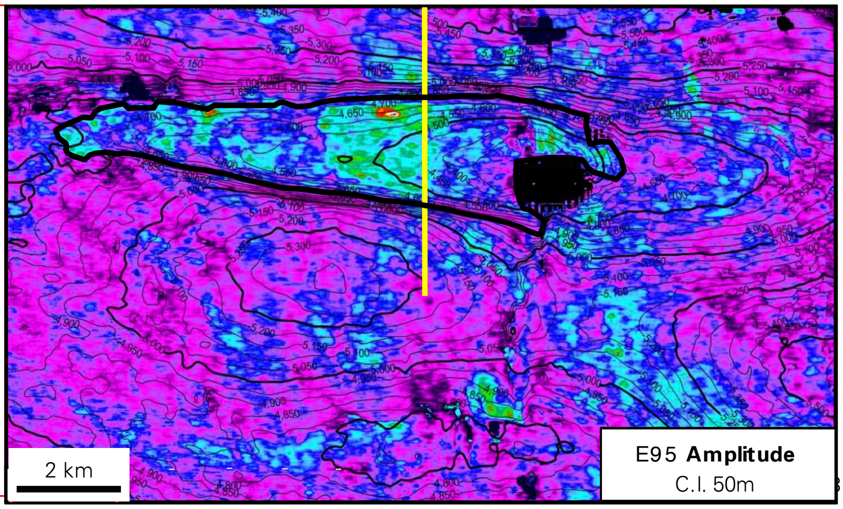


Source: USGS 2008

Arctic frontiers: untested basins with great DHI's

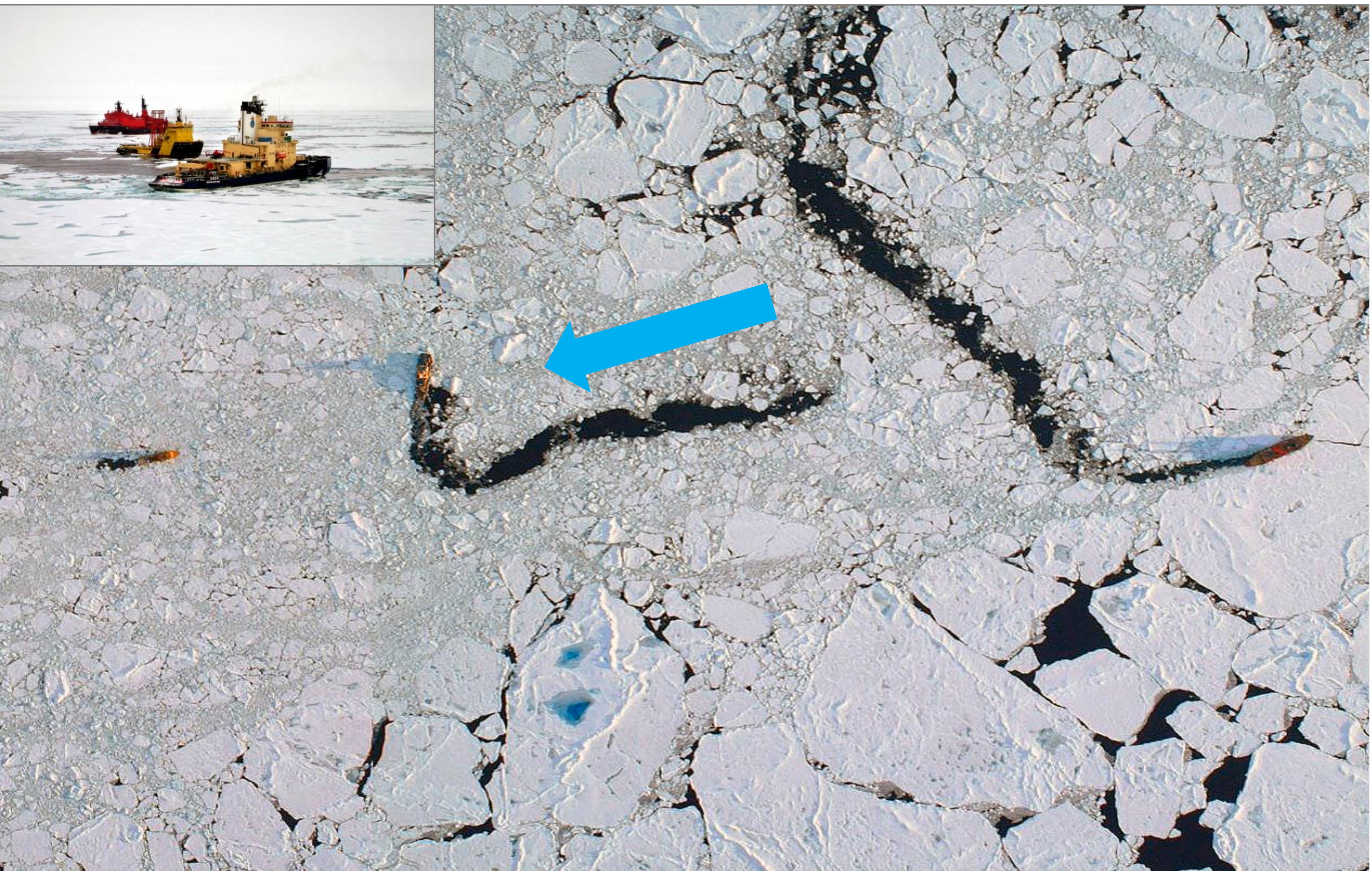






Ice management key issue

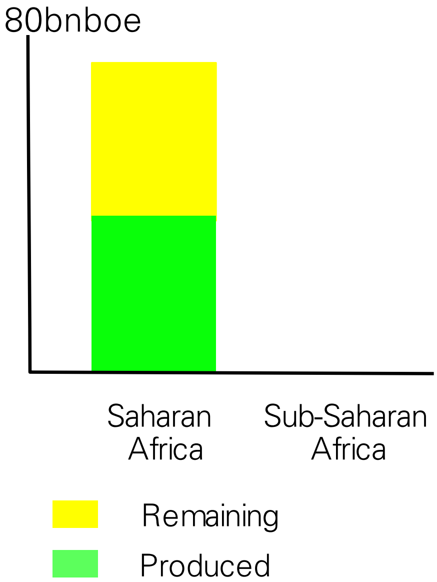
Lomonosov Ridge, 2004: seabed coring, drifting pack ice

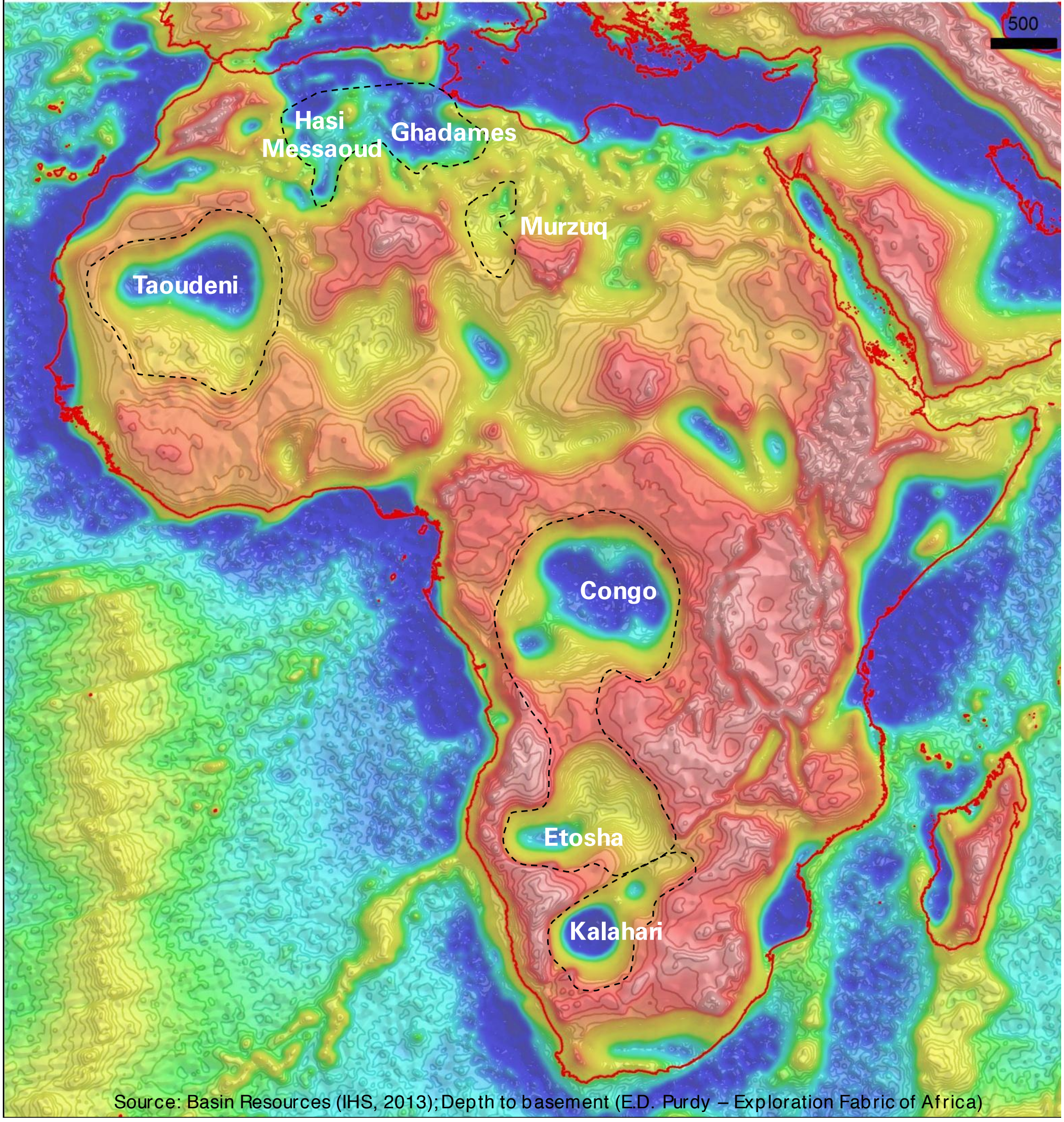


And society's opinion?

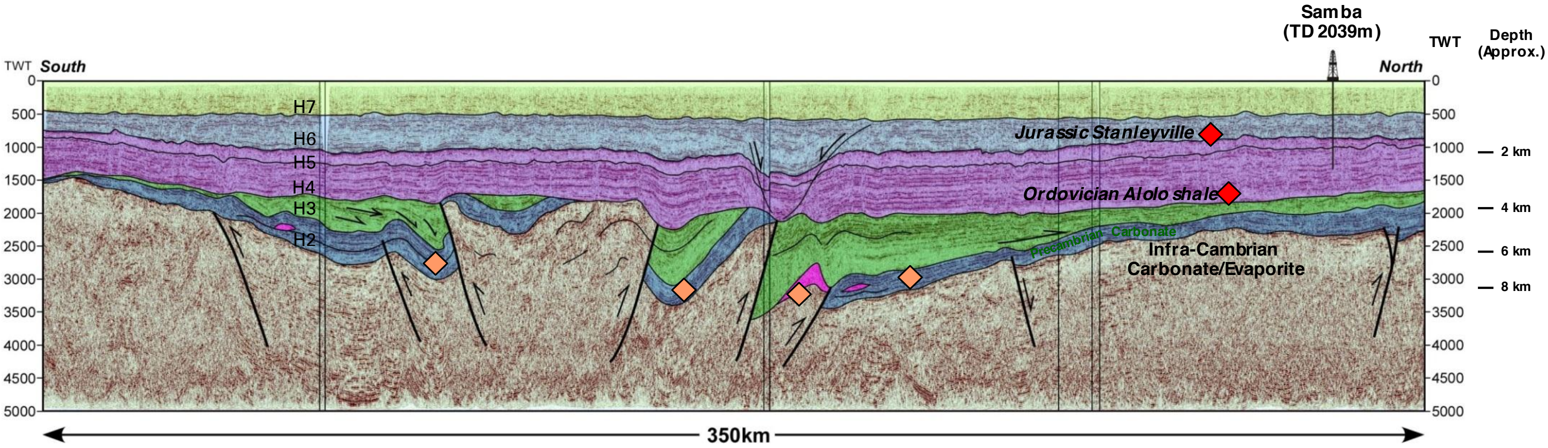
Onshore frontier basins

Strongly asymmetric resource distribution - North and South

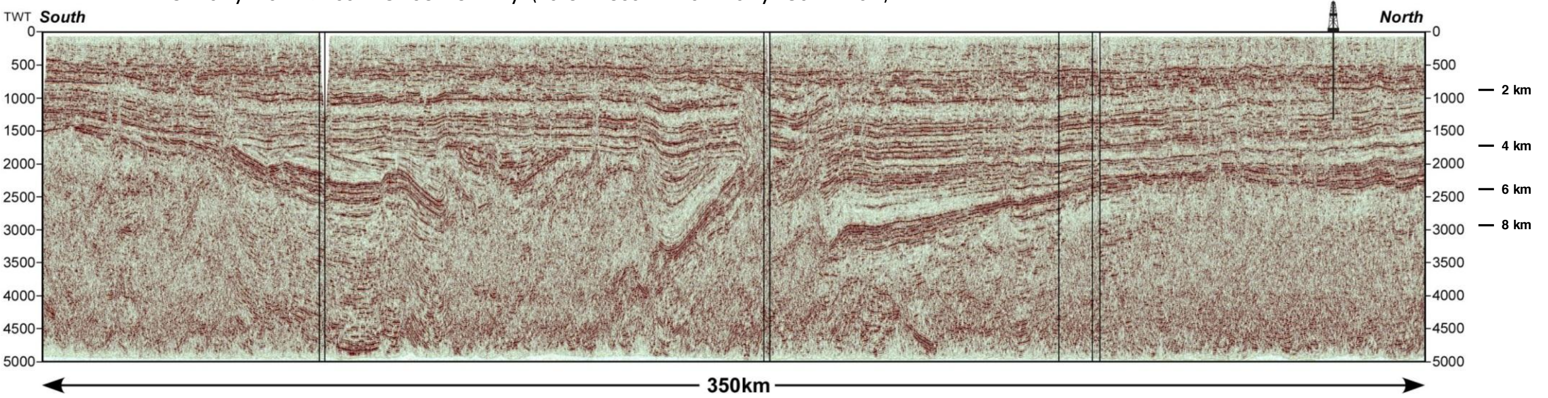




The Congo: 1.2m km^2 of unexplored basin



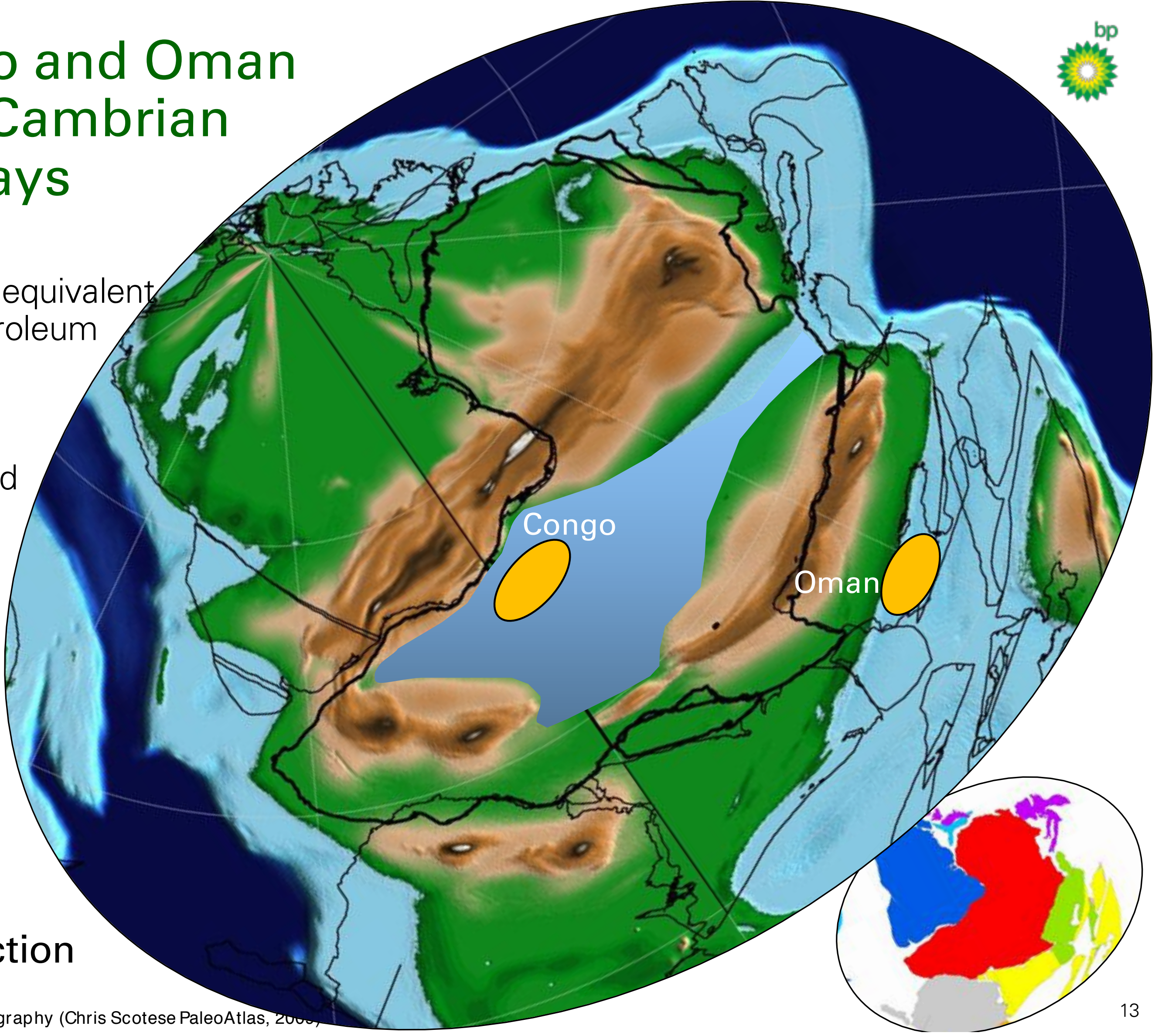
H6 Base Jurassic Unconformity
H5 Hercynian Unconformity (Late Paleozoic)
H4 Pan-African Unconformity (Early-Mid Paleozoic)
H3 Early Pan-African Unconformity (Late Precambrian-Early Cambrian)



Congo and Oman Infra-Cambrian seaways

Oman time equivalent Ara Gp. petroleum system

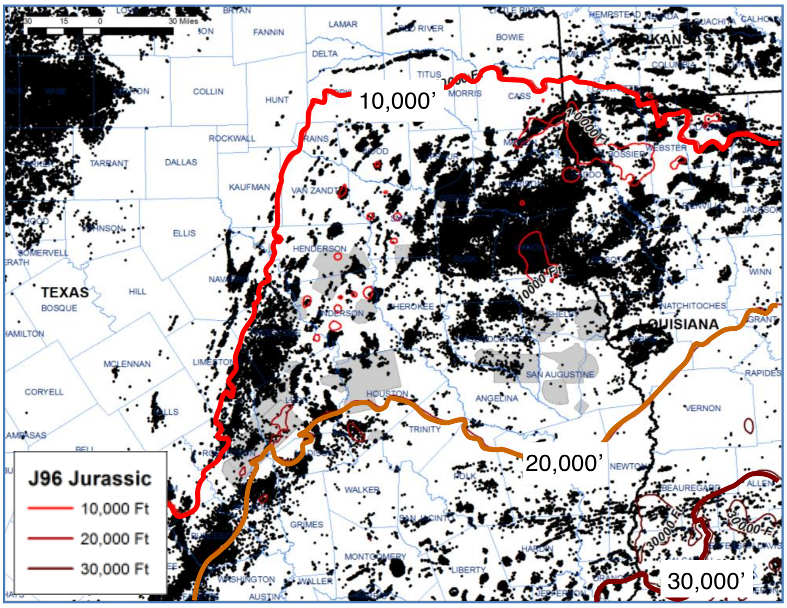
'U' shale and Athel silicilyte source rocks have delivered ~20bnboe



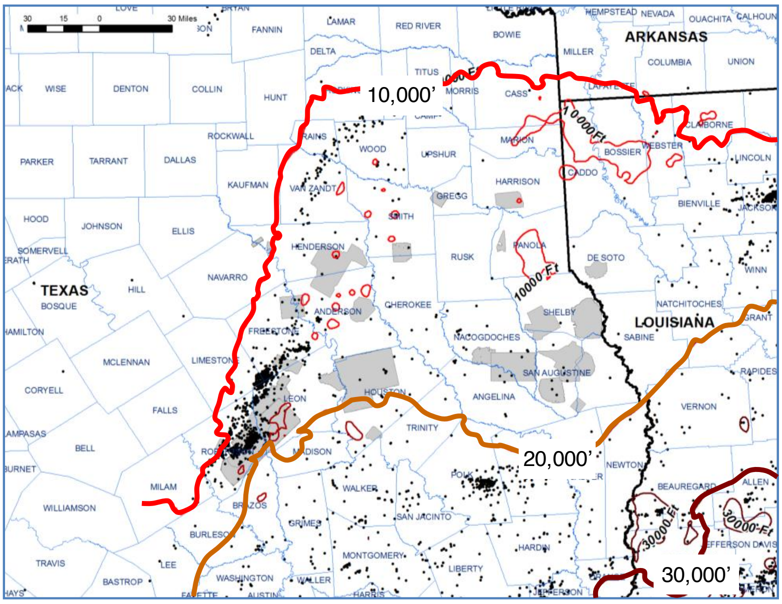
540Ma Reconstruction

Modified from: Palaeogeography (Chris Scotese PaleoAtlas, 2000)

Unexplored rock volume in mature basins



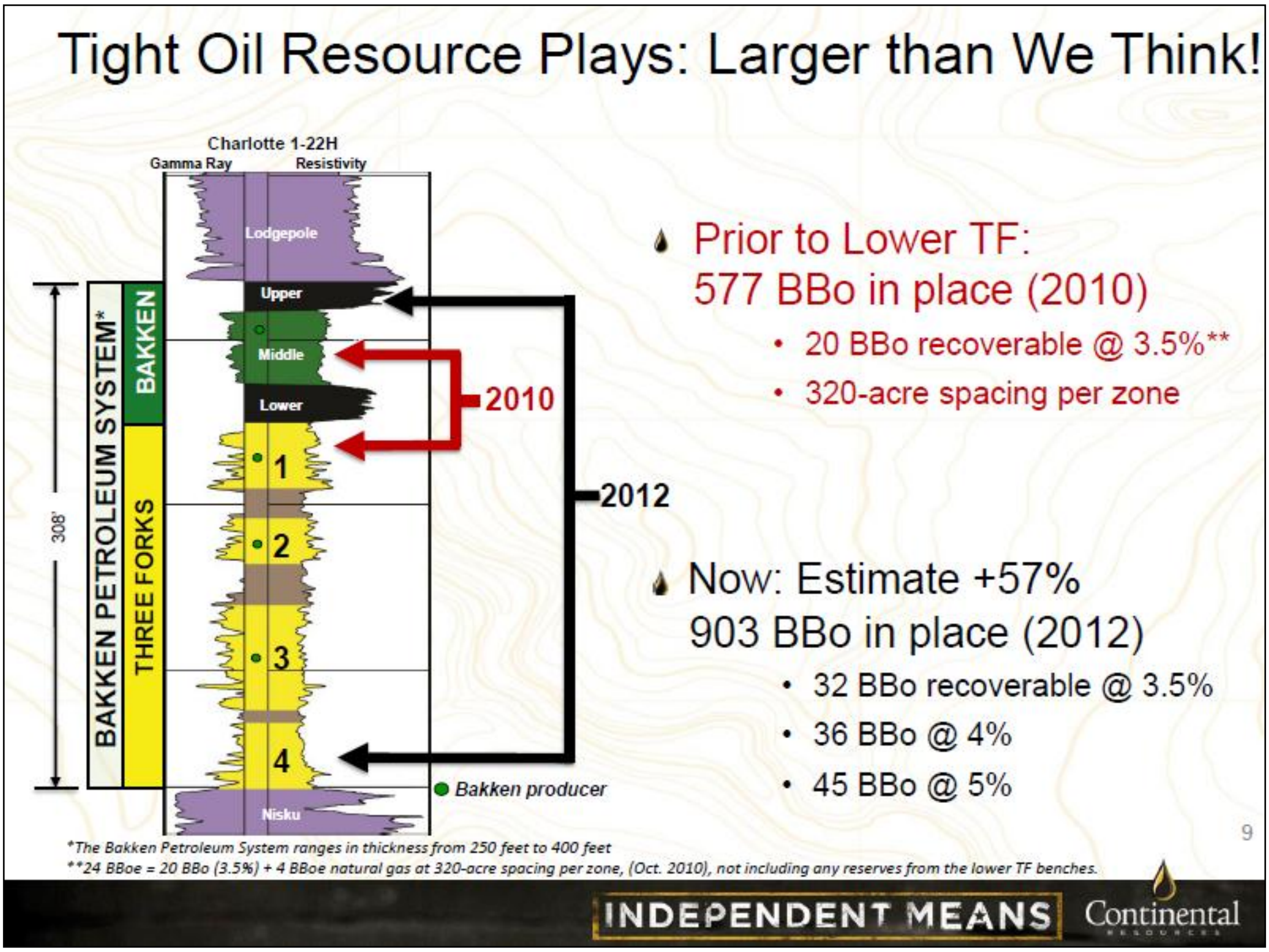
East Texas: >100,000 wells total



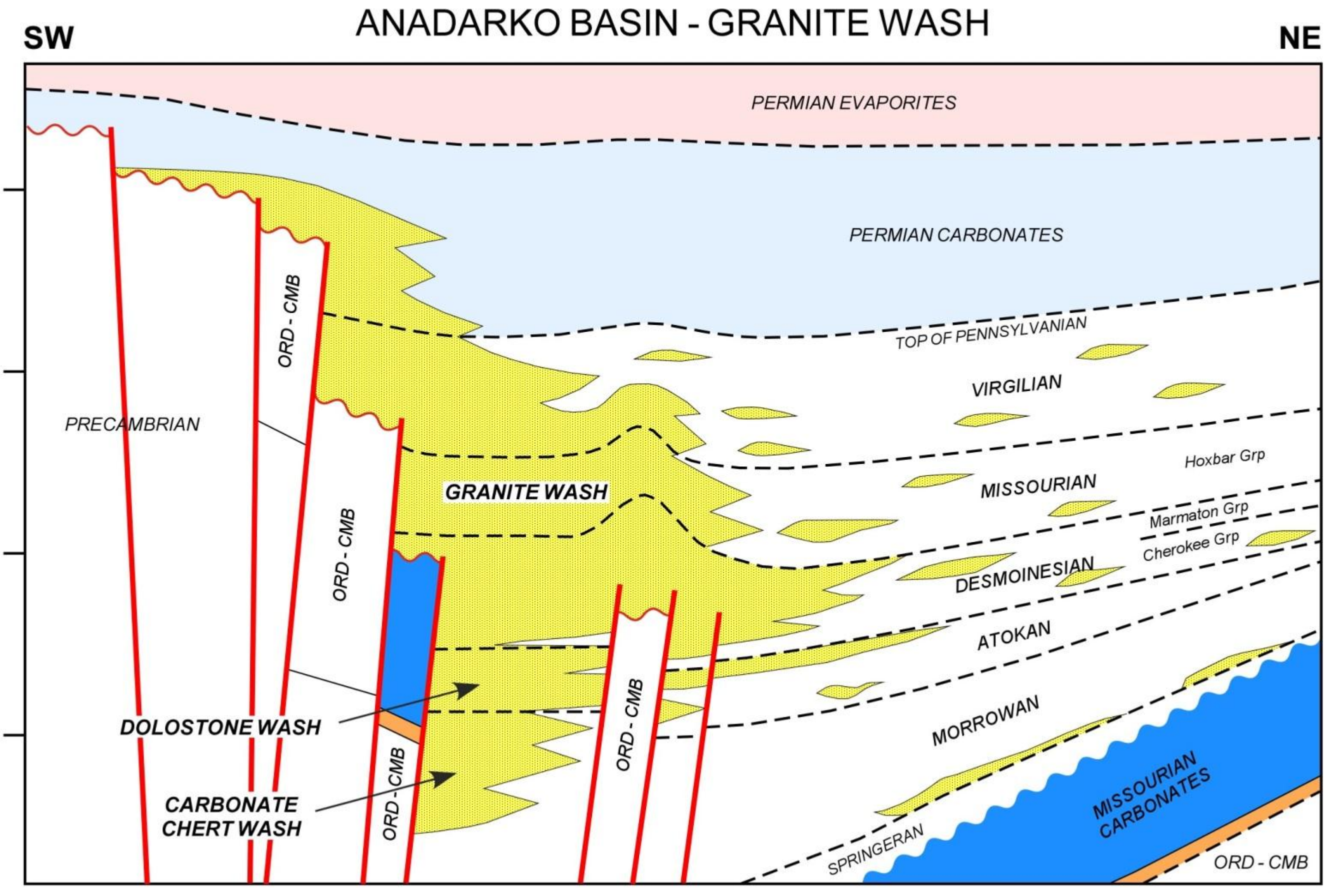
East Texas: wells below 14,000'

Industry 3D seismic data

The Bakken: dramatic reserves growth

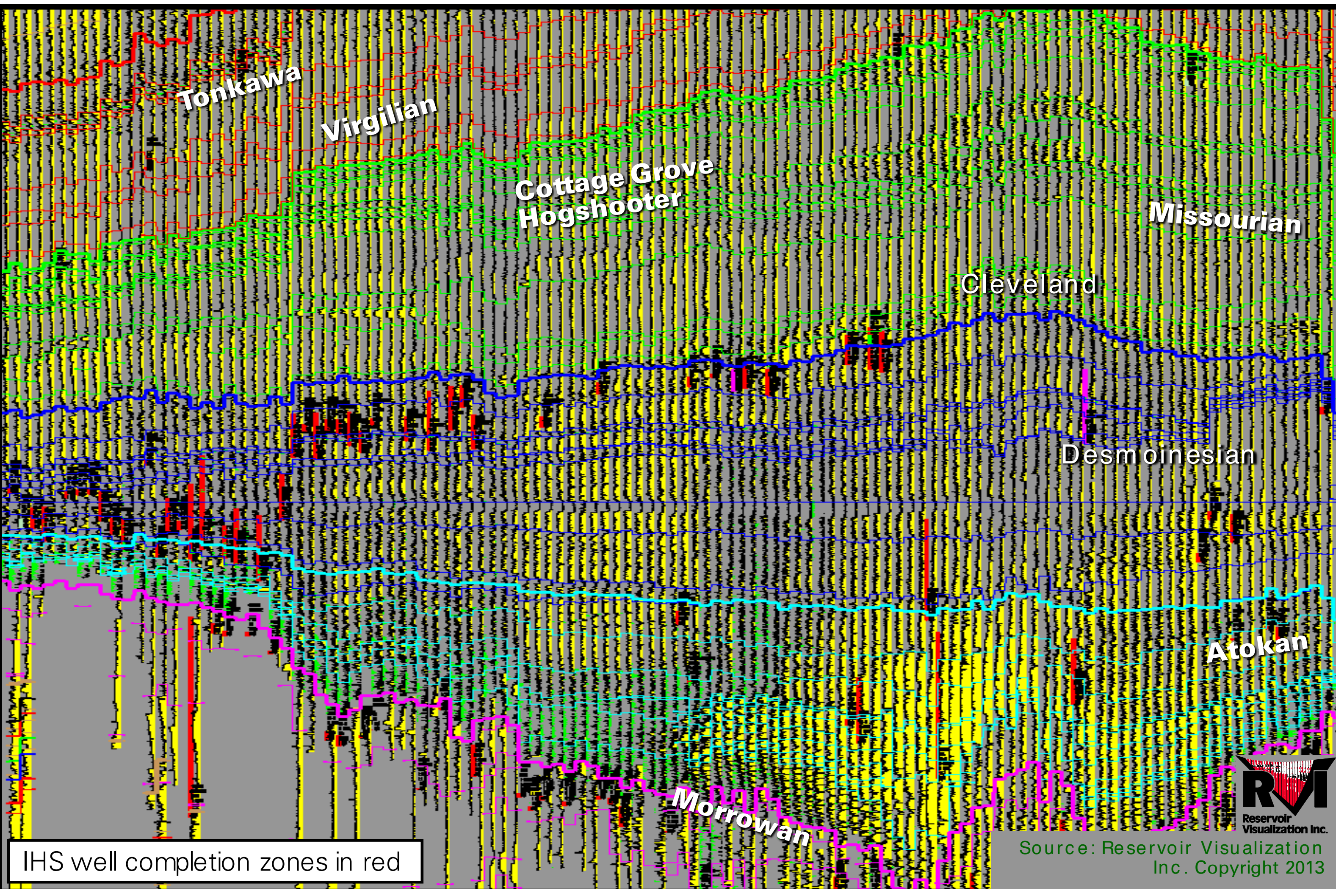


Exploring for ‘reserves growth’…



Source: Penn Virginia

By exploiting missed pay – a lot of it!



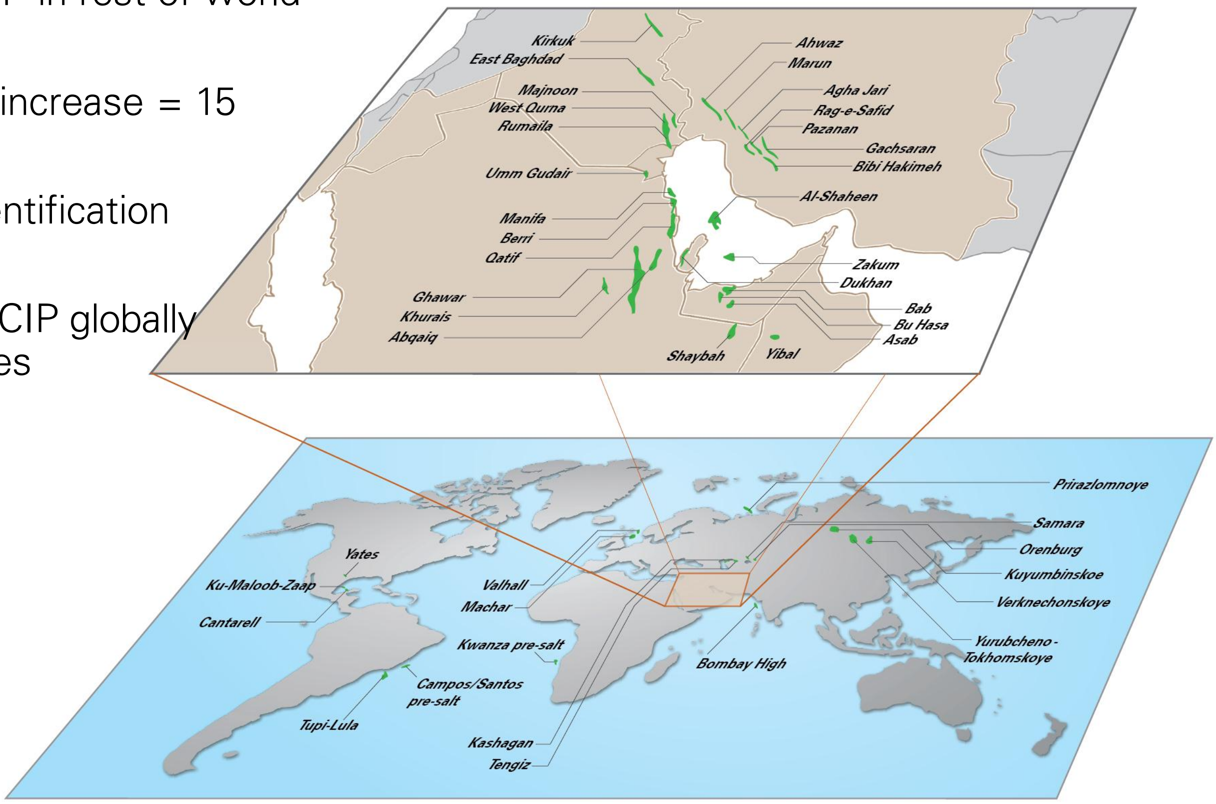
Source rock (shale) plays

Eagleford: drilling, logging and evaluating the type outcrop

Source: Reuters

Exploration convergence with EOR

- 1200 bnboe remaining HCIP in Middle East carbonates
- 300 bnboe HCIP in rest of world carbonates
- Each 1% EOR increase = 15 bnboe
- Sweet spot identification key criteria
- 1380 bnboe HCIP globally in clastics/shales



Future trends in oil & gas exploration

Resource trends

- **Deepwater**: T and K deltas; plays explored up from the source rock
- **Arctic**: ice-bound offshore, Russia is leading
- **Re-exploration of the onshore** (and shallow water) basins
  - Needs a new image, or a new idea, or new technology
    - Onshore frontier basins
    - Unexplored Rock Volume in established basins
    - Tight oil in old giants
    - Shale sweet spots
    - Convergence with EOR

Future Trends in Global Oil and Gas Exploration

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Imperial College

23 September

100 Years of Oil Technology

Thank you for the invitation to speak at your conference celebrating the centenary of Oil Technology at Imperial College. It is an honour and great pleasure to be here. I have been asked to discuss the future trends of global oil and gas exploration, a subject I am deeply passionate about and have lived with for over 30 years now (slide 1). *[Slide 2, legal disclaimer].*

Of course many factors will influence the future of exploration (slide 3). However, the fundamentals of resource quality, technology and geopolitics seem paramount to me. Today I will largely confine my remarks to the first of these, resource quality, which I believe to be the fundamental driver.

Exploration trends will follow the industry's perception of the "next best resource base" to explore and develop, which incorporates both the scale and quality of resource and the cost of its development.

Today we are some 40 years into the deepwater era. And although we are perhaps half way through it in finding terms, deepwater exploration is a trend that will be with us for some time yet.

Deepwater will likely be followed by two very different trends, both of which are beginning to emerge. Firstly, a move to the unexplored arctic frontier of ice bound continental shelves; and secondly to a re-exploration of the onshore and shallow waters of the world with new images, new technology and occasionally new ideas.

But before getting into this in detail, we need to understand the context of what there is to find, where it might be, and what it will take to find it.

This chart (slide 4) shows the cumulative global finding curve of 4.5tnboe and a global yet-to-find (YTF) estimate of approximately 1tnboe shown as a series of bricks: deepwater, arctic sub-ice, onshore and continental shelf.

To understand the trends around these resources, an understanding of the past is important to allow forecasts about what future discovery profiles could look like.

The chart (slide 5) shows annual discoveries since 1990, split out into onshore, shallow water and deepwater. It demonstrates the global deepwater story of a growing contribution over the past 25 years to being 30-50% of annual discoveries today. The inset chart shows the continued strong rise in the deepwater discovery curve with no hint of a plateau today.

The main chart also projects to 2050 how the 1tnboe YTF outlined earlier may play out. It forecasts:

(a) decline in deepwater discoveries over the next two decades

(b) rise and then fall of arctic ice-bound discoveries

(c) sustained exploration delivery from onshore basins as the continents are re-explored.

These are the three themes I intend to develop.

Starting with deepwater, the chart plays out our deepwater YTF and shows a declining contribution from the next decade to 2050. This is an uncertain model underpinned by the increasing maturity of deepwater whilst still being a substantial volume of accessible oil and gas with a relatively low barrier to entry today.

Let us now look at the recent trends in deepwater to understand what might underpin this forecast.

The material (i.e. >3bnboe) new plays discovered over the last decade are shown here in geographic and volumetric terms (slide 6). They all happen to be in deepwater and, with the exception of East India, they are all in basins where discoveries had previously been made, either in shallower reservoirs, or of uneconomic scale as in East Africa.

The exploration themes underlying these new plays are clear and give us a steer of where deepwater exploration is headed:

a) The largest, the Brazilian pre-salt play and the Paleogene play of the Gulf of Mexico, were both a result of going deeper in established basins, below salt, towards the lowest known source rock. Industry is now taking this thesis to explore the Angolan conjugate margin of Brazil and seeing early success.

b) The Rovuma delta gas discoveries of East Africa; the Krishna Godavari gas of East India; the Congo fan oil discoveries of West Africa; and the greater Nile fan gas discoveries all result from exploring the medial and distal parts of large, young delta systems where traditional source rocks remain uncertain, and where biogenic processes have resulted in large gas finds in at least two of these: Israel and India.

So what does this tell us about the future exploration trends?

- Go deeper, exploring down to the source rock
- Deltas are still delivering surprises

In conclusion, deepwater exploration has legs yet. Underpinning it will be ever improved and cheaper seismic data: seeing beneath shallow gas, salt and basalt, and allowing the mapping and de-risking through porosity and fluid indicators. However, with the elevated activity levels of the past few years, a decline in success rates is inevitable, and the discovery of new plays ever more difficult.

So where will industry go? Not west….but North

The ice-bound continental shelf and slope of the artic remains largely unexplored (slide 7). Yet 10% (19) of the world's rivers discharge into the arctic and some have formed huge Tertiary delta systems, well known in front of the Canadian Mackenzie, Russian Lena and other rivers. But even more importantly the prolific West Siberian and Timan Pechora basins plunge northwards below the ice and water of the Kara Sea.

This latter point, together with the fact that 60% of the arctic continental margin is in Russian waters, explains the dominance of Russia in terms of estimates of YTF. The bubbles here are United States Geological Survey figures, and show the dominance of the Kara Sea and Barents areas, but also predicted large volumes offshore Alaska in the USA.

Russia has recently licenced much of its frontiers at favourable terms with drilling scheduled to commence next year – so it seems that arctic exploration is going to be a Russian-led exercise.

Here, perhaps, the most important exploration question is not about volume, but petroleum phase. More stranded arctic gas will likely not be economic success for anyone.

Nevertheless putting aside the uncertainties, what does the arctic offer from a resource perspective?

The obvious opportunity of the Kara Sea aside, the arctic possibility is significant. This slide (slide 8) shows two untested basins, the Lapdev Sea in Russia and the deepwater Beaufort in Canada.

The Lapdev Sea basin is a completely unexplored, up to 10-km deep, rift basin, well illuminated by seismic reflection data. Its age is uncertain but regionally, prolific Mesozoic source rocks are well known. The potential is clear as is the challenge – the area where this line was acquired is covered in multi-year ice 9-10 months a year. This basin should be tested towards the end of this decade by the Rosneft and Exxon partnership.

The lower two images are from the deepwater Beaufort Sea offshore northern Canada. Here, single year ice covers this area for 9 months a year and I believe our 3D seismic coverage remains the northern-most survey yet acquired.

The images show the first structure of the Mackenzie delta wedge as one comes from the arctic basin. The image is good and the amplitudes appear to respond well, showing a good amplitude conformance with structure on the map and a cross-cutting reflector suggesting a possible hydrocarbon-water contact.

The geology seems favourable, even outside of the Kara Sea, responding well to modern seismic and with some big unknowns to be explored.

So what of the issues to be solved?

From an engineering perspective the issue is clearly the ice, and the temperature and to a lesser degree the lack of daylight for half of the year (slide 9). To access these great, partially ice-bound prospects will not be easy, cheap or fast.

The two photos are from the 2004 expedition to the Lomonosov Ridge very close to the North Pole. The inset photo shows three vessels; the Swedish Oden icebreaker in the foreground, the Vidar Viking drilling vessel in the middle distance, and the Russian nuclear icebreaker, Sovetskiy Soyuz, in the background.

This was a scientific shallow-coring expedition, not hydrocarbon drilling. Two Polar Class icebreakers have been used to protect the drilling vessel. The larger Russian vessel is working the furthest updrift from the drilling vessel while the Swedish Oden is providing further ice management and acting as a second line of defense.

What you can observe is that there are large blocks of ice to the right top and bottom, but that the icebreakers are doing an effective job at making sure no large ice blocks reach the drilling vessel. This type of operation requires significant levels of coordination and teamwork.

This is clearly a big issue, but perhaps not the biggest for large international companies.

Far more difficult and uncertain is the public response to arctic exploration and their response to companies that work there (slide 10).

The Arctic is perceived as the last pristine part of our planet. It has specific technical challenges to overcome. In particular, the industry should seek to assure proper oil spill response capability in ice-bound marine environments.

Yet many of the owners of the arctic waters and the communities along the arctic littoral want investment and development.

It is widely acknowledged that the arctic is a sensitive natural environment upon which some communities depend for subsistence and cultural heritage. Therefore, an open and transparent dialogue is required, based on good science and knowledge transfer, between all stakeholders.

Whilst the arctic debate plays out, the trend in the rest of the world will likely be to re-explore onshore and shallow-water areas – "going back to where we have gone before." To be successful this will require doing something new geographically, or with new technology or, even more difficult, having a truly new idea.

A good example of new geography is the sub-Saharan basins of Congo/Angola/Namibia (slide 11). This 'Depth to Basement' image of Africa (from Purdy's atlas, the Exploration Fabric of Africa), shows the major basins of Africa. I have annotated Saharan and sub-Saharan Cratonic basins of similar age and scale. The histogram shows the disparity in their resources, 75bnboe v 0bnboe. Is this simply an understandable exploration maturity issue or a profound geological shortcoming?

In the 1.2 million km^2 of the Congo basin there are 2900km of old 2D seismic and four exploratory wells, two of which touch 4km in depth. In contrast, in Algeria alone, there are thousands of wells and hundreds of thousands of line kms and sq kms of 3D seismic – there is just no comparison.

This is an example of a montage of five of the Congo seismic lines showing a 350km geoseismic cross section through the basin (slide 12). Acquired largely along rivers, and existing tracks through the equatorial jungle, it shows the essence of the basin. A central structured zone inverted periodically in the Palaeozoic, with buried structures today, and two source rocks described above the major structuring.

The blue stratigraphic interval is an evaporate/carbonate interval of Vendian age. It is mildly deformed then buried by the green onlapping clastic interval. Both are deformed in the Late Cambrian Pan-African deformation creating a major unconformity. This is overlain by the Paleozoic to Tertiary section with two known source rocks, one always immature, and one that is above the structure and apparently focussed to the basin margins.

No source rocks are known from the deeper deformed section where a simple structural play may be developed.

However, looking at analogues, the section is broadly time and depositionally equivalent to Oman's productive Infracambrian salt basins (slide 13). These basins have three source intervals in a Vendian carbonate/evaporate section that have resources of about 20bnboe, of which 5bnboe has been produced.

The image shows the depositional environments as they might have been 540 million years ago. The Congo basins formed as an internal seaway between emergent Pan-African mountain chains and Oman is shown to have been in a similar shallow-marine setting.

So, we have a huge unexplored basin, with buried fold belt structure, and with the potential for source rocks that have produced ~20bnboe approximately 3000 miles away in Oman. From such thinking oil provinces may emerge.

Of course, the Congo and the interior of Angola are not easy territories to explore, but I cannot help but feel their time is coming. And there are many other continental basins with large unexplored and little understood rock volumes.

Taking this concept of 're-exploration' down a scale, there is a large unexplored rock volume in many of our established basins – avoided for reasons of pressure ramps, poor imaging and apparent play limitations such as tight rock.

These two maps show a large part of East Texas (slide 14). The one on the left shows all the wells drilled – the black area comprises a mass of wells – and the depth contours to the Jurassic source rock. In contrast, the map on the right shows only those wells that penetrate beyond 14000', clearly a small subset.

The Jurassic source rock lies well below 14000' over at least half of the map: the contours show the Jurassic at 10 to >30,000' and deepening southwards. Similarly the small grey areas show 3D seismic coverage is sparse, perhaps 20% of the areas inside the red depth contour.

This implies that we have a huge area of unexplored rock volume, not imaged by 3D seismic, in one of the world's prolific basins.

This is not unique. Many established land provinces remain under-shot with modern seismic and consequently under-explored. In part because of the prohibitive cost of land imaging, which has lagged behind marine data, and partly because of above ground issues. The former is improving rapidly, the latter is probably getting more difficult everywhere except in the USA.

The challenge here then is for high quality 3D seismic, shot at minimal environmental impact, to be acquired in existing onshore basins to illuminate their ultimate potential. And deep drilling to test the resultant ideas.

Conceivably we could see a repeat of what happened offshore where areas such as the Gulf of Mexico deepened their area of investigation on the basis of a 'source rock-up' exploration philosophy. This led to the recognition of the potential of sub-salt reservoirs – a previously unexplored rock volume.

Continuing the theme of re-exploring established areas with new technology and perspective, the reserves growth revolution that has hit the USA's traditional producing areas is unprecedented. Led by US independents employing hydraulic fracturing technology in horizontal wells and a 'learning-by-doing' philosophy, the industry has reversed the decline in US oil production.

The Bakken Formation of the Williston basin of N Dakota is the poster child (slide 15). The Williston first produced oil in the 1920s, with the Bakken contribution starting in the 1950s from the Antelope Field. The first horizontal well in the Bakken was drilled in 1987. Since then, multiple stage, hydraulic fracturing in horizontal wells has transformed the permeability (Kh) of previously tight, non-productive reservoirs and led to the tight oil revolution over the last 10 years.

This slide is taken from Continental Oil's web page. It shows a 60% increase in OIP achieved just by the recognition that the traditional Bakken target of dolomites encased in shale, shown in red, has now expanded to include the Three Forks Sandstone Formation that is also oil bearing, apparently charged by the associated Bakken shales, and responds well to hydraulic fracturing.

A more complex example but one that is perhaps more relevant to the UK and North Sea is the Pennsylvanian, conglomeratic, fan delta play in the Anadarko basin, known parochially as the Granite Wash (slide 16). These coarse clastics were derived from the Wichita Mountain uplift.

This previously conventional play has produced oil and gas from the Desmoinsian formation since the 1950s. However, horizontal wells and multistage fracs have revolutionised the marginal and uneconomic parts of the Wash.

There are over 90,000 vertical wells in the basin and over 4500 completions in the Granite Wash. This data density is a huge opportunity and a very different problem to more conventional frontier exploration

It is highlighted here in this cross section showing 125 gamma ray logs through the Granite Wash, normalised to show clean gamma intervals, and allowing cut offs to be varied (slide 17).

The 2km thick section is flattened on the traditional DesMoineisian conventional play, targeted in the early vertical wells due to good porosity and permeability and able to achieve commercial rates. The red bars represent completions in the IHS database.

This type of visualisation has enabled detailed stratigraphic framework to be worked out, depositional facies to be attributed and the horizontal exploration of individual sands. This has expanded hugely the number of horizontal wells and fracturing to the whole section shown here and has increased reserves by an order of magnitude.

Consequently the Granite Wash has been transformed from a mediocre play into one of the USA's new star producing play fairways. IHS estimate some 500tcf and 20bnbbl of liquids. And such is the recent activity level, that >50% of Granite Wash wells have been drilled since 2005.

These two examples of "revolutionary reserves growth" from two old producing areas give an indication of the potential that exists in large fields globally. Searching for these opportunities, and then exploring them at the scale of the sand body, is going to be a significant part of onshore and shallow water exploration in the future.

The tight oil revolution was born out of the shale gas revolution (slide 18). We know where the world's great shales are distributed, they usually have prolific petroleum provinces associated with them.

Again, this is not about exploring for shales, but it is about identifying the right shales and then the sweet spots within these shales.

To date this has largely been done empirically through the drill bit, as demonstrated in North America, but as we move to explore for shale gas internationally, prediction of sweet spots will become ever more important. The first step to this is an understanding of what a sweet spot actually is, beyond an enhanced well. The fundamental science here is key and poorly understood.

The image on the slide shows a cliff of the type area of the Eagleford formation in West Texas. You can see the drilling rig on top of the escarpment. BP drilled and electric-logged this outcrop to characterise the Eagleford formation at this location and draw a detailed comparison with the outcrop that we can see, measure and analyse.

Combined with high resolution seismic we can start to move to characterise shale ahead of the drill bit. The objective being to use geological and mechanical properties to understand the impact of stimulation technology and the potential to improve reservoir deliverability.

These examples of exploring for tight oil in old giant fields, and exploring shales for the sweet spots where stimulation will be productive will likely lead exploration back into the world's great petroleum provinces. The Lower 48 of the USA, where it all started; Russia, where it is beginning to happen in the Achimov/Bazenov of West Siberia and the Domanik shales of the Volga Urals; and the Middle East where the variety and concentration of plays and carbonate rocks promises an immense and long-term 'tight oil' and 'shale' future.

Estimates are that there is over 1200 bnb hydrocarbons in place (HCIP) in the carbonate reservoirs of the Middle East, and 25% of that figure in the rest of the world (slide 19). In this, is likely a huge tight oil YTF or Enhanced Oil Recovery (EOR) potential.

That OIP is a target to be explored with techniques similar but different from conventional exploration. An understanding of regional geology and play systems will be a basis. However, exploration will be guided by the physical and mechanical attributes of rock and clay content, as well as traditional depositional understanding.

This will demand new, data-rich, exploration work flows, still underpinned by the image, but informed by a far more complex and varied mechanical data set than traditionally. However, for every 2% of improved recovery from these reservoirs, we produce one year's exploration delivery. So here, exploration and EOR converge with a final, significant prize potential.

In summary (slide 20), the future trends of exploration are diverse and will demand a wide variety of skills, many new to explorers, new data and new technology development.

The Frontiers of deepwater basins and deltas remain to be explored.

The arctic has significant potential, but the licence to operate remains uncertain outside of Russia.

And onshore, three exploration trends will dominate as the industry re-explores the onshore and shallow water regions of the world.

- Exploration of frontier basins like the Congo.
- Exploration of the unexplored rock volume of existing basins with a "source rock upwards" philosophy.
- Exploration for missed and tight pay in and around the world's giant fields and source rocks, and convergence with EOR.

The pace at which these trends play out is, of course, uncertain and will vary globally. And there will be other, disruptive trends.

However, a decline in material success rate in deep water is likely to be around the corner – but when will that corner be reached?

And Russia will lead in arctic offshore exploration, but it is unclear how fast the rest of the world will follow?

Onshore, the remaining frontiers and 'deep-land' - will follow with low cost, low impact, high quality seismic being key.

And Tight Oil and shale exploration enabled by hydraulic fracturing will converge with EOR, progressively, to the end of the Hydrocarbon Age.

* * *